

Federal Aviation Administration  
Aviation Rulemaking Advisory Committee

Executive Committee  
Fuel Tank Harmonization Working Group  
**Task 2 – Prevention of Fuel Tank Explosions**

# **Task Assignment**

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[Notices]  
[Page 43800-43802]  
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DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Aviation Rulemaking Advisory Committee--New Task

AGENCY: Federal Aviation Administration (**FAA**), DOT.

ACTION: Notice of a new task assignment for the Aviation Rulemaking Advisory Committee (ARAC).

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SUMMARY: Notice is given of a new task assigned to and accepted by the Aviation Rulemaking Advisory Committee (ARAC). This notice informs the public of the activities of ARAC.

FOR FURTHER INFORMATION CONTACT: Anthony F. Fazio, Director, Office of Rulemaking, ARM-1, Federal Aviation Administration, 800 Independence Avenue, SW., Washington, DC 20591; telephone (202) 267-9677 or fax (202) 267-5075.

SUPPLEMENTARY INFORMATION:

Background

The **FAA** has established an Aviation Rulemaking Advisory Committee to provide advice and recommendations to the **FAA** Administrator, through the Associate Administrator for Regulation and Certification, on the full range of the **FAA**'s rulemaking activities with respect to aviation-related issues. This includes obtaining advice and recommendations on the **FAA**'s commitment to harmonize its Federal Aviation Regulations and practices with Europe and Canada.

The Task

This notice is to inform the public that the **FAA** has asked ARAC to provide advice and recommendation on the following harmonization task:

The ARAC Executive Committee will establish a Fuel Tank Inerting Harmonization Working Group. The Fuel Tank Inerting Harmonization Working Group will prepare a report to the **FAA** that provides recommended regulatory text for new rulemaking and the data needed for the **FAA** to evaluate the options for implementing new regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new production, and new type design transport category airplanes. The level of reduction in

flammable vapors that would be proposed in this **FAA** rulemaking would be based on achieving the lowest flammability level that could be provided by a design that would meet **FAA** regulatory evaluation requirements. This effort is an extension of the previous work performed by the Fuel Tank Harmonization Working Group.

The report should contain a detailed discussion of the technical issues associated with the prevention of, or reduction in, the exposure of fuel tanks to a flammable environment through the use of the following inerting design methods, and any other inerting methods determined by the Working Group, or its individual members, to merit consideration.

**Ground-Based Inerting:** The system shall inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank using ground based nitrogen gas supply equipment. The affected fuel tanks shall be inerted once the airplane reaches the gate and while the airplane is on the ground between flights.

**On-Board Ground-Inerting:** The system shall inert fuel tanks that are located near significant heat sources or are not cooled at a rate equivalent to an unheated wing tank using on-board nitrogen gas generating equipment. The affected fuel tanks shall be inerted while the airplane is on the ground between flights.

**On-Board Inert Gas Generating System (OBIGGS):** The system shall inert all fuel tanks with an on-board nitrogen gas generating system such that the tanks remain inert during normal ground and typical flight operations. Non-normal operations are not to be included in the OBIGGS mission requirements. For example, the tanks should remain inert during normal takeoff, climb, cruise, descent, landing, and ground operations (except for ground maintenance operations when the fuel tank must be purged for maintenance access); however, the fuel tanks do not need to remain inert during non-normal operations such as during an emergency descent.

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For the purposes of this task, an ``unheated wing tank'' is a conventional aluminum structure, integral tank of a subsonic transport wing, with minimum heat input from aircraft systems or other fuel tanks that are heated. This is the same definition provided in draft Advisory Circular 25.981-2X that was made available for comment by the notice published in the Federal Register on February 2, 2000.

The report shall provide detailed discussion of technical considerations (both pro and con), as well as comparisons between each of the above design methods for incorporation into the following portion of the large transport airplane fleet: (a) In-service airplanes, (b) new production airplanes, and (c) new airplane designs. Because the working group may consist of members having differing views regarding the technical issues associated with inerting fuel tanks, the report should include discussion of such views and any supporting information provided by the membership.

In developing recommendations to the **FAA**, the report should also include consideration of the following:

1. The threat of fuel tank explosions used in the analysis should include explosions due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, as defined in the July 1998 ARAC Fuel Tank Harmonization Working Group report. The service history in the analysis should be further developed

to include incidents involving post crash fuel tank fires. The **FAA** awarded a research contract to develop a database that may be useful in this endeavor. This data should be evaluated when determining what benefits may be derived from implementing ground based or on-board inerting systems. The report is titled, A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion, Report Number DOT/**FAA**/AR-99/73, dated December 1999.

2. The evaluation of ground-based inerting should consider:

a. The benefits and risks of limiting inerting of fuel tanks to only those times when conditions, such as lower fuel quantities or higher temperature days, could create flammable vapors in the fuel tank. This concept would be analogous to deicing of aircraft when icing conditions exist.

b. Various means of supplying nitrogen (e.g., liquid, gaseous separation technology; centralized plant and/or storage with pipeline distribution system to each gate, individual trucks to supply each airplane after refueling, individual separation systems at each gate, etc.), and which means would be most effective at supplying the quantity of nitrogen needed at various airports within the United States and, separately, other areas of the world.

c. Methods of introducing the nitrogen gas into the affected fuel tanks that should be considered include displacing the oxygen in fuel tanks with nitrogen gas, saturating the fuel with nitrogen in ground storage facilities (for example, in the trucks or central storage tanks), injecting nitrogen directly into the fuel as the fuel is loaded onto the airplane, and combinations of methods.

d. The benefits and risks of limiting inerting of fuel tanks to only those fuel tanks located near significant heat sources, such as center wing tanks located above air conditioning packs.

3. The evaluation of on-board ground-inerting should consider the benefits and risks of limiting inerting of fuel tanks to only those fuel tanks located near significant heat sources, such as center wing tanks located above air conditioning packs.

4. The evaluation of the cost of an OBIGGS for application to new type designs should assume that the design can be optimized in the initial airplane design phase to minimize the initial and recurring costs of a system.

5. Evaluations of all systems should include consideration of methods to minimize the cost of the system. For example, reliable designs with little or no redundancy should be considered, together with recommendations for dispatch relief authorization using the master minimum equipment list (MMEL) in the event of a system failure or malfunction that prevents inerting one or more affected fuel tanks.

6. Information regarding the secondary effects of utilizing these systems (e.g., increased extracted engine power, engine bleed air supply, maintenance impact, airplane operational performance detriments, dispatch reliability, etc.) must be analyzed and provided in the report.

7. In the event that the working group does not recommend implementing any of the approaches described in this tasking statement, the team must identify all technical limitations for that system and provide an estimate of the type of improvement in the concept (i.e., manufacturing, installation, operation and maintenance cost reduction, etc.; and/or additional safety benefit required) that would be required to make it practical in the future.

8. In addition, guidance is sought that will describe analysis and/or testing that should be conducted for certification of all systems

recommended.

Unless the working group produces data that demonstrates otherwise, for the purposes of this study a fuel tank is considered inert when the oxygen content of the ullage (vapor space) is less than ten per cent by volume.

The ground-based inerting systems shall provide sufficient nitrogen to inert the affected fuel tanks while the airplanes are on the ground after landing and before taking off for the following flight. In addition to the ground equipment requirements and airframe modifications required for the nitrogen distribution system, any airframe modifications required to keep the fuel tank inert during ground operations, takeoff, climb, and cruise, until the fuel tank temperatures fall below the lower flammability range, should be defined.

The on-board ground inerting systems shall be capable of inerting the affected fuel tanks while the airplane is on the ground after touchdown and before taking off for the following flight. As for the ground-based inerting system, in addition to the inert gas supply equipment and distribution system, any airframe modifications required to keep the fuel tank inert during ground operations, takeoff, climb, and cruise, until the time the fuel tank temperatures fall below the lower flammability range, should be defined. Consideration should be given to operating the on-board inert gas generating system during some phases of flight as an option to installing equipment that might otherwise be necessary (e.g., vent system valves) to keep the fuel tank inert during those phases of flight, and as a cost tradeoff that could result in reduced equipment size requirements.

The data in the report will be used by the **FAA** in evaluating if a practical means of inerting fuel tanks can be found for the in-service fleet, new production airplanes, and new airplane designs. The **FAA** may propose regulations to further require reducing the level of flammability in fuel tanks if studies, including this ARAC task and independent **FAA** research and development programs, indicate that a means to significantly reduce or eliminate the flammable environment in fuel tanks, beyond that already proposed in Notice 99-18, is practical. Such a proposal would be consistent with the recommendations made by the ARAC Fuel Tank Harmonization Working Group in their July 1998 report.

The report shall be submitted to the **FAA** within 12 months after the date of this notice.

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#### ARAC Acceptance of Task

ARAC has accepted this task and has chosen to assign it to a new Fuel Tank Inerting Harmonization Working Group. The new working group will serve as staff to the ARAC Executive Committee to assist ARAC in the analysis of the assigned task. Working group recommendations must be reviewed and approved by ARAC. If ARAC accepts the working group's recommendations, it will forward them to the **FAA** as ARAC recommendations.

The Fuel Tank Inerting Harmonization Working Group should coordinate with other harmonization working groups, organizations, and specialists as appropriate. The working group will identify to ARAC the need for additional new working groups when existing groups do not have the appropriate expertise to address certain tasks.

## Working Group Activity

The Fuel Tank Inerting Harmonization Working Group is expected to comply with the procedures adopted by ARAC. As part of the procedures, the working group is expected to:

1. Recommend a work plan for completion of the task, including the rationale supporting such a plan, for consideration at the ARAC Executive Committee meeting held following the establishment and selection of the working group.
2. Give a detailed conceptual presentation of the proposed recommendations, prior to proceeding with the work stated in item 3 below.
3. Draft a report and/or any other collateral documents the working group determines to be appropriate.
4. Provide a status report at each meeting of the ARAC Executive Committee.

## Participation in the Working Group

The Fuel Tank Inerting Harmonization Working Group will be composed of experts having an interest in the assigned task. Participants of the working group should be prepared to devote a significant portion of their time to the ARAC task for a 12-month period. A working group member need not be a representative or a member of the committee.

An individual who has expertise in the subject matter and wishes to become a member of the working group should contact: Regina L. Jones, ARM-23, Office of Rulemaking, Federal Aviation Administration, 800 Independence Avenue, SW., Washington, DC 20591; telephone (202) 267-9822, fax (202) 267-5075, or e-mail [Regina.Jones@faa.gov](mailto:Regina.Jones@faa.gov), expressing that desire, describing his or her interest in the tasks, and stating the expertise he or she would bring to the working group. All requests to participate must be received no later than August 11, 2000. The requests will be reviewed by the ARAC chair, the executive director, and the working group chair, and the individuals will be advised whether or not requests can be accommodated.

The Secretary of Transportation has determined that the formation and use of ARAC are necessary and in the public interest in connection with the performance of duties imposed on the **FAA** by law.

Meetings of the ARAC Executive Committee will be open to the public. Meetings of the Fuel Tank Inerting Harmonization Working Group will not be open to the public, except to the extent that individuals with an interest and expertise are selected to participate. No public announcement of working group meetings will be made.

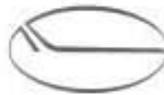
Issued in Washington, DC, on July 10, 2000.

Anthony F. Fazio,  
Executive Director, Aviation Rulemaking Advisory Committee.

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## **Recommendation Letter**



AIR TRANSPORT ASSOCIATION

March 29, 2002

Mr. Nicholas A. Sabatini  
Associate Administrator for Regulation and Certification  
Federal Aviation Administration  
800 Independence Avenue, S.W., AVR-1  
Washington, DC 20591

Dear Nick:

On March 13, 2002, the Executive Committee of the Aviation Rulemaking Advisory Executive Committee (ExCom) agreed to submit to the FAA the enclosed Fuel Tank Inerting Harmonization Report (the Report) and Addendum.

In preparing the 800-page Report, the working group (which included some 70 technical experts) spent over 50,000 hours evaluating many fuel tank inerting options and design concepts and the effects those concepts would have if implemented in the existing fleet and in new airplane designs. The concepts were evaluated in terms of safety, existing regulations, airplane configuration, airport infrastructure, and flight and maintenance operations.

The working group concluded that fuel tank inerting may provide safety benefits and that it warrants continued industry and government research. Although the Report contains several recommendations, the ExCom does not take a position regarding those recommendations. It should be noted that the Addendum reflects the working group's responses to questions raised by the ExCom during deliberation on the Report.

It was agreed that individual ExCom members may submit their individual views regarding the Report in writing to the FAA by April 13. The ExCom also agreed to place any such individual views with the Report.

If you have any questions, please call me.

Sincerely,

Albert H. Prest  
Chair, Aviation Rulemaking Advisory Committee

■  
AIR TRANSPORT ASSOCIATION OF AMERICA, INC.

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## **Acknowledgement Letter**



U.S. Department  
of Transportation

**Federal Aviation  
Administration**

800 Independence Ave., S.W.  
Washington, D.C. 20591

NOV 4 2002

Mr. Glenn Rizner, Chairperson  
Aviation Rulemaking Advisory Committee  
Helicopter Association International  
1632 Prince Street  
Alexandria, VA 22314

Dear Mr. Rizner:

Thank you for forwarding the Aviation Rulemaking Advisory Committee's (ARAC) Fuel Tank Inerting recommendation. The Federal Aviation Administration (FAA) appreciates the effort put forth by the Fuel Tank Harmonization Working Group in evaluating inerting options and design concepts, preparing the extensive report, and responding to the questions and comments from the ARAC Executive Committee. The agency accepts the report, but recognizes ARAC did not take a position on the report and some Executive Committee members filed individual views. The FAA posted the report, executive summary, addendum, appendices, and individual views on the ARAC web site ([www.faa.gov/avr/arm/arak](http://www.faa.gov/avr/arm/arak)).

After reviewing the working group's report, the FAA formed a small team to design and build an on-board ground based inerting system that would meet the mission requirements developed by the Fuel Tank Harmonization Working Group. This system has been installed on a 747SP ground-test aircraft at the FAA Technical Center. As that system was being constructed, the FAA continued to evaluate methods that could make an on-board fuel tank inerting system smaller, lighter, and use less aircraft pressurized air (engine bleed air). As a result, the team developed an on-board inerting gas generating system (simplified OBIGGS) that appears to be capable of inerting a fuel tank for the entire flight. We are configuring the 747SP inerting system to simulate the simplified OBIGGS and will perform ground tests to produce system performance data. The agency is working on a plan to conduct a flight test of the simplified system to validate in-flight performance. The enclosed documents provide a diagram of the simplified OBIGGS and show how ARAC's concerns are addressed by the simplified OBIGGS.

The FAA considers this acknowledgment and status report as completion of your task, and therefore, closes the task. I would like to thank the aviation community for its commitment to the ARAC process. Specifically, I would like to thank the members of the Fuel Tank Inerting Harmonization Working Group for the time and resources they devoted to this task.

Sincerely,

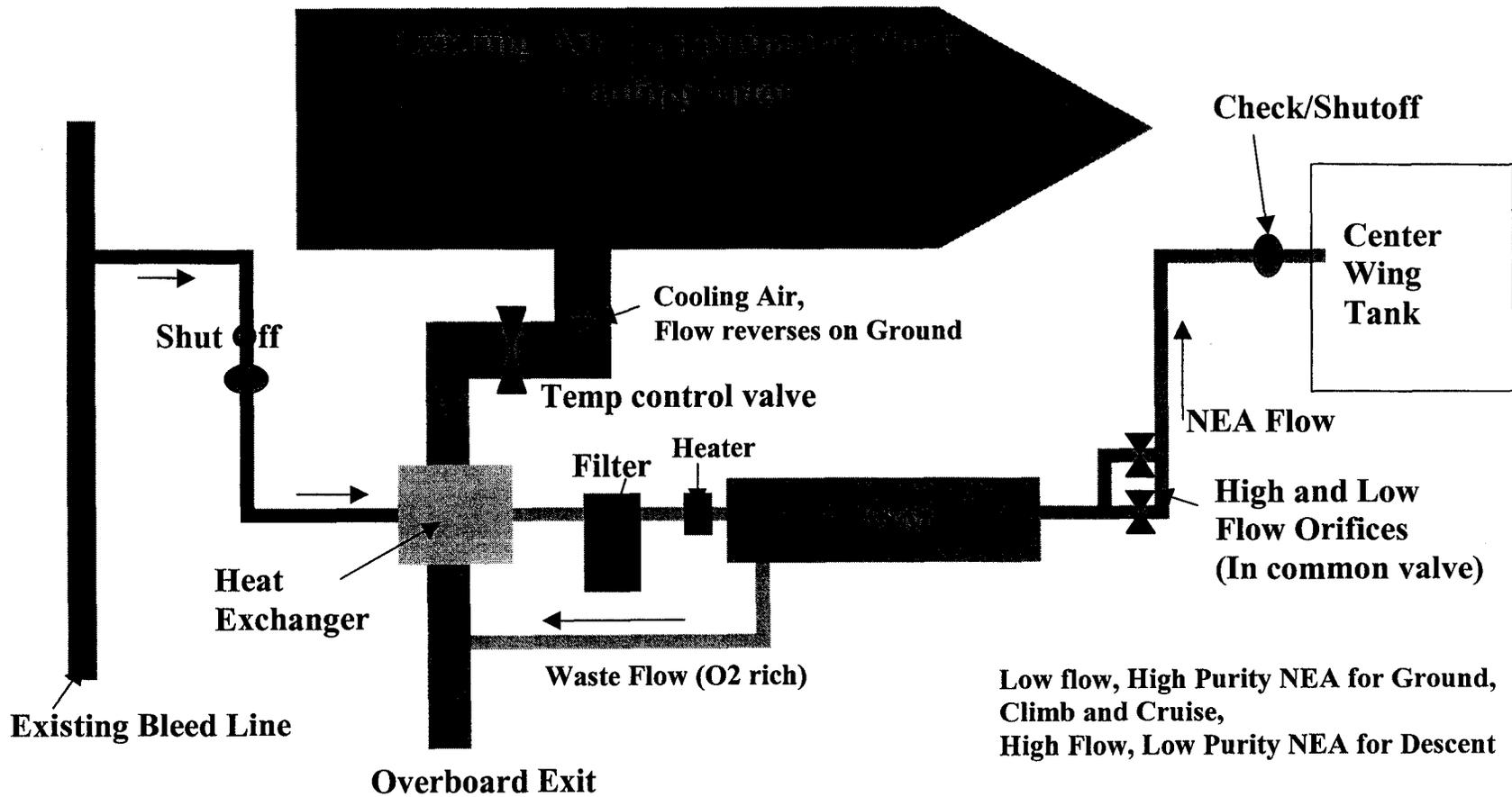


Nicholas A. Sabatini  
Associate Administrator  
for Regulation and Certification

Enclosure

cc: Mr. Albert Prest

# Simplified Onboard Inert Gas Generating System Full Time Fuel Tank Inerting



## FAA Action to Address Fuel Tank Inerting Harmonization Working Group Issues with OBIGGS

Fuel Tank Harmonization Working Group Issue	FAA Action to Reduce Cost
<p>No bleed air available to supply nitrogen separator modules, although no data was provided by the working group or in the report. Therefore, working group determined an electric motor driven air compressor was required. (High electrical load, many moving parts therefore high maintenance costs)</p>	<p>Developed simplified OBIGGS and determined nitrogen separation membranes could inert a transport airplane fuel tank with a flow rate that is too low to calculate any affect on bleed air supply.</p>
<p>Complex nitrogen distribution manifold design using computerized fluid dynamics. The manifold would be installed inside fuel tanks that would uniformly inert each tank compartment. Working group estimated it would require 7 - 10 days of dedicated airplane down time to install on inservice airplanes, resulting in high cost to lease airplanes to replace capacity. Testing of prototype during FAA-Boeing ground based inerting flight test program demonstrated it used more nitrogen to inert a tank that did a similar manifold during lab testing at FAA Technical Center.</p>	<p>Constructed a simple plywood model of the 747SP center wing tank. Testing concluded that a single point inerting nozzle (single tank penetration) was more efficient than the complex distribution manifold. Full scale testing of the simplified manifold on the FAA 747SP ground test airplane demonstrated the single point nozzle not only significantly reduces engineering and installation cost, it uses far less nitrogen than the complex distribution manifold design developed used for the working group cost estimates. A fuel tank service company using standard aerospace practices installed the single nozzle in one day.</p>
<p>Complex designs with motor driven compressor have many moving components resulting in low system reliability.</p>	<p>Simplified OBIGGS has very few moving parts - only the variable flow valve and possibly a cooling fan for heat exchanger operation when on the ground.</p>
<p>Hybrid OBIGGS: Approximately 400 lb. for Large Transport Airplane</p>	<p>Simplified OBIGGS: Approximately 100 pounds (or less) for Large Transport Airplane.</p>
<p>Calculated benefit of inerting reduced by using high benefit for ignition prevention under SFAR 88 preventing accidents.</p>	<p>Industry is finding it difficult to obtain the high estimated benefits they predicted they could achieve with ignition prevention under SFAR 88.</p>

## **Recommendation**



# Aviation Rulemaking Advisory Committee Fuel Tank Inerting Harmonization Working Group

Submitted jointly by:

AEA, AECMA, AIA,  
Air Liquide, ALPA, API, ATA,  
FAA, IAM, JAA, and NADA/F

## Final Report

February 2002



Association of European Airlines

*NATIONAL AIR DISASTER  
ALLIANCE/FOUNDATION*



European Association  
of Aerospace Industries



Air Transport Association of America



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## GLOSSARY

AC	advisory circular
AD	Airworthiness Directive
AEA	Association of European Airlines
AECMA	European Association of Aerospace Industries
AIA	Aerospace Industries Association
ALPA	Airline Pilots Association
API	American Petroleum Institute
APU	auxiliary power unit
ARAC	Aviation Rulemaking Advisory Committee
ASM	air separator module
ASTM D	an ASTM test designation
ASTM	American Society for Testing and Materials
ATA	Air Transport Association of America
ATB	air turnback
BITE	built-in test equipment
CBT	computer-based training
CFR	Code of Federal Regulations
CMR	certification maintenance requirement
CRC	Coordinating Research Council
CWT	center wing tank
DDG	dispatch deviation guide
DOT	Department of Transportation
EPA	Environmental Protection Agency
ER	extended range
ERA-7	an additive for CO <sub>2</sub> -enriched fuel
ETOPS	extended twin operations
FAR	Federal Aviation Regulation
FHA	functional hazard analysis
FTHWG	Fuel Tank Harmonization Working Group
FTIHWG	Fuel Tank Inerting Harmonization Working Group
GBI	ground-based inerting
GBIS	ground-based inerting system
GN <sub>2</sub>	gaseous nitrogen
GPM	gallons per minute
HCWT	heated center wing tank
HWG	Harmonization Working Group
IAMAW	International Association of Machinist Aerospace Workers
IATA	International Air Transport Association
JAA	Joint Airworthiness Authorities
JAR	Joint Aviation Requirements

LFL	lower flammability limit
MEL	minimum equipment list
MMEL	master minimum equipment list
MO	modification order
MSG-3	Maintenance Steering Group—Version 3
MTBF	mean time between failures
MTBMA	mean time between maintenance actions
MTBUR	mean time between unscheduled removal
NEA	nitrogen-enriched air
NIOSH	National Institute of Occupational Safety and Health
NPRM	Notice of Proposed Rulemaking
NSF	nitrogen-saturated fuel
NTSB	National Transportation Safety Board
OBI	onboard ground inerting
OBGIS	onboard ground inerting system
OBI	onboard inerting
OBIGGS	onboard inert gas generating system
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
p/m	parts per million
PRV	pressure-regulating valve
PSA	pressure-swing adsorption
SB	service bulletin
SCF	standard cubic feet
SCFM	standard cubic feet per minute
SFAR	Special Federal Aviation Regulation
TC	type certificate
TCAS	traffic collision avoidance system
UFL	upper flammability limit
VOC	volatile organic compound



## **1.0 EXECUTIVE SUMMARY**

### **1.1 OVERVIEW**

This report presents the findings of the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Inerting Harmonization Working Group (FTIHWG). The ARAC and its working groups cooperate to bring the expertise of the aviation industry, regulatory agencies, and public interest groups together to study specific subjects. The primary motivation of the FTIHWG is to save lives by enhancing airplane safety in an effective and practical manner.

The FAA tasked ARAC to provide a report recommending regulatory text and data needed by the FAA to evaluate options for new rulemaking requiring the elimination or significant reduction of flammable vapors through fuel tank inerting of transport-category airplanes. The FTIHWG studied several fuel tank inerting concepts. Fuel tank inerting is a method of reducing the oxygen concentration within fuel tanks to decrease the risk of explosions. Using methodology patterned after accepted FAA economic analysis practices, the FTIHWG found that none of these systems produced benefits, at present technology maturity levels, that were reasonably balanced by their costs.

The requested data is contained in this report. However, the FTIHWG is not recommending proposed regulatory text because this study was unable to identify any practical way of implementing the inerting designs studied.

Consequently, FTIHWG recommends that the FAA, NASA, and aviation industry conduct further research with an objective of developing more viable solutions for reducing fuel tank flammability much sooner than any of the inerting concepts evaluated could be implemented.

### **1.2 INTRODUCTION**

The FTIHWG—the author of this report—has built upon the work of the 1998 Fuel Tank Harmonization Working Group (FTHWG), which assessed a broad range of methods to improve fuel tank safety through reduced flammability exposure. The FTHWG in its 1998 final report recommended that the FAA investigate further the feasibility of what it then identified as the two most promising methods:

- Directed ventilation.
- Fuel tank inerting.

The FAA chose to evaluate directed ventilation internally and tasked the ARAC with evaluating fuel tank inerting, leading to the formation of the FTIHWG. The FAA Tasking Statement requested that this HWG define and evaluate fuel tank inerting design concepts that would eliminate or significantly reduce the development of flammable vapors in fuel tanks. The FTIHWG was given 12 months to complete this assignment and prepare this final report.

Within this report is a comprehensive evaluation of the technical, safety, and economic merits of ground-based and onboard fuel tank inerting systems for in-service, current production, and new type design transport-category airplanes.

This ARAC study includes results of ongoing work being performed by the FAA under its internal fuel tank inerting research program. This FAA research covers the evaluation of the latest-available nitrogen generating technologies, research into fuel flammability, and various methods of inerting fuel tanks. Also covered in this report is the ground and flight-test program completed by the FAA and industry in early 2001, which provided essential data for this report.

### **1.3 SYSTEMS EVALUATED**

The three basic inerting design system concepts addressed by the FTIHWG are

- Ground-Based Inerting (GBI)—a system using ground-based nitrogen gas supply equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to unheated wing tanks. The affected fuel tanks would be inerted once the airplane reaches the gate and is on the ground between flights.
- Onboard Ground-Inerting (OBGI)—an onboard system that uses nitrogen gas generating equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to an unheated wing tank. The affected fuel tanks will be inerted while the airplane is on the ground between flights.
- Onboard Inert Gas Generating System (OBIGGS)—a system that uses onboard nitrogen gas generating equipment to inert all the fuel system’s tanks so that they remain inert throughout normal ground and typical flight operations.

In addition to these three basic design concepts, derivative combinations of OBGI and OBIGGS were also studied. They are described as “hybrid systems” in this report.

### **1.4 FTIHWG STRUCTURE**

To manage and accomplish the requirements established by the FAA Tasking Statement, the FTIHWG established three primary task teams:

- Ground-Based Inerting Design (GBI).
- Airport Facilities (for GBI).
- Onboard Inerting Design (OBGI, OBIGGS, hybrid systems).

In addition, five support task teams were created:

- Airplane Operations and Maintenance.
- Estimating and Forecasting.
- Safety.
- Rulemaking.
- Integration.

### **1.5 SCOPE AND ASSUMPTIONS**

The overall mission of the FTIHWG has been to determine whether safety enhancement through fuel tank inerting systems is practical. If not, this body was asked to propose research programs that would lead to a practical system.

The task teams included representatives from U.S. and non-U.S. companies from a variety of fields (e.g., commercial airlines, major and general aviation manufacturers, petroleum refiners, industrial gas suppliers, public interest groups). These experts worked closely to devise a practical inerting system.

As defined in the Tasking Statement, the FTIHWG based its work on the assumption that the proposed fuel tank inerting systems are not considered flight critical and, therefore, airplanes may be dispatched with the system inoperative. This assumption is fundamental to the technical and cost conclusions of this report.

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For the purposes of this study, it was assumed that the resources would be made available as needed to implement a desirable inerting system. Further studies would be needed to assess the effect of the unavailability of industrial capacity, personnel, or any other resources needed to implement an inerting system.

During the study period, some 70 experts spent more than 50,000 hr evaluating a large number of fuel tank inerting options and design concepts together with the effects these systems would have if implemented in the existing fleet as well as airplanes yet to be designed. Areas specifically evaluated for resultant effects were safety (measured in the anticipated preclusion of future accidents), regulation, airplane configuration, airport infrastructure, and flight and maintenance operations. Underlying this exhaustive effort were a single defined set of *study ground rules* that were used by all participants to ensure that each team worked consistently and was aware of the requirements in all other areas.

When completed, the above efforts yielded a detailed body of knowledge that allowed the FTIHWG to draw informed conclusions based on data and analysis. These conclusions and recommendations specifically address the technical limitations of inerting, its potential benefits and hazards, and the relative costs of implementing inerting versus its projected benefits (i.e., cost-benefit analysis) as described below and in the body of this report.

## 1.6 TECHNICAL EVALUATIONS

Figure 1-1 summarizes the technical evaluation of each of the inerting system concepts considered by the FTIHWG.

<p><b>1. Ground-Based Inerting (GBI)</b></p> <p><b>Concept</b> Center wing tanks (heated or unheated) and auxiliary fuel tanks are purged at the gate with nitrogen-enriched air (NEA) from an airport supply. Airplanes are equipped with a dedicated NEA service panel and manifold connected to a series of outlets inside the appropriate tank(s), thereby inerting the ullage (air space above the liquid fuel). Large transports take 30 minutes to inert, medium transports 25 minutes, and small transports 20 minutes.</p> <p><b>Advantages</b> Simple, reliable, lightweight onboard equipment (tubes, etc.). Standard approach: every airplane supplied with NEA 1.7 times the maximum ullage volume. Service technician identifies airplane model and injects prescribed NEA volume.</p> <p><b>Disadvantages</b> Dependent on dedicated airport supply system for NEA. Not inert after landing and until after ground servicing is completed. Ullage oxygen level increases during cruise, and—depending on initial fuel load—can exceed inert limits. Supply pressure varies by airplane type. Poses confined-space hazard to ground service personnel. New worldwide standard would be needed for interface and regulating equipment. Requires vent system changes for large portion of fleet.</p> <p><b>Other issues</b> Dedicated, trained ground personnel needed. Impact on overall ground servicing operations (fuel, catering, baggage, cargo, etc.). Bigger impact will be on the airport infrastructure than on the airplane/airlines. Potential environmental issues from venting tanks overboard.</p>
<p><b>2. Onboard Ground Inerting (OBGI)</b></p> <p><b>Concept</b> Same as 1 above except airplane uses onboard equipment to generate NEA. Only operates on the ground. Time to inert a large transport: 60 minutes.</p> <p><b>Advantages</b> Airplane is self-sufficient. A better solution for flights into airports with no airport NEA supply.</p> <p><b>Disadvantages</b> Takes longer after landing to reach inert levels and may impact airplane turn time. Provides limited protection during flight cycle depending on flight duration. System is heavy, bulky, and requires external dedicated electrical power supply. System and component reliability is poor. Confined space hazard to ground support personnel.</p> <p><b>Other issues</b> Air inlet and exhaust for compressor and heat exchangers require airplane hull penetrations. Pipes must be shrouded (double-walled pipes where they enter the pressure hull to prevent filling the cabin with nitrogen gas in the event of a leak). Introduces new hazard exposure (very small) to crew and passengers. Insufficient space to retrofit aboard most current in-service and new production airplanes.</p>
<p><b>3. Onboard Inert Gas Generating Systems (OBIGGS)</b></p> <p><b>Concept</b> Airplane uses onboard equipment to generate NEA. Operates throughout the flight, keeping the fuel tanks inert.</p> <p><b>Advantages</b> Airplane is self-sufficient and thus not dependent on airports for NEA. Fuel tanks are actively inerted throughout ground and flight operations unless system is impacted by reliability.</p> <p><b>Disadvantages</b> Demands more electrical power and high-pressure engine bleed air than is available on most airplanes. Weight and size aboard airplane much greater than for GBI. Draws exhausted cabin air as a source, increasing pressurization system maintenance burden. System and component reliability is poor. Introduces new hazard exposure to crew and passengers (very small).</p> <p><b>Other issues</b> Shrouded pipes in the pressure hull. Mechanically very complex. Insufficient space available for installation aboard most in-service and current production airplanes.</p>
<p><b>4. Hybrid Systems</b></p> <p><b>Concept</b> These are variations of 2 and 3 that have been simplified in an effort to reduce weight, volume, power demands, and air consumption. Two systems are under consideration:</p> <ul style="list-style-type: none"> <li>• Hybrid OBGI system.</li> <li>• Hybrid OBIGGS (a scaled-down version of the full system).</li> </ul> <p><b>Advantages</b> Smaller, lighter; less expensive than OBGI and OBIGGS.</p> <p><b>Disadvantages</b> More time required to inert the fuel tanks; complex; limited system and component reliability; weight and space requirements for retrofit.</p>

Figure 1-1. Technical Summary of Inerting System Concepts

## **1.7 TECHNICAL LIMITATIONS**

The FTIHWG concluded that several major technical limitations and airport infrastructure obstacles must be overcome before a practical fuel tank inerting system could be implemented.

1. The technical limitations/airport infrastructure obstacles for GBI for in-service, in production, and new type design (i.e., future) airplanes are
  - Development and construction of fixed inerting equipment for large airports and medium-sized airports.
  - Development and production of mobile inerting vehicles.
  - Development of a worldwide industry standard for the nozzle, interface panel configuration, and control system that connects the airplane and inerting equipment to deliver the appropriate amount of nitrogen to the airplane fuel tank.
2. The technical limitations for OBI and OBISS inerting systems on in-service and in-production airplanes are that they
  - Demand more engine/airplane bleed air to operate than is available.
  - May demand more airplane electrical power to operate than is available.
  - Take up more space (volume) than might be available on most airplane types (a problem that increases as airplane size decreases); appropriate locations may not exist.
  - Have components that demonstrate low reliability and high failure rates at current technology levels.
3. Future airplane types can be designed with adequate bleed air, electrical power, and volume for OBI and OBISS systems, so the technical limitation of these inerting systems on future airplane types will be
  - The low-reliability/high failure rate of their current-technology components unless mitigated by the application of future technological breakthroughs.

## **1.8 BENEFITS**

The benefit of a safety enhancement system like inerting is avoided accidents resulting in lives saved and prevention of airplane and property destruction. Analyses performed by the FTIHWG established the estimated levels of this potential benefit that fleetwide inerting would achieve.

For this study, six commercial airplane categories were defined and generic models were created with fuel system characteristics as closely representative as possible of today's in-service fleet and current production models. Figure 1-2 summarizes the fleetwide flammability exposure of these generic-study-category airplanes.

	Large transport, 275 passengers	Medium transport, 195 passengers	Small transport, 117 passengers	Regional turbofan, 44 passengers	Regional turboprop, 31 passengers	Business jet, 7 passengers
Baseline fuel tank flammability—no inerting system, %						
Unheated CWTs (no adjacent heat sources)	6.8	No unheated CWT	5.1	2.6	No CWT	No CWT
Heated CWT (with adjacent heat sources)	36.2	23.5	30.6	No HCWT	No HCWT	No HCWT
Main wing tanks	3.6	2.4	3.6	1.6	0.7	1.6
Fuel tank flammability—with an operative inerting system, %						
Ground-based inerting (heated CWTs)	4.9	2.0	5.2	No HCWT	No HCWT	No HCWT
Onboard ground inerting (heated CWTs)	7.0	1.4	5.8	No HCWT	No HCWT	No HCWT
Hybrid OBIGGS (heated CWTs)	0.9	0.6	0.3	No HCWT	No HCWT	No HCWT
OBIGGS (all tanks)	~0	~0	~0	NA	NA	NA

\*Due to the estimated low reliability of these onboard systems, the fleet exposure when including inoperative systems would be 2% to 3% higher.

Figure 1-2. Flammability Exposure—Generic In-Service and Current Production Airplanes

Fleetwide flammability exposure is a measure of the percentage of the airplane operating hours during which the fuel tank analysis indicates a flammable fuel/air mixture would exist. A Monte Carlo-type simulation was used to estimate these percentages. The figure includes the estimated flammability exposure levels for current unmodified (baseline) and modified flammability percentages.

In estimating accidents avoided, the passenger counts for each of these six generic airplanes were derived based on the average number of passenger and crew seats for actual airplane type in that study category. This value was then factored by load factors (percentage of passenger seats expected to be filled) taken from the *FAA Aviation Forecasts Fiscal Years 2001-2012*.

Figure 1-3 shows the accidents anticipated to be avoided through implementation of each of the three basic inerting system design concepts. Avoided accidents are a function of the flammability exposure values and the number of hours flown by all airplanes in each of the generic airplane categories over the evaluation period. For the purpose of the cost-benefit study described below, a 16-year evaluation period was used. Although a 10-year evaluation period had been used in the 1998 ARAC study and the FAA ground-based inerting study, a 16-year period was chosen for this study because of the significant time that is required to design and achieve full fleet incorporation of these inerting system design concepts.

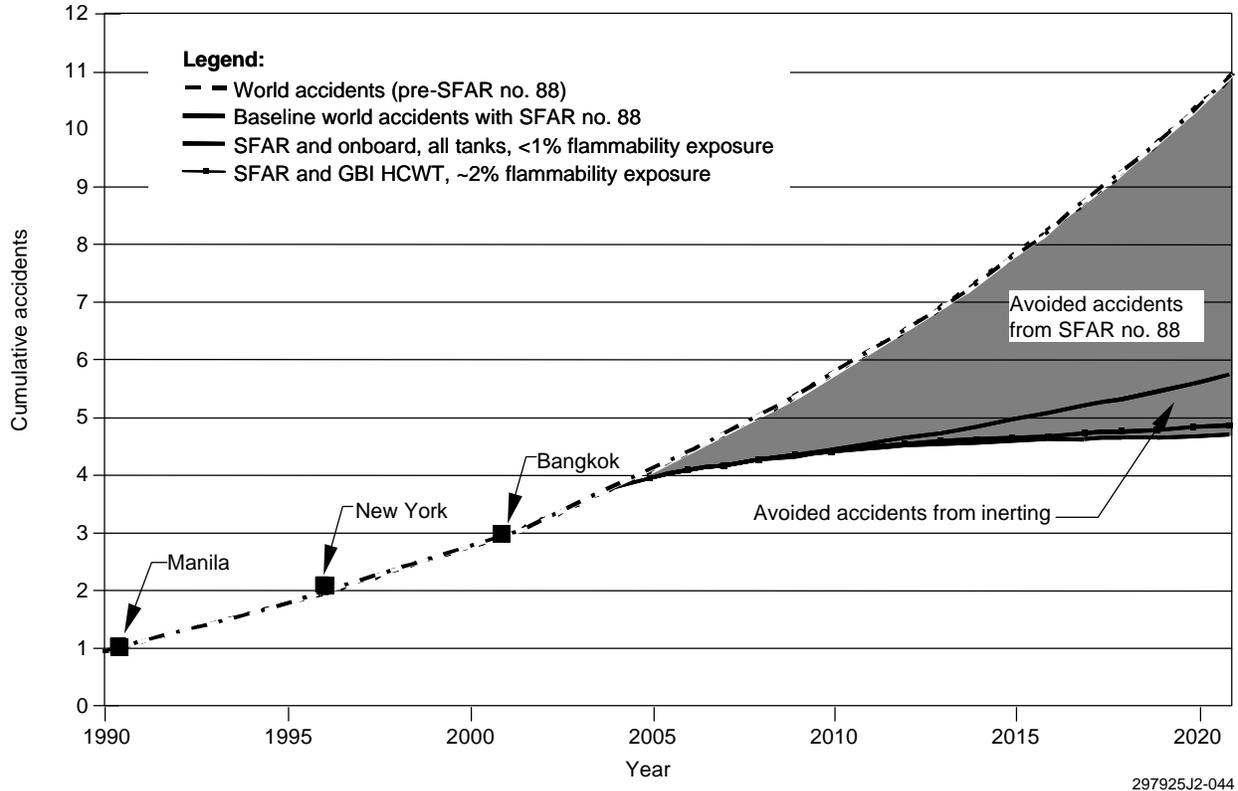


Figure 1-3. Worldwide Forecast Cumulative Accidents

The evaluation period begins in the first quarter of 2005 on the assumption that a rule change requiring fuel tank inerting would be effective at that time. Inerting systems for all applicable airplanes would be designed and certified by the first quarter of 2008 and all applicable airplanes would be modified by the first quarter of 2015. The evaluation period ends in the last quarter of 2020.

In figure 1-3 the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR no. 88. The 75% reduction had been estimated by the 1998 ARAC FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

The dotted line on figure 1-3 shows the estimated cumulative worldwide fuel tank explosion accident rate for a period 1990 through 2020. The three data points shown in the figure are actual accidents. The first two are confirmed to have resulted from fuel tank explosions while the third is suspected but has not yet been formally confirmed as such.

The estimated reduction in the accident rate resulting from SFAR no. 88 appears as a heavy black line. The third line down shows the further estimated improvement if a GBI system for inerting heated center wing tanks (CWT) were installed in the fleet. The fourth line down shows the estimated improvement if an OBIGGS system inerting all fuel tanks were adopted fleetwide. Thus, the estimated cumulative accident reductions attributable to GBI or OBIGGS are the difference between the SFAR line and those for GBI and OBIGGS.

The team evaluated accidents provided by the 1998 ARAC FTHWG study, plus the 2001 Bangkok accident, and agreed that the three most recent events (Manila 1990, New York 1996, and Bangkok 2001) should form the basis for statistically forecasting future events. These accidents each involved an explosion of the heated CWT, and the ignition source is unknown.

Figure 1-4 shows that the estimated number of avoided accidents with each inerting system design concept is approximately 1 accident (0.77 to 1.03) for the worldwide fleet in the 16-year evaluation period. Statistically, one fuel tank explosion in the 16-year evaluation period would result in approximately 1% of all fatalities from commercial airplane accidents forecast over that period. If these inerting system design concepts are fully implemented, after the implementation a ground-based system would likely prevent one fuel tank explosion in 10 years and an OBIGGS would likely prevent one fuel tank explosion in 8 years for the worldwide fleet.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet	Total
Ground-based inerting (HCWT only)	0.24	0.9	0.54	No HCWT	No HCWT	No HCWT	0.87
Onboard ground inerting (HCWT only)	0.20	0.9	0.48	No HCWT	No HCWT	No HCWT	0.77
Hybrid OBIGGS (HCWT only)	0.24	0.9	0.58	No HCWT	No HCWT	No HCWT	0.91
OBIGGS (all tanks)	0.28	0.12	0.63	NA	NA	NA	1.03

*Figure 1-4. Estimated Cumulative Worldwide Avoided Accidents, 2005 Through 2020*

The estimated number of avoided accidents for the U.S. fleet (“N” registered airplanes) would be approximately 46% of the projected accidents avoided worldwide. It is estimated that for the same time period a ground-based design system concept would likely prevent one fuel tank explosion in 19 years and the OBIGGS would likely prevent one accident in 16 years for the U.S. fleet.

Based on this analysis, an estimate could be made of the expected number of lives that might be saved through prevented fuel tank explosions and postcrash fires during the evaluation period from 2005 to 2020. Using the above process, it is estimated that once either a GBI or OBIGGS system is fully implemented in the fleet, the accumulated fractional number of prevented fatalities over the 16-year evaluation period would be 132 for GBI and 253 for OBIGGS from in-flight and ground fuel tank explosions and postcrash fires.

**1.9 HAZARDS**

Nitrogen is a colorless, odorless, nontoxic gas that is impossible for human senses to detect when excessive concentrations displace the oxygen normally present in the air. Depending on the degree of oxygen depletion, the effects of breathing nitrogen-enriched air (NEA) range from decreased ability to perform tasks to loss of consciousness and death. Fuel tank inerting procedures would include stringent measures to minimize these hazards. The risks would exist wherever gaseous or cryogenic nitrogen is handled in the global aviation infrastructure.

The FTIHWG lacks the expertise to assess these risks with confidence. However, a simple extrapolation of available data from the Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) would suggest a rate of 1.4 to 4.7 fatalities per year worldwide. Based on assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that from 24 to 81 lives may be lost over the 2005–2020 study period as a result of this hazard.

**1.10 COST-BENEFIT ANALYSIS**

Figure 1-5 shows the present value estimate of inerting system total costs and monetary value of the benefits gained by introducing each of the three basic inerting design system concepts. The benefits were calculated by multiplying the annual number of avoided accidents (presented as fractional values) by the accident cost and then discounting these values by a net discount rate of 7% to the year 2005, which is the beginning of the evaluation period. The accident costs were estimated using established Department of Transportation (DOT) values. The benefits also include the monetary value of lives saved in postcrash fires. They do not include the cost of lives lost due to the hazards of inerting. The total cost for each inerting system includes the cost for in-service, current production, and new type design airplanes. There is little difference in cost between in-service and current production airplanes, except for the 20% to 30% higher installation costs for the retrofit airplanes and the associated airplane downtime. Also, with today’s technology, there is little difference in the cost between current production and new type design airplanes.

	Benefits (\$US billion)	Cost (\$US billion)	Cost-benefit ratio
GBI (HCWT only)	0.245	10.37	42.3:1
OBGI (HCWT only)	0.219	11.60	52.9:1
Hybrid OBIGGS (HCWT only)	0.257	9.90	38.5:1
OBIGGS (all tanks)	0.441	20.78	47.1:1

*Figure 1-5. Cost-Benefit Analysis Results, Worldwide Fleet, 2005 Through 2020, Based on Present Value in Year 2005 \$US*

The benefits shown in figure 1-5 have been calculated on the basis of a 75% reduction in projected fuel tank explosions due to SFAR no. 88. If the actual reduction in fuel tank explosions due to SFAR no. 88 proves to be less than 75%, then the benefits from inerting would be proportionally greater, and vice versa.

**1.11 OVERALL CONCLUSION**

The FTIHWG has concluded that the current technology of GBI, OBGI, and OBIGGS cannot meet the desired evaluation criteria for a fuel tank inerting system. This conclusion was reached collaboratively by many involved aviation and industry experts who, after intensive efforts, could not devise a practical, timely, and cost-effective method of proposing a fuel tank inerting design concept as a viable solution based on the Tasking Statement guidelines.

The FAA Tasking Statement for this ARAC FTIHWG study requested that this Working Group provide recommended regulatory text for new rulemaking based on the lowest flammability level that could be achieved by an inerting system design concept that would meet the FAA regulatory evaluation requirements. These evaluation requirements include a cost-benefit analysis similar to the analysis performed in this study. Because this study was unable to identify any practical way of implementing the inerting design concepts studied, the FTIHWG concluded that they could not recommend regulatory text based on the flammability level of an inerting system.

The FTIHWG also concluded that if a GBI system is considered for implementation, it will be necessary, before promulgating an airplane requirement, to resolve the current lack of global regulatory authority and industry control over the introduction and construction of new airport inerting supply systems, fixed or mobile.

Consequently, this FTIHWG has also concluded that the FAA, NASA, and the industry must continue to work cooperatively to research methods to reduce fuel tank flammability exposure that can be introduced much sooner than any of the inerting concepts. They should also pursue further basic research into technical breakthroughs in fuel tank inerting system design concepts as well as alternative concepts to improve the fuel tank safety of existing and future airplane designs.

## **1.12 RECOMMENDATIONS**

The ARAC FTIHWG specifically recommends the following actions to be expeditiously carried out by the FAA, NASA, and the industry:

### *Inerting Systems*

- Continue to evaluate and, where appropriate, investigate means to achieve a practical onboard fuel tank inerting system design concept for future new type design airplanes.
- Pursue technological advancements that would result in onboard fuel tank inerting designs having decreased complexity, size, weight, and electrical power requirements, and increased efficiency, reliability, and maintainability.
- Perform NEA membrane research to improve the efficiency and performance of membranes resulting in lower non-recurring costs of NEA membrane air-separation systems. For example, basic polymer research to increase the operational temperature of membranes to a level above 302°F.
- Conduct basic research into high-efficiency, vacuum-jacketed heat exchangers, and lighter, more efficient cryogenic refrigerators for use in inerting systems.
- If a practical means of achieving a cost-beneficial fuel tank inerting system is found, establish a corresponding minimum flammability level and reevaluate and propose regulatory texts and guidance materials accordingly.

### *Fuel Tank Flammability*

- Evaluate means to reduce fuel tank flammability based on existing (e.g., directed ventilation, insulation) or new technology that might be introduced sooner into the in-service fleet and current airplane production.
- Initiate a project to improve and substantiate current flammability and ignitability analyses to better predict when airplane fuel tank ullage mixtures are flammable. This research is needed to support informed design decisions and rulemaking.
- Initiate a project to thoroughly document and substantiate the flammability model used in this study.

## **1.0 EXECUTIVE SUMMARY ADDENDUM**

At the August 8, 2001 ARAC Executive Committee meeting the FTIHWG was asked to include additional information in this report. The requested information is included within this addendum to the Executive Summary. This addendum includes: a) a summary of the cost-benefit sensitivity analysis, b) the letter written by the FAA's representative to the FTIHWG co-chairmen, c) the FTIHWG co-chairmen's response to the FAA letter and d) questions from the ARAC Executive Committee members and the FTIHWG's responses.

### Summary of the Cost-Benefit Sensitivity Analysis

After the June 2001 report was finalized, the FAA's Working Group member sent a letter to the Co-Chairs of the Working Group requesting that certain previously raised FAA questions about some of the assumptions used in the study be documented in the report. To address those concerns, the working group conducted a sensitivity analysis to evaluate the effects of changing some assumptions. This analysis evaluated the effects of: SFAR 88 benefits, labor hours and productivity, number of airports with an inerting systems installed, airplane operational data, delay costs, retrofit implementation and ground vs in-flight accident rates. The sensitivity analysis was conducted on the Ground Based Inerting (GBI) and the hybrid On-Board Inert Gas Generating System (OBIGGS) system. For the GBI system, the Net Present Value (NPV) costs to US operators ranged from \$4.2 Billion (\$US) to \$5.0 Billion. The Benefits ranged from \$69 Million to \$282 Million. For the hybrid OBIGGS system, the NPV cost to US operators ranged from \$3.7 Billion to \$4.4 Billion. The benefits ranged from \$73 Million to \$300 Million. None of these results were sufficient to change the working group's conclusions or recommendations.

Additional effects that were not considered in the sensitivity analysis: selective ground based inerting (decreases costs), flight cancellation costs (increases cost), cost of gate turn-time increases (increases cost), cost of no MMEL relief (increases cost), airport equipment depreciation and replacement costs (increases cost), airline spare parts provisioning costs (increases cost), value of lives lost in inerting accidents (decreases benefits).

Baseline assumptions for GBI assume that SFAR 88 changes are fully implemented by 2007 and give a 75% reduction in accident rate (value from 1998 ARAC and the lower of the two values proposed in the SFAR NPRM). The cost of ground operations assumes that dedicated personnel accomplish the inerting process and that large airplanes take 30 minutes, medium airplanes take 25 minutes and small airplanes take 20 minutes to inert. The baseline case assumes that the inerting labor is 100% efficient, that is, there is no idle time for the inerting crews. It assumes that all B, C and D airports would get some form of an inerting system. The airplane operational costs use the weight penalty developed in the 1998 ARAC study, which accounts for weight and fuel volume limited take-offs. The operational costs also assume that the cost of the first 30 minutes of each delay is discounted. The baseline implementation plan assumes that 70% of retrofits are done during a heavy check. The baseline benefit calculation assumes that 15% of the future accidents occur on the ground (this is consistent with calculated flammability exposure time). With these assumptions, the baseline NPV cost to US operators is \$4.8 Billion and the benefit is \$95 Million for a cost-benefit ratio of 50:1.

The first sensitivity case evaluates the effects making the following assumptions: Assume that SFAR 88 changes are delayed until 2010 and are only 25 percent effective in reducing fuel tank accidents. Assume that it only takes 10 minutes per airplane to accomplish

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inerting at large and medium airports and \$10 per airplane to accomplish inerting at small airports (values proposed in an FAA study). Assume that inerting equipment is installed only at airports currently serviced by airplanes with 100 passengers or more (175 fewer airports than the baseline case). Assume that there are no weight or fuel volume limited take-offs. The combination of these assumptions lowers the NPV cost to \$4.2 Billion and increases the benefit to \$282 Million for a cost-benefit ratio of 15:1. **Figure 1** shows the baseline costs and benefit compared to these adjusted values.

The second sensitivity case evaluates the effects of making the following assumptions: Assume that SFAR changes are implemented by 2007 (baseline) and these changes reduce the accident rate by 90% (high value used in SFAR 88 NPRM). Assume that the labor productivity for the inerting personnel is to 70%. Assume that the full delay costs (per ATA study) are incurred. Assume that 70% of the retrofits are accomplished outside of a heavy check. Assume that 1 out of 3 future accidents occur on the ground (historical rate). These assumptions increase the NPV cost to \$5.0 Billion and decrease the benefit \$69 Million for a cost-benefit ratio of 73:1. **Figure 2** shows the baseline costs and benefit compared to these adjusted values.

The baseline Assumptions for Hybrid OBIGGS are as follows: Assume that the SFAR 88 changes are fully implemented by 2007 and give a 75% reduction in accident rate (value from 1998 ARAC and the lower of the two values in the SFAR NPRM). Apply the weight penalty developed in 1998 ARAC study, which accounts for weight and fuel volume limited take-offs. Assume that the first 30 minutes of each delay is not discounted. Assume that 70% of retrofits are done during a heavy check. Assume that 15% of the future accidents occur on the ground (this is consistent with calculated flammability exposure time). These assumptions give a baseline cost of \$4.16 Billion for US operators and a benefit of \$101 Million, for a cost-benefit ratio of 41:1.

The third sensitivity case evaluates the effects of making the following assumptions: Assume that the benefits of full implementation of SFAR 88 delayed until 2010, and only 25 percent effective in reducing fuel tank accidents. Assume that there is no weight or fuel volume limited take-offs. The combination of these assumptions lowers the NPV cost to \$3.7 Billion and increased the benefit to \$300 Million for a cost-benefit ratio of 12:1. **Figure 3** shows the baseline costs and benefit compared to these adjusted values.

The fourth sensitivity case evaluates the effects of making the following assumptions: Assume SFAR 88 changes are implemented by 2007 (baseline) and these changes reduce the accident rate by 90% (high value used in SFAR 88 NPRM). Use the full delay costs per ATA study. Assume that 70% of the retrofits are accomplished outside of a heavy check. Assume that 1 out of 3 future accidents occur on the ground (historical rate). These assumptions increase the cost to \$4.46 Billion and decrease the benefit to \$73 Million for a cost-benefit ratio of 61:1. **Figure 4** shows the baseline costs and benefit compared to these adjusted values.

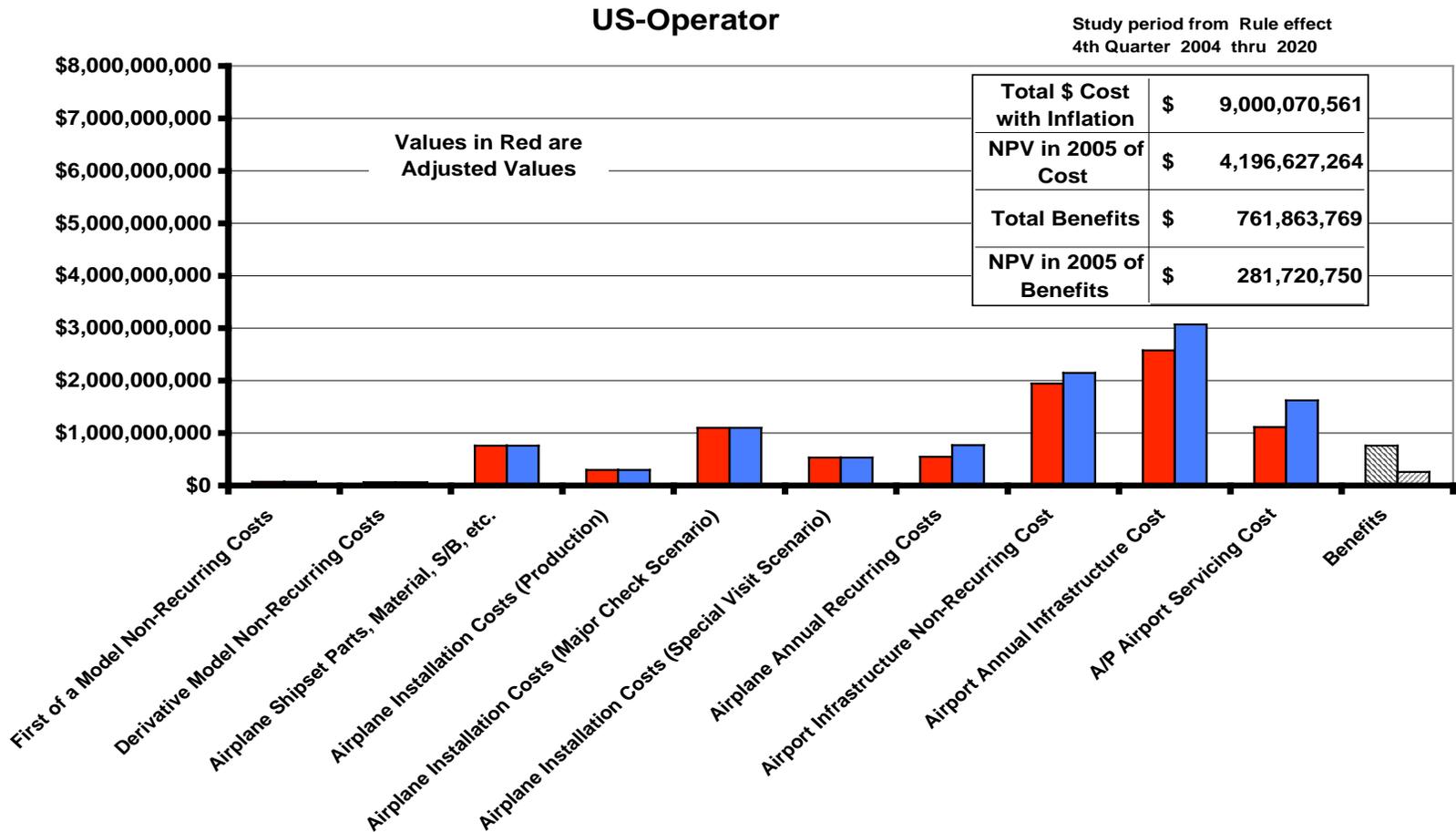
**SENSITIVITY ANALYSIS CONCLUSIONS**

Every attempt was made to fairly represent the technical requirements, estimated costs and safety benefits, and regulatory matters. The baseline cost-benefit analysis represents a balanced approach to the uncertainties in the study assumptions.

Cost Benefit Ratio  
Decreased to 15:1

# Figure 1 Sensitivity Analysis

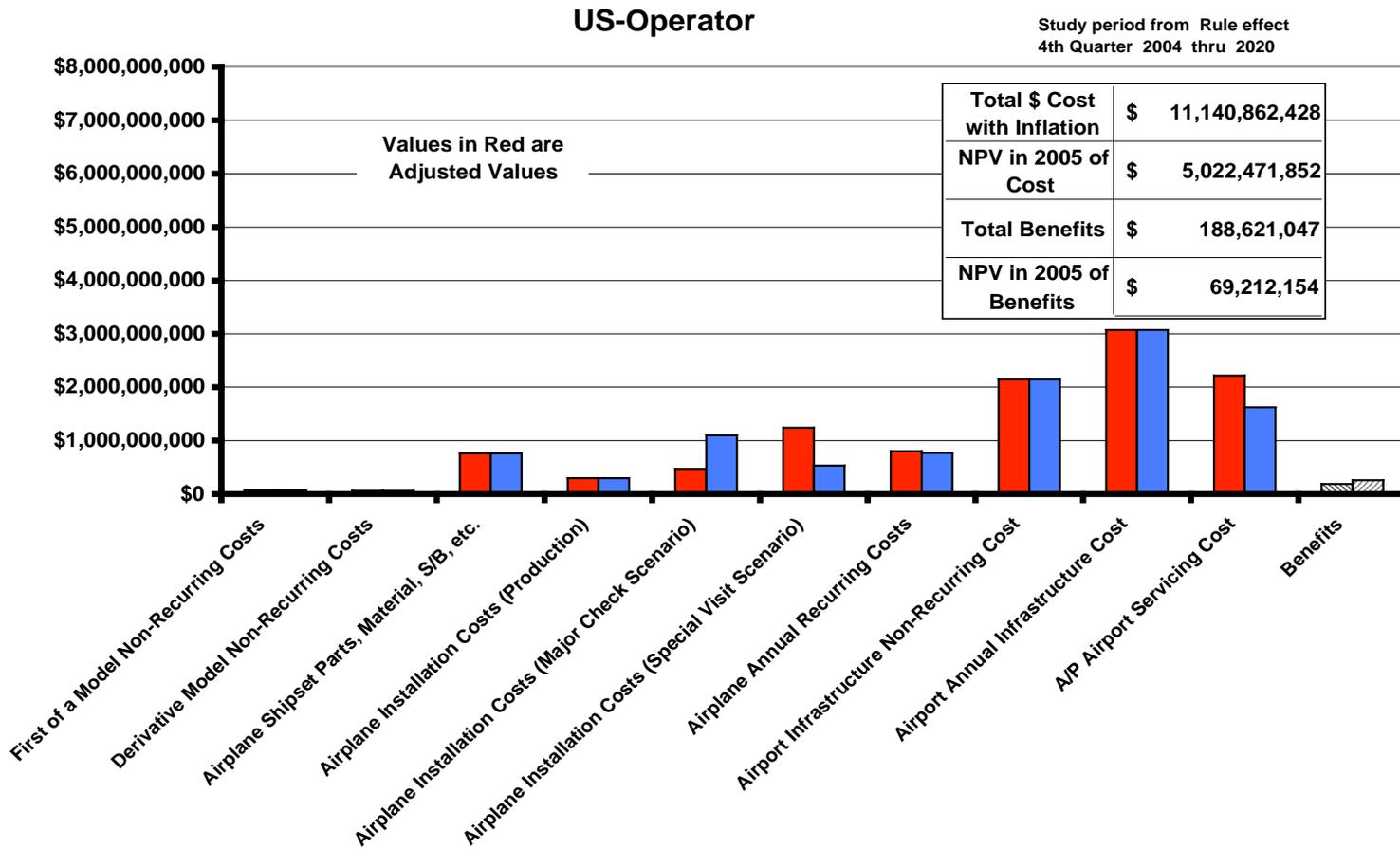
## Scenario 11 - Ground Based Inerting HCWT only, All Transports



Cost Benefit Ratio  
increased to 73:1

# Figure 2 Sensitivity Analysis

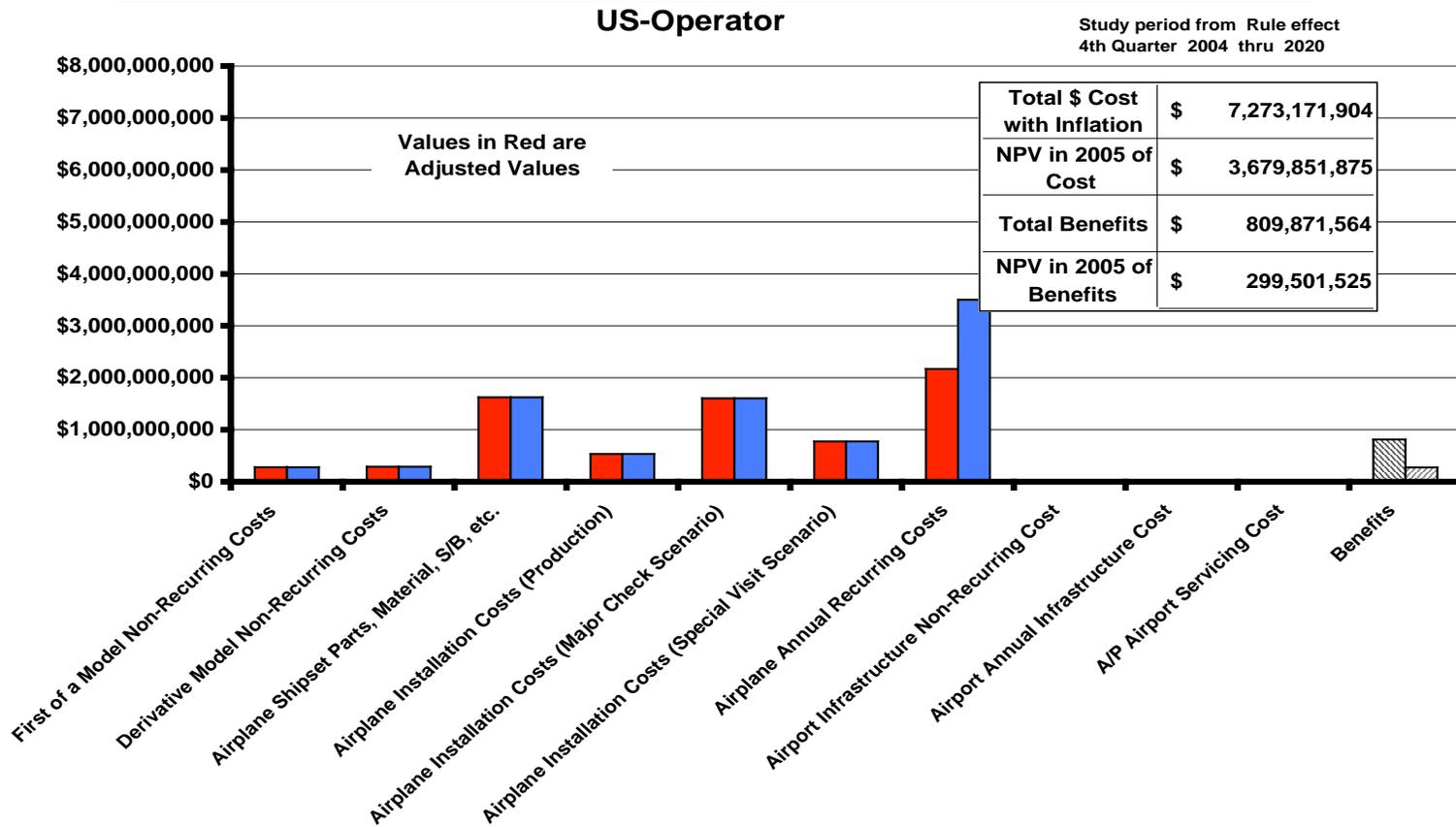
## Scenario 11 - Ground Based Inerting HCWT only, All Transports



# Figure 3 Sensitivity Analysis

Cost Benefit Ratio  
decreased to 12:1

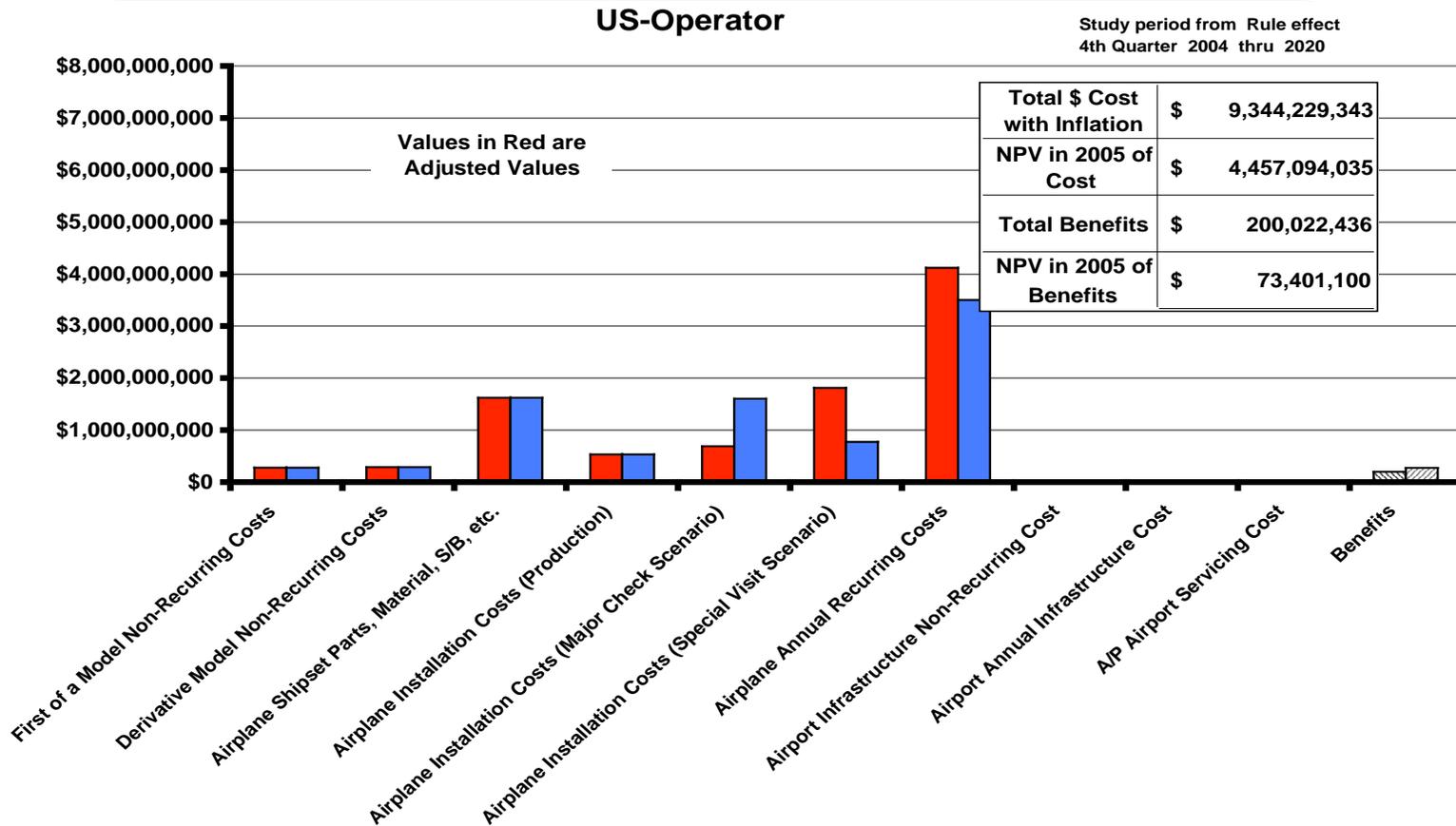
**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**



# Figure 4 Sensitivity Analysis

Cost Benefit Ratio  
increased to 61:1

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium  
Transports, Membrane Systems, & Small Transports, PSA/Membrane  
Systems**



## 2.0 INTRODUCTION

### 2.1 BACKGROUND

Following the 1996 fuel tank explosion-related accident on a 747 airplane, the FAA initiated rulemaking to re-evaluate the industry's approach to fuel tank safety by precluding ignition sources within the fuel tanks of the transport airplane fleet. The FAA also tasked the Aviation Rulemaking Advisory Committee (ARAC) with a 6-month project to provide specific recommendations and propose regulatory text for rulemaking that would significantly reduce or eliminate the hazards associated with explosive fuel vapors in transport airplanes.

In its July 1998 report, the ARAC provided a detailed evaluation of past accidents and incidents and recommended regulatory text for new rulemaking applicable to future transport airplane certifications. Because of the short time allowed to complete the task, the ARAC was unable to provide the detailed information necessary to recommend regulatory text applicable to existing in-service and current production airplanes. The ARAC did recommend that the FAA further investigate the feasibility of what it determined to be the two most promising methods:

1. **Directed ventilation.** Provides for ventilation of the areas adjacent to certain heated tanks to reduce heating within those tanks.
2. **Ground inerting.** Inerts the fuel tanks during ground operations.

On June 6, 2000, the FAA proposed the formation of an ARAC Fuel Tank Inerting Harmonization Working Group (FTIHWG). The group's purpose was to prepare a report for the FAA that (1) recommended regulatory text for new rulemaking and that (2) provided the necessary data for the FAA to evaluate the options involved in the introduction of fuel tank inerting systems that would significantly reduce or eliminate the development of flammable vapors in transport category airplane fuel tanks.

#### 2.1.1 Scope

The historical approach to fuel system safety has been to control risk by ensuring that ignition sources are not present within the tanks. All current regulation and commercial airplane design is based on this philosophy. Going beyond this philosophy, the ARAC FTIHWG was given the task of recommending new rulemaking that would further enhance safety by eliminating or significantly reducing the presence of flammable fuel-air mixtures in fuel tanks.

As part of the ARAC Tasking Record for "Fuel Tank Inerting for Transport Airplanes," the FAA included the following Tasking Statement. (The complete FAA Tasking Statement for the FTIHWG is shown in appendix A).

#### 2.1.2 Tasking Statement

*The ARAC Executive Committee will establish a Fuel Tank Inerting Harmonization Working Group. The Fuel Tank Inerting Harmonization Working Group will prepare a report to the FAA/JAA that provides data needed for the FAA to evaluate the feasibility of implementing regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new-production, and new-type-design transport-category airplanes. This effort is an extension of the previous work performed by the Fuel Tank Harmonization Working Group.*

*The report should contain a detailed discussion of the technical feasibility of the prevention of, or reduction in, the exposure of fuel tanks to a flammable environment through the use of the following inerting design methods, and any other inerting methods determined by the Working Group, or its individual members, to merit consideration.*

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**Ground-Based Inerting**—The system shall inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank using ground-based nitrogen gas supply equipment. The affected fuel tanks shall be inerted once the airplane reaches the gate and while the airplane is on the ground between flights.

**Onboard Ground-Inerting**—The system shall inert fuel tanks that are located near significant heat sources or are not cooled at a rate equivalent to an unheated wing tank using onboard nitrogen gas generating equipment. The affected fuel tanks shall be inerted while the airplane is on the ground between flights.

**Onboard Inert Gas Generating System (OBIGGS)**—The system shall inert all fuel tanks with an onboard nitrogen gas generating system such that the tanks remain inert during normal ground and typical flight operations. Non-normal operations are not to be included in the OBIGGS mission requirements. For example, the tanks should remain inert during normal takeoff, climb, cruise, descent, landing, and ground operations (except for ground maintenance operations when the fuel tank must be purged for maintenance access); however, the fuel tanks do not need to remain inert during non-normal operations such as during an emergency descent.

The report shall provide detailed discussion of technical considerations (both pro and con), as well as comparisons between each of the above design methods for incorporation into the following portion of the large transport airplane fleet: (a) in-service airplanes, (b) new-production airplanes, and (c) new airplane designs. Because the working group may consist of members having differing views regarding the feasibility of inerting fuel tanks, the report should include discussion of such views and any supporting information provided by the membership.

In developing recommendations to the FAA/JAA, the report should also include consideration of the following:

1. The threat of fuel tank explosions used in the analysis should include explosions due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, as defined in the July 1998 ARAC Fuel Tank Harmonization Working Group report. The service history in the analysis should be further developed to include incidents involving post-crash fuel tank fires. The FAA awarded a research contract to develop a database that may be useful in this endeavor. This data should be evaluated when determining what benefits may be derived from implementing ground-based or onboard inerting systems. The report is titled, A Benefit Analysis for Nitrogen Inerting of Airplane Fuel Tanks Against Ground Fire Explosion, Report Number DOT/FAA/AR-99/73, dated December 1999.
2. The evaluation of ground-based inerting should consider:
  - a. The benefits and risks of limiting inerting of fuel tanks to only those times when conditions, such as lower fuel quantities or higher temperature days, could create flammable vapors in the fuel tank. This concept would be analogous to deicing of airplane when icing conditions exist.
  - b. Various means of supplying nitrogen (i.e., liquid, gaseous separation technology; centralized plant and/or storage with pipeline distribution system to each gate, individual trucks to supply each airplane after refueling, individual separation systems at each gate, and so on), and which means would be most effective at supplying the quantity of nitrogen needed at various airports within the United States and, separately, other areas of the world.
  - c. Methods of introducing the nitrogen gas into the affected fuel tanks that should be considered include displacing the oxygen in fuel tanks with nitrogen gas, saturating the fuel

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*with nitrogen in ground storage facilities (for example, in the trucks or central storage tanks), injecting nitrogen directly into the fuel as the fuel is loaded onto the airplane, and combinations of methods.*

- 3. The evaluation of the cost of an OBIGGS for application to new type designs should assume that the design can be optimized in the initial airplane design phase to minimize the initial and recurring costs of a system.*
- 4. Evaluations of all systems should include consideration of methods to minimize the cost of the system. For example, reliable designs with little or no redundancy should be considered, together with recommendations for dispatch relief authorization using the master minimum equipment list (MMEL) in the event of a system failure or malfunction that prevents inerting one or more affected fuel tanks.*
- 5. Information regarding the secondary effects of utilizing these systems (i.e., increased extracted engine power, engine bleed air supply, maintenance impact, airplane operational performance detriments, dispatch reliability, and so on) must be analyzed and provided in the report.*
- 6. In the event that the working group does not recommend implementing any of the approaches described in this tasking statement, the team must identify all technical limitations for that system and provide an estimate of the type of improvement in the concept (i.e., manufacturing, installation, operation and maintenance cost reduction, and so on; and/or additional safety benefit required) that would be required to make it practical in the future.*
- 7. In addition, guidance is sought that will describe analysis and/or testing that should be conducted for certification of all systems recommended.*

*Unless the working group produces data that demonstrates otherwise, for the purposes of this study a fuel tank is considered inert when the oxygen content of the ullage (vapor space) is less than 10% by volume.*

*The ground-based inerting systems shall provide sufficient nitrogen to inert the affected fuel tanks while the airplanes are on the ground after landing and before taking off for the following flight. In addition to the ground equipment requirements and airframe modifications required for the nitrogen distribution system, any airframe modifications required to keep the fuel tank inert during ground operations, takeoff, climb, and cruise, until the fuel tank temperatures fall below the lower flammability range, should be defined.*

*The onboard ground inerting systems shall be capable of inerting the affected fuel tanks while the airplane is on the ground after touchdown and before taking off for the following flight. As for the ground-based inerting system, in addition to the inert gas supply equipment and distribution system, any airframe modifications required to keep the fuel tank inert during ground operations, takeoff, climb, and cruise, until the time the fuel tank temperatures fall below the lower flammability range, should be defined. Consideration should be given to operating the onboard inert gas generating system during some phases of flight as an option to installing equipment that might otherwise be necessary (e.g., vent system valves) to keep the fuel tank inert during those phases of flight, and as a cost tradeoff that could result in reduced equipment size requirements.*

*The data in the report will be used by the FAA in evaluating if a practical means of inerting fuel tanks can be found for the in-service fleet, new-production airplanes, and new airplane designs. The FAA may propose regulations to further require reducing the level of flammability in fuel tanks if studies, including this ARAC task and independent FAA research and development programs,*

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*indicate that a means to significantly reduce or eliminate the flammable environment in fuel tanks, beyond that already proposed in Notice of Proposed Rulemaking (NPRM) 99-18, is practical. Such a proposal would be consistent with the recommendations made by the ARAC Fuel Tank Harmonization Working Group in their July 1998 report.*

### **2.1.3 Charter**

The charter of the ARAC FTIHWG has been to

1. Analyze
  - The technical considerations as well as comparisons between the various fuel tank inerting design methods for incorporation into the large transport fleet.
  - The threat of fuel tank explosions due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet.
  - Various design methods of eliminating or significantly reducing exposure to flammable fuel vapors within fuel tanks.
  - Means to eliminate the resultant hazard if ignition does occur.
2. Recommend regulatory text and guidance material for new rulemaking if a practical means of inerting fuel tanks can be found.
3. Assess the cost benefit of those systems.
4. Assess the effect of the new rule on other sections of the industry.
5. Follow the rules for ARAC harmonization working groups.
6. Issue a final report within 12 months after publication of the Tasking Statement.

## **2.2 WORKING GROUP DEVELOPMENT**

On July 13, 2000, the FAA issued a notice in the *Federal Register* in Washington, D.C., establishing the current FTIHWG. This effort is an extension of the previous work performed by the 1998 ARAC Fuel Tank Harmonization Working Group (FTHWG), as reported in July 1998. The FTIHWG will coordinate with other working groups, organizations, and specialists, as necessary.

The FTIHWG addressed the following inerting systems:

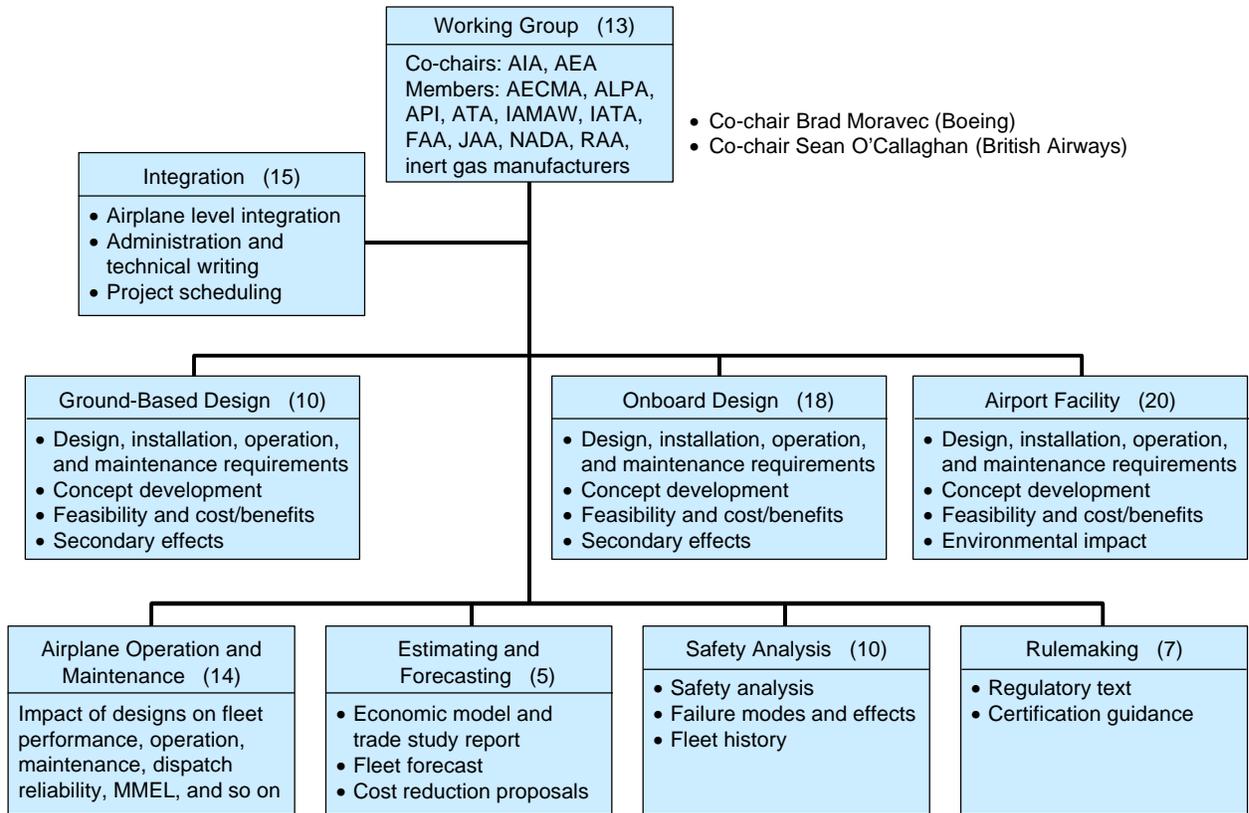
- Ground-based inerting (GBI).
- Onboard ground inerting (OBGI).
- OBIGGS.

The FTIHWG addressed the following groups of transport category airplanes:

- In-service airplanes.
- New production airplanes.
- New airplane designs.
- Commuter airplanes.
- Short-range, medium-range, and intercontinental-range airplanes.

### **2.2.1 Organization**

Figure 2-1 shows the organization of the ARAC FTIHWG leadership team.



297925J2-001R1

Figure 2-1. Working Group Team Leaders

## 2.2.2 Task Team Charters and Deliverables

### Work Plan Outline

- The FTIHWG will be responsible for overall task management.
- Task management will include overall definition of study ground rules, success criteria, work statements, plans, schedules, resources, and deliverables.
- The FTIHWG will establish task teams to assist in completing the various tasks identified in the Tasking Statement issued in Washington, D.C., by the FAA, dated July 10, 2000.

### Task Teams

- Ground-Based Inerting Designs
- Onboard Inerting Designs
- Airplane Operation and Maintenance
- Airport Facility
- Safety Analysis
- Estimating and Forecasting
- Rulemaking
- Integration

Task Team Responsibilities

**Ground-Based Inerting Designs**

- Review existing data on GBI studies and systems.
- Determine design, installation, operation, and maintenance requirements.
- Develop ground-based conceptual fuel tank inerting system designs.
- Provide a feasibility analysis of proposed designs and inerting methods.
- Prepare a cost-benefit analysis for ground-based system concepts.
- Evaluate the safety, risks, and secondary effects of these systems.
- If the concept is considered impractical, identify all technical limitations and provide an estimate of improvements necessary to make this concept practical in the future.
- Document the results of the GBI design and analysis study.

**Onboard Inerting Designs**

- Review existing data on onboard inerting studies and systems.
- Evaluate three system concepts consisting of an onboard ground inerting system (OBGIS), an OBIGGS, and a hybrid system.
- Determine design, installation, operation, and maintenance requirements.
- Develop onboard conceptual fuel tank inerting system configurations.
- Provide a feasibility analysis of proposed designs and inerting methods.
- Prepare a cost-benefit analysis for inerting system concepts.
- Evaluate the safety, reliability, risks, and secondary effects of these systems.
- If this concept is considered impractical, identify all the technical limitations and provide an estimate of improvements necessary to make the concept practical.
- Document the results of the onboard inerting design and analysis study.

**Airplane Operation and Maintenance**

- Review existing data on the impact of fuel tank inerting studies and systems on airplane operation and maintenance activities.
- Evaluate the impact of the proposed ground and onboard inerting system concepts on flight operations (such as dispatch reliability, air turnback [ATB], dispatch deviation guide [DDG], and master minimum equipment list [MMEL]).
- Evaluate the impact of inerting system concepts on maintenance operations and the subsequent effect of these concepts on fleet performance.
- Evaluate the cost impact of the inerting system concepts on flight operations, maintenance operations, fleet planning, and so on.
- Document the results of the Airplane Operation and Maintenance Task Team.

**Airport Facility**

- Review existing data on the impact of fuel tank inerting studies and systems on airports.
- Determine which airports within the United States and in other geographical areas of the world should be included in the study.
- Define the design, installation, operational, and maintenance requirements for inert gas generation, fuel scrubbing, and ullage washing.
- Develop conceptual system configurations to provide fuel-scrubbing and ullage-washing systems that can be used at airports considered in this study.

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- Evaluate the impact on airport facilities and infrastructure that would result from the incorporation of the inerting system concepts being considered.
- Determine the most reliable and cost-effective means of providing inerting supplies within the United States and in other areas of the world.
- If system concepts are not practical, identify all technical limitations and estimate what improvements would be necessary to make the concepts practical.
- Document the results of this airport facility and infrastructure study.

### **Safety Analysis**

- Review existing data regarding the safety benefits anticipated from eliminating or significantly reducing the threat of fuel tank explosion.
- Determine the safety benefits resulting from incorporation of the various proposed system concepts to eliminate or significantly reduce the development of flammable vapors in airplane fuel tanks.
- Evaluate the impact of these system concepts on previous service history fuel tank explosion threats resulting from internal and external tank ignition sources.
- Evaluate the risks and benefits of “as required” inerting system concepts.
- Document the results of the safety evaluations.

### **Estimating and Forecasting**

- Review the available existing data regarding the economic impact of airplane fuel tank inerting studies and systems.
- Develop top-level models to assist the other task teams in evaluating the economic impact of the proposed inerting system concepts on airplane and aviation operations, airport facilities and infrastructure, and the general economy.
- Where practical, propose methods to minimize the overall system costs.
- Estimate the economic impact of the recommended systems on airline operations, the transportation industry, airport facilities and infrastructure, and regional and country economy.

### **Rulemaking**

- Review existing regulations, advisory and guidance material, and continued airworthiness instructions regarding the subject of eliminating or reducing the flammable environment in airplane fuel tank systems.
- Prepare and coordinate within the FTIHWG regulatory text for new rulemaking by the FAA that would eliminate or significantly reduce the flammable environment in airplane fuel tank systems.
- For all system concepts recommended, develop and propose guidance material that describes the necessary analysis or testing that may be required to show compliance with the new regulatory text for certification and continued airworthiness.

### **Integration**

- Review existing data from previous fuel tank working groups regarding applicability to the current tasks.
- Coordinate the development of task and system requirements for use by the FTIHWG.
- Coordinate activities within the FTIHWG to ensure that the task teams are using common ground rules, definitions, assumptions, requirements, schedules, and so on.
- Facilitate activities and communication within the FTIHWG to achieve the intermediate and final task assignments in a timely manner.

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- Coordinate with other harmonization working groups, organizations, companies, and experts to support FTIHWG activities.
- Develop and implement a review process and integrated task schedule to support the requirements of the ARAC Executive Committee.
- Coordinate preparation of this final report to the ARAC Executive Committee.

Final Deliverables

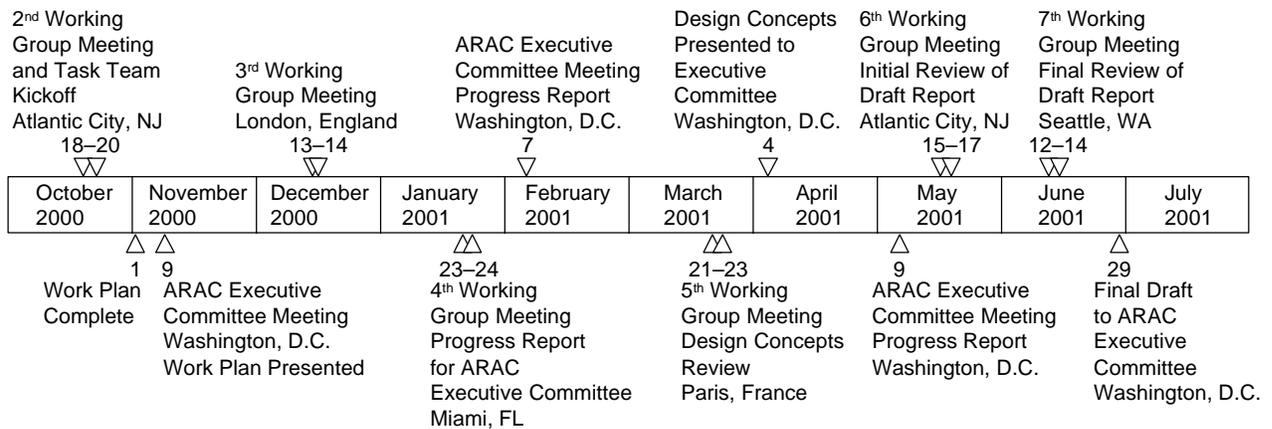
- Recommend regulatory text for new rulemaking by the FAA that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on transport category airplanes; and provide compliance guidance material for the proposed regulation.
- Evaluate options for implementing these new regulations on current and future airplanes.
- Identify all technical limitations for those design options that are determined to be currently impractical.
- Provide guidance on testing and analysis for demonstrating certification compliance and continued airworthiness.
- Submit the above by June 29, 2001, for the ARAC Executive Committee to review before forwarding to the FAA.

**2.2.3 Schedule**

A milestone schedule was developed at the first FTIHWG meeting in September 2000.

The FTIHWG agreed to meet regularly according to a defined schedule. Individual task teams were directed to meet as often as necessary to accomplish the objectives of the FAA Tasking Statement. As stated, the final report is scheduled to be complete and delivered to the ARAC Executive Committee by June 29, 2001.

Figure 2-2 shows the task team schedule.



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Figure 2-2. ARAC FTIHWG Major Milestones

## **2.3 STANDARDS**

A common set of standards was necessary to achieve consistent results in the development and evaluation of designs and cost-benefit analyses. Therefore, the Integration Task Team developed and provided a common set of definitions for use by all the FTIHWG task teams.

### **2.3.1 Assumptions**

To ensure that the potential methods of inerting were evaluated using consistent data and assumptions, a spreadsheet was created that provided a common source of data for use by the task teams. This spreadsheet included data for six generic airplane types: small, medium, and large jet transports; regional turbofans; regional turboprops; and business jets. The data included summaries for each airplane type, such as fleet size, weights, fuel volumes, and flight distributions. Mission profile data such as weight, altitude, Mach number, fuel remaining in each tank, and body angle as a function of time were included for each generic airplane type. Temperature profiles ranging from cold to extremely hot were also included in the mission profiles.

Performance and cost trade studies were included to allow consistent calculation of performance and cost impacts.

1. A fuel tank is considered inert when the oxygen content of the ullage (vapor space) is less than 10% by volume.
2. An unheated wing tank is defined as a conventional aluminum-structure integral tank of a subsonic wing with minimal heat input from airplane systems or other fuel tanks that are subject to heating.
3. The FTIHWG used the definition of fuel tank explosion threat contained in the July 1998 ARAC FTHWG report.
4. Service history used in this analysis was developed to include postcrash fuel tank fires.
5. Top-level design, reliability, maintenance, and operational study requirements were established to provide guidance for determining practical inerting systems.
6. In accordance with the Tasking Statement, design concepts evaluated had little or no redundancy in order to minimize costs.
7. Fuel tank inerting design concepts evaluated were not considered to be dispatch-critical systems and would therefore be part of the airplanes' MEL.

### **2.3.2 Ground Rules**

The Working Group applied the following ground rules to the design concepts considered, as specified by the FAA Tasking Statement:

1. The FTIHWG evaluated the impact of fuel tank inerting design concepts or designs on transport category airplanes.
2. Within the transport category, the following "generic" study airplanes were evaluated:
  - Large-category airplanes.
  - Medium-category airplanes.
  - Small-category airplanes.
  - Commuter (turboprops and jets).
  - Business jets.
3. Within each airplane category studied, an evaluation was made of the impact on in-service airplanes, current new production, and future new type design airplanes.
4. FTIHWG task teams evaluated the impact of fuel tank inerting on airplanes with heated center wing tanks (CWT).
5. Where practical, the task teams used definitions, including the fuel tank explosion threat, developed for use and contained in the 1998 ARAC FTHWG Final Report.

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6. The service history evaluated in FTIHWG studies and evaluations included postcrash fuel tank fires.
7. Fuel tank inerting design concepts considered by the FTIHWG have little or no system redundancy.
8. No fuel tank inerting system concept results in a net negative safety benefit to the airplane study category evaluated.
9. Fuel scrubbing with inert gas did not result in an adverse effect on fuel supply system performance, engine performance, or operational capability.
10. The FTIHWG identified technical and economic limitations of systems evaluated as impractical and estimated the improvements necessary to make these inerting systems practical in the future.
11. Except as noted in the report, the FTIHWG considered systems that would not result in a hazardous condition to personnel, airplanes, or airport facilities resulting from the failure of a fuel tank inerting system component during normal operation, nonnormal operation, or failure conditions.

### *Ground-Based Design Concepts Ground Rules*

12. Each design concept proposed for a particular airplane study category must be capable of providing inert fuel tanks once the airplane reaches the gate and while the airplane is on the ground between flights.
13. It was considered unnecessary to evaluate any conditions within an airplane category's operational and environmental envelopes where a combination of fuel tank temperatures and quantities would not result in flammable vapors being present in any of the fuel tanks.
14. Failure of any fuel tank inerting system component during normal operations, nonnormal operations, and failure conditions will not result in a hazardous condition to any personnel, the airplane, or airport facilities.
15. Nitrogen-enriched air (NEA) that is supplied to the airplane during refueling operations for fuel tank inerting purposes is assumed to be a minimum of 95% purity.
16. The attachment panel or interface and the appropriate interface connections and equipment will not interfere with ingress and egress and the servicing position of ground equipment while the airplane is located at the terminal gate.
17. The location and design characteristics of the installed interface connections and equipment will not result in an additional hazard to the airplane as a result of a wheels-up landing.
18. No special provisions are included in the system design concepts to prevent air from entering the airplane fuel tank or inert gas from being vented from the airplane tank during any change in ground environmental thermal cycling.
19. The time taken by any ground-based design concept to inert the required number of fuel tanks in an airplane study category will not increase the turnaround time of that category.
20. The installation of a ground-based fuel tank inerting system will not result in an adverse effect on fuel supply system performance, engine performance, or engine operational capability.
21. During evaluation of a GBI system, consideration is given to the benefits and risks resulting from inerting only those fuel tanks located near significant heat sources.

### *Onboard Design Concepts (OBIGGS) Ground Rules*

22. The OBGI design concept will be evaluated based on the ground rules defined in the section titled Ground Based Inerting Design Concepts.
23. Each design concept evaluated for a particular airplane study category is capable of providing inert fuel tanks during normal operations, such as takeoff, climb, cruise, descent, landing, and ground operations. However, nonnormal operations are not included in the ground rules in accordance with the Tasking Statement.
24. Each OBIGGS design concept is capable of inerting all fuel tanks in an airplane study category. (Reference: Tasking Statement.)
25. Any OBIGGS design concept installed will inert all fuel tanks throughout the certified airplane operating and environmental envelope during normal operation.

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26. Where a combination of fuel tank temperatures and quantities shown within an airplane category's operational and environmental envelopes will not result in flammable vapors being present in any of the airplane fuel tanks, these conditions do not require fuel tank inerting from an onboard system.
27. The installation of an onboard fuel tank inerting system will not result in an adverse effect on the fuel supply system performance, engine performance, or engine operational capability.
28. Any certification maintenance requirements (CMR) or similar periodic maintenance checks required by an OBIGGS are considered to have a minimum frequency equivalent to a C-check.
29. When installed, an OBIGGS will not result in an increase of the schedule interruption rate of 0.05 per 100 departures in an airplane category. (Reference: industry experience.)
30. When installed, an OBIGGS will have an objective mature mean time between unscheduled removal (MTBUR) of any component of 5,000 hr minimum.
31. When installed, an OBIGGS will have a mature mean time between maintenance actions (MTBMA) of 250-hr minimum.

### *Airplane Operation and Maintenance Ground Rules*

32. Regardless of the method of fuel tank inerting system used to inert the applicable fuel tanks in an airplane study category, the turnaround time of that particular airplane category will not be increased.
33. The operational and maintenance impact of continued airworthiness requirements of each fuel tank inerting system is estimated.

### *Airport Facilities Ground Rules*

34. Any facilities developed to provide NEA for use in inerting airplane fuel tanks, while the airplane is located at the terminal gate, will meet all applicable safety regulations in force as of July 10, 2000.
35. Any system evaluated is capable of providing sufficient NEA to each airplane in a particular study airport so that the current airplane turnaround times are not adversely affected.
36. Any evaluated airport-based system for inerting fuel tanks will have adequate capacity to supply the required volume of nitrogen to each gate position in a period of time that will not result in an increase in the airplane turnaround time for that study-category airplane.
37. The airport-based fuel tank inerting system must be capable of simultaneously providing 100% of the flow requirements for each airport gate, taking into consideration the assumed mix of study-category airplanes at these terminal gates.
38. NEA supplied at the terminal gate for inerting airplane fuel tanks will be 95% minimum.

### *Safety Ground Rules*

39. A functional safety hazard assessment will be performed for each ground-based or onboard inerting system evaluated. The basis for this report will be the functional hazard analysis (FHA) published by the 1998 ARAC FTHWG with appropriate changes to reflect the current evaluations.
40. A system reliability prediction will be completed for each ground-based and onboard design concept evaluated.
41. A system reliability prediction will be completed for each airport fuel tank inerting and fuel scrubbing system evaluated.
42. For the purposes of this study, the accident data set defined by the 1998 ARAC FTHWG will be used.
43. Any accident prevention analysis will consider report number DOT/FAA/AR-99/73. (Reference: Tasking Statement.)
44. A study was conducted on any proposed inerting design concept that estimated the accident prevention improvement of implementing that fuel tank inerting design concept. The methodology used for this study will be consistent with that used by the industry's Commercial Aviation Safety Team to evaluate intervention effectiveness.
45. Any fuel tank inerting design concept proposed that does not result in a positive net safety benefit will be considered unacceptable.

Estimating and Forecasting Ground Rules

46. Increases in airplane gate turnaround times will be assessed on an economic value of \$150 million/min for U.S. operations and \$380 million/min for worldwide operations. (Reference: Air Transport Association of America [ATA].)
47. The cost of fuel per U.S. gallon for this study will be \$1.00. (Reference: *Air Transport World*, January 2001.)
48. Any estimated airplane flight delays resulting from operation of either a ground-based or onboard fuel tank inerting system will be assessed an economic value of \$24.43/min. (Reference: ATA.)
49. Turnbacks to the departure airport or diversions to unscheduled landings at alternate en route airports will not be required for the system because the system will be eligible for MEL dispatch.
50. For each labor-hour estimated in the study, a burdened rate of \$110/hr will be assumed for professionals (e.g., engineers). (Reference: FAA.)
51. For each labor-hour estimated in the study, a burdened rate of \$75/hr will be assumed for technicians (e.g., line mechanics). (Reference: FAA.)
52. For each labor-hour estimated in the study, a burdened rate of \$25/hr will be assumed for ground support personnel (e.g., refuelers). (Reference: FAA.)
53. The ramp-up time for introducing a certified fuel tank inerting system into the existing and current in-production fleets will be assumed to be 3 years for production models and an additional 7 years for in-service models.
54. The time period to be considered for calculating costs of an inerting scheme will be 16 years (from 2005 to 2020.)
55. The growth forecast assumed for the purposes of this study will be 3.6% per year. (Reference: ATA.)
56. Any increases or decreases in airline operations, direct airplane operating costs, and maintenance costs will be developed to determine the subsequent impact of fuel tank inerting on each study-category airplane and the overall operational impact.
57. For evaluation of costs of an OBIGGS for application to new type designs, it will be assumed that the design can be optimized in the initial design phase to minimize initial and recurring costs. (Reference: Tasking Statement.)

Rulemaking Ground Rules

58. A review of the current 14 CFR will be conducted to consider the changes that may be necessary for the incorporation of ground-based or onboard fuel tank inerting systems.
59. Where changes to the regulations are considered to be required, the FTIHWG will propose regulatory text for each paragraph that would require a change.
60. In support of any proposed regulatory changes, guidance material will be developed to describe analysis or testing that should be conducted for certification of all systems proposed.
61. For each fuel tank inerting design concept proposed, the recurring and nonrecurring costs to achieve complete FAA certification are estimated.



### 3.0 SERVICE HISTORY

The team examined the service history of known instances of fuel tank explosions resulting from internal or external ignition sources in the transport airplane fleet (including turbofan and turboprop airplanes) over the last 40 years.

#### 3.1 METHODOLOGY

Appendix H, Safety Analysis Task Team Final Report, contains a detailed description of each event and the findings of the investigating authority. A description of the mitigating actions taken subsequent to the event to minimize its recurrence is also included in the appendix.

Appendix H summarizes 16 fuel tank explosion events, which are divided into *operational events* (i.e., those occurring on an airplane where passenger-carrying flight was intended) and *refueling and ground maintenance events*. They were grouped by cause (lightning, engine separation, refueling, maintenance, etc.) and then categorized by operational phase, ignition source, type of fuel tank involved, and fuel type.

The team established ground rules to guide this evaluation. First, the team determined that a forecast of future events should be based on the residual risk of recurrence of past events. In addition, the benefits forecast should be based on events that inerting would prevent effectively. As such, the team decided that accidents resulting from external ignition sources that breached the fuel tank would not be used to forecast future events. This ground rule is consistent with that used by the team that developed DOT/FAA/AR-99/73, *A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion*. The Safety Analysis Task Team notes that inerting may offer some benefit in preventing fuel tank explosions caused by small explosive devices that would not otherwise result in a catastrophe. However, those benefits could not be quantified because of uncertainties related to secondary ignition sources and the loss of nitrogen following breach of the fuel tank.

In addition, the effectiveness of the actions taken subsequent to the event to minimize its recurrence were assessed based on

- Identification of the ignition source.
- Confidence level that mitigating action addressed the ignition source.
- Implementation level of the mitigating action or actions.

Once these data and ground rules were in place, a trend and residual risk analysis was conducted.

#### 3.2 ANALYSIS

The starting point of this analysis was the table of events in the 1998 ARAC FTHWG final report. The events contained in that report were based on the *FAA Notice of Fuel Tank Ignition Prevention Measures* published in the *Federal Register* on April 3, 1997. The data sources used were accident and incident reports provided by investigating organizations, regulatory authorities, and original equipment manufacturers' (OEM) safety-related databases. The level of details reported in the early events was sometimes limited, depending on the event location in the world and the type of event (i.e., whether it involved an internal or external ignition source).

Late in the study period for this ARAC, a fuel tank explosion occurred in Bangkok, Thailand. While it is understood that the accident investigation is ongoing, the NTSB has released information indicating that the wreckage shows evidence that the CWT exploded and that the ignition source for that fuel tank has yet to

be determined. This team has not been involved in that investigation and does not wish to publish findings in advance of the investigating authority. However, the event appears to fit the guidelines set forth by the FAA Tasking Statement, and the team decided to include it as a statistical data point on which to base the forecast of future accidents.

### **3.2.1 Analysis of Previous Tank Explosions**

The data indicates a difference in the safety levels of wing tanks and CWTs. The former are force-cooled by air flowing over the wings, whereas the latter, being located in the fuselage between the wings, are cooled less efficiently. Other auxiliary tanks are also housed within the fuselage. Unlike wing tanks, fuselage tanks may be located adjacent to heat sources.

There have been no known internal ignition sources that resulted in a wing tank explosion in 900 million hours of operation by the commercial transport fleet. All wing tank events have been the result of known external ignition sources (e.g., lightning strike, over-wing fire, refueling, or maintenance error). Corrective actions to prevent recurrence of externally initiated wing tank events have been in place for many years and have been demonstrated to be effective. It has also been observed that the use of less volatile fuel (e.g., Jet A versus JP-4) enhances safety.

Over the years, CWTs have accumulated considerably fewer operating hours than wing tanks (e.g., a Boeing 737 has two wing tanks and one center tank, so it accumulates wing tank hours at twice the rate of CWT hours). Because the equipment in wing and center tanks is similar (i.e., equivalent in types and numbers of potential ignition sources), there should be significantly fewer CWT events than wing tank events. In actuality, however, the number of events is approximately equal for two reasons. First, flammable vapors are present in center tanks a greater percentage of the time because they are not as well cooled. Second, potential internal ignition sources in the wing tanks are more often submerged—and thus present less risk—than they are in CWTs, which are not filled unless additional range is required.

With the exception of the three most recent CWT events and the 1989 Bogotá event, the causes of all other CWT events have been addressed by actions designed to prevent or minimize their recurrence. The 1989 Bogotá accident, which involved a breach of the fuel tank because of a high-explosive charge, violated one of the ground rules this team established as the basis for forecasting future events.

For the three most recent CWT events, the exact ignition sources have not been identified. While corrective actions to identify and minimize potential ignition sources are now being put in place, a means to reduce flammability in heated CWTs should be pursued.

The team concluded that the 1990 Manila, 1996 New York, and 2001 Bangkok events should form the basis for forecasting future events.

### **3.2.2 Postcrash Fuel Tank Fires**

As suggested by the Tasking Statement, the Safety Analysis Task Team evaluated the data provided by DOT/FAA/AR-99/73. The Safety Analysis Task Team accepted the findings of this report and chose not to duplicate effort in this area. The report considered 13 survivable accidents worldwide in which a fuel tank explosion occurred but was not the prime cause of the accident. Each of the accidents was analyzed in depth to assess the number of lives that might be saved if nitrogen inerting systems were used. The predicted number of lives saved per year from this analysis were reported as

- Ground nitrogen inerting, center tank only: 0.3
- Ground nitrogen inerting, all fuel tanks: 2.4
- Onboard nitrogen inerting, all fuel tanks: 6.0

The team used this data to determine the forecast number of lives saved over the study period. Based on assumed annual fleet growth rates and the implementation assumptions (discussed in the estimating and forecasting section), the team forecasts that GBI of the CWT would save 5 lives worldwide over the 16-year study period. Similarly, onboard inerting of all fuel tanks would save 101 lives worldwide over the 16-year study period.

The report concludes

*The predicted potential number of lives saved per year is relatively small compared to other survivability factors. One of the reasons that nitrogen inerting may not be effective, in terms of saving lives in the 13 accidents analyzed, is that in many cases fuel tanks were ruptured when the airplane impacted the ground. Any nitrogen in the fuel tanks is likely to have escaped with the spilled fuel. The system is only effective when the fuel tanks are not significantly ruptured.*

### **3.3 CONCLUSIONS**

The following conclusions from the service history review can be drawn:

- There is a close relationship between the incidence of explosions in wing tanks and the use of “widecut fuel” (e.g., JP-4).
- Wing tanks operating with less volatile Jet A type fuel have demonstrated an acceptable safety record.
- In comparison, heated CWTs are more vulnerable to explosion in the presence of ignition sources.
- The three most recent events (1990 Manila, 1996 New York, 2001 Bangkok) form the basis for forecasting future events.
- Inerting fuel tanks may enhance occupant survival in accidents in which a fuel tank explosion occurs but is not the prime cause of the accident.



## 4.0 SAFETY ASSESSMENT

### 4.1 METHODOLOGY

This safety assessment is designed to determine the net safety benefit associated with inerting. Section 4.2 provides an overview of the flammability exposure analysis tool that was used to determine the effectiveness of inerting systems. Sections 4.3 and 4.4 discuss potential new hazards that must be addressed with the implementation of any inerting system design. Section 4.5 describes the approach for calculating safety benefits from inerting. Sections 5.0 through 9.0 discuss the safety benefits for each design concept.

### 4.2 FLAMMABILITY

Understanding flammability relies on the science of quantifying when a fuel vapor/air mixture will burn upon introduction of an ignition source.

Jet fuel is a blend of more than 300 different hydrocarbons. When fuel is added to a tank, a certain percentage of the fuel vaporizes, with more of the light hydrocarbons evaporating than the heavy ones. The resulting vapor displaces some of the air in the tank and mixes with the air to create a fuel-to-air mixture in the ullage (i.e., portion of the tank volume not occupied by fuel).

The amount of fuel vapor present in the fuel tank ullage is driven by the vapor pressure of the fuel, which is strongly affected by the fuel temperature. Therefore, the flammability of ullage depends on the fuel temperature while the airplane is on the ground, and on how it cools during the climb and cruise.

This fuel vapor/air mixture can be ignited when the ratio of fuel to air is within a certain range between the lean and rich limits. For jet fuels, this combustible fuel-to-air ratio ranges from a lean limit of around 0.03 (1 lb of fuel vapor to 33.3 lb of air) to a rich limit of around 0.24 (1 lb of fuel vapor to 4.2 lb of air). Within this fuel-to-air ratio range, a spark, arc, hot surface, or other ignition source can ignite the fuel vapor/air mixture. Outside these limits, the fuel is either too lean or too rich to burn.

The energy needed to ignite fuel vapors varies as a function of the fuel-to-air ratio. The lean and rich ends of this ratio require higher spark energy—more than 1,000 mJ. In the middle of the flammable fuel-to-air ratio range, at around 0.08 (1 lb of fuel vapor to 12.5 lb of air), the ignition energy needed drops to 0.25 mJ, or 5,000 times less than is needed at the lean and rich limits. For reference, a jet engine igniter plug has a single-spark discharge of around 5,000 mJ, and a person walking across a carpet in dry weather can create a spark of around 10 mJ. An increase in altitude increases the energy required to ignite the mixture.

Fuel tanks become more flammable as the airplane climbs, as a result of pressure decrease. While the amount of fuel vapor doesn't change, pressure influences the fuel-to-air ratio because the amount of air in the tank lessens with altitude. At constant temperature, this causes the fuel-to-air ratio to increase. Modeling assumes a lean flammability limit temperature reduction of 1°F for each 808 ft of altitude gained.

The amount of fuel in the tank has an effect on the fuel-to-air ratio because the mixture of different hydrocarbons in fuel evaporates to reach equilibrium. If there is only a small amount of fuel in the tank, the fuel may run out of light hydrocarbon components and a lower fuel-to-air ratio results. This effect exists at low fuel quantities, generally near the unusable quantity of the tank.

A flash point test is a simple test run at sea level to find the temperature at which a small flame will ignite a fuel vapor/air mixture in a small chamber. The flash point is useful for comparing one fuel to another and is about 10°F above the lean flammability limit for jet fuels. Testing by the University of Nevada at Reno for the FAA has established that the flash point temperature, determined by the American Society for Testing and Materials (ASTM) Standard D 56, gives a fuel-to-air ratio of 0.044 for most Jet A type fuels.

The FAA has developed a computer program to compute the fuel-to-air ratio for a wide range of temperatures, altitudes, and fuel loads for jet fuels. It uses the ASTM D2887 distillation curve to define the fuel in question. This program was made available to and modified by the FTIHWG. The following paragraphs describe the customization of this model for ARAC analysis.

#### **4.2.1 Inerting**

Inerting is the process of reducing the amount of oxygen in the tank ullage to reduce or eliminate the ability of an ignition source to ignite the fuel vapor/air mixture. Prior work had established that—even with military threats such as high-explosive shells—reducing the oxygen content of the ullage to less than 10% would eliminate ignitions. The 1998 ARAC FTHWG proposed the concept of using GBI as a means of reducing tank flammability.

The FAA has conducted research on the quantity of nitrogen or NEA needed to inert a simple tank, the cost of providing NEA to the fleet, and—in cooperation with the industry—the use of GBI on a 737 airplane.

To support this research, the FAA has also developed an inerting computer program to assess the oxygen content in the fuel tank ullage over a complete flight. The model can add NEA to the tank ullage at any time and vary both the quantity and quality of the NEA. The model computes the amount of oxygen and nitrogen present in the tank—both in the ullage and dissolved in the fuel—and the fuel vapor in the ullage at 1-min time steps, from the time the airplane arrives at the gate to be fueled, through its fueling, dispatch, flight, landing, and taxi-in at the destination airport.

This model uses Coordinating Research Council (CRC) solubility coefficients (*CRC Aviation Handbook, Fuels and Fuel Systems*, no. Naval Air Systems Command no. 06-5-504, May 1, 1967) to compute the amount of oxygen and nitrogen dissolved in the fuel, and then uses an exponential decay process to transport the gas out of or back into the fuel, depending on the driving partial-pressure differential.

During climb, the exponential time constant is reduced considerably to allow for the more rapid gas evolution seen while climbing. The FAA used data from the 737 flight test to fine-tune the constants used in the model. The model computes ullage gases based on the change in tank pressure and the amount of NEA or air added in the 1-min increments. NEA and existing gases mix instantaneously, but the outflow of oxygen and nitrogen from the fuel needed to reach a pressure balance is assumed to lag the current oxygen content by 4 min, matching the FAA laboratory data.

The FTIHWG has used this model to assess the effectiveness of different inerting systems, including GBI and several forms of onboard NEA generation and delivery systems. The effectiveness of the inerting system can be used to assess tank fleet flammability exposure, as discussed in the following paragraphs.

#### **4.2.2 Flammability Exposure Analysis**

The 1998 ARAC FTHWG studies developed a Monte Carlo simulation technique to assess fleet fuel tank flammability exposure.

This method used the thermal characteristics of a fuel tank, the given distribution of missions the airplane would fly, and a model of the range of ambient temperatures experienced to compute the tank temperature for every minute of a large number of flights. Simultaneously, this method compared the fuel tank temperature to the lower and upper flammability limits (LFL and UFL) of the fuel presumed to be loaded for that flight. From this, it was possible to determine the fleet flammability exposure, which is the number of minutes the tank temperature is in the flammable range relative to the total operational time of the airplane. The 1998 ARAC FTHWG showed that CWTs exposed to nearby heating sources would have a flammability exposure of around 30% and unheated wing tanks would have a flammability exposure of around 5%.

The 1998 ARAC FTHWG used proprietary thermal models and Monte Carlo analysis programs developed by participating manufacturers. To conduct its own assessment of flammability exposure, the FAA developed its own Monte Carlo flammability analysis program. The 1998 ARAC FTHWG and FAA made their programs available to the ARAC FTIHWG for use and enhancement as needed to conduct the appropriate studies.

The program follows the original ARAC concept of computing flammability for any number of flights and obtaining a fleet-average exposure.

Because the 1998 ARAC FTHWG was studying a range of generic airplane types, it developed a set of generic tank thermal characteristics. The concept defined an exponential time constant for the tank temperature response to changes in ambient temperature and an equilibrium temperature difference (relative to ambient temperature) to represent the thermal effect of heat input to the tank. A tank will respond to a change in ambient temperature by following an exponential decay curve to the new equilibrium temperature, defined as the new ambient temperature plus the temperature difference from heating. The program used different values for ground and flight cases, and for full and nearly empty tanks. The need to switch from a full to a nearly empty tank is defined by airplane data and the tank in question. Manufacturers' proprietary data determined the specific values for the generic airplanes, which represent an average generic configuration. The constants used do not represent any actual airplane. Figure 4-1 shows these values.

Fuel tank thermal data	Ground-heated CWT			Flight-heated CWT		
	Equil. temp delta (°F)	Time constant		Equil. temp delta (°F)	Time constant	
		Full (min)	Empty (min)		Full (min)	Empty (min)
Large transport	60	400	120	60	300	150
Medium transport	30	300	30	50	300	90
Small transport	37	300	25	50	300	90

*Figure 4-1. Generic Tank Thermal Characteristics*

A randomly selected ground temperature defines the atmospheric conditions for each flight by using a set of Gaussian distributions to define the range of temperatures and a randomly selected tropospheric temperature. The distribution of ground temperatures was based on 16 years of hourly temperature observations (7 a.m. to 11 p.m., local times) for 533 airports worldwide. The data was weighted based on the passenger volume for each specific airport. The climb period uses an interpolation scheme that computes the altitude of the tropopause and includes a temperature inversion on cold days.

A random value based on a distribution of flight lengths from fleet airline statistics determines the mission length for each flight, which is then scaled to match the maximum flight length of the generic airplanes.

Time on the ground is a random variable consisting of taxi-in time (set at 5 min), time before refueling (set at 5 min), refueling time (based on flight length and generic refueling rates), time at gate after refueling (based on a probability distribution from airline fleet statistics), and taxi-out time (set at 5 min). The approximate time on the ground for the generic large airplane is a minimum of 60 min, with 80% of the ground times shorter than 105 min and the maximum lasting 225 min. The approximate time on the ground for the small generic airplane is a minimum of 20 min (10% of flights), with 50% taking less than 50 min, 80% less than 75 min, and the longest taking 210 min.

Fuel flammability properties are defined by a randomly selected flash point for each flight and the effect of flammability temperature range computed as a function of altitude. The flash-point range is a normal Gaussian distribution, with a mean temperature of 120°F, and a standard deviation of 8°F. Generally, this results in a flash-point range of 100 to 140°F.

The model can compute a single flight and present the flight profile and resulting flammability information as a plot, or compute the fleet flammability exposure for a given airplane type and tank for a Monte Carlo run of any number of flights. The ARAC analysis used computer runs of 5,000 flight cases.

Inerting systems such as GBI can be examined in the flammability model by creating a set of rules for the system using the inerting program discussed above. These rules compute when an increment of the flight is not flammable because the tank is inert, resulting in reduced fleet flammability exposure.

The team uses the results of the flammability exposure analyses for the generic airplane types and tanks to compute the effectiveness of candidate systems at preventing potential future accidents.

#### **4.2.3 GBI Analysis**

GBI was analyzed by adding a set of rules that inerted the center tanks with the volume of 95% NEA necessary to reach 8% with an empty tank. The inerting is a step function inserted at 50% of the time at gate after refueling. Had additional modeling time been available, the team would have evaluated actual inerting flow time and varied time at the gate, though this rule seemed likely to represent the average airline operations. Section 5, Ground-Based Inerting System, presents the results of the GBI analysis.

#### **4.2.4 OBGI Analysis**

OBGI was analyzed to ensure that the ullage contained 10% or less oxygen concentration. This concentration had to be achieved while the airplane was parked at the terminal gate. The NEA purity depended on the technology being analyzed. The size of the system was highly dependent on the time available at the gate to inert the fuel tanks. A flammability exposure analysis was then performed to compare the OBGI system to the other technologies.

Hybrid OBGI was analyzed in exactly the same way except that it was able to take advantage of an additional 5 min during taxi-in, after landing, to inert the fuel tanks. This slightly decreased the system size compared to OBGI, while maintaining the same flammability exposure.

#### **4.2.5 OBIGGS Analysis**

OBIGGS was analyzed to ensure that the ullage contained 10% oxygen or less during all phases of flight. The NEA purity depended on the technology being analyzed. Based on the 737 flight testing conducted by the FAA, where the tanks remained inert for several hours after receiving nitrogen, it was assumed that OBIGGS would not operate on the ground.

Hybrid OBIGGS was designed to provide the same flammability exposure as the GBI, OBGI, and hybrid OBGI systems. The focus was on ensuring that the flammability exposure during ground operations, taxi, takeoff, and climb were consistent with the other systems.

### **4.3 FUNCTIONAL HAZARD ANALYSIS**

Because some of the inerting concepts involve technologies not currently fully mature or proven in a commercial airline environment, rigorous and detailed safety analyses could not be performed down to the component level with confidence. However, the team did perform a top-level FHA, which is included in appendix H, Safety Analysis Task Team Final Report.

### **4.4 PERSONNEL HAZARDS**

#### **4.4.1 General**

Nitrogen and other inert gases are not normally dangerous, but when used in confined spaces they can create oxygen-deficient atmospheres that can be deadly. Nitrogen is especially hazardous, because it cannot be detected by human senses and can cause injury or death within minutes. In the United States, at least 21 people have died in 18 separate incidents involving the use of nitrogen in confined spaces between 1990—when more stringent requirements were adopted—and 1996. Every year in the United Kingdom, work in confined spaces kills an average of 15 people across a wide range of industries, from those involving complex plants to those using simple storage vessels. Fatalities include not only people working in confined spaces, but also those who try to rescue them without proper training or equipment. Still more people are seriously injured.

The health risk to ground and maintenance personnel servicing airplanes that use nitrogen inerting technology is present not only in the fuel tanks themselves, but also in the location of the nitrogen-generating equipment. Wherever possible, such equipment should be located outside the airplane pressure hull. However, this is not possible on all airplanes. Therefore, it will be necessary to ensure that safety systems and procedures are in place to protect the airplanes and personnel working in and around them.

The following sections highlight some of the hazards associated with operating fuel tank inerting systems on commercial transports and the risks they pose to the airplane, its occupants, and maintenance personnel.

#### **4.4.2 Confined Spaces**

The Occupational Safety and Health Administration (OSHA) defines a confined space as a space that by design

- Has limited openings for entry and exit.
- Has unfavorable natural ventilation.
- Is not intended for continuous employee occupancy.

OSHA further defines a permit-required confined space as a confined space with

- Hazardous atmosphere potential.
- Potential for engulfment.
- Inwardly converging walls.
- Any other recognized safety hazard.

By this definition, all airplane fuel tanks meet the OSHA definition of a permit-required confined space. If the tanks were to be inerted, the current requirement to ventilate fuel tanks before entering would be critical. In addition, other locations under consideration for housing nitrogen-generating equipment, such as cargo holds, wheelwells, wing-to-body fairings, and APU bays, may also be considered confined spaces. As such, appropriate entry procedures must be in place to minimize the risk to workers entering these spaces. These areas should be clearly marked and workers thoroughly educated regarding both the hazards of confined-space entry and the insidious nature of nitrogen asphyxiation and death.

The costs associated with implementing these additional confined-space entry procedures worldwide are estimated at \$39.8 million for safety equipment and an additional \$28.3 million per year in labor (see addendum F.E.1 in appendix F). Even with these procedures in place, accidents will continue to happen as a result of people bypassing or simply ignoring the procedures, as is proven annually by the current record of injuries and fatalities.

#### 4.4.3 Gaseous Nitrogen

The most significant hazard associated with exposure to nitrogen is breathing the resulting oxygen-deficient atmosphere. Normal atmosphere is made up of approximately 21% oxygen, 78% nitrogen, and 1% argon, with smaller amounts of other gases. Nitrogen, which is colorless, odorless, and generally imperceptible to normal human senses, requires the use of oxygen-monitoring equipment to detect oxygen-deficient atmospheres. Despite its nontoxic profile, nitrogen can be quite deadly if not properly handled.

It is not necessary for nitrogen to displace all the 21% of oxygen normally found in air to become harmful to people. OSHA requires that oxygen levels be maintained at or above 19.5% to prevent injury to workers. Figure 4-2 summarizes the expected symptoms at various oxygen concentrations for people who are in good health.

Oxygen concentration, % volume	Symptoms	Maximum exposure
19.5	None	NA
14 to 19.5	Labored breathing, particularly at higher workloads	NA
12 to 14	Physical and intellectual performance impaired, increased heart rate	NA
10 to 12	Rapid breathing, dizziness, disorientation, nausea, blue lips	10 min
8 to 10	Loss of control, gasping, white face, vomiting, collapse	<ul style="list-style-type: none"> <li>• 50% of people will not survive 6 min</li> <li>• 100% of people will not survive 8 min</li> </ul>
4 to 8	<ul style="list-style-type: none"> <li>• Coma</li> <li>• Death</li> </ul>	<ul style="list-style-type: none"> <li>• 40 sec</li> <li>• 2 min</li> </ul>
<4	Death	Seconds

Figure 4-2. Personnel Hazards

The very nature of oxygen deficiency is that the victim becomes the poorest judge of when he or she is suffering from its effects. Victims may well not be aware of their condition and could fall unconscious without ever being aware of the danger.

#### 4.4.4 Liquid Nitrogen

For OBIGGS, which uses cryocooling methods, liquid nitrogen presents its own specific hazards. Although relatively safe from the point of view of toxicity, liquid nitrogen—in common with all cryogenics—presents the following hazards:

- Cold burns, frostbite, and hypothermia from the intense cold.
- Overpressurization from the large volume expansion.
- Fire from condensation of oxygen.
- Asphyxiation in oxygen-deficient atmospheres.

Skin contact with liquid nitrogen can cause tissue to freeze, resulting in severe burns, which are caused by the extremely low temperature of the cryogenic liquid, not by a chemical reaction. Liquid nitrogen contacting the airplane structure may cause degradation of materials, especially deterioration of composites and stress cracks in aluminum, and could result in structural failure.

The risk of oxygen-deficient atmospheres when using liquid nitrogen arises from the vast expansion of the substance as it boils or vaporizes. Just 1 L of liquid may produce around 700 L of gas at atmospheric pressure, displacing significant quantities of breathable air if the gas is released in a confined space such as an airplane fuel tank or pressure hull. The tendency of cool nitrogen to accumulate at low levels, where it is less easily dispersed than the ambient atmosphere, compounds this problem. Even an apparently small spill could lead to dangerously low oxygen levels, presenting a serious hazard to personnel and other occupants in the area.

Oxygen condensation from the atmosphere as a result of extreme cold is another potential hazard of using cryogenics. Liquid oxygen can create highly flammable conditions, and may also create local oxygen-enriched atmospheres, presenting a greatly increased risk of fire or explosion should an ignition source be present.

#### **4.4.5 Gaseous Oxygen**

Gaseous oxygen, a byproduct of the nitrogen generation process, presents its own potential hazards. OBIGGS concepts are designed to vent oxygen overboard; however, some form of leak detection would need to be in place. Failure to provide such detection may result in an oxygen-rich atmosphere with associated risk of fire and explosion. Many materials that would normally only smolder in air, such as clothing, will burn vigorously in an oxygen-enriched atmosphere, making it essential that staff members are alerted to high oxygen concentrations so that the risk of fire can be minimized.

### **4.5 SAFETY BENEFIT ANALYSIS**

The safety benefit forecast approach is based on the conclusions drawn from the service history review. Specifically, analysis showed that the tank explosion rate is not the same for all tank types. Further, there are similar types and numbers of potential ignition sources within all tanks, so one can expect the ignition event occurrence rate to be essentially the same for all tanks. It follows that different flammability exposures for the different tank types result in different explosion rates between wing tank and heated CWTs. Furthermore, there are differences in the exposure to potential ignition sources. On average, for example, potential ignition sources in wing tanks are submerged in fuel—and thus incapable of causing an event—more often than they are in CWTs, which are not filled if maximum airplane range is not needed.

The explosion rate for heated CWTs was calculated directly from the three events mentioned earlier. Explosion rates for each of the other tank types were determined based on their exposure to flammable vapors and the likelihood that the potential ignition source would not be submerged. Figure 4-3 shows the three events on which the analysis was based, along with the total worldwide fuel tank accident forecast.

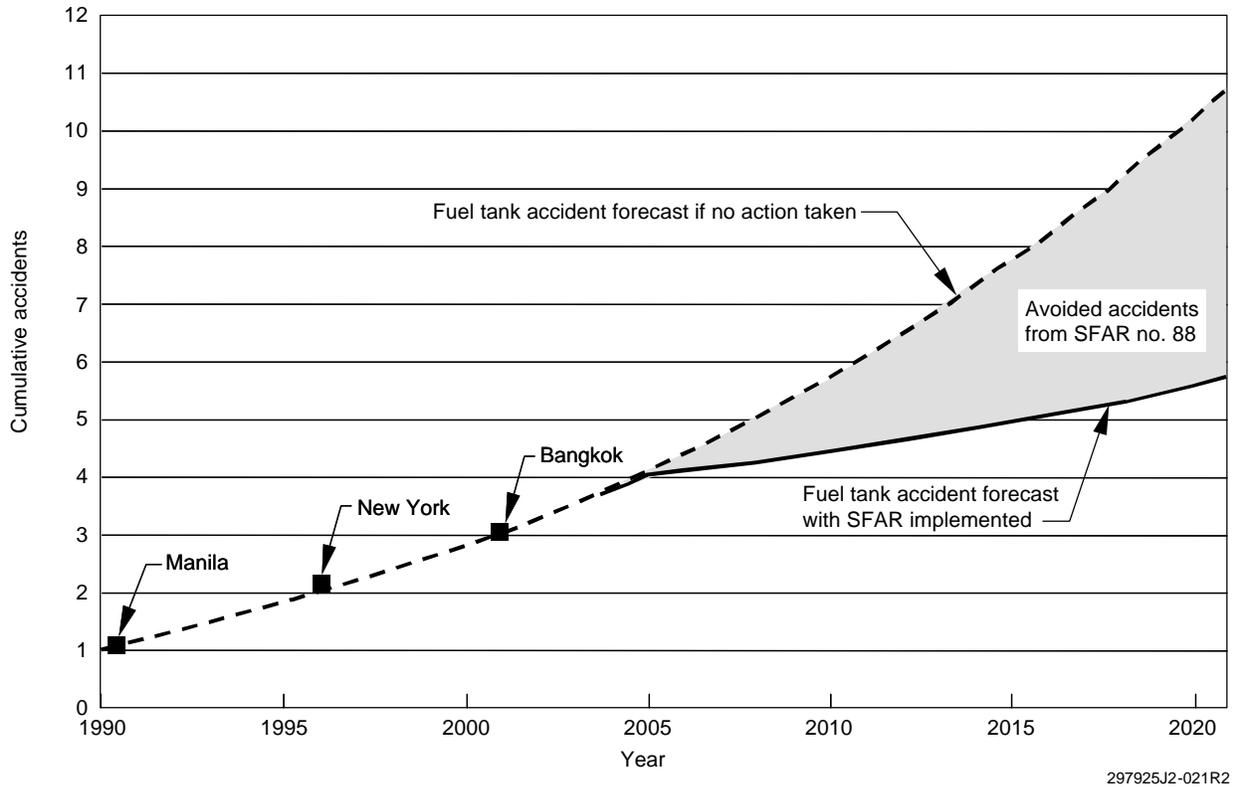


Figure 4-3. Worldwide Unexplained Fuel Tank Explosion Accident History and Forecast

This is the baseline accident forecast if no action is taken to preclude future events. Of the accidents forecast in figure 4-3, approximately 90% are predicted to involve heated CWTs.

In figure 4-3, the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR no. 88. The 75% reduction had been estimated by the 1998 ARAC FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

In addition, design, implementation, and forecast fleet growth all have a role in the number of forecast accidents that can be avoided. Appendix G, Estimating and Forecasting Task Team Final Report, documents these assumptions.

The number of prevented fatalities from a fuel tank explosion depends on the number of accidents avoided and the number of passengers on board. The number of passengers on board is a function of whether the explosion occurs in flight or on the ground. Based on the flammability exposure after inerting it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss of everyone on board. These two assumptions were based on the historical accident record. The average number of passengers depends on the size of the airplane and the expected load factor.

Using the six generic airplane categories, the FTIHWG estimated that the average number of seats is 350 (plus 12 crew) for a large turbojet, 255 (plus 9 crew) for a medium turbojet, 154.5 (plus 7 crew) for a small turbojet, 65 (plus 5 crew) for a regional jet, 45 (plus 4 crew) for a turboprop, and 11 (plus 3 crew) for a business jet. Based on the FAA Aviation Forecasts Fiscal Years 2001–2012, the load factors are 75% for a large turbojet, 73% for a medium turbojet, 71% for a small turbojet, 60% for a regional jet and turboprop, and 40% for a business jet. Figure 4-4 summarizes the average number of people on board each of the generic airplanes based on these assumptions.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet
Passengers and crew onboard	275	195	117	44	31	7

*Figure 4-4. Average Number of People on Board Each Generic Airplane*

Figure 4-5 summarizes the number of forecast accidents avoided due to GBI (sec. 5.5), OBGI (sec. 7.6), and OBIGGS (secs. 8.6 and 9.6).

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet
Worldwide accidents avoided by applying GBI to HCWT only	0.24	0.09	0.54	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBGI to HCWT only	0.20	0.09	0.47	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBIGGS to HCWT only	0.25	0.10	0.56	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBIGGS to all tanks	0.28	0.12	0.63	N/A	N/A	N/A

*Figure 4-5. Worldwide Accidents Avoided by GBI and OBIGGS*

In addition to preventing in-flight and ground fuel tank explosions, inerting also offers a benefit in enhancing occupant survival in accidents from other causes that result in a postcrash fuel tank fire or explosion. These benefits are discussed in section 3.2.2. It was found that GBI could save 5 lives worldwide over the study period, while OBIGGS could save 101 lives worldwide.

It must be observed that implementing fuel tank inerting on a global scale would introduce new hazards that previously did not exist in commercial aviation. Present wherever nitrogen is handled in the aviation infrastructure, these risks could be mitigated largely through stringent measures, but they could not be entirely eliminated.

Nitrogen is a colorless, odorless, nontoxic gas that is impossible to detect when excessive concentrations displace the oxygen normally present in the atmosphere. Depending on the level of oxygen depletion, the effects on people range from decreased ability to perform tasks to death through asphyxiation.

The adoption of inerting would introduce two types of hazards. The first would be the risk of confined-space asphyxiation from fuel tank entry for maintenance purposes. This risk is well understood and could be mitigated through training and procedures. A second and more insidious risk is the formation of localized oxygen-depleted zones as a result of undetected nitrogen leaks at airline and third-party maintenance facilities, on board airplanes, or—in the case of GBI—in airport ramp and terminal environments. Careful system design and rigorous procedures would be required to mitigate this latter risk scenario.

The FTIHWG lacked the time and expertise to assess these risks with confidence. However, the FTIHWG felt it was important to bound the risk. To do this, a simple extrapolation of available OSHA and National Institute of Occupational Safety and Health (NIOSH) data was used. According to 1980–1989 NIOSH data, the confined-space accident rate is between 0.20 (for the transportation industry) and 0.68 (for the oil and gas industries) per 100,000 employees. Of these, 43% were due to “Hazardous

Atmosphere - O<sub>2</sub> deficiency.” Assuming that these were all inert-gas related (e.g., argon, nitrogen, and carbon dioxide), this would result in a confined-space asphyxiation rate of 0.086 to 0.292 per 100,000 employees. According to OSHA, there were 1.2431 million U.S. airline employees in 1999. This would suggest the U.S. airline industry could expect 1.07 to 3.6 fatalities per year. In 1993, OSHA implemented more rigorous confined-space permit rules and estimated those rules would reduce fatalities by 85% in the United States. Assuming these rules are as effective as initially estimated, they could reduce U.S. airline industry fatalities to between 0.16 and 0.54 per year. The United States accounts for approximately 46% of worldwide airplane operations, and it was assumed that an OSHA-equivalent confined space regulation did not exist in the rest of the world. That results in a non-U.S. airline industry fatality rate of 1.26 to 4.23. The fatality rate from confined-space asphyxiation from nitrogen for the total worldwide airline industry is 1.42 to 4.77 per year. Based on assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that between 24 and 81 lives may be lost over the study period. Neither OSHA nor NIOSH participated in the FTIHWG. It is recommended that those agencies evaluate this risk based on current data before implementing inerting on a global scale.

Figure 4-6 summarizes the lives affected worldwide by inerting over the study period.

Lives affected over study period, 2005 through 2020	GBI, HCWT	OBGI, HCWT	OBIGGS, HCWT	OBIGGS, all tanks
Lives saved from fuel tank explosions in flight	125	112	132	149
Lives saved from fuel tank explosions on ground	2	2	2	3
Lives saved from post-crash fires	5	5	5	101
Lives lost due to asphyxiation	24 to 81	24 to 81	24 to 81	24 to 81

Figure 4-6. Summary of Lives Affected Worldwide by Inerting

Based on the last 10 years’ accident records, there are approximately 650 fatalities per year worldwide resulting from airplane accidents. Assuming the worldwide accident rate remains constant and applying the unconstrained fleet growth assumption, over 15,000 fatalities could result from airplane accidents—from all causes—that could occur over the study period. The lives saved from inerting represent approximately 1% of that total.

#### 4.6 SAFETY ASSESSMENT SUMMARY AND CONCLUSIONS

Over the past 12 years, the fuel tank explosion rate has remained essentially constant. Based on this observation and the forecast fleet growth, the occurrence of fuel tank explosions will be more frequent in the future. Ignition source reduction associated with SFAR no. 88 will provide a reduction in the fuel tank explosion rate.

Figure 4-7 shows the pre-SFAR no. 88 fuel tank explosion accident rate for each of the generic airplane families. Figure 4-8 shows how the accident rate is reduced by SFAR no. 88, GBI, and OBIGGS.

When evaluating the data in figure 4-7 and figure 4-8, it is important to understand that inerting systems offer little benefit to three of the six generic airplane families (regional turbofan, regional turboprop, and business jet) because none have heated CWTs and flammability of the wing tanks is already low. Furthermore, onboard systems were not found to be practical for these airplanes. One might expect the estimated time to the next accident for the OBIGGS scenario in figure 4-8, for example, to be longer. For airplanes equipped with OBIGGS (large, medium, and small transports) it is much longer still, on the order of 100 years. When forecasting so far into the future (and maintaining the unconstrained fleet growth assumption in att. B), the regional turbofan, regional turboprop, and business jet all contribute to the forecast. As a result, rather than the estimated time to the next accident being on the order of 100 years, it is forecast to be 51 years.

The flammability levels achieved by inerting systems can result in an improvement in the fuel tank explosion rate.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet	Total
Accident rate pre-SFAR no. 88	$8 \times 10^{-9}$	$8 \times 10^{-9}$	$8 \times 10^{-9}$	$6 \times 10^{-10}$	$1 \times 10^{-10}$	$4 \times 10^{-10}$	$5 \times 10^{-9}$ (weighted average)

Figure 4-7. Accident Forecast Summary Information

	Pre-SFAR no. 88	With SFAR no. 88 fully implemented	With SFAR and GBI of heated CWT fully implemented	With SFAR and OBIGGS of all tanks fully implemented
Estimated time to next accident in the United States after full implementation in year 2015	4	16	36	51
Explosion rate per operating hour for entire fleet (weighted average of all six generic airplane families)	$5 \times 10^{-9}$	$1.3 \times 10^{-9}$	$3 \times 10^{-10}$	$1.5 \times 10^{-10}$

Figure 4-8. Fuel Tank Explosion Accident Rate Comparison



## **5.0 GROUND-BASED INERTING**

The GBIS concept is based on the idea of purging the ullage of a fuel tank with NEA provided from a ground source. This externally supplied NEA will be delivered to the airplane at a given purity and pressure. The NEA is generated through hollow-fiber membrane separation technology, which does not affect the airplane's GBIS design.

Either a fixed installation at the gate or a dedicated truck will supply the NEA. Tests carried out for each applicable airplane model will determine the amount of NEA required to reduce the oxygen concentration in the tank ullage to the inert level. Maintaining the added NEA volume at a fixed amount for each different airplane type—regardless of fuel load—to be specified on a placard directly adjacent to the airplane's servicing interface will simplify operations and reduce the risk of loading incorrect quantities of NEA. This also allows for inerting to be performed before, during, or after fueling, without affecting the volume of nitrogen required.

A dedicated distribution pipe network permanently installed on the airplane will discharge the NEA into the required fuel tank. Dedicated equipment and controls will ensure that no unacceptable hazard is introduced into the airplane. At the end of the inerting procedure, the tank ullage will be at a maximum of 8% oxygen by volume.

After this process has been carried out, the tanks will remain inert on the ground for a minimum of 2 hr. After takeoff and climb, fresh air will be drawn into the tanks as fuel is consumed, which will dilute the concentration of NEA in the tank ullage.

Tests have shown that tanks containing low or only residual fuel quantities may remain inert throughout the cruise portion of the flight, as long as no altitude reductions are made. As a part of the GBI incorporation, testing has shown that it is necessary to modify vent systems of some airplane designs to eliminate crossflow through the tank from multiple-vent outlets.

The Tasking Statement defines tanks required to be inerted as those that do not cool at a rate similar to a wing tank, which includes CWTs—heated or unheated—and fuselage auxiliary tanks.

### **5.1 CONCEPT DESCRIPTION**

The final design of the system will be airplane specific and reflect the basic design philosophies and principles of the manufacturer. This generic study uses a system that incorporates the features likely to be necessary on a typical installation. As illustrated in figure 5-1, this system concept is relatively simple.

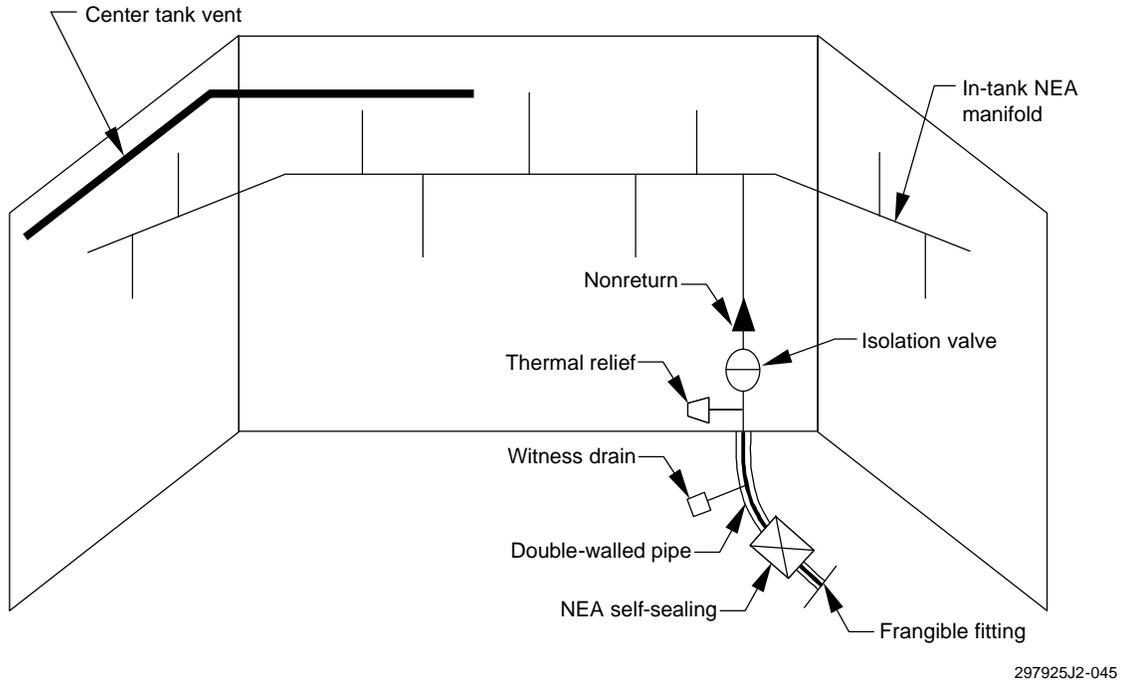


Figure 5-1. Center Tank Installation Concept

A dedicated truck or airport distribution network supplies NEA to the airplane. A new dedicated connection point and service panel will be incorporated into the airplane. The preferred location for this panel is the wing-to-body fairing. The connection point will use a new standard of coupling that ensures that there is no possibility of cross-connection with any other servicing connectors. The service panel will allow all operations associated with inerting the tanks to be carried out. It will comprise a switch to control the isolation valve and a valve position indication lamp.

From the airplane connection point, the NEA will be distributed to the center tank and additional internal or auxiliary tanks if the airplane is so equipped. Where any nitrogen plumbing has to pass within the pressurized compartment or an area of restricted ventilation, the double-walled pipes will minimize the risk of leakage into any confined area.

Within the tank, a dedicated manifold will distribute the NEA. Reviewing the various airplanes included in the study indicated that the type of internal structure could vary between airplane models. On some airplane types, ribs divide the applicable tanks into discrete cells, whereas on other types the tanks are basically open. The detail design of the manifold is airplane specific, but will generally comprise a series of pipes and outlets.

The use of a dedicated manifold allows the inerting operation to be performed before, during, or after the refueling operation. Mounting the manifold close to the top of the tank ensures that maximum mixing occurs and was shown in testing of one model to efficiently purge the ullage of oxygen to 8%, with 1.7 volumes of 95% NEA.

Close to the tank wall, the tank is isolated from the filling manifold. A frangible coupling at the airplane connection point will be provided in case the ground equipment is moved while still attached to the airplane. A self-sealing coupling may be incorporated within the frangible coupling at the connection point. A simple nonreturn valve will prevent the possibility of fuel backflow from the tank.

The generic system also incorporates the following additional equipment:

- A witness drain to detect any leakage in the double-walled pipe.
- A thermal relief valve to prevent pressure buildup in the pipe between the connection point and isolation valve.

Connecting the NEA supply to the airplane and opening the isolation valve is all that will be required to inert the tanks. When the appropriate quantity of NEA has been added, the isolation valve will be shut and the NEA supply disconnected.

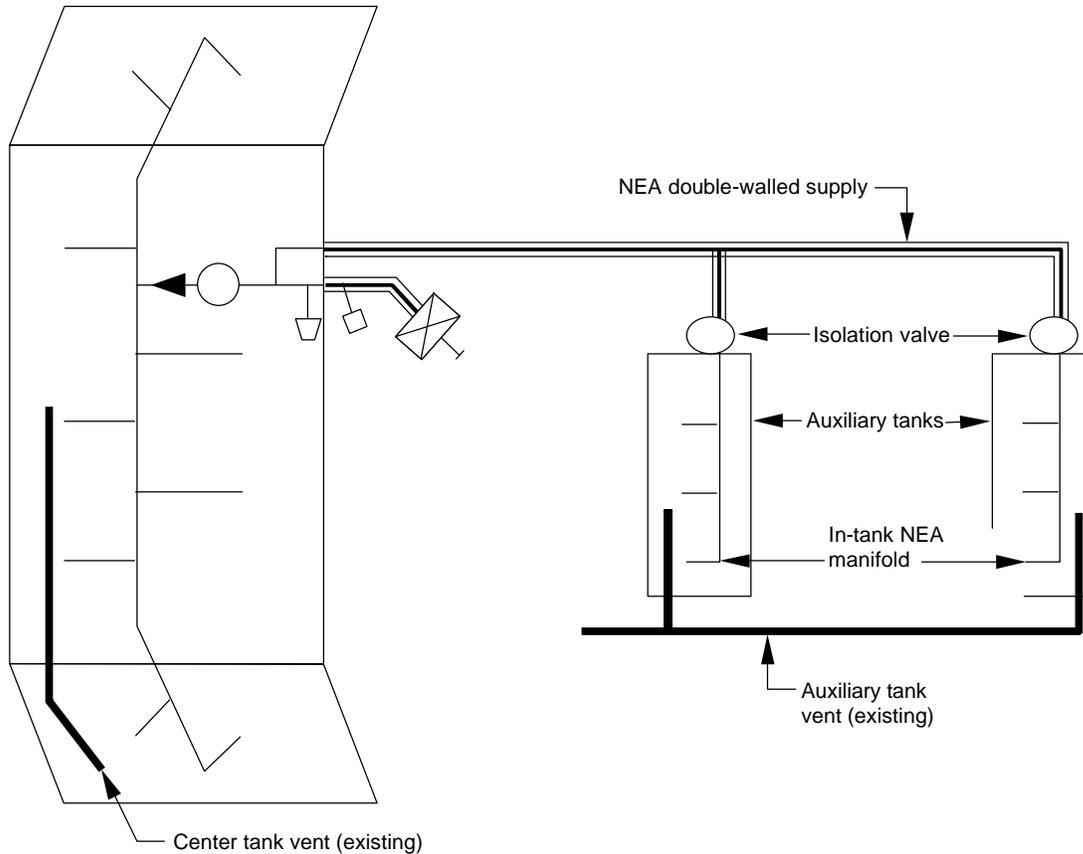
To confirm that the inerting operation has been carried out, the person responsible must record the volume of NEA supplied to the airplane and provide this record to the flight crew, who will compare it to the volume contained in the flight manual or on the load sheet.

### **5.1.1 Auxiliary Tanks**

A number of auxiliary tank configurations were reviewed, comprising installations in which the tanks are located in either or both the forward and rear cargo compartments. This review led to the conclusion that, for airplanes fitted with auxiliary tanks, a similar system arrangement and operation to that proposed for CWTs would be used.

A single NEA connection point with the previously described features will supply both the CWT and any auxiliary tanks installed.

From the connection point, the pipe will branch to the center tank and to the auxiliary tanks. The final layout will be airplane specific. The auxiliary tanks will include the same features as the CWT design (i.e., a means of isolating the tank, a nonreturn valve, and a dedicated manifold to distribute the NEA), as shown in figure 5-2.



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Figure 5-2. Center and Auxiliary Tank Installation Concept

Inerting the auxiliary tanks at the same time as the CWT will minimize any impact on turnaround times. The procedure for the auxiliary tanks will be the same as for the CWT, in that a fixed volume of NEA will be introduced into the tank.

Ensuring that each tank receives the appropriate quantity of NEA may require creating orifices or providing some additional control of the NEA tank isolation valve on the auxiliary and CWTs, depending on the final geometry of the installation and the supply pressure.

Auxiliary tank installation will require a weight increase of approximately 45 lb for each ARAC generic airplane, regardless of size. The system weights are driven primarily by the weight of the double-walled pipework between the connection point and the tank inlet. The weight for the smaller airplane also reflects the installation of auxiliary fuel tanks in both the forward and aft cargo bays.

## **5.2 APPLICABILITY TO STUDY-CATEGORY AIRPLANES**

In compliance with the FAA Tasking Statement, the proposed system design, control, and operation are applicable to all airplane fuel tank types that do not cool at a rate similar to a wing tank. New airplane types will incorporate the requirements during the initial design phase. In-production airplanes will be redesigned for incorporation during the production cycle. Service bulletin (SB) action will cover in-service airplanes within the time prescribed by the regulation.

## **5.3 AIRPORT RESOURCES SYSTEM REQUIRED**

The GBIS is designed to accept airport-supplied NEA from either a fixed installation or a mobile truck. The system design ensures that the fuel tank is inerted within 10 to 20 min. Inerting times have been selected to eliminate or minimize any gate delays.

Ground equipment will control the NEA supply to a maximum acceptable pressure value. For most airplanes, this study shows that the supply pressure must be limited to a maximum of 5 psig. Even at this pressure, a small number of airplane types will still require the installation of additional onboard equipment to further reduce the pressure to an acceptable level.

The purity level of NEA supplied will need to be agreed and standardized for the worldwide airplane fleet, because this value will be used to determine the amount of NEA required during each airplane type certification.

For this study, we have assumed that the amount of NEA required to inert an aircraft fuel tank is 1.7 times the tank volume. This assumes that 95% pure NEA is supplied, achieving a final oxygen concentration within the tank of 8%. This value has been selected as a base on a limited number of tests performed on a Boeing Next-Generation 737 airplane. It should be noted that this factor would vary with each airplane category.

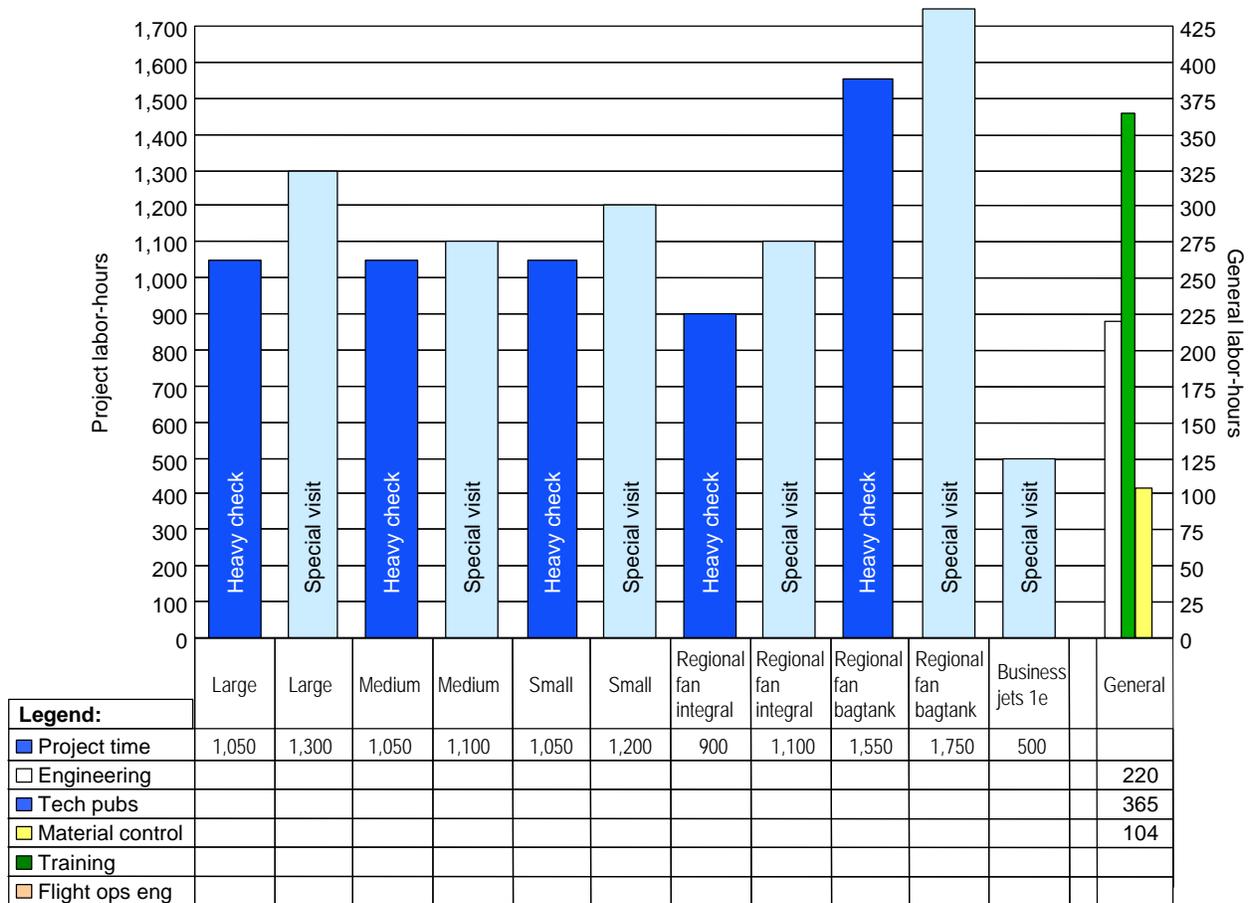
Available data suggests that the discharge of NEA from the airplane vents does not require any special precautions or procedures.

## **5.4 AIRPORT OPERATIONS AND MAINTENANCE IMPACT**

This section discusses the modification of in-service airplanes to install a GBIS and the overall effect of GBI systems on airplane operations and maintenance requirements.

### **5.4.1 Modification**

Figure 5-3 shows the modification estimates for the GBIS. For all airplane categories, estimates are shown for both a regular heavy maintenance visit and a special visit. For corporate and business airplanes (FAR Part 91 operators), the modifications would likely be accomplished during special visits to factory service centers. Consequently, the figure shows special-visit estimates only for corporate and business airplanes.



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Figure 5-3. Modification Estimates for Ground-Based Inerting Systems

Estimates for regional turbofan airplanes with bladder tanks (rubber cells) are made as well. Previous sections explain that such tanks were not taken into account. However, we felt that this estimate had to be made to obtain an idea of how many extra labor-hours would be required for the project.

No estimates have been made for regional turboprop airplanes, because no company that does the maintenance for turboprop airplanes with a CWT could be located or consulted. According to Fokker Services, who did the estimates for the regional turbofan airplanes, there are very few if any turboprop airplanes that have a CWT.

The left side of figure 5-3 shows estimated project labor-hours for the different airplane categories. General labor-hours are shown on the right. These labor-hours are the same for all airplane categories.

### 5.4.2 Scheduled Maintenance

#### Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the GBIS schematic provided by the Ground-Based Inerting Designs Task Team. Each component illustrated in the schematic was individually evaluated and tasks were written accordingly. These tasks included inspections, replacements, and operational and functional checks of the various components that make up the system. These tasks were assigned to the various scheduled checks (A, C, 2C, and heavy), and labor-hours for each task were

estimated. The estimates assume that tasks completed at an A-check would also be completed at a C-check. Similar assumptions were made for the C- and 2C-check tasks (i.e., that they would be accomplished at the 2C- and heavy checks, respectively). Appendix F, addendum F.B.1, lists these tasks.

Additional Maintenance Labor-Hours

Figure 5-4 shows the estimated additional scheduled maintenance labor-hours required at each check to maintain a GBIS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Business jet	2	5	7	17	16.46
Turboprop	2	5	7	17	16.46
Turbofan	2	5	15	17	17.21
Small	2	5	17	17	34.65
Medium	2	5	21	21	32.93
Large	2	5	25	25	34.74

Figure 5-4. GBI Additional Scheduled Maintenance Hours

**5.4.3 Unscheduled Maintenance**

In accordance with the Tasking Statement, the design of the GBIS is based on inerting fuel tanks that are near significant heat sources or that do not cool at a rate equivalent to an unheated CWT. The design concept for the GBIS considered only CWTs and auxiliary tanks. In addition, because the GBIS operates only on the ground, the system operation time was based on the minimum turn times discussed later in this report. The basic design of a GBIS for airplanes without auxiliary tanks is relatively simple. The detailed design concept was discussed previously in this report. A reliability and maintainability analysis evaluated the following system components:

- Nonreturn valve.
- Isolation valve with integral thermal relief valve.
- Self-sealing coupling incorporating a frangible fitting.
- Ducting (including distribution manifold and double-walled tubing).
- Wiring.

For airplanes with center wing and auxiliary tanks, the system components include the same components as a CWT-only installation, with the addition of one nonreturn valve and one isolation valve per auxiliary tank plus interconnect ducting. Including auxiliary tanks in the reliability and maintainability analysis will have a minimal effect because it would simply increase the quantity of nonreturn and isolation valves, depending on the number of auxiliary tanks installed. This would affect the component MTBUR for the nonreturn valve and isolation valve. However, the exclusion of the auxiliary tank components is considered well within the margin of error of the total system analysis. Just the CWT components noted above were considered in the analysis.

The system design concept took into consideration the need for a pressure-regulating valve (PRV), which would limit the delivery pressure of the NEA on some business jets and regional airplanes resulting from fuel tank construction. Conceptually, the PRV could be part of either the airplane system or the airport delivery equipment. Because of this and the limited applicability of the PRV, this analysis did not evaluate this component.

As with each of the system design concepts, component reliability was evaluated based on similar components. Once the individual component MTBUR was determined, the system MTBUR was estimated to be 9,783 hr. Because of the system’s simplicity, the GBIS had the highest level of reliability and is the only system with reliability levels considered acceptable for commercial airplane operations.

Each of the six study airplane categories used the system MTBUR. There was no attempt to determine whether the system MTBUR would vary between the different airplane categories because of system size or operational differences. Any differences were well within the margin of error used to calculate the system MTBUR.

The system annual failure rate was calculated based on the respective system MTBURs and yearly use rates for the airplane category. Section 10 describes the annual delay time as based on a standard delay rate assumption for each airplane category.

Each airplane category was looked at separately to determine component removal and replacement time, access time, and troubleshooting time. Figure 5-5 shows system maintenance labor-hours per year based on the summation of the individual component removal, replacement, access, and troubleshooting time multiplied by the component annual failure rate.

Category	Large	Medium	Small	Regional turbofan	Regional turboprop	Business
Annual failure rate	0.42	0.29	0.29	0.22	0.3	0.11
Standard delay rate (1 delay = XX min)	30	45	60	60	60	60
Annual delay time (min/year)	13	13	17	13	18	7
Unscheduled maintenance labor (hr/year)	3.13	1.96	2.02	1.35	1.89	0.77

*Figure 5-5. GBIS Reliability and Maintainability Analysis*

System weights provided by the design team determined the cost-to-carry value for the GBIS. System weights were provided for large, medium, and small airplanes, including weights of the components listed above and other equipment not included in the analysis, such as brackets and ground straps. The calculated cost-to-carry values (fig. 5-6) represent the costs associated with the additional weight of the system over 1 year of operation. Calculated from the system weight and a variable input, cost to carry per pound, per year (\$) equates to additional fuel burn.

	Large	Medium	Small
System weight, pounds	54.33	34.10	22.05
Costs per pound per year, dollars*	165.53	131.80	62.00
Cost to carry, dollars per year	8,993.24	4,494.38	1,367.10

\*Considered a nominal value; may differ by airline.

*Figure 5-6. GBI System Cost to Carry*

**5.4.4 Flight Operations**

GBI has the least impact on flight operations, in that there will be no onboard operating systems to monitor or control. Once the tanks are inerted on the ramp, the maintenance technician will need to inform the operating crew that the inerting has been properly completed. The object has been to design the servicing apparatus so that this function can be accomplished within the average minimum established turn times and thus not create delays, although very short scheduled turn flights could be affected.

Very little flight crew training should be necessary, but dispatch and ramp office personnel as well as the flight crew would have to be familiar with any operational limits or requirements for dispatching with the inerting system inoperative. Dispatch requirements need to be thoroughly defined with regard to conditions of non-availability of NEA supply and the existing conditions of a takeoff and flight from that station. Airport usage for scheduled or alternative operations would have to be evaluated, and route structures could be affected by nonavailability of NEA.

#### **5.4.5 Ground Operations**

The GBIS is one of the most labor intensive of all proposed inerting methods researched to date by this group. This results in part from GBI requiring that a dedicated technician be present during the inerting process while the airplane is parked on the ramp or at the gate. The GBIS is also solely dependent on airport infrastructure.

For the purposes of the gate operation, airplanes would undergo servicing procedures similar to the following:

A technician attaches the inerting hose from a dedicated source, which may come from either the terminal (jetway) or a tanker. After the inerting value is given, the valves are opened to allow the flow of nitrogen into the tank. At the end of the operation, the technician closes the valves and completes the process. When the inerting equipment has been secured, the flight crew receives from the technician an inerting slip that verifies the flight number, date, and quantity of inerting gas loaded, along with the signature of the individual who performed the task. The flight crew then checks the quantities against the flight release. This allows normal servicing and through-flight responsibilities (e.g., logbook items and maintenance checks) to be accomplished while at the gate. Inerting times are proportional to the type of airplane.

Small airports and remote areas of large airports and maintenance facilities will use inerting trucks, which will allow fuel tank inerting when the airplane is away from the gate.

The ground inerting process is unique in that while the inerting system is not flight critical, it is one of the few airplane systems that gives the flight crew no indication or means to verify if the process has been accomplished. The person monitoring the inerting process would be solely responsible for complying with the inerting requirements. Because low-skilled personnel generally hold ground service positions, turnover rates for ground service employees are significantly higher than those for maintenance technicians. Therefore, the team concluded that the inerting would have to be accomplished by a trained maintenance technician.

During several Working Group discussions, the question was raised as to whether the ullage washing task would have to be a dedicated position. After carefully considering the task, the team concluded that, even if the system could be left unattended, it is unlikely that this short period of time could be used efficiently. If the task were to be assigned to a fueler, for example, the inert task would extend the total refueling time per airplane by an equivalent amount of time. To compensate, additional refueling personnel and equipment would have to be added.

The team discussed the reduction in costs for labor. In the early stages of airplane single-point refueling systems, specialized technicians were tasked to this work exclusively. This is still the case in in many countries. As the systems became more automated and reliable, less specialized perrsonnel were able to successfully accomplish this task. The inerting process should mirror this model. The team concluded that in the future, the job function could be reevaluated, but for the initial phase, it is imperative that this is performed by a technician.

*GBI Ullage Washing Labor Estimate*

The fuel tank ullage washing or inerting process is similar to and accomplished in parallel with the airplane fueling process. The Airplane Operation and Maintenance Task Team reviewed the proposed ullage washing procedure and developed a labor estimate for this process. The labor estimate uses the inerting time developed for each airplane category by the Ground-Based Inerting Designs Task Team. The technician needs 10 min to connect and disconnect the ground service unit to and from the airplane and to complete the paperwork required to approve the inerting process. The estimated time a technician needs to inert an airplane’s fuel tank for each airplane category was then multiplied by the number of daily operations for each airplane type and by a 30% lost-labor rate to account for mechanics’ unproductive time. Figure 5-7 shows the resulting daily and annual labor estimates for ullage washing.

<b>GBI ullage washing labor</b>						
<b>Aircraft</b>	<b>World daily operations</b>	<b>Inerting time per turn, min</b>	<b>Connect/disconnect time per turn, min</b>	<b>Lost labor rate</b>	<b>Labor- minutes per turn</b>	<b>Daily labor-hours</b>
Business jet		15	10	0.3	36	
Turboprop	20,000	10	10	0.3	29	9,524
Turbofan	10,000	10	10	0.3	29	4,762
Small transport	48,167	10	10	0.3	29	22,937
Medium transport	5,142	15	10	0.3	36	3,061
Large transport	4,599	20	10	0.3	43	3,285
Total daily labor hours						43,568
Annual labor hours						15,902,355

*Figure 5-7. Annual Labor Estimate for Ullage Washing*

Nitrogen inerting stations could be mounted on jetways or in terminal buildings at major airports, similar to the preconditioned air systems currently in use at most major U.S. airports. Airports that currently use preconditioned air systems at the gate must consider the ramifications of placing inerting equipment in the vicinity of these units, to preclude the possibility of nitrogen being vented into the cabin.

If a centralized system is not available (e.g., at regional or smaller airports), tanker trucks or their equivalent would provide nitrogen to operators at these areas. Airplane size and flight schedules would determine the demand for these airports.

Procedures would also have to be established for airplanes that divert into stations that do not have sufficient nitrogen quantities for the inerting process.

The possibility of complications combined with experience requirements should also be considered when determining the long-term effects of both having and not having qualified technicians available to perform the inerting tasks. This may also hold true for the initial MEL process on through-flights.

Potential Future System Improvements

The basic philosophy behind GBI as discussed in this study supplies a standard volume of nitrogen to a fuel tank before each flight. This standard volume is based on an assumption of maximum ullage, or an empty tank. If the tank contains fuel, this would result in more nitrogen being used than is necessary to inert the tank. The excess nitrogen would then be discarded through the tank vent system. This philosophy satisfies the inerting requirement, but results in an increased nitrogen requirement and the release of more volatile organic compound (VOC) fuel-vapor pollutants into the atmosphere. This issue may be problematic in some of the more environmentally sensitive areas of Europe and the United States.

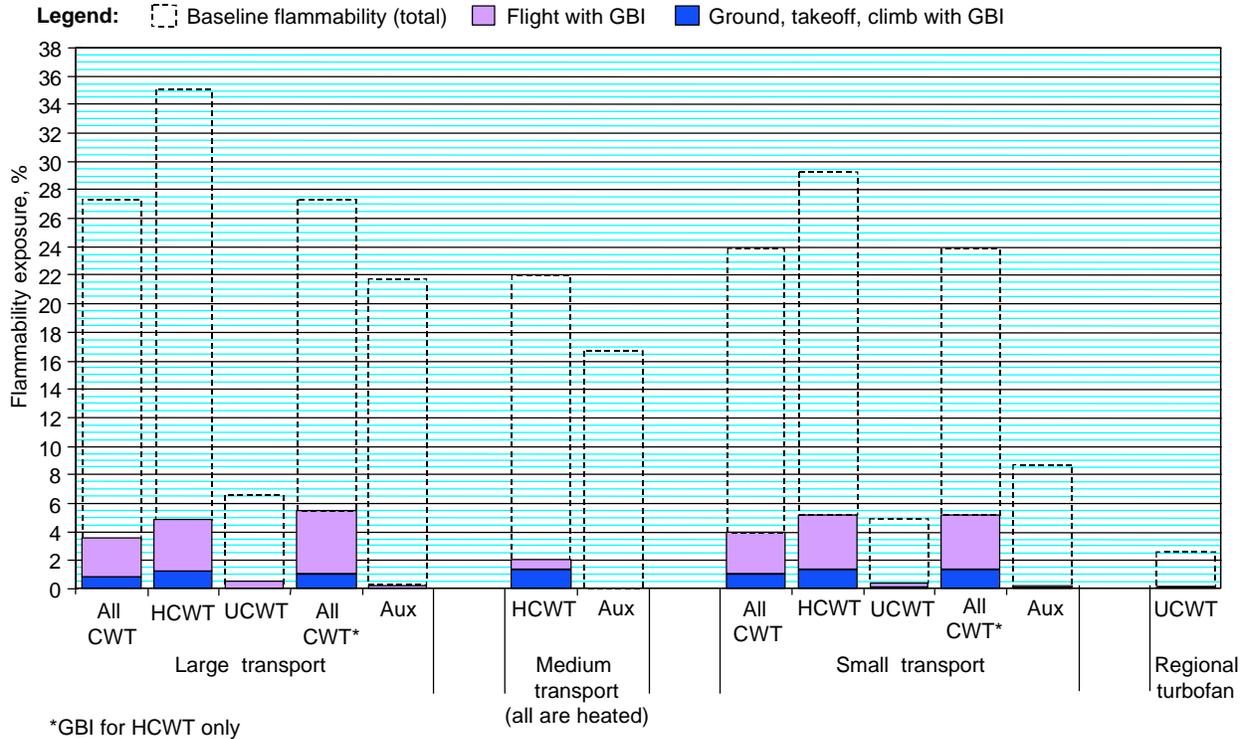
Adjusting the volume of nitrogen used to inert the tank based on the amount of fuel in the tank is one long-range solution. Once the fuel load for a flight is determined, the nitrogen load would also be calculated and included on the fueling sheet. This would require a change to the software used to calculate the fuel load at a one-time cost of \$5,000 to \$500,000 per operator, depending on the kind of fuel-load program used. Dispatchers would also need to be trained to determine the volume of NEA required. The team considered this solution as a future improvement to the GBI process. These additional costs were not taken into account in the modification estimates.

An onboard inerting computer is one possible future system improvement. The inerting computer would provide the maintenance technician the means to select a specific tank and fuel quantity. Once the information is entered, the computer calculates the proper inerting value for that tank. A monitoring function keeps the technician aware of any inerting anomalies. Sensors automatically close the inerting valves when the process is complete. Once the servicing door is closed, the computer could also provide a signal to the flight deck in case of inerting or system discrepancies. Built-in test equipment at the panel could also allow technicians to test line-replaceable units and perform maintenance checks. Such a system may streamline the inerting process.

## **5.5 SAFETY ASSESSMENT**

### **5.5.1 Flammability Exposure Analysis of GBI**

The methodology of analyzing flammability exposure is explained in section 4.2.2, Flammability Exposure Analysis. Using this modeling approach, the effects of GBI relative to the baseline flammability for the large, medium, and small transport categories are shown in figure 5-8. As noted in the discussion on modeling in section 4, these values do not represent any specific airplane, only a generic configuration selected to represent an airplane in this category. More detail about the analysis is provided in appendix C, Ground-Based Design Task Team Final Report.



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Figure 5-8. Flammability Exposure Results, Ground-Based Inerting System

The “All CWT” values represent a combination (in accordance with the ARAC estimated distribution) of the values for the heated CWTs and the unheated CWTs. Also shown are the individual values for the heated CWT- and the unheated CWT-generic airplanes.

The Tasking Statement also asks for the effect of limiting GBI to airplanes with adjacent heat sources (referred to in this report as heated CWTs) only. As shown in figure 5-8, the largest flammability reduction is for heated CWT airplanes, because the baseline flammability of the unheated CWT airplanes is already similar to the heated CWT with GBI. Therefore, limiting GBI to airplanes with heated CWTs would result in only a modest increase in fleetwide flammability exposure. Note that use of GBI for only heated CWTs is evaluated as scenario 11 and is used in the executive summary information.

Unpressurized auxiliary tanks were also evaluated; the results are shown in figure 5-8. As shown, for airplanes with unpressurized auxiliary tanks, GBI would significantly reduce the flammability. These numbers do not apply to those tanks that use pressure to transfer fuel to other tanks and remain pressurized at altitude. Because auxiliary tanks typically are not exposed to external heat sources, they typically are not flammable on the ground. Maintaining a higher ullage pressure in the auxiliary tank avoids most of the decrease in the LFL that otherwise occurs during climb, and thus most of the auxiliary tank flammability exposure. An analysis of the effects of pressurized auxiliary tanks can be found in the Ground Based Inerting Task Team Report appendix. The analysis shows that use of pressurized auxiliary tanks can result in a reduction in flammability similar to that of GBI.

**5.5.2 Safety Assessment of GBI**

Figures 5-9 and 5-10 show the potential impact of GBI on reducing future accidents in the United States and worldwide. If GBI is adopted, the forecast assumes that it will be fully implemented by the year 2015. At that time, the forecast indicates the time between accidents in the United States would be 16 years with the SFAR alone, 36 years with SFAR and inerting in heated CWTs, and 38 years with the SFAR and inerting in all fuselage tanks. The corresponding times between accidents for the worldwide fleet would be about half those estimated for the U.S. fleet.

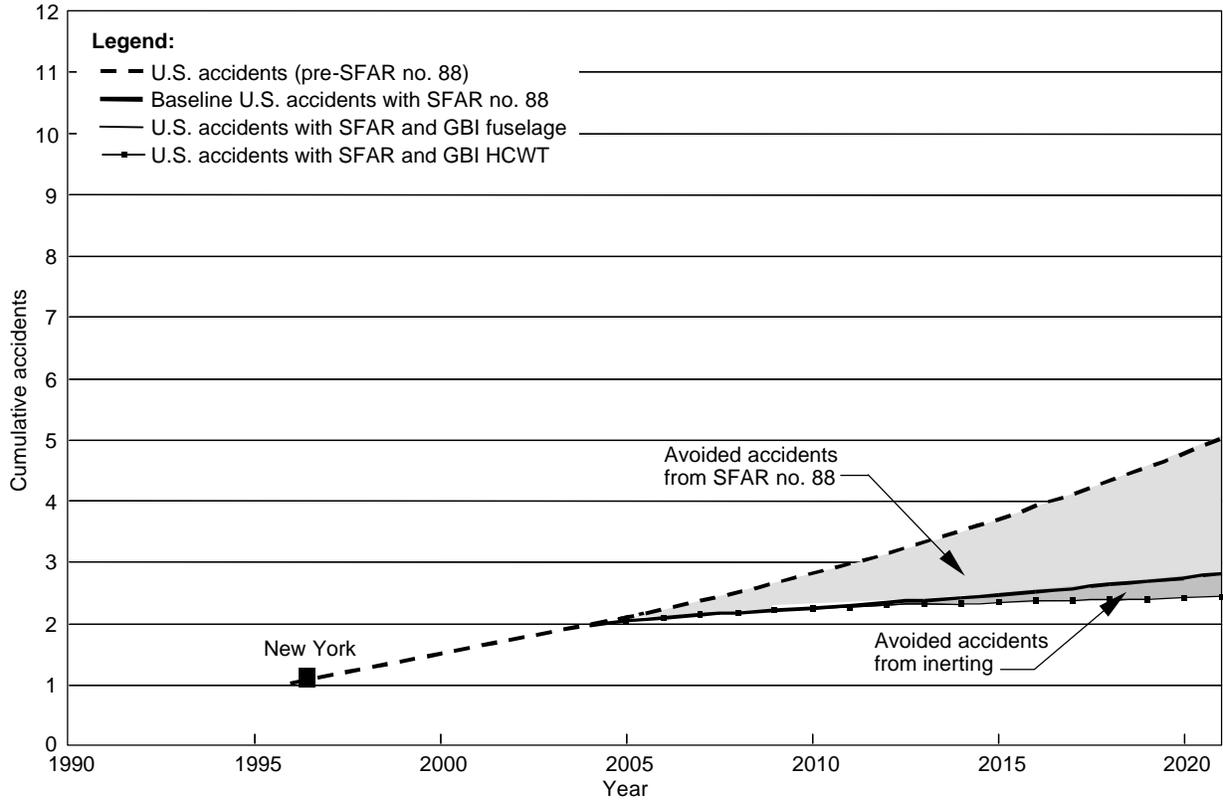


Figure 5-9. U.S. Cumulative Accidents With Ground-Based Inerting

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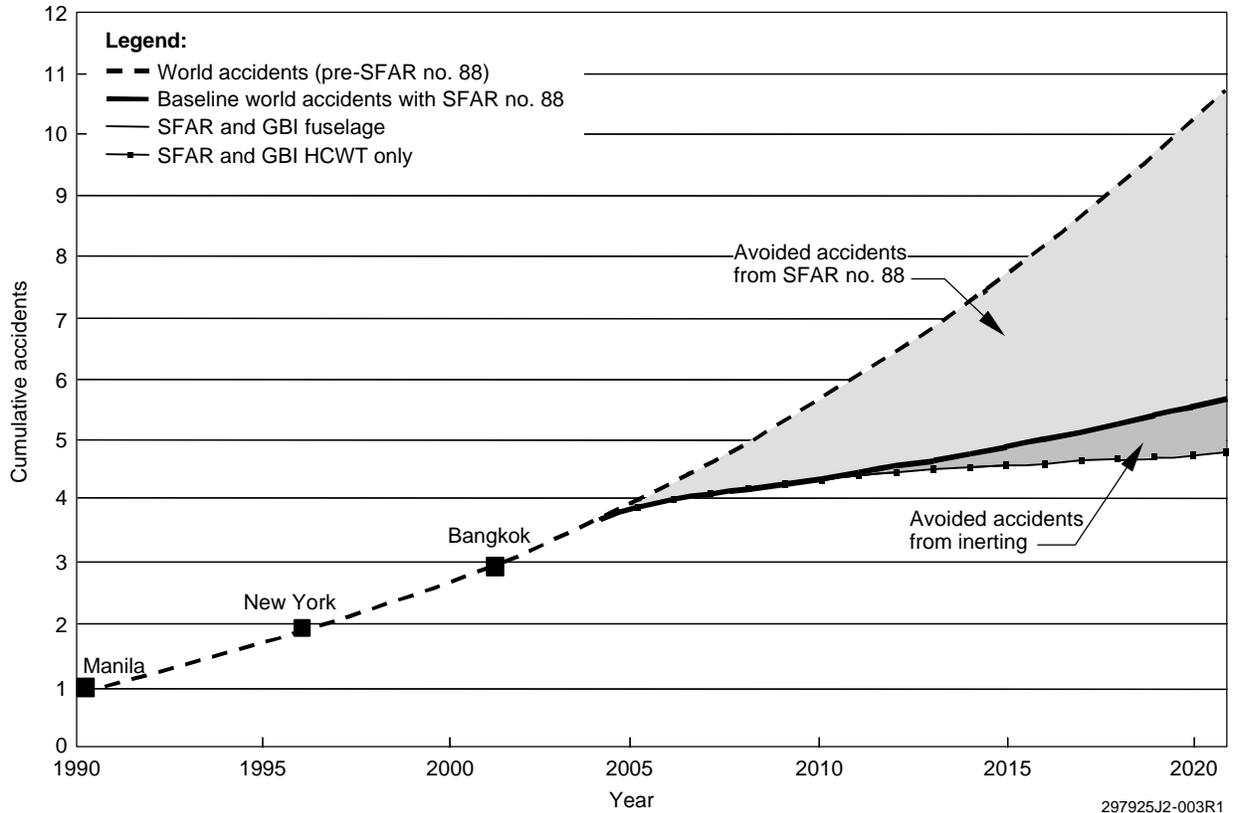


Figure 5-10. Worldwide Cumulative Accidents With Ground-Based Inerting

### 5.6 COST-BENEFIT ANALYSIS

Figures 5-11 through 5-18 graphically represent the cost-benefit analyses of the scenario combination examined for ground-based fuel tank inerting.

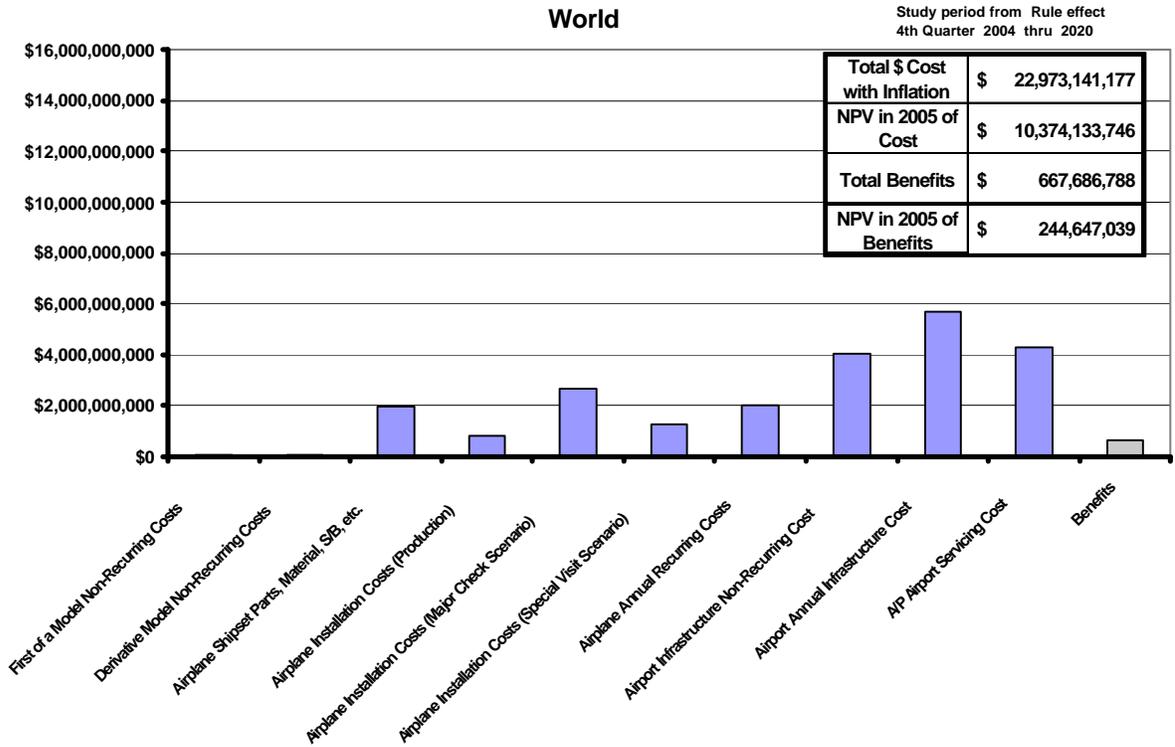


Figure 5-11. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (World)

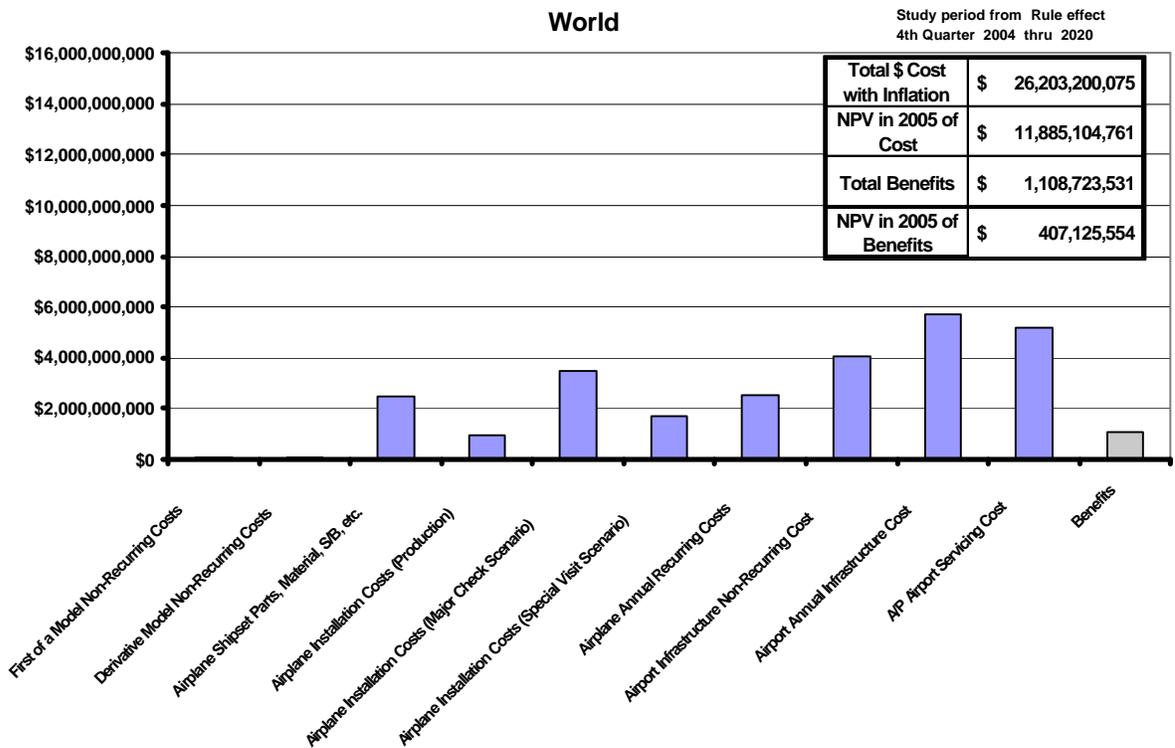


Figure 5-12. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (World)

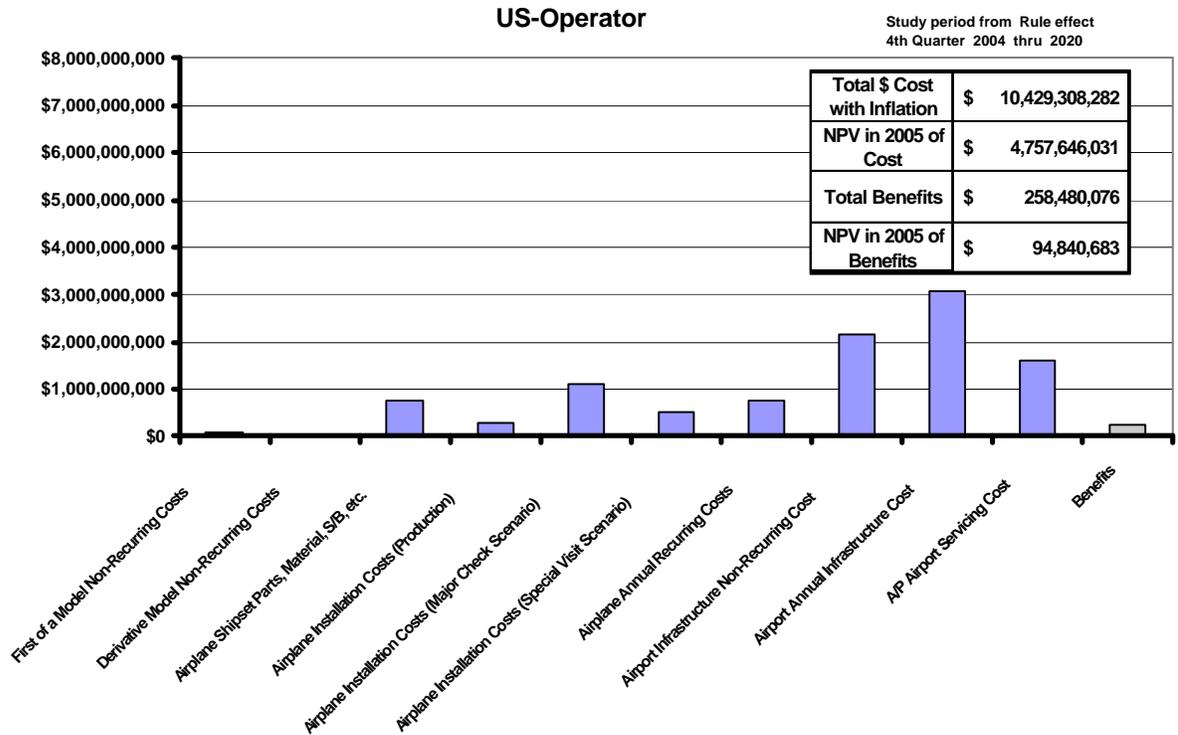


Figure 5-13. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (U.S.)

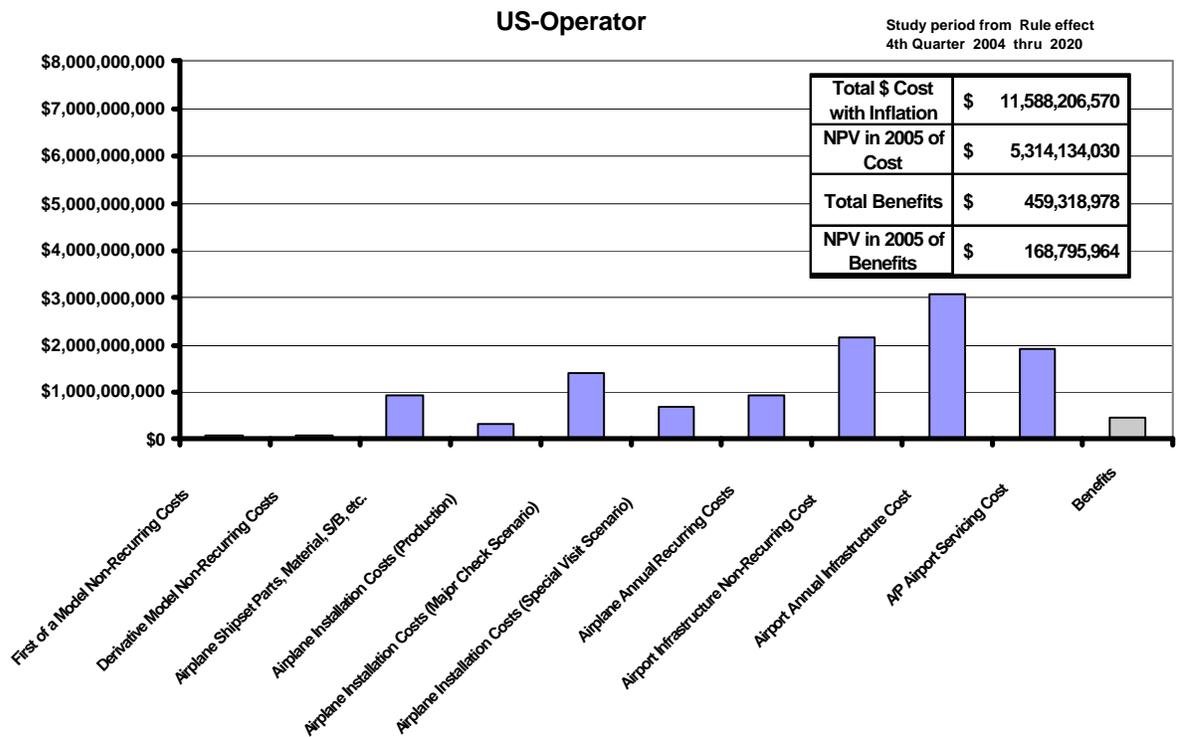


Figure 5-14. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (U.S.)

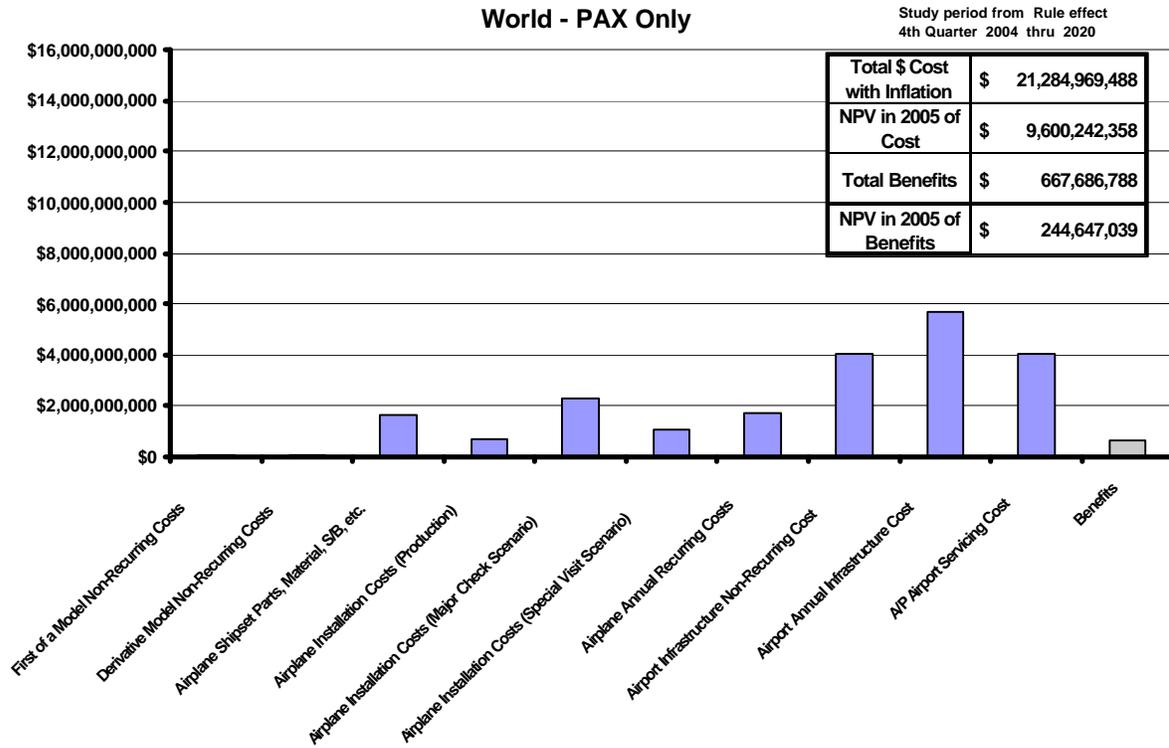


Figure 5-15. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (World, Passenger Only)

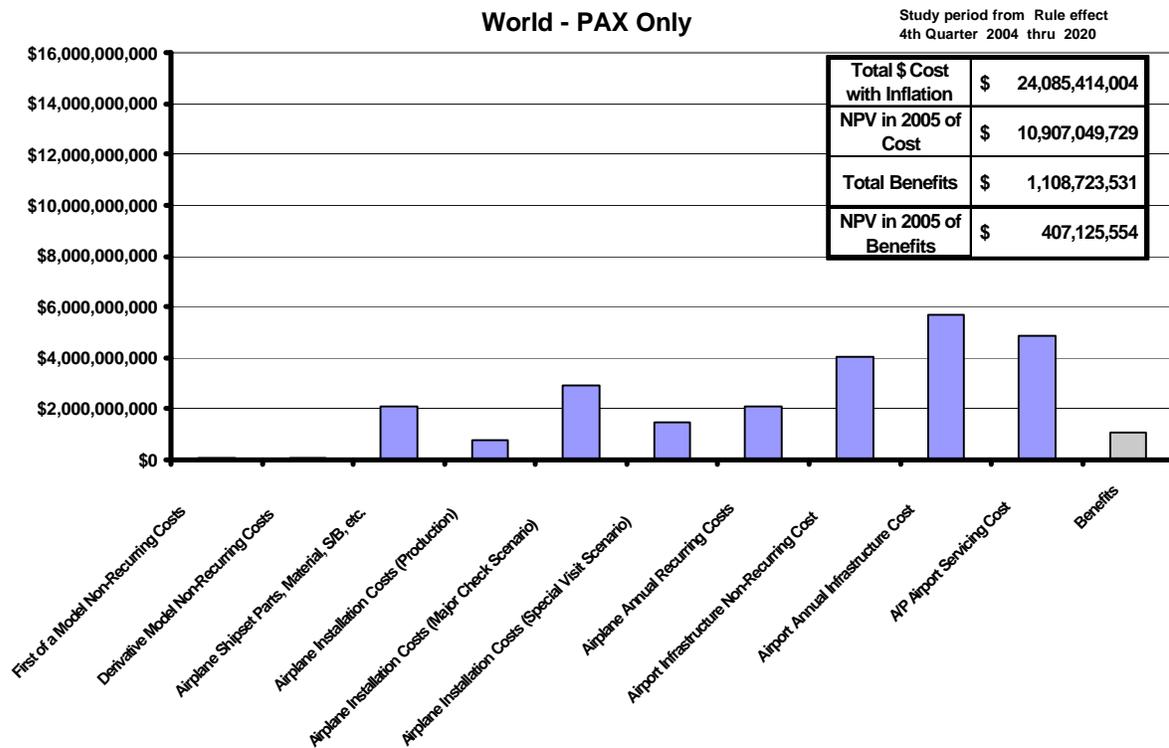


Figure 5-16. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (World, Passenger Only)

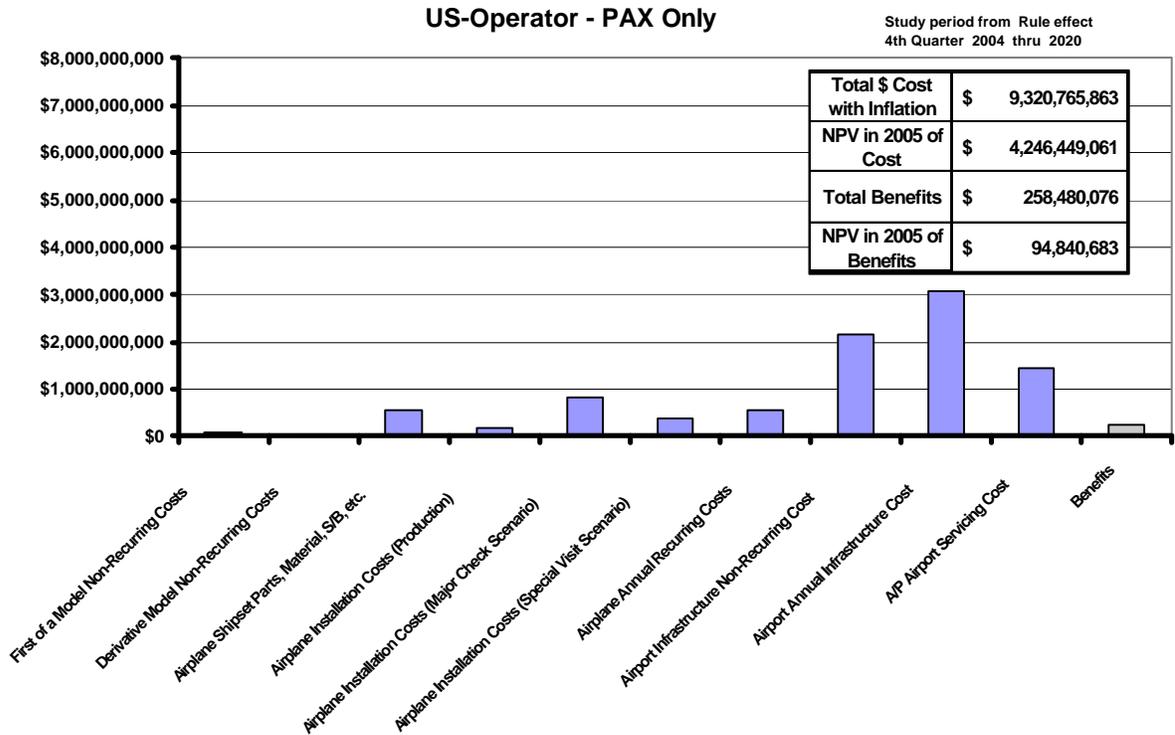


Figure 5-17. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (U.S., Passenger Only)

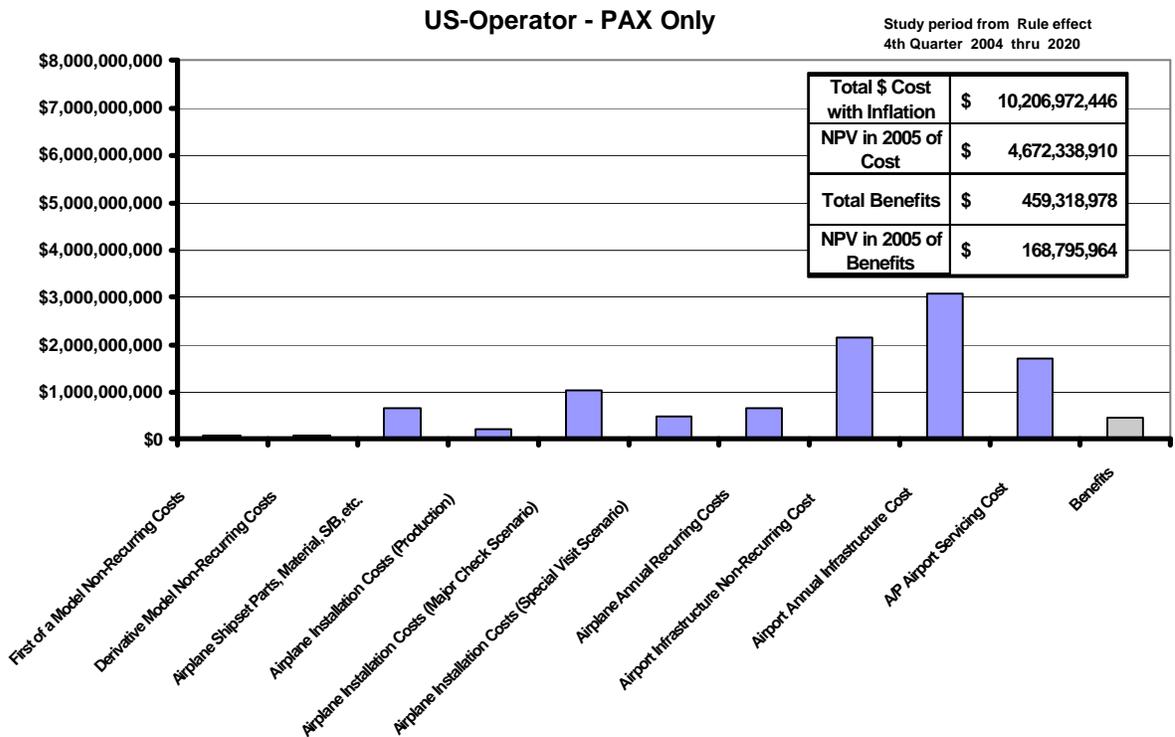


Figure 5-18. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (U.S., Passenger Only)

## **5.7 PROS AND CONS**

### Pros

- Reduces flammability exposure.
- Simple, with the least impact to the airplane.
- Involves little technical complexity on the airplane.
- Uses current technology components.
- Does not introduce any new installation technology.
- Uses straightforward system operation, in that it is not performed in sequence with the refuel operation and does not require any knowledge of the actual fuel load.

### Cons

- Does not remain inert for 100% of the flight cycle. Introduction of air resulting from fuel consumption may still be flammable during ground time after landing but before inerting on hot days.
- Depends on significant airport infrastructure.
- Requires low NEA supply pressure to avoid overpressurizing the airplane fuel tanks if the overpressure system fails.
- Needs new standard airplane interface coupling.
- Amount of NEA supplied may be in excess of that required to achieve the inert levels when the tank is already partially or completely full.
- Requires unique maintenance practices.
- Increased VOC emissions during the fueling process.

## **5.8 TECHNICAL FEASIBILITY**

### **5.8.1 New Designs**

There are no major concerns with the concept for newly designed airplanes if GBI is integrated early in the design phase. During the design cycle, the system would be subject to design reviews, safety assessment, zonal analysis, and so on. The basic design phase will finalize the manifold design, structural penetrations, wiring, and service-point location. Electrical controls and circuits associated with the inerting system equipment need to be routed so as not to introduce any new hazards. Location of the filling point would take into consideration not just the positioning of the servicing trucks but also their location, so as not to introduce additional hazards in the event of a wheels-up landing. Accessibility of the filling connection would take into consideration the acceptability of servicing steps or a platform, if necessary.

### **5.8.2 In-Production Airplane Designs**

Optimum manifold design in terms of weight and location may not be possible because of other installed systems or limitations on location of structure penetrations. Certain airplane types may require modifications to tank venting arrangements, which would require additional design and certification activity over and above that required to demonstrate the effectiveness of the modification in inerting the tank. Location of the servicing connection point may require redesign of a section of the external airplane body fairing, possibly including the introduction of a dedicated panel granting access to the servicing point. Airline spares will be affected.

### **5.8.3 In-Service Airplane Retrofit**

These same possible redesign concerns apply equally to airplanes already in service needing to be retrofitted with GBI. Modification to the tank installation or areas around the fuel tank made to the airplane since the original delivery may require further additional design work and adaptations.

Auxiliary Tank Installations

Generally, these concerns also apply to auxiliary tanks, as do several additional concerns.

- The need for double-walled tubing in the pressurized areas will further complicate tube routing in areas where space is constrained by other systems.
- More than one auxiliary tank will require a balanced flow of NEA between the tanks. This may require an NEA volume greater than the 1.7 times the total ullage volume currently envisaged, or an additional connection point and control panel.
- Some auxiliary tanks include bladders inside the tanks, which could complicate redesign because of the need for new bladders to accommodate new tubing penetrations and routing in the tank.
- New pipe penetrations will require modification of cargo bay liners.

**5.9 MAJOR ISUES AND RESOLUTIONS**

A new standard interface coupling, developed and controlled by a recognized authority, would allow the airplane to be purged at any airport location from a ground-based NEA distribution system. The schedule for accepting this standard and the availability of hardware would have to be compatible with the regulatory requirements.

The correct purging of the tank ullage depends on the performance of the ground supply. A specification will be required to control pressure and flow performance and integrity of the ground equipment. The required volume to correctly purge the tank ullage will be defined following airplane tests. Ground equipment will need to be specified before airplane tests can be performed.

Some ground equipment requirements (e.g., delivery pressure) drive the need to consider the demands of retrofitting the system onboard existing airplanes. Ground equipment must be designed so it does not constrain future airplane designs.

**5.10 CONCLUSIONS**

Installing a GBIS does not require that any new technology be developed, although the low supply pressure of the NEA will require attention to the detailed design of the distribution system. Challenging practical considerations may arise for system retrofit applications (e.g., cutting and reinforcing holes in the tank structure).

The availability of suitable ground equipment, regulatory requirements, airport nitrogen sources, and airport distribution systems will determine the time required to make such a system operational.

Certification will require ground and flight tests on each major airplane model, which in turn will require the availability of airplanes—many of which the original manufacturers do not own—on which to perform the certification tests.

Specific attention must be paid to the special ground equipment and interface connector. Both these items are new and will need to be developed. Development of a new standard will ensure worldwide compatibility. Control of this new standard must be clearly identified.



## 6.0 AIRPORT FACILITIES

### 6.1 CONCEPT DESCRIPTION

The FAA tasked the FTIHWG with developing conceptual methods to

- Introduce nitrogen gas into designated airplane fuel tanks to displace the oxygen in the unfilled portion of the tank (i.e., “ullage washing”).
- Saturate the jet fuel held in airport storage facilities (i.e., trucks and fuel-farm storage tanks) with nitrogen (i.e., “fuel scrubbing”).

In response, the FTIHWG has developed appropriate design concepts to describe the infrastructure necessary to manufacture, store, and distribute the required NEA and nitrogen-saturated fuel (NSF) from permanent airport facilities.

The following sections summarize the various design scenarios that address the on-airport manufacturing and distribution—both fixed and mobile—of NEA and NSF to the wings of airplanes under consideration for inerting.

Sections 6.1.1 and 6.1.2 describe ullage washing and fuel scrubbing. The initiating FAA task requirement can be found in appendix A, Tasking Statement.

#### 6.1.1 Ullage Washing

Ullage washing removes a large portion of the oxygen gas from the air in the fuel tank ullage. Because fuel vapors cannot ignite unless a sufficient amount of oxygen is present to support and propagate the combustion, reducing the oxygen concentration within a tank eliminates or greatly reduces the ability of an ignition source to cause a constant-volume combustion of the tank’s fuel vapors.

To reduce oxygen levels, the ullage is flushed or “washed” with a high-purity (97% to 98%) NEA stream that is produced using a membrane gas generator skid and ducted into the fuel tank. This 97% to 98% NEA was chosen as the most cost-effective inerting agent because it is less expensive than higher purity gas but contains half the oxygen content of a 95% inert product. The volume of gas for inerting has been chosen by the Ground-Based Inerting Designs Task Team to be 1.7 times the volume of the airplane tank to be washed, based on an empty tank. These conditions of inerting-agent purity and volume have been shown to reduce oxygen levels within the ullage space of an empty fuel tank to less than 9%. Therefore, no oxygen meter for gas analysis will be needed to verify ullage washing, which helps to minimize complexity. More importantly, in tanks that are even partially full of fuel, the oxygen content is also expected to be reduced to lower than 9% because of the higher actual volume of NEA flowing through the system.

NEA is generated continuously from air using membrane gas separation technology. Essentially, air is compressed, filtered free of solid particles and liquid aerosols, and fed to bundles of hollow-fiber polymeric membranes where the oxygen, carbon dioxide, and water vapor are removed from the nitrogen stream. These gaseous impurities are vented at low pressure while the high-pressure enriched nitrogen product exits the skid at 97% to 98% purity through a surge tank. Backed up by a storage vessel of liquid nitrogen and a vaporizer, a continuous, seamless transfer of NEA will be ensured through the gas supply lines. One large membrane gas generator skid and backup liquid nitrogen tank would be supplied per airport concourse, mainly to minimize the need for long piping runs between terminals. The NEA would then flow

through a header located along the roof of each concourse, at a pressure of about 150 psig. The header would be constructed of 2-in-diameter type-K copper tubing. This header would feed an array of metering stations, located one per gate, to supply nitrogen to the airplanes for ullage washing under controlled flow and pressure conditions. A diagram of the membrane gas generator skid at a concourse is shown in figure 6-1.

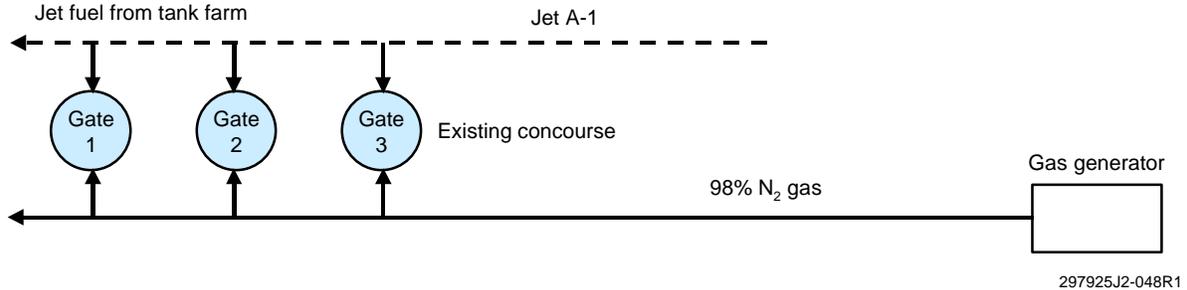


Figure 6-1. Membrane Gas Generator at Concourse for Ullage Washing

At multiple-concourse airports, it would be prudent to consider interconnecting membrane skids between terminals with a larger manifold. While the capital cost of achieving this would be significant, the benefit would be an additional level of redundancy without liquid nitrogen backup if one skid were down for extended maintenance.

The metering stations for injecting NEA gas under flow- and pressure-controlled conditions at each terminal gate are shown in figure 6-2. The station is connected to the concourse NEA header on one end and to a specially designed connector on the airplane at the other end. As stated, this system serves to reduce the oxygen content in the ullage space on airplanes by supplying a given amount of low-pressure NEA to the ullage from a high-pressure source. A solenoid valve and pressure regulator are used to initiate and complete a period of constant-rate gas flow to the airplane. By maintaining this constant flow for a time appropriate to the airplane model, the proper amount of NEA is injected into the ullage. The gas is made available by the regulator at a pressure of just a few pounds per square inch gage. In case of maintenance needs, a shutoff valve would be used to block off the station. The hose reel allows connection to the airplane from a station typically located at the end of the jetway.

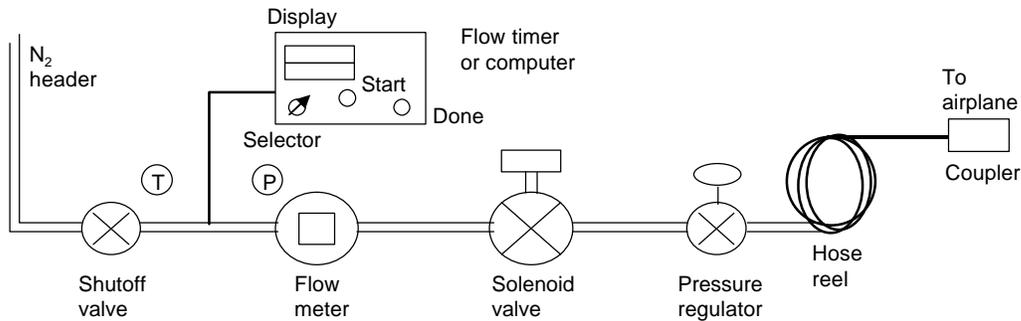


Figure 6-2. Typical Metering Station, Nitrogen Flow, and Pressure Control

The gas metering station would be designed to operate under applicable electrical-safety classifications in an unheated, outdoor service environment where it would be subject to temperature, moisture, and vibration. This station includes a flow meter, flow control terminal, and flow valve. The flow control terminal comprises a lockable, weatherproof housing that contains a flow computer and delivery receipt printer. The flow meter and flow computer deliver a preset quantity of NEA to the airplane's tank ullage. The delivery of this gas to the ullage is measured with reference to standard conditions (i.e., 60°F and 1 atmosphere). Hence, the required preset amount of gas is delivered regardless of the ambient temperature or source-gas pressure.

The flow computer essentially allows gas to flow to the airplane ullage for a given amount of time and then displays the actual volume of gas injected. The flow computer would include a selector to choose the type of airplane being inerted, a start button to control the solenoid valve, an indicator light to show when the job is done, and a dual display to illustrate required and injected gas volumes. In addition, the unit would be configured so that the operator is required to perform a security check (e.g., input an authorization code) to access the system initially. Stored within the flow computer, the appropriate inerting time will produce, at a given constant-rate gas flow, an inert ullage space in the tank above its fuel or within its entire volume if it is empty.

To inert a 737, for example, an operator would connect the coupler to the airplane, select the appropriate position on the selector, and verify the correct pressure on the flow control display. The upper display on the flow computer would show the volume required for ullage washing of a 737 airplane (e.g., 1,360 standard cubic feet [SCF]). The operator would then depress the start button. An NEA flow of 100 standard cubic feet per minute (SCFM) would occur for 13.6 min to produce the recommended volume of NEA for the 737 in this example. Then the indicator light would illuminate (indicating the task is done) and the solenoid valve would shut. The lower display would read 1,360 SCF, reflecting the total of the cumulative gas flow through the metering system at standard conditions. If the value were low, the operator could adjust for more NEA into the ullage to satisfy the requirement. The operator could either verbally inform the flight crew that the airplane has been inerted, or print a written receipt to notify them. This data could also be sent by means of a communications link to a central computer, if preferred.

Maintenance issues related to ullage washing are anticipated to be reasonably light because much of the equipment is passive. In general, the only devices containing moving parts are the solenoids in the flow valves at the metering stations and the air compressors and filters on the membrane gas generator skids. The membrane fibers are passive physical barriers with long lives when adequately protected from chemical attack, liquid impurities, and temperature and pressure excursions. A person skilled in electrical, piping, and instrument issues should be able to handle all routine and breakdown maintenance work on the metering stations at the airport easily.

Ullage washing systems will have to be customized for each airport. Nevertheless, major components required for design of a fixed, ground-based ullage washing system for various classifications (i.e., sizes) of airports may be found in the generic layouts presented in appendix E, Airport Facility Task Team Final Report.

### Mobile Ullage Washing

Where it is not practical to supply a land-based source of nitrogen to ullage wash airplane fuel tanks at the loading gate, remote mobile nitrogen-dispensing equipment will be required. This equipment can be either mobile nitrogen-generating equipment, or liquid nitrogen tankers with vaporizers to convert the liquid to a gas.

Two factors have influenced selection of nitrogen-generating equipment over liquid nitrogen and vaporizing equipment for presentation in this report:

- Training and related safety issues associated with handling cryogenic liquids.
- Cost of ongoing purchase of liquid nitrogen compared with costs of generating gaseous nitrogen directly from the air using compressors and high-purity nitrogen membranes.

The design of mobile ullage washing vehicles will emphasize ease of operation by allowing operators to select predetermined automatic cycle times specific to each airplane category. Inerting vehicles will be designed with a high-volume-output, screw-type compressor, appropriate filter, high-purity nitrogen separators, specially designed meter, pressurized nitrogen storage tanks, and a related automated control system. A vehicle brake interlock system is required to ensure that delivery hoses and nozzles are properly stowed before the truck's brakes are released.

The overall size of mobile NEA-generating equipment could become an issue because of the number of high-purity membranes required. When consideration is given to washing the ullage of the CWTs of large transport airplanes and to possibly providing "makeup" nitrogen to hold refueling tankers inert, size quickly becomes an issue.

Current ramp congestion dictates that mobile ullage washing use the smallest package and vehicle footprint possible to accomplish the task.

It is estimated that to service remotely parked or operated airplanes, especially freighters, and as a backup for land-based systems, mobile ullage washing vehicles will typically represent between 65% and 85% of the number of refueling tankers operating at a particular airport. Adding mobile inerting processes at the terminal gate is certain to exacerbate complications associated with congestion around airplanes. There are a number of existing services associated with airport ground operations, including fueling, baggage handling, catering, and cleaning services. These operations require vehicles to travel to and from the airplane in a very short period of time. Therefore, the inerting process could present an increased risk of accidents during operation. Inerting could also decrease the time available to conduct all other ground operations, further adding to the risk.

At small airports, it may be more cost effective to have all mobile equipment, compared to the fixed infrastructure costs.

Problems generally associated with a significant increase in personnel staffing while operating within the same physical area will be present.

Basic concept designs of both mobile liquid nitrogen conversion and NEA-generating ullage washing vehicles are addressed in appendix E.

### **6.1.2 Fuel Scrubbing**

In the ARAC Tasking Statement, the FTIHWG was asked to provide a concept and design methodology for a system that would saturate and maintain aviation turbine (jet) fuel with nitrogen.

The purpose of delivering NSF into the airplane during normal fueling and refueling operations is to minimize the outgassing of entrained oxygen during the takeoff, climb, and cruise flight envelope to supplement the benefit of GBI. Because of the potential impact on fuel properties, the complexity of the processes required, and the costs, the team concluded that fuel scrubbing was not practical.

The 2001 FAA/Boeing flight test showed that the oxygen evolution from the fuel was not significant to the effectiveness of GBI; therefore, scrubbing the fuel would have very little effect on maintaining an inert atmosphere. It also does nothing to alleviate the concern of empty CWTs.

Three concepts were explored during this study:

- Bulk fuel scrubbing by nitrogen injection.
- Bulk fuel cooling using a proprietary process.
- Bulk fuel saturation with carbon dioxide using a proprietary process.

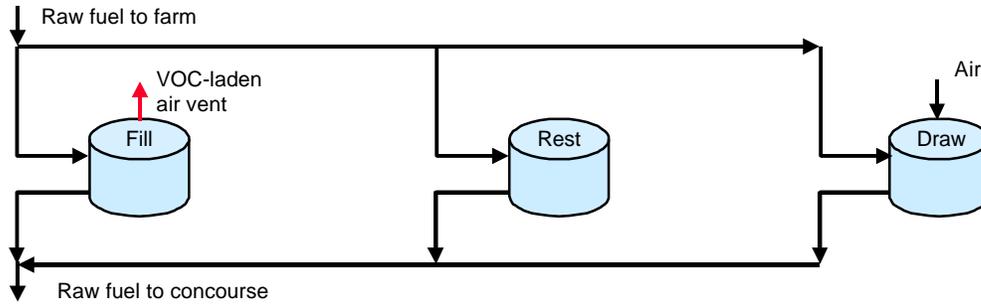
The three concepts are summarized in sections 6.1.2, 6.1.3, and 6.1.4. The detailed discussion and design concepts covering these fuel modification processes are addressed in appendix E.

#### *Fuel Scrubbing by Nitrogen Injection*

In order to prevent the oxygen inherently dissolved in the liquid fuel from coming out of solution and polluting the previously washed fuel tank ullage as the airplane climbs, it may be required to scrub the fuel of oxygen before loading onto the airplane. The logical place to do this job is at the fuel storage facility (fuel farm), where the fuel is inventoried and allowed to settle before being pumped into the hydrant system or loaded on mobile refueling vehicles (refuelers). Because jet fuel can preferentially absorb oxygen from the air, the processing technology at the fuel farm needs to focus on removing oxygen dissolved in the liquid fuel, preventing it from reentering the fuel after treatment, and dealing with environmental issues such as VOC emissions. Because of the more aggressive gas and fuel contact that would occur with implementation of fuel scrubbing technology, we anticipate that VOC emissions would be higher than current levels, causing the need for VOC abatement equipment.

The proposed fuel processing system comprises specialized gas generation and application equipment. The high-purity gas-generating skid (99.999% inert) is used to strip the fuel of dissolved oxygen and to blanket the fuel storage tanks at the farm with nitrogen to prevent reentry of oxygen from the air. The fuel scrubbing unit, which is a gas/liquid fuel contacting system, uses pure nitrogen from the high-purity gas-generating skid to replace the oxygen in the fuel. Tank blanketing management systems control the pressure and oxygen concentration in the headspace above the fuel in the individual large storage tanks. Finally, emissions of fuel vapors from the fuel storage tanks and vent gas from the fuel scrubbing unit will be controlled using an environmental abatement system that uses liquid nitrogen to cryogenically condense the VOC vapors from the vent stream and return them to the fuel tanks. Essentially, all technologies work as separate units at the fuel farm to ensure that the fuel delivered to airplanes has been scrubbed of oxygen.

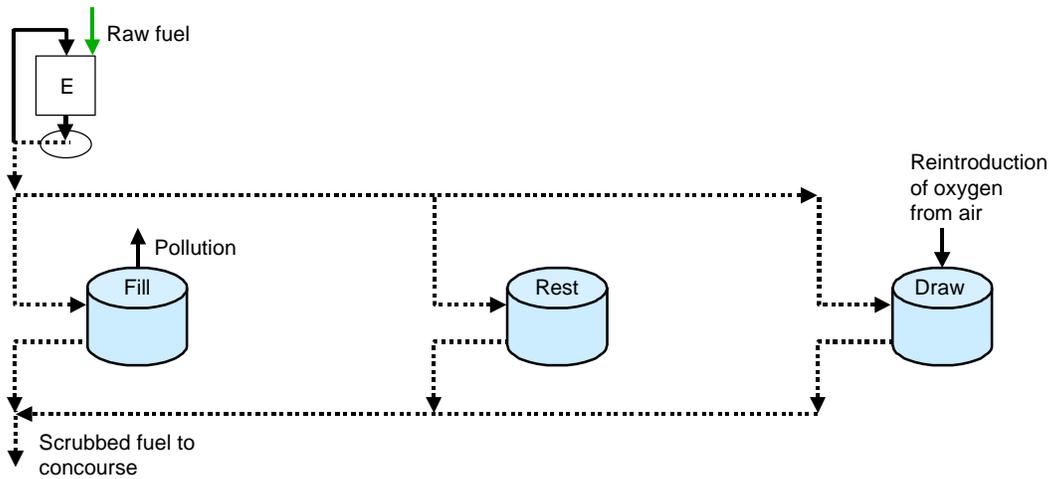
To more easily understand the integration of these various technologies to achieve fuel scrubbing, it is useful to review the existing fuel farm at a typical airport. The simplest configuration is illustrated with three tanks in figure 6-3. Jet fuel from the pipeline continuously fills the tanks as they supply the hydrant system on an active tank-rotation basis. The maximum fuel flow rates for a large airport (e.g., Chicago O'Hare International) from common carrier supply pipelines and withdrawn by hydrant system from storage may exceed 4,000 and 18,000 GPM, respectively. The supply/withdrawal cycle typically involves a piston of liquid fuel filling one tank as a similar flow rate of VOC-laden air exits the vent to maintain a constant in-tank pressure at or near ambient atmosphere. Elsewhere, another tank is being drawn down, aspirating ambient air into the headspace to break any vacuum that is formed by the retreating liquid. The third tank rests for about 24 hr to settle out any free water and debris that may be present in the fuel.



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Figure 6-3. Current Tank Farm Configuration

The concept of fuel scrubbing is easily illustrated with some relatively minor additions to the current piping configuration at a fuel farm (fig. 6-4). With this new approach, raw fuel containing 50 to 100 p/m of dissolved oxygen enters the fuel scrubbing unit and is stripped of the oxygen through intimate contact with a stream of high-purity nitrogen gas. The nitrogen replaces the oxygen dissolved in the liquid and dilutes the oxygen gas given off by the fuel. Approximately two volumes of nitrogen gas are required for each volume of fuel processed. The result is a fuel scrubbed of oxygen to about 5 p/m. It has been estimated that the outgas that exits the fuel scrubbing unit contains about 1.5% oxygen and about 0.5% VOC vapors.



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Figure 6-4. Fuel-Farm Piping With Added Fuel Scrubbing Unit

Two issues remain with this level of fuel processing, however. The outgas displaced from the fuel tank being filled and the gas that is vented from the fuel scrubbing unit, both of which contain oxygen and fuel vapors, will pollute the air if not treated. In addition, oxygen in the air aspirated into the fuel tank being drawn down will ruin the fuel treatment previously done by the fuel scrubbing unit. Additional technology needs to be added to that shown in figure 6-4 to avoid these problems and to meet all previously mentioned objectives for fuel scrubbing.

In the complete fuel scrubbing concept shown in figure 6-5, the environmental abatement system and tank blanketing management system have been integrated into the fuel farm to control pollution from VOC emissions and protect against the reoxygenation of the scrubbed fuel in the tanks.

Tank blanketing management systems, mounted one per tank, automate nitrogen blanketing of the tank headspace by measuring and controlling the pressure and oxygen content of the gas above the fuel. In this way, the tanks are continuously maintained at a given pressure and oxygen level.

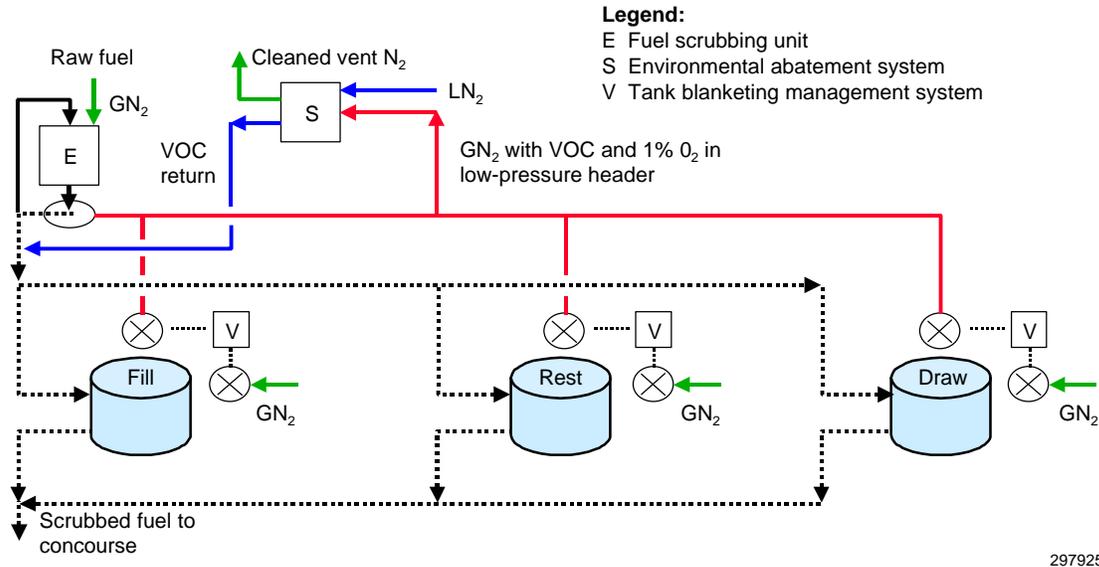


Figure 6-5. Complete Fuel Scrubbing Operation

A low-pressure header connects all vent valves on the fuel tanks and the gas vent from the fuel scrubbing unit to the inlet of the environmental abatement system. The fan on the environmental abatement system will be used to control the backpressure within this low-pressure header.

The process gas flowing through the environmental abatement system contacts stages of increasingly cold heat exchangers to remove nearly 100% of the VOCs by condensation from liquid nitrogen. The liquid fuel is then sent back into the scrubbed fuel line that flows to the storage tank so as not to deplete any compounds out of the normal jet fuel. The nitrogen, which has been stripped of fuel vapors, is then vented to the air or compressed and sent to the concourse for ullage washing if a suitable pipeline is available. The spent nitrogen gas that was vaporized to cool the environmental abatement system is pure and will be sent to the high-purity nitrogen header being fed by the high-purity gas-generator skid.

#### Distribution of Nitrogen-Scrubbed Jet Fuel by Refueling Tankers

A large number of airports around the world visited by airplanes requiring scrubbed jet fuel might not have the facilities for the bulk distribution of treated jet fuel. These airports may not incorporate a jet fuel hydrant system (underground pipeline distribution network), or the “final rule” from the work of this ARAC study may not apply to a sufficient number of air carriers to warrant bulk fuel scrubbing in the fuel storage facilities. In such cases, limited dedicated treated fuel storage may be preferred for supporting the requirements.

There are many airports that have a jet fuel hydrant system to support the passenger airplane operations, but have cargo and other “feeder” passenger air operations parked in remote (nonhydrant) locations. The mobile refueler tanker method must be modified to enable the supply of the scrubbed fuel to these locations.

This system concept proposes new design criteria and modifications for newly manufactured and in-service refueling vehicles to enable scrubbed fuel to be transported from airport storage to the wing of the airplane.

During airplane refueling, inward venting of the refueler tank is required to prevent collapse of the tank. Airplane refueling would also require NEA to be supplied to the refueler vents to prevent fuel re-oxygenation.

These vents automatically protect the tank from collapse during volumetric contraction during decreases in ambient temperature. Conversely, the vents will also prevent tank rupture resulting from thermal expansion during high ambient temperatures. The current design of typical vapor recovery system equipment does not provide for integration of the existing vent configuration. All vents will need to be interconnected within a system fed by a nitrogen supply. To accomplish this, modification to the refueler will be required.

Relocation of the in-breathing vents may require welding modifications to the tank vessel. If so, these modifications would need to be completed at a facility certified to make such repairs. After modification, the refuelers will mirror the typical vapor recovery system of vehicles transporting flammable liquids on public highways. These vehicles are required by 40 CFR Part 60 to be tested at the time of initial manufacture and periodically thereafter to ensure vapor tightness. It is anticipated that this testing and recertification will be mandated to ensure that only scrubbed fuel is delivered to the airplane and maximum control of VOC emissions is maintained. Relevant portions of 40 CFR Part 60 are found in appendix E.

Modifications include relocation of in-breathing vents to a point where vapor recovery vent hoods and associated piping can connect all vents to a common nitrogen supply. A 1-psig nitrogen pressure stream will be necessary for the vapor recovery system to operate properly at all times.

### **6.1.3 Fuel Cooling**

The Airport Facility Task Team reviewed an airplane fuel tank inerting system design concept developed under a patented process. Because fuel cooling does not directly address the issue of empty CWTs, a supplemental means of inerting these tanks would be required. Time did not allow for a complete review of the technical data. A more detailed description of this process is found in appendix E.

The fuel-cooling concept consists of both refrigerating the fuel and washing the airplane fuel tank ullage with inert gas. The two processes may be used separately or combined. The cooling systems supply fuel to the airplane at less than 40°F. Cooling facilities located away from congestion cool the entire airport fuel supply (hydrant and/or refueler) to less than 40°F. Inerting gas for ullage washing is stored away from congestion and transported to the airplane by gas service vehicles in a cryogenic phase and converted to a gaseous phase for ullage washing. Refinements include combining the two processes into a single system.

### **6.1.4 Carbon Dioxide Fuel Saturation**

The FTIHWG Airport Facility Task Team studied an airplane fuel tank inerting system design concept developed under a patent-pending ERA-7™ process. As with fuel cooling, this system does not directly address the issue of empty CWTs. A supplemental means of inerting these tanks would be required. Because the concept was not sufficiently developed to allow for a complete review of the technical data or a detailed analysis of the system's infrastructure requirements, the developer's claims are presented in abbreviated form. A more detailed description of this process is found in appendix E.

The system consists of a carbon dioxide (commercially available gas)/jet fuel mixing apparatus, which preloads the jet fuel with carbon dioxide. In one variation of the airport facility system, the carbon dioxide is derived from a liquefied carbon dioxide storage tank, converted to carbon dioxide gas, and mixed with the Jet A in a gas absorber tower at an optimum gas-to-fuel ratio. Thereafter the carbon dioxide-enriched

fuel is stored in a fuel shipping tank with a floating pan, where the combination tank and pan maintain the desired gas-to-fuel ratio of the treated fuel. The carbon dioxide-enriched fuel is then transferred from the shipping tank to airplane refueling sites using the existing fuel pipeline and hydrant systems (for hub airports) or the existing truck delivery system (at nonhub airports).

## **6.2 AIRPORT FACILITIES**

To expand on the data contained in the FAA report, “Cost of Implementing Ground Based Inerting in the Commercial Fleet,” the Airport Facility Task Team conducted additional airport surveys at three U.S. and two international airports. This section describes the methods used by the team to develop the design concepts and costs.

### **6.2.1 Methodology**

The Airport Facility Task Team comprises representatives from airlines, oil companies, industrial gas suppliers, airplane manufacturers, civil engineering firms, mobile equipment suppliers, and other airline equipment and service suppliers. The team looked at three different inerting gases, a fuel cooling concept, methods of supply, airport infrastructure modifications, mobile equipment requirements, fuel scrubbing, and the environmental impact of fuel scrubbing. On-site surveys of airport fueling operations were conducted at five airports; design concepts were developed for large, medium, and small airports. Preliminary laboratory testing was performed on the effects of fuel scrubbing on fuel properties and the environment. Cost estimates were determined from the design concepts developed by the team and typical airport construction practices.

The team used the following assumptions during the study:

#### Ullage Washing

- The process was not to affect airplane turn time.
- Only the CWT would be inerted.
- The process would start when the airplane arrived at the gate (i.e., empty tanks).
- 800 SCF was used as the average gas requirement (i.e., the volume of the small generic airplane model used in the study).
- 1.7 times the ullage volume would be required to perform the task.
- System was sized for a use of 0 to 2.4 times the average to handle peak operations.
- A maximum of 15 min to inert a small airplane would be provided.
- Large and medium airports would use fixed equipment as the primary means for gas supply; and small airports would use mobile equipment.

#### Fuel Scrubbing

- 50 p/m oxygen content in fuel would be reduced to 5 p/m.
- Fuel scrubbing would be done at the storage facility because of environmental issues and the ease of siting and constructing fairly complicated processing equipment.

### **6.2.2 Airport Evaluations**

The team conducted on-site airport surveys at Chicago O’Hare, Los Angeles International, Buffalo International Airport, Charles DeGaulle Airport, and London Heathrow to assess the available infrastructure, fueling methods, fuel supply system, and fuel storage system to use in the development of the design concepts and costs of construction. In addition, the data for Atlanta and Atlantic City airports

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from “Costs of Implementing Ground-Based Inerting in the Commercial Fleet” was used. Figure 6-6 shows a typical survey. One item of note obtained by the survey was the fact that each airport is unique and will require a tailor-made system. There does not appear to be a turnkey solution because of the great differences in airport infrastructures.

**AIRPORT FACILITY SURVEY FORM FOR FAA FUEL TANK INERTING**

**GENERAL INFORMATION**

FAA WORKGROUP TEAM MEMBER: Michael Kerr

AIRPORT: Buffalo Niagara International LOCATION: Buffalo, NY

CONTACT COMPANY: NFTA CONTACT NAME: Thomas Kane

PHONE NUMBER: (716) 832-6145 E-MAIL: none

(716) 832-6501 (Fax)

**FEED PIPELINE/HYDRANT CHARACTERISTICS:** No pipeline feed -- Truck deliveries only.

PIPELINE FILL CAPACITY, US GALLONS/DAY	Place into 16 loads of fuel/day -- 100,000 to 120,000 gallons/day
HYDRANT WITHDRAWAL CAPACITY	700 US GPM Maximum off-loading rate
MAX US GALLONS/DAY	NA
TYPICAL US GALLONS/DAY	NA
TIMES/D OF PEAK ACTIVITY	
MAXIMUM HYDRANT PRESSURE RATING, PSI	NA
TYPICAL HYDRANT PRESSURE, PSI	NA
FUEL FILTRATION PRESENT	3 Stage Filter with Teflon 2nd Stage
FILTER MICRON RATING	
ANY NON-USED PIPELINE FROM TANK FARM TO TERMINAL? (DIAMETER? PRESSURE RATING?)	No

**AIRPORT CONCOURSE**

NUMBER OF GATES	25
GATE NUMBER	1 2 3 4 5 6
HYDRANT OR REFUELER TRUCK FILL/RT	All Refueler Trucks
AVERAGE GATE TURNAROUND TIME, HRS	
SURF US POWER AVAILABLE	Unknown
DISTANCE FROM GATE TO PLANE, FT	
ESTIMATE OF AVAILABLE AREA PER, FT <sup>2</sup>	Very good area around 2000sq ft

REPEAT AS NECESSARY

**TANK FARM CHARACTERISTICS** All API-650 Tanks

TANK NUMBER	4	2	3	6	5	6
TANK NAME OR DESIGNATION	J6A	J6A	J6A			
TOTAL NUMBER OF IDENTICAL STORAGE TANKS						
PRODUCT STORED	J6A	J6A	J6A			
MAXIMUM DISTANCE TO TERMINALS, MILES	1.5	1.5	1.5			
TANK VOLUME, US GALLONS	225,000	225,000	225,000			
MAX LEVEL, % FULL	22 1/2"	22 1/2"	22 1/2"			
MIN LEVEL, % FULL	1' 8"	1' 8"	1' 6"			
NUMBER FILL CYCLES/MONTH	22	22	22			
NUMBER DAYS FUEL IS SETTLING	1	1	1			
MAX FILL RATE INTO TANK, GPM	360					
MAX WITHDRAWAL RATE FROM TANK, GPM	600					
MAXIMUM ALLOWABLE WORKING PRESSURE, Lbs/Inch <sup>2</sup> PSI (Working 50 PSI)						
DESIRED TANK PRESSURE, IN WC	MIN					
	MAX	300 C"				

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Figure 6-6. Airport Facility Survey Form for FAA Fuel Tank Inerting

**6.3 IMPACT ON AIRPORTS**

The potential impact on current airports identified by the team include

- Labor: Because the inerting process closely parallels the fueling process, it is conceivable that the labor needs would be similar.
- Ramp congestion: The space required for the fixed systems and additional vehicles for the mobile systems could create problems at many large airports where the ramp area is already limited.
- Diversion airports: There could be an impact on smaller airports presently used as diversion airports for larger hubs. The lack of inerting capabilities to handle the occasional influx of a large number of airplanes may limit their usefulness. If GBI does not become a global standard, this could create even greater problems at non-U.S. diversion airports and those used for technical stops.
- Economics: The economic impact could affect commercial airline service at smaller airports.

**6.4 ENVIRONMENTAL EVALUATION**

General environmental issues are addressed to identify basic direct and indirect environmental impact of ullage washing and fuel scrubbing. The impacts fall into the following categories:

- VOC emissions.
- Airport environment.
- Other environmental issues.

Values and quantities of undesirable materials and impacts are not given in this section. Instead, the impacts are identified as they generally relate to existing airport and airline environmental initiatives. Other than the VOC emissions, which could be mitigated by a costly vapor recovery system, environmental impact from implementing ullage washing and fuel scrubbing is assumed to be relatively minor.

Environmental protection infrastructure must be added to each airport fuel storage facility to mitigate release of VOCs during fuel scrubbing. The systems and equipment include pumps and other electric-motor-driven equipment, above-ground liquid nitrogen storage tanks, gas tanks, and piping.

VOC emission data from a simple experiment from two different sources indicates that substantial amounts of light hydrocarbon molecules would be stripped from the fuel during scrubbing. A vapor recovery system would be an essential component of this system to mitigate the adverse impact on the environment.

All refueler trucks that serve airplanes parked in cargo and other remote areas at an airport with no hydrant system have to be modified. A nitrogen-generating unit added to the rear of the vehicle will maintain an inert atmosphere in the tank headspace and a slight positive pressure in the tank by replenishing with NEA while the truck's fuel tank level is being drawn down during airplane refueling. During the refilling cycle of the refueler, a means of capturing vented emissions would have to be developed. If not properly addressed, these modifications could result in an increase in VOC emissions from this intermediate mobile fuel storage.

During airplane fuel tank ullage washing, it is expected that there would be an incremental increase in VOC emissions. This would result primarily from the application of NEA to airplane tanks that normally would not be disturbed during the routine turn-around activities.

Truck traffic to deliver liquid nitrogen to the tank farm area would result in additional use of fossil fuels if the dependence on liquid nitrogen becomes significant.

The increase in the number of ground service equipment vehicles mandated by these new systems will add to emissions from their internal combustion engines. Alternatively, these emissions could be mitigated if alternative fuel technology were incorporated into new vehicle design.

New construction to support fuel scrubbing at the airport tank farm site will require extensive environmental assessment, existing environmental remediation methods be altered, or remediation be undertaken before the construction of any supporting infrastructure.

Indirect impacts to the environment include negatively affecting airport, city, and regional air quality through the release of excessive amounts of VOCs.

No improvements to the environment were identified for any of the concepts in this report, no data is available on the soil condition of any given site, and no quantified air-emission data is available to establish an emission baseline. A baseline would be useful in measuring incremental impacts to the environment.

## **6.5 COST-BENEFIT ANALYSIS**

Figures 6-7 through 6-10 are economic evaluations of the inerting systems considered by FTIHWG for each type of airport. The estimates used a standard form common to each estimate. The economic evaluation was broken into two parts, capital (nonrecurring) and operation (recurring) costs.

The evaluations include only the cost of construction and maintenance; operator labor costs are not included.

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Capital				
Description	Cost per concourse, K	Airport size		
		Large	Medium	Small
Number of concourses		9	2	NA
• System	0	0	0	—
• Site preparation	35	315	70	—
• Piping, hoses, reels, other	408	3,672	816	—
• Electrical power upgrades	500	4,500	1,000	—
• Engineering and soft costs (19%)	179	1,613	358	—
• Contingency (25%)	281	2,525	562	—
Total	1,403	12,624	2,806	NA

**Notes:**

- Concourse is 20 gates.
- All figures are in thousands of U.S. dollars.

Operational costs per month				
Description	Cost per concourse, K	Airport size		
		Large	Medium	Small
Number of concourses		9	2	NA
• Rent at \$20/ft	2	18	4	—
• Lease system if applicable	0	0	0	—
• System maintenance	1	9	2	—
• Maintenance and operation	Per airport	25	13	—
Total		52	19	NA

**Note:** All figures are in thousands of U.S. dollars.

*Figure 6-7. ARAC Facility Estimate—Fixed Ullage System*

Capital				
Description	Cost per mobile unit, K	Airport size		
		Large	Medium	Small
Number of mobile units		12	7	2
• System and truck	330	3,960	2,310	660
• Parking and site preparation	1	12	7	2
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	1	12	7	2
• Contingency (25%)	83	996	581	166
Total	415	4,980	2,905	830

Operational costs per month				
Description	Cost per mobile unit, K	Airport size		
		Large	Medium	Small
Number of mobile units		12	7	2
• Rent at \$1.0/ft	4	48	28	8
• Lease system if applicable	0	0	0	0
• System maintenance	1	12	7	2
• Power cost	2	24	14	4
• Maintenance and operation	.5	6	3.5	1
Total	7.5	90	52.5	15

**Note:** All figures are in thousands of U.S. dollars.

*Figure 6-8. ARAC Facility Estimate—Mobile Ullage System*

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Description	Cost per tank, K	Airport size		
		Large	Medium	Small
Per tank at one fuel facility		20	4	2
• System	0	0	0	0
• Site preparation	20	400	80	40
• Piping, hoses, reels, other	101	2,014	403	201
• Electrical power upgrades	30	600	120	60
• Engineering and soft costs (19%)	29	573	115	57
• Contingency (25%)	45	897	179	90
Total	224	4,483	897	448

Operational costs per month				
Description	Cost per gal/ min delivered, K	Airport size		
		Large	Medium	Small
Thousands of gallons per minute		4.5	1.0	0.4
• Rent at \$1.0/ft	2	7	2	1
• Lease system if applicable	1	2	1	0
• System maintenance	1	5	1	0
• Inert gas cost	26	117	26	10
• Power cost (if not already included)	0	0	0	0
• Maintenance and operation	2	9	2	1
Total	31	140	31	12

Note: All figures are in thousands of U.S. dollars.

Figure 6-9. ARAC Facility Estimate—Fixed Scrubber System

Capital				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of existing refuelers		14	9	4
• System and truck	8	112	72	32
• Parking and site preparation	0	0	0	0
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	0	0	0	0
• Contingency (25%)	2	28	18	8
Total	10	140	90	40

Operational costs per month				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of refuelers		14	9	4
• Rent at \$1.0/ft	0	0	0	0
• Lease system if applicable	0	0	0	0
• System maintenance	1	7	5	2
• Inert gas cost	0	0	0	0
• Power cost (if not already included)	1	7	5	2
• Maintenance and operation	1	7	5	2
Total	2	21	14	6

Note: All figures are in thousands of U.S. dollars.

Figure 6-10. ARAC Facility Estimate—Mobile Scrubber System

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### Capital

Capital costs are those outlays made to design, install, and commission a system concept. Included in the capital estimates are (1) system and vehicle costs, (2) parking and site preparation costs, (3) piping, hoses, and reels for fixed systems, (4) electrical power upgrades, (5) engineering and soft costs, and (6) contingencies.

### Operation

Monthly operational costs are those outlays necessary to operate the system concept and are exclusive of capital costs. Depreciation has been omitted. Included in the operations estimates are (1) rent, (2) inerting system lease, (3) system maintenance, (4) inert gas costs for delivered (not generated) gas, and (5) power costs (if not already included in other line items).

Each outlay is defined for reference here.

### System and Truck Costs

- Generators
- Storage tanks for liquid nitrogen
- Controls
- Power, lights, and distribution from supply
- System enclosure (if any)
- Rolling equipment (if applicable)

### Parking Site Preparation Costs

- Fence
- Rooms, walls, and so on
- Site lighting
- Ramp striping
- Barricades

### Piping, Hoses, and Reels for Fixed Systems

- Piping
- Hoses
- Gas distribution hardware to airplane

### Electrical Power Upgrades

- New electrical service
- New supply switchboard
- Space costs and new electrical room

### Engineering and Soft Costs

- Design—6% of capital cost for the design concept
- Construction administration—3% of capital cost for the design concept
- Program management—6% of capital cost for the design concept
- Construction management—3% of capital cost for the design concept
- Permit and related costs—1% of capital cost for the design concept
- Infrastructure survey—\$25,000 per concourse
- Subtotal—19% plus \$25,000

Contingencies in Capital Budget

- Unforeseen conditions
- Conceptual unknowns

Rent

- Lease for concourse space at \$20 per year
- Lease for site space at \$1 per month, per foot

System Lease Cost

- Inert gas generating system lease cost (if applicable)

System Maintenance

- Inert gas generating system maintenance costs by manufacturer (if applicable)

Inert Gas Costs

- Delivery costs
- Capitalized system cost
- Gas cost
- Backup gas costs
- Power and energy for system

Power Costs

- Monthly power costs to run the system (if not built into other line items)

Airport Maintenance and Operation

- Labor to maintain metering, piping, connections, and so on
- Labor to operate (at \$25 per hour)
- Spare parts
- Accounting
- Testing and airport certification

**6.6 TECHNICAL LIMITATIONS**

Given sufficient implementation time and resources, no major obstacles are foreseen, although it will be necessary to prototype a full-scale system to validate the methods and technology. New worldwide airplane interface and safety standards also would be necessary.

The major cost drivers for ground-based systems are developing the infrastructure and the operating labor for the inerting process. Therefore, these limitations do not offer areas of significant cost reduction.

**6.7 POTENTIAL IMPACT ON FUEL PERFORMANCE**

The Tasking Statement requested that ARAC provide, among other tasks, an evaluation of the feasibility to saturate jet fuel with nitrogen in ground storage facilities, for example, in trucks or central storage tanks. The design concepts for saturating the fuel with nitrogen, also referred to as fuel scrubbing, provoked

concerns over maintaining jet fuel integrity during the processing.

A concept and design methodology for a system that proposes to accomplish this task has been developed. During the conceptual deliberations as to how an effective system might be designed, manufactured, installed, and made operational, concern arose with respect to the effects that ullage washing and fuel scrubbing may have on the performance characteristics of aviation turbine fuel. In addition, there were concerns expressed about the environmental impact of the inerting process, especially as a consequence of fuel scrubbing, which involves vigorously mixing nitrogen gas with a high-flow fuel stream.

This section will summarize the concerns, the findings of preliminary laboratory analyses performed by two oil company task team members, and the recommendations for further study into airplane fuel tank ullage washing and fuel scrubbing.

Concerns were raised that ullage washing and fuel scrubbing would degrade certain performance properties of jet fuel by driving off the lightweight molecular ends of the fuel. The light ends influence several specification properties of jet fuel, including distillation, flash point, and freezing point. Another concern expressed was the uncertainty of how these processes might affect the relight-at-altitude characteristics of the fuel. Questions were also raised regarding the performance of additive packages (e.g., antioxidants and antistatic additives) to enhance or modify particular characteristics of the fuel.

To obtain a broader perspective on these questions and other issues, a notice was circulated by means of the ASTM committee charged with aviation turbine fuel specification maintenance (ASTM D-1655) asking all U.S. and non-U.S. refineries and engine, airframe, and component manufacturers to provide feedback and information they may have on the performance characteristics of fuel subjected to ullage washing, scrubbing, or both. Because these inerting concepts were new to many of the responders, more questions were raised than answers received. Additional concerns expressed ranged from the belief that complete engine recertification may be required to the belief that nitrogen inerting would improve at least the fuel stability characteristics and therefore would be a benefit.

The last area of concern that arose during discussions of the fuel inerting concept involved environmental considerations. Flowing nitrogen gas over a partially filled fuel tank and the vigorous mixing of nitrogen gas with fuel during the scrubbing process would, according to general opinion, result in significant VOC release to the atmosphere at airport fuel storage depots. These VOCs would aggravate the already thorny issue of air pollution at and around today's airports. Feedback and factual data were requested from stakeholders, including the EPA. Again, more questions than answers came from this inquiry.

AirBP and Texaco performed elementary experiments on ullage washing and fuel scrubbing using nitrogen and carbon dioxide gases; final reports are in appendix E.

Preliminary results of these experiments indicate that ullage washing and fuel scrubbing with nitrogen gas have little effect on the conventional properties of jet fuel. However, a measurable change in vapor pressure occurred from fuel scrubbing, and the carbon dioxide-scrubbed fuel exhibited an increase in acidity. Significant VOCs were released during both processes, regardless of the inert gas used. VOC release may lead to serious health and safety issues that must be addressed.

**Physical Property Changes.** One experiment showed that there is an increase in fuel vapor pressure after the scrubbing process. This vapor pressure increase is not totally understood at this time; however, it does suggest that there may be a deleterious effect in controlling the flammability of the airplane fuel tank

headspace atmosphere. The increase in vapor pressure may affect the performance of the different fuel pumping devices used on today's airplanes.

There was also a decrease in the fuel's electrical conductivity, which will require further investigation. Changes in this fuel property will require a full understanding of the phenomenon because of fuel handling safety and additive performance issues.

A significant release of VOCs (addressed further in this summary) occurred during ullage washing and fuel scrubbing, which obviously change bulk fuel composition. Removing and recombining the VOC condensate after a vapor recovery process will require additional study to ensure that there is no deleterious effect on engine performance from a reconstituted fuel blend. Although no statistical difference was measured in the fuel's distillation characteristics, flash point, or freezing point, a more thorough analysis of these properties should be performed to verify the preliminary findings. Additionally, because the loss of these light ends may affect altitude relight, a thorough analysis of this characteristic should also be carried out. Unfortunately, this analysis could not be done in the time allotted to this project.

The experiments using carbon dioxide as the scrubbing gas (carbon dioxide–oxygen injection was one of the inerting processes considered during the team's discussions, but time did not allow for a complete conceptualization of this technique) showed a much greater effect on vapor pressure than nitrogen and also increased the acidity of the bulk fuel. This finding was not totally unexpected; prior experience has shown that with water-laden (including dissolved water) mixtures and subsequent carbon dioxide saturation, carbonic acid may form as a byproduct of this chemistry. The formation of any compound that may enhance or accelerate corrosion of the airplane fuel tanks is not a desirable attribute of a fuel.

**Industrial Health and Safety Issues.** The experiments indicated that the carcinogen benzene may be concentrated in the vapor phase at concentrations that could exceed the 0.1% weight limit by weight established for regulating a material as toxic. This matter is of the greatest concern with regard to employee health and the environment surrounding airport bulk storage depots and will have to be addressed.

An additional employee and facility safety problem is also introduced when fuel is exposed to the scrubbing process, which creates an extremely flammable vapor atmosphere from light-end VOC emissions. Very careful attention will have to be paid in the design of any mechanical equipment used to recover and dispose of VOCs.

Ullage washing will result in the release of a low-oxygen, high-inert-gas concentration mixture (nitrogen or carbon dioxide) from the CWT vents. People working in and around this area may be exposed to air with an oxygen level below that which is required to sustain normal respiration. The hazard level will increase as the number of airplanes in a localized area undergoing the inerting process increases. This asphyxiation hazard must be studied in more depth before any large-scale inerting is implemented.

**Environmental Impact Issues With Fuel Scrubbing.** The fuel scrubbing process has been shown to release a significant amount of VOCs. These VOC releases were measured in the more than 1% range by volume during the experiments. To put this volume in perspective, it represents an equivalent volume to more than 21,000 gal of jet fuel from a typical 50,000-barrel storage tank found at many airports. This release is expected to occur each time this amount of fuel is received into storage and subsequently processed through the scrubbing cycle. The environmental as well as economic impact of releases of this magnitude will require careful design and operation of costly vapor recovery systems near bulk storage facilities. As more regulatory pressure is exerted on today's management and operators to clean up the air

on and around airports, the release of additional pollutants caused by any new process becomes unacceptable, regardless of the perceived benefits.

The EPA representative queried during the feedback process succinctly put future work on this issue into perspective by recommending *(1) a literature search for theoretical and experimental analysis of the effects of fuel tank inerting or similar fuel treatments on engine exhaust emissions, (2) explicit discussion, involving appropriate experts of this concern in FAA rulemaking activities relating to fuel tank inerting; and (3) experimental research to validate expectations regarding impacts of inerting methods on engine exhaust emissions.*

As this discussion indicates, a number of issues need to be addressed and better understood, and solutions need to be found before ullage washing, fuel scrubbing, or both are implemented on a large scale. The following is only a short list of the issues that come to mind.

- The performance characteristics of scrubbed fuel in today's turbine engines need further investigation.
- The impact of ullage washing and fuel scrubbing on employee health and safety will have to be better understood so appropriate action can be taken.
- The impact of ullage washing and fuel scrubbing on the environment will have to undergo an extensive review. There was not enough time or readily available information during this ARAC project to become fully knowledgeable on the subject or propose concept designs to address the impediments identified.



## **7.0 ONBOARD GROUND INERTING**

The OBGIS is a self-contained method of providing inert gas to the airplane's fuel tanks without relying on an airport to supply the inert gas.

The Onboard Inerting Designs Task Team reviewed the 1998 ARAC FTHWG report for inerting and determined that most of the nitrogen inerting technologies discussed in that report remained unchanged. The team chose to focus on air separator technology because of improvements in technology and manufacturing and a probable benefit of reduced cost.

### **7.1 SYSTEM REQUIREMENTS**

The Tasking Statement requires that the OBGIS inert fuel tanks be located near significant heat sources or fuel tanks that do not cool as quickly as unheated wing tanks. The affected fuel tanks will be inerted on the ground between flights. We will provide the benefits and risks of limiting inerting to fuel tanks near significant heat sources. This report will consider methods to minimize system cost, such as reliable designs with little or no redundancy, and recommendations for dispatching in the event of a system failure or malfunction that prevents inerting one or more of the affected fuel tanks.

We will describe secondary effects of the system, along with an analysis of extracted engine power, engine bleed air supply, maintenance effects, airplane operational performance detriments, dispatch reliability, and so on.

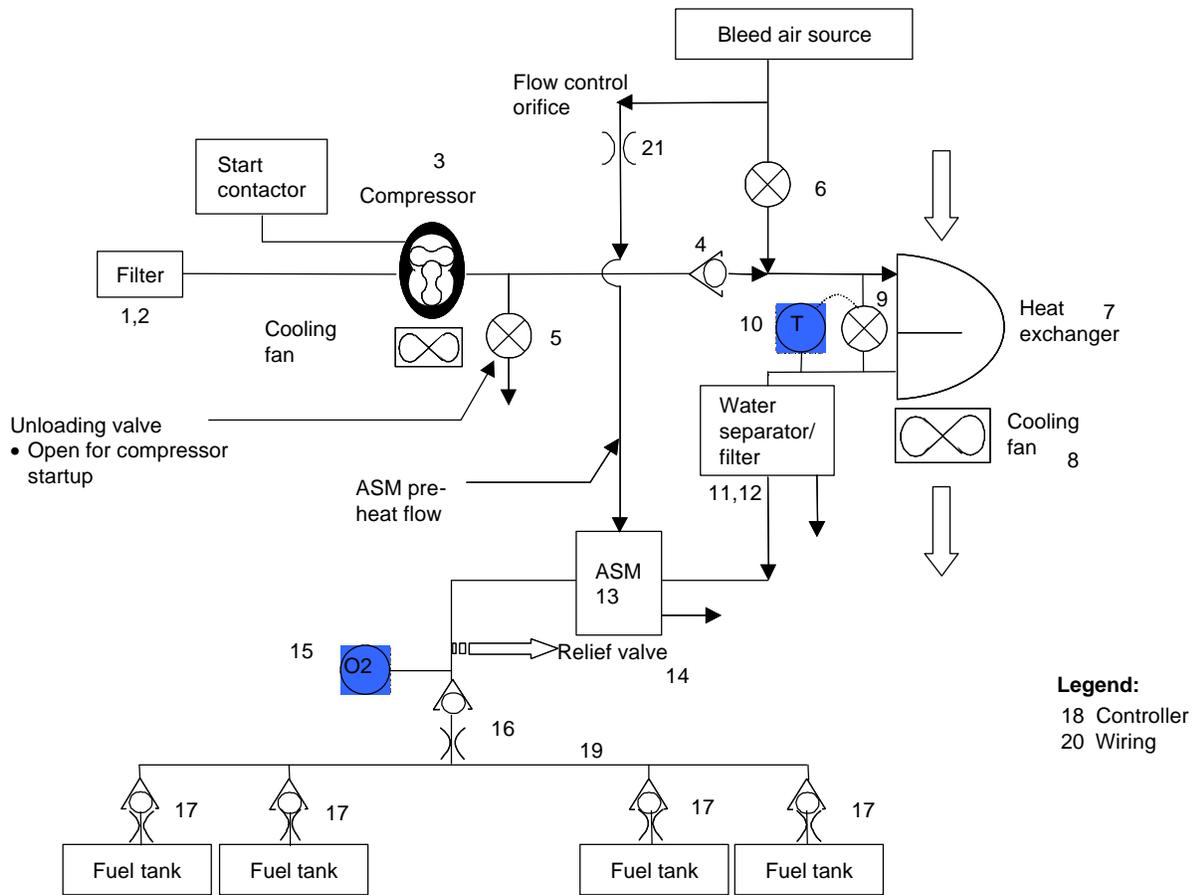
The Tasking Statement also required that information and guidance be provided for the analysis and testing that should be conducted to certify the system.

If the Working Group cannot recommend a system, the group is to identify all technical limitations and provide an estimate of the type of concept improvement that would be required to make it practical in the future.

### **7.2 CONCEPT DESCRIPTION**

Figure 7-1 shows the OBGIS. In its simplest terms, an air separator module (ASM) separates pressurized air into nitrogen and other gases. The ASM supplies nitrogen to the fuel tanks and exhausts the other gases overboard.

The ASM gets pressurized air from either the engine as bleed air or from an electric compressor. This air is cooled if necessary, water is removed to avoid icing, and the dry air is then filtered to avoid ASM contamination.



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Figure 7-1. OBGIS Schematic

### 7.2.1 Air Source

The concept uses multiple air sources. Pressurized air can be provided by engine and APU bleed air or by the electric compressor. The air pressure supplied to the ASM is nominally 45 psia.

### 7.2.2 Pressure Ratio: Match APU Pressure

The electric compressor was sized for a 3:1 pressure ratio in an attempt to supplement bleed air with compressor air to minimize the compressor size and cost. However, check valves would need to be installed to prevent bleed air from creating backflow in the compressor or compressor air from backflowing into the engine. Neither pressure source could supplement the other because the source of higher pressure would close the check valve on the other source. A more complex flow-sharing concept was not pursued.

### 7.2.3 Air Separator

We studied three concepts for air separation. Hollow-fiber membranes separate nitrogen through molecule-sized passages when air passes through the length of the fiber. Pressure-swing adsorption (PSA) adsorbs oxygen as air passes over the module, leaving nitrogen in the flowstream. Cryogenic distillation relies on separation of a partially liquefied airstream using a distillation column. The product is a high-purity nitrogen gas, which can be sent to the fuel tanks, or a high-purity nitrogen liquid, which can be stored for later use.

#### **7.2.4 Time for Inerting**

Like the Ground-Based Inerting Designs Task Team, the Onboard Ground Inerting Designs Task Team assumed that airline operation should not be affected by the addition of the inerting system, if possible, to minimize the cost to the airlines. The primary operation where an impact should be avoided is “gate time,” that is, the time between flights when the airplane arrives at the gate, passengers deplane, the airplane is refueled, and new passengers board for the next flight. One of the design ground rules then was to inert the fuel tanks within the average minimum turnaround time at the gate.

Gate time depends on the airplane size and its use by the airline. Large airplanes have longer gate times because they have long flights and need more time to refuel and board passengers. Small airplanes have short gate times because they have shorter flights.

System size depends on the ullage volume and the gate time. A large ullage volume will require a lot of inert gas to fill it and, if the gate time is short, the inert gas will have to be generated quickly. This requires that the compressor, ASM, heat exchanger, and all interfacing components be large. The weight increases and the electrical power demand of the compressor increases.

“Initialization time,” or the time to inert a fuel tank after it has been opened and vented for maintenance, was estimated after the system size was determined. This was not considered an operational constraint because operators can plan their effort to allow time to inert the fuel tanks after maintenance.

This was a reasonable assumption at the beginning of this ARAC effort because fuel tank maintenance was normally performed only when a failure was noted. This may change and incur potential cost increases because of SFAR no. 88, the result of which may require more frequent tank entries. However, no effort has been made to determine the potential added cost impact of SFAR no. 88.

#### **7.2.5 Flammability Exposure**

The flammability exposure is defined as the percentage of the airplane mission when the fuel ullage is flammable and not inert. The 1998 ARAC FTIHWG found that CWTs had a flammability exposure of approximately 30% and wing tanks had a flammability exposure of approximately 7%. The FAA has since been refining a model for flammability exposure, which was provided to this ARAC to compare system benefits. The OBGIS reduces the flammability exposure of a heated CWT to at or below the exposure of an unheated wing tank.

### **7.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES**

The design concept applies to all the airplanes in the study category. However, the high electrical demand may exceed the capacity of the existing airplane electrical systems and, at airports that discourage APU operation, the airport’s ability to provide the electricity.

An inerting system can be designed into future airplanes, provided the inerting system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available to supply the inerting system.

### **7.4 AIRPORT RESOURCES REQUIRED**

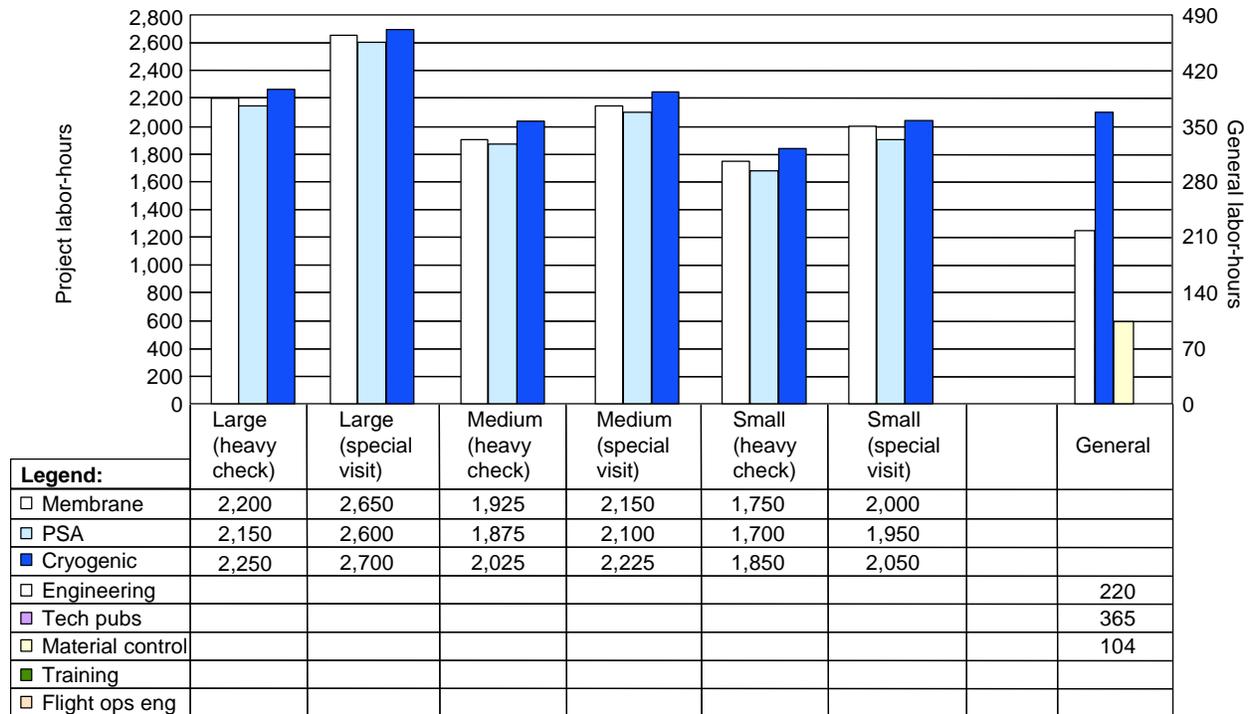
Electrical power from the airplane APU is needed to power the OBGIS. Some airports are sensitive to noise and do not permit APU operation, requiring a ground power source to supply the system.

### 7.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT

This section discusses the modification of in-service airplanes to install an OBGIS and the overall effect of OBGIS on airplane operations and maintenance requirements.

#### 7.5.1 Modification

Figure 7-2 shows the modification estimates for the OBGIS. Because there is insufficient space for the OBGIS in the unpressurized areas of regional turbofan, regional turboprop, and business jet category airplanes, we have excluded these airplanes from this estimate. Estimates are made for both a regular heavy maintenance visit and a special visit.



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Figure 7-2. Modification Estimates for the OBGIS

The modification estimates for the OBGIS are based on the estimates of the OBIGGS; however, because the OBGIS is designed only for the CWT and auxiliary tanks, we have reduced the labor estimates to account for installation differences. The following reductions are used:

- For the large-airplane category: 300 labor-hours.
- For the medium-airplane category: 250 labor-hours.
- For the small-airplane category: 200 labor-hours.

The left side of figure 7-2 shows the estimated modification labor-hours per airplane for the different airplane categories. The right side shows the general support labor-hours. The support labor-hours are incurred on a per-operator basis as opposed to per-airplane and are approximately the same for all airplane categories. Task-level detail data used for the estimate is presented in addenda F.A.1 and F.A.2 of appendix F, Airline Operations Task Team Final Report.

**7.5.2 Scheduled Maintenance**

Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the OBGIS schematic provided by the design team. The team evaluated each component illustrated in the schematic individually and wrote the tasks accordingly. These tasks included inspections, replacements, and operational and functional checks of the various system components.

The OBGIS consists of several more components than the GBIS, requiring additional tasks and substantially increasing the added labor-hours required in the 2C- and heavy checks. The team assigned these tasks to the various checks (A, C, 2C, and heavy) and also estimated the labor-hours for each task. Appendix F contains a complete list of these tasks. The team assumed that tasks completed at an A-check would also be completed at a C-check. Similar assumptions were made for the C-check and 2C-check tasks (i.e., they would be accomplished at the 2C-check and heavy check, respectively).

Because the size and complexity of the OBGIS concept made the system infeasible for existing turbofan, turboprop, and business jet category airplanes, we did not complete an analysis for these airplanes.

Additional Maintenance Labor-Hours

Figure 7-3 shows the estimate of additional scheduled maintenance labor-hours that would be required at each check to maintain an OBGIS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	4	18	51	50.55
Medium	3	4	18	55	48.31
Large	3	4	18	59	46.51

Figure 7-3. OBGIS Additional Scheduled Maintenance Hours

**7.5.3 Unscheduled Maintenance**

The OBGIS consists of approximately 26 major components and is significantly more complex than the GBIS. Like the full OBIGGS, the airplane system is self-sufficient, which is the reason for the increased complexity.

System Annual Use Rate

Although the OBGIS equipment is similar to that of the full OBIGGS, the operating philosophy is significantly different. Unlike OBIGGS, the classic OBGIS—although an onboard system—operates only while the airplane is at the gate. Therefore, the operating time of the OBGIS is significantly less than for full OBIGGS over the same period of time, reducing the wear and tear on system components. To account for the reduced operating time, the system annual use rate (fig. 7-4) for OBGIS is then a function of the typical gate time and number of daily operations for each airplane category.

Airplane category	Airplane use rate, flight-hours/year	OBGIS system operational time, hours/year
Large transport	4,081	1,095
Medium transport	2,792	1,278
Small transport	2,869	1,916
Regional turbofan	2,957	1,080
Regional turboprop	2,117	1,034
Business jet	500	365

Figure 7-4. OBGIS Annual Use Rate

System Reliability

As with the unscheduled maintenance analysis on the other system concepts, we based the reliability of OBGIS components primarily on a comparison with similar components currently in use on commercial airplanes. The significant decrease in the reliability level of the OBGIS, compared with that of the GBIS, is a result of increased system complexity. The increase in the number of parts and the introduction of lower reliability, higher maintenance components such as compressors and ASMs decrease the system reliability by a factor of 10 times. The OBGIS MTBUR was calculated to be 945 hr for the PSA system and 960 hr for the membrane system. The difference between the systems was the slightly higher reliability of the membrane ASM.

Because similar component reliability data for a range of component sizes was not available, the analysis assumes that the OBGIS reliability is the same for all airplane sizes. In reality, system reliability may vary with the system size but, for the purposes of this study, the variation is assumed to be well within the margin of error for the reliability estimate.

System Annual Failure Rate

The annual failure rate for the inerting system is a function of its reliability and the system annual use rate. Using the OBGIS annual use rate, the frequency of inerting system failures on each airplane was predicted to be approximately two failures per year for an OBGIS.

The system annual failure rate, shown in figure 7-5, is significant because it indicates how maintenance intensive the inerting system is and what level of impact the system will have on flight operations. In the case of the OBGIS, an operator with a fleet of 300 airplanes could expect to have to address 600 additional maintenance problems per year because of the inerting system.

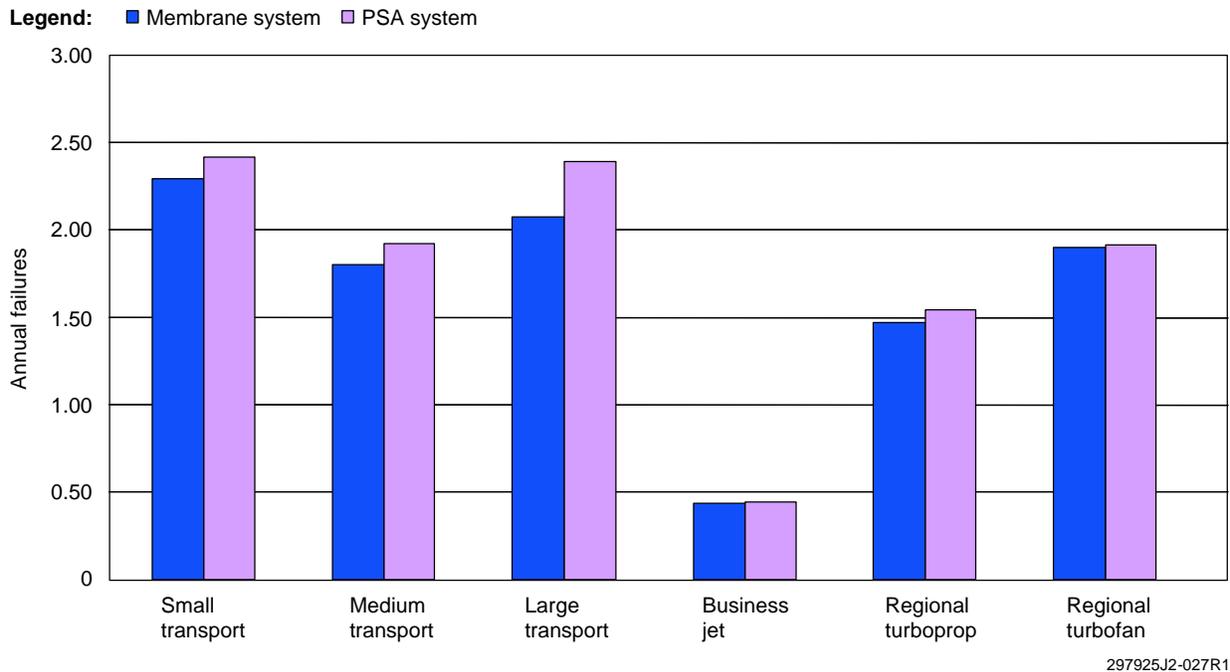


Figure 7-5. Predicted OBGIS Annual Failure Rate

Unscheduled Maintenance Labor Estimate

As with other system concepts, we surveyed potential component locations for each airplane category. Based on this survey, we developed estimates for troubleshooting, removal, and installation of each component. The tables in addendum F.C.2 of appendix F detail the troubleshooting, removal, and installation labor-hour assumptions. We also considered probable component locations, size, and weight in developing this estimate. We used the labor estimate and the component’s predicted failure rate to estimate annual unscheduled maintenance labor rate for the OBGIS on each airplane category, summarized in figure 7-6.

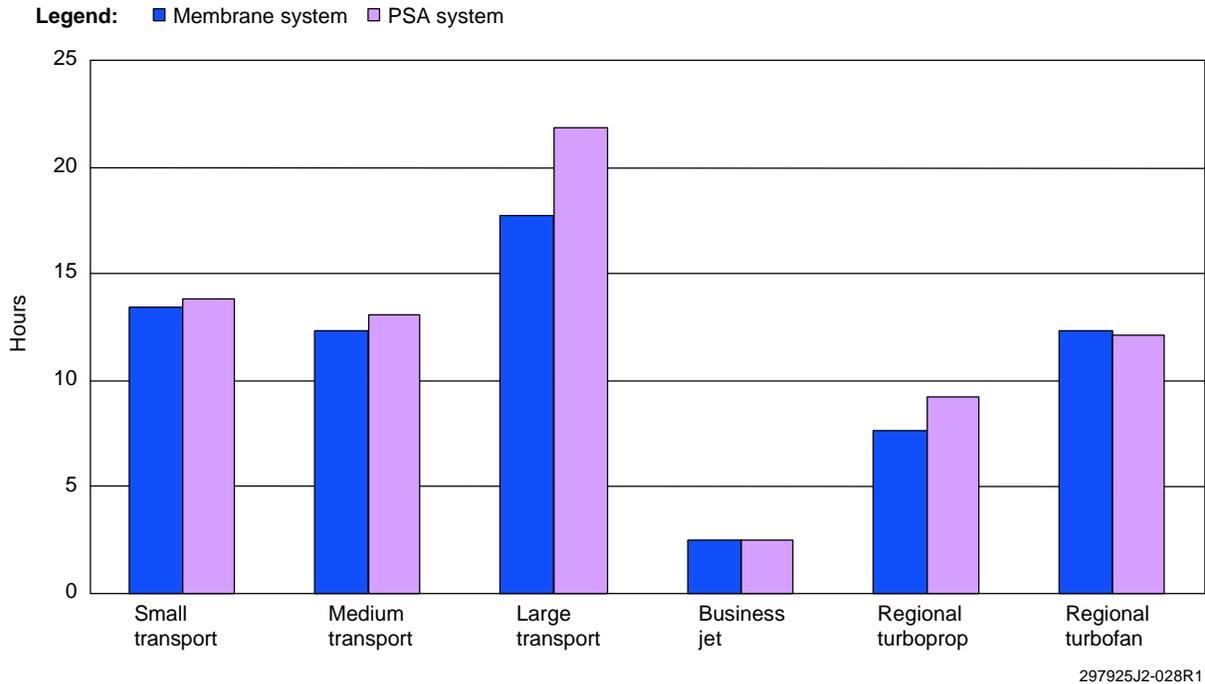
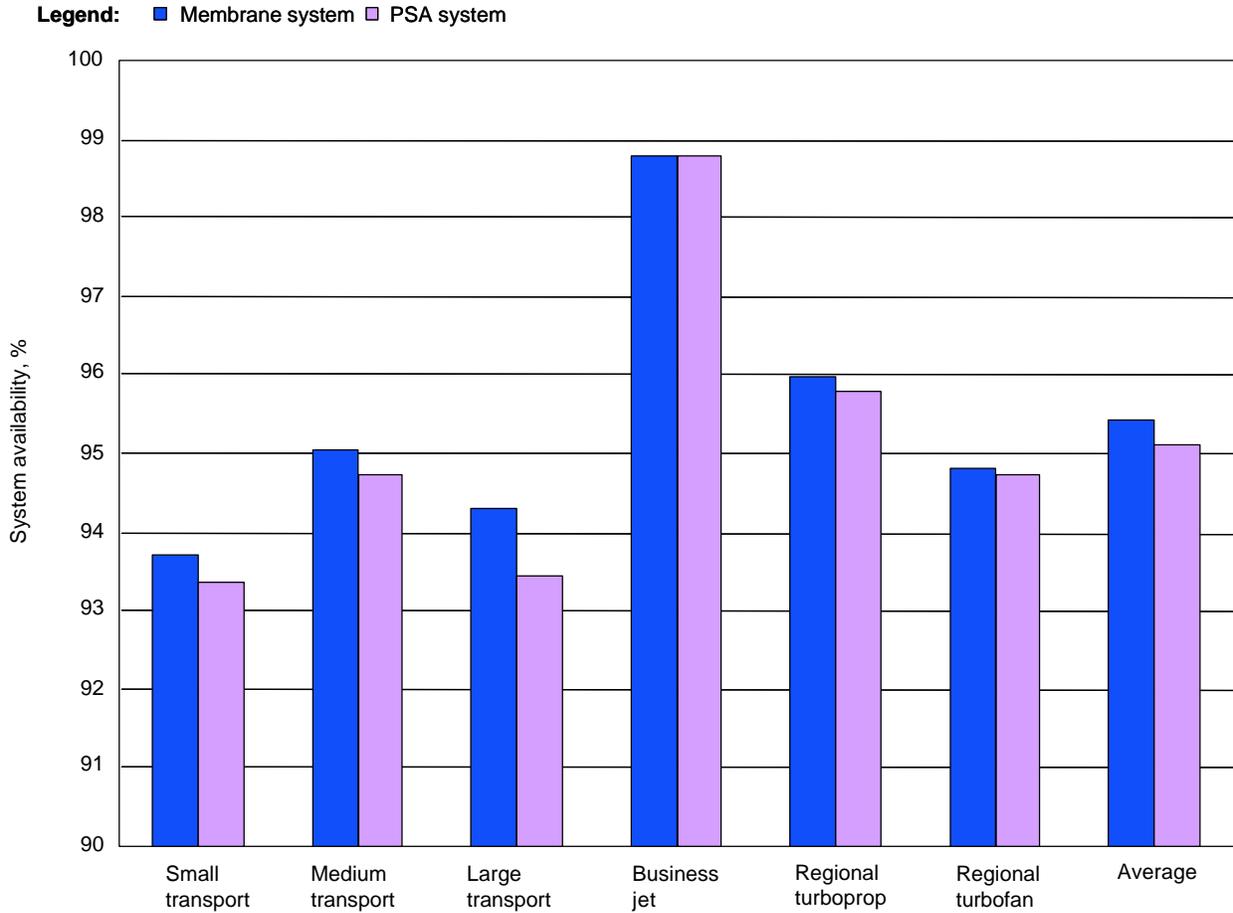


Figure 7-6. Annual Unscheduled Maintenance Labor Estimate per Airplane

Inerting System Availability

The OBGIS availability (fig. 7-7) is a function of the system reliability and the repair interval assumed for MEL dispatch relief. For example, if the system has an annual system failure rate of two failures per year and the MEL dispatch relief allows a 3-day repair interval, the inerting system may be assumed to be inoperative 6 days per year. Another way to look at system availability is as a percentage of departures. If the airplane typically has seven departures per day (as the small transport does), then the airplane would depart on 42 flights per year out of 2,555 with the inerting system inoperative. Assuming that an inerting system would remain inoperative for the maximum allowable number of days is a worst case scenario. In reality, the systems would likely spend 50% to 75% of the allowable time on MEL but, for the purposes of this study, we assumed that the full repair interval is used all the time. When considering the effect of the number of days a system is allowed to remain on MEL, decreasing the number of days improves system availability but comes at a price of increased flight delays, cancellations, and operating costs.



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Figure 7-7. OBGIS Availability

MEL Dispatch Relief Effect

Section 10.0 discusses the effect of the MEL dispatch relief assumption in detail. The availability of MEL dispatch relief for noncritical airplane systems and the length of time allowed before the system must be repaired have a large impact on the airplane’s dispatch reliability and cost of operation. As an illustration, we calculated the number of delays and cancellations an operator might experience for a typical small transport airplane equipped with an OBGIS. This estimate is based on the projected OBGIS annual failure rate and some assumptions on the frequency of delays and cancellations based on a system failure.

If no MEL dispatch relief, shown in figure 7-8, is available, there is a high probability that system failure would result in multiple flight cancellations. If dispatch is available, the likelihood of flight delays and cancellations decreases as more time is allowed to route the airplane to a location where maintenance is available. The system can then be repaired during an overnight maintenance visit. The specific assumptions used here are based on typical operator experience and are presented in appendix F.

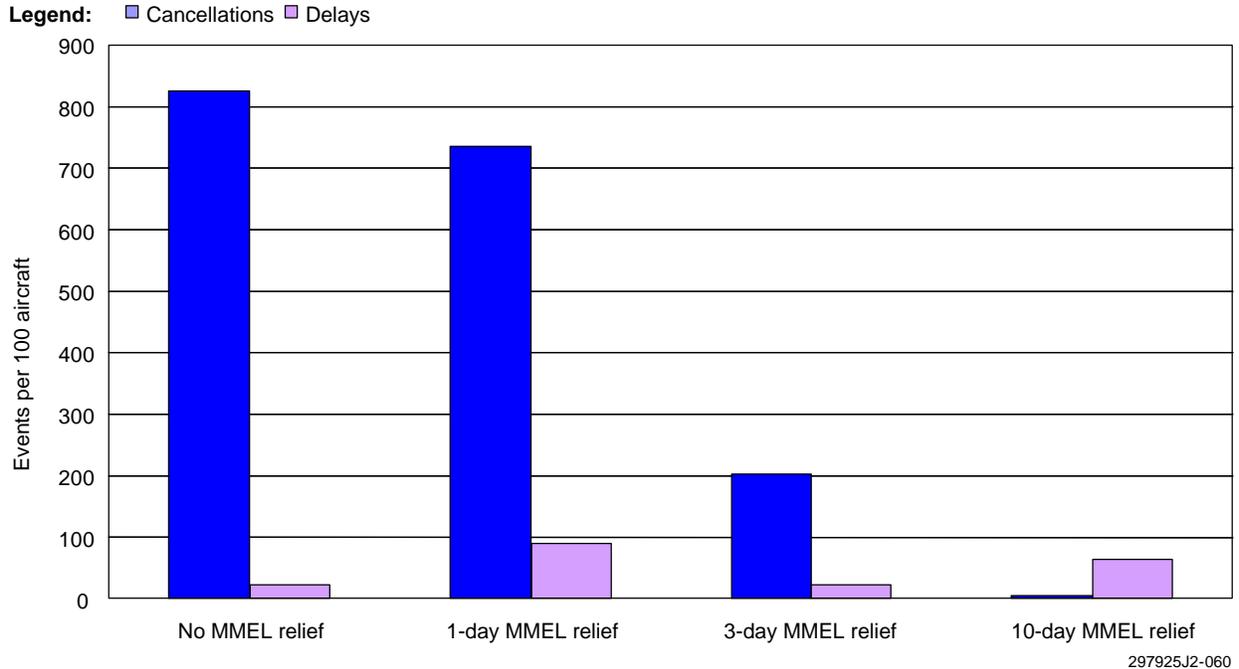


Figure 7-8. MEL Dispatch Relief Effect

Delay Hours per Year

The team estimated the effect of inerting system failures on flight departure schedules based on the OBGIS annual failure rate. Section 10.0 discusses the delay assumptions used for this estimate (fig. 7-9). Although not every system failure causes a delay, it is equally true that a single maintenance delay frequently causes multiple downline delays as a result of a cascade effect in the daily flight schedule. The number of delays and delay hours per year affect customer service. The airlines, through experience, have determined the impact of the reduction in customer satisfaction as a result of delays on operational revenue. Flight delays also affect operating costs through schedule changes, downline flight cancellations, and loss of passengers.

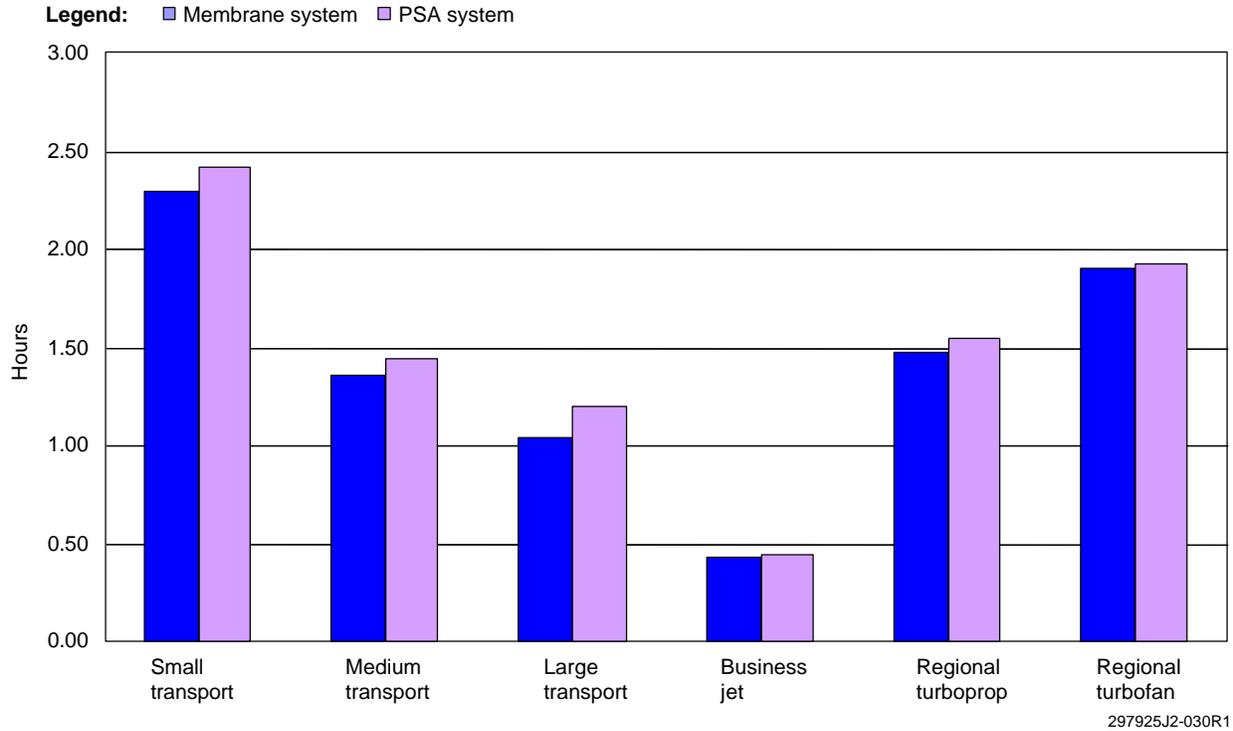


Figure 7-9. Annual OBGIS Flight Delay Hours

#### 7.5.4 Flight Operations

The OBGIS allows for the availability of NEA for ground inerting techniques to be used at any airport that the airplane is deployed to if an adequate electrical power source is available. The system is designed to have adequate output to preclude delays beyond what are considered average minimum turn times for that airplane. The system is designed to require minimal activation and supervision by the flight crew with minimal cockpit indication and a simple on/off switch being redundant to automatic activation. Training for flight crews would serve to familiarize them with the system’s benefits, functions, and characteristics. Additional training for crew and dispatchers would have to address MEL and dispatch provisions and requirements. The system should be designed to be fail-safe so that no hazard is presented by its operation to passenger or ground personnel.

A moderate weight penalty is incurred in carrying this system on board, which is manifested in additional fuel burn. However, there are no power drain requirements during flight.

#### 7.5.5 Ground Operations

Both GBIS and OBGIS are operating only on the ground. The major difference between GBI and OBGIS is that inerting with the OBGIS is accomplished without the requirement for additional airport facilities, except for additional ground-power requirements. The OBGIS is a self-contained system.

Maintenance training requirements should be incorporated within the initial training programs similar to those discussed earlier, but tailored to this specific design. One concern that differs from the GBIS is that the OBGIS would require constant monitoring, particularly while fuel tanks are being inerted before the first flight of the day. The system design is such that the systems will have to be turned on 2 hr before the first flight of the day. Once power is put on the airplane and the inerting system is turned on, a normal safety procedure requires that a maintenance technician must monitor the airplane for problems. This does

not necessarily mean that a maintenance technician must sit in the cockpit, but someone must be close enough to respond to alarms or other problems. Activation and monitoring the airplane an hour earlier than is currently required adds significant work to line maintenance during an already busy time of day.

Other added responsibilities include making sure that the cabin is ventilated properly to ensure there is no possibility for nitrogen buildup in the cabin. These tasks would typically be the responsibility of the remain-overnight technician. In the event a flight crew member is not available, then a qualified technician should also monitor the inerting process during all through-flights. All other maintenance concerns typically go hand in hand with the concerns mentioned earlier for GBI.

### 7.6 SAFETY ASSESSMENT

Figures 7-10 and 7-11 show the impact that OBGIS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes the system will be fully implemented by the year 2015 (see sec. 11.0 for implementation assumptions). At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 31 years with SFAR and inerting in heated CWTs, and 33 years for SFAR and inerting in fuselage tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.

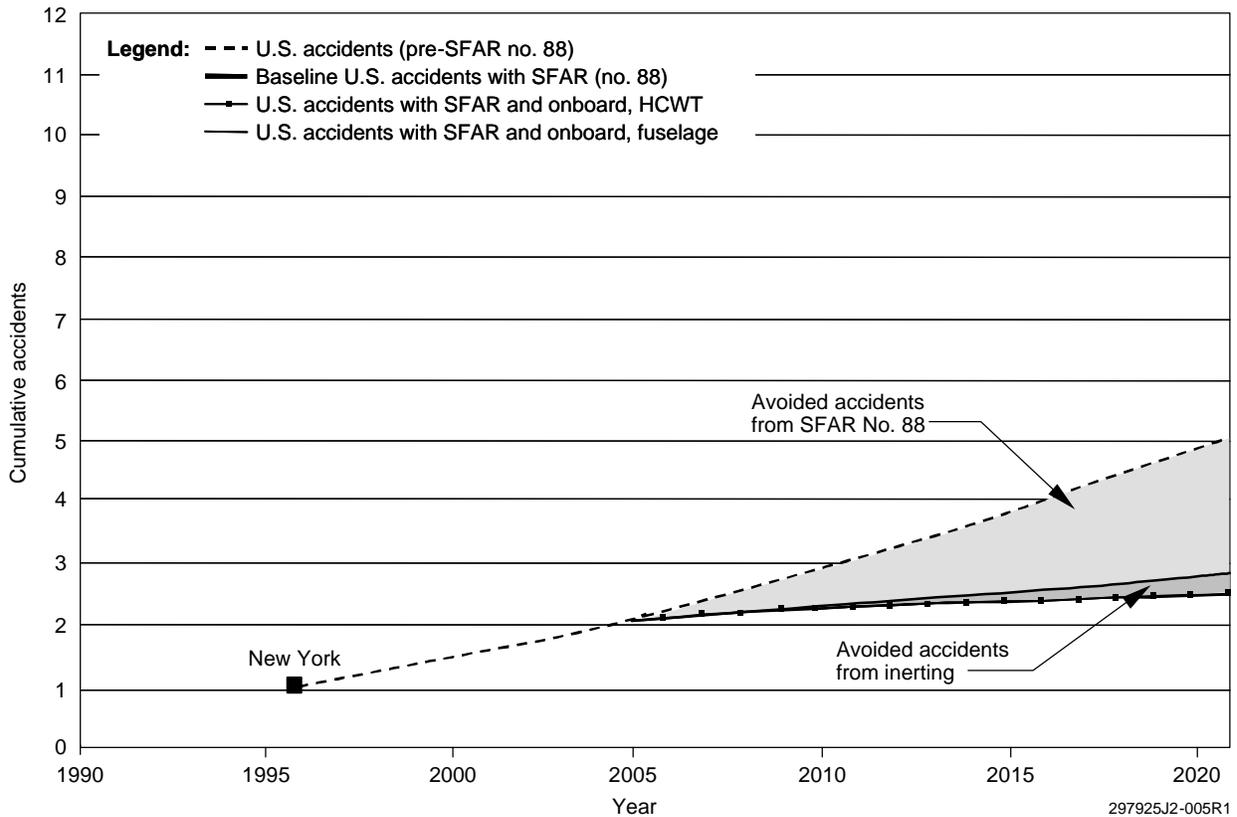


Figure 7-10. U.S. Cumulative Accidents With Onboard Ground Inerting

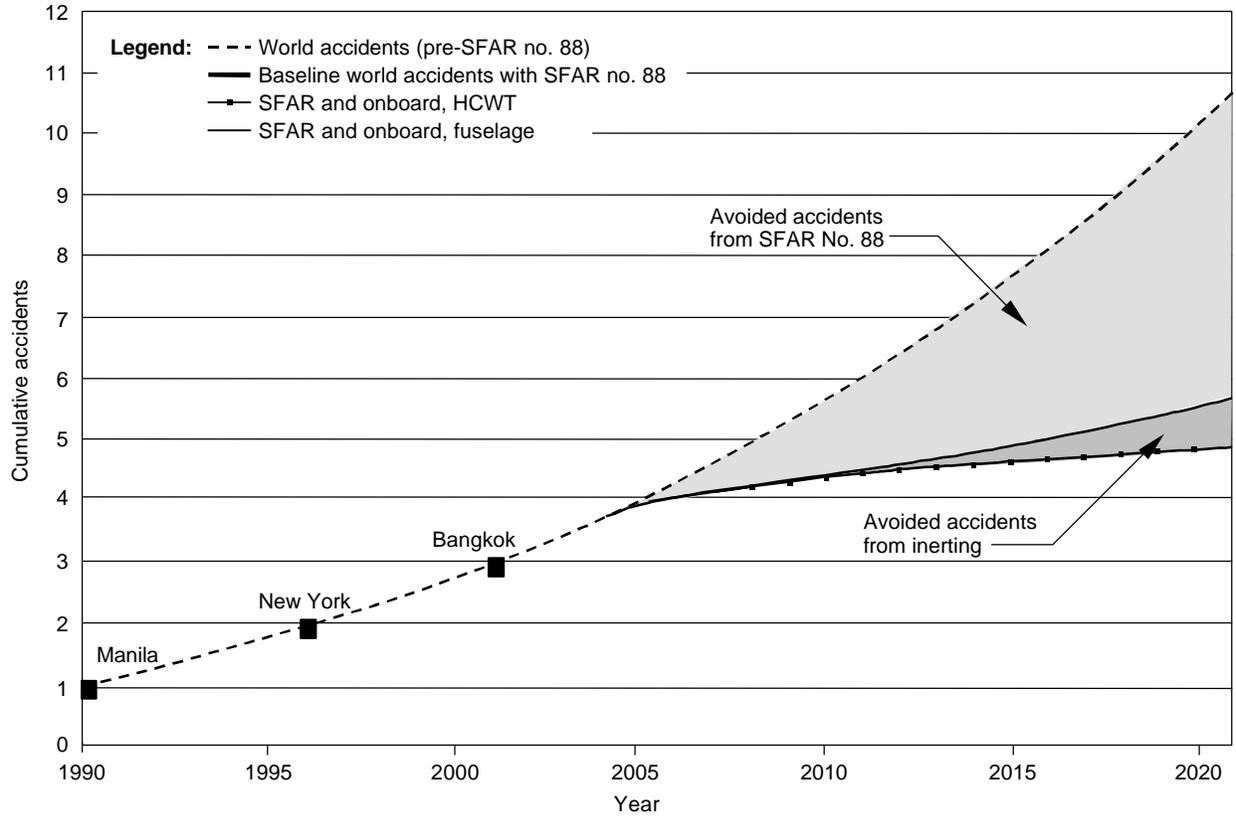


Figure 7-11. Worldwide Cumulative Accidents With Onboard Ground Inerting

### 7.7 COST-BENEFIT ANALYSIS

Figures 7-12 through 7-19 graphically represent the cost-benefit analyses of the scenario combination examined for onboard ground inerting.

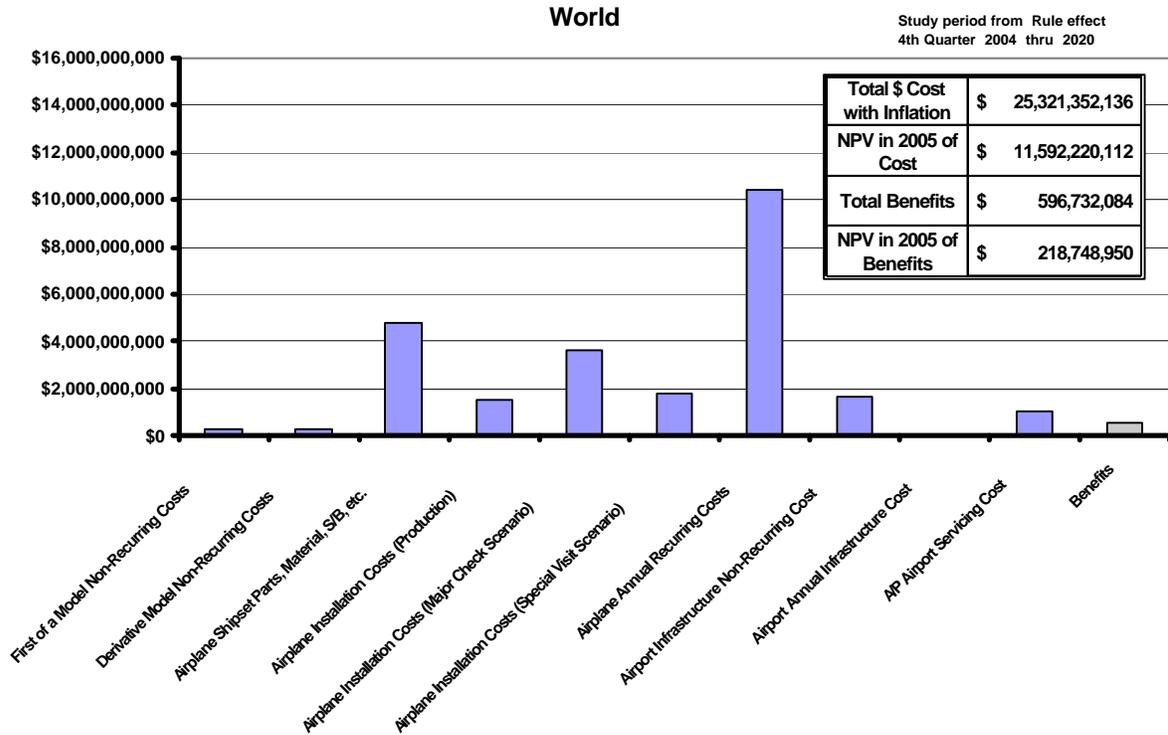


Figure 7-12. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

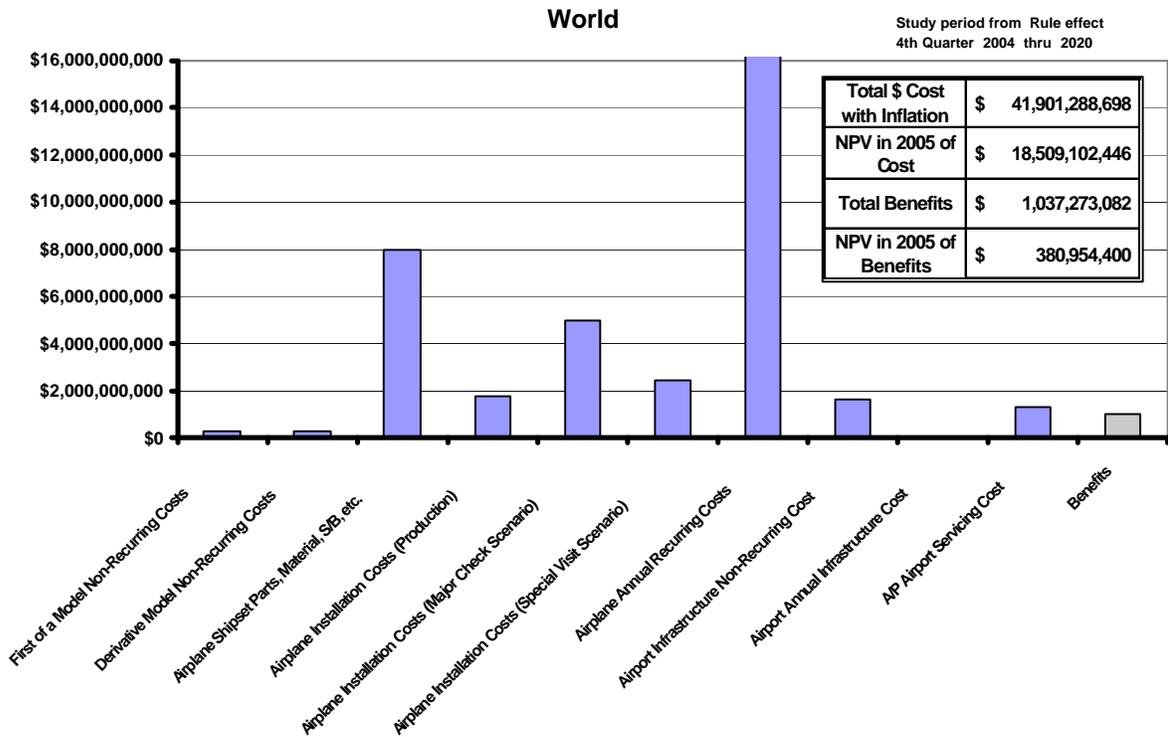


Figure 7-13. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

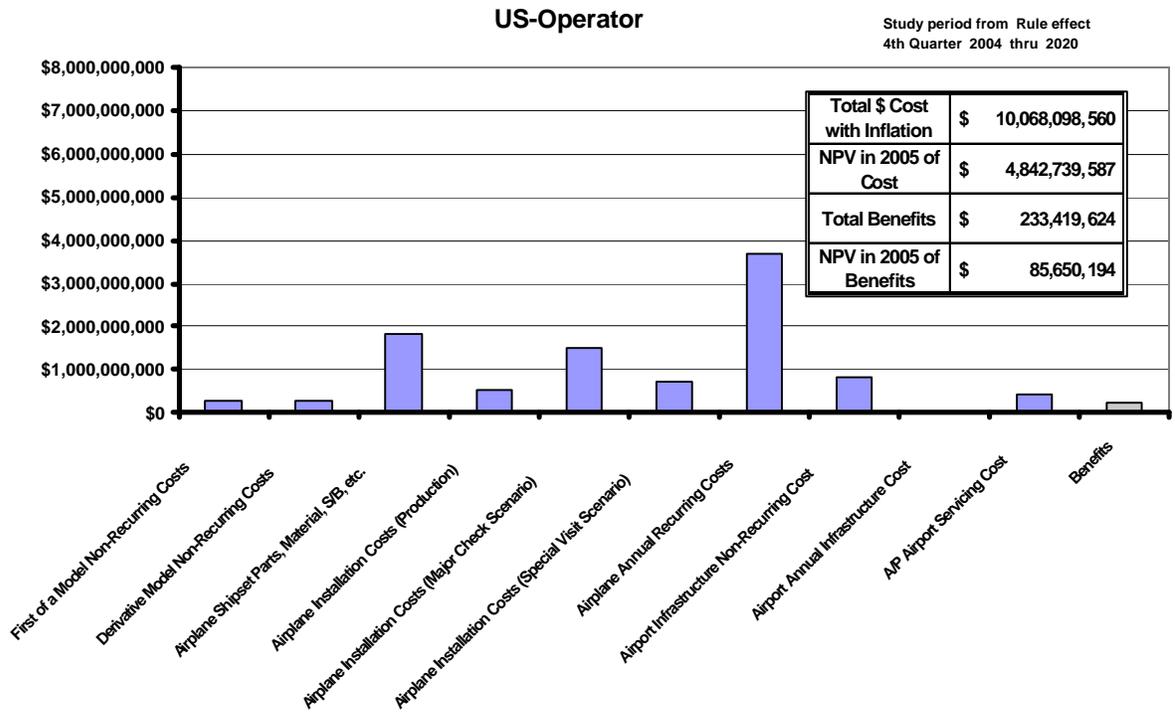


Figure 7-14. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

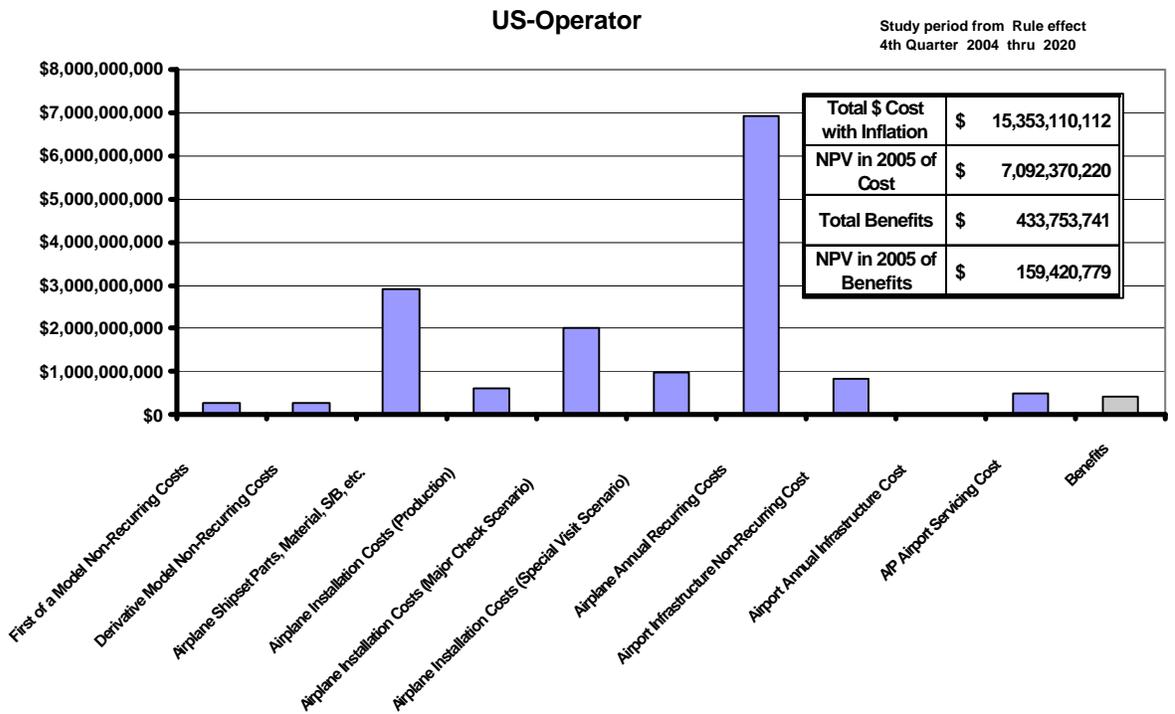


Figure 7-15. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

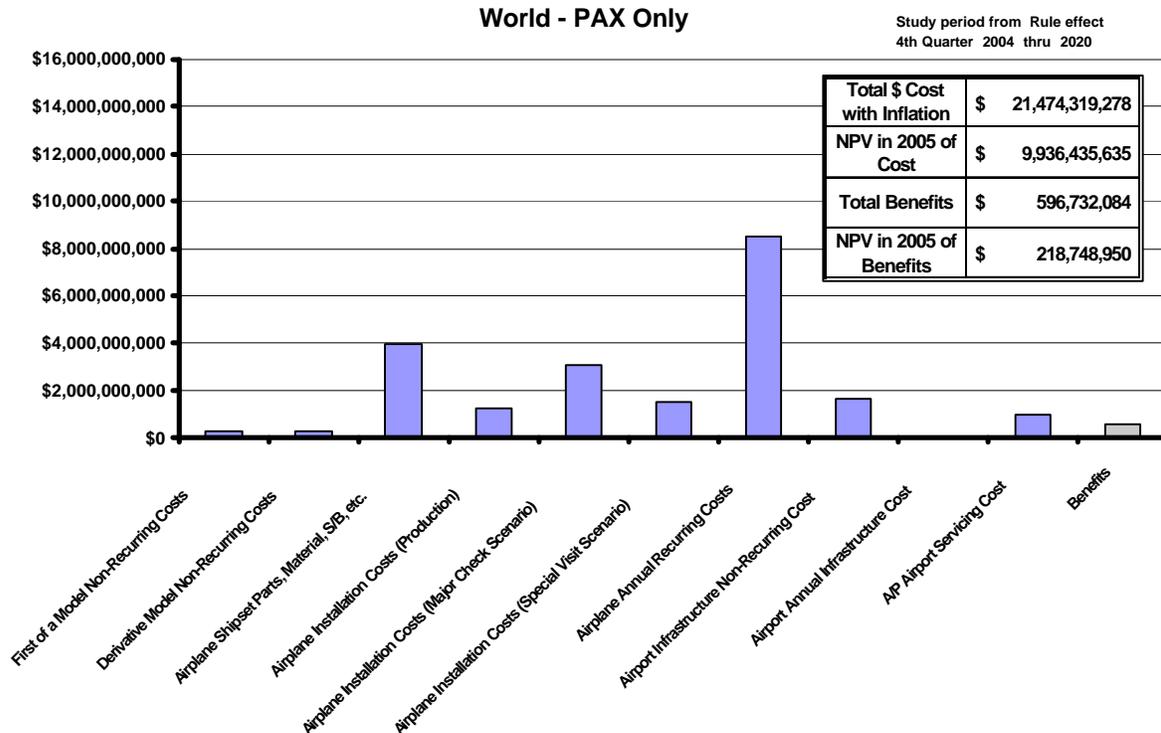


Figure 7-16. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

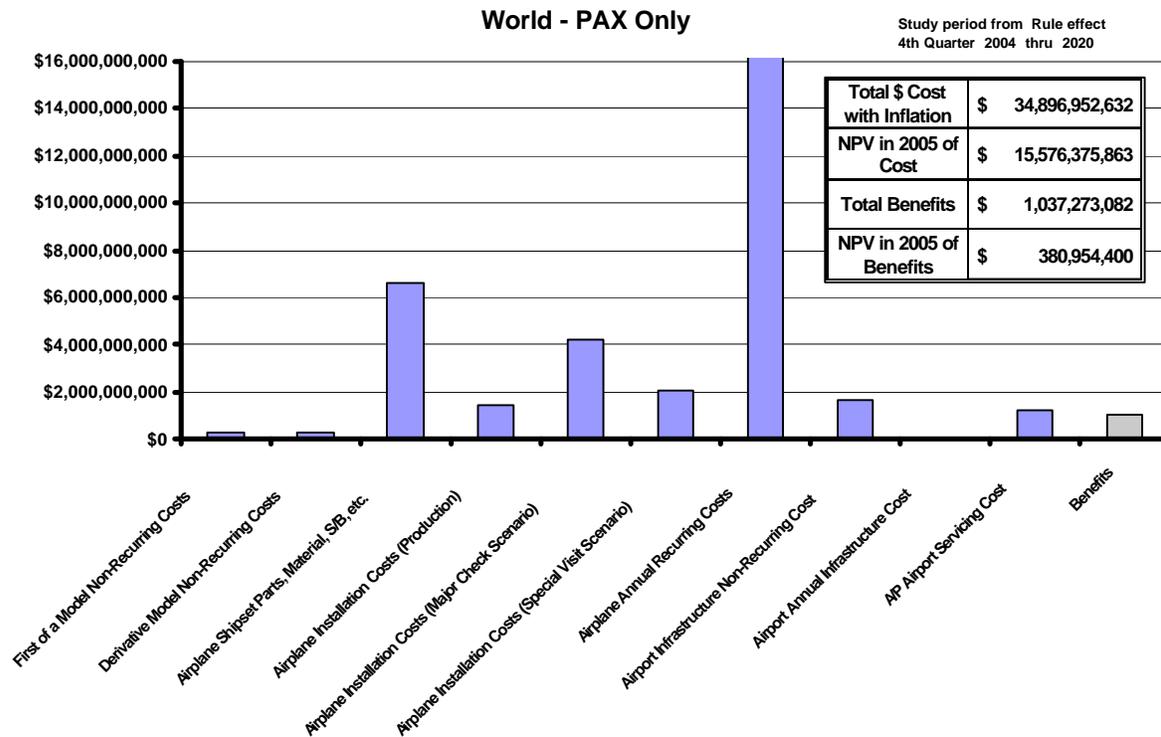


Figure 7-17. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

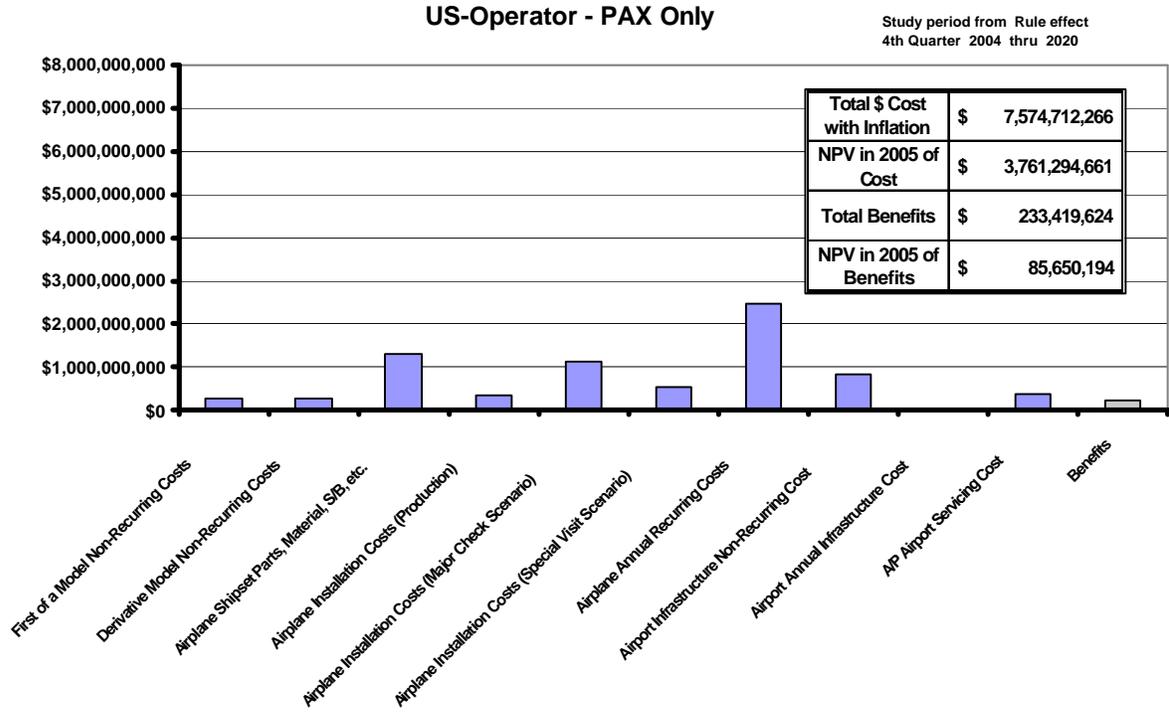


Figure 7-18. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

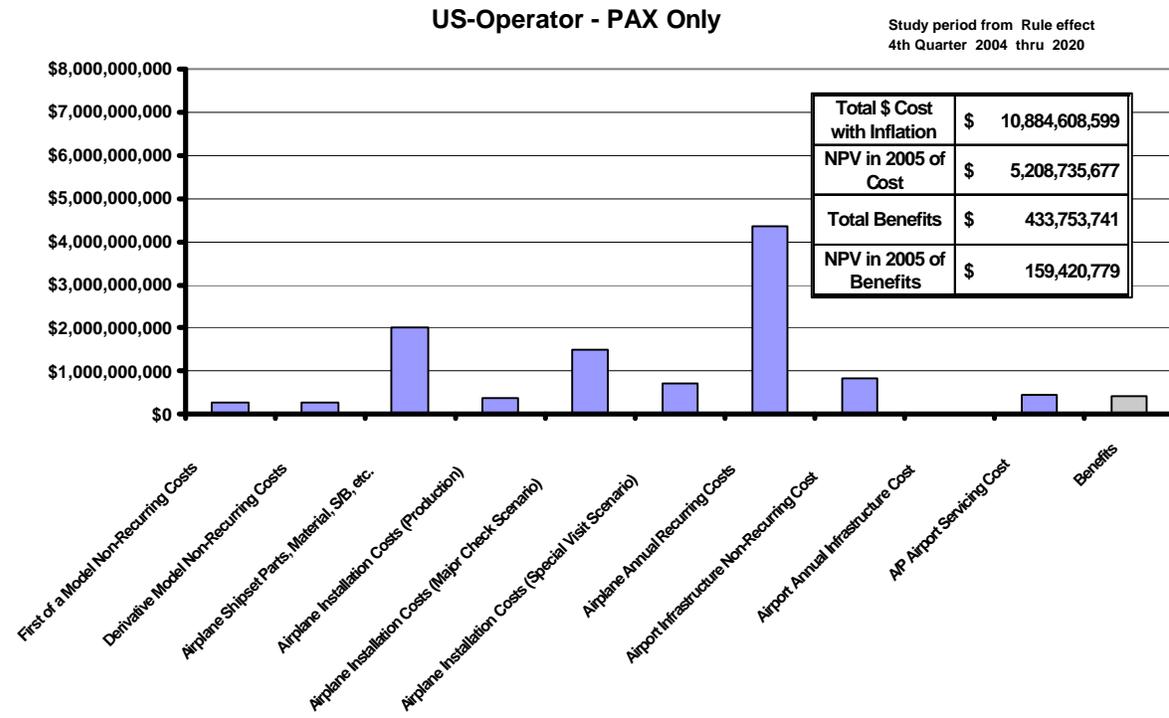


Figure 7-19. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

## 7.8 PROS AND CONS

### Pros

- The OBGIS reduces total flammability exposure comparable with that of GBI.
- Certification is simpler than for an OBIGGS because it runs only on the ground, so interference with other airplane systems is minimized.
- The OBGIS potentially reduces corrosion and condensation in the fuel tanks, depending on where and how the operator uses the system.

### Cons

- The OBGIS is the heaviest system studied, takes up the same or slightly more volume than full-time OBIGGS, and requires as much or more electrical power.
- The cost of components (only a part of the total system cost) far exceeds the potential benefit.
- Additional cost is incurred as a result of the weight of the system—which causes a fuel penalty—and airplane drag is increased because of inlet and exhaust ports for the system.
- The airplane's center of gravity may be adversely affected because of the system's location in some airplane models, which would also incur a fuel penalty.
- Compressor and fan noise may have to be damped, depending on local noise standards.

### Indeterminate

#### Pollution:

- Normally, some fuel vapor exits the tanks during refueling, and some vapor will be pushed out when adding nitrogen to the tank.
- Fuel vent systems will need to be isolated to prevent crosswinds from diluting the nitrogen, which would be an improvement over present-day conditions.

No attempt was made to quantify this because of the complexity of the problem for each airplane model at each airport.

## 7.9 MAJOR ISSUES AND RESOLUTIONS

The technical limitations for retrofit of the OBGIS are its size, contamination issues with the ASMs, and a potential hazard with static electricity. The system size cannot be resolved without relaxing the requirements. A description of the improvements needed for the other limitations follows.

### 7.9.1 System Size

Some OBGIS issues relate to the large system size. For the large-transport CWT only, the system weighs between 500 and 1,000 lb (depending on the separator technology) and consumes almost all the power available from the APU generator. Little power remains for running the airplane's normal electrical equipment, such as lights, galleys, avionics, and their cooling fans, while on the ground (see fig. 7-20).

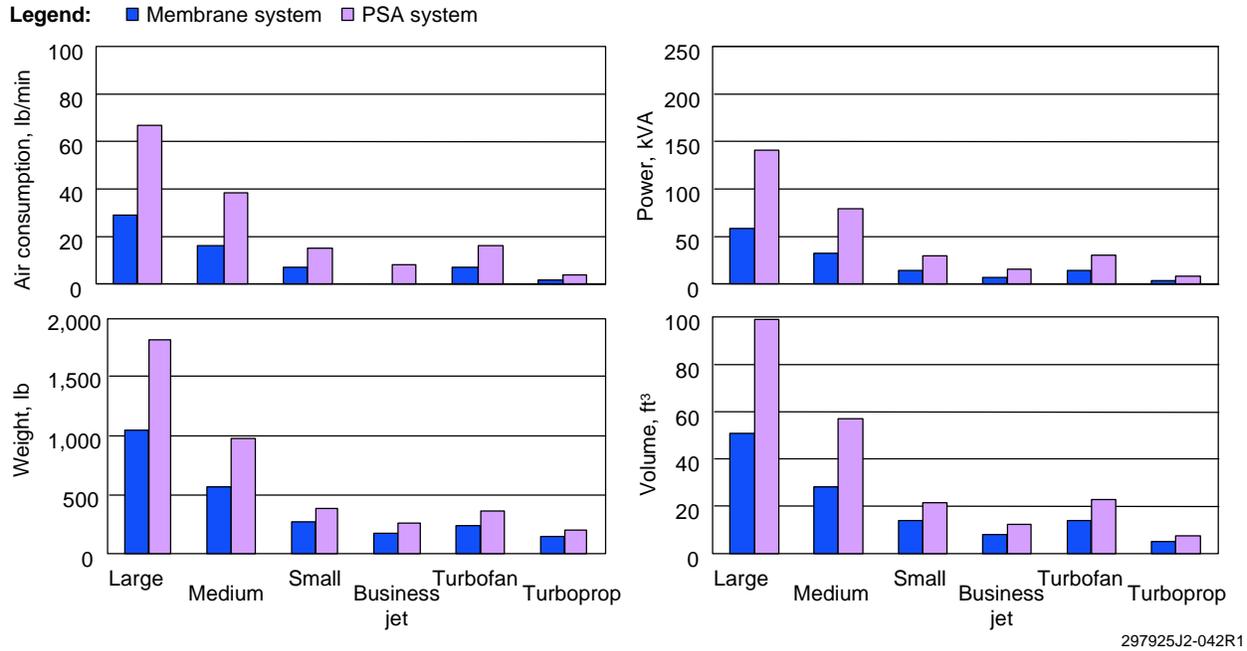


Figure 7-20. OBGI Required Resources for All Tanks

No matter what size the airplane, the system requires significant electrical power to run, may not fit in all airplanes because of its size, and is heavy. The only reasonable resolution is to increase the gate time, which will incur cost penalties for the operators.

Another issue is the compressor weight, which for the large and medium transports is too heavy for an average mechanic to lift. This can be resolved by changing the design to incorporate multiple compressors in parallel, making each compressor smaller and lighter but increasing overall volume.

### 7.9.2 Air Separator Modules

ASMs are susceptible to water contamination, which reduces performance. A water separator has been included in the design concept to avoid this problem.

Permeable membrane modules also are susceptible to hydrocarbon contamination from the fuel and oil vapor in engine bleed air. A coalescing filter has been included in the design concept to capture the vapor before it reaches the membrane.

In addition, permeable membranes have no service history onboard airplanes to prove their durability. They have been used in ground applications, however, where they have demonstrated a very long life.

### 7.9.3 Static Electricity

The rapid flow of dry gas in a distribution manifold inside the fuel tank can generate static electricity and cause sparks. This can be mitigated by using large-diameter manifolds to keep the gas velocity low and by bonding the manifold to structure (electrical ground).

## 7.10 CONCLUSIONS

The OBGIS reduces flammability exposure. But the concept suffers from the limited gate time available between flights and the large ullage volumes (small fuel load) required for short missions. The protection offered is approximately that of the ground-based concept but at a much higher price. Therefore, we do not recommend this concept.



## **8.0 ONBOARD INERT GAS GENERATING**

The OBIGGS is a self-contained method of providing inert gas to the fuel tanks without relying on an airport to supply the inert gas.

The Onboard Inerting Designs Task Team reviewed the 1998 ARAC FTHWG report for inerting and determined that most of the nitrogen inerting technologies discussed in that report remained unchanged. The team chose to focus on air separator technology because of improvements in technology and manufacturing and the probable benefit of reduced cost.

The 1998 ARAC FTHWG found OBIGGS to be a heavy and expensive system. The FAA Tasking Statement for this ARAC has provided the means to reduce weight and cost, with specific recommendations to design without redundancy and to allow airplane operation when OBIGGS is inoperative. This has provided some improvements over the 1998 study.

Cryogenic distillation was investigated as a means to reduce the demands on the airplane. This technology produces nitrogen gas and stores liquid nitrogen by partially liquefying incoming air and separating the nitrogen. The nitrogen gas is used for on-demand inerting through all phases of flight. The liquid nitrogen is used to initialize and inert the fuel tanks at the start of the day. The cryogenic distillation system is not yet an available technology but is near term; that is, with current funding it could be available within 5 years.

### **8.1 SYSTEM REQUIREMENTS**

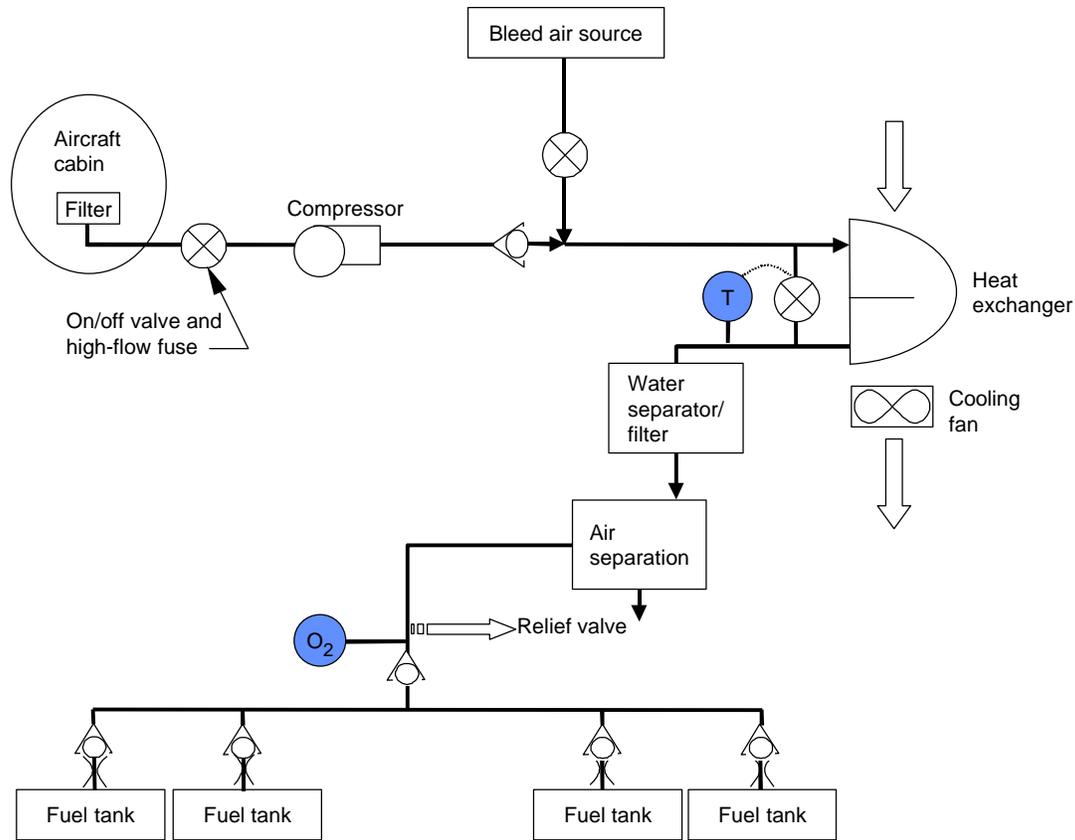
The Tasking Statement requires that OBIGGS inert all fuel tanks during normal ground and typical flight operations. Nonnormal operations, such as an emergency descent, are not to be considered typical flight operations. This report will consider methods to minimize system cost, such as reliable designs with little or no redundancy, and recommendations made for dispatching in the event of a system failure or malfunction that prevents inerting one or more of the affected fuel tanks.

Secondary effects of the system must be described. The Tasking Statement requires that the FTIHWG analyze and report on extracted engine power, engine bleed air supply, maintenance impacts, airplane operational performance detriments, dispatch reliability, and so on. FTIHWG also is required to provide information and guidance for the analysis and testing that should be conducted to certify the system.

If the Working Group cannot recommend a system, the group is to identify all technical limitations and provide an estimate of the type of concept improvement required to make it practical in the future.

### **8.2 SYSTEM CONCEPT DESCRIPTION**

Figure 8-1 shows the OBIGGS. In its simplest terms, the ASM pressurizes cabin air and separates it into nitrogen and other gases. This nitrogen is supplied to the fuel tanks while the other gases are exhausted overboard.



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Figure 8-1. OBIGGS Schematic

The team reviewed and substantiated the 1998 ARAC FTHWG finding that engine bleed air is insufficient at critical times to supply OBIGGS. An electric compressor was deemed a viable primary source of air, when supplemented by engine bleed air as available.

The source air is cooled if necessary, water is removed to avoid icing, air is filtered to avoid ASM contamination, and the ASM separates nitrogen and supplies it to the fuel tanks.

The team hoped that using cabin air would reduce costs because it lowers the compressor's pressure ratio. ASMs require approximately 45 psia for their best performance. Ambient air at altitude is roughly 3 psia, requiring a compressor with a 15:1 pressure ratio. This is a daunting task. However, the cabin air is already pressurized to roughly 8 to 12 psia and is normally exhausted overboard, so this seemed a reasonable supply for the inerting system and only required a pressure ratio of between 4:1 and 6:1 from the compressor.

For passenger protection, a high-flow fuse closes to keep air inside the cabin in the event of a duct rupture in the inerting system. Similar valves are incorporated in airplane environmental systems today.

### 8.2.1 Air Source

The concept uses multiple air sources. Pressurized air can be provided by engine and APU bleed air or by the electric compressor. The air pressure supplied to the ASM is nominally 45 psia.

### **8.2.2 Pressure Ratio**

The electric compressor was sized for a pressure ratio between 4:1 and 6:1. This provides 48 to 60 psia to the ASMs on the ground (depending on airport altitude) and about 44 psia in flight (depending on airplane altitude).

### **8.2.3 Air Separator**

We studied three concepts for air separation. Hollow-fiber membranes separate nitrogen through molecule-sized passages when air passes through the length of the fiber. PSA adsorbs oxygen as air passes over the module, leaving nitrogen in the flowstream. Cryogenic distillation relies on separation of a partially liquefied airstream using a distillation column. The product is a high-purity nitrogen gas, which can be sent to the fuel tanks, or a high-purity nitrogen liquid, which can be stored for later use.

### **8.2.4 Descent Rate**

Descent is the dominant airplane operation that determines the size of OBIGGS, and the faster the airplane descends, the larger the system required. OBIGGS prevents outside air from entering the fuel tank and increasing the oxygen concentration, so it must generate more gas during descent than at any other time in flight.

Military airplanes use climb-dive vent valves to keep outside air out of the fuel tanks, but these valves are quite complex because their failure could severely damage the fuel tanks. The FAA sought to avoid this complexity for the hybrid, and the Onboard Inerting Designs Task Team also wanted to avoid it for full-time OBIGGS. This goal requires that OBIGGS provide a high flow of nitrogen or high-purity nitrogen to dilute outside air as it enters the fuel tank (military systems with climb-dive vent valves can afford to provide slightly less flow). The team believes a somewhat larger OBIGGS was a lighter, cheaper choice than one using the complex vent valves.

### **8.2.5 Flammability Exposure**

The flammability exposure is defined as the percentage of the airplane mission when the fuel ullage is flammable and not inert. The 1998 ARAC FTHWG found that CWTs had a flammability exposure of approximately 30%, and wing tanks had a flammability exposure of approximately 7%. The FAA has since been refining a model for flammability exposure, which was provided to this ARAC to compare system benefits. OBIGGS reduces the flammability exposure of all tanks to nearly zero.

## **8.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES**

The design concept applies to all the airplanes in the study category. However, the high electrical demand may exceed the capacity of the existing airplane electrical systems and, at airports that discourage APU operation, the airport's ability to provide the electricity.

An inerting system can be designed into future airplanes, provided the inerting system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available to supply the inerting system.

## **8.4 AIRPORT RESOURCES REQUIRED**

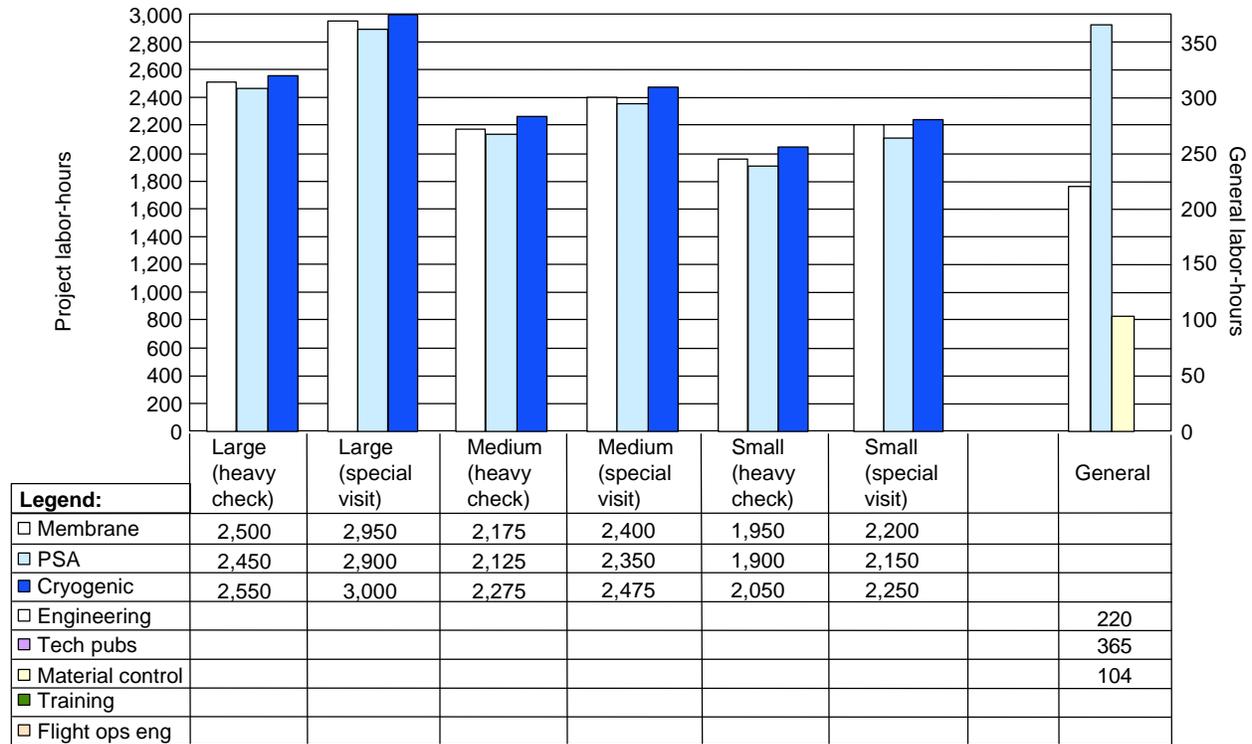
OBIGGS is a self-contained system that does not normally require any airport resources. However, ground electrical power may be preferred by some operators for systems without storage capabilities to power the system after tank maintenance and to inert the fuel tanks before the next flight.

### 8.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT

This section discusses the modification of in-service airplanes to install an OBIGGS and describes the overall effect of OBIGGS on airplane operations and maintenance requirements.

#### 8.5.1 Modification

Figure 8-2 shows the modification estimates for the OBIGGS. Because there is insufficient space for the OBIGGS in the unpressurized areas of regional turbofan, regional turboprop, and business jet category airplanes, we have excluded these airplanes from this estimate. For the other airplane categories, estimates are made for both a regular heavy maintenance visit and a special visit. Appendix F, Airline Operations Task Team Final Report, addenda F.A.1 and F.A.2, contains a detailed table with costs and labor-hours.



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Figure 8-2. Modification Estimations for OBIGGS

After OBIGGS installation, an operational test flight may be required. The estimates do not account for costs of test flight.

#### 8.5.2 Scheduled Maintenance

##### Scheduled Maintenance Tasks

The Scheduled Maintenance Subteam developed concepts for two types of OBIGGS and considered them separately. The subteam developed a list of scheduled maintenance tasks for a cryogenic OBIGGS and for a membrane OBIGGS using the system schematics provided by the Onboard Inerting Designs Task Team. The subteam evaluated each component illustrated in the schematic individually and wrote the tasks accordingly. These tasks included inspections, replacements, and operational and functional checks of the various system components. The subteam assigned these tasks to the various checks (A-, C-, 2C-, and heavy) and estimated labor-hours for each. Appendix F lists these tasks for each airplane category.

We assumed that tasks completed at a C-check would also be completed at a 2C-check. We made similar assumptions for the 2C-check tasks (i.e., they would be accomplished at the heavy check [or 4C-check equivalent]).

Both OBIGGS concepts consist of unique components that require additional tasks when compared with the GBI and OBGI systems. Thus, additional tasks are required, substantially increasing the extra labor-hours required in the C-, 2C-, and heavy checks.

Because of the size and complexity of the OBIGGS concept, we did not complete an analysis for turbofan, turboprop, and business jets category airplanes.

Pressure Check

Extra labor-hours have been added to each C- and heavy checks to perform a fuselage pressure decay check and rectification. The system uses cabin air as a supply for the inerting system, which increases the demand on the airplane air-conditioning packs. Consequently, the maximum allowable cabin leakage rate will have to be maintained at a lower level to ensure that the airplane air-conditioning packs will be able to maintain the required cabin pressurization.

Additional Maintenance Labor-Hours

Figure 8-3 shows the estimate for additional scheduled maintenance labor-hours required at each check to maintain a cryogenic OBIGGS. Figure 8-4 shows the estimate of additional scheduled maintenance labor-hours required at each check to maintain a membrane OBIGGS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	55	74	87	124.03
Medium	3	55	74	91	126.03
Large	3	55	74	95	115.52

*Figure 8-3. OBIGGS Additional Scheduled Maintenance Times—Cryogenic System*

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	50	65	76	113.96
Medium	3	50	65	80	114.56
Large	3	50	65	84	105.77

*Figure 8-4. OBIGGS Additional Scheduled Maintenance Times—Membrane System*

**8.5.3 Unscheduled Maintenance**

The full OBIGGS inerting system is the most complex system of all the design concepts studied. The characteristics that make OBIGGS different for other systems studied from a reliability and maintainability standpoint are its size and its operating time.

Because OBIGGS operates during all phases of flight it has an additional effect on other airplane systems. The demand the inerting system puts on the airplane electrical power generation, cabin pressurization, and engine bleed air systems will reduce the reliability and increase the maintenance requirements for these systems.

The larger size and weight of OBIGGS components will make performing maintenance more difficult and in some cases may create an additional safety risk when lifting the components during removal and installation.

System Annual Utilization Rate

The system annual utilization rate for OBBIGS, shown in figure 8-5, reflects the amount of time that any of the systems would operate in 1 year. We calculated this figure from the airplane daily utilization rate plus the minimum turn times, multiplied by the number of daily cycles. The large transport airplane with a high daily rate had the highest system annual utilization rate; the small transport came in a close second because of its high daily cycles.

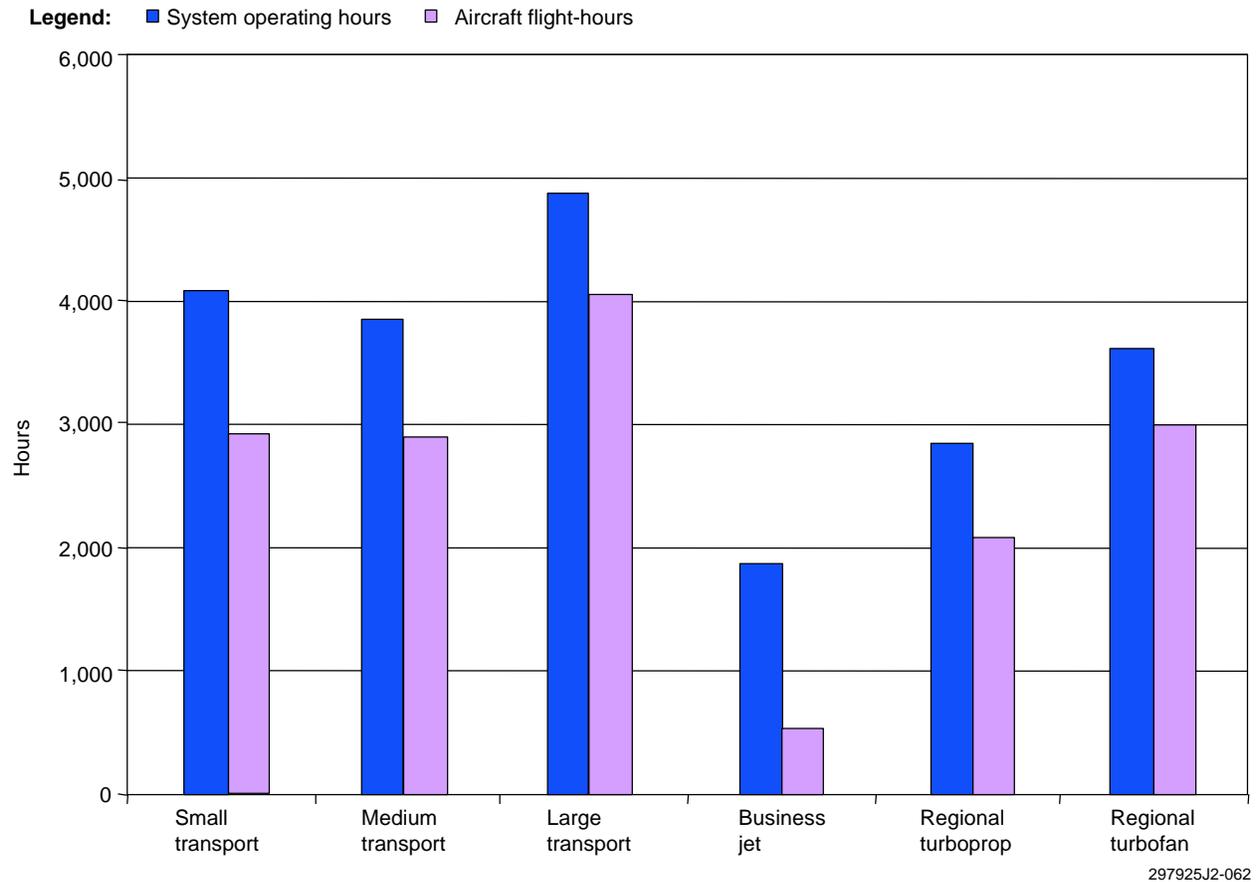


Figure 8-5. System Annual Utilization Rate

Component Reliability

To estimate the impact and related costs associated with the operation and maintenance of an OBBIGS we had to first establish a likely system reliability figure. From the system design we could compile a list of components for each system. In most cases it was possible to use historical data from similar components to suggest an OBBIGS component MTBUR. Where possible, more than one similar component was used.

One example of component reliability calculation was the OBBIGS shutoff valve. This valve would typically be a motorized butterfly-type valve that is found in many positions on different airplanes. Several similar valves were identified and, using the historical component MTBUR data from more than one operator, we calculated an average MTBUR figure. The OBBIGS design team suggested an MTBF of 50,000 hr; the average MTBUR figure was in fact calculated at 38,315 hr. This differential was expected and indeed confirmed that this method of MTBUR calculation was valid.

Where insufficient historical data was available, we used an MTBF figure, set by the system design team, or a most likely figure, based on team members' experience.

Establishing the component reliability in the form of an MTBUR figure was crucial in determining system reliability and in enabling the team to determine not only the component and system annual failure rate but overall impact on airplane maintenance and operations that result from system failures. This includes

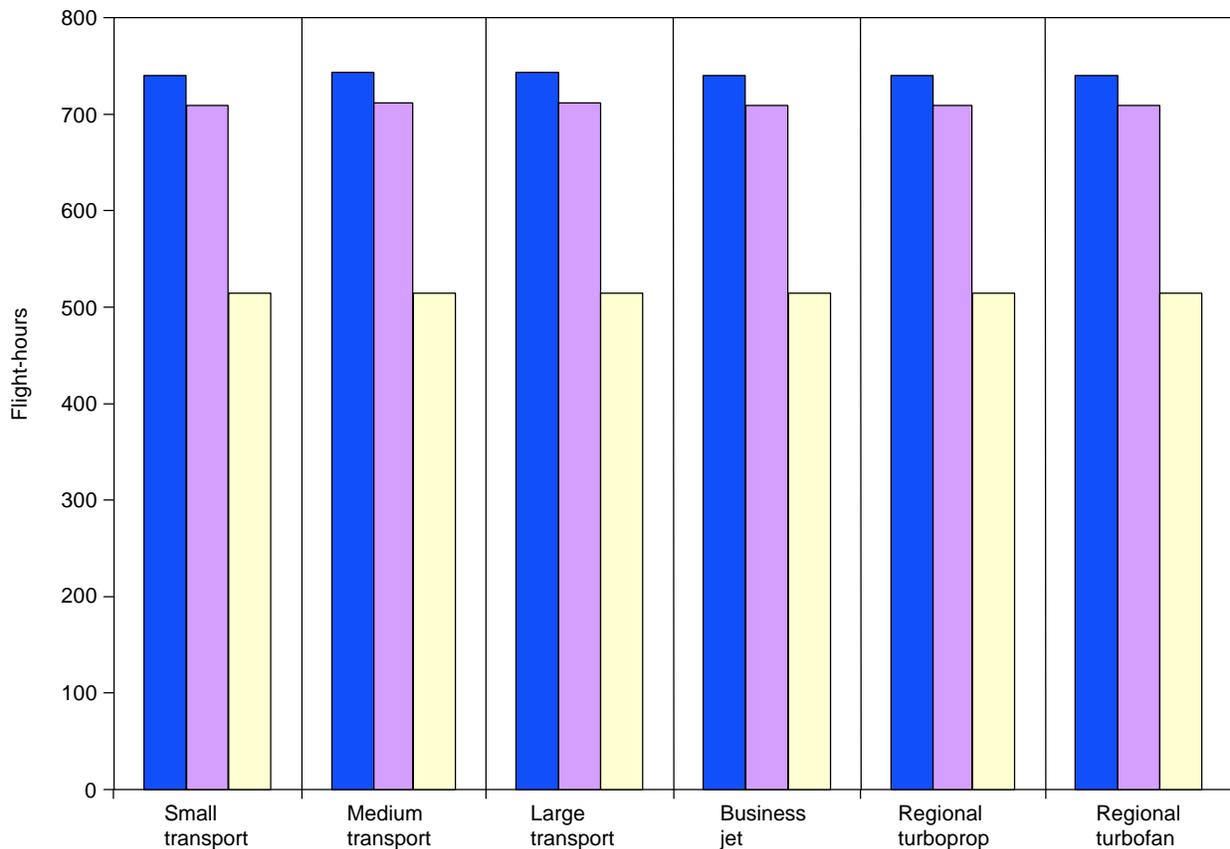
- System weight.
- Cost to carry per airplane per year (\$).
- System availability (driven by number of days of MMEL relief).
- Delays per year (hours).
- Delay costs per airplane per year (\$).
- MMEL relief ranging from 0 to 120 days.

System Reliability

The MTBUR for the system was then determined from the individual component estimates.

We made an effort to determine the difference in MTBUR among airplane categories (fig. 8-6). Where sufficient component data was available, we found that there was little difference in MTBURs among the different airplane sizes. We felt that it did not prove to be a significant factor in further calculations. Therefore, with the resources available, we did not develop these figures further.

**Legend:** ■ Membrane system ■ PSA system ■ Cryogenic system



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Figure 8-6. System MTBUR

System Annual Failure Rate

Using the component MTBURs and the airplane yearly utilization rate, we calculated the annual failure rate for each component. The system annual failure rate was the sum of these component annual failure rates.

As expected from the increased system complexity and the maturity of the cryogenic and PSA system technology, OBIGGS has a much higher predicted failure rate, shown in figure 8-7. This calculation was crucial for many further calculations such as system availability and the effects of different MMEL repair periods.

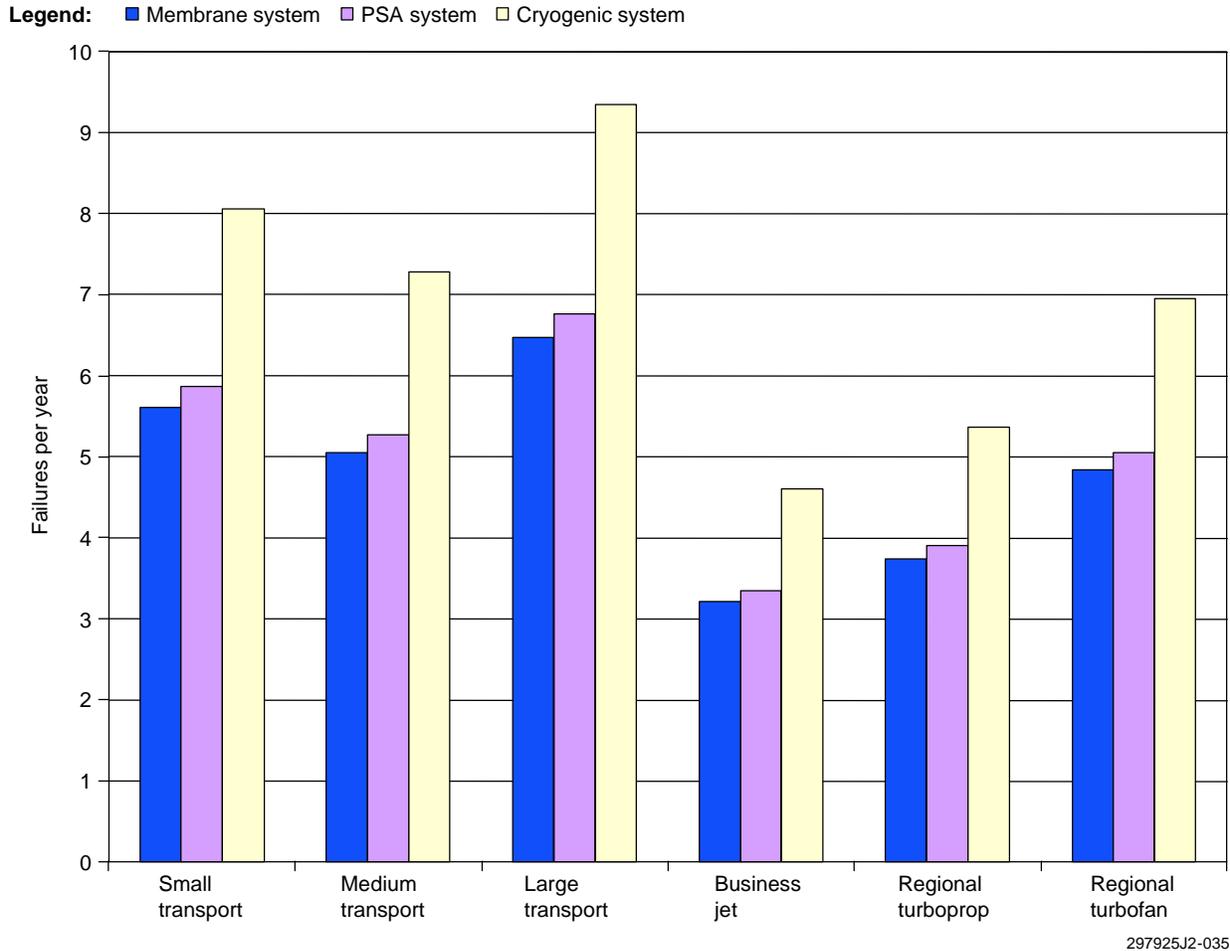


Figure 8-7. System Annual Failure Rate

Unscheduled Maintenance Labor Estimate

The amount of additional workload an OBIGGS would add to an airplane’s maintenance requirements is a function of the annual failure rate and the component maintenance time, which in turn is a combination of the following:

- Component removal and replacement time.
- Component access time.
- Troubleshooting time.

To calculate the labor-hours per year we must make some assumptions as to the locations of the

components. For example, the heaviest components would be located in areas that would allow access with lifting equipment (e.g., air-conditioning bay or wing-to-body fairing areas). We assessed each component individually and estimated the time to troubleshoot, access, and remove and replace based on similar tasks on existing airplanes.

The figures calculated refer only to the hours taken to rectify OBIGGS failures. It does not take into consideration the additional hours to maintain other airplane systems that are required to support OBIGGS (i.e., electrical or pneumatic systems) or systems affected by OBIGGS (i.e., cabin pressurization).

These figures may appear to be minimal but, where an operator has many airplanes arriving and departing within a short period of time, existing staffing levels may not be able to perform the rectification tasks, and additional staff will need to be recruited. This additional labor requirement is very difficult to quantify and has not been included. Therefore, the labor-hour estimate shown in figure 8-8 is presented as an indicator of the requirement for an increased number of maintenance technicians.

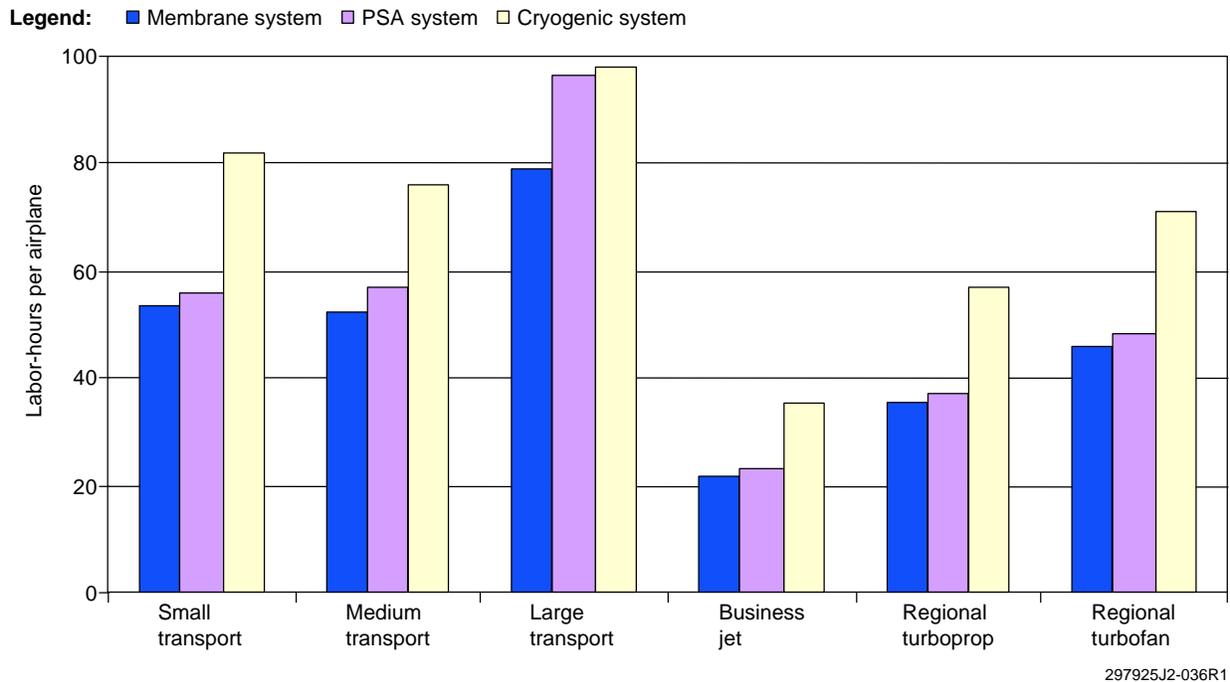


Figure 8-8. Additional Annual Labor-Hours

Annual Labor Costs

This is a product of the additional unscheduled labor-hours per year and the FAA’s standard burdened labor rate for airplane maintenance technicians of \$75/hr.

The costs shown in figure 8-9 are for the additional labor-hours only. Operators may have to hire additional staff to fulfil these requirements, resulting in an increased financial burden for recruitment, administration, and training of the required staff.

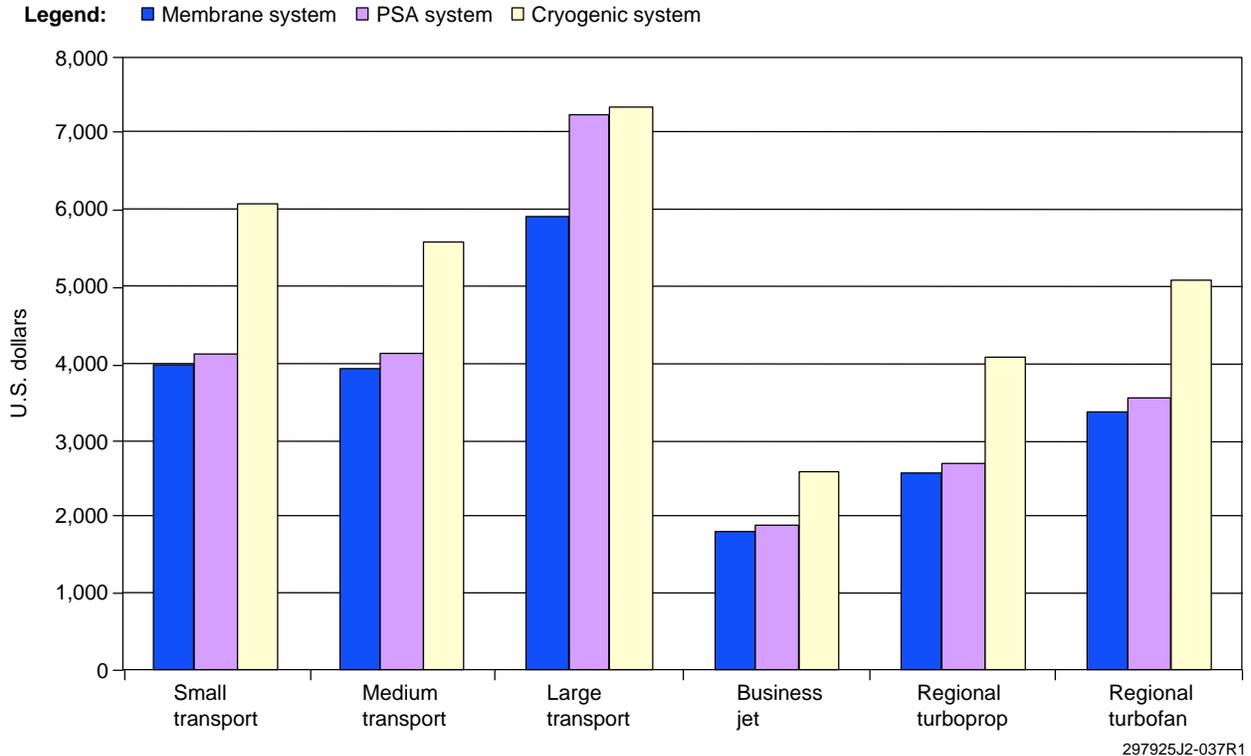


Figure 8-9. Additional Annual Labor Costs

System Weight

System weight has been calculated from the sum of the component weights specified by the design teams. The additional weight of the system installed on an airplane will not be limited only to the additional components. This estimate does not include the added weight of structural modifications to support heavy components.

Many operators are trying hard to reduce the weight of their airplane in an effort to achieve best economy.

This system weight has been used to calculate the cost to carry per airplane per year (\$).

System Availability

System availability is a product of system annual failure rate and the variable input, MMEL repair interval. For example, if the system has a failure rate of five times per year and has 10 days’ MMEL relief, the worst case scenario could mean that it is inoperative for 50 days per year, or 14% of the time. This would result in a system availability rate of 86%.

As mentioned earlier in this report, we evaluated the potential impact of 3-day and 10-day MEL repair intervals. Because system repairs are frequently accomplished in less time than the allowed per the MEL repair interval limits, we made assumptions on the average amount of time an inerting system would be inoperative under MEL relief. Under the 2-day MEL relief repair interval we assumed that the average system would be inoperative for 2 days. For the 10-day MEL relief repair interval the average system would be inoperative for 7 days.

The complexity of OBIGGS and the immaturity of both the PSA and cryogenic inerting technology result in a relatively high system annual failure rate, which drives the system availability rate down. Information from the Safety Analysis Task Team suggested that a system availability of 97.5% is desired to ensure the concept’s predicted benefits. On most OBIGGSs, to achieve higher than 97% availability a 1-day MMEL repair interval is required but will seriously affect airline operations.

Figure 8-10 shows a comparison of the system availability of the membrane system with 1, 3, and 10 days’ relief.

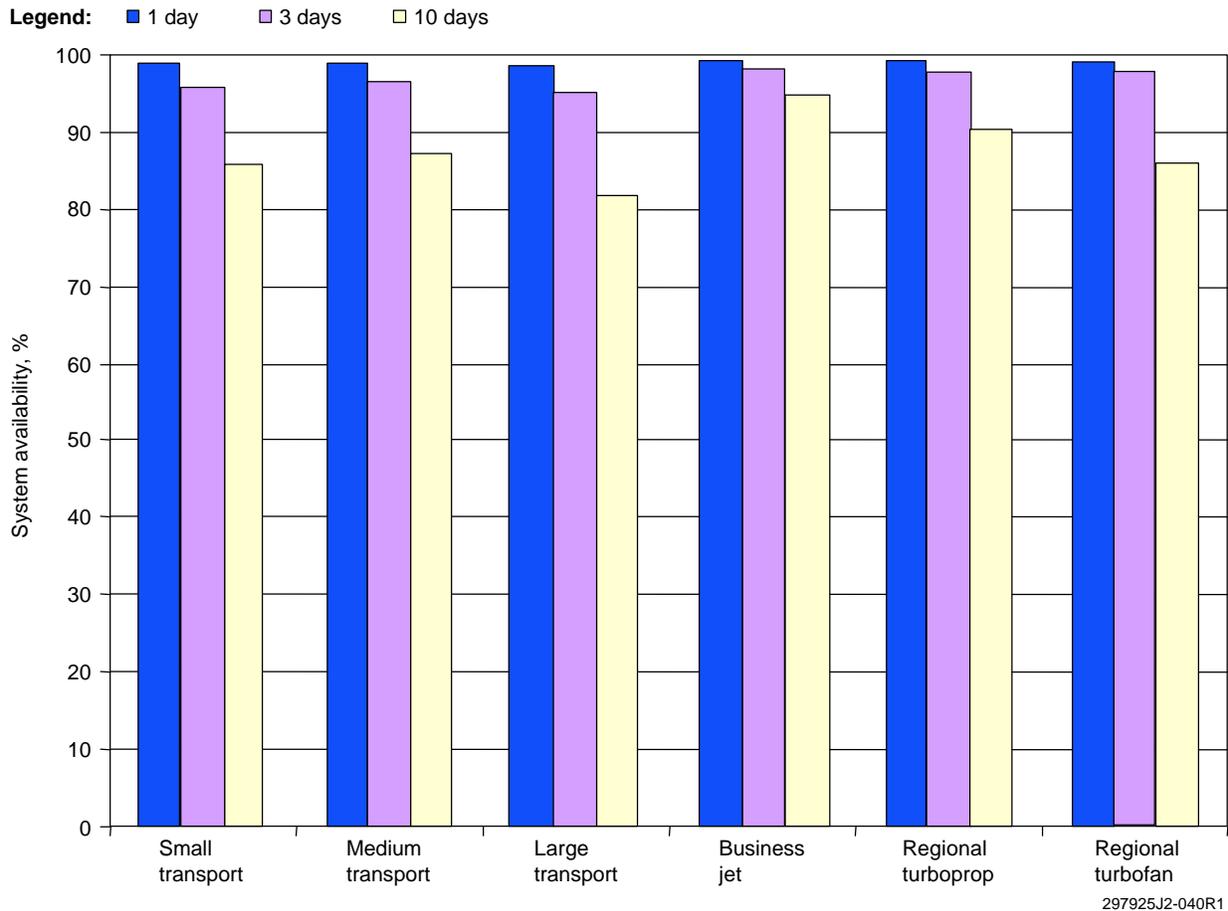


Figure 8-10. System Availability (10 Days’ MMEL Relief)

Delays per Year (Hours)

We calculated the number of hours in annual delays, shown in figure 8-11, by making a delay assumption that if an airplane has a fault in the system it will take a period of time for the mechanics to assess the situation, perform any maintenance action in accordance with the MMEL, and complete any paperwork. Each airplane category has a delay assumption value that, when multiplied by the component annual failure rate, results in a total time delay for each component. The sum of the component delays results in the total annual system delay time (hours).

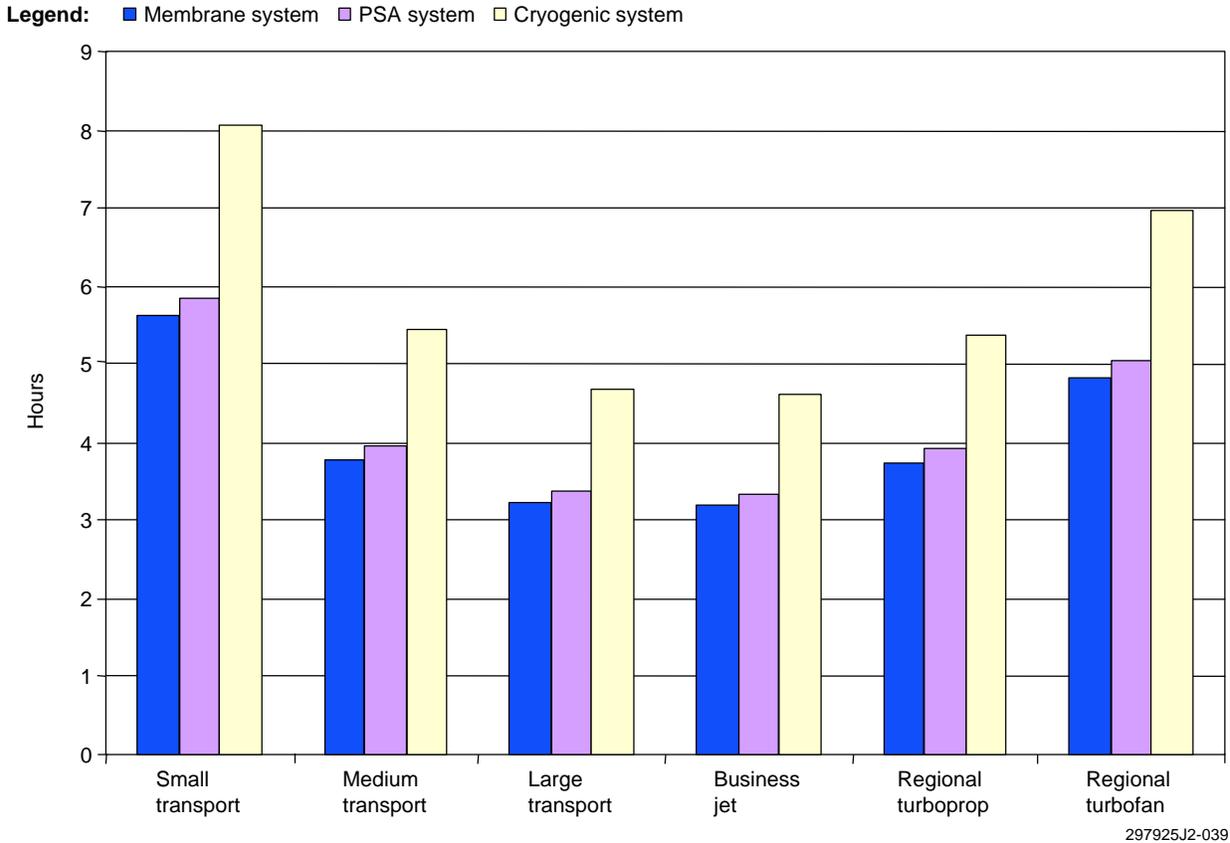


Figure 8-11. Delays per Year (Hours)

World reliability figures are measured against delays and cancellations. Customers are often driven by such figures, and operators make every effort to ensure on-time departures. Such delays and cancellations not only directly affect operators with costs of customer accommodation and remuneration but also loss of repeat customers and reputation.

The causes of such delays and cancellations are actively pursued by operators with a view to reducing them to the minimum, adding another system to the airplane that could affect such figures and is of great importance to operators.

Personnel Safety

It is a major concern for the operators and ground service agencies that installing an inerting system might threaten the safety of personnel. The danger to personnel from entering confined spaces that could be contaminated with NEA is a real possibility. In most developed countries health and safety legislation is adhered to much of the time, but in designing a system that reduces oxygen in some of the airplane’s confined spaces, we could be building a trap for people to fall into.

Another major concern is the size and weight of some of the components in the various systems. These range from lightweight valves and other components to heavy compressors, heat exchangers, cryocoolers, and ASMs. These range in weight from 100 lb to more than 225 lb. There is a recognized need for specialized lifting equipment, but the risk of damage and injury from falling heavy components would exist where it previously did not.

OBIGGS Effects on Other Airplane Systems

The installation of an OBIGGS on an airplane will affect the reliability and cost of operation for other airplane systems. The OBIGGS concepts studied by this Working Group would add a very large additional electrical load on the airplane electrical system. The OBIGGS also relies on the airplane pneumatic system as a supplemental air supply, increasing the demand on this system. Last, in an attempt to reduce the size and power requirements of the OBIGGS air compressors, the design team chose to take the system's supply air from the passenger cabin. This will put an additional demand on the cabin air-conditioning and pressurization systems.

Electrical Power Generation

The OBIGGS power requirements may exceed the current available power.

For example, as shown in figure 8-12, the large transport airplane will require between 115 and 145 kVA. A typical Boeing 747 Classic will produce a maximum continuous rate of 216 kVA, of which 175 kVA is required in cruise, leaving a maximum of 41 kVA. A further consideration is that this remaining power would be distributed among four power-supply buses that cannot be permanently linked.

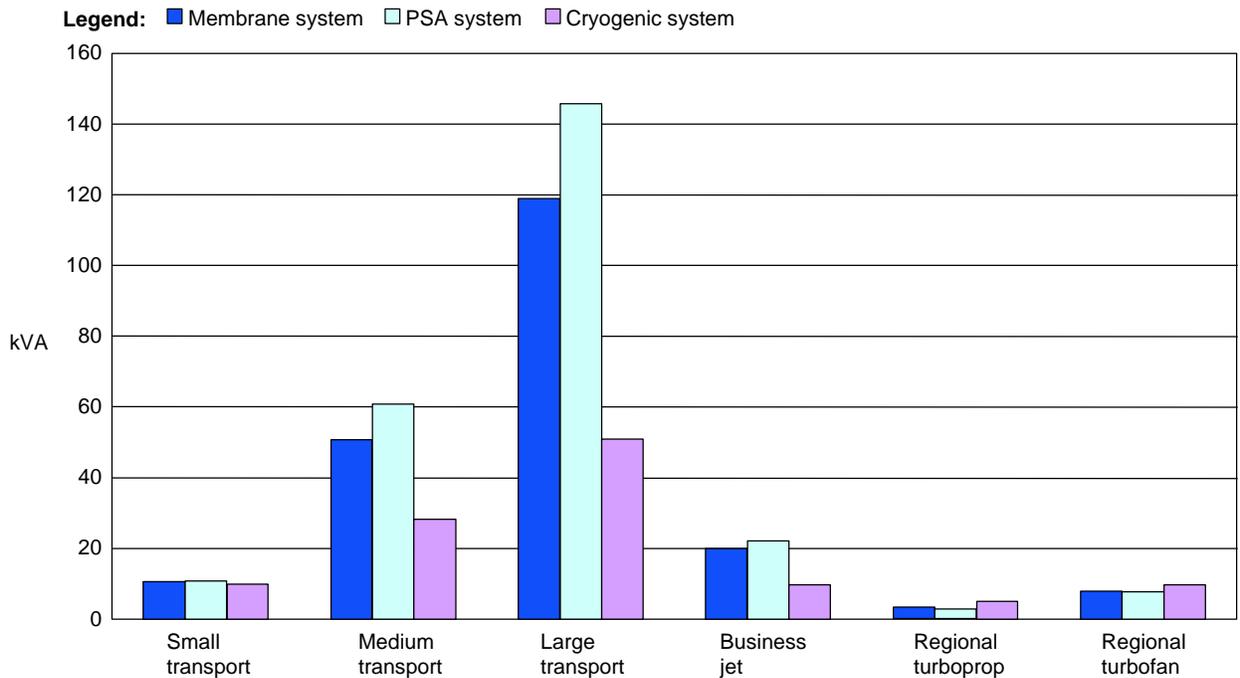


Figure 8-12. OBIGGS Power Requirements (kVA)

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A Boeing 747-400 can produce more power because of greater capacity generators, but greater loads are required and the remaining power is again spread among power-supply buses that cannot be permanently linked.

Depending on the airplane, the increased power demands may require an increase to the capacity of the power-generating system. The cost of increasing the electrical system capacity and the cost of maintaining a larger system were not calculated. Increasing system capacity would require larger generators, heavier wiring, and modifications to the electrical buses to handle the loads. This may not even be an option on some airplanes because of engine limitations. Needless to say these changes would be expensive and time consuming.

Increased capacity power-generating systems will increase unscheduled maintenance requirements. This additional unscheduled maintenance figure has not been quantified, either.

*Airplane Pressurization System*

As previously discussed in the Scheduled Maintenance section, extra labor-hours have been added to the scheduled maintenance checks to perform a fuselage pressure decay check and accomplish repairs. Most operators' experience has shown that airplanes currently in service periodically require this pressure decay check to maintain leakage limits prescribed in airplane maintenance manuals.

Because OBIGGS takes air from the cabin, operators will have to reduce the allowable cabin air leakage rate to compensate for the demand and maintain a safety margin.

Should a leak occur during operation it may not allow continued operation of OBIGGS, which uses some cabin air pressure. Instead of allowing the airplane to continue in service until the next scheduled pressure decay check, immediate rectification will be required.

We have not quantified these extra unscheduled maintenance costs.

*Bleed Air System*

Bleed air also is used by OBIGGS. Where this system interfaces with OBIGGS, use and associated scheduled and unscheduled maintenance will be increased. Again, we have not quantified this increase in unscheduled maintenance.

*Spare Parts Holding*

The amount of spare components required to be held by an operator to ensure a reliable system varies according to system reliability, number of airplanes operated, and the type of operation, such as ETOPS. It was not possible to make a detailed study of the costs for all systems and airplane categories, but from the figures already calculated it was possible to see that a pool of spares of more than \$900,000 would be required to operate one airplane with a membrane system. This figure is a conservative estimate and does not take into account the storage, transportation, administration, or capital investment costs or any lease fees.

**8.5.4 Flight Operations**

OBIGGS provides full-time inerting protection in normal operations including descent, landing, and postlanding incidents that might present a tank ignition hazard. The system should be designed to be fully automatic and to be automatically shed in case of engine power, electrical, bleed source, or cabin pressure failures. It is assumed that it will be monitored by the flight management systems and annunciation of failure modes will be provided to the flight crew for recording in the maintenance log. Little if any cockpit instrumentation should be provided because inerting is considered a safety enhancement with MEL provisions and the crew is not expected to troubleshoot it to reactivate the system or discontinue routing operations. Some basic descriptions of the inerting concept and the OBIGGS equipment, location, power sources, heat exchangers, and so forth need to be provided as additional training but should be limited to need to know. "If the crew cannot affect it, don't train for it." Both flight crew and dispatch personnel will be trained as far as MEL operating rules, and the airplane may need to be rerouted to a suitable repair facility. OBIGGS will draw power, bleed air, and incur drag from intercooler openings, and the increased fuel burn costs will result in reduced range and endurance. This could affect some long-haul and international routes.

### 8.5.5 Ground Operations

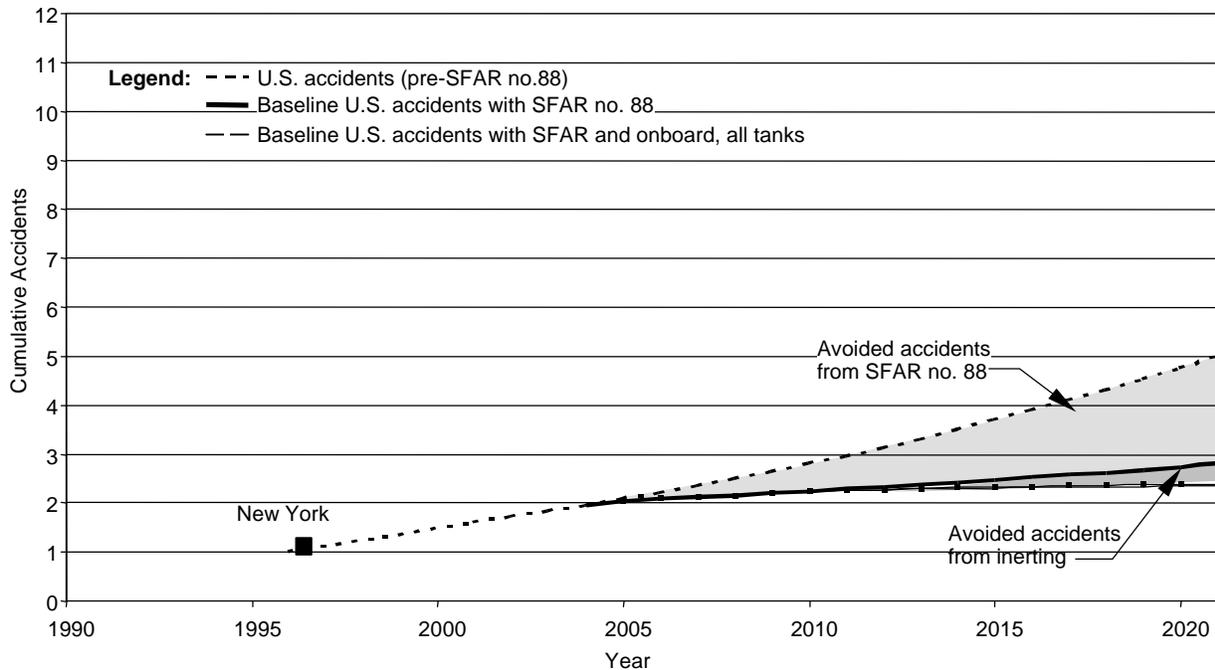
OBIGGS ideally would solve many of these ground-base concerns and issues after installation. The FTIHWG believes that a continual monitoring system should be installed on the flight deck to ensure that proper inerting takes place during the more critical phases of the airplane’s route structure, such as taxi and takeoff. Any anomalies should immediately be put on a master caution light to alert the flight crew. The flight crew would then have the ability to shut the system down, if needed. Like the APU fire warning system on many commercial airplanes, an aural warning system should be considered while the airplane is on the ground in the event this system malfunctions without a flight crew member on board.

A valid concern was raised with the possibility of nitrogen entering the cabin during continuous inerting with this system. Considerations should be given to redundancy with the material used to enhance safety for passengers and crew. Examples include using double-walled pipe for plumbing purposes and installing nitrogen sensors in the cabin.

Maintenance training procedures fall within the above-mentioned training recommendations, and would merely be tailored again to the system desired for installation.

### 8.6 SAFETY ASSESSMENT

Figures 8-13 and 8-14 show the impact that OBIGGS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes that the system would be fully implemented by the year 2015 (see sec. 11.0 for implementation assumptions). At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 41 years with SFAR and inerting in heated CWTs, and more than 51 years for SFAR and inerting in all tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.



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Figure 8-13. U.S. Cumulative Accidents With OBIGGS

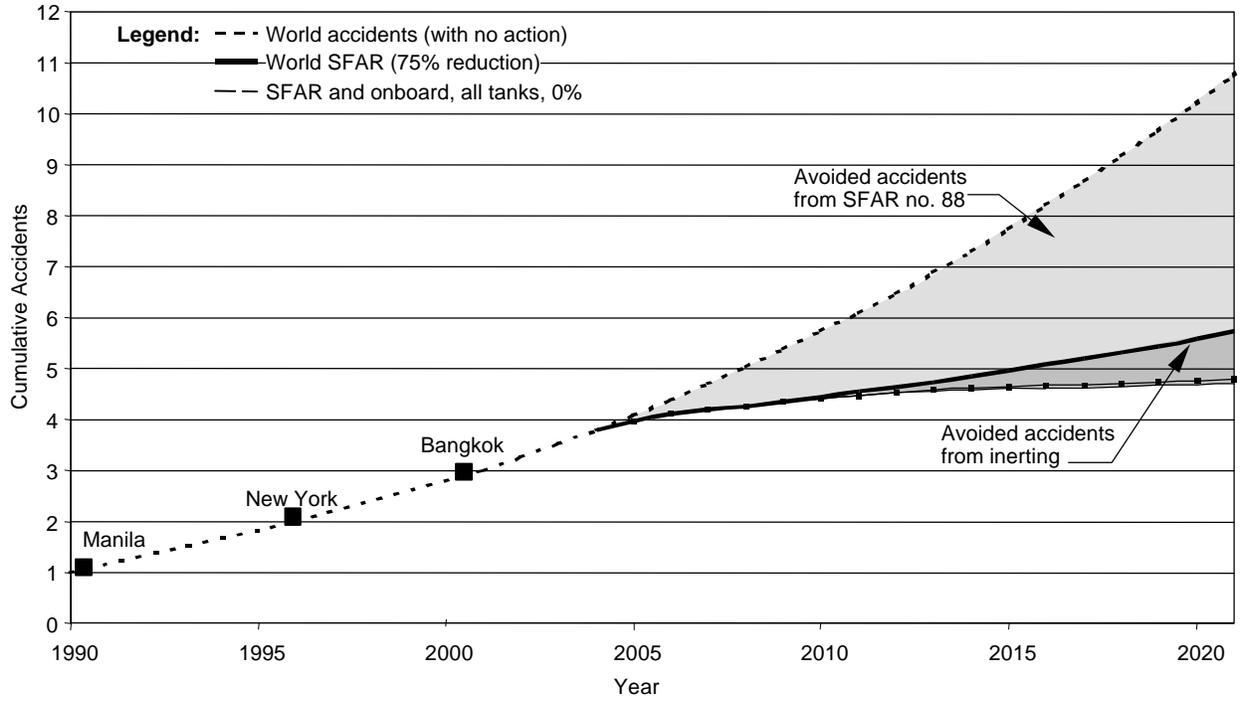


Figure 8-14. Worldwide Cumulative Accidents With OBIGGS

### 8.7 COST-BENEFIT ANALYSIS

Figures 8-15 through 8-21 graphically represent the cost-benefit analyses of the scenario combination examined for the OBIGGS concept.

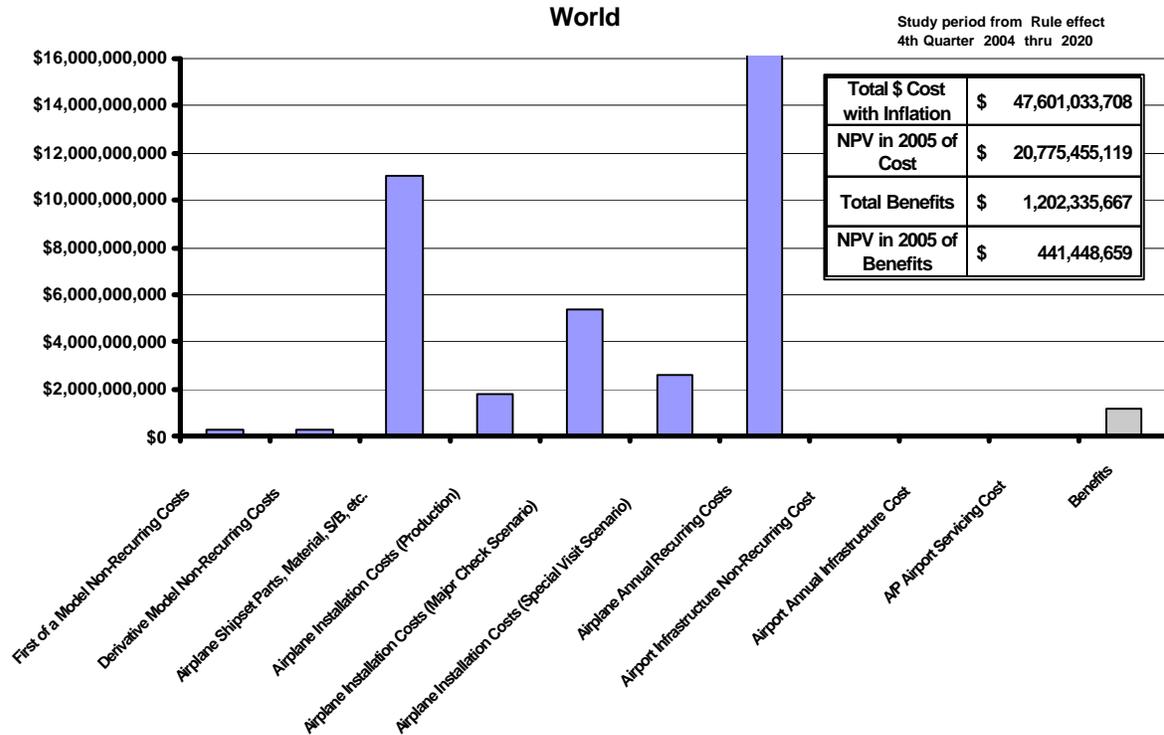


Figure 8-15. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

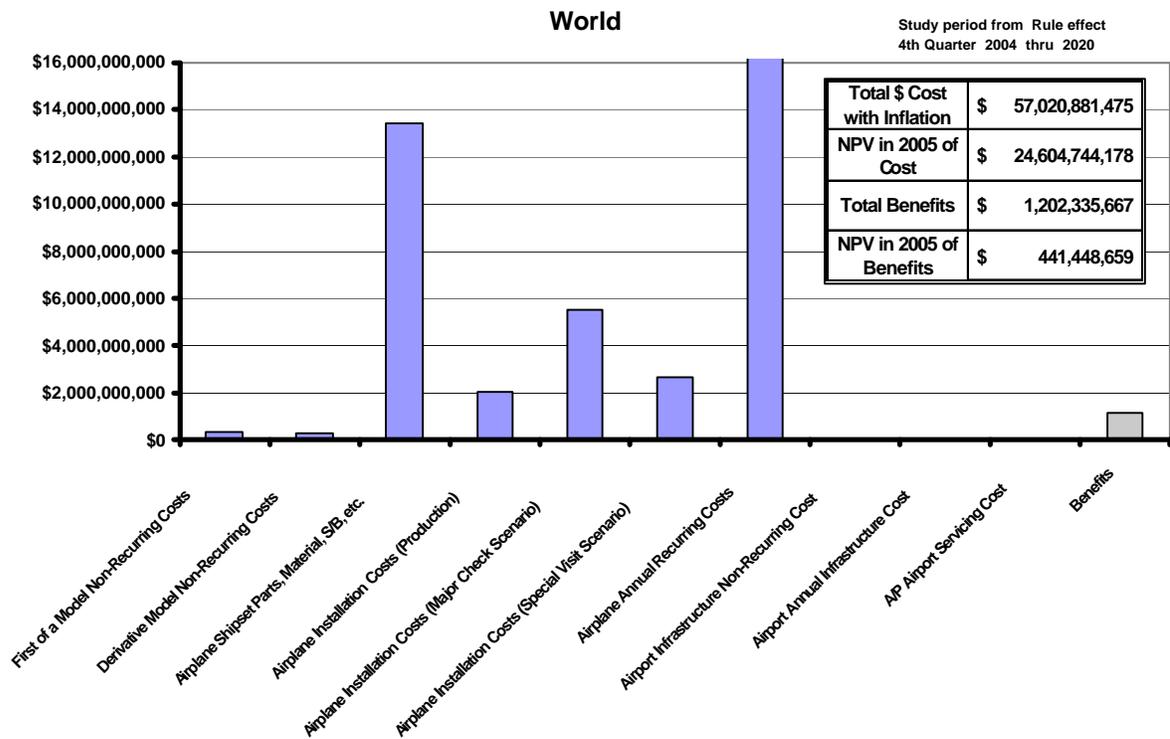


Figure 8-16. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

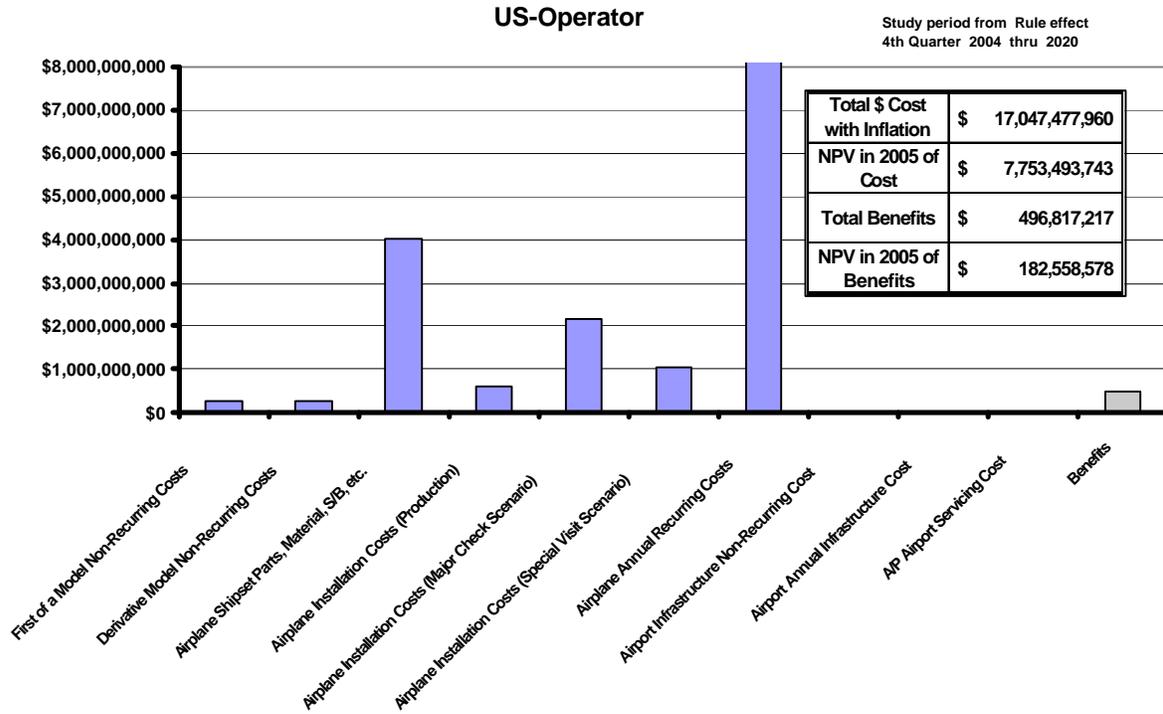


Figure 8-17. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

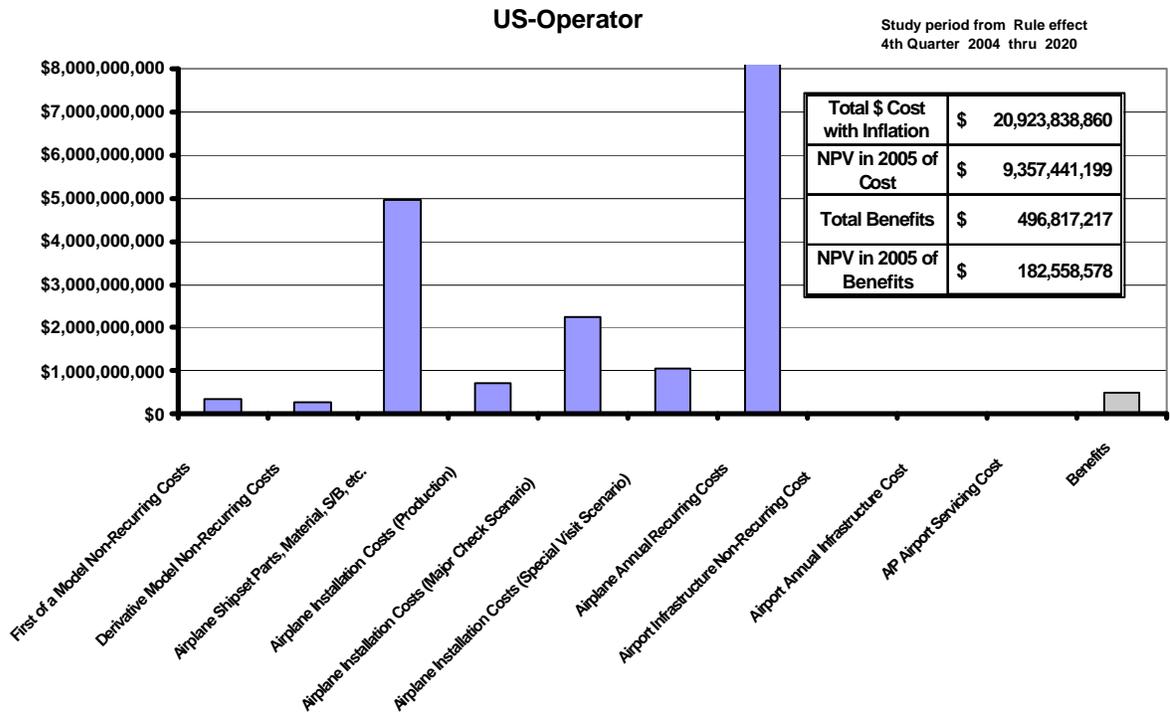


Figure 8-18. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

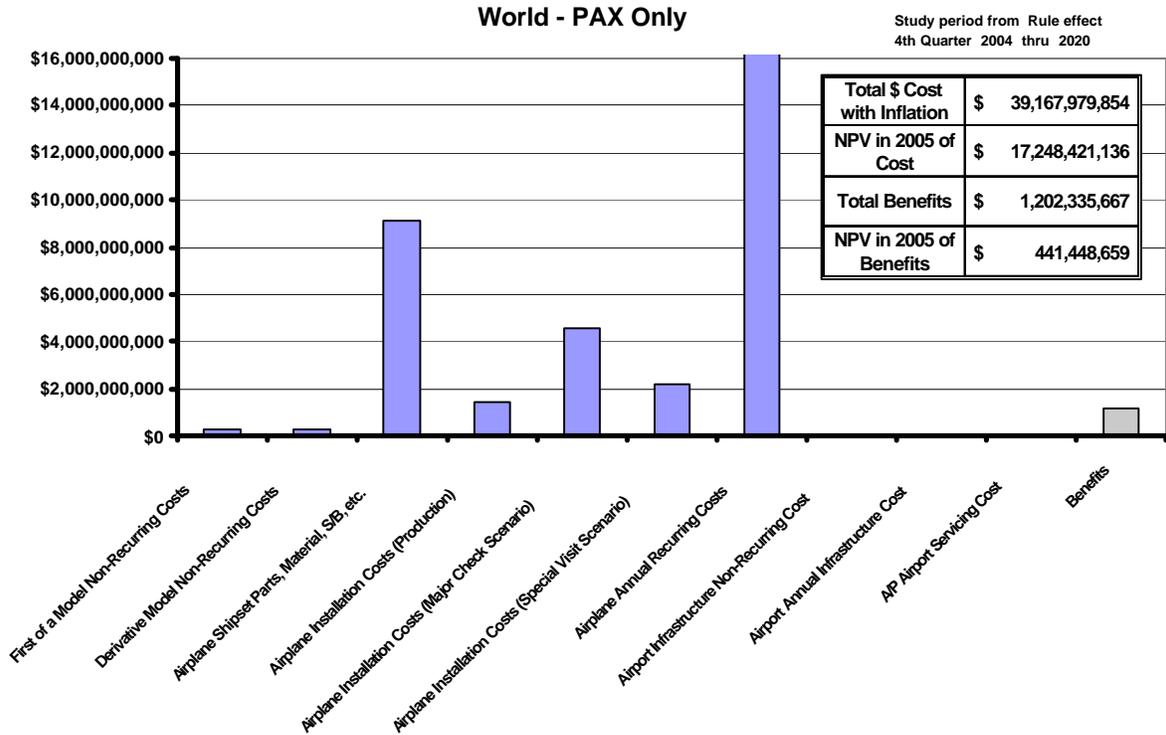


Figure 8-19. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

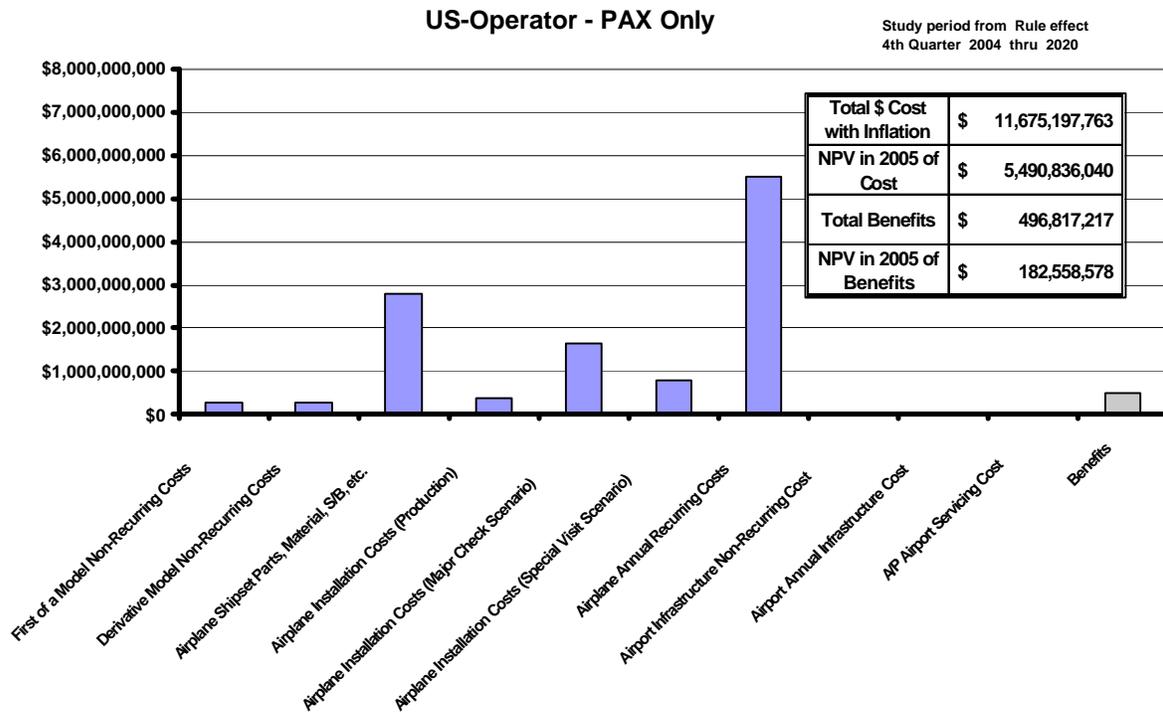


Figure 8-20. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

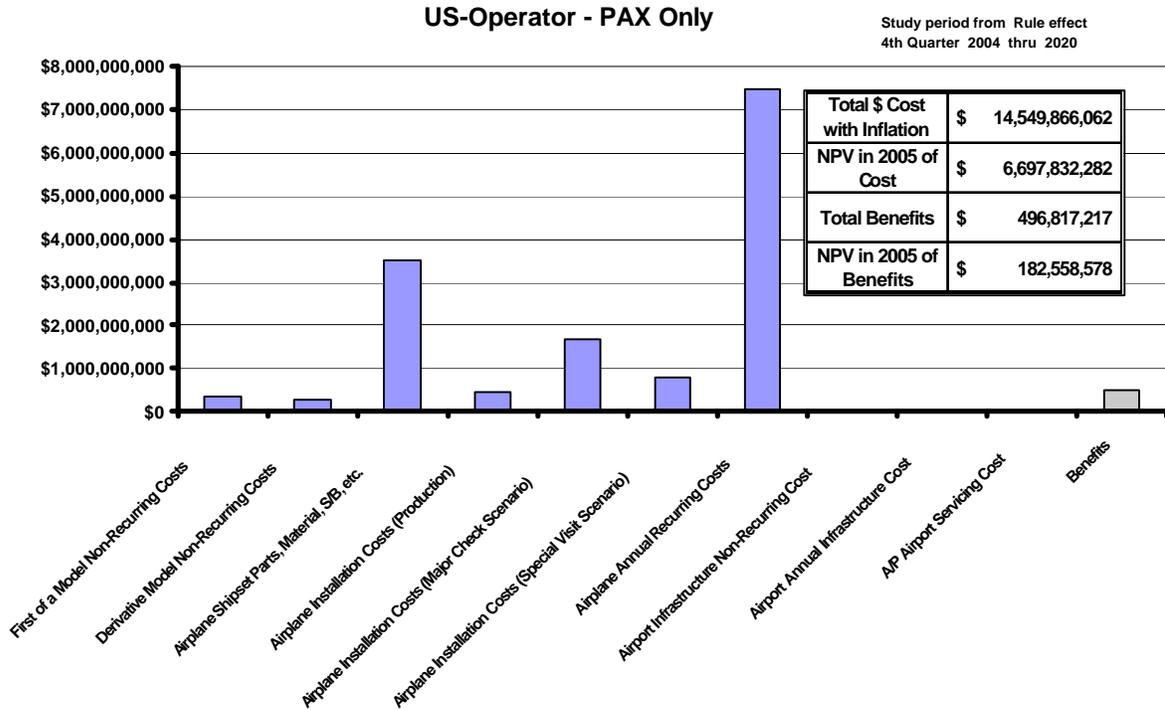


Figure 8-21. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

## 8.8 PROS AND CONS

### Pros

- a. OBIGGS reduces total flammability exposure almost to zero, except for those times when the airplane is not powered or the maneuvers exceed typical maneuvering.
- b. OBIGGS potentially reduces corrosion and condensation in the fuel tanks, depending on how the operator uses the system.

### Cons

- a. OBIGGS is the most costly option of those examined and weighs approximately the same as the OBGIS.
- b. The cost of components (only a part of the total system cost) far exceeds the potential benefit.
- c. Additional cost is incurred because of the weight of the system—which causes a fuel penalty—and airplane drag is increased, because of inlet and exhaust ports for the system.
- d. The airplane’s center of gravity may be adversely affected because of the system’s location in some airplane models, which would also incur a fuel penalty.
- e. Compressor and fan noise may have to be damped, depending on local noise standards.

### Indeterminate

#### Pollution:

- a. Normally, some fuel vapor exits the tanks during refueling and some vapor will be pushed out when adding nitrogen to the tank.

- b. Fuel vent systems will need to be isolated to prevent crosswinds from diluting the nitrogen, which would be an improvement over present-day conditions.
- c. No attempt was made to quantify this, because of the complexity of the problem for each airplane model at each airport.

### 8.9 MAJOR ISSUES AND RESOLUTIONS

The technical limitations for retrofit of the OBIGGS are its size, contamination issues with the ASMs, and a potential hazard with static electricity. A description of the improvements needed for the other limitations follows.

#### 8.9.1 System Size

Some OBIGGS issues relate to the large system size, as shown in figure 8-22. For the large transport, the system weighs between 1,120 and 1,600 lb (depending on the separator technology) and consumes between 55 and 160 kVA of electrical power during descent. These power levels are a significant fraction of the large transport electrical capacity (240 kVA). The team was unable to obtain estimates of the electrical power available by flight phase to determine whether these power requirements could be met.

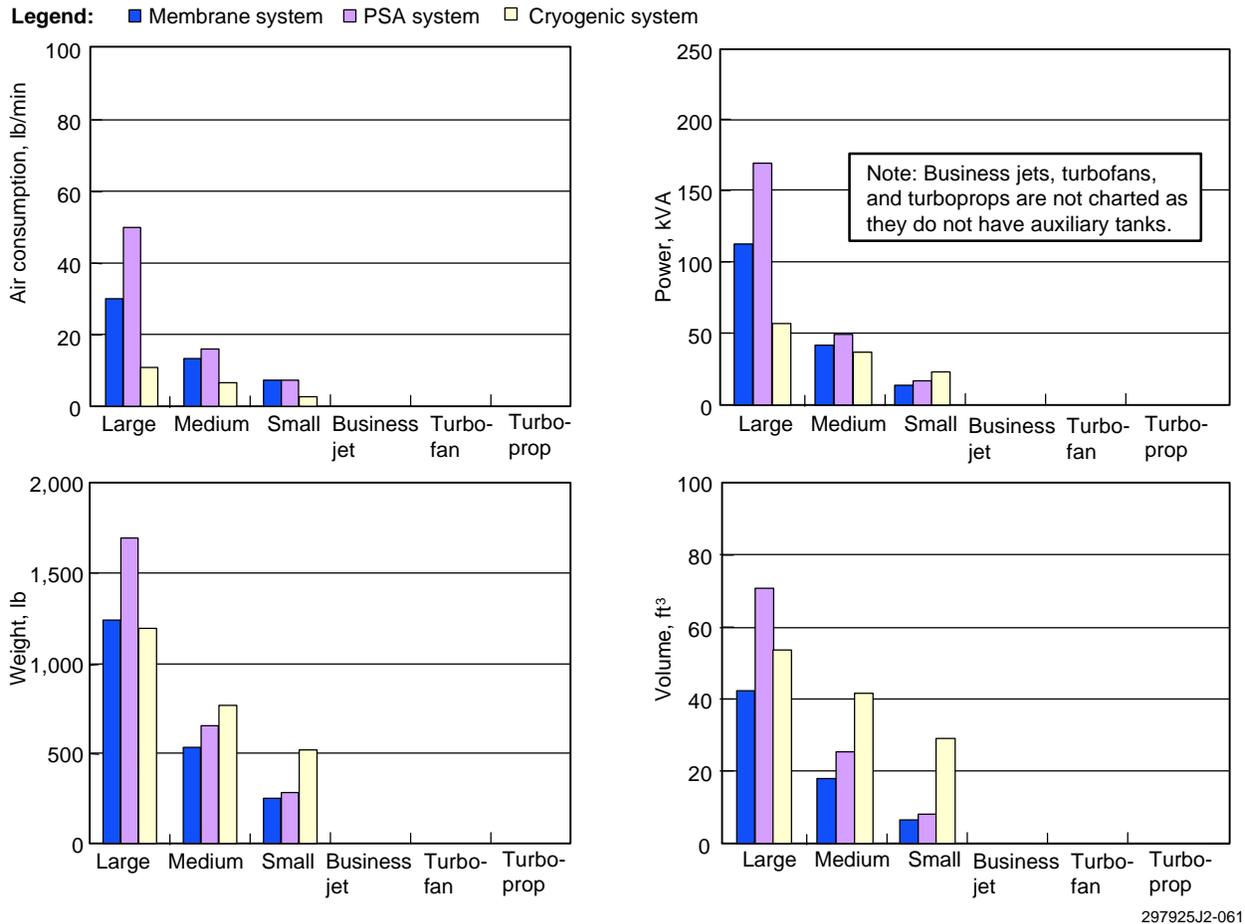


Figure 8-22. OBIGGS System Size Issues

No matter what size the airplane, the system requires significant electrical power to run, may not fit in all airplanes because of its size, and is heavy.

Another issue is the compressor weight, which for the large and medium transports is too much for an average mechanic to lift. This can be resolved by changing the design to incorporate multiple compressors in parallel, making each compressor smaller but increasing overall volume.

### **8.9.2 Air Separator Modules**

ASMs are susceptible to water contamination, which reduces performance. A water separator has been included in the design concept to avoid this problem.

Some permeable membrane modules also are susceptible to hydrocarbon contamination from the fuel and oil vapor in engine bleed air. A hydrocarbon element may be required to be added to the coalescing filter included in the design concept.

In addition, permeable membranes have no service history onboard airplanes to prove their durability. They have been used in ground applications, however, where they have demonstrated a very long life.

Like permeable membranes, the cryogenic distillation system has no flight history. However, cryogenic distillation technology has been used for years on naval ships with high reliability.

### **8.9.3 Static Electricity**

The rapid flow of dry gas in a distribution manifold inside the fuel tank can generate static electricity and cause sparks. This can be mitigated by using large-diameter manifolds to keep the gas velocity low and by bonding the manifold to structure (electrical ground).

## **8.10 CONCLUSIONS**

OBIGGS reduces flammability exposure to nearly zero. But the concept suffers from keeping all fuel tanks inert during descent and from large ullage volumes required for short missions. The protection offered is the best a nonredundant system can offer, but at the highest price. Therefore, the FTIHWG does not recommend this concept.



## **9.0 HYBRID INERT GAS GENERATING SYSTEM**

The team has developed two hybrid concepts, each concentrating on reducing the major constraint to the size of the OBGIS and the OBIGGS. The hybrid OBGIS assumes that the baseline OBGIS would operate during taxi-in to the gate and while at the gate. The hybrid OBIGGS assumes the baseline OBIGGS is sized for all operations except descent. Both these systems offer reductions in flammability exposure similar or superior to that of the GBIS.

The average taxi-in time was determined to be 5 min. This adds 25% more time to inert for the small transport (which has the shortest gate time at 20 min) and 8% more time to the large transport (gate time of 60 min). However, this additional gate time does not reduce the weight, volume, power required, or cost of the OBGIS hybrid significantly from that of the baseline OBGIS.

The hybrid OBIGGS managed a more substantial improvement, reducing the weight, volume, power required, and cost by 25% to 70% compared with that of full OBIGGS. Ultimately, the overall cost of the system is still many times that of any potential benefit.

### **9.1 SYSTEM REQUIREMENTS**

The Tasking Statement requires that the hybrid system be operated during some phases of flight as an option to installing equipment that might otherwise be necessary to keep the fuel tank inert during those phases of flight (e.g., vent system valves), and as a cost tradeoff that could result in reduced equipment size.

The Tasking Statement also requires that the team describe secondary effects of the system and analyze and report extracted engine power, engine bleed air supply, maintenance impacts, airplane operational performance detriments, and dispatch reliability.

The team must also provide information and guidance for the analysis and testing that will be conducted to certify the system.

If the FTIHWG cannot recommend a system, then all technical limitations must be identified and an estimate of the type of concept improvement that would be required to make it practical in the future must be provided.

### **9.2 CONCEPT DESCRIPTION**

The hybrid OBGIS is schematically identical to the full OBGIS. It would be slightly smaller than the full OBGIS and would have to be certified not to interfere with other airplane equipment because it would be running during taxi-in.

The hybrid OBIGGS is simpler than full OBIGGS because it provides a constant flow of NEA to the fuel tanks, whereas full OBIGGS has a variable flow scheme.

### **9.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES**

The OBGIS hybrid is applicable to the same in-service and production airplanes as the full OBGIS.

The hybrid OBIGGS is applicable to all the airplanes in the study category. There is insufficient information to determine whether the airplanes can meet the electrical demand of the system. Preliminary estimates by the Airplane Operation and Maintenance Task Team indicate that this system may exceed available electrical power.

An inerting system can be designed into future airplanes, provided the system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available.

#### **9.4 AIRPORT RESOURCES REQUIRED**

Powering the hybrid OBGIS requires electrical power from the airplane APU. Some airports are sensitive to noise and do not permit APU operation, requiring a ground power source to supply the system.

Hybrid OBIGGS is a self-contained system that does not normally require any airport resources. Some operators, however, may prefer using ground electrical power to operate the system after tank maintenance and inert the fuel tanks before the next flight.

#### **9.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT**

From an airplane operations and maintenance perspective, there is very little difference between the full OBGIS and OBIGGS and their hybrid systems. The Airplane Operation and Maintenance Task Team looked at the hybrid systems, but when it was determined that these systems were nearly identical from an operational and maintenance perspective, further work was discontinued. The reader may assume that the maintenance, operations, and modifications impact described in the OBGIS and OBIGGS sections also apply to the hybrid systems.

#### **9.6 SAFETY ASSESSMENT**

Figures 9-1 and 9-2 show the impact that the hybrid OBIGGS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes the system will be fully implemented by the year 2015. At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 40 years with SFAR and inerting heated CWTs, and 48 years for SFAR and inerting all tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.

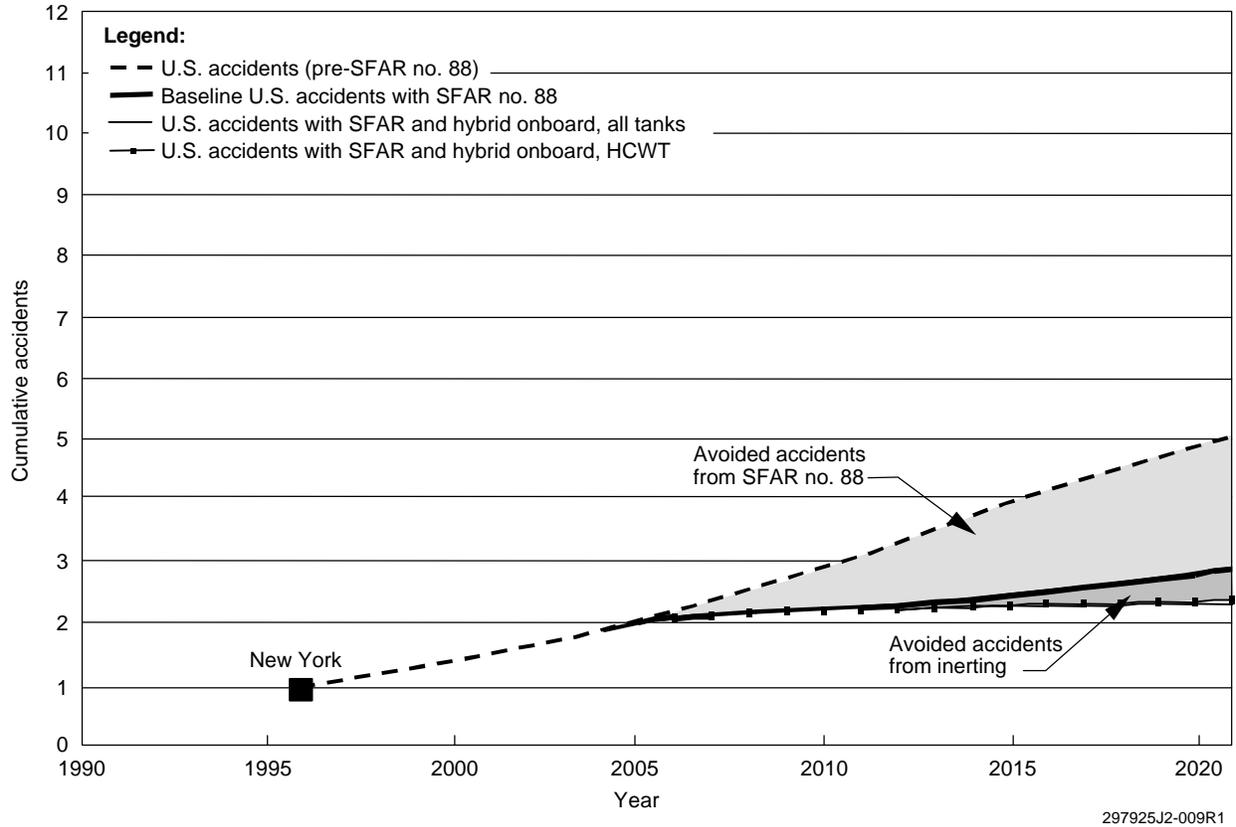


Figure 9-1. U.S. Cumulative Accidents With Hybrid OBIGGS

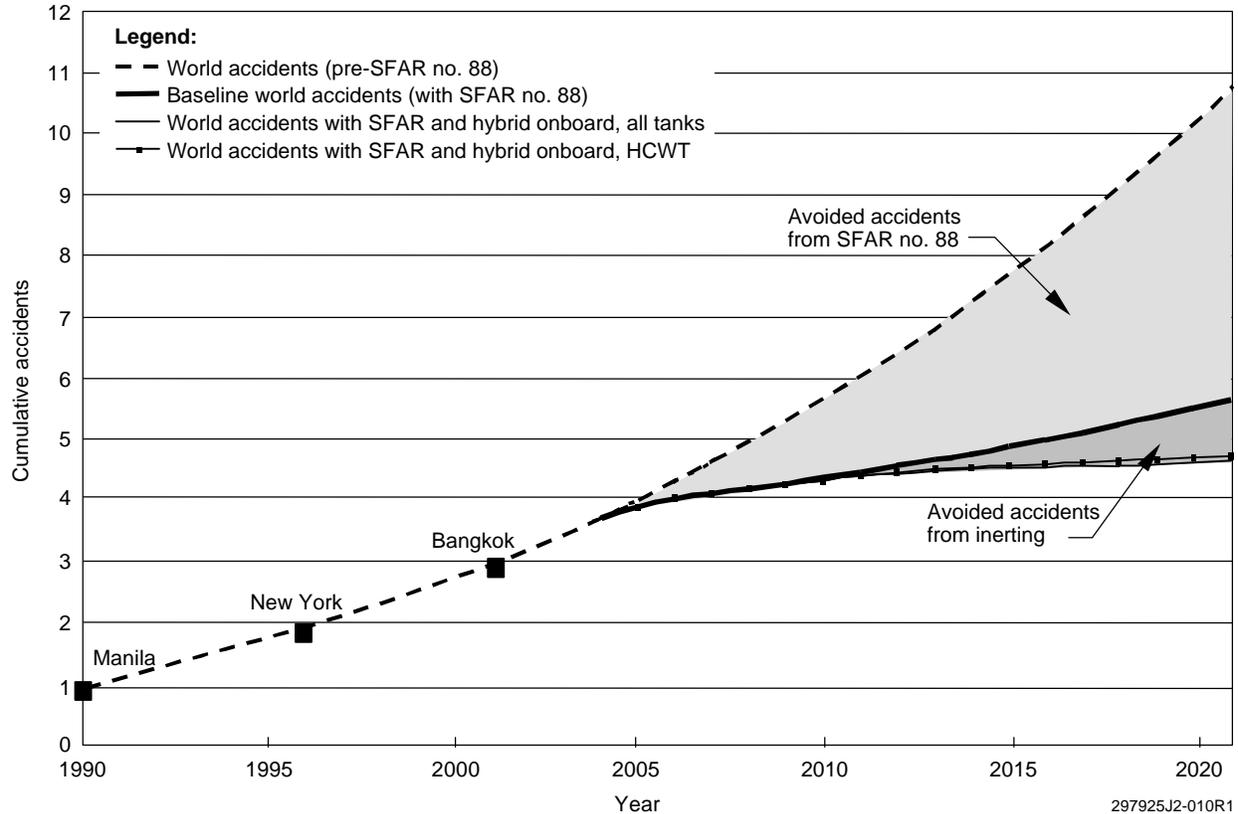


Figure 9-2. Worldwide Cumulative Accidents With Hybrid OBIGGS

Figures 9-3 and 9-4 show the impact that the hybrid OBGIS could have on reducing future accidents in the United States and worldwide, respectively. If the hybrid OBGIS were selected, the forecast assumes this system will be fully implemented by 2015. At that time, the forecast anticipates a time between accidents in the United States of 16 years with the SFAR alone, 31 years with the SFAR and hybrid OBGIS inerting of heated CWTs, and 32 years with the SFAR and hybrid OBGIS inerting of all fuselage tanks.

Corresponding times between accidents for the worldwide fleet would be approximately half those forecast above for the U.S. fleet, or about 8, 15, and 16 years, respectively.

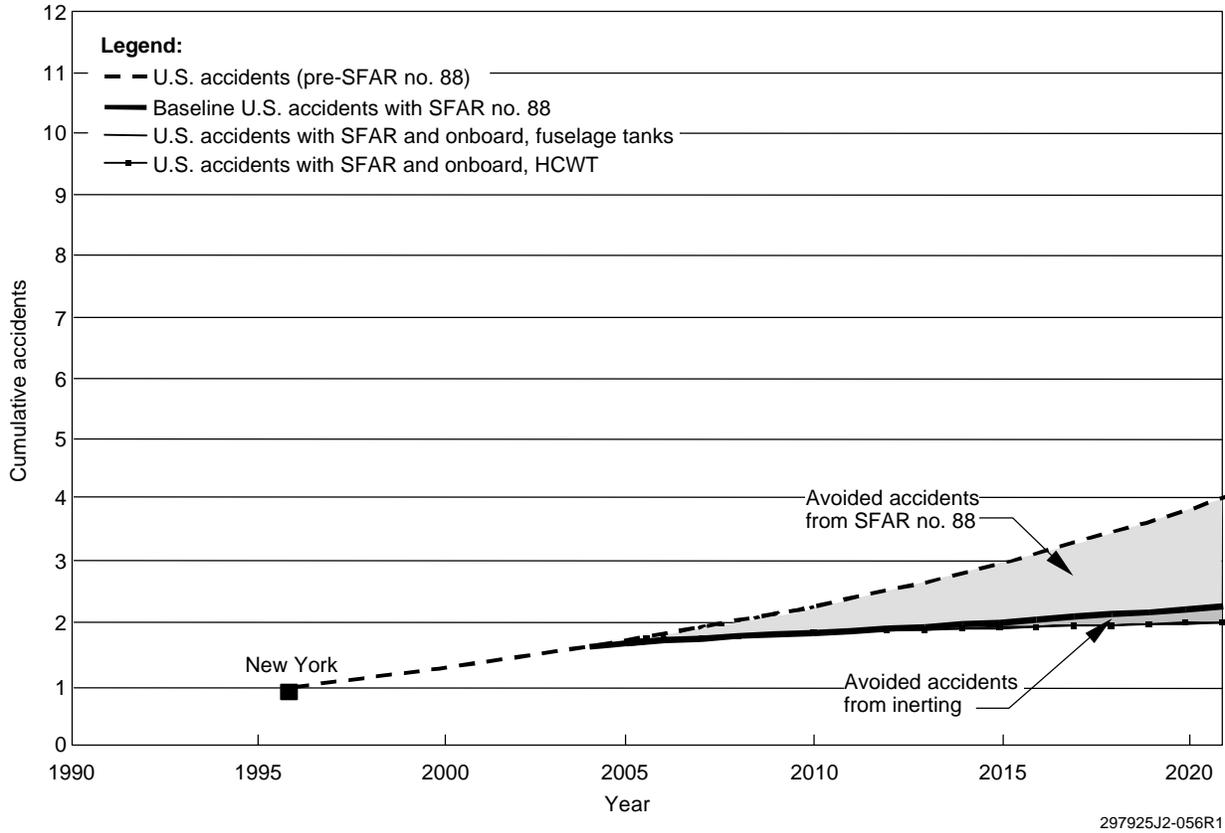


Figure 9-3. U.S. Forecast Cumulative Accidents With Hybrid OBGIS

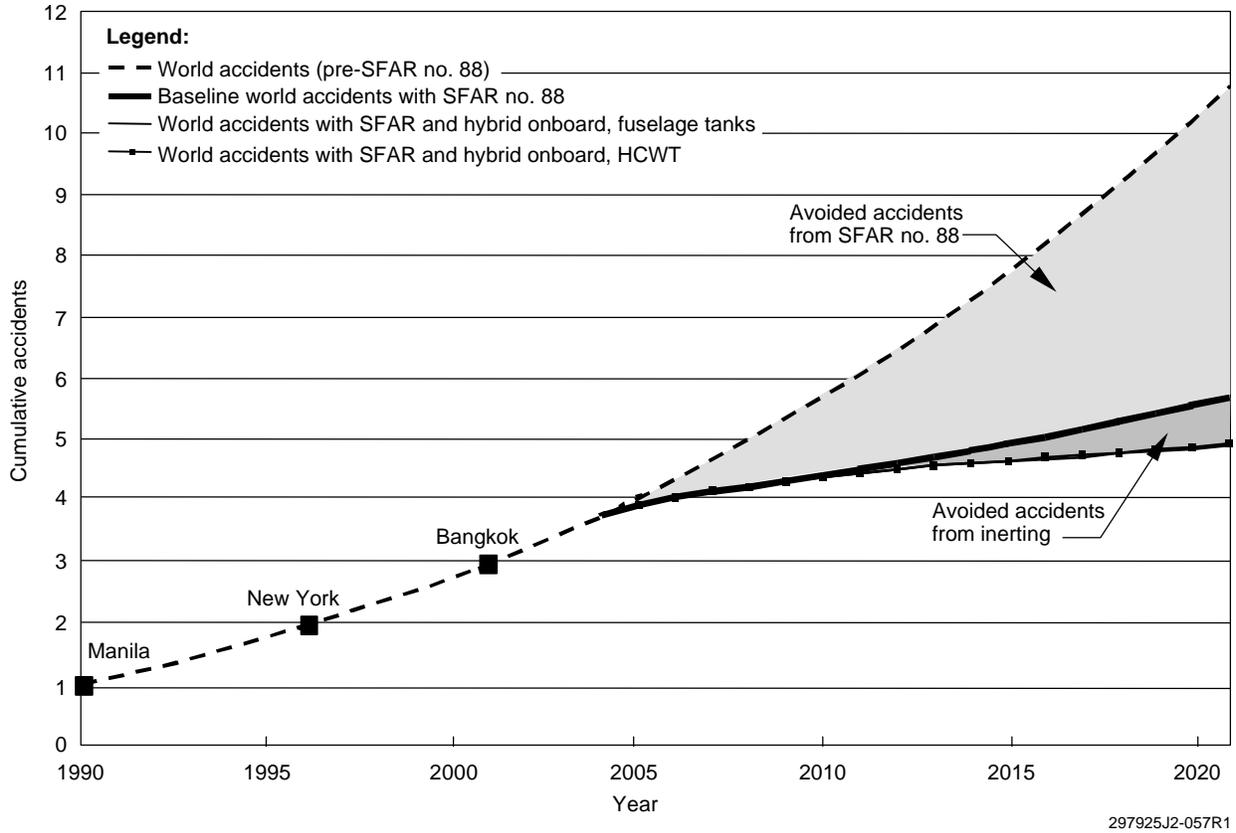


Figure 9-4. World Forecast Cumulative Accidents With Hybrid OBGIS

### 9.7 COST-BENEFIT ANALYSIS

Figures 9-5 through 9-29 graphically represent the cost-benefit analyses of the scenario combination examined for the hybrid inert gas generating system concept.

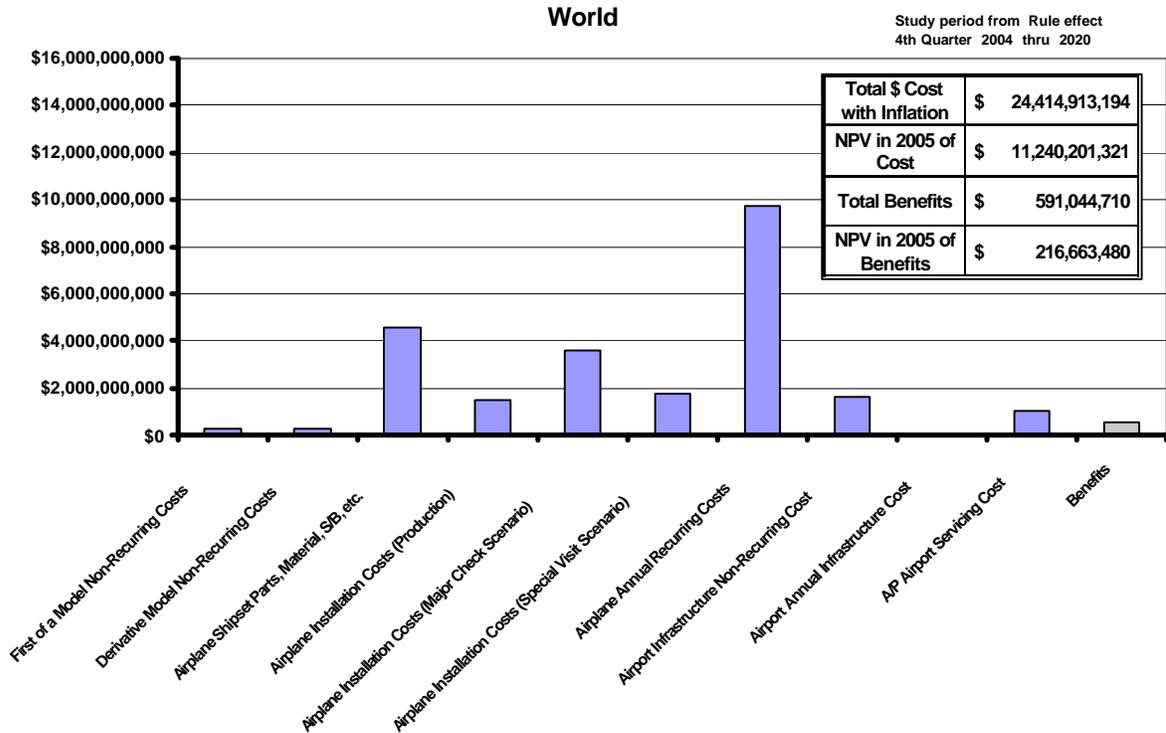


Figure 9-5. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

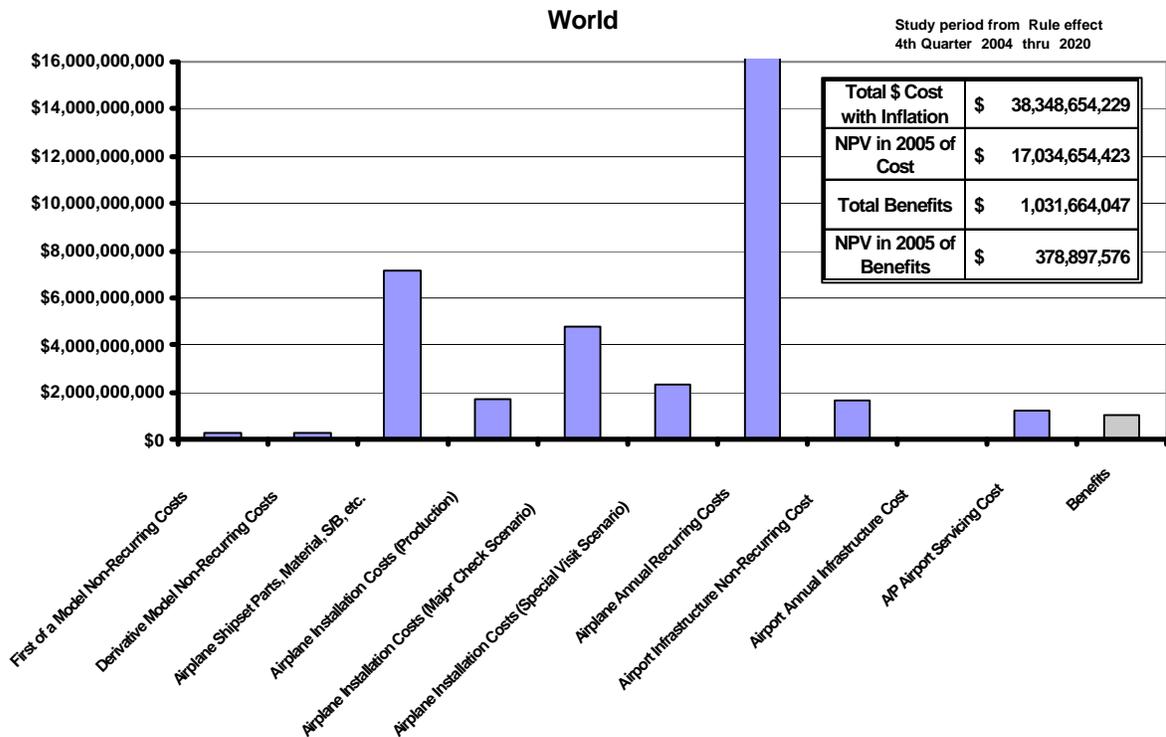


Figure 9-6. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

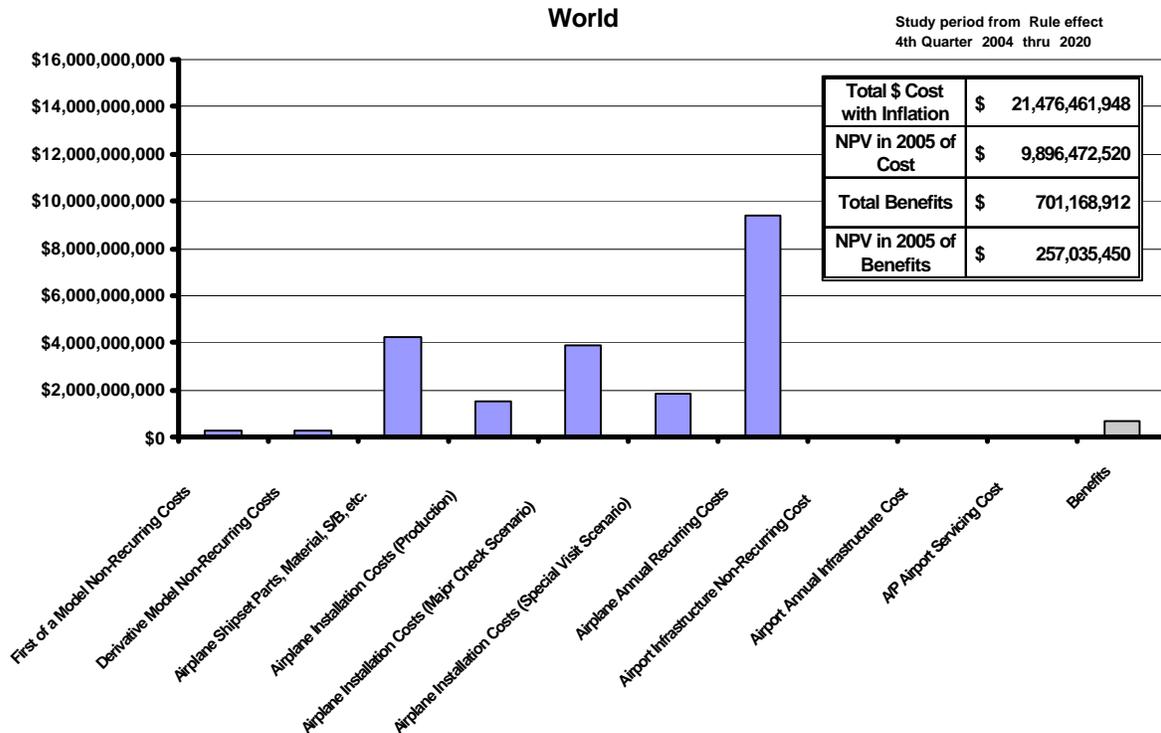


Figure 9-7. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

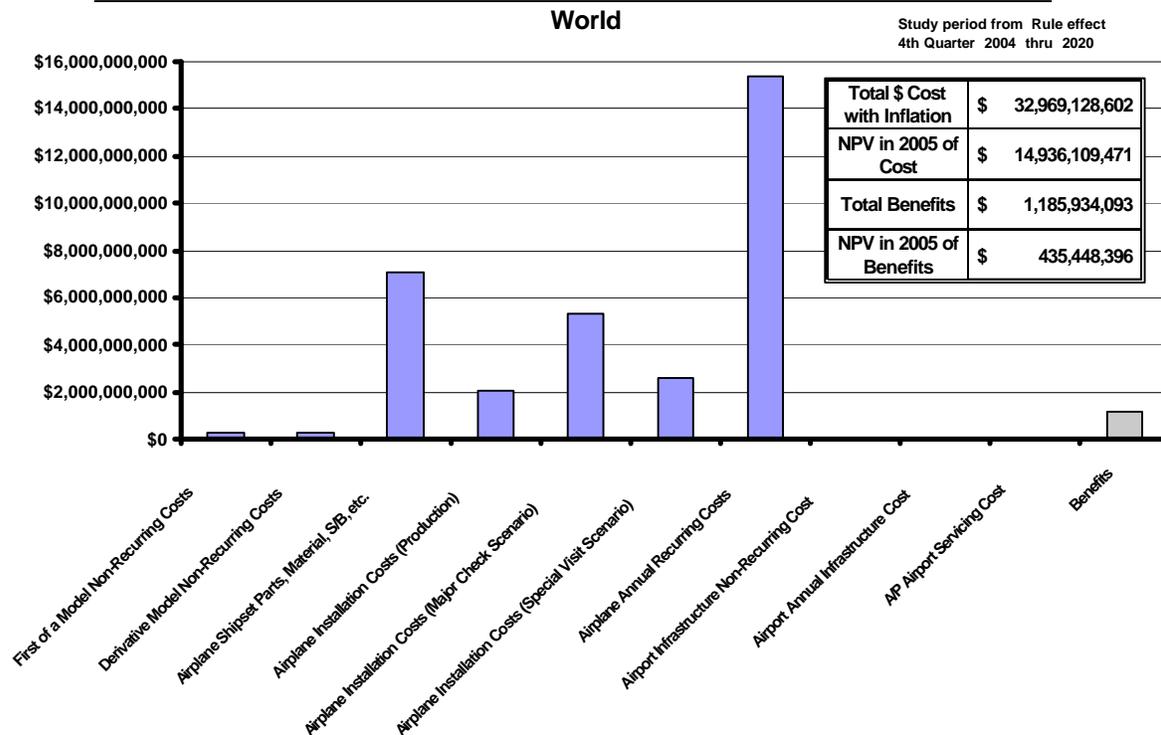


Figure 9-8. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

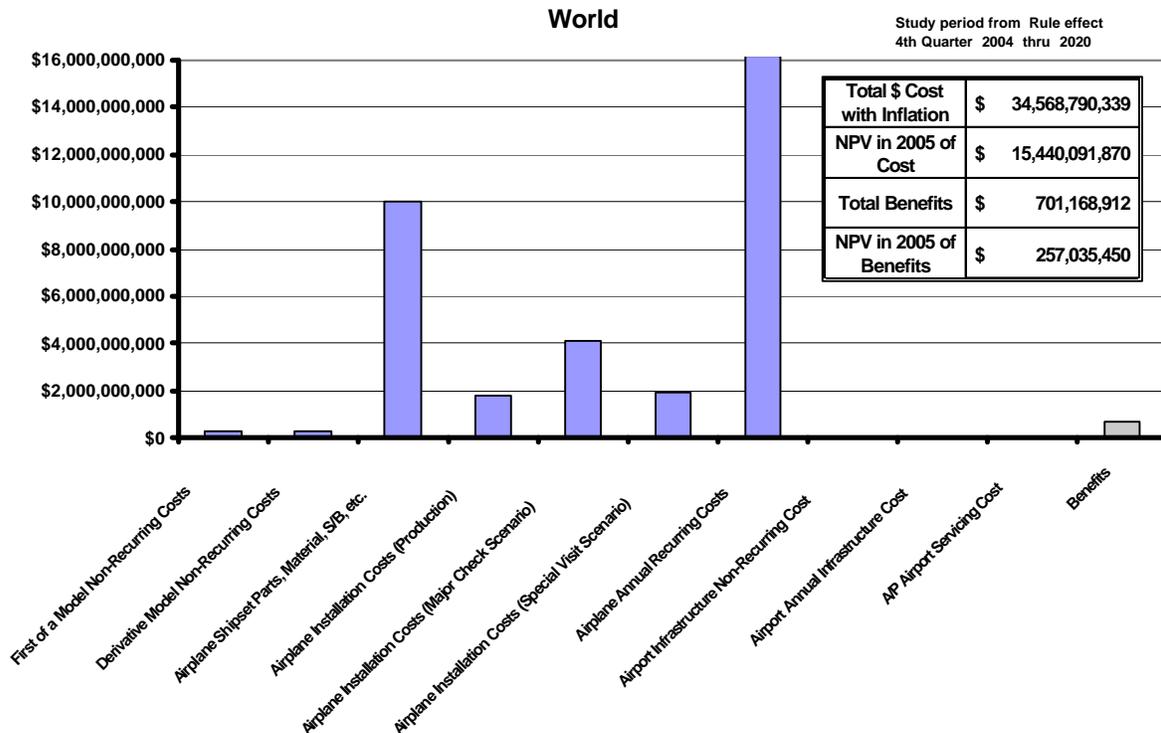


Figure 9-9. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

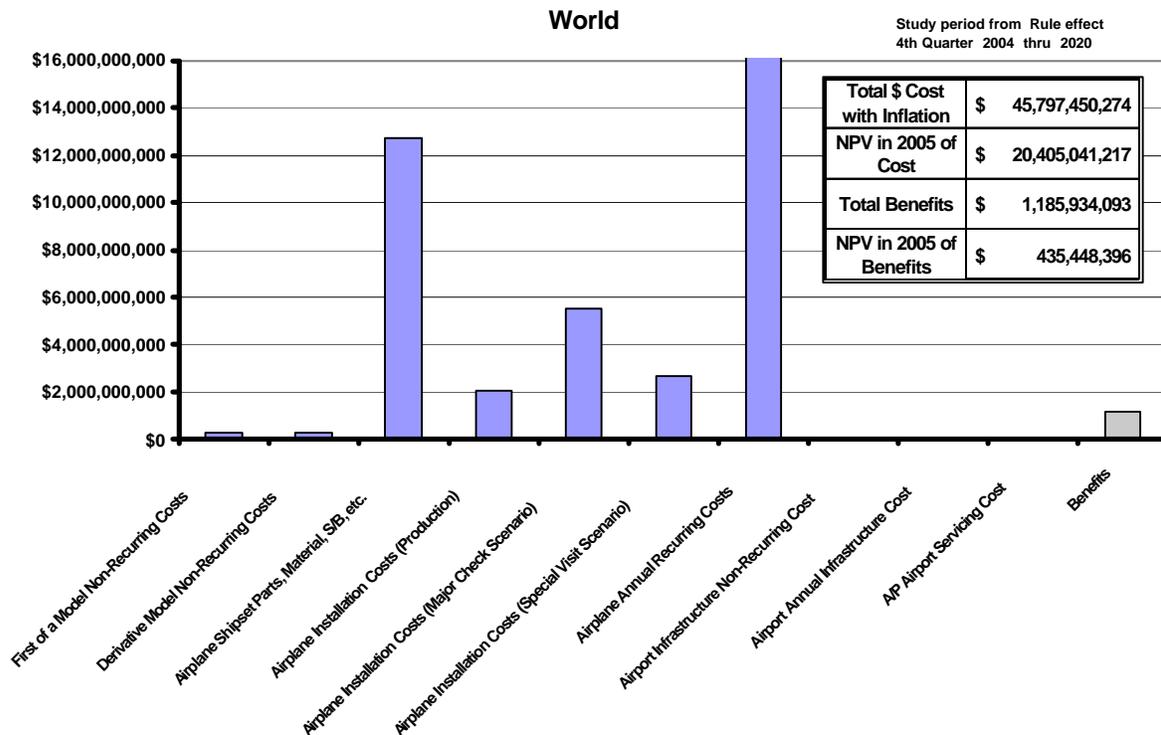


Figure 9-10. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

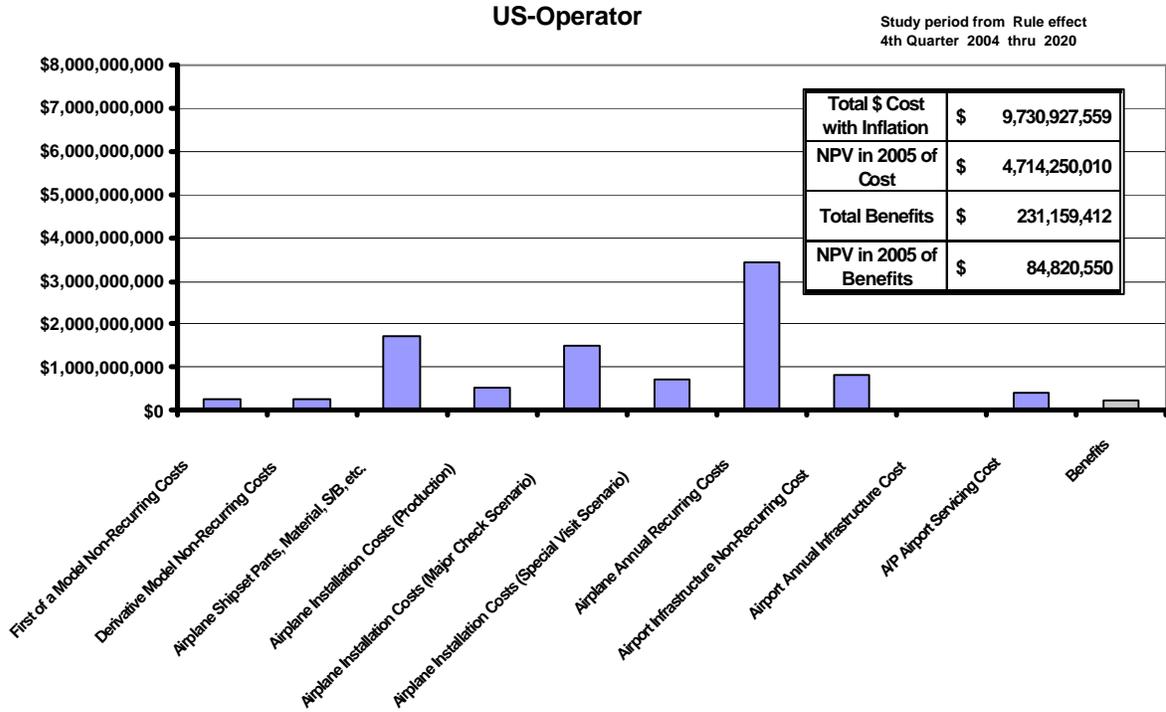


Figure 9-11. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, and Small Transports, PSA/Membrane Systems (U.S.)

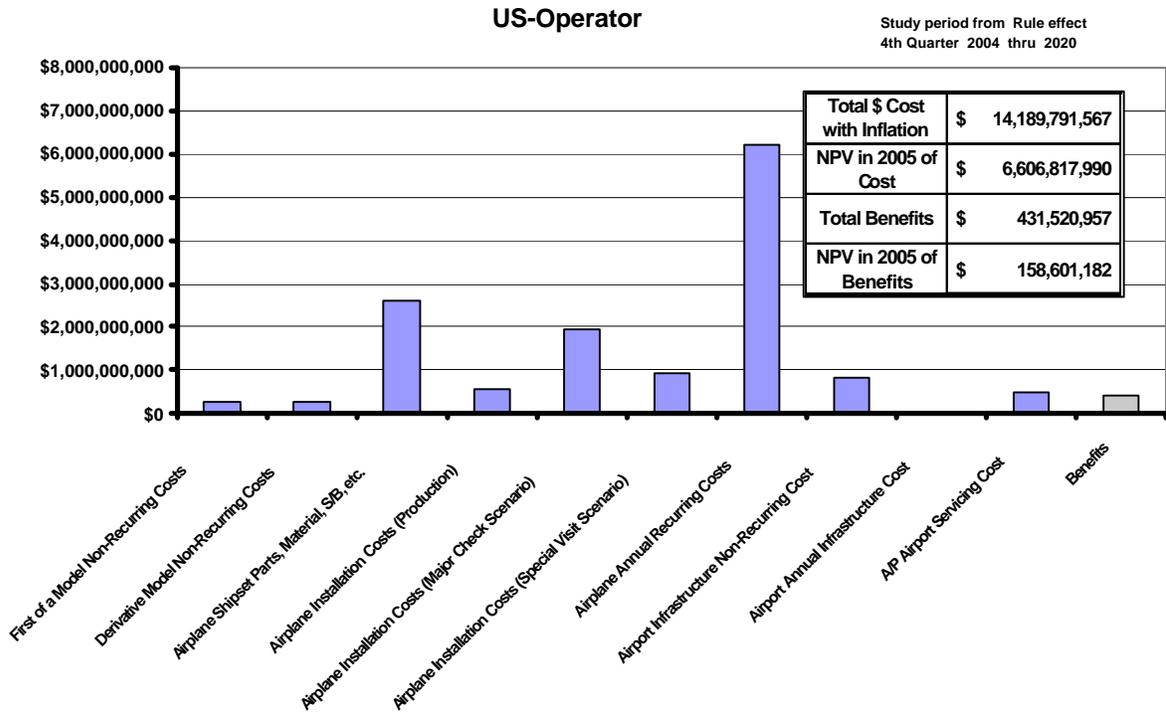


Figure 9-12. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, and Small Transports, PSA/Membrane Systems (U.S.)

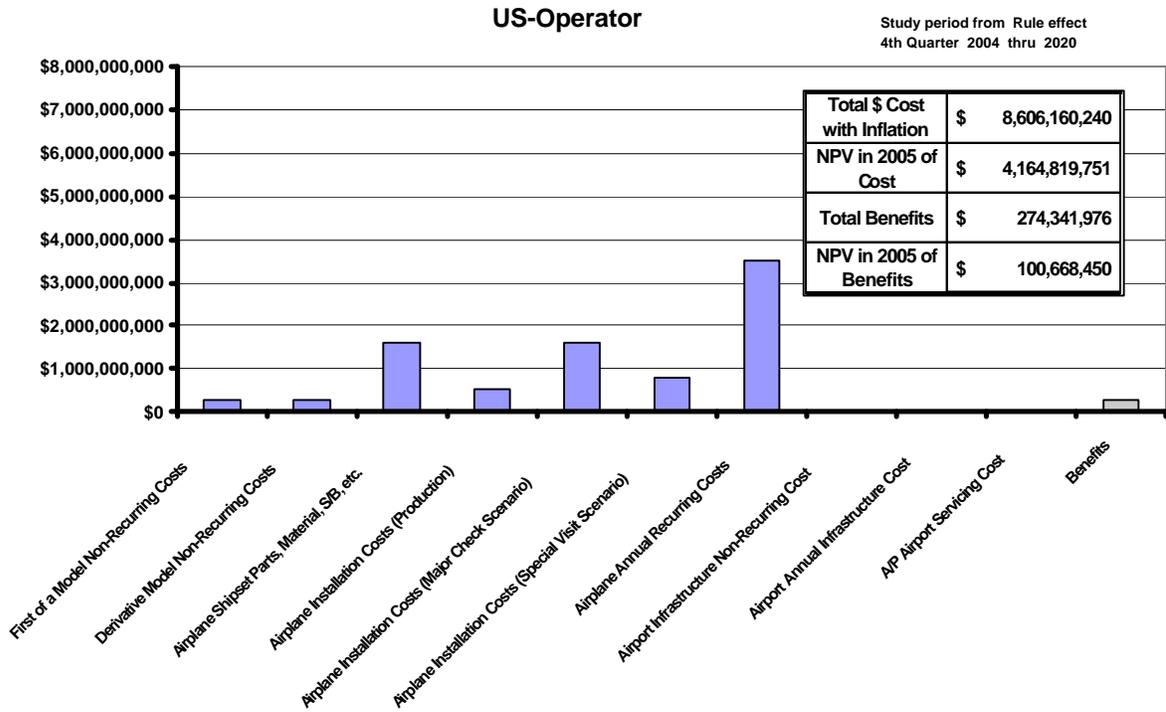


Figure 9-13. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

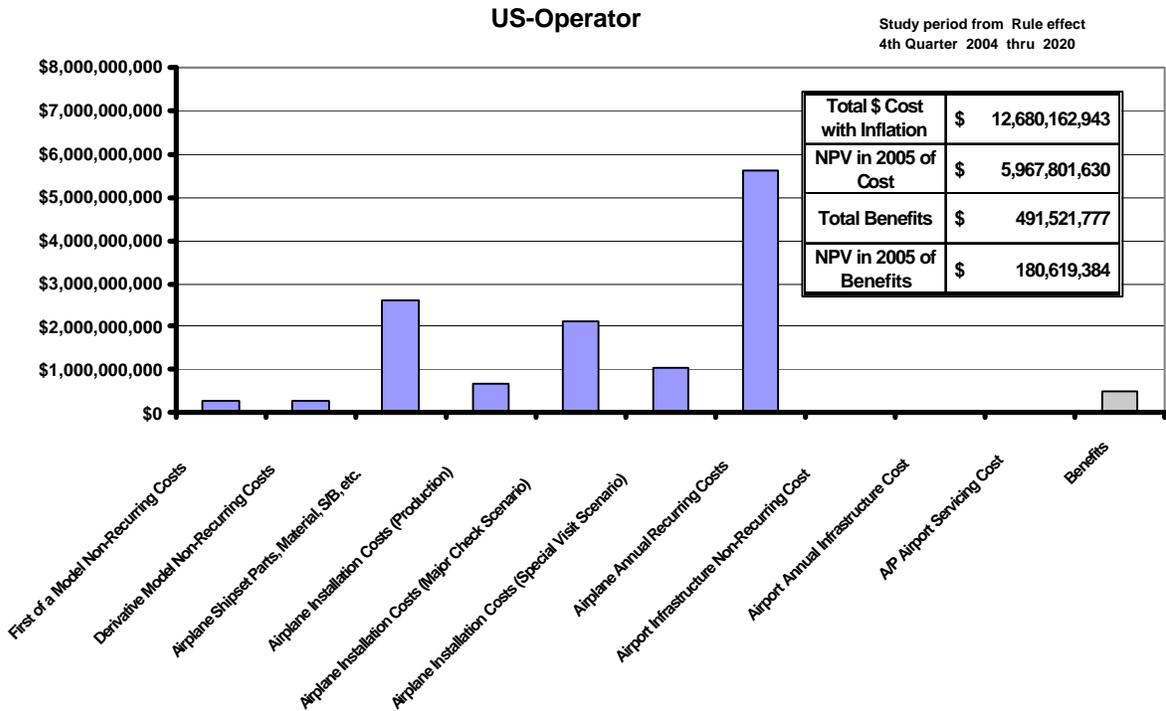


Figure 9-14. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

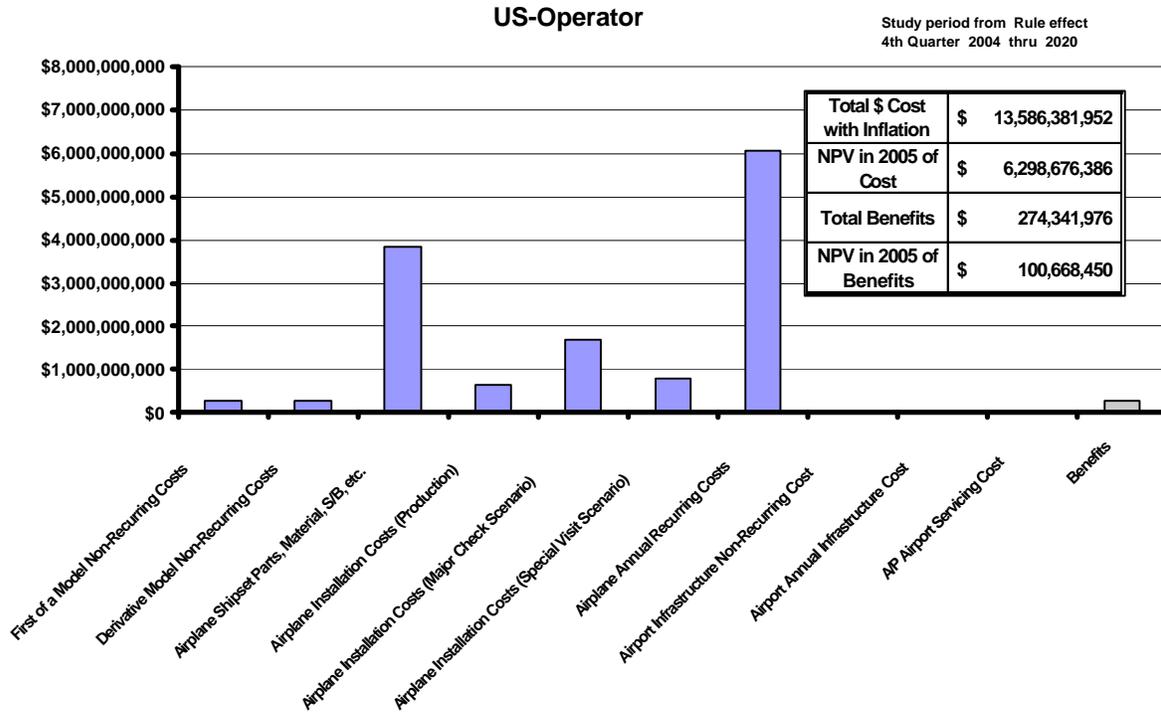


Figure 9-15. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

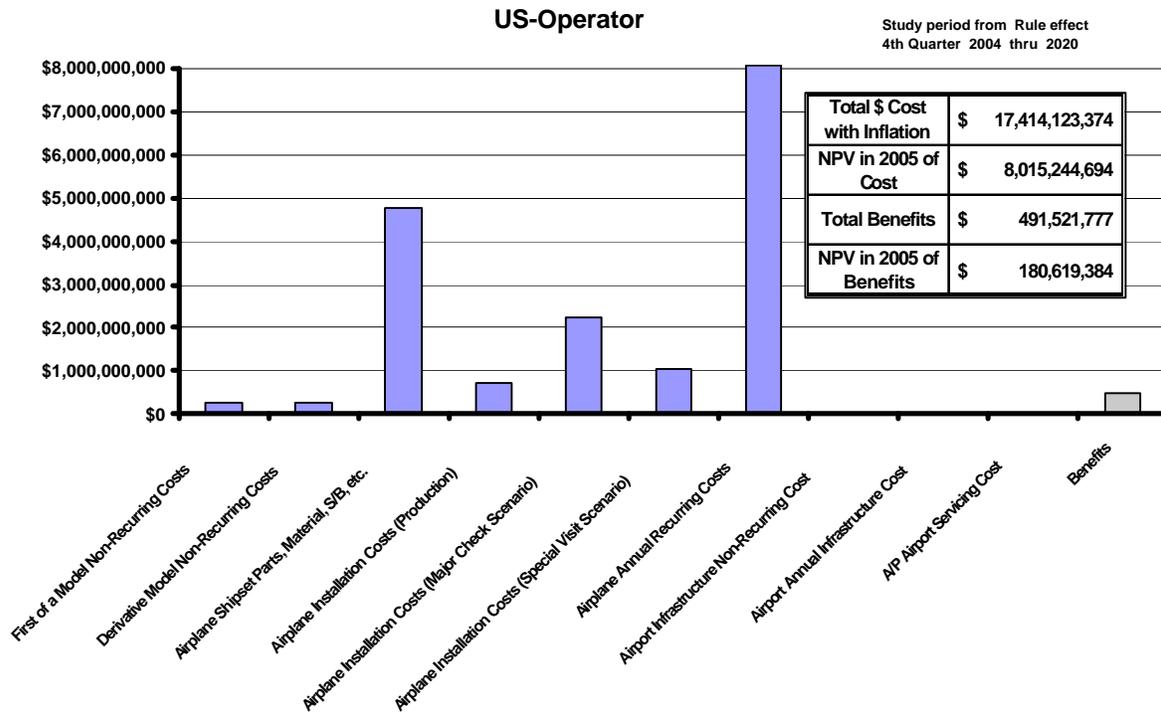


Figure 9-16. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

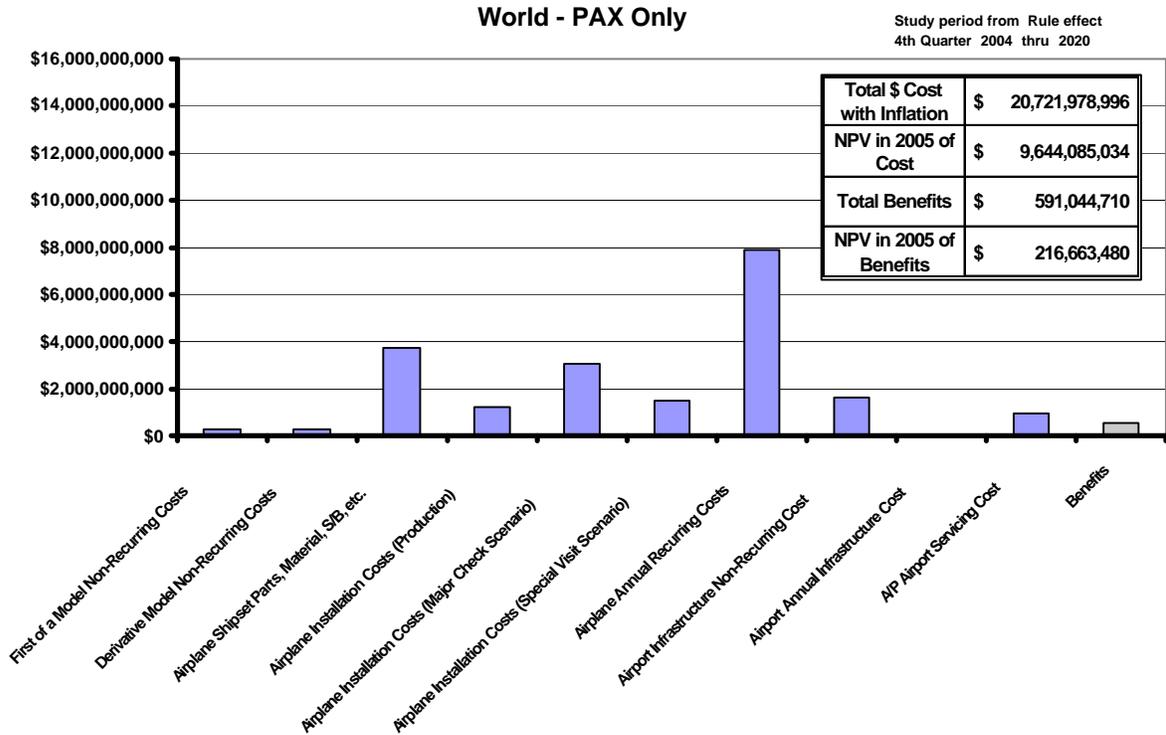


Figure 9-17. Scenario 3—Hybrid OBG, Heated CWT Only, Large, Medium, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

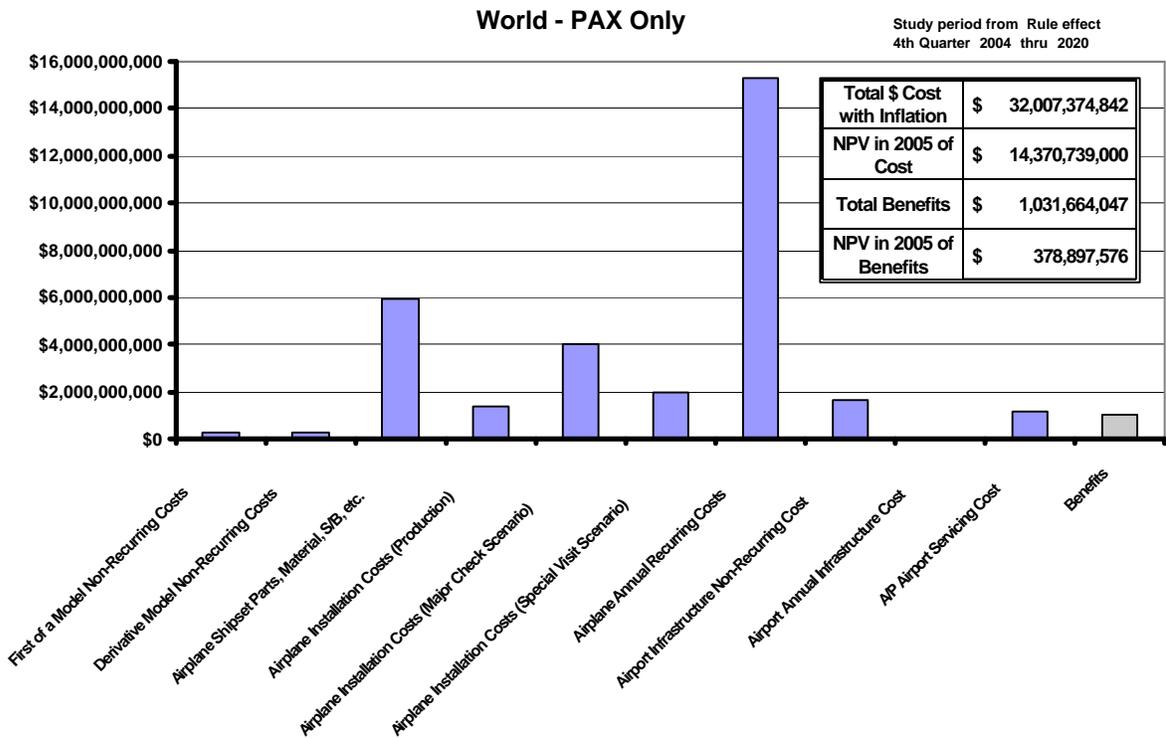


Figure 9-18. Scenario 4—Hybrid OBG, All Fuselage Tanks, Large, Medium, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

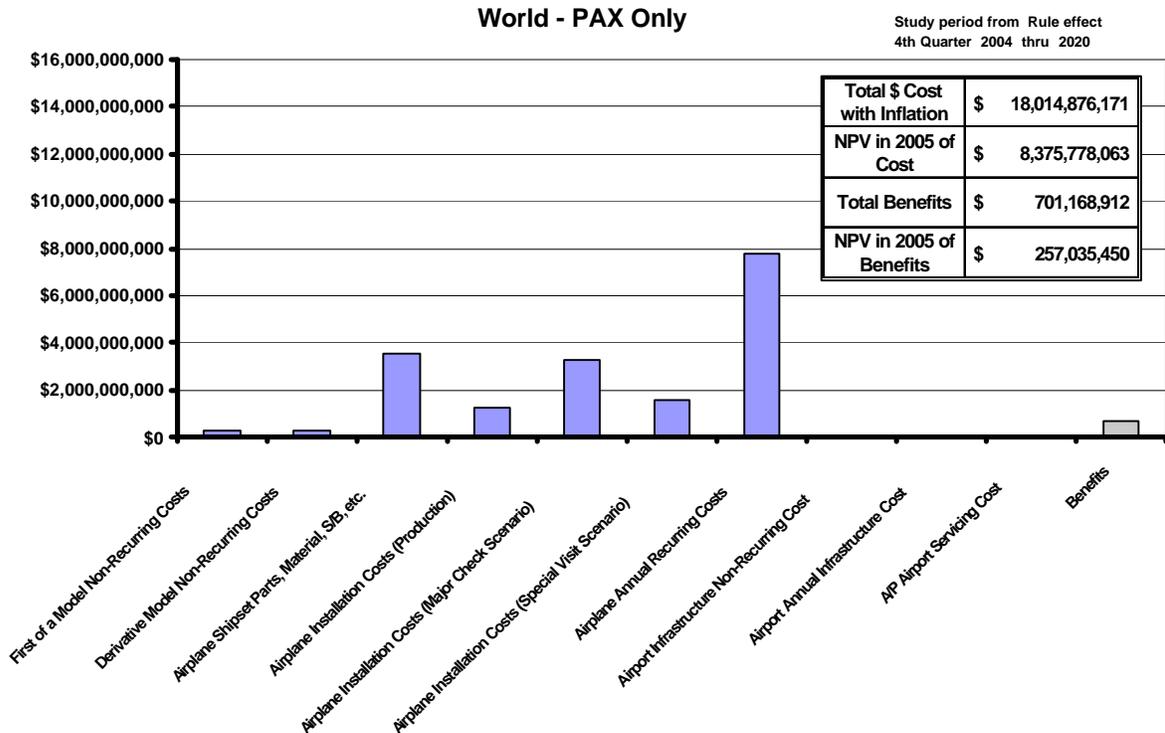


Figure 9-19. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

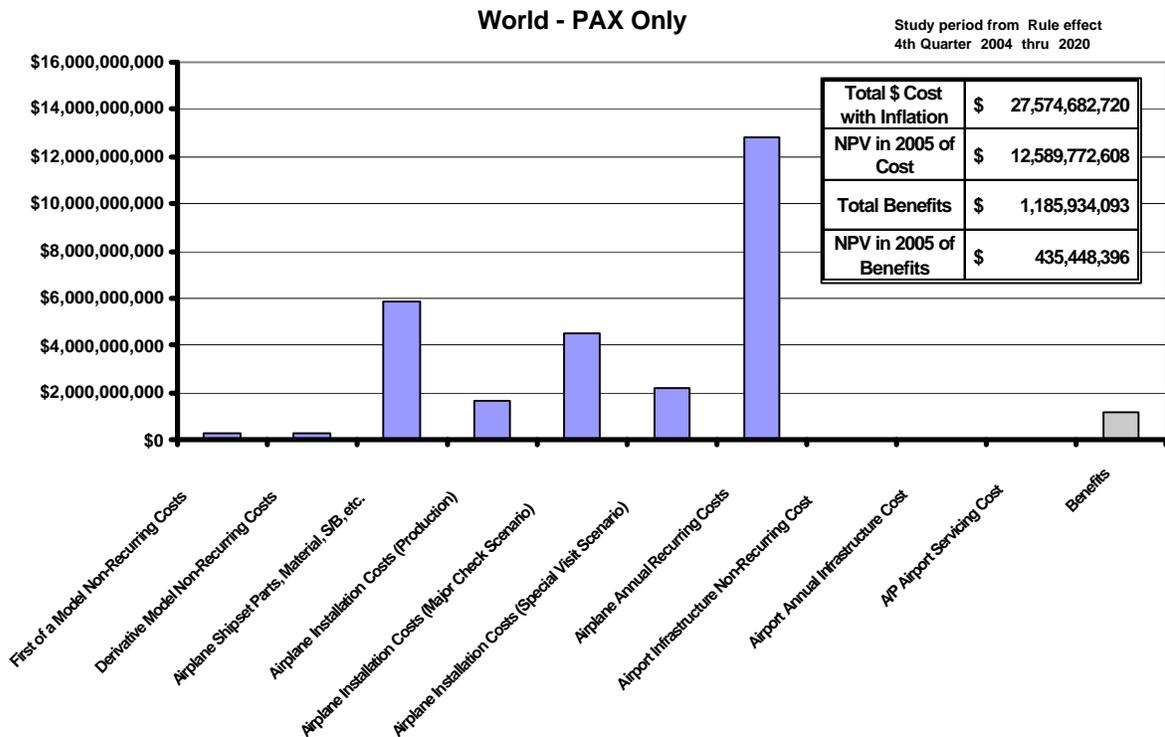


Figure 9-20. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

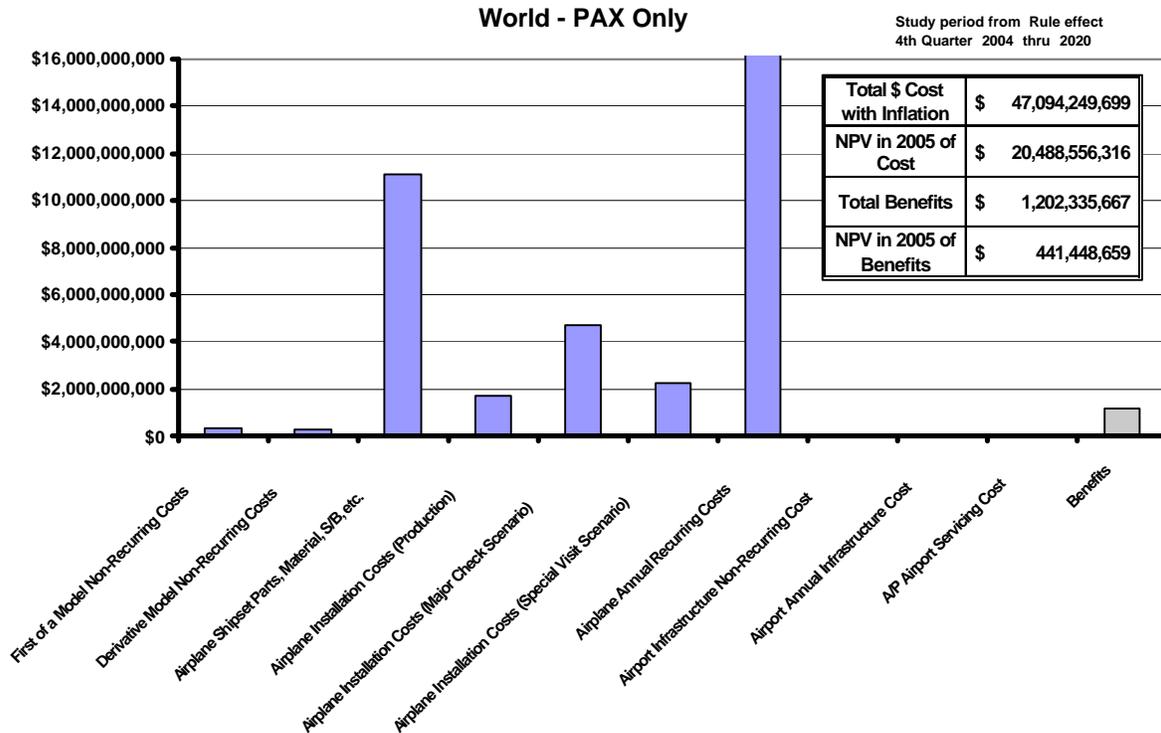


Figure 9-21. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

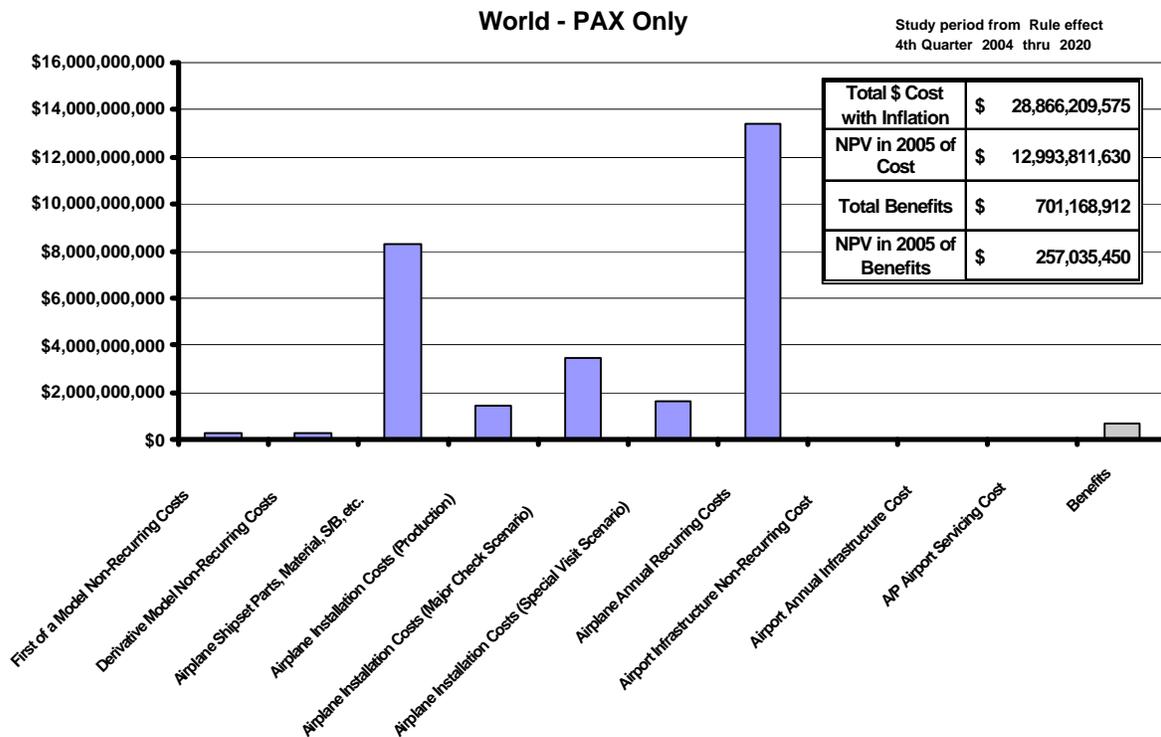


Figure 9-22. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

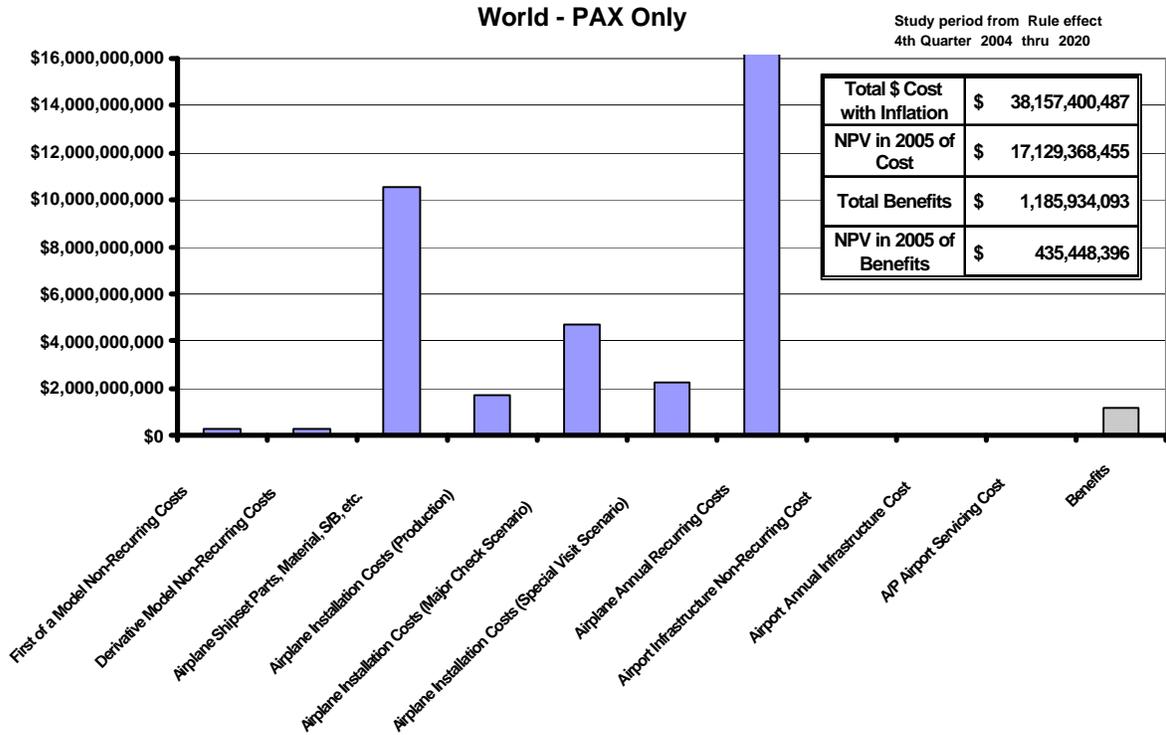


Figure 9-23. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

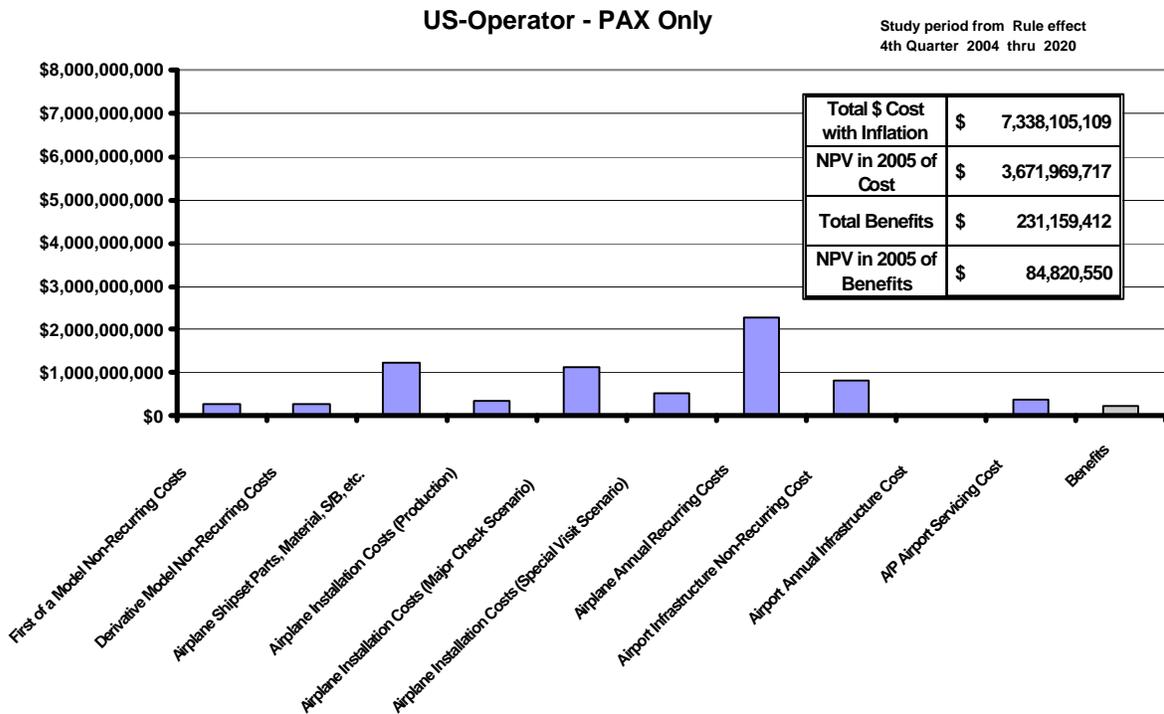


Figure 9-24. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

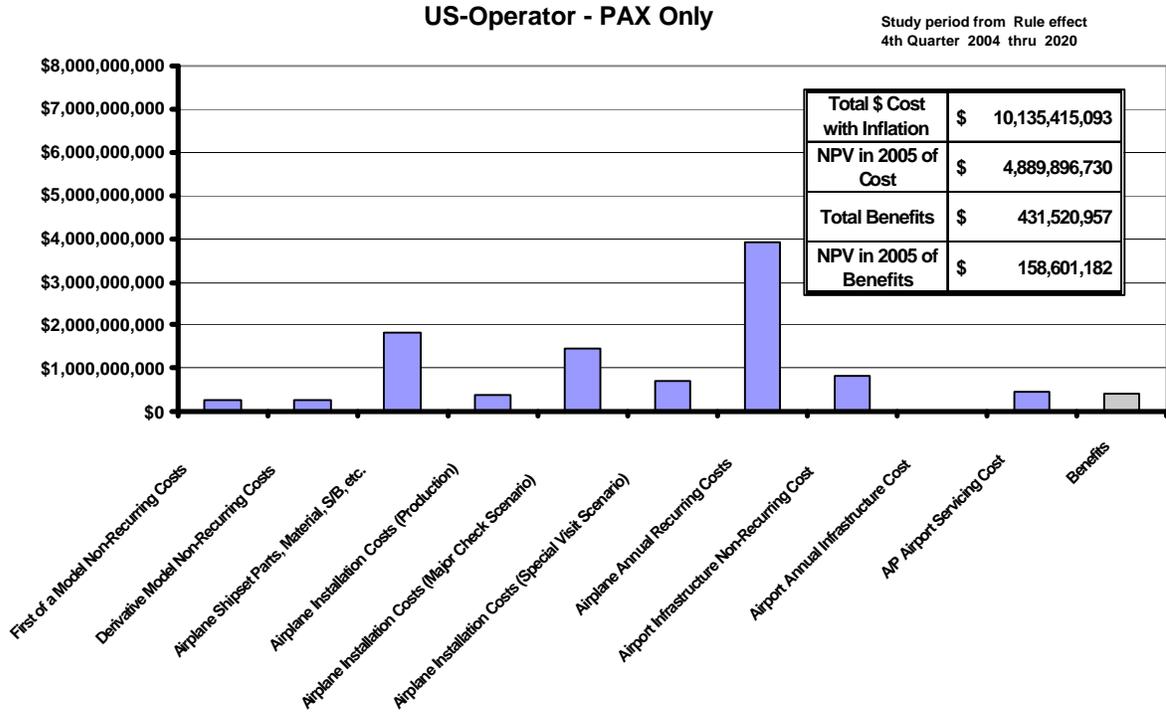


Figure 9-25. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

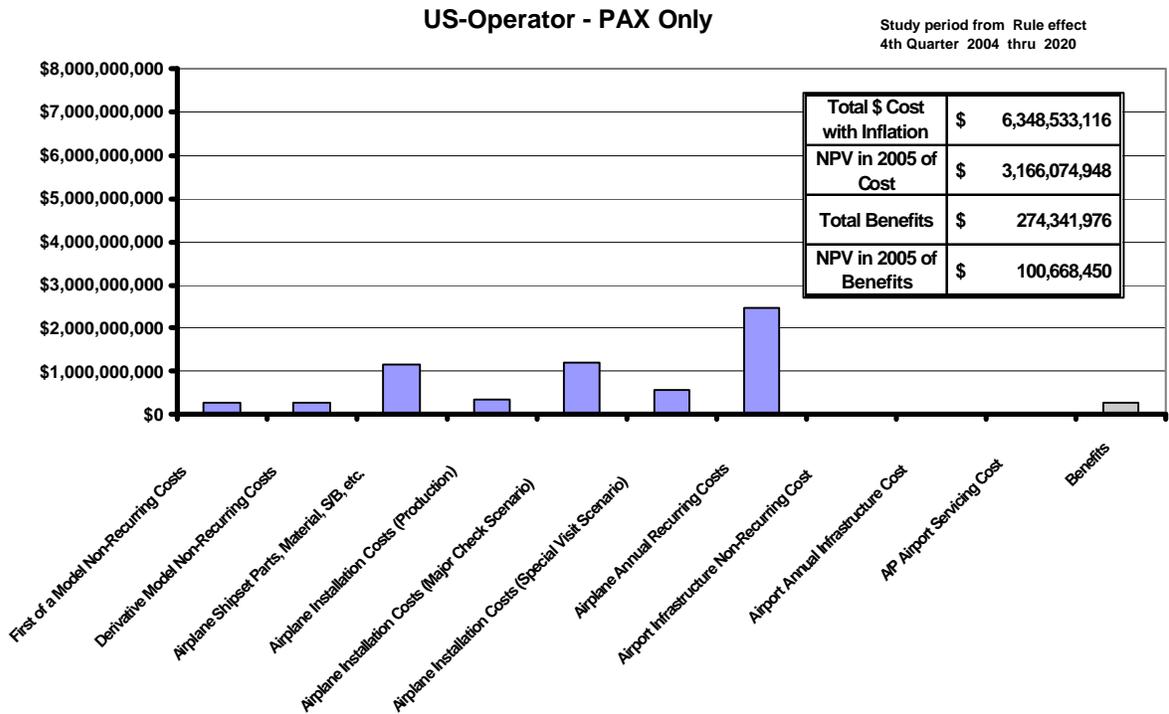


Figure 9-26. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

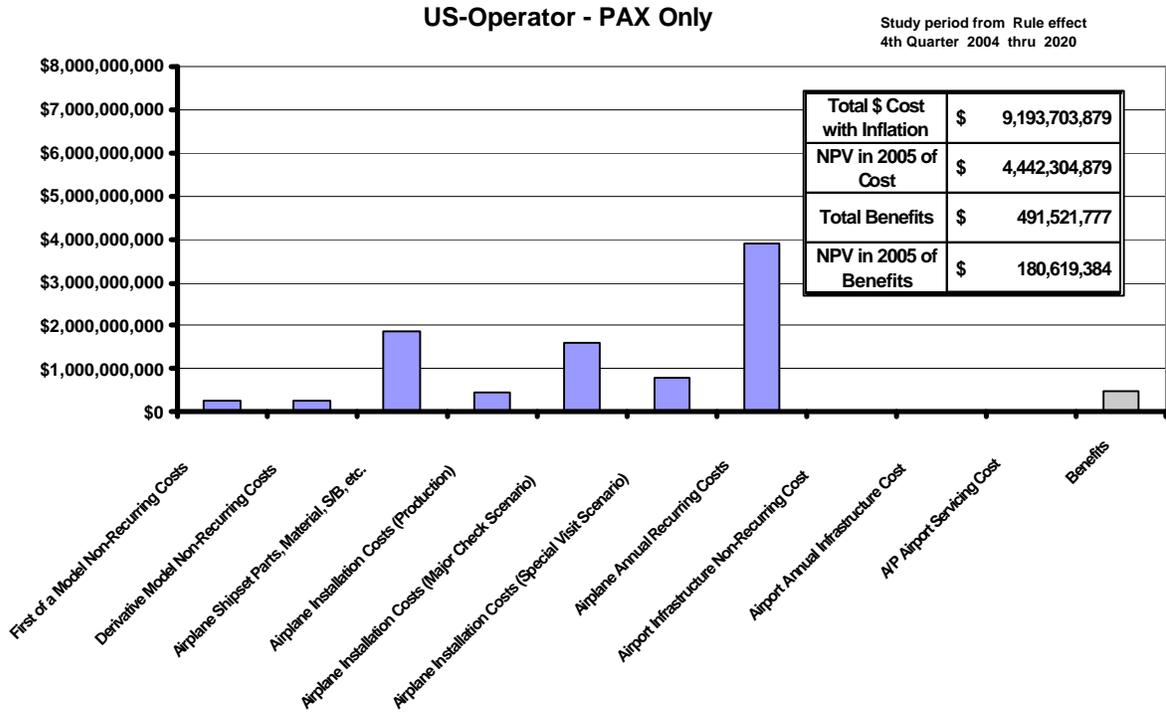


Figure 9-27. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

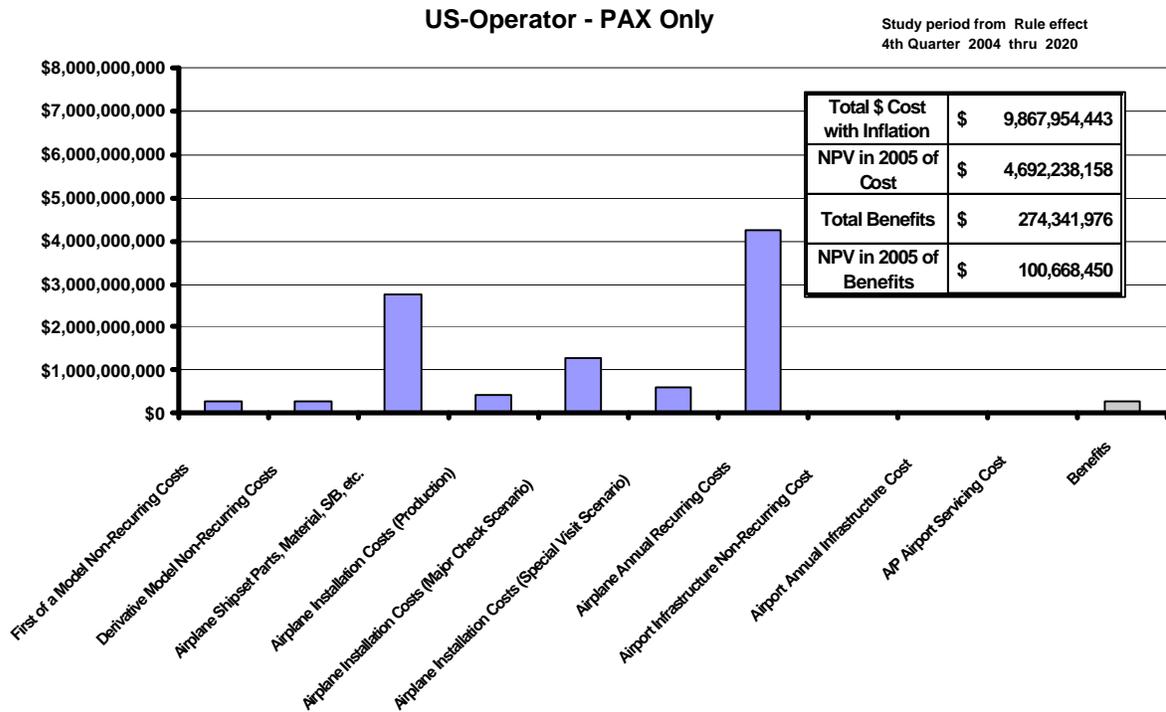


Figure 9-28. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

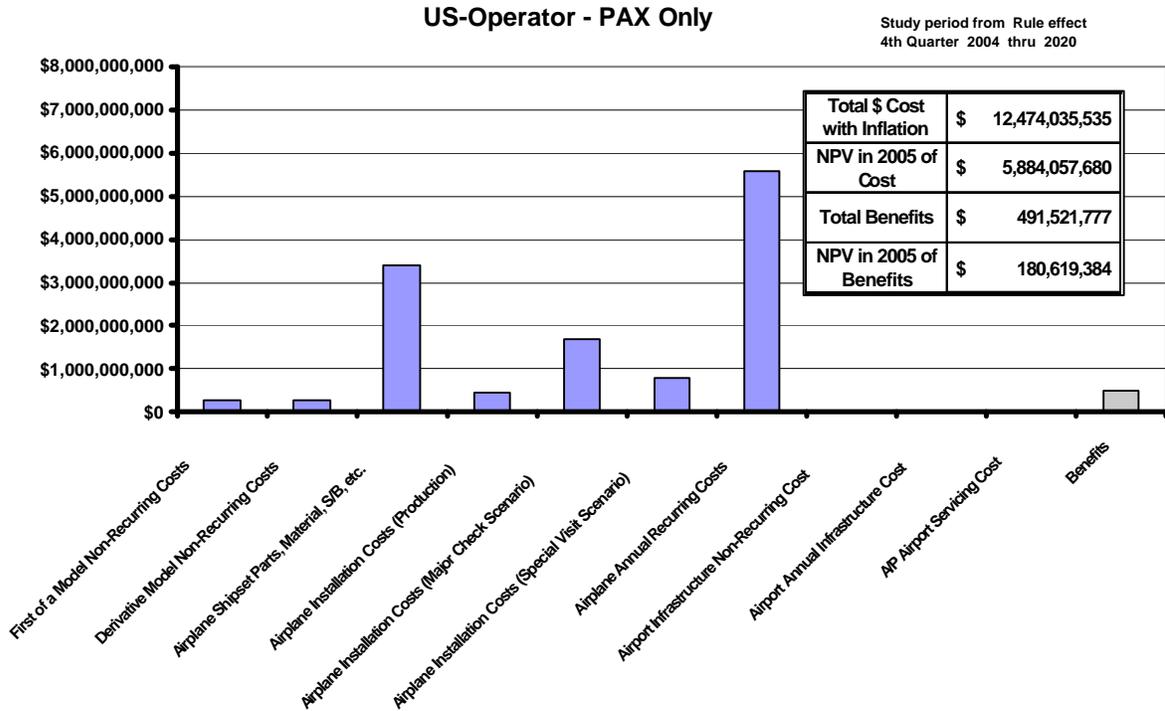


Figure 9-29. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

## 9.8 PROS AND CONS OF SYSTEM DESIGN CONCEPT

### Pros of the Hybrid OBGIS

- a. The hybrid OBGIS provides a reduction in total flammability exposure comparable to that of GBI.
- b. The hybrid OBGIS potentially reduces corrosion and condensation in the fuel tanks, depending on where and how the operator uses the system.

### Cons of the Hybrid OBGIS

- a. The hybrid OBGIS is almost as large as the full OBGIS.
- b. The cost of components (only a part of the total system cost) far exceeds the potential benefit.
- c. Additional cost is incurred because extra fuel is burned as a result of the weight of the system plus the added aerodynamic drag caused by its inlet and exhaust ports.
- d. The airplane's center of gravity may be adversely affected by the system's location in some airplane models, which will also cause a fuel penalty.
- e. Compressor and fan noise may have to be damped, depending on local noise regulations.

### Pros of the Hybrid OBIGGS

- a. The hybrid OBIGGS provides a reduction in total flammability exposure comparable to that of GBI.
- b. It is the smallest and least expensive of all the onboard design concepts.
- c. The hybrid OBIGGS potentially reduces corrosion and condensation in the fuel tanks, depending on how the operator uses the system.

Cons of the Hybrid OBIGGS

- a. The cost of components (which is just one component of the total system cost) far exceeds the potential benefit.
- b. Additional cost is incurred because extra fuel is burned as a result of the weight of the system plus the added aerodynamic drag caused by its inlet and exhaust ports.
- c. The airplane's center of gravity may be adversely affected by the system's location in some airplane models, which will also cause a fuel penalty.
- d. Compressor and fan noise may have to be damped, depending on local noise standards.

**9.9 MAJOR ISSUES AND RESOLUTIONS ASSOCIATED WITH CONCEPT**

The issues and resolutions for these hybrids are similar to those of their full-sized counterparts, except that each is smaller than the full-sized version. See figure 9-30 for the hybrid OBGIS and figure 9-31 for the hybrid OBIGGS.

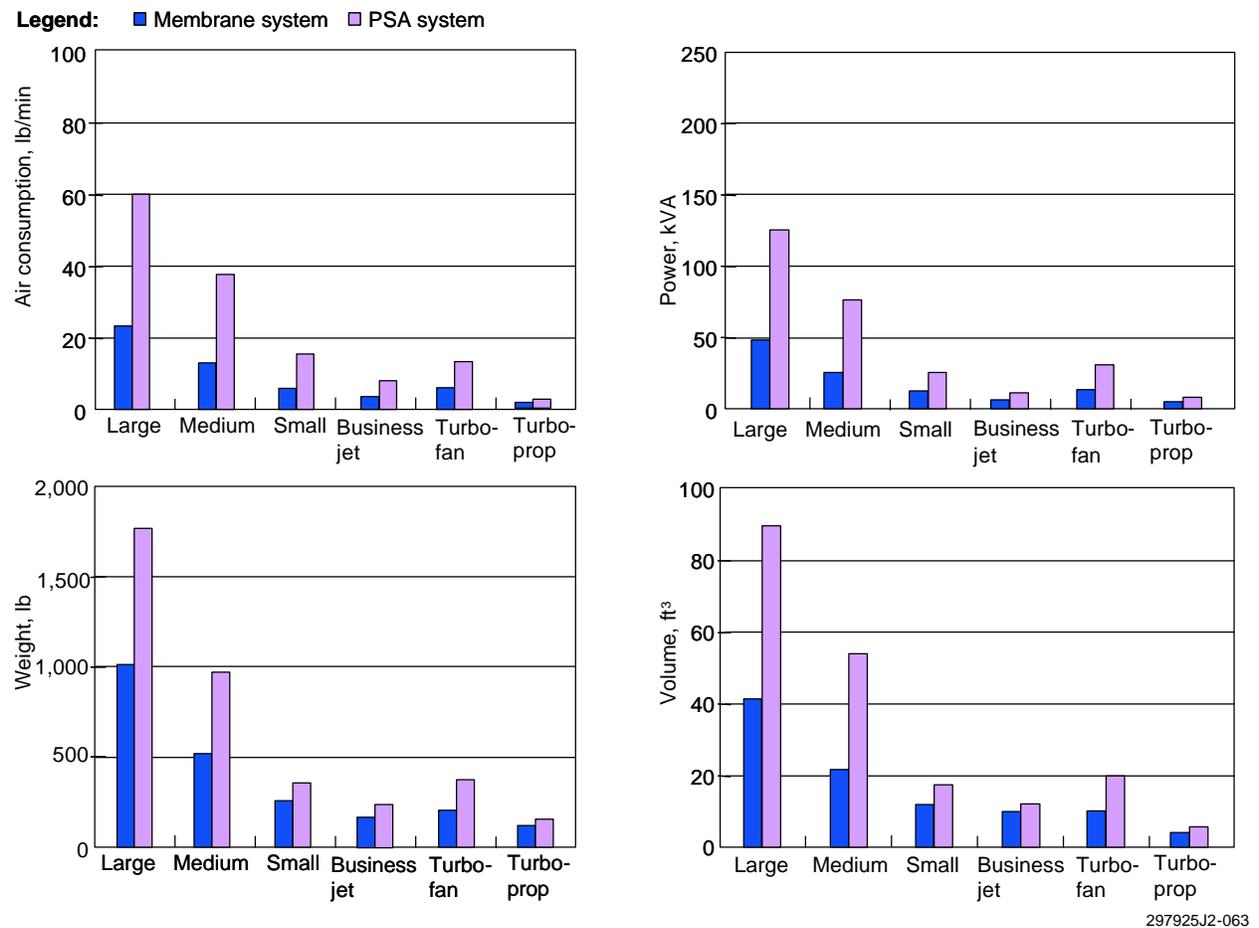
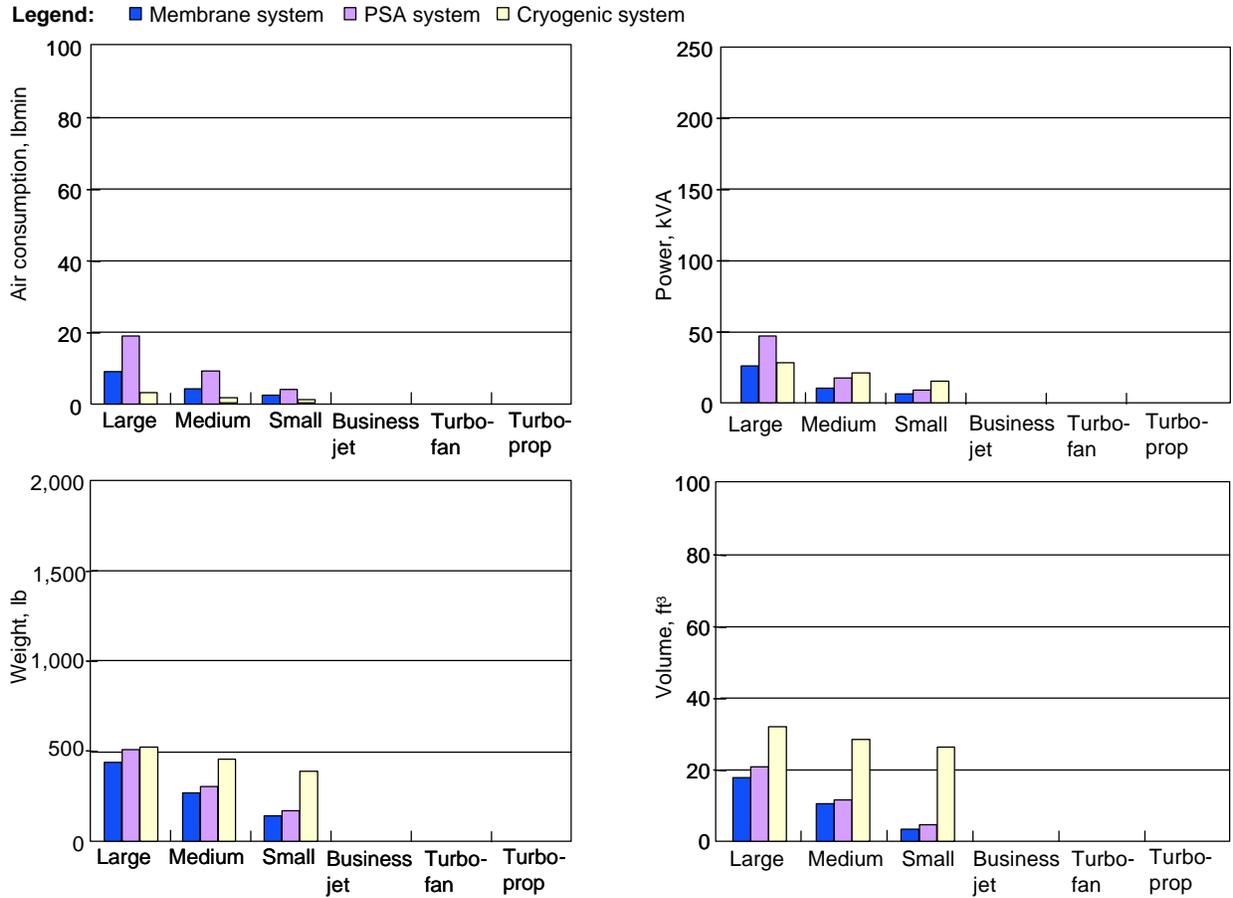


Figure 9-30. Hybrid OBGIS Installation Issues

297925J2-063



297925J2-064

Figure 9-31. Hybrid OBIGGS Installation Issues

**9.10 CONCLUSIONS**

The hybrid OBGIS does not offer significant benefit for the extra certification effort required to operate it during taxi-in. Therefore, the FTIHWG does not recommend this concept.

The hybrid OBIGGS offers the flammability exposure of a GBIS, with a small and relatively inexpensive onboard system. However, its cost still far exceeds the potential benefit. Therefore, the FTIHWG does not recommend this concept.



## **10.0 AIRPLANE OPERATIONS AND MAINTENANCE**

The Airplane Operation and Maintenance Task Team was assembled by the Working Group to support the fuel tank inerting study. The primary functions of this team were to

- Review operational and maintenance data on existing fuel tank inerting systems.
- Evaluate the effect of the proposed inerting system design concepts on airplane operations, maintenance, and fleet planning.
- Evaluate the cost impact of the proposed inerting system concepts on flight operations, ground operations, and maintenance.
- Provide technical expertise in the area of airline and airplane operations and maintenance to the other Working Group teams.
- Document the results of the team's findings.

The team comprised individuals with extensive experience in airline flight operations, maintenance, ground operations, engineering, and aviation regulations.

### **10.1 METHODOLOGY**

#### Data Review

The team's first task was to search for and review all available documentation relating to the operation, maintainability, and reliability of airplane fuel tank inerting systems. The team searched libraries and databases belonging to U.S. and European regulatory agencies, the Airline Pilots Association (ALPA), the petroleum industry, airplane manufacturers, and U.S. military services. The team also searched the Internet for information.

Little publicly available data on airplane fuel tank inerting systems exists. The team did identify some reports, primarily FAA studies, including one on the modification of a DC-9 to incorporate a fuel tank inerting system 30 years ago. With the exception of the data produced as a result of the 1998 ARAC FTIHWG report and a 2000 FAA Technical Center report on GBI, none of these reports included any operational or maintenance data relevant to the current study.

The team identified several military fuel tank inerting system applications similar to those being considered for this study. However, the team obtained very little operational, maintenance, or reliability data on those systems because that data is classified.

#### Inerting System Concept Review

As information became available from the Ground-Based Inerting Designs and the Onboard Inerting Designs teams, the Airplane Operation and Maintenance Task Team began reviewing the systems to identify operational and maintainability considerations for each concept. We initially evaluated each concept to identify how it might affect airplane flight operations, ground operations, dispatch reliability, maintainability, and training requirements. We also considered the potential effect on passenger, crew, and maintenance personnel safety.

After this initial evaluation, the team split up into subteams to begin detailed analyses. The four subteams addressed flight and ground operations, airplane modification and retrofit, scheduled maintenance, and unscheduled maintenance and reliability.

**Flight and Ground Operation Subteam.** This subteam identified and quantified the operational issues, impact, and costs associated with flight operations and gate or ramp operations needed to support airplanes equipped with inerting systems for each of the inerting systems concepts. They also analyzed and developed data relating to training requirements, airplane servicing, flight dispatch requirements and resources, cost-to-carry estimates, flight operating manual procedures, and manual revisions for each of the airplane-system combinations.

**Modification and Retrofit Subteam.** This subteam identified and quantified the costs and impact associated with modification of each existing airplane types to install the various inerting systems. The subteam assumed that the modification would be done according to an airplane manufacturer service bulletin that provided modification data, and that the manufacturer would make available modification kits. The subteam considered two different modification scenarios: First, the airplane is modified during a regularly scheduled heavy maintenance check. Second, the airplane is modified during a dedicated maintenance visit. The advantage of the first scenario is that access to most maintenance areas is already open for the regular maintenance check, which would reduce the total labor requirement, cost of modification, and airplane time out of service.

They developed data and estimations for each of the airplane-system combinations. These estimates were to include but not be limited to material and kit costs, modification labor-hours, engineering support requirements, technical publication revisions, airplane time out of revenue service, spares and training requirements, and any other issues related to the retrofit of inerting systems on existing airplanes.

**Scheduled Maintenance Subteam.** This subteam identified and quantified the costs and impact associated with the routine maintenance of the inerting system as well as any effects the inerting systems might have on the maintenance requirements of other airplane systems or equipment.

The subteam developed data for each of the airplane-system combinations. This data would include but would not be limited to airplane and component maintenance tasks, task intervals, task labor-hours, estimate of annual scheduled maintenance labor-hours, annual material costs, and the impact on check schedules, tooling requirements, and all other aspects of scheduled maintenance.

**Unscheduled Maintenance Subteam.** This subteam identified and quantified the costs and impacts associated with the nonroutine maintenance of the inerting system. They also would work with the Design, Rulemaking, and Safety teams to define MMEL requirements and limitations.

They also developed data for the cost and impact of unscheduled maintenance on each of the airplane-system combinations, including but not limited to

- Line maintenance tasks.
- Line maintenance labor-hours for troubleshooting and repair based on reliability data.
- Delay and cancellation rates.
- Airplane-on-ground time.
- Line maintenance training requirements and costs
- Component overhaul interval, labor, and material costs.
- All other impacts related to unscheduled maintenance and system reliability as measured in MTBF or MTBUR.

### **10.1.1 Modification**

#### General

The inerting systems would be installed by way of modification or retrofit. OEMs would retrofit airplanes in production. OEMs would also need to provide modification to operators through a service bulletin. Operators, maintenance facilities, or OEMs will modify in-service airplanes.

An FAA-approved OEM service bulletin for retrofitting an inerting system should be available before any final rule compliance date is set for retrofit of in-service airplanes. Failure to do this has caused problems for operators in the past. For example, in 1998 the FAA issued an AD for 747-100/-200/-300/-SP/-SR-series airplanes on changing wire separation requirements for fuel quantity indicating system wiring. Although an approved retrofit solution was not available, a 3-year AD compliance time for airplane modification was set. The FAA expected the OEM to complete design changes, gain approval, and make service bulletins available within 1 year of the effective date of the AD. This would have allowed the operators 2 years to modify their affected fleet. However, the FAA-approved retrofit solutions did not become available until almost 24 months into the compliance period, thereby significantly affecting the operator's ability to complete the modifications within the remaining compliance time. Because of the potential for delays in the design approval, it is critical that before the establishment of any compliance date requiring installation of an inerting system, an approved service bulletin must be available. This will ensure that operators have sufficient time to complete the modifications within the compliance period of a rule. Because of the scope of the modification, it must be accomplished during a heavy maintenance check or a special visit. Estimates have been developed for both scenarios.

The modification estimations are split into two major parts. The first is the nonrecurring costs that comprise engineering time, technical publication changes, and material control. The labor-hour estimates for these nonrecurring costs are the same for all airplane categories and are per airplane type per operator. The second part of the modification estimate includes recurring costs and comprises actual airplane modification time. This part of the estimate is per airplane.

Appendix F, Airplane Operation and Maintenance Task Team Final Report, addendum F.A.1, shows the total modification estimate. The following sections present a short description of each topic.

#### Engineering

Before a modification can be accomplished, the operator's engineering department must review the OEM service bulletin to determine applicability and check for variations in airplane configurations. Then Engineering must write modification orders, including creation of the necessary drawings and job cards, and coordinate with the maintenance and material planning groups. After the modification order has been completed and is ready for production, Engineering has to create the necessary tracking numbers and maintain the records for all components and their trends. The maintenance program must be updated before release of the first modified airplanes. The engineer assigned to this modification becomes the project manager. In addition to the responsibilities described here, he or she will be assisting and monitoring the progress of this modification.

#### Technical Publications

The introduction of the inerting system affects the following technical publications:

- Aircraft Maintenance Manual.
- Illustrated Part List.
- Component Maintenance Manual.
- Aircraft Flight Manual.

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- Flight Operations Manual.
- Structural Repair Manual.
- Fueling Manual.
- Ramp Maintenance Manual.
- General Maintenance Manual (including company procedures).
- Wiring Diagram Manual.
- Weight and Balance Manual.

In the modification estimation analyses, the team assumes that the normal revision procedures of the airplane manufacturer are used. The estimated time is the time required to revise the manuals.

### Material Control and Kits

The inerting system introduces new serialized parts and consumable parts. Those new parts have to be added to the company's databases. Because insufficient data exists on the inerting system, we did not account for the material cost of consumables.

Before the establishment of any compliance date requiring installation of an inerting system, modification kits must be available and the airframe manufacturers should coordinate the flow of kits to the operators. In this way, large operators will not adversely affect the availability of kits for smaller operators.

Kit costs—the price of the kit, its storage costs, and the labor-hours needed to check it—are not taken into account because of the large variation among airplanes, which prevents the use of detailed generic data and pricing.

### Project Estimation

For the modification estimation, the following airplanes were used as examples of each of the six category airplanes:

- Large-airplane category: Boeing 747 series.
- Medium-airplane category: Boeing 767 and MD-11.
- Small-airplane category: Boeing 737.
- Regional turbofan–airplane category: Fokker 28 and 70.
- Regional turboprop–airplane category: No airplane<sup>1</sup>.
- Business jet–airplane category: Gulfstream IV.

Appendix F, addendum F.A.2, shows the task with the labor-hours to perform the project. For this estimation, we assumed that the airplane has integrated tanks. Rubber cells are used by the Fokker 28/70/100–series airplane and as auxiliary tanks on some other transport airplanes. Introduction of the inerting system requires modification or redesign of the rubber cells. For the regional turbofan airplanes estimates were developed to show the differences in labor-hours of integral and bagged fuel tanks. Neither is the time required for moving or replacing existing installations to accommodate the piping of the inerting system.

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<sup>1</sup> We made no estimate for the regional turboprop airplane category because we could not find a company that does the maintenance for propeller airplanes with a CWT. Fokker Services, which made the estimate for the regional turbofan airplanes, told us that the Fokker 27, 50, and 60 airplanes (turboprop airplanes) do not have a CWT.

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The engineering support requirements (e.g., engineering, technical publications, and material management) for retrofit of an operator fleet are based on a nominal fleet size.

### ***Airplane Out-of-Service Time Estimate***

We made the following assumptions to estimate the downtime for the airplane:

- Modification is accomplished based on a 5-day workweek.
- There are three shifts each with 10 people (5 mechanics, 3 avionics, and 2 sheet metal workers).

### ***Maintenance Training***

The basic training requirement for this fuel tank inerting modification consists of classroom lectures, use of the jet airplane maintenance fundamentals, CBT courseware, basic training workshops, and practical training on in-service airplanes at a maintenance organization. Substantial time is needed to educate and train the professional maintenance technicians who will be responsible for safely handling and maintaining airplanes equipped with inerting systems.

Operator maintenance and ground training departments and vendor and manufacturer training departments will need substantial time to create and present all necessary training materials for the different kinds of inerting systems. The diversity of airplane fleets and available inerting systems will compound this challenge.

Existing training manuals will need to be revised to reflect airplane modifications and operational requirements created by fuel tank inerting.

There are significant differences in training regulations among various countries. An accurate estimate would require knowing the exact number of licensed mechanics and the average number of licensed mechanics per airplane per operator. An additional factor is the fact that some operators contract with training centers to educate their maintenance personnel. Because of these and other factors the team was not able to make a labor-hours estimate for training costs. However, the team described the impact on maintenance training from the introduction of inerting systems.

#### **10.1.2 MEL Relief**

FARs require that all equipment installed on an airplane be in compliance with the airworthiness standards and that operating rules be operative. However, the FARs also permit the publication of an MEL where compliance with certain equipment requirements is not necessary in the interests of safety under all operating conditions. Experience has shown that with the various levels of redundancy designed into an airplane, operation of every system or installed component may not be necessary when the remaining operative equipment can provide an acceptable level of safety. Under the MEL, dispatch relief is granted for listed components and systems for specific periods of time before the system or component must be repaired or made operational. If repair is not made before the specified time period expires, the airplane may not be flown again until the repairs are made. The FAA uses several standard repair intervals that range from one flight to 120 days.

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### Primary Assumptions

As defined in the Tasking Statement, the FTIHWG's *Evaluations of all systems should include consideration of methods to minimize the cost of the system. For example, reliable designs with little or no redundancy should be considered, together with recommendations for dispatch relief authorization using the master minimum equipment list (MMEL) in the event of a system failure or malfunction that prevents inerting one or more affected fuel tanks.* The FTIHWG in general and the Airplane Operation and Maintenance Task Team specifically felt that these instructions were contradictory to the normal application of the MMEL.

These assumptions vastly affect the maintenance and operational costs for an airplane equipped with a fuel tank inerting system. Requiring system redundancy would greatly increase the cost and complexity of the inerting system and also would greatly increase maintenance and operating costs.

Likewise, if dispatch relief were not available on a system without redundancy, the maintenance requirements would be greatly increased. In addition, the rate of flight delays and cancellations would increase significantly because the system would have to be repaired before flight.

After lengthy discussions at the team and Working Group levels, we decided to proceed with the evaluation using the guidelines in the Tasking Statement. It must be understood, however, that airplane operations and maintenance costs would significantly increase with a change to either assumption. Because all FTIHWG analyses are based on these two assumptions, changing them would invalidate most of the results.

For purposes of the study, the Airplane Operation and Maintenance Task Team made an attempt to evaluate the impact of a category B or 3-day repair interval and a category C or 10-day repair interval. The impact was evaluated based on the reliability of the system, the typical amount of ground time between flights, and the typical maintenance capture rate or the frequency that an airplane overnights at a maintenance base. An effort also was made to predict the impact of having no dispatch relief, which essentially meant that one or more flights would be canceled while repairs were being accomplished. While these estimates are not comprehensive, they suggest the potential impact of the various options.

### Frequency of Dispatch on MEL

To determine how frequently an airplane might be dispatched with the inerting system inoperative, the average annual flight-hours for the specific airplane category were divided by the inerting system reliability factor of MTBUR to determine the typical frequency of inerting system failures. Available time to troubleshoot and repair the system between flights is typically very short. Therefore, the assumption was made that, given the availability of dispatch relief per the MEL, maintenance would probably place the system on MEL and dispatch the airplane with the system inoperative rather than creating a lengthy flight delay.

### Flight Delays

To dispatch an airplane with a system or component on MEL, some minimal amount of troubleshooting by a mechanic is required to identify the problem and verify that the system is safe for continued flight in its existing condition. The mechanic also must check the MEL to determine if there are maintenance procedures to deactivate or reconfigure the system before dispatch. The mechanic then must fill out the proper paperwork to place the system on MEL and release the airplane. The shorter the turn time, the

more likely that a significant flight delay would occur. The availability of maintenance also is a factor because the number of available mechanics is very limited at many airports. Typical flight delays can range from a few minutes to several hours, depending on conditions, such as the maintenance workload at the time and weather. To reflect the potential impact on flight schedules for each dispatch on MEL, we assumed flight delay times (fig. 10-1) based on the typical turn time for that category airplane.

Airplane category	Flight delay per MEL dispatch, min
Large transport	30
Medium transport	45
Small transport	60
Regional turbofan	60
Regional turboprop	60
Business jet	60

Figure 10-1. Flight Delay Assumptions

The annual number of delays and delay time is then a function of the number of times the system fails and must be put on MEL times the estimated delay time in accordance with MEL dispatch.

### 10.1.3 Scheduled Maintenance

The Scheduled Maintenance Subteam was tasked with identifying and quantifying the costs and impact associated with the routine maintenance of an inerting system. Each proposed inerting system was addressed for each of the six airplane categories. (Airplanes were grouped according to standard seating configuration, and the airplane models were then placed into the six categories under consideration.) Because of the size and complexity of the onboard inerting concepts, however, we did not complete the analysis for turbofan, turboprop, or business jet categories.

Scheduled maintenance requirements should be minimal, based on the following assumptions:

- Most components will be maintained on condition.
- The system will be designed so that the risk of an undetected accumulation of nitrogen in spaces occupied by people or animals in flight or on the ground will be minimized.
- Failure of the inerting system will not provide any immediate risk to the airplane or its occupants.

A Boeing 757 (small airplane category) was chosen to establish a baseline of maintenance tasks and intervals. From there, we determined that maintenance intervals and data could be established for other airplane categories by scaling the Boeing 757 data as applicable.

To facilitate the calculation of scheduled maintenance labor-hours for each of the selected inerting systems, average use rates and maintenance intervals were obtained from Boeing and Airbus for all their jetliner models. From this information, we calculated the average maintenance intervals presented in figure 10-2. This information was used to determine the frequency, or portion, of each maintenance check per year. From that, we could establish the average additional labor-hours per year required for scheduled maintenance of an inerting system.

Airplane category	Check intervals, hr		
	A	C	Heavy
Large transport	650	5,000*	4C
Medium transport	500	4,350**	4C
Small transport	500	6,000**	4C
Regional turbofan	400	4,000	4C
Regional turboprop	500	3,200	9,600
Business jet	400	4,000	16,000

\*Or 24 mo

\*\*Or 18 mo

Figure 10-2. Average Fleetwide Maintenance Intervals

Maintenance Labor-Hours

We estimated maintenance labor-hours for the Boeing 757. These labor-hours were to be scaled to determine the additional scheduled maintenance labor-hours for other airplane categories, but no significant differences among categories were discovered. From the information available, components among airplane categories do not vary significantly. Although the size of components may differ, the scheduled maintenance labor-hours needed to inspect or remove and replace these components do not. When compared with a small-airplane category, medium- and large-airplane categories will require additional labor-hours during a heavy check to inspect the wiring and ducting of the additional wiring and tubing.

Scheduled maintenance tasks and inspection intervals for components within each concept were obtained using tasks and intervals for similar components on existing airplanes, or components performing similar functions on the V-22 Osprey. It is important to note that the V-22 Osprey currently operates with a fuel tank nitrogen inerting system.

To obtain the estimated labor-hours, the team identified maintenance tasks for similar components (e.g., components in ATA<sup>2</sup> 21, 28, and 36) used on in-service airplane models and then queried maintenance personnel as to whether the labor-hours per task were reasonable. The estimate was based partly on the expertise of the maintenance personnel because the actual locations of components will not be known until an inerting system is actually designed.

Cycles Versus Operating Time

It is important to note that GBIS and OBGIS maintenance intervals are based on cycles and an average system operating time per cycle. OBIGGS maintenance intervals are based on flight-hours plus ground operating time.

The team excluded scheduled maintenance for the GBIS at the heavy check for small, medium, and large airplanes. Because the amount of equipment internal to the airplane or the fuel tanks is limited, we assumed that C-check inspections would suffice.

Scheduled maintenance for the GBIS on turboprop and turbofan airplanes is required at heavy check because of the time between heavy checks.

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<sup>2</sup> Airplane manuals are divided in chapters according to ATA standards. Each chapter describes a specific airplane system. The ATA chapters referred to here are “Air-Conditioning” (ATA 21), “Fuel System” (ATA 28), and “Pneumatic System” (ATA 36), respectively.

Scheduled maintenance for the GBIS on business jets would be required annually.

#### Additional Maintenance Tasks

Numerous maintenance checks will be required but cannot be evaluated until final designs are determined. These would include, but are not necessarily limited to, preflight checks (i.e., BITE checks, fault checks, extended-range checks) and pretank entry checks (which will depend on the actual operator, the equivalent of OSHA, or both). In addition, we do not include unusual scheduled tasks based on the system chosen (e.g., daily warmup period for membrane OBIGGS).

We cannot include other scheduled maintenance items because of the peculiarities of each system, which will not be known until the system has been designed. Without knowing the design life of many of the components to be used in the proposed inerting systems, the team could not estimate labor-hours required for scheduled removals. These include specific consumables, other than filters, that are only required by the design itself (e.g., liquid nitrogen for the cryogenic inerting system).

The team recognized that a true picture of the maintenance program could be achieved only by performing an MSG-3 analysis. However, lack of design data prevented that from being accomplished for this report. (MSG-3 is a document produced by the ATA that outlines a decision and selection process for determining the scheduled maintenance requirements initially projected for an airplane system or powerplant.)

### **10.1.4 Unscheduled Maintenance**

#### Component Reliability

As mentioned in previous sections, little or no documentation exists relating to the operation, maintainability, and reliability of airplane fuel tank inerting systems. The challenge for the team has been to develop a reasonably accurate method to estimate the reliability of the fuel tank inerting system design concepts.

After a review of each of the design concepts, the similarity between the proposed inerting systems and other existing airplane systems became evident. For many components, strong similarities exist with fuel, pneumatic, and air-conditioning system components that are currently used on commercial airplanes. In fact, there is a possibility that some existing valves, sensors, or fans currently used in other systems could be used in an inerting system. Therefore, for each inerting system component, the team identified as many similar airplane components as possible. The team gathered information on similar components and averaged available reliability data for those components. For components that are unique to the inerting systems, such as ASMs, the team used the manufacturers' estimates of the component reliability.

#### MTBF Versus MTBUR

We determined that the MTBUR would be a better indicator of the impact on the airplane maintenance requirements and operational performance than the system MTBF. Using MTBUR factors in some of the typical maintenance inefficiencies in system troubleshooting and repair, and therefore more accurately reflects the real-world problems encountered in airplane maintenance.

#### Airplane Use Rate

To ensure that uniform and consistent analysis methods were used to evaluate the effect on maintenance and operations, we determined airplane use rates for each of the study-category airplanes based on industry data (fig. 10-3). These use rates included daily and annual airplane flight-hours and the number of

	Daily flight-hours (hr)	Annual flight-hours (hr)	Flights per day (avg. no.)	Minimum turn time (min)
Large transport	11.18	4,081	2	60
Medium transport	7.65	2,792	3.5	45
Small transport	7.86	2,869	7	20
Regional turbofan	5.8	2,117	7.1	15
Regional turboprop	8.1	2,957	6.8	15
Business jet	1.37	500	1.5	60

Figure 10-3. Airplane Use by Category

System Reliability

The team calculated the system reliability as an inverse sum of the MTBUR inverses. We used the same method to determine the system reliability for each of the inerting system concepts.

System Annual Use Rates

Because of differences in the operating requirements and characteristics of each inerting system design concept, the amount of operating time a specific system experiences varies. System operating time is important because it directly affects system reliability and, therefore, operating costs. To account for these differences, the team developed the system annual use rates based on the operating requirements for each inerting system concept and each category of airplane.

System Annual Failure Rate

The team determined the inerting system failure rate by multiplying the system MTBUR by the system annual use rate for the category airplane. This rate was then used as an estimate of the frequency that the airplane would be dispatched with the system inoperative (MEL). We used it with the MEL repair interval requirements to estimate the percentage of time the system would be operational.

System Maintenance Workload

To determine the amount of additional workload an inerting system would add to an airplane’s maintenance requirements, the team made some assumptions about the location of the inerting system components. We worked with the design teams to identify the likely locations of components. Identifying potential locations on some airplane categories was relatively easy. On the 747, for example, the teams determined that an area beneath the CWT adjacent to the air-conditioning packs was large enough for an onboard system; it met most of the design and safety requirements. This location also would provide good access for maintenance. On other airplanes, space was limited. Many of these spaces were inside the fuselage pressure vessel, raising safety concerns, and they had poor access for maintenance. On some airplanes, space inside wheelwells and wing-to-body fairings was available. In many others, the only potential locations tended to be in the aft fuselage area just forward or behind the aft pressure bulkhead. The team also considered differences in access time as a result of the time necessary to purge the fuel tanks because of the differences in fuel tank volumes.

Based on this survey of potential locations, we developed estimates for troubleshooting, removal, and installation of each component. We used this estimate and the components’ predicted failure rate to develop a maintenance labor estimate for the system onboard each airplane category.

**10.1.5 Flight Operations**

To evaluate this process and come to the conclusions and recommendations stated further in this document, the team used several implications and assumptions. First and foremost was the assumption that, in the event the inerting system was inoperative or ground inerting equipment was not available, a means to dispatch the airplane without the fuel tanks inerted must be defined. Much discussion went into

this decision, ranging from requiring inerting on every flight regardless of circumstances to treating the system as supplementary only. In the event that MEL or dispatch relief was not available, operators would incur major limitations. The scope of such limitations could be great enough to change entire route structures. Airports that could not provide nitrogen or maintenance procedures would not be available as alternatives, refueling stops, or diversions because their use would have the potential to ground airplanes and passengers short of their destinations. If inerting systems were required for safety of flight, then additional air turnbacks, flight cancellations, and delays would also have to be considered. This and the guidelines set forth in the Tasking Statement led us to our final premise. Consequently, our evaluation and methodology regarded the system as being a safety enhancement system similar to the present traffic collision and avoidance systems required on airplanes today.

The cost-to-carry estimates are a function of the weight of the system and the cost of the fuel to carry the additional load. The loss of revenue from the decrease in useful load on flights routinely operating at maximum gross weight is also considered. Because determination of the cost associated with the production of power and the resulting drag incurred by onboard systems requires detailed design data, we have not quantified these costs.

We derived flight crew procedures and associated training expenses from past typical training events similar to the requirements of the proposed system. We also assumed that an AC will be published by the FAA as a training aid from a high-level or general standpoint.

Based on the assumption that fuel tank inerting systems would not be considered a requirement for safety of flight, the Airplane Operation and Maintenance Task Team concluded that in-flight indication requirements for an onboard system would be minimal. The flight crew must be able to shut down the system in case of a catastrophic failure and would need some indication of inerting system status. This could include positive indication that the system had powered down in the event of manual system shutdown. Failure of an onboard inerting system would also be annunciated to maintenance personnel after landing. These assumptions reduce the potential for flight delays, diversions, air turnbacks, and their associated costs. Any change in the assumptions would greatly increase flight interruptions and operating costs.

#### **10.1.6 Ground Operations**

The effect an inerting system has on ground operations depends on the system concept being considered. Training, ground handling, and line maintenance requirements were considered along with the associated costs. To accomplish this, we developed conceptual models of operations with ground-based and onboard inerting systems based on inerting system concepts and airline operational experience.

The team also assumes that the FAA will provide an AC that addresses training for operators and technicians. Recent modifications to 737 CWTs and installation of smoke detection and fire suppression systems in class-D cargo compartments allow the team to draw some parallels in the processes under review. Based on the modification and training requirements involving these systems, a generic description of the model follows:

Training programs for line maintenance technicians should cover system operation, MMEL processes, and special procedures, including troubleshooting procedures. While operator training requirements and internal policies and procedures vary widely, task-specific training for technicians accomplishing the initial airplane modification should be implemented. A separate or additional program dealing with nitrogen safety and usage should be developed for those individuals working around the airplane during inerting. This team estimates that 8 hr of initial, and 4 hr of annually recurring training would be required for each technician.

## **10.2 MAINTENANCE IMPACTS**

The retrofit and operation of any of the proposed inerting systems will significantly affect airplane maintenance programs and schedules, dispatch reliability, maintenance workload in the line environment, and safety of the maintenance personnel.

### **10.2.1 Modification and Retrofit**

This team concludes that because of the scope of the modifications, most operators would not be able to schedule the modifications to incorporate the inerting system during an airplane's regular heavy maintenance visit (app. F, add. F.A.1). The additional labor-hours would extend the scheduled maintenance visit so much that it would interfere with the airline's maintenance schedules. Operators must complete the maintenance requirements on schedule or risk grounding airplanes. Most operators would likely start dedicated modification lines or contract the modifications out to other maintenance facilities. The disadvantage of this approach is that the existing access available during heavy maintenance visits would be lost. This would increase the total labor-hours required for the modification. Another disadvantage of this approach is that it may cause a worldwide problem with hangar availability. The team estimated that approximately 100 dedicated hangars would be necessary for modification of the existing fleet during the proposed compliance period. If the operators need to perform the modifications in a special modification line extra slots are necessary; this may result in insufficient hangar space.

Because of the number of airplanes affected, the Airplane Operation and Maintenance Task Team has serious concerns about the availability of trained maintenance technicians required to modify the airplanes within the proposed compliance period. Completing the modification of all the affected airplanes in a 7-year period would require 3,000 to 4,000 trained maintenance technicians working full time.

### **10.2.2 MEL Relief**

The assumption of dispatch relief for the fuel tank inerting system is fundamental to estimating its potential impact on airplane operations and maintenance. If the assumption changes, the approach to evaluating the scheduled maintenance requirements would also need to change, resulting in a significant increase in estimated time and costs.

If a typical airline could not dispatch an airplane with its inerting system inoperative, the airplane would have to be taken out of service to repair the failed inerting system. The result would be a heightened burden on the airline's line maintenance functions to get the airplane back into service. Therefore, airlines would most likely focus on the inerting system's scheduled maintenance program, driving many components off the airplane for overhaul earlier in an attempt to reduce system failures in service. This would significantly increase the scheduled maintenance, overhaul, and operating costs for the inerting system.

### **10.2.3 Scheduled Maintenance**

As shown in the specific inerting design concept sections, scheduled maintenance impact reflects access, inspection of component, and closure, but does not reflect any nonroutine correction of discrepancies. Neither does it include the cost of any special equipment or tooling required to accomplish the inspections or any of the costs related to the airplane's modification. It begins after the inerting system has been incorporated.

The heavy check inspections shown for the different inerting design concepts do not reflect any additional workforce required to comply with safety requirements for fuel tank entry into confined spaces with NEA present.

Airplane fuselage seal deterioration occurs because of increasing airplane age, and pressure decay checks allow discovery of seals that require replacement or rework. The use of cabin air to supply the inerting system increases the demand on the airplane air-conditioning packs. Consequently, the maximum allowable cabin leakage rate will have to be maintained at a lower level to ensure that the air-conditioning packs will continue to maintain the required cabin pressurization.

We have added extra labor-hours to each C- and heavy check to allow for a fuselage pressure decay check and rectification if cabin air is used to supply the inerting system. Operator experience has shown that in-service airplanes periodically require a pressure decay check in order to maintain limits prescribed in airplane maintenance manuals.

The extra labor-hours are averages obtained from those operators whose maintenance programs currently require fuselage pressure decay checks.

#### **10.2.4 Unscheduled Maintenance**

Each of the design concepts included in this study, from the least complex (GBI) to the most complex (OBIGGS), will affect line maintenance, as will the introduction of any new system onto an airplane. From a general perspective, the introduction of a new system, and hence the introduction of new components or line-replaceable units, will affect line maintenance by affecting airplane dispatch reliability.

In simple terms, the more components there are, the less reliable the system, resulting in a lower overall airplane dispatch reliability rate. The reliability of each component or line-replaceable unit and its MTBUR directly relates to unscheduled line maintenance activity. This in turn means increases in labor-hours (i.e., troubleshooting, component access, and component removal and replacement times), material, and labor costs, and most likely in airplane delays and cancellations. The introduction of a new system and its components can also affect other systems by limiting access to their components, thus affecting unrelated component replacement times.

The specific effect on line maintenance as a result of the introduction of inerting is best evaluated by looking at component MTBUR data for similar or related systems. The effect on other systems resulting from operating the various inerting systems must also be considered. For example, the proposed OBIGGS design concept extracts cabin air as an air source during certain flight phases. Although a scheduled maintenance task to accomplish a periodic fuselage pressure decay check will need to be implemented, cabin air extraction will undoubtedly affect airplane pressurization, especially on older airplanes. This leads to unscheduled maintenance activities and associated costs to isolate and rectify air losses. The effect on line or unscheduled maintenance varies depending on the inerting system used. We discussed these differences in more detail in each of the system design concept sections.

We did not include unscheduled maintenance costs associated with component overhaul, including labor and material costs, and costs associated with special equipment and tooling in the analysis because of insufficient data.

Special precautions must be taken when performing line maintenance on some inerting system components such as confined space entry procedures, depending on their location. Additional hazards associated with gaseous and liquid nitrogen must also be considered. These special precautions and additional hazards result in increased line maintenance costs through increased training (both initial and recurring), equipment, and procedure and policy implementation. The specific issue related to maintenance personnel safety associated with nitrogen inerting systems is discussed in more detail in the Maintenance Safety section.

Because of the unique safety precautions associated with performing line maintenance tasks on inerting system components, specially trained line maintenance personnel would be required, similar to wet cell entry-skilled personnel. Some airlines may use contracted personnel to perform such tasks.

### **10.2.5 Maintenance Training**

To provide a safe working environment, operators are required to provide maintenance training before introducing an inerting system. Training instructors may need to modify their schedules, additional instructors may need to be hired, and training personnel may need to attend vendor and manufacturer classes. Afterward, these instructors will need to spend time adapting vendor training materials to their operators' standards. Only after the new training material is finished and approved by the local regulatory authorities can regularly scheduled classes begin for maintenance and ground support personnel. The variety of airplane fleets and available inerting systems will require mechanics and ground support personnel to be trained for all systems applicable to all airplane categories in the operator's fleet. This fuel tank inerting training requirement will consist of classroom lectures, jet airplane maintenance fundamentals, CBT courseware, and basic training workshops, as well as practical training on in-service airplanes after the new system is introduced.

## **10.3 OPERATIONAL IMPACT**

The installation and operation of a fuel tank inerting system on an airplane significantly affects the daily operations of that airplane, its flight crew, and its ground support personnel. System reliability affects flight schedules and airplane dispatch rate. Flight crews will have to monitor the system to maintain operational safety. Ground support personnel will have to service ground-based systems, and everyone working on or around the airplane will have to be aware of the potential hazards associated with working around large quantities of nitrogen.

### **10.3.1 Flight Operations**

Schedule, MEL and dispatch relief, lost revenue, operational safety, and training will likely have the greatest impact on flight operations. The following is a brief discussion of the severity of the impact in relation to the degree of restriction in a final rule. The impact ranges from inerting having a relatively minor impact on flight operations to its being rendered impractical in service.

#### **10.3.1.1 Schedule Impact**

Potential impacts to flight schedules will vary greatly depending on the type of inerting system used, the type of operation, and the availability of MEL and dispatch relief. Schedule delays from inadequate turn times are likely to be significant in those operations that routinely turn their airplanes around in less time than the systems were designed to accommodate. These types of delays are most likely to occur while using GBI. To minimize the potential impact on flight operations, we collected average minimum turn time data (fig. 10-4) from operators to determine the design goals for the inerting system concepts. This data was used by the Ground-Based Inerting Design and the Onboard Inerting Design teams to minimize the impact of inerting on airplane turn times. Under normal situations, the concept design goals preclude the requirement for extended gate time, however, some operators with very quick airplane turns could still be affected.

	Average minimum turn time (min)	Average airplane cycles per day	Airplane annual use rate
Small transport	20	7	2,869
Medium transport	45	3.5	2,792
Large transport	60	2	4,081
Business jet	60	1	500
Regional turboprop	15	6.8	2,117
Regional turbofan	15	7.1	2,957

Figure 10-4. Average Minimum Turn Times

The costs associated with such delays may be quantified by taking the percentage of flights that normally operate below the minimum scheduled time and multiplying it by the industry standard delay costs for each minute incurred.

MEL and dispatch relief, or lack thereof, have the greatest potential to escalate costs exponentially. The following section addresses this issue more fully. The installation implementation time for this proposal may also have a great effect if the modification cannot be accomplished during normally scheduled maintenance visits.

#### Airplane Out-of-Service Time

Most operators would not be able to schedule the inerting modification project during a regular heavy maintenance visit because of the scope of the project (app. F). The large number of required labor-hours would significantly extend the maintenance visit, which in turn would disturb the airline's operational schedule.

#### **10.3.1.2 MEL Relief**

The potential impact of MEL and dispatch relief, or lack thereof, cannot be emphasized enough, especially for onboard inerting systems. Without dispatch relief, every system malfunction would likely result in one or more flight cancellations. With estimated system failure rates ranging from two to six per year for each airplane, the average operator could experience 1,000 to 2,000 additional flight delays and cancellations per year.

#### **10.3.1.3 Lost Revenue**

The factor of lost revenue is an issue only on the percentage of flights operating at or near maximum takeoff weight for the specific flight. We took no other flights into consideration because the additional weight of the inerting system would not be expected to affect the planned revenue load. See appendix F for costs associated with this function. Cost to carry, however, must be applied to all systems on every flight. This is basically a function of design weight multiplied by the average industry cost per pound to demonstrate the increased fuel burn required to support the system. See appendix F for industry average costs to carry specific weights. These costs will vary greatly according to fluctuations in fuel prices. The costs associated with producing the power to run systems, such as electrical load, bleed load, or drag, will also need to be considered.

#### **10.3.1.4 Flight Operations Safety**

The major safety issues relating to flight operations are in regard to NEA leaking into the cockpit or passenger cabin and the accumulation of highly concentrated oxygen at or near a fuel source. Because of these concerns, it is recommended that nitrogen- and oxygen-level sensors be installed to provide a warning in case of a leak in critical areas. Flight crews and cabin crews will also need to be trained on how to react in the event of such an alarm. Under normal in-flight conditions, the air-conditioning system on an airplane will supply sufficient fresh air to prevent leaks from reducing the oxygen level in the cabin. However, under abnormal conditions and on the ground this may not be the case. We believe strongly that this warning system will be required to prevent subsequent loss of life in case of an unknown failure.

### **10.3.1.5 Flight Operations Training**

Flight operations training for the purpose of this report will include training requirements for both pilots and dispatchers. A general course should be administered to both groups describing the benefits and hazards associated with nitrogen inerting systems. Also, a review of the basic fire triangle and flammability characteristics of jet fuel should be conducted to familiarize both groups with the dangers associated with warm ullage temperatures. This will allow them to evaluate operational practices, such as ground air-cart usage on warm days, to control these circumstances. Dispatchers will also need to be trained to understand any dispatch deviation requirements necessary for dispatch with an inoperative inerting system. Pilot training requirements vary greatly depending on equipment type, inerting design, and operational environment. For example, a corporate pilot operating in or out of a remote airport may have responsibilities that a pilot in airline operations may not. A typical in-house training program would basically consist of a training bulletin followed up by a regularly scheduled module during recurrent training. Outside or contracted training would typically consist of a training program established by a commercial training facility and administered during special training events. Both would greatly benefit from an AC provided by the FAA to assist operators with developing training materials.

### **10.3.2 Ground Operations**

Installation and operation of any inerting system will affect ground operation regardless of which inerting concept is considered. Introduction of any system will add new considerations regarding safety, new tasks, or dealing with new support equipment. Obviously, GBI has the largest impact on ground operations because of the servicing requirement before each flight.

#### **10.3.2.1 Ground Operations Safety**

The safety training course for ground operations should include the hazards of nitrogen and other inert gases. Some gases such as nitrogen are particularly insidious because of their poor warning properties. Oxygen-depleted environments from the inerting process have been reported to cause fatalities to workers in confined spaces. NIOSH has provided data from a 10-year study (National Traumatic Occupational Fatalities Data) pertaining to the number of victims in single and multiple fatalities for all types of confined-space incidents.

A startling 585 separate fatal incidents in confined spaces claiming 670 lives occurred within the 10-year study period. This data strongly underscores the need for increased ground operational safety requirements by all operators before introducing any inerting systems. Because of the nature of this type of gas, confined areas such as cargo bins and equipment bays are particularly susceptible to this hazard.

The minimum ARAC recommendation is that all ground operation personnel be aware of these dangers and know what to do in the event that something goes wrong while using nitrogen to accomplish inerting. Airport fire, rescue, and safety personnel would also require additional training on the uses of nitrogen and confined-space rescue in airplane fuel tanks.

The possibility of overpressurizing the airplane fuel tanks is also a serious safety concern when using nitrogen to inert the ullage. This concern can be alleviated by having trained technicians safely and efficiently perform inerting.

#### **10.3.2.2 Ground Operations Training**

Mandatory awareness training on the dangers of using nitrogen in the quantities required to inert airplane fuel tanks is recommended. An 8-hr initial program should be provided for all technicians involved with installation and servicing.

We recommend up to a 4-hr annual recurrent program to maintain the heightened awareness on the hazards of working with nitrogen in these volumes. As an example, 1 hr could include a video on servicing while another hour encompasses troubleshooting and servicing. The remainder of the time can be used for applicable system training and open discussions. Other groups working on and around the airplane should also be aware of the dangers associated with nitrogen. These groups should receive recurrent safety training annually. These different groups should include but are not limited to cleaners, fuelers, baggage handlers, caterers, ticket and customer service agents, flight attendants, and pilots. The video, for example, may adequately educate these individuals on the dangers and cautions involved with nitrogen inerting.

For maintenance training purposes, a \$75 per hr rate provided by the FAA (app. G) establishes a value for estimating an operator's cost to properly train a technician to install and service inerting systems. All other group rates will vary respectively.

### **10.3.2.3 Ground Servicing**

With the above-mentioned dangers of using nitrogen to inert airplane fuel tanks, the servicing of airplanes with GBI systems should not be performed by ground service employees unless they are specifically trained maintenance technicians for the required inerting task. With the continual industry concerns with on-time performance, having the technician in place will help facilitate that process. Numerous discussions took place on this topic and this group concluded that, after the system has been in operation for several years, reconsideration could be given to who should perform the inerting task.

Trained technicians with a thorough understanding of the system and the consequences of improper operation would be better prepared to monitor and interrupt the inerting process at all times for diagnosis and troubleshooting of system anomalies. To enhance on-time performance, having a technician in place will provide the operator with immediate troubleshooting capability for a system discrepancy during the inerting process, thus minimizing any ground delay from maintenance problems associated with the inerting system. This process would require technicians in all airplane stations, and considerations should be given to contract maintenance personnel requirements at locations not staffed by operator-employed technicians.



## 11.0 ESTIMATING AND FORECASTING

### 11.1 METHODOLOGY

Cost-benefit analysis considers a range of costs and benefits in monetary terms. The benefits in this study include the prevention of potential airplane accidents and possible resulting injuries and fatalities from postcrash fires. This analysis accounts for the annual costs and benefits over a 16-year period from the first quarter of 2005 to the fourth quarter of 2020 (rule released first quarter 2005, designs completed first quarter 2008, fully implemented first quarter 2015, and end of study fourth quarter 2020). The analysis applies an inflation factor to the monetary values of both cost and benefit cash flows and discounts these cash flows to the year 2005. This allows the continuous stream of costs and benefits to be compared directly.

This analysis evaluated 13 different combinations of inerting, airplanes, and fuel tanks, as well as both a worldwide and a U.S.-only implementation (see fig. 11-1). The analysis was also divided into in-service, and new and future production airplanes. Freighter and passenger airplanes were evaluated separately.

Number	Inerting scenario	Fuel tanks	Airplanes	Systems
1	Onboard ground inerting	HCWT only	Large, medium, and small transports	PSA/membrane systems
2	Onboard ground inerting	All fuselage tanks	Large, medium, and small transports	PSA/membrane systems
3	Hybrid onboard ground inerting	HCWT only	Large, medium, and small transports	PSA/membrane systems
4	Hybrid onboard ground inerting	All fuselage tanks	Large, medium, and small transports	PSA/membrane systems
5	OBIGGS	All tanks	Large and medium transports	Membrane systems
			Small transports	PSA/membrane systems
6	Hybrid OBIGGS	HCWT only	Large and medium transports	Membrane systems
			Small transports	PSA/membrane systems
7	Hybrid OBIGGS	All tanks	Large and medium transports	Membrane systems
			Small transports	PSA/membrane systems
8	Ground-based inerting	HCWT only	All transports	—
9	Ground-based inerting	All fuselage tanks	All transports	—
10	OBIGGS	All tanks	Large and medium transports	Cryogenics systems
			Small transports	PSA/membrane systems
11	Hybrid OBIGGS	HCWT only	Large and medium transports	Cryogenics systems
			Small transports	PSA/membrane systems
12	Hybrid OBIGGS	All tanks	Large and medium transports	Cryogenics systems
			Small transports	PSA/membrane systems
13	Onboard liquid nitrogen inerting	—	—	—

Figure 11-1. Inerting Combinations Evaluated

#### Methodology Used to Quantify the Benefits

The following assumptions define the methodology used to estimate the benefits of an inerting system:

- The worldwide fuel tank explosion rate, as modified by the implementation of SFAR, provides an accurate model for future fuel tank explosion rates.
- Based on the DOT's latest estimate, the amount that society would pay to prevent a potential fatality is \$2.7 million.
- The average value of a destroyed airplane would be approximately \$20 million (Note: this is an average value that includes both new and older airplanes of different sizes that are susceptible to fuel tank explosions).

- Based on the Lockerbie, Scotland, investigation updated to 1997 dollars, the FAA estimates that investigation of an in-flight airplane explosion would cost the U.S. Government \$30 million. Although the cost of the TWA Flight 800 accident investigation will be considerably greater than \$30 million, that accident investigation cost was compounded by its location in the Atlantic Ocean. The number of fatalities for an in-flight accident is determined by the weighted average number of seats within each category multiplied by the weighted average load factor.
- The monetary value of the accidents is distributed annually and treated the same as the costs (i.e., escalated with inflation and discounted to year 2005).
- The estimated accident rate is based on the worldwide rate. The estimated number of accidents in the United States is based on the worldwide rate divided by U.S. operating hours.
- Each system's flammability exposure is used to calculate the expected benefits.
- Benefits for the U.S. fleet assume that N-registered airplanes are modified by the end of the implementation period (first quarter 2015). Benefits for the worldwide fleet assume that all airplanes have been modified by the end of the implementation period.

## **11.2 ECONOMIC MODEL FACTORS**

### Data Sources

This analysis used data constructed from several different sources, because no single database contained all the necessary data. Nevertheless, we believe that this data provides a sufficiently accurate base from which to complete a valid analysis. To the extent possible, this analysis used data from the 1998 ARAC fuel tank study.

The analysis based costs on 2000 US\$ and calculated costs for in-service, production, and future airplane designs separately. This study does not include costs for supplemental type certificate fuel tanks, regulatory flexibility analysis, or international trade impact assessments.

Airplane costs are divided into recurring and nonrecurring, and then into the first of a model and each of its follow-on derivative models. The derivative model costs are generally lower than those for the first of a model. Nonrecurring costs include

- OEM engineering hours, including modifications and additions to fuel system components, interfaces, instruments and displays, relocation of other equipment, wiring, tubing and ducting, and avionics software and modules.
- Documents, including specifications and internal control documents.
- Manuals, including Airplane Flight Manual, Operations Manual, and Maintenance Manual.
- Production change records.
- Lab, ground, and flight tests.
- FAA or JAA certification.

Airplane costs for parts and installation include

- Major supplier parts.
- Major assemblies.
- Tubing, wiring, and ducting.
- SB and kitting costs for retrofitting.
- Special tooling.
- Labor for planning, installation, and inspection of production airplanes.
- Airline engineering.
- Airline technical publications.

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- Material control.
- Initial maintenance training.
- Flight operations engineering.
- Installation labor.
- Airplane downtime.
- Consumables.

Annual airplane recurring costs include

- Maintenance checks and inspections.
- Unscheduled maintenance.
- Delay.
- Weight.
- Maintenance, ground service, and flight crew training.

Airport costs for ullage washing—both hydrant and cart systems—were divided into large, medium, and small airport costs. The nonrecurring costs include

- Engineering design.
- System installation labor, including relocation of other equipment.
- System parts and materials.
- Other equipment, including ground service equipment, electrical, and tooling.
- Emissions controls.

Recurring annual costs for the hydrant and cart systems include

- Nitrogen for washing.
- Washing labor.
- Washing power costs.
- Washing system maintenance, inspection, and training.

This study assumes that there is no systemic increase in airplane gate turn time. Appendix G lists added costs of a systemic delay caused by an inerting system. Turnaround times for the six airplane models are

- Large: 60 min
- Medium: 45 min
- Small: 20 min
- Regional turbofan: 15 min
- Regional turboprop: 15 min
- Business jet: 60 min

The cost analysis assumes that there are no cancellations, ATBs, or diversions for any of the systems.

This study assumes

- Fuel costs of \$1 per gallon (see *Air Transport World*, January 2001).
- Cost for professionals of \$110 per labor-hour (FAA estimate).
- Cost for technicians and mechanics of \$75 per labor-hour (FAA estimate).
- Cost for ground service personnel of \$25 per labor-hour (FAA estimate).

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The cost-benefit analysis assumed the ramp-up time for introducing a fuel tank inerting system into existing and current in-production fleets to be 7 years from design certification. The analysis assumed no constraints on engineering, manufacturing, parts, or facilities.

The analysis used the Campbell-Hill forecast of unconstrained growth to estimate annual changes in airplane model types, after adjusting the Campbell-Hill data for ARAC airplane categories. This weighted average growth rate is estimated at 3.6%.

For cost estimates of applying an onboard system to new airplane designs, this study assumed the designs could be optimized in the initial design phase to minimize initial and recurring costs.

Number of airports: worldwide total, 1,200 (85 large, 101 medium, 1,014 small)

Number of U.S. airports modified for U.S.-operated airplanes:

- B category: 31
- C category: 37
- D category: 354

Number of foreign airports modified for U.S.-operated airplanes:

- All categories: 158

The Airport Facility Task Team provided recurring and nonrecurring airport costs (except for inerting labor). Inerting labor estimates were based on 20 min for small airplanes, 25 min for medium airplanes, and 30 min for large airplanes at \$25 per hour for burdened ground service labor.

Airplane out-of-service costs are equivalent to the average lease rates for each airplane category.

Nonrecurring development and certification costs were based on the number of major and derivative airplane models within each category (large: 6 major, 16 derivative; medium: 3 major, 9 derivative; and small: 11 major, 42 derivative).

Airline per-fleet costs were based on an average of major and minor fleet costs.

The cost penalty per pound of added weight for each airplane category is based on 1998 ARAC cost estimates.

The worldwide and U.S. average nitrogen cost in US\$ is \$0.13 per 100 ft<sup>3</sup>.

### **11.3 STUDY PERIOD**

The costs and benefits are accounted for annually over a 16-year period from the first quarter of 2005 to the fourth quarter of 2020 (rule released first quarter 2005, designs completed first quarter 2008, fully implemented first quarter 2015, and end of study fourth quarter 2020).

### **11.4 IMPLEMENTATION**

We assumed that any proposed new rules would affect, at a minimum, both type certificate and supplemental type certificate design approval holders under FAR Parts 21 and 25, or equivalent.

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We also assumed that any proposed new operational rules would affect all turbine-powered transport airplanes with a type certificate issued to large, medium, and small transport category airplanes operated under FAR Parts 91, 121, 125, or 129, or equivalent.

**11.5 COST SUMMARIES**

Figures 11-2 through 11-5 are cost summaries of all the inerting scenarios considered for the worldwide fleet, U.S. fleet, world passenger-only fleet, and U.S. passenger-only fleet.

Summary of Inerting Scenario Results		World															
Values in Millions		Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 2 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 5 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 6 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 7 - Hybrid On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 8 - On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 9 - Hybrid On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 10 - Hybrid On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Transports	Scenario 12 - Ground Based Inerting HCWT only, All Transports	Scenario 13 - On-Board Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 14 - Hybrid On-Board Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 15 - Hybrid On-Board Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting
Total \$ Cost with Inflation		25,321	41,901	24,415	38,349	47,601	21,476	32,969	22,973	26,203	57,021	34,569	45,797	77,735			
NPV in 2005 of Cost		11,592	18,509	11,240	17,035	20,775	9,896	14,936	10,374	11,885	24,605	15,440	20,405	31,527			
Total Benefits		597	1,037	591	1,032	1,202	701	1,186	666	1,109	1,202	701	1,186	1,202			
NPV in 2005 of Benefits		219	381	217	379	441	257	435	245	407	441	257	435	441			

Figure 11-2. Cost Summary—Worldwide Fleet, All Transports

Summary of Inerting Scenario Results		US-Operator															
Values in Millions		Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 2 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 5 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 6 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSM-Membrane Systems	Scenario 7 - Hybrid On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 8 - On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 9 - Hybrid On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 10 - Hybrid On-Board Ground Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Transports	Scenario 12 - Ground Based Inerting HCWT only, All Transports	Scenario 13 - On-Board Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 14 - Hybrid On-Board Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 15 - Hybrid On-Board Inerting HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSM-Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting
Total \$ Cost with Inflation		10,082	15,367	9,744	14,203	17,047	8,606	12,680	10,429	11,588	20,924	13,586	17,414	27,692			
NPV in 2005 of Cost		4,849	7,099	4,721	6,613	7,753	4,185	5,968	4,758	5,314	9,357	6,299	8,015	11,656			
Total Benefits		233	434	231	432	497	274	492	258	459	497	274	492	497			
NPV in 2005 of Benefits		86	159	85	159	183	101	181	95	169	183	101	181	183			

Figure 11-3. Cost Summary—U.S. Fleet, All Transports

Summary of Inerting Scenario Results		World - PAX Only															
Values in Millions		Scenario 1 - On-board Ground Inerting HCWT only, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 2 - On-board Ground Inerting HCWT only, Tank, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 3 - Hybrid On-board Ground Inerting HCWT only, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 4 - Hybrid On-board Ground Inerting HCWT only, Tank, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 5 - On-board Ground Inerting All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 6 - On-board Ground Inerting All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 7 - Hybrid On-board HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 8 - Hybrid On-board All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 9 - On-board Ground Inerting HCWT only, All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 10 - On-board Ground Inerting HCWT only, All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 11 - On-board Ground Inerting HCWT only, All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 12 - On-board Ground Inerting All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 13 - On-board Ground Inerting All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 14 - Hybrid On-board HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 15 - Hybrid On-board All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 16 - On-board Liquid Nitrogen Inerting
Total \$ Cost with Inflation		21,474	34,897	20,722	32,007	39,168	18,015	27,575	21,285	24,085	47,094	28,866	38,157	65,236			
NPV in 2005 of Cost		9,936	15,576	9,644	14,371	17,248	8,376	12,590	9,600	10,907	20,489	12,994	17,129	26,698			
Total Benefits		597	1,037	591	1,032	1,202	701	1,186	668	1,109	1,202	701	1,186	1,202			
NPV in 2005 of Benefits		219	381	217	379	441	257	435	245	407	441	257	435	441			

Figure 11-4. Cost Summary—Worldwide Fleet, Passenger Planes Only

Summary of Inerting Scenario Results		US-Operator - PAX Only															
Values in Millions		Scenario 1 - On-board Ground Inerting HCWT only, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 2 - On-board Ground Inerting HCWT only, Tank, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 3 - Hybrid On-board Ground Inerting HCWT only, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 4 - Hybrid On-board Ground Inerting HCWT only, Tank, Large, Medium, Small Transports, PAM-Membrane Systems	Scenario 5 - On-board Ground Inerting All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 6 - On-board Ground Inerting All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 7 - Hybrid On-board HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 8 - Hybrid On-board All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 9 - On-board Ground Inerting HCWT only, All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 10 - On-board Ground Inerting HCWT only, All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 11 - On-board Ground Inerting HCWT only, All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 12 - On-board Ground Inerting All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 13 - On-board Ground Inerting All Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 14 - Hybrid On-board HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 15 - Hybrid On-board All Tank, Large and Medium Transports, Membrane Systems & Small Transports, PAM-Membrane Systems	Scenario 16 - On-board Liquid Nitrogen Inerting
Total \$ Cost with Inflation		7,588	10,898	7,352	10,149	11,675	6,349	9,194	9,321	10,207	14,550	9,868	12,474	19,817			
NPV in 2005 of Cost		3,768	5,215	3,678	4,896	5,491	3,166	4,442	4,246	4,672	6,698	4,692	5,884	8,598			
Total Benefits		233	434	231	432	497	274	492	258	459	497	274	492	497			
NPV in 2005 of Benefits		86	159	85	159	183	101	181	95	169	183	101	181	183			

Figure 11-5. Cost Summary—U.S. Fleet, Passenger Planes Only



## 12.0 REGULATORY IMPACT

Fuel tank inerting systems affect regulations embracing type certification, airplane operations, maintenance operations, and (possibly) airport facilities. This section addresses the impact on the regulations of these areas.

### 12.1 TYPE CERTIFICATION

#### 14 CFR Part 25

The certification of a fuel tank inerting system would involve two aviation regulations:

- *Flammability Rule*—sets flammability exposure standards for which an inerting system may be designed to reach compliance.
- *Inerting System Rule*—governs the design of inerting systems.

#### Flammability Rule

The purpose of the Flammability Rule is to regulate the allowable flammability level of the fuel tank ullage.

Because the FTIHWG has determined that all fuel tank inerting systems are impracticable in accordance with the FAA regulatory evaluation requirements, new regulatory content cannot be recommended for a Flammability Rule. Therefore, no change is recommended to the text of the current Flammability Rule (14 CFR §25.981(c), introduced by FAR Amendment 25-102, effective June 6, 2001) to establish a new acceptable minimum flammability level that is equivalent to that which could be achieved by an inerting system design concept.

This decision is based on the overall work of the FTIHWG, which used the following ground rules established by the FAA Tasking Statement:

- “Flammability” is defined as the susceptibility of the fuel/air vapor (ullage) present in a fuel tank to readily ignite or to explode.
- For the proposed regulatory text, fuel tank inerting could be an acceptable method of compliance.
- Flammability is to be treated independently from fuel tank ignition prevention.
- A performance-based definition provides the applicant with a set of design requirements, not a prescriptive design requirement.
- Flammability reduction only through fuel tank inerting was to be considered by the FTIHWG, which was asked not to address or consider other methods for controlling the flammability of fuel tank ullage.

The pros and cons of five different regulatory text proposals were evaluated against the 13 fuel-tank-inerting design proposals. No improvements to the current regulatory text could be found because the current text clearly states that *in the context of this rule, ‘minimize’ means to incorporate practicable design methods to reduce the likelihood of flammable vapors*. This wording allowed current applicants to comply with the Flammability Rule without being required to incorporate an inerting system, which the FTIHWG determined not to be practicable.

The team decided to discard the other options (discussed in app. I) because they were

- Not practical to impose a numerical limitation because of the lack of an industry-agreed pass/fail criteria (option A).

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- Too shortsighted to limit the rule to a flight phase considering that the “risk” may occur in a flight phase other than ground (option B).
- Too restrictive for inerting and the Tasking Statement because the primary means of compliance would be through heat control (option C).
- Linked to ignition source control and, therefore, outside the scope of the Tasking Statement. Not practical to impose a numerical limitation because of the lack of an industry-agreed pass/fail criteria (option D).

### *Flammability Assessment—Guidance Material*

Because of the adverse results of the cost-benefit evaluation performed by the FTIHWG, we recommend not to set a flammability design objective that is achievable only with an inerting system.

We therefore recommend that, if possible, the FAA formulate with industry experts a flammability evaluation method and follow-on flammability standard that meet the FAA regulatory evaluation requirements.

### *Inerting System Rule*

Although the FTIHWG determined that fuel tank inerting systems were not practicable, the existing Flammability Rule, 14 CFR §25.981(c), does not preclude an applicant from voluntarily fitting an inerting system on its airplane.

If an inerting system is fitted, the Rulemaking Task Team determined that certain design features should be regulated within the inerting system design. This control can be done either by means of a special condition or by a change to 14 CFR Part 25.

This determination was made following a certification-compliance evaluation of the proposed ground-based and onboard inerting designs. The evaluation considered the inerting system’s safety, design (including installation requirements), and operational performance requirements.

This review process identified a total of

- Three insufficiencies in 14 CFR 1-1-00 Edition (current regulation could be slightly modified to address the specifics of the inerting design).
- Thirty-six applicable paragraphs in 14 CFR 1-1-00 Edition, but not requiring regulatory text modifications.
- Three new concerns unique to inerting systems.

Because of the number of considerations that must be regulated within a fuel system inerting design, the team recommends that a dedicated 14 CFR Part 25 paragraph titled “Fuel Tank Inerting System” be adopted if inerting systems are to be installed on transport category airplanes. This paragraph should be worded in such a way that it can apply to both ground-based and onboard inerting systems. A proposed wording is provided later in this section.

### *Inerting System—Guidance Material*

If inerting systems are to be considered as aviation equipment, guidance material needs to be prepared and published. This guidance material should be consistent with the inerting technology under certification.

14 CFR Part 21

14 CFR Part 21 provides airplane certification procedure for products and parts. It was reviewed to determine if any current certification procedures would need to be changed if inerting systems were implemented on transport category airplanes.

The FTIHWG concluded that there is no impact on the current regulations versus type certification or modification activities.

The team also concluded that 14 CFR Part 21 is affected if the FAA were to initiate a retroactive rule action. The retroactive rule action would require a change to 14 CFR Part 21, which is the SFAR section. The SFAR regulatory action would need to state the airplane applicability and the required compliance, including the task accomplishment statement and FAR 25 rule references, the time frame for compliance, and the reference to any maintenance or inspection activities.

**12.2 MAINTENANCE AND AIRPLANE OPERATIONS**

The Rulemaking Task Team identified and assessed the following 14 CFR sections that relate to airplane maintenance and operations, considering that either a ground-based or onboard inerting system was installed in the airplane:

- Part 43, Maintenance, Preventative Maintenance, Rebuilding, and Alteration.
- Part 91, General Operating and Flight Rules.
- Part 121, Operating Requirements: domestic, flag, and supplemental operations.
- Part 125, Certification and Operations: airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 or more.
- Part 129, Operations: foreign air carriers and foreign operators of U.S.-registered airplanes engaged in common carriage.

The Part 43 assessment was carried out independently.

The other parts were assessed using Part 121. That is, the team assumed that any change applicable to Part 121 could be read over to Parts 91, 125, and 129. This assumption was made based on the FAA's ignition source prevention activity (NPRM 99-18/SFAR no. 88, effective June 6, 2001).

The team did not consider Part 135 operating requirements, which cover commuter and on-demand operations. The Rulemaking Task Team decided that the FAA could adapt the recommendations made for 14 CFR Parts 91, 121, 125, and 129 to other similar 14 CFR sections.

The Rulemaking Task Team also assessed the impact on retroactive rulemaking.

Maintenance and Airplane Operational Regulations

**14 CFR Part 43.** The Rulemaking Task Team determined that, if a fuel tank inerting system were installed on an airplane, the 14 CFR Part 43 standards did not need to be modified. Today's standards can adequately accommodate an inerting system.

**14 CFR Parts 91, 121, 125, and 129.** The Rulemaking Task Team determined that the type of inerting design and the final decisions by the designers, airlines, and operators would greatly influence the types of changes needed for 14 CFR operational sections.

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The following conclusions are provided:

*General Conclusions.* The Rulemaking Task Team recognized that the regulatory impact of the operational sections of 14 CFR sections may go well beyond the conclusions made within this report.

The group acknowledged that, if inerting systems were incorporated, considerations on how to grant MMEL relief in accordance with prescribed FAA procedures need to be further studied. The number of potential installations, the complexity of these installations, and the method by which they are introduced all influence allowed MMEL.

*Regulatory Impact on All Fuel Tank Inerting Systems.* Three specific concerns that affect the regulations and apply to all inerting systems were identified:

- The requirement to have an approved operational and maintenance program.
- Assurance that NEA (oxygen-depleted air) cannot physically harm passengers and crew.
- Statement of when and under what conditions an airplane may need a fuel tank inerting system.

**Approved Operational and Maintenance Program.** The team recommends that the regulatory change be presented in a new 14 CFR 121 (or equivalent) paragraph in a manner similar to §121.629, Operation in Icing Conditions. In this way, all the information can be found in one place and not dispersed between a variety of paragraphs. A proposed wording is offered later in this section.

**NEA's Physiological Effects.** Because nitrogen-enriched or oxygen-depleted air can physically harm passengers and crew in confined spaces without adequate ventilation, we propose that §121.229(c), Location of Fuel Tanks, be amended to state that nitrogen gas should be isolated from personnel compartments. The isolation should be shown for nitrogen gas present in both the fuel tanks and the inerting system equipment (pipes, valve, and so on).

**Conditions Under Which a Fuel Tank Inerting System Is Installed.** If the FAA decides to mandate fuel tank inerting systems, then the perceived role of this system should be stated within 14 CFR Part 121 (or equivalent).

The team recommends creating a new §121.300 paragraph to state when and under what conditions airplanes may need a fuel tank inerting system. This may be accomplished by a sentence stating that a fuel tank inerting system may be installed on an airplane as a means of meeting the requirements of §25.xxx of the chapter in effect on a given date.

An alternative recommendation is to modify §121.316, Fuel Tanks, using the same wording.

**Ground-Based Inerting Systems.** For GBIS, five additional regulatory paragraphs need to be created or modified. We have identified the concept of what these paragraphs should contain. Specific regulatory changes should be reviewed with the operational specialists using a design concept for in-service use.

The Rulemaking Task Team's conclusions on these impacts were based on three facts:

- Ground-based inerting is a specific action that requires a specific, independent procedure.
- Ground-based inerting cannot be accomplished without the complementary airport facilities.
- The operational program will be developed using procedures inherent to the ground-based inerting design concept.

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Because ground-based inerting systems are not self-contained aboard the airplane and thus require interface with the airport and ground personnel, the team recommends that the new fuel tank regulatory paragraph make references to other applicable paragraphs within 14 CFR.

The team proposes that five additional 14 CFR 121 paragraphs be modified (or concepts be included within the new fuel tank inerting paragraph):

- §121.97, Airports: Required Data—add nitrogen supply capability under (b)(1), Airports.
- §121.105, Servicing and Maintenance Facilities—include nitrogen supply capability in equipment example.
- §121.117, Airports: Required Data—add nitrogen supply capability under (b)(1), Airports.
- §121.123, Servicing Maintenance Facilities—include nitrogen supply capability in equipment example.
- 121.135(b)(8), Contents, information contained in the manual—add new equipment, (b)(25), concerning inerting facilities or modify (b)(18) to add inerting to the refueling procedures.

### Onboard Inerting Systems

**OBIGGS.** For onboard inerting systems, we anticipate no impact on the operational regulatory sections; no additional paragraphs were identified for creation or modification.

If pressure-vessel air is used for inerting, regulatory changes may need to be implemented somewhere in the 14 CFR code to ensure that cabin air pressure is maintained as the airplane ages or if it is dispatched on MMEL relief with an inoperative pack.

Onboard hybrid systems may require the regulatory modifications as described under ground-based inerting, recognizing that the airport facility requirements would be different (onboard ground electrical source requirement; ground-based inerting nitrogen supply requirement). Specific regulatory changes should be reviewed with the operational specialists using a design concept proposed for in-service use.

The Rulemaking Task Team's conclusion was based on three facts:

- Onboard inerting is a system integral to the airplane; airport facilities are not needed.
- The activation of the onboard system would be done on the airplane (automatically or manually).
- The team determined that the operational program would be developed using procedures inherent to the onboard inerting design concept.

**OBGI.** If an onboard ground system is developed, both ground-based inerting recommendations should be considered, recognizing that the airport facility requirements would be different (onboard ground electrical source requirement; ground-based inerting nitrogen supply requirement).

**Impact on 14 CFR Part 121 (or equivalent) Subparts L, N, and T.** Given the amount of knowledge that the Rulemaking Task Team had on the inerting systems and their impact on airplane operations, it concluded that there was no impact on Subparts L, N, and T. The current wording is sufficient to ensure proper training on inerting systems. Modifications or new paragraphs may need to be introduced once an inerting system is actually proposed for in-service use.

**Retroactive Rule Action.** A retroactive rule would be initiated by FAA decision and by a simultaneous change to 14 CFR Parts 21 and 121 (or equivalent). The retroactive rule needs to be closely coordinated within both the FAA's certification and airworthiness standard branch and the Aircraft Evaluation Group. The FAA needs to consider carefully any retroactive rule action against its impact on the MMEL or MEL.

FAR 121.300 will have to be updated to be in line with the SFAR (FAR 21) rule change. The new 121 rule will have to contain provisions concerning time required to introduce the new rule, airplanes affected, operational requirements, and any grandfather clauses (especially if there is a time factor linked to equipping domestic and foreign airports).

Operational Guidance Material

An operator will need to have an approved inerting maintenance and operational program. This program is very important because there is a risk of death if nitrogen is not handled properly. Guidance material should be issued to that effect before any inerting system is operated.

Considering that no commercial aviation operation has ever operated or maintained a fuel tank inerting system, the guidance material should be updated on a regular basis until the subject becomes mature.

### **12.3 AIRPORT FACILITIES**

The Rulemaking Task Team assessed 14 CFR Part 139 as to whether the standards for certification and operation of airports serving certain carriers would be affected by fuel tank inerting systems.

The team determined that one change to 14 CFR Part 139 standards would be needed if ground-based inerting were implemented.

The regulatory change could be justified in one of two ways: (1) regulate the safety of the public and airport when handling nitrogen and (2) regulate the hazard of the airplane and state that the airport must ensure that this hazard does not exist. The proposed regulatory text composition is found in the regulatory text section 12.5.2.

No changes to 14 CFR Part 139 have been identified if onboard inerting were to be implemented.

### **12.4 ENVIRONMENTAL**

There is currently no regulatory impact identified from the increase in the amount of VOCs vented from the fuel tank as a result of inerting.

It was determined that 14 CFR Part 34, Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes, would not be affected because these regulations concern the intentional discharge of liquid fuel to the atmosphere that is drained from the nozzle manifold after the airplane gas turbine engines are shut down.

### **12.5 REGULATORY TEXT AND GUIDANCE MATERIAL**

The FAA Tasking Statement requested that the FTIHWG do the following:

- Review existing regulations, advisory material, and continued airworthiness instructions concerning the elimination or reduction of the flammable environment in the airplane fuel tank system.
- Prepare regulatory text for new rulemaking by the FAA to eliminate or significantly reduce the flammable environment in airplane fuel tank systems.
- Develop and propose guidance material for all recommended system concepts that describes the necessary analysis, testing, or both that may be required to show compliance with the new regulatory text for certification and continuing airworthiness.

The Tasking Statement further requested that the FTIHWG propose recommendations based on achieving the lowest flammability level that can be provided by an inerting system design that would meet FAA regulatory evaluation requirements.

In this section, we summarize the regulatory assessment method, provide specific regulatory text recommendations, and present an overview of potential guidance material that is associated with the regulatory text proposals.

### **12.5.1 Methodology**

This section describes the method adopted by the Rulemaking Task Team to meet the requirements stated above.

#### *Basic Assumptions*

The Rulemaking Task Team assumed that both the ground-based and onboard inerting designs would be certified and used. This broad assumption was made because the absolute and relative practicality of these individual design approaches was not known.

#### *Determination of 14 CFR Sections to Be Evaluated*

The team examined the airplanes used to determine which sections of 14 CFR might be affected by the two inerting designs. The team confirmed that, at a minimum, airplane certification, maintenance, operational approval, and airport facilities would be affected. The team concluded that an assessment of the major issues affecting 14 CFR could easily be transferred to a Joint Aviation Requirements assessment if final rulemaking were pursued.

#### *Analyses of the Regulatory Impact on the Existing Codes*

The Rulemaking Task Team then used the design concepts developed by the other FTIHWG task teams to analyze the impact on the existing regulations, advisory material, and continued airworthiness instructions. This analysis was performed throughout the FTIHWG process to ensure that all design issues were accounted for in the final 14 CFR change recommendations.

#### *Development of Guidance Material*

The team developed guidance material to support the 14 CFR change proposals.

#### *Flammability Regulatory Text Proposals*

Finally, regulatory text was proposed within the FTIHWG that could be used by the FAA to regulate an airplane's fuel tank environment to the level of flammability reduction achieved by a practicable inerting system design concept. The Rulemaking Task Team highlighted the pros and cons of each proposal, including its possible certification interpretations and its capability to allow an inerting system as an acceptable means of compliance.

#### *Certification Cost Assessment*

The Rulemaking Task Team calculated a certification cost estimate for both ground-based and onboard inerting systems. These costs were inputted into the overall cost-benefit study.

HWG Flammability Regulatory Text Recommendation

The FTIHWG was tasked with determining which proposal, if any, to recommend. This recommendation would be based on the outcome of the regulatory evaluation for new rulemaking as required by the Tasking Statement.

**12.5.2 Regulatory Text**

Flammability Regulatory Text Proposal

No new regulatory text is proposed because there are no inerting systems that are practicable. Therefore, a minimum allowable flammability level based on an inerting design concept cannot be incorporated into a regulatory text.

Inerting System Regulatory Text Proposal

An applicant who decides to incorporate an inerting system should include a minimum number of design precautions for the system. The regulatory text proposal in this section provides words that address the concerns identified within the certification compliance evaluation. This text can be used either as a special condition or be added as a new paragraph to 14 CFR Part 25.

*§25.xxx Fuel Tank Inerting System*

*If, in order to show compliance with §25.981(c), a fuel tank inerting system is installed,*

*(a) the fuel tank inerting system must not, under normal and failure conditions:*

- (i) allow any inerting agent leakage into the pressurized or personnel compartments, or confined spaces; and*
- (ii) allow overpressure of the fuel system.*

*(b) The fuel tank inerting system must have:*

- (i) A connecting port such that a cross-connection with any other supply line is not possible (applicable if supplied by an external inerting gas source).*
- (ii) At each inerting agent filler opening and each airplane opening leading to direct contact with the inert gas, a placard at or near the filler cover or opening with the words "Fuel tank inerting" and the agent denomination.*
- (iii) A means to prevent the escape of hazardous quantities of fuel from the system in the case of loss of system supply pressure.*
- (iv) A shutoff or isolation means, whose failure to function is evident, that prevents undesirable system functioning and possible fuel leakage.*
- (v) A tolerance to variable inerting gas pressures or surges in the gas delivery system.*

*(c) Cautions (placards) and warnings (indication system) should be provided to prevent unintentional entry into a confined space filled with a hazardous inert gas.*

*(d) The characteristics and designation of the inert gas that ensure correct operation of the fuel tank inerting system shall be recorded in the operating limitations section of the Aircraft Flight Manual or equivalent.*

Maintenance and Airplane Operational Regulatory Text

If an inerting system is installed on an airplane, then a new 14 CFR 121 (or equivalent) paragraph should be introduced in a manner similar to §121.629, Operation in Icing Conditions. In this way, all the information can be found in one place and not dispersed between a variety of paragraphs.

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The fuel tank inerting paragraph should include the following topics and include or refer to specific concerns that are only relevant to ground-based inerting operations or onboard inerting operations.

*§121.xxxx (or equivalent) Operation of Fuel Tank Inerting System.*

- (a) A section providing a statement of the dispatch or release condition of an airplane containing a fuel tank inerting system.*
- (b) A section providing a requirement for an approved fuel tank inerting program including details of:*
  - (i) How the certificate holder determines that he or she needs to inert the airplane fuel tanks.*
  - (ii) Who is responsible for this decision.*
  - (iii) The procedures for implementing this decision.*
  - (iv) The specific duties and responsibilities of each operational position.*
  - (v) Define confined space procedure for the inerting system.*
  - (vi) Initial and annual recurrent ground training and testing for all affected personnel that addresses the:*
    - Identification of system limitations (e.g., minimum time to inert on landing or before takeoff).*
    - Creation of communication procedures.*
    - Identification of flight crew's role at dispatch and at landing.*
    - Identification of the nitrogen's specifications and characteristics.*
    - General conditions under which the more specific requirements are alleviated.*

More specific regulatory text wording was not developed because it was undetermined at the time of the evaluation which if any of the inerting systems would be practicable.

### *Airport Facilities Regulatory Text*

If ground-based inerting were to be implemented, then a regulatory text change to 14 CFR Part 139 would be recommended to ensure that the services are available to carry out ground-based inerting.

The regulation should address

- The availability of nitrogen gas.
- Facility, procedures, and personnel training standards.
- Infrastructure to ensure that airplanes are inerted within a minimum time before their next scheduled departures.

More specific wording was not developed because of the immaturity and impracticality of ground-based inerting.

### *Environmental Regulatory Text*

There are no regulatory text proposals associated with addressing environmental concerns because no regulatory impact has been identified.

### **12.5.3 Intent of Proposed Guidance Material**

The Rulemaking Task Team developed guidance material to support the regulatory text recommendations.

The Rulemaking Task Team defined a working methodology, developed the foundation of a guidance material proposal using the work developed within the FTIHWG, and formed recommendations for further improvements.

#### *Methodology Used to Develop the Inerting System Guidance Material*

The regulatory text change review identified four core subjects:

- Retroactive rule, SFAR (14 CFR Parts 21 and 121).
- Design and certification (14 CFR Parts 25 and 34).
- Operation and maintenance (14 CFR Parts 43, 91, 121, 125, and 129).
- Airport facilities (14 CFR Part 139).

The Rulemaking Task Team developed guidance material for two of the four subjects:

- Design and certification (14 CFR Parts 25 and 34), further split into two topics:
  - Flammability Rule guidance material.
  - Inerting System Rule guidance material.
- Operation and maintenance (14 CFR Parts 43, 91, 121, 125, and 129) as applicable to the use of an inerting system.

The team determined that the retroactive rule did not need associated guidance material by nature and that issues surrounding airport infrastructure were too immature to develop effectively.

#### *Flammability Rule Guidance Material*

The Rulemaking Task Team agreed that the flammability regulatory text (or the existing FAA flammability recommendation, where a flammability regulatory text could not be recommended) should be associated with some guidance material.

The purpose of the guidance material should be to define the “standard” by which the applicant’s product is going to be evaluated and judged acceptable. It should be used to identify the design, the procedures, or both that are needed to ensure the safety of the airplane design. The guidance material should not identify how to design a system. For example, the guidance material associated with this rule should not provide advice to an applicant on how to design and operate a fuel tank inerting system.

The standard should be subdivided into four subtopics:

- The circumstances for conducting an assessment of flammability.
- The decision to pursue regulatory text evaluation.
- The assessment of the flammability—the state under which the product needs to be placed to obtain the parameters needed to make a judgment on performance (i.e., the “playing field” and “rules of the game”).
- The standard itself—the basis on which the compliance decision will be based (determination of compliance).

The team agreed that an acceptable performance-based rule is one in which the regulatory text and the standard are compatible and ensure an equivalent safety level across all product lines.

**Development of the Standard as Limited by the Tasking Statement.** The Tasking Statement limited the team's ability to develop a flammability standard. The Tasking Statement required the team to determine whether fuel tank inerting could be used as the practicable industry standard to show compliance with a flammability regulatory text. The FAA considered that subtopics a through c were addressed by FAA AC 25.981-2.

**Development of a Standard Excluding the Tasking Statement Instructions.** Some team members felt that if the FTIHWG were to endorse or create a flammability regulatory text, then all subtopics within the standard's definition should be addressed irrespective of the Tasking Statement.

The team decided to discuss each subtopic and document its general concerns. These concerns could then be expanded as appropriate to the regulatory text development.

**Circumstances for Conducting an Assessment of Flammability.** AC 25.981-2 provides guidance in this area. However, some team members felt that a flammability rule should not be applied to fuel tank ullage if all the mechanical and electrical potential ignition sources were removed.

This determination could be made by developing a qualitative pass/fail criterion; no credit is given for probability of failure. The design either complies with the condition (i.e., "pass") or it does not (i.e., "fail"). If the applicant passes the checklist, then the flammability regulatory text is not applicable.

**Decision to Pursue Regulatory Text Evaluation.** The team agreed that the purpose of the flammability regulatory text needed to be clearly stated within the guidance material.

The airplane design goal (airplane safety objective) needs to be stated. Any performance-based words (e.g., "minimize" or "limit") need to be defined. The goal can be defined as specific (e.g., X% flammability exposure) or can be defined by a design assessment associated with a pass/fail criterion.

Some team members felt that the guidance material should give credit for mitigation of ignition sources by either of two means:

- Protection of the fuel tank from structural and systems damage in the event of an ignition of the tank's fuel/vapor air mixture.
- Snubbing of the spark before it comes in contact with the flammable fuel/air vapor mixture so that ignition does not occur.

In the first of the above approaches, an example of an acceptable means is the use of appropriate foam. The fuel tank is filled with a type of foam that ensures the control of the pressure rise following ignition of the fuel/air vapor mixture.

**Assessment of the Flammability.** AC 25.981-2 provides a method to determine the average flammability exposure of a given tank.

Some team members raised concerns over whether an average flammability exposure calculation really provides the correct type of assessment needed to prevent the "accident risk."

The team estimated that at least seven parameters needed to be assessed to determine whether in fact the accident risk has been mitigated:

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- *Influence of outside ambient air temperature.* ISA/ISA +73.4°F variation can be used to determine operational limitations and measure the effectiveness of any design or operational changes based on outside conditions.
- *Effect of fuel loading on the fuel tank heat transfer characteristics.* The results can be used to show the thermodynamic influence of fuel on the overall ullage cooling behavior and resultant flammability exposure.
- *Thermodynamic characteristics of each piece of equipment or each system.* The results can be used to identify the contribution of each piece of equipment or each system to the overall ullage characteristics. This in turn can be used to identify design changes or operational constraints (e.g., MMEL or ground operation procedures).
- *Influence of ground operation time.* The results can be used to understand the influence of ground operation on the fuel tank ullage temperature. The results can be used to substantiate design decisions or operational procedures.
- *Identification of hot spots.* The results can identify whether there is a local change in the flammability characteristics of the ullage.
- *Differences or similarities between the tanks.* The results can identify whether any tank has an unusual thermodynamic characteristic as compared to the others. The reason for this difference can be evaluated and then used to determine whether any design or operational actions need to be taken.
- *Identification of the degree to which a design is influenced by natural physical properties versus by design choices.* The results can be used to establish a comparison basis with ambient conditions. The results from the unheated configuration show the flammability exposure characteristic of the design based only on fuel loading, pressure, and aerodynamic effects. The results from the heated configuration show the influence of the internal fuel system mechanical components and the adjacent systems on the flammability exposure. The comparison of heated and unheated results can be used to show the direct benefit on flammability exposure of any design or operational changes under a certain fuel loading and outside ambient air condition.

Team members agreed that probably both the average risk and specific risk were needed to ensure that all hazards were addressed within the design.

**Determination of Compliance.** Team members voiced concerns over use of subjective, imprecise words and phrases such as “minimize” or “limit the development.”

Experience has shown that differing opinions between the applicant and regulatory authority as to what constitutes “minimize” or “limit” has led to costly delays in some certification programs.

Industry team members encouraged the FAA and the JAA to work with them as an industry group to develop a process and associated numerical conditions by which the word “applicable” can be judged. An example of a process is a flowchart that provides acceptable design conditions and choices about how to proceed depending on conditions. An example of a numerical condition is an average flammability exposure percentage or a temperature limit.

### *Inerting System Rule Guidance Material*

The guidance material was created using the fuel tank inerting systems design proposals of two FTIHWG design teams and the regulatory evaluation assessment.

The team recommends, however, that this guidance material be refined using real fuel tank inerting design concepts that are proposed for in-service airplanes.

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The objective of the guidance material is to provide information and guidance on the design, installation, and certification of an NEA inerting system. It can then be used, if desired, to create an FAA AC pertaining to fuel tank inerting systems.

The team assumed that the applicant chose to install an NEA inerting system on one or all of its airplane's fuel tanks. The design objective of the inerting system is to reduce or eliminate the flammable environment created in the fuel tanks' fuel/air vapor ullage (the means by which to show compliance to FAR/JAR 25.xxx).

The team took for granted that this guidance material would not become mandatory and would not constitute a regulation. Its purpose is to provide the applicant with advice and a method of compliance that has been found acceptable to the FAA and the JAA (certifying authorities).

### ***Maintenance and Airplane Operations Guidance Material***

The guidance material was created using the fuel tank inerting systems design proposals of two FTIHWG design teams, the regulatory evaluation assessment, and guidance material written on systems that interface with airport facilities or systems that are implemented because of environmental concerns.

The team recommends that this guidance material be refined using real fuel tank inerting design concepts that are proposed for in-service airplanes.

The objective of the guidance material is to provide

- Information and guidance on the operation and maintenance of an NEA inerting system.
- Guidance in obtaining approval for a fuel tank inerting program.

This material may be used, if desired, to create an AC pertaining to fuel tank inerting systems.

The team assumed that the airplane had a fuel tank inerting system (ground or onboard) installed and that the applicant (AC user) is an operator seeking to gain approval of its fuel tank inerting maintenance and operation program.

The team took for granted that this guidance material would not become mandatory and would not constitute a regulation. Its purpose is to provide the applicant with advice and a method of compliance that has been found acceptable to the FAA and the JAA (certifying authorities).

#### **12.5.4 Guidance Material**

Guidance material was developed for

- Fuel tank inerting system—design, installation, and certification.
- Fuel tank inerting system—operation and maintenance.

This section provides a general overview of the contents of each guidance material evaluation.

#### ***Fuel Tank Inerting System—Design, Installation, and Certification***

The detailed guidance material proposal is found in appendix I, attachment 1. It complements the guidance material already published in AC 25.981-2. That AC describes the general concept of an inerting system, whereas this proposal discusses not only the general concept but specific design considerations as well.

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This guidance material provides an overview and background details about its purpose, background, related documents, and definitions and abbreviations.

The guidance material then discusses the general concept of fuel tank inerting and explains the fundamental principles behind the different fuel tank inerting design concepts (based on the FTIHWG's design concept studies). This section further provides an applicant with information concerning the flight phases for which the design is most likely effective, the general impact on the airplane design and operation (system criteria and operational impact, including airport facilities interface), and specific information concerning dedicated inerting system equipment.

Also discussed are specific concerns relating to

- System installation considerations.
- Airplane interfaces.
- Certification plan and compliance demonstration.
- Continued airworthiness and maintenance considerations.
- Nitrogen precautions.
- Environmental impact.
- MMEL assessment.

If inerting systems are installed on airplanes, the team recommends that either AC 25.981-2 be expanded to include fuel tank inerting design considerations, or that a dedicated AC titled "Fuel Tank Inerting Design and Certification" be created.

It is recommended that any AC be again reviewed using an actual certified inerting design because the design considerations recommended in this guidance material are based on hypothetical designs. The lessons learned during an actual design project may assist others in designing and certifying airplanes.

### *Fuel Tank Inerting System—Operation and Maintenance*

The detailed guidance material proposal is found in appendix I, attachment 2. There are no other known recommended guidance material or ACs existing in the public domain.

The guidance material provides an overview and background details about its purpose, background, related documents, and definitions and abbreviations. This material then states that all fuel tank inerting operation and maintenance programs will contain six parts:

- Management plan.
- Dispatch conditions, including any timetables.
- Operations manual—inerting operational procedures.
- Maintenance program—maintenance manual.
- Training.
- Health and safety standards.

Note that local airport emission requirements may have to be evaluated against the possible excess of fuel tank emissions resulting from inerting (these emission effects will be design and airplane dependent).

Next, the guidance material explains the specifics of each of the above six parts.

**Management Plan.** The management plan is a detailed description of the operational responsibilities and procedures associated with the implementation and conduct of the certificate holder’s “fuel tank inerting program.” The management plan may differ depending on the type of inerting system.

The purpose of the management plan is to ensure operational control over the execution of a fuel tank inerting program.

**Dispatch Conditions, Including Any Timetables.** Certain design features of airplanes (e.g., their fuel tank vent system) and fuel tank inerting system may impose certain usage conditions or limitations. These conditions and limitations may be related to time, outside ambient temperatures, flight phase, fuel tank loading, or a set of multiple conditions.

If limitations exist, then the certificate holder’s program should define operational responsibilities and develop procedures to instruct the flight crews, airplane dispatchers, flight followers, and maintenance and ground personnel on the condition limitations, evaluation of these limitations, and resultant actions to be taken.

**Operations Manual—Inerting Operational Procedures.** Operational procedures associated with the fuel tank inerting system installed on the airplane type should be approved as part of an operator’s initial operational manual approval or as a revision to that manual, the Airport Handling Manual, or the MEL.

A quality assurance program should be established in accordance with the management plan and applicable 14 CFR regulations.

The MEL should be developed based on the manufacturer’s recommendations and the operator’s operational policies and national operational requirements.

**Maintenance Program—Maintenance Manual.** Maintenance procedures for the fuel tank inerting system installed on the airplane type should be approved as part of an operator’s initial maintenance manual approval or as a revision to that manual.

For ground-based inerting, the characteristics and specification of the nitrogen that will be used to inert the fuel tanks should be defined and recorded in the appropriate manuals.

For onboard inerting, particular attention should be paid to the efficiency (service life) of the ASM (which provides nitrogen), noting that NEA will not be produced if this component does not perform its intended function.

**Training.** Initial and recurrent ground training and testing for all affected personnel (e.g., airplane dispatchers, ground crews, contract personnel, and flight crew) need to be conducted.

A quality assurance program should be established in accordance with the management plan and applicable 14 CFR regulations.

**Health and Safety Standards.** The operator’s health and safety standards should be updated to include working with nitrogen.

If inerting systems are installed on airplanes, the team recommends that this guidance material be used to issue an AC titled “Fuel Tank Inerting Operational Program Approval.”

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It is recommended that any AC be again reviewed using an actual operation and a maintenance program developed for using a certified fuel tank inerting system. The lessons learned during the implementation of the operation and maintenance program may assist others in any future implementation exercise.

### ***Other Potential Regulatory Impact***

Fuel tank inerting systems implemented on a large scale may increase VOCs vented from fuel tanks as their fuel/air vapors are displaced by the inerting process. However, environmental regulations are outside the scope of FAA jurisdiction and the scope of this task.

**13.0  
Conclusions &  
Recommendations**

## 13.0 CONCLUSIONS AND RECOMMENDATIONS

### 13.1 OVERALL CONCLUSIONS

Based on the investigation and evaluation conducted, the FTIHWG has concluded the following:

#### Service History

- There is a close relationship between the incidence of explosions in wing tanks and the use of “wide-cut aviation fuel.”
- Wing tanks operating with less volatile Jet A type fuel have demonstrated an acceptable safety record.
- In comparison, heated CWTs are more vulnerable to explosion in the presence of ignition sources.
- The three most recent events (1990 Manila, 1996 New York, and 2001 Bangkok) form the basis for forecasting future events.
- Inerting fuel tanks may enhance occupant survival in accidents in which a fuel tank explosion is the primary cause.

#### Safety Assessment

- Because the fuel tank explosion rate has been statistically shown to be fairly consistent, the actual occurrence of incidents will increase in the future as a result of forecasted fleet growth.
- Ignition source reduction activities associated with SFAR no. 88 are expected to provide a reduction in the fuel tank explosion rate.
- Inerting systems will offer little benefit to three categories of airplanes studied: regional turboprops, regional turbofans, and business jets. These categories of airplanes do not have heated CWTs, and the flammability exposure of the wing tanks is already low.
- The flammability exposure levels achieved by inerting systems can result in an improvement in the accident rate.

#### Ground-Based Inerting (GBI and OBGI)

- Installing the airplane portion of a GBI system does not require any new technology to be developed. However, retrofit GBI systems will be extremely difficult and will require an evaluation of each airplane category model to determine if a retrofit installation is practical.
- The availability of airport supply systems to supply NEA at each terminal gate and remote parking area is a serious problem that needs to be resolved before GBI can be implemented.
- Development of a new NEA-to-airplane interface panel and associated components is necessary and requires agreement on configuration and control for a worldwide standard before a GBI system operation is practical.
- OBGIS was the heaviest system evaluated. System size is determined by the relatively short turnaround time between existing commercial flights at the gate and by the large ullage volumes (small fuel load) required for short missions.
- Because an OBGIS runs only on the ground, interference with other airplane systems would be minimized and the certification process should be simpler.

#### Airport Facilities

- Before promulgating an airplane GBI requirement, it will be necessary to resolve the current lack of global regulatory authority and industry control over the introduction and construction of new airport inerting supply systems, either fixed or mobile.
- Developing, constructing, and integrating into the current airport infrastructure fixed inerting equipment for large and medium-sized airports will be a major problem.

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- Test data from elementary testing, using nitrogen and carbon dioxide, indicated that ullage washing and fuel scrubbing with either gas has little effect on the conventional properties of jet fuel. However, a measurable change in vapor pressure occurred as a result of fuel scrubbing, and the carbon dioxide-scrubbed fuel had an increase in acidity.
- Significant quantities of VOC were released during both processes, regardless of the inert gas used. This increase in VOC emissions should be investigated and resolved to avoid any serious potential health, environmental, and safety issues.
- Because a fuel cooling process does not address the scenario of operating with an empty CWT, this system of reducing flammability exposure was not pursued.
- The lack of NEA availability at smaller airports currently used as diversion airports for larger hubs would affect airline operations. In addition, if GBI is not implemented worldwide, the impact may be significant on non-U.S. diversion airports or those used for technical stops.

### *Onboard Inert Gas Generating System*

- An OBIGGS would reduce the flammability exposure to almost zero, except when the airplane is not powered, operating under the MEL, or is in a nonnormal operational mode.
- When the OBIGGS is installed, noise reduction measures may have to be taken as a result of system compressor and fan noise.
- The electrical power requirements to run an OBIGGS are large and constitute a majority of the total electrical power available on an airplane category.
- The weight of an installed OBIGGS is significant; for example, for a large transport category airplane, the OBIGGS weighs between 1,120 and 1,600 lb.
- Retrofit of OBIGGS will require an evaluation of each airplane category model to determine if a retrofit installation is practical for that airplane model.
- Current technology components of an OBIGGS have demonstrated low reliability.
- Technological advancements that will decrease the complexity, size, weight, and electrical power requirements of an OBIGGS are needed.
- NEA membrane air separation systems that have improved efficiency and performance, and lower nonrecurring costs would be a necessary part of a practical membrane-type OBIGGS.
- For cryogenic systems, basic research into high-efficiency, vacuum-jacketed heat exchangers and lighter, more efficient cryogenic refrigerators is required to achieve a practical cryogenic-type OBIGGS.

### *Hybrid Systems (OBGI and OBIGGS)*

- The issues and resolutions for hybrid systems are similar to their respective full-sized systems stated above.
- The OBGIS provides a reduction in flammability exposure comparable to that of the GBI system.
- The hybrid OBGIS is almost as large as the full-sized OBGIS.
- A hybrid OBIGGS that would provide the flammability exposure of a GBI system is the smallest onboard system of all onboard designs.

### *Airplane Operations and Maintenance*

- The Tasking Statement defined an inerting system with little or no redundancy as a basis for this evaluation. Therefore, no inerting design concept evaluated was considered flight critical and airplanes could be dispatched with an inoperative inerting system (MEL). This assumption is fundamental to the technical and cost conclusions reached by this report.
- If the inerting system is not included in the MEL, then the complexity and cost of the system design concepts and airplane operational impact evaluated in this study would be significantly increased.

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- If inerting systems are required to be installed in existing in-service airplanes, the resultant maintenance burden on the airline industry will be substantial and there may not be sufficient modification facilities, depending on the allowed modification incorporation time period and skilled personnel available.
- The current reliability of inerting system technology is unacceptable from a maintenance and operational viewpoint and requires an order of magnitude improvement to make them operationally viable.

### Estimating and Forecasting

- The cost-benefit methods used by the FTIHWG to determine a practical inerting system were the same as the economic analysis practices used by the FAA.
- Based on the above economic analysis, none of the inerting design system concepts studied were found to be reasonably balanced by their incurred costs.
- Of the design concepts studied, the one with the lowest cost-benefit ratio was the GBI and the hybrid OBIGGS concept applicable to heated CWTs only.
- There is little difference in system costs between in-service and current production of a particular airplane model except for higher (20% to 30%) installation costs for retrofit of service airplanes and associated airplanes because of downtime during installation. Also, with today's technology, there is little difference in system cost between current production and new type design airplanes.

### Regulatory Impact

- Because this evaluation has not found a practical fuel tank inerting system, a new 14 CFR regulatory text should not be proposed.
- The environmental and regulatory impact of any future practical fuel tank inerting system needs to be addressed by the appropriate regulatory organizations when such a system is developed and proposed.
- Any requirement to incorporate a fuel tank inerting system would significantly affect existing CFR Title 14 parts, for example, Airworthiness Standards: Transport Category Airplanes (Part 25), Flight Operations (Parts 91 and 121), and possibly Airport Facilities.

## **13.2 RECOMMENDATIONS**

The ARAC FTIHWG specifically recommends the following actions to be expeditiously carried out by the FAA, NASA, and the industry:

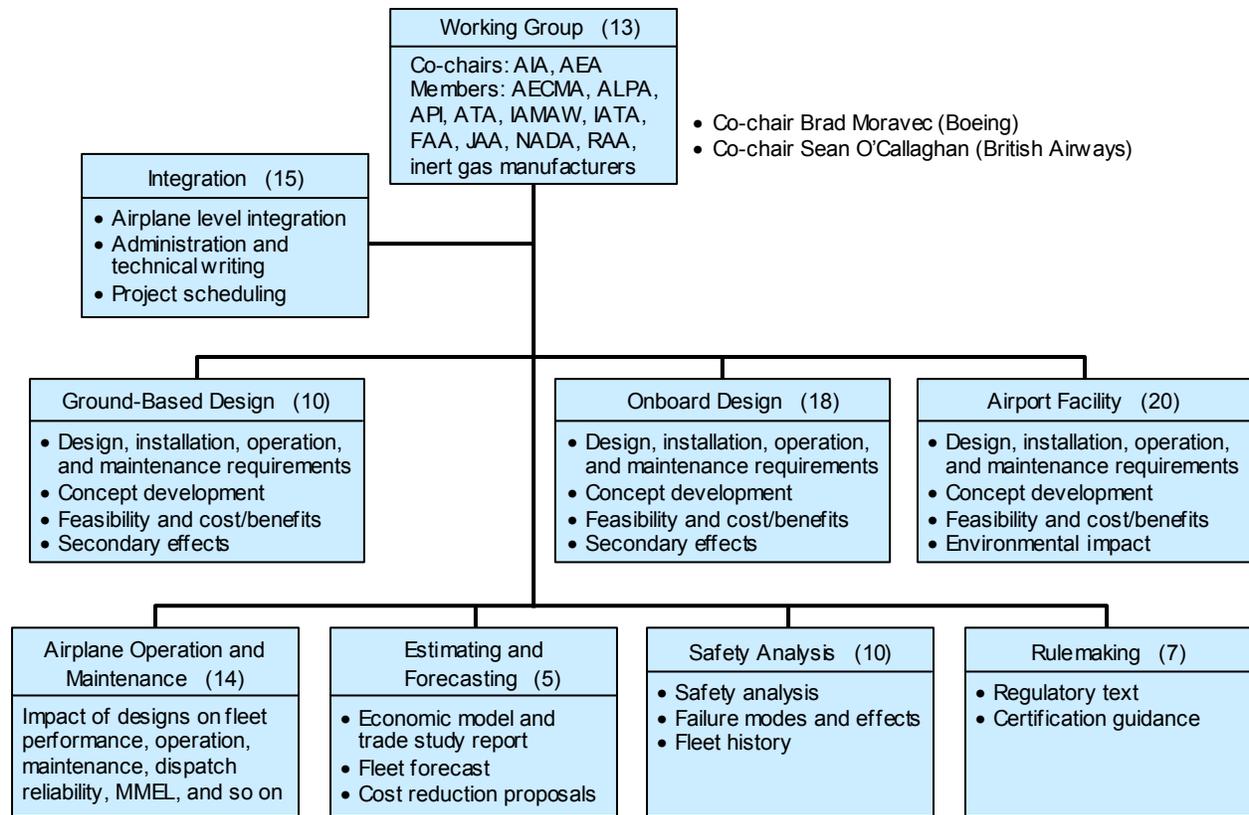
### Inerting Systems

- Continue to evaluate and, where appropriate, investigate means to achieve a practical onboard fuel tank inerting system design concept for future new type design airplanes.
- Pursue technological advancements that would result in onboard fuel tank inerting designs having decreased complexity, size, weight, and electrical power requirements, and increased efficiency, reliability, and maintainability.
- Perform NEA membrane research to improve the efficiency and performance of membranes resulting in lower nonrecurring costs of NEA membrane air separation systems, for example, basic polymer research to increase the operational temperature of membranes to a level above 302°F.
- Conduct basic research into high-efficiency, vacuum-jacketed heat exchangers, and lighter, more efficient cryogenic refrigerators for use in inerting systems.
- If a practical means of achieving a cost-beneficial fuel tank inerting system is found, establish a corresponding minimum flammability level and reevaluate and propose regulatory texts and guidance materials accordingly.

*Fuel Tank Flammability*

- Evaluate means to reduce fuel tank flammability based on existing (e.g., directed ventilation, insulation) or new technology that might be introduced sooner into the in-service fleet and current airplane production.
- Initiate a project to improve and substantiate current flammability and ignitability analyses to better predict when airplane fuel tank ullage mixtures are flammable. This research is needed to support informed design decisions and rulemaking.
- Initiate a project to thoroughly document and substantiate the flammability model used in this study.

# ARAC Fuel Tank Inerting Harmonization Group Organization



297925J2-001R1

Figure 1.2.1-1. ARAC FTIHWG Team Leaders

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## Appendix C

### Ground-Based Inerting Designs Task Team Final Report

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## **1.0 ABSTRACT**

The following documents the technical considerations of the design of a ground based inerting system for aircraft. This system would function to further minimize the flammability of fuel tanks through the use of an inerting gas provided by a ground source to reduce the naturally occurring oxygen in the ullage (airspace) above the fuel. Reducing the oxygen content of the ullage to 10% or less inhibits the flammability of the ullage, thereby reducing the probability of a potential aircraft fuel tank ignition event.

## **2.0 INTRODUCTION**

The design of the ground based inerting system presented here has been the result of careful examination of the technical parameters and considerations, and those parameters required and defined in the FAA Tasking Statement 4910-13; Fuel Tank Inerting Harmonization Working Group (FTIHWG). This Tasking Statement requires various means of inerting fuel tanks to be considered. While this time restraint prevented the examination of design details required for the actual inerting design implementation on a specific aircraft model, it has allowed a ground based design to be evaluated sufficiently to identify the potential benefits and complications.

The aircraft design presented here is for a system that would allow inert gas to be distributed in the center wing tanks (heated or unheated), and auxiliary tanks as requested in the Tasking Statement. Inert gas generation takes place in the airport facility and is then transported to the aircraft via pipeline or servicing truck. A servicing hose with a special interface coupling only used for the introduction of inert gas to the aircraft is utilized. Each aircraft would be certified through testing to validate the specific volume of inert gas required to reduce the fuel tank oxygen concentration to a level below that considered flammable. The Tasking Statement defines that level as 10% oxygen.

The design presented here is a generic system that would apply to any size or configuration aircraft. For the purposes of this report and evaluation, the system is defined in terms of the standard aircraft sizes and definitions derived in the previous Aviation Rulemaking Advisory Committee (ARAC) study completed in 1998. The following airplane configurations will form a standard basis for this study:

ARAC Large Aircraft

ARAC Medium Aircraft

ARAC Small Aircraft

ARAC Regional Turbofan

ARAC Regional Turboprop

ARAC Bizjet

It should be noted that because this study is concerned with the center and auxiliary tanks only, per the Tasking Statement, the ARAC Regional Turboprop is not addressed in this study since it has no center tanks per ARAC definition. The ARAC Bizjet also has no center tank per ARAC definition, but information gained late in the study became available that indicated some Bizjets have center tanks and thus they have been included in this ground based inerting study to the extent possible.

Numerous airplane configurations exist in the world aircraft community and these ARAC configurations allow a study to be conducted with configuration baselines for design and cost estimating purposes. Because there are differences between the ARAC standard aircraft and the specific aircraft designs of the world, the designs developed herein would require detail changes to actually implement into existing airplane models or future airplane models.

It should also be noted that, in general, less precise technical information was known about the structure and systems of regional turbofan, regional turboprop and business jets, as compared to the larger commercial based models. While this is not considered to be a significant issue due to the generic nature

of this GBI design and the adaptability of the design, it is noted here for reference. Also, to avoid confusion regarding the ARAC airplane class terminology, the business jets based on standard commercial airplane configurations are included with their respective commercial classes rather than the ARAC Bizjet category.

Some manufacturers may choose to approach the detail aircraft design in an alternate fashion based on their specific design philosophy. The design study in this report would not preclude these different approaches to the task. However, it has been assumed that all designs would utilize standard features for minimization of operational costs. For example, it is assumed a standard inerting gas interface for servicing would be used. The world aircraft community would utilize this standard interface configuration unless an aircraft manufacturer at some future date chooses to market a product with a different standard and impose this impact on their customer's operations. This study has assumed the servicing pressure maximum would be standardized as well to protect all the aircraft being serviced. If a manufacturer desires a new pressure standard, this new standard must include built-in features for protection of the original existing systems, both onboard and in the ground servicing equipment.

### **3.0 BACKGROUND**

The 1998 ARAC report recommended that additional study be conducted on Ground Based Inerting (GBI) of aircraft fuel tanks to minimize their flammability. The current ARAC activity requires a detailed assessment of fuel tank inerting to be carried out to identify the issues associated with inerting airplane fuel tanks. This ARAC study examines a number of methods of inerting. The focus of this particular section of the overall report is the Ground Based Inerting system. The general design configuration that is considered the best alternative is described in detail along with the supporting arguments for the decisions made. The basic design is for gaseous nitrogen or Nitrogen Enriched Air (NEA) to be supplied from a ground based source to a servicing hose. This servicing hose would be connected to the airplane and the gaseous nitrogen or NEA would then be distributed inside the aircraft by a simple manifold to outlets in each bay or space of each affected tank. This design configuration forms the basis for the design presented here.

The designs considered here have been derived by a team with experience in aircraft fuel systems, gas production/ handling, and research in fuel tank flammability.

### **4.0 APPLICABILITY**

The Tasking Statement for this study specifically designated this system to be applicable for all aircraft fuel tanks that are not cooled at a rate similar to a wing fuel tank. As such, there are a number of aircraft designs that are not required to have inerting systems installed in their fuel tanks by the Tasking Statement. The owners or manufacturers of those aircraft could choose to install a ground based inerting system without regulatory direction at their option.

The proposed ground based inerting system design, control, and operation are applicable to newly designed commercial aircraft, in-production commercial aircraft and in-service commercial aircraft as stated in the FAA Tasking Statement. Newly designed aircraft would incorporate the requirements of the rule to integrate the ground based inerting system during the initial design phases. In-production aircraft would require that the system be integrated into the manufacture of the aircraft concurrently with production in a manner that minimizes the impact to production, retains the certified design, and meets the requirements of the rule. In-service aircraft would be covered by Service Bulletin action with a timetable prescribed by the rule.

Auxiliary fuel tanks that are not cooled at the rate equivalent to wing tanks are also applicable to actions of this study as directed by the Tasking Statement. Auxiliary fuel tanks are typically located within either the forward or rear cargo compartment and are connected to the center fuel tank and/or center fuel tank system plumbing. Because of their location within the fuselage, shielded from the outside air stream and temperatures, all auxiliary tanks of this typical configuration are subject to this study and installation of a

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ground based inerting system. These auxiliary tanks may be pressurized tanks or unpressurized tanks depending on the tank design, but both types of systems would utilize the same type of ground based inerting hardware if required. It should be stated that even though all typical auxiliary fuel tanks are applicable to this study, the schedule did not allow detailed assessment of all aircraft auxiliary fuel tank installations to confirm space is available for the provisions required for the proposed inerting system.

### **5.0 SYSTEM DESIGN ASSUMPTIONS**

In order to perform the design and analysis for the ground based inerting system in the time allowed by the Tasking Statement, a number of assumptions have been made based on the Tasking Statement requirements with the general oversight of the ARAC Working Group. The assumptions have been documented and are explained below:

- A 10% oxygen concentration constitutes an inert tank for the sake of the exposure/risk analysis in this study.
- Oxygen concentration measurement in fuel tanks to be inerted is not necessary to ensure tank is inert to required levels.
- Aircraft will receive a minimum of 95% NEA (5% oxygen maximum by volume) from a ground source which is available upon demand at all required gate and/or operational areas.
- The discharge of NEA from the aircraft vents does not require any special precautions or procedures to eliminate any associated hazards.
- Fuel tanks to be inerted are defined by the Tasking Statement as all tanks that do not cool at a rate equivalent to the main wing tanks. This includes non-cooled auxiliary tanks mounted inside the fuselage, but not tail or trim tanks since they are located away from heat sources and are subject to exposed ambient air similar to main wing tanks.
- The airport NEA supply pressure at the servicing interface to the airplane is controlled by the ground equipment to ensure the delivered static pressure does not exceed the maximum allowable value for the aircraft type being serviced.
- For the purposes of estimating in this study, 95% NEA delivered at 1.7 times the tank volume (as demonstrated by FAA/Boeing testing on a B737NG) provides 8% ullage oxygen concentration by volume. This 8% oxygen concentration is assumed to maintain a sufficient fuel tank inert level during ground operations and initial flight operations before the oxygen concentration becomes great enough to exceed the 10% maximum required by the Tasking Statement.
- The ground based inerting system is designed to not require “scrubbed” fuel to be effective. No on-board fuel scrubbing is being provided by, or proposed for, the ground based inerting system. If scrubbed fuel is considered to be desirable or is determined to provide a cost effective benefit, the scrubbing will be accomplished by ground equipment or facilities.
- The exact NEA flow rate is not critical to ensure the required oxygen concentration on a volume basis is achieved. A wide range of flow rates could be accommodated and still achieve the required oxygen concentration in the tank. In general, system pressure, NEA purity, and total volume are required parameters instead of flow rate.

### **6.0 DESIGN CONSIDERATIONS**

#### **6.1 SPECIFIC INERT GAS SELECTION**

A number of different gases or inert gases are available for use in the inerting task. Each of these gases have drawbacks as discussed below. The Tasking Statement specifically states that the ground based inerting system should consider using ground based nitrogen supply equipment. Nitrogen has been

identified in previous research as a good alternative for inerting. Nitrogen continues to be considered the best gas for this application. However, other gases have been examined per request of other members of the ARAC task team as a part of this study.

Carbon dioxide based systems were proposed as an alternative to nitrogen, partly because the heavier molecular weight was expected to keep the gases in fuel tanks better than nitrogen. There have been past military studies of inerting with carbon dioxide. These studies concluded the higher solubility of carbon dioxide in jet fuel would have a negative affect on fuel pump performance that could result in loss of engine fuel feed. This would introduce an unacceptable risk. In addition, inerting with carbon dioxide can result in production of carbonic acids. The potential of introducing carbonic acids to fuel tanks and the resulting corrosion potential on system components and structure was unacceptable. We have no data to indicate these concerns have been eliminated, thus we concluded carbon dioxide was not a good alternative to nitrogen. In addition, testing by the FAA and Boeing have shown the loss of nitrogen due to its molecular weight to be small, and thus not a major factor leading to the need for this alternate gas.

Use of argon gas was also proposed as an alternative to nitrogen, because its' heavier molecular weight was expected to keep the gases in fuel tanks better than nitrogen as well. Argon is currently available only in smaller quantities. Air consists of roughly 78% nitrogen, 21% oxygen and 1% argon gas. Argon production is very scarce as compared to nitrogen and considerably more expensive. Argon is very similar to oxygen in molecular size, and thus requires expensive liquefaction processes to produce. The world demand for argon gas for inerting systems would push or exceed the available supplies as well as driving the cost higher. The current cost of argon is already in excess of 100 times more than nitrogen. In addition, it is believed that argon has a higher solubility in fuel than nitrogen. There is concern that fuel exposed to high argon gas levels could result in higher dissolved gas content in the fuel which could also lead to fuel pump performance problems. Thus we concluded argon was also not a good alternative to nitrogen.

No system utilizing an inert gas other than nitrogen has shown itself to be without basic problems and drawbacks. Nitrogen and specifically NEA is considered the preferred choice for the inerting gas for a ground based inerting system. It is readily available, inexpensive, and with the emergence of membrane separation technologies, easy to use in large scale industrial applications. Nitrogen and NEA have the advantage in that they have been used in military applications for fuel tank inerting for a number of years. As such, there is some information available on its in-service performance. Not all applications have met with the reliability desired of them, but the body of information is there to better refine the inerting system designs. While NEA is readily available commercially, a drawback to nitrogen, and in fact any inerting gas for a GBI system is that its availability at airports is limited. Providing the necessary volumes required to inert the aircraft fleet will require a very large increase in gas generation capacity. That infrastructure issue is addressed elsewhere in this report. Safety is also considered a drawback for nitrogen, as with other gases that displace oxygen, since it poses confined space hazards. Even with this safety issue and the airport facilities availability issue, NEA is considered the inerting gas of choice.

### **6.2 BASIC INERT GAS INTRODUCTION**

The method of introducing nitrogen gas into the fuel tanks was a basic design parameter evaluated. Displacement of oxygen with the inerting nitrogen is the primary requirement of the inerting system. In general, the inerting gas can be introduced into the fuel tank ullage by using the following methods:

- “Ullage washing”
- “Fuel scrubbing”
- “Fuel flow injection”
- Some combination of any, or all of these

## 6.2.1 Ullage Washing

Ullage washing, or the displacement of the oxygen in the space above the fuel (ullage), would give the best efficiency since the inert gases could be better directed to purge the total fuel tank ullage of gases including oxygen. This process could also be scheduled at any time during the airplane turn around. This method would require a special inert gas servicing interface and distribution system to supply inerting gases to that servicing interface. This approach does not remove any oxygen dissolved in the fuel that will evolve from the fuel during climb due to the altitude pressure decrease. Oxygen evolution does have some effect, but testing showed it to be a small impact on the oxygen level, except when the tank is relatively full. Further, when the tank is relatively full the effects of fuel consumption, which draws ambient air into the tank, causes the rapid loss of the inert levels, thus overshadowing oxygen evolution from the fuel. One could compensate for this oxygen evolution on climb by lowering the oxygen content below the 10% when inerting before takeoff to allow some room for the oxygen to come out of solution and not have the fuel tank oxygen concentration rise above the 10% maximum to minimize flammability. Directly injecting NEA into the fuel tanks through ullage washing, whether they are full, partially full, or empty is considered the best option for the basic introduction of the inerting gases onboard for a GBI system. This method would be controllable, predictable, and certifiable even though a new servicing connection is required.

## 6.2.2 Fuel Scrubbing

Fuel scrubbing, or the “washing” of fuel with nitrogen, is the method of processing the fuel to strip the oxygen gases out of the fuel down to levels that would not evolve oxygen above a certain level in the fuel tanks during climb. Fuel contains dissolved oxygen and as the pressure above the fuel is reduced during climb this oxygen will tend to be evolved out of the fuel into the tank ullage. Since this oxygen will raise the oxygen concentration in the ullage, the effect of replacing this dissolved oxygen with nitrogen was considered to maintain the lower oxygen levels as long as possible. Fuel scrubbing for GBI can be accomplished in two basic methods:

1. **Fuel Scrubbing Using Onboard Scrubbers and Ground Supplied NEA.** One method of scrubbing which has been used on a limited number of military aircraft types is an ‘ASPI’ type scrubber. This unit, if installed onboard, would be supplied by a ground source of NEA. This type of scrubbing generally requires a higher purity of NEA than the 95% assumed for ullage washing in this study. Assuming the scrubbing NEA supply is the same supply used for ullage washing, this requires simultaneous refueling and ullage washing to accomplish the fuel scrubbing task. If the process of scrubbing was carried out after the ullage washing, then any oxygen released during the scrubbing would dilute the NEA in the ullage if not vented elsewhere. Procedures would therefore be required. This process would also take away some of the flexibility of when the inerting operation could be carried out. It is unclear what impact, if any, this would have on the cost of GBI, but it is generally accepted that it would cost more to have this procedural requirement. It is unlikely a significant benefit would be garnered from this type of scrubbing. Although not examined in detail, this type of scrubbing unit is not considered to be readily adaptable to inerting tanks that are not refueled.

Other methods of scrubbing fuel onboard the aircraft using ground based NEA could be developed such as a specialized scrubbing manifold or other onboard scrubbing equipment. These systems are also not considered to be effective enough to justify their usage at this point.

2. **Fuel Scrubbing Using Dedicated Scrubbing NEA at the Fuel Farm or Fuel Truck.** The method deemed to be most practical is fuel scrubbing with dedicated NEA at the fuel farm or fuel truck. This method requires no additional aircraft equipment or procedural modifications to implement. It is generally considered the most cost-effective method of scrubbing as the fuel is scrubbed in bulk before deposit into the aircraft. For airport hydrant systems, a large scrubber would scrub the fuel before being pumped out of the airport fuel farm. For airports with only trucks, every truck could be

equipped with a portable fuel scrubber that is transported in tow or mounted on the truck, or there could be a central scrubbing facility at the fuel storage area where the trucks receive their fuel load.

Fuel scrubbing also effectively saturates the fuel with nitrogen which would introduce nitrogen to the fuel tanks when refueling to some degree as the nitrogen comes out of solution due to agitation. The primary means for the nitrogen to come out of solution is the ambient pressure decrease as the airplane goes up in altitude. However, as the fuel is used at altitude the nitrogen levels would not be able to keep up with the volumetric decrease in the tanks due to fuel burn, and air would be brought in via the vent system to effectively increase the oxygen levels. This system also does not displace the oxygen in the ullage when tanks are not required to be filled, or are only partially filled. This study of GBI was primarily based on center tanks and center tanks are not filled on the majority of flights due to flight lengths that are less than the maximum of which the aircraft is capable. Because of this, a GBI system based solely on refueling with scrubbed or nitrogen saturated fuel does not comply with the Tasking Statement and would not be considered effective enough for consideration especially when the additional airplane complications, airplane weight penalty, and airport complications are factored in.

### **6.2.3 Fuel Flow Injection**

Fuel Flow Injection, or directly injecting nitrogen into the fuel as it is being loaded into the airplane also has the drawback of not inerting the tanks when the tanks are not loaded with fuel or are partially loaded. It does have the same positive aspect as fuel scrubbing of allowing nitrogen to come out of solution as the airplane is climbing, but this method was not considered acceptable for the same basic reasons as fuel scrubbing.

### **6.2.4 Combinations**

Combinations of these methods could be utilized, but no combination has shown itself to be effective enough to consider based on either the airport facilities or airplane equipment required versus the potential gains in inerting effectivity. The limited evolution of oxygen during climb can be addressed by ways having less impact including using higher purity NEA or slightly longer NEA loading times. Flight testing also showed that ullage washing was sufficient to accomplish the inerting task. The further complication and expense of any combination is not considered required to accomplish the GBI inerting task of ensuring the tanks are inert while the airplane is on the ground.

## **6.3 ULLAGE GAS DISTRIBUTION**

It was postulated that ullage washing could be accomplished in one of three ways:

1. Through the existing refueling manifold
2. Through the existing aircraft fuel tank vent system
3. Through a dedicated distribution manifold

It was also determined that ullage washing and fuel scrubbing in combination could be accomplished by utilizing the best method for tank ullage washing and one of two primary scrubbing philosophies if scrubbing was to be considered.

### **6.3.1 Ullage Washing Through Existing Refueling Manifold**

It was determined that providing NEA to the fuel tanks via the refueling manifold was not practical because it precluded simultaneous refueling and inerting of fuel tanks. It was determined, due to the short turn-around time of many operational aircraft and the length of time associated with inerting a large center-wing tank that inerting and refueling would have to occur simultaneously for some operations. Precluding this would have a substantial impact on the turn-around times of certain operations. Also, introducing inert gas in this manner is not particularly efficient or desirable. The refuel distribution tube

placement is optimized for fluid flow into the individual tanks. This would not yield efficient distribution of the inert gases or efficient purging of the oxygen from the tanks. Ullage washing through the existing refueling manifold was rejected for these reasons.

### **6.3.2 Ullage Washing Through Existing Fuel Tank Vent System**

Using the fuel tank vent for inerting was not considered viable because, similar to inerting through refueling manifold, it would provide a poor distribution of inerting gas, requiring significant increase in the amount of inerting gas required to inert a given tank. This could also have significant impact on the cost of GBI in the commercial fleet. In addition, many aircraft tanks only have one vent. This would not allow simultaneous tank venting during refueling operations and the NEA loading for inerting. It was found in testing that those tanks that have more than one vent would need to install some modification to make the multiple vent systems act like a single vent system to minimize the loss of nitrogen and the accompanying increase in oxygen concentration in the tanks. As a consequence, inerting through the existing vent system could result in over-pressurization during refueling. This has significant system safety issues for refueling operations and would require additional redesign of the vent system to maintain the existing level of refueling safety.

### **6.3.3 Ullage Washing Through a Dedicated Distribution Manifold**

It was concluded that the preferred method for ullage washing would be through a dedicated distribution manifold installed in all tanks requiring inerting. This distribution manifold would have a dedicated servicing interface port for a NEA supply hose to be connected during ground operations. The design approach considered most effect and evaluated was a manifold with outlets mounted high in the tank. These outlets would direct the nitrogen flow throughout the tank helping to mix and circulate the ullage space for expulsion through the vent system as NEA entered the tank. This oxygen-rich ullage would be displaced out through the airplane vent system to reduce the oxygen concentration down to the required level. This design was tested in the FAA/Boeing flight tests and is the preferred option for most aircraft designs available today.

### **6.3.4 Alternatives for Gas Distribution**

One alternative method for this would be to have the injection of the nitrogen be accomplished via a dedicated manifold located on the bottom of the tanks to allow the nitrogen to bubble up through the fuel when fuel was present. While this system has the advantage of helping purge oxygen directly from the fuel through the bubbling process, or effectively scrubbing the fuel to some extent, it also requires additional manifold plumbing be installed to help distribute the nitrogen throughout the entire tank. Without this additional manifold distribution plumbing to spread the distribution of NEA over the entire tank area, there is a potential that areas of the tanks may not reach the required oxygen level without some additional period of time to allow equilibrium to take place. It may be possible to use this design type, but implementation of the design would require careful consideration of the tank geometry to optimize the inert gas distribution in a timely manner.

## **6.4 SERVICING CONSIDERATIONS**

A study of servicing turn around times for the standard ARAC airplane models concluded that turn around times of approximately 20 minutes for small commercial aircraft, and 55 minutes for large aircraft are not uncommon with today's operating schedules. Wherever possible, operators may also use the turn around time to recover any schedule delays. For example, they might reduce aircraft cleaning time and passenger loading times to recover time. Therefore, one aim of this system is to give the operator the greatest flexibility as to when the inerting process is actually performed so minimal delays will be incurred. This design presented here is centered around balancing minimum turn around times with the other system design requirements to minimize the impact to the airlines.

The design was developed to minimize the need for extra servicing equipment such as ladders or step stools to the maximum extent possible. The proposed sites for the servicing interface locations have been chosen to minimize requirements for special servicing equipment and minimize interference with existing service trucks and personnel.

**6.5 OTHER SYSTEM CONSIDERATIONS**

Another system design consideration for ground based inerting systems was to factor in the temperature effects that could effect the need to inert on a specific day. There would be no flammability benefit to inert if the temperature of the day, tank, and fuel were below those values where the fuel would become flammable either on the ground, or during the ensuing flight. While this is possible to implement, the necessary procedures would be difficult to coordinate due to delays that often occur in dispatch and departure. An additional study to determine the manner in which temperatures guidelines could be determined and utilized in-service would be required since factors such as fuel quantity, refueling sequencing, heat load from external heat sources, and ambient temperatures could influence the guidelines. If such an approach is pursued, it is not considered to significantly reduce the ground based infrastructure requirements, since most airports would still need to be able to inert airplanes due to the annual range of ambient temperatures experienced.

For tanks that are partially or completely loaded with fuel prior to flight, the consumption of fuel during flight would lead to a loss of the inert levels early in the cruise phase of flight. A method of extending the period in which the oxygen concentration level in the fuel tank ullage remains below the required level would be to provide an additional supply of NEA from onboard storage tanks. The airplane fuel tanks would be inerted by supplying ground based NEA to the servicing interface which would connect directly to the onboard storage tanks at higher pressures than the 5.0 psi maximum defined for the baseline system to maximize the tank storage capabilities. These storage tanks would feed the fuel tanks through a primary pressure regulator and a secondary backup pressure regulator for safety to maintain the 5.0 psi maximum servicing pressure. Other system complexity may be required to ensure discharge pressure from the storage tanks does not cause fuel tank pressure limits to be exceeded.

As an example, the following table gives an indication of the storage volume required to maintain the center tank on the Large ARAC aircraft category below the 10% oxygen threshold given by the Tasking Statement. The following table shows the storage volume required as a function of the initial storage pressure to maintain the ullage inert while the fuel volume is used down to 50% full assuming the tank was initially full. The estimate is also based on a gas temperature of 0 degrees C and a cruise altitude of 35,000 feet.

Storage Pressure (psi)	Storage Volume (Nm <sup>3</sup> )
5	10
20	5.2
100	1.4

Other onboard storage tank design concerns include the additional weight and complexity of the system, the physical size of the onboard storage tanks to be effective, and the safety and maintenance issues associated with large high pressure tanks carried on board. Because of these concerns with this storage tank concept, this design possibility has not been pursued further in this study.

**6.6 MMEL/MAINTENANCE CONSIDERATIONS**

Per the Tasking Statement, MMEL relief will be available for situations where the ground based NEA supply is not available for airplane inerting.

The simple concept and the use of mature technology for the equipment in the system should ensure the system achieves a reliability level that is acceptable for commercial aircraft operations, without the need to build in system redundancy. This approach also means that there are only a very limited number of

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failures that will prevent the system from allowing the tanks to be inerted. In the case of the more likely failures, i.e., failure of the shut off valve, maintenance procedures can be devised which will still allow the airplane to be dispatched with the tanks inerted. This aspect is considered further in the Safety Analysis Team Appendix H and the Airline Operations & Maintenance Team Appendix F.

### **6.7 SYSTEM COSTS**

System costs are examined in detail in the Estimating and Forecasting Team Appendix G.

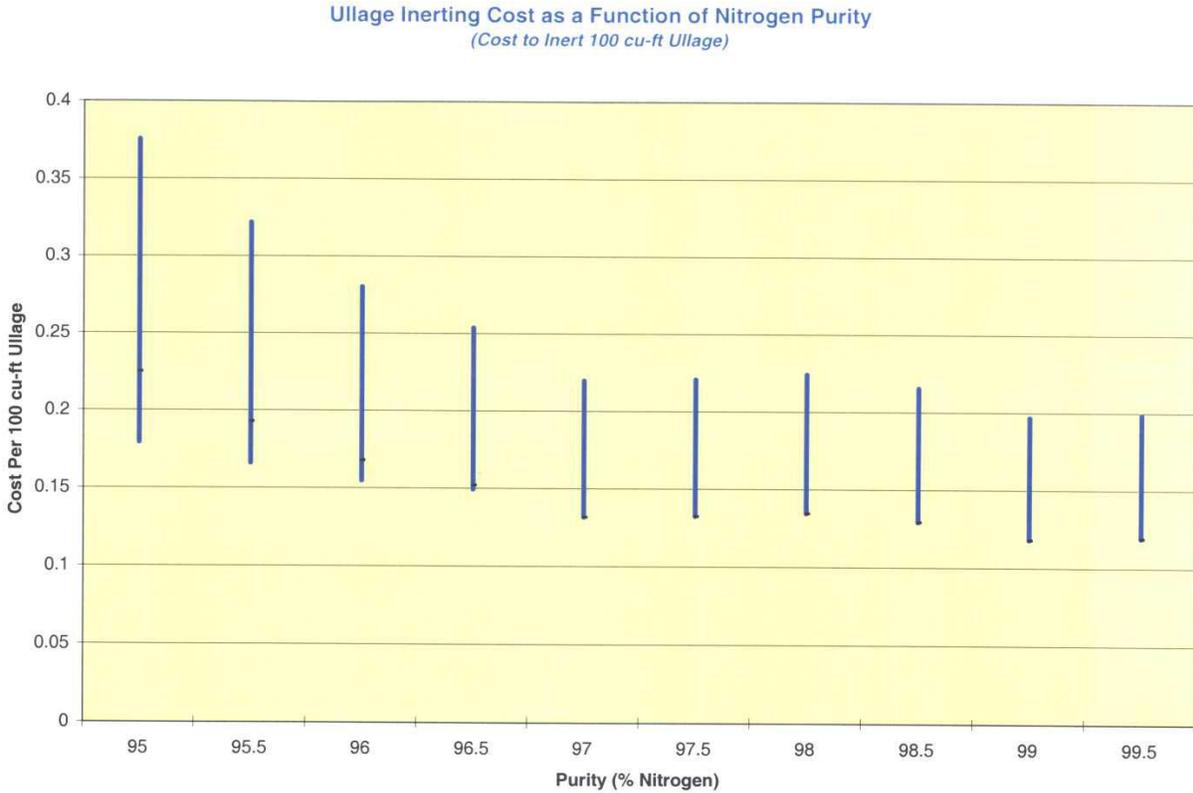
### **6.8 ENVIRONMENTAL ISSUES**

The GBI system may introduce additional VOCs to the atmosphere as a result of the ullage washing procedure. Since the center tanks would be inerted every flight, the ullage and its associated VOCs from residual fuel would be exhausted out the vent system at each turn around whether the center tank was utilized or not. The detailed environmental analysis of this GBI system is beyond the scope of the Tasking Statement and is not addressed here.

## **7.0 GROUND SUPPLY REQUIREMENTS**

### **7.1 NEA PURITY**

Nitrogen Enriched Air (NEA) purity effects a number of different aspects of the ground based inerting system, however the primary effect on the aircraft system is one of varying the volume of NEA required to be loaded. The precise volume would be determined during development (analysis and testing) testing of the particular aircraft model and would be for a particular purity of NEA. NEA purity can also have an effect on the initial design to support the desired turn times to inert the aircraft. NEA 95% (95% nitrogen and 5% oxygen) was recommended for use in this inerting study in the beginning. Later, it was determined that NEA of slightly higher nitrogen concentration of 97 % or 98 % may be more desirable from overall cost and commercial standpoint. (See Figure 7.1-1 below). The cost of the gas is slightly higher for the higher purity, but the volume required to inert the fuel tank would be less. Consequently, the price of the total load of NEA may be lower.



*Figure 7.1-1. Ullage Cost as a Function of Purity*

**7.2 NEA VOLUMES REQUIRED**

The volume of NEA gas required to inert the fuel tanks to a reduced oxygen level is a function of the design of specific aircraft and the detail design of the NEA manifold installed in it. Early laboratory testing indicated that the required NEA volume was 1.5 times the total volume of the tank using 95% NEA to obtain an ullage oxygen concentration of 8%. 8% oxygen was considered a good target oxygen concentration for ground-based inerting as it is below the 10% level stated in the Tasking Statement, thus allowing for some dissipation during ground and initial flight operations and some variation in the inerting process. The volume exchange necessary was refined with actual aircraft testing that was conducted on a Boeing 737NG as part of a FAA test program. That aircraft, which was modified with the installation of an NEA distribution manifold, required 1.7 times the total volume of the fuel tanks being inerted when using 95% NEA (see figure 7.2-1). As a result, 1.7 has been used for calculations in this study. It should be noted however, that this factor would vary from aircraft to aircraft due to the variations in different aircraft models and different manifold designs. Each aircraft design will require testing to determine the NEA volume required to bring the oxygen level in the fuel tank down to the required level for that airplane design. The manifold will use outlets that will be configured to help mix the ullage gases in the tank to the maximum degree possible before they are pushed out the tank vent system by the incoming NEA. More efficient mixing and purging of the ullage gases will allow the NEA volumes to be less for a given tank configuration and manifold design.

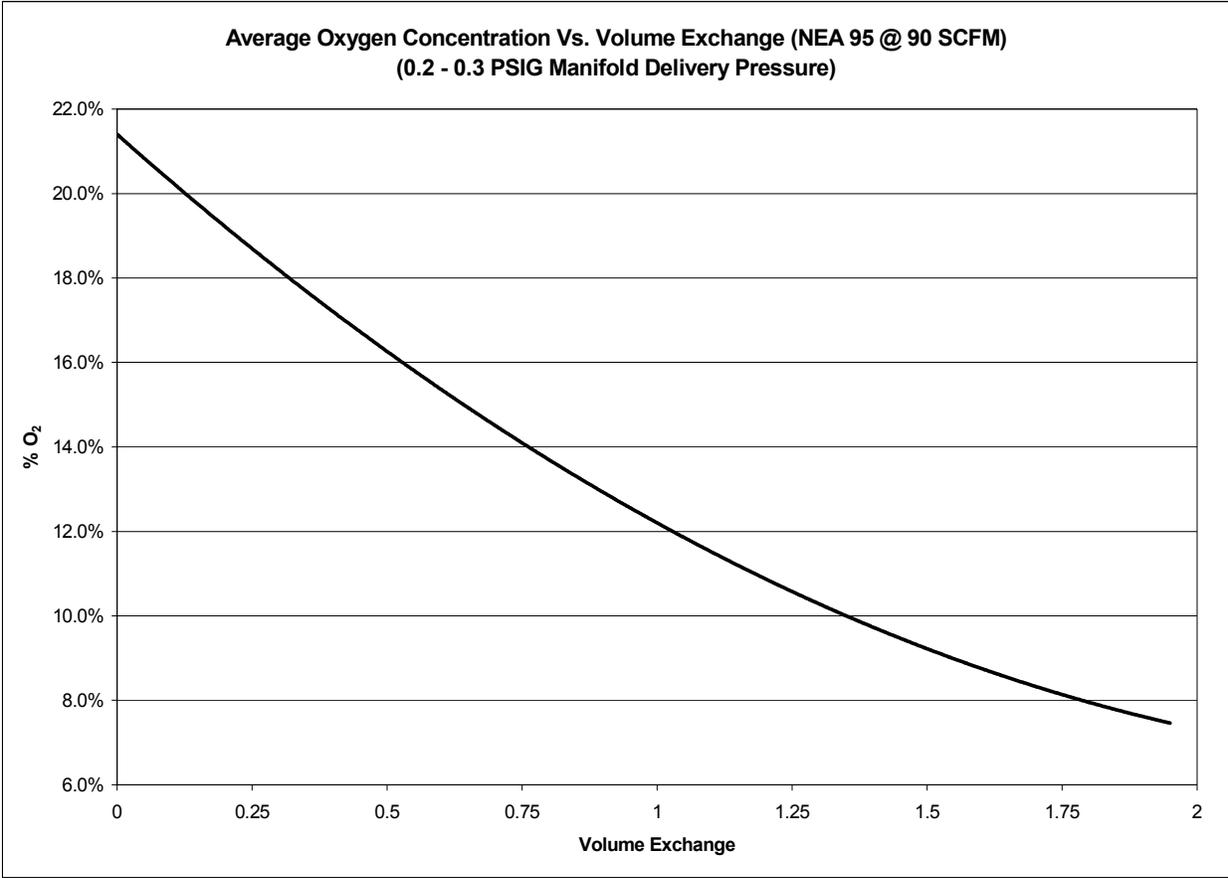


Figure 7.2-1. Flight Test Actual Purge Volume to Ullage Oxygen Content Relationship (737NG Testing)

The theoretical curves (supplied by a gas supplier) for the amount of nitrogen to purge a tank at various purities are shown in figure 7.2-2. This closely supports the actual test findings determined in the 737NG testing that took place in support of this study.

Inerting Curves for Various NEA Purities (Based on 100 cu-ft Ullage)

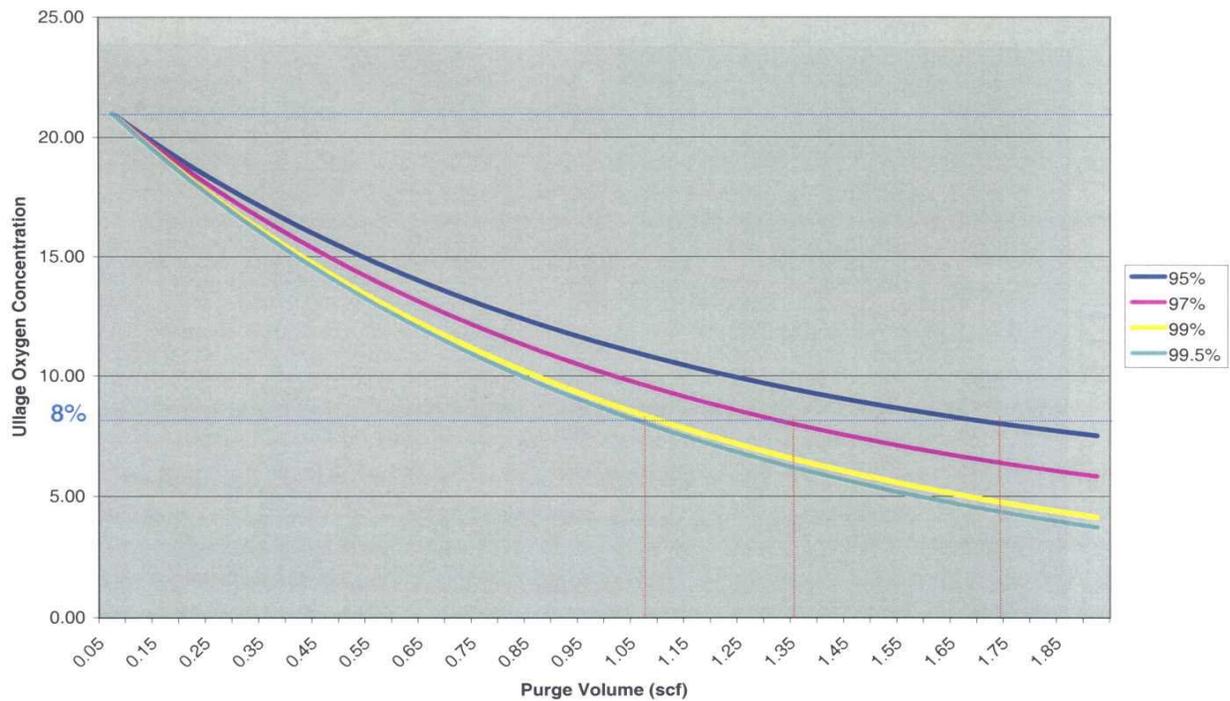


Figure 7.2-2. Theoretical NEA Purge Volume to Ullage Oxygen Content Relationship

The NEA volume required also depends on the NEA purity. A study recently performed by the FAA shows the evolution of the volumetric tank exchange as a function of the NEA oxygen percentage: “Inerting of a vented aircraft fuel tank test article with Nitrogen Enriched Air” reference DOT/FAA/AR-01/6. Inerting a tank with NEA 94% requires 1.9 volumes of NEA, as compared to requiring only 1.1 volumes with NEA 98%.

### 7.3 GROUND SUPPLY PRESSURE

The airport facilities supplying NEA would be required to be controlled to insure the delivered static pressure does not exceed the maximum allowable value. In order to prevent overpressurization and resulting structural damage to the fuel tank (wing), the maximum static allowable pressure has been determined to be 5.0 psi for most all aircraft. This provides a balance between aircraft structure safety for most of the world’s aircraft and the pressure required to quickly service those aircraft with a minimum turn time. All airport facilities and all ground servicing equipment would be required to deliver no more than 5.0 psi static maximum. Secondary overpressure protection must also be provided by the airport facility or ground servicing equipment to ensure the aircraft would not be damaged in the event of a primary pressure regulation failure.

Aircraft models that require the maximum pressure to be some value less than 5.0 psi static pressure would be required to carry onboard pressure regulation to reduce the pressure to the value required for that model. These models would include some models of Business Jets, some auxiliary fuel tanks, and some early aircraft models with fuel bladder cells where their maximum static pressure are typically 0.5 psi. The design of these systems would require secondary onboard pressure protection in addition to the primary pressure regulation to preclude overpressurization.

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The introduction of onboard over pressure protection does have undesirable side effects. Procedures would need to be in place to regularly check for dormant failures of these devices, and the additional design issue of locating these devices where their discharge does not introduce additional hazards to the aircraft or personnel. One alternative approach would be for ground equipment to be designed to have two independent pressure supplies with mutually independent servicing interface connections. The disadvantage of this is that the equipment would require two different servicing interface connectors on each piece of NEA servicing equipment and careful design to ensure the pressure supplies could not be cross connected in any case. This extra complexity would also have additional cost implications.

### **7.4 GROUND BASED GAS SUPPLIES**

There are several methods to produce nitrogen and Nitrogen Enriched Gas (NEA), but the two basic methods are as follows:

1. **Off-Site Production:** The classical method to provide nitrogen is the distillation of ambient air. This separation process produces high quantities of nitrogen at high purity. This scheme is generally one where liquid nitrogen is produced at a plant and it is then transported through pipelines or with trucks to the final user location. The liquid nitrogen is stored in insulated storage and it is heated and vaporized to produce gaseous nitrogen. In general, liquid nitrogen is used where high quality nitrogen and large quantities of nitrogen are desired. If liquid nitrogen systems are used for aircraft inerting, the liquid nitrogen must be in gaseous form before entering the airplane, and a temperature above the minimum certified temperature for the airplane fuel tanks and equipment.
2. **On-Site Production:** On-site production involves installation of a nitrogen generation unit installed at the customer site for production of on-demand gas. The heart of this on-site equipment is typically an Air Separation Module (ASM), composed of polymeric fibers. The driving force of the separation process is a difference of pressure between the gas sent into the membrane and the atmospheric pressure. Hence, ASMs are fed with compressed air typically powered with electricity. The gas produced is either stored in buffers or directly sent to the process requiring the gas, or in this specific case, the aircraft. This process allows production of Nitrogen Enriched Air (NEA) with oxygen contents varying from 5% to 0.1% or less. The choice of the oxygen percentage present in the NEA is made by a simple adjustment in the equipment. Flow delivered by on-site equipment can vary from 10 to 3000 Nm<sup>3</sup>/h (Normal cubic meters per hour), depending on the size of the equipment.

Numerous on-site options for the airplane inerting itself exist. One option would be to install a nitrogen generator at each concourse with distribution of the NEA to each gate through a network of pipes and hoses. For remote airplane parking or smaller airports, other options include the following:

1. Mobile nitrogen generators mounted on trucks or trailers that could be moved near the airplane for fuel tank inerting. The NEA generator would produce and feed the fuel tank directly.
2. Mobile nitrogen generators mounted on trucks or trailers combined with mobile storage. The NEA generator would continuously fill the storage and NEA is taken from the storage to inert the airplanes. This could reduce the size of the generator with a resulting decrease in power consumption.
3. Mobile storage filled at a nitrogen refilling station located at or near the airport. This solution would lead to requirements for equipment with large volumetric capacities, and the additional burden of the logistics of getting the correct amount of NEA to the airplane at the right time to support the desired turnaround time.

The details of this part of the design are considered by the Airport Facility Team. The methods for supplying nitrogen or NEA may vary around the world, but the GBI system can accommodate any method provided it has the common servicing interface and the required pressures and purity levels.

## **8.0 GENERAL AIRPLANE SYSTEM DESIGN**

The final design of the GBI system will be aircraft specific, being dependent on the basic design philosophies/principles of the manufacturer. For this generic study, the inerting system described can be considered as one incorporating all the features likely to be necessary on any GBI system installation. They may not all be required or desired any specific design. Including all these potential features does not overcomplicate the system being described, since the overall concept remains basically simple. To keep the system simple, the approach has been to assume that the aircraft will be supplied with a fixed volume of NEA irrespective of the amount of fuel in the tank when the operation is carried out. This volume is determined during the inerting design of the aircraft. During certification tests, this volume would be supplied at a minimum NEA purity allowed and a worse case pressure. It is accepted that the required volume is a larger volume of NEA than may be theoretically necessary. This approach also ensures that the system concept is not dependent on new technologies or complex ground procedures.

### **8.1 GENERAL SYSTEM LAYOUT**

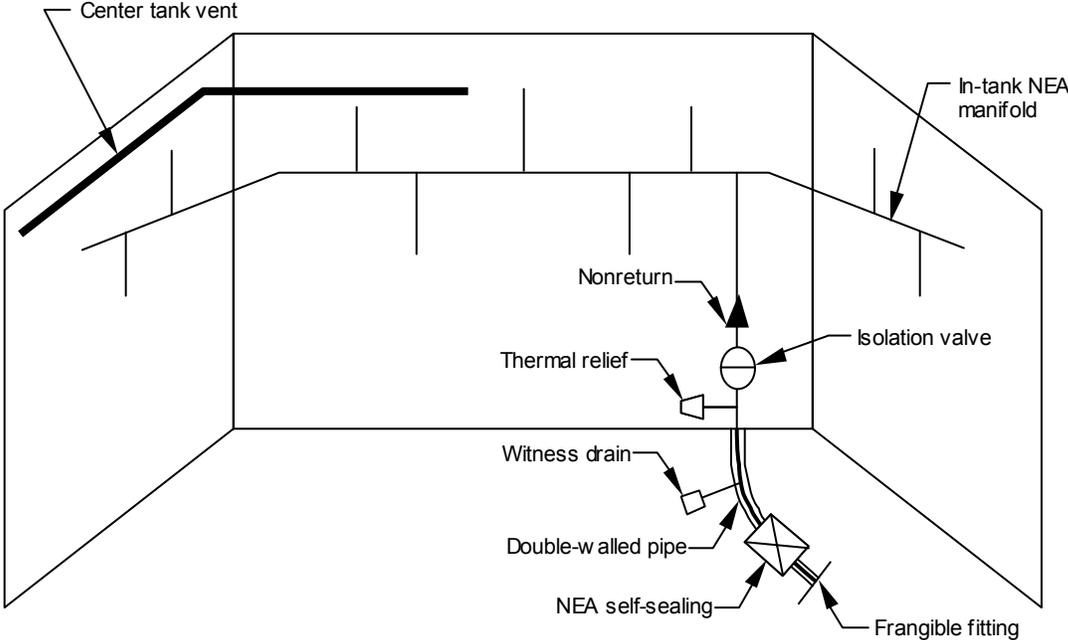
NEA will be supplied to the aircraft from a dedicated truck or distribution network present at all airports or aircraft servicing facilities. NEA will be delivered to the fuel tanks via a dedicated manifold within the aircraft fuel tanks. The review of various aircraft indicated that the type of internal structures can vary between aircraft models. On some aircraft types, the applicable tanks are divided by ribs into what can be considered as discrete cells, and in other tanks, they are basically open type structures. The internal layout and details of the distribution network to achieve the required dispersion of NEA will therefore be aircraft specific. Plumbing that is routed within the pressurized compartment or in confined spaces will be doubled walled to prevent hazardous leakage.

A valve will be mounted close to the tank wall to provide a means of isolating the internal portion of the tank from the plumbing that extends from the fuel tank wall to the NEA servicing interface. A second valve for redundancy maybe required, and these may be either manual valves, electrically actuated valves, or check valves or a combination depending on the features desired. This portion of plumbing must also be carefully designed to minimize the potential for fuel spillage after damage from a gear-up landing. This plumbing most likely will be routed up as far as possible and then back down again either inside the tank or outside the tank in an attempt to keep fuel from collecting at the servicing interface from normal operations. This portion of plumbing would be double walled if it is mounted in an enclosed space for personnel safety. A witness drain would be installed either as part of the servicing interface coupling assembly or very near the servicing interface to identify when the valves are leaking between the tank and the servicing interface. A second witness drain would be installed to confirm the integrity of the double walled plumbing.

Drain valves may be necessary in the manifold design to keep fuel from collecting in the manifold and preventing the expected NEA flow characteristics. This would not be a recognizable fault to the servicing person. Careful evaluation of the pressures available and the potential for a fuel-plugged areas would be required. Consideration for water collection and freezing would also be required when evaluating for the installation of drain valves and their placement.

Design of the manifold may include shaped and sized nozzles to better direct the NEA for more efficient purging of the tank. Other designs may only require an outlet cut to a certain size in the plumbing. These details are not addressed in this report other than to recognize them as design options.

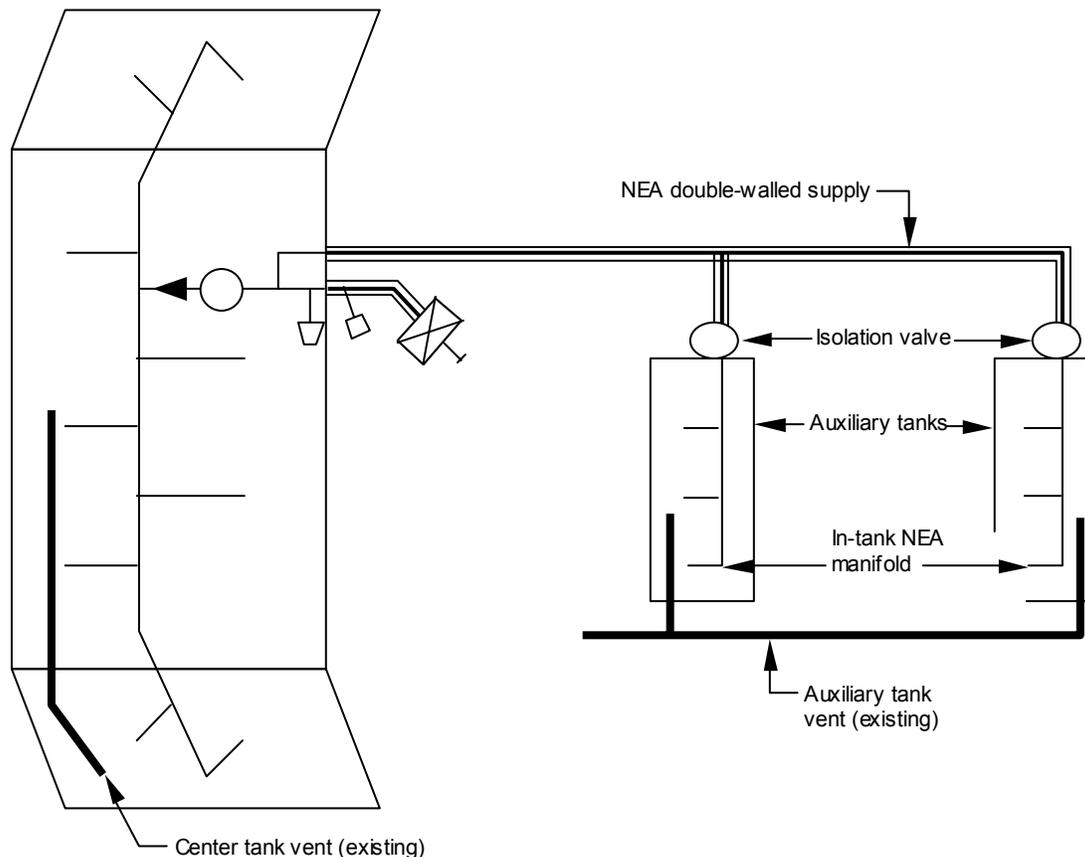
The schematic for a standard configuration aircraft is shown in Figure 8.1-1.



297925J2-045

Figure 8.1-1. System Schematic for Airplane With Center Wing Tanks

Auxiliary fuel tanks, when installed in the aircraft, will be serviced with NEA from the same servicing interface location. A schematic of the system for an airplane with auxiliary fuel tank(s) is shown in Figure 8.1-2.



297925J2-046

Figure 8.1-2. System Schematic for Airplane with Auxiliary Fuel Tank(s)

## 8.2 SERVICING INTERFACE

The ground based inerting design requires development of a new airplane servicing interface for the NEA servicing hoses. This new design would preclude interconnection of other servicing hoses or devices to protect the various airplane systems including the inerting system. The potential design would incorporate a frangible self-sealing coupling interface to prevent damage to the aircraft in the event the hose or coupling itself is forcibly removed. The servicing interface would be designed to not pose a safety hazard if any part or the entire servicing interface assembly and/or installation is damaged or forcibly removed from the aircraft, as in a wheels up landing.

## 8.3 SERVICING PANEL LOCATION

The new service panel will be located in the aircraft to accept the new NEA servicing interface coupling and hose. Due to this study being limited in scope to center wing and auxiliary tanks, the NEA servicing interface location has been located near the fuselage of the aircraft to minimize tubing installations. However, the specific location of the NEA servicing point will be a detail design task for each aircraft type. The location should be chosen to minimize system design and aircraft structure impacts, as well as, providing as much consideration for other servicing efforts being carried out in the same area. Most notably, interference with baggage handling personnel would need to be minimized. The ATA has suggested that small/regional aircraft would prefer the NEA connection on the aircraft right side, and all other aircraft would prefer the servicing location be on the left side. The location should also be chosen to

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minimize the safety hazard if any part or the entire servicing interface assembly and/or installation is damaged or forcibly remove from the aircraft.

Other locations considered did not exhibit desirable servicing environments. Landing gear attached locations are not desirable due to the complexity of plumbing and equipment in a harsh, moveable environment. Location towards the front or rear of the fuselage is not desirable, as additional tubing is required to connect to the center wing tank adding routing complexity and system weight. Rear fuselage locations also may be further from the ground in many models requiring other ground equipment like ladders or step stools. Wheel well locations are not desirable from a personnel safety and aircraft safety concern. If the servicing panel is mounted in the wheel well area, additional personnel training would be required to allow entry due to the complexity of the equipment in the area. The wheel well areas are also more confined, and as such, hold more risk for personnel due to the potential for a confined space exposure to undetectable gases including NEA. The servicing point should also be located so as to facilitate the easy movements of the NEA servicing personnel to the maximum degree possible. Presently it is believed that the wing-to-body fairing under the wing provides the most reasonable site for the NEA servicing location. Other locations may be more suitable on smaller aircraft. The addition of a servicing panel door in the fairing would be required in this location, but may not be required in all locations depending on the airplane design. This location was also chosen to minimize the wing structure impact and simplify the design for in-service and production aircraft installations by minimizing the plumbing runs in the wing to hookup to a wing mounted servicing interface

**8.4 GENERAL SYSTEM DESIGN ANALYSIS**

The ground based inerting system has been sized to load the required NEA volume in the generic sized ARAC configurations in the following times:

ARAC Large aircraft	20 minutes
ARAC Medium aircraft	15 minutes
ARAC Small aircraft	10 minutes
ARAC Regional turbofan	10 minutes
ARAC Regional turbofan	----- (not fitted with center tanks)
ARAC Bizjet	10 minutes -- (ARAC and most not fitted with center tanks)

These times do not include time to connect/disconnect the ground equipment. The time to connect is projected to be no more than 5 minutes, and the time to disconnect and provide paperwork to the pilot is projected to be no more than 5 minutes, or a total of 10 minutes per aircraft NEA servicing. These times were chosen to eliminate or minimize any gate delays to allow for short aircraft turn times. Longer times would not significantly change the aircraft design cost, but could provide less impact to existing aircraft structure due to the decrease in the required diameter for the NEA manifold and tubing. Airport Facilities will need to optimize the airport capability to handle the peaks through equipment sizing or accumulators. (See the Airport Facilities appendix)

The general GBI system was analyzed to estimate the flow performance with typically sized tubing and manifolds. As would be expected, the performance depends on a number of parameters that can be varied. Those parameters included the tubing and manifold diameters, the tubing lengths, the flow velocities, the various fuel tank volumes, NEA flow rates desired, and time to complete the required servicing. Tubing and manifold diameters were kept as small as practical to keep to minimize the structural modification and weight aspect of the design as much as possible. The tubing lengths are a function of the tank configuration and size of the specific model. The flow velocities were minimized to be consistent with existing Environmental Control System (ECS) recommendations to minimize erosion, noise, and other

adverse gas flow effects. The volume of each fuel tank was determined and multiplied by the number of volumes required to reduce the oxygen content to 8% or below as determined by flight testing. That number was determined to be 1.7 times the ullage volume as described elsewhere in this Appendix. The various ARAC airplane configurations with and without auxiliary fuel tanks were estimated to have the basic manifold plumbing lengths and diameters in figure 8.4-1.

Model	Manifold Length-Total	Diameter
ARAC Large aircraft	75 feet	2.0 inch
ARAC Medium aircraft	50 feet	1.5 inch
ARAC Small aircraft	25 feet	1.0 inch
ARAC Regional turbofan	15 feet	0.5 inch
ARAC Regional turboprop	not included	Not included
ARAC Bizjet	15 feet	0.5 inch

Model	Length between center tank and aux tank	Diameter	Manifold Length-Inside tank	Diameter
ARAC Large aircraft with aux tank	50 ft double wall external to tank	2 in internal diameter/3 in external diameter	15 ft inside tank	2 in diameter
ARAC Medium aircraft with aux tank	50 ft double wall external to tank	2 in internal diameter/3 in external diameter	15 ft inside tank	2 in diameter
ARAC Small aircraft with aux tank	42ft double wall external to tank	1.5in internal diameter/2.5in external diameter	13ft inside tank	1in diameter
ARAC Regional turbofan aircraft & ARAC Bizjet aircraft with aux tank	30ft double wall external to tank	1.0in internal diameter/2.0 in external diameter	10ft inside tank	1in diameter

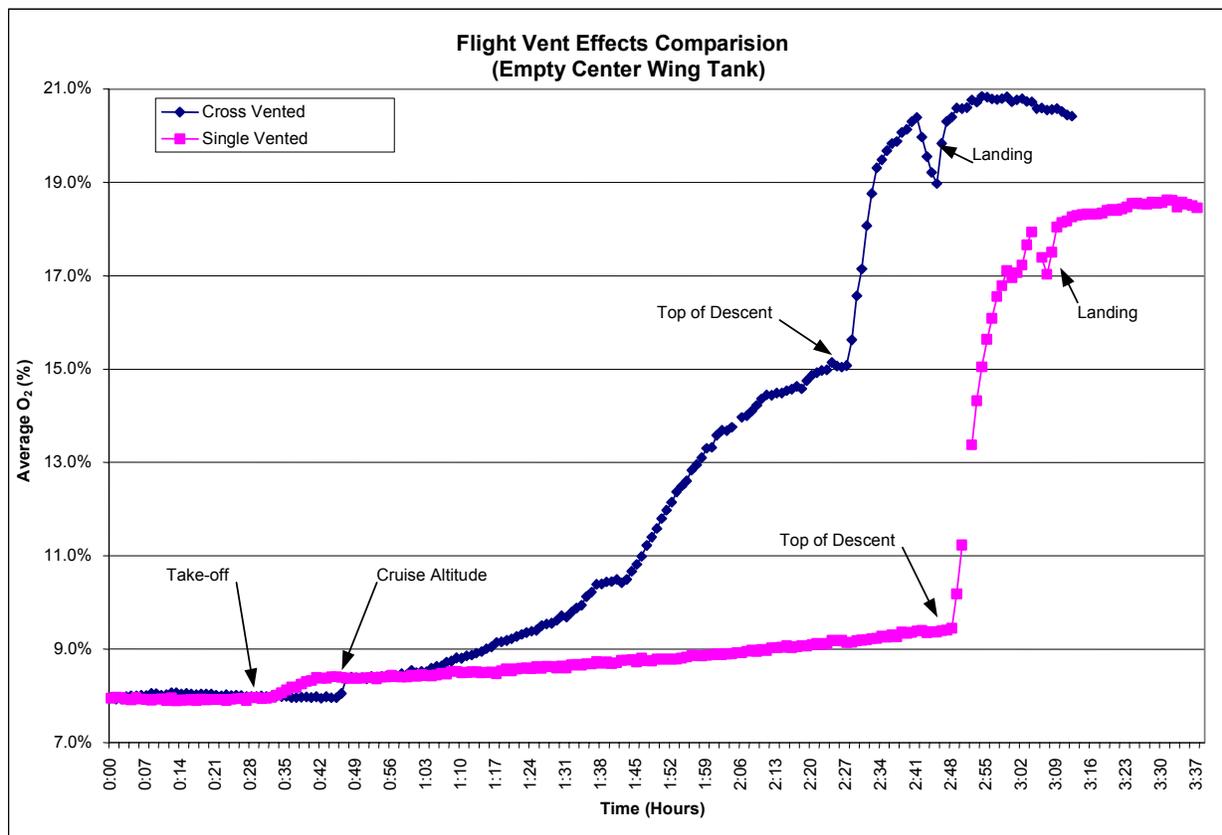
*Figure 8.4-1. System Manifold Lengths and Diameters*

This design information was used to model and analyze the basic system for overall system performance. The results were then utilized to balance the design within the desired turn around times.

**8.5 GROUND AND FLIGHT TESTING EXPERIENCE**

Ground and flight test was performed on a B737NG airplane in February of 2001 to better understand the issues applicable to the ground based inerting system. A temporary inerting system was installed in a customer’s new B737NG prior to delivery. System installation and testing was performed over several weeks. The test airplane was equipped with instrumentation to record pertinent variables for future analysis. Oxygen sensors were installed in eight locations to sample the ullage space in the center tank of the airplane. The system required considerable review and analysis to confirm it was safe for personnel and the aircraft. NEA was supplied by a ground based NEA generator located adjacent to the airplane. By changing the two primary variables, fuel load and NEA loading sequencing, various GBI system scenarios were run to further understand the impact of the primary variables. Tests were also performed to better understand the impact of having a fuel tank with multiple vents. Testing did not use scrubbed fuel.

Testing has shown that multiple center fuel tank vents can result in the flow of ambient air through the tank ullage and result in the loss of the desired inert oxygen levels after the NEA inerting process (see figure 8.5-1). Local wind and certain flight situations accelerated this loss. All airplane designs that utilize more than one vent per tank may exhibit this behavior. When one of the two vents installed on the test airplane was blocked, the ability to retain the desired oxygen level was considerably enhanced. The test airplane maintained an oxygen level below 10% through taxi, takeoff, climb, and into cruise (see figure 8.5-1).



*Figure 8.5-1. FAA/Boeing (B737NG) Flight Test Results Showing Effects of Crossventing*

Testing also showed the evolution of gases out of the fuel did occur as the altitude increased. This effect did not induce a significant oxygen level change when fuel levels in the CWT were low (i.e., less than 20%) at takeoff. Fuel scrubbing could reduce this effect. However, because the CWT is the last tank typically filled and the majority of flights occur with low or empty CWT fuel levels, the majority of flights would not benefit from fuel scrubbing. Further, CWT’s with high fuel levels at takeoff lose their inert levels early during cruise due to ambient air in-flow to replace the fuel consumed. Thus, fuel scrubbing would only slightly change the GBI fleet exposure analysis of tanks with high fuel levels at takeoff. Overall, it was concluded fleet wide GBI performance would not be significantly enhanced by the use of scrubbed fuel.

Testing also showed that there was some difference in the oxygen levels when the sequencing of the NEA gas loading was changed around the refueling event, but here again it was not considered to be significant enough to impair the system. The ability to be able to have the GBI occur at any time in the airplane ground turn around time independent of the refueling was demonstrated.

**8.6 SYSTEM CONTROLS**

A control panel near the NEA filling point would be provided. This panel would contain the following items:

1. A switch to operate the NEA isolation valve for each tank, if installed
2. An indicator light for each valve, if installed
3. A placard clearly indicating the required volume of NEA, purity, and pressure requirements

Additional control of the NEA tank isolation valve may also be required depending on airplane system details and the supply pressure of the NEA. This control would cause the inlet valve to close under refuel overflow conditions thus limiting any tank over-pressure condition.

Certain Auxiliary tank configurations would require specific manual procedures to supply each tank with a suitable quantity of NEA during the ground operation to minimize the amount of NEA to be supplied.

### **8.7 SYSTEM OPERATION AND SERVICING**

The system may be operated at any time throughout the aircraft gate time available. The system may be operated before the refueling operation commences, during the refueling process, or after the refueling process has ceased. The quantity of NEA will be the same by definition in any refueling scenario to simplify the NEA servicing processes.

One particular quantity of NEA at a specified pressure range will be required for each aircraft model. Supplemental Type Certificates (STC) or other modification involving the fuel system may require different amounts of NEA for similar aircraft and this must be clearly defined on placard at the NEA servicing location and in the Airplane Flight Manual. Detailed operational differences of the GBI system may be slightly different between manufacturers, but the intent is for them to be similar in operation.

A printed NEA flowmeter output receipt would be provided to the pilot at the end of every NEA servicing provides the check that the NEA has been loaded and the volume loaded is correct. The ideal NEA flowmeter system would print the quantity, minimum purity and minimum pressure for the pilots' comparison to the AFM.

Future aircraft designs may utilize a more sophisticated control over the NEA servicing activity, including the volume of nitrogen delivered. Onboard aircraft computers and information from the ground based equipment could work together to optimize the NEA delivery particularly when the NEA is added after refueling. Ground equipment manufacturers and facilities designers may want to work with the aircraft manufacturers to ensure this option is made possible and interface requirements are defined. That detailed definition is out of the scope of this study.

Typical NEA servicing instructions:

1. Open access panel.
2. Verify servicing equipment/source meets aircraft placard requirements for pressure and NEA purity.
3. Connect the servicing hose with the aircraft NEA servicing location and lock in place.
4. Select the isolation valve open. Verify indicator light illuminates confirm valve has opened.
5. Add required volume of NEA as identified on the placard.
6. Close isolation valve and verify indicator light extinguishes.
7. Unlock and disconnect NEA servicing hose coupling.
8. Fill in control sheet to indicate operation has occurred and amount of NEA added if not printed in sheet by flowmeter.
9. Verify the volume delivered meets or exceeds the required volume on the NEA servicing placard.
10. Deliver NEA servicing sheet to the flight crew.

### **8.8 AUXILIARY TANK DESIGN ISSUES**

For aircraft fitted with auxiliary fuel tanks, system operation and equipment arrangement for inerting the tanks would be similar to that for a center tank installation. Aircraft with center tanks and auxiliary tanks installed would utilize a common NEA service interface connection and associated controls. The procedures to inert the auxiliary fuel tanks would be the same as the center tank, except for the potential

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difference in NEA volume required. The aircraft plumbing would be arranged to split and balance the incoming NEA flow so that each tank receives the correct volume of NEA. This would allow the auxiliary tanks to be inerted at the same time as the center tanks to minimize impacts on turn around time. It also may be possible to use the auxiliary tank refueling line for inerting due to the configuration and smaller size of the tank. Certification testing would be required to show proper inerting in all tanks.

The plumbing between the center tank and the auxiliary tanks (in all locations within the pressurized cabin area) must be double walled to preclude NEA leaks from entering the pressurized passenger area. In addition, the introduction of the ground based inerting system for aircraft auxiliary tanks would require modifications to cargo compartment panels, linings, and new rubber auxiliary tank liners where so equipped. Additional penetrations will be required through structure and the center wing tanks to route the required tubing to deliver NEA to the auxiliary tanks.

Suppliers of auxiliary fuel tanks that are not covered under the original airplane certification must obtain a Supplemental Type Certificate (STC) to install an auxiliary fuel tank system. If properly integrated, the fuel tank distribution manifold and auxiliary tank NEA distribution system would be interconnected to utilize a single servicing interface location. The auxiliary tank system would be designed such that the inert gas supplied by the ground system at the single servicing interface location provides sufficient NEA to inert the auxiliary tanks and the normal airplane fuel tanks with no additional interaction by ground personnel. The actual volume of inert gas required would be determined at certification and would be clearly shown on the placard directly adjacent to the servicing interface location. Other systems may be possible that include automatic sequencing of the inerting system valves to control the NEA distribution. These interactive systems would be required to demonstrate that they meet the applicable requirements at certification while minimizing servicing personnel induced error.

STC providers would be solely responsible for showing that the original airplane inerting system certification was not degraded when the STC auxiliary tank(s) were fitted to the modified airplane. This may include conducting the complete airplane inerting certification testing over to verify the total airplane inerting system meets the applicable requirements. New placards showing the new NEA volumes would be required at the servicing interface location. Auxiliary tanks fitted by the original airplane manufacturer prior to certification would be covered as part the routine certification process.

### **8.8.1 Auxiliary Tank Pressurization Alternative**

Some auxiliary tank designs reviewed transfer fuel using pressurized air. Pressurizing the tank means that the tank ullage is effectively at a lower altitude. This results in a higher fuel LFL and thus a higher fuel temperature is required to produce a flammable atmosphere within the tank. Therefore, an alternative method of achieving a lower flammability exposure for auxiliary tanks may be to increase the pressurization level in the tanks at all times, or convert tanks which are open vented, to pressurized systems. Application of this technique may show that the resulting flammability exposure is similar to that which would have been achieved by inerting (see discussion of auxiliary tanks in Flammability Exposure Analysis Appendix J). In order to provide this alternative, all design factors and considerations affecting the design and safety must be addressed including, but not limited to, structural considerations, venting, loss of cargo bay pressurization, etc.

## **9.0 EQUIPMENT REQUIRED**

The following equipment is required for inerting with a ground based inerting system:

### **9.1 NEA SERVICING INTERFACE**

As stated earlier, the ground based inerting design requires development of a new airplane servicing interface for the NEA servicing hoses. A new worldwide engineering standard for the servicing interface coupling halves would need to be developed and controlled in a similar manner to the current refuel coupling. This interface would consist of a nozzle portion attached to the servicing hose and a matching

airplane mounted receptacle. The interface would be designed to prevent incorrect connections of other servicing hoses or devices to protect the various airplane systems, including the inerting system. The design would incorporate a frangible self-sealing coupling interface to prevent damage to the aircraft in the event the hose or coupling itself is forcibly removed. An example of this might be a NEA servicing truck driving away still connected to the aircraft interface or a NEA servicing hose being snagged by other service vehicles driving away. The coupling design and materials would be required to be a non-sparking design to prevent ignition sources where fuel is or could be present. This non-sparking requirement would also include all potential failure modes.

As presently envisioned, the interface would include at least one internal check valve. The insertion and engagement of the ground hose end of the interface would actuate this check valve. This would allow NEA pressure into the interface coupling followed by the check valve(s) opening to the fuel tank. The purpose of this timing is to prevent fuel from draining into the hose assembly and allowing the pressure of the NEA to push back the fuel if any has leaked into the manifold assembly. The insertion and engagement of the two halves of the servicing interface could be a manual operation similar to a refueling single point coupling, or an automatic mechanism. The method chosen should be standardized to ensure servicing commonality. The automatic mechanism is preferred from an overall system standpoint to assist less skilled or trained personnel to safely service the inerting system. A witness drain to identify leakage past the isolation or nonreturn valves may also be required here.

Each aircraft manufacturer would have the option of integrating a servicing interface module into their particular model or designing something specific for their airplanes using the standard coupling interface. The NEA servicing interface would ideally be a modular design and assembly that could be produced by an aerospace component supplier. The assembly would consist of the servicing interface for the NEA servicing hose describe above and a generic mounting configuration that would allow easy mounting adaptation to various models. This mounting configuration may include mounts to attach the service doors required in the fairing application. Since all fairings would be different, this service door design would need to be flexible and yet provide some degree of commonality to maximize manufacturing efficiency and minimize cost.

### **9.1.1 Witness Drains**

A witness drain would be required to detect leakage in the double walled portions of tubing exterior to the fuel tank. This could also be accomplished by routing the inter-shroud drains to overboard drain masts if those masts drain while on the ground. This would give ground personnel and the pilots visibility if the double walled tubing (or hose) configurations are leaking fuel. Gaseous leakage would be difficult to detect on a daily basis. A maintenance plan would be required to do leak checks on this double walled tubing at reasonable intervals to ensure the secondary barrier is intact.

### **9.1.2 Isolation Valve**

An isolation valve may be required to isolate the tank from the external tubing. It is envisioned that this valve would be an electrically operated valve and mounted directly to the internal surface of the tank.

### **9.1.3 Non-Return Valve**

A non-return valve (check valve) to prevent backflow of fuel into the NEA supply would be required internal to the center tank at the main NEA manifold penetration into the tank. It is envisioned that this valve could be mounted directly to the tank wall surface if the isolation valve was not required.

## **9.1.4 Thermal Relief Valve**

Thermal relief valves are required to relieve any pressure that may build up in the tubing due to temperatures changes. Thermal relief valves may be incorporated into the other valves or equipment present in the system.

## **9.1.5 Indication and Control**

A control switch and position lamp for the isolation valve may be required. This switch and indicator would be required to be intrinsically safe or environmentally/hermetically sealed in a manner to not present a potential ignition source due to the potential presence of fuel. Any control hardware located near the NEA interface would also be required to be housed or protected to not present a potential ignition source.

## **9.1.6 Drain Valves**

Drain valves may be required in the tubing and/or manifold where locations do not drain fuel to minimize interference with the trapped fuel and the incoming inerting gases. Drain valves would not be necessary where the design could be shown to always clear itself and provide the proper volume of inerting gas.

## **9.1.7 Placards**

Placards would be affixed to those areas requiring cautionary and/or safety instructions, and placards would be provided directly adjacent to the interface coupling servicing installation area. The servicing coupling placard would clearly identify the certified, NEA volume to be loaded on the aircraft. Placards would be clearly readable and of materials consistent with the usage.

## **9.2 AUXILIARY TANKS**

Auxiliary fuel tanks would require similar equipment as the main center tanks in the aircraft. Auxiliary fuel tanks are envisioned to be inerted through the same NEA servicing coupling as the center tanks. As such, the auxiliary tanks could receive their inert gas from the same manifold. Depending on how the system is designed and operated, it may require additional control circuitry for the auxiliary tank isolation valves to control the time the auxiliary tank isolation valves are open. This would be to ensure that a sufficient volume of inert gas is distributed to the auxiliary tank as the center tanks are being inerted. The details of this are presented at this time due to the variability of auxiliary tank systems.

## **9.3 ADDITIONAL EQUIPMENT REQUIRED**

Aircraft designed with crossvented fuel tanks will need to have the vent system design modified and demonstrate methods to minimize NEA exchanges due to the crossventing configurations. This is envisioned as a low cracking pressure bi-directional flapper check valve that is installed in all but one vent passages used for the center tanks. These changes will need to be implemented carefully to take all vent system design issues into account. These changes will also need to account for interaction by auxiliary fuel tanks.

## **10.0 INSTALLATION REQUIREMENTS**

### **10.1 NEW DESIGN**

The design of a ground based inerting system requires the careful and balanced selection of a number of design parameters to optimize the system's performance versus the aircraft servicing time. The prime requirement of the system will be to distribute the NEA to achieve a reduced oxygen concentration to comply with the rule and the specific certification.

No major concerns are seen with the GBI inerting concept, assuming the design is launched in the early phase of the design. During the design cycle the system would be subject to design reviews, safety assessment, zonal analysis, etc. The manifold design, structural penetrations, wiring and service point

location would be worked in the basic design phase. Routing of any electrical controls or circuits associated with any of the equipment used would need to be implemented carefully to not introduce any new hazards. Location of the servicing interface point would need to consider not only the location of the servicing trucks, but be located so as not to introduce additional hazards in the event of a wheels up landing. Accessibility of the servicing interface connection would need to consider the acceptability of servicing steps/platform if necessary.

Installation requirements for all designs will be very similar. Installations for new designs will have the most flexibility to optimize plumbing and its associated placement. It is expected the NEA manifold would be mounted as close to the top of the tank as possible. This would be to ensure that the maximum mixing and venting of the tank gases occurs to efficiently purge the fuel tanks of oxygen with the minimum quantity of NEA in any refueling scenario. Effort to minimize the formation of fuel collection sites within the manifold should be made. This may include drain valves in those designs that may not be capable of clearing these fuel obstructions through the normal NEA servicing procedures and the servicing pressures available.

### **10.2 IN-PRODUCTION**

Optimum manifold design in terms of weight and location may not be possible due to other systems installed and limitations on location of structure penetrations. Optimum plumbing configurations and lengths may not be possible due to the restrictions on getting plumbing into the airplane after assembly. Modifications to tank venting arrangements may be required on certain aircraft types. This will require additional design and certification activity over and above that required to demonstrate the effectiveness of the modification for inerting the tank. Depending on the location of the servicing interface point, redesign of a section of the external aircraft body fairing may be required including the introduction of a specific access panel to gain access to the servicing point. Airline spares will be impacted.

### **10.3 RETROFIT**

Concerns expressed for the in-production design are equally applicable. If modifications to the tank installation or areas around the fuel tank have been made to the aircraft since the original delivery then further additional design work and adaptations may be required.

### **10.4 AUXILIARY TANK INSTALLATIONS**

Generally, the comments above also apply to auxiliary tanks. Several additional concerns also apply:

- The need for double walled tubing in the pressurized areas will further complicate tube routing in areas where space is already constrained by other systems.
- If more than one auxiliary tank is installed it will be necessary to balance the flow of NEA between the tanks. This may require a NEA volume greater than that currently envisaged of 1.7 times the total ullage or other design changes unknown at this time.
- Some auxiliary tanks include bladders inside the tanks. This will complicate redesign because of the need for new bladders to accommodate new tubing penetrations and routing in the tank.
- Modification of cargo bay liners will be required, due to the new plumbing penetrations.

### **11.0 SYSTEM IMPACT ON OTHER SYSTEMS**

Because the NEA may be dissolved in the fuel differently than other gases, there may be some impact of other systems in the aircraft. Those impacts must thoroughly investigated to ensure a detrimental effect is not introduced by these inerting systems. The detailed testing required to ensure safe and proper operation of these systems is beyond the scope of this report, other than to address and note these concerns in a general manner. The concerns are as follows:

## **11.1 PUMP PERFORMANCE**

NEA coming out of solution from the fuel, particularly when the aircraft climbs, may be different from the evolution of air or other existing dissolved gases. Those differences most likely would be explained as a function of bubble size and/or the rate the bubbles are evolving from the fuel. The ability of the engine pumps, fuel boost pumps and ejector style pumps to successfully prime, pump, and reprime in a predictable manner identical to past performance is essential. If it were demonstrated that this was not the case, then all fuel pumping equipment would require re-qualification at considerable expense. Further, these differences would require evaluation of engine feed operational issues and it is likely to require re-certification testing, again at considerable expense.

## **11.2 IMPACT ON FUEL QUANTITY INDICATION SYSTEM (FQIS) PERFORMANCE**

The effects of nitrogen inerting on the various fuel measurement techniques are not fully understood at this time. The process of injecting the NEA into the fuel tanks may have effects including:

- Introducing larger quantities of dissolved nitrogen into the fuel
- Potential for displacing other dissolved gases in the fuel
- Causing the formation of bubbles both in the fuel and on the fuel surface
- Causing the bubbles to manifest themselves differently than before
- Changing the properties of the fuel

Detailed testing of the chemical and physical effects of nitrogen inerting in this new environment should be done to insure that the functional integrity of the various fuel measurement techniques are not degraded. The consequences of these changes may effect the accuracy or reliability of the specific FQIS measurement techniques and equipment used. That would need to be carefully studied and characterized to ensure there were no side effects in-service. That detailed testing is beyond the scope of this report.

## **11.3 IMPACTS ON CROSS VENTED SYSTEMS**

“Cross vented” venting systems, or those that have center tank vents that run out to both wing tips, appear to be less desirable for inerting systems. The potential for flow through the tanks between the two vent locations can produce a scavenging effect that will cause the ullage to exchange with the outside air in a short period of time. This increases the oxygen content in the tank to rise as the outside air is brought in. Those airplanes that have these venting systems would be required to design a means to retain low oxygen contents in the ullage space.

## **11.4 POTENTIAL IMPACT ON FUEL PROPERTIES**

Through the process of inerting the fuel tank ullage, the lighter fractions contained in the fuel are removed. The effect of this change on fuel properties has not been characterized for the engines and their performance. Detailed testing to characterize this issue is beyond the scope of this report.

## **12.0 SYSTEM SAFETY**

The primary focus of the GBI design team was to carefully and thoroughly evaluate ground based inerting systems with a heavy emphasis on not introducing new safety hazards for either personnel or the airplanes. While the safety impacts of the GBI system are discussed in detail elsewhere in this report, the primary safety concerns of this system are stated here again for reference. The safety concerns are primarily associated with the following:

- The use of nitrogen, NEA, or other oxygen displacing gas in confined spaces.
- The flow of oxygen depleted gases from the aircraft wingtip vents.

- Overpressurization of the wing structure due to malfunction of the ground or airplane mounted inert gas pressurization equipment.
- Minimizing new safety hazards associated with a “wheels up” landing. This is primarily a servicing interface location issue.
- Minimizing new ignition source hazards associated with incorporation of a GBI system. Non-sparking materials and components at the servicing interface coupling, careful use of electrical components, and minimizing new electrostatics issues due to the ullage purging are examples.
- Safeguards to prevent fuel spillage

### 13.0 SYSTEM WEIGHT

The estimated weight required for each ARAC aircraft is outlined below to assess the system impacts on the aircraft performance and it’s associated economic impact. Weights for the ARAC Turbofan, Turboprop and Bizjets are estimates based on the ARAC Small aircraft data as detailed information on the actual systems and configurations were not known. The ARAC Turboprop is not included below because that configuration does not have a center tank by definition. The ARAC Bizjet does not have a center tank by definition, but information that some Bizjets have a center tank in reality became available late in the study and these configurations are shown as well. Figure 13.0-1 lists the estimated weights for the various systems.

ARAC Standard Configuration Model	Total Weight US Pounds	Total Equipment Weight US Pounds	Total Plumbing Weight (including couplings) US Pounds	Total Other Installation Weights (including brackets, bonding jumpers, structure modifications, and hardware) US Pounds)
Large Aircraft	54	6	36	12
Medium Aircraft	34	6	20	8
Small Aircraft	22	6	10	6
Turbofan	15	5	7	3
Turboprop	---	---	---	---
Bizjet	15	5	7	3
Aux tank for Large	45	3	39	3
Aux tank for Medium	45	3	39	3
Aux tank for Small	47	13	27	7

Note: 1. Auxiliary tank weights listed are for the tank equipment and its associated external manifold equipment only. Does not include the associated additional airplane structural and systems weights.

Note: 2. Auxiliary tank weights for the Small aircraft is based on tanks located in both the front and the rear cargo areas of the aircraft.

*Figure 13.0-1. Estimated System Weights*

## 14.0 EVALUATION OF REDUCTION IN EXPOSURE TO FLAMMABLE ATMOSPHERE

### 14.1 REDUCTION IN EXPOSURE TO FLAMMABLE ATMOSPHERE ANALYSIS

The methodology of analyzing flammability exposure is explained in the main body of this report in Section 4.2 Flammability. Utilizing this modeling approach, the baseline flammability for the Large, Medium and Small Transport categories were performed and the corresponding values are shown in figure 14.1-1 below. As noted in the discussion on modeling, these values do not represent any specific airplane, only a generic configuration selected to represent an airplane in this category.

Incorporating GBI on these airplanes is analyzed based on the following assumptions:

- Every airplane is inerted with the volume of 95% NEA necessary to reduce the oxygen content to 8% with an empty tank. Thus, flights with a partially full center tank actually start at less than 8% oxygen.

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- The inerting is a step function inserted at halfway through the “time at gate after refueling”. Additional modeling refinement was not made to model the actual inerting flow time or a random distribution of when the inerting may occur during the gate time, as would occur in actual implementation. However, it is expected that the results presented here are similar.
- The model assumes no loss of nitrogen during steady state cruise. Depending upon the openness of the tank venting and the duration of the flight, there may be some loss not accounted for in this analysis.

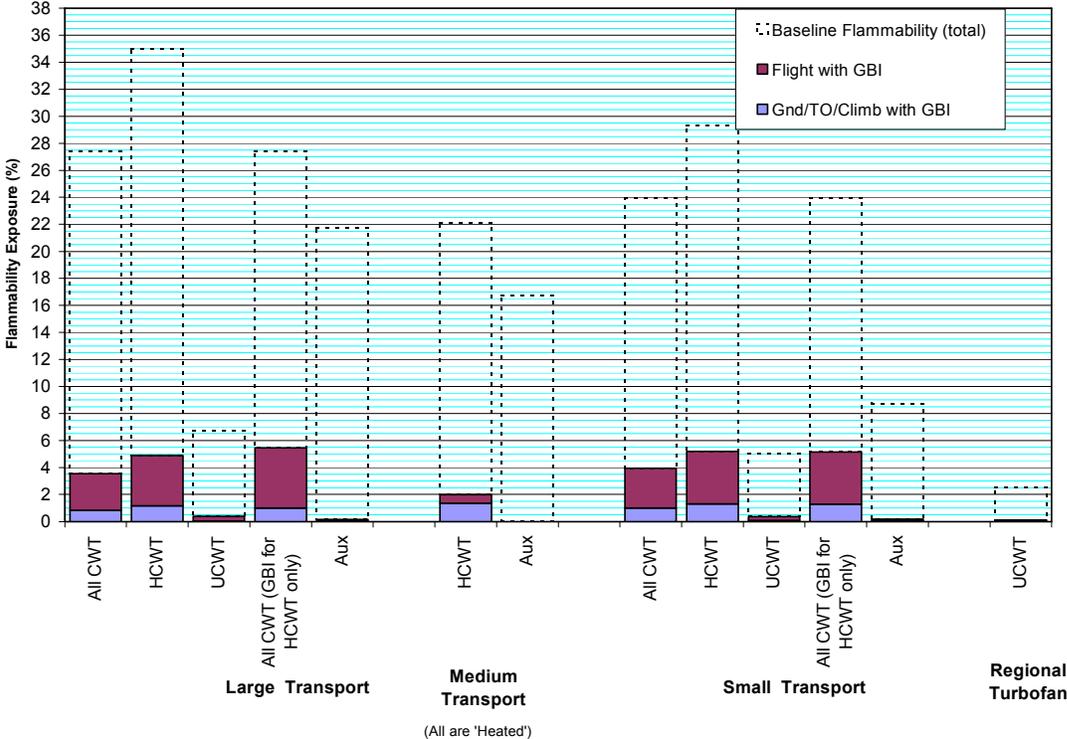


Figure 14.1-1. Flammability Exposure Results for the Ground-Based Inerting System

The results of the analysis are that the fleet wide (All CWT) Flammability Exposure after GBI is as shown in figure 14.1-1 for the Large, Medium and Small Transports. The “All CWT” values represent a combination (per the ARAC estimated distribution) of the Heated Center Wing Tanks (HCWT) and the Unheated Center Wing Tanks (UCWT) values. Also shown are the individual values for the HCWT and the UCWT generic airplanes. The difference in the exposures between the different sizes of transport airplanes is a function of the generic definition of the models, and demonstrates the variation from model to model that would exist due to difference in tank sizes, mission profiles and other variables. Also shown is the effect of GBI on an ARAC defined Regional Turbofan airplane, which has an unheated center tank.

Per the Tasking Statement, GBI has been analyzed only for tanks which do not cool at a rate equivalent to a wing tank. Therefore, wing tanks, the regional turboprops, and the business jets are not included in the analysis as they do not include tanks that fit this criterion.

The tasking statement also asks for the effect of limiting GBI to airplanes with only Heated Center Wing Tanks (HCWT). As shown in the numbers, the largest benefit is for HCWT airplanes, as the baseline flammability of the UCWT airplanes is already approximately the same as the HCWT with GBI. Therefore, limiting GBI to airplanes with HCWTs would result in only a modest increase in fleet wide flammability exposure. Note that GBI for only HCWTs, which is defined as Scenario 11 in the Estimating

and Forecasting section (Section 11.0) of the main report, has been used in the Executive Summary Information (Section 1.0).

Auxiliary tanks were also evaluated and the results are also shown in Figure 14.1-1. As shown, for airplanes with unpressurized auxiliary tanks, GBI would significantly reduce the flammability. The use of pressurized auxiliary tank systems may be an alternative method of reducing the flammability as discussed below.

**14.2 ALTERNATE METHOD FOR REDUCTION OF FLAMMABLE ATMOSPHERE FOR AUXILIARY FUEL TANKS**

Estimated Percentage of Fleet equipped with Auxiliary Tanks:

ARAC Transport Category	Heritage Boeing	Heritage MDC	Airbus	Total Fleet Percent	Fleet Percent Ambient Pressure	Fleet Percent Pressurized Tanks
Large	1%	15%	-	5%	5%	-
Medium	0.1%	-	5%	2.5%	-	2.5%
Small	5%	20%	4%	8%	5%	3%

Flammability is highly dependent upon the usage of the auxiliary tank. While only a fraction of the fleet has auxiliary tanks, it is estimated that the usage of the tanks on the specific airplanes equipped with auxiliary tanks would be similar to the overall usage of center tank fuel for the entire fleet. Therefore, we are assuming 20% of flights on airplanes equipped with auxiliary tanks load some fuel in the auxiliary tanks.

Flammability is dependent on tank ullage pressure. The pressure decrease associated with cruise altitude results in an effective decrease in the Lower Flammability Limit (LFL) temperature of about 40 degrees F. By maintaining the tank pressure at a lower altitude, the LFL decrease is less. Designs that maintain auxiliary tank pressure exist. For the purposes of this estimate, we have assumed they maintain a 20,000 foot altitude pressure during cruise. Auxiliary tanks are not exposed to temperature increase from A/C packs and are located in the cargo areas. Thus, flammability is a function of the ground ambient temperature, the cruise cargo area temperature and the tank ullage pressure.

Given the above factors, the baseline flammability of auxiliary tanks are calculated as:

ARAC Transport Category	Fleet Size - Ambient Pressure Aux Tanks	Flammability Exposure -Ambient Pressure Aux Tanks		Fleet Size - Pressurized Aux Tanks	Flammability Exposure - Pressurized Aux Tanks (20,000 feet)
Large	5%	22%		-	3.0%
Medium	-	17%		2.5%	2.2%
Small	5%	9%		3%	3.2%

Finally, maintaining auxiliary tank pressure altitude at or below 10,000 feet can further limit the LFL decrease at cruise and thus limit flammability.

ARAC Transport Category	Flammability- (10,000 feet) Pressure Tanks
Large	0.3%
Medium	0.4%
Small	0.6%

Thus, an auxiliary tank pressurized to 10,000 foot altitude is approximately equivalent to GBI. It is expected that modifying or replacing auxiliary tanks to utilize pressurized systems limited to 10,000 foot

ambient pressure altitudes would be an acceptable (and potentially preferred) alternative to incorporating GBI on auxiliary tanks.

**14.3 BACKGROUND INFORMATION ON FLAMMABILITY**

The critical combustion concentrations are known as the limits of flammability of the system and are defined as the fuel-lean, or lower flammability limit (LFL), and the fuel-rich, or upper flammability limit (UFL). When fuel is raised above the LFL, the fuel/air vapor mixture it produces (once it reaches an equilibrium state, will be flammable). If the temperature is too high, the fuel/air vapor mixture may be too rich (too much fuel) to be flammable. Likewise, when the mixture temperature is decreased, the fuel condenses and the mixture decreases. See figure 14.3-1 for an illustration of these concepts for JP-8, which is similar to Jet A and Jet A1 fuel used for commercial jet aviation.

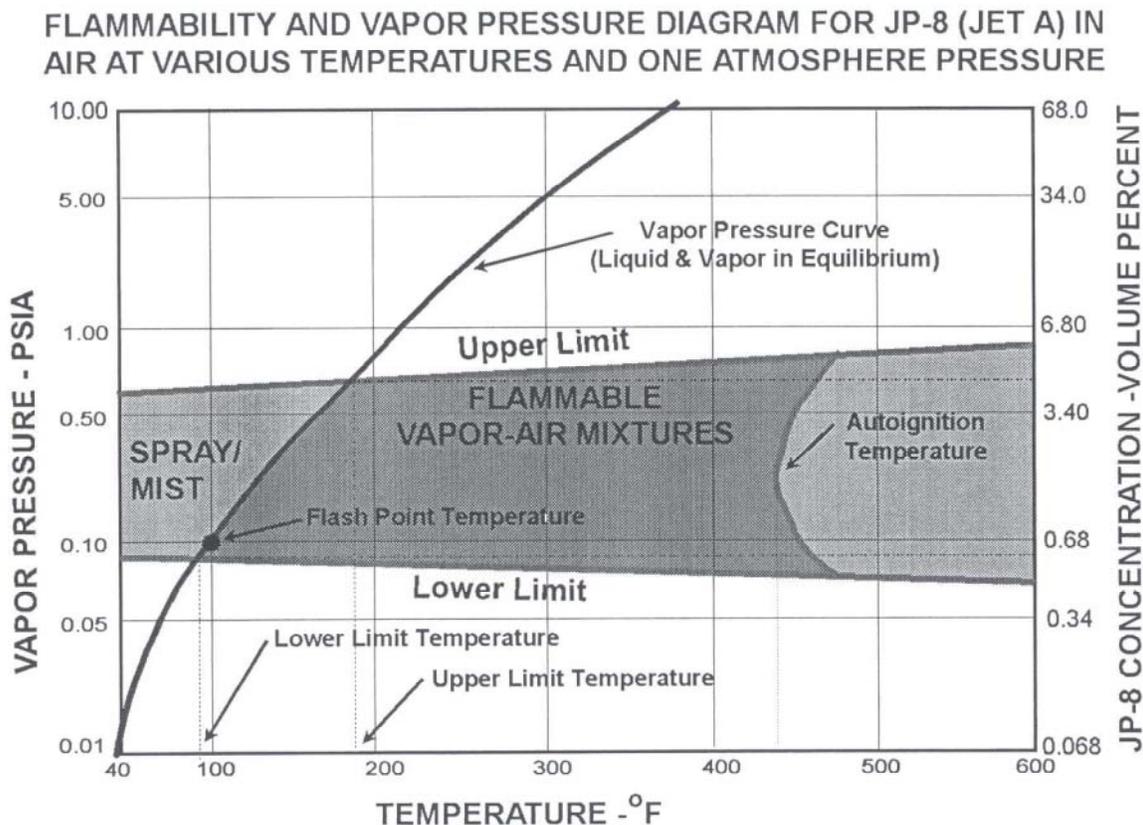


Figure 14.3-1. JP-8 (Jet A) Flammability and Vapor Pressure

Regarding Figure 14.3-1, it should be noted that the flash point of the fuel varies with each batch, but the specified minimum for Jet A is 100F. The flash point of the fuel is determined by a closed cup method, which correlates somewhat with the LFL. This test is conducted at ambient conditions, the amount of oxygen is fixed and the ignition source is specified. Note that the flash point of a given batch of fuel is about 10F above the LFL. The flash point will decrease with a decreasing ambient pressure. Correspondingly, the pressure, and therefore altitude, affect the LFL and UFL's. This is illustrated in figure 14.3-2 for several aviation fuels. As the pressure in the fuel tank is reduced during ascent, the effective flammability range is lowered as is shown in figure 14.3-2.

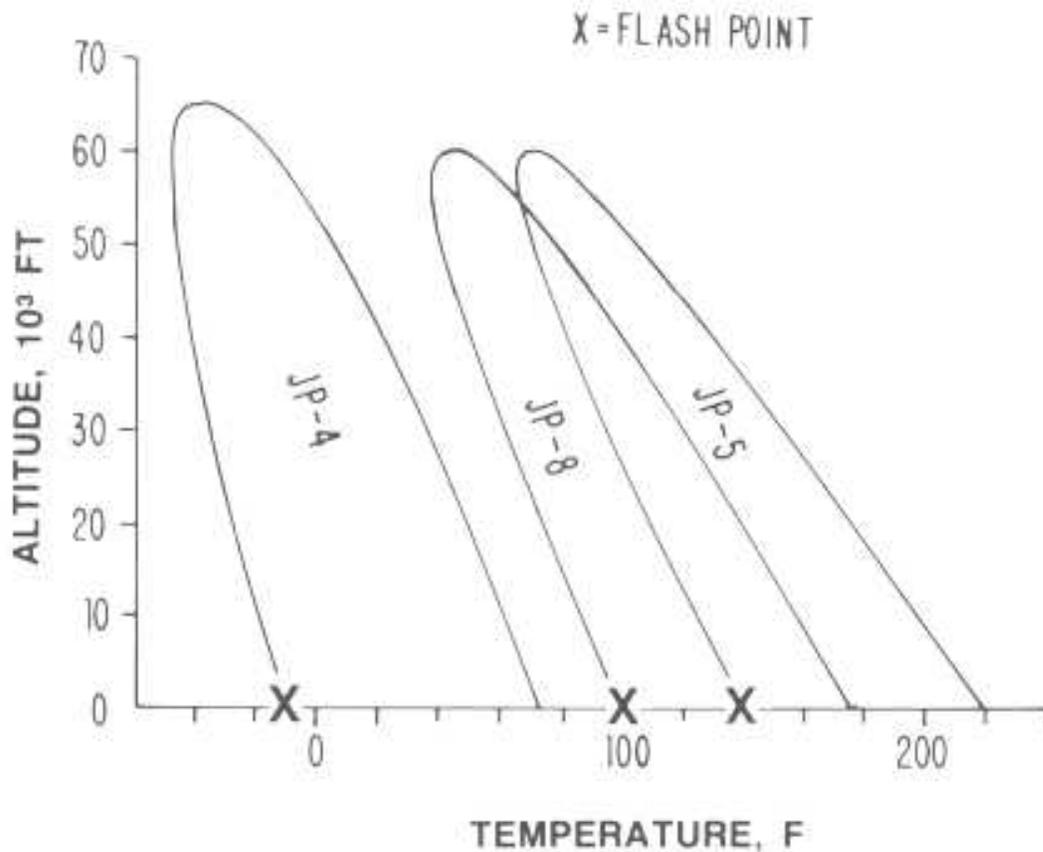


Figure 14.3-2. Aircraft Fuel Flash Point as a Function of Altitude and Temperature

### 14.3.1 Inerting

Figure 14.3.1-1 shows the recommended oxygen percentage for aviation fuels is 9% which indicates no explosions are possible if the level of oxygen inside the fuel tank is 9% or lower. The “maximum recommended oxygen percentage” applies to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Further by starting out at a lower oxygen content, the inert level will remain longer in the ullage. This level should be maintained for as long as possible throughout the flight profile.

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### Maximum Permissible Oxygen Percentage to Prevent Ignition of Flammable Gases and Vapors Using Nitrogen and Carbon Dioxide for Inerting

	N-Air		CO <sub>2</sub> -Air	
	O <sub>2</sub> Percent Above Which Ignition Can Take Place	Maximum Recommended O <sub>2</sub> Percent	O <sub>2</sub> Percent Above Which Ignition Can Take Place	Maximum Recommended O <sub>2</sub> Percent
Acetone	13.5	11	15.5	12.5
Benzene (Benzol)	11	9	14	11
Butadiene	10	8	13	10.5
Butane	12	9.5	14.5	11.5
Butene-1	11.5	9	14	11
Carbon Disulfide	5	4	8	6.5
Carbon Monoxide	5.5	4.5	6	5
Cyclopropane	11.5	9	14	11
Dimethylbutane	12	9.5	14.5	11.5
Ethane	11	9	13.5	11.0
Ether	—	—	13	10.5
Ether (Diethyl)	10.5	8.5	13	10.5
Ethyl Alcohol	10.5	8.5	13	10.5
Ethylene	10	8	11.5	9
Gasoline	11.5	9	14	11
Gasoline 73-100				
Octane	12	9.5	15	12
100-130 Octane	12	9.5	15	12
115-145 Octane	12	9.5	14.5	11.5
Hexane	12	9.5	14.5	11.5
Hydrogen	5	4	6	5
Hydrogen Sulfide	7.5	6	11.5	9
Isobutane	12	9.5	15	12
Isopentane	12	9.5	14.5	11.5
JP-1 Fuel	10.5	8.5	14	11
JP-3 Fuel	12	9.5	14	11
JP-4 Fuel	11.5	9	14	11
Kerosene	11	9	14	11
Methane	12	9.5	14.5	11.5
Methyl Alcohol	10	8	13.5	11
Natural Gas (Pittsburgh)	12	9.5	14	11
Neopentane	12.5	10	15	12
n-Heptane	11.5	9	14	11
Pentane	11.5	9	14.5	11.5
Propane	11.5	9	14	11
Propylene	11.5	9	14	11

#### Notes to Table

1. Data in this Table were obtained from publication of the U.S. Bureau of Mines.
2. Data were determined by laboratory experiments conducted at atmospheric temperature and pressure. Vapor-air inert-gas samples were placed in explosion tubes and exposed to a small electric spark or open flame.
3. In the absence of reliable data, the U.S. Bureau of Mines or other recognized authority should be consulted.
4. The "Maximum Recommended O<sub>2</sub> Percent" applies only to maintaining an inert atmosphere for protection against unexpected or unlikely sources of ignition. Much higher factors of safety are required for conditions where sources of ignition are deliberately applied such as hot work. See Purging, Paragraph 223.

Figure 14.3.1-1. Maximum Oxygen Content for Inerting System Flammability as a Function of Fuel Type

Figure 14.3.1-2, 14.3.1-3 and 14.3.1-4 are included for additional reference.

Figure 14.3.1-2 contains data for military gun fire testing on inert tanks. While this data is included for reference, the military data demonstrates that the 9% oxygen level is supportive of a non-explosive, safe, and survivable environment.

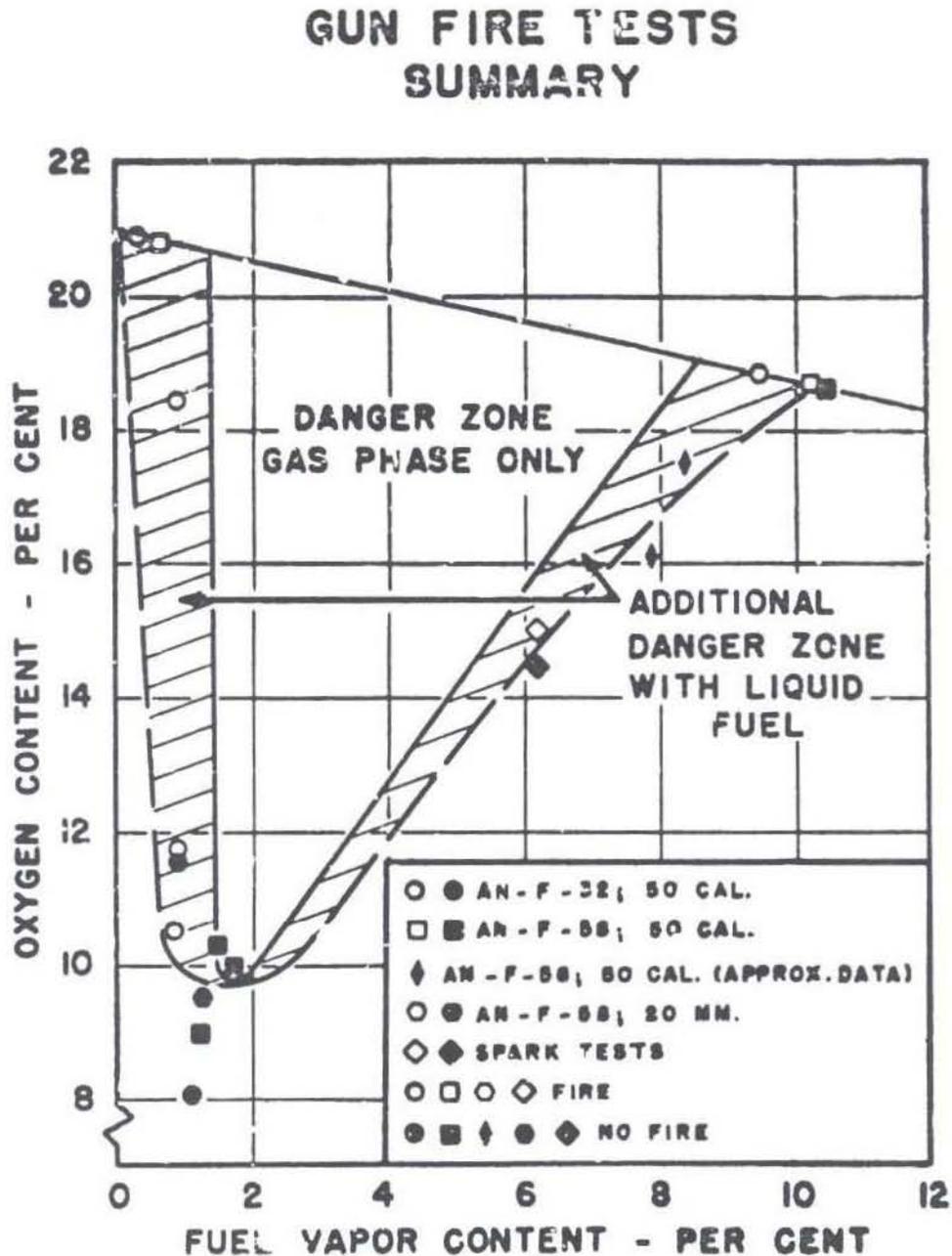


Figure 14.3.1-2. Tank Combustibility With Gun Fire as a Function of Oxygen and Fuel Content

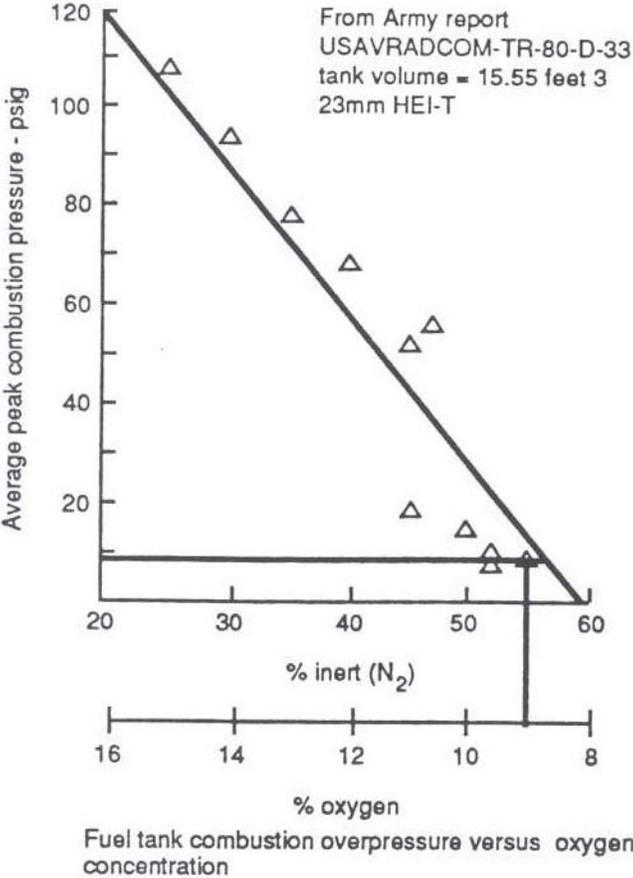
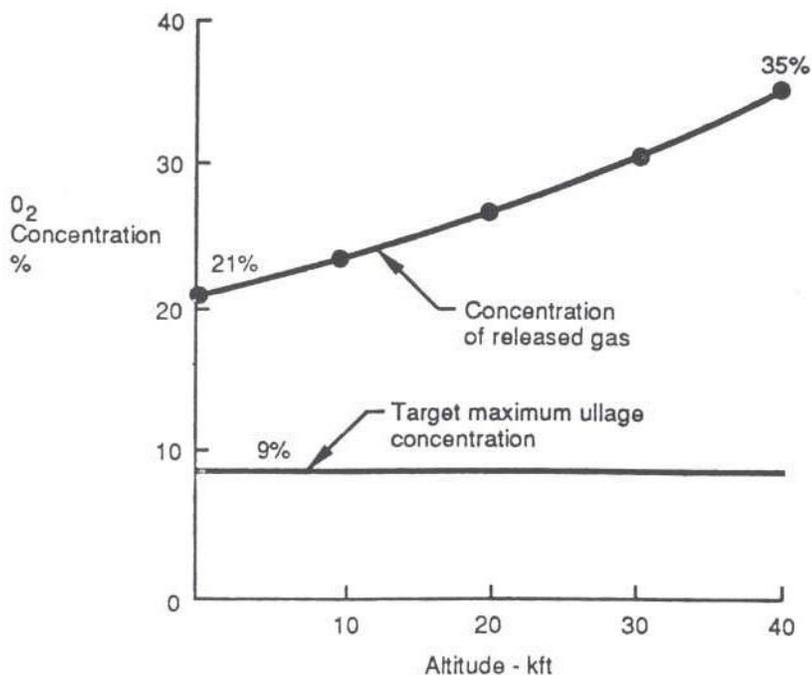


Figure 14.3.1-3. Fuel Tank Combustion Overpressure Versus Oxygen Concentration



Unprotected fuel tank ullage oxygen concentration versus altitude

*Effect of Ullage Oxygen Concentrations on Fuel Tank Vulnerability*

*Figure 14.3.1-4. Effects of Dissolved Oxygen Released From the Fuel on Ullage Oxygen Concentrations*

After an evaluation of additional literature, it is evident that a minimum 9% oxygen level should be considered for complete fuel tank inerting. The 9% oxygen level (or lower) gives a longer sustained inert level throughout the flight profile. If the 9% is to be utilized rather than the 10% level mentioned in the Tasking Statement, then it would only increase the volume of NEA to be added. It would not fundamentally change the system design concept

**15.0 CERTIFICATION COMPLIANCE**

Certification and compliance to a new fuel tank flammability rule utilizing ground based inerting systems as the method of compliance would likely be based on demonstration testing. The certification of each aircraft model, or variation thereof, would likely require actual aircraft testing on each new, variation, or retrofit design. The purpose of the testing would be to verify that the operation of the GBI system on that particular aircraft would result in reducing the oxygen level below a value set forth in the rule in all areas of the fuel tanks for which the rule required. The testing would also validate the quantity and quality of NEA required for the particular aircraft manifold design. This would establish the certified volume of NEA at a particular purity and pressure range that would be required to be loaded into the aircraft to meet the requirements of the rule. In addition, it is likely that flight testing would be necessary on each aircraft design type to validate that the inert levels are maintained adequately during flight to demonstrate compliance with the new rule.

Other means of compliance certification may be utilized if they can be shown to accurately represent, model, and duplicate the inerting process in actual aircraft testing. Any modeling system would require a demonstration in parallel with an aircraft inerting system testing to validate the modeling system. This alternate method of showing compliance to the rule would likely only be accepted after FAA approval and validation with actual aircraft testing.

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It is assumed that guidance on the detailed parameters associated with the certification testing would be discussed in the Advisory Circulars associated with the new rule. The Advisory Circular would also provide guidance on a method to certify the aircraft model. Testing, test equipment, and test procedures would be conducted in a manner consistent with that prescribed in the Advisory Circular, unless the associated FAA Certification Office accepted another means of demonstrating compliance. Compliance of each aircraft model would likely require instrumentation of an actual aircraft fitted with the new ground based inerting equipment to be tested. Testing would then be conducted monitoring the oxygen concentration in the fuel tanks applicable to verify that the concentration does not exceed the maximum levels set forth in the rule. Guidance on the oxygen sensor placement, distribution, and mounting in the fuel tanks being tested would also be provided in the Advisory Circular.

It is expected that each new aircraft model, or variation thereof, would be required to carry adequate placarding to insure the servicing of the ground based inerting system meets the parameters required to insure the system operates per its original certification.

If an aircraft is subsequently changed or modified by Supplemental Type Certificate, or other change medium, after the original issuance of the type certificate, the new or affected GBI system operation and effectiveness would require re-testing to show the proper oxygen levels are obtained with the new design. Revised Placarding would be required to clearly identify the new configuration and its associated new total NEA requirements. Placarding on same or similar models that may have minor changes due to certification activities beyond the original certification should employ methods to clearly make the certification differences known to those servicing the aircraft. These differences could be, as an example, color or size variations in the placarding.

To demonstrate that the reduced oxygen level has been achieved and is retained in the tank as predicted, it is anticipated that the following series of ground and flight tests will be required:

1. For center tank installations, the operation of the NEA distribution system will need to be demonstrated over a range of initial tank conditions of:
  - a. Tank at unusable quantity, but not sumped
  - b. Tank at 50% capacity
  - c. Tank maximum declared volume with required expansion space
2. It will also be necessary to demonstrate the ullage conditions when refueling is carried out simultaneously with loading NEA. The objective of the test would be to show that the required oxygen concentration is achieved in the ullage space when the specified quantity of NEA is added even as the refueling process is taking place. For this test where refueling and NEA are added simultaneously, the objective would be to demonstrate correct dispersion and concentration of the NEA is achieved when the specified NEA quantity has been added within a time interval shown by analysis, or additional testing, as an acceptable range.
3. For auxiliary fuel tank installations where the vent system is through the center tank, the same series of center tank tests would be necessary to demonstrate the auxiliary fuel tank inerting system. The exception to this is that testing would be an additional requirement to demonstrate that the auxiliary tank system meets the requirements regardless of the level of center tank fuel. The operational characteristics of the individual systems would determine the extent of their test program in order to fully demonstrate the system operation.
4. Flight testing to demonstrate the fuel tank retains the required oxygen concentration over a determined test period including a take off and climb will be required. During the climb the effects of maneuvers will need to be demonstrated. The extent of this testing is unknown at this time, but most likely the test would be performed starting with the inerted tanks initially empty, partially full, and then full. For aircraft with auxiliary tanks, a similar series of tests may need to be performed. The

specifics of that testing is also unknown at this time. During these flight tests a means of continuously sampling the oxygen content of the ullage will be required.

### **16.0 PRO AND CONS OF THE SELECTED DESIGN CONCEPT**

#### **Pros**

- Proposed system design concept is simple with the least effect on airplane.
- Involves little technical complexity
- Utilizes current technology components
- Does not introduce any new installation technology
- System operation is straightforward in that it is not sequenced with the refuel operation and does not require any knowledge of the actual fuel load.

#### **Cons**

- Does not remain inert for 100% of the flight cycles. Introduction of air due to fuel consumption, and ground time after landing but before inerting, may result in still being flammable on hot days.
- Dependent on significant airport infrastructure
- Low NEA supply pressure required to avoid over pressurizing the aircraft tanks
- New standard required to be developed for the aircraft interface coupling
- Amount of NEA supplied may be in excess of that required to achieve the inert levels when the tanks is already partially, or completely full.
- Requires special / unique maintenance practices.
- Increased volatile organic compounds (VOC) emissions.

### **17.0 MAJOR ISSUES AND RESOLUTIONS**

- GBI use on aircraft on is dependent upon high capital investment for airport NEA production and servicing systems, not currently available at any airports.
- To allow the aircraft to be purged from the ground based distribution system at any airport location a new standard interface coupling must be developed and controlled by a recognized authority. The timescale for acceptance of this standard and the availability of hardware must be compatible with the regularity requirements.
- The correct purging of the tank ullage is dependent upon the performance of the ground supply. A specification will be required to control pressure /flow performance and integrity of the ground equipment. The required volume to correctly purge the tank ullage will be defined following aircraft tests. The specification of the ground equipment will therefore need to be established before the aircraft tests can be performed.
- Some of the ground equipment requirements (i.e., delivery pressure) are driven by the need to consider the potential requirements to retrofit the system onto existing aircraft. The ground equipment is must be defined so that it does not constrain future aircraft designs.



## Appendix D

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## **i. TASKING STATEMENT ABSTRACT**

The Tasking Statement specifies three forms of onboard inerting systems: an onboard ground inerting (OBGI) system; an onboard inert gas generating system (OBIGGS); and a simplified OBIGGS system.

The OBGI system function is to inert fuel tanks near significant heat sources or fuel tanks that do not cool as fast as wing tanks do. Essentially this system is equivalent to the ground-based inerting system except that the source of inert gas is carried onboard the aircraft.

The OBIGGS system function is to inert all fuel tanks during normal aircraft operations. A “non-normal” operation is defined as an emergency descent and is interpreted by the team to mean any rarely occurring maneuver that would cause enough ambient air to enter the fuel tank that the oxygen concentration exceeds 10 % (the FAA defined level for fuel tank inerting in this study).

The Team interprets the FAA’s intent for the hybrid to be a simplification of the typical military OBIGGS system. The Tasking Statement requires that the OBIGGS system be operated at times when it ordinarily would not be to avoid implementing inerting support systems such as climb/dive vent valves.

In addition, the evaluation of these systems must consider ways to minimize cost. This should be achieved with reliable designs with little or no redundancy and by recommending ways to provide dispatch relief when the inerting system, or a portion of it, fails. The evaluation also needs to account for secondary effects to the airplane that might impact its performance, maintenance, and dispatch.

The team is also to provide guidance for the analysis and testing of inerting systems or, if no system can be recommended the team is to identify the technical limitations of the system and what improvements would be required for the system to be feasible in the future

## **ii. TEAM OBJECTIVES**

**Meet the Tasking Statement.** The team defined a simple schematic for the OBGI and OBIGGS systems. The team took advantage of the minimum equipment list provision in the Tasking Statement to simplify the systems. Both system concepts were “bare bones” i.e. they have no redundancy and no “extra” systems, such as the C-17 type of climb/dive vent valves, were included.

Subsequently, two hybrid systems were derived, one from the baseline OBGI system and one from the baseline OBIGGS system.

**Additional Tasks.** The Working Group proposed an additional task for the hybrid system. Although the hybrid was smaller than the OBIGGS system, its weight and electrical demand were still considerable. The Working Group proposed a low-flow system that allowed some amount of exposure to a flammable, non-inert ullage. The purpose of this task was to determine if the system could become significantly smaller for a slight increase in exposure.

## **iii. GENERAL APPROACH**

After the initial schematic development, the Onboard Design Team was divided into two sub-teams. Initially, one team was tasked with defining an OBGI system and the other was tasked with defining an OBIGGS system. The hybrid was deferred.

The sub-teams were asked to define concepts for the OBGI and OBIGGS systems, determine the feasibility of the systems, define any secondary effects to the airplane for these systems, and define the operation and maintenance requirements of the systems.

After these concepts were defined and feasibility was determined, each sub-team was asked to define a hybrid design derived from their individual concepts. The Tasking Statement only requested a hybrid based on the OBIGGS concept but it appeared both systems might yield viable hybrids. Each team eliminated the system’s primary constraint to achieve a smaller, cheaper system. In the case of the

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OBIGGS hybrid, the design was not required to inert the fuel tanks during descent. The OBGI hybrid took advantage of additional time during taxi, from landing rollout to the terminal, to inert the fuel tanks.

Finally, the additional task for a low-flow OBIGGS hybrid was studied in stages and compared to the ground-based inerting and OBGI systems for flammability exposure. The final hybrid system was sized to provide similar exposure at various stages of flight as the ground-based and OBGI systems.

The team consisted of interested parties from several companies. Each of the team members was supported by members of their company. The talents and time invested by each of the members and support personnel are greatly appreciated, as the job could not have been done without their assistance. The companies involved in this team were:

- Aero Controlex
- Airbus
- Air Liquide/Medal
- BAE
- Boeing
- Creare
- FAA Tech Center
- Litton
- Parker Aero
- Shaw Aero
- Smiths Industries
- Valcor
- US Air Force
- US Navy

# Onboard Inerting Designs Task Team Final Report

## 1.0 OBGIS

The On-Board Ground Inerting System (OBGIS) is one of four main system categories studied by the 2000 ARAC FTIHWG Onboard Airplane Design Task Team. The Onboard team studied the system size for a variety of “modeled” aircraft center wing and auxiliary fuel tanks. In addition, the Team performed additional analysis, in excess of the Tasking Statement’s requirements, by determining the system size for all fuel tanks. The team also defined the physical size and weight of the multitude of components needed to support OBGIS. Finally, power and air consumption needs were defined.

### 1.1 REQUIREMENTS

There are several main requirements for the OBGIS design that were considered during the Team’s design efforts:

**Oxygen Concentration at Pushback.** All applicable fuel tank ullage volumes are to have an oxygen concentration of 10% maximum before the aircraft is pushed back from the gate. This requirement allowed a direct comparison with the ground based inerting design concept.

**Nitrogen as Inerting Agent.** As required by the tasking statement, the Team only considered on-board nitrogen gas inerting equipment.

**Equipment Location.** All equipment needed to inert the aircraft is installed on the airframe, except for diagnostic equipment.

**Redundancy.** The tasking statement encourages a simple system with little or no redundancy.

### 1.2 DATA SUPPLIED FROM OTHER SOURCES

Data was taken from various sources so that the Team could define the OBGIS concept. This included aircraft fuel tank sizes, mission profiles, and aircraft turn times.

#### 1.2.1 Aircraft Turn Times

The mission scenarios that were used in the July 1998 ARAC Fuel Tank Harmonization Working Group Report had turn times listed for the various aircraft. The turn times can be seen summarized in Figure 1.2.1-1 below:

Generic Aircraft	Pre-flight Time (Minutes)
Turbofan	20
Turboprop	20
Business Jet	45
Small	45
Medium	60
Large	90

Figure 1.2.1-1. FTIHWG Aircraft Pre-flight Times

To ensure the turn times being used were representative of the aircraft in service today, a survey was conducted of several major airlines. They were asked to supply the times that they were currently using as part of their normal operations today. Airlines that responded to the survey were Airborne, Aloha, America West, British Airways, Continental, Delta, Northwest, Southwest, UPS, and Virgin. A summary of the data collected can be seen in Figure 1.2.1-2 below:

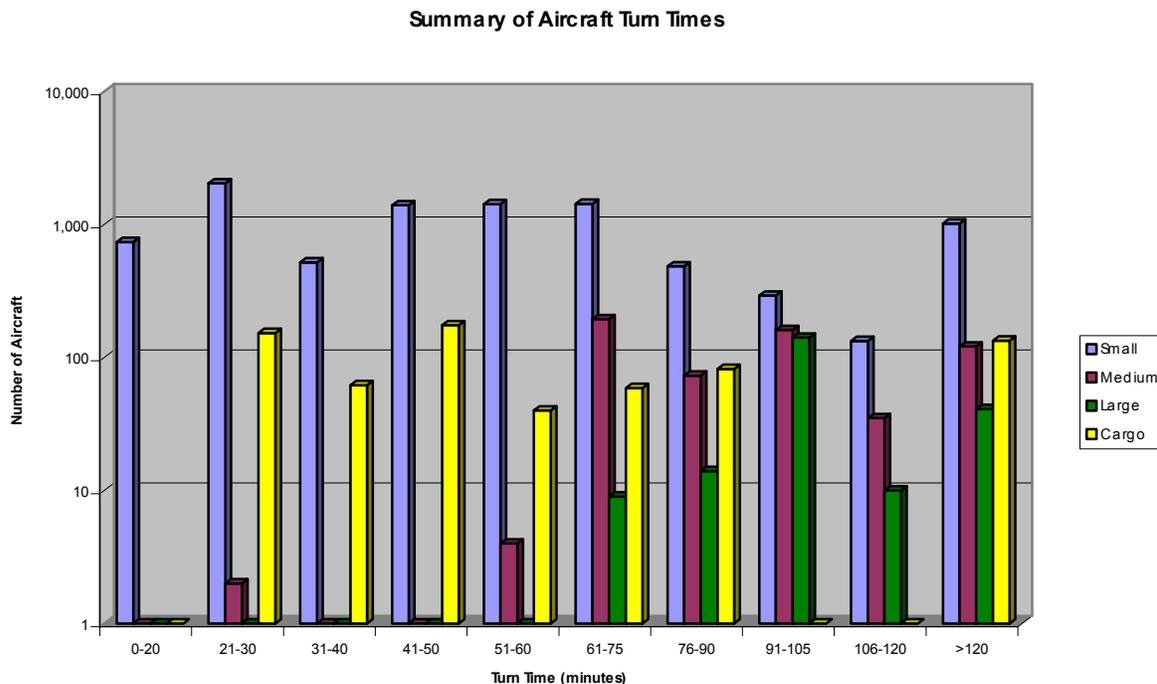


Figure 1.2.1-2. Summary of Aircraft Turn Times

The FTIHWG made the decision to modify the Aircraft turn times to the values seen in Figure 1.2.1-3 below. These values were used in the sizing of the components for the various OBGI systems because the working group concluded that they were representative of the in-service fleet.

Generic Aircraft	Turn Time (Minutes)
Turbofan	15
Turboprop	15
Business Jet	60
Small	20
Medium	45
Large	60

Figure 1.2.1-3. FTIHWG Aircraft Turn Times

### 1.2.2 Generic Aircraft Types

The FTIHWG made the decision to use the same generic aircraft data and mission scenarios that were used in the July 1998 ARAC Fuel Tank Harmonization Working Group Report. These generic airplane definitions and missions were used in assessing potential system designs under consideration by the various task teams. Mission profile data such as weight, altitude, Mach number, fuel remaining in each tank and aircraft attitude as a function of time was included for each generic airplane type. Temperature profiles were also included in the mission profiles.

The worst-case flight conditions for sizing OBGIS were determined to be the shortest-ranged flights provided. Low fuel loads, for any given fuel tank configuration, result in the largest ullage volumes to inert and the largest system size.

## 1.2.3 Generic Aircraft Fuel Tank Volumes

For all system sizing the 1998 ARAC Generic Aircraft fuel tank sizes were used. These are listed in Figure 1.2.3-1.

Generic Aircraft	CWT Volume (Gal.)	CWT + Wing Tank Volume (Gal.)	CWT + Wing + Aux Tank Volume (Gal.)
Turbofan	816	3,264	N/A
Turboprop	N/A	1,428	N/A
Business Jet	N/A	6,273	N/A
Small	3,060	5,100	7,600
Medium	10,200	24,480	27,480
Large	25,500	55,080	58,080

Figure 1.2.3-1. Generic Aircraft Fuel Tank Volumes

### 1.3 ASSUMPTIONS

The following are the assumptions that the Team developed and used for the system design and analysis.

**Initial Oxygen Concentration.** The starting oxygen content in the ullage is always 20.9%.

**Hydraulic Power Availability.** The task team assumed that hydraulic power to operate OBGIS equipment was not available while the aircraft was on the ground. To use hydraulic power it would be necessary to upgrade the existing on-board systems. This would in many cases be costly and difficult and would require a system review on a case-by-case basis.

**Electrical Power Available From the Aircraft Gate.** The task team assumed that sufficient ground power could be made available to operate an OBGIS system. This power could be made available from either a ground cart or from a connection made directly to the terminal electrical system. This would allow the on-board system to operate on the ground without either the APU or aircraft engines operating.

**Electrical Power Available From Aircraft Sources.** The task team assumed for the design that sufficient aircraft power could be made available to operate an OBGIS system. This would allow the on-board system to operate on the ground with either the APU or aircraft engines operating. This source of power would be used when gate power is not available.

**Compressed Air.** The availability of aircraft bleed air was assumed not to be available at all times because some local laws prohibit engine or APU operation at the gate. The assumption was made that an alternate source of compressed air was required.

**Vent Systems Modifications.** It was assumed that necessary vent system modifications will be made to prevent cross-venting during crosswind conditions.

### 1.4 CONCEPT DEVELOPMENT

The system is required to provide ullage inerting in the aircraft fuel tanks prior to take-off using on-board equipment. The main objective was to define system parameters, such as cost, weight, performance and size, for comparison purposes with OBIGGS systems and ground-based systems. The effectiveness of the system was predicted using FAA-supplied flammability exposure computer models, which were also used by both the OBIGGS and ground-based teams.

The approach was to define a system that would minimize the impact and required changes for retrofit to existing aircraft and provide optimum efficiency for new aircraft designs. This required that issues related to system operation be addressed, such as on-board resources available to operate the system, available space, weight, cost, and necessary aircraft modifications. The most crucial issue was the power available to run the system. On-board power is available on aircraft in several forms, such as pressurized air, hydraulic power, and electricity. Each of the available air separation module (ASM) technologies, capable of generating nitrogen enriched air (NEA) for use to inert aircraft fuel tanks, requires that pressurized air be supplied to the ASM. The system was therefore required to convert the available power

to airflow at an elevated pressure for delivery to the ASM and subsequent NEA delivery to the fuel tanks. System efficiency, safety and failure protection were major considerations. These parameters also dictated the addition of components to the system.

### 1.4.1 Concept Characteristics

The generic OBGI concept involves a variety of possible solutions, which the Team evaluated. The following items were evaluated.

**Pressurized Air Supply.** Several ASM supply sources were considered. It was determined that the air should be pressurized to the outlet pressure of the aircraft APU allowing system operation when the primary air source is not available. A three-to-one (3:1) pressure ratio was chosen to match the most common APU compressor ratio. For the larger aircraft tank applications, high NEA flow and maintenance issues dictated multiple components in parallel and the provision for a start contactor on the compressor.

In addition to the above, the following compressor and electric motor technologies were identified:

- Screw-type, positive displacement
- Vane-type, positive displacement
- Piston, positive displacement
- Rotor dynamic (Radial, mixed flow, axial)
- Free piston (diesel) engine
- Three-phase induction motor
- Brushless DC motors
- Switched reluctance motors

**Preconditioning.** Other system equipment was required to ensure that the air supplied to the ASM is cooled and filtered. This equipment included a heat exchanger with cooling fan and a coalescing filter.

**Air Separation.** The technologies for the ASMs were defined as membrane, pressure swing adsorption (PSA), and cryogenic distillation. Each of these operates at differing levels of efficiency, depending on NEA flow requirements, and therefore required different amounts of pressurized air for a given condition. The NEA flow was defined by the size of the tank to be inerted and the amount of time available to operate the system at the gate after hook-up and before pushback.

**Distribution.** A means of NEA distribution to the fuel tanks was required to ensure delivery and adequate mixing. It was determined that the NEA distribution would be common to any OBGI design and would not be significantly affected by the choice of ASM technology.

**Control.** A system controller is required to provide signals to operate the compressor, cooling system, and ensure proper system valve operation. It was determined that the controller would be common to any OBGI design and would not be significantly affected by the choice of ASM technology.

### 1.4.2 Generic Concept Development

Taking the previous characteristics into account, system concepts were generated for the candidate ASM technologies. There were some considerations regarding the type of concepts that would be viable:

- The use of high pressure NEA storage with its associated compressor in a system was highly undesirable because of the perceived unreliability of such systems.

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- The technology associated with the concepts should be either in current use, or be near-term and low-risk.

The concepts that resulted from the process are summarized below. The concepts are presented in terms of a baseline, air/energy supply alternatives, and ASM configurations and technologies.

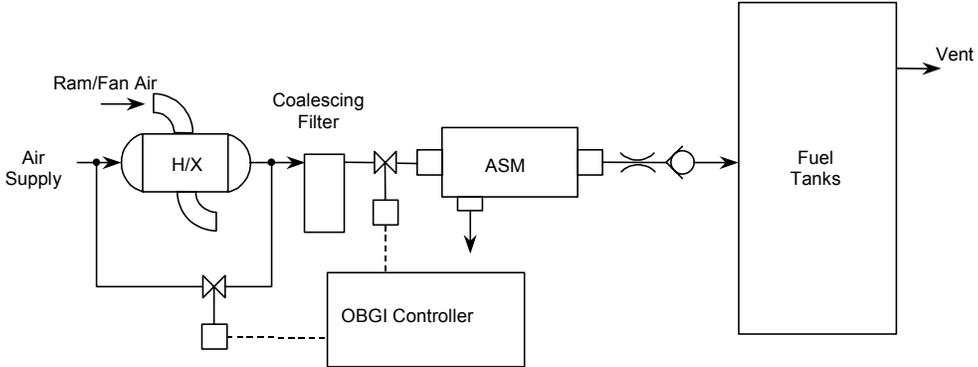
**Concepts Evaluated.** The baseline concept (Concept 1) is shown in Figure 1.4.2-2. Concepts 2 through 6 are similar with variations to the bleed air source. Concept 7 (Figure 1.4.2-3) illustrates a configuration in which improved ASM efficiency is achieved by applying vacuum to the ASM waste port with an OEA eductor. Concept 8 (Figure 1.4.2-4) illustrates a system in which bleed air is used to recirculate ullage gas through the ASM and back into the fuel tank. Concept 9 (Figure 1.4.2-5) is similar to Concept 8 except that an electric blower drives the ullage gas recirculation.

All of the concepts require conditioning by a heat exchanger and a coalescing filter to control the bleed air temperature to the ASM and to remove any free water. All of the concepts employ a controller to regulate the air supply temperature and the flow into the ASM such that the required concentration and purity of NEA is delivered.

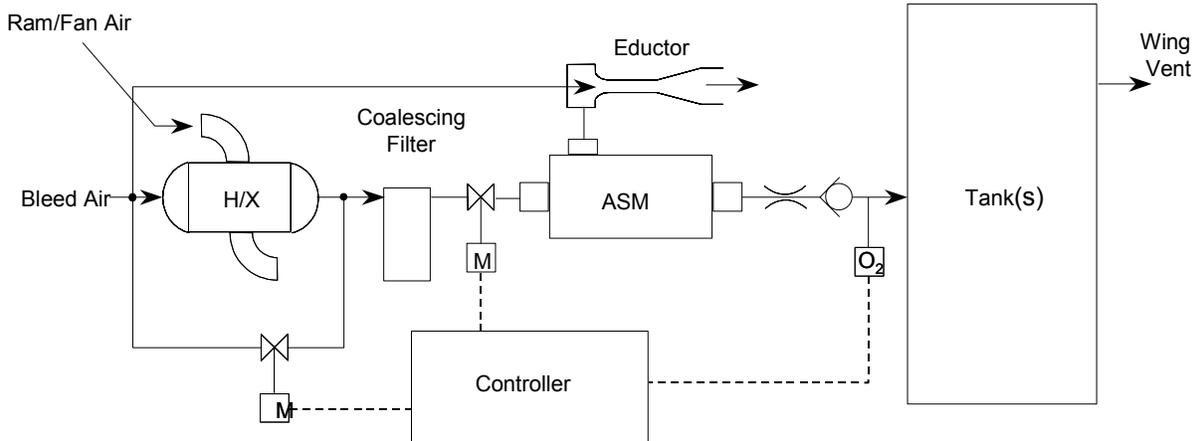
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Concept No.	Title (Fig. Ref.)	Analysis	Conclusion
<b>System Concepts</b>			
1	Engine Bleed Only (1.4.2-2)	<ul style="list-style-type: none"> <li>Works only when main engines on. Small part of the on -ground time.</li> <li>Implies a larger system.</li> <li>Can tap off the bleed air gallery.</li> <li>Expected to result in a large ASM – superseded by 4 &amp; 6</li> </ul>	Rejected
2	APU Only (1.4.2-2)	<ul style="list-style-type: none"> <li>Operational restrictions to use of APU. Ground use of APU not allowed by some airport authorities. APU has no spare flow capacity on hot days on retrofit aircraft.</li> <li>Larger system because of limited flow / pressure.</li> <li>Superseded by 4 &amp; 6</li> </ul>	Rejected
3	Air Cart Only (1.4.2-2)	<ul style="list-style-type: none"> <li>Only available at the gate. Not universally available. Additional ground equipment investment. Labor cost of connection.</li> <li>Superseded by 6</li> </ul>	Rejected
4 Retrofit	Engine APU & Ground Cart (1.4.2-2)	<ul style="list-style-type: none"> <li>Restricted by availability unless ECS (Cabin Cooling) degraded, as protection needed most on hot days: needs an excess of air to ECS packs.</li> <li>Superseded by 6</li> </ul>	Rejected
4 New	Engine APU & Ground Cart (1.4.2-2)	<ul style="list-style-type: none"> <li>Can design for required bleed capacity BUT still restricted by availability.</li> </ul>	Consider
5	Compressor. Electrically, hydraulic or bleed-air driven from the aircraft power sources (1.4.2-2)	<ul style="list-style-type: none"> <li>Easier installation. Power may be restricted at gate. Increases size and weight. Less impact on ECS.</li> <li>Spare Power is 10kW per engine, may be restricted on ground.</li> <li>Not available on ground.</li> <li>Only useful to boost low pressure/high flow bleed air.</li> </ul>	Rejected
5a	Compressor (1.4.2-2)	<ul style="list-style-type: none"> <li>Electrically driven from a ground power supply. If power requirements are within the rating of existing supplies provided at the gate, expected to be viable.</li> </ul>	Consider
6	Integrated Air supply (1.4.2-2)	<ul style="list-style-type: none"> <li>Combines the electric compressor with bleed air as an alternative source. Gives the operator some flexibility in the event that a compressor fails as either an engine or APU can be run if ambient conditions are such that the flammability risk is high.</li> </ul>	Preferred
7	ASM with eductor or suction pump (1.4.2-3)	<ul style="list-style-type: none"> <li>An optimization of ASM (membrane &amp; PSA)</li> <li>Eductor requires additional bleed air.</li> <li>Suction Pump requires integration with compressor.</li> </ul>	Consider
8	Closed Loop. Bleed air assisted (1.4.2-4)	<ul style="list-style-type: none"> <li>Smaller, reduced hydrocarbon emissions.</li> <li>Only works with additional compressor. ASM has to be hydrocarbon compatible. Risk of contamination. Compressing fuel vapor air mix considered a safety hazard. Unproven technology. Dependent on Bleed Air supply</li> </ul>	Rejected
9	Closed Loop (1.4.2-5)	<ul style="list-style-type: none"> <li>Smaller, reduced hydrocarbon emissions.</li> <li>Only works with additional compressor. ASM has to be hydrocarbon compatible. Risk of contamination. Compressing fuel vapor air mix considered a safety hazard. Unproven technology.</li> </ul>	Rejected
<b>ASM Technologies</b>			
	Cryogenic	Viable ASM technology	Consider
	Membrane	Viable ASM technology	Consider
	PSA	Viable ASM technology.	Consider

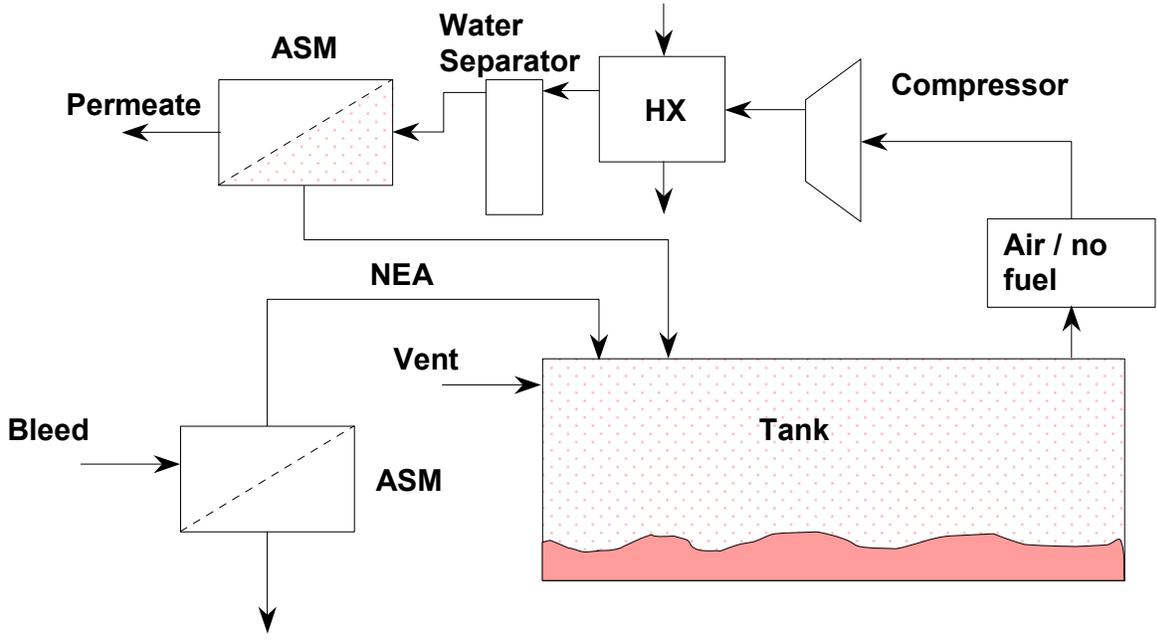
*Figure 1.4.2-1. System Evaluation Summary*



*Figure 1.4.2-2. Baseline Concept - Bleed Air Only*



*Figure 1.4.2-3. Exhaust Eductor System Concept*



**Concept 7 - Closed Loop System - Bleed assisted**

*Figure 1.4.2-4. Bleed Assisted Closed Loop System Concept*

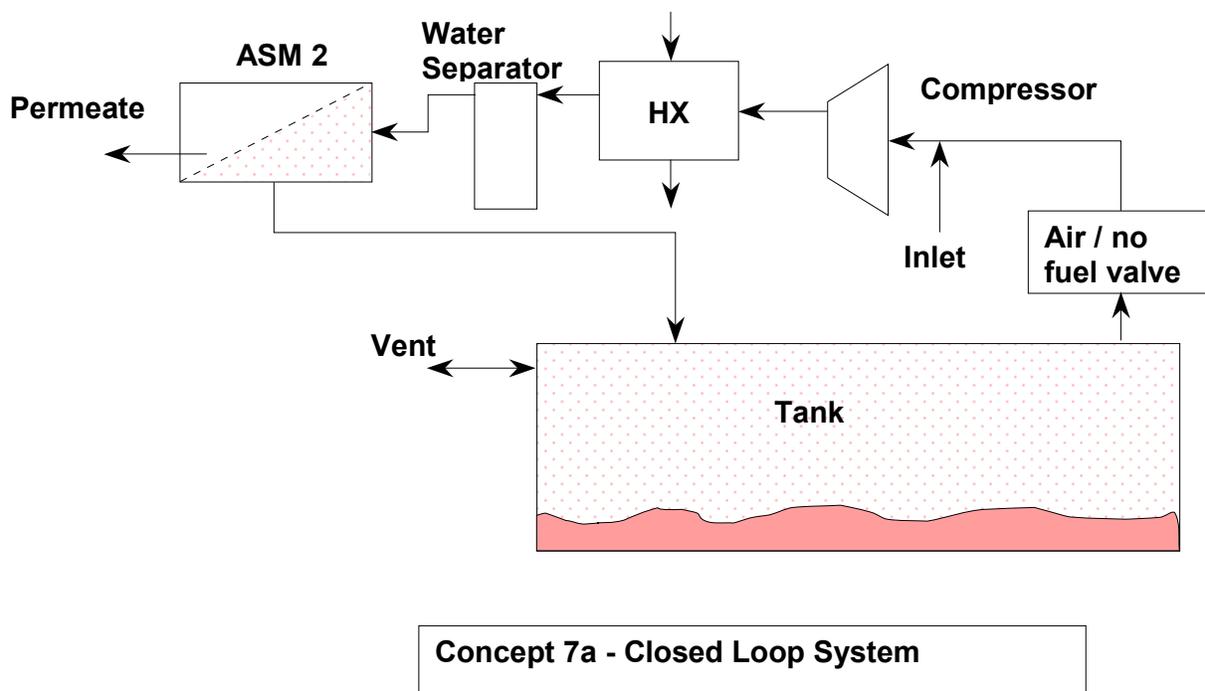


Figure 1.4.2-5. Closed Loop System Concept

### 1.4.3 Down-Selection

The initial design study for the ASM Technology down selection was concerned with just the ASM alternatives and their impact upon the major components in the other two sub systems, namely the integrated air supply and temperature control subsystems. It was clear that for OBG, turnaround time was a main system design driver.

The preferred source of pressurized air was a subsystem that integrated a compressor, driven from a ground power source and bleed air available from the aircraft engines or APU. It will be seen that this choice fixed the operating pressure of the OBG System to that of the APU, namely to a pressure ratio of 3:1. This meant that any reduction in ASM size that might be gained from a higher supply pressure ratio could not be exploited. It was judged, however that the operational flexibility of using either ground power or bleed air out-weighed this. Furthermore, this relatively low-pressure ratio avoided the increased complexity needed to handle the potentially higher air temperatures associated with higher pressure ratios. Examples of increased complexity were two-stage compression, inter-cooling and duct insulation to avoid exposed surface temperatures above fuel auto-ignition temperature, assumed to be 450°F. With regard to the ground power source, it was concluded that the most readily available source was electrical power, and the most convenient form was the existing 400 Hz, three-phase supply provided for other aircraft systems when at the gate.

An initial order-of-magnitude sizing estimate was made for the identified cryogenic distillation, PSA and membrane ASM types. It was found that unless the cryogenic system could be run in the air to exploit the inherent liquid gas storage capability and so reduce the instantaneous gas generation rate required, it was an order of magnitude larger than the other two systems. Operation in the air was explicitly outside the terms of reference for the OBG and for this reason the cryogenic ASM technology was not taken forward into the full study.

A generic OBG concept was created that was not specific to either compressor or ASM technology but identified in more detail the components necessary to implement the functions described earlier.

**1.4.4 Cryogenic Distillation System – Reasons for Discontinuing Concept**

The cryogenic distillation technology is not well suited to an OBI system. Before producing nitrogen gas from ambient air, certain parts of the cryogenic distillation system must be cooled to cryogenic temperatures. This cool-down time must be minimized to allow ample time to make nitrogen gas from the ambient air for fuel tank inerting at the gate. For full-time and hybrid OBIGGS, the cryogenic distillation system makes and store liquid nitrogen during periods of low demand. This liquid is then used at the start of the next day to quickly cool down to cryogenic temperatures. No opportunity exists to make liquid for OBI. Thus, the cryogenic refrigerator must supply all of the cooling for the OBI system. The resulting cryogenic refrigerator would be heavy and would consume more electrical power than is available. The cryogenic distillation system was therefore not investigated further as a realistic option for OBI.

**1.5 FINAL CONCEPT DESCRIPTION**

The schematic of the final OBI system concept is depicted in Figure 1.5-1. The components identified within each of the OBI subsystems are summarized in Figure 1.5-2.

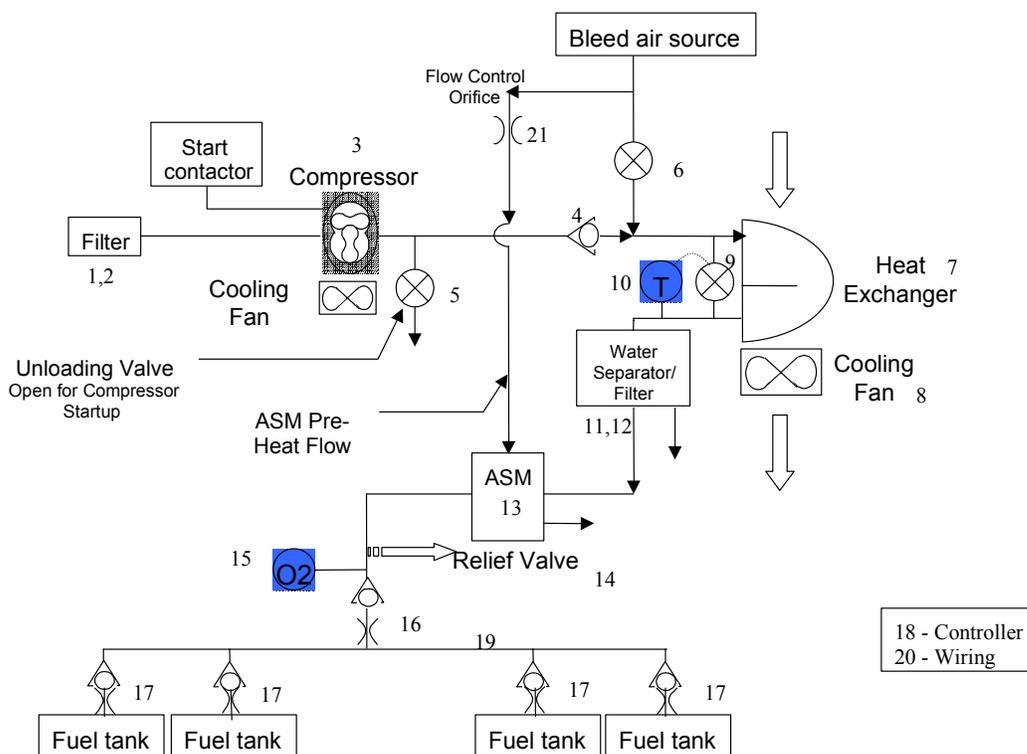


Figure 1.5-1. OBI System Schematic Diagram

Component	Item Number	Component	Item Number
Compressor inlet air filter assembly	1	Water separator/filter assembly	11
Compressor inlet air filter element	2	Water separator/filter element	12
Compressor, cooling & start system	3	Air separation module	13
Compressor discharge check valve	4	Relief valve	14
Compressor unloading valve	5	Oxygen sensor	15
Bleed Air shutoff valve	6	ASM check valve & restrictor assembly	16
Heat exchanger	7	Fuel tank check valve	17
Cooling fan & ram ducts assembly	8	Controller / control card	18
Heat Exchanger bypass valve	9	Ducting	19
Temperature sensor & controller	10	Wiring	20
		Bleed Orifice & duct	21

*Figure 1.5-2. OBGI System Component List*

**1.5.1 Operating Concept**

The system is arranged to replace the air in the tank ullage with nitrogen enriched air (NEA), thereby reducing its flammability. The main device used to accomplish this is the Air Separation Module (ASM), which separates ambient air into nitrogen, oxygen, and the other constituents of air. The ASM requires that the air be compressed to force it through the device. During the compression process, the air is heated, and must subsequently be cooled before it is supplied to the tanks. This is accomplished by use of a heat exchanger, which rejects the heat to ambient air. A distribution system ensures that the NEA is supplied to the fuel tanks in a manner that assumes a relatively uniform concentration throughout the tanks.

An electrically powered compressor pressurises ambient air for the ASM. The air is filtered prior to entry into the compressor inlet, to prolong compressor life. For some aircraft types / sizes, the power requirement for the compressor is relatively high, which dictates the use of a start contactor and pressure unloading valve. These allow the compressor to start, while avoiding high power surges during wind-up. The unloading valve helps accomplish this by reducing the compressor back-pressure, and consequently reducing the start-up power load. The compressor outlet requires a check valve, to prevent reverse flow through the compressor and filter.

An alternate source of pressurized air for the system is engine bleed air. This is introduced into the system downstream of the compressor, and is controlled by a shut-off valve, which also acts to prevent reverse flow to the engine bleed system when in the closed position.

In its pressurised form, from either the compressor or the engine bleed air system, the air will be at an elevated temperature. Prior to flowing to the ASM, it must therefore be cooled to ensure that it is sufficiently cool to prevent damage of the ASM, and to prevent hot gas flowing to the fuel tanks. Cooling of the air is accomplished by the use of an air-to-air heat exchanger. In the event that the air is already sufficiently cool, as may be associated with cold climates, the heat exchanger may be by-passed through the temperature control valve. The temperature control valve will modulate the bypass flow to optimize the temperature of the airflow.

As the air exits the heat exchanger, it is again filtered to a finer level than the primary filter, and ensures that the airflow is acceptable for the ASM. The secondary filter also filters engine bleed air in the event that air is supplied from this source. The filter assembly also reduces the relative humidity of the air by separating water vapor and ejecting it in liquid form from the aircraft through a drain line.

The ASM accepts warm pressurized air from the upstream system and discharges NEA to the fuel tanks. A second ASM outlet port discharges oxygen enriched air (OEA) to the ambient air around the aircraft.

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Concentrated OEA may be a fire hazard so it must be mixed with ambient air. The discharge port must be designed to ensure the mixing.

At the ASM outlet, a relief valve ensures that tank over-pressure conditions are avoided in the event of a refuel system failure during refuel operations. This is accomplished by jettison of the NEA during the refuel failure condition, which results in normal refuel failure tank over pressure protection.

Flow to the fuel tanks is controlled by means of fixed restrictions which are designed to balance the flow to the individual fuel tanks. Flow balance ensures that tank NEA ullage concentrations are relatively uniform. The restrictors also feature check valves which, together with the in-line check valve, provide dual redundant reverse flow protection against hydrocarbon contamination of the ASM.

### **1.5.2 Component Functional Description**

The following provides a brief description of the components incorporated in the developed OBGIS concept.

#### **1.5.2.1 Inlet Filter**

The inlet filter provides filtration for the air prior to entry into the compressor, and subsequently to the heat exchanger, ASM and fuel tanks. It is a line-mounted unit, consisting of a housing and replaceable filter element. Filter technology identical to current cabin air filters is used, with known performance and filter cartridge replacement requirements.

#### **1.5.2.2 Compressor, Start Contactor, Compressor Cooling Fan**

The compressor is an electrically powered device, with integral cooling. Technologies considered for the compressor centered on screw-type, and centrifugal rotating groups. Efficiency optimization of these various types of compressor will dictate the optimum application. The Team considered that details of this would be subject to detail application design, and may vary by aircraft model. Compressing the airflow by a factor of three results in significant heating. Integral cooling of the electric motor and case will therefore be required, and was included for purposes of component definition. The rotating group within the compressor housing may rotate at relative high speeds. Containment of the rotor section is therefore required, to prevent high velocity impingement of rotor fragments on other adjacent components in the event of rotor failure. Rotor clearances were optimized for the purposes of sizing and efficiency calculations. This demands pre-filtration to prevent excessive wear with contaminated air.

Two types of compressor were considered for each of the aircraft and system types. These were the positive displacement screw type and the centrifugal (CF) roto-dynamic type. The latter type are generally lighter and less expensive but have a limitation that they do not readily scale down to small sizes. Rotational speeds become high (in excess of 100,000 rpm) and efficiency reduces owing to small flow passages and high gas velocity. The minimum practical size of CF compressor was taken as a 10kW shaft power machine for the study. A further consideration was that above 15 kW the compressor motor needs a start winding and contactor to reduce the initial current surge. The view was that with this level of current transient there was a risk that the whole electrical power distribution system of the aircraft would be adversely affected. Thus above 30kW shaft power, two or more compressors are proposed.

Larger aircraft applications therefore demand high torque on start-up, and a start contactor is necessary, to ensure that the compressor motor remains as small and compact as possible, while maintaining the ability to overcome high torque at start-up. Similarly, a compressor-unloading valve is necessary to reduce torque at start-up due to backpressure. Air flow for the larger applications, and for some ASM technologies, demand the use of two compressors in parallel due to their high power requirements.

The screw and CF compressors were estimated to have similar efficiencies of 70%. The thermodynamic efficiency of the CF compressor was slightly better than that of the screw compressor. However the CF compressor had additional mechanical losses owing to the need for a step up gear box to increase the shaft

speed from that of the three phase induction motor at 23,000 rpm, to that of the compressor disc. The compressor disc speed depended upon the mass flow requirement of each aircraft and system type but was in the range of 70,000 to 130,000 rpm.

### **1.5.2.3 Compressor Discharge Check Valve**

The check valve is necessary to prevent back-flow through the compressor when the system is operated by the bleed air source only. This is a simple in-line unit with integral poppet and return spring, similar to existing units used in aircraft pneumatic and fuel systems.

### **1.5.2.4 Compressor Unloading Valve**

The line-mounted valve allows depressurization of the compressor outlet during startup, as previously described. This may be of either motor-operated butterfly valve design or a solenoid-operated poppet valve. The valve architecture is identical to existing aircraft fuel and pneumatic valves.

### **1.5.2.5 Bleed Air Isolation Valve**

The bleed air isolation valve allows engine bleed air to supply the ASM. This is a similar valve to the compressor-unloading valve, and also of either the motor-operated butterfly valve type or solenoid-operated poppet valve type. In the event that the available air may only be tapped from a location prior to the aircraft pre-cooler, the bleed air valve may need to control air at a temperature that is higher than the unloading valve. It is expected that this will not require that the valve be of stainless steel construction. If temperatures are higher than anticipated in this evaluation, the weight and cost impact of stainless steel usage may need to be considered.

### **1.5.2.6 Heat Exchanger**

A conventional plate / fin contra-flow heat exchanger was used for this application. Its configuration is conventional and of similar construction to current fuel / oil / air heat exchangers used in high quantities on current aircraft. The unit is self-contained, including headers, and in-line tube connectors. An electrically powered cooling fan, with associated ducting, is used to provide cooling air.

### **1.5.2.7 Heat Exchanger Temperature Control Valve**

This valve provides temperature control of the air down stream of the heat exchanger, by selective bypass of the heat exchanger. It is a motor-operated butterfly valve controlled by the system controller, as a function of heat exchanger outlet temperature. It is necessarily a relatively complex valve, in that it must modulate the flow, rather than being of a simple on-off design.

### **1.5.2.8 Temperature Sensor**

Similar to existing thermocouple temperature sensors, it provides active temperature data to the system controller.

### **1.5.2.9 Water Separator / Filter**

This device removes and discards free water in the compressed air flow. It also provides additional filtration of the air, because the air may be contaminated when supplied from the bleed air source. This is similar to existing aircraft units and sized, based on airflow requirements, from empirical data. The unit has a removable filter element to allow maintenance of the unit, and is line-mounted.

### **1.5.2.10 Air Separation Module**

The ASM receives pressurized air from the system, and separates it into two outlet airflows. NEA is provided to the fuel tank ullage. OEA is mix with ambient air and ejected. ASMs that have been cold-

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soaked at altitude may require 5 to 15 minutes of operation to warm and provide their optimum NEA. To get optimum flow immediately when the OBG system is started, provision has been made to use a small amount of engine bleed air to warm the ASM in flight. Regardless of the technology used, the unit is self-contained and line-mounted. It is expected to be sized for a given application, but will be of modular design, using existing sub-component sizing.

### **1.5.2.11 Relief Valve**

The relief valve is necessary to allow harmless venting of the NEA flow in the event of fuel system refuel failure conditions. Current aircraft fuel systems are usually sized to prevent over-pressure conditions inside the tanks, in the event that a refuel valve fails to close when the tank is full. The addition of NEA flow into the tank could increase the pressure in the tank during this condition, such that the tank is over-pressurized. The relief valve would be opened for this condition, thereby by-passing the tank. The unit is of either a motor operated butterfly design, or solenoid-operated configuration, similar to existing aircraft system units.

### **1.5.2.12 ASM Discharge Check Valve and Restrictor**

This provides redundant back flow prevention in the event that a fuel tank check valve fails open. It therefore protects the ASM from fuel / vapor back flow that would otherwise significantly degrade ASM performance. The unit also provides a backpressure to the ASM while flowing, necessary to optimize its efficiency.

### **1.5.2.13 Fuel Tank Check Valve and Restrictor**

Similar to the ASM check valve assembly, this unit prevents back flow of fuel / vapor to the ASM. The restrictor provides a means of balancing the flow to each of the tanks.

### **1.5.2.14 Ducting**

Conventional aluminium aircraft ducting is used to flow air to the ASM and NEA to the fuel tanks. This will feature conventional flexible couplings with O ring seals, to provide axial and angular motion required for relative motion during flight and tolerance build-up during manufacture. Minimum wall thickness' are used to minimize weight, but must be damage tolerant. Double containment may be required where NEA flow passes through the pressurized cabin, to prevent nitrogen contamination of the cabin air after failure of the primary tube wall. This will be minimized by the close location of the ASM relative to the fuel tanks. Similarly, stainless steel ducting is required for the ducts between the compressor and the heat exchanger, due to the elevated temperature of the airflow. Close-coupling the compressor and heat exchanger will also minimize this.

### **1.5.2.15 Controller**

The system controller provides the actuation signals to the various components in the system. This includes such items as the control signal to start the compressor, open the unloading valve, modulate the temperature control valve etc. It is a digital microprocessor based unit, and may be integrated as a card on an existing aircraft computer or as a separate computer on older aircraft. Some health monitoring and failure annunciation may be included in the software.

### **1.5.2.16 Wiring**

Power wires and control signal wires are included in the system to allow connection to the power source, and connect the controller with system components. This is defined as conventional system wiring.

## 1.5.2.17 Flow Control Orifice

The flow control orifice uses a small bleed flow of warm air to be used to maintain the ASM temperature during protracted high altitude flights. This is a simple plate orifice or metered tube design.

## 1.6 SYSTEM SIZING AND PERFORMANCE

The ullage was required to be inert to 10% O<sub>2</sub> at pushback from the gate, to simplify comparison with the ground-based system. Parameters such as ASM efficiency and fuel tank volumes were primary factors for system sizing. The ASM performance determines the amount of feed air needed to make the NEA needed to fill the fuel tank(s). The feed air quantity and the ambient temperature then size the compressor and the feed air heat exchanger.

The primary tool used by the Team for determining the performance of the system was the FAA inerting computer model. This analysis tool determines flammability exposure of the fuel tank ullage during the mission.

The key parameters explored to optimize the OBG System components were the effect of feed pressure, NEA oxygen content, feed air temperature, and turn-time (the time available to operate the system prior to pushback from the gate).

### 1.6.1 Key Sizing Parameters

The OBG system NEA flow rate (and, therefore, the system size, cost, and weight) is directly proportional to the minimum aircraft turn-time, as this dictates the time available to operate the system.

Another key parameter is the ASM feed pressure. Because the system can operate on engine or APU bleed air, it was sized using the minimum pressure available from existing aircraft bleed air pressure data. This consideration had an effect on the size and weight of the ASM selected.

The system heat exchangers use ambient air to cool the hot ASM feed air to the temperature that the ASM can tolerate. In order to predict the cooling loads on the system, 111°F ambient air temperature was used as the worst-case ambient air heat sink. This detail dictates the size and weight of the cooling system, because the PSA ASM feed air had to be cooled to 125°F. Membrane ASMs operate efficiently at 180°F and were sized accordingly to minimize the size of the cooling system. However, operating the membrane ASMs at this temperature requires more feed air than operating at cooler temperatures. Figure 1.6.1-1 also shows the effect of temperature on performance.

The NEA flow rate required to inert the tank is a function of the NEA purity generated by the system. The OBGIS weight, volume, power consumption, and cost results in this report are based on membrane NEA purity of 6.76% oxygen and PSA purity of 7.4% oxygen. An analysis was done by the Team to insure there was not a high dependency of system weight and size on NEA concentration. This analysis was done by performing several sizing iterations using the inerting model and only varying the concentration of the NEA.

Through the entire range of purity, the weight of the system changed only 5%. (Note: the weights in the chart only consider the main system components.) This was ignored for the purposes of this report because the Team considered the savings minimal and overall the fleet-wide savings would be negligible.

### 1.6.2 Parametric Sizing Curves

The results of the system analysis were the weight, volume, electrical power consumption, and acquisition cost for the various aircraft models. These results are plotted as parametric charts in Figures 1.6.2-1 through 1.6.2-5.

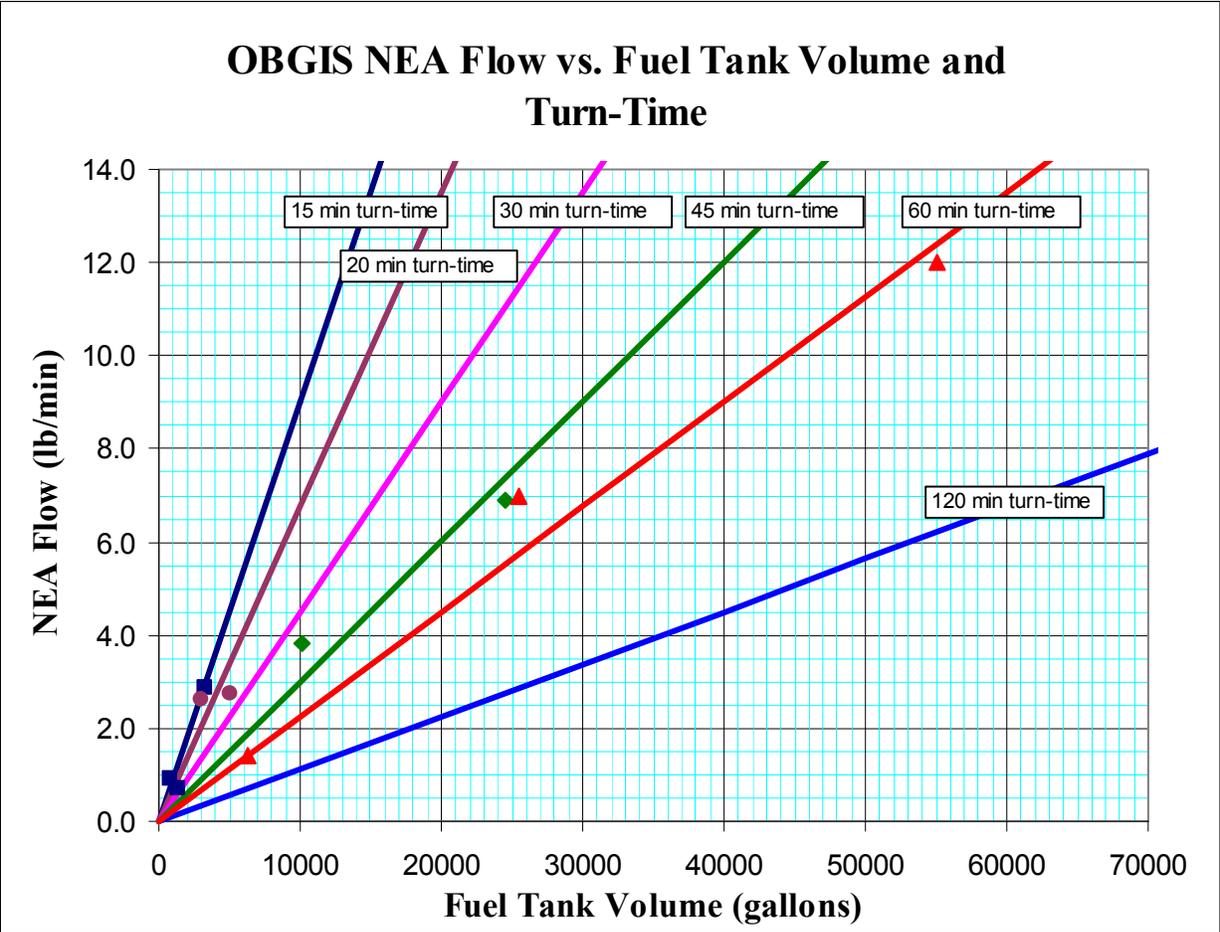


Figure 1.6.2-1. NEA Flow vs Tank Volume

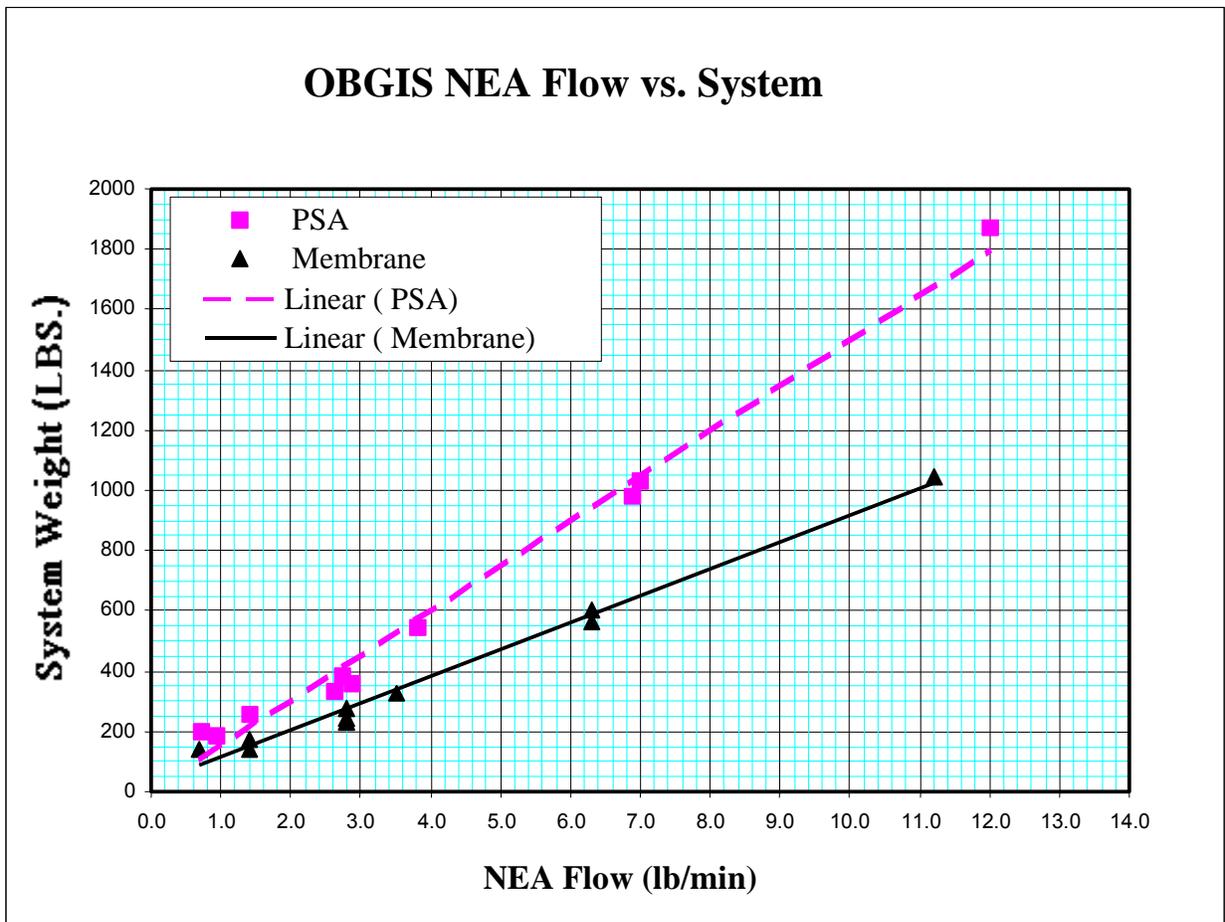


Figure 1.6.2-2. Weight vs NEA Flow

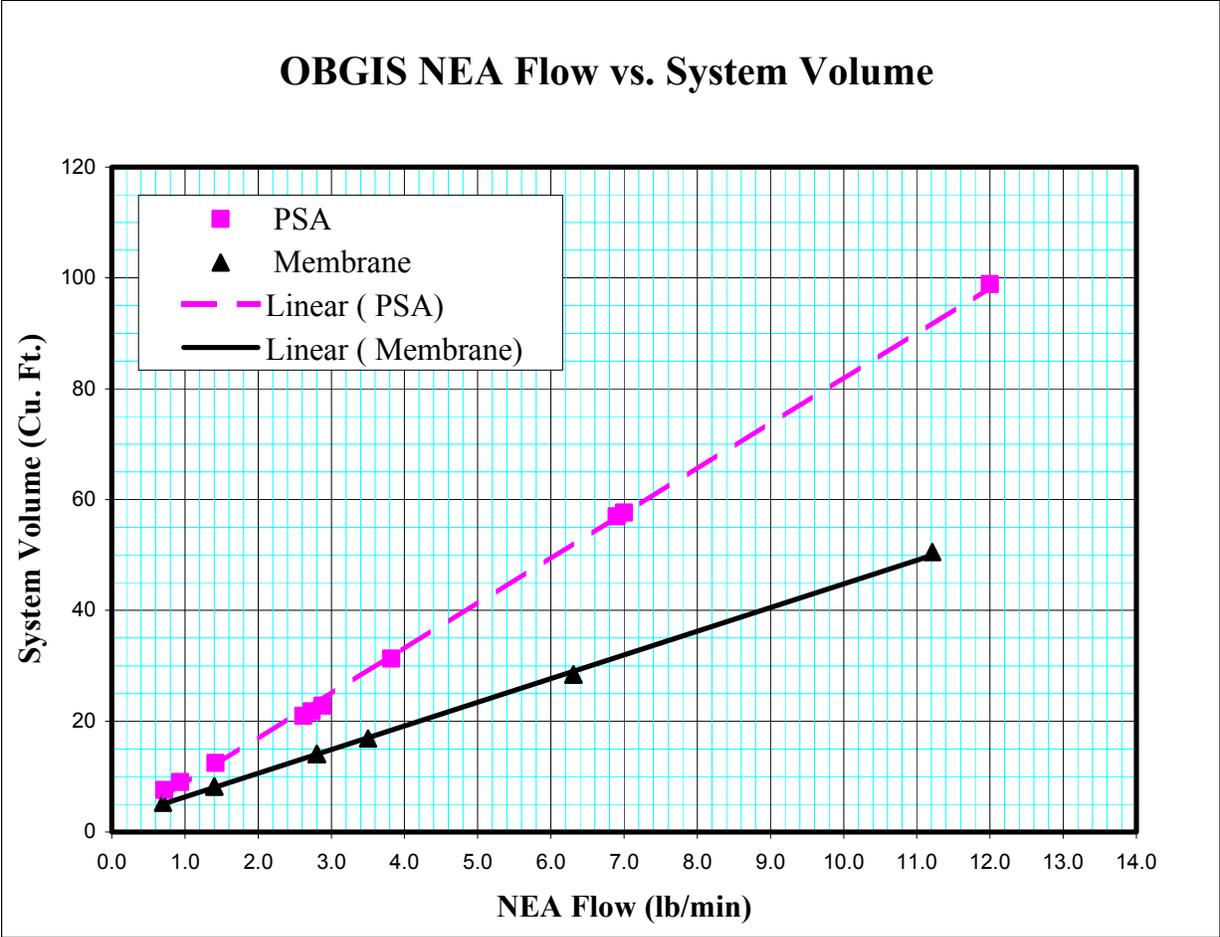


Figure 1.6.2-3. Volume vs NEA Flow

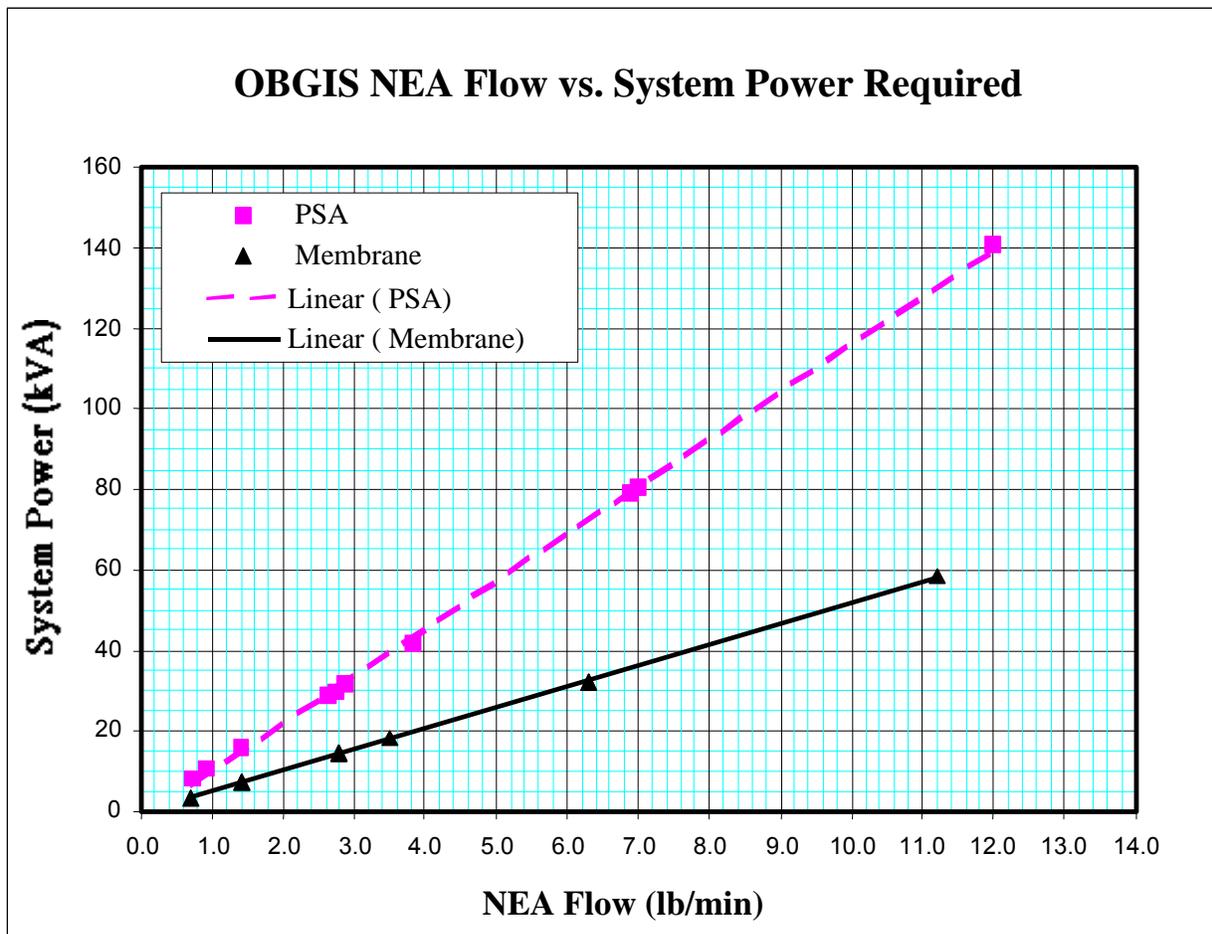
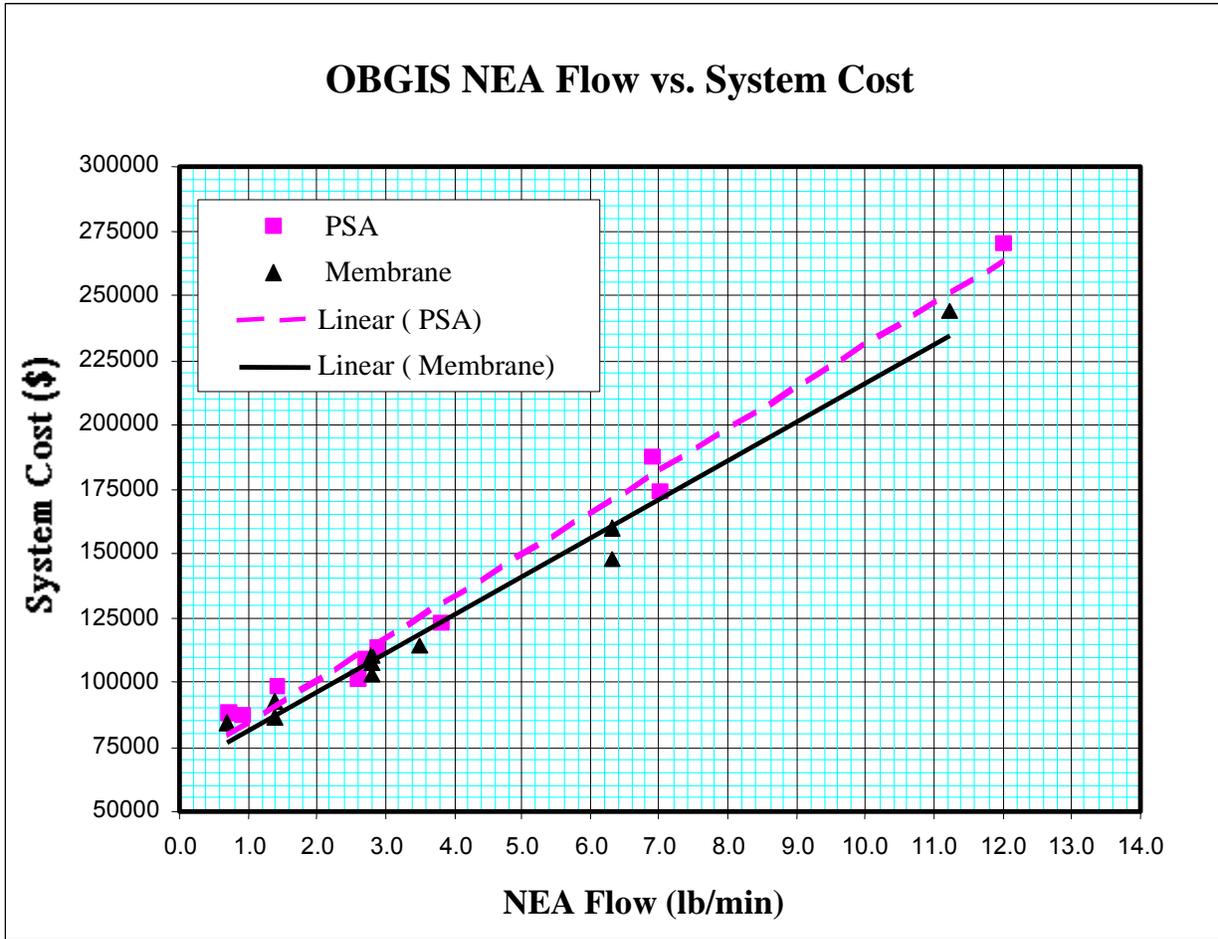


Figure 1.6.2-4. Power vs NEA Flow



*Figure 1.6.2-5. Cost vs NEA Flow*

These charts allow system sizing for any aircraft model not specifically studied in this report. Figure 1.6.2-1 plots the NEA flow required for an OBGIS to inert the fuel tanks before pushback based on fuel tank volume and turn-time. Figures 1.6.2-2 through 1.6.2-5 then provide estimation of OBGIS system weight (pounds), system volume (cubic feet), required electrical power (kVA), and system cost (dollars). Cost data are for initial acquisition only of the systems themselves and are provided for comparison purposes; they do not include any other costs such as certification or integration by the aircraft manufacturer or commercial airline. The charts are based on NEA purity of approximately 7% oxygen and may not be valid for different NEA purity.

The following examples of the use of the charts are for an aircraft with a total fuel capacity of 15,000 gallons (including main, center wing, and auxiliary tanks) and a minimum turn-time of 45 minutes:

**Membrane System:** Figure 1.6.2-1 indicates that 4.5 pounds per minute of NEA at 7%O<sub>2</sub> is required to inert the 15,000 gallon tank volume within 45 minutes. Figures 1.6.2-2 through 1.6.2-5 show that a membrane OBGIS which produces 4.5 lbs/min of NEA7 weighs approximately 425 pounds, occupies 22 cubic feet, consumes 24 kVA of electrical power, and has initial costs of \$135,000.

**PSA System:** Figure 1.6.2-1 again indicates that 4.5 lbs/min of NEA7 are required. Figures 1.6.2-2 through 1.6.2-5 show that a PSA OBGIS would weigh approximately 675 pounds, occupy 37 cubic feet, consume 52 kVA of electrical power, and cost \$140,000.

**1.6.3 System Results**

The OBGIS air consumption, weight, electrical power requirements, and volume for the different models and tank configurations are plotted in the bar charts in Figures 1.6.3-1 and 1.6.3-2.

OBGI - Center Wing Tank

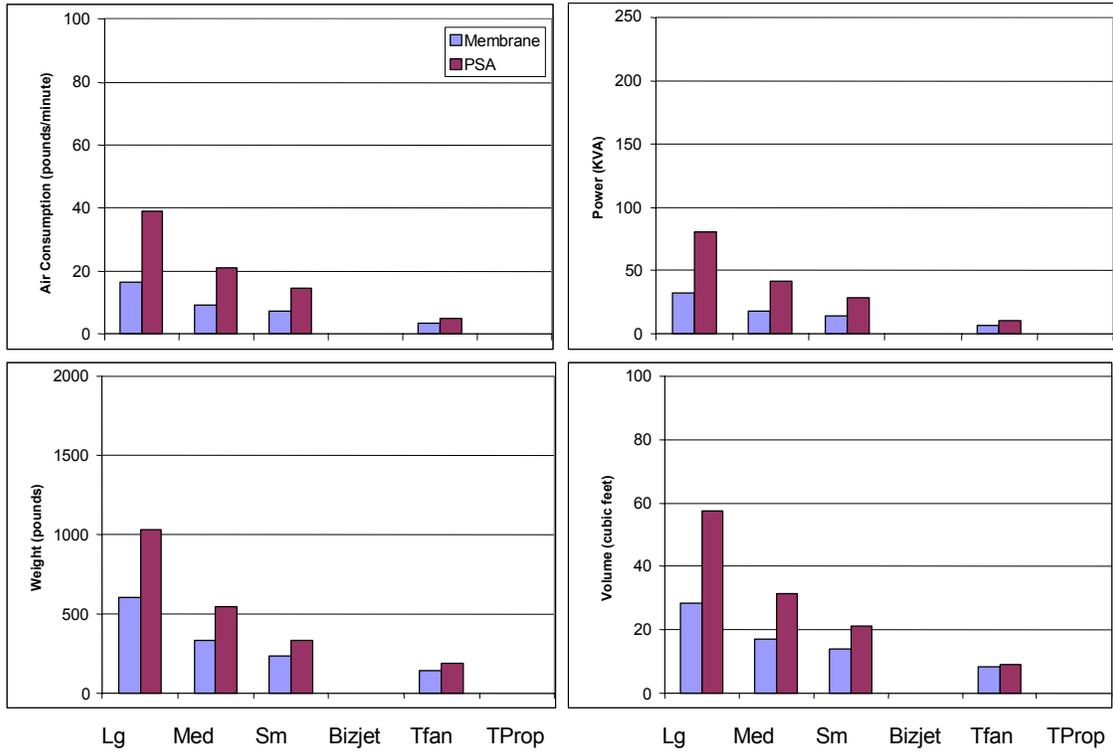
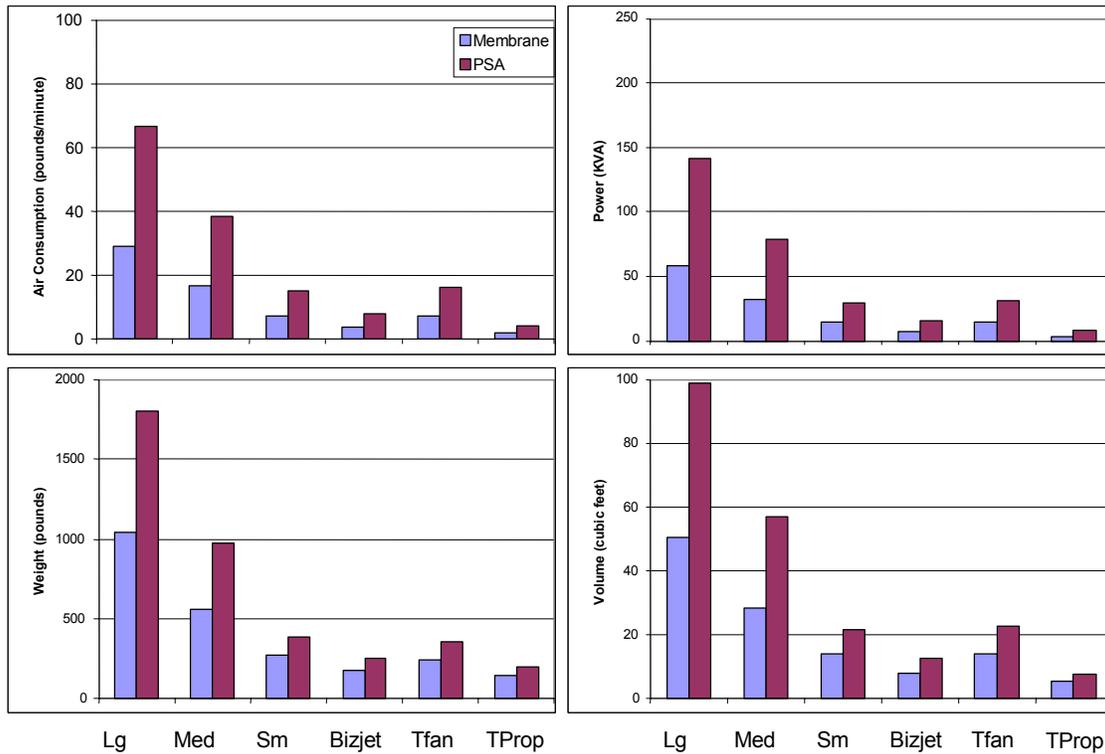


Figure 1.6.3-1. OBGIS Air Consumption, Power, Volume and Weights for Center Tanks

**OBGI - All Tanks**



*Figure 1.6.3-2. OBGIS Air Consumption, Power, Volume and Weights for All Tanks*

**1.6.4 Flammability Exposure**

Flammability exposure for each of the generic aircraft types was determined for each fuel tank type by simulating 5,000 random flights. Both the PSA and membrane ASM systems were evaluated based on the system sizing that ensured tanks were inert at pushback from the gate for all ground scenarios. Flammability exposure results for the OBGI systems are shown in Figures 1.6.4-1 and 1.6.4-2. A comparison of OBGI system performance to other fuel tank inerting options is provided in Section 5.

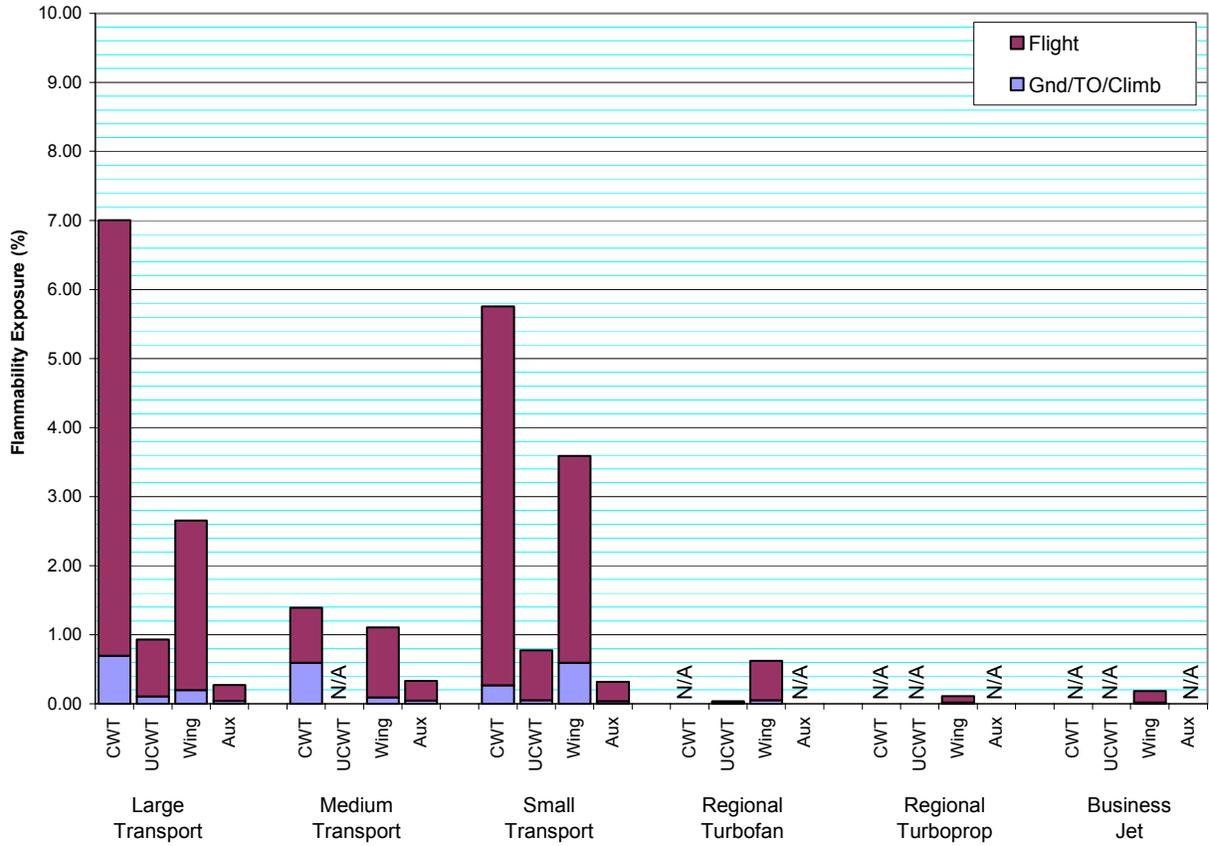


Figure 1.6.4-1. Flammability Exposure Results for the OBGI Systems PSA ASM

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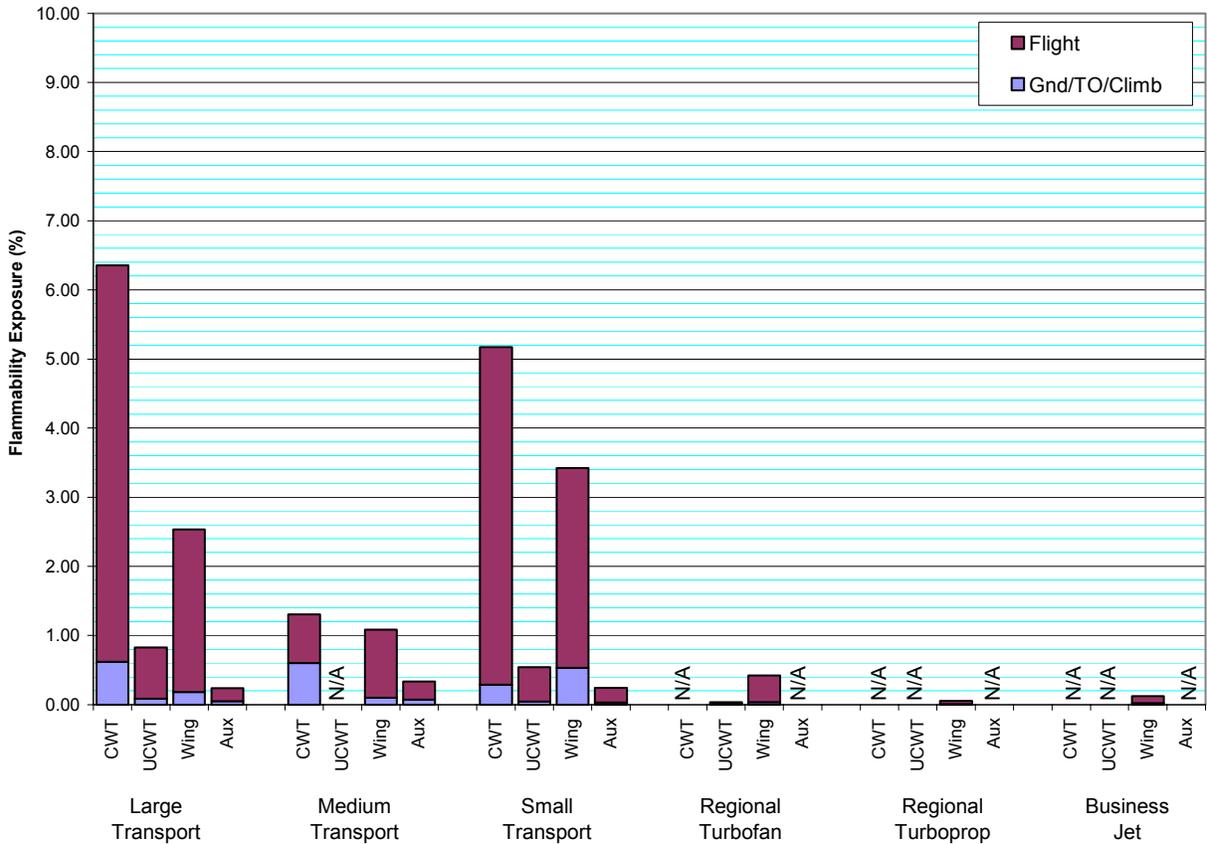


Figure 1.6.4-2. Flammability Exposure Results for the OBGI Systems Membrane ASM

Total flammability exposure represents the total flight and ground time spent flammable and not inert as a percentage of the total flight and ground time. The portion of the total flammability exposure corresponding to gate time, taxi out, takeoff and climb segments were separately summed, to allow for direct comparisons of each inerting option in the portion of the mission where the risk of an explosion was higher. Because the FAA flammability model conservatively uses sea level criteria at altitude, the total exposure is not necessarily the best measure for comparing overall performance between inerting system types. For instance, a one-percent reduction in flammability exposure during cruise does not represent the same benefit as a one-percent reduction on the ground.

**1.7 WEIGHT**

Figures 1.7-1 and 1.7-2 summarize the weight data developed by the Onboard Design Task Team for the membrane and PSA OBGI systems for each of the ARAC generic aircraft. Each table provides the total weight for the “major” and “other” components identified for each system. “Other” components include such items as wiring, ducting and valves, and their total estimated weights have been combined.

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Weight Summary Table - Membrane Systems (Lbs.)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	62.2	35.4	35.4	22.3	19.0	19.0	9.2	19.0	12.5	12.5
Heat exchanger	5.0	4.8	4.8	2.3	3.0	3.0	0.6	3.5	0.7	1.1
Cooling fan & ram ducts assembly	7.1	7.3	7.3	6.5	5.3	5.3	0.6	4.8	2.9	2.4
Air separation module	320.0	180.0	180.0	100.0	80.0	80.0	20.0	80.0	40.0	40.0
<b>Main Parts Sub-Total</b>	<b>394.3</b>	<b>227.5</b>	<b>227.5</b>	<b>131.1</b>	<b>107.3</b>	<b>107.3</b>	<b>30.4</b>	<b>107.3</b>	<b>56.0</b>	<b>56.0</b>
<b>Other Parts</b>										
Compressor inlet air filter assy	6.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Compressor inlet air filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Compressor discharge check valve	1.5	1.5	1.3	1.2	1.0	1.0	0.8	1.2	1.0	1.5
Compressor unloading valve	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.2	2.0	2.5
Bleed Air shutoff valve	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.8	2.5	2.5
Heat Exchanger bypass valve	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.8	0.8	1.0
Temperature sensor & controller	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Water separator/filter assy	10.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Water separator/filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ASM check valve & restrictor assy	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Relief valve	1.9	1.9	1.5	1.5	1.0	1.0	0.8	1.0	1.2	1.5
Fuel tank check valve	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Ducting	133.2	44.2	115.8	30.4	52.5	16.8	38.1	38.1	9.5	38.1
Wiring	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Bleed Orifice & Duct	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Compressor Wiring	236.2	118.1	56.7	34.8	15.4	15.4	3.3	12.8	4.1	4.1
Installation Hardware	118.5	65.7	67.0	36.5	32.9	27.6	17.3	30.5	17.1	21.6
Structural Modifications	100.0	100.0	50.0	50.0	20.0	20.0	10.0	10.0	10.0	10.0
<b>Other Parts Sub-Total</b>	<b>641.0</b>	<b>376.1</b>	<b>336.3</b>	<b>198.5</b>	<b>165.2</b>	<b>124.1</b>	<b>112.6</b>	<b>136.5</b>	<b>85.3</b>	<b>119.9</b>
<b>System Totals</b>	<b>1035.4</b>	<b>603.7</b>	<b>563.8</b>	<b>329.5</b>	<b>272.5</b>	<b>231.4</b>	<b>143.0</b>	<b>243.8</b>	<b>141.3</b>	<b>175.9</b>
Oxygen sensor	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Figure 1.7-1. Summary of OBGIS Component Weights – Membrane Systems

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Weight Summary Table - PSA Systems (Lbs.)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	135.4	78.4	77.4	43.7	32.8	31.8	13.0	34.3	15.1	19.9
Heat exchanger	64.2	37.2	32.6	19.3	13.4	12.9	3.2	14.3	4.3	10.0
Cooling fan & ram ducts assembly	23.0	13.2	17.0	9.1	8.7	8.5	6.6	8.8	6.7	4.0
Air separation module	586.0	333.0	327.0	188.0	141.0	132.0	50.0	144.0	65.0	80.0
<b>Main Parts Sub-Total</b>	<b>808.6</b>	<b>461.8</b>	<b>454.1</b>	<b>260.1</b>	<b>196.0</b>	<b>185.2</b>	<b>72.8</b>	<b>201.4</b>	<b>91.1</b>	<b>113.9</b>
<b>Other Parts</b>										
Compressor inlet air filter assy	11.0	8.0	8.0	6.0	4.0	4.0	4.0	4.0	4.0	4.0
Compressor inlet air filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Compressor discharge check valve	2.0	2.0	2.0	1.5	1.0	1.0	0.8	1.2	1.0	1.5
Compressor unloading valve	3.0	3.0	3.0	2.5	2.0	2.0	2.0	2.2	2.0	2.5
Bleed Air shutoff valve	4.0	4.0	4.0	3.0	2.5	2.5	2.5	2.8	2.5	2.5
Heat Exchanger bypass valve	1.2	1.2	1.2	1.2	0.8	0.8	0.7	0.8	0.8	1.2
Temperature sensor & controller	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Water separator/filter assy	18.0	13.0	13.0	10.0	7.0	7.0	7.0	7.0	7.0	7.0
Water separator/filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Relief valve	1.9	1.9	1.9	1.5	0.8	1.0	0.8	1.0	1.2	1.5
ASM check valve & restrictor assy	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fuel tank check valve	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Ducting	133.2	44.2	115.8	30.4	52.5	16.8	38.1	38.1	9.5	38.1
Wiring	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Bleed Orifice & Duct	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Compressor Wiring	472.3	236.2	177.1	88.6	23.2	23.2	7.8	19.4	6.5	12.8
Installation Hardware	289.9	132.1	121.0	64.7	47.5	40.5	24.5	45.7	22.9	31.8
Structural Modifications	100.0	100.0	50.0	50.0	20.0	20.0	10.0	10.0	10.0	10.0
<b>Other Parts Sub-Total</b>	<b>1063.3</b>	<b>559.3</b>	<b>510.9</b>	<b>276.2</b>	<b>181.1</b>	<b>138.7</b>	<b>118.2</b>	<b>151.6</b>	<b>87.1</b>	<b>131.7</b>
<b>System Totals</b>	<b>1871.9</b>	<b>1021.1</b>	<b>964.9</b>	<b>536.3</b>	<b>377.1</b>	<b>323.9</b>	<b>191.0</b>	<b>352.9</b>	<b>178.3</b>	<b>245.6</b>
Oxygen sensor	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Figure 1.7-2. Summary of OBGIS Component Weights – PSA Systems

## 1.7.1 Air Separation Modules

**Permeable Membranes.** The proposed ASM's are an assembly of a hollow fiber membrane module in an aluminum lightweight aircraft quality pressure vessel. The hollow fiber membrane module is constructed with manufacturing methods and technology that are used commonly in the industrial gas generation industry. The aluminum housing is configured to meet the mounting requirements of the ASM and service conditions for aircraft mounting.

The ASM weight includes the hollow fiber membrane module, the inlet/outlet headers and the connections to the NEA and feed air manifolds/tubing. The structural modification weight required, where the ASM interfaces with the aircraft structure, was accounted for separately. The NEA flow rate for each of the different aircraft sizes and tank volumes determined the total number of a single standard size of ASMs required to meet the flow requirements. With the known weight for the standard ASM the total weight for each aircraft ASM was calculated.

**PSA.** The PSA air separator calculations were made empirically. A production OBIGGS ASM was operated in the lab at the altitudes and supply pressures consistent with the OBGIS study. The product gas output flows were scaled upward or downward to meet the NEA requirements from the inert gas simulations, as discussed previously.

The weight of the molecular sieve needed to produce the gas was likewise scaled upward or downward based on NEA flow. The structural weight including the mounting structure and sieve containers was also scaled, although some economies of scaling were assumed, similar to existing PSA systems.

## 1.7.2 Compressor

The compressor weight includes compressor, motor, motor cooling fan and start contactor. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately. The weight estimates were based on design schemes prepared for 15kW shaft power compressors of the screw and centrifugal type. From this, a linear metric of weight as a function of power was generated. It is considered that this tends to give an overestimate of weight for high power machines and an underestimate for low power machines, which is conservative in the weight critical cases. Above 30kW shaft power, two or more compressors are proposed.

## 1.7.3 Heat Exchanger/Cooling Fan

The heat exchanger and cooling fan were sized by vendors of aircraft quality heat exchangers and cooling fans. The heat exchangers and cooling fans for each aircraft were sized to cool air from the compressor to the appropriate ground temperature limits (125 degrees Fahrenheit for the PSA systems and 165 degrees Fahrenheit for the membrane systems) using 111 degrees Fahrenheit ambient air. An effort was made to minimize the overall size of the system by performing parametrics on heat exchanger and fan sizes to determine the best overall system.

Heat exchanger and cooling fan weights were determined for each of the aircraft and system types. Heat exchanger weight includes the core, inlet/outlet headers, and connections to the mating tubing. The weight of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

## 1.7.4 Other Components

The weight of the other components in the system is mainly dependent on the required airflow or NEA flow. The higher flows associated with the larger aircraft demand larger components than those used in the smaller aircraft applications. The specific methods used to estimate the weight of the other components is discussed below.

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**Filters.** A large supplier of aircraft filters estimated the weight of the filters for the different models, based on the required airflow rates.

**Valves.** The system valves were also sized as a function of airflow, and based on existing components used in similar aircraft systems, to ensure that the pressure drop across the unit is acceptable.

**Ducting.** The ducting weight was based on the lengths and diameters in Figure 1.7.4-1. The duct material was assumed to be .032 aluminum for all models. It was assumed that flexible couplings are required every two feet and the mounting hardware adds 50 percent to the total duct weight. It was also assumed that the ASM could be located close to the fuel tanks, which would preclude the need for any significant length of double-walled tubing, and that the compressor and the heat exchanger would be located close together so that the length of additional high temperature stainless steel ducting is also negligible.

Aircraft Type	Length (feet)	Diameter (inches)
Large Transport	266	3.0
Medium Transport	217	2.5
Small Transport	125	2.0
Regional Turbofan	120	1.5
Regional Turboprop	120	1.5
Business Jet	120	1.5

Figure 1.7.4-1. Ducting Length and Diameter

**Compressor Wiring.** The compressor power-supply wiring parameters were based on the lengths and gauge size shown in Figure 1.7.4-2. The wiring material was assumed to be Mil-W-22759/41B, 600 volt, nickel-plated high strength copper conductors with cross-linked ETFE insulation and jacket and a service temperature range of -65 to +200degC.

Aircraft Type	Length (feet)	Wire Size Mem-brane (AWG)	Wire Size PSA (AWG)
Large Transport	120	41-2	41-2
Medium Transport	90	41-2	41-4 (41-6)
Small Transport	60	41-6	41-8
Regional Turbofan	50	41-6 (41-10)	41-8 (41-12)
Regional Turboprop	50	41-10	41-14
Business Jet	60	41-8	41-12

(Numbers in parentheses are CWT systems when different from all tanks)

Figure 1.7.4-2. Compressor Wiring

**Installation Hardware.** The installation hardware for each system was calculated as a function of the weight of the installed components. The hardware weight was calculated based on commercial aircraft experience as 15% of the installed component weight.

**Structural Modifications.** Based on weight of the installed components, the Team assigned values for the weight of the material that would have to be added to the structure to support the new equipment.

### 1.8 VOLUME

Figures 1.8-1 and 1.8-2 summarize the volume data developed by the Task Team for the membrane and PSA OBGI systems for each of the ARAC generic aircraft. Each table provides the total volume for the “major” and “other” components identified for each system necessary to inert the fuel tank. “Other” components include such items as wiring, ducting and valves, and their total estimated volumes have been combined.

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Volume Summary Table - Membrane Systems (Cu Ft)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	1.08	0.62	0.62	0.36	0.29	0.29	0.10	0.29	0.16	0.16
Heat exchanger & Fan	0.50	0.28	0.28	0.17	0.15	0.15	0.03	0.15	0.07	0.07
Air separation module	13.90	7.82	7.82	7.82	3.47	3.47	0.87	3.47	1.74	1.74
<b>Main Parts Sub-Total</b>	15.5	8.7	8.7	8.3	3.9	3.9	1.0	3.9	2.0	2.0
<b>Other Parts Sub-Total</b>	35.05	19.73	19.73	12.03	10.12	10.12	4.29	10.12	6.24	6.24
<b>System Totals</b>	50.5	28.4	28.4	20.4	14.0	14.0	5.3	14.0	8.2	8.2

*Figure 1.8-1. Summary of OBGIS Component Volumes – Membrane Systems*

Volume Summary Table - PSA Systems (Cu Ft)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	2.41	1.40	1.38	0.78	0.57	0.54	0.18	0.59	0.22	0.31
Heat exchanger & Fan	2.93	1.69	1.66	0.88	0.63	0.60	0.18	0.66	0.21	0.32
Air separation module	23.27	13.57	13.38	13.57	5.30	5.08	1.40	5.58	1.81	2.75
<b>Main Parts Sub-Total</b>	28.6	16.7	16.4	15.2	6.5	6.2	1.8	6.8	2.2	3.4
<b>Other Parts Sub-Total</b>	70.25	41.00	40.53	22.22	15.28	14.74	5.81	15.97	6.77	9.06
<b>System Totals</b>	98.9	57.7	57.0	37.4	21.8	21.0	7.6	22.8	9.0	12.4

*Figure 1.8-2. Summary of OBGIS Component Volumes – PSA Systems*

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### **1.8.1 Air Separation Modules**

**Permeable Membrane.** The volume of the proposed air separation module includes the Hollow Fiber Membrane Module, the inlet/outlet headers and the connections to the NEA and Feed air manifolds/tubing. The NEA flow rate for each of the different aircraft sizes and tank volumes determined the total number of a single standard size of ASMs required to meet the flow requirements. With the known volume for the standard ASM the total volume for each aircraft ASM was calculated.

**PSA.** The PSA air separator calculations were made empirically. A production OBIGGS air separator was operated in the lab at the supply pressure consistent with the ARAC study. The product gas output flows were scaled upward or downward to meet the product gas needs that resulted from the inert gas simulations as discussed previously.

The volume of PSA air separator was therefore scaled from a production unit based on the projected quantity of molecular sieve needed vs. the actual molecular sieve present in the production unit.

### **1.8.2 Compressor**

Compressor types (screw or centrifugal) were selected and volumes were determined for each of the aircraft and system types in a similar manner and to the same considerations of compressor scalability as outlined in the section concerning weight. The compressor volume includes compressor, motor, motor cooling fan and start contactor. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately. The volume estimates were based on design schemes prepared for 15kW shaft power compressors of the screw and centrifugal types. From this a linear metric of volume as a function of power was generated. It is considered that this tends to give an overestimate of volume for high power machines and an underestimate for low power machines, which is generally conservative with regard space envelop constraints. Above 30kW shaft power, two or more compressors are proposed.

### **1.8.3 Heat Exchanger/Cooling Fan**

Heat exchanger and cooling fan volumes were determined for each of the aircraft and system types. Heat exchanger volume includes the core, inlet/outlet headers, and connections to the mating tubing. The volume of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

### **1.8.4 Other Components**

In a manner similar to that of the weight, component volumes were individually computed as a function of airflow, NEA flow and power. Some components do not scale in a linear fashion with flow, however. As an example of this phenomenon, motor actuated valves often use a common valve actuator for smaller and larger valves, for spares cost considerations. Therefore the volume of the actuator portion of the valve may not change for an increased flow condition. The majority of component volumes were therefore scaled or derived from existing components for similar applications on aircraft. Duct volume and wire volume were a simple computation based on length and diameter.

## **1.9 ELECTRICAL POWER**

Figures 1.9-1 and 1.9-2 summarize the electrical power data developed by the Onboard Design Task Team for the membrane and PSA OBI systems for each of the ARAC generic aircraft. Each table provides the total electrical power for the “major” and “other” components identified for each system. “Other” components include such items as wiring, motors and valves, and their total estimated electrical power have been combined.

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Electrical Power Summary Table - Membrane Systems (kVa)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	57.63	31.85	31.85	17.64	14.10	14.10	3.49	14.10	7.00	7.00
Heat exchanger & Fan	0.66	0.37	0.37	0.26	0.25	0.25	0.00	0.25	0.08	0.08
Air separation module	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Main Parts Sub-Total</b>	<b>58.3</b>	<b>32.2</b>	<b>32.2</b>	<b>17.9</b>	<b>14.3</b>	<b>14.3</b>	<b>3.5</b>	<b>14.3</b>	<b>7.1</b>	<b>7.1</b>
<b>Other Parts Sub-Total</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>
<b>System Totals</b>	<b>58.4</b>	<b>32.3</b>	<b>32.3</b>	<b>18.0</b>	<b>14.4</b>	<b>14.4</b>	<b>3.6</b>	<b>14.4</b>	<b>7.2</b>	<b>7.2</b>

*Figure 1.9-1. Summary of OBGIS Component Power Consumption – Membrane Systems*

Electrical Power Summary Table - PSA Systems (kVa)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	130.52	75.24	74.15	40.83	29.09	27.91	7.63	30.70	9.90	15.07
Heat exchanger & Fan	9.18	4.57	4.40	0.60	0.34	0.34	0.27	0.34	0.33	0.34
Air separation module	1.06	0.62	0.61	0.62	0.24	0.23	0.00	0.26	0.08	0.13
<b>Main Parts Sub-Total</b>	<b>140.8</b>	<b>80.4</b>	<b>79.2</b>	<b>42.0</b>	<b>29.7</b>	<b>28.5</b>	<b>7.9</b>	<b>31.3</b>	<b>10.3</b>	<b>15.5</b>
<b>Other Parts Sub-Total</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>	<b>0.00</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>
<b>System Totals</b>	<b>140.9</b>	<b>80.5</b>	<b>79.3</b>	<b>42.1</b>	<b>29.8</b>	<b>28.6</b>	<b>7.9</b>	<b>31.4</b>	<b>10.4</b>	<b>15.6</b>

*Figure 1.9-2. Summary of OBGIS Component Power Consumption – PSA Systems*

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## **1.9.1 Air Separation Modules**

**Permeable Membrane.** The permeable membrane air separation modules do not consume any electrical power. Membrane technology is passive and has no moving parts.

**PSA.** Power consumption numbers are relatively low, since the mechanism to operate the PSA distribution valve is pneumatic. The electrical power is consumed by simple timing and power circuits that operate the pneumatic control valves.

## **1.9.2 Compressor**

Compressor types (screw or CF) were selected and powers were determined for each of the aircraft and system types in a similar manner to the compressor scalability as outlined in the section concerning weight.

The compressor is driven by an electric motor supplied from a ground power source external to the aircraft. The compressors for each aircraft were sized to supply the mass flow of air required as input to each of the differing ASM types. The shaft power of the compressor is a function of the mass flow, pressure ratio and inlet temperature. The maximum power design point for the compressors was Sea level and the maximum ambient temperature operating condition was 110°F. An effort was made to minimize the electrical power requirement by investigating alternative architectures such as two-stage compression with inter-cooling. It was found that power reduction with these features was small.

## **1.9.3 Heat Exchanger/Cooling Fan**

Heat exchanger and cooling fan power were determined for each of the aircraft and system types. The heat exchanger requires no power to operate. The cooling fan power requirement was determined based on the cooling air flow rate and pressure rise requirements. The system was designed to minimize the cooling fan power requirements wherever possible.

## **1.9.4 Other Components**

The power consumption of the other system components are minimal compared with that of the compressor. The only units that consume power are the valves; most of the time they are dormant and consume no power. The exception to this is the temperature control valve, which uses a small amount of power on a continuous basis to modulate the outlet temperature of the heat exchanger. This power is very small compared to the compressor and fan power requirements.

## **1.10 RELIABILITY**

Figures 1.10-1 through 1.10-4 summarize OBGIS reliability in terms of mean-time-between-maintenance-actions (MTBMA), and mean-time-between-failure (MTBF) developed by the Task Team for the membrane and PSA systems for each of the generic aircraft. Other components include such items as wiring, motors and valves, and their total estimated reliability have been combined. The airplane operations and maintenance team used this component data as a starting point for the system level reliability estimates.

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Reliability Summary Table - Membrane Systems MTBMA (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
ASM check valve & restrictor assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structual Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 1.10-1. Summary of OBIGGS MTBMA – Membrane Systems

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Reliability Summary Table - PSA Systems MTBMA (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
ASM check valve & restrictor assy	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structual Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 1.10-2. Summary of OBIGGS MTBMA – PSA Systems

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Reliability Summary Table - Membrane Systems MTBF (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
ASM check valve & restrictor assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structual Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 1.10-3. Summary of OBIGGS MTBF – Membrane Systems

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Reliability Summary Table - PSA Systems MTBF (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
ASM check valve & restrictor assy	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 1.10-4. Summary of OBIGGS MTBF – PSA Systems

### **1.10.1 Air Separation Modules**

Reliability estimates were developed for OBGIS membrane and pressure-swing adsorption air separation equipment.

**Permeable Membrane.** The membrane module consists of a membrane fiber bundle contained in a metal housing. There are no moving parts. The most likely failure causes are contamination and over-temperature damage. The OBGIS concepts include upstream filtration and redundant temperature sensors to minimize the possibility of these failures. There are commercial membrane modules that have operated continuously for many years without failure. There is no scheduled maintenance requirement for the membrane modules.

**PSA.** The PSA hardware consists of a distribution valve that is pilot operated by relatively small pneumatic valves and controlled by a timing circuit. Also included are air and product manifolds, molecular sieve beds, and purge orifices. The distribution valve assembly contains two wear parts, which are recommended to be serviced at 6000 to 8000 hour intervals. The Mean-Time-Between-Failure estimate in the summary table assumes a scheduled overhaul is performed every 8000 hours.

### **1.10.2 Compressor**

The compressor reliability for screw-type units is based on a recommended service interval of 7000 hours. The centrifugal compressors use a different bearing technology that does not require periodic servicing. Suppliers of existing flight-worthy equipment provided the reliability estimates.

### **1.10.3 Heat Exchanger/Cooling Fan**

The heat exchanger and cooling fan reliability estimates are based on commercial aircraft experience and were provided by suppliers of existing flight-worthy equipment.

### **1.10.4 Other Components**

Reliability estimates for the other OBGIS components were based on commercial aircraft experience with similar components. Common reliability estimates were used for the components that were used in all of the systems to ensure a fair comparison between the different inerting concepts and technologies.

## **1.11 COST**

The On-Board Design Task Team estimated the initial acquisition costs for the membrane and PSA OBGIS systems for each of the ARAC generic aircraft. Design and certification, operations, maintenance, and installation costs for the OBGIS are described later in this section. The Estimating and Forecasting Team used this data to analyze the cost-benefit.

### **1.11.1 Acquisition Cost**

Figures 1.11.1-1 and 1.11.1-2 summarize the OBGIS costs developed by the Task Team for the membrane and PSA systems, respectively, for each of the generic aircraft. No costs were developed for OBGIS systems using cryogenic distillation ASM technology as this technology had been eliminated from consideration. Each table provides the total cost for the individual components identified for each system. Except for the regional turboprop and business jet aircraft, two sets of costs are provided for each of the generic aircraft, one for components required to provide inerting for all tanks and another for components required to provide inerting for CWT only. The estimated component costs include the amortized non-recurring development costs. Several component costs were also integrated into the cost for the next higher assembly. The cost of the cabin air filter element and water separator/filter element was included in the costs for the cabin air filter assembly and the water separator/filter assembly, respectively; and the

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cost of the cooling fan was integrated into the cost of the heat exchanger. The team also separately estimated the cost for an on-board oxygen sensor, though this cost was not included in the system totals.

Acquisition costs for OBGI systems were developed by the participating vendors of the Onboard Design Task Team using the following guidelines:

- Final rule requiring fuel tank inerting becomes effective in year 2004.
- Production of the first certified system occurs in year 2009.
- Retrofit of existing aircraft is completed by year 2014.
- Continued production of OBGI systems for new production aircraft is through year 2020.
- As of year 2000, existing fleet of in-service aircraft is 13,813 aircraft, per Campbell Hill survey of world fleet forecast data provided by ATA.
- Average annual new aircraft production rate is 837 aircraft per year, per Campbell Hill survey of world fleet forecast data provided by ATA.
- When applying Campbell Hill survey of world fleet forecast data, between 5,500 and 5,800 shipsets per year total would be produced by the OBGI vendors starting in 2009 and running through 2014.
- When applying Campbell Hill survey of world fleet forecast data, continued production of between 980 and 1,300 shipsets per year would occur by the OBGI vendors starting in 2015 and running through 2020.
- Each vendor assumed a market share of 30%.
- New designs are assumed to be optimized to minimize non-recurring and recurring costs. The time frame for non-recurring efforts was estimated as 39 months.
- Non-recurring development costs were amortized into the per-system pricing provided by each vendor.

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<b>Cost Summary Table - Membrane Systems (\$)</b>										
<b>Component</b>	<b>Large Transport</b>		<b>Medium Transport</b>		<b>Small Transport</b>		<b>Turbo Prop</b>	<b>Turbo Fan</b>		<b>BizJet</b>
	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>
<b>Main Parts</b>										
Compressor, cooling & start system	15287	7764	7764	7201	7061	7061	6640	7061	6780	6780
Heat exchanger	7830	4450	4450	4012	3413	3632	2668	3632	2989	2989
Cooling fan & ram ducts assembly	1949	2168	2168	1949	2168	1949	693	1949	1112	1112
Air separation module	100160	56340	56340	31300	25040	25040	6260	25040	12520	12520
<b>Main Parts Sub-Total</b>	<b>125227</b>	<b>70722</b>	<b>70722</b>	<b>44462</b>	<b>37681</b>	<b>37681</b>	<b>16261</b>	<b>37681</b>	<b>23401</b>	<b>23401</b>
<b>Other Parts</b>										
Compressor inlet air filter assy	500	350	350	350	350	350	350	350	350	350
Compressor inlet air filter element	0	0	0	0	0	0	0	0	0	0
Compressor discharge check valve	475	475	425	425	275	300	250	400	300	475
Compressor unloading valve	1560	1560	1560	1560	1350	1300	1250	1450	1450	1560
Bleed Air shutoff valve	1250	1250	1250	1250	1100	1150	1100	1250	1250	1250
Heat Exchanger bypass valve	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Temperature sensor & controller	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Water separator/filter assy	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Water separator/filter element	0	0	0	0	0	0	0	0	0	0
ASM check valve & restrictor assy	185	185	185	185	185	185	185	185	185	185
Relief valve	680	680	580	500	450	500	450	500	500	550
Fuel tank check valve	675	675	675	675	675	675	675	675	675	675
Controller / control card	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Ducting	45470	8840	23160	6080	10500	3360	7620	7620	1900	7620
Wiring	750	750	750	750	750	750	750	750	750	750
Bleed Orifice & Duct	300	300	300	300	300	300	300	300	300	300
Compressor Wiring	4471	2236	811	541	310	310	64	286	75	75
Installation Hardware	5925	3285	3351	1823	1647	1379	867	1525	856	1082
Structual Modifications	2000	2000	1000	1000	400	400	200	200	200	200
<b>Other Parts Sub-Total</b>	<b>113242</b>	<b>71585</b>	<b>83397</b>	<b>64439</b>	<b>67292</b>	<b>59959</b>	<b>63061</b>	<b>64490</b>	<b>57791</b>	<b>64072</b>
<b>System Totals</b>	<b>238468</b>	<b>142308</b>	<b>154119</b>	<b>108901</b>	<b>104973</b>	<b>97641</b>	<b>79323</b>	<b>102172</b>	<b>81192</b>	<b>87473</b>
Oxygen sensor	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000

*Figure 1.11.1-1. Summary of OBGIS Costs – Membrane Systems*

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Cost Summary Table - PSA Systems (\$)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	31179	15985	15942	8120	7654	7608	6804	7718	6894	7099
Heat exchanger	55326	32534	32006	5203	11681	11227	4833	12300	4340	6279
Cooling fan & ram ducts assembly	7879	4847	4804	14371	2531	2498	973	2577	1989	2130
Air separation module	65000	40000	42000	28000	19000	19000	12000	25000	16000	18000
<b>Main Parts Sub-Total</b>	<b>159384</b>	<b>93366</b>	<b>94752</b>	<b>55694</b>	<b>40867</b>	<b>40333</b>	<b>24610</b>	<b>47595</b>	<b>29224</b>	<b>33508</b>
<b>Other Parts</b>										
Compressor inlet air filter assy	500	500	500	350	350	350	350	350	350	350
Compressor inlet air filter element	0	0	0	0	0	0	0	0	0	0
Compressor discharge check valve	525	525	525	450	275	300	250	400	300	475
Compressor unloading valve	1560	1560	1560	1560	1350	1300	1250	1450	1450	1560
Bleed Air shutoff valve	1350	1350	1350	1350	1100	1150	1100	1250	1250	1250
Heat Exchanger bypass valve	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Temperature sensor & controller	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Water separator/filter assy	8000	8000	8000	5000	5000	5000	8000	5000	5000	5000
Water separator/filter element	0	0	0	0	0	0	0	0	0	0
Relief valve	680	680	680	550	450	500	450	500	500	550
ASM check valve & restrictor assy	185	185	185	185	185	185	185	185	185	185
Fuel tank check valve	925	925	925	925	925	925	925	925	925	925
Controller / control card	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Ducting	26640	8840	23160	6080	10500	3360	7620	7620	1900	7620
Wiring	750	750	750	750	750	750	750	750	750	750
Bleed Orifice & Duct	300	300	300	300	300	300	300	300	300	300
Compressor Wiring	8943	4471	3354	1677	361	361	122	301	0	259
Installation Hardware	14495	6604	6052	3237	2374	2027	1224	2285	1143	1589
Structural Modifications	2000	2000	1000	1000	400	400	200	200	200	200
<b>Other Parts Sub-Total</b>	<b>110853</b>	<b>78105</b>	<b>89755</b>	<b>65053</b>	<b>66345</b>	<b>58958</b>	<b>64876</b>	<b>63316</b>	<b>56153</b>	<b>62627</b>
<b>System Totals</b>	<b>270237</b>	<b>171471</b>	<b>184507</b>	<b>120747</b>	<b>107212</b>	<b>99291</b>	<b>89486</b>	<b>110911</b>	<b>85377</b>	<b>96135</b>
Oxygen sensor	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000

Figure 1.11.1-2. Summary of OBGIS Costs – PSA Systems

## 1.11.1.1 Air Separation Modules

Cost estimates were developed for OBGIS membrane and pressure-swing adsorption air separation equipment.

**Permeable Membrane.** For the membrane-based ASMs, cost, weight, volume, and purity analyses performed by the ASM supplier indicated no sizable benefit to developing new membrane units for the ARAC generic aircraft. Thus membrane costs were developed based on commercially available off-the-shelf membrane units. Common costs were applied for common-sized membrane and PSA ASMs across all OBGIS and OBIGGS concepts, where applicable.

**PSA.** The costs of the PSA separators were estimated with the assumption that the molecular sieve beds and mechanical assembly would not be off-the-shelf, but that there is no technical risk in developing these items. The supplier applied trends from current PSA hardware to derive competitive costs. However, these costs were adjusted as the ASM filter and controller would not be integrated into the ASM assembly for commercial aircraft, in contrast to current PSA systems fielded on some U.S. military aircraft.

## 1.11.1.2 Compressor

Compressor costs were established for the two compressor types, screw and CF. A linear cost model as a function of compressor shaft power, was derived using vendor-estimated costs for 15 kW and 30 kW compressors of both compressor types. From this model, compressor costs were established as a function of compressor type, power required, and number of compressors required. As compressor design requirements were established and iterated for each of the aircraft models, the Task Team applied this metric to derive the optimum compressor configuration and cost.

## 1.11.1.3 Heat Exchanger/Cooling Fan

Heat exchanger costs were established from a vendor-derived cost model to develop costs for compact heat exchangers with fan cooling. Heat exchanger costs included the core, inlet/outlet headers, and connections to the mating tubing. The cost of the cooling fan included the fan and any ducting between the fan and the heat exchanger. Ducting that interfaces with the aircraft structure or plumbing was accounted for separately under other OBGIS system parts. Heat exchanger costs were baselined against commercially available equipment and scaled as a function of heat exchanger flow rate required to provide stable-temperature input airflow to the ASM and the cooling airflow output required by the cooling fan. As heat exchanger design requirements were established and iterated for each of the aircraft models, the Task Team applied this metric to derive the optimum heat exchanger and cooling fan costs.

## 1.11.1.4 Other Components

Original equipment manufacturer (OEM) costs were assumed for the majority of all components other than the ASMs, compressors, and heat exchangers with cooling fans. Cost information for valves, the temperature sensor, and ASM controller are based on production costs plus a spares factor. Exceptions to the OEM pricing include ASM water separator/filter costs, which are based on ROM estimates provided by a filter vendor, and the ASM controller, which was estimated by scaling from the cost for a commercially-available controller used in aircraft subsystems applications. Other costs applied commonly across all OBGIS and OBIGGS concepts include the following:

- Ducting - cost estimated at \$200/lb
- Wiring - cost estimated at \$50/lb
- Installation Hardware - cost estimated at \$50/lb
- Structural Modifications - cost estimated at \$20/lb

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- Ram Ducting - cost estimated at \$200/lb

### **1.11.2 Design & Certification**

Design and certification man-hour estimates were developed by the Working Group to encompass the engineering hours required by an aircraft manufacturer for modifications and additions to fuel system components, interfaces, structure, instruments or displays, wiring, tubing, ducting, avionics software and, if required, relocation of other equipment on each aircraft. Non-recurring design costs for OBGIS components were amortized into the component costs listed in the previous summary cost tables.

The design and certification man-hour estimates were applied by the E&F team as part of the analysis to determine OBGIS cost benefit and are described in the E&F team final report. These estimates address design and certification of OBGIS systems to inert all tanks on a new first of a model aircraft and on derivative model aircraft for all of the generic aircraft. They also address design and certification of OBGIS systems to inert CWT's only on a new first of a model aircraft and on derivative model aircraft, which only applies to the generic large, medium, and small transports, and to the generic regional turbo fan aircraft.

Neither FAA nor JAA will assess additional certification costs for OBGIS. However, non-U.S. governmental authorities may assess additional costs related to the certification of OBGIS systems. For example, JAA indicates that the CAA-UK will charge airlines for all certification costs, including engineering man hours, whereas DGAC France will charge airlines only for the travel costs associated with an OBGIS certification effort. These potential additional costs were not included in the design and certification cost estimates.

### **1.11.3 Operating Costs**

Recurring OBGIS operating costs evaluated by the E&F team encompassed frequency of delays, delay time, OBGIS system weight, performance loss, and additional training required for ground and flight crews. The Task Team developed system weights for use in the E&F cost models. The team also applied a method for determining performance loss due to an on-board inerting system as described in report AFWAL-TR-82-2115, Aircraft Fuel Tank Inerting System, and provided resulting performance loss values to the E&F team. This method evaluates by mission segment the performance loss in lbs-fuel and dollars/flight-hour associated with additional aircraft resource demands (i.e., bleed air, electrical power) and increased weight due to the on-board inerting system. This methodology was applied to determine performance losses associated with the bleed air consumption and electrical power demands required by OBGIS. Performance loss associated with system weight is the predominant element in performance loss, which was determined by the E&F team using the methodology applied in the previous ARAC FTHWG effort. All other recurring OBGIS operating costs were developed by the E&F and Airplane Operations and Maintenance (O&M) teams.

### **1.11.4 Maintenance Costs**

Recurring OBGIS operating costs evaluated by the ARAC E&F team encompassed mean time between unscheduled repair (MTBUR) and hours for maintenance checks, inspections, removals, unscheduled maintenance, maintenance training, and confined space entry labor. The On-Board Design Task Team developed estimates for MTBMA and MTBF for each system component. These values were provided to the O&M team who then compared them to values of comparable components used currently on commercial aircraft. Those comparable values were then used to develop average MTBUR values for use by the E&F team in estimating recurring maintenance costs. For components currently not in service on commercial aircraft, such as the ASMs, the O&M team evaluated the on-board team's MTBF and MTBMA values and identified, based on their commercial aviation expertise, values to apply as MTBUR. Typically, these values were similar to the on-board team's MTBMA values. All of the other

mentioned recurring OBGIS maintenance cost elements were provided to the E&F team by the O&M team.

### 1.11.5 Installation Costs

Installation cost associated with OBGIS systems are described in the E&F team final report. No installation costs were developed by the On-Board Design Task Team.

### 1.12 SAFETY

The inclusion of an OBGIS on an aircraft introduces a number of new or increased safety concerns. These concerns can be divided into normal operation, system leaks, component failure, and catastrophic failure. It should be noted that since the system only operates on the ground, when the aircraft is at the gate, that these hazards, except as noted, only exist during that time and not during taxi or flight of the aircraft.

#### 1.12.1 Normal Operation

The hazards associated with the normal operation of an OBGIS are the discharge of oxygen enriched waste gas, the venting of NEA out of the fuel vent, the possibility of fuel tank over pressure during refuel over-fill, and those associated with electrical wiring and high temperature components.

**Oxygen-Rich Waste Gas.** Oxygen-rich waste gas could be a fire hazard and should be vented in an area with no potential ignition sources. If possible it should be vented in an area and in a manner where it will be quickly diluted.

**NEA Around Fuel Vent.** NEA vented from the fuel tank vent could create breathing problems if inhaled. Testing during the inerting of a 737 aircraft indicated that the exiting NEA was rapidly diluted and posed little hazards. A placard warning near the vent should be sufficient.

**Increased Tank Overpressure During Refuel Failure.** The operation of the OBGIS during a fueling over fill may exacerbate the issue of tank overpressure. The system should be designed to limit inlet pressure to the tank and quickly relieve pressure. This is accomplished in the outline system by the inclusion of an NEA relief valve down stream of the ASM.

**Electrical Wiring.** Electrical requirements of the system add to the amount of electrical wiring in the aircraft and the potential for electrical related smoke or fire in the aircraft. These safety concerns can be minimized through normal design practice.

**High Component Temperatures.** The operating temperature of some components may exceed 400 degrees F and should be placarded as such.

#### 1.12.2 System Leaks

Various system leaks could occur and create safety concerns. Leaks could include hot air, NEA, OEA and fuel vapor.

**Compressor Discharge Air Leaks.** Compressed air between compressor and heat exchanger could be in the range of 400 degrees F. It should be treated the same as bleed air ducting, and may require overheat detection.

**NEA Leaks.** The NEA line from the ASM to fuel tank could produce an environment, in a confined space, with a reduced oxygen level. The line should, wherever possible, be run in an area of high ventilation. Where it does run in a confined space with low ventilation the line should feature double containment.

**Oxygen-Rich Waste Gas Leaks.** The O<sub>2</sub> waste line from the air separation module could produce an environment, in a confined space, with an elevated oxygen level. The line should, wherever possible, be run in an area of high ventilation and the absence of ignition sources. Where it does run in a confined

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space with low ventilation or in an area with any possible ignition sources, the line should feature double containment.

**Fuel Backflow Into ASM.** Fuel vapor from the fuel tank can backflow through the NEA line into the ASM and compressor. Check valves should be installed in the system to prevent this from occurring. This hazard could occur at any time since it is not dependent on system operation.

### **1.12.3 Component Failure**

It is possible that a component in the system could fail and create a hazardous condition while the system continues to operate.

**Compressor Overheat.** A compressor overheat could cause a potential fire hazard. Thermal cutout protection should be incorporated.

**Heat Exchanger Overheat.** NEA being too hot could cause a safety problem by possibly damaging the system and pumping high temperature gas into the fuel tank. Thermal cutout protection would provide mitigation from this hazard.

**Rotating Equipment Sparks.** Sparks or flames could occur in the system lines and protection should be provided by flame arrestors and/or spark arrestors in-line.

### **1.12.4 Catastrophic Failure**

Catastrophic failure of the system could occur with the failure of the high speed rotating parts of the compressor or a pressure vessel burst.

**Uncontained Rotating Equipment Failure.** Uncontained rotating equipment failure could cause a hazard. The system design should provide containment for such failures.

**Pressure Vessel Burst.** Although pressure in the system is only 30 psig, a pressure vessel burst could occur and should be designed for.

## **1.13 INSTALLATION**

The OBGIS installation will require extensive airplane interfaces and can be installed in unpressurized or pressurized areas (or both), depending on the equipment size and the space available on the particular airplane model.

Specific aircraft installation locations or impacts cannot be provided at this time. The scope of this study has determined approximate component and system weight and volume based on the assumptions detailed in the Weight and Volume sections. When a system is developed in the future for a particular airplane model, it should be done with possible locations and size constraints provided for that airplane model. Since that level of detail was not available for this study, the installation was investigated on a generic level. Therefore, the installation areas and items in the following sub-sections are intended to provide a guideline for future development of an OBGIS. The limited analysis of the available space on actual aircraft indicated that the installation would be most difficult on the smaller aircraft models. Installation on a small transport may require that the inerting equipment be distributed into multiple locations or even take up cargo space.

There are four different implementation scenarios that will have different installation impacts:

**New Designs.** For aircraft not yet on the drawing board, the system installation can be optimally integrated simultaneously with the design of the other aircraft systems. This scenario is the simplest of the four.

**Frozen Design, Not Yet in Production.** For aircraft already designed, even though not yet in production, the installation challenges are greater. Other equipment may have to be relocated or the

OBGIS components may have to be installed in sub-optimal locations. Bleed air, hydraulic, and electrical sources may have to be re-evaluated to ensure they can supply the OBGIS requirements.

**In-Production.** For aircraft that are still being produced, it is possible that production changes could be made on aircraft not yet delivered to install the entire OBGIS or a portion of this system to simplify future retrofit. Previously delivered aircraft would have to be retrofitted. The retrofit installations will likely be complicated by space limitations from other systems and further complicated by customer-specific modifications.

**Out-of-Production.** All aircraft that are no longer in production would have to be retrofitted. The same complications due to other systems and customer modifications would apply.

Structural modifications will be required for installing equipment onto previously delivered airplanes. Attachment hardware must be added to support the equipment installation, and be designed to support any possible airplane load situation. Any wiring routed to equipment located in the unpressurized areas will be required to be shielded.

The following characteristics are desirable for the installation of the OBGIS components. If such locations are not available on a given aircraft model, the installation will be more complicated (though not necessarily infeasible).

**Unpressurized.** The ASM OEA outlet exhausts to ambient pressure. Further, if the air separation equipment is located outside of the pressurized area, it would not need to be shrouded to keep leaking NEA out of the cabin. Unpressurized locations also reduce the complexity of the ram ducting, the distribution tubing, and the number of penetrations through the pressure shell.

**Ventilated.** A ventilated compartment reduces potential hazards from NEA leakage because it doesn't create the hazard of a confined space to maintenance and other personnel.

**Close to Fuel Tanks.** If the OBGIS components can be located close to the fuel tanks, less ducting is required.

### **1.13.1 Possible Equipment Installation in Unpressurized Areas**

There are several unpressurized areas on typical large, medium, and small transport aircraft where OBGIS equipment might be installed. These areas include the air conditioning pack bay, wing root, wheel well, belly fairing, and behind the aft bulkhead.

**Air Conditioning Pack Bay.** On some airplanes, it will be possible to locate the OBGIS equipment in the A/C Pack Bay. This provides convenient access to a bleed source (except on airplanes where the engines are not wing mounted) and uncomplicated access to ram air. Any parts and ducting located in this area will be required to have the appropriate flammable fluid leakage zone protection. None of the distribution system will be required to have double walled tubing, since all of the equipment is in the unpressurized area.

**Wing Root.** On some airplanes, it will be possible to locate the OBGIS equipment in the wing root. This provides convenient access to a bleed source (except on airplanes where the engines are not wing mounted). Access to ram air will be more difficult, as it will have to be routed through more structure to reach this area. Any parts and ducting located in this area may be required to have the appropriate flammable fluid leakage zone protection. None of the distribution system will be required to have double walled tubing, since all of the equipment is in the unpressurized area.

**Wheel Well.** On some airplanes, it will be possible to locate OBGIS equipment in the wheel well, although in this installation it would not be likely to be possible to fit all of the equipment together in one location. In this location access to a bleed source will be more difficult, more so on airplanes where the engines are not wing mounted. Access to cooling air will be more difficult, as it will have to be routed through more structure to reach this area. Any parts and ducting located in this area may be required to

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have the appropriate flammable fluid leakage zone protection. None of the distribution system will be required to have double walled tubing, since all of the equipment is in the unpressurized area. Photographs of possible wheel well locations on a typical large, medium, and small transport aircraft are shown in Figures 1.13.1-1 through 1.13.1-6.

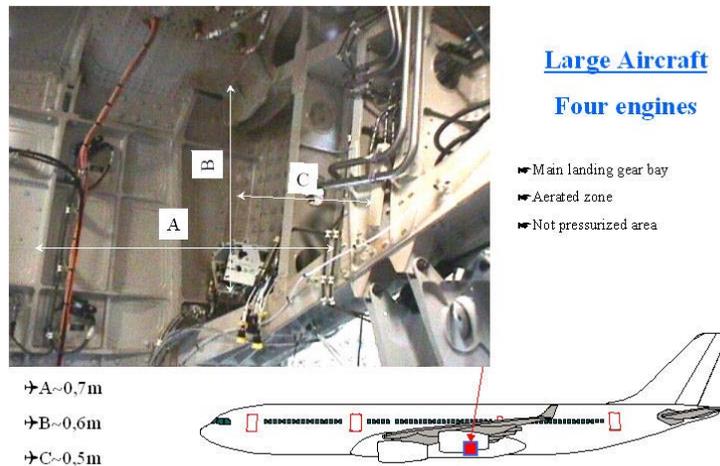


Figure 1.13.1-1. Potential Installation Area in Main Landing Gear Bay on a Typical Large Transport Aircraft

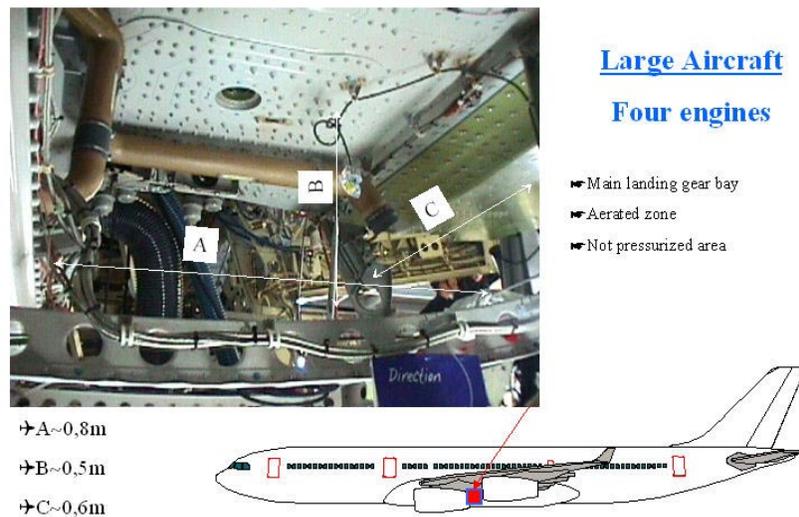


Figure 1.13.1-2. Potential Installation Area in Main Landing Gear Bay on a Typical Large Transport Aircraft (Additional Location)

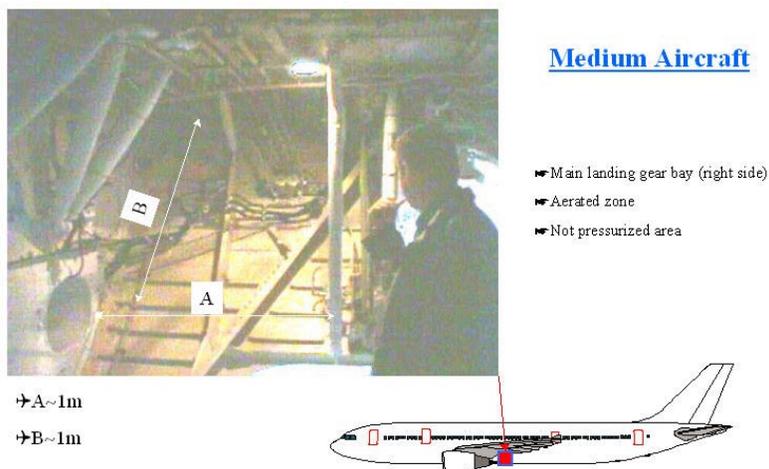


Figure 1.13.1-3. Potential Installation Area in Right Wheel Well on a Typical Medium Transport Aircraft

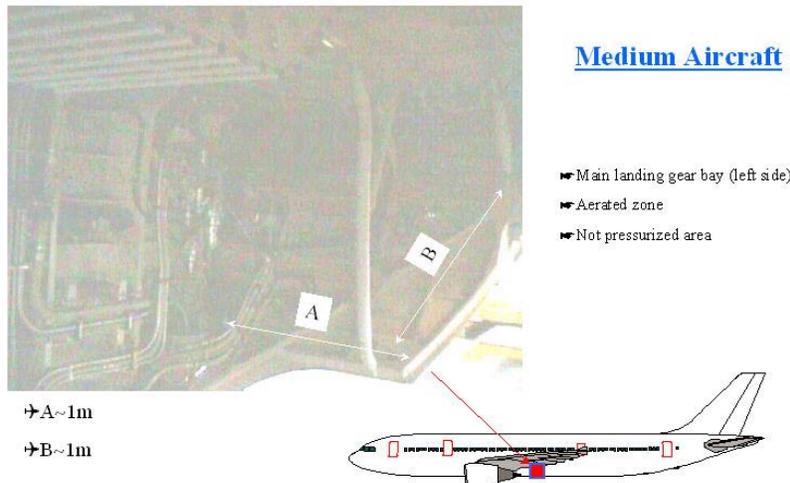


Figure 1.13.1-4. Potential Installation Area in Left Wheel Well on a Typical Medium Transport Aircraft

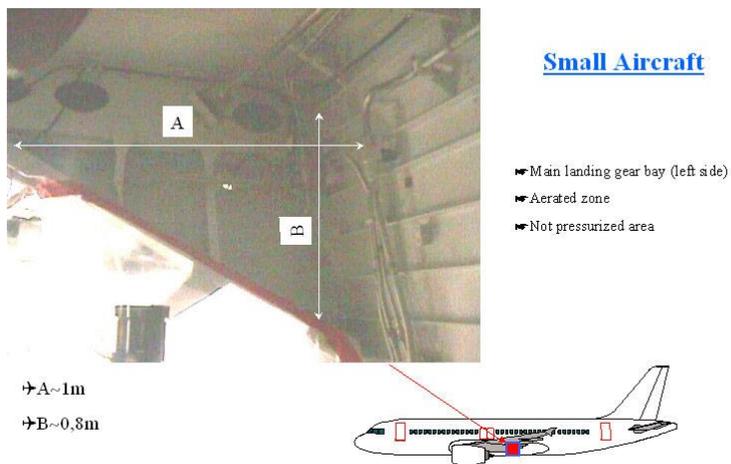


Figure 1.13.1-5. Potential Installation Area in Left Wheel Well on a Typical Small Transport Aircraft

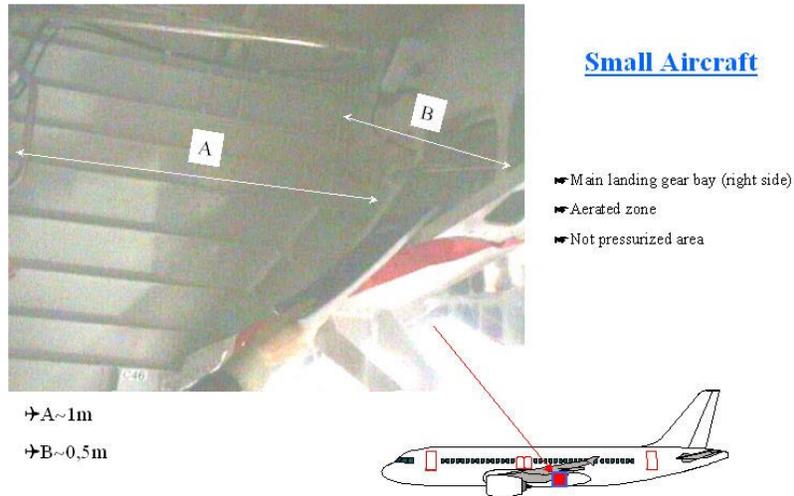


Figure 1.13.1-6. Potential Installation Area in Right Wheel Well on a Typical Small Transport Aircraft

**Belly Fairing.** Some aircraft have a belly fairing in which OBGIS equipment could be located. This location is unpressurized with good access to bleed air, cooling air, and a convenient overboard waste connection. It is a flammable fluid leakage zone and the equipment would have to have the appropriate protection. Photographs of possible belly fairing locations on a typical large transport aircraft are shown in Figures 1.13.1-7 through 1.13.1-9.

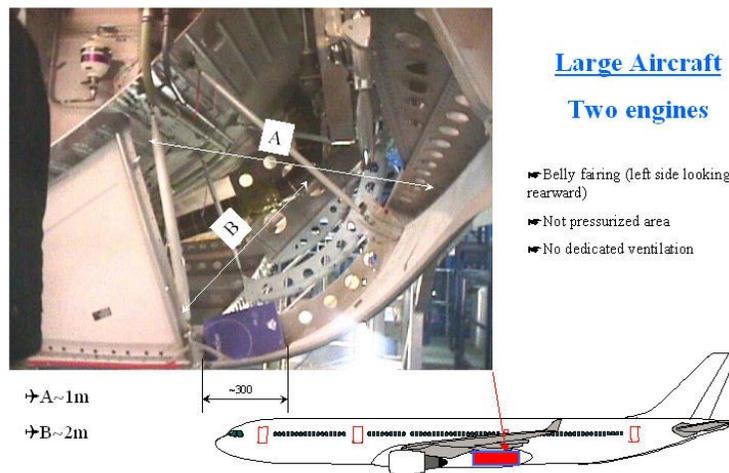


Figure 1.13.1-7. Potential Installation Area in Belly Fairing on a Typical Large Transport Aircraft (Left Side, Looking Aft)

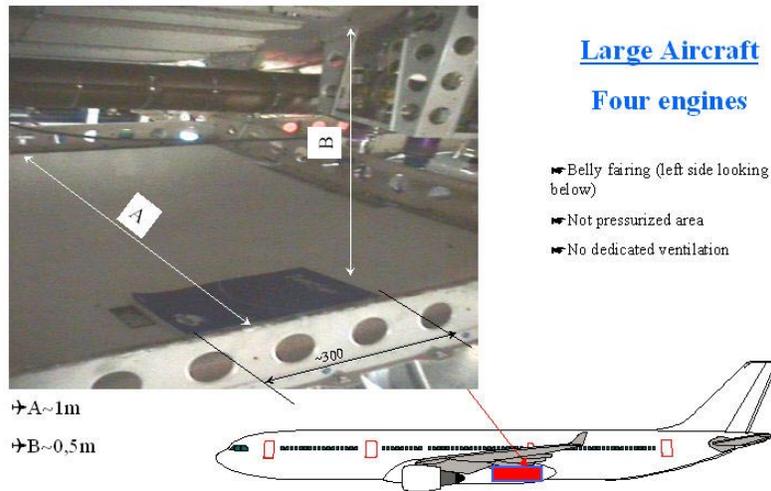


Figure 1.13.1-8. Potential Installation Area in Belly Fairing on a Typical Large Transport Aircraft (Left Side, Looking Down)

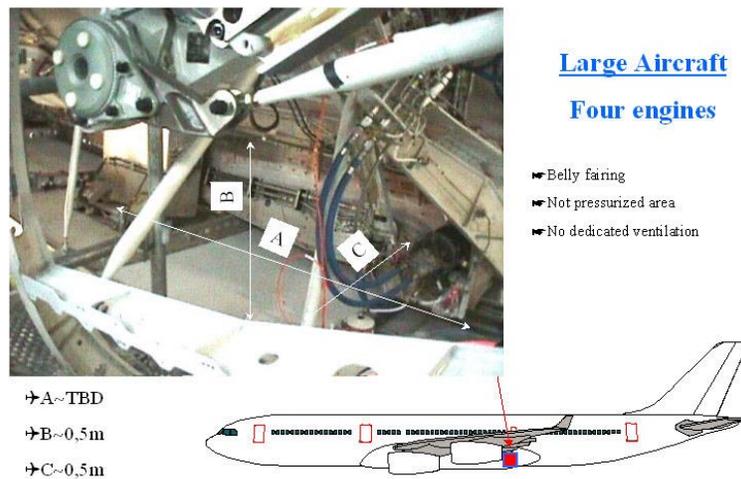
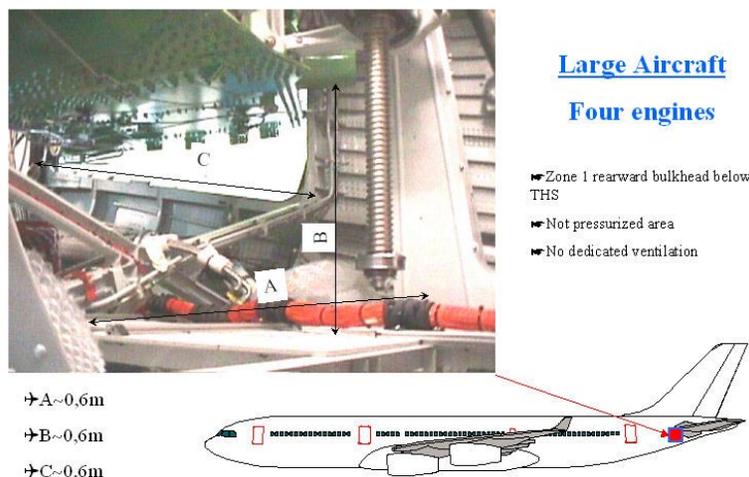
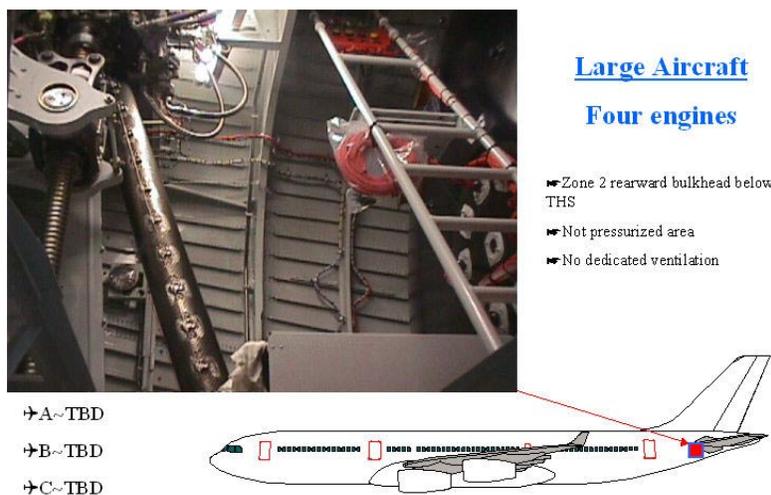


Figure 1.13.1-9. Potential Installation Area in Belly Fairing on a Typical Large Transport Aircraft (Additional Location)

**Behind Aft Bulkhead.** Some aircraft have an unpressurized area near the tail behind the aft bulkhead. This area would not have flammable fluid leakage concerns, but the bleed air connection could be difficult. Further, the distribution lines to the fuel tanks would be long and would have to be double-walled since they would pass through the pressurized area to reach the fuel tanks. In addition, the weight of the system may adversely affect the aircraft center of gravity. Photographs of possible locations behind the aft bulkhead on a typical large transport aircraft are shown in Figures 1.13.1-10 and 1.13.1-11.



*Figure 1.13.1-10. Potential Installation Area Behind Aft Bulkhead on a Typical Large Transport Aircraft*



*Figure 1.13.1-11. Potential Installation Area Behind Aft Bulkhead on a Typical Large Transport Aircraft (Additional Location)*

**1.13.2 Possible Equipment Installation in Pressurized Areas**

If the OBGIS equipment cannot be installed in an unpressurized area of the airplane, there are several potential pressurized areas on typical large, medium, and small transport aircraft where OBGIS equipment might be installed. These include the areas forward of the aft bulkhead and the cargo bay.

**Forward of Aft Bulkhead.** There is space forward of the aft bulkhead on some aircraft. The area is pressurized and would require shrouding and/or ventilation provisions. Cooling air and overboard connections would require fuselage penetrations. The bleed air connection would also require a long run of insulated ducting. The distribution tubing would be long and would have to be double-wall in case of leakage. The location is not in a flammable fluid leakage zone. Photographs of possible locations forward of the aft bulkhead on typical large, medium and small transport aircraft are shown in Figures 1.13.2-1 through 1.13.2-3.

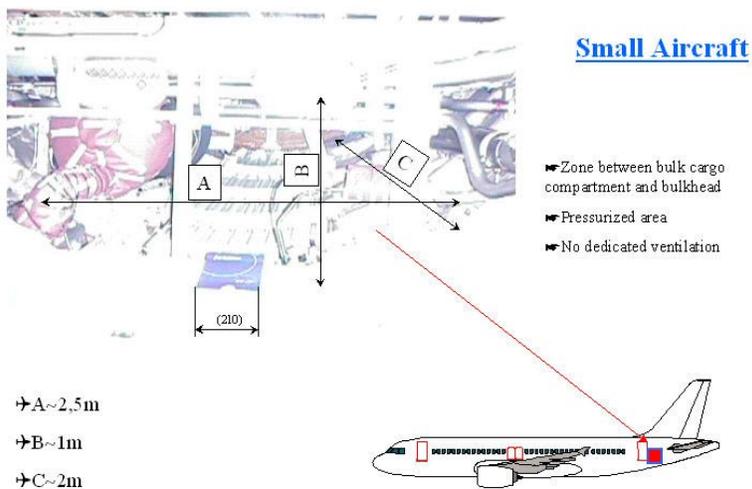


Figure 1.13.2-1. Potential Installation Area Forward of Aft Bulkhead on a Typical Small Transport Aircraft

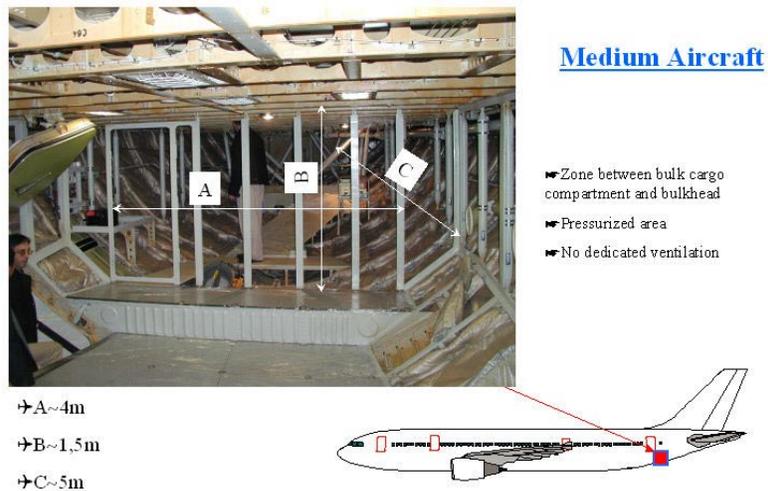


Figure 1.13.2-2. Potential Installation Area Forward of Aft Bulkhead on a Typical Medium Transport Aircraft

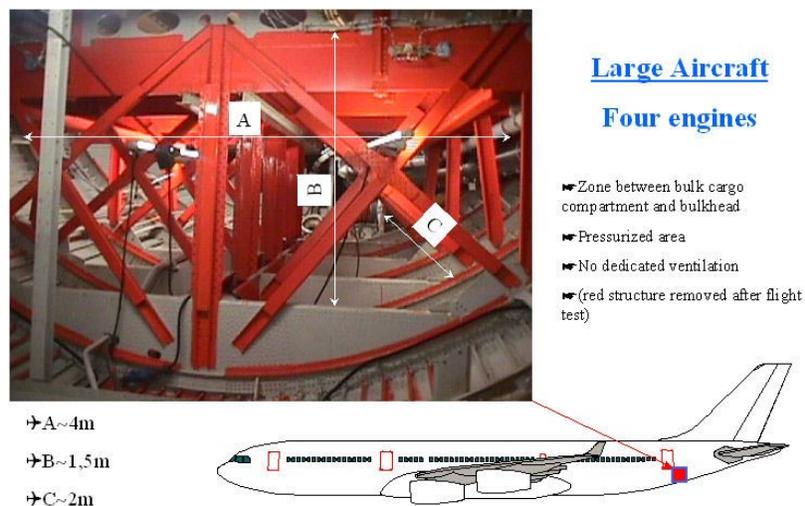


Figure 1.13.2-3. Potential Installation Area Forward of Aft Bulkhead on a Typical Large Transport Aircraft

**Cargo Bay.** Installing the equipment in the cargo bay allows the equipment to be packaged together to reduce the space utilized. However, installing the equipment in the cargo bay will reduce the available cargo volume, resulting in a cargo payload penalty. There are also other difficulties: The bleed air inlet must now enter into the pressurized area, and be insulated anywhere inside the pressurized area. An enclosure must be added around all of the OBGIS equipment. This enclosure may need to be insulated to prevent heat from entering the cargo bay, and must be resistant to possible damage from cargo handling. The cooling air must now enter and exit the pressurized area, which will make this a heavier installation. The waste gas must be routed outside of the pressurized area, and possibly be shielded to prevent leaks into the pressurized area. The distribution system must be shielded to prevent leaks into the pressurized area. In addition, it may a requirement to certify the cargo fire protection with the OBGIS equipment installed.

### 1.13.3 Aircraft Interfaces

**Distribution System.** A distribution system must be installed to deliver the NEA to the desired fuel tanks. Applicable mounting hardware and possible structural modifications must be accounted for. The distribution system must be sized to minimize the pressure drop by using the maximum diameter compatible with the installation constraints. Pipes feeding the tanks and installed in, or passing through, pressurized areas, must be shrouded in case of NEA leakage. Drains should be installed at the lowest point of the feeding pipes to avoid water accumulation.

**Controller/Control Card.** A controller/control card must be designed and added to control the OBGIS equipment. This controller/control card may be mounted near the equipment, in an equipment rack, or in a card file, depending on the type of controller/control card utilized.

**Wiring.** Wiring must be added between the controller/control card and all components controlled by the controller/control card. Any wiring installed in an unpressurized area must be protected against more extreme environmental conditions. In addition, extra precaution must be utilized when adding wiring in a flammable leakage zone. Depending on location, wiring may need to be segregated for protection against engine rotor or tire burst.

**Indications.** The necessary indications need to be added to the flight crew interface for the applicable airplane to allow the maintenance and flight crews to determine the OBGIS health. This information will be used to determine when the airplane can be dispatched, when corrective action must be taken by the

flight crew (if applicable), and when maintenance action must be performed. The cockpit wiring will be affected.

### 1.13.4 Other Installation Considerations

The following other considerations must be evaluated in selecting potential OBGIS installation locations:

**Uncontained Engine Rotor or Tire Burst.** If possible, the OBGIS components should be installed outside of the engine rotor burst or tire burst zones.

**Flammable Fluid Leakage Zones.** Any equipment located within a flammable fluid leakage zone will require special precautions.

**Temperature Environment.** The compressor and heat exchanger operate at high temperatures and will have to be thermally insulated to protect nearby structure and equipment. Similarly, the OBGIS equipment will have to be designed to withstand the temperature environment of the compartment in which it is located.

**Noise.** The compressor and fan installations will have to minimize the noise transmitted to the cabin or to the areas where ground personnel frequently work.

### 1.14 PROS AND CONS OF SYSTEM DESIGN CONCEPT

**System Effectiveness and Limitations.** The design concept of the onboard ground inerting system is to have a self contained system on the aircraft that will operate only when the aircraft is on the ground and at the gate. The system will provide an inert atmosphere in the “protected” tanks at some time during the gate stay of the aircraft. The system is designed to inert the “protected” tanks in the shortest turn time for the type of aircraft it is installed on. Therefore, on short turn times the aircraft “protected” tanks may remain non-inert for a large portion of the gate time. However, the “protected” tanks will be inerted at any time in excess of the shortest turn time.

At all times the protected tanks are inerted, with an O<sub>2</sub> level less than 10% at time of push back from the gate. Under most conditions, the protected tanks will stay inert through taxi, climb, and into cruise. Protected tanks with very little or no fuel will stay inerted, for most flights, until the descent. The more fuel in the tank, the earlier the tank will become non-inert. A full tank that is used during taxi and/or climb may become non-inert during those phases of flight, albeit the tank ullage may not be flammable. Although the system does not provide for inerting of the tanks 100% of the time, it does provide inerting when the tanks are most likely to be flammable.

**System Safety.** The installation of the system adds additional hazards to the aircraft, which must be mitigated. The hazards include electrical wiring, high-speed rotation machinery, ducting carrying NEA and OEA and additional penetrations into the fuel tank. The design of the system should be such to minimize or eliminate the hazards. The safety section contains a more detailed analysis of all the hazards and means of mitigation. It should be noted that since the system only operates on the ground at the gate, almost all of the hazards are only at that time, and not during taxi or flight.

**System Cost.** There is a cost associated with the design, installation, certification, operation and maintenance of an OBGIS. Those costs can be broken down into: 1) cost of the system, 2) cost of system operation, and 3) maintenance cost of the system. The cost of the system includes design and construction as well as certification and installation. The system operation costs include those associated with the carriage of additional weight and possible shift in center of gravity of the aircraft, possible increase in drag, and the additional use of electrical power. The maintenance cost includes maintenance of the OBGIS and to other systems, such as electrical generators, affected by it. A more detailed breakdown of costs can be found in the Cost Section.

**System Environmental Impact.** The main impact to the environment from an OBGIS is the possible increase in fuel vapors being forced overboard as the nitrogen is injected into the fuel tank. The amount of

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fuel vapor that is vented depends on the fuel air mixture and ullage volume, at the time of inerting, as well as other variables. Testing has shown that present designed cross-vented fuel tanks, under certain wind conditions, can vent fuel vapors into the atmosphere. A redesign for the OBGIS would minimize that venting, thus helping to offset some of the fuel vapor lost during the inerting process.

The installation of an OBGIS would reduce the number of fuel tank explosions, thus reducing the amount of spilled fuel both on the ground and in the atmosphere.

In addition to the fuel vapor there is a potential issue with the addition of noise from the compressor/fan.

The use of dry NEA may reduce corrosion and condensation in the protected tanks depending on the conditions at the airports where the airplane is operated.

### **1.15 MAJOR ISSUES / MITIGATION**

The OBGIS system has been defined by the Team based on the operating parameters defined during the study period or by others, such as the 1998 Fuel Tank Harmonization Working Group (FTHWG) ARAC. The parameters which had most of the effect on system sizing were the time available at the gate to operate the system, and the size of the tanks to be inerted. The time available to operate the system was determined by the shortest expected time available. This was a major factor particularly for the small and medium transport aircraft, where the minimum gate time was short, thereby dictating a large, high-capacity system. An alternative to this approach would be to use a gate time which relates to the average or fleet majority gate time, thereby significantly reducing system size, cost and weight. In this instance, airlines which require short turn-around times could use up-rated systems (larger compressors / ASMs), and the majority of the fleet would not pay the penalty associated with a short turn around time which they do not require. The ultimate effect of this consideration has not been evaluated by this study.

Several existing aircraft were analyzed to derive data for the conclusions of this study. However not all existing aircraft could be evaluated, due to time constraints. Issues such as available space and details of electrical equipment power ratings, vary significantly from aircraft to aircraft. System feasibility, although a major factor in this study cannot and does not consider all aircraft applications. Space may not be available to accommodate OBGIS in all aircraft. One possibility is to install the OBGIS system in the baggage space but there will be a cost impact to the operators due to lost revenue. This cost was not evaluated during this study.

Technology available to the Team at the time of the conduct of the study dictated feasibility to a certain extent, and detail features to a great extent. In the time required to enforce the requirements of the rulemaking that will be the ultimate result of this report, other, more advanced technologies may be available. As the Team was unable to predict such developments, the rulemaking recommendation was thus derived from currently available technology, with its associated limitations.

The Team approached the study with the intention of defining the feasibility of Onboard Ground operating systems, and their relative performance compared to other possible solutions. Detail design for all configurations of existing aircraft could not be evaluated in the available time. Such aircraft-specific designs were not attempted; it was concluded that detail design should be conducted when rulemaking compliance is defined. Details of these designs may at that time, conclude that some parameters do not appear feasible, or may result in different weight, cost or size. The Team concludes, however, that ultimately no parameters will be infeasible, albeit that other items may be affected.

Not all-possible permutations of tank size, aircraft type and turn around times (among other parameters) were evaluated in the study. The Team has, however, attempted to provide enough empirical data and predictive analysis that the reader may extrapolate the information presented herein to other specific application conditions and sizes.

A major objective for the study was to produce predictions of flammability exposure for the system. This was based on the FAA-produced predictive analysis software, with its inherent assumptions. Limited

testing has concluded that the assumptions are sound, and the predictive analysis is of sufficient quality for these comparative studies. However, not all operating conditions which have been analytically simulated as part of this study have been verified by experiment, and may therefore ultimately result in divergence from the actual ultimate performance.

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## 2.0 HYBRID OBGIS

The hybrid On-Board Ground Inerting System (OBGIS) is one of four main system categories studied by the 2000 ARAC FTIHWG Onboard Airplane Design Task Team. The term ‘hybrid’, as used here, refers to a potentially smaller system that leverages additional ground time available to operate the system. The Onboard team studied the system size for a variety of “modeled” aircraft center wing and auxiliary fuel tanks. In addition, the Team performed additional analysis, in excess of the Tasking Statement’s requirements, by determining the system size for all fuel tanks. The team also defined the physical size and weight of the multitude of components needed to support the hybrid OBGIS. Finally, power and air consumption needs were defined.

### 2.1 REQUIREMENTS

There are several main requirements for the hybrid OBGIS concept that were considered during the Team’s system design efforts. These are identical to those of the baseline OBGIS system and are discussed under requirements in Section 1 of this report.

All applicable fuel tanks were to have a 10% oxygen content in the tank ullages before the aircraft is pushed back from the gate, using nitrogen generating equipment installed on the airframe. Also, the system does not require redundancy of components.

### 2.2 DATA SUPPLIED FROM OTHER SOURCES

Data was taken from various sources so that the Team could define the hybrid OBGIS concept. This included aircraft fuel tank sizes, mission profiles, and aircraft turn times.

#### 2.2.1 Aircraft Turn Times and System Operational Times

As with the baseline OBGIS system, the aircraft pre-flight times were derived from the July 1998 ARAC FTIHWG as summarized in Figure 2.2.1-1 below:

Generic Aircraft	Pre-flight Time (Minutes)
Turbofan	20
Turboprop	20
Business Jet	45
Small	45
Medium	60
Large	90

Figure 2.2.1-1. FTIHWG Aircraft Pre-Flight Times

To ensure the turn times being used were representative of in-service aircraft, the airline survey described in Section 1 of this report was conducted for several major airlines. The FTIHWG made the decision to modify the aircraft turn times to the values seen in Figure 2.2.1-2 below. These values were used in the sizing of the components for the system, being representative of the in-service fleet.

Generic Aircraft	Turn Time (Minutes)
Turbofan	15
Turboprop	15
Business Jet	60
Small	20
Medium	45
Large	60

Figure 2.2.1-2. FTIHWG Aircraft Turn Times

For the hybrid OBG system, the time available for system operation after touchdown, during the taxi-in period may be added to this, to define the total system operational time available for the inerting process. Using in-service available data, the FTIHWG determined that 5 minutes should be added to this taxi-in time, to derive the total inerting time listed in Figure 2.2.1-3.

Generic Aircraft	Inerting Time (Minutes)
Turbofan	20
Turboprop	20
Business Jet	65
Small	25
Medium	50
Large	65

*Figure 2.2.1-3. Hybrid OBG Inerting Times*

**2.2.2 Generic Aircraft Types**

The FTIHWG made the decision to use the same generic aircraft data and mission scenarios that were used in the July 1998 ARAC FTHWG report. As with the baseline OBG system, these generic airplane definitions and missions were used in assessing the operational parameters. Discussion of the data is included in the ‘Generic Aircraft Types’ part of Section 1 of this report. As with the baseline OBG system, the worst-case flight conditions were the shortest-ranged flights.

**2.2.3 Generic Aircraft Fuel Tank Volumes**

For all system sizing the 1998 ARAC generic aircraft fuel tank sizes listed in Figure 2.2.3-1 were used.

Generic Aircraft	CWT Volume (Gal.)	CWT + Wing Tank Volume (Gal.)	CWT + Wing + Aux Tank Volume (Gal.)
Turbofan	816	3,264	N/A
Turboprop	N/A	1,428	N/A
Business Jet	N/A	6,273	N/A
Small	3,060	5,100	7,600
Medium	10,200	24,480	27,480
Large	25,500	55,080	58,080

*Figure 2.2.3-1. Generic Aircraft Fuel Tank Volumes*

**2.3 ASSUMPTIONS**

The assumptions for the hybrid OBGIS are identical to those described under OBGIS assumptions.

The initial oxygen concentration was assumed to be 20.9%. The team assumed that hydraulic power on the aircraft to operate OBGIS equipment was not available while the aircraft was on the ground. The team assumed for the design that sufficient ground power could be made available to operate a hybrid OBG system. The team assumed that sufficient power could be made available to operate a hybrid OBG system from on-board sources during taxi-in. This would allow the system to operate on the ground with either the APU or aircraft engines operating. This source of power would be used when either the aircraft is taxiing or when gate power is not available.

**2.4 CONCEPT DEVELOPMENT**

The hybrid OBG system was developed to optimize the concept of system operation on the ground only, using on-board equipment. The baseline OBG system assumed that the only available time for system operation was while the aircraft was at the gate. As the time at the gate available for system operation was a major system sizing parameter, the Team decided that additional ground operation time would provide the opportunity to reduce the size, cost and weight of the system. The OBG hybrid accomplishes

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this by operating the system from the time of touchdown, through taxi-in (using the engine bleed air pressure source to operate the system), gate hook-up, and up to the time of pushback. This provides the additional time of touchdown to hook-up, when compared to the baseline OBG system. Otherwise, the system architecture and operating parameters are identical to the baseline OBG system.

The elements of system development and configuration considerations are therefore identical to the baseline OBG system. For details of this, please refer to the ‘Concept Development’ paragraphs of Section 1 of this report. This includes the basic requirement to provide inerting of the fuel tank ullage spaces to an oxygen content of 10% at pushback, for the six standard aircraft models. The baseline OBG system uses available power at the gate. Membrane and PSA solutions were considered for the ASM, supplied by air at a pressure ratio of three-to-one (3:1) from the available sources. Other system equipment is required to filter, cool and distribute the air to the fuel tanks.

### **2.4.1 Concept Development Process**

The hybrid OBG system was developed directly from the baseline OBG system, being of identical architecture and operation; the difference being that the hybrid system operates for a longer period of time on the ground prior to flight.

The concept development process was therefore identical to that of the baseline OBG system, as detailed in the ‘Concept Development Process’ part of Section 1 of this report. This details consideration of nine concepts, including aspects of the air pressure source and ASM configurations. Many of these considerations were eventually incorporated into the basic system architecture to provide the benefits of optional air pressure sources and optimized ASM architecture. It was assumed that for the hybrid OBG system, the operation after touchdown and prior to gate hook-up would be achieved by the use of engine bleed air and that sufficient air is available. This is a reasonable assumption, as the demand on the bleed air system is normally low during the time that the aircraft is taxiing to the gate. In the event that this is not the case, the compressor could be operated to supply the required airflow. The assumption that electrical power is available during this time is also reasonable, as electrical load is also typically low.

### **2.5 FINAL CONCEPT DESCRIPTION**

The hybrid OBG system architecture is identical to that of the baseline OBG system, and is depicted in Figure 2.5-1. The components identified within each of the hybrid OBG subsystems are summarized in Figure 2.5-2.

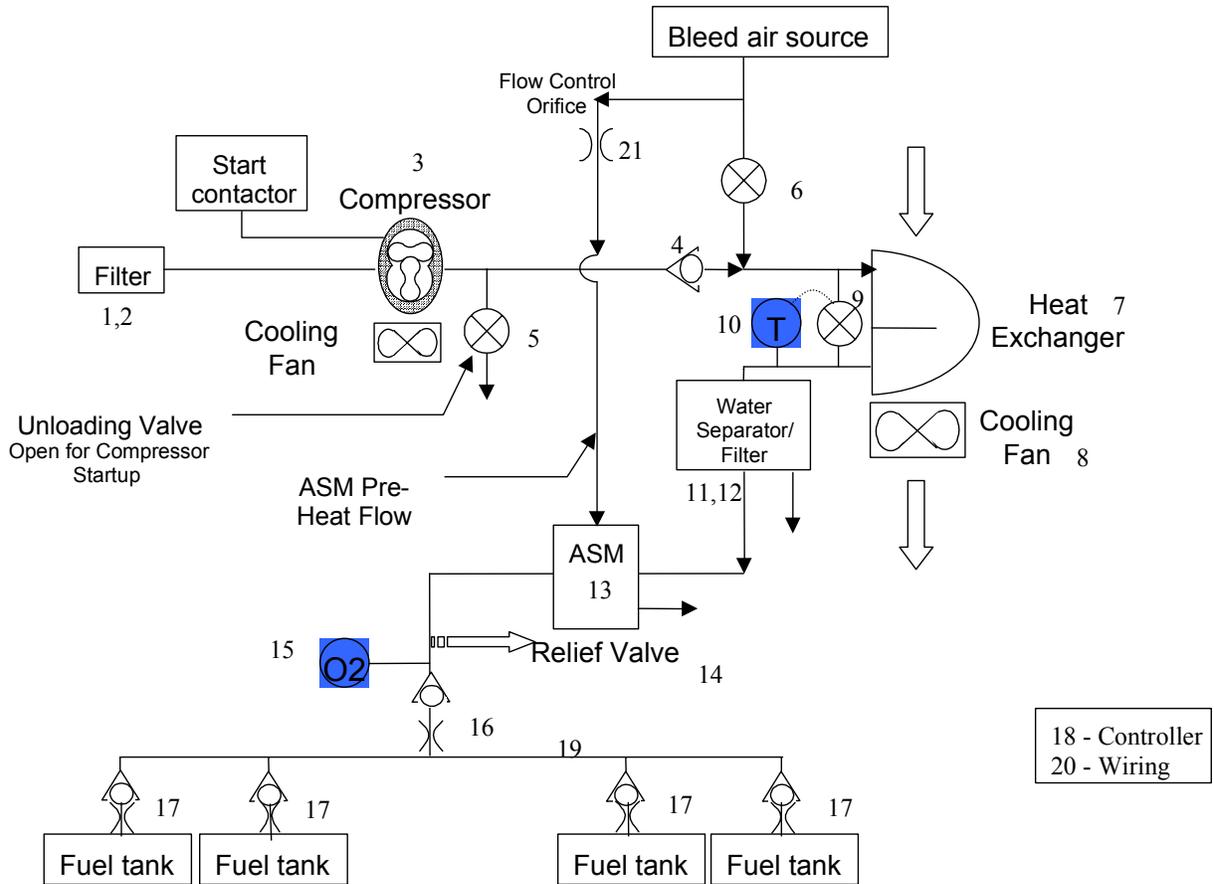


Figure 2.5-1. Hybrid OBGI System Schematic Diagram

Component	Item Number	Component	Item Number
Compressor inlet air filter assembly	1	Water separator/filter assembly.	11
Compressor inlet air filter element	2	Water separator/filter element	12
Compressor, cooling & start system	3	Air separation module	13
Compressor discharge check valve	4	Relief valve	14
Compressor unloading valve	5	Oxygen sensor	15
Bleed Air shutoff valve	6	ASM check valve & restrictor assembly	16
Heat exchanger	7	Fuel tank check valve	17
Cooling fan & ram ducts assembly	8	Controller / control card	18
Heat Exchanger bypass valve	9	Ducting	19
Temperature sensor & controller	10	Wiring	20
		Bleed Orifice & duct	21

Figure 2.5-2. Hybrid OBGI System Component List

### 2.5.1 Operating Concept

As with the baseline OBGI system, the system is arranged to replace the air in the tank ullage with NEA, thereby reducing its flammability. The main device used to accomplish this is the ASM which separates ambient air into nitrogen, oxygen, and the other constituents of air .. The system requires a compressor and a heat exchanger, to compress and subsequently cool the air, which is then distributed to the fuel tanks via a distribution manifold.

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An electrically powered compressor pressurises ambient air for the ASM. The air is filtered prior to entry into the compressor inlet, to prolong compressor life.. For some aircraft types / sizes, the power requirement for the compressor is relatively high, which dictates the use of a start contactor and pressure unloading valve. These allow the compressor to start, while avoiding high power surges during wind-up. The unloading valve helps accomplish this by reducing the compressor backpressure, and consequently reducing the start-up power load. The compressor outlet requires a check valve, to prevent reverse flow through the compressor and filter.

An alternate source of pressurized air for the system is engine bleed air. This is introduced into the system downstream of the compressor, and is controlled by a shut-off valve, which also acts to prevent reverse flow to the engine bleed system when in the closed position.

In its pressurized form, from either the compressor or the engine bleed air system, the air will be at an elevated temperature. Prior to flowing to the ASM, it must therefore be cooled to ensure that it is sufficiently cool to prevent damage of the ASM, and to prevent hot gas flowing to the fuel tanks. Cooling of the air is accomplished by the use of an air-to-air heat exchanger. In the event that the air is already sufficiently cool as may be associated with cold climates, the heat exchanger may be by-passed through the temperature control valve. The temperature control valve will modulate the bypass flow to optimize the temperature of the airflow.

As the air exits the heat exchanger, it is again filtered to a finer level than the primary filter, and ensures that the airflow is acceptable for the ASM. The secondary filter also filters engine bleed air in the event that air is supplied from this source. The filter assembly also removes entrained moisture from the air by separating water vapor and ejecting it in liquid form from the aircraft through a drain line.

The ASM accepts warm pressurized air from the upstream system and discharges NEA to the fuel tanks. A second ASM outlet port discharges oxygen enriched air (OEA) to the ambient air around the aircraft. Concentrated OEA may be a fire hazard so it must be mixed with ambient air. The discharge port must be designed to ensure the mixing.

At the ASM outlet, a relief valve ensures that tank over pressure conditions are avoided in the event of a refuel system failure during refuel operations. This is accomplished by jettison of the NEA during the refuel failure condition, which results in normal refuel failure tank over pressure protection.

Flow to the fuel tanks is controlled by means of fixed restrictions that are designed to balance the flow to the individual fuel tanks. Flow balance ensures that tank NEA ullage concentrations are relatively uniform. The restrictors also feature check valves that together with the in-line check valve, provide dual redundant reverse flow protection against hydrocarbon contamination of the ASM.

### **2.5.2 Component Functional Description**

The functions of the components in the hybrid OBGI system are identical to the baseline OBGI system. The ‘Component Functional Description’ part of Section 1 of this report details these component functions. The components included in this section are as listed below:

- Inlet Filter
- Compressor, Start Contactor, Compressor Cooling Fan
- Compressor Discharge Check Valve
- Compressor Unloading Valve
- Bleed Air Isolation Valve
- Heat Exchanger
- Heat Exchanger Temperature Control Valve

- Temperature Sensor
- Water Separator / Filter
- Air Separation Module
- Relief Valve
- ASM Discharge Check Valve and Restrictor
- Fuel Tank Check Valve and Restrictor
- Ducting
- Controller
- Wiring
- Flow Control Orifice

### **2.6 SYSTEM SIZING AND PERFORMANCE**

As with the baseline OBG system, the sizing of hybrid OBG system for the various generic aircraft is a function of several key parameters. The main ones are the efficiency of the separating technology used in the system, the size of the fuel tank to be inerted, and the amount of time available to inert the tank. The resulting analysis will provide the weight, volume, power consumption, and cost of the system.

#### **2.6.1 Key Sizing Parameters**

Sizing for hybrid OBG systems are identical to those considered for the baseline OBG system, namely fuel tank volume, aircraft turn time, and ASM feed pressure and temperature. These parameters are described in further detail in Section 1 under OBG key sizing parameters.

The increased operating time on the ground for hybrid OBG systems, relative to the baseline OBG systems, due to the added time for taxi-in, serves to reduce the necessary hybrid OBG system NEA flow rate.

#### **2.6.2 Parametric Sizing Curves**

The parametric sizing methodology for the hybrid OBG system was the same as that for the baseline OBG system. The results of the system analysis were the weight, volume, input power, and inlet air for the various aircraft models. These results are plotted as parametric charts. The charts are shown in Figures 2.6.2-1 through 2.6.2-5. The data for the systems that include auxiliary tanks was scaled from the other systems based on tank volume.

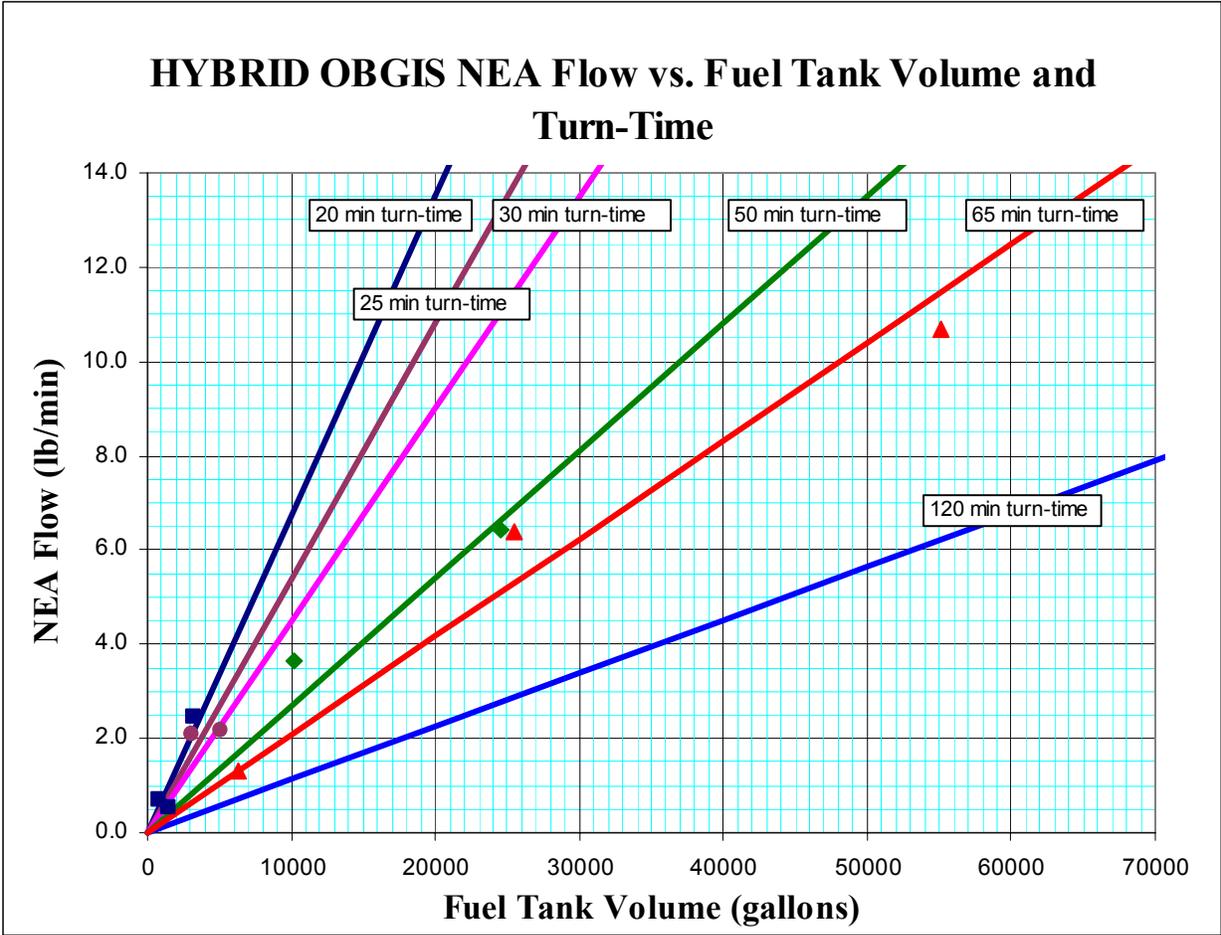


Figure 2.6.2-1. NEA Flow vs. Tank Volume

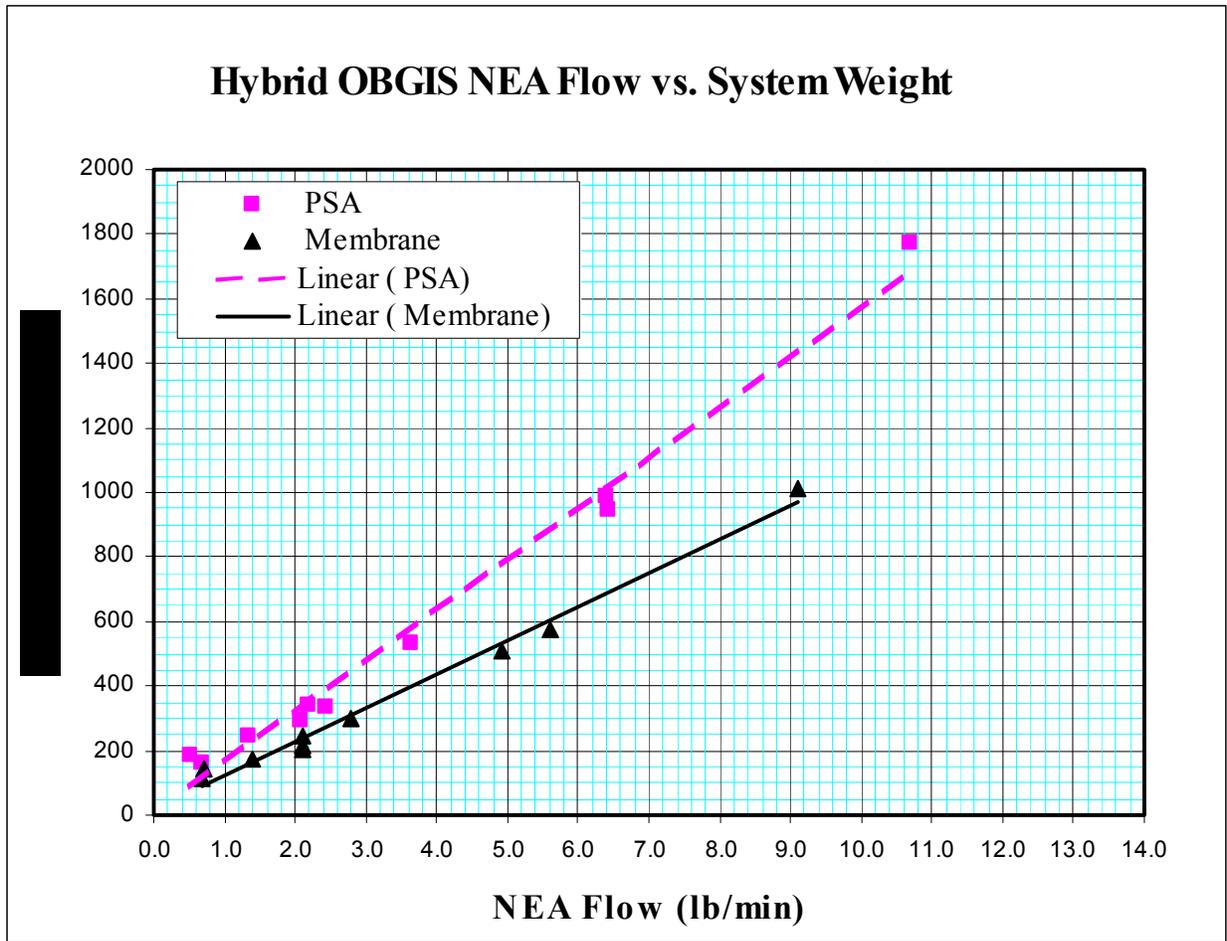


Figure 2.6.2-2. Weight vs. NEA Flow

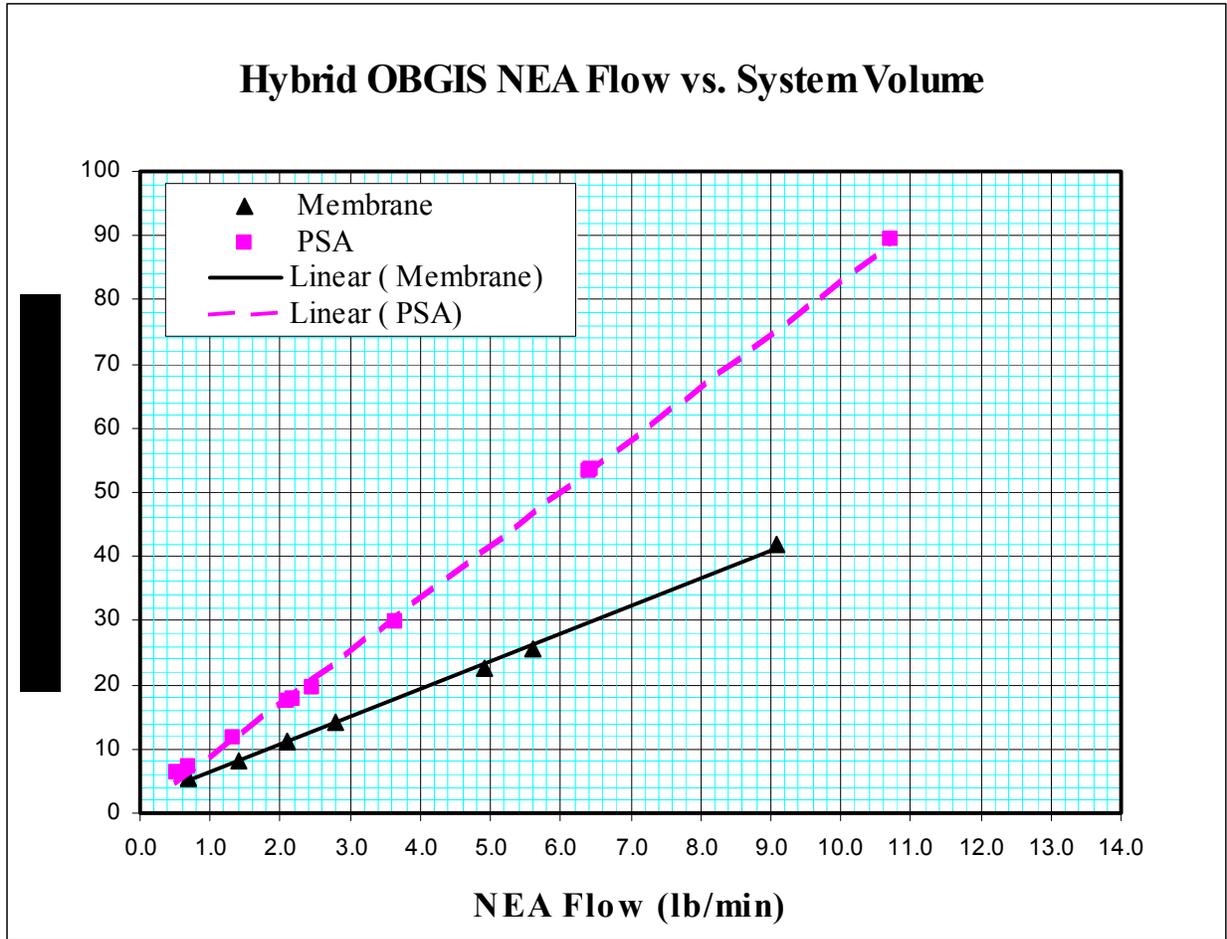


Figure 2.6.2-3. Volume vs. NEA Flow

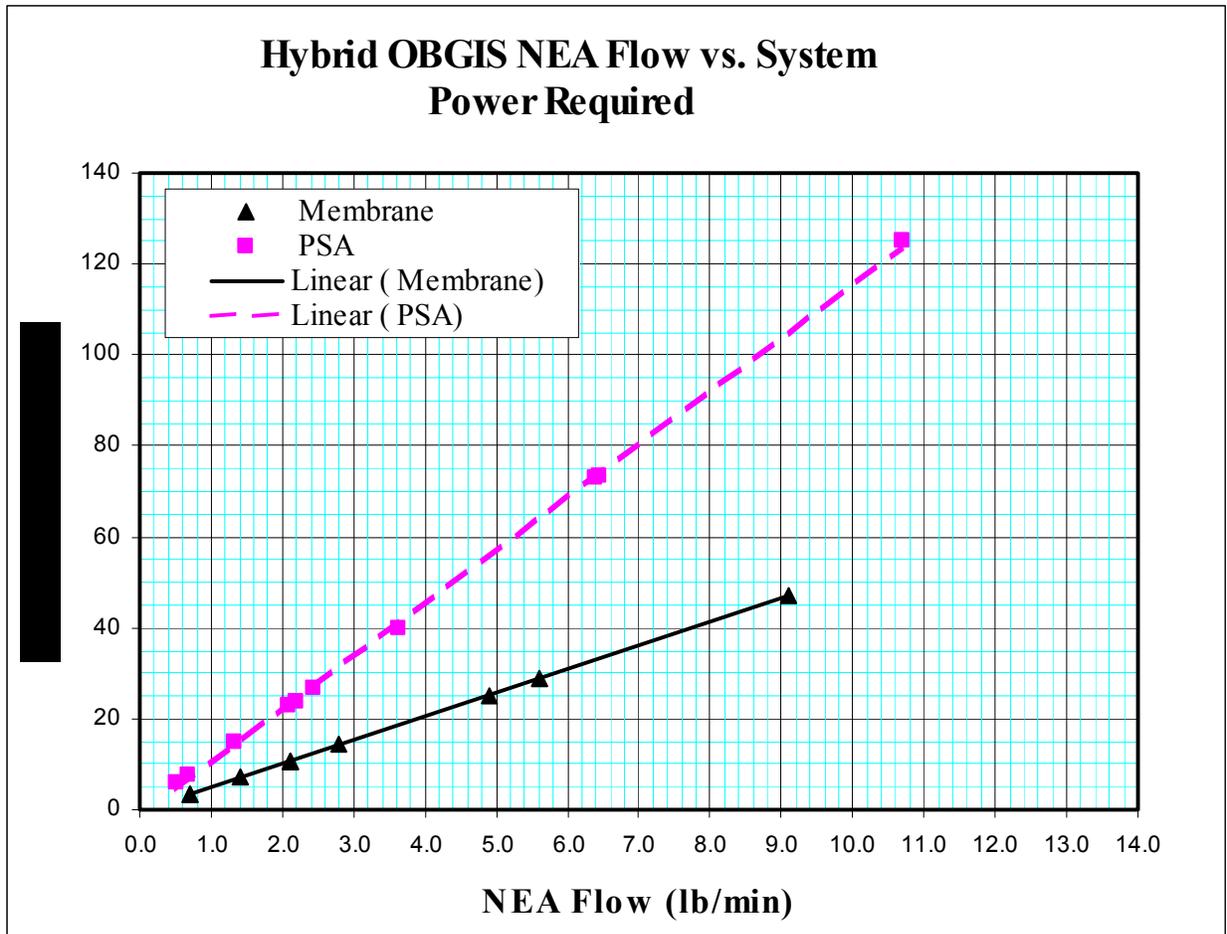
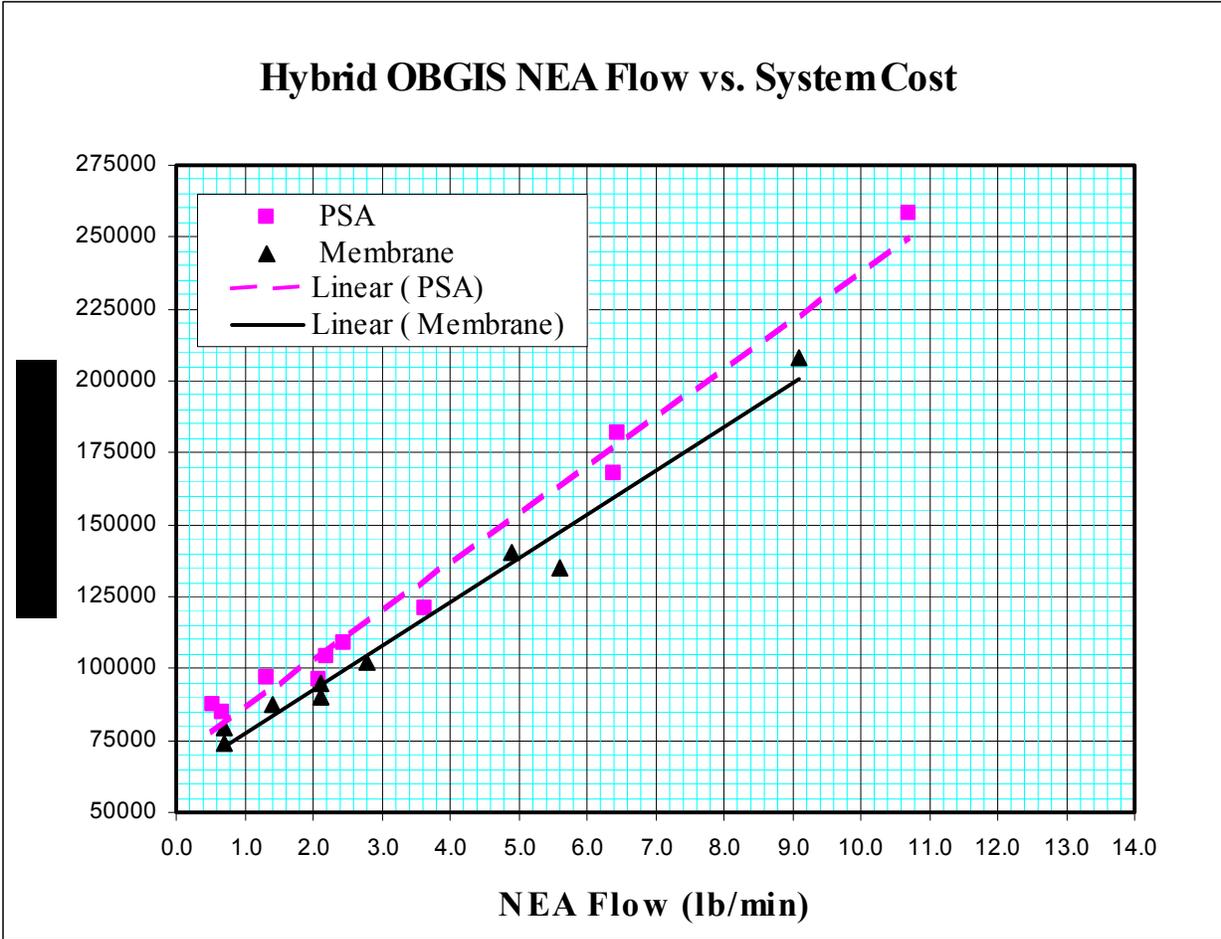


Figure 2.6.2-4. Power vs. NEA Flow



*Figure 2.6.2-5. Cost vs. NEA Flow*

These charts allow system sizing for any aircraft models not specifically studied in this report. Figure 2.6.2-1 plots NEA flow versus fuel tank volume and turn-time to allow for estimation of the hybrid OBGIS system NEA flow requirement for a given aircraft. Figures 2.6.2-2 through 2.6.2-5 then provide estimation of hybrid OBGIS system weight (pounds), system volume (cubic feet), required electrical power (kilowatts), and system cost (dollars). Cost data are for initial acquisition only of the systems themselves and are provided for comparison purposes; they do not include any other costs such as certification or integration by the aircraft manufacturer or commercial airline. The charts are used identically as the example provided for the baseline OBGIS system in Section 1. The charts were generated for NEA flow with an oxygen concentration of about 7% and may not be valid for different NEA purity.

**2.6.3 Results**

Summary results of the hybrid OBGIS air consumption, weight, electrical power usage, and volume for the different aircraft models and tank configurations are plotted in the bar charts in Figures 2.6.3-1 and 2.6.3-2.

### Hybrid OBGIS - Center Wing Tank

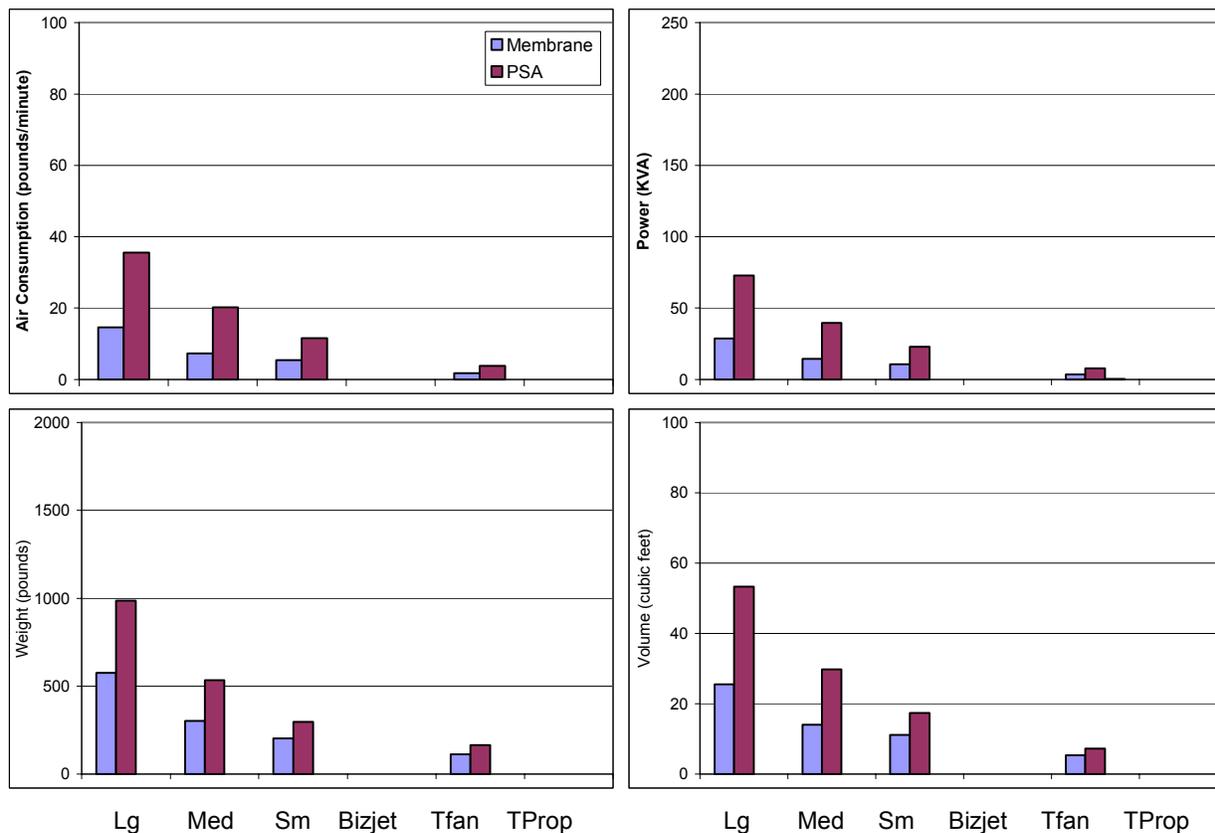
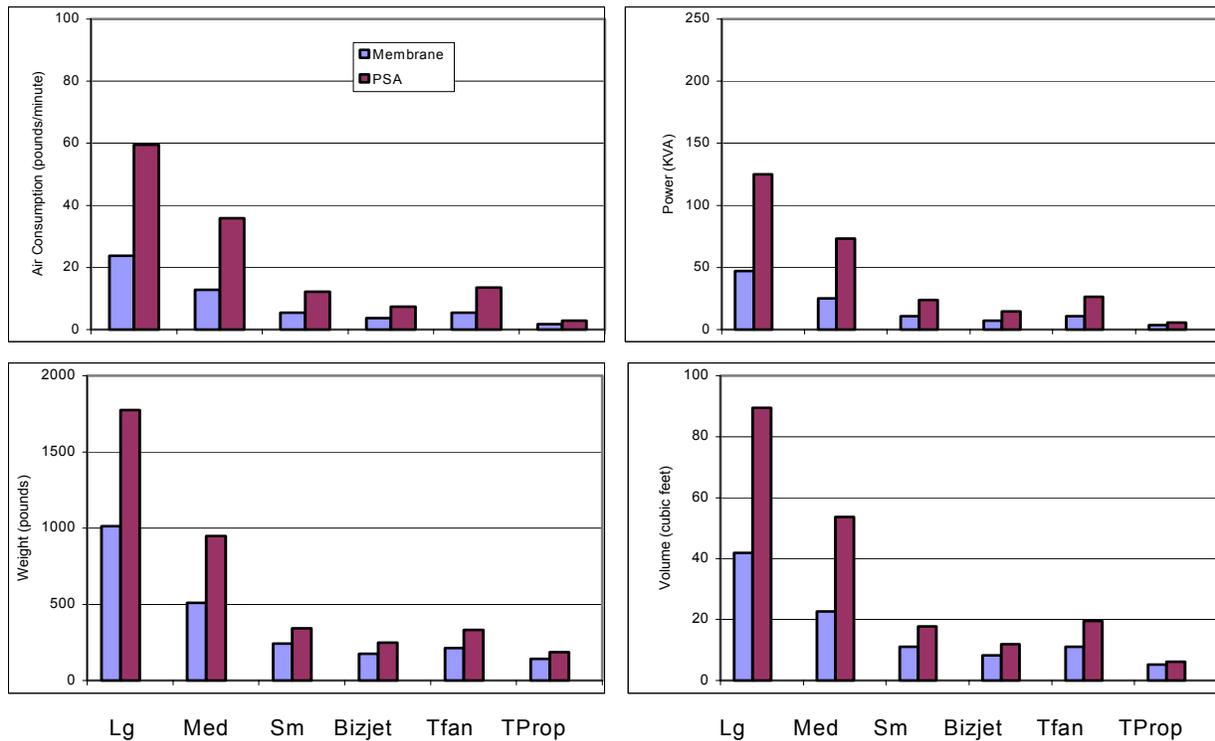


Figure 2.6.3-1. Hybrid OBGIS Air Consumption, Power, Volume and Weights for Center Tanks

**Hybrid OBGIS - All Tanks**



*Figure 2.6.3-2. Hybrid OBGIS Air Consumption, Power, Volume and Weights for All Tanks*

**2.6.4 Flammability Exposure**

The methodology to compute the flammability exposure for the hybrid OBGIS system for each of the generic aircraft types was identical to that of the baseline OBGIS system. This is detailed in the flammability exposure discussion in Section 1 of this report. A comparison of the hybrid OBGIS system performance to other fuel tank inerting options is shown Section 5.0 of this report. The specific flammability exposure for the system is shown in Figure 2.6.4-1 and 2.6.4-2.

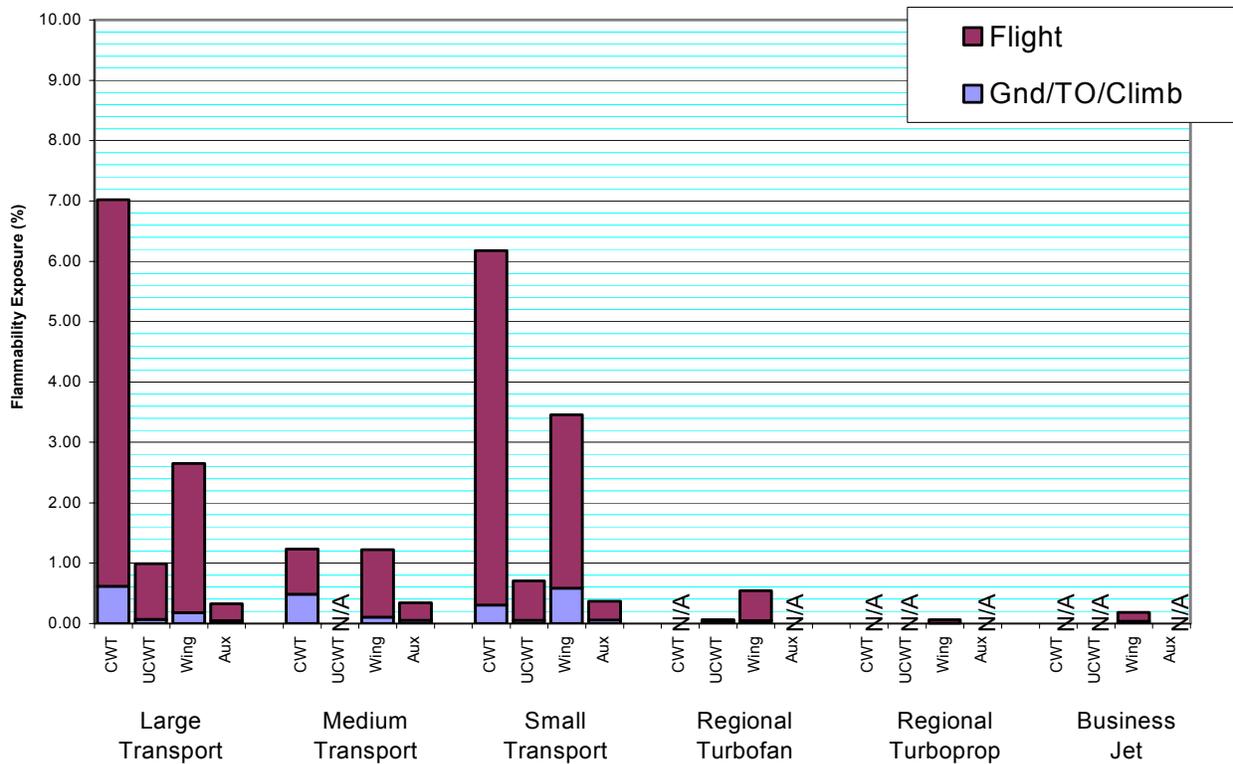


Figure 2.6.4-1. Flammability Exposure Results for the Hybrid OBGI Membrane System

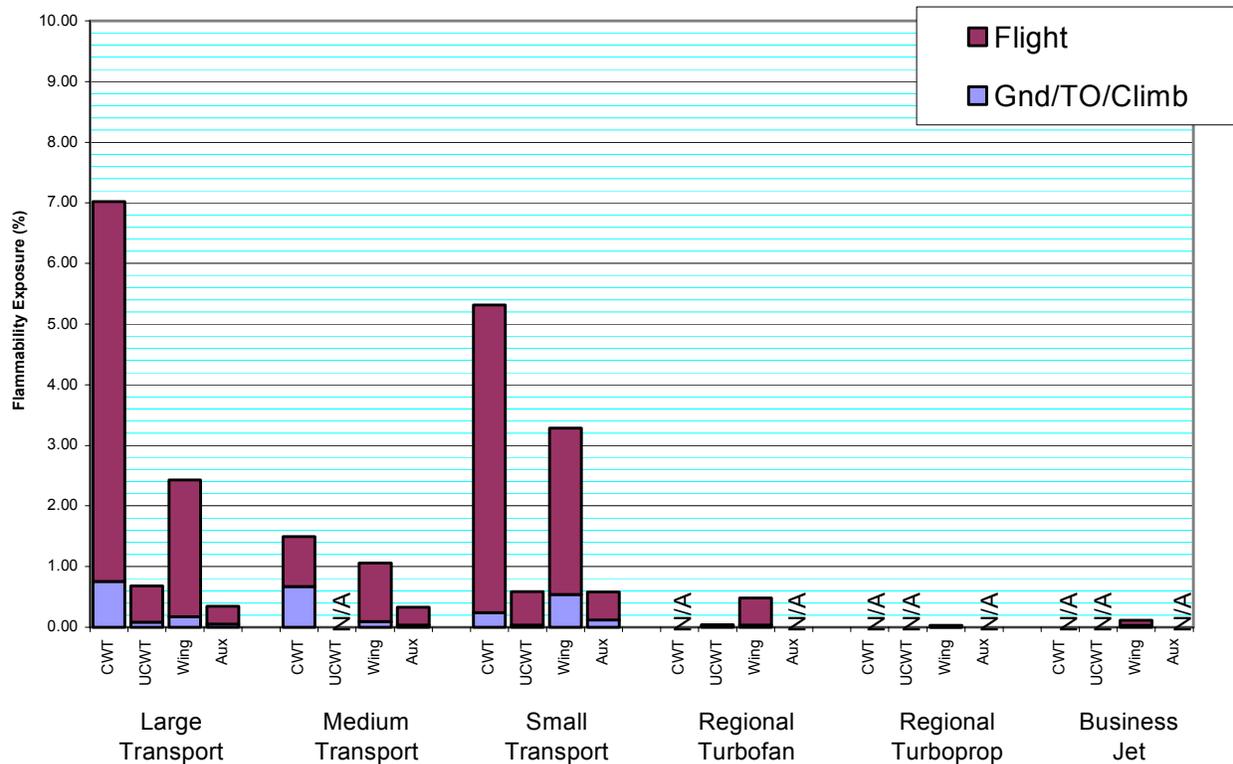


Figure 2.6.4-2. Flammability Exposure Results for the Hybrid OBGI PSA System

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Total flammability exposure represents the total flight and ground time spent flammable and not inert as a percentage of the total flight and ground time. The portion of the total flammability exposure corresponding to gate time, taxi out, takeoff and climb segments were separately summed together to allow for direct comparisons of each inerting option where the risk of an explosion was higher.

### **2.7 WEIGHT**

Figures 2.7-1 and 2.7-2 summarize the weight data developed by the Onboard Design Task Team for the membrane and PSA hybrid OBGIS systems for each of the ARAC generic aircraft. Each table provides the total weight for the “major” and “other” components identified for each system. “Other” components include such items as wiring, ducting and valves, and their total estimated weights have been combined.

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<b>Weight Summary Table - Membrane Systems (Lbs.)</b>										
<b>Component</b>	<b>Large Transport</b>		<b>Medium Transport</b>		<b>Small Transport</b>		<b>Turbo Prop</b>	<b>Turbo Fan</b>		<b>BizJet</b>
	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>	<b>All Tanks</b>	<b>CWT Only</b>	<b>All Tanks</b>
<b>Main Parts</b>										
Compressor, cooling & start system	51.9	32.1	28.8	19.0	15.7	15.7	9.2	15.7	9.2	12.5
Heat exchanger	8.6	4.8	4.8	1.8	2.1	2.1	0.6	1.8	0.6	1.1
Cooling fan & ram ducts assembly	8.9	6.0	5.3	6.5	3.8	3.8	0.6	4.1	0.6	2.4
Air separation module	260.0	160.0	140.0	80.0	60.0	60.0	20.0	60.0	20.0	40.0
<b>Main Parts Sub-Total</b>	<b>329.4</b>	<b>202.9</b>	<b>178.9</b>	<b>107.3</b>	<b>81.6</b>	<b>81.6</b>	<b>30.4</b>	<b>81.6</b>	<b>30.4</b>	<b>56.0</b>
<b>Other Parts</b>										
Compressor inlet air filter assy	6.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Compressor inlet air filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Compressor discharge check valve	1.5	1.5	1.3	1.2	1.0	1.0	0.8	1.2	1.0	1.5
Compressor unloading valve	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.2	2.0	2.5
Bleed Air shutoff valve	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.8	2.5	2.5
Heat Exchanger bypass valve	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.8	0.8	1.0
Temperature sensor & controller	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Water separator/filter assy	10.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Water separator/filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ASM check valve & restrictor assy	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Relief valve	1.9	1.9	1.5	1.5	0.8	1.0	0.8	1.0	1.2	1.5
Fuel tank check valve	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Ducting	178.2	44.2	115.8	30.4	52.5	16.8	38.1	38.1	9.5	38.1
Wiring	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Bleed Orifice & Duct	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Compressor Wiring	236.2	118.1	58.7	34.8	15.4	15.4	3.3	12.8	4.1	4.1
Installation Hardware	116.6	62.0	60.0	32.9	29.1	23.7	17.3	26.6	13.3	21.6
Structural Modifications	100.0	100.0	50.0	50.0	20.0	20.0	10.0	10.0	10.0	10.0
<b>Other Parts Sub-Total</b>	<b>684.1</b>	<b>372.4</b>	<b>331.3</b>	<b>194.9</b>	<b>161.1</b>	<b>120.3</b>	<b>112.6</b>	<b>132.6</b>	<b>81.4</b>	<b>119.9</b>
<b>System Totals</b>	<b>1013.5</b>	<b>575.3</b>	<b>510.2</b>	<b>302.2</b>	<b>242.8</b>	<b>201.9</b>	<b>143.0</b>	<b>214.3</b>	<b>111.8</b>	<b>175.9</b>
Oxygen sensor	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

*Figure 2.7-1. Summary of Hybrid OBGIS Component Weights – Membrane Systems*

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Weight Summary Table - PSA Systems (Lbs.)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	119.0	72.4	72.8	41.8	27.5	26.5	11.1	30.0	12.7	19.0
Heat exchanger	23.0	32.5	16.6	19.3	13.4	9.6	3.2	14.3	4.3	6.9
Cooling fan & ram ducts assembly	54.8	13.2	29.4	8.1	5.4	8.5	5.4	6.0	5.3	6.5
Air separation module	541.0	312.0	309.0	180.0	114.0	110.0	43.0	127.0	50.0	76.0
<b>Main Parts Sub-Total</b>	<b>737.8</b>	<b>430.1</b>	<b>427.9</b>	<b>249.2</b>	<b>160.3</b>	<b>154.7</b>	<b>62.7</b>	<b>177.3</b>	<b>72.3</b>	<b>108.4</b>
<b>Other Parts</b>										
Compressor inlet air filter assy	11.0	8.0	8.0	6.0	4.0	4.0	4.0	4.0	4.0	4.0
Compressor inlet air filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Compressor discharge check valve	2.0	2.0	2.0	1.5	1.0	1.0	0.8	1.2	1.0	1.5
Compressor unloading valve	3.0	3.0	3.0	2.5	2.0	2.0	2.0	2.2	2.0	2.5
Bleed Air shutoff valve	4.0	4.0	4.0	3.0	2.5	2.5	2.5	2.8	2.5	2.5
Heat Exchanger bypass valve	1.2	1.2	1.2	1.2	0.8	0.8	0.7	0.8	0.8	1.2
Temperature sensor & controller	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Water separator/filter assy	18.0	13.0	13.0	10.0	7.0	7.0	7.0	7.0	7.0	7.0
Water separator/filter element	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Relief valve	1.9	1.9	1.9	1.5	0.8	1.0	0.8	1.0	1.2	1.5
ASM check valve & restrictor assy	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fuel tank check valve	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Ducting	178.2	44.2	115.8	30.4	52.5	16.8	38.1	38.1	9.5	38.1
Wiring	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Bleed Orifice & Duct	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Compressor Wiring	472.3	236.2	177.1	88.6	23.2	23.2	7.8	19.4	6.5	12.8
Installation Hardware	218.4	115.6	117.1	63.1	42.1	36.0	23.0	42.1	20.0	31.0
Structural Modifications	100.0	100.0	50.0	50.0	20.0	20.0	10.0	10.0	10.0	10.0
<b>Other Parts Sub-Total</b>	<b>1036.9</b>	<b>542.8</b>	<b>506.9</b>	<b>274.6</b>	<b>175.8</b>	<b>134.1</b>	<b>116.6</b>	<b>147.9</b>	<b>84.3</b>	<b>130.9</b>
<b>System Totals</b>	<b>1774.6</b>	<b>973.0</b>	<b>934.8</b>	<b>523.7</b>	<b>336.0</b>	<b>288.8</b>	<b>179.3</b>	<b>325.2</b>	<b>156.6</b>	<b>239.3</b>
Oxygen sensor	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Figure 2.7-2. Summary of OBGIS Component Weights – PSA Systems

### **2.7.1 Air Separation Modules**

**Permeable membrane.** The hollow fiber membrane module construction is identical to that of the baseline OBGI system, as described in Section 1. The ASM weight includes the hollow fiber membrane module, the inlet/outlet headers and the connections to the NEA, feed air manifolds/tubing. The NEA flow rate for each of the different aircraft sizes and tank volumes determined the total number of a standard size ASM's required to meet the flow requirements.

**PSA.** The PSA air separator calculations were made empirically based on an existing production OBIGGS air separator. The methodology for the use of these data is identical to that of the baseline OBGI system, as detailed in Section 1 of this report.

The weight of the molecular sieve needed to produce the gas was similarly scaled upward or downward based on NEA flow. The structural weight (such as the mounting structure and sieve containers) was also scaled upward or downward, although some economies of scaling were assumed, similar to the relationship observed between various existing PSA units.

### **2.7.2 Compressor**

The compressor was sized by vendors of existing aircraft and ground-based compressors. The compressor for each aircraft model was sized in a manner that is identical to that of the baseline OBGI system, as detailed in Section 1.

As with the baseline OBGI system, the compressor weight includes the rotating group and housing, integral fan cooling, lubrication system, connections to the mating tubing, and start contactor when applicable (larger aircraft types). Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

### **2.7.3 Heat Exchanger/Cooling Fan**

The heat exchanger and cooling fan were sized by vendors of existing aircraft heat exchangers and cooling fans. The heat exchangers and cooling fans for each aircraft model were sized in a manner that is identical to that of the baseline OBGI system, as detailed in Section 1.

Heat exchanger weight includes the core, inlet/outlet headers, and connections to the mating tubing. The weight of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

### **2.7.4 Other Components**

The weight of the other components in the system was mainly dependent on the required airflow or NEA flow. The higher flows associated with the larger aircraft demand components that are larger than those used in the smaller aircraft applications. The weight of filters, system valves, ducting, tube supports and brackets and the power cable was computed in a manner identical to that of the baseline OBGI system, as detailed in Section 1.

## **2.8 VOLUME**

Figures 2.8-1 and 2.8-2 summarize the volume data developed by the Onboard Design Task Team for the membrane and PSA hybrid OBGI systems for each of the ARAC generic aircraft. Each table provides the total volume for the "major" and "other" components identified for each system. "Other" components include such items as wiring, ducting and valves, and their total estimated volumes have been combined.

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Volume Summary Table - Membrane Systems (Cu Ft)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	0.88	0.55	0.49	0.29	0.23	0.23	0.10	0.23	0.10	0.16
Heat exchanger & Fan	0.41	0.25	0.22	0.15	0.11	0.11	0.03	0.11	0.03	0.07
Air separation module	11.29	6.95	6.08	6.95	2.61	2.61	0.87	2.61	0.87	1.74
<b>Main Parts Sub-Total</b>	12.6	7.8	6.8	7.4	2.9	2.9	1.0	2.9	1.0	2.0
<b>Other Parts Sub-Total</b>	29.25	17.80	15.87	10.12	8.18	8.18	4.29	8.18	4.29	6.24
<b>System Totals</b>	41.8	25.5	22.7	17.5	11.1	11.1	5.3	11.1	5.3	8.2

Figure 2.8-1. Summary of Hybrid OBGI Component Volumes – Membrane Systems

Volume Summary Table - PSA Systems (Cu Ft)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	2.14	1.29	1.29	0.74	0.46	0.44	0.14	0.51	0.17	0.29
Heat exchanger & Fan	2.62	1.53	1.54	0.83	0.50	0.48	0.16	0.56	0.18	0.30
Air separation module	20.70	12.40	12.50	12.40	4.20	4.10	1.00	4.70	1.30	2.60
<b>Main Parts Sub-Total</b>	25.5	15.2	15.3	14.0	5.2	5.0	1.3	5.8	1.6	3.2
<b>Other Parts Sub-Total</b>	63.95	38.10	38.34	21.23	12.62	12.33	4.88	13.83	5.60	8.68
<b>System Totals</b>	89.4	53.3	53.7	35.2	17.8	17.3	6.2	19.6	7.2	11.9

Figure 2.8-2. Summary of Hybrid OBGIS Component Volumes – PSA Systems

## 2.8.1 Air Separation Modules

**Permeable membrane.** The volume of the proposed air separation module includes the Hollow Fiber Membrane Module, the inlet/outlet headers and the connections to the NEA and Feed air manifolds/tubing. The methodology for the volume computation is identical to that of the baseline OBGI System, as detailed in Section 1 of this report.

**PSA.** The hybrid OBGI system PSA air separator volume calculations were made empirically. This was done in a manner that was identical to that of the baseline OBGI system, as detailed in Section 1 of this report. The result of this was the amount of sieve needed to produce the product gas for the system. The volume of PSA air separator was similarly scaled upward or downward based on the projected quantity of molecular sieve needed.

## 2.8.2 Compressor

The compressor volume was determined for each of the aircraft and system types. The compressor volume was derived in a manner that is identical to that of the baseline OBGI system, as detailed in Section 1.

As with the baseline OBGI system, the compressor volume includes the rotating group and housing, integral fan cooling, lubrication system, connections to the mating tubing, and start contactor when applicable (larger aircraft types).

## 2.8.3 Heat Exchanger/Cooling Fan

Heat exchanger and cooling fan volumes were determined for each of the aircraft and system types. Heat exchanger volume includes the core, inlet/outlet headers, and connections to the mating tubing. The volume of the cooling fan includes the fan and any ducting between the fan and the heat exchanger.

## 2.8.4 Other Components

In a manner similar to that of the weight, component volumes were individually computed as a function of airflow, NEA flow and power. The majority of component volumes were scaled or derived from existing components for similar applications on aircraft. The methodology for this is identical to that of the baseline OBGI system, as detailed in Section 1 of this report

## 2.9 ELECTRICAL POWER

Figures 2.9-1 and 2.9-2 summarize the electrical power data developed by the Onboard Design Task Team for the membrane and PSA hybrid OBGI systems for each of the ARAC generic aircraft. Each table provides the total electrical power for the “major” and “other” components identified for each system. “Other” components include such items as wiring, motors and valves, and their total estimated electrical powers have been combined.

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Electrical Power Summary Table - Membrane Systems (kVa)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	46.48	28.24	24.71	14.10	10.54	10.54	3.49	10.54	3.49	7.00
Heat exchanger & Fan	0.54	0.33	0.31	0.25	0.17	0.17	0.00	0.17	0.00	0.08
Air separation module	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Main Parts Sub-Total</b>	47.0	28.6	25.0	14.3	10.7	10.7	3.5	10.7	3.5	7.1
<b>Other Parts Sub-Total</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	47.1	28.7	25.1	14.4	10.8	10.8	3.6	10.8	3.6	7.2

Figure 2.9-1. Summary of Hybrid OBGIS Component Power Consumption – Membrane Systems

Electrical Power Summary Table - PSA Systems (kVa)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	115.98	68.70	69.17	38.78	23.30	22.22	5.51	25.97	7.31	14.11
Heat exchanger & Fan	8.19	3.56	3.63	0.51	0.34	0.34	0.22	0.34	0.26	0.34
Air separation module	0.95	0.57	0.57	0.57	0.19	0.19	0.00	0.22	0.06	0.12
<b>Main Parts Sub-Total</b>	125.1	72.8	73.4	39.9	23.8	22.8	5.7	26.5	7.6	14.6
<b>Other Parts Sub-Total</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.10
<b>System Totals</b>	125.2	72.9	73.5	40.0	23.9	22.9	5.7	26.6	7.7	14.7

Figure 2.9-2. Summary of Hybrid OBGI Component Power Consumption – PSA Systems

## 2.9.1 Air Separation Modules

**Permeable membrane.** As with the baseline OBGI system, the membrane air separator consumes no power.

**PSA.** The PSA power consumption projections were made empirically. The methodology for this is identical to that of the baseline OBGI system, as detailed in Section 1 of this report. The power consumption for the PSA air separator was scaled upward or downward based on the projected quantity of molecular sieve needed. Power consumption numbers are relatively low, since the mechanism to operate the PSA distribution valve is pneumatic.

## 2.9.2 Compressor

The compressor power was determined for each of the aircraft and system types. The compressor power was derived in a manner that is identical to that of the baseline OBGI system, as detailed in Section 1.

As with the baseline OBGI system, the compressor power includes the power for the rotating group, integral fan cooling, and lubrication system. For the larger aircraft types, multiple compressor assemblies were necessary to provide the required amount of airflow. The larger compressors also required start contactors to reduce the peak power draw on start-up.

## 2.9.3 Heat Exchanger/Cooling Fan

Heat exchanger and cooling fan power were determined for each of the aircraft and system types. The heat exchanger requires no power to operate. The cooling fan power requirement was determined based on the cooling air flow rate and pressure rise requirements in a manner identical to that of the baseline OBGI system, as detailed in Section 1 of this report.

## 2.9.4 Other Components

The power consumption of the other system components are minimal compared with that of the compressor. The only units that consume power are the valves; most of the time they are dormant and consume no power. The methodology for this is identical to that of the baseline OBGI system, as detailed in Section 1 of this report.

## 2.10 RELIABILITY

Figures 2.10-1 through 2.10-4 summarize the reliability data in terms of mean-time-between-maintenance-actions (MTBMA) and mean-time-between-failure (MTBF), as developed by the Onboard Design Task Team for the membrane and PSA hybrid OBGI systems for each of the ARAC generic aircraft. Each table provides the reliability for the “major” and “other” components identified for each system. “Other” components include such items as wiring, motors and valves, and their total estimated reliability have been combined. The Airplane Operations and Maintenance Team used this data as a starting point for the system level reliability estimates.

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Reliability Summary Table - Membrane Systems MTBMA (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
ASM check valve & restrictor assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 2.10-1. Summary of Hybrid OBGi MTBMA – Membrane Systems

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Reliability Summary Table - PSA Systems MTBMA (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
ASM check valve & restrictor assy	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structual Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 2.10-2. Summary of Hybrid OBGI MTBMA – PSA Systems

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Reliability Summary Table - Membrane Systems MTBF (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
ASM check valve & restrictor assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 2.10-3. Summary of Hybrid OBG I MTBF – Membrane Systems

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Reliability Summary Table - PSA Systems MTBF (Hrs)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan & ram ducts assembly	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
<b>Other Parts</b>										
Compressor inlet air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor inlet air filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed Air shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Heat Exchanger bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor & controller	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
ASM check valve & restrictor assy	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Bleed Orifice & Duct	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Oxygen sensor	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 2.10-4. Summary of Hybrid OBGI MTBF – PSA Systems

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## **2.10.1 Air Separation Modules**

Reliability figures for two ASM technologies were developed for hybrid OBGI Systems: membrane, PSA.

**Membranes.** As with the basic hybrid OBGI system, membrane system reliability was based on all major and minor components needed for a standard membrane unit. The membrane module, as defined by the ARAC Onboard Design Team consists of a membrane module contained in a metal housing.

**PSA.** As with the basic hybrid OBGI system, the PSA hardware, as defined by the ARAC Onboard Design Team consists of a distribution valve that is pilot operated by relatively small pneumatic valves and controlled by a timing circuit, air and product manifolds, molecular sieve beds, and purge orifices. The distribution valve assembly contains two parts that are subject to wear, which should be serviced at 6000 to 8000 hour intervals. The MTBF estimate for the PSA separator in the summary table is based on a scheduled overhaul every 8000 hours.

## **2.10.2 Compressor**

The compressor reliability for screw-type units is based on a recommended service interval of 7000 hours. The centrifugal compressors used different bearing technology which do not require periodic servicing. As with the baseline OBGI system described in Section 1, the reliability figures included in the referenced table were provided by vendors of existing flight and ground-based equipment

## **2.10.3 Heat Exchanger**

The heat exchanger reliability values are based on commercial aircraft heat exchanger experience, provided by vendors of existing flight-worthy equipment.

## **2.10.4 Other Components**

As with the baseline OBGI system described in Section 1 of this report, the Team estimated the reliability of the other components based on their experience with similar existing ECS and fuel system components. Common reliability estimates were used when the same components were used in different systems, so that fair comparisons could be made between technologies and concepts.

## **2.11 COST**

The On-Board Design Task Team estimated the initial acquisition costs for the membrane and PSA hybrid OBGI systems for each of the ARAC generic aircraft. Design and certification, operations, maintenance, and installation costs for the hybrid OBGI systems are described later in this section. Inclusion of those costs to determine hybrid OBGIS cost benefit was performed by the Estimating and Forecasting (E&F) Team and is described in their final report.

### **2.11.1 Acquisition Cost**

Figures 2.11.1-1 and 2.11.1-2 summarize the hybrid OBGIS costs developed by the On-Board Design Task Team for the membrane and PSA inerting systems, respectively, for each of the ARAC generic aircraft. Figure 2.11.1-3 compares total OBGI system costs to hybrid OBGI system costs. Each table provides the total cost for the individual components identified for each system. Except for the regional turboprop and business jet aircraft, two sets of costs are provided for each ARAC generic aircraft, one for inerting all tanks and another for inerting center wing tanks (CWT) only. Common costs were applied for similar components across both OBGI systems and hybrid OBGI systems. The estimated component costs include the amortized non-recurring development costs. Several component costs were also integrated into the cost for the next higher assembly similar to same components used in OBGI systems.

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The team also separately estimated the cost for an on-board oxygen sensor, though this cost was not included in the system totals.

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Cost Summary Table - Membrane Systems (\$)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	14845	7621	7481	7061	6920	6920	6640	6920	6640	6780
Heat exchanger	6476	4001	3931	3632	2673	2673	2668	2892	2668	2989
Cooling fan & ram ducts assembly	1949	2168	2168	1949	2168	2168	693	1949	693	1112
Air separation module	81380	50080	43820	25040	18780	18780	6260	18780	6260	12520
Main Parts Sub-Total	104650	63869	57400	37681	30541	30541	16261	30541	16261	23401
<b>Other Parts</b>										
Compressor inlet air filter assy	350	350	350	350	350	350	350	350	350	350
Compressor inlet air filter element	0	0	0	0	0	0	0	0	0	0
Compressor discharge check valve	475	475	425	425	275	300	250	400	300	475
Compressor unloading valve	1560	1560	1560	1560	1350	1300	1250	1450	1450	1560
Bleed Air shutoff valve	1250	1250	1250	1250	1100	1150	1100	1250	1250	1250
Heat Exchanger bypass valve	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Temperature sensor & controller	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Water separator/filter assy	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Water separator/filter element	0	0	0	0	0	0	0	0	0	0
ASM check valve & restrictor assy	185	185	185	185	185	185	185	185	185	185
Relief valve	680	680	580	500	450	500	450	500	500	550
Fuel tank check valve	675	675	675	675	675	675	675	675	675	675
Controller / control card	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Ducting	35640	8840	23160	6080	10500	3360	7620	7620	1900	7620
Wiring	750	750	750	750	750	750	750	750	750	750
Bleed Orifice & Duct	300	300	300	300	300	300	300	300	300	300
Compressor Wiring	4471	2236	811	541	310	310	64	259	75	75
Installation Hardware	5828	3100	3002	1645	1453	1187	867	1332	664	1082
Structural Modifications	2000	2000	1000	1000	400	400	200	200	200	200
<b>Other Parts Sub-Total</b>	<b>103165</b>	<b>71400</b>	<b>83047</b>	<b>64261</b>	<b>67098</b>	<b>59767</b>	<b>63061</b>	<b>64271</b>	<b>57599</b>	<b>64072</b>
<b>System Totals</b>	<b>207815</b>	<b>135270</b>	<b>140448</b>	<b>101943</b>	<b>97639</b>	<b>90307</b>	<b>79323</b>	<b>94811</b>	<b>73861</b>	<b>87473</b>
Oxygen sensor	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000

Figure 2.11.1-1. Summary of Hybrid OBGI Costs – Membrane Systems

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Cost Summary Table - PSA Systems (\$)										
Component	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
<b>Main Parts</b>										
Compressor, cooling & start system	24101	20237	15744	8038	7425	7383	6720	7531	6792	7061
Heat exchanger	48756	29108	29380	16292	8480	8879	3347	10351	3744	5880
Cooling fan & ram ducts assembly	7879	4847	4804	2255	3340	2498	1970	2577	1989	2130
Air separation module	61000	38000	40000	27000	17000	17000	12000	23000	14000	17000
Main Parts Sub-Total	141736	92193	89928	53585	36245	35760	24037	43459	26524	32071
<b>Other Parts</b>										
Compressor inlet air filter assy	500	500	500	350	350	350	350	350	350	350
Compressor inlet air filter element	0	0	0	0	0	0	0	0	0	0
Compressor discharge check valve	525	525	525	450	275	300	250	400	300	475
Compressor unloading valve	1560	1560	1560	1560	1350	1300	1250	1450	1450	1560
Bleed Air shutoff valve	1250	1350	1350	1350	1100	1150	1100	1250	1250	1250
Heat Exchanger bypass valve	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Temperature sensor & controller	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Water separator/filter assy	8000	8000	8000	5000	5000	5000	5000	5000	5000	5000
Water separator/filter element	0	0	0	0	0	0	0	0	0	0
Relief valve	680	680	680	550	450	500	450	500	500	550
ASM check valve & restrictor assy	185	185	185	185	185	185	185	185	185	185
Fuel tank check valve	925	925	925	925	925	925	925	925	925	925
Controller / control card	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Ducting	35640	8840	23160	6080	10500	3360	7620	7620	1900	7620
Wiring	750	750	750	750	750	750	750	750	750	750
Bleed Orifice & Duct	300	300	300	300	300	300	300	300	300	300
Compressor Wiring	8943	4471	3354	1677	361	361	122	301	0	259
Installation Hardware	10922	5778	5855	3155	2107	1798	1149	2104	1002	1548
Structual Modifications	2000	2000	1000	1000	400	400	200	200	200	200
<b>Other Parts Sub-Total</b>	116179	77280	89559	64972	66078	58729	61800	63135	56012	62586
<b>System Totals</b>	257915	169472	179487	118557	102323	94489	85837	106594	82536	94657
Oxygen sensor	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000

Figure 2.11.1-2. Summary of Hybrid OBGIS Costs – PSA Systems

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System	Large Transport		Medium Transport		Small Transport		Turbo Prop	Turbo Fan		BizJet
	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	CWT Only	All Tanks	All Tanks	CWT Only	All Tanks
OBGIS - Membrane	238,468	142,308	154,119	108,901	104,973	97,641	79,323	102,172	81,192	87,473
OBGIS Hybrid - Membrane	207,815	135,270	140,448	101,943	97,639	90,307	79,323	94,811	73,861	87,473
OBGIS - PSA	270,237	171,471	184,507	120,747	107,212	99,291	89,486	110,911	85,377	96,135
OBGIS Hybrid - PSA	257,915	169,472	179,487	118,557	102,323	94,489	85,837	106,594	82,536	94,657

*Figure 2.11.1-3. Comparison of Hybrid OBGIS Costs to OBGIS Costs*

## 2.11.1.1 Air Separation Modules

Hybrid OBGI membrane and PSA ASM costs were developed similarly to those costs developed for OBGI systems. Common costs were applied for common ASM components across all OBGI and OBIGGS concepts.

## 2.11.1.2 Compressor

Compressor costs for hybrid OBGI systems were developed similarly to those costs developed for OBGI systems.

## 2.11.1.3 Heat Exchanger/Cooling Fan

Heat exchanger and cooling fan costs for hybrid OBGI systems were developed similarly to those costs developed for OBGI systems.

## 2.11.1.4 Other Components

Costs for all other hybrid OBGI system components were developed similarly to those costs developed for OBGI systems.

## 2.11.2 Design & Certification

Design and certification man-hour estimates were developed by the Working Group to encompass the engineering hours required by an aircraft manufacturer for modifications and additions to fuel system components, interfaces, structure, instruments or displays, wiring, tubing, ducting, avionics software and, if required, relocation of other equipment on each aircraft. Non-recurring design costs for hybrid OBGI system components (e.g., ASMs) were amortized into the component costs listed in the previous summary cost tables.

The design and certification man-hour estimates were applied by the E&F team as part of their analysis to determine hybrid OBGI system cost benefit and are described in the E&F team final report. These estimates address design and certification of hybrid OBGI systems to inert all tanks on a new first of a model aircraft and on derivative model aircraft for all of the ARAC generic aircraft. They also address design and certification of hybrid OBGI systems to inert CWTs only on a new first of a model aircraft and on derivative model aircraft, which only applies to the generic large, medium, and small transports, and to the generic regional turbo fan aircraft.

Neither FAA nor JAA will assess additional certification costs for hybrid OBGI systems. However, non-U.S. governmental authorities may assess additional costs related to the certification of hybrid OBGI systems. For example, JAA indicates that the CAA-UK will charge airlines for all certification costs, including engineering man hours, whereas DGAC France will charge airlines only for the travel costs associated with an hybrid OBGI systems certification efforts. These potential additional costs were not included in the design and certification cost estimates.

## 2.11.3 Operating Costs

Recurring hybrid OBGI system operating costs were developed similarly to those costs developed for OBGI systems. Recurring cost impacts attributed to frequency of delays, delay time, and additional training required for ground and flight crews were assumed to be the same as for OBGI systems. Since hybrid OBGI system resource requirements are constrained to the ground turn time mission segment plus additional time during taxi (to include landing and rollout), system weight remains the predominant element in performance loss versus other losses associated with aircraft resources (i.e., bleed air, electrical power).

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### **2.11.4 Maintenance Costs**

Recurring hybrid OBG system maintenance costs were developed similarly to those costs developed for OBG systems. Except for MTBUR, hours estimated for all other recurring Hybrid OBG system maintenance costs were assumed to be the same as for OBG systems.

### **2.11.5 Installation Costs**

Installation cost associated with hybrid OBG systems are described in the E&F team final report. No installation costs were developed by the On-Board Design Task Team.

## **2.12 SAFETY**

The inclusion of the hybrid OBG System on an aircraft introduces a number of new or increased safety concerns. These concerns can be divided into four distinct areas. They are normal operation, system leaks, component failure, and catastrophic failure. It should be noted that since the system only operates on the ground, when the aircraft is at the gate and during taxi-in, that these hazards (except as noted) only exist during that time and not during taxi-out or flight of the aircraft.

### **2.12.1 Normal Operation**

The hazards associated with the normal operation of the hybrid OBG system are the discharge of oxygen enriched waste gas, the venting of NEA out of the fuel vent, the possibility of fuel tank over pressure during refuel over-fill, and those associated with electrical wiring and high temperature components.

**Oxygen-rich waste gas.** Oxygen-rich waste gas could be a fire hazard and should be vented in an area with no potential ignition sources. It should be vented in an area and in a manner where it will be quickly diluted.

**NEA around fuel vent.** NEA vented from the fuel tank vent could create breathing problems, if inhaled. Testing during the inerting of a 737 aircraft indicated that the exiting NEA was rapidly diluted and results in a small hazard. A placard warning near the vent should be sufficient to mitigate this issue.

**Increased tank overpressure during refuel failure.** The operation of the hybrid OBG system during a refuel over-fill condition, may exacerbate the problem of tank overpressure. The system is configured to limit inlet NEA flow to the tank in this event, such that the flow is relieved over-board and is not additional to the tank pressure.

**Electrical wiring.** Electrical requirements of the system add to the amount of electrical wiring in the aircraft and the potential for electrical related smoke or fire in the aircraft. These safety concerns can be minimized through normal design practice.

**High component temperature.** The operating temperature of some components may exceed 400 degrees F and should be placarded as such.

### **2.12.2 System Leaks**

Various system leaks could occur and create safety concerns. Leaks could include hot air, NEA, OEA and fuel vapor.

**Compressor discharge air leaks.** Compressed air between compressor/bleed air supply and heat exchanger could be at a temperature of the order of 400 degrees F. It should be treated the same as bleed air ducting, and may require overheat detection. A very small amount of bleed flow will be provided during flight to keep the system warm, therefore in-flight overheat detection may also be necessary.

**NEA leaks.** The NEA line from the ASM to fuel tank could produce an environment, in a confined space, with a reduced oxygen level. The line should, wherever possible, be run in an area of high

ventilation. Where it does run in a confined space with low ventilation the duct may be required to be of double containment design.

**Oxygen-rich waste gas leaks.** The OEA waste line could produce an environment, in a confined space, with an elevated oxygen level. The line should, wherever possible, be run in an area of high ventilation and where there is an absence of ignition sources. When it does run in a confined space with low ventilation or in an area with any possible ignition sources, the duct may be required to be of double containment design.

**Fuel backflow into ASM.** Check valves should be installed in system to prevent fuel vapor from the fuel tank flowing back through the NEA line into the system. This hazard could occur at any time since it is not dependent on system operation.

### **2.12.3 Component Failure**

It is possible that a component of the system could fail and create a hazardous condition as the system continues to operate.

**Compressor overheat.** A compressor overheat could cause a potential fire hazard. Thermal cutout protection should be incorporated to mitigate this risk.

**Heat exchanger overheat.** NEA being too hot (heat exchanger by-pass valve failure) could cause a safety problem by possibly damaging the system and flowing high temperature gas into the fuel tank. Thermal system cutout protection would provide mitigation from this hazard.

**Rotating equipment sparks.** Sparks or flames could occur in the system lines and protected should be provided by flame arrestors in line.

### **2.12.4 Catastrophic Failure**

Catastrophic failure of the system could occur with the failure of the high speed rotating parts of the compressor or a pressure vessel burst.

**Uncontained rotating equipment failure.** Uncontained rotating equipment failure could cause a hazard. The compressor design should provide containment for such failures.

**Pressure vessel burst.** Although pressure in the system is relatively low at 30 psig, a pressure vessel burst could occur and should be designed for.

## **2.13 INSTALLATION**

The installation objectives and concerns for the hybrid OBG system are identical to those already discussed for the baseline OBG system, described in Section 1 of this report. Specific design solutions for the many different aircraft models that would be affected by an inerting rule were beyond the scope of this study. The installation challenges are expected to be greater for retrofits where other systems already occupy many locations and customer-specific modifications may require different installation approaches for the same aircraft model. In some areas, structural modifications will be needed to support the additional weight of the new components.

As with the baseline OBG system, the optimal installation locations are unpressurized, ventilated, and close to the fuel tanks. If locations that meet these criteria cannot be found, the installations will be more complex.

Several existing aircraft models were surveyed for potential installation locations. Unpressurized locations in the air conditioning pack bay, wing root, wheel well, belly fairing, and behind the aft pressure bulkhead were examined. Pressurized locations exist in the cargo compartments and in a space forward of the aft bulkhead on some aircraft. Use of cargo space for inerting equipment carries the additional cost

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of the displaced cargo capacity. Installation locations on typical large, medium, and small transports are similar to those depicted for OBG (Section 1).

As with the baseline OBG system, the NEA distribution system must be sized for pressure drop, be double-walled within pressurized areas, and include drains for condensation. The system controller may be rack-mounted, part of a card file, or remotely located near the inerting equipment depending on the aircraft model. Wiring between the controller and components will require different degrees of protection depending on its location. The expected cockpit interface is an on/off switch and a fail light as with the baseline OBG system. The installation will also require additional protection if located within an engine rotor burst, tire burst, or flammable fluid leakage zone. The compressor and heat exchanger will be thermally insulated to prevent temperature damage to other equipment. The compressor must be installed to minimize noise transmission.

### **2.14 PROS AND CONS OF SYSTEM DESIGN CONCEPT**

**Effectiveness and Limitations.** The design concept of the hybrid OBG system is to have a self-contained system on the aircraft that will operate only when the aircraft is on the ground during taxi-in and at the gate. The system will provide an inert atmosphere in the “protected” (all tanks, or center tank only) tanks at some time during the gate stay of the aircraft. The system is designed to inert the “protected” tanks in the shortest turn time plus the taxi-in time, for the type of aircraft it is installed on. Therefore, for short turn times the aircraft “protected” tanks may be non-inert for a large portion of the gate time. However, the “protected” tanks will be inert at any time in excess of the shortest turn time. Under most conditions, the protected tanks will stay inert through taxi-out, climb, and into cruise. Protected tanks with very little or no fuel will stay inert until the descent, for most flights. A full tank that is used during taxi and/or climb may become non-inert during those phases of flight. Although the system does not provide for inerting of the tanks 100% of the time, it does provide inerting when the tanks are most likely to be flammable.

**Safety.** As described in the safety part of this Section, the installation of the system adds additional hazards to the aircraft, which must be mitigated. The design of the system should be such to minimize or eliminate the hazards. It should be noted that since the system only operates on the ground during taxi-in and at the gate, almost all of the hazards are only at that time, and not during taxi or flight. The system greatly minimizes the time a flammable mixture is present in a protected tank.

**Cost.** There is a cost associated with the design, installation, certification, operation and maintenance of a hybrid OBG system. Those costs can be broken down into the cost of the system, cost of system operation, and maintenance cost of the system. The cost of the system includes design and construction as well as certification and installation. The system operation costs include those associated with the carriage of additional weight and possible shift in center of gravity of the aircraft, possible increase in drag, and the additional use of electrical power during the taxi-in phase particularly. The maintenance cost includes maintenance of the hybrid OBG and to other systems, such as electrical generators, which are effected by it.

**Environmental Impact.** The main impact to the environment from a hybrid OBG system is the possible increase in fuel vapors being forced overboard as the nitrogen is injected into the fuel tank. The amount of fuel vapor that is vented depends on the fuel air mixture and tank ullage volume at the time of inerting, as well as many other variables. Testing has shown that present designed cross-vented fuel tanks, under certain wind conditions, can vent fuel vapors into the atmosphere. A redesign of this for the hybrid OBG system would minimize that venting helping to offset some of the fuel vapor lost during the inerting process.

The installation of a hybrid OBG system would, as shown previously, reduce the number of fuel tank explosions, thus reducing the amount of spilled fuel both on the ground and in the atmosphere.

In addition to the fuel vapor there is a potential problem with the addition of noise from the compressor/fan.

The use of dry NEA may reduce corrosion and condensation in the protected tanks depending on the conditions at the airports where the airplane is operated.

### **2.15 MAJOR ISSUES/MITIGATION**

As with the baseline OBG system, the hybrid OBG system has been defined by the Team based on the operating parameters defined during the study period or by others, such as the 1998 Fuel Tank Harmonization Working Group (FTHWG) ARAC. The parameters that had most of the effect on system sizing were the time available at the gate to operate the system, and the size of the tanks to be inerted. The time available to operate the system was determined by the shortest expected gate time available, plus the taxi-in time prior to gate hook-up. These were major factors particularly for the small and medium transport aircraft, where the minimum gate time was short, thereby dictating a large, high-capacity system. As with the baseline OBG system, an alternative to this approach would be to use a gate time which relates to the average or fleet majority gate time, thereby significantly reducing system size, cost and weight. The ultimate effect of this consideration has not been evaluated by this study.

Several existing aircraft were analyzed to derive data for the conclusions of this study. However not all existing aircraft could be evaluated, due to time constraints. System feasibility, although a major factor in this study, was not considered for all aircraft applications. Space may not be available to accommodate Hybrid OBG in all aircraft. One possibility is to install the Hybrid OBG system in the baggage space but there will be a cost impact to the operators due to lost revenue. This cost was not evaluated during this study.

Technology available to the Team at the time of the conduct of the study dictated feasibility to a certain extent, and detail features to a great extent. In the time required to enforce the requirements of the rulemaking that will be the ultimate result of this report, other, more advanced technologies may be available. As the Team was unable to predict such developments, the rulemaking recommendation was thus derived from currently available technology, with its associated limitations.

The team approached the study with the intention of defining the feasibility of Hybrid OBG systems, and their relative performance compared to other possible solutions. Detail design for all configurations of existing aircraft could not be evaluated in the available time. Such aircraft-specific designs were not attempted; it was concluded that detail design should be conducted when rulemaking compliance is defined. Details of these designs may at that time, conclude that some parameters do not appear feasible, or may result in different weight, cost or size. The team concludes, however, that ultimately no parameters will be infeasible, albeit that other items may be affected.

Not all-possible permutations of tank size, aircraft type and turn around times (among other parameters) were evaluated in the study. The team has, however, attempted to provide enough empirical data and predictive analysis that the reader may extrapolate the information presented herein to other specific application conditions and sizes.

A major objective for the study was to produce predictions of flammability exposure for the system. This was based on the FAA-produced predictive analysis software, with its inherent assumptions. Limited testing has concluded that the assumptions are sound, and the predictive analysis is of sufficient quality for these comparative studies. However, not all of the operating conditions that have been analytically simulated as part of this study have been verified by experiment, and may therefore ultimately result in divergence from the actual ultimate performance.

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## 3.0 FULL-TIME OBIGGS

The full-time On-board Inert Gas Generating System (OBIGGS) is one of four main system categories studied by the 2000 ARAC FTIHWG Onboard Airplane Design Task Team. The on-board team studied systems that were sized to provide inerting for various fuel tank configurations of six generic models. The team also defined the physical size and weight of the components that make up the OBIGGS. Finally, power and air consumption needs were defined.

### 3.1 REQUIREMENTS

The OBIGGS is required to keep the oxygen concentration in the ullage of all fuel tanks below 10% by volume throughout all mission phases. The system produces nitrogen as the inerting agent and all equipment is installed on the airframe, except for certain diagnostic equipment. The system does not require redundancy of components.

### 3.2 DATA SUPPLIED FROM OTHER SOURCES

Data was taken from various sources so that the team could define the full-time OBIGGS concept. This included aircraft turn times, generic aircraft definition and mission profiles, fuel tank sizes, bleed air data, and cabin pressure schedules.

#### 3.2.1 Aircraft Turn Times

Turn times do not affect full-time OBIGGS sizing since the aircraft will normally land with inert fuel tanks and remain inert while at the gate.

#### 3.2.2 Generic Aircraft Types

The FTIHWG made the decision to use the same generic aircraft data and mission scenarios that were used in the July 1998 ARAC FTHWG Report. As with the other on-board systems, these generic airplane definitions and missions were used in assessing the operational parameters. Discussion of the data is included in the 'Generic Aircraft Types' part of Section 1 of this report and the complete definitions and missions compiled during the 1998 FTHWG effort are included as an attachment to this report. As with the other systems, the worst-case flight conditions were the shortest-ranged flights.

#### 3.2.3 Fuel Tank Volumes

The 1998 Generic Aircraft fuel tank sizes listed in Figure 3.2.3-1 were used for all system sizing.

Generic Aircraft	CWT Volume (Gal.)	CWT + Wing Tank Volume (Gal.)	CWT + Wing + Aux Tank Volume (Gal.)
Turbofan	816	3,264	N/A
Turboprop	N/A	1,428	N/A
Business Jet	N/A	6,273	N/A
Small	3,060	5,100	7,600
Medium	10,200	24,480	27,480
Large	25,500	55,080	58,080

Figure 3.2.3-1. Generic Aircraft Fuel Tank Volumes

#### 3.2.4 Bleed Air

The team determined that bleed air availability for OBIGGS is limited. The team received the generic bleed air data listed in Figure 3.2.4-1 from airframe manufacturers.

<b>Flight segment</b>	<b>Sufficient Flow available</b>	<b>Pressure available</b>	<b>Temperature</b>
Ground, APU	no	25 to 54 psia	325 to 430°F
TTT	no	45 psia	350 to 380°F
Climb	yes	40 to 55 psia	330 to 380°F
Cruise	yes	25 to 40 psia	350 to 380°F
Idle descent	no	20 to 35 psia	350 to 380°F

*Figure 3.2.4-1. Bleed Air Availability*

### 3.2.5 Cabin Pressure

The team received the typical cabin pressures listed in Figure 3.2.5-1 for the six aircraft models from airframe manufacturers.

<b>Altitude, feet</b>	<b>Cabin pressure, psia</b>
0	14.7
5,000	14.3
10,000	13.9
15,000	13.5
20,000	13.2
25,000	12.8
30,000	12.4
35,000	12.0
40,000	11.2
45,000	10.9
50,000	10.9
55,000	10.9

*Figure 3.2.5-1. Cabin Pressure Schedule*

### 3.3 ASSUMPTIONS

The following are assumptions that the team developed and used for the analysis.

**Initial Oxygen Concentration.** The starting oxygen concentration in the ullage is assumed to be equal to the final concentration from the previous flight. However, for the first flight of the day or following maintenance actions, the oxygen concentration is assumed to be 20.9% by volume.

**Hydraulic Power Availability.** Even though the full-time OBIGGS does not have to routinely operate between flights, it will have to be capable of ground operation for initialization every morning and following maintenance. The team assumed that aircraft hydraulic power to operate OBIGGS equipment was not available while at the gate. It was further assumed that in order to utilize hydraulic power to operate OBIGGS in flight, it would be necessary to upgrade the existing on-board systems.

**Electrical Power at Aircraft Gate.** The aircraft fuel tanks will land inert and inerting will continue through taxi to the gate. Based on the limited test data that is available, the team assumed that inerting through taxi is sufficient to offset any increase in oxygen concentration during the refueling operation. The team assumed that sufficient ground power could be made available to operate the OBIGGS to initialize the fuel tanks for the first flight of the day or following maintenance.

**Electrical Power in Flight.** The team assumed that sufficient electrical power from the aircraft generators was available to operate the OBIGGS in flight.

**Cabin Air Supply.** The team assumed that the cabin air that normally exhausts through the outflow valve is available to the OBIGGS.

**Ullage Mixing.** It was assumed that as air enters the fuel vent system during a descent, that it quickly mixes with the ullage and with the inert gas produced during the descent.

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**Vent System Modifications.** It was assumed that necessary vent system modifications would be made to prevent cross-venting during crosswind conditions.

**Fuel Tank Initialization.** The team assumed that an extended ground time would be allowed to initialize the tanks for the first flight of the day and following maintenance actions.

### **3.4 CONCEPT DEVELOPMENT**

#### **3.4.1 Concept Characteristics**

In developing the full-time OBIGGS concept, the following fundamental system characteristics were defined:

**Air Separation Technologies.** The team evaluated three different methods of generating NEA: permeable membranes, pressure-swing adsorption, and cryogenic distillation. All three methods remove oxygen from a pressurized, conditioned air stream leaving a nitrogen-rich source that can be supplied to the fuel tanks. Detailed descriptions of the three methods and how the sizing analysis was performed can be found in Addenda A1, A2, and A3.

**Continuous Flow vs. Storage.** Both continuous flow and storage-based OBIGGS were studied in this report. The permeable membrane and the pressure swing-adsorption systems are continuous flow systems. They provide a continuous flow of inert gas to the fuel tanks during the flight and on the ground when the engines are operating.

The cryogenic distillation system also provides a continuous flow of inert gas during these conditions. In addition, low-pressure (~35 psia) cryogenic liquid is made and stored during periods of low demand (e.g. cruise) to initialize the tanks and cool-down the system prior to the first flight of the following day.

Each system has advantages and disadvantages. For example, continuous flow systems do not have the hardware or the safety concerns associated with storage, but systems with storage capability have a shorter initialization time for the first flight of the day and require less input power.

**No Fuel Tank Vent Valves or Tank Pressurization.** Adding fuel tank vent valves to pressurize the fuel tank reduces the required NEA flow rate during descent, but slows down initialization unless provisions are made to bypass the vent valves until initialization is over. Vent valves would require back-up valves, new sensors and indications to prevent catastrophic structural damage when the vent valves fail closed. The cost of this redundancy and instrumentation was judged not to be worth the relatively small allowable tank pressures defined for the six generic aircraft models, so vent valves were not included in the full-time OBIGGS concepts studied. For new designs, if the fuel tank structure was designed for higher pressures, the full-time OBIGGS savings in reduced electrical power, weight, volume, and acquisition cost might offset the weight and cost of the vent valves and the increased structural weight and cost.

#### **3.4.2 Generic OBIGGS concept**

The team initially defined a generic OBIGGS concept that applied to all six generic aircraft (Figure 3.4.2-1) with the three different inerting technologies. It was later found that some characteristics of the generic concept were more valuable on some aircraft models and that an OBIGGS optimized for one particular model may not be identical to a system optimized for a different aircraft. Detailed descriptions of the concept as applied to each of the six generic aircraft models are in the Concept Description section below.

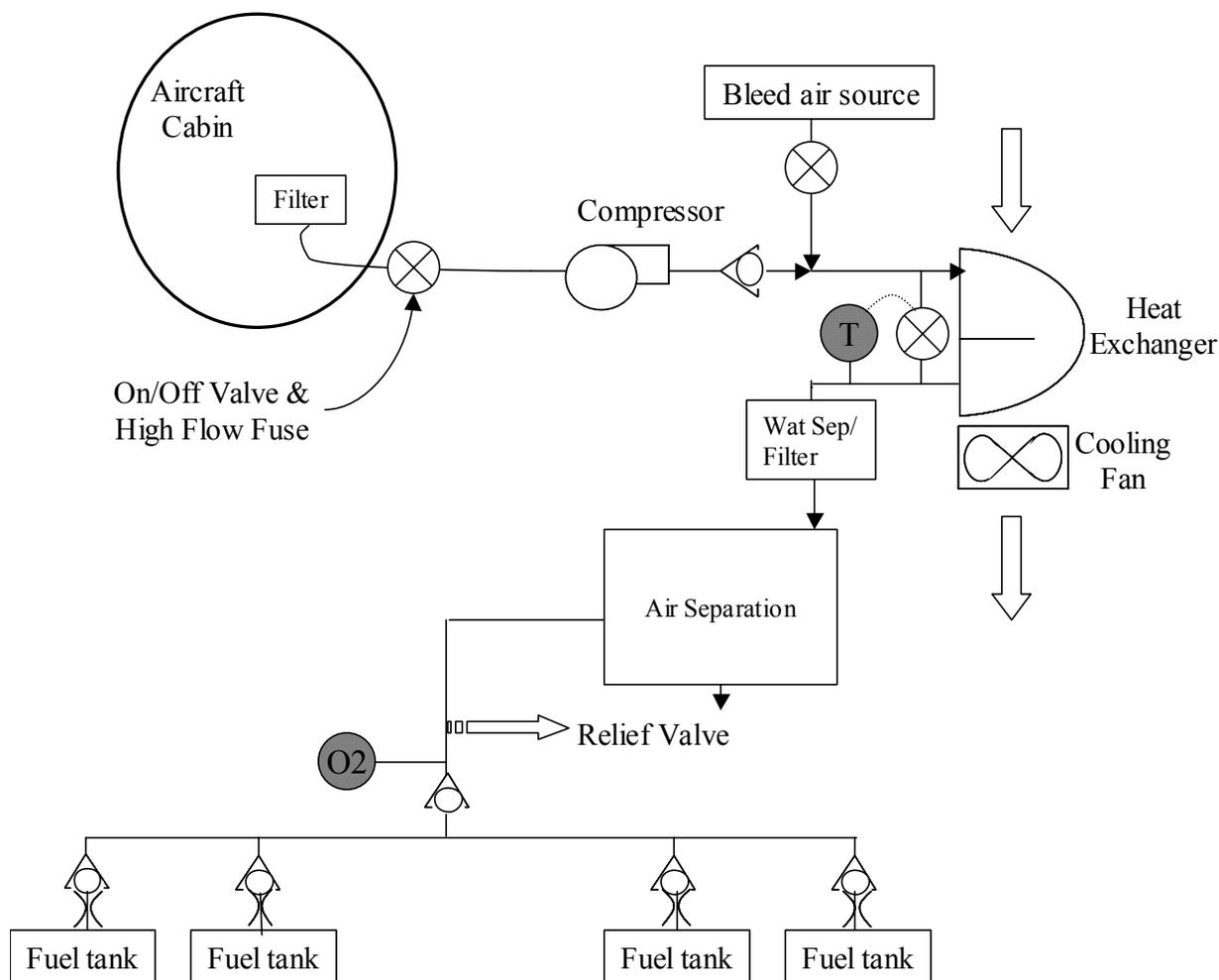


Figure 3.4.2-1. Generic OBIGGS Concept Schematic

**Filtration.** There are two filters in the generic OBIGGS concept. The first is a simple filter at the cabin air compressor inlet intended to keep dust and foreign objects out of the compressor. The second is immediately upstream of the air separation equipment and includes a high efficiency particulate and water separator to remove the solid and liquid particulates from the ASM inlet. Some permeable membranes lose efficiency when exposed to certain hydrocarbons and an appropriate hydrocarbon element would be incorporated into this filter as needed.

**OBIGGS Shutoff Valve.** The OBIGGS shutoff valve opens to allow cabin air into the OBIGGS. The valve contains a flow fuse that will automatically close the valve when the airflow is higher than the maximum normal rate to prevent the cabin from depressurizing in the event of a burst duct outside of the pressure shell.

**Compressor.** The first air source considered for a full-time OBIGGS was the engine bleed air system. However, there were disadvantages to this approach: the available pressures during descent were less than desired for any of the air separation technologies; diverting air from the air conditioning packs would negatively affect the cabin temperatures; the anti-icing systems would be impacted for operations during descent through icing; and the APU cannot always be run to supply bleed air at the gate (the full-time OBIGGS doesn't typically run between flights, but does need to initialize the tanks on the ground before the first flight of the day). These led the team toward an independent source of bleed air. An electric motor-powered compressor supplied by air from the cabin was selected for the generic OBIGGS concept. Hydraulic or turbine powered compressors were rejected, because those power sources are not usually

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available at the gate. By using cabin air instead of ram air, the compressor size and electrical power is significantly reduced (to produce 40 psia at cruise altitude, a cabin pressure compressor requires a pressure ratio of 4:1 while a ram air compressor requires a pressure ratio of 13:1). A 4:1 pressure ratio was selected for the initial generic concept, because it was the highest pressure ratio typically attainable with a single stage compressor. The specific type of compressor (piston, vane, screw, or centrifugal) was later selected for each model, as the airflow rates required by the different technologies were determined.

**Unloading Valve.** The unloading valve opens to reduce the compressor motor loads during start-up. After the motor is running at normal speed, the unloading valve closes. The system controller commands the unloading valve position.

**Temperature Control.** Each of the three different inerting technologies requires a different inlet temperature. The permeable membranes operate at peak efficiency with inlet temperatures at around 180 degrees Fahrenheit. The pressure-swing adsorption and cryogenic distillation systems require inlet temperatures closer to room temperature. The generic OBIGGS concept uses a ram air-cooled heat exchanger that is sized for the worst- case heat load. A modulating bypass valve bypasses the heat exchanger to control the ASM inlet temperature. Redundant temperature sensors prevent damage to the downstream ASM in the event of a sensor failure. An electric fan draws cooling air through the heat exchanger for ground operations.

**Air Separation.** The three different air separation technologies produce NEA from a stream of conditioned, high pressure air. The permeable membrane air separator consists of a large bundle of hollow fibers; each fiber has a porous skin. The pressurized air flows through the inner diameter of the hollow fibers and oxygen molecules preferentially permeate through the fiber walls to an overboard waste port. Some nitrogen molecules also permeate overboard, but the flow that comes out of the hollow fiber is NEA.

The pressure-swing adsorption air separator consists of two parallel beds filled with a molecular sieve material. The material in each bed has many adsorption sites that preferentially adsorb oxygen while at pressure. Within a few seconds the adsorption sites saturate with oxygen and a valve shuttles to connect the pressure to the fresh sieve bed and to connect the saturated bed to an overboard waste port. Exposed to the pressure swing, the oxygen desorbs from the saturated molecular sieve and is exhausted. The cycle then repeats with the two sieve beds alternating between pressure and exhaust. Again the product flow is NEA.

The cryogenic distillation air separator consists of a cryocooler that cools the inlet air flow until it is partially liquefied. The two-phase mixture flows into the distillation column where the nitrogen is separated from the air flow. The high-purity (>99%) nitrogen product can be in the form of a liquid or a gas or both. The oxygen enriched waste gas exits from the column waste port. Other recuperative heat exchangers are included to increase the thermodynamic efficiency of the system and to warm the NEA before it is supplied to the fuel tanks. The gaseous NEA is distributed directly to the fuel tanks. The liquid NEA is stored in a cryogenic dewar that is used to quickly initialize the system and inert the fuel tanks for the first flight of the day.

More details of the theory behind each air separation technology are in Addenda A1, A2, and A3.

**Flow Schedule.** A very simple OBIGGS would produce enough NEA flow at a constant rate and oxygen concentration so that the tanks would remain inert during descent and simply exhaust the excess overboard during the other phases of flight, when less NEA is needed. However by reducing the NEA flow during cruise, the operating costs are reduced, the membrane and PSA produce better quality NEA, and the fuel tanks will reach a lower oxygen concentration over time. Similar benefits apply to the cryogenic distillation system, but it produces high-purity (> 99%) NEA gass all the time, regardless of the flow rate.

The generic full-time OBIGGS concept studied supplies a lower NEA flow rate to the tanks during cruise than during descent. This is accomplished with a valve located downstream of the ASM, called the high flow valve on the schematic. The high flow valve has a fixed leakage rate that provides a significant flow restriction when closed and very little restriction when open. A typical compressor will not be capable of supplying air at both high and low airflow rates. To avoid the need for two separate compressors, the full-time OBIGGS concept uses the cabin pressure compressor to supply the air to the ASM for high flow and bleed air from the engine for low flow. Because the engine bleed is not used during descent or ground operations, the disadvantages of an exclusively bleed air supplied system, discussed in the Compressor paragraph above, are not applicable.

An electronic system controller determines the phase of flight and commands the high flow valve, the bleed shutoff valve, and the compressor to the proper state.

**Relief Valve.** A relief valve is included that is capable of porting all of the system product flow out of the tanks in the event of a rapid pressure rise in the fuel tank due to fuel overflow.

**Distribution Orifices.** Orifices in the distribution lines split the flow between tanks so that proportionally more NEA flow is directed to the tanks with the largest ullage at descent fuel levels.

### 3.5 CONCEPT DESCRIPTIONS

The final concept descriptions for each model and ASM technology are tabulated in Figure 3.5-1. The differences between the generic concept and the final concept for each model can be seen in the table and are discussed below.

	Number of Compressors	Compressor Pressure Ratio	Number of Compressor Stages	Compressor Precooler and Inter-cooler	Air Separation Module Inlet Temperature	Lower NEA Flow Rate during Cruise
<b>Generic Concept</b>						
Membrane	1	4:1	1	No	180F	Yes
PSA	1	4:1	1	No	75F	Yes
Cryo	1	4:1	1	No	75F	Yes
<b>Large Transport</b>						
Membrane	2	6:1	2	Yes	140F	Yes
PSA	2	5:1	2	Yes	75F	Yes
Cryo	1	3:1	1	No	75F	Yes
<b>Medium Transport</b>						
Membrane	1	6:1	2	Yes	140F	Yes
PSA	1	5:1	2	Yes	75F	Yes
Cryo	1	3:1	1	No	75F	Yes
<b>Small Transport</b>						
Membrane	1	4:1	1	No	180F	Yes
PSA	1	4:1	1	No	75F	Yes
Cryo	1	4:1	1	No	75F	Yes
<b>Regional Turboprop</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	Yes
Cryo	1	4:1	1	No	75F	Yes
<b>Regional Turbofan</b>						
Membrane	1	4:1	1	No	180F	Yes
PSA	1	4:1	1	No	75F	Yes
Cryo	1	4:1	1	No	75F	Yes
<b>Business Jet</b>						
Membrane	1	4:1	1	No	180F	Yes
PSA	1	4:1	1	No	75F	Yes
Cryo	1	4:1	1	No	75F	Yes

*Figure 3.5-1. System Characteristics for Each Model and Technology*

### **3.5.1 Large and Medium Transport**

Based on the OBIGGS concept, the team defined the size of the OBIGGS system on each of the aircraft models for each of the ASM technologies. It became obvious that the electrical power requirement for the Large and Medium Transports (LT and MT) was too high to be realistically available (100-150 kVA). The team examined the concepts to determine whether refinements for the LT and MT could be developed that would reduce the electrical power demand to a more reasonable level. This analysis successfully identified a series of refinements to the concept that resulted in power consumption that is still high, but limited to the descent phase when more power is available (galleys are off, etc.) These refinements are discussed below. A detailed schematic for the large and medium transport aircraft membrane and PSA inerting systems is shown in Figure 3.5.1-1 and includes these refinements to lower the power consumption. The cryogenic distillation system power requirements for the LT and MT were lower than the membrane or the PSA, but further power reductions were achieved by using bleed air during the climb and cruise phase, instead of using the cabin pressure compressor as the exclusive bleed source. A detailed schematic for the cryogenic distillation inerting system is shown in Figure 3.5.1-2.

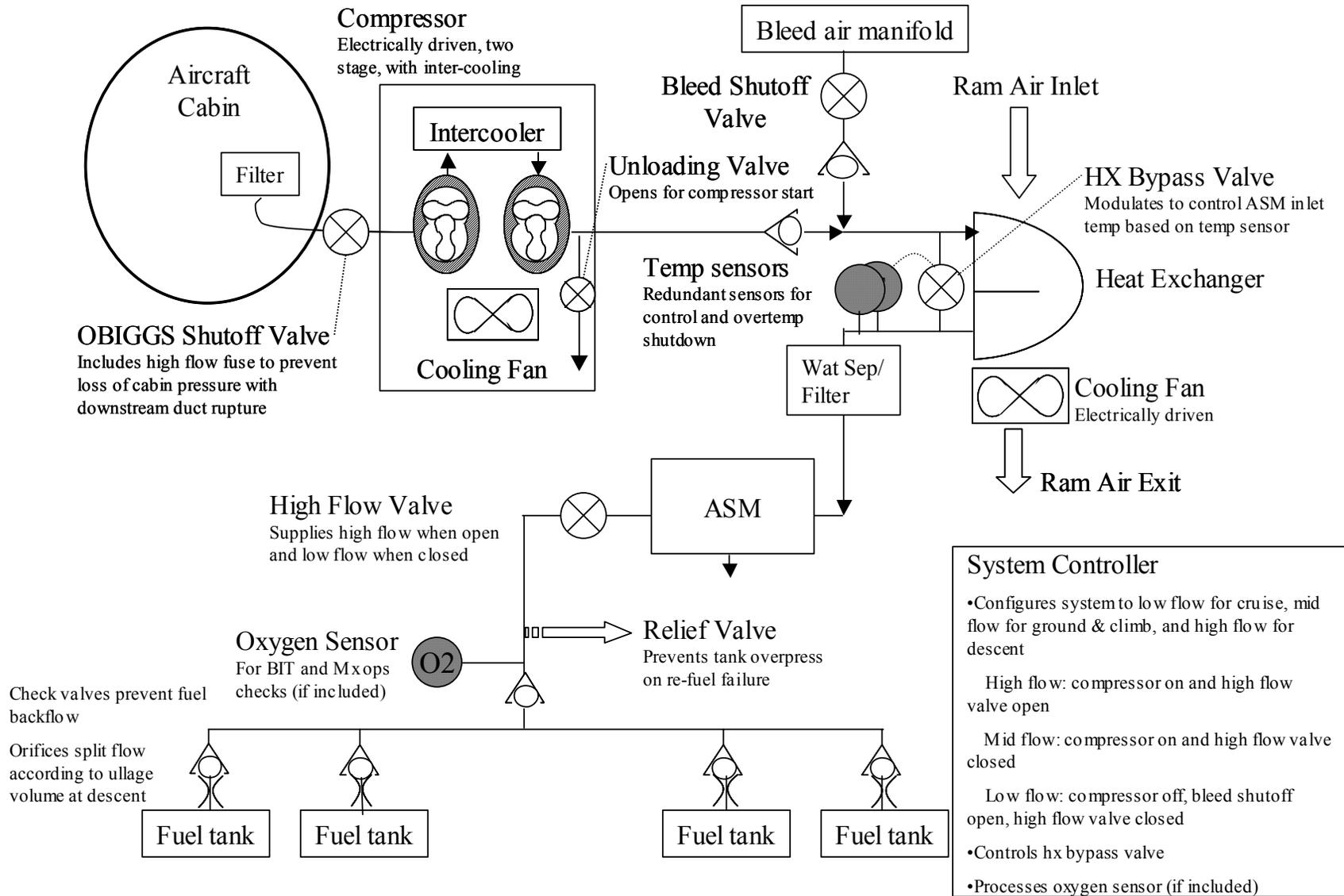


Figure 3.5.1-1. Large and Medium Transport Membrane and PSA Inerting Systems

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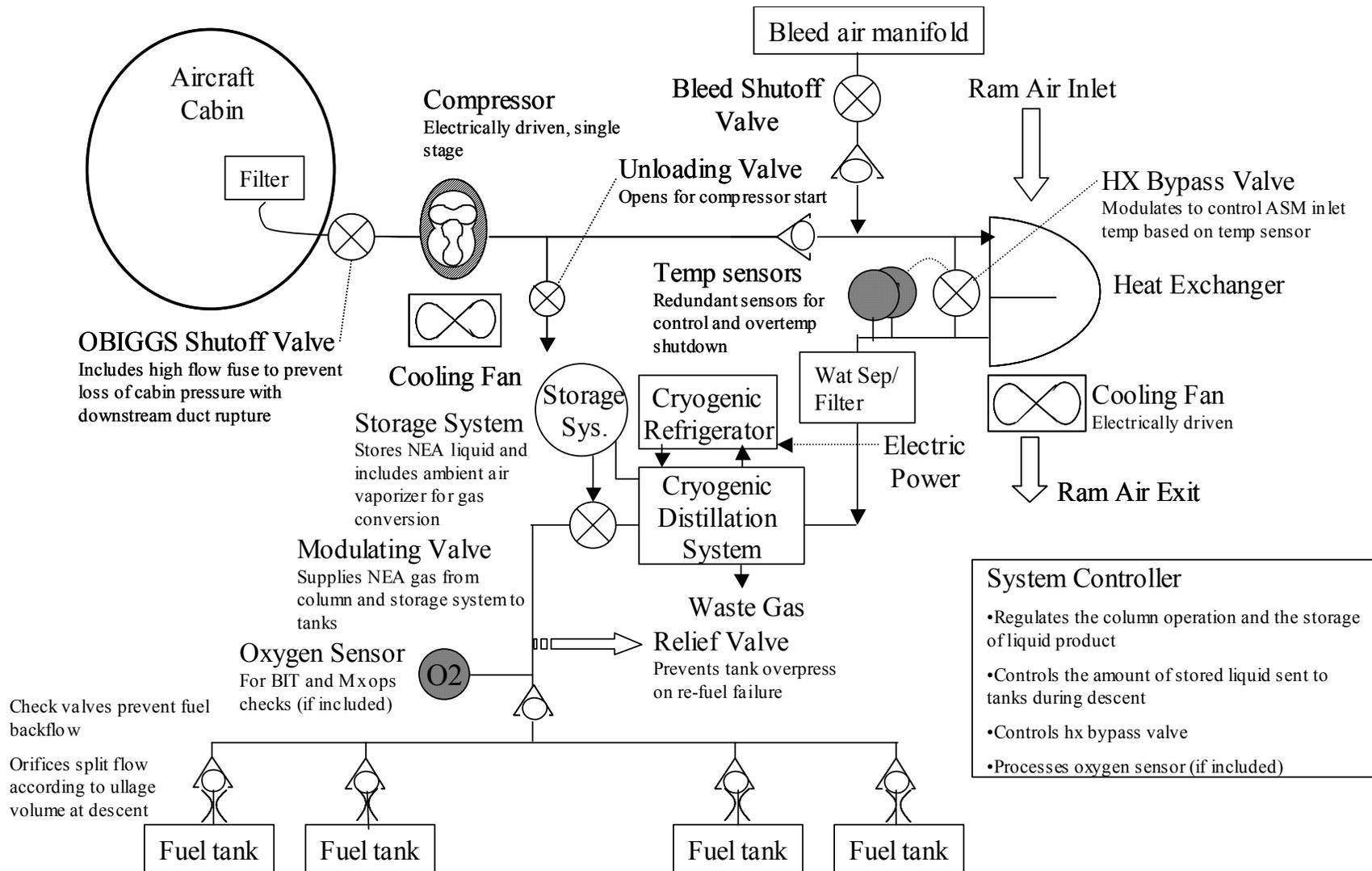


Figure 3.5.1-2. Cryogenic Distillation Inerting System

**Use of Bleed Air During Climb.** Most of the power consumption was from the compressor, which was operated during climb and descent for the generic OBIGGS concept (the compressor was off for low flow during cruise ). The first refinement for the LT and MT membrane and PSA systems was to use the bleed air system as the air source during climb, instead of the compressor. Because the engines are at climb power settings, the bleed pressures and flows are sufficient to generate good quality NEA. The air conditioning and anti-icing systems should have enough pressure to operate normally during the climb. With this refinement, the highest power phases of operation were limited to descent for all of the ASM technologies and ground initialization for the membrane and PSA. The cryogenic distillation system uses stored liquid to initialize on the ground.

**Two-Stage Precooled and Inter-Cooled Compressor.** To reduce power during descent, a two stage compressor with precooled inlet air and an inter-cooler were incorporated into the LT and MT membrane and PSA concepts. At the higher inlet pressures, the ASMs can produce the same quality NEA with less feed air flow which translates to lower compressor electrical power required. The precooler and inter-cooler cause the compressor to operate more efficiently and further reduce the power demand.

**Improved Low Flow Performance.** By further restricting the NEA flow rate at low flow (increased restriction in the high flow valve) the NEA produced by the membrane and PSA can be less than 1% oxygen. The cryogenic distillation system always makes NEA that is less than 1% oxygen. Because of the longer cruise times associated with the LT and MT, the oxygen concentration in the tank can effectively reach the 1% O<sub>2</sub> level. By starting the descent with this low oxygen concentration in the tanks, a lower rate of NEA can be supplied to the tanks while ambient air is entering the tanks.

**Lower Membrane Inlet Temperature.** By controlling the inlet temperature to 140 degrees Fahrenheit, instead of 180, the membrane ASM uses less compressed air but incurs a weight penalty.

**Initialization With Only One Compressor.** A motor for a single compressor, for the membrane or PSA LT system, is too big to start due to the in-rush current. This was resolved with two compressors in parallel to provide the same air flow. The power demand is reduced by running only one of the two compressors when the system is operated on the ground (to initialize the fuel tanks for the first flight of the day or following maintenance).

### **3.5.2 Small Transport, Regional Turbofan and Turboprop, and Business Jet**

When the high flow rates were determined for the four smaller aircraft models, there was not enough difference between the low flow and high flow rates to justify the minor, additional complexity associated with a dual flow membrane or PSA system. Even though unnecessary, all of the membrane and PSA systems in this report, except the Regional Turboprop membrane system, were sized with high and low flow settings. There is not enough difference between the single flow and the dual flow systems to affect the results of the study. While a dual flow schedule should be evaluated for any OBIGGS application, the generic model results indicate that there are diminishing returns as the aircraft size decreases. A detailed schematic of the simplified full-time OBIGGS membrane and PSA concepts for the smaller aircraft models is shown in Figure 3.5.2-1. The cryogenic concept remains unchanged for the smaller aircraft models.

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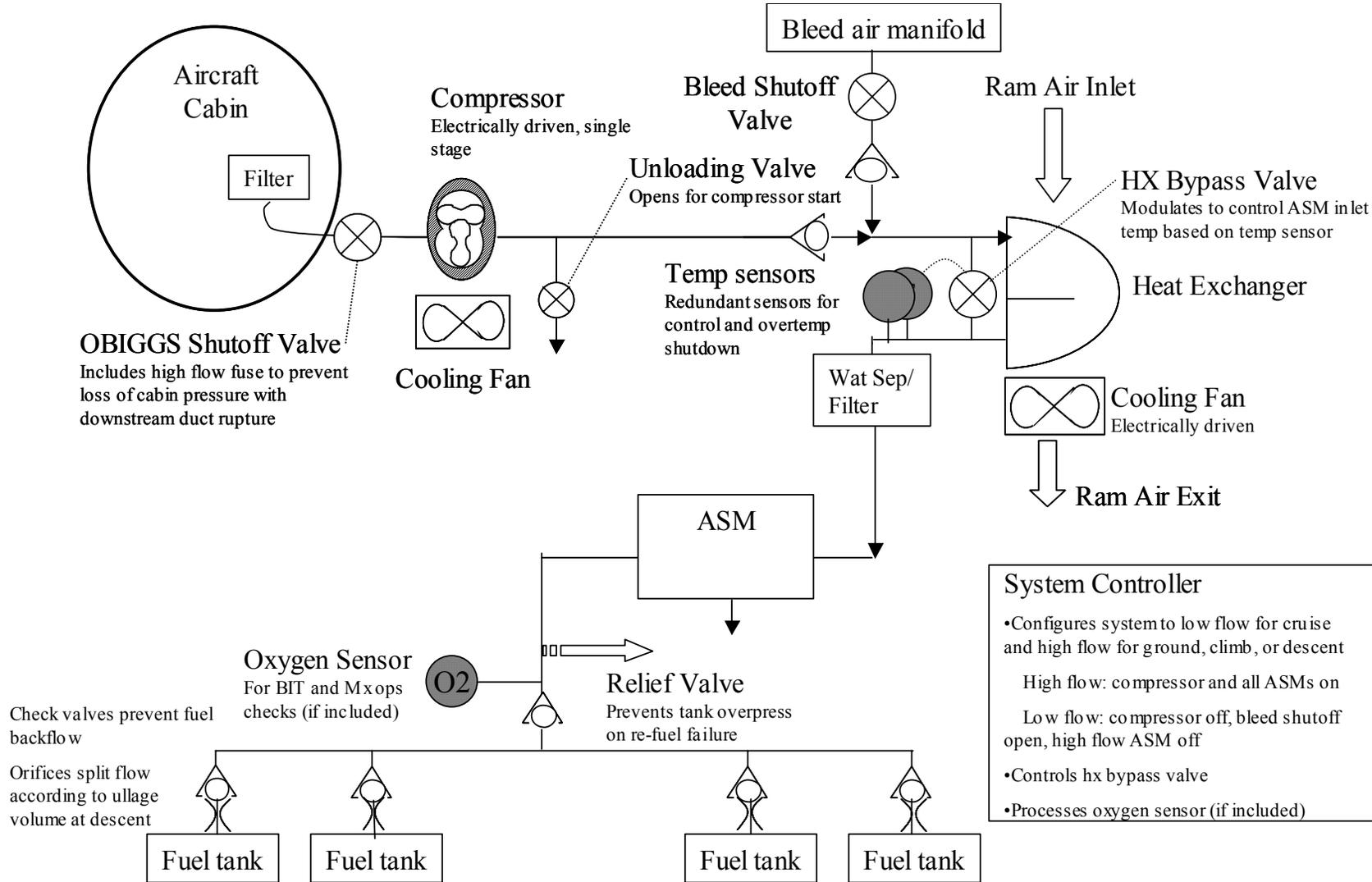


Figure 3.5.2-1. Simplified Membrane and PSA OBIGGS Concept for Small Aircraft

### 3.6 SYSTEM SIZING AND PERFORMANCE

#### 3.6.1 Sizing Criteria

The required NEA high flow rate for a full-time OBIGGS is determined by the descent. The other factors that affect NEA demand (ullage cooling, fuel burn, and oxygen evolution during climb) all turned out to be of lesser magnitude. The short mission is more severe than the longer missions, because of the lower starting fuel quantities. The low fuel quantities result in large ullage volumes that take longer to inert early in the flight. Also, the shorter cruise segments result in less system operating time and so the tank concentration, at the top of descent, is higher for the short mission.

The team determined the required NEA flows for each model and tank configuration using the aircraft and mission data from the 1998 FTHWG and the FAA-supplied inerting model. The team used the inerting model to confirm that the tank oxygen concentrations did not exceed the 10% inert limit during any phase of the short, medium, or long missions for any of the OBIGGS concepts.

The turn-time does not affect the NEA flow rate required for the full-time OBIGGS. Because the ullage is inert on landing, the system is not required to operate while the aircraft is at the gate. The team assumed that any oxygen that might evolve from the new fuel would be offset by the system operation during taxi in and out of the gate.

After the NEA flows were determined, the ASM suppliers sized the air separation equipment and calculated the feed air flow that would be required to produce the NEA. This allowed the sizes of the compressor, heat exchangers, and other equipment to be estimated.

#### 3.6.2 Parametric Sizing Curves

The system weights, volumes, peak power consumption, and acquisition costs of the full-time OBIGGS for the generic aircraft models and tank configurations are plotted in parametric sizing curves for easy interpolation to other aircraft models. To use the curves, the required NEA flow for OBIGGS is found in Figure 3.6.2-1 based on the tank size. For that NEA flow, the system weight, volume, electrical power consumption, and acquisition cost can be estimated from Figures 3.6.2-2 through 3.6.2-5.

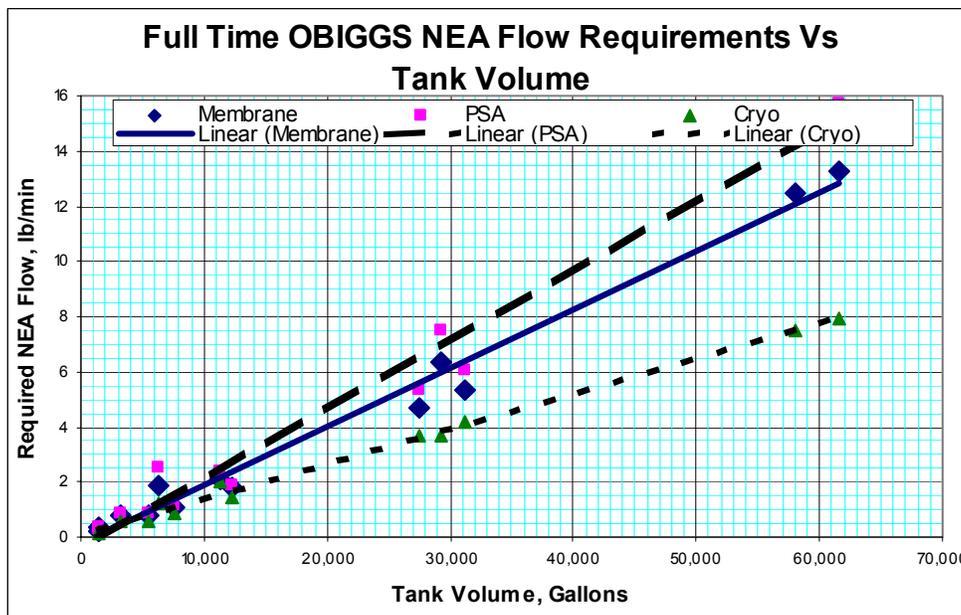


Figure 3.6.2-1. NEA Flow vs Tank Volume

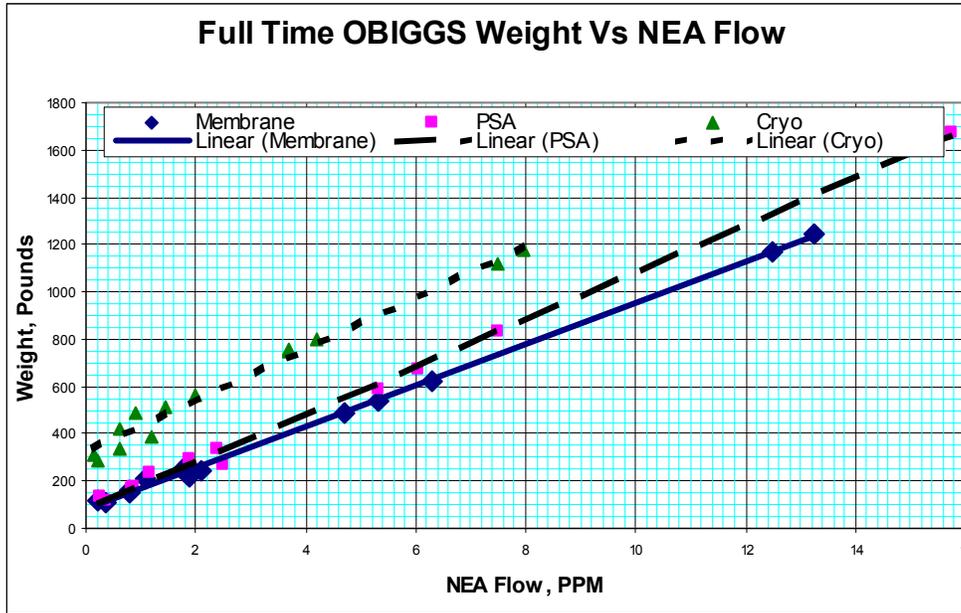


Figure 3.6.2-2. Weight vs NEA Flow

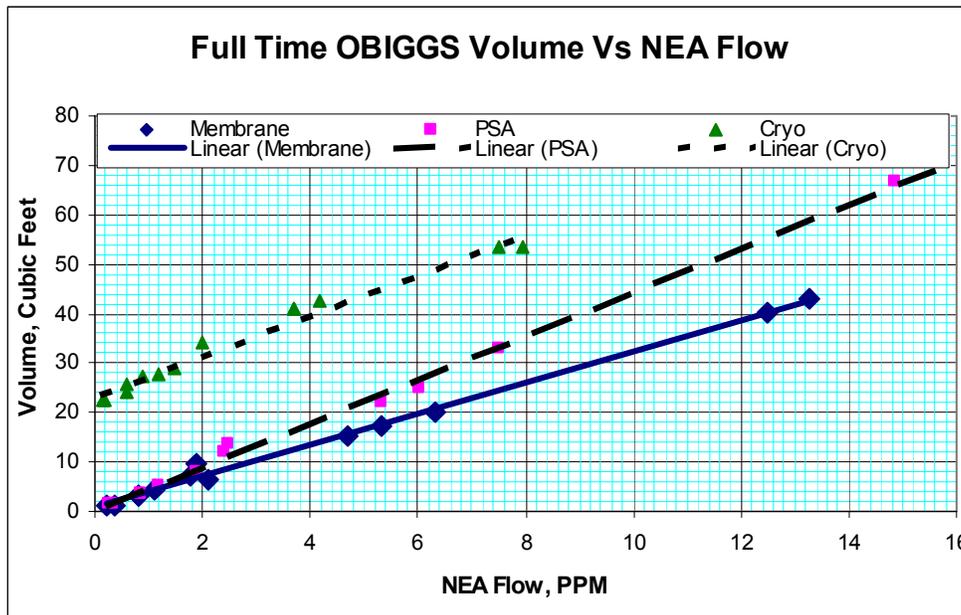


Figure 3.6.2-3. Volume vs NEA Flow

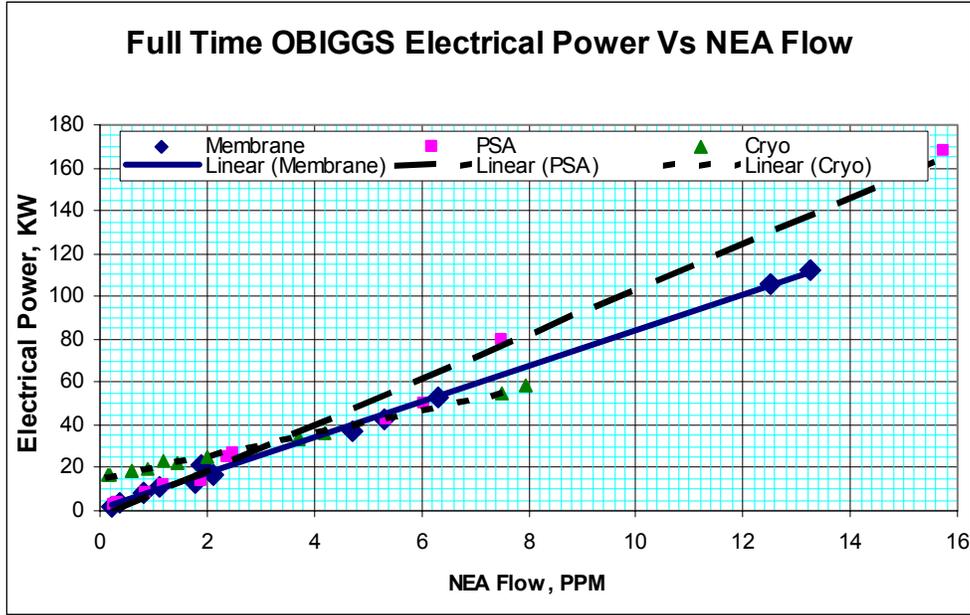


Figure 3.6.2-4. Power vs NEA Flow

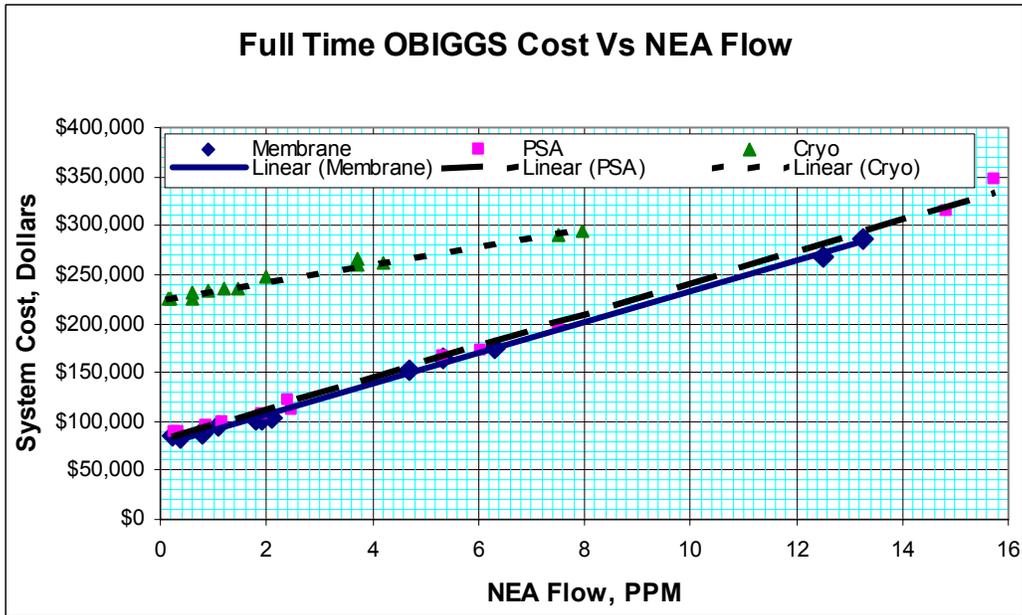


Figure 3.6.2-5. Cost vs NEA Flow

The NEA flow rate referenced in the parametric sizing curves is the high flow rate required during descent. The low flow rate used during cruise does not affect the equipment sizing. The NEA oxygen concentrations, for each ASM technology and flight phase that were used to generate the curves, are tabulated in Figure 3.6.2-6. The parametric sizing curves are not valid for other NEA oxygen concentrations.

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	Ground	Climb	Cruise	Descent
Membrane	7.5%	5%	3%	5%
PSA	7%	5.3%	4.3%	8.1%
Cryo	1%	1%	1%	1%

Figure 3.6.2-6. Full-Time OBIGGS NEA Oxygen Concentrations

A quick look at Figures 3.6.2-2 to 3.6.2-5 can give the mistaken impression that the cryogenic distillation system is not competitive with the other inerting technologies. Because the cryogenic distillation system requires significantly lower NEA flows for the same tank volume, the actual system parameters must be calculated for a given model to get a valid comparison.

The following examples demonstrate membrane, PSA, and cryogenic distillation system sizing for an aircraft with a total fuel capacity of 35,000 gallons (including all main and center wing tanks plus auxiliary tanks):

**Membrane System.** Figure 3.6.2-1 shows that a 35,000 gallon tank capacity requires approximately 7 pounds per minute of NEA at membrane purity. Figures 3.6.2-2 to 3.6.2-5 indicate that a membrane system to produce 7 lb/min of NEA weighs approximately 700 lbs, occupies 23 cubic feet, requires 60 kVA of electrical power during descent, and has initial acquisition costs of \$180,000.

**PSA System.** Figure 3.6.2-1 shows that about 8.5 pounds per minute of NEA at PSA purity are required. Figures 3.6.2-2 to 3.6.2-5 indicate that the corresponding PSA system weighs approximately 950 pounds, occupies 38 cubic feet, requires 88 kVA of electrical power during descent, and has initial acquisition costs of \$220,000.

**Cryogenic Distillation System.** Figure 3.6.2-1 shows that about 4.5 pounds per minute of NEA at cryo purity are required. Figures 3.6.2-2 to 3.6.2-5 indicate that the corresponding cryogenic distillation system weighs approximately 825 pounds, occupies 42 cubic feet, requires 45 kVA of peak electrical power and has initial acquisition costs of \$260,000.

### 3.6.3 System Results

The system weight, volume, peak electrical power consumed, and initial acquisition cost for the OBIGGS sized for each model and tank configuration are shown in Figures 3.6.3-1 through 3.6.3-3.

### OBIGGS - Center Wing Tank

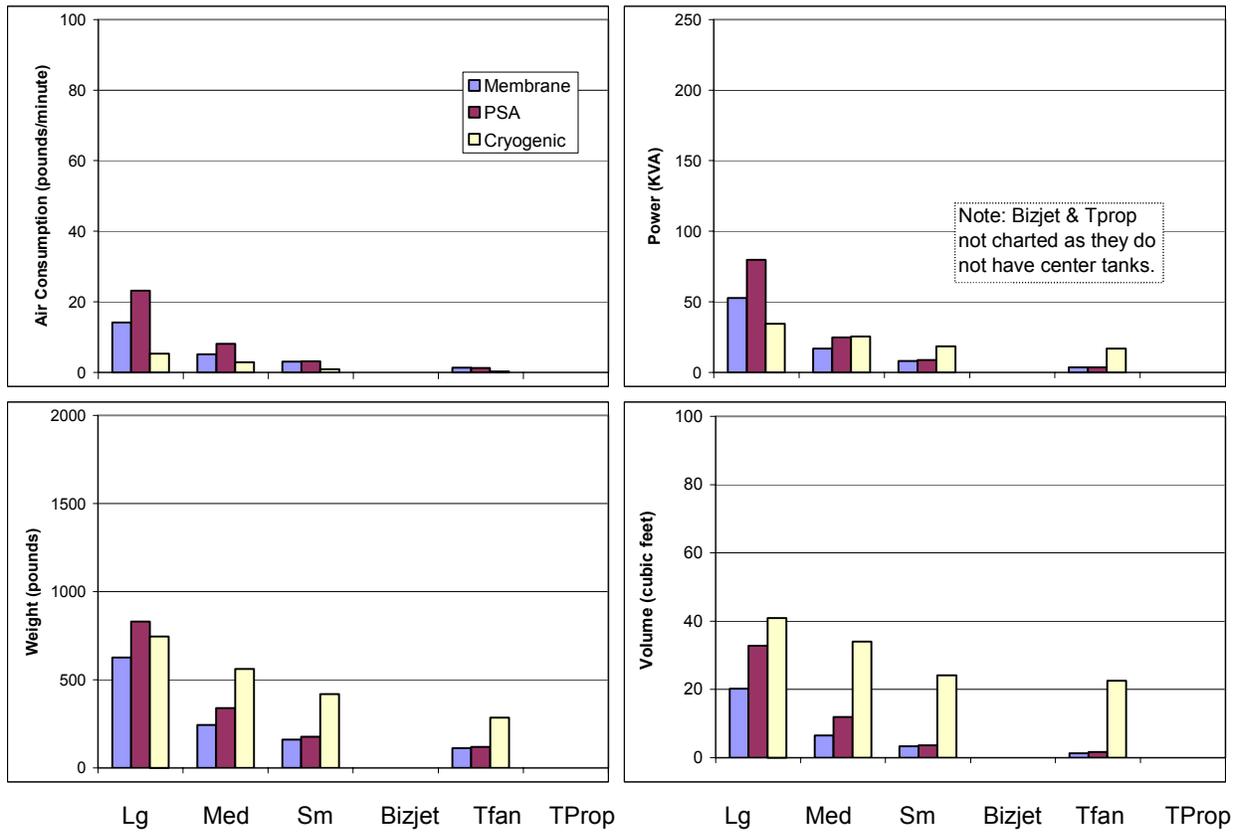
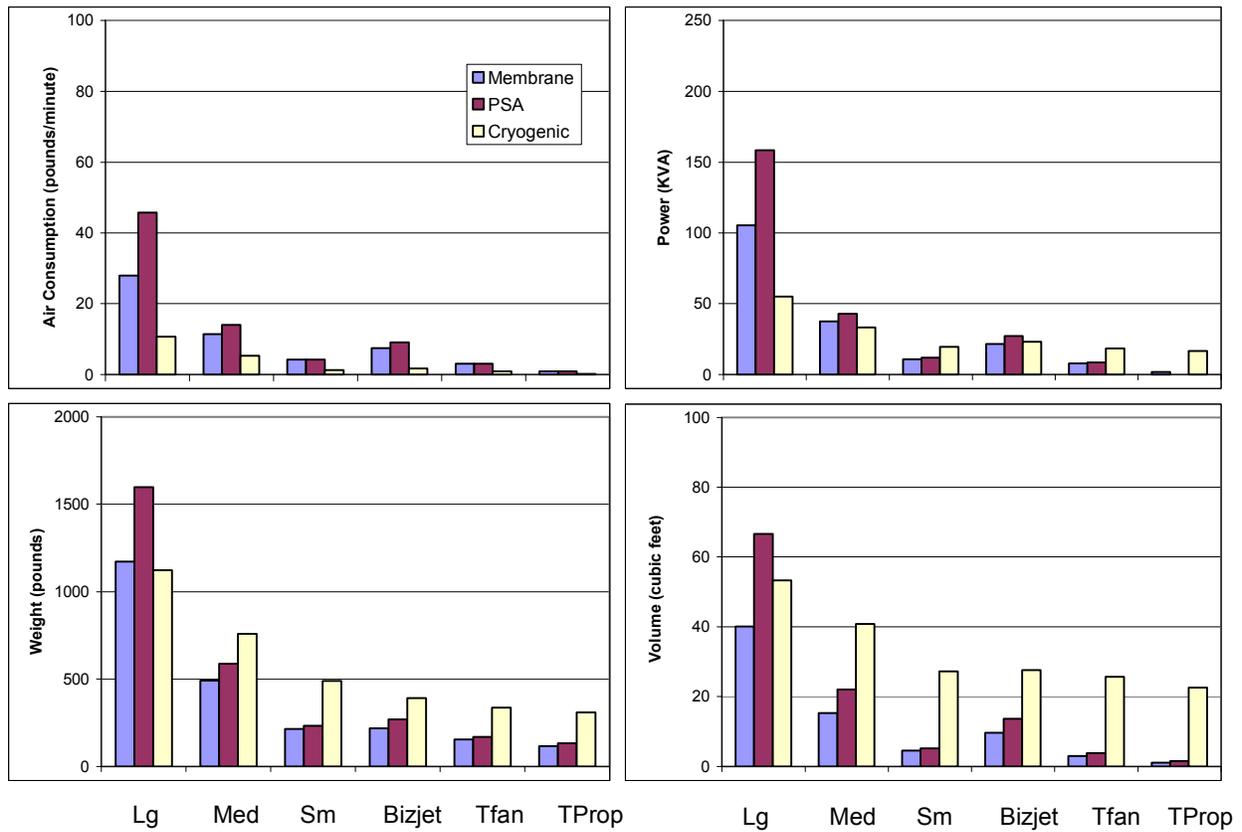


Figure 3.6.3-1. OBIGGS Air Consumption, Power, Volume, and Weights for Center Tanks

**OBIGGS - Center & Wing Tanks**



*Figure 3.6.3-2. OBIGGS Air Consumption, Power, Volume, and Weights for Center and Main Tanks*

OBIGGS - Center, Wing & Aux Tanks

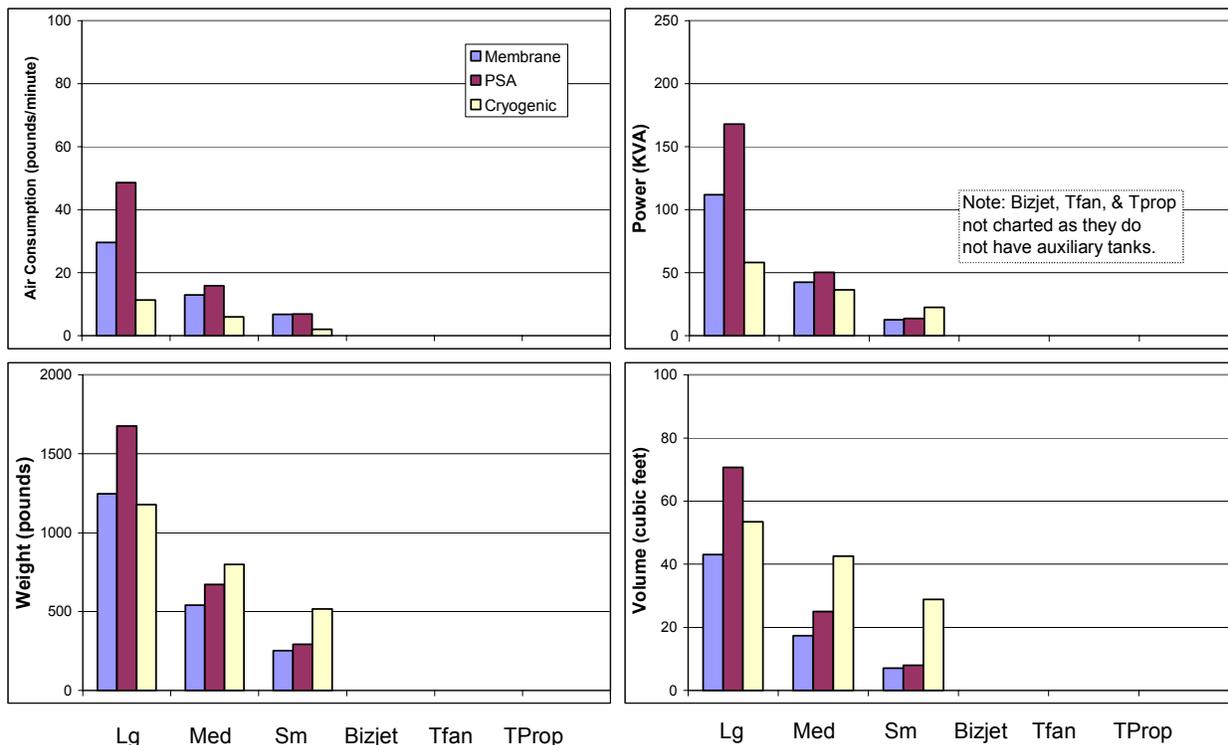


Figure 3.6.3-3. OBIGGS Air Consumption, Power, Volume, and Weights for Center, Main, and Auxiliary Tanks

3.6.4 Flammability Exposure

The full-time OBIGGS was designed to maintain an inert ullage concentration for all normal ground and flight conditions. During emergency conditions or operation with the system failed, the tanks may not remain inert. As a result, there remains a very small flammability exposure for the full time OBIGGS. A comparison of OBIGGS performance with the other fuel tank inerting options is shown in the Conclusions.

3.7 WEIGHT

Figures 3.7-1 through 3.7-3 summarize the OBIGGS weights for the membrane, PSA, and cryogenic distillation inerting systems for each of the generic aircraft. Each table provides the total weight for the “major” and “other” components identified for each system. “Other” components include such items as wiring, ducting, and valves, and their total estimated weights have been combined.

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Membrane System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight	MT CWT Only Shipset Weight	ST CWT Only Shipset Weight (lbm)	RTF CWT Only Shipset Weight (lbm)	LT CWT+Main +Aux Shipset Weight (lbm)	MT CWT+Main+ Aux Shipset Weight (lbm)	ST CWT+Main +Aux Shipset Weight
Major Components:													
Compressor	93.4	34.2	15.1	10.9	2.6	12.2	46.6	15.3	11.0	4.9	99.2	39.0	24.4
Heat exchanger / fan	58	23.7	13.5	9.8	5	15.4	29.3	10.6	9.9	4.4	65.7	26.8	21.9
Air separation module	234	90	27.5	20	5.4	54	118.2	36.9	20.1	9.0	248.0	102.0	44.6
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Major component sub-totals	385	148	56	41	13	82	194	63	41	18	413	168	91
Other Components:													
Cabin air filter assv	6	4	4	4	4	4	**	**	**	**	**	**	**
OBIGGS shutoff valve	4	3	3	3	3	3	**	**	**	**	**	**	**
Precooler	20	10	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Inter-cooler	20	10	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Temperature sensor	0.3	0.15	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Bypass valve	6	2.5	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Compressor unloading valve	6	3	2	2	2	2	**	**	**	**	**	**	**
Compressor discharge check valve	1	0.75	0.75	0.5	0.5	0.75	**	**	**	**	**	**	**
Bleed shutoff valve	3	2.5	2.5	2.5	2.5	2.5	**	**	**	**	**	**	**
Bleed check valve	1	0.75	0.75	0.75	0.75	0.75	**	**	**	**	**	**	**
Bypass valve	3	2.5	2.5	2.5	2.5	2.5	**	**	**	**	**	**	**
Temperature sensor	0.3	0.3	0.3	0.3	0.3	0.3	**	**	**	**	**	**	**
Water separator/filter assv	10	7	7	7	7	7	**	**	**	**	**	**	**
High flow valve	3	2.5	2.5	2.5	n/a	2.5	**	**	**	**	**	**	**
Relief valve	2.5	2	2.0	2	2	2	**	**	**	**	**	**	**
Fuel tank check valve	2.5	2.5	2.5	2.5	2.5	2.5	**	**	**	**	**	**	**
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	**	**	**	**	**	**	**
Ducting	178	116	52.5	38	38	38	**	**	**	**	**	**	**
Wiring	15	10	5.0	5	5	8	**	**	**	**	**	**	**
Installation Hardware	71.1	30.2	12.9	10.5	6.0	16.7	**	**	**	**	**	**	**
Structural Modifications	100	50	20.0	10	10	10	**	**	**	**	**	**	**
Ram Ducting	60	30	15.0	10	10	10	**	**	**	**	**	**	**
Compressor wiring	301	58.7	15.4	4.1	1.7	12.8	**	**	**	**	**	**	**
Overheat sensors	1	1	1	1	1	1	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Other component sub-totals</b>	820	355	157	114	104	132	449	186	119	92	868	388	178
<b>System Totals</b>	1206	503	213	154	117	213	643	249	160	110	1281	556	269
On-board oxygen sensor (not included in system totals)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

\*\* Indicates scaled data

Figure 3.7-1. Summary of OBIGGS Weights—Membrane Systems

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PSA System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight	MT CWT Only Shipset Weight	ST CWT Only Ship- set Weight (lbm)	RTF CWT Only Ship- set Weight (lbm)	LT CWT+Main +Aux Shipset Weight (lbm)	MT CWT+Main+ Aux Shipset Weight (lbm)	ST CWT+Main +Aux Ship- set Weight
<b>Maior Components:</b>													
Compressor	140	39.1	16.3	11.8	3.3	15.3	70.4	22.6	12.0	4.8	148.4	45.7	26.5
Heat exchanger / fan	177	54.2	12.5	9	6	34.9	89.4	31.3	9.2	3.7	187.6	61.4	20.3
Air separation module	315	115	44.3	34	15.6	75	153.0	69.4	31.2	18.1	333.9	130.3	71.9
<b>Maior component sub-totals</b>	<b>632</b>	<b>208</b>	<b>73</b>	<b>55</b>	<b>25</b>	<b>125</b>	<b>313</b>	<b>123</b>	<b>52</b>	<b>27</b>	<b>670</b>	<b>237</b>	<b>119</b>
<b>Other Components:</b>													
Cabin air filter assy	8	4	4	4	4	4	**	**	**	**	**	**	**
OBIGGS shutoff valve	4	3	3	3	3	3	**	**	**	**	**	**	**
Precooler	20	10	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Inter-cooler	20	10	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Temperature sensor	0.3	0.15	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Bypass Valve	6	2.5	n/a	n/a	n/a	n/a	**	n/a	n/a	n/a	**	**	n/a
Compressor unloading valve	6	3	2	2	2	2	**	**	**	**	**	**	**
Compressor discharge check valve	1	0.75	0.75	0.5	0.5	0.75	**	**	**	**	**	**	**
Bleed shutoff valve	3	2.5	2.5	2	2	2.5	**	**	**	**	**	**	**
Bleed check valve	1	0.75	0.75	0.5	0.5	0.75	**	**	**	**	**	**	**
Bypass valve	3	2.5	2.5	2	2	2.5	**	**	**	**	**	**	**
Temperature sensor	0.3	0.3	0.3	0.3	0.3	0.3	**	**	**	**	**	**	**
Water separator/filter assv	13	7	7	7	7	7	**	**	**	**	**	**	**
High flow valve	3	2.5	2.5	2.5	2.5	2.5	**	**	**	**	**	**	**
Relief valve	2.5	2	2	2	2	2	**	**	**	**	**	**	**
Fuel tank check valve	2.5	2.5	2.5	2.5	2.5	2.5	**	**	**	**	**	**	**
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	**	**	**	**	**	**	**
Ducting	178	116	52.5	38	38	38	**	**	**	**	**	**	**
Wiring	15	10	5	5	5	8	**	**	**	**	**	**	**
Installation Hardware	108.8	39.3	15.4	12.5	8.0	23.3	**	**	**	**	**	**	**
Structural Modifications	100	50	20	10	10	10	**	**	**	**	**	**	**
Ram Ducting	60	30	15	10	10	10	**	**	**	**	**	**	**
Compressor wiring	452	88.6	15.4	4.1	1.7	12.8	**	**	**	**	**	**	**
Overheat sensors	1	1	1	1	1	1	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Other component sub-totals</b>	<b>1014</b>	<b>394</b>	<b>160</b>	<b>114</b>	<b>107</b>	<b>138</b>	<b>449</b>	<b>186</b>	<b>119</b>	<b>92</b>	<b>868</b>	<b>388</b>	<b>178</b>
<b>System Totals</b>	<b>1646</b>	<b>602</b>	<b>233</b>	<b>169</b>	<b>132</b>	<b>264</b>	<b>762</b>	<b>309</b>	<b>171</b>	<b>119</b>	<b>1538</b>	<b>625</b>	<b>297</b>
On-board oxygen sensor (not included in system totals)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

\*\* Indicates scaled data

Figure 3.7-2. Summary of OBIGGS Weights—PSA Systems

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Cryogenic Distillation System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight	MT CWT Only Shipset Weight	ST CWT Only Shipset Weight (lbm)	RTF CWT Only Shipset Weight (lbm)	LT CWT+Main +Aux Shipset Weight (lbm)	MT CWT+Main+ Aux Shipset Weight (lbm)	ST CWT+Main +Aux Shipset Weight
<b>Major Components:</b>													
Compressor	27	12.2	2.8	2.6	0.3	4.3	13.5	6.6	1.8	0.6	28.6	13.8	4.5
Heat exchanger / fan	42.5	21.3	2.4	2.2	1.3	6.8	21.3	11.6	1.5	0.5	45.1	24.1	3.9
<b>Cryo Air Separation Components:</b>													
Inlet shutoff valve	5	**	4	3	3	5	**	**	**	**	**	**	**
Cryocooler bleed air valve	5	**	4	3	3	5	**	**	**	**	**	**	**
Flow sensor	0.1	**	0.1	0.1	0.1	0.1	**	**	**	**	**	**	**
Molecular sieve control valves	10	**	8	6	6	10	**	**	**	**	**	**	**
Molecular sieve system	50	**	2.5	9	2.5	16	**	**	**	**	**	**	**
Purge heat exchanger	5	**	5	5	5	5	**	**	**	**	**	**	**
Purge heat exchanger valve-Air Side	5	**	4	4	4	5	**	**	**	**	**	**	**
Purge heat exchanger valve-Waste Side	5	**	4	4	4	5	**	**	**	**	**	**	**
LNEA Dewar Cooldown Valve	5	**	4	4	4	4	**	**	**	**	**	**	**
Inlet Recuperator	120	**	44	12	6	16	**	**	**	**	**	**	**
Inlet cooler	3	**	3	3	3	3	**	**	**	**	**	**	**
Cryocooler	195	**	161	135	127	130	**	**	**	**	**	**	**
LNEA Dewar	100	**	50	0	0	0	**	**	**	**	**	**	**
Dewar level sensor	0.5	**	0.5	0	0	0	**	**	**	**	**	**	**
Distillation column	40	**	15	15	15	16	**	**	**	**	**	**	**
Distillation column gas valve	5	**	4	4	3	5	**	**	**	**	**	**	**
Distillation column liquid valve	5	**	4	4	3	5	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Cryo component subtotals	559	414	317	211	189	230	414	338	283	173	580	440	330
<b>Major component subtotals</b>	<b>628</b>	<b>448</b>	<b>322</b>	<b>216</b>	<b>190</b>	<b>241</b>	<b>449</b>	<b>356</b>	<b>286</b>	<b>174</b>	<b>654</b>	<b>478</b>	<b>338</b>
<b>Other Components:</b>													
Cabin air filter assy	4	4	4	4	4	4	**	**	**	**	**	**	**

\*\* Indicates scaled data

Figure 3.7-3. Summary of OBIGGS Weights—Cryogenic Distillation Systems (Sheet 1 of 2)

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Cryogenic Distillation System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight (lbm)	MT CWT Only Shipset Weight (lbm)	ST CWT Only Shipset Weight (lbm)	RTF CWT Only Shipset Weight (lbm)	LT CWT+Main +Aux Shipset Weight (lbm)	MT CWT+Main+ Aux Shipset Weight (lbm)	ST CWT+Main +Aux Shipset Weight (lbm)
OBIGGS shutoff valve	4	2	2	2	2	2	**	**	**	**	**	**	**
Compressor unloading valve	3	3	2	2	2	2	**	**	**	**	**	**	**
Compressor discharge check valve	0.5	0.5	0.5	0.5	0.5	0.5	**	**	**	**	**	**	**
Bleed shutoff valve	2.5	2	2	2	2	2	**	**	**	**	**	**	**
Bleed check valve	0.5	0.5	0.5	0.5	0.5	0.5	**	**	**	**	**	**	**
Bypass valve	2.5	2	2	2	2	2	**	**	**	**	**	**	**
Temperature sensor	0.3	0.3	0.3	0.3	0.3	0.3	**	**	**	**	**	**	**
Water separator/filter assy	7	7	7	7	7	7	**	**	**	**	**	**	**
Temperature sensor	0.15	0.15	0.15	0.15	0.15	0.15	**	**	**	**	**	**	**
Relief valve	2.5	1.5	1.5	1.5	1.5	1.5	**	**	**	**	**	**	**
Fuel tank check valve	2.5	2.5	2.5	2.5	2.5	2.5	**	**	**	**	**	**	**
Controller / control card	5.5	5.5	5.5	5.5	5.5	5.5	**	**	**	**	**	**	**
Ducting	178	116	52.5	38	38	38	**	**	**	**	**	**	**
Wiring	15	10	5	5	5	5	**	**	**	**	**	**	**
Installation Hardware	83.8	62.7	47.6	31.8	28.5	34.4	**	**	**	**	**	**	**
Structural Modifications	65	45	25	10	10	25	**	**	**	**	**	**	**
Ram Ducting	15	12	10	10	10	10	**	**	**	**	**	**	**
Compressor wiring	78	23.1	1.5	1.4	0.4	2.8	**	**	**	**	**	**	**
Overheat sensors	1	1	1	1	1	1	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Other component sub-totals</b>	471	301	173	127	123	146	449	186	119	92	868	388	178
<b>System Totals</b>	1099	748	495	343	313	387	898	542	405	266	1522	866	516
On-board oxygen sensor (not included in system totals)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

\*\* Indicates scaled data

Figure 3.7-3. Summary of OBIGGS Weights—Cryogenic Distillation Systems (Sheet 2 of 2)

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### **3.7.1 Air Separation Modules**

Weights were developed for OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** Membrane weight was based on a standard module size of 18 pounds. Knowing the total flow for each of the 6 aircraft models and the flow capabilities of a standard module, simple division determines the number of modules required. This number of modules multiplied by the module weight yielded the total weight for the ASMs.

**Pressure-Swing Adsorption.** The PSA air separator calculations were made empirically. A production OBIGGS air separator manufactured by the PSA supplier was operated in an altitude chamber at the altitudes and supply pressures consistent with the ARAC study. At each altitude, the air consumption, product flow and product purity was measured. The downstream flow was restricted with a simple throttling device. The throttling valve was set to produce a nominal 10% oxygen level in the NEA product at approximately sea level to simulate high flow. A separate set of tests were run with the throttling valve set to produce NEA at 7% oxygen to verify low flow performance.

Based on the testing, the weight of the molecular sieve needed for each model was estimated from the number of separators needed to produce the required NEA at high flow. The structural weight (such as the mounting structure and sieve containers) was also scaled upward or downward based on supplier experience, although some economies of scaling were assumed.

**Cryogenic Distillation.** The weight of the cryogenic distillation system was not determined by scaling. Based on prior experience and design data, the team developed relationships for each component based upon critical parameters. For example, the inlet airflow was related to the volume and weight of the inlet recuperator. This relationship was not linear. Each component was characterized in this way and each system was uniquely specified for the particular aircraft and tank configuration.

### **3.7.2 Compressor**

Compressor weight was based on the number, size, and type needed for each ASM technology. The compressor weight includes the compressor, motor, motor cooling fan and start contactor. The weight estimates were based on design schemes prepared for 15kW shaft power compressors of the screw and centrifugal type. From this a linear metric of weight as a function of power was generated. It is considered that this tends to give an overestimate of weight for high power machines and an underestimate for low power machines, which is conservative in the weight-critical cases. Above 30kW shaft power, two or more compressors are proposed.

### **3.7.3 Heat Exchanger/Cooling Fan**

The heat exchangers and cooling fans were sized by suppliers of aircraft quality heat exchangers and cooling fans. The heat exchangers and cooling fans for each aircraft were sized to cool air from the compressor to the appropriate ground temperature limits (125 degrees Fahrenheit for the PSA and cryogenic distillation systems and 165 degrees Fahrenheit for the membrane systems) using 111 degrees Fahrenheit ambient air as the heat sink. For OBIGGS, the heat exchanger and cooling fan sizes were also evaluated at the worst-case in-flight conditions to ensure that all requirements were met. An effort was made to minimize the overall size of the system by performing parametrics on heat exchanger and fan sizes to determine the best overall system. The final results are based on a system that had favorable weight, volume, power and costs numbers.

Heat exchanger and cooling fan weights were determined for each of the aircraft and system types. Heat exchanger weight includes the core, inlet/outlet headers, and connections to the mating tubing. The weight of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

**3.7.4 Other Components**

The team estimated the weight of each of the "Other" Components in the full-time OBIGGS for several of the different model and tank configurations for the three air separation technologies. The estimates were based on similar equipment used in existing ECS and fuel systems.

**Compressor Wiring.** The compressor wiring weight was based on four wires per compressor that would run half of the fuselage length (the approximate length from the aircraft electrical power centers to the ideal compressor locations near the wing). This resulted in compressor wire data presented in Figure 3.7.4-1. The wire gage was based on the compressor operating current for each model.

<b>Aircraft</b>	<b>Length (feet)</b>
Large Transport	120
Medium Transport	90
Small Transport	60
Regional Turbofan	50
Regional Turboprop	60
Business Jet	50

*Figure 3.7.4-1. Compressor Wire Lengths*

**Ducting.** The ducting weight was based on the lengths and diameters in Figure 3.7.4-2. The lengths were approximated from the aircraft dimensions and the diameters were based on the air flow rates sized for each model. The duct material was assumed to be .032 aluminum for all models. Flexible couplings were assumed to be required every two feet and the mounting hardware was assumed to add 50 percent to the total duct weight. It was assumed that the air separation module could be located somewhere close to the fuel tanks, which would preclude the need for double-walled tubing. It was also assumed that the compressor and the heat exchanger would be located close together so that the length of high temperature ducting would also be negligible.

<b>Aircraft</b>	<b>Length (feet)</b>	<b>Diameter (inches)</b>
Large Transport	266	3.0
Medium Transport	217	2.5
Small Transport	125	2.0
Regional Turbofan	120	1.5
Regional Turboprop	120	1.5
Business Jet	120	1.5

*Figure 3.7.4-2. Ducting Length and Diameter*

**Installation Hardware.** The installation hardware weight was estimated as 15 percent of the weight of the components that would be mounted with external hardware (ducting installation hardware was included in the duct weight and not here).

**Scaled Data.** After the detailed estimates were completed for a range of different systems, the total "Other" Component weights for the remaining tank configurations were estimated as a function of NEA flow. The results are shown in Figures 3.7.4-3, 3.7.4-4, and 3.7.4-5. The systems for which every component was estimated are depicted by solid symbols and the scaled data are the empty symbols.

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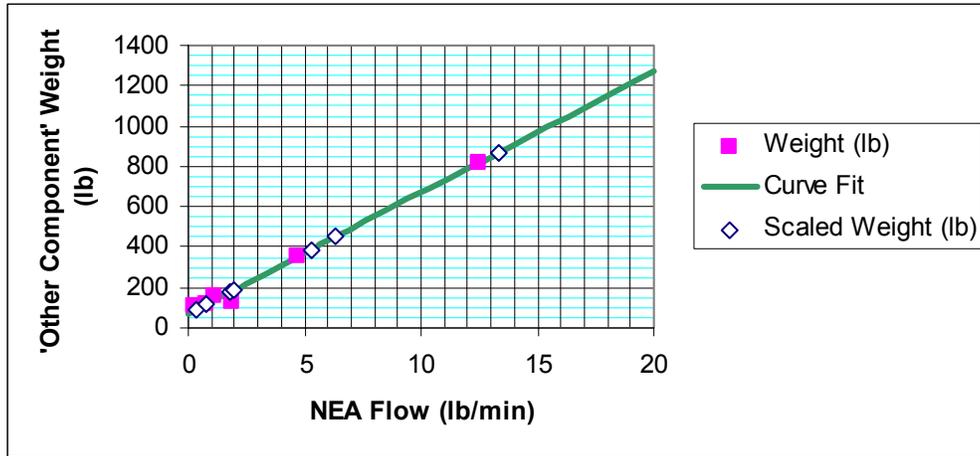


Figure 3.7.4-3. Permeable Membrane Full-Time OBIGGS "Other" Component Weight

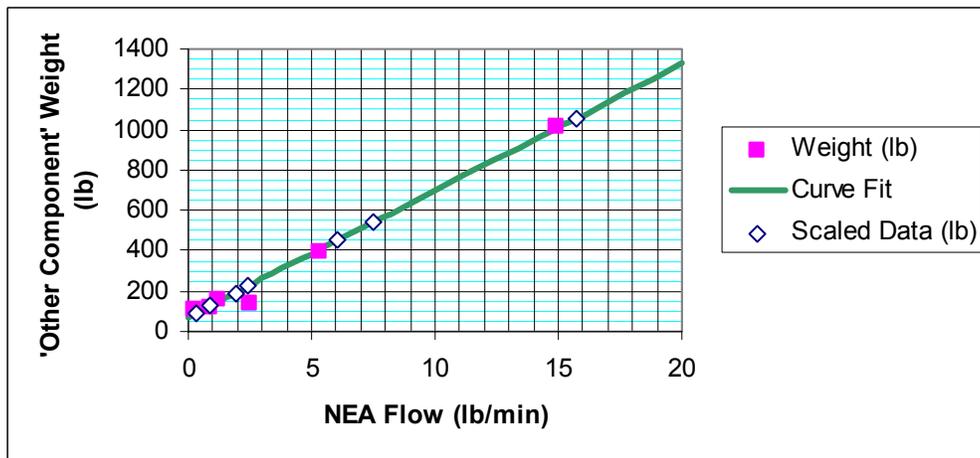


Figure 3.7.4-4. Pressure-Swing Adsorption Full-Time OBIGGS "Other" Component Weight

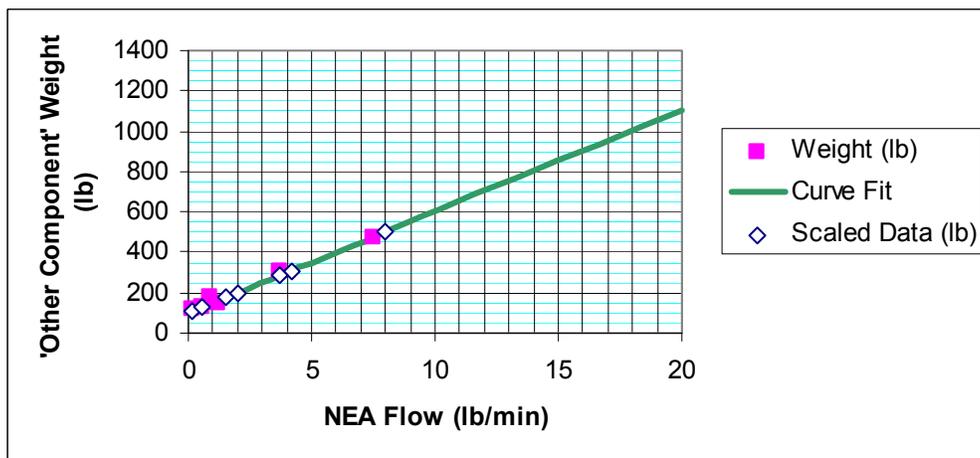


Figure 3.7.4-5. Cryogenic Distillation Full-Time OBIGGS "Other" Component Weight

**3.8 VOLUME**

Figures 3.8-1 through 3.8-3 summarize the OBIGGS volumes for the membrane, PSA, and cryogenic distillation inerting systems for each of the generic aircraft. Each table provides the total volume for the “major” and “other” components identified for each system. “Other” components include such items as wiring, ducting, and valves, and their total estimated volumes have been combined.

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Membrane System Component	LT CWT+Main Shipset Volume (cu ft)	MT CWT+Main Shipset Volume (cu ft)	ST CWT+Main Shipset Volume (cu ft)	RTF CWT+Main Shipset Volume (cu ft)	RTP CWT+Main Shipset Volume (cu ft)	BzJ CWT+Main Shipset Volume (cu ft)	LT CWT Only Shipset Volume (cu ft)	MT CWT Only Shipset Volume (cu ft)	ST CWT Only Ship- set Volume (cu ft)	RTF CWT Only Ship- set Volume (cu ft)	LT CWT+Main+ Aux Shipset Volume (cu ft)	MT CWT+Main+ Aux Shipset Volume (cu ft)	ST CWT+Main+ Aux Shipset Volume (cu ft)
<b>Maioir Components:</b>													
Compressor	1.435	0.510	0.190	0.138	0.033	0.366	0.716	0.227	0.139	0.062	1.523	0.578	0.209
Heat exchanger / fan	2.678	1.092	0.220	0.160	0.102	0.713	1.353	0.490	0.161	0.072	3.034	1.238	0.357
Air separation module	9.230	3.500	1.100	0.710	0.220	2.130	4.661	1.435	0.805	0.320	9.784	3.966	1.784
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Maioir component sub-totals</b>	13.34	5.10	1.51	1.01	0.35	3.21	6.73	2.15	1.11	0.45	14.34	5.78	2.35
<b>Other component sub-totals</b>	26.69	10.20	3.02	2.02	0.71	6.42	13.46	4.31	2.21	0.91	28.68	11.56	4.70
<b>Svstem Totals</b>	40.03	15.31	4.53	3.02	1.06	9.63	20.19	6.46	3.32	1.36	43.02	17.34	7.05

Figure 3.8-1. Summary of OBIGGS Volume—Membrane Systems

Psa system Component	LT CWT+Main Shipset Volume (cu ft)	MT CWT+Main Shipset Volume (cu ft)	ST CWT+Main Shipset Volume (cu ft)	RTF CWT+Main Shipset Volume (cu ft)	RTP CWT+Main Shipset Volume (cu ft)	BzJ CWT+Main Shipset Volume (cu ft)	LT CWT Only Shipset Volume (cu ft)	MT CWT Only Shipset Volume (cu ft)	ST CWT Only Ship- set Volume (cu ft)	RTF CWT Only Ship- set Volume (cu ft)	LT CWT+Main+ Aux Shipset Volume (cu ft)	MT CWT+Main+ Aux Shipset Volume (cu ft)	ST CWT+Main+ Aux Shipset Volume (cu ft)
<b>Maioir Components:</b>													
Compressor	2.151	0.582	0.206	0.149	0.041	0.459	1.082	0.336	0.151	0.060	2.281	0.680	0.227
Heat exchanger / fan	8.058	2.467	0.307	0.221	0.158	1.589	4.069	1.425	0.225	0.090	8.541	2.795	0.497
Air separation module	12.000	4.300	1.200	0.880	0.310	2.500	5.787	2.203	0.839	0.386	12.720	4.872	1.946
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Maioir component sub-totals</b>	22.21	7.35	1.71	1.25	0.51	4.55	10.94	3.96	1.21	0.54	23.54	8.35	2.67
<b>Other component sub-totals</b>	44.42	14.70	3.43	2.50	1.02	9.10	21.88	7.93	2.43	1.07	47.08	16.69	5.34
<b>Svstem Totals</b>	66.63	22.04	5.14	3.75	1.53	13.64	32.82	11.89	3.64	1.61	70.63	25.04	8.01

Figure 3.8-2. Summary of OBIGGS Volumes—PSA Systems

Cryogenic Distillaton System Component	LT CWT+Main Shipset Volume (cu ft)	MT CWT+Main Shipset Volume (cu ft)	ST CWT+Main Shipset Volume (cu ft)	RTF CWT+Main Shipset Volume (cu ft)	RTP CWT+Main Shipset Volume (cu ft)	BzJ CWT+Main Shipset Volume (cu ft)	LT CWT Only Shipset Volume (cu ft)	MT CWT Only Shipset Volume (cu ft)	ST CW Only Ship- set Volume (cu ft)	RTF CWT Only Ship- set Volume (cu ft)	LT CWT+Main+ Aux Shipset Volume (cu ft)	MT CWT+Main+ Aux Shipset Volume (cu ft)	ST CWT+Main+ Aux Shipset Volume (cu ft)
<b>Maioir Components:</b>													
Compressor	0.630	0.274	0.062	0.042	0.009	0.127	0.311	0.148	0.042	0.014	0.668	0.310	0.101
Heat exchanger / fan	1.887	0.943	0.076	0.069	0.050	0.300	0.943	0.515	0.048	0.017	2.000	1.069	0.123
Crvo component subtotals	33.000	26.000	18.000	17.000	15.000	18.000	26.000	22.000	16.000	15.000	33.000	27.000	19.000
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Maioir component subtotals</b>	35.52	27.22	18.14	17.11	15.06	18.43	27.25	22.66	16.09	15.03	35.67	28.38	19.22
<b>Other component sub-totals</b>	17.76	13.61	9.07	8.56	7.53	9.21	13.63	11.33	8.04	7.52	17.83	14.19	9.61
<b>Svstem Totals</b>	53.27	40.83	27.21	25.67	22.59	27.64	40.88	33.99	24.13	22.55	53.50	42.57	28.84

Figure 3.8-3. Summary of OBIGGS Volumes—Cryogenic Distillation Systems

## 3.8.1 Air Separation Modules

Volumes were developed for OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** Membrane volume was based on a standard module size of 0.75 cubic feet. Knowing the total flow for each of the 6 aircraft models and the flow capabilities of a standard module, simple division determined the number of modules required. This number of modules multiplied by the module volume yielded the total volume for the ASMs.

**Pressure-Swing Adsorption.** The PSA air separator calculations were made empirically as described in the weight section above. The NEA flow rate of a given PSA separator operating at high flow conditions was measured in the lab. The volume of the PSA separators were then determined from the number of units required to produce the NEA flow for each aircraft model.

**Cryogenic Distillation.** The volume of the cryogenic distillation system was determined in the same manner as the weight. Scaling was not used to determine component volume. Rather, each system was uniquely sized for the particular application.

## 3.8.2 Compressor

Compressor volume estimates were based on the number, size, and type needed for each ASM technology. Compressor types (screw or centrifugal) were selected for each aircraft model with the same considerations of power and compressor scalability as outlined in the weight section above. The compressor volume includes the compressor, motor, motor cooling fan and start contactor. The volume estimates were based on design schemes prepared for 15kW shaft power compressors of the screw and centrifugal types. From this a linear metric of volume as a function of power was generated. It is considered that this tends to give an overestimate of volume for high power machines and an underestimate for low power machines, which is generally conservative with regard to space envelope constraints. Above 30kW shaft power, two or more compressors are proposed.

## 3.8.3 Heat Exchanger/Cooling Fan

Heat exchanger and cooling fan volumes were determined for each of the aircraft and system types. Heat exchanger volume includes the core, inlet/outlet headers, and connections to the mating tubing. The volume of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

## 3.8.4 Other Components

The team estimated the volume of each of the "Other" Components in the full-time OBIGGS by multiplying the volume of the major components by 2.0 for the membrane and PSA systems and by .5 for the cryogenic distillation system. The multipliers were derived by comparing the volume of the "major" components to the major component volume and total volume occupied by typical ECS installations on existing commercial aircraft. The multiplier for the cryo system is lower, because the major components are larger than the comparable ECS systems. The total volume for all of the equipment will always be greater than the sum of the major components, because of duct bend radius limitations, the need to leave space for maintenance access, and the competition for space with other systems and equipment.

## 3.9 ELECTRICAL POWER

Figures 3.9-1 through 3.9-3 summarize the OBIGGS electrical power consumption estimates developed for the membrane, PSA, and cryogenic distillation inerting systems for each of the ARAC aircraft standards that were modeled. Each table provides the total peak electrical power for the "major" and

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“other” components identified for each system. “Other” components include such items as wiring, motors, and valves, and their total estimated electrical powers have been combined.

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Membrane System Component	LT CWT+Main Shipset Elect Pwr (kVA)	MT CWT+Main Shipset Elect Pwr (kVA)	ST CWT+Main Shipset Elect Pwr (kVA)	RTF CWT+Main Shipset Elect Pwr (kVA)	RTP CWT+Main Shipset Elect Pwr (kVA)	BzJ CWT+Main Shipset Elect Pwr (kVA)	LT CWT Only Shipset Elect Pwr (kVA)	MT CWT Only Shipset Elect Pwr (kVA)	ST CWT Only Ship- set Elect Pwr (kVA)	RTF CWT Only Ship- set Elect Pwr (kVA)	LT CWT+Main+ Aux Shipset Elect Pwr (kVA)	MT CWT+Main+ Aux Shipset Elect Pwr (kVA)	ST CWT+Main+ Aux Shipset Elect Pwr (kVA)
<b>Major Components:</b>													
Compressor	104.501	37.116	10.464	7.596	1.817	21.402	52.137	16.568	7.657	3.417	110.932	42.111	12.228
Heat exchanger / fan	0.770	0.314	0.300	0.218	0.020	0.205	0.389	0.141	0.220	0.098	0.816	0.356	0.487
Air separation module	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	105.27	37.43	10.76	7.81	1.84	21.61	52.53	16.71	7.88	3.51	111.75	42.47	12.71
<b>Other component sub-totals</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	105.37	37.53	10.86	7.91	1.94	21.71	52.63	16.81	7.98	3.61	111.85	42.57	12.81

Figure 3.9-1. Summary of OBIGGS Electrical Power—Membrane Systems

Membrane System Component	LT CWT+Main Shipset Elect Pwr (kVA)	MT CWT+Main Shipset Elect Pwr (kVA)	ST CWT+Main Shipset Elect Pwr (kVA)	RTF CWT+Main Shipset Elect Pwr (kVA)	RTP CWT+Main Shipset Elect Pwr (kVA)	BzJ CWT+Main Shipset Elect Pwr (kVA)	LT CWT Only Shipset Elect Pwr (kVA)	MT CWT Only Shipset Elect Pwr (kVA)	ST CWT Only Ship- set Elect Pwr (kVA)	RTF CWT Only Ship- set Elect Pwr (kVA)	LT CWT+Main+ Aux Shipset Elect Pwr (kVA)	MT CWT+Main+ Aux Shipset Elect Pwr (kVA)	ST CWT+Main+ Aux Shipset Elect Pwr (kVA)
<b>Major Components:</b>													
Compressor	156.677	42.361	11.348	8.196	2.281	26.862	78.808	24.451	8.303	3.325	166.157	49.550	13.275
Heat exchanger / fan	1.400	0.429	0.320	0.231	0.029	0.276	0.707	0.248	0.234	0.094	1.484	0.486	0.519
Air separation module	0.275	0.100	0.025	0.020	0.010	0.060	0.139	0.048	0.018	0.011	0.292	0.113	0.041
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	158.35	42.89	11.69	8.45	2.32	27.20	79.65	24.75	8.56	3.43	167.93	50.15	13.83
<b>Other component sub-totals</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	158.45	42.99	11.79	8.55	2.42	27.30	79.75	24.85	8.66	3.53	168.03	50.25	13.93

Figure 3.9-2. Summary of OBIGGS Electrical Power—PSA Systems

Membrane System Component	LT CWT+Main Shipset Elect Pwr (kVA)	MT CWT+Main Shipset Elect Pwr (kVA)	ST CWT+Main Shipset Elect Pwr (kVA)	RTF CWT+Main Shipset Elect Pwr (kVA)	RTP CWT+Main Shipset Elect Pwr (kVA)	BzJ CWT+Main Shipset Elect Pwr (kVA)	LT CWT Only Shipset Elect Pwr (kVA)	MT CWT Only Shipset Elect Pwr (kVA)	ST CWT Only Ship- set Elect Pwr (kVA)	RTF CWT Only Ship- set Elect Pwr (kVA)	LT CWT+Main+ Aux Shipset Elect Pwr (kVA)	MT CWT+Main+ Aux Shipset Elect Pwr (kVA)	ST CWT+Main+ Aux Shipset Elect Pwr (kVA)
<b>Major Components:</b>													
Compressor	34.690	15.104	3.436	2.295	0.475	7.004	17.109	8.163	2.291	0.765	36.772	17.081	5.543
Heat exchanger / fan	0.300	0.150	0.010	0.009	0.000	0.048	0.150	0.082	0.006	0.002	0.318	0.170	0.016
Cryo component subtotals	20.000	18.000	16.000	16.000	16.000	16.000	17.000	17.000	16.000	16.000	21.000	19.000	17.000
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component subtotals</b>	54.99	33.25	19.45	18.30	16.48	23.05	34.26	25.25	18.30	16.77	58.09	36.25	22.56
<b>Other component sub-totals</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	55.09	33.35	19.55	18.40	16.58	23.15	34.36	25.35	18.40	16.87	58.19	36.35	22.66

Figure 3.9-3. Summary of OBIGGS Electrical Power—Cryogenic Distillation Systems

### **3.9.1 Air Separation Modules**

Electrical power estimates were developed for the OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** Membrane modules do not require any electrical power.

**Pressure-Swing Adsorption.** Electrical power consumption for PSA separators is low, since the mechanism to operate the PSA distribution valve is pneumatic. The electrical power is consumed by simple timing and power circuits that operate the pneumatic control valves.

**Cryogenic Distillation.** Almost all of the electrical power needed for the cryogenic distillation system is used by the cryogenic refrigerator. The supplier's database of analytical calculations and system tests was used to specify the power requirements of the cryogenic refrigeration systems for this study. As in the case of the weight and volume, no scaling was used to determine the cryogenic distillation electrical power requirements.

### **3.9.2 Compressor**

Compressor electrical power was based on the number, size, and type needed for each ASM technology. Compressor types (screw or centrifugal) were selected and electrical power was determined for each aircraft model with the same considerations of power and compressor scalability as outlined in the weight section.

The compressors for each aircraft were sized for the mass flow of supply air required to each of the differing ASM types. The shaft power of the compressor is a function of the mass flow, pressure ratio and inlet temperature. For full-time OBIGGS, the maximum power design point for the compressors was sea level and the maximum ambient temperature operating condition was 110°F. An effort was made to minimize the electrical power requirement by investigating two-stage compressors with inter-cooling. This was selected for the Large and Medium Transport membrane and PSA OBIGGS.

### **3.9.3 Heat Exchanger/Cooling Fan**

Heat exchanger and cooling fan power were determined for each of the aircraft and system types. The heat exchanger requires no power to operate. The cooling fan power requirement was determined based on the cooling air flow rate and pressure rise requirements. The system was designed to minimize the cooling fan power requirements whenever possible.

### **3.9.4 Other Components**

The team estimated the total electrical power required by the "Other" Components in the full-time OBIGGS as 0.1 kVA for all models and tank configurations. This represents a reasonable average power draw of the controller, sensors, and bypass valve which are active all the time and the intermittent power draw of the other valves that only move when commanded.

## **3.10 RELIABILITY**

Figures 3.10-1 through 3.10-6 summarize the OBIGGS component reliability estimates, in terms of Mean-Time-Between-Maintenance-Actions (MTBMA) and Mean-Time-Between-Failure (MTBF), developed for the membrane, PSA, and cryogenic distillation inerting systems for each of the generic aircraft. Each table provides the reliability for the "major" and "other" components identified for each system. "Other" components include such items as wiring, motors and valves, and their total estimated electrical powers have been combined. The Airplane Operations and Maintenance Team used this component data as a starting point for the system level reliability estimates.

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Membrane System Component	LT CWT+Main Component MTBMA (hrs)	MT CWT+Main Component MTBMA (hrs)	ST CWT+Main Component MTBMA (hrs)	RTF CWT+Main Component MTBMA (hrs)	RTP CWT+Main Component MTBMA (hrs)	BzJ CWT+Main Component MTBMA (hrs)	LT CWT Only Component MTBMA (hrs)	MT CWT Only Component MTBMA (hrs)	ST CWT Only Component MTBMA (hrs)	RTF CWT Only Component MTBMA (hrs)	LT CWT+Main+ Aux Component MTBMA (hrs)	MT CWT+Main+ Aux Component MTBMA (hrs)	ST CWT+Main+ Aux Component MTBMA (hrs)
Major Components:													
Compressor	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Other Components:													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cabin air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Precooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Inter-cooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Temperature sensor	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Bypass valve	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 3.10-1. Summary of OBIGGS MTBMA—Membrane Systems

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PSA System Component	LT CWT+Main Component MTBMA (hrs)	MT CWT+Main Component MTBMA (hrs)	ST CWT+Main Component MTBMA (hrs)	RTF CWT+Main Component MTBMA (hrs)	RTP CWT+Main Component MTBMA (hrs)	BzJ CWT+Main Component MTBMA (hrs)	LT CWT Only Component MTBMA (hrs)	MT CWT Only Component MTBMA (hrs)	ST CWT Only Component MTBMA (hrs)	RTF CWT Only Component MTBMA (hrs)	LT CWT+Main+ Aux Component MTBMA (hrs)	MT CWT+Main+ Aux Component MTBMA (hrs)	ST CWT+Main+ Aux Component MTBMA (hrs)
Major Components:													
Compressor	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	8,000	34,000	34,000	34,000	34,000	34,000	8,000	34,000	34,000	34,000	8,000	34,000	34,000
Other Components:													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cabin air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Precooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Inter-cooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Temperature sensor	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Bypass valve	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 3.10-2. Summary of OBIGGS MTBMA—PSA Systems

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Cryogenic Distillation System Component	LT CWT+Main Component MTBMA (hrs)	MT CWT+Main Component MTBMA (hrs)	ST CWT+Main Component MTBMA (hrs)	RTF CWT+Main Component MTBMA (hrs)	RTP CWT+Main Component MTBMA (hrs)	BzJ CWT+Main Component MTBMA (hrs)	LT CWT Only Component MTBMA (hrs)	MT CWT Only Component MTBMA (hrs)	ST CWT Only Component MTBMA (hrs)	RTF CWT Only Component MTBMA (hrs)	LT CWT+Main+ Aux Component MTBMA (hrs)	MT CWT+Main+ Aux Component MTBMA (hrs)	ST CWT+Main+ Aux Component MTBMA (hrs)
<b>Major Components:</b>													
Compressor	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000
Heat exchanger	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Cooling fan	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000	25.000
Crvo Air Separation Compo-													
Inlet shutoff valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Cryocooler bleed air valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Flow sensor	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000
Molecular sieve control valves	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Molecular sieve svstem	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Purge heat exchanger	80.000	100.000	100.000	100.000	100.000	100.000	80.000	100.000	100.000	100.000	80.000	100.000	100.000
Purge heat exchanger valve-Air Side	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Purge heat exchanger valve-Waste Side	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
LNEA Dewar Cooldown Valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Inlet Recuperator	60.000	100.000	100.000	100.000	100.000	100.000	60.000	100.000	100.000	100.000	60.000	100.000	100.000
Inlet cooler	80.000	100.000	100.000	100.000	100.000	100.000	80.000	100.000	100.000	100.000	80.000	100.000	100.000
Cryocooler	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
LNEA Dewar	75.000	75.000	75.000	n/a	n/a	n/a	75.000	75.000	75.000	n/a	75.000	75.000	75.000
Dewar level sensor	50.000	50.000	50.000	n/a	n/a	n/a	50.000	50.000	50.000	n/a	50.000	50.000	50.000
Distillation column	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Distillation column gas valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Distillation column liquid valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
<b>Other Components:</b>													
Cabin air filter assv	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Cabin air filter element	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
OBIGGS shutoff valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Compressor	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000
Compressor unloading valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Compressor discharge check valve	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Bleed shutoff valve	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000	50.000
Bleed check valve	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

Figure 3.10-3. Summary of OBIGGS MTBMA—Cryogenic Distillation Systems (Sheet 1 of 2)

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Cryogenic Distillation System Component	LT CWT+Main Component MTBMA (hrs)	MT CWT+Main Component MTBMA (hrs)	ST CWT+Main Component MTBMA (hrs)	RTF CWT+Main Component MTBMA (hrs)	RTP CWT+Main Component MTBMA (hrs)	BzJ CWT+Main Component MTBMA (hrs)	LT CWT Only Component MTBMA (hrs)	MT CWT Only Component MTBMA (hrs)	ST CWT Only Component MTBMA (hrs)	RTF CWT Only Component MTBMA (hrs)	LT CWT+Main+ Aux Component MTBMA (hrs)	MT CWT+Main+ Aux Component MTBMA (hrs)	ST CWT+Main+ Aux Component MTBMA (hrs)
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assv	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 3.10-3. Summary of OBIGGS MTBMA—Cryogenic Distillation Systems (Sheet 2 of 2)

## Onboard Inerting Designs Task Team Final Report

Membrane System Component	LT CWT+Main Component MTBF (hrs)	MT CWT+Main Component MTBF (hrs)	ST CWT+Main Component MTBF (hrs)	RTF CWT+Main Component MTBF (hrs)	RTP CWT+Main Component MTBF (hrs)	BzJ CWT+Main Component MTBF (hrs)	LT CWT Only Component MTBF (hrs)	MT CWT Only Component MTBF (hrs)	ST CWT Only Component MTBF (hrs)	RTF CWT Only Component MTBF (hrs)	LT CWT+Main+ Aux Component MTBF (hrs)	MT CWT+Main+ Aux Component MTBF (hrs)	ST CWT+Main+ Aux Component MTBF (hrs)
<b>Maior Components:</b>													
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
<b>Other Components:</b>													
Cabin air filter assv	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Precooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Inter-cooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Temperature sensor	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Bypass valve	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assv	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 3.10-4. Summary of OBIGGS MTBF—Membrane Systems

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PSA System Component	LT CWT+Main Component MTBF (hrs)	MT CWT+Main Component MTBF (hrs)	ST CWT+Main Component MTBF (hrs)	RTF CWT+Main Component MTBF (hrs)	RTP CWT+Main Component MTBF (hrs)	BzJ CWT+Main Component MTBF (hrs)	LT CWT Only Component MTBF (hrs)	MT CWT Only Component MTBF (hrs)	ST CWT Only Component MTBF (hrs)	RTF CWT Only Component MTBF (hrs)	LT CWT+Main+ Aux Component MTBF (hrs)	MT CWT+Main+ Aux Component MTBF (hrs)	ST CWT+Main+ Aux Component MTBF (hrs)
<b>Major Components:</b>													
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
<b>Other Components:</b>													
Cabin air filter assv	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Precooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Inter-cooler	100,000	100,000	n/a	n/a	n/a	n/a	100,000	n/a	n/a	n/a	100,000	100,000	n/a
Temperature sensor	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Bypass valve	50,000	50,000	n/a	n/a	n/a	n/a	50,000	n/a	n/a	n/a	50,000	50,000	n/a
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assv	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 3.10-5. Summary of OBIGGS MTBF—PSA Systems

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Cryogenic Distillation System Component	LT CWT+Main Component MTBF (hrs)	MT CWT+Main Component MTBF (hrs)	ST CWT+Main Component MTBF (hrs)	RTF CWT+Main Component MTBF (hrs)	RTP CWT+Main Component MTBF (hrs)	BzJ CWT+Main Component MTBF (hrs)	LT CWT Only Component MTBF (hrs)	MT CWT Only Component MTBF (hrs)	ST CWT Only Component MTBF (hrs)	RTF CWT Only Component MTBF (hrs)	LT CWT+Main+ Aux Component MTBF (hrs)	MT CWT+Main+ Aux Component MTBF (hrs)	ST CWT+Main+ Aux Component MTBF (hrs)
<b>Major Components:</b>													
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
<b>Cryo Air Separation Com-</b>													
Inlet shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Cryocooler bleed air valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Flow sensor	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Molecular sieve control	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Molecular sieve system	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Purge heat exchanger	80,000	100,000	100,000	100,000	100,000	100,000	80,000	100,000	100,000	100,000	80,000	100,000	100,000
Purge heat exchanger	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Purge heat exchanger valve-Waste Side	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
LNEA Dewar Cooldown Valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Inlet Recuperator	60,000	100,000	100,000	100,000	100,000	100,000	60,000	100,000	100,000	100,000	60,000	100,000	100,000
Inlet cooler	80,000	100,000	100,000	100,000	100,000	100,000	80,000	100,000	100,000	100,000	80,000	100,000	100,000
Cryocooler	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
LNEA Dewar	75,000	75,000	75,000	n/a	n/a	n/a	75,000	75,000	75,000	n/a	75,000	75,000	75,000
Dewar level sensor	50,000	50,000	50,000	n/a	n/a	n/a	50,000	50,000	50,000	n/a	50,000	50,000	50,000
Distillation column	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Distillation column gas	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Distillation column liquid	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000

Figure 3.10-6. Summary of OBIGGS MTBF—Cryogenic Distillation Systems (Sheet 1 of 2)

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Cryogenic Distillation System Component	LT CWT+Main Component MTBF (hrs)	MT CWT+Main Component MTBF (hrs)	ST CWT+Main Component MTBF (hrs)	RTF CWT+Main Component MTBF (hrs)	RTP CWT+Main Component MTBF (hrs)	BzJ CWT+Main Component MTBF (hrs)	LT CWT Only Component MTBF (hrs)	MT CWT Only Component MTBF (hrs)	ST CWT Only Component MTBF (hrs)	RTF CWT Only Component MTBF (hrs)	LT CWT+Main+ Aux Component MTBF (hrs)	MT CWT+Main+ Aux Component MTBF (hrs)	ST CWT+Main+ Aux Component MTBF (hrs)
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller / control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 3.10-6. Summary of OBIGGS MTBF—Cryogenic Distillation Systems (Sheet 2 of 2)

## 3.10.1 Air Separation Modules

Reliability estimates were developed for OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** The membrane module consists of a membrane fiber bundle contained in a metal housing. There are no moving parts. The most likely failure causes are contamination and over-temperature damage. The OBIGGS concepts include upstream filtration and redundant temperature sensors to minimize the possibility of these failures. There are commercial membrane modules that have operated continuously for many years without failure. There is no scheduled maintenance requirement for the membrane modules.

**Pressure-Swing Adsorption.** The PSA hardware consists of a distribution valve that is pilot operated by relatively small pneumatic valves and controlled by a timing circuit. Also included are air and product manifolds, molecular sieve beds, and purge orifices. The distribution valve assembly contains two wear parts, which are recommended to be serviced at 6000 to 8000 hour intervals. The Mean-Time-Between-Failure estimate in the summary table assumes a scheduled overhaul is performed every 8000 hours.

**Cryogenic Distillation.** The cryogenic system consists of several components including heat exchangers, valves, a cryogenic refrigerator (cryocooler), and distillation columns. The reliability estimates for the valves, heat exchangers, and columns were provided by the specifications from various component suppliers for off-the-shelf items. The reliability estimates obtained from the component suppliers for the heat exchangers and the valves were reduced by the Team to conform to reliability values for other systems. Thus, the actual reliability for the cryogenic distillation system is slightly higher than the values presented in this report. The reliability value for the cryogenic refrigerator is a conservative estimate.

## 3.10.2 Compressor

The compressor reliability for screw-type units is based on a recommended service interval of 7000 hours. The centrifugal compressors use a different bearing technology that does not require periodic servicing. Suppliers of existing flight-worthy equipment provided the reliability estimates.

## 3.10.3 Heat Exchanger/Cooling Fan

The heat exchanger and cooling fan reliability estimates are based on commercial aircraft experience and were provided by suppliers of existing flight-worthy equipment.

## 3.10.4 Other Components

Reliability estimates for the other OBIGGS components were based on commercial aircraft experience with similar components. Common reliability estimates were used for the components that were used in all of the systems to ensure a fair comparison between the different inerting concepts and technologies.

## 3.11 COST

The Team estimated the initial acquisition costs for the membrane, PSA, and cryogenic distillation OBIGGS for each of the generic aircraft. Design and certification, operations, maintenance, and installation costs for the OBIGGS are described later in this section. Inclusion of those costs to determine cost benefit was performed by the Estimating and Forecasting (E&F) team and is described in the E&F team final report.

### 3.11.1 Acquisition Cost

Acquisition costs for OBIGGS systems were developed by the participating suppliers on the team following the same guidelines as used for OBI acquisition, which include:

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- Final rule requiring fuel tank inerting becomes effective in year 2004.
- Production of the first certified system occurs in year 2009.
- Retrofit of existing aircraft is completed by year 2014.
- Continued production of OBIGGS for new production aircraft is through year 2020.
- As of year 2000, existing fleet of in-service aircraft is 13,813 aircraft, per Campbell Hill survey of world fleet forecast data provided by ATA.
- Average annual new aircraft production rate is 837 aircraft per year, per Campbell Hill survey of world fleet forecast data provided by ATA.
- When applying Campbell Hill survey of world fleet forecast data, between 5,500 and 5,800 shipsets per year total would be produced by the OBIGGS suppliers starting in 2009 and running through 2014.
- When applying Campbell Hill survey of world fleet forecast data, continued production of between 980 and 1,300 shipsets per year would occur by the OBIGGS suppliers starting in 2015 and running through 2020.
- Each supplier assumed a market share of 30%.
- New designs are assumed to be optimized to minimize non-recurring and recurring costs. The time frame for non-recurring efforts was estimated as 39 months.
- Non-recurring development costs were amortized into the per-system pricing provided by each supplier.

Figures 3.11.1-1 through 3.11.1-3 summarize the OBIGGS acquisition costs developed by the team for the membrane, PSA, and cryogenic distillation inerting systems for each of the generic aircraft. In Figures 3.11-1 through 3.11-3 the total cost for the individual components is identified for each system to provide inerting of main tanks and CWTs, CWTs only, and all tanks (main tanks, CWTs and auxiliary tanks). The estimated component costs include the amortized non-recurring development costs. The team also separately estimated the cost for an on-board oxygen sensor, though this cost was not included in the system totals.

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Membrane System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+ Aux Shipset Cost (\$)	MT CWT+Mai Aux Shipset Cost (\$)	ST CWT+Main+ Aux Shipset Cost (\$)
<b>Maior Components:</b>													
Compressor	49,122	8,415	10,392	10,198	9,807	6,598	15,779	7,438	10,202	9,915	25,225	15,303	6,146
Heat exchanger/fan	33,397	15,134	3,804	3,462	3,109	10,761	18,130	8,203	3,469	2,963	37,839	16,807	4,581
Air separation module	68,575	26,375	7,912	5,275	5,275	13,187	34,630	10,814	5,792	2,374	72,690	29,883	12,833
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	151,094	49,924	22,108	18,935	18,191	30,546	68,540	26,454	19,463	15,252	135,753	61,993	23,560
<b>Other Components:</b>													
Cabin air filter assv	350	350	350	350	350	350	**	**	**	**	**	**	**
OBIGGS shutoff valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Precooler	8,000	4,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Inter-cooler	8,000	4,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Temperature sensor	2,000	1,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Bypass valve	4,000	2,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Compressor unloading valve	3,120	1,560	1,350	1,560	1,250	1,560	**	**	**	**	**	**	**
Compressor discharge check valve	475	425	275	475	250	475	**	**	**	**	**	**	**
Bleed shutoff valve	1,250	1,250	1,100	1,250	1,100	1,250	**	**	**	**	**	**	**
Bleed check valve	475	425	275	475	250	475	**	**	**	**	**	**	**
Bypass valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Temperature sensor	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Water separator/filter assv	5,000	5,000	5,000	5,000	5,000	5,000	**	**	**	**	**	**	**
High flow valve	1,250	1,250	1,100	1,250	0	1,250	**	**	**	**	**	**	**
Relief valve	680	580	450	550	450	550	**	**	**	**	**	**	**
Fuel tank check valve	675	675	675	675	675	675	**	**	**	**	**	**	**
Controller / control card	40,000	40,000	40,000	40,000	40,000	40,000	**	**	**	**	**	**	**
Ducting	35,600	23,200	10,500	7,600	7,600	7,600	**	**	**	**	**	**	**
Wiring	750	500	250	250	250	400	**	**	**	**	**	**	**
Installation Hardware	3,555	1,510	644	527	300	836	**	**	**	**	**	**	**
Structural Modifications	2,000	1,000	400	200	200	200	**	**	**	**	**	**	**
Ram Ducting	12,000	6,000	3,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Compressor wiring	5,976	811	310	75	58	259	**	**	**	**	**	**	**
Overheat sensors	1,000	1,000	1,000	1,000	1,000	1,000	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Other component sub-totals</b>	142,156	102,536	72,679	69,237	66,733	69,880	106,000	78,000	70,000	67,000	151,000	103,000	77,000
<b>System Totals</b>	293,250	152,460	94,787	88,171	84,925	100,426	174,540	104,454	89,463	82,252	286,753	164,993	100,560
On-board oxygen sensor (not included)	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000

\*\*Indicates scaled data

Figure 3.11.1-1. Summary of OBIGGS Costs—Membrane Systems

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PSA System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+ Aux Shipset Cost (\$)	MT CWT+Mai Aux Shipset Cost (\$)	ST CWT+Main+ Aux Shipset Cost (\$)
<b>Major Components:</b>													
Compressor	18,000	9,000	11,000	10,239	9,838	6,868	17,047	7,813	10,246	9,909	41,151	15,656	6,197
Heat exchanger/fan	85,000	28,000	5,000	4,413	3,266	18,752	44,041	17,085	4,438	3,308	89,636	31,047	6,729
Air separation module	46,000	20,000	11,000	12,000	9,000	17,000	22,000	15,000	10,000	10,000	48,760	22,660	17,842
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	149,000	57,000	27,000	26,651	22,105	42,620	83,089	39,898	24,684	23,217	179,547	69,363	30,768
<b>Other Components:</b>													
Cabin air filter assv	500	350	350	350	350	350	**	**	**	**	**	**	**
OBIGGS shutoff valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Precooler	8,000	4,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Inter-cooler	8,000	4,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Temperature sensor	2,000	1,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Bypass Valve	4,000	2,000	n/a	n/a	n/a	n/a	**	**	n/a	n/a	**	**	n/a
Compressor unloading valve	3,120	1,560	1,100	1,560	1,250	1,560	**	**	**	**	**	**	**
Compressor discharge check valve	475	425	275	475	250	475	**	**	**	**	**	**	**
Bleed shutoff valve	1,250	1,250	1,100	1,250	1,100	1,250	**	**	**	**	**	**	**
Bleed check valve	475	425	275	475	250	475	**	**	**	**	**	**	**
Bypass valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Temperature sensor	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Water separator/filter assv	8,000	5,000	5,000	5,000	5,000	5,000	**	**	**	**	**	**	**
High flow valve	1,250	1,250	1,100	0	1,100	1,250	**	**	**	**	**	**	**
Relief valve	680	580	450	550	450	550	**	**	**	**	**	**	**
Fuel tank check valve	675	675	675	675	675	675	**	**	**	**	**	**	**
Controller / control card	40,000	40,000	40,000	40,000	40,000	40,000	**	**	**	**	**	**	**
Ducting	35,600	23,200	10,500	7,600	7,600	7,600	**	**	**	**	**	**	**
Wiring	750	500	250	250	250	400	**	**	**	**	**	**	**
Installation Hardware	5,442	1,963	772	623	399	1,163	**	**	**	**	**	**	**
Structural Modifications	2,000	1,000	400	200	200	200	**	**	**	**	**	**	**
Ram Ducting	12,000	6,000	3,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Compressor wiring	8,964	1,677	310	75	58	259	**	**	**	**	**	**	**
Overheat sensors	1,000	1,000	1,000	1,000	1,000	1,000	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Other component sub-totals</b>	150,181	103,855	72,557	68,083	67,932	70,207	114,000	81,000	71,000	67,000	167,000	104,000	77,000
<b>System Totals</b>	299,181	160,855	99,557	94,735	90,037	112,827	197,089	120,898	95,684	90,217	346,547	173,363	107,768
On-board oxygen sensor (not included in system totals)	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000

\*\*Indicates scaled data

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Figure 3.11.1-2. Summary of OBIGGS Costs—PSA Systems

Cryogenic Distillation System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+ Aux Shipset Cost (\$)	MT CWT+Mai Aux Shipset Cost (\$)	ST CWT+Main+ Aux Shipset Cost (\$)
<b>Major Components:</b>													
Compressor	10,891	10,256	9,816	9,805	10,000	9,953	10,842	10,236	9,839	9,736	12,172	10,840	10,059
Heat exchanger/fan	14,181	8,368	3,007	2,966	3,000	4,404	8,368	5,725	2,842	2,653	14,879	9,141	3,288
<b>Cryo Air Separation Components:</b>													
Inlet shutoff valve	400	400	400	400	400	400	**	**	**	**	**	**	**
Cryocooler bleed air valve	300	300	300	300	300	300	**	**	**	**	**	**	**
Flow sensor	300	300	300	300	300	300	**	**	**	**	**	**	**
Molecular sieve control valves	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Molecular sieve system	15,000	7,500	7,500	7,500	7,500	15,000	**	**	**	**	**	**	**
Purge heat exchanger	4,500	4,500	4,500	4,500	4,500	4,500	**	**	**	**	**	**	**
Purge heat exchanger valve-Air Side	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Purge heat exchanger valve-Waste Side	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
LNEA Dewar Cooldown Valve	500	500	500	500	500	500	**	**	**	**	**	**	**
Inlet Recuperator	5,500	5,500	5,500	5,500	5,500	5,500	**	**	**	**	**	**	**
Inlet cooler	4,000	4,000	4,000	4,000	4,000	4,000	**	**	**	**	**	**	**
Cryocooler	100,000	100,000	100,000	100,000	100,000	100,000	**	**	**	**	**	**	**
LNEA Dewar	10,000	5,000	5,000	0	0	0	**	**	**	**	**	**	**
Dewar level sensor	200	200	200	200	200	200	**	**	**	**	**	**	**
Distillation column	10,000	10,000	10,000	10,000	10,000	10,000	**	**	**	**	**	**	**
Distillation column gas valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Distillation column liquid valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
Cryo component subtotals	160,700	148,200	148,200	143,200	143,200	150,700	155,075	155,075	148,200	143,200	160,700	151,950	148,200
<b>Major component subtotals</b>	<b>185,772</b>	<b>166,824</b>	<b>161,023</b>	<b>155,970</b>	<b>156,200</b>	<b>165,057</b>	<b>174,284</b>	<b>171,037</b>	<b>160,881</b>	<b>155,589</b>	<b>187,751</b>	<b>171,931</b>	<b>161,547</b>
<b>Other Components:</b>													
Cabin air filter assy	350	350	350	350	350	350	**	**	**	**	**	**	**
OBIGGS shutoff valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**

\*\*Indicates scaled data

Figure 3.11.1-3. Summary of OBIGGS Costs—Cryogenic Distillation Systems (Sheet 1 of 2)

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Cryogenic Distillation System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+ Aux Shipset Cost (\$)	MT CWT+Mai Aux Shipset Cost (\$)	ST CWT+Main+ Aux Shipset Cost (\$)
Compressor unloading valve	1,560	1,560	1,100	1,560	1,100	1,560	**	**	**	**	**	**	**
Compressor discharge check valve	475	425	275	475	250	475	**	**	**	**	**	**	**
Bleed shutoff valve	1,250	1,250	1,100	1,250	1,100	1,250	**	**	**	**	**	**	**
Bleed check valve	475	425	275	475	250	475	**	**	**	**	**	**	**
Bypass valve	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Temperature sensor	2,000	2,000	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Water separator/filter assy	5,000	5,000	5,000	5,000	5,000	5,000	**	**	**	**	**	**	**
Temperature sensor	1,000	1,000	1,000	1,000	1,000	1,000	**	**	**	**	**	**	**
Relief valve	680	580	450	550	450	450	**	**	**	**	**	**	**
Fuel tank check valve	675	675	675	675	675	675	**	**	**	**	**	**	**
Controller / control card	40,000	40,000	40,000	40,000	40,000	40,000	**	**	**	**	**	**	**
Ducting	35,600	23,200	10,500	7,600	7,600	7,600	**	**	**	**	**	**	**
Wiring	750	500	250	250	250	250	**	**	**	**	**	**	**
Installation Hardware	4,191	3,136	2,379	1,592	1,423	1,719	**	**	**	**	**	**	**
Structural Modifications	1,300	900	500	200	200	500	**	**	**	**	**	**	**
Ram Ducting	3,000	2,400	2,000	2,000	2,000	2,000	**	**	**	**	**	**	**
Compressor wiring	1,081	465	57	48	33	33	**	**	**	**	**	**	**
Overheat sensors	1,000	1,000	1,000	1,000	1,000	1,000	**	**	**	**	**	**	**
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Other component sub-totals</b>	104,387	88,866	72,911	70,025	68,681	70,337	85,000	77,000	71,000	69,000	106,000	89,000	75,000
<b>System Totals</b>	290,159	255,690	233,934	225,995	224,881	235,394	259,284	248,037	231,881	224,589	293,751	260,931	236,547
On-board oxygen sensor (not included in system totals)	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000

\*\*Indicates scaled data

Figure 3.11.1-3. Summary of OBIGGS Costs—Cryogenic Distillation Systems (Sheet 2 of 2)

### **3.11.1.1 Air Separation Modules**

Cost estimates were developed for OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** For the membrane-based ASMs, cost, weight, volume, and purity analyses performed by the ASM supplier indicated no sizable benefit to developing new membrane units for the generic aircraft. Thus membrane costs were developed based on commercially available off-the-shelf membrane units. Common costs were applied for common-sized membrane and PSA ASMs across all OBGIS and OBIGGS concepts, where applicable.

**Pressure-Swing Adsorption.** The costs of the PSA separators were estimated with the assumption that the molecular sieve beds and mechanical assembly would not be off-the-shelf, but that there is no technical risk in developing these items. The supplier applied trends from current PSA hardware to derive competitive costs. However, these costs were adjusted as the ASM filter and controller would not be integrated into the ASM assembly for commercial aircraft, in contrast to current PSA systems fielded on some U.S. military aircraft.

**Cryogenic Distillation.** The cryogenic distillation system costs were estimated with the assumption that the cryogenic refrigerator and distillation column would be new manufacture items (i.e., these items are typically not stocked on a shelf) but no new development would be associated with these items. Costs for other cryogenic distillation OBIGGS components are based on commercially available items.

### **3.11.1.2 Compressor**

Compressor costs for OBIGGS were developed similarly to those costs developed for OBGIS systems. Compressor costs were established for two compressor types, screw and centrifugal. A linear cost model was derived using supplier-estimated costs for 15 kW and 30 kW compressors of both compressor types, and compressor costs were established as a function of compressor type, power required, and number of compressors required. As compressor design requirements were established and iterated for each of the ARAC aircraft models, the team applied this metric to derive the optimum compressor configuration and cost. For membrane and PSA inerting systems, for the large transport and medium transport aircraft models, costs for compressor precooler and intercooler components were extrapolated from the heat exchanger costs developed for the regional turbofan aircraft model.

### **3.11.1.3 Heat Exchanger/Cooling Fan**

Heat exchanger costs for membrane, PSA, and cryogenic distillation OBIGGS were developed similarly to those costs developed for OBGIS systems by applying a supplier-derived linear cost model to develop costs for compact heat exchangers with fan cooling. Heat exchanger costs included the core, inlet/outlet headers, and connections to the mating tubing. The cost of the cooling fan included the fan and any ducting between the fan and the heat exchanger. Ducting that interfaces with the aircraft structure or plumbing was accounted for separately under other OBIGGS parts. Heat exchanger costs were baselined against commercially available equipment and scaled as a function of heat exchange rate required to provide stable-temperature input airflow to the ASM and the cooling airflow output required by the cooling fan. The cost of the cooling fan was integrated into the cost for the heat exchanger.

### **3.11.1.4 Other Components**

Costs for all other membrane, PSA, and cryogenic distillation OBIGGS components were developed similarly to costs for other components developed for OBGIS systems. Original equipment manufacturer (OEM) costs were assumed for the majority of all components other than the ASMs, compressors, and heat exchangers with cooling fans. Common costs were applied for components common across OBGIS and OBIGGS concepts. Exceptions to the OEM pricing include ASM water separator/filter costs, which

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are based on rough order of magnitude (ROM) estimates provided by a filter supplier, and the ASM controller, which was estimated by scaling from the cost for a commercially-available controller used in aircraft subsystem applications. Other costs applied commonly across all OBGIS and OBIGGS concepts include the following:

- Ducting - cost estimated at \$200/lb
- Wiring - cost estimated at \$50/lb
- Installation Hardware - cost estimated at \$50/lb
- Structural Modifications - cost estimated at \$20/lb
- Ram Ducting - cost estimated at \$200/lb

### **3.11.2 Design & Certification Cost**

Design and certification man-hour estimates were developed by the Working Group to encompass the engineering hours required by an aircraft manufacturer for modifications and additions to fuel system components, interfaces, structure, instruments or displays, wiring, tubing, ducting, avionics software and, if required, relocation of other equipment on each aircraft. As mentioned previously, the Team developed OBIGGS component costs, and the non-recurring design costs for the components (e.g., ASMs) were amortized into the component costs listed in the previous summary cost tables.

The design and certification man-hour estimates were applied by the E&F team as part of their analysis to determine OBIGGS cost benefit and are described in the E&F team final report. These estimates address design and certification of OBIGGS systems to inert all tanks on a new first of a model aircraft and on derivative model aircraft for all of the generic aircraft. They also address design and certification of OBIGGS systems to inert CWTs only on a new first of a model aircraft and on derivative model aircraft, which only applies to the generic large, medium, and small transports, and to the generic regional turbo fan aircraft.

Neither FAA nor JAA will assess additional certification costs for OBIGGS. However, non-U.S. governmental authorities may assess additional costs related to the certification of OBIGGS systems. For example, JAA indicates that the CAA-UK will charge airlines for all certification costs, including engineering man hours, whereas DGAC France will charge airlines only for the travel costs associated with an OBIGGS certification effort. These potential additional costs were not included in the design and certification cost estimates.

### **3.11.3 Operating Cost**

Recurring OBIGGS operating costs evaluated by the ARAC estimating and forecasting (E&F) team encompassed frequency of delays, delay time, OBIGGS system weight, performance loss, and additional training required for ground and flight crews. The On-Board Design Task Team developed system weights for use in the E&F cost models. The team also applied a method for determining performance loss due to an on-board inerting system as described in report AFWAL-TR-82-2115, Aircraft Fuel Tank Inerting System, and provided resulting performance loss values to the E&F team. This method evaluates by mission segment the performance loss in lbs-fuel and dollars/flight-hour associated with additional aircraft resource demands (i.e., bleed air, electrical power) and increased weight due to the on-board inerting system. This methodology was applied to determine performance losses associated with the bleed air consumption and electrical power demands required by OBIGGS. Performance loss associated with system weight is the predominant element in performance loss, which was determined by the E&F team using the methodology applied in the previous ARAC FTHWG effort. All other recurring OBIGGS operating costs were developed by the E&F and Airplane Operations and Maintenance (O&M) teams.

## 3.11.4 Maintenance Cost

Recurring full-time OBIGGS operating costs evaluated by the ARAC E&F team encompassed mean time between unscheduled repair (MTBUR) and hours for maintenance checks, inspections, removals, unscheduled maintenance, maintenance training, and confined space entry labor. The On-Board Design Task Team developed estimates for MTBMA and MTBF for each system component. These values were provided to the O&M team who then compared them to values of comparable components used currently on commercial aircraft. Those comparable values were then used to develop average MTBUR values for use by the E&F team in estimating recurring maintenance costs. For components currently not in service on commercial aircraft, such as the ASMs, the O&M team evaluated the on-board team's MTBF and MTBMA values and identified, based on their commercial aviation expertise, values to apply as MTBUR. Typically, these values were similar to the on-board team's MTBMA values. All of the other aforementioned recurring full-time OBIGGS maintenance cost elements were provided to the E&F team by the O&M team.

## 3.11.5 Installation Cost

Installation cost associated with OBIGGS systems are described in the E&F team final report. No installation costs were developed by the On-Board Design Task Team.

## 3.12 SAFETY

The inclusion of an OBIGGS on an aircraft introduces a number of new or increased safety concerns. These concerns can be divided into normal operations, system leaks, component failures, and catastrophic failures.

### 3.12.1 Normal Operations

The hazards associated with the normal operation of the OBIGGS system are the discharge of oxygen enriched waste gas, the venting of NEA out of the fuel vent, the possibility of fuel tank over pressure during refuel over-fill, and those associated with electrical wiring and high temperature components, and possible disruption of cabin airflow patterns.

**Oxygen-Rich Waste Gas.** Oxygen-rich waste gas could be a fire hazard and should be vented in an area with no potential ignition sources. If possible it should be vented in an area where it will be quickly diluted.

**NEA Around Fuel Vent.** NEA vented from the fuel tank vent could create breathing problems, if inhaled. Testing during the inerting of a 737 aircraft indicated that the exiting NEA was rapidly diluted and posed little hazards. A placard warning near the vent should be sufficient.

**Increased Tank Overpressure During Refuel Failure.** The operation of the OBIGGS during a fueling over-fill may exacerbate the problem of tank overpressure. The system should be designed to limit inlet pressure to the tank and quickly relieve pressure.

**Electrical Wiring.** Electrical requirements of the system add to the amount of electrical wiring in the aircraft and the potential for electrical related smoke or fire in the aircraft. These safety concerns can be minimized through normal design practice.

**High Component Temperatures.** The operating temperature of some components may exceed 400 degrees F and should be placarded as such.

**Cabin Airflow Patterns.** The use of cabin air as inlet air to the compressor could cause a change in cabin airflow patterns, which could be hazardous during smoke or fire conditions. The air should be taken from as close to the out flow valve as possible. The new airflow patterns should be determined for compliance with the certification base of the aircraft.

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### **3.12.2 System Leaks**

Various system leaks could occur and create safety concerns. Leaks could include hot air, NEA, OEA and fuel vapor.

**Compressor Discharge Air Leaks.** Compressed air between compressor and heat exchanger could be in the range of 400 degrees F. It should be treated the same as bleed air ducting, and may require overheat detection.

**NEA Leaks.** The NEA line from the ASM to fuel tank could produce an environment, in a confined space, with a reduced oxygen level. The line should, wherever possible, be run in an area of high ventilation. Where it does run in a confined space with low ventilation the line should be a double line.

**Oxygen-Rich Waste Gas Leaks.** The waste line from the air separation module carries oxygen-rich air and could produce an environment, in a confined space, with an elevated oxygen level. The line should, wherever possible, be run in an area of high ventilation and the absence of ignition sources. Where it does run in a confined space with low ventilation or in an area with any possible ignition sources, the line should be a double line.

**Fuel Backflow Into ASM.** Fuel vapor from the fuel tank back through the NEA line into the system. Check valves should be installed in system to prevent this from occurring. This hazard could occur at any time since it is not dependent on system operation.

**Cryogenic Liquid Leaks.** A cryogenic system could leak liquid nitrogen or liquid air possibly causing damage to surrounding materials. Protection for this occurrence should be provided.

### **3.12.3 Component Failures**

It is possible that a component of the system could fail and create a hazardous condition as the system continues to operate.

**Compressor Overheat.** A compressor overheat could cause a potential fire hazard. Thermal cutout protection should be incorporated.

**Heat Exchanger Overheat.** NEA being too hot could cause a safety problem by possibly damaging the system and pumping high temperature gas into the fuel tank. Thermal cutout protection would provide mitigation from this hazard.

**Rotating Equipment Sparks.** Sparks or flames could occur in the system lines and protected should be provided by flame arrestors in line.

**Overpressure From Trapped Cryogenic Liquids.** A failure in the refrigeration components of a cryogenic system could cause an over pressure and should be prevented through the use of relief valves.

### **3.12.4 Catastrophic Failures**

**Uncontained Rotating Equipment Failure.** Uncontained rotating equipment failure could cause a hazard. The system design should provide containment for such failures.

**Pressure Vessel Burst.** Overpressure in the system could cause a pressure vessel burst and should be designed for.

**In-Flight Loss of Cabin Pressure.** Failure between pressurized and unpressurized areas could result in an in-flight loss of cabin pressure and would require the installation of a high flow fuse and shutoff valve.

## **3.13 INSTALLATION**

The installation objectives and concerns for the full-time OBIGGS are identical to those already discussed for the OBGIS. Specific design solutions for the many different aircraft models that would be affected by an inerting rule were beyond the scope of this study. The installation challenges are expected to be

greater for retrofits where other systems already occupy many locations and customer-specific modifications may require different installation approaches for the same aircraft model. In some areas, structural modifications will be needed to support the additional weight of the new components.

As with the OBGIS, the best installation locations are unpressurized, ventilated, and close to the fuel tanks. If locations that meet these criteria cannot be found, the installations will be more complicated.

Several existing aircraft models were surveyed for potential installation locations. Unpressurized locations in the air conditioning pack bay, wing root, wheel well, belly fairing, and behind the aft pressure bulkhead were examined. Pressurized locations exist in the cargo compartments and in a space forward of the aft bulkhead on some aircraft. Use of cargo space for inerting equipment carries the additional cost of the displaced cargo capacity. Typical installation locations on generic small, medium, and large transports are similar to those depicted for OBGIS (Section 1).

As with the OBGIS, the NEA distribution system must be sized for pressure drop, be double-walled within pressurized areas, and include drains for condensation. The system controller may be rack-mounted, part of a card file, or remotely located near the inerting equipment depending on the aircraft model. Wiring between the controller and components will require different degrees of protection depending on its location. The expected cockpit interface is an on/off switch and a fail light as with the OBGIS. The installation will also require additional protection if located within an engine rotor burst, tire burst, or flammable fluid leakage zone. The compressor and heat exchanger will be thermally insulated to prevent temperature damage to other equipment. The compressor must be installed to minimize noise transmission.

### 3.14 PROS AND CONS OF SYSTEM DESIGN CONCEPT

**Effectiveness and Limitations.** Full-time OBIGGS reduces the tank flammability exposure through all phases of flight and is more effective than any of the other inerting concepts studied. However, there is still a small flammability exposure since the equipment is defined as not required for flight; there is no redundancy to back up in-flight failures; and the system is not sized for faster than normal descents. Since the tanks are inert the vast majority of the time, the full-time OBIGGS is very effective against randomly occurring one-time ignition sources like lightning or a fuel-pump failure. However, because the tanks will eventually be flammable, the full-time OBIGGS may only delay an explosion for repetitive, undetected ignition sources like electrical arcing or an inadequate static bond. Unlike the ground-based inerting concepts, the full-time OBIGGS does not require a minimum time on the ground to be inert for the next flight. Further, no ground support equipment or personnel are required for operation of the system.

**Safety.** The installation of the system adds additional hazards to the aircraft, which must be mitigated. The hazards include electrical wiring, high-speed rotation machinery, ducting carrying nitrogen-enriched air and oxygen enriched air and additional penetrations into the fuel tank, and the fuselage. The design of the system should be such to minimize or eliminate the hazards. The safety section contains a more detailed description of all the hazards and means of mitigation. It should be noted that since the system operates during all phases of flight the hazards could exist at any time.

The system greatly minimizes the time a flammable mixture is present in a protected tank, thus greatly reducing the probability of a fuel tank explosion. For a more detailed discussion on the risk reduction see the section on flammability reduction.

**Cost.** There is a cost associated with the design, installation, certification, operation and maintenance of an OBIGGS. Those costs can be broken down into the cost of the system, the cost of system operation, and the cost of system maintenance. The cost of the system includes design and construction as well as certification and installation. The system operation costs include those associated with the additional weight and possible shift in center of gravity of the aircraft, possible increase in drag, and the additional use of electrical power. The full-time OBIGGS is heavier than the Ground-Based Inerting equipment that

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would be carried on board the aircraft, but lighter than the OBGIS. It uses electrical power in-flight and a small amount of bleed air. The maintenance cost includes maintenance of the OBIGGS and to other systems, such as electrical generators, affected by it. A more detailed breakdown of costs can be found in the Cost Section.

Designs are presently being explored that use a similar system for fire suppression in aircraft cargo compartments. If successful, it would allow for a dual role for the OBIGGS, thus offsetting some of the overall system weight and cost. It should be noted that on-demand OBIGGS, with no storage capability, used for fire suppression would cost more than the estimates in this report, because the system would be required for flight. This would either require additional redundancy or an increase in the expected number of flight delays, cancellations, and turn-backs.

**Environmental Impact.** The main impact to the environment from an OBIGGS is the possible increase in fuel vapors being forced overboard as the nitrogen is injected into the fuel tank. The amount of fuel vapor that is vented depends on the fuel air mixture and ullage volume, at the time of inerting, as well as many other variables. Testing has shown that presently designed cross-vented fuel tanks under certain wind conditions can vent fuel vapors into the atmosphere. A redesign for the OBIGGS would minimize that venting, thus helping to offset some of the fuel vapor lost during the inerting process.

The installation of an OBIGGS would, as shown previously, reduce the number of fuel tank explosions, thus reducing the amount of spilled fuel both on the ground and in the atmosphere.

In addition to the fuel vapor there is a potential problem with the addition of noise from the compressor/fan.

The use of dry nitrogen as an inerting agent may reduce corrosion and condensation in the protected tanks depending on the conditions at the airports where the airplane is operated.

### **3.15 MAJOR ISSUES/MITIGATION**

#### **3.15.1 High Electrical Power Consumption**

The full-time OBIGGS on the larger aircraft (Large and Medium Transports) requires high electrical power consumption during the descent phase of flight. The cryogenic distillation system uses the least electrical power of the full-time systems with the demand fairly balanced throughout the flight profile. The membrane system uses almost no power during the ground, climb, and cruise phases and then consumes a significant amount during descent. The power usage during descent is high while the power available to run the system is unknown. The pressure-swing adsorption system has a similar power consumption profile to the membrane system, but the power required for descent is higher than for the membrane system.

##### **3.15.1.1 Power Reduction Scheme for Membrane and PSA**

Some refinement of the concept, as already discussed in Concept Development, has already been performed to reduce the power consumption on the larger aircraft and additional improvement is possible. Further power reduction for both membrane or PSA systems could likely be achieved with the concept shown in Figure 3.15.1.1-1 in which the NEA out of the ASM is used to drive the second compression stage. By eliminating the electric motor drive from the second compressor the system power draw is reduced by about half. The cold NEA from the turbine is used as a heat sink to reduce the amount of ram air needed. Though not shown on the schematic, the turbine inlet NEA could be heated in the one of the heat exchangers to increase the turbine power drive and provide additional post-compression cooling.

The team did not have time to study the above concept in detail within the study period. If not practical, other methods of driving one or both compressor stages with a ram air turbine or hydraulic motor could also reduce the membrane or PSA system electrical load during descent.

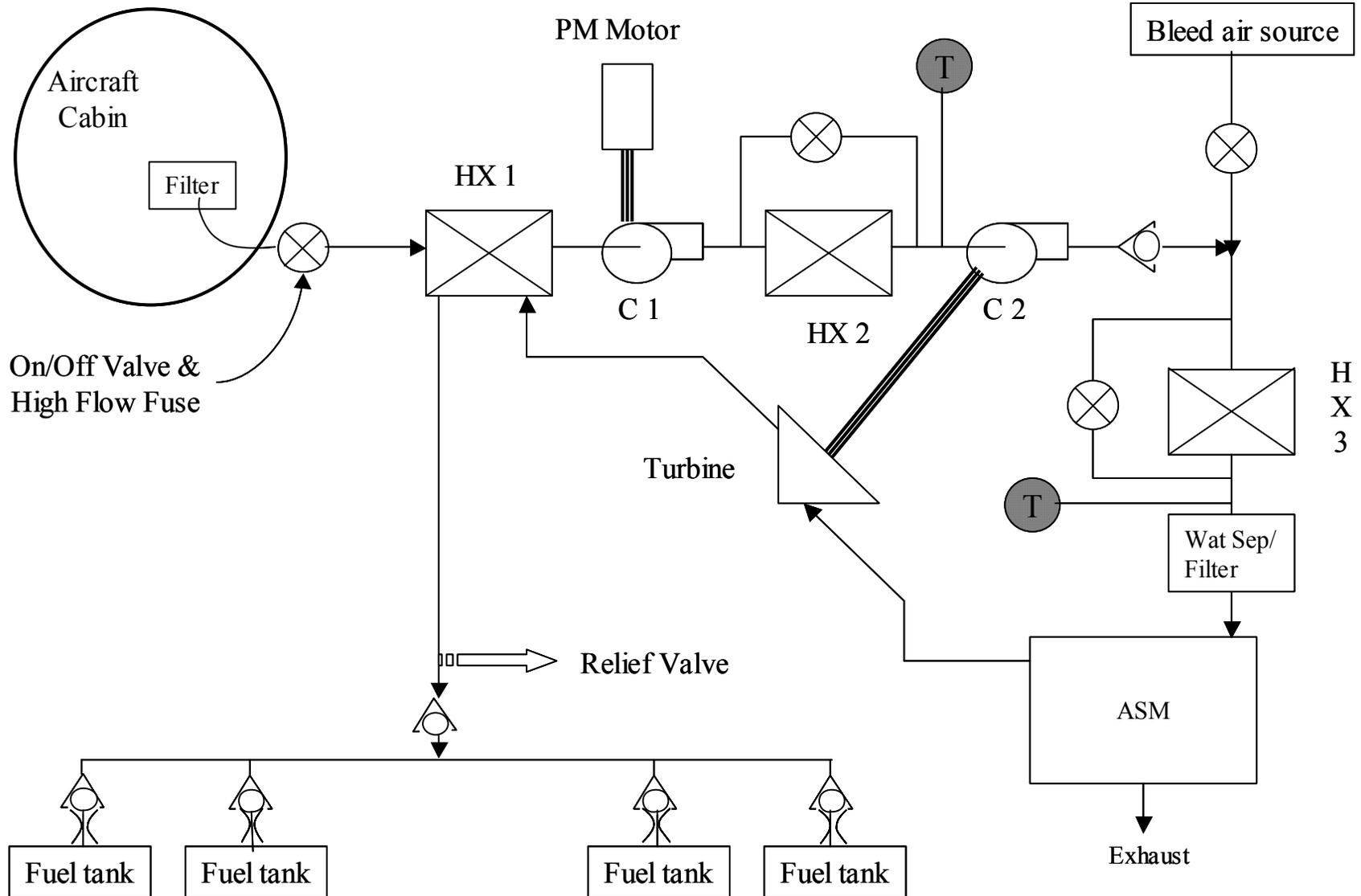


Figure 3.15.1.1-1. Potential Power Conservation Concept for Large Aircraft Membrane or PSA OBIGGS

**3.15.1.2 Power Reduction Scheme for Cryogenic Distillation**

The cryogenic refrigerator in the cryogenic distillation OBIGGS provides cooling to partially liquefy incoming air and to make up for heat exchanger losses. Heat exchanger losses account for about half of the refrigerator power for the cryogenic distillation OBIGGS described in this report. The feasibility and practicality of vacuum jacketing the heat exchangers has been confirmed by the heat exchanger supplier and could reduce the electrical power by 40% or more. Power reductions increase, as the aircraft becomes smaller, because the heat leaks are constant and thus become a larger portion of the total refrigeration load with decreasing aircraft size.

On the other hand, weight reductions improve as the aircraft size decreases because the cryocooler is a larger fraction of the system weight for smaller aircraft. Figure 3.15.1.2-1 gives the actual electrical power and weight values for full-time inerting of the CWT from the LT through the ST.

	Present Cryo OBIGGS			Improved Cryo OBIGGS		
	LT-CWT	MT-CWT	ST-CWT	LT-CWT	MT-CWT	ST-CWT
Electrical Power (kVA)	17	17	16	8	7	6
Weight (lbs.)	414	338	283	401	298	238

*Figure 3.15.1.2-1. Electrical Power and Weight for the Improved Cryogenic Distillation Components With Vacuum Jacketing*

**3.15.2 Potential Interference With Cabin Re-Pressurization During Descent**

Compressing cabin air instead of ram air significantly reduces the weight and electrical power required for the system. The air conditioning system constantly supplies air to the cabin, some of which exits the cabin through a modulating outflow valve, which controls cabin pressure, and the remainder leaks out through the fuselage. The cabin leakage rate is directly proportional to the aircraft altitude (higher altitude means higher leakage). During descent, the outflow valve drives toward closed to slowly re-pressurize the cabin. If the aircraft leakage exceeds the maintenance manual limit, drawing air from the cabin for a full-time OBIGGS will slow down the re-pressurization of the aircraft until the aircraft reaches the altitude at which the leakage decreases to the point that the outflow valve can again regulate the cabin pressure. This condition is much more likely to affect older aircraft, which may leak more. Although this is only a problem when the cabin leakage exceeds the maintenance manual limit, the ops and maintenance team has included an estimate of the increased maintenance labor to fix cabin leakage more frequently than would otherwise be required.

#### 4.0 HYBRID OBIGGS

The hybrid On-Board Inert Gas Generating System (OBIGGS) is one of four main system categories studied by the 2000 ARAC FTIHWG Onboard Airplane Design Task Team. The term ‘hybrid’, as used here, refers to a potentially smaller system that does not require the fuel tanks to be inert during descent. The on-board team studied systems that were sized to provide inerting for various fuel tank configurations of six generic models. The team also defined the physical size and weight of the components that make up the hybrid OBIGGS. Finally, power and air consumption needs were defined.

#### 4.1 REQUIREMENTS

The NEA flow rate for the hybrid OBIGGS is sufficient to produce the same flammability exposure during the ground and climb phases as the ground-based systems. This requirement allowed a direct comparison with the GBI and OBI systems. As such, the hybrid OBIGGS does not necessarily keep the tanks inert through all mission phases.

Like the other on-board systems, the hybrid OBIGGS produces nitrogen as the inerting agent and all equipment is installed on the airframe, except for certain diagnostic equipment. The system does not require redundancy.

#### 4.2 DATA SUPPLIED FROM OTHER SOURCES

Data was taken from various sources so that the team could define the hybrid OBIGGS concept. This included aircraft turn times, generic aircraft definition and mission profiles, fuel tank sizes, bleed air data, and cabin pressure schedules.

##### 4.2.1 Aircraft Turn Times

As with the OBI systems, the aircraft pre-flight times were initially derived from the July 1998 ARAC FTIHWG as summarized in Figure 4.2.1-1 below:

Generic Aircraft	Pre-flight Time (Minutes)
Turbofan	20
Turboprop	20
Business Jet	45
Small	45
Medium	60
Large	90

*Figure 4.2.1-1. FTIHWG Aircraft Pre-Flight Times*

To ensure the turn times were representative of in-service aircraft, the airline survey described in Section 1 of this report was conducted for several major airlines. The FTIHWG made the decision to modify the aircraft turn times to the values seen in Figure 4.2.1-2 below. These values were used as the minimum turn-times in the hybrid OBIGGS sizing analysis, since they were representative of the in-service fleet.

Generic Aircraft	Turn Time (Minutes)
Turbofan	15
Turboprop	15
Business Jet	60
Small Transport	20
Medium Transport	45
Large Transport	60

*Figure 4.2.1-2. FTIHWG Minimum Turn-Times*

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## 4.2.2 Generic Aircraft Types

The FTIHWG made the decision to use the same generic aircraft data and mission scenarios that were used in the July 1998 ARAC FTHWG Report. As with the baseline OBI System, these generic airplane definitions and missions were used in assessing the operational parameters. Discussion of the data is included in the 'Generic Aircraft Types' part of Section 1 of this report and the complete definitions and missions compiled during the previous FTHWG effort are included as an attachment to the Working Group report. As with the other systems, the worst-case flight conditions are the shortest-ranged flights.

## 4.2.3 Generic Aircraft Fuel Tank Volumes

The 1998 ARAC Generic Aircraft fuel tank sizes listed in Figure 4.2.3-1 were used for all system sizing.

Generic Aircraft	CWT Volume (Gal.)	CWT + Wing Tank Volume (Gal.)	CWT + Wing + Aux Tank Volume (Gal.)
Turbofan	816	3,264	N/A
Turboprop	N/A	1,428	N/A
Business Jet	N/A	6,273	N/A
Small	3,060	5,100	7,600
Medium	10,200	24,480	27,480
Large	25,500	55,080	58,080

Figure 4.2.3-1. Generic Aircraft Fuel Tank Volumes

## 4.2.4 Bleed Air

The team determined that bleed air availability for the hybrid OBI is limited. The team received the generic bleed air data listed in Figure 4.2.4-1 from airframe manufacturers.

Flight segment	Sufficient Flow available	Pressure available	Temperature
Ground, APU	no	25 to 54 psia	325 to 430°F
Ground idle	no	45 psia	350 to 380°F
Climb	yes	40 to 55 psia	330 to 380°F
Cruise	yes	25 to 40 psia	350 to 380°F
Idle descent	no	20 to 35 psia	350 to 380°F

Figure 4.2.4-1. Bleed Air Availability

## 4.2.5 Cabin Pressure

The team received the typical cabin pressures listed in Figure 4.2.5-1 for the six aircraft models from airframe manufacturers.

Altitude, feet	Cabin pressure, psia
0	14.7
5,000	14.3
10,000	13.9
15,000	13.5
20,000	13.2
25,000	12.8
30,000	12.4
35,000	12.0
40,000	11.2
45,000	10.9
50,000	10.9
55,000	10.9

Figure 4.2.5-1. Cabin Pressure Schedule

## 4.3 ASSUMPTIONS

The following are assumptions that the team developed and used for the analysis.

**Initial Oxygen Concentration.** The starting oxygen concentration in the ullage is assumed to be equal to the final concentration from the previous flight. However, for the first flight of the day or following maintenance actions, the oxygen concentration is assumed to be 20.9% by volume.

**Hydraulic Power Availability.** The team assumed that aircraft hydraulic power to operate the hybrid OBIGGS is not available while at the gate. It was further assumed that in order to utilize hydraulic power to operate the system in flight, it would be necessary to upgrade the existing on-board systems.

**Electrical Power at Aircraft Gate.** The team assumed that sufficient ground power could be made available to operate the hybrid OBIGGS.

**Electrical Power in Flight.** The team assumed that sufficient electrical power from the aircraft generators is available to operate the hybrid OBIGGS in flight.

**Cabin Air Supply.** The team assumed that the cabin air that normally exhausts through the outflow valve is available to the system.

**Ullage Mixing.** It was assumed that as air enters the fuel vent system during a descent, that it quickly mixes with the ullage and with the inert gas produced during the descent.

**Vent System Modifications.** It was assumed that necessary vent system modifications would be made to prevent cross-venting during crosswind conditions.

**Fuel Tank Initialization.** The team assumed that an extended ground time would be allowed to initialize the tanks for the first flight of the day and following maintenance actions.

#### **4.4 CONCEPT DEVELOPMENT**

**Similar to Full-Time OBIGGS.** The hybrid OBIGGS is a simplification of the full-time OBIGGS concept that achieves most of the flammability reduction with a significantly smaller system. The hybrid OBIGGS concept uses smaller versions of the same type of components as the full-time system. Both the hybrid and full-time systems process compressed cabin air in an air separation module to create NEA that is distributed to the fuel tanks. Permeable membrane, pressure-swing adsorption, and cryogenic distillation air separation technologies were all evaluated for use in a potential hybrid OBIGGS. A complete explanation of the Concept Development is in the full-time OBIGGS section and more information about the three air separation technologies is in Addenda A1, A2, and A3.

**Lower NEA Flow.** The NEA flow rates in the hybrid OBIGGS are greatly reduced from the full-time OBIGGS (the hybrid flows are approximately 25 per cent of full-time OBIGGS for both the medium and large transports and approximately 12 percent for the other four models). The NEA flow in the full-time system is primarily driven by the worst-case requirement to keep the tanks inert during descent. The hybrid OBIGGS takes advantage of the fact that the fuel and ullage are typically cold during descent, so the oxygen concentration in the tanks can exceed the 10% inert limit during this flight phase with little increase in flammability exposure.

**Single NEA Flow Rate.** The hybrid OBIGGS generates NEA at a single, constant flow rate during all phases of flight and ground operations, rather than the full-time OBIGGS approach of generating multiple flow rates dependant on flight phase. The membrane and PSA hybrid systems distribute the NEA as it is generated.

The cryogenic distillation hybrid OBIGGS also generates NEA at a constant rate through all phases of flight and distributes all the NEA generated during ground, climb, and descent. During cruise, the cryo system distributes a lower NEA flow rate to the fuel tanks and stores the remainder as liquid NEA which will be used the next morning to initialize the tanks and the system.

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### 4.5 CONCEPT DESCRIPTIONS

The generic hybrid OBIGGS concept was applied to all six aircraft models and tank configurations with no obvious feasibility issues. The concept descriptions of the hybrid OBIGGS for each model and ASM technology are tabulated in Figure 4.5-1. For future implementation, if the membrane or PSA size or power consumption is determined too large for a given model, the air consumption and electrical power required could be further reduced, with a small increase in system complexity, by incorporating a low flow setting during cruise. Detailed schematics of the membrane, PSA and cryogenic distillation hybrid OBIGGS concepts are shown in Figures 4.5-2 and 4.5-3.

	Number of Compressors	Compressor Pressure Ratio	Number of Compressor Stages	Compressor Precooler and Inter-cooler	Air Separation Module Inlet Temperature	Lower NEA Flow Rate during Cruise
<b>Generic Concept</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes
<b>Large Transport</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes
<b>Medium Transport</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes
<b>Small Transport</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes
<b>Regional Turboprop</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes
<b>Regional Turbofan</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes
<b>Business Jet</b>						
Membrane	1	4:1	1	No	180F	No
PSA	1	4:1	1	No	75F	No
Cryo	1	3:1	1	No	75F	Yes

Figure 4.5-1. System Characteristic for Each Model and Technology

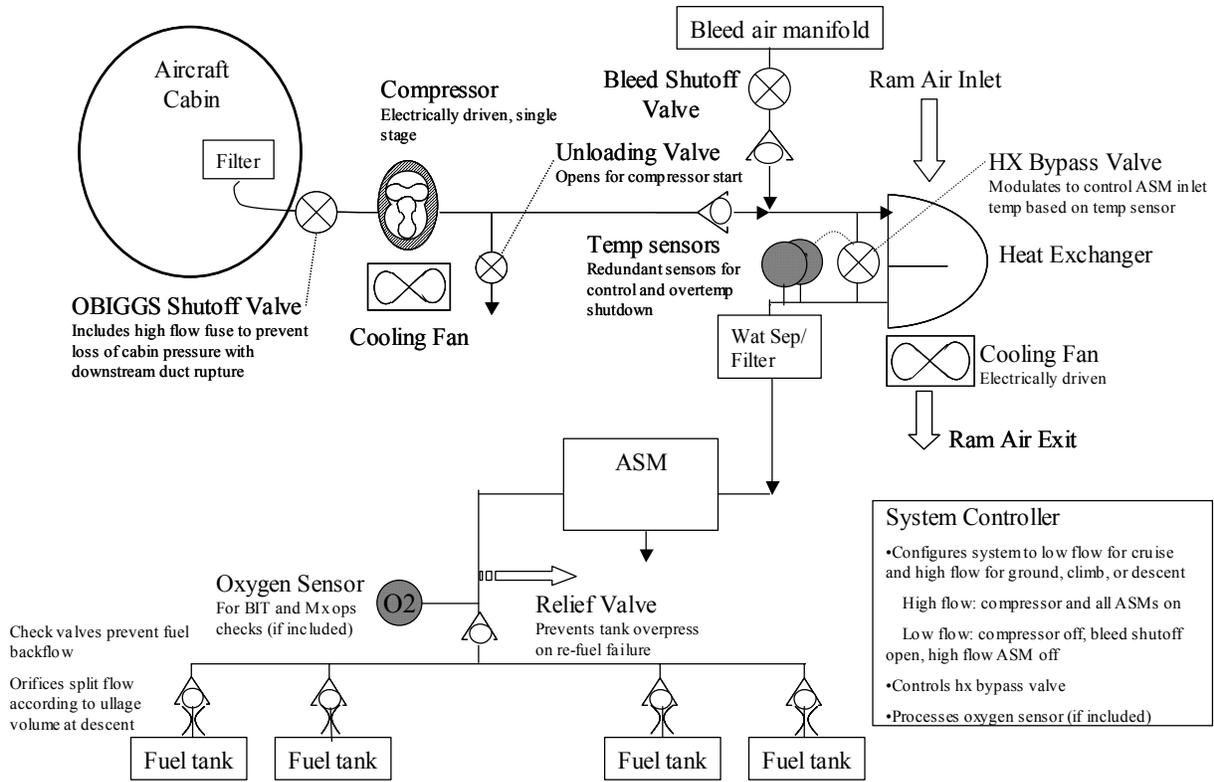


Figure 4.5-2. Membrane and PSA Hybrid OBIGGS Concept

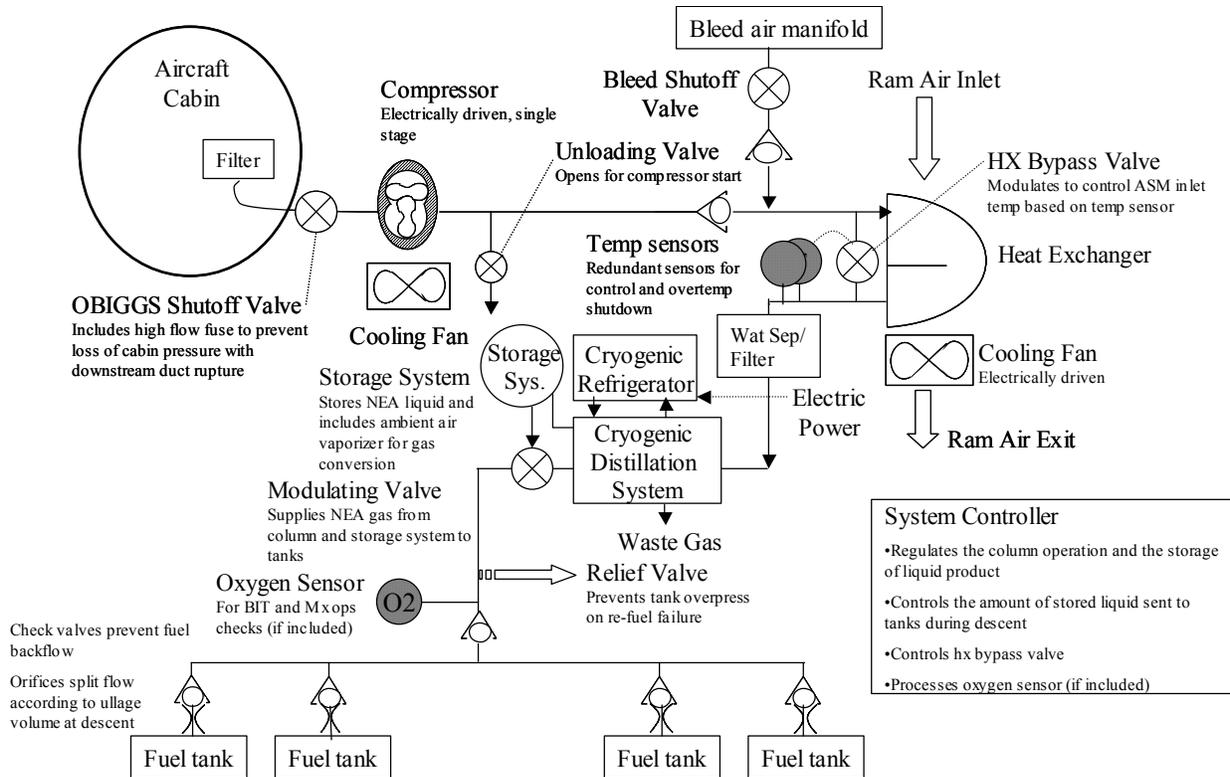


Figure 4.5-3. Cryogenic Distillation Hybrid OBIGGS Concept

4.6 SYSTEM SIZING AND PERFORMANCE

4.6.1 Sizing Criteria

The NEA flow rates for the hybrid OBIGGS were selected so that the ground and climb flammability exposure for each model and tank configuration would be equivalent to that of the ground-based options evaluated for that model. The ground and climb exposures were used instead of the total exposure, because the flammability model conservatively applies sea level flammability criteria at altitude. A very small hybrid OBIGGS would produce an apparent reduction in total flammability, but most of the gain would occur during cruise (where the true risk is overstated) with very little improvement during the ground or climb phases. Since all of the recent accidents have occurred on the ground or in climb, the actual benefit of such a system is minimal. By using the equivalent ground and climb exposure, the team ensured that the performance of hybrid OBIGGS was equivalent to the GBI, OBGI, and the hybrid OBGI. Because the hybrid OBIGGS continues to operate during flight, the total flammability exposures for the hybrid systems are lower than the ground-based systems.

An example of the relationship between NEA flow rate and flammability exposure for a large transport, center wing tank hybrid OBIGGS supplied by a PSA separator is shown in Figure 4.6.1-1. Both the total and ground/climb exposures are shown. The exposure with no NEA flow is equivalent to the aircraft without inerting. Once the relationship between flammability and NEA flow was determined for each model and tank, the selected exposure dictated the required NEA flow and component sizes.

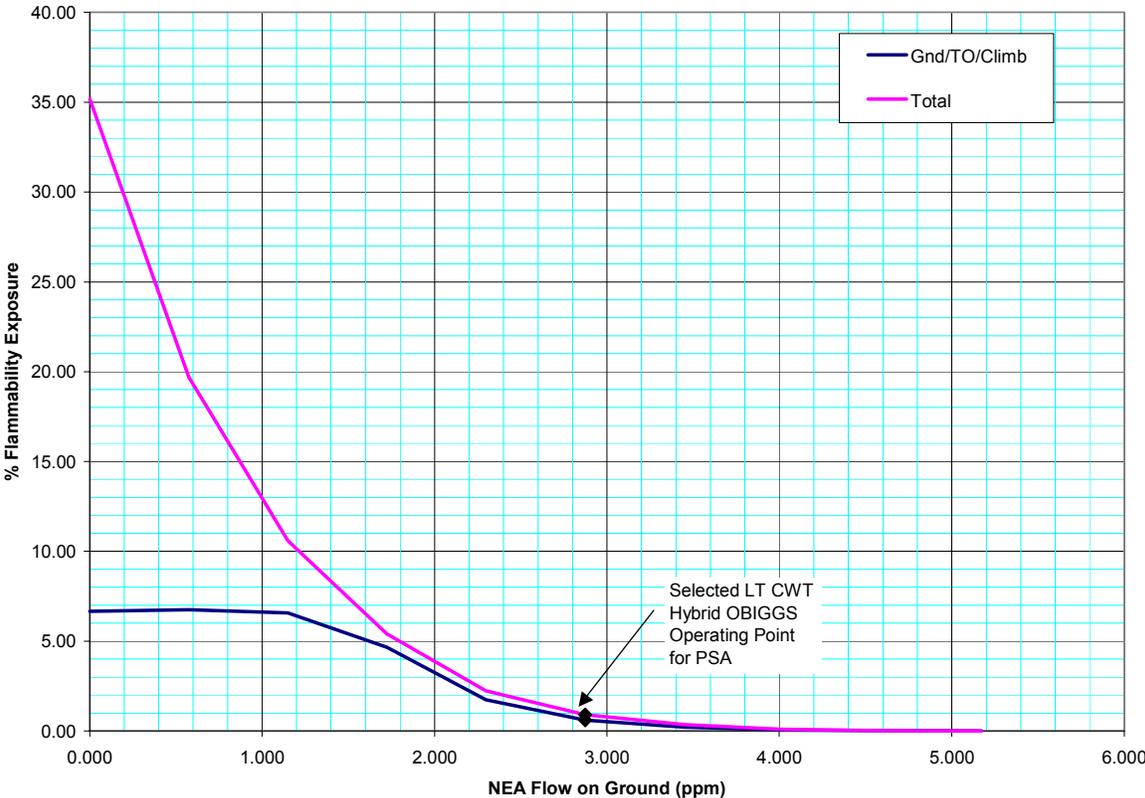


Figure 4.6.1-1. Flammability Exposure vs. NEA Flow for a Large Transport CWT, PSA Hybrid OBIGGS

**4.6.2 Parametric Sizing Curves**

The system weights, volumes, peak power consumption, and acquisition costs of the hybrid OBIGGS for the generic aircraft models and tank configurations are plotted in parametric sizing curves for easy interpolation to other aircraft models. To use the curves, the required NEA flow (to produce similar ground and climb flammability exposure with the ground-based systems) is found in Figure 4.6.2-1 or 4.6.2-2 based on tank size. For that NEA flow, the system weight, volume, electrical power consumption, and acquisition cost can be estimated from Figures 4.6.2-3 through 4.6.2-6. For future cost-benefit analyses, the NEA flow is broken out separately, to facilitate evaluation of systems with different NEA flows that produce other flammability exposure results

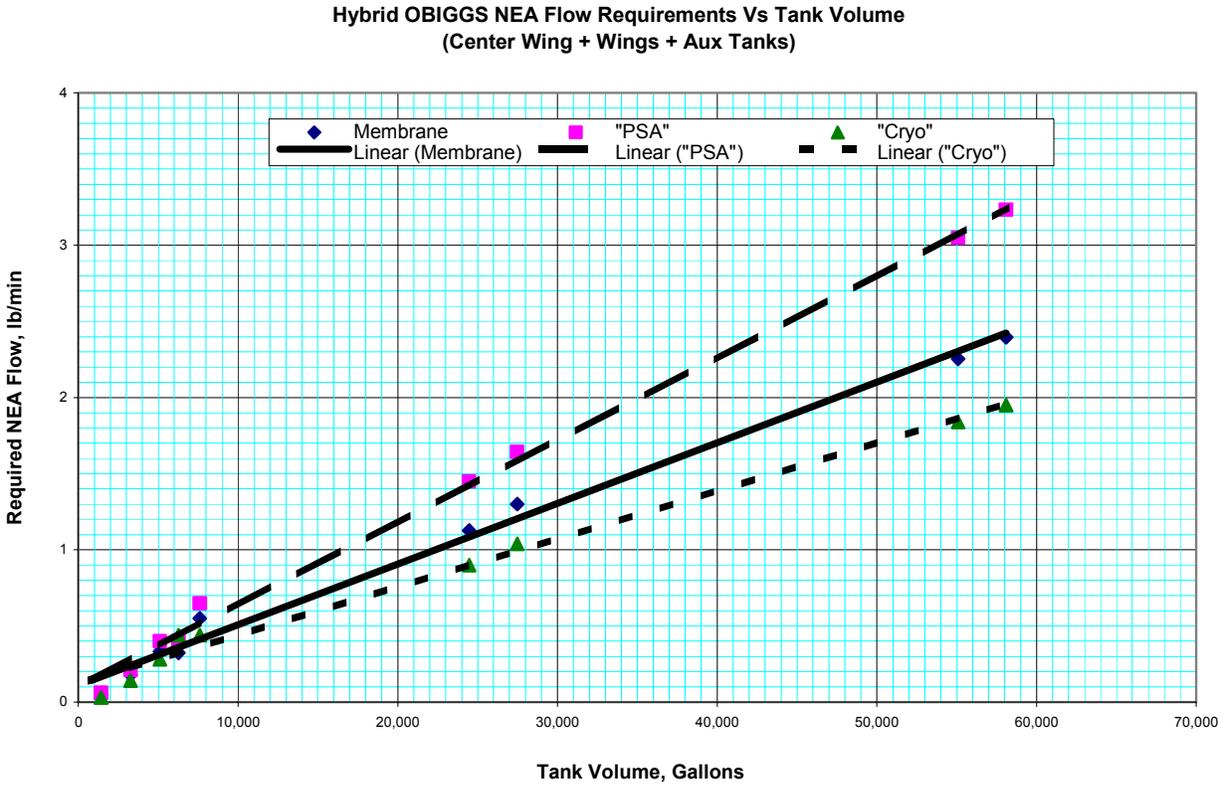


Figure 4.6.2-1. NEA Flow vs. Tank Volume—Center, Wing, and Auxiliary Tanks

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Hybrid OBIGGS NEA Flow Requirements Vs Tank Volume  
(Center Wing Tanks Only)

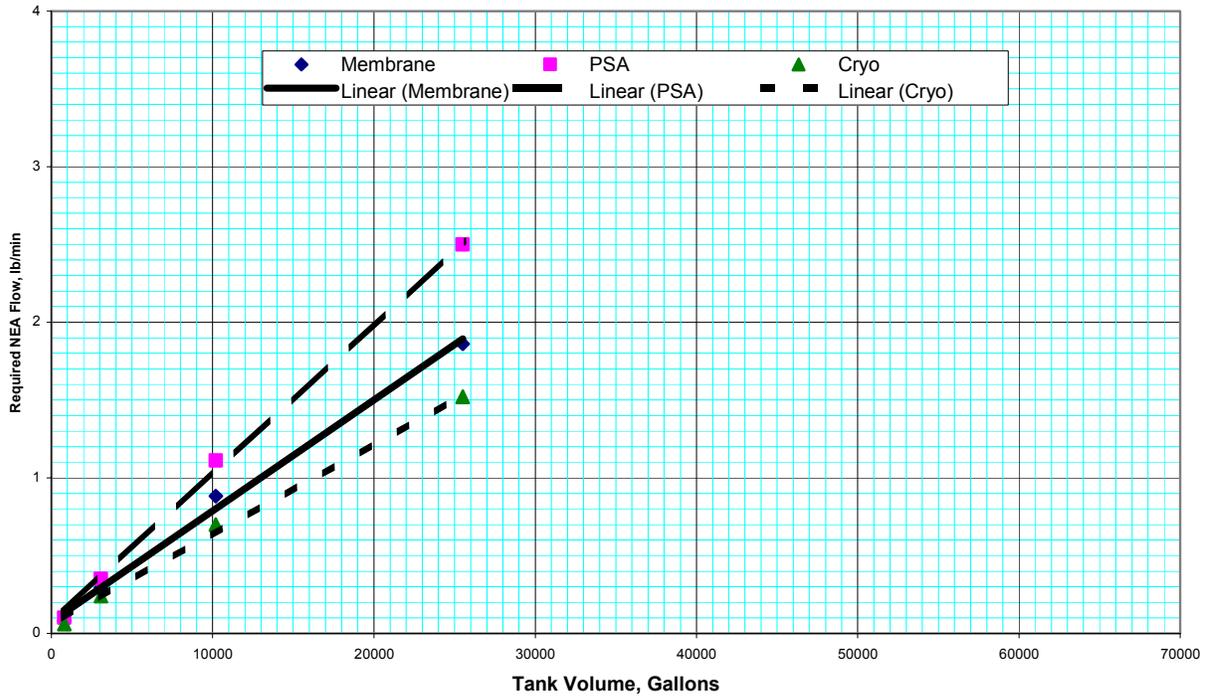


Figure 4.6.2-2. NEA Flow vs. Tank Volume—Center Tanks Only

Hybrid OBIGGS Weight Vs NEA Flow

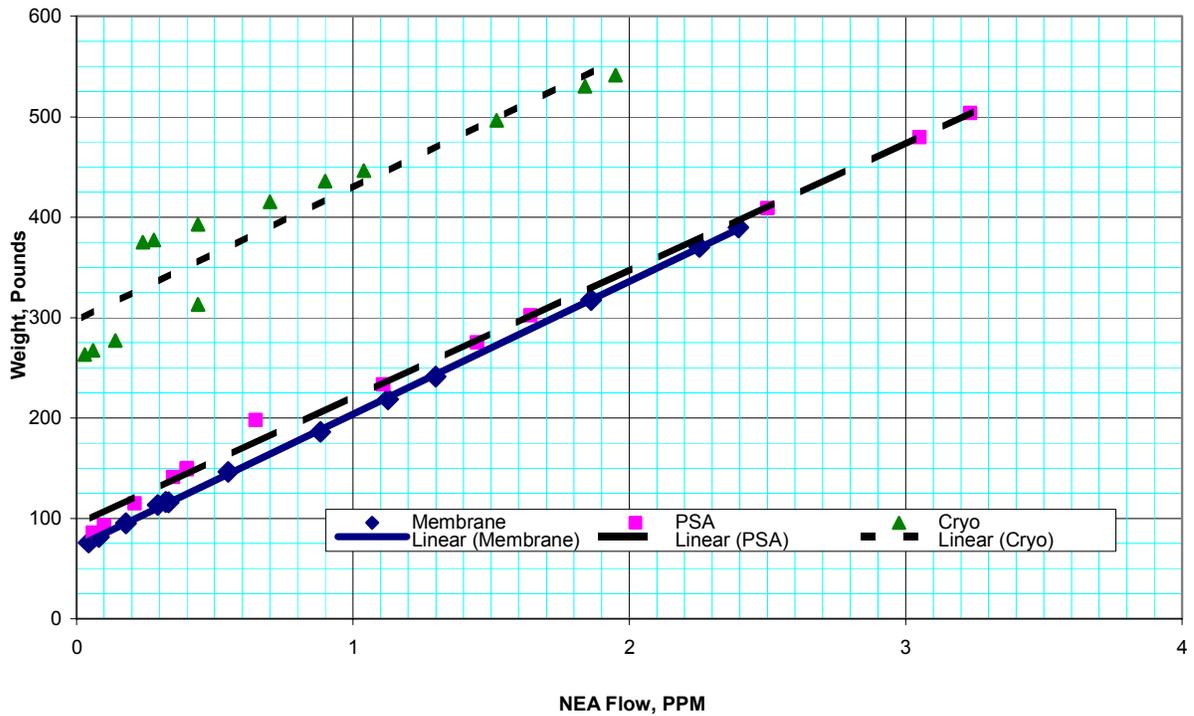


Figure 4.6.2-3. Weight vs. NEA Flow

Hybrid OBIGGS Volume Vs NEA Flow

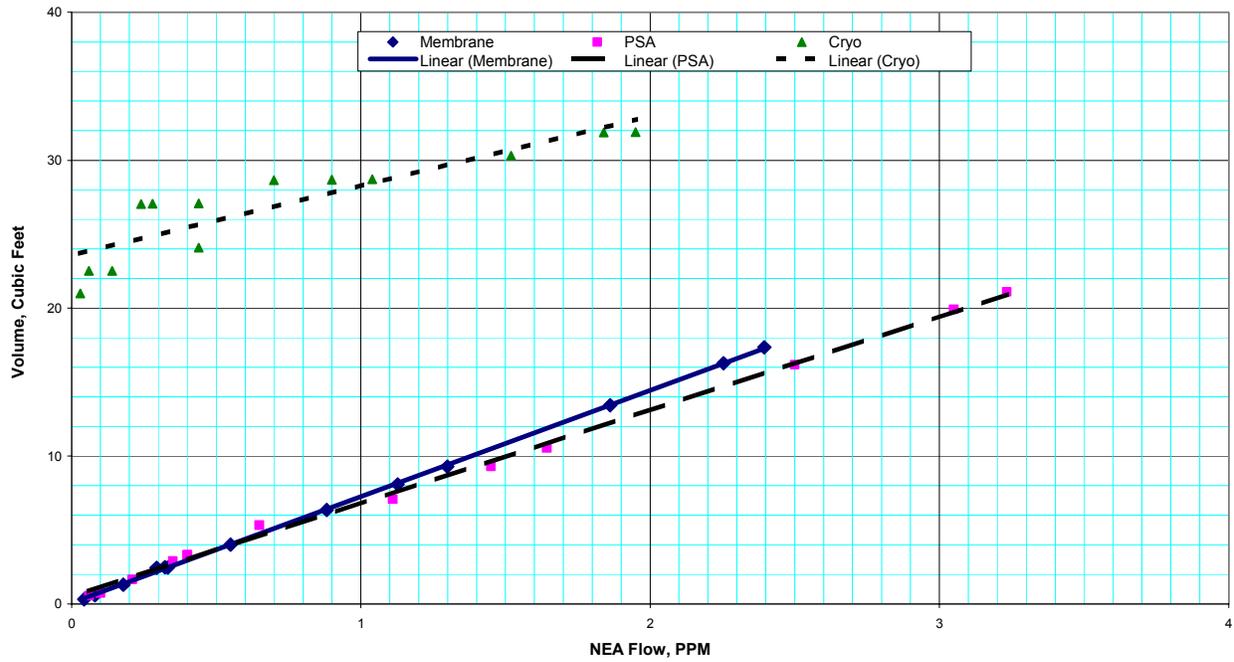


Figure 4.6.2-4. Volume vs. NEA Flow

Hybrid OBIGGS Electrical Power Vs NEA Flow

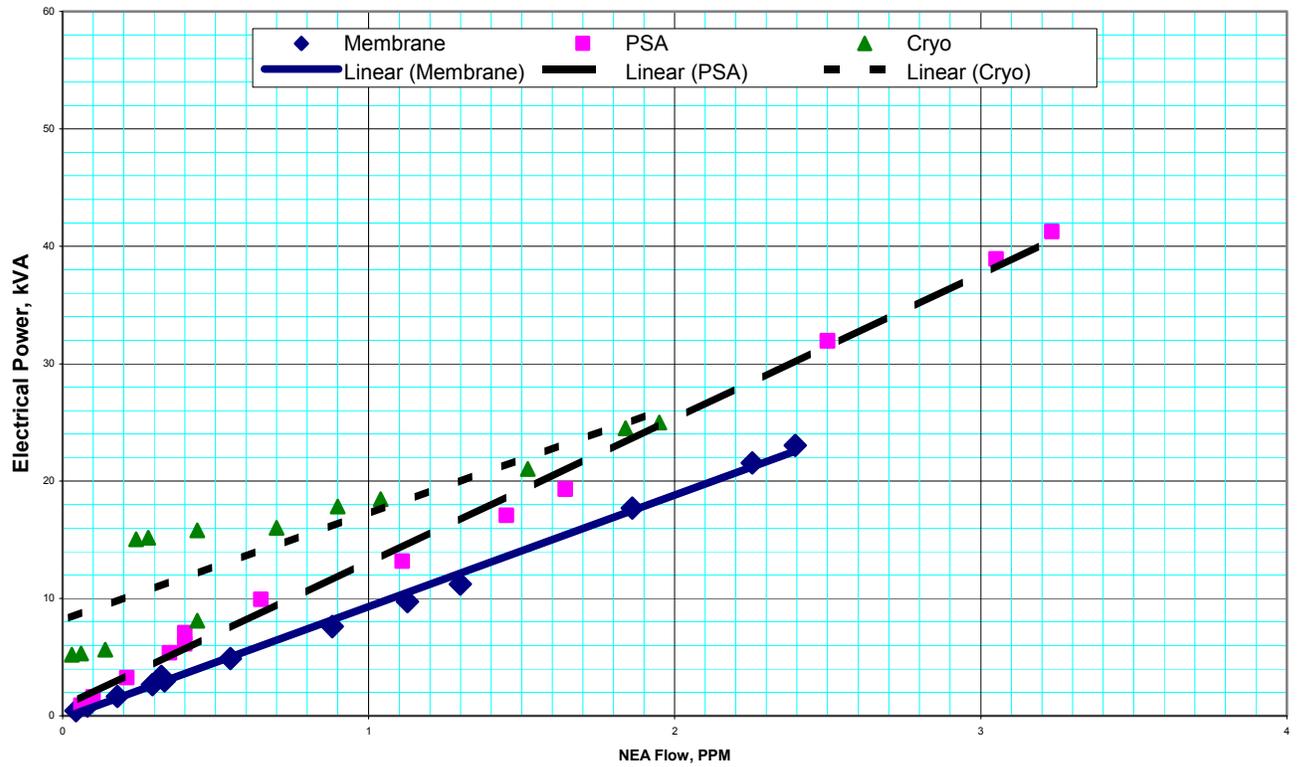
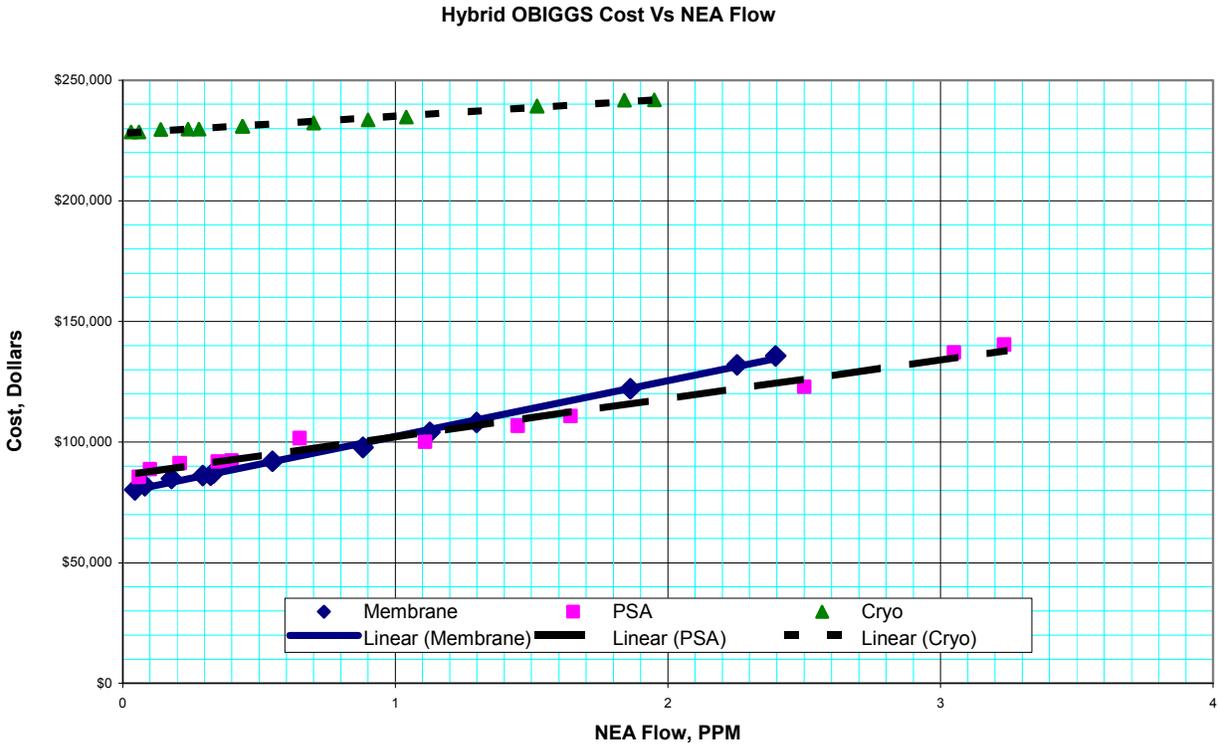


Figure 4.6.2-5. Power vs. NEA Flow



*Figure 4.6.2-6. Cost vs. NEA Flow*

A heated center wing tank requires significantly more hybrid OBIGGS NEA flow to lower the flammability exposure than other tank types. To account for this difference, the NEA flow required for hybrid OBIGGS systems that supply center tanks only are plotted separately (Figure 4.6.2-2) from the flows required for combined center, wing, and auxiliary tanks (Figure 4.6.2-1). The full-time OBIGGS NEA flows reported in the previous section are much less sensitive to the difference between center and other tank types and don't require a separate curve.

The NEA flow rate referenced in the parametric sizing curves is the nominal hybrid OBIGGS flow rate at sea level. The NEA oxygen concentrations, for each ASM technology and flight phase that were used to generate the curves, are tabulated in Figure 4.6.2-7. The parametric sizing curves are not valid for other NEA oxygen concentrations.

	<b>Ground</b>	<b>Climb</b>	<b>Cruise</b>	<b>Descent</b>
Membrane	5%	3.5%	3.5%	3.5%
PSA	7.3%	5.5%	4.3%	5.5%
Cryo	1%	1%	1%	1%

*Figure 4.6.2-7. Hybrid OBIGGS NEA Oxygen Concentrations*

A quick look at Figures 4.6.2-3 to 4.6.2-6 can give the mistaken impression that the cryogenic distillation system is not competitive with the other inerting technologies. Because the cryogenic distillation system requires significantly lower NEA flows for the same tank volume, the actual system parameters must be calculated for a given model to get a valid comparison.

The following examples demonstrate membrane, PSA, and cryogenic distillation system sizing for an aircraft with a total fuel capacity of 35,000 gallons (including all main and center wing tanks plus auxiliary tanks):

- Membrane System: Figure 4.6.2-1 indicates that a 35,000 gallon tank capacity requires approximately 1.5 pounds per minute of NEA at the membrane system purity. Figures 4.6.2-3 to 4.6.2-6 show that a membrane system to produce 1.5 lb/min of NEA weighs approximately 270 lbs, occupies 11 cubic feet, requires 14 kVA of electrical power during descent, and has initial acquisition costs of \$115,000.
- PSA System: Figure 4.6.2-1 shows that about 2 pounds per minute of NEA at PSA purity are required. Figures 4.6.2-3 to 4.6.2-6 indicate that the corresponding PSA system weighs approximately 350 pounds, occupies 13 cubic feet, requires 25 kVA of electrical power during descent, and has initial acquisition costs of \$120,000.
- Cryogenic Distillation System: Figure 4.6.2-1 shows that 1.25 pounds per minute of NEA at cryo purity are required. Figures 4.6.2-3 to 4.6.2-6 indicate that the corresponding cryogenic distillation system weighs approximately 460 pounds, occupies 29 cubic feet, requires 19 kVA of peak electrical power and has initial acquisition costs of \$235,000.

**4.6.3 System Results**

The system weight, volume, peak electrical power consumed, and initial acquisition cost for the hybrid OBIGGS sized for each model and tank configuration are shown in Figures 4.6.3-1 through 4.6.3-3. These results are based on a hybrid OBIGGS that produces the same flammability exposure during ground and climb as the GBI, OBGI, and hybrid OBGI systems. Larger or smaller hybrid systems could be sized using other flammability exposure criteria.

Hybrid OBIGGS - Center Wing Tank

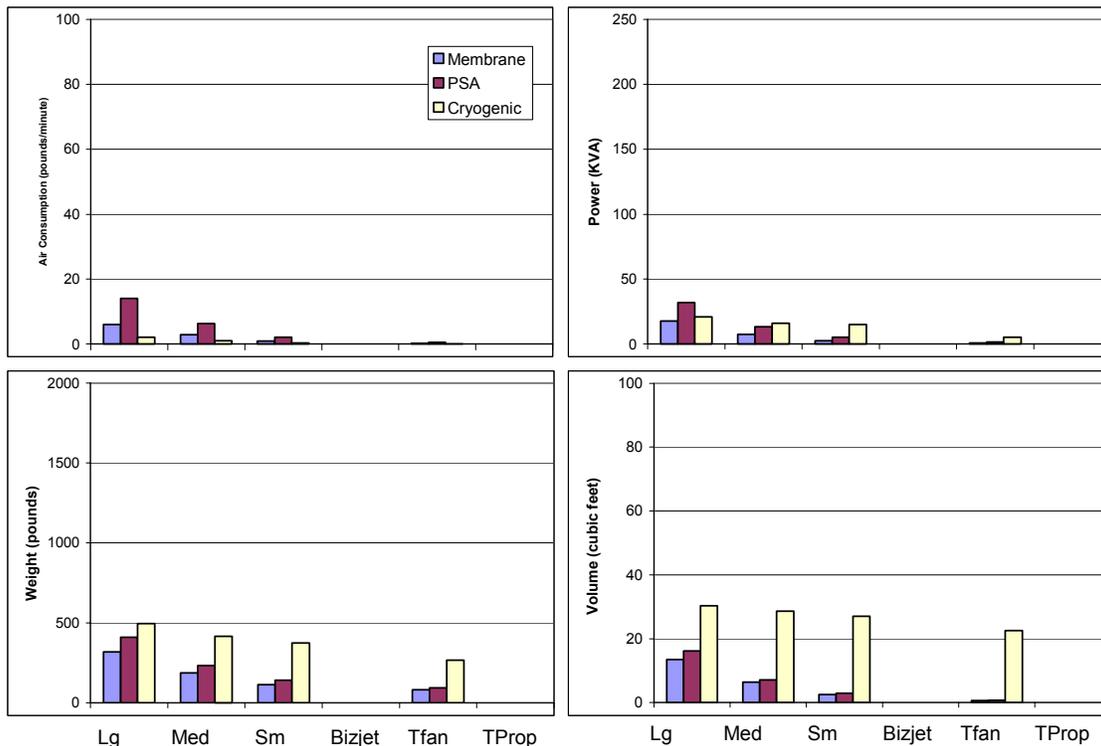
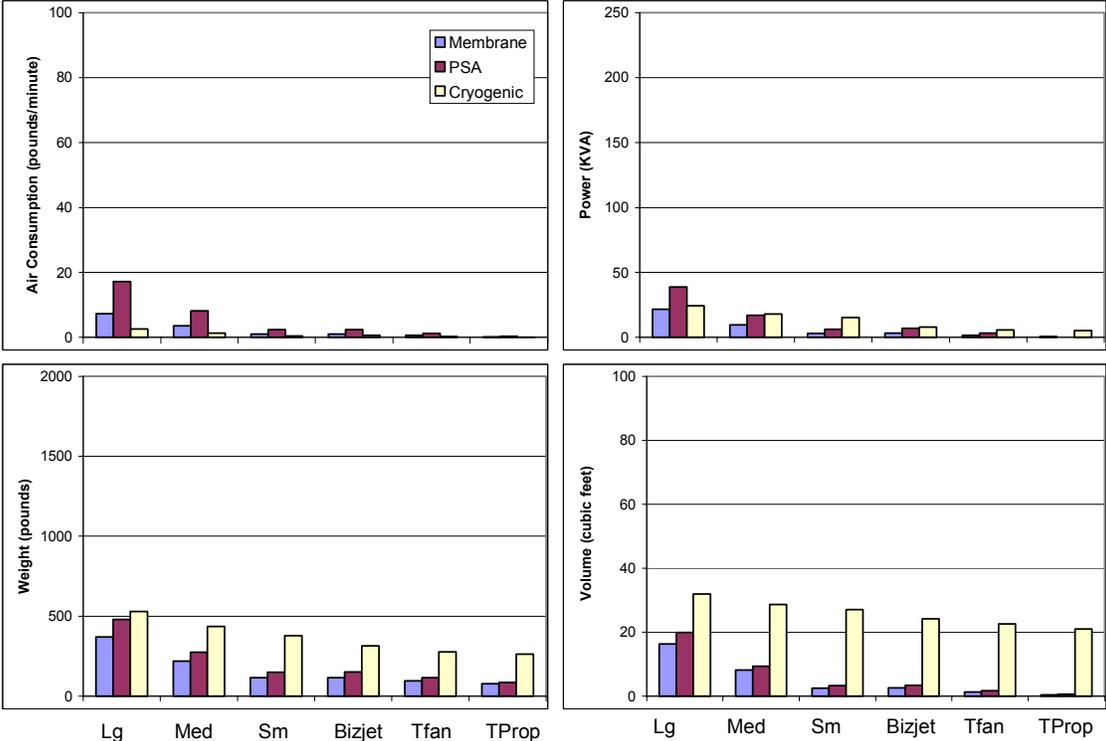


Figure 4.6.3-1. Hybrid OBIGGS Air Consumption, Power, Volume, and Weights for Center Tanks

**Hybrid OBIGGS - Center Wing & Wing Tank**



*Figure 4.6.3-2. Hybrid OBIGGS Air Consumption, Power, Volume, and Weights for Center and Main Tanks*

Hybrid OBIGGS - Center, Wing, & Aux Tank

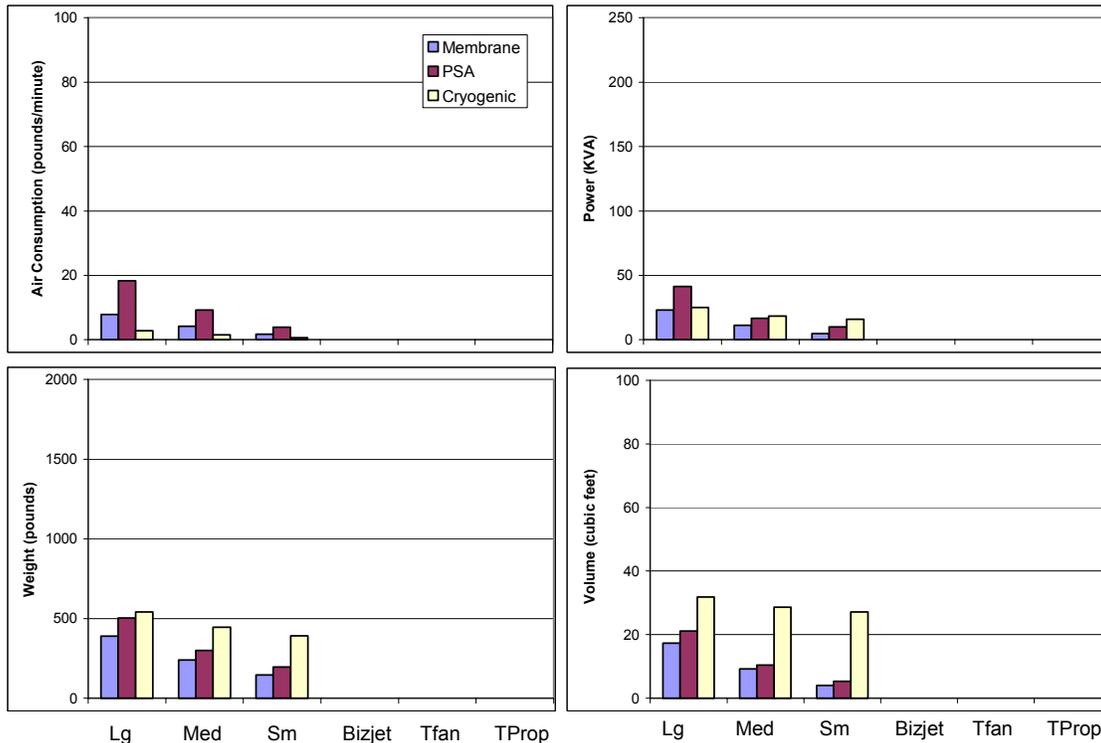


Figure 4.6.3-3. Hybrid OBIGGS Air Consumption, Power, Volume, and Weights for Center, Main, and Auxiliary Tanks

4.6.4 Flammability Exposure

The total and ground/climb flammability exposures for the hybrid OBIGGS with each of the three air separation technologies applied to each model and tank type are shown in Figures 4.6.4-1 to 4.6.4-3. A flammability exposure comparison between the different inerting concepts studied can be found in the Conclusions.

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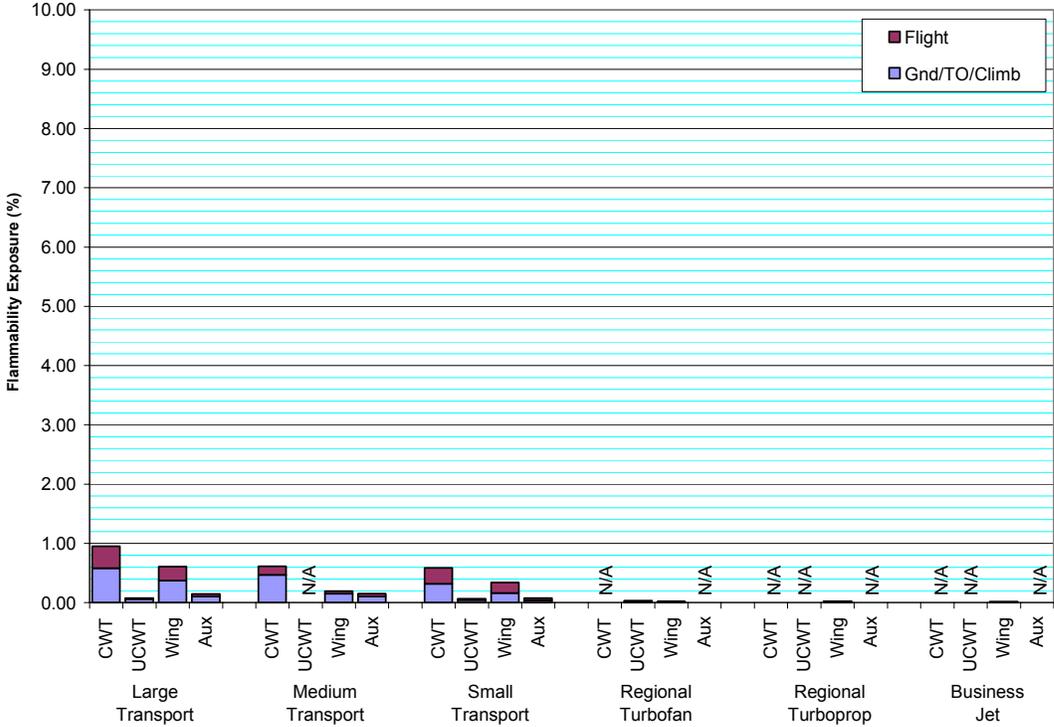


Figure 4.6.4-1. Membrane Hybrid OBIGGS Flammability Exposure

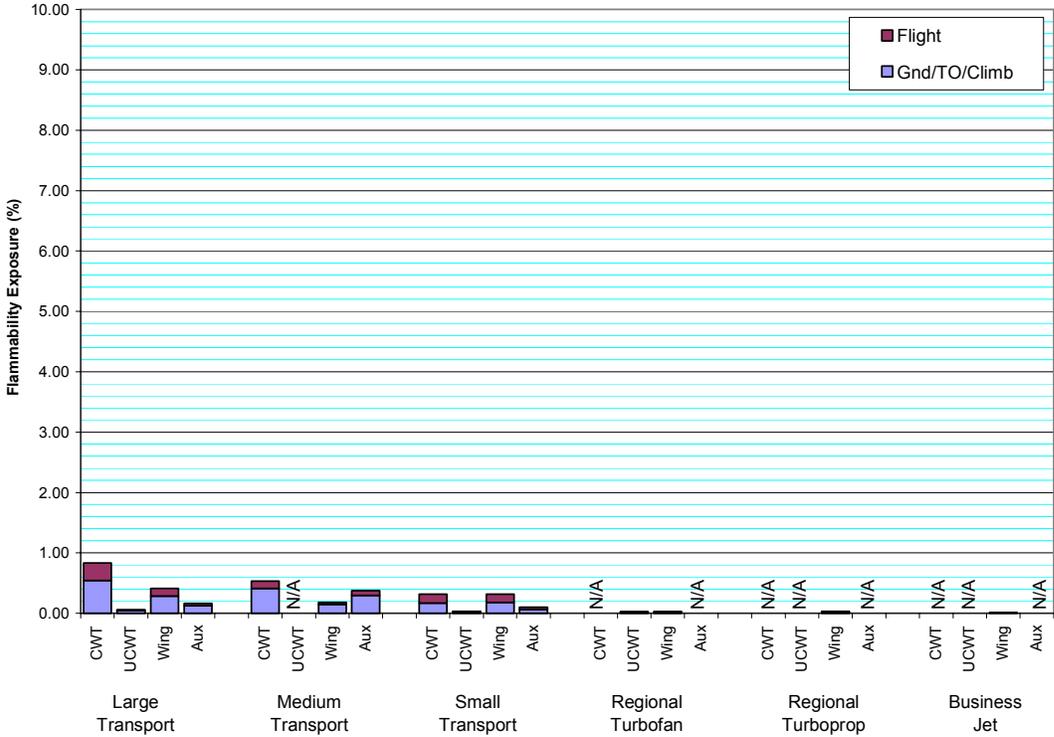


Figure 4.6.4-2. Pressure-Swing Adsorption Hybrid OBIGGS Flammability Exposure

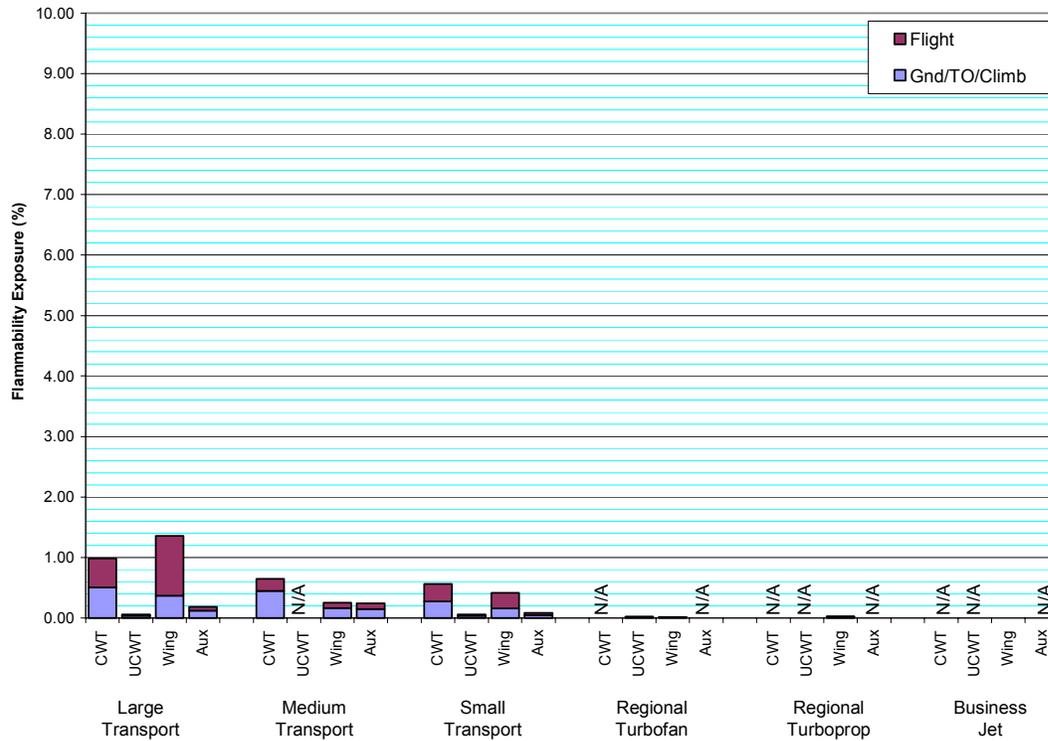


Figure 4.6.4-3. Cryogenic Distillation Hybrid OBIGGS Flammability Exposure

#### 4.7 WEIGHT

Figures 4.7-1 through 4.7-3 summarize the hybrid OBIGGS weights for the membrane, PSA, and cryogenic distillation inerting systems for each of the ARAC generic aircraft. Each table provides the total weight for the “major” and “other” components identified for each system. “Other” components include such items as wiring, ducting, and valves, and their total estimated weights have been combined.

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Membrane System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight (lbm)	MT CWT Only Shipset Weight (lbm)	ST CWT Only Shipset Weight (lbm)	RTF CWT Only Shipset Weight (lbm)	LT CWT+Main+Aux Shipset Weight (lbm)	MT CWT+Main+Aux Shipset Weight (lbm)	ST CWT+Main+Aux Shipset Weight (lbm)
<b>Major Components:</b>													
Compressor	12.2	5.5	4.2	2.2	0.5	4.7	10.0	4.3	3.7	1.1	13.1	6.3	6.9
Heat exchanger/fan	10.0	4.4	0.8	0.4	0.1	0.8	8.0	3.2	0.7	0.2	10.7	5.2	1.3
Air separation module	119.0	59.5	18.0	9.5	2.3	18.0	98.3	46.8	18.0	4.3	126.9	68.6	29.2
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	141	69	23	12	3	23	116	54	22	6	151	80	37
<b>Other component sub-totals</b>	229	149	93	83	73	93	201	132	91	76	239	161	109
<b>System Totals</b>	370	218	116	95	76	116	317	186	113	82	390	241	146
On-board oxygen sensor (not included in system totals)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Figure 4.7-1. Summary of OBIGGS Weights—Membrane Systems

PSA System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight (lbm)	MT CWT Only Shipset Weight (lbm)	ST CWT Only Shipset Weight (lbm)	RTF CWT Only Shipset Weight (lbm)	LT CWT+Main+Aux Shipset Weight (lbm)	MT CWT+Main+Aux Shipset Weight (lbm)	ST CWT+Main+Aux Shipset Weight (lbm)
<b>Major Components:</b>													
Compressor	29	13	8	4	1	10	24	10	7	2	31	12	14
Heat exchanger/fan	24	14	4	2	1	4	20	12	4	1	25	15	7
Air separation module	136	74	37	23	10	37	114	61	35	13	144	84	60
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	189	100	50	30	12	51	158	82	46	16	200	111	81
<b>Other component sub-totals</b>	291	175	99	85	74	99	251	151	95	77	304	189	117
<b>System Totals</b>	480	275	149	115	86	150	409	233	141	93	504	300	198
On-board oxygen sensor (not included in system totals)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Figure 4.7-2. Summary of OBIGGS Weights—PSA Systems

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Cryogenic Distillation System Component	LT CWT+Main Shipset Weight (lbm)	MT CWT+Main Shipset Weight (lbm)	ST CWT+Main Shipset Weight (lbm)	RTF CWT+Main Shipset Weight (lbm)	RTP CWT+Main Shipset Weight (lbm)	BzJ CWT+Main Shipset Weight (lbm)	LT CWT Only Shipset Weight (lbm)	MT CWT Only Shipset Weight (lbm)	ST CWT Only Shipset Weight (lbm)	RTF CWT Only Shipset Weight (lbm)	LT CWT+Main+Aux Shipset Weight (lbm)	MT CWT+Main+Aux Shipset Weight (lbm)	ST CWT+Main+Aux Shipset Weight (lbm)
Major Components:													
Compressor	11.8	5.3	1.5	0.8	0.1	2.8	9.8	4.1	1.3	0.3	12.6	6.1	2.4
Heat exchanger/fan	5.5	2.7	0.8	0.4	0.1	1.3	4.5	2.1	0.7	0.2	5.8	3.1	1.3
Air separation module	321.0	283.0	261.0	169.0	161.0	187.0	306.0	274.0	261.0	164.0	325.0	285.0	267.0
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	338	291	263	170	161	191	320	280	263	165	343	294	271
<b>Other component sub-totals</b>	192	145	114	107	102	122	176	135	112	103	198	152	122
<b>System Totals</b>	530	436	377	277	263	313	496	415	375	268	541	446	393
On-board oxygen sensor (not included in system totals)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

*Figure 4.7-3. Summary of OBIGGS Weights—Cryogenic Distillation Systems*

### **4.7.1 Air Separation Modules**

Weights were developed for hybrid OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** Membrane weight was based on a standard module size of 18 pounds. Knowing the total flow for each of the 6 aircraft models and the flow capabilities of a standard module, simple division determined the number of modules required. This numbers of modules multiplied by the module weight yielded the total weight for the membrane ASM.

**Pressure-Swing Adsorption.** The PSA air separator calculations were made empirically. A production OBIGGS air separator manufactured by the PSA supplier, was operated in an altitude chamber at the altitudes and supply pressures consistent with the study. At each altitude, the air consumption, product flow and product purity was measured. The fuel tank orifices were simulated with a simple throttling device that was not adjusted during the test. The throttling valve was set to produce a nominal 7% oxygen level in the NEA product at sea level?.

Based on the testing, the weight of the molecular sieve needed for each model was estimated from the number of separators needed to produce the required NEA flows. The structural weight (such as the mounting structure and sieve containers) was also scaled upward or downward based on supplier experience, although some economies of scaling were assumed.

**Cryogenic Distillation.** The weight of the cryogenic distillation system was not determined by scaling. Based on prior experience and design data, the team developed relationships for each component based upon critical parameters. For example, the inlet air flow was related to the volume and weight of the inlet recuperator. This relationship was not linear. Each component was characterized in this way and each system was uniquely specified for the particular aircraft and tank configuration.

### **4.7.2 Compressor**

Compressor weight was based on the number, size, and type needed for each ASM technology and aircraft model. The compressor weight includes the compressor, motor, motor cooling fan and start contactor. The weight estimates were based on design schemes prepared for 15kW shaft power compressors of the screw and centrifugal type. From this a linear metric of weight as a function of power was generated. It is considered that this tends to give an overestimate of weight for high power machines and an underestimate for low power machines, which is conservative in the weight-critical cases. Above 30kW shaft power, two or more compressors are proposed.

### **4.7.3 Heat Exchanger/Cooling Fan**

The heat exchangers and cooling fans were sized by suppliers of aircraft quality compact heat exchangers and cooling fans. The heat exchangers and cooling fans for each aircraft were sized to cool air from the compressor to the appropriate ground temperature limits (125 degrees Fahrenheit for the PSA and cryogenic distillation systems and 165 degrees Fahrenheit for the membrane systems using 111 degrees Fahrenheit ambient air as the heat sink. For hybrid OBIGGS, the heat exchanger and cooling fan sizes were also evaluated at the worst-case in-flight conditions to ensure that all requirements were met. An effort was made to minimize the overall size of the system by performing parametrics on heat exchanger and fan sizes to determine the best overall system. The final results are based on a system that had favorable weight, volume, power and costs numbers.

Heat exchanger and cooling fan weights were determined for each of the aircraft and system types. Heat exchanger weight includes the core, inlet/outlet headers, and connections to the mating tubing. The weight of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

**4.7.4 Other Components**

The team estimated the total weight of the "Other" Components for the hybrid OBIGGS by scaling the other component totals sized for the full-time OBIGGS. The full-time other component weights were plotted against NEA flow rate and the hybrid NEA flow rates fall well within the range. The results for the three technologies are shown in Figures 4.7.4-1, 4.7.4-2, and 4.7.4-3. The full-time systems for which every component was estimated are depicted by solid symbols and the scaled hybrid data are the empty symbols.

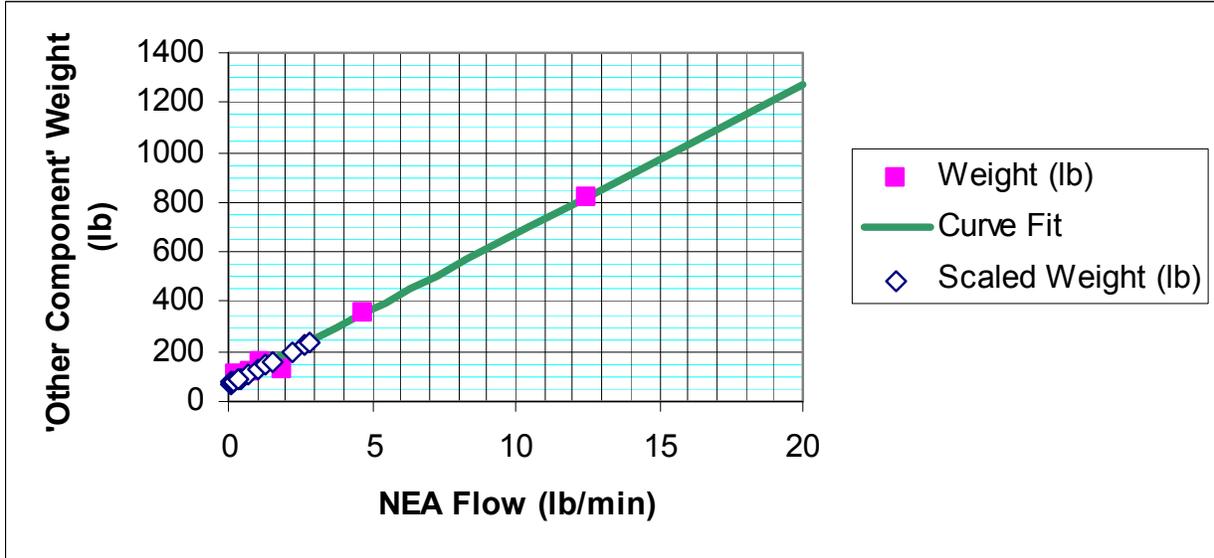


Figure 4.7.4-1. Permeable Membrane Hybrid OBIGGS Other Component Weight

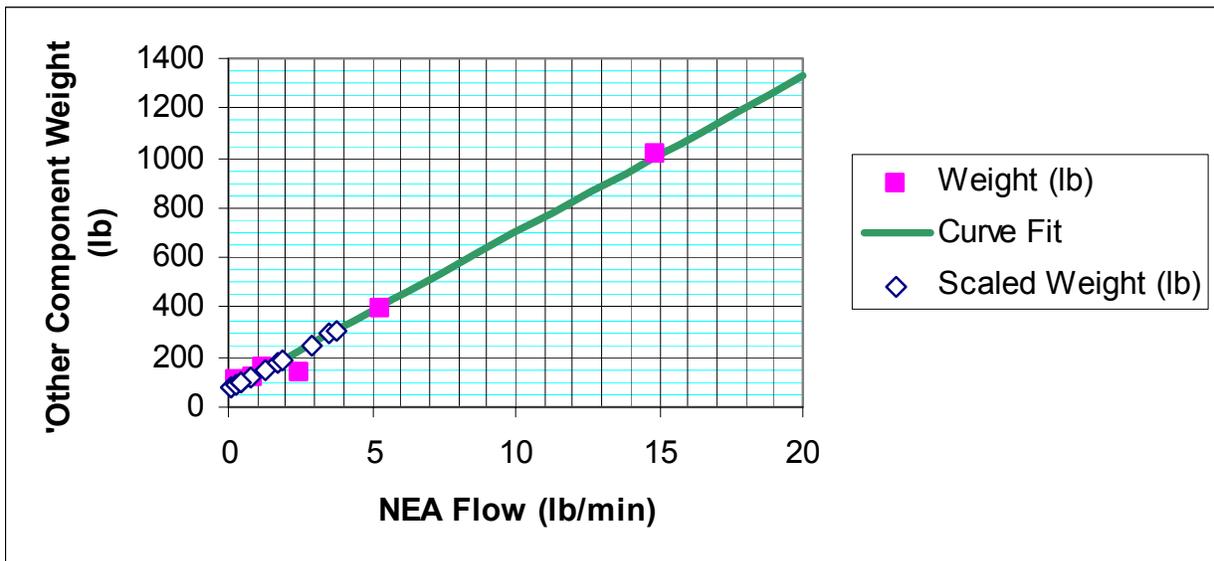


Figure 4.7.4-2. Pressure-Swing Adsorption Hybrid OBIGGS Other Component Weight

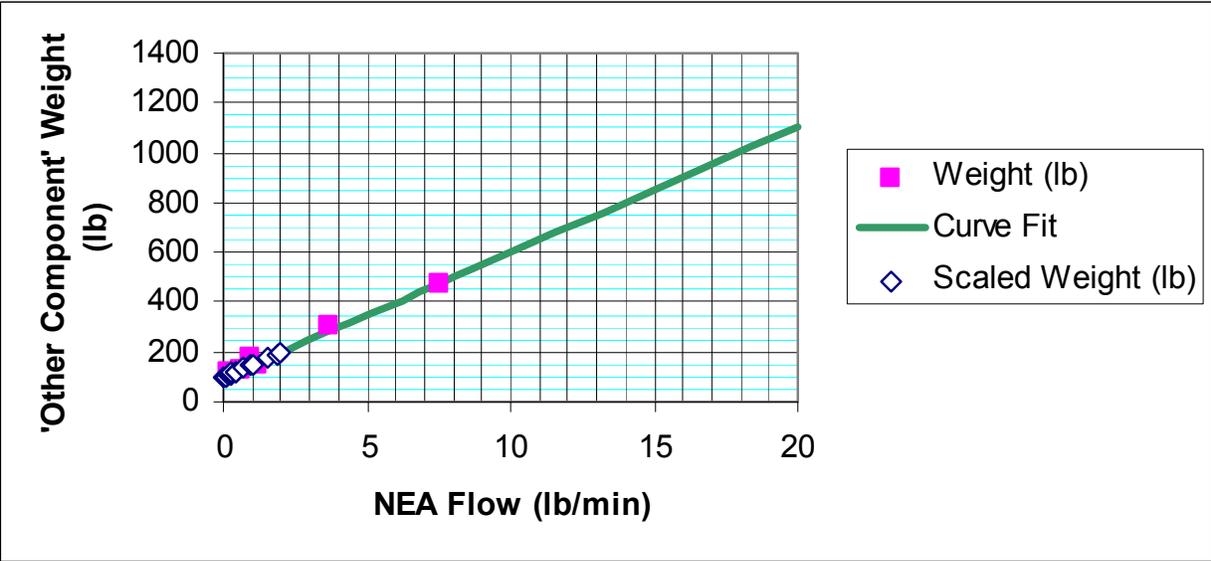


Figure 4.7.4-3. Cryogenic Distillation Hybrid OBIGGS Other Component Weight

**4.8 VOLUME**

Figures 4.8-1 through 4.8-3 summarize the hybrid OBIGGS volumes for the membrane, PSA, and cryogenic distillation inerting systems for each of the ARAC generic aircraft. Each table provides the total volume for the “major” and “other” components identified for each system. “Other” components include such items as wiring, ducting, and valves, and their total estimated volumes have been combined.

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Membrane System Component	LT CWT+Main Shipset Volume (cu ft)	MT CWT+Main Shipset Volume (cu ft)	ST CWT+Main Shipset Volume (cu ft)	RTF CWT+Main Shipset Volume (cu ft)	RTP CWT+Main Shipset Volume (cu ft)	BzJ CWT+Main Shipset Volume (cu ft)	LT CWT Only Shipset Volume (cu ft)	MT CWT Only Shipset Volume (cu ft)	ST CWT Only Shipset Volume (cu ft)	RTF CWT Only Shipset Volume (cu ft)	LT CWT+Main+Aux Shipset Volume (cu ft)	MT CWT+Main+Aux Shipset Volume (cu ft)	ST CWT+Main+Aux Shipset Volume (cu ft)
<b>Major Components:</b>													
Compressor	0.229	0.154	0.042	0.023	0.005	0.047	0.189	0.120	0.037	0.010	0.245	0.177	0.069
Heat exchanger/fan	0.116	0.053	0.014	0.007	0.002	0.014	0.094	0.039	0.012	0.003	0.124	0.063	0.023
Air separation module	4.970	2.480	0.750	0.400	0.096	0.800	2.510	1.114	0.549	0.180	5.268	2.810	1.217
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	5.32	2.69	0.81	0.43	0.10	0.86	2.79	1.27	0.60	0.19	5.64	3.05	1.31
<b>Other component sub-totals</b>	10.63	5.37	1.61	0.86	0.21	1.72	5.59	2.55	1.20	0.39	11.27	6.10	2.62
<b>System Totals</b>	15.95	8.06	2.42	1.29	0.31	2.58	8.38	3.82	1.79	0.58	16.91	9.15	3.93

*Figure 4.8-1. Summary of OBIGGS Volume—Membrane Systems*

PSA System Component	LT CWT+Main Shipset Volume (cu ft)	MT CWT+Main Shipset Volume (cu ft)	ST CWT+Main Shipset Volume (cu ft)	RTF CWT+Main Shipset Volume (cu ft)	RTP CWT+Main Shipset Volume (cu ft)	BzJ CWT+Main Shipset Volume (cu ft)	LT CWT Only Shipset Volume (cu ft)	MT CWT Only Shipset Volume (cu ft)	ST CWT Only Shipset Volume (cu ft)	RTF CWT Only Shipset Volume (cu ft)	LT CWT+Main+Aux Shipset Volume (cu ft)	MT CWT+Main+Aux Shipset Volume (cu ft)	ST CWT+Main+Aux Shipset Volume (cu ft)
<b>Major Components:</b>													
Compressor	0.653	0.281	0.107	0.056	0.014	0.124	0.533	0.215	0.094	0.027	0.693	0.329	0.174
Heat exchanger/fan	0.682	0.320	0.087	0.046	0.011	0.087	0.556	0.244	0.076	0.021	0.724	0.364	0.142
Air separation module	5.300	2.500	0.900	0.450	0.160	0.900	4.300	1.900	0.800	0.200	5.618	2.833	1.460
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	6.64	3.10	1.09	0.55	0.19	1.11	5.39	2.36	0.97	0.25	7.03	3.53	1.78
<b>Other component sub-totals</b>	13.27	6.20	2.19	1.10	0.37	2.22	10.78	4.72	1.94	0.50	14.07	7.05	3.55
<b>System Totals</b>	19.91	9.30	3.28	1.66	0.56	3.33	16.17	7.08	2.91	0.74	21.10	10.58	5.33

*Figure 4.8-2. Summary of OBIGGS Volumes—PSA Systems*

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Cryogenic Distillation System Component	LT CWT+Main Shipset Volume (cu ft)	MT CWT+Main Shipset Volume (cu ft)	ST CWT+Main Shipset Volume (cu ft)	RTF CWT+Main Shipset Volume (cu ft)	RTP CWT+Main Shipset Volume (cu ft)	BzJ CWT+Main Shipset Volume (cu ft)	LT CWT Only Shipset Volume (cu ft)	MT CWT Only Shipset Volume (cu ft)	ST CWT Only Shipset Volume (cu ft)	RTF CWT Only Shipset Volume (cu ft)	LT CWT+Main+Aux Shipset Volume (cu ft)	MT CWT+Main+Aux Shipset Volume (cu ft)	ST CWT+Main+Aux Shipset Volume (cu ft)
<b>Major Components:</b>													
Compressor	0.149	0.067	0.019	0.010	0.002	0.035	0.123	0.052	0.017	0.004	0.158	0.077	0.031
Heat exchanger/fan	0.106	0.052	0.016	0.008	0.002	0.025	0.087	0.040	0.014	0.003	0.112	0.060	0.025
Cryo component subtotals	21.000	19.000	18.000	15.000	14.000	16.000	20.000	19.000	18.000	15.000	21.000	19.000	18.000
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	21.26	19.12	18.04	15.02	14.00	16.06	20.21	19.09	18.03	15.01	21.27	19.14	18.06
<b>Other component sub-totals</b>	10.63	9.56	9.02	7.51	7.00	8.03	10.11	9.55	9.02	7.50	10.64	9.57	9.03
<b>System Totals</b>	31.88	28.68	27.05	22.53	21.01	24.09	30.32	28.64	27.05	22.51	31.91	28.71	27.08

Figure 4.8-3. Summary of OBIGGS Volumes—Cryogenic Distillation Systems

### 4.8.1 Air Separation Modules

Volumes were developed for hybrid OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** Membrane volume was based on a standard module size of .75 cubic feet. Knowing the total flow for each of the 6 aircraft models and the flow capabilities of a standard module, simple division determined the number of modules required. This numbers of modules multiplied by the module volume yielded the total volume for the ASM.

**Pressure-Swing Adsorption.** The PSA air separator calculations were made empirically as described in the weight section above. The NEA flow rate of a given PSA separator operating at the designated oxygen concentration was measured in the lab. The volume of the PSA separators were then determined from the number of units required to produce the NEA flow for each model.

**Cryogenic Distillation.** The volume of the cryogenic distillation system was determined in the same manner as the weight. Scaling was not used to determine component volume. Rather, each system was uniquely sized for the particular application.

### 4.8.2 Compressor

Compressor volume estimates were based on the number, size, and type needed for each ASM technology. Compressor types (screw or centrifugal) were selected for each aircraft model with the same considerations of power and compressor scalability as outlined in the weight section above. The compressor volume includes the compressor, motor, motor cooling fan and start contactor. The volume estimates were based on design schemes prepared for 15kW shaft power compressors of the screw and centrifugal types. From this a linear metric of volume as a function of power was generated. It is considered that this tends to give an overestimate of volume for high power machines and an underestimate for low power machines, which is generally conservative with regard to space envelope constraints. Above 30kW shaft power, two or more compressors are proposed.

### 4.8.3 Heat Exchanger/Cooling Fan

Heat exchanger and cooling fan volumes were determined for each of the aircraft and system types. Heat exchanger volume includes the core, inlet/outlet headers, and connections to the mating tubing. The volume of the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.

### 4.8.4 Other Components

As for full-time OBIGGS, the team estimated the volume of the "Other" Components in the hybrid OBIGGS by multiplying the volume of the major components by 2.0 for the membrane and PSA systems and by .5 for the cryogenic distillation system.

## 4.9 ELECTRICAL POWER

Figures 4.9-1 through 4.9-3 summarize the hybrid OBIGGS electrical power consumption estimates for the membrane, PSA, and cryogenic distillation inerting systems for each of the generic aircraft. Each table provides the total peak electrical power for the "major" and "other" components identified for each system. "Other" components include such items as wiring, motors, and valves, and their total estimated electrical powers have been combined.

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Membrane System Component	LT CWT+Main Shipset Elect Pwr (kVA)	MT CWT+Main Shipset Elect Pwr (kVA)	ST CWT+Main Shipset Elect Pwr (kVA)	RTF CWT+Main Shipset Elect Pwr (kVA)	RTP CWT+Main Shipset Elect Pwr (kVA)	BzJ CWT+Main Shipset Elect Pwr (kVA)	LT CWT Only Shipset Elect Pwr (kVA)	MT CWT Only Shipset Elect Pwr (kVA)	ST CWT Only Shipset Elect Pwr (kVA)	RTF CWT Only Shipset Elect Pwr (kVA)	LT CWT+Main+Aux Shipset Elect Pwr (kVA)	MT CWT+Main+Aux Shipset Elect Pwr (kVA)	ST CWT+Main+Aux Shipset Elect Pwr (kVA)
<b>Major Components:</b>													
Compressor	21.143	9.523	2.895	1.555	0.341	3.260	17.365	7.423	2.560	0.739	22.590	10.972	4.800
Heat exchanger/fan	0.309	0.114	0.000	0.000	0.000	0.000	0.241	0.071	0.000	0.000	0.335	0.143	0.000
Air separation module	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	21.45	9.64	2.90	1.55	0.34	3.26	17.61	7.49	2.56	0.74	22.92	11.11	4.80
<b>Other component sub-totals</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	21.55	9.74	3.00	1.65	0.44	3.36	17.71	7.59	2.66	0.84	23.02	11.21	4.90

Figure 4.9-1. Summary of OBIGGS Electrical Power—Membrane Systems

PSA System Component	LT CWT+Main Shipset Elect Pwr (kVA)	MT CWT+Main Shipset Elect Pwr (kVA)	ST CWT+Main Shipset Elect Pwr (kVA)	RTF CWT+Main Shipset Elect Pwr (kVA)	RTP CWT+Main Shipset Elect Pwr (kVA)	BzJ CWT+Main Shipset Elect Pwr (kVA)	LT CWT Only Shipset Elect Pwr (kVA)	MT CWT Only Shipset Elect Pwr (kVA)	ST CWT Only Shipset Elect Pwr (kVA)	RTF CWT Only Shipset Elect Pwr (kVA)	LT CWT+Main+Aux Shipset Elect Pwr (kVA)	MT CWT+Main+Aux Shipset Elect Pwr (kVA)	ST CWT+Main+Aux Shipset Elect Pwr (kVA)
<b>Major Components:</b>													
Compressor	38.363	16.584	5.890	3.091	0.784	6.808	31.399	12.684	5.153	1.473	40.685	18.800	9.567
Heat exchanger/fan	0.340	0.340	0.136	0.071	0.018	0.136	0.340	0.340	0.119	0.033	0.340	0.340	0.221
Air separation module	0.120	0.057	0.016	0.008	0.002	0.016	0.100	0.044	0.014	0.004	0.127	0.065	0.026
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	38.82	16.98	6.04	3.17	0.80	6.96	31.84	13.07	5.29	1.51	41.15	19.20	9.81
<b>Other component sub-totals</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	38.92	17.08	6.14	3.27	0.90	7.06	31.94	13.17	5.39	1.61	41.25	19.30	9.91

Figure 4.9-2. Summary of OBIGGS Electrical Power—PSA Systems

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Cryogenic Distillation System Component	LT CWT+Main Shipset Elect Pwr (kVA)	MT CWT+Main Shipset Elect Pwr (kVA)	ST CWT+Main Shipset Elect Pwr (kVA)	RTF CWT+Main Shipset Elect Pwr (kVA)	RTP CWT+Main Shipset Elect Pwr (kVA)	BzJ CWT+Main Shipset Elect Pwr (kVA)	LT CWT Only Shipset Elect Pwr (kVA)	MT CWT Only Shipset Elect Pwr (kVA)	ST CWT Only Shipset Elect Pwr (kVA)	RTF CWT Only Shipset Elect Pwr (kVA)	LT CWT+Main+Aux Shipset Elect Pwr (kVA)	MT CWT+Main+Aux Shipset Elect Pwr (kVA)	ST CWT+Main+Aux Shipset Elect Pwr (kVA)
<b>Major Components:</b>													
Compressor	8.229	3.678	1.069	0.535	0.102	1.946	6.795	2.860	0.916	0.229	8.722	4.265	1.680
Heat exchanger/fan	0.166	0.081	0.025	0.013	0.003	0.040	0.137	0.063	0.022	0.005	0.175	0.094	0.040
Cryo component subtotals	16.000	14.000	14.000	5.000	5.000	6.000	14.000	13.000	14.000	5.000	16.000	14.000	14.000
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	24.39	17.76	15.09	5.55	5.10	7.99	20.93	15.92	14.94	5.23	24.90	18.36	15.72
<b>Other component sub-totals</b>	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
<b>System Totals</b>	24.49	17.86	15.19	5.65	5.20	8.09	21.03	16.02	15.04	5.33	25.00	18.46	15.82

*Figure 4.9-3. Summary of OBIGGS Electrical Power—Cryogenic Distillation Systems*

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### **4.9.1 Air Separation Modules**

Electrical power estimates were developed for the hybrid OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** Membrane modules do not require any electrical power.

**Pressure-Swing Adsorption.** Electrical power consumption for PSA separators is low, since the mechanism to operate the PSA distribution valve is pneumatic. The electrical power is consumed by simple timing and power circuits that operate the pneumatic control valves.

**Cryogenic Distillation.** Almost all of the electrical power needed for the cryogenic distillation system is used by the cryogenic refrigerator. The supplier's database of analytical calculations and system tests was used to specify the power requirements of the cryogenic refrigeration systems for this study. As in the case of the weight and volume, no scaling was used to determine the cryogenic distillation electrical power requirements.

### **4.9.2 Compressor**

Compressor electrical power was based on the number, size, and type needed for each ASM technology. Compressor types (screw or centrifugal) were selected and electrical power was determined for each aircraft model with the same considerations of power and compressor scalability as outlined in the weight section.

The compressors for each aircraft were sized for the mass flow of supply air required to each of the differing ASM types. The shaft power of the compressor is a function of the mass flow, pressure ratio and inlet temperature.

### **4.9.3 Heat Exchanger/Cooling Fan**

Heat exchanger and cooling fan power were determined for each of the aircraft and system types. The heat exchanger requires no power to operate. The cooling fan power requirement was determined based on the cooling air flow rate and pressure rise requirements. The system was designed to minimize the cooling fan power requirements whenever possible.

### **4.9.4 Other Components**

As for the other on-board systems, the team estimated the total electrical power required by the other components in the hybrid OBIGGS as 0.1 kVA for all models and tank configurations.

## **4.10 RELIABILITY**

Figures 4.10-1 through 4.10-6 summarize the hybrid OBIGGS component reliability estimates, in terms of Mean-Time-Between-Maintenance-Actions (MTBMA) and Mean-Time-Between-Failure (MTBF), developed by the for the membrane, PSA, and cryogenic distillation inerting systems for each of the ARAC generic aircraft. Each table provides the reliability for the "major" and "other" components identified for each system. "Other" components include such items as wiring, motors, and valves, and their total estimated electrical powers have been combined. The Airplane Operations and Maintenance Team used this component data as a starting point for the system level reliability estimates.

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Membrane System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Major Components:</b>													
Compressor	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cabin air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller/control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 4.10-1. Summary of Hybrid OBIGGS MTBMA—Membrane Systems

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PSA System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Major Components:</b>													
Compressor	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cabin air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller/control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 4.10-2. Summary of Hybrid OBIGGS MTBMA—PSA Systems

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Cryogenic Distillation System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Major Components:</b>													
Compressor	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
<b>Cryo Air Separation Components:</b>													
Inlet shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Cryocooler bleed air valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Flow sensor	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Molecular sieve control valves	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Molecular sieve system	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Purge heat exchanger	80,000	100,000	100,000	100,000	100,000	100,000	80,000	100,000	100,000	100,000	80,000	100,000	100,000
Purge heat exchanger valve-Air Side	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Purge heat exchanger valve-Waste Side	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
LNEA Dewar Cool-down Valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Inlet Recuperator	60,000	100,000	100,000	100,000	100,000	100,000	60,000	100,000	100,000	100,000	60,000	100,000	100,000
Inlet cooler	80,000	100,000	100,000	100,000	100,000	100,000	80,000	100,000	100,000	100,000	80,000	100,000	100,000
Cryocooler	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
LNEA Dewar	75,000	75,000	75,000	n/a	n/a	n/a	75,000	75,000	75,000	n/a	75,000	75,000	75,000
Dewar level sensor	50,000	50,000	50,000	n/a	n/a	n/a	50,000	50,000	50,000	n/a	50,000	50,000	50,000
Distillation column	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Distillation column gas valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Distillation column liquid valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000

Figure 4.10-3. Summary of Hybrid OBIGGS MTBMA—Cryogenic Distillation Systems (Sheet 1 of 2)

## Onboard Inerting Designs Task Team Final Report

Cryogenic Distillation System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cabin air filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Water separator/filter element	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller/control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 4.10-3. Summary of Hybrid OBIGGS MTBMA—Cryogenic Distillation Systems (Sheet 2 of 2)

## Onboard Inerting Designs Task Team Final Report

Membrane System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Major Components:</b>													
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller/control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 4.10-4. Summary of Hybrid OBIGGS MTBF—Membrane Systems

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PSA System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Major Components:</b>													
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Air separation module	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
High flow valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller/control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 4.10-5. Summary of Hybrid OBIGGS MTBF—PSA Systems

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Cryogenic Distillation System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Major Components:</b>													
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Heat exchanger	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Cooling Fan	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
<b>Cryo Air Separation Components:</b>													
Inlet shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Cryocooler bleed air valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Flow sensor	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Molecular sieve control valves	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Molecular sieve system	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Purge heat exchanger	80,000	100,000	100,000	100,000	100,000	100,000	80,000	100,000	100,000	100,000	80,000	100,000	100,000
Purge heat exchanger valve-Air Side	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Purge heat exchanger valve-Waste Side	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
LNEA Dewar Cool-down Valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Inlet Recuperator	60,000	100,000	100,000	100,000	100,000	100,000	60,000	100,000	100,000	100,000	60,000	100,000	100,000
Inlet cooler	80,000	100,000	100,000	100,000	100,000	100,000	80,000	100,000	100,000	100,000	80,000	100,000	100,000
Cryocooler	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
LNEA Dewar	75,000	75,000	75,000	n/a	n/a	n/a	75,000	75,000	75,000	n/a	75,000	75,000	75,000
Dewar level sensor	50,000	50,000	50,000	n/a	n/a	n/a	50,000	50,000	50,000	n/a	50,000	50,000	50,000
Distillation column	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Distillation column gas valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Distillation column liquid valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000

Figure 4.10-6. Summary of Hybrid OBIGGS MTBF—Cryogenic Distillation Systems (Sheet 1 of 2)

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Cryogenic Distillation System Component	LT	MT	ST	RTF	RTP	BzJ	LT	MT	ST	RTF	LT	MT	ST
	CWT+Main Component MTBMA (hrs)	CWT Only Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)	CWT+Main+Aux Component MTBMA (hrs)								
<b>Other Components:</b>													
Cabin air filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
OBIGGS shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Compressor unloading valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Compressor discharge check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bleed shutoff valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Bleed check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Bypass valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Water separator/filter assy	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Temperature sensor	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Relief valve	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Fuel tank check valve	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Controller/control card	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Installation Hardware	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Structural Modifications	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Ram Ducting	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Compressor wiring	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Overheat sensors	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
On-board oxygen sensor (information only)	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933	26,933

Figure 4.10-6. Summary of Hybrid OBIGGS MTBF—Cryogenic Distillation Systems (Sheet 2 of 2)

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### **4.10.1 Air Separation Modules**

Reliability estimates were developed for hybrid OBIGGS membrane, pressure-swing adsorption, and cryogenic distillation air separation equipment.

**Permeable Membrane.** The membrane module consists of a membrane fiber bundle contained in a metal housing. There are no moving parts. There is no scheduled maintenance requirement for the membrane modules.

**Pressure-Swing Adsorption.** The PSA hardware consists of a distribution valve that is pilot operated by relatively small pneumatic valves and controlled by a timing circuit. Also included are air and product manifolds, molecular sieve beds, and purge orifices. The distribution valve assembly contains two wear parts, which are recommended to be serviced at 6000 to 8000 hour intervals. The Mean-Time-Between-Failure estimate in the summary table assumes a scheduled overhaul is performed every 8000 hours.

**Cryogenic Distillation.** The cryogenic system consists of several components including heat exchangers, valves, a cryogenic refrigerator (cryocooler), and distillation columns. The reliability estimates for the valves, heat exchangers, and columns were provided by the specifications from various component suppliers for off-the-shelf items. The reliability estimates obtained from the component suppliers for the heat exchangers and the valves were reduced by the Team to conform to reliability values for other systems. Thus, the actual reliability for the cryogenic distillation system is slightly higher than the values presented in this report. The reliability value for the cryogenic refrigerator is a conservative estimate.

### **4.10.2 Compressor**

The compressor reliability for screw-type units is based on a recommended service interval of 7000 hours. The centrifugal compressors use a different bearing technology that does not require periodic servicing. Suppliers of existing flight-worthy equipment provided the reliability estimates.

### **4.10.3 Heat Exchanger/Cooling Fan**

The heat exchanger and cooling fan reliability estimates are based on commercial aircraft experience and were provided by suppliers of existing flight-worthy equipment.

### **4.10.4 Other Components**

Reliability estimates for the other components of the hybrid OBIGGS were based on commercial aircraft experience with similar components.

## **4.11 COST**

The Team estimated the initial acquisition costs for the membrane, PSA, and cryogenic distillation inerting systems for each of the generic aircraft. Design and certification, operations, maintenance, and installation costs for the hybrid OBIGGS are described later in this section. Inclusion of those costs to determine cost benefit was performed by the Estimating and Forecasting (E&F) Team and is described in the E&F team final report.

### **4.11.1 Acquisition Cost**

Figures 4.11.1-1 through 4.11.1-3 summarize the hybrid OBIGGS acquisition costs developed by the team for the membrane, PSA, and cryogenic distillation inerting systems for each of the ARAC generic aircraft. The acquisition costs for the hybrid OBIGGS were developed according to the same guidelines as described for OBIGGS and OBGI systems acquisition. Figure 4.11.1-4 compares the totals of the OBIGGS costs to the hybrid OBIGGS costs. In Figures 4.11-1 through 4.11-3 the total cost for the individual components is identified for each system to provide inerting of main tanks and CWTs, CWTs only, and all tanks (main tanks, CWTs and auxiliary tanks). The estimated component costs include the

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amortized non-recurring development costs. The team also separately estimated the cost for an on-board oxygen sensor, though this cost was not included in the system totals.

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Membrane System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+Aux Shipset Cost (\$)	MT CWT+Main+Aux Shipset Cost (\$)	ST CWT+Main+Aux Shipset Cost (\$)
<b>Major Components:</b>													
Compressor	\$7,656	\$7,103	\$9,880	\$9,789	\$9,707	\$9,905	\$7,476	\$7,003	\$9,857	\$9,734	\$7,724	\$7,172	\$10,009
Heat exchanger/fan	\$7,558	\$5,550	\$4,108	\$3,808	\$3,544	\$4,091	\$6,860	\$5,112	\$4,033	\$3,624	\$7,824	\$5,849	\$4,532
Air separation module	\$34,880	\$17,447	\$5,275	\$5,275	\$2,000	\$5,275	\$28,814	\$13,649	\$5,275	\$2,638	\$37,188	\$20,097	\$8,493
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	\$50,094	\$30,100	\$19,263	\$18,872	\$15,251	\$19,271	\$43,150	\$25,765	\$19,165	\$15,996	\$52,737	\$33,118	\$23,033
<b>Other Components:</b>	\$82,000	\$74,000	\$68,000	\$66,000	\$65,000	\$67,000	\$79,000	\$72,000	\$67,000	\$66,000	\$83,000	\$75,000	\$69,000
<b>System Totals</b>	\$132,094	\$104,100	\$87,263	\$84,872	\$80,251	\$86,271	\$122,150	\$97,765	\$86,165	\$81,996	\$135,737	\$108,118	\$92,033
On-board oxygen sensor (not included in system totals)	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000

Figure 4.11.1-1. Summary of OBIGGS Costs—Membrane Systems

PSA System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+Aux Shipset Cost (\$)	MT CWT+Main+Aux Shipset Cost (\$)	ST CWT+Main+Aux Shipset Cost (\$)
<b>Major Components:</b>													
Compressor	\$15,562	\$7,624	\$10,083	\$9,893	\$9,737	\$10,145	\$8,497	\$7,394	\$10,033	\$9,784	\$15,701	\$7,790	\$10,331
Heat exchanger/fan	\$15,291	\$8,385	\$4,105	\$3,364	\$2,757	\$4,105	\$12,889	\$6,921	\$3,903	\$2,925	\$16,081	\$9,219	\$5,070
Air separation module	\$21,000	\$16,000	\$10,000	\$11,000	\$8,000	\$10,000	\$19,000	\$14,000	\$10,000	\$10,000	\$22,260	\$18,128	\$16,220
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major components sub-totals</b>	\$51,853	\$32,009	\$24,188	\$24,257	\$20,494	\$24,250	\$40,386	\$28,315	\$23,936	\$22,709	\$54,042	\$35,137	\$31,622
<b>Other Components:</b>	\$88,000	\$76,000	\$68,000	\$67,000	\$65,000	\$68,000	\$84,000	\$73,000	\$68,000	\$66,000	\$89,000	\$77,000	\$70,000
<b>System Totals</b>	\$139,853	\$108,009	\$92,188	\$91,257	\$85,494	\$92,250	\$124,386	\$101,315	\$91,936	\$88,709	\$143,042	\$112,137	\$101,622
On-board oxygen sensor (not included in system totals)	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000

Figure 4.11.1-2. Summary of OBIGGS Costs—PSA Systems

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Cryogenic Distillation System Component	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+Aux Shipset Cost (\$)	MT CWT+Main+Aux Shipset Cost (\$)	ST CWT+Main+Aux Shipset Cost (\$)
<b>Major Components:</b>													
Compressor	10,241	9,933	9,756	9,720	9,691	9,816	10,144	9,877	9,746	9,700	10,274	9,973	9,798
Heat exchanger/fan	4,436	3,475	2,841	2,698	2,585	3,004	4,109	3,270	2,800	2,616	4,549	3,618	3,004
Air separation module	150,075	148,200	148,200	148,200	148,200	148,200	150,075	148,200	148,200	148,200	150,075	148,200	148,200
	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
<b>Major component sub-totals</b>	164,752	161,608	160,797	160,618	160,476	161,020	164,328	161,348	160,746	160,515	164,898	161,791	161,002
<b>Other Components:</b>	77,000	72,000	69,000	69,000	68,000	70,000	75,000	71,000	69,000	68,000	77,000	73,000	70,000
<b>System Totals</b>	241,752	233,608	229,797	229,618	228,476	231,020	239,328	232,348	229,746	228,515	241,898	234,791	231,002
On-board oxygen sensor (not included in system totals)	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000

Figure 4.11.1-3. Summary of OBIGGS Costs—Cryogenic Distillation Systems

System	LT CWT+Main Shipset Cost (\$)	MT CWT+Main Shipset Cost (\$)	ST CWT+Main Shipset Cost (\$)	RTF CWT+Main Shipset Cost (\$)	RTP CWT+Main Shipset Cost (\$)	BzJ CWT+Main Shipset Cost (\$)	LT CWT Only Shipset Cost (\$)	MT CWT Only Shipset Cost (\$)	ST CWT Only Shipset Cost (\$)	RTF CWT Only Shipset Cost (\$)	LT CWT+Main+Aux Shipset Cost (\$)	MT CWT+Main+Aux Shipset Cost (\$)	ST CWT+Main+Aux Shipset Cost (\$)
Membrane - OBIGGS	\$293,250	\$152,460	\$94,787	\$88,171	\$84,925	\$100,426	\$174,540	\$104,454	\$89,463	\$82,252	\$286,753	\$164,993	\$100,560
Membrane - Hybrid OBIGGS	\$132,094	\$104,100	\$87,263	\$84,872	\$80,251	\$86,271	\$122,150	\$97,765	\$86,165	\$81,996	\$135,737	\$108,118	\$92,033
PSA - OBIGGS	\$299,181	\$160,855	\$99,557	\$94,735	\$90,037	\$112,827	\$197,089	\$120,898	\$95,684	\$90,217	\$346,547	\$173,363	\$107,768
PSA - Hybrid OBIGGS	\$139,853	\$108,009	\$92,188	\$91,257	\$85,494	\$92,250	\$124,386	\$101,315	\$91,936	\$88,709	\$143,042	\$112,137	\$101,622
Cryogenic Distillation - OBIGGS	\$290,159	\$255,690	\$233,934	\$225,995	\$224,881	\$235,394	\$259,284	\$248,037	\$231,881	\$224,589	\$293,751	\$260,931	\$236,547
Cryogenic Distillation - Hybrid OBIGGS	\$241,752	\$233,608	\$229,797	\$229,618	\$228,476	\$231,020	\$239,328	\$232,348	\$229,746	\$228,515	\$241,898	\$234,791	\$231,002

Figure 4.11.1-4. Comparison of OBIGGS Costs to Hybrid OBIGGS Costs

**4.11.1.1 Air Separation Modules**

The hybrid OBIGGS air separation module costs were estimated by the equipment suppliers based on their experience with similar flight worthy equipment.

**4.11.1.2 Compressor**

Compressor costs for the hybrid OBIGGS were estimated by the equipment suppliers based on their experience with similar flight worthy equipment.

**4.11.1.3 Heat Exchanger/Cooling Fan**

Heat exchanger and cooling fan costs for the hybrid OBIGGS were estimated by the equipment suppliers based on their experience with similar flight worthy equipment.

**4.11.1.4 Other Components**

The team estimated the total cost of the ‘Other Components’ for the hybrid OBIGGS by scaling the other component totals sized for the full-time OBIGGS. The full-time other component costs were plotted against NEA flow rate and the hybrid NEA flow rates fall well within the range. The results for the three technologies are shown in Figures 4.11.1.4-1, 4.11.1.4-2, and 4.11.1.4-3. The full-time systems for which every component was estimated are depicted by solid symbols and the scaled hybrid data are the empty symbols.

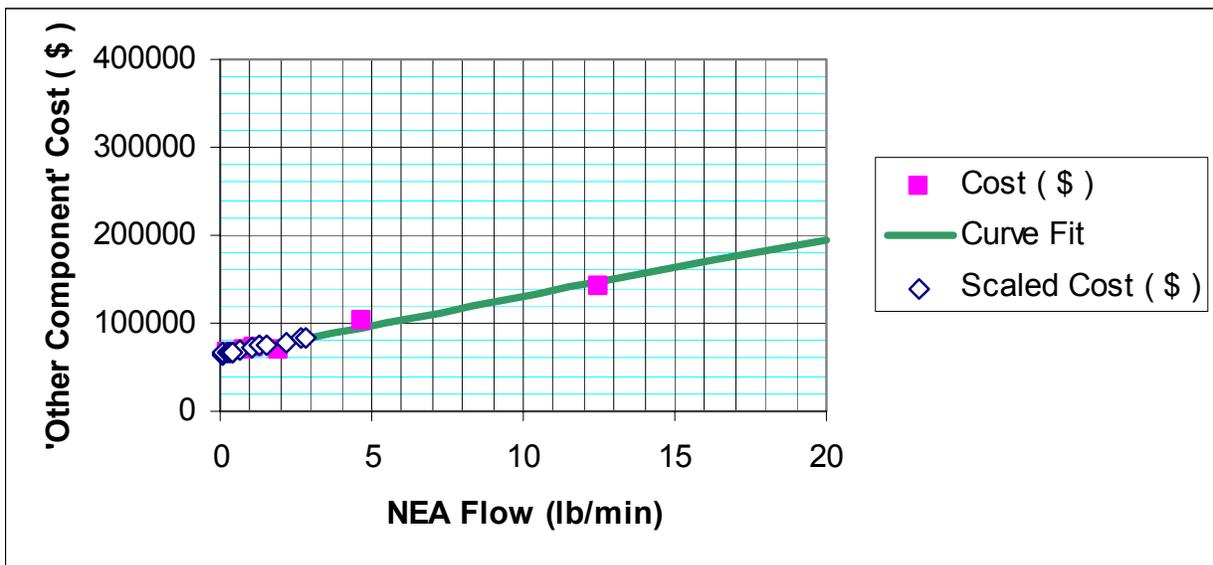


Figure 4.11.1.4-1. Permeable Membrane Hybrid OBIGGS Other Component Cost

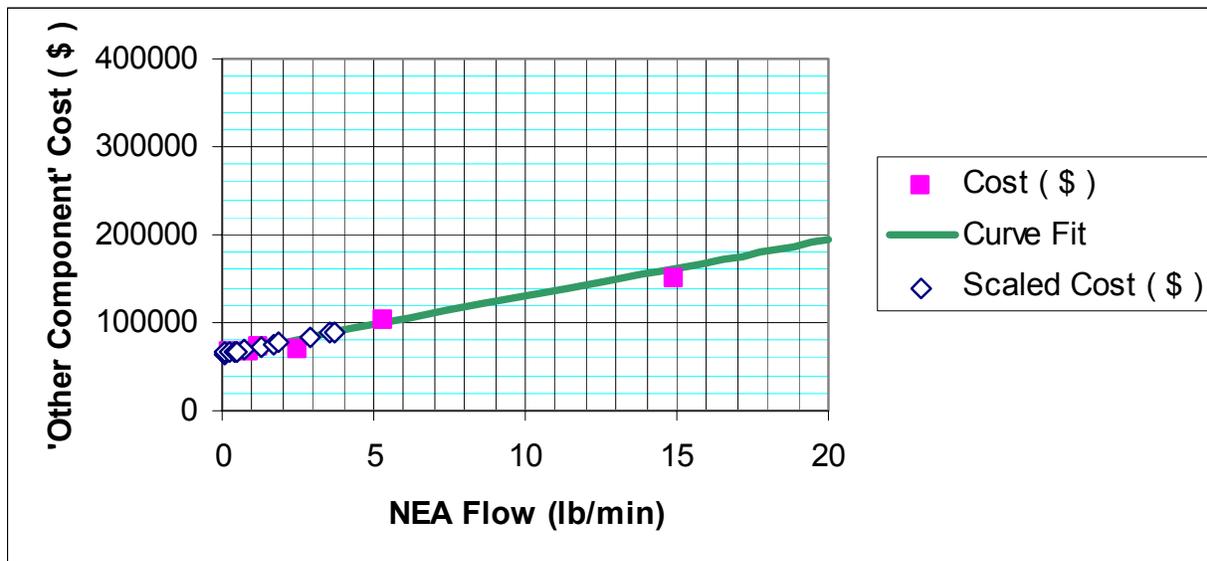


Figure 4.11.1.4-2. Pressure-Swing Adsorption Hybrid OBIGGS Other Component Cost

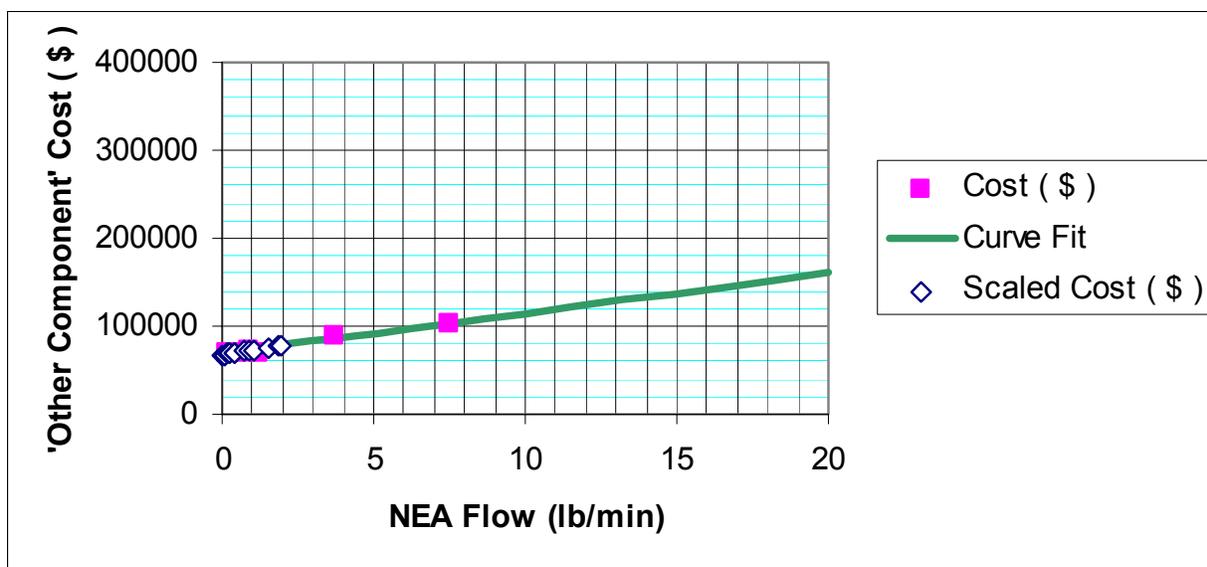


Figure 4.11.1.4-3. Cryogenic Distillation Hybrid OBIGGS Other Component Cost

**4.11.2 Design & Certification Cost**

Design and certification man-hour estimates developed by Working Group for full-time OBIGGS were also applied to hybrid OBIGGS. Non-recurring design costs for hybrid OBIGGS components (e.g., ASMs) were amortized into the component costs listed in the previous summary cost tables.

The design and certification man-hour estimates were applied by the E&F team as part of their analysis to determine hybrid OBIGGS cost benefit and are described in the E&F team final report. These estimates address design and certification of hybrid OBIGGS to inert all tanks on a new first of a model aircraft and on derivative model aircraft for all of the generic aircraft. They also address design and certification of hybrid OBIGGS to inert CWTs only on a new first of a model aircraft and on derivative model aircraft,

which only applies to the generic large, medium, and small transports, and to the generic regional turbo fan aircraft.

Neither FAA nor JAA will assess additional certification costs for hybrid OBIGGS. However, non-U.S. governmental authorities may assess additional costs related to the certification of the hybrid OBIGGS. For example, JAA indicates that the CAA-UK will charge airlines for all certification costs, including engineering man hours, whereas DGAC France will charge airlines only for the travel costs associated with hybrid OBIGGS certification efforts. These potential additional costs were not included in the design and certification cost estimates.

### **4.11.3 Operating Cost**

Recurring hybrid OBIGGS operating costs were developed similarly to those costs developed for OBIGGS. Recurring cost impacts attributed to frequency of delays, delay time, and additional training required for ground and flight crews were assumed to be the same as for OBIGGS.

### **4.11.4 Maintenance Cost**

Recurring hybrid OBIGGS maintenance costs were developed similarly to those costs developed for OBIGGS. Except for MTBUR, hours estimated for all other recurring hybrid OBIGGS maintenance costs were assumed to be the same as for OBIGGS.

### **4.11.5 Installation Cost**

Installation costs for the hybrid OBIGGS were provided by the Project Integration and Airplane Operations and Maintenance Teams and evaluated by the E&F team for new design, in production, and in service aircraft.

## **4.12 SAFETY**

The inclusion of a hybrid OBIGGS on an aircraft introduces a number of new or increased safety concerns. These concerns can be divided into normal operations, system leaks, component failures, and catastrophic failures.

### **4.12.1 Normal Operations**

The hazards associated with the normal operation of the hybrid OBIGGS system are the discharge of oxygen enriched waste gas, the venting of NEA out of the fuel vent, the possibility of fuel tank over pressure during refuel over-fill, and those associated with electrical wiring and high temperature components, and possible disruption of cabin airflow patterns.

**Oxygen-Rich Waste Gas.** Oxygen-rich waste gas could be a fire hazard and should be vented in an area with no potential ignition sources. If possible it should be vented in an area where it will be quickly diluted.

**NEA Around Fuel Vents.** NEA vented from the fuel tank vent could create breathing problems, if inhaled. Testing during the inerting of a 737 aircraft indicated that the exiting NEA was rapidly diluted and posed little hazards. A placard warning near the vent should be sufficient.

**Increased Tank Overpressure During Refuel Failure.** The operation of the hybrid OBIGGS during a fueling over-fill may exacerbate the problem of tank overpressure. The system should be designed to limit inlet pressure to the tank and quickly relieve pressure.

**Electrical Wiring.** Electrical requirements of the system add to the amount of electrical wiring in the aircraft and the potential for electrical related smoke or fire in the aircraft. These safety concerns can be minimized through normal design practice.

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**High Temperature Components.** The operating temperature of some components may exceed 400 degrees F and should be placarded as such.

**Cabin Airflow Patterns.** The use of cabin air as inlet air to the compressor could cause a change in cabin airflow patterns, which could be hazardous during smoke or fire conditions. The air should be taken from as close to the out flow valve as possible. The new airflow patterns should be determined for compliance with the certification base of the aircraft.

### **4.12.2 System Leaks**

Various system leaks could occur and create safety concerns. Leaks could include hot air, NEA, OEA and fuel vapor.

**Compressor Discharge Air Leaks.** Compressed air between compressor and heat exchanger could be in the range of 400 degrees F. It should be treated the same as bleed air ducting, and may require overheat detection.

**NEA Leaks.** The NEA line from the ASM to fuel tank could produce an environment, in a confined space, with a reduced oxygen level. The line should, wherever possible, be run in an area of high ventilation. Where it does run in a confined space with low ventilation the line should be a double line.

**Oxygen-Rich Waste Gas Leaks.** The waste line from the air separation module carries oxygen-rich air and could produce an environment, in a confined space, with an elevated oxygen level. The line should, wherever possible, be run in an area of high ventilation and the absence of ignition sources. Where it does run in a confined space with low ventilation or in an area with any possible ignition sources, the line should be a double line.

**Fuel Backflow Into ASM.** Fuel vapor from the fuel tank back through the NEA line into the system. Check valves should be installed in system to prevent this from occurring. This hazard could occur at any time since it is not dependent on system operation.

**Cryogenic Liquid Leaks.** A cryogenic system could leak liquid nitrogen or liquid air possibly causing damage to surrounding materials. Protection for this occurrence should be provided.

### **4.12.3 Component Failures**

It is possible that a component of the system could fail and create a hazardous condition as the system continues to operate.

**Compressor Overheat.** A compressor overheat could cause a potential fire hazard. Thermal cutout protection should be incorporated.

**Heat Exchanger Overheat.** NEA being too hot could cause a safety problem by possibly damaging the system and pumping high temperature gas into the fuel tank. Thermal cutout protection would provide mitigation from this hazard.

**Rotating Equipment Sparks.** Sparks or flames could occur in the system lines and protected should be provided by flame arrestors in line.

**Overpressure From Trapped Cryogenic Liquids.** A failure in the refrigeration components of a cryogenic system could cause an overpressure and should be prevented through the use of relief valves.

### **4.12.4 Catastrophic Failures**

**Uncontained Rotating Equipment Failure.** Uncontained rotating equipment failure could cause a hazard. The system design should provide containment for such failures.

**Pressure Vessel Burst.** Overpressure in the system could cause a pressure vessel burst and should be designed for.

**In-Flight Loss of Cabin Pressure.** Failure between pressurized and unpressurized areas could result in an in-flight loss of cabin pressure and would require the installation of a high flow fuse and shutoff valve.

### **4.13 INSTALLATION**

The installation objectives and concerns for the hybrid OBIGGS are identical to those already discussed for the other on-board systems. Specific design solutions for the many different aircraft models that would be affected by an inerting rule were beyond the scope of this study. The installation challenges are expected to be greater for retrofits where other systems already occupy many locations and customer-specific modifications may require different installation approaches for the same aircraft model. In some areas, structural modifications will be needed to support the additional weight of the new components.

As with the other on-board systems, the best installation locations are unpressurized, ventilated, and close to the fuel tanks. If locations that meet these criteria cannot be found, the installations will be more complicated.

Several existing aircraft models were surveyed for potential installation locations. Unpressurized locations in the air conditioning pack bay, wing root, wheel well, belly fairing, and behind the aft pressure bulkhead were examined. Pressurized locations exist in the cargo compartments and in a space forward of the aft bulkhead on some aircraft. Use of cargo space for inerting equipment carries the additional cost of the displaced cargo capacity. Typical installation locations on generic small, medium, and large transports are similar to those depicted for OBI (Section 1).

As with the other on-board systems, the NEA distribution system must be sized for pressure drop, be double-walled within pressurized areas, and include drains for condensation. The system controller may be rack-mounted, part of a card file, or remotely located near the inerting equipment depending on the aircraft model. Wiring between the controller and components will require different degrees of protection depending on its location. The expected cockpit interface is an on/off switch and a fail light. The installation will also require additional protection if located within an engine rotor burst, tire burst, or flammable fluid leakage zone. The compressor and heat exchanger will be thermally insulated to prevent temperature damage to other equipment. The compressor must be installed to minimize noise transmission.

### **4.14 PROS AND CONS OF SYSTEM DESIGN CONCEPT**

**Effectiveness and Limitations.** The hybrid OBIGGS was sized so that the flammability exposure during the ground and climb was equivalent to that of the ground-based inerting concepts. Therefore, the overall flammability exposure for the hybrid OBIGGS is better than the ground-based, because the hybrid provides additional protection in flight. While not as good as the full-time OBIGGS, the flammability exposure for the hybrid OBIGGS is low enough to offer effective protection against randomly occurring one-time ignition sources like lightning or a fuel pump failure. Because the tanks will eventually be flammable, the hybrid OBIGGS will likely only delay an explosion for repetitive, undetected ignition sources like electrical arcing or an inadequate static bond.

The hybrid OBIGGS reduces the flammability exposure very significantly with a much smaller system than the full-time OBIGGS. As with the full-time OBIGGS, no ground support equipment or personnel are required for operation of the system. The hybrid OBIGGS is heavier than the Ground-Based Inerting equipment that would be carried on board the aircraft, but weighs less than the full-time OBIGGS or the On-Board Ground Based Inerting systems.

**Safety.** The installation of the system adds additional hazards to the aircraft, which must be mitigated. The hazards include electrical wiring, high-speed rotation machinery, ducting carrying nitrogen-enriched air and oxygen enriched air and additional penetrations into the fuel tank, and the fuselage. The design of

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the system should be such to minimize or eliminate the hazards. The safety section contains a more detailed description of all the hazards and means of mitigation. It should be noted that since the system operates during all phases of flight the hazards could exist at any time.

The system greatly minimizes the time a flammable mixture is present in a protected tank, thus greatly reducing the probability of a fuel tank explosion. For a more detailed discussion on the risk reduction see the section on flammability reduction.

**Cost.** There is a cost associated with the design, installation, certification, operation and maintenance of a hybrid OBIGGS. Those costs can be broken down into the cost of the system, the cost of system operation, and the cost of system maintenance. The cost of the system includes design and construction as well as certification and installation. The system operation costs include those associated with the additional weight and possible shift in center of gravity of the aircraft, possible increase in drag, and the additional use of electrical power. The maintenance cost includes maintenance of the hybrid OBIGGS and other systems, such as electrical generators, affected by it. The lower air consumption rates for the hybrid also lower the operating costs of diverting electrical power, bleed air, and ram air relative to the full-time OBIGGS.

Designs are presently being explored that use a similar system for fire suppression in aircraft cargo compartments. If successful, it would allow for a dual role for the hybrid OBIGGS, thus offsetting some of the overall system weight and cost. It should be noted that an on-demand hybrid OBIGGS, with no storage capability, used for fire suppression would cost more than the estimates in this report, because the system would be required for flight. This would either require additional redundancy or an increase in the expected number of flight delays, cancellations, and turn-backs.

**Environmental Impact.** The main impact to the environment from a hybrid OBIGGS is the possible increase in fuel vapors being forced overboard as the nitrogen is injected into the fuel tank. The amount of fuel vapor that is vented depends on the fuel air mixture and ullage volume, at the time of inerting, as well as many other variables. Testing has shown that presently designed cross-vented fuel tanks under certain wind conditions can vent fuel vapors into the atmosphere. A redesign for the hybrid OBIGGS would minimize that venting, thus helping to offset some of the fuel vapor lost during the inerting process.

The installation of a hybrid OBIGGS would, as shown previously, reduce the number of fuel tank explosions, thus reducing the amount of spilled fuel both on the ground and in the atmosphere.

In addition to the fuel vapor there is a potential problem with the addition of noise from the compressor/fan.

The use of dry nitrogen as an inerting agent may reduce corrosion and condensation in the protected tanks depending on the conditions at the airports where the airplane is operated.

### **4.15 MAJOR ISSUES/MITIGATION**

The Major Issues of the full-time OBIGGS also apply to the hybrid OBIGGS. There are no separate major issues identified with the hybrid OBIGGS.

**5.0 CONCLUSION**

The Onboard Design Team studied onboard ground inerting (OBGI), a simplified OBIGGS (compared to a military system), a hybrid OBGI where the inerting time was increased, and a hybrid OBIGGS tailored to match the flammability exposure of ground-based inerting. The systems were simplified by removing redundancy in accordance with the minimum-equipment-list-provision in the Tasking Statement.

The inerting systems reduce the flammability exposure of fuel tanks. The following flammability comparison charts show the average performance of the inerting systems studied compared to fuel tanks that have not been inerted. (Ref Figures 5-1, 5-3, and 5-5 for the Large, Medium, and Small Transports) The OBIGGS system nominally provides full-time protection; however, this does not account for the times when the aircraft departs with the OBIGGS system inoperative. The actual flammability exposure is somewhat more than zero and depends on the reliability of the system chosen.

Below the flammability exposure charts are summary tables for the impact of the system on the aircraft. (Ref Figures 5-2, 5-4, and 5-6) The impact is measured in airflow required to feed the air separator modules, electrical power required to run the compressor, weight and volume of the system.

By comparing systems, it's obvious that the Hybrid OBIGGS has the least impact on the aircraft. The flammability exposure it provides is equal to or, in some cases, better than the other systems.

Future aircraft could be designed to provide the resources required to operate an inerting system. However, it is unknown if in-production airplanes can accommodate any of these systems due to the electrical power demands.

**Large Transport Flammability Comparison**  
Average of Inerting Systems in Category

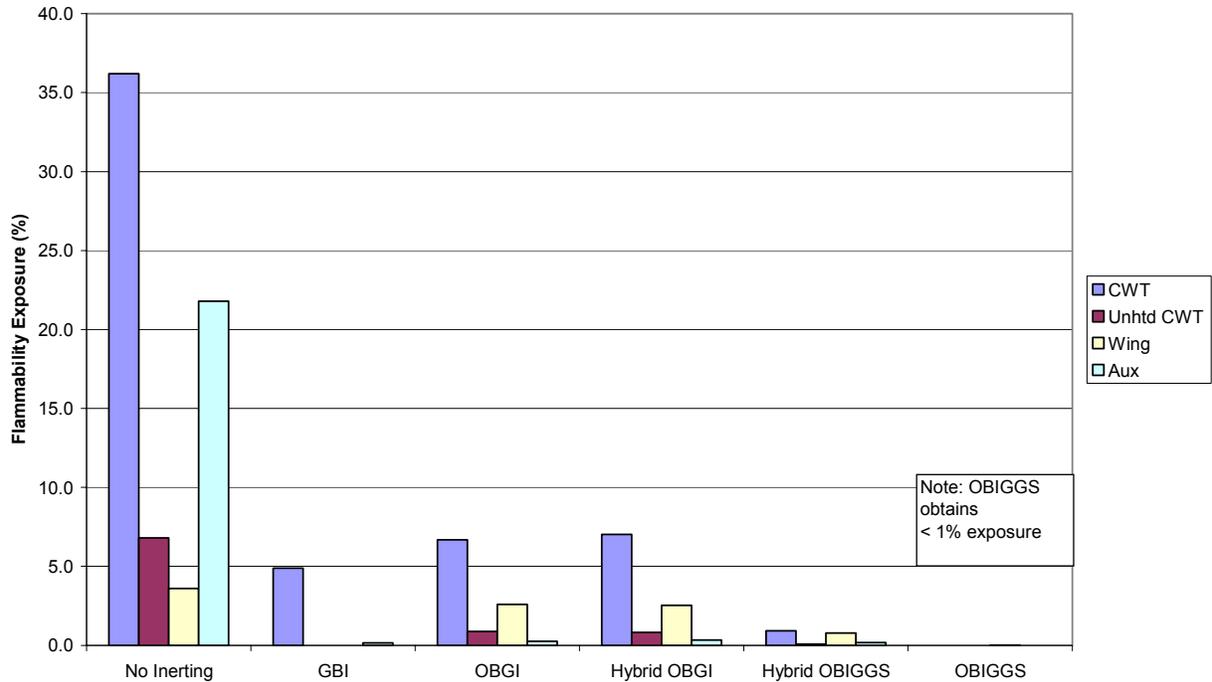


Figure 5-1. Performance in Large Transport

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	OBGI	Hybrid OBGI	Hybrid OBIGGS	OBIGGS
Air Flow (lb/min)	48	42	9	30
Power (KVA)	100	86	28	113
Weight (lbs)	1458	1394	460	1367
Volume (cubic ft)	75	66	23	56

Figure 5-2. System Impact to Large Transport

## Medium Transport Flammability Comparison Average of Inerting Systems in Category

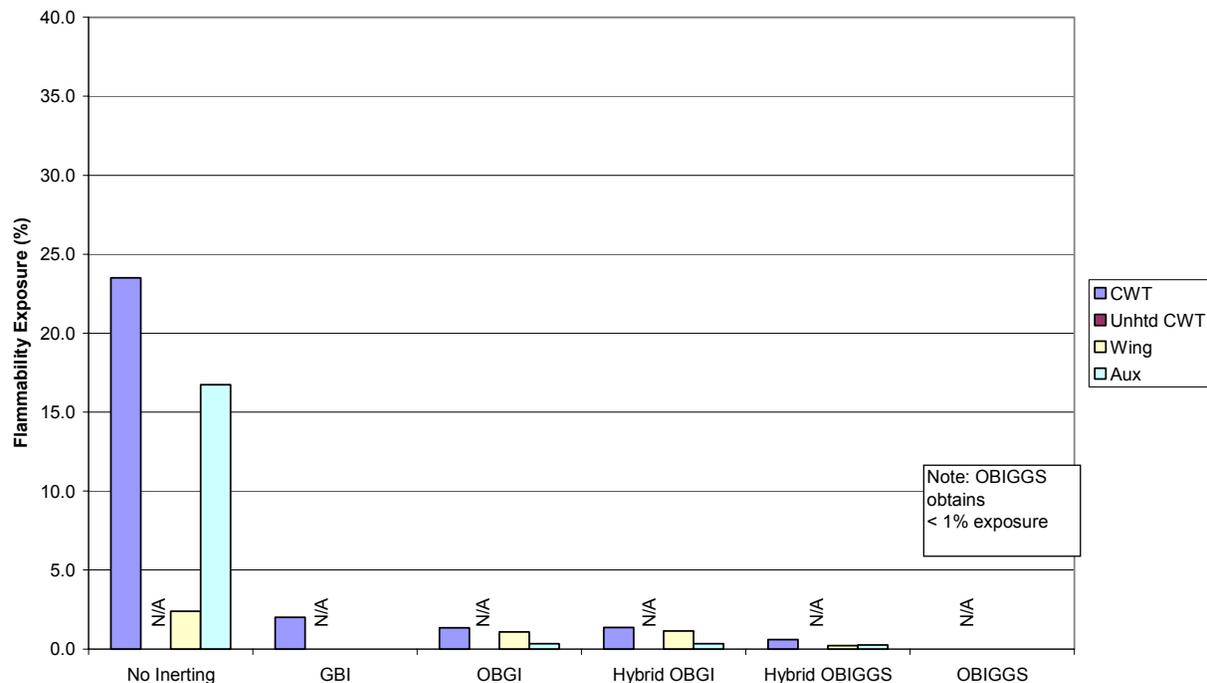


Figure 5-3. Performance in Medium Transport

	OBGI	Hybrid OBGI	Hybrid OBIGGS	OBIGGS
Air Flow (lb/min)	27	24	4	12
Power (KVA)	56	49	15	43
Weight (lbs)	771	729	310	670
Volume (cubic ft)	43	38	15	28

Figure 5-4. System Impacts to Medium Transport

In the flammability chart, the unhtd CWT is not zero but rather it was not analyzed because there are no aircraft in the category that have unheated center wing tanks.

**Small Transport Flammability Comparison**  
Average of Inerting Systems in Category

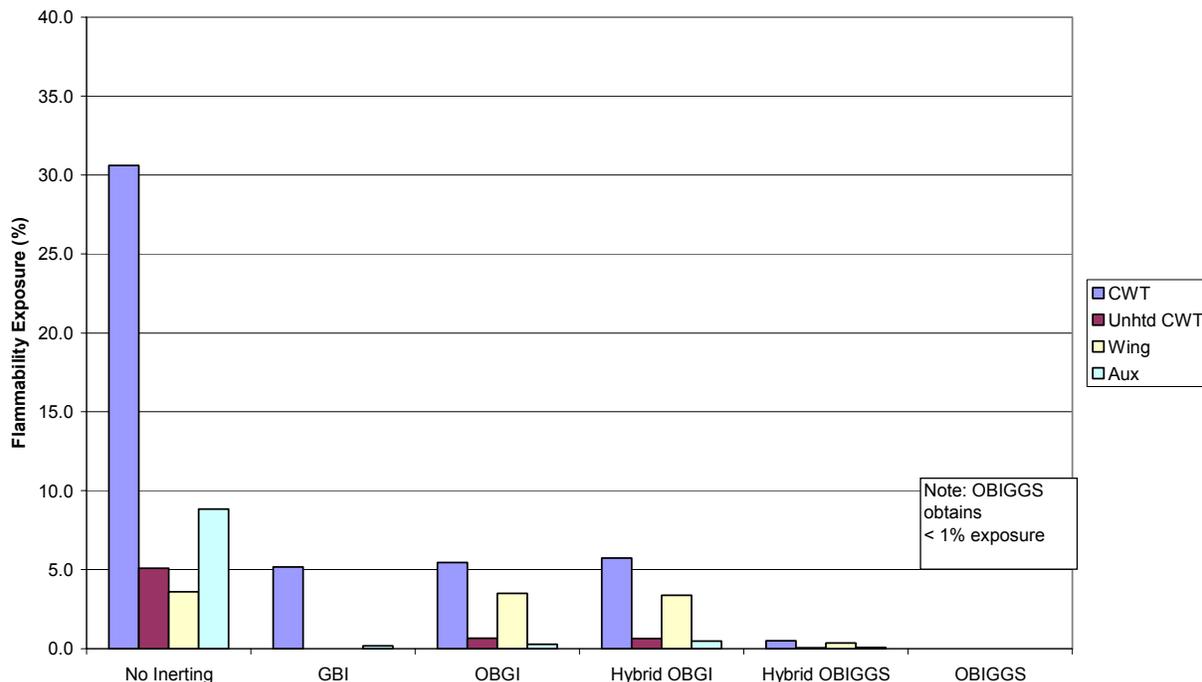


Figure 5-5. Performance in Small Transport

	OBGI	Hybrid OBGI	Hybrid OBIGGS	OBIGGS
Air Flow (lb/min)	11	9	1	5
Power (KVA)	22	17	8	16
Weight (lbs)	328	293	214	354
Volume (cubic ft)	18	14	11	15

Figure 5-6. System Impacts to Small Transport

**Conclusions**

The Onboard Design Task Team determined the following:

- Engine bleed air may not always be available to supply OBGIS and hybrid OBGIS on in-service and in-production aircraft.
- Engine bleed air is insufficient to supply OBIGGS and hybrid OBIGGS during descent and on the ground on in-service and in-production aircraft.
- However, a system could be designed into a new aircraft if the system requirements are established prior to specifying engine, APU, and ECS performance. This does not imply there is a cost benefit to this action, only that it's technically possible.
- The availability of electrical power to operate a compressor all of the time for any of the systems is unknown. A study of power available by mission phase will be required for the ARAC Executive Committee or FAA to properly evaluate inerting system operation, at a later date.
- Proving the feasibility of the inerting systems requires specific aircraft design information that was not available.

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- The PSA and the membrane systems were not shown to be infeasible for OBGI and hybrid OBGI.
- The PSA, membrane, and cryogenic distillation systems were not shown to be infeasible for OBIGGS and hybrid OBIGGS.
- The power availability study, mentioned above, is needed to determine if the systems are infeasible in their present form and require modification to the inerting system, aircraft, or airport to be feasible.
- The flammability model requires improvements to be valid as a certification tool. It does, however, provide a relative measure of a system's capability.

### **Recommendations**

- A comprehensive study of electrical power available on several different size aircraft should be undertaken by the FAA or ARAC to establish the capability to power inerting systems on in-service and in-production aircraft.
- Improve the flammability model to more accurately:
  - predict flammability at altitude.
  - predict inert level at altitude.
- Combine an ignition energy model with the flammability model to establish a certification tool and provide it to industry for comment and validation.
- Continue research into polymers and membranes focused on improving their efficiency and performance. This should include studies to improve the temperature performance of the membranes.
- Investigate vacuum-jacketed, high-effectiveness heat exchangers and lighter, more efficient cryogenic refrigerators.
- Investigate using a turbo-compressor to recover energy from the ASM and avoid the penalty of a second electric compressor.

## **ADDENDUM**

### **A1 AIR SEPARATION TECHNOLOGY DETAILED DESCRIPTIONS AND SIZING METHODOLOGY**

#### **A1.1 PERMEABLE MEMBRANE SUMMARY**

Hollow fiber permeable membranes can be used to create nitrogen enriched air or NEA for aircraft fuel tank inerting. Low weight and high reliability are essential requirements for components used aboard an aircraft system. For this reason membranes have high permeability which translates into weight savings, high selectivity to maintain energy efficiency, and high reliability because they are a passive technology which requires no moving parts.

The polymeric hollow fiber permeable membranes currently manufactured for nitrogen separation from compressed air are essentially a molecular filter and today's modern membranes are manufactured using several different techniques. This discussion is going to be limited to asymmetric composite type membranes which are one of the modern membranes in wide use today. Air separation asymmetric composite membranes are a multi-layer laminate hollow fiber that is manufactured with an efficient single-step coextrusion solution-spinning process developed over 30 years ago by chemical manufacturing companies, the early pioneers of the technology. The separation efficiency, permeation rates, and mechanical durability of the membrane are optimized via the selection of high-performance polymers for each layer. The selection of these polymers is based on years of dedicated research that included the testing of thousands of different polymers for both permeance and selectivity.

Polymers are classified by their glass-transition temperature where the glassy type have high-T<sub>g</sub>, are easily manufacturable, and are extremely durable in gas separation service. The polymers in membrane service today have glass transition temperatures in excess 200°C (425°F). Through extensive research and development, polymers are selected for the construction of membranes that offer a technology that is extremely efficient, light weight, and reliable. Many membrane modules that were placed in N<sub>2</sub> service at 165psig and above 9 to 10 years ago are still in service today.

The terms permeance and selectivity are used to define the membrane performance. Permeance of a gas across a polymeric membrane is based on the solubility of the gas in the polymer as well as the rate of the gas diffusion through the membrane. That is, in order for a gas to permeate across the membrane, the gas must dissolve in the membrane material, diffuse across the thickness of the membrane layer, and then desorb into the permeate phase. The rate of solution and desorption in the membrane material are very fast, so the limiting step to the rate of flow across the membrane is the rate of diffusion within the polymer. Each constituent of a mixed gas, like air, has its own flow rate values or permeance across the membrane. For air, there are values for the nitrogen and oxygen permeances, and the ratio of these flow rates is a measure of the efficiency at which the membrane will operate. The ratio of these permeance values is called selectivity. Each of the different membrane manufacturers today offer the highest combination of permeance and selectivity that their manufacturing process and polymer will permit.

The membrane performance is also a function of pressure across the membrane separation layer, which creates driving force for permeation across the membrane. Simply stated, for an on board system, feed pressure and temperature are significant variables of the system that can impact performance. The higher the system operating pressure, the more NEA flow per unit surface area is available. This increased flow rate can be directly translated into a lower system weight.

Earlier it was mentioned that the fiber has a composite structure. To give you a better idea of what the fiber looks like, refer to Figure A1.1-1 below. The picture is a cross section of a typical permeable hollow fiber magnified many times. Currently the technology exists to manufacture hollow fiber, like the one shown in the figure, with outside diameters in the range of 150 to 600 μm and inside diameters from 80 to 500μm, depending on the application. The bulk of the cross-section of these fibers is a rugged porous support layer, which supports a thin, dense highly selective skin where the gas separation takes

place. The total thickness of this skin is only a few microns and it is the outer skin of this layer, whose thickness is measured in angstroms, that determines the membrane performance. As is, these fibers today can operate at temperatures up to 100°C (212°F).



Figure A1.1-1. Fiber Cross Section

A schematic of a hollow fiber membrane module can be seen below in Figure A1.1-2. The hollow fiber membrane technology is passive by definition, that is, there are no moving, high-maintenance parts required for the gas separation to take place.

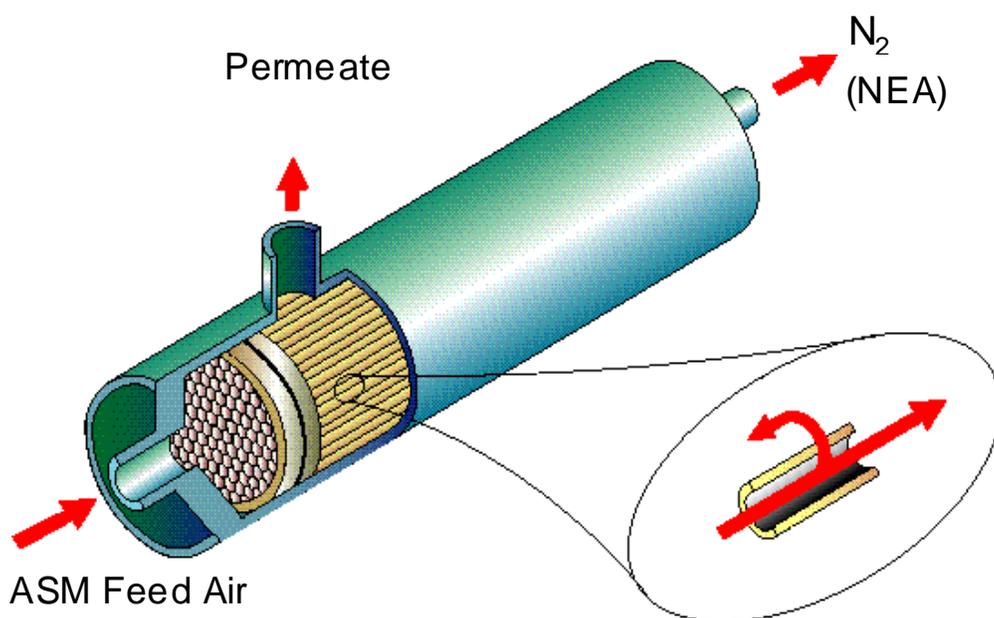


Figure A1.1-2. Membrane Module Schematic

Compressed air is simply introduced at the feed end of the module at the proper temperature and pressure. Regulation of the NEA flow ensures that the product gas will be at the proper oxygen level. A by-product of the membrane performance is that the dew point of the NEA is considerably lower than the feed air. This is due to the fact that the water vapor in the feed air is more permeable than the oxygen (by approximately 100X). This means the NEA to be directed into the fuel tank is very dry, even if the feed air is fully saturated with water.

Another critical part of the ASM is the tube sheet which is the epoxy closing at either end of the fiber bundle (see the above membrane module schematic). This provides the seal that allows the separation of the product gas stream from the permeate stream. The technology of tube sheets has greatly developed for

ASM manufacturing. Resin materials have been developed based on a combination of physical properties, hot/wet aging properties of the resins, and manufacturability of the materials. Tube sheet components have an excellent CTE (coefficient of thermal expansion) match which leads to excellent thermal cycling resistance and fatigue resistance of the membrane modules.

### **A1.1.1 System Sizing (Full-Time and Hybrid OBIGGS)**

Membrane cartridges are produced in standard sizes, that is approximately 6 inch in diameters and 36 inches long. These standard cartridges have fixed NEA outlet performance at specific inlet conditions of temperature and pressure. The mechanics of changing the performance of a cartridge, purity and flow, is accomplished by changing a flow control orifice downstream of the cartridges. Restricting the flow and maintaining the pressure will decrease the oxygen concentration. Once the system designer has specified the operating conditions for the aircraft, it is a simple task to pick the proper number of cartridges to meet the systems needs for NEA flow based on the temperature, pressure and available feed flows.

The systems for each of the 6 modeled aircraft types were sized by using a software simulation. The large, medium and small transport aircraft, plus the Business Jet had three types of mission profiles, long, medium and short; and the other two model aircraft had only one mission profile. Each mission profile included such items as; fuel tank volumes of the different tank configurations, re-fueling rates, percent ullages, burn rates for the different phase of a flight, altitudes, flight distance, ambient temperatures, and amounts of time spent at each of the different phases of the mission. The program calculated the required NEA flow, with a given purity, based on the type of inerting being studied, that is, full time or hybrid. A full time system was sized to provide a 10 percent maximum oxygen concentration under all conditions. Hybrid systems were sized to provide a minimum flammability exposure as scaled down from an arbitrary system.

The total NEA flow, as determined by the program, was divided by the amount of NEA produced by a standard cartridge at sea level conditions to determine the number of cartridges needed. Corresponding to the cartridge's NEA flow is the required feed flow needed by the cartridge. This feed flow, times the number of cartridges is the amount of total feed flow required by the system which determines the overall system size. Once the feed flow is known, the orifice is sized and set for sea level conditions. The inerting system as designed has a fixed compressor ratio. The compressor draws inlet air from the aircraft cabin (whose pressure varies from 14.7 psia at sea level to 10.7 psia at altitudes of 8000 feet or more) rather than from outside. The pressure to the inlet of the cartridge will then vary with the aircraft's altitude. The membrane cartridges perform better at higher pressures. The reduced pressure combined with the fixed orifice results in a reduced flow for the cartridges as the aircraft gain altitude. The reduction in pressure/flow results in the cartridges producing higher purity NEA. The cartridge also benefits from the altitude increase because the lower pressure at the waste outlet improves the productivity of the cartridge. In other words, the reduction in performance caused by the decrease in inlet pressure from the altitude increase, is fractionally increased by the decrease in ambient pressure at the waste port. The cartridge performance at altitude is approximately 80-85 percent of the sea level performance.

After the amount of feed flow has been determined, the system's heat exchanger and compressor were sized. Calculated from these sizes are corresponding weight, volume, electrical power and cost. These values were then analyzed and it was found that the driving size parameter was electrical power. The NEA flow and purity were varied, along with the temperature and pressures and the program re-run to calculate new parametric values. These different systems were evaluated iteratively until a system was sized and designed to provide the least amount of electrical power consumption.

### **A1.1.2 NEA Concentration (Full-Time and Hybrid OBIGGS)**

The NEA concentration varied with the different flight phases. The full time OBIGGS reacts as follows. Typically the concentration of the oxygen would be 7 percent while on the ground. Once the aircraft

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departed and started the climb phase the NEA would drop to 5 percent for altitudes above 8000 feet. This is due to decreased flow and pressure from the effect of the altitude increases. The flow mode again changes in the cruise phase, because the system changes air supply from the compressor to engine bleed (low flow mode). The low flow through the cartridge reduces the concentration to the 3 percent range. As the aircraft starts descent the system would go back to high flow mode at 5 percent. Under the 8000 feet altitude the concentration will again go back to 7 percent.

In the hybrid OBIGGS the system reacts as follows. Concentration of the oxygen was set to 5 percent while on the ground. Once the aircraft departed and started the climb phase the NEA would drop to 3.5 percent above 8000 feet altitude. This again is due to decreased flow and pressure from the effect of the altitude increases. The flow mode did not change because the hybrid system is a single flow system, but could be changed to a dual flow system if necessary. As the aircraft descended the concentration would change from 3.5 percent back to 5 percent at the 8000 feet altitude.

### **A1.1.3 Effects of Feed Air Temperature (Full-Time and Hybrid OBIGGS)**

Membrane performance is directly affected by temperature. The conversion ratio of NEA from feed air increases as the temperature decreases, however the amount of both NEA and feed decreases at a ratio less than the ratio above. This simply means as the cartridge inlet temperature drops, it will require more cartridges to produce the same NEA amounts as at the higher inlet temperature, but at a favorable decrease for the amount of feed air required. To gain the full benefit of the temperature decrease the pressure must also be increased, like in the systems designed for the large and medium transport model. These systems were designed to minimize the power consumption, but their gain was offset by weight, volume and cost increase (though less than the power impact).

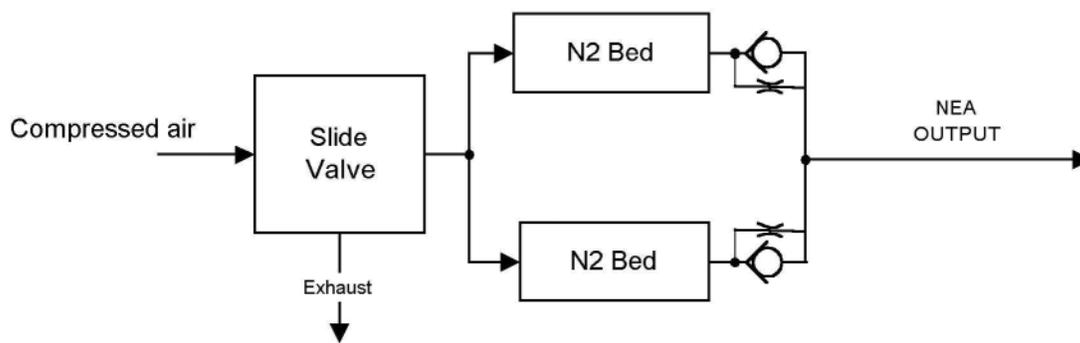
### **A1.2 PRESSURE-SWING ADSORPTION (PSA) SUMMARY**

PSA is a logical choice to consider for inerting commercial aircraft. It is used on a majority of the military applications that currently fly with OBIGGS. It has proven to be reliable and effective and is not susceptible to damage by normal levels of contaminants in bleed air. It is easily scalable in size and may be packaged in a variety of shapes and sizes. This may be useful in fitting such equipment into the available spaces on the commercial airframes that exist today that were not designed with inerting in mind.

**Background.** The pressure-swing-adsorption (PSA) process uses pressure as the controlling adsorption/desorption variable. In this process, the oxygen in pressurized air is adsorbed in a bed of molecular sieve, while the nitrogen passes through. The nitrogen sieve utilizes synthetic zeolites which are crystalline minerals with a large number of channels and cavities of atomic dimensions. Zeolites selectively adsorb almost any size molecule based on the strength of molecular interaction, size of the gas molecule, temperature, and pressure.

When the molecular sieve in the bed has become nearly saturated, the bed is vented to atmosphere. This causes most of the oxygen-adsorbed gases to be desorbed and discharged from the bed. Simultaneously when producing nitrogen, some of the enriched product gas from the other molecular sieve bed is flushed back through the bed to further lower the partial pressure of the adsorbed gases in the bed and to complete the desorption process. The use of two beds, which are pressurized and flushed alternately, provides a continuous flow of product gas and ensures sufficient pressure for the flushing operation. As the pressure swing increases with altitude, the efficiency of the process increases.

**Block Diagram.** Refer to the PSA functional block diagram, Figure A1.2-1 for the following operational description.



*Figure A1.2-1. PSA Block Diagram*

Compressed air (bleed or compressor air) is conditioned by the system heat exchanger and filter and then flows to the pilot-pressure driven slide valve, which sequentially ports it to the molecular sieve beds.

The two nitrogen beds are cycled alternately by the slide valve between the pressurization or nitrogen-producing mode and the vented, regenerative, oxygen-purging mode. The nitrogen enriched air (NEA) product gas from the pressurized bed flows through the bed check valves, and on to the fuel-tank-inerting distribution lines.

**Slide Valve.** Pressure-swing cycling of the molecular sieve beds is accomplished using a reciprocating slide valve. The valve is activated by two opposing air cylinders, which are pressurized and vented by pilot solenoid valves. When one cylinder is pressurized, the other is vented, and the valve is pushed to one side. This pressurizes one nitrogen bed and vents the other. An electronic timing circuit in the controller causes the solenoid valves to change state. The slide valve moves to the other side, and the other bed is pressurized while the original bed is vented.

**Bed Check Valves and Purge Orifices.** The check valves direct the output of the producing bed to the concentrator outlet. A purge orifice at the outlet end of each bed allows some product gas to flow into the non-producing bed, causing a rapid evacuation of the stored oxygen.

**ASM Sizing Methodology.** Most PSA hardware has been sized for weight-specific performance and not air conservation. Where air consumption becomes the primary driver, measures can be taken to reduce PSA air consumption below the baseline values used for this ARAC study.

The PSA air separator sizing calculations were made empirically. A production PSA air separator manufactured by one of the participating OBIGGS vendors was operated in an altitude chamber at the altitudes and supply pressures consistent with the ARAC study. At each altitude, the key physical performance parameters were measured: air consumption, product flow and product purity. For OBIGGS work, two sets of purity curves were produced, “low flow” at a nominal 7% oxygen level at lab altitude, and “high flow” at a nominal 10% oxygen level at lab altitude. Product gas flows were established by a simple throttling device that was not adjusted during the test (except to change from “low” flow to “high” flow), to simulate the various fuel tank orifices. The product gas outputs were scaled upward or downward to meet the product gas needs that resulted from the inert gas simulations. The scale factors were generally driven by high flow gas rates, so that a surplus of “low flow” would be available.

Further, for the OBIGGS effort, some data was taken at 1% inert gas, at altitudes related to the medium and large transport, to ensure that a third flow was practical. It was determined that the desired (low) flows of 1.2 lb./minute for the medium transport and 2.0 lb./minute for the large transport were achievable with the PSA ASM’s that were sized. These “very low” flows were not carried out at low altitudes as there was no need to do so.

## A1.3 CRYOGENIC DISTILLATION SUMMARY

The cryogenic distillation inerting system evaluated for the generic aircraft is an adaptation to the commercial aircraft environment of military technology currently in development for the Air Force's C-17 aircraft. A simplified schematic of the approach is shown in Figure A1.3-1. Bleed air from the engines is first filtered and dried in the inlet air cleaning system. The air is then liquefied and passed through a cryogenic distillation column where it is separated into oxygen and nitrogen. Cryogenic distillation column technology is very mature and has been used for years in Naval applications with excellent reliability and performance. High purity (>99% nitrogen) liquid and gaseous product can be extracted from the column simultaneously or independently. The cold product and waste streams from the distillation process are used to pre-cool the incoming air to minimize the amount of cooling that the cryogenic refrigerator must supply. The refrigerator is based on a reverse-Brayton technology developed for spacecraft sensor cooling. This refrigerator is very similar to the air-cycle machines currently on passenger aircraft. The cryogenic refrigerator requires electrical input power and rejects heat to the environment.

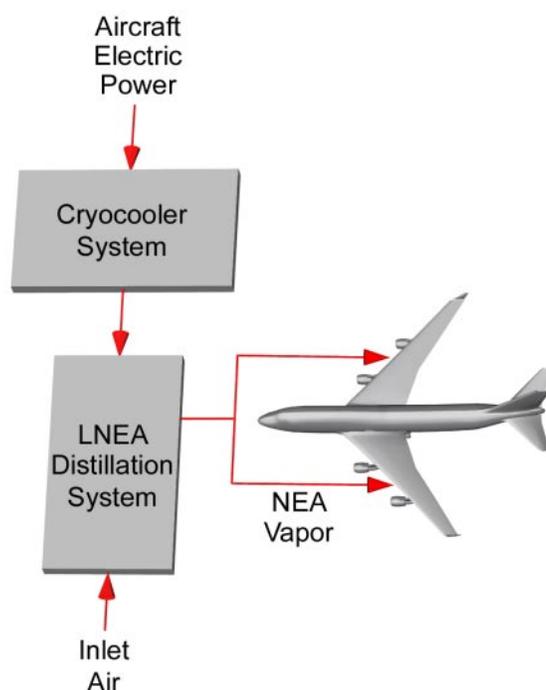


Figure A1.3-1. Cryogenic Distillation Fuel Tank Inerting System Concept

A full-time cryogenic distillation inerting system has several advantages over other available technologies for fuel tank inerting for large transports. For these large aircraft, the weight and volume are comparable to the minimum competing system while the electrical power and bleed air requirements are both several times lower. The disadvantage of the cryogenic distillation inerting system is that it does not scale well to smaller aircraft due to the weight and cool-down requirements of the components. Membrane or PSA-based systems are the best choice of the available technology for small transport, regional turboprop, regional turbofan, or a business jet.

The ability to store liquid makes the cryogenic distillation inerting system uniquely able to quickly cool-down and inert at the start of each day and provide *zero-power, full-time ground inerting*. The full-time system is sized such that sufficient liquid is made during periods of low demand (i.e. cruise) to (a) cool the cryogenic components to their operating temperatures while inerting the fuel tanks at the start of the

day and (b) keep the tanks inert during refueling. This sizing strategy ensures that the system initialization time will be short (<1 hour) and the fuel tanks will be inert 100% of the time.

### A1.3.1 The Cryogenic Distillation Inerting System

The next few paragraphs describe the subsystem components within the cryogenic distillation inerting system. Figure A1.3.1-1 illustrates where each of this components fit into the overall system.

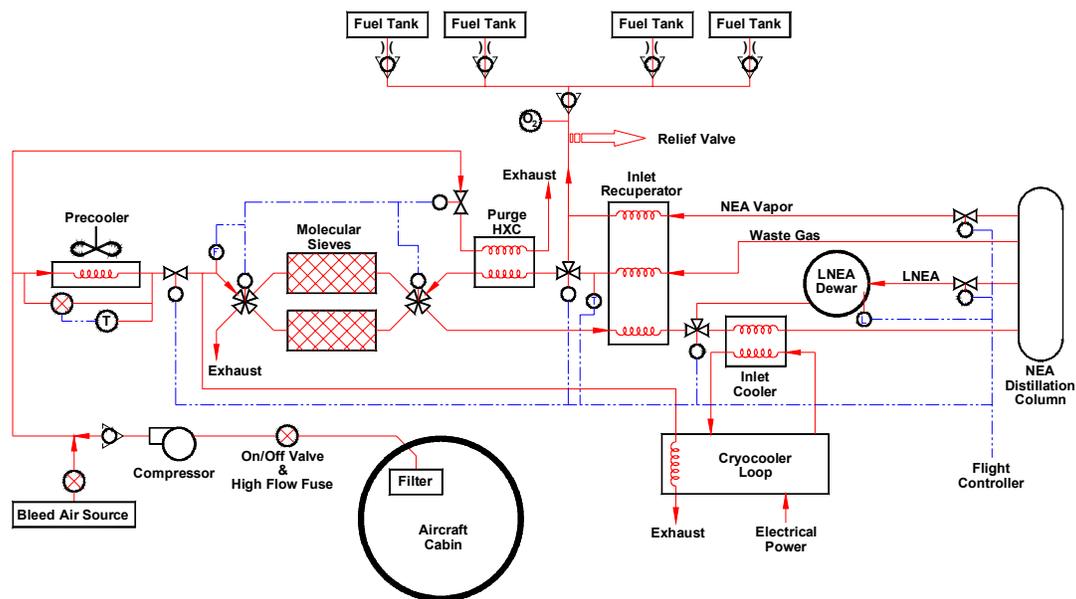


Figure A1.3.1-1. Cryogenic Distillation Fuel Tank Inerting System Schematic

**Inlet Air Subsystem.** The cryogenic distillation inerting system requires a supply of pressurized air. The Team assumed that this high-pressure air supply would be supplied by compressed air from one or more engines at a pressure of approximately 45 psia or greater and a temperature of 317 K or lower. This air contains vapors that are considered to be contaminants to the cryogenic distillation system. The most notable contaminants are water vapor and CO<sub>2</sub>. These contaminants must be removed prior to entering critical cryogenic components. If they are not removed, the resulting frozen buildup could cause small heat exchanger passages to plug and/or cause valves to operate improperly. Consequently, an air cleanup system has been designed to remove the water and CO<sub>2</sub> vapors. This subsystem employs molecular sieve beds to remove the water vapor and the CO<sub>2</sub>. The molecular sieves are regenerated with warmed waste gas, and they have been designed to operate without fixed cycle times due to the varying inlet air flow rate experienced during a typical mission. The sieves are cycled when the total mass of waste gas through the regenerating molecular sieve equals a fixed, known value. Downstream of the molecular sieves, any remaining water vapor or CO<sub>2</sub> in the air stream will freeze out harmlessly in the inlet recuperator, by design. This recuperator also pre-cools the inlet air, recovers valuable thermal energy from the waste flows or the exiting NEA gas, and helps to minimize the required cryocooler capacity.

**Cryogenic Refrigerator.** The cryogenic refrigerator subsystem is based on a single-stage reverse-Brayton cryocooler technology. The system consists of an electrically-driven compressor that compresses the cycle gas, neon in this case. The heat of compression is removed by the aftercooler that rejects heat to an open-loop air stream of either bleed air or ram air. The compressed and cooled cycle gas enters the recuperator where it is further cooled to approximately 98 K. This cold gas is then expanded through a turboalternator, and it experiences a further drop in temperature to about 84 K. Work is absorbed in the turboalternator by using an electrical stator and a rotating permanent magnet to generate electrical power, which is dissipated in a bank of electrical resistors. The colder and now lower pressure

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gas absorbs energy in the liquid oxygen (LOX) and liquid nitrogen enriched air (LNEA) heat exchangers and is warmed to about 92.5 K. This gas then passes back through the recuperator where it cools the counter-flowing, high-pressure gas stream.

**Core Distillation Column Technology.** After passing through the inlet air subsystem, the then clean, dry, and somewhat cold bleed air gets further cooled and partially liquefied by the cryocooler subsystem. The two-phase mixture of air then enters the distillation column, which is designed to produce 99% pure NEA vapor. To recover 90% of the available nitrogen from the air, the cryogenic distillation inerting system was designed with dual columns. These dual columns act like one tall column without the height penalty.

The NEA column is called a rectifying column. The inlet air stream is injected into the bottom of the column. This vapor then travels upward through the packing material and interacts with the down-flowing, oxygen-depleted liquid. The oxygen-depleted liquid strips the oxygen from the vapor so that the vapor exiting the top of the packing material has a purity of greater than 99% nitrogen. The nitrogen vapor is condensed by a reflux condenser, which is fed by the column bottom.

The key to making cryogenic distillation inerting technology practical for aircraft applications is to develop compact distillation columns capable of operating in an aircraft environment. Key environmental concerns include vibration and tilt. Tilt-insensitive column designs have been developed with the assistance of a distillation column manufacturer that utilize advanced trays to make the compact column tilt and vibration insensitive. Previous distillation column testing has demonstrated that vibration loads characteristic of those encountered on military cargo aircraft have no detrimental effect on distillation column performance.

**Gaseous Nitrogen Enriched Air (GNEA) Delivery.** This subsystem provides direct delivery of GNEA from the top of the distillation column to the fuel tanks. The cold (~90 K), low-pressure (~40 psia) GNEA passes through the inlet recuperator. The GNEA is warmed to nearly ambient temperature (290-300 K) by cooling the counter-flowing inlet air stream in the high-effectiveness inlet recuperator. Recovering the cooling capacity from the product flow is key to significantly reducing the required cryocooler capacity.

**Liquid Nitrogen Enriched Air (LNEA) Storage and Delivery.** This subsystem provides storage and delivery of LNEA to support ground operations and initialization. The LNEA is stored in a standard aircraft cryogenic dewar. When the fuel tanks call for NEA, the LNEA from the dewars passes the inlet recuperator. The LNEA is vaporized and warmed by cooling the counter-flowing inlet air stream or by a separate vaporizer. The system may also produce liquid during periods of low demand for the next day's cool-down or to support inerting on the ground.

### **A1.3.2 System Sizing Methodology**

Cryogenic distillation inerting system sizing is driven by the size of the cryogenic refrigerator, which is fixed by the liquid production requirement. To produce nitrogen gas, the cryogenic refrigerator must provide enough cooling to make up for heat leaks and inlet recuperator ineffectiveness. To produce nitrogen liquid, the cryogenic refrigerator must have additional capacity to liquefy the product. In the case of the cryogenic distillation inerting systems sized for the generic aircraft, the thermal capacity of the cryogenic refrigerator is within the range of machines that have been manufactured previously in terms of cooling capacity and load temperature. From other internal projects and parallel efforts for the military, we have empirical data for the other system components such as the column, the heat exchangers, and the storage dewar(s). Using this information in combination with proprietary thermodynamic process models, systems were sized based on the inert gas flow and liquid production requirements for a particular aircraft. The inert gas flows were fixed by FAA models of typical missions for various aircraft sizes. The liquid production flow rates were established by: (a) the need to cool the cryogenic components and provide inert gas at the start of the day and (b) the requirement to keep the fuel tanks

inert during refueling. The aircraft utilization time was fixed at 15 hours per day based on input from aircraft operators.

The cryogenic distillation technology is well suited to OBIGGS and hybrid OBIGGS for large and medium transports but is not well suited to an On-Board Ground Inerting (OBGI) system. The major driver for the system sizing for OBGI is the cool-down time. Because the inerting system cannot operate in flight, the system cannot make liquid nitrogen during periods of low demand for cool-down and initialization, as it can in the case of full-time or hybrid OBIGGS. For OBGI, the cryogenic refrigerator supplies all of the cooling for the system during the limited ground time. This makes the system too heavy and demanding of electric power. The cryogenic distillation system was therefore not investigated further as a realistic option for OBGI.

## A2 COMPRESSOR DESCRIPTIONS AND SIZING METHODOLOGY

### A2.1 INTRODUCTION

Compressors are widely used to increase the pressure of gas or vapor phase fluids. Energy is supplied to drive the compressor, and most of this energy is converted into fluid pressure increase. There are various ways of supplying energy, such as electric motors and turbines. Likewise, there are several types of compressors available including piston, radial vane, screw, centrifugal, and axial vane compressors. There are also other types of compressors that are less commonly used. Each type of compressor has advantages and limitations that will be discussed under the descriptions below. The types of compressors most appropriate for the inerting systems discussed in this report are the piston, screw and centrifugal compressors.

A typical compression cycle is shown in Figure A2.1-1. The compression cycle follows a process line such that  $pv^n = \text{constant}$ . The value of  $n$  varies depending on the cycle design and the compressor design. The cycle is said to be isentropic when the value of  $n$  equals the ratio of specific heats,  $k$ . For air,  $k = 1.4$ . The shaded area in the figure is proportional to the work to compress the fluid. This area will depend on the value of  $n$ . Compressor analysis can be simplified if the concept of efficiency is introduced.

Compressor efficiency  $\eta$ , is defined as the ratio of work for isentropic compression to the actual work of compression between two pressures. Using this concept it is possible to analyze compressor performance using isentropic relationships and correct the results for real effects.

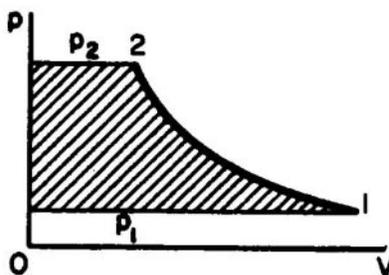


Figure A2.1-1. Compression Cycle

There are a number of relations that are useful in analyzing compressor performance. The pressure ratio  $r$  is defined as the ratio of outlet to inlet pressures  $p_2/p_1$ . The outlet absolute temperature  $T_{2i}$  for isentropic conditions and inlet absolute temperature  $T_1$  is:

$$\frac{T_{2i}}{T_1} = r^{\frac{k-1}{k}}$$

Knowing  $T_{2i}$  and efficiency, the actual exit temperature  $T_2$  can be found from the relationship:

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$$\eta = \frac{T_{2i} - T_1}{T_2 - T_1}$$

Finally, the power required P to run the compressor with a mass flow rate of m for a gas with specific heat at constant pressure of  $c_p$  is calculated as:

$$P = mc_p(T_2 - T_1)$$

The operational parameters of “dynamic” compressors (screw and centrifugal) are volume flow (Q), head or discharge pressure (H), and speed (N). These operational variables can be expressed in a single term called *specific speed*  $N_s$ .

$$N_s = \frac{N\sqrt{Q}}{H^{\frac{3}{4}}}$$

A certain value of specific speed leads to similar flow conditions in geometrically similar machines. The specific speed is usually evaluated at the point of best efficiency, and defines the general type of machine required. Low values of specific speed imply low values of Q and high values of H. High specific speed implies high values of Q and low values of H. For a given head and capacity the use of a high specific speed means a smaller machine and this usually results in less cost.

Overall compressor cycle efficiency can be improved by cooling the fluid between stages of compression. For example, the performance of a two stage centrifugal compressor can be improved by cooling between the two stages. It is most convenient to consider a temperature-entropy diagram for the process. This is shown in Figure A2.1-2.

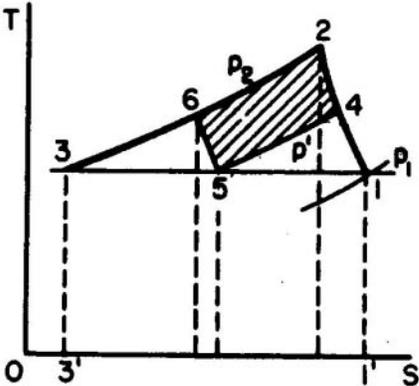


Figure A2.1-2. Compressor Inter-Stage Cooling

The line 12 represents the compression from  $p_1$  to  $p_2$  for a single stage of compression. The constant pressure line 23 represents cooling of the fluid to its inlet temperature. The work required for this process is the area 1'1233'. If two stages of compression are used with inter-stage cooling, 14 represents the compression from  $p_1$  to an intermediate pressure  $p'$ . Inter-stage cooling occurs at constant pressure process 45, and the second stage of compression from  $p'$  to pressure  $p_2$  is 56. Finally, constant pressure cooling 63. The work for this process is 1'145633', and the savings is represented by the area 4265. The work savings is maximized when the intermediate pressure  $p' = \sqrt{p_1 p_2}$ .

## A2.2 ELECTRICAL DRIVE MOTORS

### A2.2.1 Inductive

The induction motor is constructed from two electromagnetic components, the stator and the rotor.

The stator has a three phase winding, connected to a three phase alternating current power supply, producing a rotating magnetic field. Inside the stator is the rotor with a polyphase winding consisting of copper or aluminium bars set in the rotor slots interconnected by rings at each end of the rotor.

The rotating magnetic field induces currents in the conductors of the rotor as in the secondary windings of a transformer. These currents oppose the magnetic field changes that set them up, generating forces that act on the rotor bars as a torque so as to cause rotation in the direction of the magnetic field. If the rotor has the same angular velocity as the magnetic field then no current induced, therefore when a torque load is applied, the rotor is slowed down and runs with slip. This slip is typically less than 5%.

Figure A2.2.1-1 is a schematic showing the principle of the induction motor.

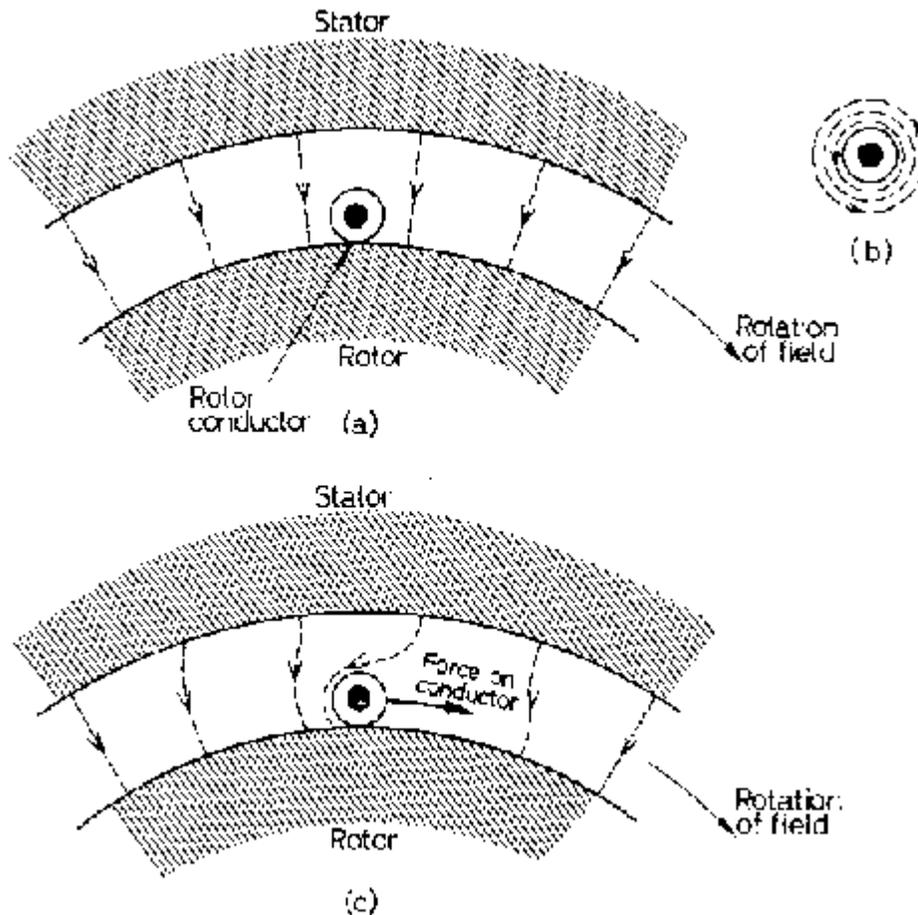


Figure A2.2.1-1.

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Figure A 2.2.1-2 shows a rotor. Skewed Aluminium rotor bars may be seen within a laminated iron rotor stack.



*Figure A2.2.1-2. Induction Motor Rotor*

The electrical supply is the aircraft standard of 400 Hz, 115 Volts line to line, three phase, alternating current.

Figure A 2.2.1-3 shows the torque/speed and efficiency curves of a 40 kWatt motor as might be used in an Onboard Inerting solution. The operating efficiency is 90%.

An induction motor may be designed for a no-load rotor speed that is an integral fraction of the supply frequency. For a 400 Hz supply the nominal speeds are: 24,000, 12,000, 8,000, 6,000, 4,800 rpm and so on. It can be seen from the torque/speed curve in Figure A 2.2.1-3 that to a first approximation the motor is a fixed speed device for a given supply frequency.

The power to weight ratio of the induction motor is a function of design speed; the trend being, the higher the speed the lower the weight for a given power. However, for reasons of magnetic circuit design a motor designed for 24,000 rpm is about the same weight as for 12,000 rpm. In this Onboard Inerting System design study, the nominal motor speed was selected as a 24,000 rpm. This gave an efficient operating point for a screw compressor with a direct drive, and in the case of the centrifugal compressor, minimised the ratio of the gear box required to increase the drive speed to that of the compressor wheel.

The weight of the motor is approximately proportional to the shaft power output. The following expression was used in the study.

$$\text{Weight (lbm)} = 0.95 \text{ Power (kWatts)}$$

This weight is inclusive of the motor housing, bearings, lubrication and cooling system. It is exclusive of the supply cable, contactor and aircraft installation for ram air to cool the motor.

A characteristic of an induction motor is, that if started direct on line, a transient current of up to three times the normal running value occurs.

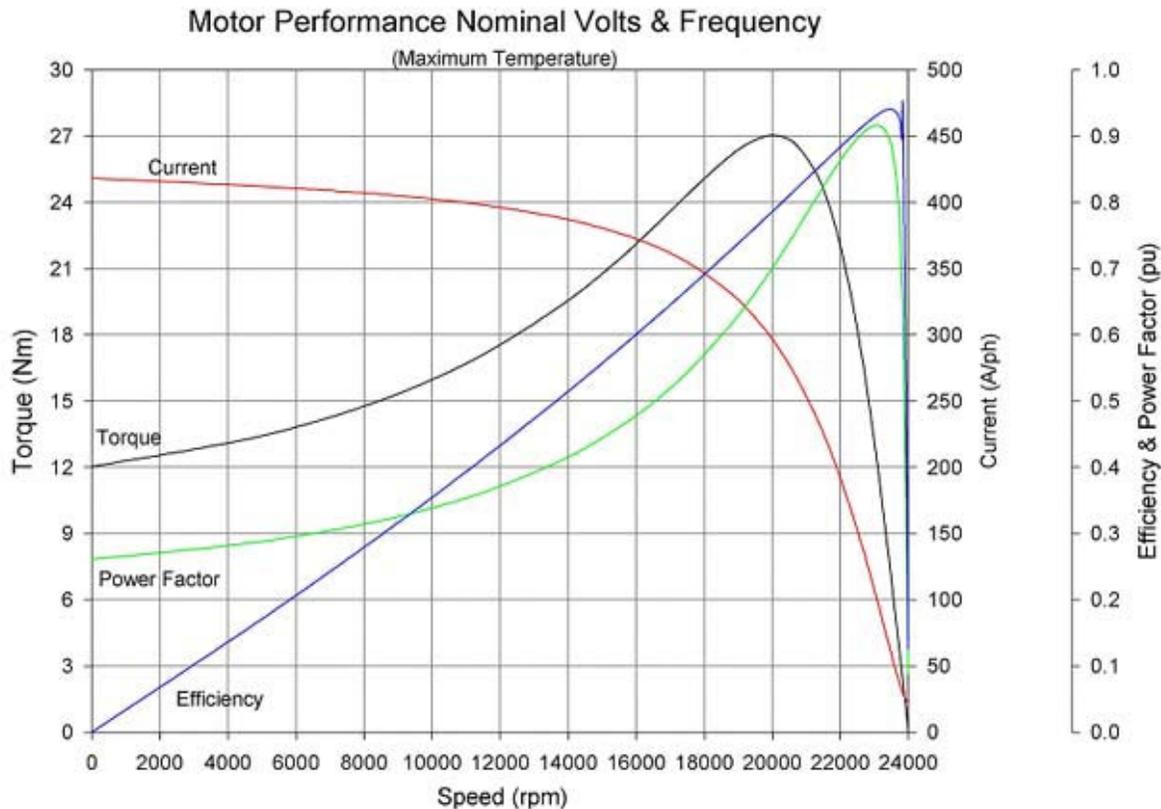


Figure A2.2.1-3.

It is considered that motors of greater than 15kW shaft power would require a start winding and associated contactors to prevent other equipment on the aircraft electrical system from being disturbed by the surge current.

30kW shaft power is greater than any induction motor currently used on an aircraft and it was assumed that multiple units would be used to deliver higher powers than this as they could be started in sequence,

The 400 Hz, three phase supply is standard for existing passenger transport aircraft and thus the induction motor described above is appropriate for retrofit installations.

Future aircraft however are expected to have variable frequency 3 phase supplies. This will not affect the Onboard Ground Inerting Systems that will still take power from either a fixed frequency APU or the external ground supply. However in the case of Full Time On Board Inerting and the Hybrid system. The variation in frequency and hence motor and compressor speed is likely to be of the order of 2 to 1. The acceptability of this depends on how engine speed varies with OBIGGS duty cycle.

It may therefore be necessary to drive the motor with a 3 phase inverter.

The primary advantages of the induction motor is its simplicity of construction which results in high reliability. Indeed induction motors in aircraft fuel and hydraulic system achieve mean times between failures in excess of 100,000 hours. This is greater than other motor types because of the absence of electronic power switching and control devices that are within brushless motor and drives and inverters.

The power density, when operated from a 400 Hz is about 1.0lbm/kW. This is because of the absence of any external additional power electronics and associated cooling subsystems. In addition the magnetic

flux density in the machine is not limited by the saturation properties of the permanent magnetic materials.

### A2.2.2 Permanent Magnet

Magnetically a permanent magnet motor (PM motor) works on the same principal as an induction motor, magnetic fields between the rotor and stator exert a torque on the rotor which rotates it. In the case of a permanent magnet motor, the magnetic field from the rotor is provided by permanent magnets instead of by coils, as is the case for induction motors. Permanent magnet motors therefore do not require a commutator ring to cycle electrical power to the rotor coils. Instead, the rotor position is sensed by magnetic sensors (usually Hall effect sensors) and the stator voltages controlled to be in the proper relative phase to the rotating rotor. The control of the voltages to each stator coil is provided by an electronic controller commonly referred to as an inverter. A typical system schematic is shown in Figure A2.2.2-1.

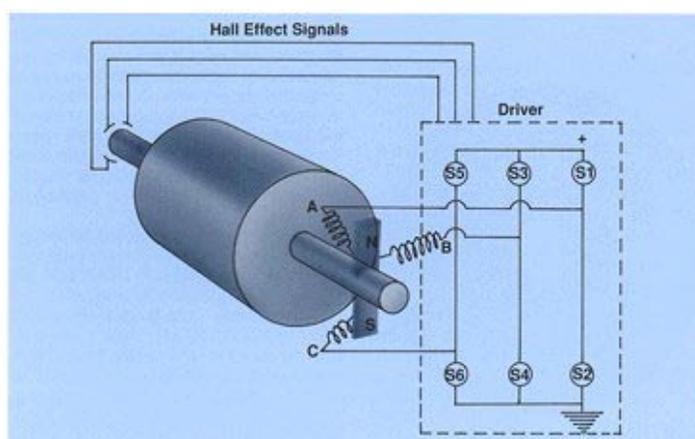


Figure A2.2.2-1. PM Motor Schematic

There are two types of brushless motors; the type that has an outer rotating magnet assembly, and the “inside out” type that has an inner rotating magnet assembly. The latter design is most suitable for applications requiring a shaft drive. These variations are shown below in Figure A2.2.2-2.

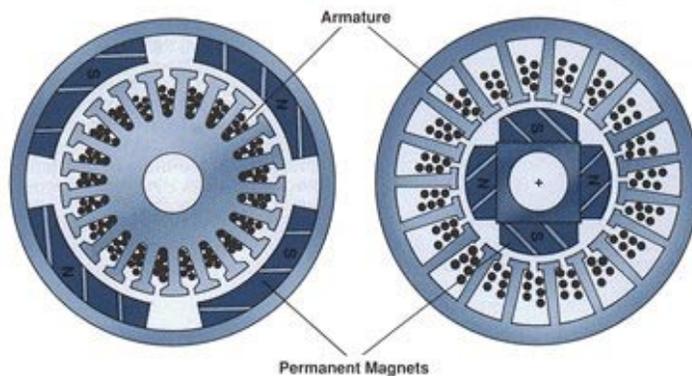


Figure A2.2.2-2. PM Motor Design Variations

PM motors have an operating efficiency between 90 and 98%. This is due to not requiring electrical current to generate the rotor magnetic field including associated winding losses, and because the voltage to the stator coils is precisely timed by the inverter (power factor of unity). Figure A2.2.2-3 shows a typical operating curve for a motor rated at 55 kW continuous.

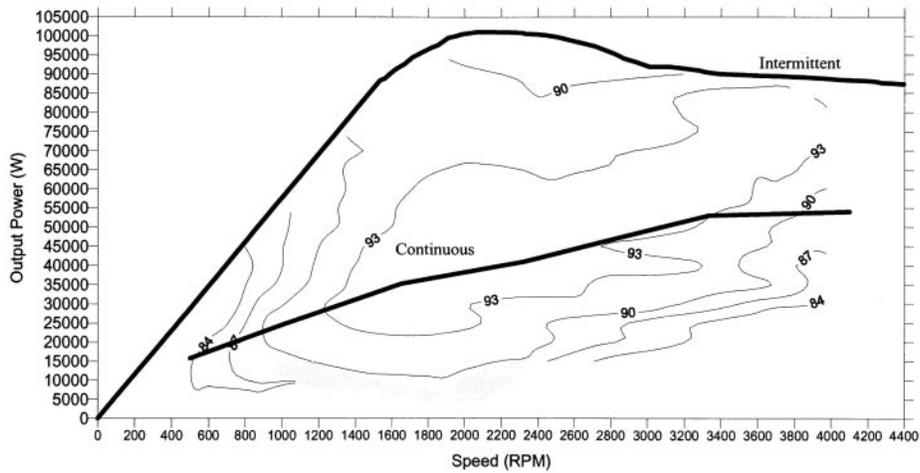
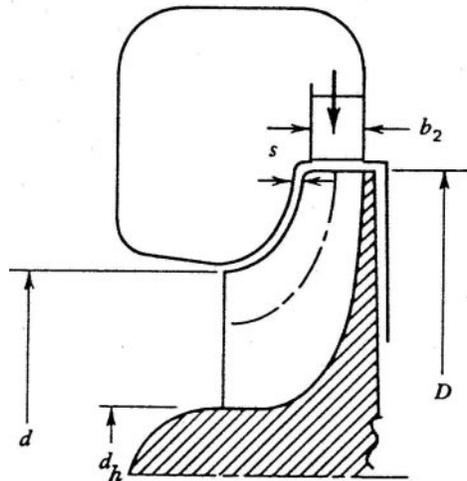


Figure A2.2.2-3. Typical Operating Parameters for a 55 kW PM Motor

The primary advantages of PM motors are high power to volume, long life with no brushes to wear, and high efficiency. Disadvantages are heat dissipation requirements due to high power densities, and the need for a power inverter. An estimate of motor weight is 2.8 pounds/kW. Motor volume can be estimated as 25 inch<sup>3</sup>/kW.

### A2.3 TURBINE DRIVES

A radial turbine is just the opposite of a centrifugal compressor (Figure A2.3- 1 depicts a radial turbine cross section). Their design and basic energy relations are similar to centrifugal compressors. The term radial usually refers to a radial inflow type turbine with rotor blade inlet angles of 90 degrees (straight radial blades). The direction of the flow path is reversed, meaning that the flow, after passing through the radially arranged nozzle, enters the rotor in a radial direction flowing towards the axis and is discharged from the rotor in the axial direction.



$$\epsilon = \frac{D}{d}$$

Figure A2.3-1. Radial Turbine Cross Section

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The energy transfer between the fluid and the rotor is rather simple. High-pressure fluid from the inlet chamber (scroll) flows to stationary blades. The blades can take the form of vanes or holes and are called stators or nozzles. The function of the nozzles is to direct the fluid tangentially into the rotating rotor at a slightly lower pressure and higher velocity (expansion). The blading in the rotor is designed such that further expansion takes place to the exit. Kinetic energy is converted to mechanical energy (torque) in the turning of fluid flow in the blading resulting in a pressure difference across the blades. The difference in the entering to exit tangential velocity provides the energy per unit mass flowing exchanged between fluid and rotor and is proportional to a total temperature drop. Leaving velocity can then be recovered at exit by slowing the fluid velocity through diffusion (increasing fluid flow area).

The operational parameters of the turbine are volume flow (Q), expansion head (H), and speed (N). Volume flow for the turbine is defined as the exit volume flow instead of inlet volume flow, as for the compressor. These operational variables can be expressed in a term called *specific speed*  $N_s$ . A certain value of specific speed leads to similar flow conditions in geometrically similar machines. Low diameter ratios (rotor-exit tip diameter to rotor-inlet tip diameter) are desired for lower specific speed designs and higher diameter ratios for higher specific speed designs up to an imposed limit of 0.70.

$$N_s = \frac{N\sqrt{Q}}{H^{\frac{3}{4}}}$$

Turbines are designed to convert fluid energy into mechanical energy and the major performance factor is the ratio of the actual shaft work produced to the energy supplied. The energy available to the rotor is the sum of the inlet fluid kinetic energy and the energy available from pressure drop across the rotor. Efficiency of turbines is typically 75 to 85%. Nozzle and rotor losses account for most of the losses for low specific speed designs and exit velocity losses account for the major efficiency loss for high specific designs. An important consideration for the rotor flow path design is the rotor exit conditions. Uniform flow distribution and nearly swirl-free exit is desired to obtain high efficiencies.

The major advantage of radial turbines is their application in small expansion machines (small gas turbines, turbo-expanders, turbo-compressors and turbo-chargers) owing to their ruggedness and relatively simple manufacture. One limitation of the radial turbine is introduced by the radial inward flow in that a rather high exit velocity may be required due to the expansion of the fluid and the restricted flow area at the exit.

### A2.4 BEARING CHOICES

#### A2.4.1 Rolling Element Bearings

Rolling element bearings are constructed by enclosing balls or rollers between an inner and outer track or race. The inner track moves upon the balls or rollers in the ideal case with pure rolling and without sliding associated with plain bearings. The manufacture of rolling element bearings with the necessary precision to operate at high speed with a long life is a mature technology. The general construction is shown in figure A2.4.1-1.

For high speed applications such as the motor and compressor bearings, the rotating assemblies would be mounted in angular contact hybrid bearings.

Hybrid bearings are so called as they are constructed with hardened steel races with ceramic balls. The races are typically a martensitic steel alloyed with nitrogen which substantially improves corrosion resistance at high temperatures and also improves material toughness strength and fatigue life. The balls are silicon nitride controlled by a one piece phenolic cage. The ceramic balls are harder, stiffer and lighter than steel with a lower coefficient of thermal expansion resulting in lower centrifugal forces, lower vibration levels, less heat build up, reduced ball skidding and thermo mechanical stability. The rotational speed capability of hybrid bearings is 50% more than that required for compressor or motor.



*Figure A2.4.1-1. Rolling Element Bearing General Construction*

The disadvantage of rolling element bearings is that they require lubrication and have a finite life. Careful seal design is required to ensure that oil does not migrate into the compressor discharge and contaminate the ASM. This is made easier by the compressor discharge pressure being greater than the ambient pressure within the motor and compressor bearing case. With respect to the life of hybrid bearings, this is typically 10,000 hours running time.

The main advantage of rolling element bearings is their relatively low cost, good reliability within the operating life and tolerance to transient interruptions in the lubricant or power supply.

#### **A2.4.2 Magnetic Bearings**

Magnetic bearings employ the magnetic force generated by a electrical coil-magnetic material pair of elements to keep the shaft positioned properly. At each bearing location on the shaft two such electromagnetic actuators will be required, perpendicular to each other, to properly maintain shaft position. This can be implemented by including a section of magnetic material on the shaft, and by placing two coils at 90 degree orientation. A thrust bearing is also necessary, which can be accomplished with a single coil.

In order to control the position of the shaft at each bearing location it is necessary to have a position sensor that works in conjunction with each positioning coil. Shaft position is fed to a control which adjusts current to the coil so as to maintain a precalibrated position. A complete shaft bearing system for typical compressors considered in this report will consume 3 to 5 amps of 28 VDC power.

The controller must provide protection for the bearing system during startup and shut down. During startup it is necessary to ensure that power is supplied to the bearings before the compressor shaft is rotated by the prime mover. Likewise on shut down the controller must ensure that power remains to the bearings during spin-down, until completely stopped. These functions are easily incorporated using modern microprocessor based control systems.

The major advantages of magnetic bearings are first, since there is no metal contact there is no wear to be concerned about. While other bearing types, such as roller bearings, require periodic replacement,

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magnetic bearings do not. Second, since there is no lubrication used with magnetic bearings, there are no hydrocarbons present to contaminate the Air Separation Module elements.

### **A2.4.3 Air Bearings**

Air bearings are used for high speed shafts when it is desirable to minimize friction. The design of air bearings is similar to the design of bearings that use other fluid lubricants such as oil, except that for most practical cases air compressibility must also be considered. The compressibility parameter  $\Lambda$  is important for air bearing design.

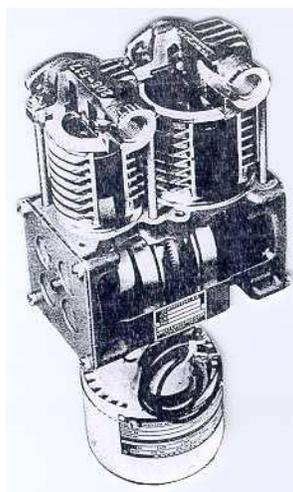
$$\Lambda = \frac{6\mu\omega}{P_a m^2}$$

In the above equation  $\mu$  is fluid viscosity,  $\omega$  is rotational speed (radians/sec.),  $P_a$  is fluid pressure and  $m$  is diametrical clearance ratio (diametrical clearance/diameter). Details of air bearing design can be found in Elrod and Burgdorfer, Proceedings First International Symposium on Gas-lubricated Bearings, 1959, and Raimondi, Trans. ASLE, vol. IV, 1961.

Air bearings can become unstable under certain conditions, exhibiting a phenomenon known as swirl. The air used to lubricate the bearings must be free from any particulate matter, as the bearing clearances must be small to support the loads. Also, an air bearing develops its load carrying capacity through rotation of the shaft. If the shaft remains stationary while loads are applied damage can result to the bearing surfaces. This might be the case for example if a compressor is shut down during flight and landing, and turned on only while on the ground.

### **A2.5 PISTON COMPRESSORS**

The piston compressor is a positive displacement, intermittent flow machine and operates at a fixed volume in its basic configuration. Capacity may be regulated in a single or double acting cylinder with single or multiple stage configuration. A piston compressor is generally used where low flow/high pressure output is needed. For a single stage compressor, an output pressure of 80 psig at 5 SCFM is realistic. Increasing the number of stages in a compressor results in the ability to substantially increase output pressure. This type of compressor is shown below in Figure A2.5-1 and would be applicable, in a flight version, for small air flow, on-board applications.



*Figure A2.5-1. Two-Stage Piston Compressor*

Figure A2.5-2 identifies some typical upper limit piston compressor performance characteristics. A discharge pressure of 40 psig was selected.

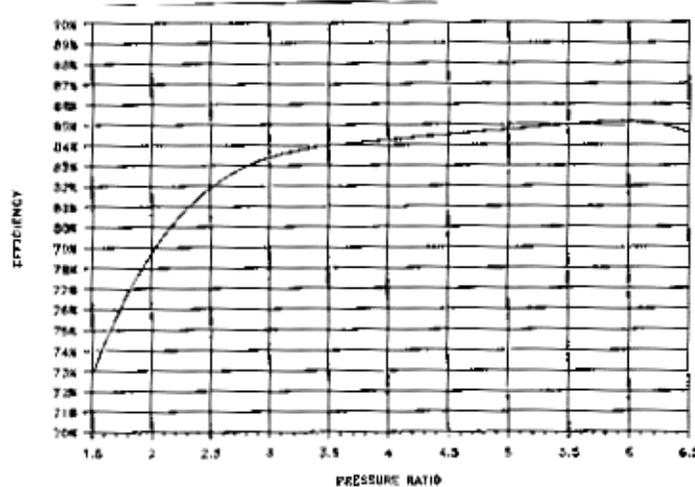
<b>Power (HP)</b>	<b>Pressure (psig)</b>	<b>Flow (CFM)</b>	<b>Power Consumption (kW)</b>	<b>Approximate Weight (lbs.)</b>	<b>Approximate Volume (cu-ft.)</b>
1/4	40	1.8	0.19	35	0.85
1/3	40	1.9	0.24	40	0.90
1/2	40	2.65	0.37	45	0.98
3/4	40	4.25	0.56	50	1.07
1	40	6.4	0.75	70	1.80
1-1/2	40	8	1.12	80	2.00

*Figure A2.5-2. Piston Compressor Sizing for 40 psig Discharge Pressure*

Piston compressors are available in both lubricated and non-lubricated models. The lubricated compressor is by far more widely used with post separation hardware required for clean, oil-less air. Labyrinth piston compressors use non-contact seals that sacrifice efficiency for low maintenance and oil free discharge air.

Piston compressors require cylinder cooling. This is usually provided by a water jacket (larger compressors) or by air cooling (smaller compressors).

Compressor efficiencies are affected by different parameters such as pressure ratio, air temperature, cooling ability, air density. Figure A2.5-3 provides a fair representation of compressor efficiency at standard ambient temperature and atmosphere.



*Figure A2.5-3. Piston Compressor Efficiency*

Though piston compressors vary greatly in size, capacity and configuration, the following advantage/disadvantage comparison will serve provide some basic input.

## Piston Compressor Advantages:

- High discharge pressure capacity
- Can start under load
- Matured technology
- Oil-less discharge air (if optimized)
- Direct drive or offset drive capabilities

## Disadvantages of Piston Compressors:

- Low discharge air flow
- Cylinder cooling required
- Large size (when compared to vane, screw and some centrifugal compressors)

## A2.6 SCREW COMPRESSORS

### A2.6.1 Description

A screw compressor is a positive displacement, continuous flow machine and operates at a fixed volume and compression ratio. Capacity may be regulated by a varying the operating speed but with some loss of efficiency. A screw compressor is generally used where intermediate flow and pressure is required.

The operating principle is similar to that of a piston compressor in that fluid is drawn first into an expanding volume, trapped within that volume, compressed and finally expelled into a receiver.

Figure A2.6-1 shows a schematic of a screw compressor.

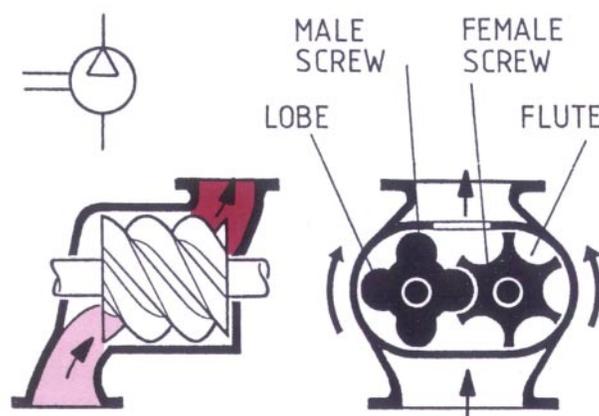


Figure A2.6-1. Screw Compressor

The compressor has two rotors that have helical lobes that closely interlock. The rotors are precisely synchronised by timing gears that maintain the small clearances between the lobes without contact. The circumference of the rotors are sealed by closely fitting intersecting cylinders. The timing gears are sealed from rotors and are oil lubricated, however the rotors themselves are oil free.

Figure A2.6-2 illustrates the function of the compressor. Gas enters through a port at one end of the cylinders, is trapped and compressed until a port at the other end is exposed by the end face of the lobes allowing the gas to be delivered. The timing of the exit port allows time compression to take place giving good efficiency at the end design compression ratio.

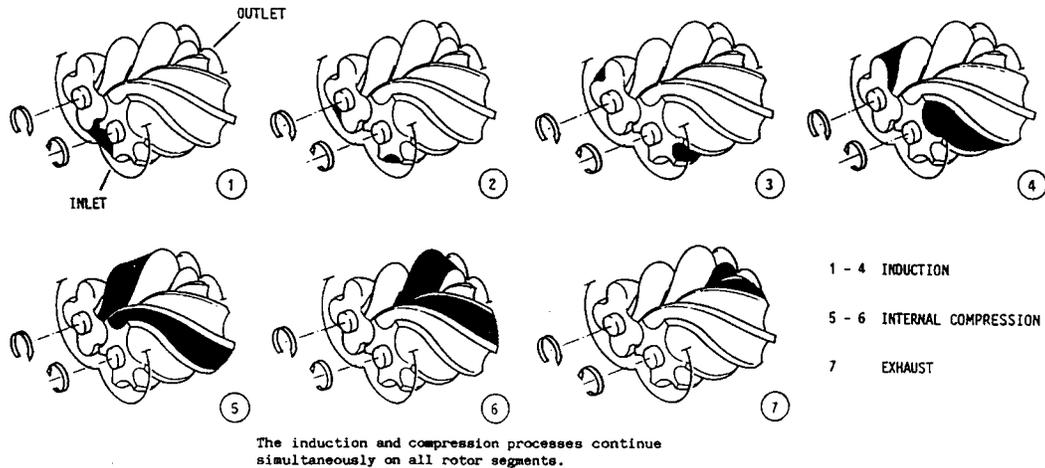


Figure A2.6-2.

### Screw Compressor Advantages

- Can start underload
- Mature technology
- Oil-free discharge
- Direct drive or offset drive capability
- No contacting seals to wear

### Disadvantages of Screw Compressors

- Cooling of the housing required
- Large and heavy compared with centrifugal compressors

### A2.6.2 Optimal CFM Range/Limitations

Screw compressors may be scaled from fractions of lbm/min to hundreds of lbm/min. Their construction limits the differential pressure to of the order of 100 psig. This is because at high differential pressure the rotors are deflected and increased clearances between rotors and casing are required. This compromises efficiency through increased internal leakage. Efficiency also is reduced as flow decreases to the order of 1 lbm/min. This is because clearances do not scale with size and internal leakage again becomes significant.

### A2.6.3 Typical Parameters

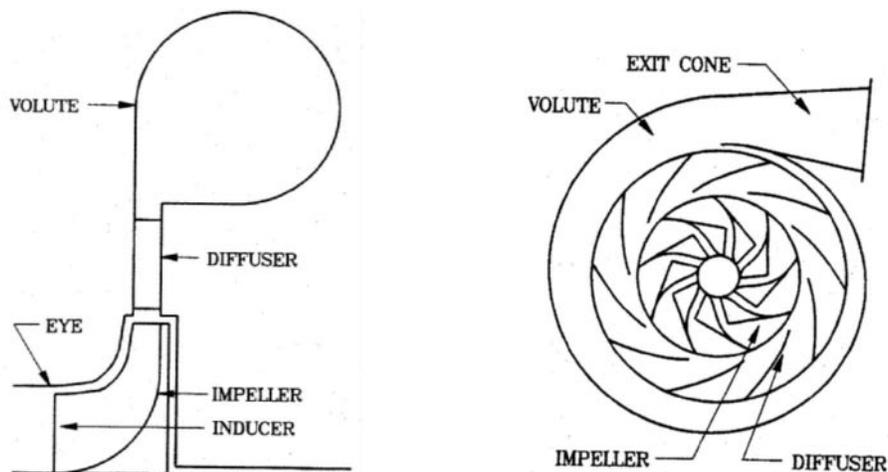
For a single stage compressor running at sea level with a 4:1 compression ratio the following approximations may be made for weight and volume.

$$\begin{aligned} \text{lbs} &= 3.2 \text{ lbm/min} \\ \text{Ft}^3 &= 0.037 \text{ lbm/min} \end{aligned}$$

## A2.7 CENTRIFUGAL COMPRESSORS

### A2.7.1 Description

A centrifugal compressor is a “dynamic” machine. That is, the fluid to be compressed is not positively contained but is continually in steady flow through the machine, undergoing changes of pressure primarily by means of dynamic effects. Unlike other types of compressors, when the machine motion is stopped, the fluid will pass to some other state controlled by the surroundings. Figure A2.7-1 depicts centrifugal compressor geometry.



A2.7-1. Centrifugal Compressor Geometry

The energy transfer between the fluid and the rotor is rather simple. Fluid enters the impeller (called an “eye”) and passes through the impeller, guided by blades, and is discharged at the tip. The velocity of the exiting fluid is higher than entering. This change of fluid velocity is dynamic head or dynamic pressure. To provide useful energy, the dynamic head must be converted into static head or static pressure in a fixed casing following the rotor. This conversion is called diffusion, and is simply reducing the high discharge velocity exiting the rotor by increasing flow area and converting the velocity energy into pressure.

Efficiency of a centrifugal compressor is defined as the ratio of useful energy in the fluid at final discharge to the mechanical energy supplied to the rotor. If the mechanical energy supplied to the rotor includes energy absorbed by bearings, lands, couplings, etc., the efficiency is an overall efficiency. Mechanical loss tends to be a higher proportion at low speeds than at high speeds. Typical maximum efficiency of centrifugal compressors of pressure ratio up to 2 is near 82%, and for pressure ratio up to 4 is 78%. For multi-stage industrial type compressors efficiencies of 60 to 70% are typical.

The advantages of centrifugal compressors are simplicity and ruggedness of construction. They provide wide range of operation between surging and choking limits and less severe surging behavior. Centrifugal compressors provide greater possibility of flexibility of performance by use of adjustable pre-whirl and diffuser vanes. If inter-stage cooling is introduced, the tangential discharge of circular cross-section of the radial centrifugal compressor is well suited for heat exchanger connection.

Centrifugal compressors are limited by the stress in the rotor. As rotor speed is increased, the rotor stresses also increase. Similarly, as rotor diameter increases stresses also increase. There is also a limitation on the rotor tip speed remaining subsonic to avoid shock wave losses. Centrifugal compressors operate at speeds up to 100,000 RPM. Centrifugal compressors generally operate in the specific speed range from 40 to 900, which for air implies flows in the range of 200 to 200,000 CFM or 15 to 15,000 PPM. The maximum pressure ratio is approximately 4 to 1. When operating at the low end of a designed

flow range, centrifugal compressors may experience surge, which can lead to unsteady flow conditions and damage to the equipment.

For a two stage compressor running at a pressure ratio of 4 to 1, the following approximations can be used for volume and weight.

$$FT^3 = 0.6 + 0.0035PPM + 0.0004PPM^2$$

$$LBS = 25 + 0.6PPM + 0.01PPM^2$$

These relationships apply for air flows in the range of 5 to 60 PPM. For a single stage compressor running at a pressure ratio of 1.5 to 1 use 40% of the above estimates.

### A2.7.2 Typical Parameters vs CFM (weight, eff., etc.)

### A2.7.3 Optimal CFM Range/Limitations

## A3 HEAT EXCHANGER/FAN SIZING METHODOLOGY

Suppliers of aircraft-quality compact heat exchangers and cooling fans sized the heat exchangers and cooling fans. The heat exchangers and cooling fans for each aircraft were sized to cool air from the compressor to the appropriate ground temperature limits. The ground limit for the PSA and cryogenic distillation systems is 125 degrees Fahrenheit. The membrane has a ground limit of 165 degrees Fahrenheit. The heat exchanger and cooling fan for each aircraft was designed assuming a maximum ambient air heat sink temperature of 111 degrees Fahrenheit. For OBIGGS and hybrid OBIGGS, the heat exchanger and cooling fan sizes were also evaluated at the worst-case in-flight conditions to ensure that all of the temperature requirements were met. An effort was made to minimize the overall size of the system by trading of heat exchanger size with fan flow to determine the best overall system. The final results are based on a system that had favorable weight, volume, power and costs numbers.

Weight, volume, power consumption and cost data were determined for a number of the systems analyzed. The remaining system's heat exchanger and cooling fan sizes were determined by interpolation of this data.

Heat exchanger data includes the core, inlet/outlet headers, and connections to the mating tubing. Data for the cooling fan includes the fan and any ducting between the fan and the heat exchanger. Ducting which interfaces with the aircraft structure or plumbing was accounted for separately.



## Appendix E

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## **INTRODUCTION**

The Federal Register of July 14, 2000 (Vol. 65, No. 136, pgs. 43800-43802) announced the formation of a new Aviation Rulemaking Advisory Committee (ARAC) with a "Tasking Statement" covering the formation of an Aircraft Fuel Tank Inerting Harmonization Working Group.

The tasking statement requested that the ARAC provide, among other tasks, methods of introducing nitrogen gas into the affected airplane fuel tanks to displace the oxygen in the ullage space and to saturate the fuel with nitrogen in ground storage facilities, e.g., in the trucks or central storage tanks (Ref. Section 2.c of the Tasking Statement). The process of saturating the fuel with nitrogen will be referred to as "fuel scrubbing" herein.

Concepts and design methodology for systems that accomplish the above referenced tasks have been developed. The concepts detailed in this Appendix E will describe the systems for: scrubbing the jet fuel of intrained O<sub>2</sub> while the fuel is in bulk storage tanks at the airport fuel storage facility; they will describe the mobile vehicle fleet that will be necessary to transport the fuel to the wing of the aircraft at airports where hydrant systems are not installed or where airplanes are parked in non-hydrant supplied remote locations; they will describe the production facilities necessary to generate NEA locally and the distribution system necessary to deliver NEA to the wing of the aircraft for Ullage Washing; they will briefly describe a patented system proposed to cool the fuel in order to provide an alternative to scrubbing and washing and; they will describe a patented system proposed to scrub the fuel with an alternate inert gas-CO<sub>2</sub>.

This Appendix will also discuss issues associated with environmental concerns as it relates to fuel scrubbing and ullage washing as well as the effect of these processes on the performance properties of today's jet fuels.

### **Scoping Statement**

- The Airport Facilities Task Team will investigate and develop design concepts covering the following areas associated with airplane fuel tank inerting:
- The installation, operation and maintenance requirements for an on-field inert gas generation, bulk fuel scrubbing with NEA and airplane fuel tank ullage washing system.
- System configurations to provide fuel scrubbing and ullage washing for various size airports and fuel handling (hydrant or mobile) processes.
- The physical impact on airport facility utility infrastructure resulting from the incorporation of an on-field NEA inerting system.
- The technical impediments, if any, associated with a suitable system design if the objective appears to be impractical or cost prohibitive.
- The economic impact associated with a viable method of delivering gaseous NEA and NEA saturated fuel into the wing of the airplane.

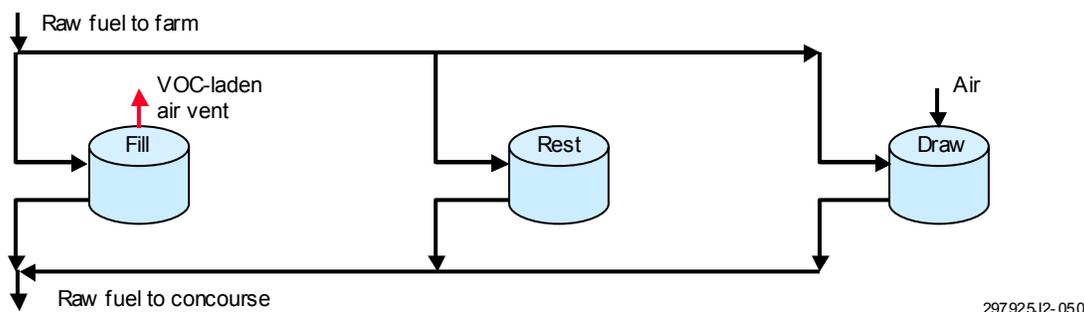
### **1.0 FUEL SCRUBBING AT THE TANK FARM**

In order to prevent the O<sub>2</sub> inherently dissolved in the liquid fuel from coming out of solution and polluting the previously washed fuel tank ullage as the aircraft climbs, it may be required to scrub the fuel of O<sub>2</sub> before loading on the plane. The logical place to do this job is at the fuel farm where the fuel is inventoried and allowed to settle before being pumped into the hydrant system. However, because of the ability of Jet A-1 fuel to preferentially absorb O<sub>2</sub> from air, the entire purpose of the processing technology at the fuel farm needs to be removal of O<sub>2</sub> dissolved in the liquid fuel, preventing it from re-entering the fuel after treatment and dealing with environmental issues, such as VOC emissions, present at the tank

farm. Due to the more aggressive gas/fuel contacting that would occur if the fuel scrubbing technology were implemented, it is anticipated that VOC emissions would be higher than current levels, causing the need for the VOC abatement equipment. In addition to the processing technology at the farm, there is also a certain amount of LN<sub>2</sub> storage to back up the gas generation equipment to enhance reliability, as done at the concourse for ullage washing.

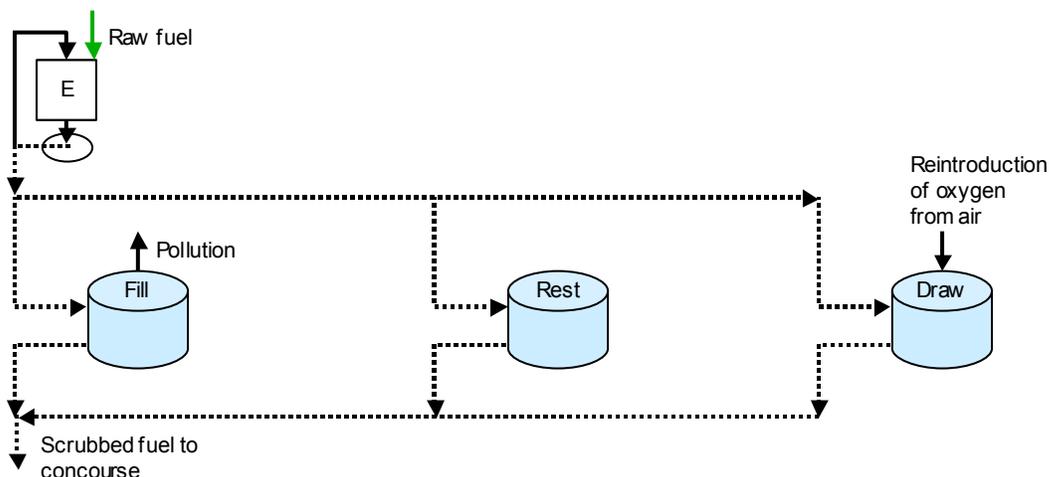
This fuel farm processing system is comprised of specialized gas generating and application equipment. The HIGH-PURITY GAS GENERATOR SKID (99.999% inerts) is used to strip the fuel of dissolved O<sub>2</sub> and to blanket the fuel storage tanks at the farm with N<sub>2</sub> to prevent re-entry of O<sub>2</sub> from air. The FUEL SCRUBBING UNIT, which is a gas/liquid fuel contacting system, uses the pure product gas from the HIGH PURITY GAS GENERATOR SKID to replace the O<sub>2</sub> in the fuel with N<sub>2</sub>. TANK BLANKETING MANAGEMENT SYSTEMS control the pressure and O<sub>2</sub> concentration in the headspace above the fuel in the individual large storage tanks at the farm. Finally, emissions of fuel vapors from the fuel storage tanks, and vent gas from the FUEL SCRUBBING UNIT, will be controlled using an ENVIRONMENTAL ABATEMENT SYSTEM that employs liquid N<sub>2</sub> to cryo-condense the VOC vapors from the vent stream and return it to the fuel tanks. Essentially, all of these technologies work as separate unit operations at the fuel farm to ensure the delivery of fuel to the concourse that is scrubbed of oxygen.

To more easily understand the implementation of these various technologies to achieve fuel scrubbing, it is useful to consider the existing fuel tank farm at a typical airport. The simplest configuration is illustrated with three tanks in Figure 1-1 below. Liquid fuel from the pipeline continuously fills the tanks as the hydrant system is being supplied from them on a variable basis. The maximum flowrates for an airport the size of O'Hare can be filled and withdrawal rates in excess of 4,000 and 18,000 GPM, respectively. The cycle typically sees a piston of liquid fuel filling one tank as a similar flowrate of VOC laden air exits the vent to maintain constant pressure. Elsewhere, another tank is being drawn down, aspirating ambient air into the headspace to break any vacuum that is formed by the retreating liquid. The third tank rests for about 24 hours to settle out any liquid water that may be present in the system.



*Figure 1-1. Current Tank Farm Configuration*

The concept of fuel scrubbing is easily illustrated with some relatively minor additions to the current piping configuration at a fuel farm. This is shown in Figure 1-2 below, entitled Illustration of Fuel Farm Piping with Added Fuel Scrubbing Unit. With this new approach, raw fuel, containing 50 to 100 PPM of dissolved O<sub>2</sub>, enters the FUEL SCRUBBING UNIT and is stripped of the O<sub>2</sub> via intimate contact with a stream of high purity N<sub>2</sub> gas. The N<sub>2</sub> replaces the O<sub>2</sub> dissolved in the liquid and dilutes the O<sub>2</sub> gas given off by the fuel. Approximately 2 volumes of N<sub>2</sub> gas are required for each volume of fuel processed. The end result is a fuel that is scrubbed of oxygen down to about 5 PPM. It has been estimated that the off-gas that exits the FUEL SCRUBBING UNIT unit contains about 1.5% O<sub>2</sub>, as well as about 0.5% VOC vapors.



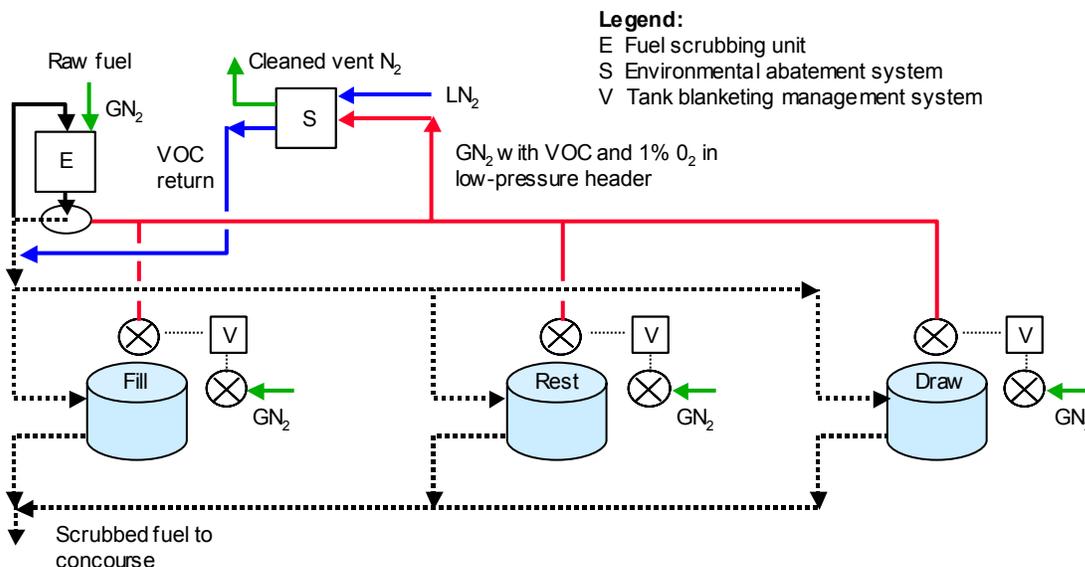
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*Figure 1-2. Illustration of Fuel Farm Piping with Added Fuel Scrubbing Unit*

However, two issues still remain with this level of solution. The off gas that is displaced from the fuel tank being filled and the gas that is vented from the FUEL SCRUBBING UNIT, both of which contain some O<sub>2</sub> gas and fuel vapors, will pollute the air if not treated. In addition, O<sub>2</sub> in the air that would be aspirated into the fuel tank being drawn down, will ruin the fuel treatment job previously done by the FUEL SCRUBBING UNIT. Additional technology needs to be added to what is shown in Figure 1-2 to avoid these problems in order to meet all of the previously mentioned objectives for fuel scrubbing.

In the complete fuel scrubbing concept, as shown in Figure 1-3, the ENVIRONMENTAL ABATEMENT SYSTEM and TANK BLANKETING MANAGEMENT SYSTEM units have been integrated into the fuel farm to control pollution from VOC emissions and protect the re-oxygenation of the scrubbed fuel in the tanks.

The TANK BLANKETING MANAGEMENT SYSTEMS, mounted one per tank, automate the N<sub>2</sub> blanketing of the tank headspace by measuring and controlling the pressure and O<sub>2</sub> content of the gas above the fuel. The inlet valve is opened to introduce high-purity N<sub>2</sub> from the HIGH PURITY GAS GENERATOR SKID (not shown) to drive up the pressure and/or decrease the gaseous O<sub>2</sub> content. Similarly, if the pressure is too high, the vent valve is opened to exhaust some headspace gas into the low pressure gas header. Thus the tanks are continuously maintained at a given pressure and O<sub>2</sub> level, such as 8-inches W.C. and 1% O<sub>2</sub>, respectively.



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Figure 1-3. Complete Aspect of Fuel Scrubbing Operation

A low-pressure header connects all of the vent valves on the fuel tanks and the gas vent from the FUEL SCRUBBING UNIT with the inlet of the ENVIRONMENTAL ABATEMENT SYSTEM. The fan on the ENVIRONMENTAL ABATEMENT SYSTEM will be used to control the back pressure within this low-pressure header. A target of about 5-inches W.C. has been selected for this header pressure which should be sufficiently low to easily exhaust gas from the fuel tanks and FUEL SCRUBBING UNIT.

The process gas flowing through the ENVIRONMENTAL ABATEMENT SYSTEM then contacts stages of increasingly cold heat exchangers to remove nearly 100% of the VOC's by condensation driven by LN<sub>2</sub>. The liquid fuel is then sent back into the scrubbed fuel line that flows to the storage tank being filled. This is done so as not to deplete any compounds out of the normal JET A-1 mixture. The process gas, which has been stripped of fuel vapors, it then vented to the air, or possibly compressed and sent to the concourse for ullage washing, if a suitable pipeline is available. The spent N<sub>2</sub> gas, which was vaporized to cool the ENVIRONMENTAL ABATEMENT SYSTEM, is pure and will be sent to the high-purity N<sub>2</sub> header being fed by the HIGH PURITY GAS GENERATOR SKID.

### 1.1 FUEL SCRUBBING SYSTEM OPERATION AND MAINTENANCE

Maintenance requirements at an airport equipped with fuel scrubbing technology at the fuel farm would be moderate. The equipment is a bit more orientated towards chemical operations compared to the system for ullage washing. The endeavor would need a higher level of supervision with probably one employee overseeing the operation on a 24/7 basis. However, due to the reasonably passive nature of the heat transfer and gas generation systems, the maintenance & operating support for the farm would not be excessive. In most Air Liquide customer installations, equipment skids of the type used for fuel scrubbing typically run unattended.

Like the membrane skids, the HIGH PURITY GAS GENERATOR SKID would require the support typical for a large compressed air/filtration system. Oil and filter changes and bearing life issues on the compressors, filter drainage and carbon tower replacement for filtration and instrument calibration would require periodic attention. In addition, the LN<sub>2</sub> storage tank to supply the HIGH PURITY GAS GENERATOR SKID & ENVIRONMENTAL ABATEMENT SYSTEM would need refilling. The FUEL SCRUBBING UNIT is a passive gas/liquid contacting unit that would need little support except instrument cleaning & calibration. TANK BLANKETING MANAGEMENT SYSTEMS would need a semi-annual change of the oxygen cell, as well as typical instrument calibration. The

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ENVIRONMENTAL ABATEMENT SYSTEM unit would require some mechanical support for the fan (lubrication, bearings, etc.), solenoid coil replacement, instrument calibration and liquid VOC pump service. It is anticipated that operation & maintenance duties would be handled by chemical technicians or engineers with a reasonably high skill level.

### **1.2 COST OF FUEL SCRUBBING APPLICATION AT O'HARE AIRPORT**

The cost to implement fuel scrubbing for the eight fuel tanks currently at O'Hare Airport has been estimated in a preceding section. The estimate includes the installed capital cost for the HIGH PURITY GAS GENERATOR SKID, FUEL SCRUBBING UNIT, ENVIRONMENTAL ABATEMENT SYSTEM and TANK BLANKETING MANAGEMENT SYSTEMS, along with interconnecting piping, foundations and electrical service upgrades. As with ullage washing, it is intended that Air Liquide would install and service the major equipment while the airport would be responsible for the piping and electrical to battery limits. Note that the cost of the HIGH PURITY GAS GENERATOR SKID and additional LN2 storage will be on a gas charge or leased basis.

A description of the components in the N<sub>2</sub> based fuel scrubbing design is as follows:

- QTY(3) HIGH PURITY GAS GENERATOR SKID; 46,000 SCFH at 100 PSI & 99.99% N<sub>2</sub> w/13,000 Gal LN<sub>2</sub> Tank, Vaporizer and Buffer Tank(includes foundation & lights)
- QTY(2) 13,000 Gal LN<sub>2</sub> Tanks for additional capacity
- QTY(1) 2000' of 150 PSI N<sub>2</sub> piping, 6-inch, SCH 40 steel to FUEL SCRUBBING UNIT & Fuel Tanks.
- QTY(1) FUEL SCRUBBING UNIT to treat 4550 GPM of JET A-1; 1000 Gal Liquid/Gas Separator, PID control.
- QTY(2) Low Pressure Regulator for FUEL SCRUBBING UNIT off gas return to L.P. gas header; 1200 SCFM; 100 PSI in/1 PSI out.
- QTY(1) 2000' of 12" piping for Low Pressure Gas Header from FUEL SCRUBBING UNIT to Fuel Tanks; Sch 40, steel.
- QTY(8) TANK BLANKETING MANAGEMENT SYSTEMS for fuel tank; pressure & O<sub>2</sub> control; incl. H.P. N<sub>2</sub> B-fly valve.
- QTY(1) ENVIRONMENTAL ABATEMENT SYSTEM for recovery of VOC; 2400 SCFM Flow with 1% VOC; Incl. 2 parallel trains of multi-stage condensers; 98% VOC recovery.
- QTY(1) 200' of 2" super-insulated piping with 6" of Calcium Silicate jacket for LN<sub>2</sub> to ENVIRONMENTAL ABATEMENT SYSTEM.
- QTY(1) TeleFLO Telemonitoring Package; 100 I/O w/RS-285 network & custom screen.
- QTY(1) Electrical service connection for Concourse, 2600Amps at 480 VAC, 3P

### **2.0 METHODS OF HOLDING "N<sub>2</sub> SCRUBBED" JET FUEL STORED IN THE REFUELING TANKERS**

#### *System Concept*

Propose design/modification changes to "in-service" and newly manufactured aircraft refueling (tanker type) vehicles which will enable "scrubbed fuel" to be transported from airport storage to the wing of the aircraft.

#### *Design Description*

- During fueling, tanker inward venting is required to prevent collapse of the refueler tank

- Predominantly less than “tank full” delivery requires nitrogen to be supplied to the refueling tanker vents to prevent fuel contamination
- Tankers also utilize small “in-breathing” vents that thread into the manhole cover assemblies
- These vents automatically protect the tank from collapse during volumetric contraction of the stored fuel during decreases in ambient temperature
- Current design of typical vapor recovery system equipment does not provide for integration of these vents within the vapor recovery system
- All vents will need to be inter-connected within a system that will be feed by a N<sub>2</sub> supply. To accomplish this, modification of the tanker will be required
- Relocation of the in-breathing vents may require welding modification to the tank vessel. If so, these modifications would need to be completed at a facility certified to make such repairs
- After modification, tankers will mirror function of a “typical” vapor recovery system found on vehicle transporting flammable liquids on public highways
- These vehicles are required by the Code of Federal Regulations (40 CFR, Part 60) to be tested at the time of initial installation and then periodically thereafter to ensure vapor tightness
- It would seem advisable to require this testing/re-certification be mandated within the ruling

### System Design Description

- Modifications include, relocation of in-breathing vent to a point that vapor recovery vent hoods and associated piping can connect all tank vents to common nitrogen supply
- psig N<sub>2</sub> pressure stream will be supplied to the vapor recovery system at all times
- The N<sub>2</sub> supply can be from stored gaseous or liquid nitrogen vessels mounted on each tanker vehicle
- Handling LN<sub>2</sub> will present a host of additional training and conversion issues, so gaseous nitrogen is presented for review in this report
- Our example is based upon the quantity of gaseous nitrogen required to fully displace the product dispensed from a 10,000 gallon capacity refueling tanker (approx. 1400 cu. ft.)
- If commercially available 300 cu. ft. high pressure gas cylinders were used, five tanks would be required mounted to the vehicle to accomplish one full fuel tank delivery
- Liquid nitrogen could be used, carried in a much small vessel (dewar) as it gases at a rate of 93 SCF per gallon. However vaporizers required to convert the liquid to gas with out freeze-up presents a spaces available problem on most existing units
- Given the volume of nitrogen required to hold tankers inert, it would appear a land-based connection to the tanker at the gate, using the same stream available for ullage washing the aircraft, is optimal
- 1 psig out-breathing vents will be installed in the nitrogen supply piping to vent excess pressure to atmosphere protecting the tanker against thermal expansion
- A pressure sensor in the nitrogen piping system will also be required. This sensor will shut-down the pumping operation to prevent collapse of the tank if a negative pressure (vacuum of 26 mbars) is sensed within the nitrogen supply system
- This safety system would be interconnected with the vehicle pumping system to close the tank internal valve, disengage the pump, or stop the engine based upon the original system design

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- To provide a constant 1 psig nitrogen pressure to hold scrubbed fuel inert overnight or short-term storage will require much less nitrogen
- Again, for the purpose of this report, the 10,000 tanker referenced above will see a maximum volumetric shrinkage of approximately 200 gallons, based upon a 40°F change in ambient temperature
- 200 gallon reduction in fuel quantity x .1337 (conversion factor to CF) = 27 SCF of gaseous nitrogen required to prevent negative tank pressure in this extreme case
- Standard 300 cu. ft. high-pressure (2000 psig) nitrogen cylinder/s could hold a 10,000 gallon capacity refueler inert for a period of approximately ten days or longer

### *Impact on Current Airports*

- To maintain a nitrogen blanket on top of scrubbed jet fuel, a land-based source of nitrogen will need to be provided to supply the tanker make-up venting during fuel delivery
- Proper sizing of the nitrogen supply system to be used for aircraft fuel tank ullage washing can provide a collateral benefit in this area
- When servicing remotely parked or operated aircraft where a land-based supply is not available, a mobile nitrogen dispensing vehicle will be required
- At a minimum, this will add to already congested ramp areas and will require additional personnel
- Typical infrastructure impact associated with additional personnel working within the existing facilities will apply

### *Safety Assessment*

- Possible benefits associated with use of liquid nitrogen are outweighed by training issues associated with handling cryogenic liquids
- Addition of a mobile nitrogen supply vehicle in some locations (and as a back-up for land-based nitrogen delivery systems) will create additional congestion hazards
- Inerting tankers with nitrogen will pose additional risks associated with confined space entry of all tanks for inspection and cleaning
- All confined space (tank) entry procedures will need to be reviewed and amended to identify that the space is totally void of oxygen and cannot sustain life for any period of time

### *Environmental Evaluation (Identified)*

- Modification of tanks to include vapor recovery type equipment along with blanket of nitrogen to prevent re-oxygenation of fuel may reduce VOC emissions at the airport
- This benefit will come if corresponding vapor recovery piping is present at the fuel farm to receive these vapors during re-loading of the tanker

### *Economic Evaluation*

- Tanker modifications required will in most cases cause the vehicle to be taken to a certified tank welding/repair facility
- Estimated cost of modifications will range between approximately \$3,800 for 3,000/5,000 gallon capacity refuelers to \$6,800 per unit for larger capacity refuelers up to 17,500 gallons, excluding transportation
- Yearly pressure/vacuum testing (CFR 40, Part 60) will add re-occurring costs of approximate \$600 per tanker for inspection.

- Other costs associated with manpower requirements are covered separately in other sections of the report

## **2.1 GAS SUPPLY**

The airport facility team looked at the supply of three potential gases as possible candidates for fuel tank inerting – NEA (gaseous and liquid), CO<sub>2</sub>, and Argon. Gaseous NEA was found to be the best candidate for use.

### Gaseous N<sub>2</sub>

Gaseous N<sub>2</sub> can be generated on site using ASMs. Systems can be sized for various types of operations, only requirement is electrical power. Redundancy can be obtained by use of liquid N<sub>2</sub> or additional compressors. Issues:

- Large Power requirements
- Need adequate real estate for installation.
- Systems will require high pressure for distribution. Aircraft fuel tanks have very low pressure restrictions. Accurate and reliable pressure control will be critical.

### Liquid N<sub>2</sub>

Liquid N<sub>2</sub> is primarily being considered for a backup to the fixed gaseous systems. It may have applications for mobile ullage washing for large transports. Issues:

- Cannot be produced on site.
- Cryogenic liquid will require special handling.

### CO<sub>2</sub>

There was concern about the ability of the gas industry to meet the estimated 1300 ton/day increase in demand that inerting and fuel scrubbing would create CO<sub>2</sub>. The team contacted Barbara Heydorn, author of the SRI Chemical Economics Handbook on CO<sub>2</sub>, to get a forecast on the impact this much increase in CO<sub>2</sub> demand for commercial aviation use would have. Barbara gave us the following comments:

- Given enough lead time, say 2-3 years, Industrial Gas companies would obtain capacity to meet the extra demand, BUT the market would be different than it is today. The new capacity would come from lower purity feedstreams or from sources that are farther away from demand centers. Lower purity feed streams mean higher costs to purify and therefore higher FOB prices. Sources further from demand centers mean higher distribution costs therefore higher prices.
- Volatility in supply and pricing could be a problem for commercial aviation use. CO<sub>2</sub> is usually a byproduct of a chemical process. Many of those processes are susceptible to natural gas prices. For example, with the current high price for natural gas, many ammonia producers are not operating. All the CO<sub>2</sub> that was usually available from ammonia producers dried up.
- Three areas that do not currently have enough supply appear to be where commercial aviation demand could be the highest -- the Northeast US (La Guardia, Newark, JFK, Boston), Florida (Miami, Orlando, Tampa) and Southern California (Los Angeles). In the past 5 years there have been many allocations and interruptions in supply to those areas.

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## Argon

Argon was suggested as an alternative to NEA. The theory was that due to argon's higher molecular weight, it would perform better in cross-vented tanks. The team was unable to find any evidence to support this. Since argon is not as readily available as NEA and the cost was estimated to be ten times as much as NEA, argon was not pursued further.

## **3.0 FUEL COOLING**

This concept was insufficiently developed to allow the AFT to fully evaluate it and develop the economics of the proposed concept. Also, since this is basically a form of fuel scrubbing, a means to inert the CWT would be required.

### System Description

The fuel-cooling concept consists of both refrigerating fuel and/or washing the airplane fuel tank ullages with inert gas. The two separate processes may be used separately or combined. The cooling systems supply fuel to the airplane at less than 40 degrees F. Cooling facilities (located away from congestion) cool the entire airport fuel supply (hydrant and/or truck) to less than 40 degrees F. Inerting gas for ullage washing is stored (located away from congestion) and transported to the airplane on gas service vehicles in a cryogenic phase and converted to a gaseous phase as needed for ullage washing.

### Impact on the Airport

Fuel cooling installations are designed to result in a minimal addition to airport gate congestion as all fixed cooling facilities are installed at or in the vicinity the fuel farm which is away from the gate areas. As the entire airport fuel supply will be cooled to a lesser temperature, to meet the massive peak flow demands caused by banks of airplane arrivals, thermal energy will be manufactured and stored in thermal banks or ice tanks. The stored cold energy will be applied to the fuel supply en masse. Large airport facilities will be of substantial size and require full time staffing. In locations where space at the fuel farm is limited, cooling systems can be located off the airport and cold energy brought to the fuel farm hydrant via pipeline. Hydrant modification involves installation of in-line heat exchangers at or near the fuel farm. Power demand will be substantial and likely exceed available power supplies at or near the fuel farm.

### Pros and Cons

#### 1. Small & Medium Airport

Small and medium size airports can obtain self-contained, semi-permanent, packaged cooling and gassing units avoiding the complexities of nitrogen manufacturing equipment.

#### 2. Empty tanks

Under these circumstances, ullage washing with an inert gas is relied upon until flight conditions naturally make the tank non-flammable.

#### 3. More than just the CWT

The cooled fuel concept and inerting gas injection extends the flammability reductions into all tanks, not only the CWT.

### Environmental Impact

#### 1. Airplane vented VOC emissions and their contribution to air pollution must be studied further.

#### 2. Static charging of the fuel and its effect must be studied further.

#### 3. The effect of precipitating water from solution during cooling and its effect upon filtration equipment must be studied further. The effect of precipitating water from solution during cooling and its effect upon airplane flight performance must be studied further.

#### **4.0 CO<sub>2</sub> FUEL SATURATION**

This concept was insufficiently developed to allow the AFT to fully evaluate it and develop the economics of proposed concept. Before a full evaluation can be done more study will be required. Areas that will need more work are details of the actual components that would be required by the ground portion of the system, modifications required by the fueling vehicles to maintain the CO<sub>2</sub> in solution, the aircraft modifications that would be necessary, and a further study of the availability of CO<sub>2</sub>.

Issues have also been raised regarding the possible impacts on pump cavitation and possible corrosion due to the possible formation of carbonic acid in the presence of water. These would have to be resolved before this can be pursued further. Also since this is basically a form of fuel scrubbing, a means of inerting the empty CWT would be required.

#### **4.1 SYSTEM DESIGN CONCEPT**

The system consists of a CO<sub>2</sub> (commercially available gas) and jet fuel mixing apparatus, which preloads the jet fuel with CO<sub>2</sub>. In one variation of the Airport Facility System, the CO<sub>2</sub> is derived from a liquefied CO<sub>2</sub> storage tank, converted to CO<sub>2</sub> gas and mixed in the Jet-A in a gas absorber tower (at an optimum gas-to-fuel ratio). Thereafter the CO<sub>2</sub>-enriched fuel is stored in a fuel shipping tank having a floating pan (the combination tank and pan maintain the desired gas-to-fuel ratio of the treated fuel). The CO<sub>2</sub>-enriched fuel is then transferred as needed from the shipping tank to all aircraft re-fueling sites using the existing fuel pipeline and hydrant systems (for hub airports) or the existing truck delivery system (at non-hub airports).

#### **4.2 ENVIRONMENTAL EVALUATION (KNOWN ISSUES)**

As an environmental benefit there may be reductions in engine exhaust soot particulate due to the mixing of >0.1 volumes of CO<sub>2</sub> in kerosene-based fuels. For example in EPA Test Data soot reductions in the range of 20-25% are seen with concentrations of 20-45% CO<sub>2</sub> in Diesel #2 (a close cousin to jet fuel). Soot reductions up to 60% were recorded in a variety of other calibrated emissions tests performed on Diesel fuel at different independent test facilities. It is not known if similar effects would be obtained in aircraft operations. Depending on the method that would be required to scrub the fuel with CO<sub>2</sub>, an increase in VOC emissions similar to those found with NEA scrubbing could be possible.

#### **4.3 ISSUES**

Two of the major issues that have been identified are covered below. The solutions offered are those of the system developer and have not be evaluated by the AFT for effectiveness or cost. More research would be needed.

##### **4.3.1 Cavitation**

Absorbed air concentrations in Jet Fuel are known to reach gas-to-fuel ratios as high as 15% in Jet Fuel, which to date have not produced fuel pump cavitation problems. Nonetheless, the literature indicates that the presence of bubbles facilitates cavitation (NOTE: CO<sub>2</sub>-enriched fuel is comprised of CO<sub>2</sub> *micro-bubbles*). Although the concentrations of CO<sub>2</sub> in the proposed CO<sub>2</sub>-enriched fuel might be expected to exceed 15%, experimentation with boost pumps is needed to determine 1.) if cavitation will in fact, be an issue, and if so, 2.) what is the lowest gas concentration of *micro-bubbles* that causes cavitation?

There are two basic solutions to reducing inert gas in fuel before the gas-enriched fuel reaches a boost pump: 1) the use of a centrifugal pump prior to the boost pump to separate gas from the fuel, 2) the use of high-area contactors that have a medium not wet by the fuel but that does attract gas bubbles (this system can be made with no moving parts and with no power source). Both approaches are being examined by the developer of the system.

**4.3.2 Corrosion**

There was concern about corrosion on aluminum surfaces in fuel tanks. Corrosion is caused by the presence of carbonic acid. Carbonic acid is formed when enough CO<sub>2</sub> contacts free water. When very high concentrations of CO<sub>2</sub> were tested in fuel, a very small amount of fuel was converted to organic acids, but there was no detectable change in the energy content of the fuel. The carbonic acid Aircraft fuel tanks are equipped with and regularly employ water-scavenging means. Hydrant and Refueler truck fuel systems also remove water from fuel before it is pumped aboard an aircraft. Other water drying approaches may also be a possibility.

**5.0 ULLAGE WASHING**

Washing the ullage of O<sub>2</sub> gas in an airplane fuel tank has been proposed in order to eliminate, or greatly reduce, the ability of an ignition source in the tank from causing constant-volume combustion of the fuel vapors present. Simply stated, fuel vapors cannot burn unless a sufficient amount of oxygen is available to support and propagate the combustion. The ullage in the airplane fuel tank is washed with a lower NEA, 97% to 98% purity, to remove a large portion of the O<sub>2</sub> gas from the air that is initially present in the ullage. The 97 to 98% NEA stream is produced using a membrane gas generator skid.

The 97 to 98% NEA purity was chosen to be the most cost effective inerting agent, as it is less expensive than higher purity gas but contains half the O<sub>2</sub> content of a 95% inert product. The volume of gas for the inerting duty has been chosen by the Ground Based Design Team to be 1.7 times the volume of the airplane tank to be washed, based on an empty tank. Under these conditions of inerting agent purity and volume, tests have shown those O<sub>2</sub> levels of less than 9% will be produced within the ullage space of an empty fuel tank. Therefore, no O<sub>2</sub> meter for gas analysis will be needed to verify ullage washing, which helps to minimize complexity. More importantly, with tanks that are even partially full of fuel, the O<sub>2</sub> content is expected to be reduced to even lower than the 9% level, due to the larger number of actual volumes of NEA flowing through the system.

NEA is generated continuously, from air, using membrane gas separation technology. Essentially, air is compressed, filtered of solid particles and liquid aerosols and fed to bundles of hollow fiber polymeric membranes where the CO<sub>2</sub>, O<sub>2</sub> and water vapor is removed from the N<sub>2</sub> stream. These gaseous impurities are vented at low pressure while the high-pressure enriched N<sub>2</sub> product, at 97 to 98% purity, exits the skid, via a surge tank. Backed up with a storage vessel of liquid N<sub>2</sub> (LN<sub>2</sub>) and a vaporizer a continuous seamlessly transfer of NEA through the gas supply lines will be assured. It is envisioned that one large membrane gas generator skid and back up LN<sub>2</sub> tank would be supplied per airport concourse, mainly to minimize the need for long piping runs between terminals. The NEA would then flow through a header, which would be located along the roof of each concourse, at a pressure of about 150 PSIG. The header is anticipated to be constructed of 2-inch diameter, Type K copper tubing. This header would feed an array of metering stations, located one per gate, to supply gas to the airplanes for ullage washing under controlled flow and pressure conditions. A diagram of the membrane gas generator skid at a given concourse is shown below in figure 5-1.

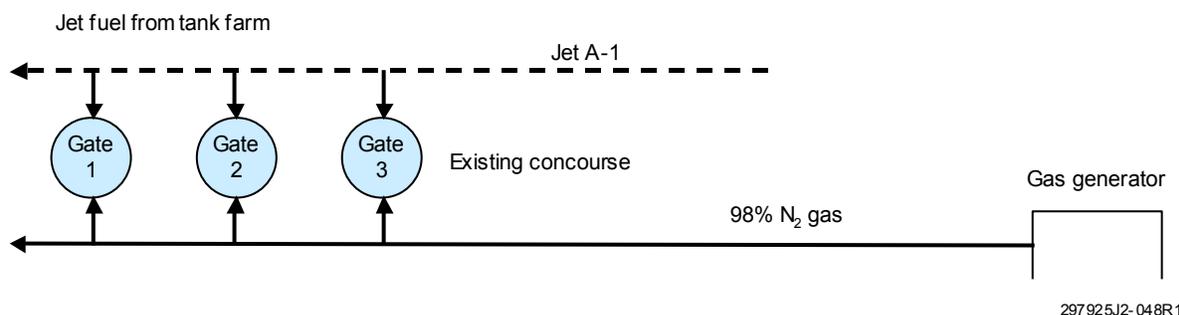
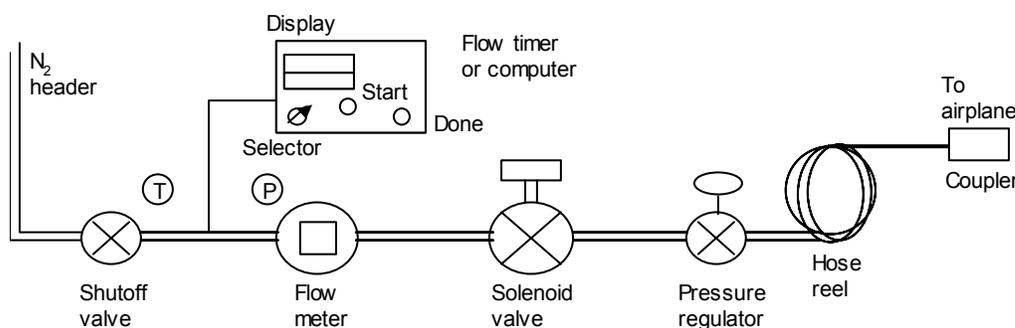


Figure 5-1. Membrane Gas Generator at Concourse for Ullage Washing

At multiple concourse airports it would be prudent to consider the inter-connection of membrane skids between terminals, with a larger manifold. While the capital cost to achieve this would not be insignificant, the benefit would be an additional level of redundancy, without LN<sub>2</sub> backup if one skid were down for extended maintenance.

The metering stations, for injecting NEA gas under flow & pressure controlled conditions at each terminal gate, are shown pictorially in Figure 5-2. The station is connected to the concourse NEA header on one end, and to a specially designed connector on the airplane at the other end. The function of this system is to reduce the O<sub>2</sub> content in the ullage space on the airplane by supplying a given amount of low pressure NEA to the ullage from a high-pressure source. A solenoid valve and a pressure regulator are used to initiate and complete a period of constant gas flow rate to the airplane. By maintaining this constant flow for a time appropriate for a given airplane, NEA is then injected into the ullage. The gas is made available by the regulator at a pressure of only a few pounds per square inch gauge (PSIG). In case of maintenance needs, the shut off valve would be used to block off the station. The hose reel allows for connection from the station typically located at the end of the jet-bridge, to the airplane.



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*Figure 5-2. Typical Metering Station NEA Flow and Pressure Control*

The heart of the gas metering station is the flow meter, flow control terminal and flow valve. The flow control terminal comprises a lockable weather- proof housing that contains a flow computer and delivery receipt printer. The gas metering station would be designed to operate in an unheated, outdoor service environment (temperature, moisture and vibration) under applicable electrical safety classifications. As previously described, the flow meter and flow computer delivers a pre-set quantity of NEA to the aircraft's tank ullage. The delivery of this gas to the ullage is measured with reference to standard conditions (i.e. 60°F and 1 atmosphere). Hence, the required pre-set amount of gas is delivered regardless of the ambient temperature or source gas pressure.

The flow computer is essentially a device to allow gas to flow to the airplane ullage for a given amount of time, and then to display the actual volume of gas injected. The flow computer would include a selector to choose the type of airplane being inerted, a start button to control the solenoid valve, an indicator light to show when the job is done and a dual display to illustrate required and injected gas volumes. In addition, the unit could be configured so that the operator is required to perform a security check (e.g., input an authorization code) to initially access the system. Stored within the flow computer would be the appropriate inerting times which will, at a given constant gas flow rate, produce an inert ullage space above the fuel (or in the event of an empty tank – complete tank contents) in the airplane tank.

As an example, if an operator is required to inert a 737, he would connect the coupler to the plane, select the appropriate volume on the selector and verify the correct pressure value on the flow control display. The upper display on the flow computer would show the volume required for ullage washing of a 737 aircraft, say 1360 SCF. The operator would then depress the Start button. A NEA flow of 100 SCFM would occur for 13.6 minutes to produce the recommended volume of NEA for the 737 in this example. Then the indicator light would illuminate (indicating the task is done) and the solenoid valve shut. The

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lower display would read 1360 SCF based upon a total of the cumulative gas flow through the metering system, at standard conditions. If the value were low, an option would exist for the operator to adjust for more NEA into the ullage to satisfy the requirement. He could either verbally inform the crew that the plane has been inerted, or a written receipt could be printed to do the same. Delivery of this data could also be sent via a suitable communications link to a central computer, if required.

It became obvious that ullage washing systems will have to be customized for each airport. However, the major components required for design of a fixed, ground based ullage washing system for various classifications (sizes) of airports may be found in the generic layouts presented in Appendix E.

### **5.1 ASSUMPTIONS**

- During the study assumptions had to be made by the Working Group and the AFT. The following are the assumptions that the AFT used in developing the design concepts for the ullage washing systems.
- The process was not to affect the airplane turn time. This was a goal agreed upon by the Working Group.
- Other studies have assumed that the inerting would be done after fueling. While this would reduce the amount of start when the airplane arrived at the gate (i.e., empty tanks). This was according NEA required, it would have possibly increased the aircraft turn times
- Only the CWT would be inerted.
- 800 SCF was used as the average gas requirement. This is the volume of the small generic airplane model used in the study.
- 1.7 times ullage volume would be required to perform the task. Testing that had been done showed various ranges of volume to accomplish the inerting. The team settled on this figure. It may be possible in actual operation the amount of NEA required could be more or less.
- Fixed system sized for a utilization of 0 to 2.4 times the average to handle peak operations. At large hub airports the aircraft arrive in banks. This creates a high demand over a very short period of time. The systems will need to be able to recover between banks. The amount of real estate available may also limit the size of the backup storage.
- A maximum of 15 min to inert a small airplane. This was based on the average turn times supplied by the Maintenance and Operations team.
- Large and medium airports would use fixed equipment as the primary means for gas supply, and small airports would use mobile equipment. The team felt this would be the most practical approach.

### **5.2 MOBILE ULLAGE WASHING DESCRIPTION**

Where it is not practical to supply a land-based source of nitrogen to ullage wash airplane fuel tanks at the loading gate, remote-mobile nitrogen dispensing equipment will be required. This equipment can be either mobile nitrogen generating equipment, or LN<sub>2</sub> tankers, with vaporizers to convert the liquid to a gas.

Two factors have influenced selection of nitrogen generating equipment over LN<sub>2</sub> and vaporizing equipment for presentation in this report:

- Training and related safety issues associated with handling cryogenic liquids
- Cost of ongoing purchase of LN<sub>2</sub> as compared with costs of generation of gaseous N<sub>2</sub> directly from the air using compressors and high purity nitrogen membranes

Design of mobile ullage washing vehicles will emphasize ease of operation, by allowing operators to select predetermined automatic cycle times specific to each aircraft type. Vehicles will be designed with a

high volume output screw-type compressor, appropriate filter, high purity nitrogen separators, specially designed meter, pressurized nitrogen storage tanks and related automated control system. A vehicle brake interlock system is required to ensure delivery hoses/nozzles are properly stowed, prior to release of the vehicle brakes.

The overall size of mobile NEA generating equipment could become an issue due to the quantity of high purity membranes required. When consideration is given to ullage washing large transport category aircraft center fuel tanks, as well as possibly providing “make-up” nitrogen to hold refueling tankers inert, size clearly becomes an issue.

Current ramp congestion dictates mobile “ullage washing” vehicles utilize the smallest package/footprint possible to accomplish the task.

It is estimated that to service remotely parked or operated aircraft, especially freighters, and as back-up for land-based system, mobile ullage washing vehicles will typically number from 65-85% of the number of refueling tankers operating at a particular airport. The addition of mobile inerting processes at the terminal gate is certain to exacerbate complications associated with congestion around the aircraft. There are a number of existing services associated with airport ground operations including fueling, baggage handling, food, and cleaning services among others. All operations require vehicles to travel to and from the aircraft in a very short period of time. There exists an increased risk of accidents during operations attributable to the inerting process. The addition of the inerting process could decrease the available time to conduct all other ground operations, further adding to the risk.

At small airports or at foreign airports with a U.S. only implementation, it may be more cost effective to have all mobile equipment when compared to fixed infrastructure costs.

All problems generally associated with a significant increase in personnel staffing while operating within the same physical area will be present.

Small to medium size transport aircraft mobile inerting vehicle:

- Where remote ullage washing for medium size transport aircraft and smaller is required, a mobile nitrogen-generating vehicle can be provided in a very user-friendly package.
- This vehicle would also utilize a high-flow rate air compressor to supply large volumes (270 CFM) of air to a high purity nitrogen membrane separation system.
- However, the smaller demand for air pressure will allow the compressor to be powered by the chassis power-plant/drive-line via a transfer case.
- A unit of this type could typically manufacturer 97% pure gaseous nitrogen at a rate of 6,500 CFH while only having a footprint comparable to that of a typical hydrant system dispenser (approximately 20' OAL x 8' OAW x 9' OAH).

Large transport aircraft inerting vehicle -using liquid nitrogen vaporizer:

- Another consideration for mobile ullage washing of larger transport which could easily be used for all aircraft size categories is conversion of liquid nitrogen
- Liquid nitrogen converts at a rate one gallon of liquid nitrogen to 93.1 CF of gaseous N<sub>2</sub>
- Equipment size is dictated by providing adequate vaporizing units to prevent freezing up.
- For this study, a concept vehicle having a 400-gallon LN<sub>2</sub> storage tank and adequate vaporizers to convert 193 gallon into 18,000 CF of gas within a 20 minute period are used.

### **6.0 ENVIRONMENTAL ISSUES FOR FUEL SCRUBBING SYSTEM CONCEPT**

General environmental issues are addressed as part of this document to identify basic direct and indirect environmental impacts with the fuel-scrubbing concept discussed within this section of the overall report. The impacts fall into the following categories:

- VOC emissions
- The airport environment
- Other environmental issues

Values and quantities of undesirable materials and impacts are not quantified in this section of the report. Instead, the impacts are identified as they generally relate to existing airport and airline environmental initiatives. Quantification of these impacts is deferred until a more thorough and complete analysis can be completed (presumably after a specific SYSTEM CONCEPT is selected for further development.) Other than the VOC emissions, which could be mitigated by a costly vapor recovery system, the environmental impact resulting from the implementation of fuel scrubbing is assumed to be relatively minor.

Environmental protection infrastructure must be added to each airport fuel storage facility. The systems and equipment include pumps and other electric motor driven equipment, aboveground liquid nitrogen storage tanks, gas tanks and piping.

#### *VOC Emissions*

- Installation of vapor recovery system. Data from a simple experiment from two different sources indicate that substantial amount of light hydrocarbon molecules would be stripped from the fuel during the scrubbing process. A vapor recovery system would be an essential component of this system to mitigate this adverse impact on the environment.
- All refueler trucks, that serve aircraft parked in remote or in the cargo areas or at an airport where there is no hydrant system, have to be modified. A nitrogen generating unit added to the rear of the vehicle will maintain an inert atmosphere in the tank head space and maintain a slight positive pressure in the tank by replenishing with nitrogen while the tank fuel level is being drawn down during aircraft refueling. During the refilling cycle of the refueler a means of capturing vented emissions would have to be developed. These modifications may result in an increase in VOC emissions from this intermediate mobile fuel storage.

#### *Airport Environment*

- Truck traffic to deliver liquid nitrogen to the tank farm area results in additional use of fossil fuels.
- The increase in the number of Ground Service Equipment (GSE) vehicles mandated by this system will add to the emissions from the internal combustion engines that power them.

#### *Other Environmental Considerations*

- Environmental remediation of land. Any building activities atop the airport tank farm site will require that existing environmental remediation methods be altered and/or that remediation be undertaken prior to the construction of any supporting infrastructure.
- Indirect impacts include items such as negatively influencing airport, city and regional air quality.

#### *Summary*

- No positive environmental impacts (improvements to the environment) were identified for any of the concepts in this report.

- No data are available on the soil condition of any given site nor is quantified air emission data available to establish an emission baseline. A baseline would be useful in measuring incremental impacts to the environment.

## **6.1. POTENTIAL IMPACT ON FUEL PERFORMANCE FROM ULLAGE WASHING AND FUEL SCRUBBING**

The Federal Register of July 14, 2000 (Vol. 65, No. 136, pgs. 43800-43802) announced the formation of a new Aviation Rulemaking Advisory Committee (ARAC) with a “Tasking Statement” covering the formation of an Aircraft Fuel Tank Inerting Harmonization Working Group.

The tasking statement requested that the ARAC provide, among other tasks, methods of introducing nitrogen gas into the affected fuel tanks to displace the oxygen in the ullage space and to saturate the fuel with nitrogen in ground storage facilities, e.g., in the trucks or central storage tanks. The process of saturating the fuel with nitrogen will be referred to as “fuel scrubbing” herein.

A concept and design methodology for a system that proposes to accomplish the above referenced tasks has been developed. However, during the conceptual deliberations as to how an effective system might be designed, manufactured, installed and made operational, concern arose with respect to the effects ullage washing and fuel scrubbing may have on the performance characteristics of aviation turbine fuel. In addition, there were concerns expressed about the environmental impact resulting from the inerting process, especially as a consequence of fuel scrubbing which involves vigorously mixing nitrogen gas with a high flow fuel stream.

This report subsection is intended to summarize the concerns, the findings of preliminary laboratory analysis performed by two oil company task team members, and recommendations for further study of the fuel tank inerting scenario.

### **6.1.1 Concerns**

Concerns were raised that ullage washing and fuel scrubbing would degrade certain performance properties of jet fuel by driving off the “light weight molecular ends” of the fuel. The “light ends” influence several specification properties of jet fuel including distillation, flash point and freezing point. Another concern expressed was the uncertainty of how these processes might impact the re-light-at-altitude characteristics of the fuel. Questions were also raised regarding the performance of additive packages, e.g., anti-oxidants, anti-static additive, added to the fuel to enhance or modify particular characteristics of the fuel.

In order to obtain a broader perspective on these questions and other issues, a notice was circulated via the ASTM committee charged with Aviation Turbine Fuel specification (ASTM D-1655) maintenance asking all U. S. and non-U. S. Refineries, engine, airframe and component manufacturers to provide feedback and/or information they may have on the performance characteristics of fuel subjected to ullage washing and/or scrubbing. Because these inerting concepts were new to many of the responders, more questions were raised than answers received. The additional concerns expressed ranged from complete engine re-certification may be required, to the other extreme where it was believed nitrogen inerting would improve at least the fuel stability characteristics and therefore would be a benefit.

The last area of concern that arose during discussions of the fuel inerting concept was that involving environmental considerations. Again, flowing nitrogen gas over a partially filled fuel tank and/or the vigorous mixing of nitrogen gas with fuel during the scrubbing process would, according to general opinion, result in significant volatile organic compound (VOC) release to the atmosphere at the airports’ fuel storage depot. These VOCs would aggravate the already thorny issue of air pollution on and around today’s airports. Feedback and factual data was requested from stakeholders, including the U. S. Environmental Protection Agency (EPA). Again, more questions than answers came from this inquiry.

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### **6.1.2 Preliminary Laboratory Analysis**

AirBP and Texaco performed elementary experiments on ullage washing and fuel scrubbing using nitrogen and carbon dioxide gases (final reports are addenda to this section).

Preliminary results of these experiments indicate that ullage washing and fuel scrubbing with nitrogen gas has little effect on the conventional properties of jet fuel. However, a measurable change in vapor pressure occurred from fuel scrubbing and the CO<sub>2</sub> scrubbed fuel exhibited an increase in acid number. Significant quantities of VOCs were released during both processes regardless of the inert gas used. The VOC release may lead to serious health and safety issues that must be addressed.

First, the physical properties change; in one experiment it was shown that there is an increase in the fuel's vapor pressure after the scrubbing process. This vapor pressure increase phenomenon is not totally understood at this time; however, it does suggest that there may be a deleterious effect in controlling the flammability of the aircraft fuel tank headspace atmosphere. The increase in vapor pressure may affect the performance of the different fuel pumping devices used on today's aircraft.

There was also a decrease in the fuel's electrical conductivity, which will require further investigation. Changes in this fuel property will require a full understanding of the phenomenon because of fuel handling safety and additive performance issues.

A significant release (addressed further in this summary) of VOCs occurred during the ullage washing and scrubbing processes which obviously changes the bulk fuel composition. The removal and recombining of the VOC condensate, after a vapor recovery process, will require additional study to ensure that there is no deleterious effect on engine performance due to a reconstituted fuel blend. Although no statistical difference was measured in the fuel's distillation characteristics, flash point or freezing point, a more thorough analysis of these properties should be performed to verify the preliminary findings. Additionally, because the loss of these light-ends may effect altitude re-light, a thorough analysis of this characteristic should also be carried out, unfortunately this analysis could not be done in the time allotted to this project.

The experiments conducted using CO<sub>2</sub> as the scrubbing gas (CO<sub>2</sub> injection was one of the inerting processes considered during the team's discussions, but time did not allow for a complete conceptualization of this technique) showed a much greater effect on vapor pressure than N<sub>2</sub> and also caused the Acid Number of the bulk fuel to increase. This finding was not totally unexpected because prior experience has shown that with water laden (including dissolved water) mixtures and subsequent CO<sub>2</sub> saturation, carbonic acid may form as a by-product of this chemistry. Obviously the formation of any compound that may enhance or accelerate corrosion of the aircraft fuel tanks is not a desirable attribute of a fuel.

Second, the industrial health and safety issues; the experiments indicated that the carcinogen Benzene may be concentrated in the vapor phase at concentrations that could exceed the 0.1% (wt) limit established for regulating a material as toxic. Obviously, this matter is of the greatest concern with regard to employee health and the environment surrounding the airports' bulk storage depot and will have to be addressed.

An additional employee and facility safety problem is also introduced when fuel is exposed to the scrubbing process and this is the extremely flammable vapor atmosphere created by the light-end VOC emissions. Very careful attention will have to be taken in the design of any mechanical equipment used to recover and dispose of these VOCs.

Ullage washing will result in the release of a low oxygen, high inert gas concentration mixture (N<sub>2</sub> or CO<sub>2</sub>) from the center wing tank vents. Persons working in and around this area may be exposed to air with an oxygen level below that which is required to sustain normal respiration. The hazard level will increase as the number of aircraft in a localized area undergoing the inerting process increase. This asphyxiation hazard must be studied in more depth before any large-scale inerting is implemented.

Third, the environmental impact issues; the ullage washing and fuel scrubbing processes have been shown to release a significant amount of VOCs. These VOC releases were measured in the 1%+ (volume) range during the experiments. To put this volume number in perspective it represents a release of an equivalent volume of 21,000+ gallons of jet fuel from a typical 50,000-barrel (2.1m gal.) storage tank found at many airports. This release would be expected to occur each time a fuel receipt of this size is received into storage and subsequently processed through the scrubbing cycle. The environmental, as well as the economic, impact of releases of this magnitude will require careful design and operation of costly vapor recovery systems near the bulk storage facilities. As more regulatory pressure is exerted on today's management and operators to "clean up the air" on and around the airport, release of additional pollutants, caused by some new process, becomes unacceptable regardless of the perceived benefits.

The EPA representative queried during the "get-some-feedback" process succinctly put future work on this issue into perspective by recommending a "1) literature search for theoretical and experimental analysis of the effects of fuel tank inerting or similar fuel treatments on engine exhaust emissions, 2) explicit discussion, involving appropriate experts of this concern in FAA rulemaking activities relating to fuel tank inerting; and 3) experimental research to validate expectations regarding impacts of inerting methods on engine exhaust emissions."

### **6.1.3 Future Work**

As the foregoing indicates there are a number of issues that need to be addressed, better understood, and solutions found before ullage washing and/or fuel scrubbing is implemented on a large scale. The following is only a short list of the issues that come to mind:

- The characteristics of scrubbed fuel performance in today's turbine engines need further investigation.
- The impact of ullage washing and fuel scrubbing on employee health and safety will have to be better understood so appropriate action can be taken.

The impact of ullage washing and fuel scrubbing on the environment will have to undergo an extensive review. There was not enough time or readily available information during this ARAC project to become fully knowledgeable on the subject and propose concept designs around the impediments identified.

## **7.0 LABORATORY REPORTS**

### **ADDENDUM 1:**

#### **AIR BP LABORATORY REPORT**

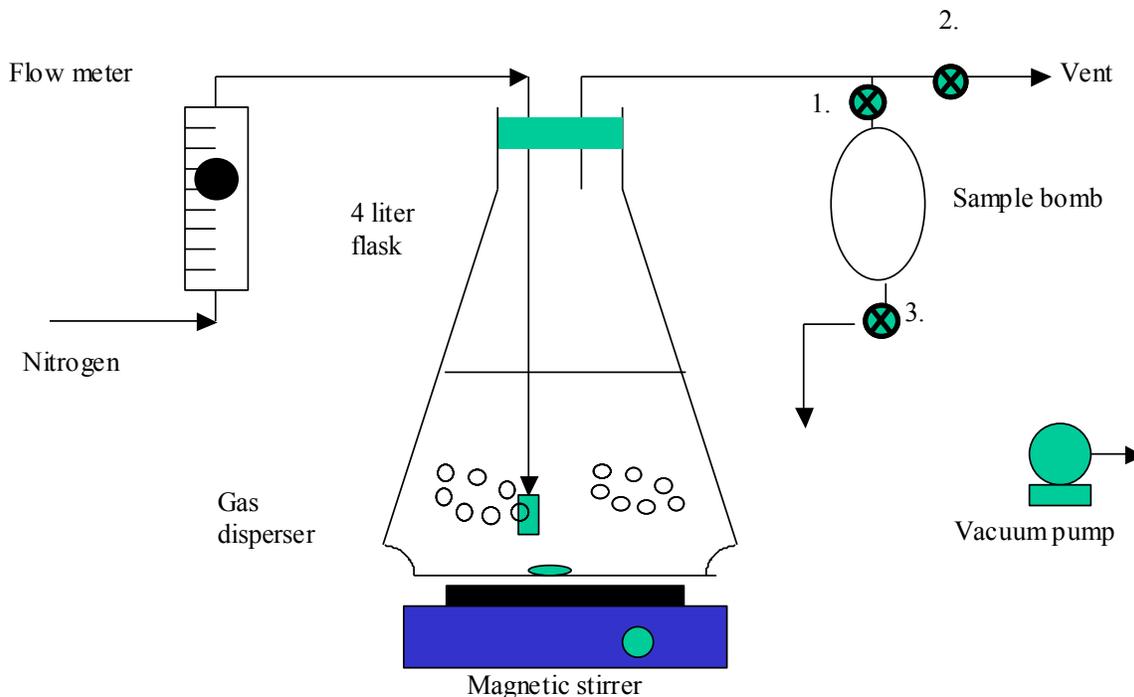
#### **Nitrogen/Carbon Dioxide Inerting of Jet Fuel Tanks**

### **7.1 SUMMARY**

A limited study to evaluate the impact of ullage washing and fuel scrubbing using carbon dioxide and nitrogen on the properties of jet fuel has been performed. Displaced vapor was found to contain up to 18 mg/liter light hydrocarbons, which on condensation would give a volatile, highly flammable liquid similar to gasoline. The liquid jet fuel remained largely unchanged after exposure to nitrogen, however, exposure to carbon dioxide resulted in a significant increase in vapor pressure (+16.7 kPa) and acidity ( $\geq +0.041$  mgKOH/g).

### **7.2 BACKGROUND**

Air BP performed a study to examine the use of nitrogen and carbon dioxide gases to inert jet aircraft fuel tanks and remove dissolved oxygen from the fuel. This study examined fuel quality before and after nitrogen/carbon dioxide has been introduced, and the composition of the vapor above the fuel.



*Figure 7-1.*

### **7.3 APPARATUS**

Figure 7-1 provides a schematic diagram of the apparatus.

### **7.4 METHOD**

1. Three liters of commercial jet fuel, reference number W01/067, was introduced into the 4-liter sample flask.
2. The temperature of the fuel was recorded.
3. Valves 1 and 2 were set such that nitrogen would flow via valve 2 to vent.
4. Nitrogen was introduced into the fuel at a steady flow rate of 380 ml/min.
5. The sample vessel was evacuated and connected to the line.
6. Valve 1 was opened to draw vapor into the sample vessel.
7. Valve 2 was then shut while simultaneously opening valve 3 such that all vapor flowing from the flask would pass through the sample vessel.
8. After a period of 20 minutes, the sample vessel was sealed while simultaneously opening valve 2.
9. Steps 3.5 to 3.8 were repeated to give a second sample 40 minutes after the start of the experiment. Both samples were then analysed by gas chromatography.
10. The liquid fuel was transferred from the sample flask to an epoxy lined can, air displaced from the headspace with nitrogen, sealed and analysed.
11. Steps 3.1 to 3.10 were repeated with a fresh sample of jet but the nitrogen flowing into the flask was set to only pass over, rather than through, the liquid.
12. Steps 3.1 to 3.11 were repeated with a fresh sample of fuel but the nitrogen was replaced with carbon dioxide.

## 7.5 RESULTS AND DISCUSSION

### Vapor Phase

Vapor phase analysis for the nitrogen and carbon dioxide studies are provided in Tables 7-1 and 7-2 respectively. The hydrocarbon concentration in the vapor phase showed some time dependence, particularly for the nitrogen sparge through liquid fuel which increased from 8.1 mg/liter at 20 minutes to 17.8 mg/liter at 40 minutes. This was significantly higher than other results obtained and may warrant further investigation. In general, gas sparge over, rather than through the fuel gave slightly lower concentrations of hydrocarbon in the vapor. The chemical species present were indicative of light hydrocarbons left entrained in the fuel during manufacture. Condensation and recovery of such hydrocarbons would give a product similar in hazard to motor gasoline, i.e. high vapor pressure, low flash point and requiring carcinogenic labelling due to the presence of benzene.

### Liquid Phase

Liquid phase analysis, featuring standard jet fuel inspection data, for nitrogen and carbon dioxide studies after 40 minutes gas sparge, are provided in Tables 7-3 and 7-4. Nitrogen sparge had very little effect, if any, on the properties of the jet fuel. However, carbon dioxide gave a significant increase in fuel acidity,  $\geq +0.041$  mgKOH/g above base fuel level. This could potentially result in product failing the ASTM D1655 specification of 0.10 mgKOH/g maximum. The sparged samples themselves exceed European Def Stan 91-91 limits of 0.015 mgKOH/g maximum.

## 7.6 ADDITIONAL TESTS

### Vapor Phase

The observation that a significant amount of light hydrocarbons were still present in jet fuel following manufacture was confirmed by a further experiment. A second sample of jet fuel was sparged with nitrogen as in Section 3 and the vapor phase analysed by GC-Mass Spectrometry. The spectra confirmed the species present, Table 7-5. Benzene concentration was significantly lower on a pro-rata basis compared to the previous samples, possibly indicating a link with the original crude oil used to manufacture the fuel.

### Gas Entrained in Fuel

Following the experiment where carbon dioxide was sparged into the fuel, it was observed that a sample stored in a one liter can was under pressure. A further simple experiment was undertaken to investigate this effect. One liter samples of base fuel were sparged through the liquid phase with nitrogen and carbon dioxide for ca. 20 minutes. A sample of fuel was taken for vapor pressure determination using standard industry apparatus (ASTM D5191). In addition, each fuel was subjected to low pressure utilizing a vacuum line and any unusual effects observed.

Results were determined as:

	DVPE kPa	Observations under nominal vacuum
Base fuel.	0.9	No gas bubbles.
Base fuel following nitrogen sparge through liquid.	1.7	Few gas bubbles in liquid.
Base fuel following carbon dioxide sparge through liquid.	17.6	Many gas bubbles in liquid.

Results suggest that fuels sparged with carbon dioxide have the potential to solubilize a significant amount of gas. This is later released when the fuel experiences lower pressure/higher temperature. The vapor pressure of the fuel is also increased to a level typical of jet B/wide-cut aviation fuel. Nitrogen gives a similar, but much lower, effect.

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Literature [1,2] data for the solubility of the two gases in hydrocarbons support these observations:

1 atm, 25 °C	n-Octane	n-Nonane	n-Decane
Nitrogen			
g/kg Hydrocarbon	0.327	0.287	0.247
ml/kg Hydrocarbon*	262	230	198
Carbon Dioxide			
g/kg Hydrocarbon	4.648	4.845	5.567
ml/kg Hydrocarbon*	2366	2467	2834

\* Assuming ideal gas at standard temperature and pressure

Given the known risk to safety from vapor bubbles forming in aircraft fuel systems, for example through the use of jet B, this effect is important and warrants further investigation.

## Thermal Stability

Removal of oxygen from jet fuel by sparging with an inert gas may have the potential to increase jet fuel thermal stability. A limited test was undertaken to examine this effect using a fuel of JFTOT rating 3 'Abnormal, Peacock'. The fuel was sparged with nitrogen for a period of 40 minutes as detailed in Section 3. JFTOT was then determined with no air sparge:

	Reference	JFTOT
Base fuel	W01/046	3AP
Nitrogen into liquid phase	W01/048	>4P
Nitrogen above liquid phase	W01/050	4P

Thus, for the sample of jet fuel tested, the thermal stability was not improved following nitrogen sparge.

## 7.7 CONCLUSIONS

### Vapor Phase

- The vapor phase above jet fuel contains a proportion of light hydrocarbons which have become entrained in the fuel during manufacture.
- When recovered and liquefied, the vapor phase hydrocarbons form a highly flammable, volatile mixture of low flash point unlike the original jet fuel but similar to motor gasoline.
- Benzene may be concentrated to such an extent in the recovered vapor to render the liquefied product carcinogenic (>0.1% benzene).
- In the case of nitrogen, passing gas through the fuel gave a greater concentration of hydrocarbons in the vapor phase than passing gas over the fuel. Some time dependence was observed which might require further investigation.
- Based on the results, a large aircraft receiving 200,000 liters of fuel could potentially emit about 4 kg of hydrocarbon vapor for recovery.

### Liquid Phase

- No significant effect on product quality, using standard test methods, was observed following exposure of fuel to nitrogen.
- An increase in fuel acidity ( $\geq +0.041$  mgKOH/g) was observed following exposure of fuel to carbon dioxide. The resultant fuel failed European Defence Standard specifications of 0.015 mgKOH/g maximum.
- Additional tests indicated the vapor pressure of the fuel increased when gases had been sparged through the liquid. Nitrogen and carbon dioxide sparge resulted in a +0.8 kPa and + 16.7 kPa rise in fuel vapor pressure respectively. On exposure to low pressure, both fuels exhibited the formation of gas bubbles in the liquid phase. Given the risk to safety from vapor formation in aircraft fuel systems, this effect warrants further investigation.

**References**

- [1] Makranczy, J; Megyery-Balog, Mrs. K; Ruzs, L.; Patyi, L; Hung. J. Ind. Chem. 1976 4(2), 269-280.
- [2] Tong Jingshan; Gao Guanghua; Wang Xiagong; Qinghua Dazue Xuebao 1988, 28(3), 28-32.

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	Gas through liquid phase		Gas over liquid phase	
	20 minutes W01/073 mg/liter	40 minutes W01/074 mg/liter	20 minutes W01/075 mg/liter	40 minutes W01/076 mg/liter
C3	0.1	0.1	0	0
C4	0.2	0.5	0.2	0.2
C5	0.6	1.2	0.6	0.6
C6	1.8	3.7	1.8	1.5
C7	2.7	5.5	2.3	2.6
Benzene	0.3	0.5	0.2	0.2
C8	1.8	5.1	2.6	3.3
Toluene	0.6	1.2	0.2	0.4
TOTAL*	8.1	17.8	8.1	8.9

Table 7-1. Vapor Analysis, Nitrogen Sparge 21 °C

	Gas through liquid phase		Gas over liquid phase	
	20 minutes W01/091 mg/liter	40 minutes W01/092 mg/liter	20 minutes W01/093 mg/liter	40 minutes W01/094 mg/liter
C3	0.1	0.1	0	0
C4	0.2	0.3	0.2	0.1
C5	0.6	0.6	0.6	0.4
C6	1.7	1.8	1.4	1.2
C7	2.3	2.4	1.9	1.8
Benzene	0.2	0.2	0.2	0.2
C8	2.0	2.3	1.9	1.7
Toluene	0.4	0.5	0.4	0.3
TOTAL*	7.5	8.2	6.6	5.7

• Total excludes trace components >C8 carbon number which were not determinable.

Table 7-2. Vapor Analysis Carbon Dioxide Sparge 21 °C

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ANALYSIS	Base Fuel	Base fuel after 40 minute N <sub>2</sub> sparge through liquid	Base fuel after 40 minute N <sub>2</sub> wash over liquid	UNITS
D1319 FIA Aromatics	17.7	17.7	18.1	% v/v
D1322 Smoke point	25.0	25.0	25.0	mm
D3338 Specific Energy	43.256	43.257	43.245	MJ/kg
D381 Existent Gum (Steam)	<1	<1	<1	mg/100ml
D3948 WSIM (microsep)	83	93	79	-
IP365 Composite Density	798.7	798.7	798.7	kg/m <sup>3</sup>
D4294 Sulfur	<0.01	<0.01	0.01	% m/m
D86 Initial Boiling Point	149.9	150.3	147.7	°C
D86 05 % Recovered	162.9	162.7	162.4	°C
D86 10 % Recovered	166.3	166.7	166.1	°C
D86 20 % Recovered	171.9	172.2	171.4	°C
D86 30 % Recovered	177.8	178.3	177.8	°C
D86 40 % Recovered	184.3	184.1	183.9	°C
D86 50 % Recovered	190.9	191.1	190.9	°C
D86 60 % Recovered	198.4	198.5	198.3	°C
D86 70 % Recovered	206.9	207.0	206.9	°C
D86 80 % Recovered	217.1	217.1	217.0	°C
D86 90 % Recovered	230.5	230.5	230.5	°C
D86 95 % Recovered	241.6	241.7	241.7	°C
D86 Final Boiling Point	258.8	260.9	257.9	°C
D86 Loss	0.4	0.3	0.7	% v/v
D86 Recovery	98.4	98.4	98.3	% v/v
D86 Residue	1.2	1.3	1.0	% v/v
IP16 Freeze point	-58.0	-57.2	-57.2	°C
IP154 Copper Corrosion 2Hrs @100 °C	1A	1B	1B	-
IP170 Flashpoint	40.5	40.0	40.0	°C
IP274 Conductivity	175	125	117	
IP274 Temperature	20	22	22	°C
IP289 Water Reaction Interface Rating	1B	1B	1B	-
IP30 Doctor Test	N	N	N	-
IP323 JFTOT Pressure Difference	0	0	0	mmHg
IP323 JFTOT Visual tube rating	1	1	1	-
IP354 Total Acidity	0.006	0.006	0.006	mg KOH/g
KV at -20 °C	3.482	3.451	3.464	cSt

*Table 7-3. Jet Fuel Inspection Data, Nitrogen Sparge 21°C*

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ANALYSIS	Base Fuel	Base fuel after 40 minute CO <sub>2</sub> sparge through liquid	Base fuel after 40 minute CO <sub>2</sub> wash over liquid	UNITS
D1319 FIA Aromatics	17.7	18.1	17.5	% v/v
D1322 Smoke point	25.0	24.0	24.0	mm
D1840 Naphthalenes		1.55	1.88	% v/v
D3338 Specific Energy	43.256	43.244	43.252	MJ/kg
D381 Existent Gum (Steam)	<1	1	0	mg/100ml
D3948 WSIM (microsep)	83	92	91	-
IP365 Composite Density	798.7	799.0	799.1	kg/m <sup>3</sup>
D4294 Sulfur	<0.01	<0.01	0.01	% m/m
D86 Initial Boiling Point	149.9	148.2	148.2	°C
D86 05 % Recovered	162.9	162.2	161.9	°C
D86 10 % Recovered	166.3	165.5	165.6	°C
D86 20 % Recovered	171.9	171.9	172.2	°C
D86 30 % Recovered	177.8	178.1	177.4	°C
D86 40 % Recovered	184.3	184.2	184.0	°C
D86 50 % Recovered	190.9	190.8	191.0	°C
D86 60 % Recovered	198.4	198.7	198.7	°C
D86 70 % Recovered	206.9	207.2	207.1	°C
D86 80 % Recovered	217.1	217.2	217.0	°C
D86 90 % Recovered	230.5	230.5	231.2	°C
D86 95 % Recovered	241.6	242.6	243.7	°C
D86 Final Boiling Point	258.8	257.8	257.8	°C
D86 Loss	0.4	0.7	1.0	% v/v
D86 Recovery	98.4	98.1	97.8	% v/v
D86 Residue	1.2	1.2	1.2	% v/v
D5901 Freeze point	-58.0	-57.2	-57.3	°C
IP154 Copper Corrosion 2Hrs @100 °C	1A	1A	1A	-
IP170 Flashpoint	40.5	40.5	41.0	°C
IP274 Conductivity	175	120	118	
IP274 Temperature	20	22	22	°C
IP289 Water Reaction Interface Rating	1B	1B	1B	-
IP30 Doctor Test	N	N	N	-
IP323 JFTOT Pressure Difference	0	0	0	mmHg
IP323 JFTOT Visual tube rating	1	1	1	-
IP354 Total Acidity	0.006	0.066	0.047	mg KOH/g
KV at -20 °C	3.482	3.441	3.435	cSt

*Table 7-4. Jet Fuel Inspection Data, Carbon Dioxide Sparge 21 °C*

Component	W01/050 Relative Amount
Isobutane	4.9
n-Butane	10.2
Pentanes	37.1
Hexanes	10.8
Methylcyclopentane	1.9
Benzene	<0.6
Heptanes	4.9
Methylcyclohexane	5.9
Toluene	4.0
Octanes	12.4
Ethylcyclohexane	1.9
Xylenes	2.5
Nonanes	3.1
Decanes	0.6

*Table 7-5 GC-Mass Spectrometry Analysis of Vapor Recovered From Jet Fuel Sparged With Nitrogen*

**ADDENDUM 2  
TEXACO INC. LABORATORY REPORT**

The following is a final summary report with results of the testing conducted here at Beacon for the ARAC Steering Committee. Also attached are the original reports of the two sets of experiments as Attachments A and B and the gas chromatography studies as Attachments C and D.

The initial set of experiments involved sparging nitrogen through a flask containing commercial jet A fuel. The flask was closed with a stopper and vapors were allowed to escape through a glass tube. Details may be found in Attachment A.

The second set of experiments independently included both closed flask and open cylinder testing. The closed flask set up simulated the interior of a closed tank (and replicated the first experiments), and the open cylinder was a more scientific approach to study the effects of the fuel after bubbling nitrogen through it, but allowing virtually all gases to escape from the container (minimum condensation). Details of this work may found in Attachment B.

Despite the various experimental arrangements and conditions, results indicated there was little or no change to properties tested for compliance with ASTM D 1655, Standard Specification for Aviation Turbine Fuels. However, in the second experiment, visual observations of the open cylinder and analysis of the fuel by gas chromatography (GC) clearly indicated the loss of lighter components from the base fuel. This report, attached as Attachment C, elaborates on the techniques used to arrive at the GC results.

As noted in Attachment B, several samples from each condition were taken and GC analysis was repeated on each sample. This provided confidence in the final analysis and helped to identify any outliers in the data set. Because of the distribution of hydrocarbon species, the fuel was segmented into groups based on the molecular weight (carbon number) of the components. It was determined that by separating the fuel into four groups, the analysis could be simplified while still retaining the accuracy required for statistical significance.

The groups were identified as:

1. C6-C10 alkanes and C1-C3 alkyl substituted cyclohexanes;
2. C11-C14 alkanes and C4-C7 alkyl substituted cyclohexanes;
3. C15-C16 alkanes and C8-C9 alkyl substituted cyclohexanes;
4. C17-C20 alkanes and C10 alkyl substituted cyclohexane.

Chromatographic subtraction was used to facilitate the analysis. For each hydrocarbon group, the areas under the peaks were measured or calculated at the before-sparging and after-sparging conditions then compared to each other. The differences were considered to be the losses attributed to outgassing and kinetic expulsion of lighter ends from the base fuel during sparging. Because the hydrocarbon molecular weight distribution within the fuel varied from C6 to C20 alkanes and from C1 to C10 alkyl substituted cyclohexanes, it was necessary to develop specific scales for each hydrocarbon group so that areas could be determined accurately. Chromatographs that typify the results are included as Appendix C.

As noted in the report, the commercial jet fuel (as purchased from the airport) consisted of 10 volume percent (vol%) of the lightest material (Group 1), 40 vol% moderate material (Group 2), 40 vol% heavier material (Group 3), and 10 vol% heaviest material (Group 4). As expected, most of the hydrocarbons displaced by scrubbing came from Group 1 with lesser amounts being lost as molecular weight (and group number) increased. There was no loss of hydrocarbon from the heaviest group. The volumetric loss determined by GC analysis was corroborated with visual inspection of the open cylinder. Details of the study are contained within Attachments B and C.

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At your request, a second analysis to quantify and qualify aromatic loss from the base fuel was performed on the retained samples from the previous experiments. This analysis was conducted using a double-column GC, the results of which are attached as Attachment D.

### **ATTACHMENT A**

2 sub-samples of commercial jet fuel (Jet A) were sparged with gaseous nitrogen, then subjected to full ASTM D 1655 testing and analysis by gas chromatography (GC). A third sub-sample (the unsparged airport sample) was also analyzed using these techniques so that results could be compared.

Attachment A1 contains the properties listed in Table 1 of ASTM D 1655, Standard Specification for Aviation Turbine Fuels (Volume 05.01, Annual Book of Standards, 2000). In addition to the requirements of Table 1, Attachment A1 also contains all ASTM D 1655 test results and other pertinent information. Where duplicate runs were made (density and net heat of combustion) an additional line was added and both results are reported.

To facilitate the experiment and based on laboratory requirements for testing, commercial jet fuel was purchased locally and stored in a laboratory at 70°F ambient temperature.

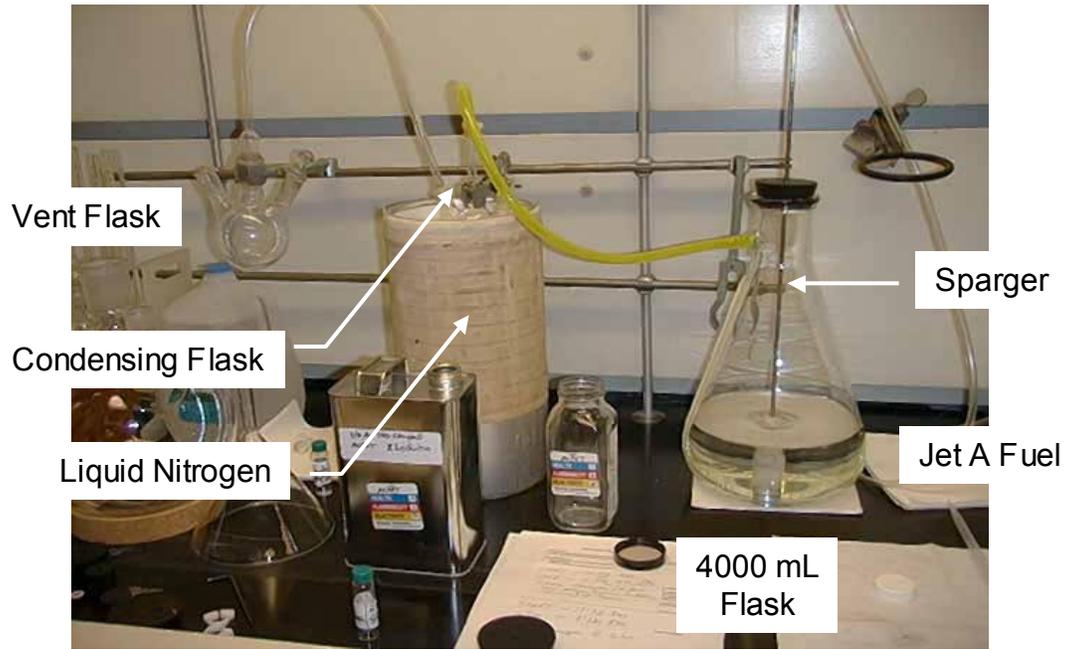
Set-Up: A 4000 milliliter (mL) sub-sample was placed in a 4000 mL flask and a sparger was inserted so that it just cleared the bottom of the flask. Gaseous nitrogen with a purity of 99.999% (maximum moisture = 1 ppm, maximum oxygen = 1 ppm, maximum hydrocarbon content = 0.5 ppm) was used throughout the experiment, and was regulated to flow 350 mL/minute. Using Tygon® tubing, the 4000 mL flask was attached to a 250 mL condensing flask which was partially submerged in liquid nitrogen. The condensing flask was connected to another 250 mL flask which was vented into the hood through a water bath. Although liquid was captured in the condensing flask, it was not possible to extract it without immediate vaporization; thus no analysis could be made of the condensate. Following the initial 20 minute sparging phase, a small sample was taken for gas chromatography and approximately 2000 mL was poured into two separate containers for ASTM D 1655 tests. The sparger was replaced and the experiment was continued for an additional 1 hour 40 minutes. At that time the nitrogen flow was stopped, another small sample was taken for gas chromatography, and the remaining fuel was transferred to two separate containers to await ASTM D 1655 testing. The experimental apparatus is shown in Attachments A2 and A3.

Observations/Conclusions: among the three samples (Airport, 20 Minute Sparge, 120 Minute Sparge) most ASTM D 1655 test results varied little or none from each other. However, density and heat of combustion values changed measurably between samples from the sparging process, and the samples were re-tested about two days after the original tests to verify the differences. Interestingly, the re-runs indicated now consistent, albeit different than the original, results across the three samples. This was in direct conflict with the earlier results and caused a great deal of apprehension among those working on this project. It is hypothesized that immediately following sparging the fuel/ullage is in a state of non-equilibrium (during outgassing) and that after some period of time the fuel/ullage equilibrates. Depending on the composition of the vapors, this could explain the changes in both density and heat of combustion, and their eventual (and inevitable) return to a state of equilibrium. The second experiment will be designed to investigate these possibilities. It should also be noted that although the gas chromatography analysis is incomplete at this writing, the chromatographs indicate obvious changes to the composition of the fuel during sparging. It is hoped that the GC identification of the hydrocarbon species driven out of the fuel during sparging will corroborate the differences observed in density and heat of combustion.

**Attachment A1**

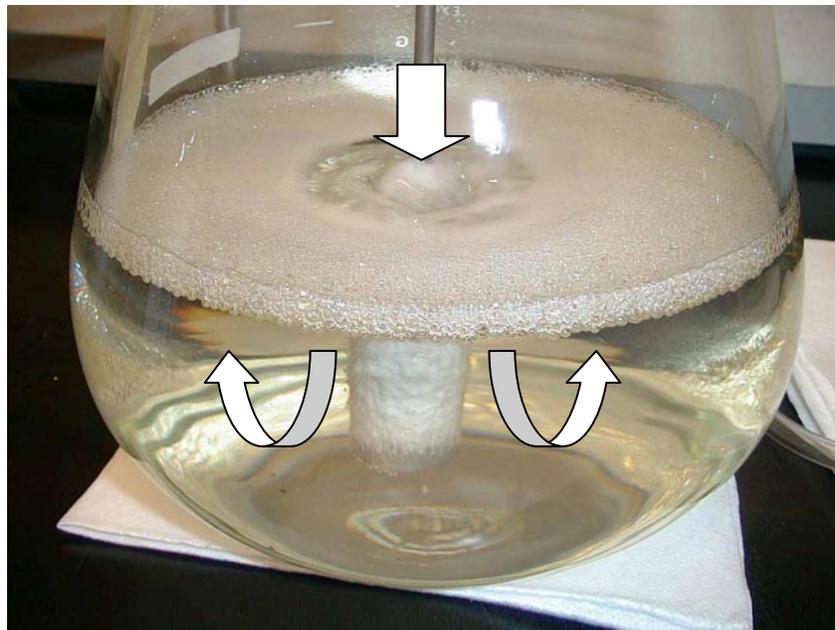
Detailed Requirements for ASTM D 1655, Jet A Fuel						
Property (January 23, 2001)	Sample					Test Method
			20 Minute N <sub>2</sub> Sparging	120 Minute N <sub>2</sub> Sparging		
	D 1655	Airport ID 3342	ID 3343	ID 3344		
<b>COMPOSITION</b>						
Acidity, total mg KOH/g	max	0.10	n/a	n/a	n/a	
Aromatics, vol %	max	25	20.0	20.2	19.9	
Sulfur, mercaptan, weight %	max	0.003	n/a	n/a	n/a	
Sulfur, total weight %	max	0.30	0.085	0.085	0.086	XRF
<b>VOLATILITY</b>						
Distillation temperature, °C:						D 86
Initial boiling point, temperature		n/a	168.1	168.4	169.3	
5% recovered, temperature		n/a	182.7	181.5	182.3	
10% recovered, temperature	max	205	185.9	184.7	184.9	
20% recovered, temperature	max	...	194.3	193.0	194.2	
30% recovered, temperature		n/a	201.5	200.4	200.9	
40% recovered, temperature		n/a	209.0	207.5	208.1	
50% recovered, temperature	max	report	216.6	215.3	216.0	
60% recovered, temperature		n/a	224.4	223.5	223.9	
70% recovered, temperature		n/a	233.3	232.5	232.9	
80% recovered, temperature		n/a	243.7	242.7	242.9	
90% recovered, temperature	max	report	256.9	256.0	256.2	
95% recovered, temperature		n/a	268.8	268.4	268.0	
Final boiling point, temperature	max	300	282.9	281.5	281.5	
Distillation residue, %	max	1.5	0.9	1.0	0.9	
Distillation loss, %	max	1.5	1.3	1.5	1.1	
Flash point, °C	min	38	51.0	51.5	51.5	D 56
Density at 15°C, kg/m <sup>3</sup>		775-840	809.7	796.8	809.6	D 4052
API gravity			43.2	46.0	43.2	Conv.
Density, second run				809.6		D 4052
API Gravity, second run				43.2		Conv.
Vapor pressure, 38°C, kPa	max	...	19.2	7.1	10.1	Conv.
Vapor pressure, 38°C, psi			0.19	0.07	0.10	D 5191
<b>FLUIDITY</b>						
Freezing point, °C	max	-40	-43.8	-44.0	-44.0	D 5901
Viscosity -20°C, mm <sup>2</sup> /s	max	8.0	n/a	n/a	n/a	
			1.41@40C	1.41@40C	1.41@40C	D 445
<b>COMBUSTION</b>						
Net heat of combustion, MJ/kg	min	42.8	47.825	46.120	45.930	D 4809
Net heat of combustion, 2nd Run			46.090	46.085	46.080	D 4809
Smoke point, mm	min	25				
<b>CORROSION</b>						
Copper strip, 2 h at 100°C	max	No. 1	1a	1a	1a	D 130
<b>STABILITY</b>						
Thermal:						
Filter pressure drop, mm Hg	max	25	0.1	0.1	0.0	D 3241
Tube deposit less than		Code 3	3	3	3	
<b>CONTAMINANTS</b>						
Existent gum, mg/100 mL	max	7	3	2	2	D 381
Water reaction:						
Interface rating	max	1b	1	2/1b	1b	
<b>ADDITIVES</b>						
Electrical conductivity, pS/m			n/a	n/a	n/a	

*Attachment A2. Experimental Apparatus*



**Experimental Apparatus**

*Attachment A3. Detail of Sparging in Closed Flask*



## **ATTACHMENT B**

Commercial jet fuel (Jet A) was scrubbed with gaseous nitrogen, then subjected to analysis by gas chromatography (GC), ASTM D 4052<sup>1</sup>, and ASTM D 4809<sup>2</sup>. The physical tests were conducted based on results of previous testing (complete ASTM D 1655, Standard Specification for Aviation Turbine Fuels) of jet fuel from the same base source. In that experiment, it was determined that nitrogen scrubbing affected only density and heat content.

The experimental design is explained below, and Attachment B1 contains the results of ASTM D 4052 and ASTM D 4809. The same commercial jet fuel that was used for the first experiment was stored at 70°F, and was also used for this experiment.

**Design Set-Up, Closed Flask:** A 4000 milliliter (mL) sub-sample was placed in a 4000 mL Erlenmeyer flask and a sparger was inserted so that it just cleared the bottom of the flask. The flask was placed in a laboratory hood with airflow of 166 cubic feet per minute with the front glass at 12 inches above the threshold. Gaseous nitrogen with a purity of 99.999%<sup>3</sup> was used throughout the experiment, and was regulated to flow 350 mL/minute at 120 kPa pressure. Using Tygon® tubing, the 4000 mL flask was attached to a 250 mL condensing flask, which was partially submerged in liquid nitrogen. The condensing flask was connected to another 250 mL flask, which was vented into the hood. Following the initial 20 minute sparging phase, a sample was drawn from the top, center of the flask with a pipette, and three 15 mL test tubes were filled with fuel and sealed with rubber stopples. Also, two 65 mL glass bottles were filled and sealed with plastic caps. To help determine whether stratification of the upper flask volume had occurred, the fuel in the flask was then stirred for approximately one minute until homogeneously mixed and then another sample was drawn and three additional test tubes and two additional bottles were filled and sealed. Two thousand milliliters were then removed from the flask to replicate the previous experiment. The sparger was replaced and the experiment was continued for an additional 1 hour 40 minutes. At that time the nitrogen flow was stopped and a sample was drawn from the top, center of the fuel in the flask with a pipette, and three 15 mL test tubes were filled with fuel and sealed with rubber stopples. Again, two 65 mL bottles were filled and sealed with plastic caps. The fuel in the flask was again stirred for approximately one minute until the fuel was homogeneously mixed and another sample was drawn and three additional test tubes and two additional bottles were filled and sealed. The closed-flask experimental apparatus is shown in Appendix B2.

**Design Set-Up, Open Flask:** A 325 milliliter (mL) sub-sample was placed in a 500 mL open cylinder and a sparger was inserted so that it just cleared the bottom of the cylinder. Gaseous nitrogen with a purity of 99.999%<sup>4</sup> was used throughout the experiment, and was regulated to flow 180 mL/minute at a pressure of 120 kPa. The top of the cylinder was completely open to the hood. As in the closed-flask experiment, the nitrogen scrubbing was conducted while in a laboratory hood that had an air flow of 166 cubic feet per minute with the front glass at 12 inches above the threshold. Following the initial 20 minute sparging phase, a sample was drawn from the cylinder with a pipette, and three 15 mL test tubes were filled with fuel and sealed with rubber stopples. Also, two 65 mL glass bottles were filled and sealed with plastic caps. The sparger was then replaced and the experiment was continued for an additional 1 hour 40 minutes. At that time the nitrogen flow was stopped and a sample was drawn from the cylinder with a pipette, and three 15 mL test tubes were filled with fuel and sealed with rubber stopples. Again, two 65 mL glass bottles were filled and sealed with plastic caps. The open cylinder experimental apparatus is shown in Appendix B3.

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<sup>1</sup> ASTM D 4052: Standard Test Method for Density and Relative Density of Liquids by Digital Density Meter

<sup>2</sup> ASTM D 4809: Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)

<sup>3</sup> Maximum moisture = 1 ppm, maximum oxygen = 1 ppm, maximum hydrocarbon content = 0.5 ppm

<sup>4</sup> Maximum moisture = 1 ppm, maximum oxygen = 1 ppm, maximum hydrocarbon content = 0.5 ppm

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**Observations/Conclusions:** Based on results of ASTM D 4052 and D 4809, there appears to be virtually no change between unscrubbed base fuel, 20 minute scrubbed fuel, and 120 minute scrubbed fuel, whether scrubbing occurred in a closed flask (see Attachment B2), or open flask (see Attachment B3). These results also refute the possibility that significant stratification occurred at the top of the closed flask during sparging, because results from stirred and unstirred samples showed no differences. Although an exchange of gases or condensation and recombining of evaporated fuel with the base fuel (closed flask) may or may not have taken place, the bulk fuel properties (per ASTM D 4052 and D 4809) were not affected.

The density and net heat of combustion results (required in ASTM D 1655, Standard Specification for Aviation Turbine Fuels) indicated no changes to the fuel during scrubbing. However, visual examination of the cylinder and GC analysis of samples indicated a loss of approximately 4 mL (1.2 volume %) of fuel during scrubbing and a change in fuel composition attributed to this operation.

Gas Chromatography Analysis of Changes due to Nitrogen Scrubbing:

There are measurable, statistically significant changes in the chromatogram indicating that scrubbing at the rates used in the lab (180 mL/min, @ 120 kPa N<sub>2</sub>,) drives off a portion of the fuel.

The speciation of which fractions and how much are being driven off is presented below:

- Alkanes (C6–C12)
- Alkylcyclohexane (C1-C5 ) substituted cyclohexane

With much less or no change in the higher molecular weight

- Alkanes (C13-C20)
- Alkylcyclohexanes (C6-C10) substituted alkyl cyclohexanes.

In addition heavier somewhat branched two ring aliphatic compounds showing little change.

Isoprenoids (substituted bicyclo C15 and C16 compounds) show little change.

The open cylinder experiment yielded the following distribution and loss:

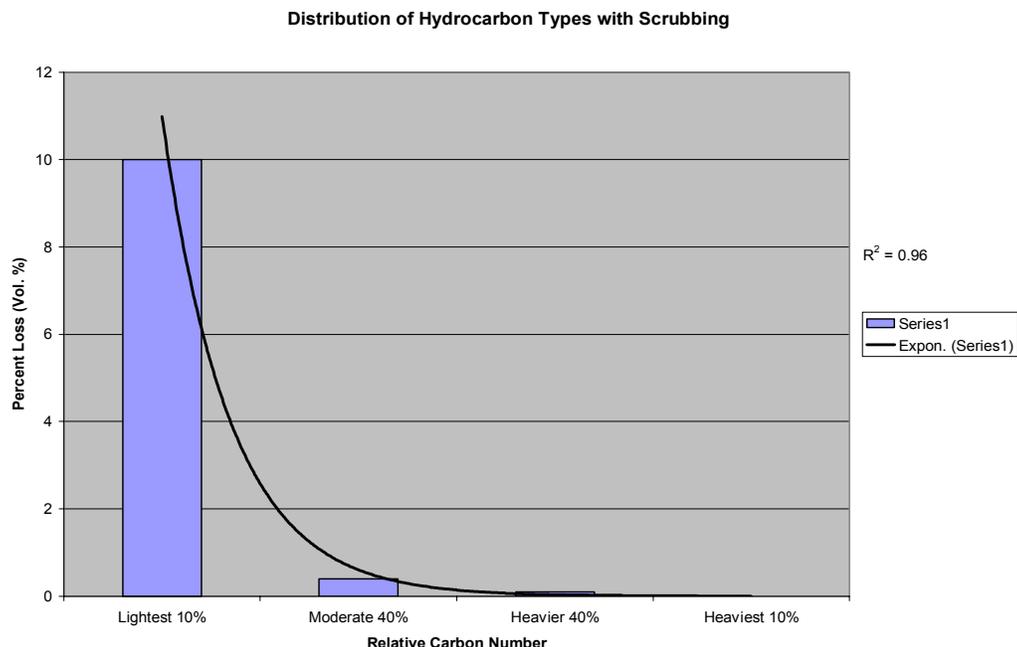
From the 325 mL, open cylinder, 120 minute scrubbed sample the following changes were measured:

1. There is a 10% loss from scrubbing of the lightest fuel compounds (initially 10% of the AvJet A): **(C6-C10 alkanes), and (C1-C3 alkyl substituted cycloalkanes)** (1% of original 325 mL)
2. There is a 0.4% loss from scrubbing of the moderate weight compounds (initially 40% of the AvJet A): **(C11-C14 alkanes) and (C4-C7 alkyl substituted cycloalkanes)** (0.16% of original 325 mL)
3. There is a 0.1% loss from scrubbing of the heavier weight compounds (initially 40% of the AvJet A): **(C15–C16 alkanes) and (C8-C9 alkyl substituted cycloalkanes)** (0.01% of original 325 mL)
4. There is no loss from scrubbing of the heaviest weight compounds (initially 10% of the AvJet A): (C17-C20 alkanes) and (C10 alkyl substituted cycloalkanes)

Note: Based on the Gas Chromatography 3.8 mL out of 325 mL of fuel should be lost from the scrubbing.

Independent visual volumetric measurements of the remaining fuel in the cylinder indicated 4 mL (1.2 vol.%) of fuel was lost. This supports the Gas Chromatography work directly. The hydrocarbon distribution follows an exponentially decreasing loss with increasing carbon number:

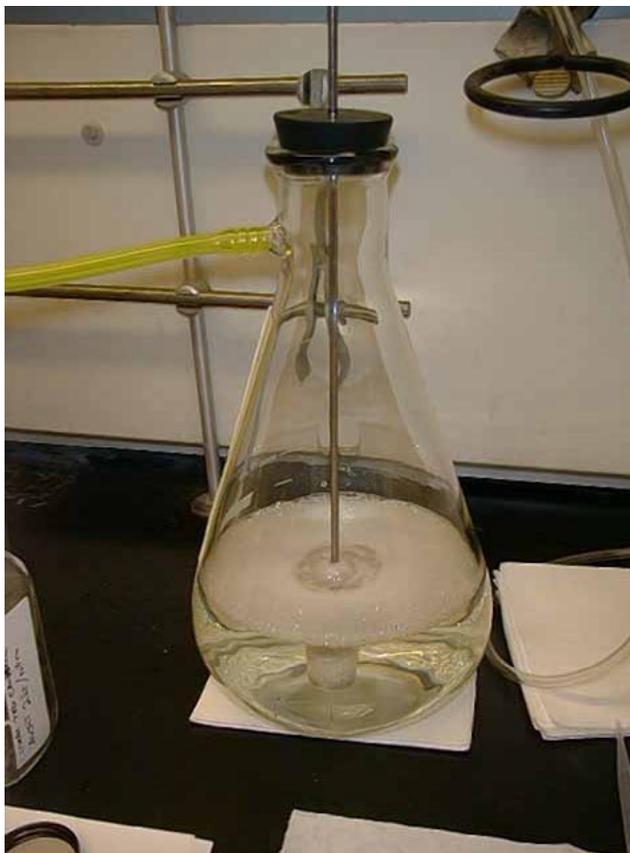
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While results of the physical tests (ASTM D 4052 and D 4809) showed virtually no change to the “bulk” properties of the fuel, gas chromatography analyses clearly indicated changes to hydrocarbon distribution. Furthermore, the bulk properties are tolerant of this 1.2 volume % loss of boiling-point dependent hydrocarbons and their distribution within the fuel as illustrated in the figure above. However, the reader should take heed of the conditions under which these experiments were conducted. Note especially the flow and pressure of nitrogen, hood air flow, and quantities of fuel used. Although the fractions that were driven out of the fuel by nitrogen scrubbing could not be captured for analysis, the technique of chromatogram subtraction (as used here) is quite accurate and provides reliable insight as to the dynamic nature of these experiments.

### Attachment B1

Sample ID	Description	ASTM D 4052	ASTM D 4809 (MJ/kg)
		0.8095	46.1
3450	Closed Flask, 20 Minute Sparge, Top	0.8095	46.1
3451	Closed Flask, 20 Minute Sparge, Top	0.8094	46.3
3452	Closed Flask, 20 Minute Sparge, Stirred	0.8095	46.0
3453	Closed Flask, 20 Minute Sparge, Stirred	0.8094	46.1
3454	Closed Flask, 120 Minute Sparge, Top	0.8095	46.1
3455	Closed Flask, 120 Minute Sparge, Top	0.8094	46.1
3456	Closed Flask, 120 Minute Sparge, Stirred	0.8095	46.0
3457	Closed Flask, 120 Minute Sparge, Stirred	0.8094	46.1
3458	Open Cylinder, 20 Minute Sparge	0.8093	46.1
3459	Open Cylinder, 20 Minute Sparge	0.8094	46.0
3460	Open Cylinder, 120 Minute Sparge	0.8094	46.2
3461	Open Cylinder, 120 Minute Sparge	0.8095	46.1



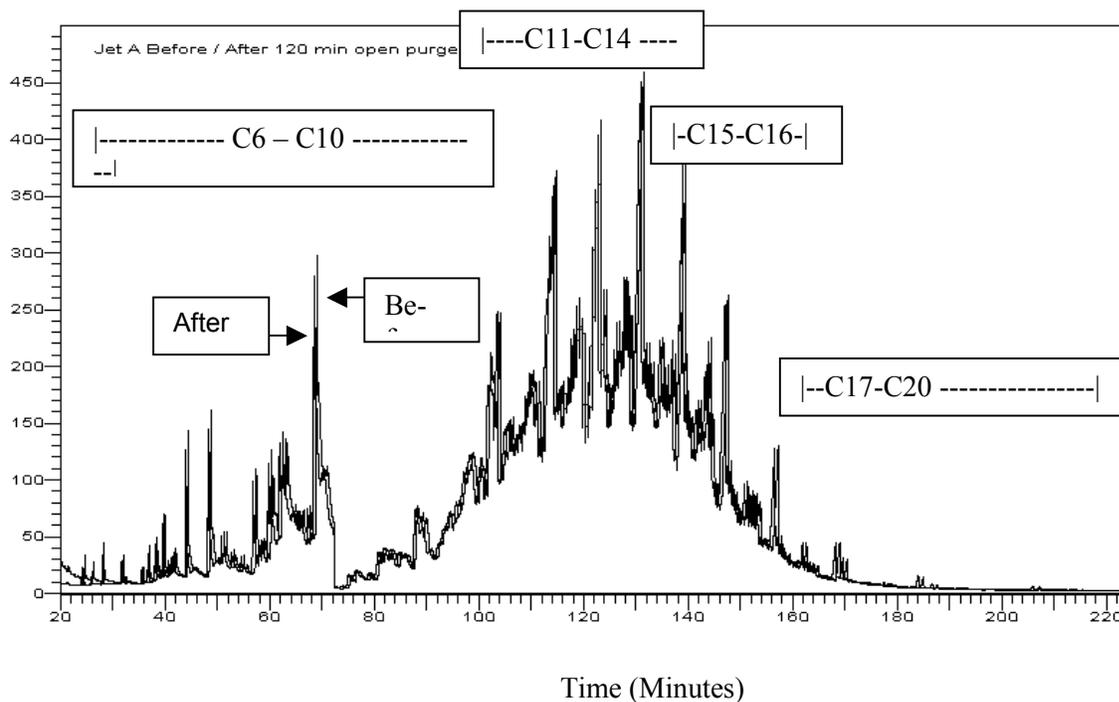
*Attachment B2. Closed Flask With Sparger*



*Attachment B3. Open Cylinder With Sparger*

**ATTACHMENT C**

Typical GC chromatograms: Jet A base fuel studied before and after 120 minutes of nitrogen scrubbing. The chromatogram with the higher peak heights (especially at early elution time and lower carbon no.) is that of the original starting fuel before scrubbing. As time increases the differences clearly diminish indicating the heavier components are not removed by the scrubbing.



20 – 100 minutes, Group 1: C6-C10 alkanes and C1-C3 alkyl substituted cycloalkanes  
 100 – 140 minutes, Group 2: C11-C14 alkanes and C4-C7 alkyl substituted cycloalkanes  
 140 – 160 minutes, Group 3: C15-C16 alkanes and C8-C9 alkyl substituted cycloalkanes  
 160 - 220 minutes, Group 4: C17-C20 alkanes and C10 alkyl substituted cycloalkanes

The experimental parameters include:

Varian model STAR 3600 Cx Gas Chromatograph  
 Using a Supelco 2-4160 PETROCOL DH 100 M x 0.25 mm and 0.5 micron film  
 1 microliter injection using a Hamilton # 7101 1 microliter syringe  
 Initial column Temp: 35 (C)  
 Initial column Hold time 15 minutes  
 Program 1 rate in degree (C) per minute 1.0  
 Program 1 hold time 20  
 Program 2 final column temp (C) 200  
 Program 2 rate in degree (C) per minute 2.0  
 Program 2 hold time 95  
 Injector Temp (C) 300  
 Detector Temp (C) 300  
 FID Attenuation 8  
 A two step ramp was used such that at 72.36 minutes the FID range changed from 8 to 11  
 Total time 225 minutes

**ATTACHMENT D**

Retains from original fuel scrubbing experiments were reviewed to determine the concentration of benzene and toluene by a Gas Chromatography procedure developed to be more suitable for low concentrations of benzene in complex mixtures. The procedure includes:

- Increasing the sample size from 1 to 4 microliters
- Calculating benzene and toluene concentration based on:
  - The same GC experimental conditions for D3606
  - Varian Model 3700 Gas chromatograph
    - Column A: 8 m x 3.2 mm column with 10% (m/m) dimethylpolysiloxane in Chromosorb W, 60-80 mesh;
    - Column B a 4.6 m x 3.2 mm 20% (m/m) TCEP on Chromosorb P, 80 – 100 mesh.

The ratio of the integrated peak area of the analyte peak to that of the methyl-ethyl ketone internal standard peak.

Finding the relationship of analyte concentration to peak area ratio from measurements of a certified D3606 standard where the concentrations of the analytes (benzene and toluene) are known.

The results of these analyses are given in the table below:

Sample ID	Benzene		Toluene		% Removed	
	Vol. %	(ppm)	Vol.%	(ppm)	Benzene	Toluene
Basefuel Jet A	0.00575	(57.5)	0.108	(1080)	0.00	0.0
Closed Flask 20 min	0.00574	(57.4)	0.108	(1080)	0.17	0.0
Closed Flask 120 min	0.00569	(56.9)	0.108	(1080)	1.04	0.0
Open Cylinder 20 min	0.00475	(47.5)	0.100	(1000)	17.39	8.0
Open Cylinder 120 min	0.00465	(46.5)	0.100	(1000)	19.13	8.0

In general the Closed Flask scrubbing removes from a fraction at 20 minutes up to 1 percent at 2 hrs. In contrast, the Open Cylinder scrubbing removes 17% of the fuel’s benzene in as little as 20 minutes, which increases to 19 % removal after 2 hrs. As we saw in the overall chemical emission case, the Closed Flask allows condensation back to the liquid.

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## 8.0 ECONOMICS

Cost estimates were determined using the design concepts developed by the team and typical airport construction practices.

Figures 8-1 through 8-4 are economic evaluations of the inerting systems considered by the Working Group for each type of airport. The estimates used a standard form common to each estimate. The economic evaluation was broken into two parts, capital (non recurring) and operation (recurring) costs.

The evaluations include only the cost of construction and maintenance; operator labor costs are not included.

Capital				
Description	Cost per mobile unit, K	Airport size		
		Large	Medium	Small
Number of mobile units		12	7	2
• System and truck	330	3960	2310	660
• Parking and site preparation	1	12	7	2
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	1	12	7	2
• Contingency (25%)	83	996	581	166
Total	415	4980	2905	830

Operational costs per month				
Description	Cost per mobile unit, K	Airport size		
		Large	Medium	Small
Number of mobile units		12	7	2
• Rent at \$1.0/ft	4	48	28	8
• Lease system if applicable	0	0	0	0
• System maintenance	1	12	7	2
• Power cost (if not already included)	2	24	14	4
• Maintenance and operation	.5	6	3.5	1
Total	7.5	90	52.5	15

**Note:** All figures are in thousands of U.S. dollars.

Figure 8-1. ARAC Facility Estimate—Mobile Ullage System

Capital				
Description	Cost per concourse, K	Airport size		
		Large	Medium	Small
Number of concourses		9	2	NA
• System	0	0	0	—
• Site preparation	35	315	70	—
• Piping, hoses, reels, other	408	3,672	816	—
• Electrical power upgrades	500	4,500	1000	—
• Engineering and soft costs (19%)	179	1,613	358	—
• Contingency (25%)	281	2,525	562	—
Total	1,403	12,624	2806	NA

**Notes:**

- Concourse is 20 gates.
- All figures are in thousands of U.S. dollars.

Figure 8-2. ARAC Facility Estimate—Fixed Ullage System (Sheet 1 of 2)

Operational costs per month				
Description	Cost per concourse, K	Airport size		
		Large	Medium	Small
Number of concourses		9	2	NA
• Rent at \$20/ft	2	18	4	—
• Lease system if applicable	0	0	0	—
• System maintenance	1	9	2	—
• Maintenance and operation	Per Airport	25	13	—
<b>Total</b>		<b>52</b>	<b>19</b>	<b>NA</b>

**Note:** All figures are in thousands of U.S. dollars.

*Figure 8-2. ARAC Facility Estimate—Fixed Ullage System (Sheet 2 of 2)*

Capital				
Description	Cost per tank, K	Airport size		
		Large	Medium	Small
Per tank at one fuel facility		20	4	2
• System	0	0	0	0
• Site preparation	20	400	80	40
• Piping, hoses, reels, other	101	2,014	403	201
• Electrical power upgrades	30	600	120	60
• Engineering and soft costs (19%)	29	573	115	57
• Contingency (25%)	45	897	179	90
<b>Total</b>	<b>224</b>	<b>4,483</b>	<b>897</b>	<b>448</b>

Operational costs per month				
Description	Cost per gal/ min delivered, K	Airport size		
		Large	Medium	Small
Thousands of gallons per minute		4.5	1.0	0.4
• Rent at \$1.0/ft	2	7	2	1
• Lease system if applicable	1	2	1	0
• System maintenance	1	5	1	0
• Inert gas cost	26	117	26	10
• Power cost (if not already included)	0	0	0	0
• Maintenance and operation	2	9	2	1
<b>Total</b>	<b>31</b>	<b>140</b>	<b>31</b>	<b>12</b>

**Note:** All figures are in thousands of U.S. dollars.

*Figure 8-3. ARAC Facility Estimate—Fixed Scrubber System*

Capital				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of existing refuelers		14	9	4
• System and truck	8	112	72	32
• Parking and site preparation	0	0	0	0
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	0	0	0	0
• Contingency (25%)	2	28	18	8
<b>Total</b>	<b>10</b>	<b>140</b>	<b>90</b>	<b>40</b>

*Figure 8-4. ARAC Facility Estimate—Mobile Scrubber System (Sheet 1 of 2)*

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Operational costs per month				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of refuelers		14	9	4
• Rent at \$1.0/ft	0	0	0	0
• Lease system if applicable	0	0	0	0
• System maintenance	1	7	5	2
• Inert gas cost	0	0	0	0
• Power cost (if not already included)	1	7	5	2
• Maintenance and operation	1	7	5	2
Total	2	21	14	6

Note: All figures are in thousands of U.S. dollars.

Figure 8-4. ARAC Facility Estimate—Mobile Scrubber System (Sheet 2 of 2)

## 8.1 ESTIMATE LEGEND AND LINE ITEM EXPLANATIONS

### General

The estimates for each type of airport and each CONCEPT estimated used a form that is common to each estimate. The form was broken into two pieces, CAPITAL and OPERATION

**CAPITAL:** Capital costs are those outlays made to design, install and commission a system (CONCEPT). Included in the CAPITAL estimates are (1) System/Truck costs, (2) Parking and Site Prep costs, (3) Piping, hoses and reels for fixed systems, (4) Electrical Power upgrades, (5) Engineering and soft costs, (6) Contingencies.

**OPERATION:** Monthly operational costs are those outlays necessary to operate the system (CONCEPT) and are exclusive of capital costs. Depreciation is ignored. Included in the OPERATION estimates are (7) Rent, (8) System (CONCEPT) lease, (9) System (CONCEPT) maintenance, (10) Inert gas costs for delivered (not generated) gas, (11) Power costs (if not already included in other line items, and (12) Maintenance and Operation costs.

Each 'outlay' is defined for reference below:

### 1. SYSTEM/TRUCK COSTS

- a) Generators
- b) Storage Tanks LN<sub>2</sub>
- c) Controls
- d) Power, Lights and Distribution from Supply (See Item 4 for electrical supply infrastructure)
- e) System Enclosure ( if any )
- f) Rolling Equipment ( if applicable)

### 2. PARKING AND SITE COSTS

- a) Fence
- b) Rooms / Walls / etc.
- c) Site Lighting
- d) Ramp Striping
- e) Barricades

3. PIPING / HOSES / REELS / ETC. FOR FIXED SYSTEMS (CONCEPTS)
  - a) Piping
  - b) Hoses
  - c) Gate Distribution elements to aircraft
4. ELECTRICAL POWER UPGRADES
  - a) Utility Sets a New Service
  - b) New Supply Switch board
  - c) Space Costs / New Electrical Room
5. ENGINEERING and SOFT COSTS
  - a) Design 6 %
  - b) Construction Administration 3 %
  - c) Program Management 6 %
  - d) Construction Management 3 %
  - e) Permit and related costs 1 %
  - f) Infrastructure Survey \$25,000 each Concourse
  - g) Subtotal 19 % + \$25,000
6. CONTINGENCIES in CAPITAL BUDGET
  - a) Unforeseen conditions
  - b) Conceptual Unknowns
7. RENT
  - a) Lease for Concourse space @ \$20/yr
  - b) Lease for Site space @ \$1/month per foot
8. SYSTEM LEASE COST
  - a) Inert Gas Generating System Lease cost (if applicable)
9. SYSTEM MAINTENANCE
  - a) Inert Gas Generating System maintenance costs by manufacturer (if applicable)
10. INERT GAS COSTS
  - a) Delivery Costs
  - b) Capitalized System Cost
  - c) Gas Cost
  - d) Back-up Gas costs
  - e) Power/energy for System
  - f) Depreciation of System (if manufacturer builds this in)

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## 11. POWER COSTS

- a) Monthly power costs to run the system (if not built in to other line items)

## 12. AIRPORT MAINTENANCE & OPERATION

- a) Labor to maintain Metering, Piping / Connections, etc.
- b) Labor to Operate @ \$22.00/hr.
- c) Space Parts
- d) Accounting
- e) Testing and Airport Certification

## **9.0 CONCLUSIONS AND RECOMMENDATIONS**

### **9.1 CONCLUSIONS**

Based on the work performed the team reached the following conclusions:

#### Ground-Based Inerting

Supplying NEA for ground-based inerting is technically possible. It was beyond the task of this team to do a full analysis to determine if GBI was practical from a cost/benefit standpoint. Large and medium airports would use a fixed system supplemented with mobile equipment for remote operations. Small airports would be served with mobile equipment. Each airport is unique and the systems would have to be custom designed. This could impact the overall cost.

#### Gas Supply

Gaseous NEA generated using Air Separation Modules (ASM) would be the most practical gas to use for GBI due to the ability to make it on-site. This reduces the labor and costs associated with the delivery and storage of other gases. Cryogenic liquid nitrogen may have some limited application such as remote inerting of large transport category aircraft.

#### Fuel Scrubbing

The purpose of delivering nitrogen-saturated fuel into the airplane during normal fueling and refueling operations is to minimize the outgassing of entrained oxygen during the takeoff, climb, and cruise flight envelope to supplement the benefit of ground-based inerting. Because of the potential impact on fuel properties, the complexity of the processes required, and the costs the team concluded that fuel scrubbing was not practical. Fuel scrubbing adds nothing to the protection of the empty CWT.

#### Fuel Cooling

Fuel cooling does not by itself address the issue of the empty CWT. While fuel cooling will reduce fuel tank flammability, it will only do so in those tanks that have fuel added. It still requires a means of providing an inert gas for ullage washing the empty tanks. This will add to the cost and therefore it was concluded that fuel cooling was not feasible for the purpose of this study.

#### Standards

A global standard would need to be developed for the components of the system systems that interface with the aircraft, i.e. connections, metering systems, pressure control, safety system, etc. There would also need to be standards for the mobile equipment.

**9.2 RECOMMENDATIONS**

The AFT recommends that the FAA continue to research ways to supply NEA to the aircraft. Specifically, they should build a pilot plant that closely simulates the conditions that would occur in actual use. They should also research the use of liquid NEA to remotely inert the large transport category aircraft.



Appendix F  
Airplane Operation and Maintenance  
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## **GLOSSARY**

A	A letter for airplane maintenance interval
AD	Airworthiness Directive
ALPA	Airline Pilots Association
AOG	Airplane on Ground
ARAC	Aviation Rulemaking Advisory Committee
ASM	air separator module
ATA	Air Transport Association of America
ATB	air turn back
BITE	built-in test equipment
C	A letter for airplane maintenance interval
CBT	computer-based training
CWT	center wing tank
DDG	dispatch deviation guide
e.g.	for example
ER	extended range
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation; fuel/air ratio
GBI(S)	ground-based inerting (system)
HWG	Harmonization Working Group
JAA	Joint Aviation Authorities
LRU	line-replaceable unit
LS	lump sum
MEL	minimum equipment list
MMEL	master minimum equipment list
MO	modification order
MSG-3	Maintenance Steering Group—volume 3
MTBF	mean time between failure
MTBUR	mean time between unscheduled removal
NEA	nitrogen-enriched air
NIOSH	national institute for occupational safety and health
NTOF	National Traumatic Occupational Fatalities
O <sub>2</sub>	oxygen
OBGI(S)	onboard ground inerting (system)
OBIGG(S)	onboard inert gas generating (system)
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
PC, PCA	preconditioned air
PRV	pressure relief valve

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PSA	pressure-swing adsorption
SB	service bulletin
TCAS	traffic collision avoidance system
U.S.	United States

## 1.0 INTRODUCTION

### 1.1 THE TASK

The Airplane Operations & Maintenance Task Team was assembled by the Working Group to support the Fuel Tank Inerting Study. The primary functions of this team were to.

- Review operational and maintenance data on existing fuel tank inerting systems.
- Evaluate the impact of the proposed inerting system design concepts on airplane operations, maintenance, and fleet planning.
- Evaluate the cost impact of the various proposed inerting system concepts on flight operations, ground operations, and maintenance
- Provide technical expertise in the area of airplane operations and maintenance to the other working group teams.
- Document the results of the Team’s findings.

### 1.2 THE TEAM

The Team’s membership was comprised of individuals with extensive experience in airplane flight operations, maintenance, ground operations, engineering, and aviation regulations.

To divide the workload and to address all impacts on operations and maintenance the Team splited up into four sub-teams. The sub-teams are:

- Modification/Retrofit,
- Scheduled Maintenance,
- Un-scheduled Maintenance/Reliability, and
- Flight/Ground Operations.

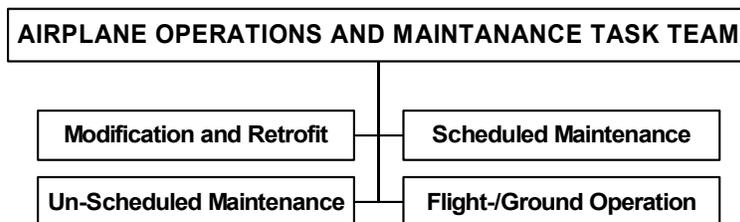


Figure 1-1. Team Structure

#### 1.2.1 Modification/Retrofit Sub-team

This sub-team identified and quantified the costs and impact associated with modification of each of the existing airplane types to install the various inerting systems. The sub-team assumed that the modification would be done per an airplane manufacturer’s service bulletin (SB) that provided modification data, and that the manufacturer would make available modification kits. The sub-team considered two different modification scenarios: First, the airplane is modified during a regularly scheduled heavy maintenance check. Second, the airplane is modified during a dedicated maintenance visit. The advantage of the first scenario is that access to most maintenance areas is already open for the regular maintenance check, which would reduce the total labor requirement, cost of modification, and airplane time out of service.

They developed data and estimations for each of the airplane/system combinations. These estimates were to include but not be limited to material/kit costs, modification labor-hours, engineering support

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requirements, technical publication revisions, airplane time out of revenue service, spares and training requirements, and any other issues related to the retrofit of inerting systems on existing airplane.

## **1.2.2 Scheduled Maintenance Sub-team**

This sub-team identified and quantified the costs and impact associated with the routine maintenance of the inerting system as well as any effects the inerting systems might have on the maintenance requirements of other airplane systems or equipment.

The sub-team developed data for each of the airplane/system combinations. This data would include but would not be limited to airplane and component maintenance tasks, task intervals, task labor-hours, estimate of annual scheduled maintenance labor-hours, annual material costs, and the impact on check schedules, tooling requirements, and all other aspects of scheduled maintenance.

## **1.2.3 Unscheduled Maintenance Sub-team**

This sub-team identified and quantified and quantifying the costs and impacts associated with the non-routine maintenance of the inerting system. They would also work with the Design, Rulemaking, and Safety Teams to define master minimum equipment list (MMEL) requirements and limitations.

They also developed data for the cost and impact of unscheduled maintenance on each of the airplane/system combinations, including but not limited to:

- Line maintenance tasks,
- Line maintenance labor-hours for troubleshooting/repair based on reliability data
- Delay and cancellation rates
- Airplane-on-ground (AOG) time
- Line maintenance training requirements and costs
- Component overhaul interval, labor, and material costs

And all other impacts related to unscheduled maintenance and system reliability as measured in mean time between failures (MTBF) or mean time between unscheduled removals (MTBUR).

## **1.2.4 Flight/Ground Operation Sub-team**

This sub-team identified and quantified the operational issues, impact, and costs associated with flight operations and gate or ramp operations needed to support airplane equipped with inerting systems for each of the inerting systems concepts. They also analyzed and developed data relating to training requirements, airplane servicing, flight dispatch requirements and resources, cost-to-carry estimates, flight operating manual procedures, and manual revisions for each of the airplane/system combinations.

## **2.0 METHODOLOGY**

### **2.1 DATA REVIEW**

The Team's first task was to search for and review all available documentation relating to the operation, maintainability, and reliability of airplane fuel tank inerting systems. Searches of libraries and databases belonging to U.S. and European regulatory agencies, the Airplane Pilots Association (ALPA), the petroleum industry, airplane manufacturers, and U.S. military services were conducted as well as a search of the Internet.

For the most part, very little publicly available data on airplane fuel tank inerting systems exists. The Team did identify some reports, primarily FAA studies, including one on the modification of a DC-9 to

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incorporate a fuel tank inerting system 30 years ago. With the exception of the data produced as a result of the 1998 ARAC Fuel Tank Harmonization Working Group and a year 2000 FAA Technical Center report on ground-based inerting, none of these reports included any operational or maintenance data relevant to the current study.

Several military fuel tank inerting system applications similar to those being considered for this study were identified. However, the Team could obtain very little operational, maintenance, or reliability data on those systems because that data is classified.

## **2.2 INERTING SYSTEM CONCEPT REVIEW**

As information became available from the Ground Based and On-Board inerting Design teams the Operations and Maintenance team began reviewing the systems to identify operational and maintainability considerations for each of the concepts. Each of the concepts was initially evaluated to identify how it might impact airplane flight operations, ground operations, dispatch reliability, maintainability, and training requirements. The potential impact to passengers, crews, and maintenance personnel safety was also considered.

After this initial evaluation, the Team split up into sub-teams to begin detailed analyses. The four sub-teams addressed Modification/Retrofit, Scheduled Maintenance, Unscheduled Maintenance/Reliability, and Airplane Flight/Ground Operations.

## **2.3 MODIFICATION**

### **2.3.1 General**

The inerting systems would be installed via modification or retrofit. The original equipment manufacturers (OEM) would retrofit airplanes in production. The OEMs would also need to provide modification to operators via a service bulletin. Operators, maintenance facilities, or OEMs will modify in-service airplanes.

An FAA approved OEM service bulletin for retrofit of an inerting system should be available before any final rule compliance date is set for retrofit of in-service airplanes. Failure to do this has caused problems for operators in the past. For example, in 1998 the FAA issued an Airworthiness Directive (AD) for 747-100/200/300/SP/SR series airplanes to change the wire separation requirements for Fuel Quantity Indicating System (FQIS) wiring. Although an approved retrofit solution was not available, a 3-year AD compliance time for airplane modification was set. The FAA expected the OEM to complete design changes, gain approval and make a service bulletin available within 1 year of the effective date of the AD. This would allow the operators two years to modify their affected fleet. However, FAA approved retrofit solutions did not become available until almost 24 months into the compliance period, thereby significantly impacting the operator's ability to complete the modifications within the remaining compliance time. Because of the potential for delays in the design approval, it is critical that prior to the establishment of any compliance date requiring installation of an inerting system, an approved service bulletin must be available. This will insure that operators have sufficient time to complete the modifications within the compliance period of a rule.

Due to the scope of the modification, it must be accomplished during a heavy maintenance check or a special visit. Estimates have been developed for both scenarios.

The modification estimations are split into two major parts. The first is the non-recurring costs that comprise engineering time, technical publication changes, and material control. The labor-hour estimate for these nonrecurring costs is the same for all airplane categories. The nonrecurring estimates shown in attachment A-1 are per airplane type per operator. The second part of the modification estimate includes recurring costs and comprises actual airplane modification time. This portion of the estimate is per airplane.

The total modification costs and labor-hours estimation is shown in addendum F.A.1. A short description of each topic is presented below.

## **2.3.2 Engineering**

Before a modification can be accomplished, the operators engineering department must review the OEM service bulletin to determine applicability and check for variations in airplane configurations. Then the modification order (MO) must be written, including creation of the necessary drawings and job cards, and coordinate with the maintenance and material planning organizations. After the MO has been completed and is ready for production, engineering has to create the necessary tracking numbers and maintain the records for all components and their trends. The maintenance program must be updated prior to release of the first modified airplanes. The engineer assigned to this modification becomes the project manager. In addition to the above-mentioned responsibilities, he/she will be assisting and monitoring the progress of this modification.

## **2.3.3 Technical Publications**

The introduction of the inerting system affects the following technical publications:

- Airplane Maintenance Manual
- Illustrated Part Catalog
- Component Maintenance Manual
- Airplane Flight Manual
- Flight Operations Manual
- Structural Repair Manual
- Fuelling Manual
- Ramp Maintenance Manual
- General Maintenance Manual (including company procedures)
- Wiring Diagram Manual
- Weight and Balance Manual

In the modification estimation analyses, the Team assumes that the normal revision procedures of the airplane manufacturer are used. The estimated time is the time that is required to revise the manuals.

## **2.3.4 Material Control and Kits**

The inerting system introduces new serialized parts and consumable parts. Those new parts have to be added to the company's databases. Due to the lack of data on the inerting system, the material cost of consumables is not taken into account.

Prior to the establishment of any compliance date requiring installation of an inerting system, modification kits must be available and the airframe manufacture should coordinate the flow of kits to the operators. In this way, large operators will not adversely affect the availability of kits for smaller operators

Kit costs—the price of the kit, storage costs, and the labor-hours needed to check it—are not taken into account because of the large variation between airplanes, which prevents the use of detailed generic data and pricing.

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## **2.3.5 Project Estimation**

For the modification estimation, the following airplane types were used as examples of each of the six category airplanes:

- Large airplane type category—Boeing 747 series.
- Medium airplane type category—Boeing 767 and MD11.
- Small airplane type category—Boeing 737.
- Regional fan airplane type category—Fokker 28 and 70.
- Regional prop airplane type category—No airplane<sup>1</sup>.
- Business jet airplane type category- Gulfstream IV.

Addendum F.A.2 shows the task with the labor-hours to do the project. For this estimation, it is assumed that the airplane has integrated tanks. Rubber cells are used by the Fokker 28/70/100 series airplanes and as auxiliary tanks on some other transport airplanes. Introduction of the inerting system requires modification or redesign of the rubber cells. For the regional turbofan airplane category, estimates for airplanes with bag-tank (rubber cells) are made as well. Neither is the time that is required for moving or replacing existing installations to accommodate the piping of the inerting system.

The engineering support requirements (e.g., engineering, technical publications, material management) for retrofit of an operator fleet are based on a nominal fleet size.

## **2.3.6 Airplane Out of Service Time Estimate**

To estimate the downtime for the airplane, the following assumptions are made:

- Modification is accomplished on a five-day workweek.
- There are three shifts each with 10 people (5 mechanics, 3 avionics, and 2 sheet metal workers).

## **2.3.7 Maintenance Training**

The basic training requirement for this fuel tank inerting modification consists of classroom lectures, use of the jet airplane maintenance fundamentals, computer-based training (CBT) courseware, basic training workshops, and practical training on in-service airplane at a maintenance organization. A substantial amount of time is needed to educate and train the professional maintenance technicians who will be responsible for safely handling and maintaining airplanes that are equipped with inerting systems.

Operator maintenance and ground training departments, and vendor and manufacturer training departments, will need a substantial amount of time to create and present all necessary training materials for the different kinds of inerting systems. The diversity of airplane fleets and available inerting systems will compound this challenge.

Existing training manuals will need to be revised to reflect airplane modifications and operational requirements posed by fuel tank inerting.

There are significant differences in training regulations between the various countries. An accurate estimation would require knowing the exact number of licensed mechanics and the average number of

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<sup>1</sup>For the regional prop airplane types no estimation is made, this because the Team could not find a company that does the maintenance for propeller airplanes with a center wing tank. Fokker Services, who did the estimation for the regional turbofan airplanes, indicated that the Fokker 27, 50 and 60 airplanes, which are turboprop airplanes, do not have a center wing tank.

licensed mechanics per airplane per operator. An additional factor is the fact that some operators contract with training centers to educate their maintenance personnel. Due to these and other factors the Team was not able to make a labor-hours estimate for training costs. However the Team described the impact on maintenance training due to the introduction of inerting systems.

### **2.4 MEL RELIEF**

The Federal Aviation Regulations (FAR) require that all equipment installed on an airplane be in compliance with the airworthiness standards and operating rules must be operative. However, the FARs also permits the publication of a minimum equipment list (MEL) where compliance with certain equipment requirements is not necessary in the interests of safety under all operating conditions. Experience has shown that with the various levels of redundancy designed into an airplane, operation of every system or installed component may not be necessary when the remaining operative equipment can provide an acceptable level of safety. Under the MEL, dispatch relief is granted for listed components and systems for specific periods of time before the system or component must be repaired or made operational. If repair is not made before the specified time period expires, the airplane may not be flown again until the repairs are made. The FAA uses several standard “repair intervals” that range from one flight to 120 days.

#### **2.4.1 Primary Assumptions**

As defined in the Tasking Statement, “Evaluations of all systems should include consideration of methods to minimize the cost of the system. For example, reliable designs with little or no redundancy should be considered, together with recommendations for dispatch relief authorization using the master minimum equipment list (MMEL) in the event of a system failure or malfunction that prevents inerting one or more affected fuel tanks. The Working Group in general and the Airplane Operations and Maintenance Task Team specifically felt that these instructions were contradictory to the normal application of the MMEL.

These assumptions vastly affect the maintenance and operational costs for an airplane equipped with a fuel tank inerting system. Requiring system redundancy would greatly increase the cost and complexity of the inerting system. System redundancy would also greatly increase maintenance and operating costs.

Likewise, if dispatch relief were not available on a system without redundancy, the maintenance requirements would be greatly increased. In addition, the rate of flight delays and cancellations would increase significantly because the system would have to be repaired before flight.

After lengthy discussions at the Team and Working Group levels it was decided to proceed with the evaluation using the guidelines in the tasking statements. However, it must be understood that airplane operations and maintenance costs would significantly increase with a change to either of these assumptions. Because all of the working group’s analysis is based on these two assumptions, changing them would invalidate most of the results.

For purposes of the study, the Airplane Operations and Maintenance Task Team made an attempt to evaluate the impact of a Category B or three-day repair interval and a Category C or 10-day repair interval. The impact was evaluated based on the reliability of the system, the typical amount of ground time between flights, and the typical maintenance capture rate or the frequency that an airplane overnights at a maintenance base. An effort was also made to predict the impact of having no dispatch relief, which essentially meant that one or more flights would be cancelled while repairs were being accomplished. While these estimates are not comprehensive, they suggest the potential impact of the various options.

#### **2.4.2 Frequency of Dispatch on MEL**

To determine how frequently an airplane might be dispatched with the inerting system inoperative, the average annual flight hours for the specific airplane type was divided by the inerting system reliability factor of mean time between unscheduled removals (MTBUR) to determine the typical frequency of

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inerting system failures. Available time to troubleshoot and repair the system between flights is typically very short. Therefore, the assumption was made that, given the availability of dispatch relief per the MEL, maintenance would probably place the system on MEL and dispatch the airplane with the system inoperative rather than creating a lengthy flight delay.

### 2.4.3 Flight Delays

To dispatch an airplane with a system or component on MEL, some minimal amount of troubleshooting by a mechanic is required to identify the problem and verify that the system is safe for continued flight in its existing condition. The mechanic must also check the MEL to determine if there are maintenance procedures to deactivate or reconfigure the system prior to dispatch. The mechanic must then fill out the proper paperwork to place the system on MEL and release the airplane. The shorter the turn time, the more likely a significant flight delay would occur. The availability of maintenance is also a factor because the number of available mechanics is very limited at many airports. Typical flight delays can range from a few minutes to several hours depending on the maintenance workload at the time, weather conditions, and so on. To reflect the potential impact on flight schedules for each dispatch on MEL, the following flight delay times (Figure 2-1) were assumed based on the typical turn time for that category airplane.

Airplane Category	Flight Delay per MEL Dispatch
Large Transport	30 Minutes
Medium Transport	45 Minutes
Small Transport	60 Minutes
Regional Turbofan	60 Minutes
Regional Turboprop	60 Minutes
Business jet	60 Minutes

Figure 2-1. Flight Delay Assumptions

The annual number of delays and delay time is then a function of the number of times the system fails and must be put on MEL times the estimated delay time per MEL dispatch.

## 2.5 SCHEDULED MAINTENANCE

The Scheduled Maintenance sub-team was tasked with identifying and quantifying the costs and impact associated with the routine maintenance of an inerting system. Each of the proposed inerting systems was to be addressed for each of the six airplane types. (Airplanes had been grouped according to standard seating configuration and the airplane models were then placed into the six categories under consideration.) However, due to the size and complexity of the On-board Inerting concepts, analysis was not completed for Turbofan, Turboprop, and business jet category airplanes.

Scheduled maintenance requirements should be minimal based on the following assumptions:

- Most components will be maintained on condition.
- The design of the system will be such that the risk of an undetected accumulation of nitrogen in spaces occupied by people or animals in flight or on the ground will be minimized.
- Failure of the inerting system will not provide any immediate risk to the airplane or its occupants.

A Boeing 757 (small airplane category) was chosen to establish a baseline of maintenance tasks and intervals. From there, it was believed that maintenance intervals and data could be established for other airplane categories by scaling the B757 data as applicable.

In order to facilitate the calculation of scheduled maintenance labor-hours for each of the selected inerting systems, average utilization rates (Figure 2-2) and maintenance intervals were obtained from Boeing and Airbus for all their jetliner models. From this information, the average maintenance intervals were calculated and are presented in Figure 2-3. This information was used to determine the frequency, or

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portion, of each maintenance check per year. From that, the average additional labor-hours per year required for scheduled maintenance of an inerting system could be established.

Airplane Category	Daily flight hours (hrs.)	Annual flight hours (hrs.)	Flights per day (avg. no.)	Min. Turn time (min.)
Large Transport	11.18	4081	2	60
Medium Transport	7.65	2792	3.5	45
Small Transport	7.86	2869	7	20
Regional Turbofan	5.8	2117	7.1	15
Regional Turboprop	8.1	2957	6.8	15
Business jet	1.37	500	1.5	60

Figure 2-2. Airplane Average Utilization by Category

Airplane Category	Check Intervals (hours)		
	A	C	Heavy
Large Transport	650	5,000*	4C
Medium Transport	500	4,350**	4C
Small Transport	500	6,000**	4C
Regional Turbofan	400	4,000	4C
Regional Turboprop	500	3,200	9,600
Business jet	400	4,000	16,000

\* = or 24 months \*\* = or 18 months

Figure 2-3. Average Fleetwide Maintenance Intervals

### 2.5.1 Maintenance Labor-Hours

Maintenance labor-hours were estimated for the model B757 airplane. These labor-hours were to be scaled to determine the additional scheduled maintenance labor-hours for other airplane categories, but no significant differences between categories were discovered. From the information available, components between airplane categories do not vary significantly. Although the size of components may differ, the scheduled maintenance labor-hours needed to inspect and/or remove and replace these components does not. When compared with a small airplane type, medium and large airplane types will require additional labor-hours during a heavy check to inspect the wiring and ducting because of the additional wiring and tubing.

Scheduled maintenance tasks and inspection intervals for components within each concept were obtained using tasks and intervals for similar components on existing airplanes, or components performing similar functions on the V-22 Osprey. It is important to note that the V-22 Osprey currently operates with Fuel Tank Nitrogen Inerting System.

To obtain the estimated labor-hours for each maintenance task for similar components (e.g., components in ATA<sup>2</sup> 21, 28, and 36) used in-service airplane models were identified, and maintenance personnel were then queried as to whether the labor-hours per task were reasonable. The reason that this estimate was based partly on the expertise of the maintenance personnel is that the actual locations of components would not be known until an inerting system is actually designed.

### 2.5.2 Cycles vs. Operating Time

It is important to note that the Ground Based Inerting System (GBIS) and the On Board Ground Inerting System (OBGIS) maintenance intervals are based on cycles and an average system operating time per

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<sup>2</sup>Airplane manuals are divided in chapters according the ATA standards. Each chapter described a specific airplane system. The ATA chapters referred here are respective “Air-conditioning” (ATA 21), “Fuel System” (ATA 28), and “Pneumatic System” (ATA 36).

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cycle. On Board Inerting Gas Generator System (OBIGGS) maintenance intervals are based on flight hours plus ground operating time.

Scheduled maintenance for the Ground Based Inerting system was excluded at the heavy check for small, medium, and large airplanes. Due to the limited amount of equipment internal to the airplane or the fuel tanks, it was assumed that C-check inspections would suffice.

The team excluded scheduled maintenance for the GBIS at the heavy check for small, medium, and large airplanes. Because the amount of equipment internal to the airplane or the fuel tanks is limited, we assumed that C-check inspections would suffice.

Scheduled maintenance for the Ground Based Inerting System on business jets would be required on an annual basis.

## **2.5.3 Additional Maintenance Tasks**

There are numerous maintenance checks that will be required but cannot be evaluated until final designs are determined. These would include, but are not necessarily limited to, pre-departure checks (BITE checks, fault checks, extended range checks, and so on) as well as pre-tank entry checks (which will be dependent upon the actual operator and/or equivalent of OSHA). In addition, unusual scheduled tasks based on the system chosen (e.g., daily warm-up period for membrane OBIGGS) are not included here.

There are other scheduled maintenance items that cannot be included because of the peculiarities of each system, because they will not be known until the system has been designed. Without knowing the design life of many of the components to be used in the proposed inerting systems, the labor-hours required for scheduled removals could not be estimated. These include specific consumables, other than filters, that are only required by the design itself (e.g., liquid nitrogen for the cryogenic inerting system).

It was recognized that a true picture of the maintenance program could only be achieved by performing an MSG-3<sup>3</sup> analysis. However, lack of design data prevented that from being accomplished for this report.

## **2.6 UNSCHEDULED MAINTENANCE**

### **2.6.1 Component Reliability**

As mentioned earlier in this report, there is little or no existing documentation relating to the operation, maintainability, and reliability of airplane fuel tank inerting systems. The challenge for the Team has been to develop a reasonably accurate method to estimate the reliability of the fuel tank inerting system design concepts.

After a review of each of the design concepts, the similarity between the proposed inerting systems and other existing airplane systems became evident. For many of the components, there are even strong similarities with fuel, pneumatic, and air conditioning system components currently used on commercial airplanes. In fact, there is a possibility that some existing valves, sensors, or fans currently used in other systems could be used in an inerting system. Therefore, for each inerting system component, as many similar airplane components were identified as possible. The information on similar components and available reliability data for those components were gathered and averaged. For components that are unique to the inerting systems, such as air separation modules, the manufacturers' estimates of the components' reliability were used.

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<sup>3</sup>MSG-3 (Maintenance Steering Group – Version 3) is a document produced by the Air Transport Association of America that outlines a decision and selection process for determining the scheduled maintenance requirements initially projected for an airplane system or power plant

**2.6.2 MTBF vs. MTBUR**

It was determined that the mean time between unscheduled removals (MTBUR) rather than the system mean time between failures (MTBF) would be a better indicator of the impact on the airplane maintenance requirements and operational performance. MTBUR factors in some of the typical maintenance inefficiencies in system troubleshooting and repair and, therefore more accurately reflects the real-world problems encountered in airplane maintenance.

**2.6.3 Airplane Utilization Rate**

To assure uniform and consistent analyses methods when evaluating the impact to maintenance and operations, airplane utilization rates were determined for each of the study category airplanes based on industry data (Figure 2-4). These utilization rates included daily and annual airplane flight hours as well as the number of daily operations per airplane. Industry data was also used to determine minimum turn times with input from airplane representatives on the Working Group (Figure 2-4).

Airplane Category	Daily flight hours (hrs.)	Annual flight hours (hrs.)	Flights per day (avg. no.)	Min. Turn time (min.)
Large Transport	11.18	4081	2	60
Medium Transport	7.65	2792	3.5	45
Small Transport	7.86	2869	7	20
Regional Turbofan	5.8	2117	7.1	15
Regional Turboprop	8.1	2957	6.8	15
Business jet	1.37	500	1.5	60

*Figure 2-4. Airplane Average Utilization by Category*

**2.6.4 System Reliability**

The system reliability was then simply calculated as an inverse sum of the MTBUR inverses. The same method was used to determine the system reliability for each of the inerting system concepts.

**2.6.5 System Annual Utilization Rates**

Because of differences in the operating requirements and characteristics of each inerting system design concept, the amount a specific system operates varies. System operating time is important because it directly affects system reliability and therefore operating costs. To account for these differences, the system annual utilization rates were developed based on the operating requirements for each inerting system concept and each category of airplane.

**2.6.6 System Annual Failure Rate**

The inerting system failure rate was determined by multiplying the system MTBUR by the system annual utilization rate for the category airplane. This rate was then used as an estimate of the frequency that the airplane would be dispatched with the system inoperative (MEL). Along with the MEL repair interval requirements, it was used to estimate the percentage of time the system would be operational.

**2.6.7 System Maintenance Workload**

To determine the amount of additional workload an inerting system would add to an airplane’s maintenance requirements, some assumptions about the location of the inerting system components had to be made. Working with the design teams, the likely locations of components were identified. Identifying potential locations on some airplane types was relatively easy. On the 747, for example, an area beneath the center wing tank adjacent to the air-conditioning packs was determined to be large enough for an on-board system and it met most of the design and safety requirements. This location would also provide good maintenance accessibility. On other airplanes, space was found to be very limited. Many of these spaces were inside the fuselage pressure vessel, raising safety concerns, and they tended to have poor

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accessibility for maintenance. On some airplanes, space inside wheel wells and wing-to-body fairings was determined to be available. In many others, the only potential locations tended to be in the aft fuselage area just forward or behind the aft pressure bulkhead. The Team also considered differences in access time due to the time necessary to purge the fuel tanks because of the differences in fuel tank volumes.

Based on this survey of potential locations, estimates were developed for troubleshooting, removal, and installation of each component. From this estimate and the components' predicted failure rate, a maintenance labor estimate was developed for the system aboard each airplane type.

### **2.7 FLIGHT OPERATIONS**

In order for Team to evaluate this process and come to the conclusions and recommendations stated further in this document, several implications and assumptions needed to be applied uniformly. First and foremost was the assumption that in the event that the inerting system was inoperative or that ground inerting equipment was not available, a means to dispatch the airplane without the fuel tanks inerted must be defined. Much discussion went into this decision, ranging from requiring inerting on every flight regardless of circumstances to treating the system as supplementary only. In the event MEL or dispatch relief was not available, operators would incur major limitations. The scope of such limitations could be so great as to cause changes to entire route structures. Airports without the capability to provide nitrogen or maintenance procedures would not be available as alternates, refueling stops, or for diversions as their use would have the potential to ground airplanes and passengers short of their destinations. If the inerting systems were required for safety of flight additional air turn-backs, flight cancellations and delays would also have to be considered. This and the guidelines set forth in the Tasking Statement led the Team to a final premise. Consequently, the Team's evaluation and methodology regarded the system as being a safety enhancement system similar to the present TCAS systems required on airplanes today.

The cost-to-carry estimates are a function of the weight of the system and the cost of the fuel to carry the additional load. The loss of revenue due to the decrease in useful load on flights routinely operating at maximum gross weight is also considered. Because determination of the cost associated with the production of power and resultant drag incurred by on board system designs requires detailed design data, these costs have not been quantified.

Flight crew procedures and associated training expenses were derived from past typical training events similar to the requirements of the proposed system. It was also assumed that the FAA as a training aid from a high-level or general standpoint would publish an Advisory Circular.

### **2.8 GROUND OPERATIONS**

The effect an inerting system has on ground operations depends on the system concept being considered. Training, ground handling and line maintenance requirements were considered along with the associated costs. To accomplish this, a conceptual model of operations with ground based & on-board inerting systems were developed based on the inerting system concepts and airplane operational experience.

The Team also assumes that the FAA will provide guidelines in Advisory Circular material addressing training specifically for Operators and Technicians. Recent modifications to Boeing 737 center fuel tanks, along with the installation of the Smoke Detection and Fire Suppression system in class "D" cargo compartments, allowed the Team to draw some interesting parallels in the processes under review. Based on the modification and training requirements involving the aforementioned systems, a generic description of the model is as follows:

Training programs for line maintenance technicians should cover system operation, MMEL processes and special procedures, including troubleshooting procedures. While Operator training requirements, internal policies and procedures vary widely, task specific training for technicians accomplishing the initial airplane modification should be implemented. A separate or additional program dealing with nitrogen safety and usage

should be developed for those individuals working around the airplane during the inerting process. This team estimates that eight hours (8) of initial, and four hours (4) of annual recurrent training would be required for each technician.

### **3.0 MAINTENANCE IMPACTS**

#### **3.1 INTRODUCTION**

The retrofit and operation of any of the proposed inerting systems will significantly effect airplane maintenance programs & schedules, dispatch reliability, the maintenance work load in the line environment, and the safety of the maintenance personnel.

#### **3.2 MODIFICATION AND RETROFIT**

It is the conclusion of this Team that due to the scope of the modifications, most operators would not be able to schedule the modifications to incorporate the inerting system during an airplane's regular heavy maintenance visit (see addendum F.A.1). The large number of additional labor-hours would extend the scheduled maintenance visit so much that it would interfere with the airline's maintenance schedules. Operators must complete the maintenance requirements on schedule or risk grounding airplanes. Therefore, most operators would likely start-up dedicated modification lines or contract the modifications out to other maintenance facilities. The disadvantage of this approach is that the existing access that is available during heavy maintenance visits is lost. This increases the total labor-hours required for the modification slightly. Another disadvantage of this approach is it may cause a worldwide problem with the hangar availability. The Team estimated that approximately 100 dedicated hangars would be necessary for modification of the existing fleet during the proposed compliance period. When the operators need to do the modification in a special modification line extra slots are necessary, this may result in insufficient hangar space.

Because of the number of airplanes effected, the Airplane Operations & Maintenance team has serious concerns about the availability of enough trained Airplane Maintenance Technicians that would be required to modify the airplanes in the proposed compliance period. Completing the modification of all the effected airplane in a seven-year period would require 3000 - 4000 trained Maintenance Technicians working full time.

#### **3.3 MEL RELIEF**

As discussed earlier, the assumption of dispatch relief for the fuel tank inerting system is fundamental to estimating its potential impact on airplane operations and maintenance. If the assumption changes, the approach taken to evaluate the scheduled maintenance requirements would also need to change, resulting in a significant increase in estimated time and costs.

If a typical airplane could not dispatch an airplane with its inerting system inoperative, the airplane might have to be taken out of service to repair failed inerting systems. The result would be a heightened burden on the airplane's line maintenance functions to get the airplane back into service. Therefore, airplanes would most likely focus on the inerting system's scheduled maintenance program, driving many components off the airplane for overhaul earlier in an attempt to reduce system failures in service. This would significantly increase the scheduled-maintenance, overhaul, and operating costs for the inerting system.

#### **3.4 SCHEDULED MAINTENANCE**

Scheduled maintenance impact, as shown in the specific inerting design concept sections, reflects access, inspection of component, and closure but does not reflect any non-routine correction of discrepancies. Nor does it include the cost of any special equipment or tooling that may be required to accomplish the inspections.

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Scheduled maintenance impact, as shown in each specific inerting design concept sections, does not reflect any of the costs related to the airplane's modification. Instead, it begins after the inerting system has been incorporated.

The heavy check inspections shown for the different inerting design concepts do not reflect any additional manpower that might be required to comply with safety requirements on fuel tank entry into confined spaces with NEA present.

Airplane fuselage seal deterioration occurs because of increasing airplane age, and pressure decay checks allow discovery of seals, which require replacement or rework. The use of cabin air as a supply for the inerting system increases the demand on the airplane air-conditioning packs. Consequently, the maximum allowable cabin leakage rate will have to be maintained at a lower level to ensure that the airplane air-conditioning packs will be able to continue to maintain the required cabin pressurization.

For the On-Board Inerting Gas Generator system, extra labor-hours have been added to the C-check and heavy check to perform a fuselage pressure decay check and rectification because of the use of cabin air as supply for the inerting system. Operator experience has shown that airplanes that are currently in service periodically require this pressure decay check in order to maintain limits prescribed in airplane maintenance manuals.

The extra labor-hours are averages obtained from those operators whose maintenance program currently require fuselage pressure decay checks.

### **3.5 UNSCHEDULED MAINTENANCE**

Each of the design concepts that were included in this study, from the least complex (ground-based inerting) to the more complex (onboard inerting gas generating system), will impact line maintenance, as would the introduction of any new system onto an airplane. From a general perspective, the introduction of a new system—and hence the introduction of new components or line replaceable units (LRU)—will impact line maintenance by affecting airplane dispatch reliability.

In simple terms, the more components there are, the less reliable the system, which results in a lower overall airplane dispatch reliability rate. The reliability of each component or LRU, and specifically its MTBUR, directly relates to an unscheduled line maintenance activity. This, in turn, means an increase in labor-hours (troubleshooting, component access, and component removal and replacement times), material and labor costs, and most likely an increase in airplane delays and cancellations. Additionally, the introduction of a new system and its components can impact other systems by affecting access to their components, thus affecting unrelated component replacement times.

As discussed previously, the specific impact on line maintenance due to the introduction of inerting is best evaluated by looking at component MTBUR data for similar or related systems. Additionally, the impact on other systems due to operation of the various inerting systems must be considered. For example, the proposed OBIGGS design concept extracts cabin air as an air source during certain flight phases. Although a scheduled maintenance task to accomplish a periodic fuselage pressure decay check will need to be implemented as indicated earlier, cabin air extraction will undoubtedly affect airplane pressurization, especially on older airplanes, leading to unscheduled maintenance activities and associated costs to isolate and rectify air losses. The impact to line/unscheduled maintenance varies depending on the inerting system utilized. These differences are discussed in more detail in each of the system design concepts sections. Unscheduled maintenance costs associated with component overhaul (including labor and material costs) and costs associated with special equipment and tooling were not included in the analysis due to insufficient data.

Finally, special precautions must be enforced when performing line maintenance on some inerting system components (depending on their location), such as confined space entry procedures. Additional hazards associated with gaseous or liquid nitrogen must also be considered. These special precautions and

additional hazards result in increased line maintenance costs through increased training (both initial and recurring), equipment, and procedural/policy implementation costs. The specific issue related to maintenance personnel safety associated with nitrogen inerting systems is discussed in more detail in section 3.5 below. Also, because of the unique safety precautions associated with performing line maintenance tasks on inerting system components, specially trained line maintenance personnel (similar to wet cell entry-skilled personnel) may be required. Some airplane operations may opt to utilize contracted personnel to perform such tasks.

## **3.6 MAINTENANCE SAFETY**

### **3.6.1 General**

Nitrogen and other inert gases are not normally dangerous, but when used in confined spaces they can create oxygen-deficient atmospheres that can be deadly. Nitrogen is especially hazardous, because it cannot be detected by human senses and can cause injury or death within minutes. In the United States, at least 21 people have died in 18 separate incidents between 1990—when more stringent requirements were adopted—and 1996, involving the use of nitrogen in confined spaces. Every year in the United Kingdom, work in confined spaces kills an average of 15 people across a wide range of industries, from those involving complex plants to those using simple storage vessels. Fatalities include not only people working in confined spaces, but also those who try to rescue them without proper training or equipment. Still more people are seriously injured.

The health risk to ground and maintenance personnel servicing airplanes that use nitrogen inerting technology is present not only in the fuel tanks themselves, but also in the location of the nitrogen-generating equipment. Wherever possible, such equipment should be located outside the airplane pressure hull. However, this is not possible on all airplanes. Therefore, it will be necessary to ensure that safety systems and procedures are in place to protect the airplanes and personnel working in and around them.

The following sections highlight some of the hazards associated with operating fuel tank inerting systems on commercial transports and the risks they pose to the airplane, its occupants, and maintenance personnel.

### **3.6.2 Confined Spaces**

The Occupational Safety and Health Administration (OSHA) defines a confined space as a space that by design

- Has limited openings for entry and exit.
- Has unfavorable natural ventilation.
- Is not intended for continuous employee occupancy.

OSHA further defines a “permit-required confined space” as a confined space with

- Hazardous atmosphere potential.
- Potential for engulfment.
- Inwardly converging walls.
- Any other recognized safety hazard.

By this definition, all airplane fuel tanks meet the OSHA definition of a permit-required confined space. If the tanks were to be inerted, the current requirement to ventilate fuel tanks before entering will be critical. In addition, other locations under consideration for housing nitrogen-generating equipment, such as cargo holds, wheel wells, wing-to-body fairings, and APU bays, may also be considered confined

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spaces. As such, appropriate entry procedures must be in place to minimize the risk to workers entering these spaces. These areas should be clearly marked and workers thoroughly educated regarding both the hazards of confined space entry and the insidious nature of nitrogen asphyxiation and death.

The costs associated with implementing these additional confined-space entry procedures worldwide are estimated at \$39.8 million for safety equipment and an additional \$28.3 million per year in labor (see addendum F.D.1 in appendix F). Even with these procedures in place, accidents will continue to happen as a result of people bypassing or simply ignoring the procedures, as is proven annually by the current record of injuries and fatalities.

### 3.6.3 Gaseous Nitrogen

The most significant hazard associated with exposure to nitrogen is breathing the resulting oxygen-deficient atmosphere. Normal atmosphere is made up of approximately 21% oxygen, 78% nitrogen, and 1% argon, with smaller amounts of other gases. Nitrogen, which is colorless, odorless, and generally imperceptible to normal human senses, requires the use of oxygen-monitoring equipment to detect oxygen-deficient atmospheres. Despite its nontoxic profile, nitrogen can be quite deadly if not properly handled.

It is not necessary for nitrogen to displace all the 21% of oxygen normally found in air to become harmful to people. OSHA requires that oxygen levels be maintained at or above 19.5% to prevent injury to workers. Figure 3-1 summarizes the expected symptoms at various oxygen concentrations for people who are in good health.

Oxygen Concentration (% vol.)	Symptoms	Maximum Exposure
19.5%	None	N/A
14 – 19.5%	Labored breathing, particularly at higher workloads	N/A
12 – 14%	Physical and intellectual performance impaired, Increased heart rate	N/A
10 – 12%	Rapid breathing, dizziness, disorientation, nausea, blue lips	10 Minutes
8 – 10%	Loss of control, gasping, white face, vomiting, collapse	50% of people will not survive 6 Minutes 100% of people will not survive 8 Minutes
4 – 8%	Coma, Death	40 seconds 2 Minutes
< 4%	Death	Seconds

Figure 3-1. Personnel Hazards

The very nature of oxygen deficiency is that the victim becomes the poorest judge of when he or she is suffering from its insidious effects. Victims may well not be aware of their condition and could fall unconscious without ever being aware of the danger.

### 3.6.4 Liquid Nitrogen

For OBIGGS, which uses cryogenic methods, liquid nitrogen presents its own specific hazards. Although relatively safe from the point of view of toxicity, liquid nitrogen—in common with all cryogen—presents the following hazards:

- Cold burns, frostbite, and hypothermia from the intense cold.
- Over-pressurization from the large volume expansion.
- Fire from condensation of oxygen.
- Asphyxiation in oxygen-deficient atmospheres.

Skin contact with liquid nitrogen can cause tissue to freeze, resulting in severe burns. The extremely low temperature of the cryogenic liquid causes these burns, not by a chemical action. Liquid nitrogen contacting the aircraft structure may cause degradation of materials—especially deterioration of composites and stress cracks in aluminum—resulting in possible structural failure.

The risk of oxygen-deficient atmospheres when using liquid nitrogen arises from the vast expansion of the substance as it boils or vaporizes. Just one liter of liquid may produce around 700 liters of gas at atmospheric pressure, displacing significant quantities of breathable air if the gas is released in a confined space, such as an aircraft fuel tank or pressure hull. The problem is compounded by nitrogen's tendency to accumulate at low levels where it is less easily dispersed than the ambient atmosphere. Even an apparently small spillage could lead to dangerously low oxygen levels, presenting a serious hazard to personnel and other occupants in the area.

Another potential hazard when using cryogenics is the risk of oxygen condensation from the atmosphere due to the extreme cold. Liquid oxygen is highly flammable, and may also create locally oxygen-enriched atmospheres carrying a greatly increased risk of fire or explosion, should an ignition source be present.

### **3.6.5 Gaseous Oxygen**

Produced as a byproduct of the nitrogen generation process, gaseous oxygen presents its own potential hazards. The OBIGGS concepts are designed to vent oxygen overboard. However, some form of leak detection would need to be in place. Failure to do so may result in an oxygen-rich atmosphere with associated risk of fire and explosions. Many materials, such as clothing, that would normally only smolder in air will burn vigorously in an oxygen-enriched atmosphere, making it essential that staff members are alerted to high oxygen concentrations so that the risk of fire can be minimized.

## **3.7 MAINTENANCE TRAINING**

To provide a safe working environment, operators are required to provide maintenance training prior to introduction of an inerting system. Training instructors have to modify their schedules, additional instructors may need to be hired, and training personnel will have to attend the vendors' and manufactures' classes. Afterward, these instructors have to spend time adapting vendors' training materials to their operator's standard. Only after the new training materials are finished and approved by the local regulatory authorities can regularly scheduled classes begin for maintenance and ground support personnel. The variety of airplane fleets and available inerting systems will require the mechanics and ground support personnel to be trained for all systems applicable to all airplane types in the operator's fleet. This fuel tank inerting training requirement will consist of classroom lectures; use of the jet airplane maintenance fundamentals, CBT courseware, and basic training workshops, as well as practical training on in-service airplane after the new systems is introduced.

## **4.0 OPERATIONAL IMPACTS**

### **4.1 INTRODUCTION**

The installation and operation of a fuel tank inerting system onboard an airplane significantly effects the daily operations of that airplane, the flight crew and ground support personnel. The system reliability will have an effect on flight schedules and airplane dispatchability. Flight crews will have to monitor the system to maintain operational safety. Ground support personnel will have to service ground based systems and everyone working on or around the airplane will have to maintain awareness of the potential hazards associated working around large quantities of nitrogen.

### **4.2 FLIGHT OPERATIONS**

Potential impacts having the greatest effect on flight operations consist primarily of schedule effects, MEL and dispatch relief, lost revenue, operational safety, and training. The follow is a briefly discussion of the severity of the impact in relation to the degree of restriction chosen in a final rule. The impact

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spectrum ranges from inerting having a relatively minor affect on flight operations to it being impractical in service.

## 4.2.1 Schedule Impact

Potential impacts to flight schedules will vary greatly depending on the type of inerting system used, the type of operation and the availability of MEL/dispatch relief. Schedule delays due to inadequate turn times are likely to become significant in those operations that today routinely turn their airplanes around in less time than the systems were designed to accommodate. These types of delays are most likely to occur while using the ground based inerting design. To minimize the potential impact on flight operations, average minimum turn time data was collected from operators to determine the design goals for the inerting system concepts. Refer to Figure 4-1 below. The Ground Based Inerting and On-board design teams with the goal of minimizing the impact of inerting time on airplane turn times used this data. Under normal situations, the concept design goals should preclude the requirement for extended gate time. However, some operators with very quick airplane turns could still be affected.

Aircraft Category	Average Minimum Turn Time (Minutes)	Average Aircraft Cycles Per Day	Airplane Annual Utilization Rate
Small Transport	20	7	2869
Medium Transport	45	3.5	2792
Large Transport	60	2	4081
Business Jet	60	1	500
Regional Turboprop	15	6.8	2117
Regional Turbofan	15	7.1	2957

Figure 4-1. Average Minimum Turn Times

The costs associated with such delays may be quantified by taking the percentage of flights that normally operate below the minimum scheduled allotment and multiplying it by the industry-standard delay costs for each minute incurred.

MEL/dispatch relief or lack thereof, has the greatest potential to escalate costs exponentially. For this reason, the following section more fully addresses this issue. The installation implementation time for this proposal may also have a great effect if the modification cannot be accomplished during normally scheduled maintenance visits. If this proves to be the case, airplane out-of-service costs and drastically increased maintenance and hangar requirements will further escalate costs greatly as shown in addendum F.A.1.

## 4.2.2 Airplane Out-of-Service Time

For most operators, it would not be possible to schedule the inerting modification project during a regular heavy maintenance visit. The reason is the scope of the project (see appendix F, addendum F.A.1). The large number of required labor-hours would significantly extend the maintenance visit, which in turn would disturb the airplane's operational schedule.

## 4.2.3 MEL Relief

As discussed earlier the potential impact of MEL/dispatch relief or the lack thereof can not be emphasized enough, especially for on-board inerting systems. Without dispatch relief, every system malfunction would likely result in one or more flight cancellations. With estimated system failure rates ranging from 2-6 per year for each airplane the average operator could experience 1000-2000 additional flight delays and cancellations per year.

## 4.2.4 Lost Revenue

The factor associated with lost revenue is only an issue on the percentage of flights operating at or near maximum take-off weight for the specific flight. All other flights are not taken into consideration simply

because the additional weight of the inerting system would not be expected to effect the planned revenue load, see the different design sections in this report<sup>4</sup> for costs associated with this function. Cost to carry, however, must be applied to all systems on every flight. This is a function of the inerting system design weight multiplied by the average industry cost per pound to demonstrate the increased fuel burn required supporting the system, see the different design sections in the report<sup>4</sup> for industry average costs to carry specified weights. Please note that these costs will vary greatly according to fluctuations in fuel prices. The costs associated with producing the power to run the systems such as electrical load, bleed load, or drag, will also need to be considered.

### **4.2.5 Flight Operations Safety**

The major safety issues relating to flight operations are in regard to NEA leaking into the cockpit or passenger cabin, or the accumulation of highly concentrated O<sub>2</sub> at or near a fuel source. Due to these concerns, it is recommended that nitrogen/oxygen level sensors be installed to provide a warning case of a leak in critical areas. Flight crews and cabin crews will also need to be trained on how to react in the event of such an alarm. Under normal conditions in-flight, the air-conditioning system onboard the airplane will supply sufficient fresh air to prevent leaks from reducing the oxygen level in the cabin. However, under abnormal conditions and on the ground this may not be the case. Therefore, it is strongly believed that this warning system will be required to prevent subsequent loss of life in case of an unknown failure.

### **4.2.6 Flight Operations Training**

Flight operations training for this purpose will consist of training requirements for both pilots and dispatchers. A general course should be administered to both sectors describing the benefits and hazards associated with nitrogen inerting systems. Also, a review of the basic fire triangle and flammability characteristics of jet fuel should be accomplished to familiarize both groups with the dangers associated with warm ullage temperatures. This will allow them to establish operational practices, such as ground air-cart usage on warm days, to control these circumstances. Dispatchers will also need to be trained to understand any dispatch deviation requirements necessary for dispatch with an inerting system inoperative. Pilot training requirements vary greatly depending on equipment type, inerting design, and operational environment. For example, a corporate pilot operating in or out of a remote airport may have greater responsibilities than a pilot may in airline type operations. A typical training program operated in-house would consist of a training bulletin followed up by a regularly scheduled module during recurrent training. Outside or contracted training would typically consist of a training program established by a commercial training facility and administered during special training events. Both would greatly benefit from an Advisory Circular provided by the FAA to assist operators with development of training materials.

## **4.3 GROUND OPERATIONS**

Installation and operation of any inerting system will effect ground operation regardless of which inerting concept is considered. Introduction of any of the systems will add new considerations whether it be safety, new tasks, or dealing with new support equipment. Obviously the Ground Based Inerting system has the largest impact on ground operations because of the servicing requirement prior to each flight.

### **4.3.1 Ground Operations Safety**

The safety-training course for ground operations should include the hazards of nitrogen and other inert gases. Some gases such as nitrogen are particularly insidious because of their poor warning properties.

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<sup>4</sup>For the GBIS see section 5.3.2 *Cost to Carry* and for the OBIGGS see section 7.3.8 *Cost to Carry per Airplane per Year* (\$).

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Oxygen-depleted environments from the inerting process have been reported to cause fatalities to workers in confined spaces. The National Institute for Occupational Safety and Health (NIOSH) has provided data from a ten-year study (NTOF data) pertaining to the number of victims in single and multiple fatalities for all types of confined-space incidents.

A startling 585 separate fatal incidents in confined spaces claiming 670 victims occurred within the 10-year study period. This data strongly underscores the need for increased ground operational safety requirements by all operators prior to introducing any inerting system. Due to the nature of this type of gas, confined areas—such as cargo bins and equipment bays—are particularly susceptible to this hazard.

The minimum recommendation of this ARAC committee is that all ground operation personnel should be aware of these dangers and know what to do in the event that something goes wrong using nitrogen to accomplish the inerting process. Airport fire, rescue, and safety personnel would also require additional training on the uses of nitrogen and confined-space rescue in airplane fuel tanks.

The possibility of over pressurizing the airplane fuel tanks is also a serious safety concern when using nitrogen to inert the ullage space of airplane fuel tanks. Having technicians who have had the recommended training perform the inerting tasks safely and efficiently should alleviate this concern.

### **4.3.2 Ground Operations Training**

Mandatory awareness training is recommended on the dangers of using nitrogen in the quantities required to inert airplane fuel tanks. As mentioned above, an eight-hour initial program should be provided for all technicians involved with installation and servicing.

Up to a four-hour annual recurrent program is also recommended to maintain the heightened awareness on the hazards of working with nitrogen in these volumes. As an example, one hour could include a video on servicing while another hour encompasses troubleshooting and servicing. The remainder of the time can be utilized for applicable system training and open discussions. Other groups working on and around the airplane should also be aware of the dangers associated with nitrogen. These groups should receive recurrent safety training annually. These different groups should include but are not limited to cleaners, fuelers, baggage handlers, caterers, ticket/customer service agents, flight attendants and pilots. The video for example may adequately educate these individuals on the dangers and cautions involved with nitrogen inerting.

For maintenance training purposes, a \$75/hour cost rate provided by the FAA, and discussed in the Estimating & Forecast Team Report (Appendix G), establishes a value for estimating an operator's cost to have a technician install, service, and be properly trained for the continuing performance of these functions. All other group rates will vary respectively.

### **4.3.3 Ground Servicing**

With the above-mentioned dangers of using nitrogen to inert airplane fuel tanks, ground service employees should not perform the servicing of airplane with GBI systems unless they are specifically trained maintenance technicians for the required inerting task. With the continual industry concerns with on-time performance, having the technician in place will help in facilitating that process. Numerous discussions took place on this topic and this group concluded that, after the system has been in operation for several years, reconsideration could be given on who should perform the inerting task.

Trained technicians with a thorough understanding of the system and the consequences of improper operation would be better prepared to monitor and interrupt the inerting process at any time for diagnosis and troubleshooting of system anomalies. To enhance on-time performance, having a technician in place will provide the operator with immediate troubleshooting capability for a system discrepancy during the inerting process, thus minimizing any ground delay due to maintenance problems associated with the inerting system. This process would require technicians in all airplane stations, and considerations should

be given to contract maintenance personnel requirements at locations not staffed by operator-employed technicians.

**5.0 GROUND BASED INERTING SYSTEM**

This section discusses the modification of in-service aircraft to install a ground based inerting system. The overall effect of ground based inerting systems on airplane operations and maintenance requirements are also described.

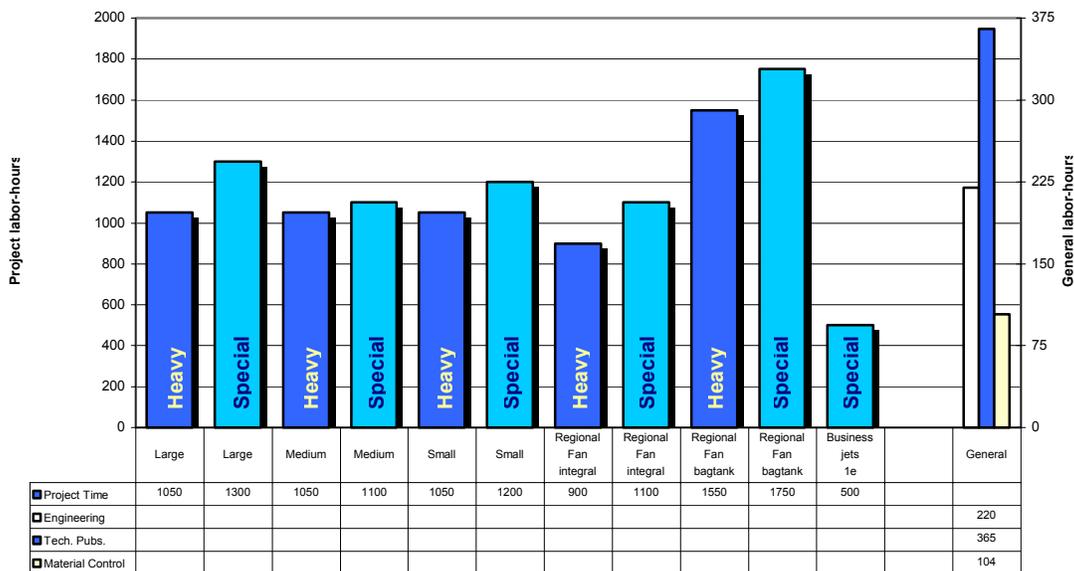
**5.1 MODIFICATION**

In Figure 5-1 the modification estimations for the GBIS are shown. For all airplane categories estimations were made for both a regular heavy maintenance visit and a special visit. However, for corporate and business airplanes (part 91 Operators) the modification would likely be accomplished at the factory service centers. For this airplane category there is only special visit estimates shown. A detailed table with costs and labor-hours is shown in addendum F.A.1 and F.A.2.

For the regional fan airplane types estimation for airplanes with bag-tanks (rubber cells) was made as well. The Team felt that this had to be estimated to determine how many extra man-hours would be required to do the project.

For the regional turboprop airplane types no estimation was made, because the Team could not find a company that does the maintenance for turboprop airplanes with a center wing tank. It should be noted that, Fokker Services, who did the estimates for the regional turbofan airplanes, indicated that there are very few if any turboprop airplanes that have a center wing tank.

On the left side of Figure 5-1 the project estimated labor-hours are shown for the different airplane categories. On the right side the general labor-hours are shown. These labor-hours are equal for all airplane categories. See addendum F.A.1 and F.A.2 for detailed data of the estimate.



*Figure 5-1. Modification Estimations for Ground Based Inerting Systems*

## 5.2 SCHEDULED MAINTENANCE

### 5.2.1 Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the Ground Based Inerting system schematic provided by the Ground Based Inerting team. Each component illustrated in the schematic was evaluated individually and tasks were written accordingly.

These tasks included inspections, replacements, and operational/functional checks of the various components that make up the system. These tasks were assigned to the various scheduled checks (A, C, 2C and Heavy) and labor hours for each task were estimated. Figures F5.2.1-1 through Figure F5.2.1-6 (found in addendum F.B.1) lists these tasks for each of the airplane types.

It was assumed that tasks completed at a C-check, would also be completed at a 2C-check. Similar assumptions were made for the 2C-check (i.e. they would be accomplished at the Heavy check).

### 5.2.2 Additional Maintenance Labor-Hours

Figure 5-2 shows the estimate of additional scheduled maintenance man-hours that would be required at each check to maintain a Ground Based Inerting system.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Business jet	2	5	7	17	16.46
Turboprop	2	5	7	17	16.46
Turbofan	2	5	15	17	17.21
Small	2	5	17	17	34.65
Medium	2	5	21	21	32.93
Large	2	5	25	25	34.74

Figure 5-2. Scheduled Maintenance Times

## 5.3 UNSCHEDULED MAINTENANCE

As per the tasking statements, the design basis for the GBI system is to inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank. Hence, the design concept for the GBI system considered only center wing tanks and auxiliary tanks. Additionally, since the GBI system only operates on the ground, the system operation time was based on the average turn times. The basic design of a GBI system for airplanes without auxiliary tanks is considered relatively simple and the detailed design concept was discussed previously in this report.

### 5.3.1 System Reliability

For the purpose of conducting a reliability and maintainability analysis, the following system components were evaluated:

- Non-return valve
- Isolation valve with integral thermal relief valve
- Self sealing coupling incorporating a frangible fitting
- Ducting (including distribution manifold and double wall tubing)
- Wiring

For airplanes with center wing and auxiliary tanks, the system components would include the same components as a center wing tank installation with the addition of one non-return valve and one isolation valve per auxiliary tank plus interconnect ducting. The impact of including auxiliary tanks in the

reliability and maintainability analysis was considered minor, as it would simply increase the quantity of non-return valves and isolation valves depending on the number of auxiliary tanks installed. This would affect the component Mean Time Between Unscheduled Removal (MTBUR) for the non-return valve and isolation valve, however the exclusion of the auxiliary tank components is considered well within the margin of error of the total system analysis. As a result, only the center wing tank components noted above were considered in the analysis.

Additionally, the need for a pressure regulating valve (PRV) that would limit the delivery pressure of the NEA on some business jets and regional airplanes due to fuel tank construction was discussed in the system design concept above. Conceptually, the PRV could be part of the airplane system or the airport delivery equipment. Because of this and the limited applicability of the PRV, this component was not considered in the analysis.

As with each of the system design concepts the component reliability was evaluated based on similar components. Once the individual component MTBUR was determined, the system MTBUR was estimated to be 9,783 hours. Because of the systems simplicity the GBI system had the highest level of reliability and is the only system with reliability levels considered acceptable for commercial airline service.

The system MTBUR was used for each of the six-transport category airplanes. There was no attempt to determine whether the system MTBUR would vary between the different categories, due to system size or operational differences. It was felt that any differences were well within the margin of error used to calculate the system MTBUR.

The system annual failure rate was then calculated based on the system MTBUR and yearly utilization rate for the respective airplane.

As discussed in the Methodology section, the annual delay time was determined based on standard delay rate assumption for each airplane type.

As described earlier, each airplane type was then looked at separately to determine component removal and replacement time, access time and troubleshooting time. The system maintenance labor hours/year were determined based on the summation of the individual component removal, replacement, access, and troubleshooting time multiplied by the component annual failure rate (Figure 5-3).

Category	Large	Medium	Small	Regional turbofan	Regional turboprop	Business
Annual failure rate	0.42	0.29	0.29	0.22	0.3	0.11
Standard delay rate (1 delay = XX min)	30	45	60	60	60	60
Annual delay time (min/year)	13	13	17	13	18	7
Unscheduled maintenance labor (hr/year)	3.13	1.96	2.02	1.35	1.89	0.77

*Figure 5-3. GBI System Reliability and Maintainability Analysis*

**5.3.2 Cost to Carry**

A cost to carry value for the GBI system was calculated based on system weights provided by the design team. System weights were provided for large, medium and small airplane types and included weights of components listed above as well other equipment that were not included in the analysis, such as brackets and ground straps. The calculated cost to carry value represents the costs associated with the additional weight of the system over one year of operation.

**5.4 FLIGHT OPERATIONS**

Ground based inerting has the least impact to flight operations in that there would be no on-board operating systems to monitor or control. There would only be the calculation of the quantity of NEA to on load at the ramp, which would be a dispatch/ramp office function, to be verified by the operating crew.

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The object has been to design the servicing apparatus so that this function can be accomplished within the average minimum established turn times and thus not creates delays, although scheduled very short turn flights could be impacted. Very little flight crew training should be necessary, but dispatch and ramp office personnel must be proficient in calculating and verification of the procedure. Dispatch requirements need to be thoroughly established with regard to conditions of non-availability of NEA supply and the existing conditions of take off and flight from a station. Airport usage for scheduled or alternate operations will have to be evaluated and indeed route structures could be impacted by non-availability of NEA.

### **5.5 GROUND OPERATIONS**

This group easily established the GBI system as one of the most labor-intensive of all proposed inerting methods researched to date. This is partly due to the fact that the GBI system would require that a dedicated Technician be present during the inerting process while parked on the ramp, or at the gate. The GBI system is also solely dependent on the airport infrastructure.

For the purposes of the gate operation, airplanes would undergo servicing procedures something similar as follows:

A technician will attach the inerting hose from a dedicated source. This source may either be from the terminal (Jetway) or tanker based. After the inerting value is given, the valves are opened to allow the flow of nitrogen into the tank. At the end of the operation, the technician closes the valves completing the process. When the inerting equipment has been secured, the Technician will provide the flight crew an inerting slip. This slip will verify the flight number, date and quantity of inerting gas loaded, along with a signature of individual who performed the task. The flight crew would then check the quantities against the flight release. This would allow normal servicing and through-flight responsibilities such as log book items, and maintenance checks to be accomplished as they are in the present gate environment. Inerting times would be proportional to the type of airplane.

Inerting trucks would also be utilized at small airports and in remote areas of the airport and maintenance facilities, to allow maintenance to inert tank when the airplane is away from the gate.

The ground inerting process would be unique in that while the inerting system is not flight critical, it is one of the few aircraft systems that gives the flight crew no indication or means to verify if the process has been accomplished. The person monitoring the inerting process would be solely responsible for compliance with the inerting requirements. Because ground service positions are generally held by low skilled personnel and historically, aviation turn over rates for ground service employees vs. the Maintenance Technician is significantly higher.

As a result, the team came to the conclusion that the inerting would have to be accomplished by a trained maintenance technician. Discussion regarding the reduction in costs for labor did take place during these ARAC meetings. In the early stages of “aircraft single point refueling systems”, the technician was exclusive to this work and still is in many countries. As the system became more automated and reliable, less aircraft specific personnel were able to successfully accomplish this task. The inerting process should mirror this model. It was concluded that in the future, the job function could be reevaluated, but for the initial phase, it is imperative this is performed by a technician.

#### **5.5.1 GBI Ullage Washing Labor Estimate**

The fuel tank ullage washing or inerting process is very similar to and is accomplished in parallel with the airplane fueling process. The Operations & Maintenance team reviewed the proposed ullage washing procedure and developed a labor estimate for this process. The labor estimate uses the inerting time developed for each airplane category by the GBI design team. Ten minutes was added to the inerting time

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for connection and disconnection of the ground service unit to the airplane and to complete the paperwork require to sign off the inerting process as completed. This resulted in an estimated amount of time for each airplane category required for a technician to inert an airplane fuel tank. These estimates were then multiplied by the number of daily operations for each airplane type and by a 30% lost labor rate to account for the mechanics non-productive time. The result is the daily and annual labor estimate for ullage washing as shown in Figure 5-4.

GBI Ullage Washing Labor						
Aircraft	World Daily Operations	Inerting Time Per Turn (min.)	Connect/Disconnect Time per Turn (min.)	Lost Labor Rate	Labor Minutes per Turn	Daily Labor Hours
Business Jet		15	10	0.3	36	
Turboprop	20,000	10	10	0.3	29	9524
Turbofan	10,000	10	10	0.3	29	4762
Small Transport	48,167	10	10	0.3	29	22937
Medium Transport	5,142	15	10	0.3	36	3061
Large Transport	4,599	20	10	0.3	43	3285
				<b>Total Daily Labor Hours</b>		43568
				<b>Annual Labor Hours</b>		15,902,355

*Figure 5-4. GBI Ullage Washing Labor Estimate*

Nitrogen inerting stations could be mounted on the jet-ways or terminal buildings at major airport similar to the preconditioned (PC) air systems currently in use at most major U.S. airports. The specifics of this type of system will be expanded on in the portion of the report provided by the facilities team. At airports that currently use PC air systems at the gate, the ramifications placing inerting equipment in the vicinity of these units must be considered to preclude the possibility of nitrogen from being vented into the cabin.

At major hubs during nitrogen dispensing at gate areas, the major airport hubs can utilize a Jetway system that mirrors the preconditioned (PC) air systems currently in use at most major United States airports. Individual nitrogen hoses with a central supply would be affixed to all jetways and or terminal buildings. The specifics of this type of system will be expanded on in the portion of the report provided by the facilities team. Considerations should be given though to the airports that currently have PC air in place and the ramifications of inerting while the PC air is connected to the airplane and in use.

In the event that a centralized system is not available at places such as regional or smaller airports, tanker trucks or their equivalent, would provide nitrogen to operators at these areas. Airplane size and flight schedules would determine the demand for these airports.

Procedures would also have to be established for airplanes that divert into stations that do not have sufficient nitrogen quantities for the inerting process.

Complications combined with experience requirements should also be of consideration when determining the long-term effects of having, verses not having qualified Technicians available to perform the inerting tasks. This may also hold true for the initial MEL process on through flights.

### 5.5.2 Potential Future System Improvements

The basic philosophy for the Ground Based Inerting system as it is discussed in this study is to supply a standard volume of nitrogen to a fuel tank prior to each flight. This standard volume would be based on the assumption of a maximum ullage space or that the tank is empty. If the tank contains a quantity of fuel, this would result in more nitrogen being used than is necessary to inert the tank. The excess nitrogen would then be discarded through the tank vent system. The philosophy satisfies the inerting requirement but results in an increased nitrogen requirement and more VOC's being released in the atmosphere. This may be a problem in some of the more environmentally sensitive areas in Europe and the U.S.

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One long-range solution to this problem would be to adjust the volume of nitrogen used to inert the tank based on the amount of fuel in the tank. When the fuel load for a flight is determined the nitrogen load would also be calculated and included on the fueling sheet. This would require a change to the software used to calculate the fuel load at a one-time cost of \$5000 to \$500,000 per operator, depending on the kind of fuel load program used. Dispatchers would also need to be trained to determine the volume of NEA required. This was considered as a future improvement to the GBI inerting process and therefore these costs are not taken into account in the modification estimations.

Further possibilities for future system improvements could include an on-board inerting computer. The inerting computer would provide the maintenance Technician the means to select a specific tank and fuel quantity. Once the information is entered, the computer calculates the proper inerting value for that tank. A monitoring function keeps the technician aware of any inerting anomalies. Sensors automatically close the inerting valves when the process is complete. Once the servicing door is closed, the computer could also provide a signal to the flight deck in case of inerting discrepancies or system. Built in test equipment at the panel could also allow Technicians to test line replaceable units and perform maintenance checks. Such a system may streamline the inerting process.

### **6.0 ON-BOARD GROUND INERTING SYSTEM**

This section discusses the modification of in-service aircraft to install an On-Board Ground Inerting System. The overall effect of OBGIS on airplane operations and maintenance requirements are also described.

#### **6.1 MODIFICATION**

In Figure 6-1 the modification estimations for the OBGIS are shown. Due A survey of regional and business jet aircraft indicated that insufficient space is available to accommodate an OBGIS system in the unpressurized areas these category airplanes. As a result these airplanes have been excluded from this estimate. Estimations are made for both a regular heavy maintenance visit and a special visit.

The modification estimations for the OBGIS are based on the estimations of the OBIGGS, however since the OBGIS are only designed for the center wing tank and auxiliary tanks the labor estimates have been reduced to account for installation differences. The following reductions are used:

- For the large airplane category: 300 man-hours
- For the medium airplane category: 250 man hours,
- For the small airplane category: 200 man-hours.

On the left side of Figure 6-1 the estimated modification labor-hours per aircraft are shown for the different airplane categories. On the right side the general support labor-hours are shown. The support labor-hours are incurred on a per operator basis as opposed to per aircraft and are approximately the same for all airplane categories. See addendum F.A.1 and F.A.2 for detailed data of the estimate.

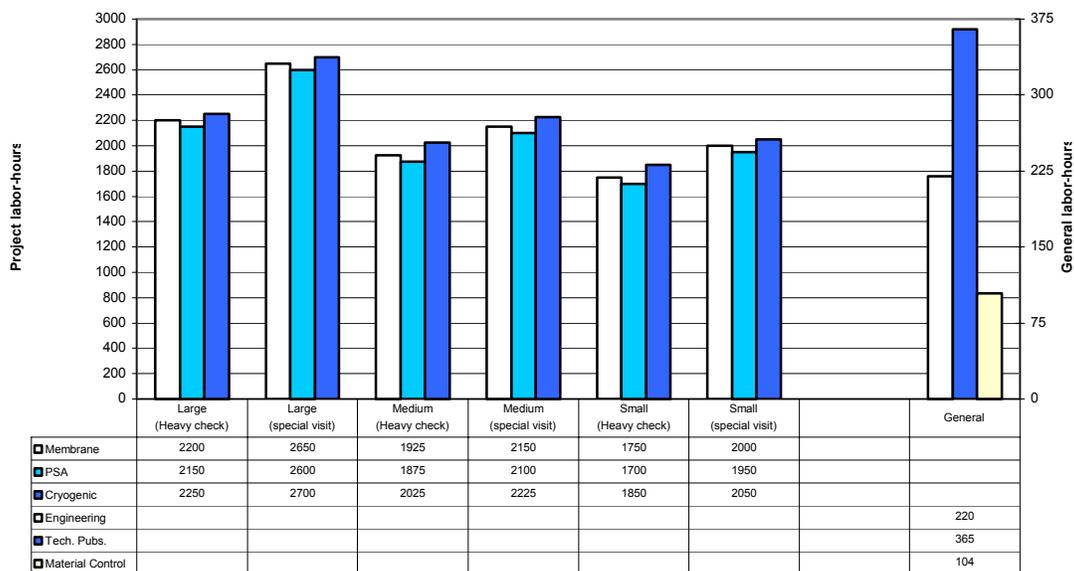


Figure 6-1. Modification Estimations for On-Board Ground Inerting Systems

## 6.2 SCHEDULED MAINTENANCE

### 6.2.1 Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the On Board Ground Inerting system schematic provided by the On-Board Design team. Each component illustrated in the schematic was evaluated individually and tasks were written accordingly. These tasks included inspections, replacements, and operational/functional checks of the various components that make up the system.

Tasks were assigned to the various checks (A, C, 2C, and heavy) and labor-hours for each task were estimated. Figures F6.2.1-1 through Figure F6.2.1-6 (found in addendum F.B.1) contain a complete list of these tasks. The team assumed that tasks completed at a C-check would also be completed at a 2C-check. Similar assumptions were made for the 2C-check (i.e., they would be accomplished at the heavy check).

The OBGIS consists of several more components than the GBIS. Thus, additional tasks are required, substantially increasing the additional labor-hours required in the 2C- and heavy checks.

Because the size and complexity of the onboard ground inerting (OBGI) concept made the system infeasible for turboprop, turboprop, and business jet category airplanes, analysis was not completed for these airplanes.

### 6.2.2 Additional Maintenance Labor-Hours

Figure 6-2 below shows the estimate of additional scheduled maintenance man-hours that would be required at each check to maintain an On Board Ground Inerting system.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	4	18	51	50.55
Medium	3	4	18	55	48.31
Large	3	4	18	59	46.51

Figure 6-2. Scheduled Maintenance Times

## 6.3 UNSCHEDULED MAINTENANCE

The OBGIS which consists of approximately 26 major components is significantly more complex than the GBIS,. Like the full OBIGGS, the airplane system is self-sufficient, which is the reason for the increased complexity.

### 6.3.1 System Annual Utilization Rate

Although the Onboard Ground Inerting System equipment is very similar to the full OBIGGS system, the operating philosophy is significantly different. Unlike OBIGGS the classic On-board Ground based Inerting system operates only while the airplane is at the gate. Therefore the operating time on the OBGIS system is significantly less than for full OBIGGS over the same period of time reducing the wear & tear on system components. To account for the reduced operating time the System Annual Utilization rate for OBGIS is based on the typical gate time and number of daily operations for each category airplane.

Airplane category	Aircraft usage rate, flight-hours/year	OBGIS system operational time, hours/year
Large transport	4,081	1,095
Medium transport	2,792	1278
Small transport	2,869	1,916
Regional turbofan	2957	1080
Regional turboprop	2117	1034
Business jet	500	365

Figure 6-3. OBGIS System Annual Utilization Rate

### 6.3.2 System Reliability

As with the unscheduled maintenance analysis on the other system concepts the reliability of the On-board Ground Inerting systems components was primarily based on a comparison to similar components currently in use on commercial airplane. The tables in Addendum F.C.2 show the estimated MTBF and MTBUR for individual system components. The significant decrease in the reliability level of the OBGIS system as compared to the Ground Based Inerting system is due to the increased complexity of the system. The increase in the number of parts and the introduction of lower reliability, higher maintenance components such as compressors and air separation modules decreases the system reliability by a factor of 10 times. The OBGIS system Mean Time Between Unscheduled Removals was calculated to be 945 hours for the PSA system and 960 hours for the membrane system. The difference between the systems is due to the slightly higher reliability of the membrane air separation module.

Because similar component reliability data for a range of component sizes was not available the analysis assumes that the reliability of the OBGIS system is the same for all sizes of airplane. In reality system reliability may vary with the systems size but the purposes of this study the variation is assumed to be well within the margin of error for the reliability estimate.

### 6.3.3 System Annual Failure Rate

The annual failure rate for the inerting systems is a function of its reliability (MTBUR) and the System Annual Utilization rate. Using OBGIS system Annual Utilization rate, the frequency of inerting system failures on each airplane was predicted to be approximately two failures per year for an OBGIS system.

The system annual failure rate is significant because it is an indicator of how maintenance intensive the inerting system is and what the level of impact the system will have on flight operations. In the case of the OBGIS system an operator with a fleet of 300 airplanes could expect to have to address 600 additional maintenance problems per year due to the inerting system.

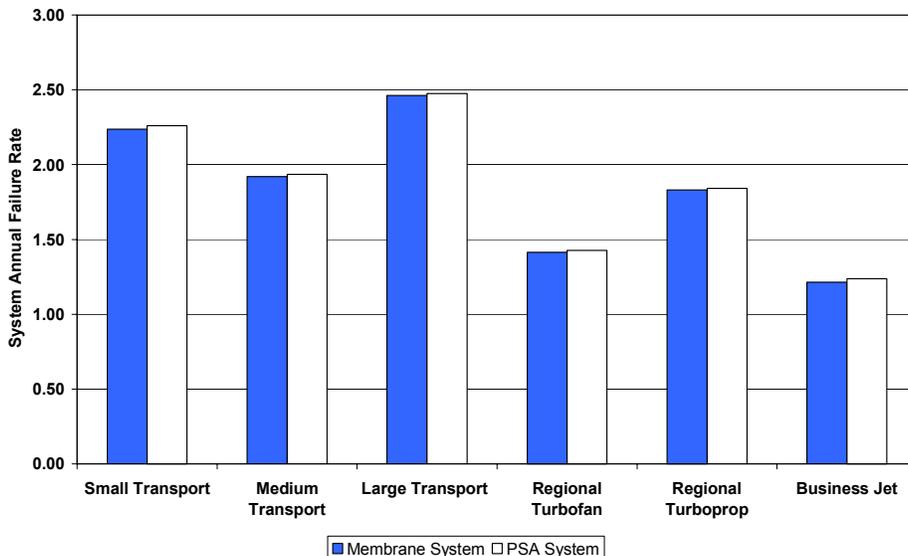


Figure 6-4. Predicted OBG System Annual Failure Rate

**6.3.4 Unscheduled Maintenance Labor Estimate**

As with other system concepts, a survey of potential component locations was done for each of the category airplane. Based on this survey, estimates were developed for troubleshooting, removal and installation of each component. The tables in Addendum F.C.2 detail the troubleshooting, removal and installation labor hour assumptions. Probable component locations, size and weight were considered in developing this estimate. The labor estimate and the components predicted failure rate were used to estimate annual unscheduled maintenance labor rate for the OBG system on each airplane type and is summarized below.

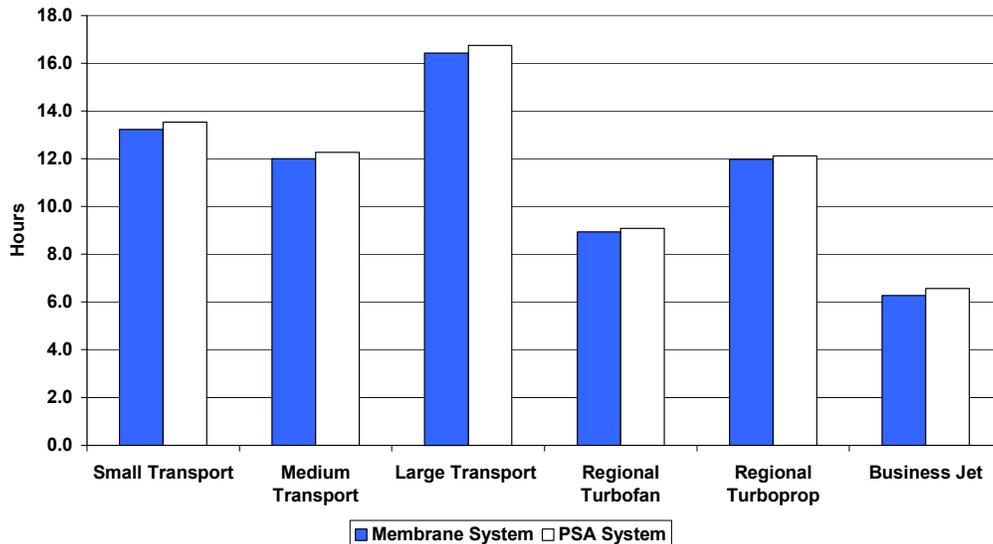
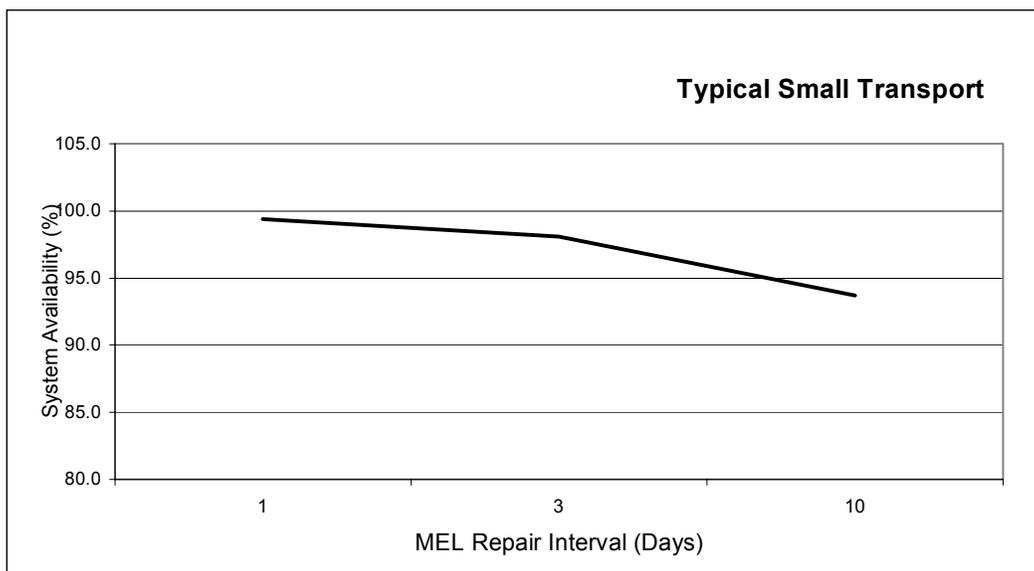


Figure 6-5. Annual Unscheduled Maintenance Labor Estimate per Airplane

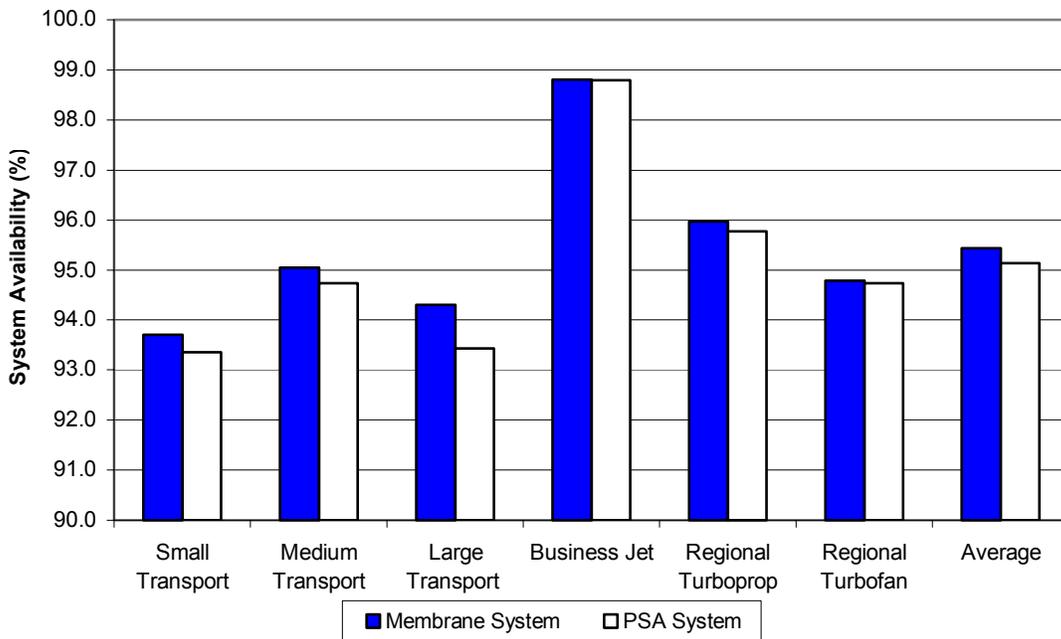
### **6.3.5 Inerting System Availability**

The availability of an OBGI system is a function of the system reliability and the repair interval assumed for MEL dispatch relief. For example, if the system has an annual system failure rate of 2 failures per year and the MEL dispatch relief allows a 3 day repair interval the inerting system maybe assumed to be inoperative 6 days per year. Another way to look at system availability is as a percentage of departures. If the airplane typically has 7 departures per day as the small transport does, then the airplane would depart on 42 flights per year out of 2555 with the inerting system inoperative. Assuming that an inerting system would remain inoperative for the maximum allowable number of days is a worst-case scenario. In reality, the systems would likely spend 50-75% of the allowable time on MEL, but for the purposes of this study, it is assumed that the full repair interval is used all the time. When considering the effect of the number of days a system is allowed to remain on MEL that decreasing the number of days improves the system availability but comes at a cost in terms of increased flight delays, cancellations, and operating costs.



*Figure 6-6. Impact of MEL Relief on System Availability*

Figure 6-7 shows the expected OBGI system availability for each category aircraft based on 10 day MEL relief availability.

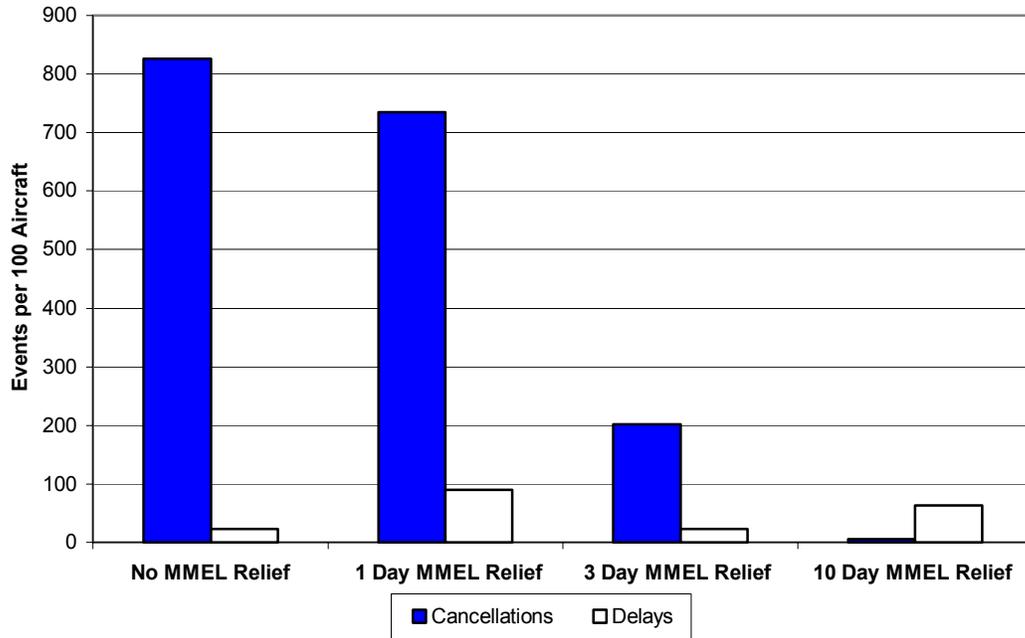


*Figure 6-7. OBGI System Availability*

**6.3.6 MEL Dispatch Relief Effect**

The effect of the MEL dispatch relief assumption is discussed in detail in Section 10 of this report. The availability of MEL dispatch relief for none critical aircraft systems and the length of time allowed before the system must be repaired has a large impact the airplanes dispatch reliability and cost of operation. As an illustration the number of delays and cancellations an operator might experience for a typical small transport airplane equipped with an OBGI system was calculated. This estimate is based on the projected OBGI system annual failure rate and some assumptions about the frequency of delays and cancellations based on a system failure.

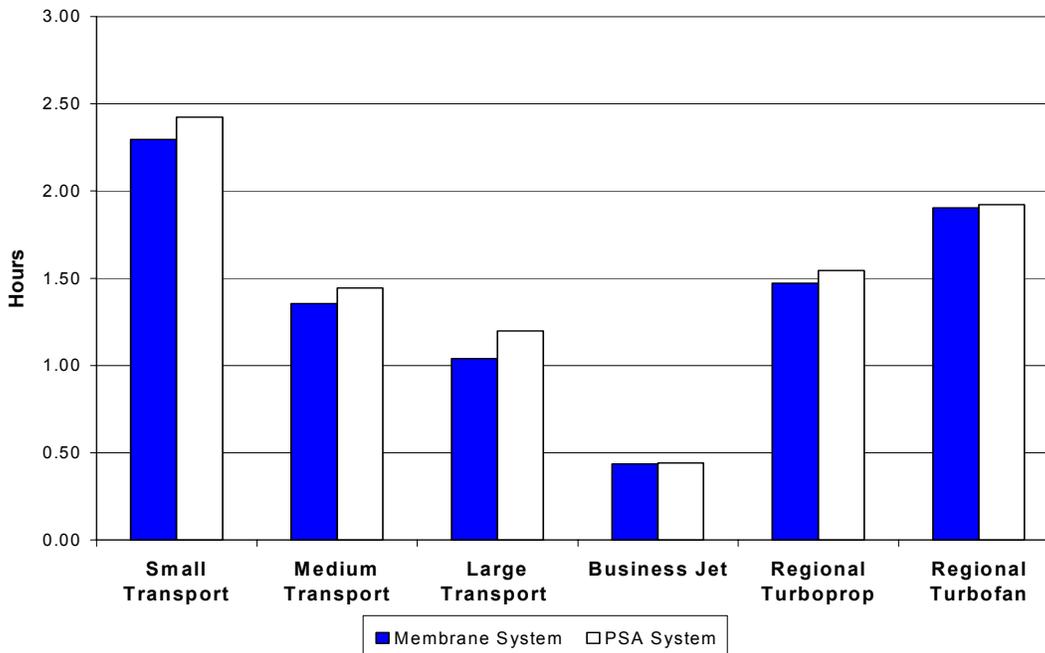
If no MEL dispatch relief is available there is a high probability the system failure would result in multiple flight cancellations. If dispatch is available the likelihood of flight delays and cancellations decreases as more time is allowed to route the aircraft to a location were maintenance is available. The system can then be repaired during an overnight maintenance visit. The specific assumptions used here are based on typical operator experience and are presented in Appendix F.



*Figure 6-8. MEL Dispatch Relief Effect*

**6.3.7 Delay Hours per Year**

An estimate of the effect of inerting system failures on flight departure schedules was made based on the OBGI systems annual failure rate. The delay assumptions used for this estimate were discussed earlier under the "Flight Delay" analysis methodology; section 2.4.3. Although not every system failure causes a delay, it is equally true that a single maintenance delay frequently causes multiple down line delays due to a cascade effect in the daily flight schedule. The number of delays and delay hours per year effect customer service. The airlines, through experience have determined the impact of the reduction in customer satisfaction due to delays on operational revenue. Flight delays also effect operating costs through schedule changes, down line flight cancellations, and lost passengers.



*Figure 6-9. Annual OBG System Flight Delay Hours*

**6.4 FLIGHT OPERATIONS**

The on-board ground inerting system allows for the availability of NEA for ground inerting techniques to be employed at any airport that the airplane is deployed to if an adequate electric power source is available. The system is designed to have adequate output to preclude delays beyond what are considered average turn times for that airplane. The system is designed to require minimal activation and supervision by the flight crew with little or no cockpit instrumentation and a simple on/off switch being redundant to automatic activation. Training for flight crew would be mostly educational to the system protections and functions and characteristics. Since it is largely automatic and if inoperative there would be additional training for crew and dispatchers in MEL provisions in order to allow dispatch of the airplane if repair is not possible at a station. The system should be designed to be failsafe so that no hazard is presented by its operation to passenger or ground personnel.

A moderate weight penalty is incurred in carrying this system on board and manifested in additional fuel burn. However, there is no power drain requirement during flight.

**6.5 GROUND OPERATIONS**

Both GBIS and OBGIS are operating only on the ground. The major difference between GBI and OBGIS is that inerting with the OBGIS is accomplished without the requirement for additional airport facilities, except for additional ground-power requirements. The OBGIS is a self-contained airplane system.

Maintenance training requirements should be incorporated within the initial training programs similar to those discussed earlier, but tailored to this specific design. One of the concerns that differ from the GBI is that the OBGIS would require constant monitoring, particularly while fuel tanks are being inerted before the first flight of the day. The system design is such that the systems will have to be turned on 2 hr before the first flight of the day. Once power is put on the airplane and the inerting system is turned on, a normal safety procedure requires that a maintenance technician must monitor the airplane for problems. This does not necessarily mean that an maintenance technician must sit in the cockpit, but someone must be close enough to respond to alarms or other problems. Activation and monitoring the airplane an hour earlier than is currently required adds a significant work to line maintenance during an already busy time of day.

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Other added responsibilities would be to ensure that the cabin is ventilated properly to ensure there is no possibility for a buildup of nitrogen in the cabin. These tasks would typically be the responsibility of the remain overnight technician. In the event a flight crewmember is not available, then a qualified technician should also monitor the inerting process during all through-flights. All other maintenance concerns typically go hand in hand with the concerns mentioned earlier with the GBIS.

## 7.0 ON-BOARD INERTING GAS GENERATING SYSTEM

This section discusses the modification of in-service aircraft to install an On-Board Inert Gas Generating System. The overall effect of OBIGGS on airplane operations and maintenance requirements are also described.

### 7.1 MODIFICATION

In Figure 7-1 the modification estimations for the OBIGGS are shown. Due to insufficient space for the OBIGGS in the unpressurized areas of regional fan, regional prop, and business jet category airplanes, these airplanes have been excluded from this report. For the other airplane categories estimations are made for both a regular heavy maintenance visit and a special visit. A detailed table with costs and labor-hours is shown in addendum F.A.1 and F.A.2.

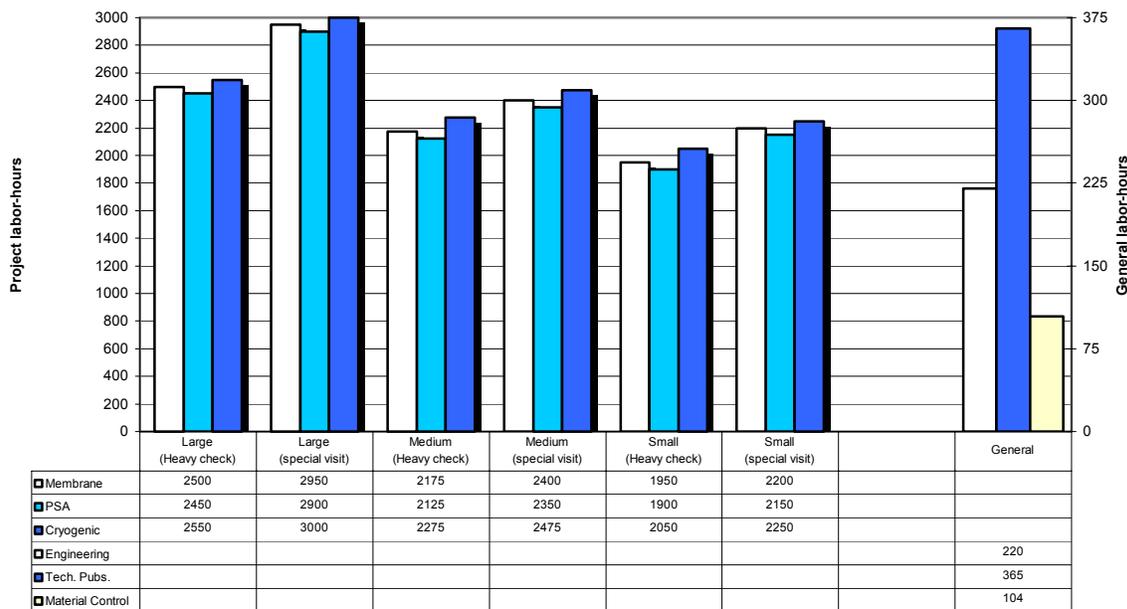


Figure 7-1. Modification Estimations for On-Board Inerting Gas Generating Systems

After installation of the OBIGGS systems it may be required to do an operational test flight. These test flight costs are not taken into account in the estimations.

## 7.2 SCHEDULED MAINTENANCE

### 7.2.1 Scheduled Maintenance Tasks

Concepts for two types of On-Board Inert Gas Generating Systems (OBIGGS) were developed, and considered separately by the Scheduled Maintenance sub-team. A list of scheduled maintenance tasks for an On-Board Inert Gas Generating Cryogenic System and for an On Board Inert Gas Generating Membrane System was developed using the system schematics provided by the On Board Design team. Each component illustrated in the schematic was evaluated individually and tasks were written

accordingly. These tasks included inspections, replacements, and operational/functional checks of the various components that make up the system. These tasks were assigned to the various checks (A, C, 2C and Heavy) and labor hours for each task were estimated. Figures F7.2.1-1 through Figure F7.2.1-6 (found in addendum F.B.1.) lists these tasks for each of the airplane types.

It was assumed that tasks completed at a C-check, would also be completed at a 2C-check. Similar assumptions were made for the 2C-check tasks (i.e. they would be accomplished at the Heavy check (or 4C-check equivalent)).

Both of the OBIGGS concepts consist of unique components, which require additional tasks when compared with the GBI and OBI systems. Thus, additional tasks are required, substantially increasing the extra man-hours required in the C, 2C and Heavy checks.

Due to the size and complexity of the OBIGGS concept, analysis was not completed for Turbofan, Turboprop, and business jets category airplanes.

**7.2.2 Pressure Check**

Extra labor-hours have been added to each C-check and Heavy check to perform a fuselage pressure decay check and rectification. OBIGGS uses cabin air as a supply for the inerting system, which increases the demand on the airplane air-conditioning packs. Consequently, the maximum allowable cabin leakage rate will have to be maintained at a lower level to ensure that the airplane air-conditioning packs will be able to continue to maintain the required cabin pressurization.

**7.2.3 Additional Maintenance Labor-Hours**

Figure 7-2 below shows the estimate of additional scheduled maintenance man-hours that would be required at each check to maintain a On-Board Inert Gas Generating Cryogenic System. And similarly, Figure 7-3 below shows the estimate of additional scheduled maintenance man-hours that would be required at each check to maintain an On-Board Inert Gas Generating Membrane System.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	55	74	87	124.03
Medium	3	55	74	91	126.03
Large	3	55	74	95	115.52

*Figure 7-2. Cryogenic System—Scheduled Maintenance Times*

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	50	65	76	113.96
Medium	3	50	65	80	114.58
Large	3	50	65	84	105.77

*Figure 7-3. Membrane System—Scheduled Maintenance Times*

**7.3 UNSCHEDULED MAINTENANCE**

The full OBIGGS inerting system is the most complex system of all the design concepts studied. The characteristics that make OBIGGS different for other systems studied from a reliability and maintainability standpoint are its size and its operating time.

Because OBIGGS operates during all phases of flight it has an additional effect on other airplane systems. The demand the inerting system puts on the airplane electrical power generation, cabin pressurization and engine bleed air systems will reduce the reliability and increase the maintenance requirements for these systems.

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The larger size and weight of the components in the OBIGGS system will make performing maintenance more difficult and in some cases may create an additional safety risk when lifting of the components during removal and installation.

### 7.3.1 System Annual Utilization Rate

The system annual utilization rate for OBIGGS reflects the amount of time that any of the systems would operate in one year. This figure was calculated from the airplane daily utilization rate plus the minimum turn times, multiplied by the number of daily cycles. The Large transport airplane with a high daily rate had the highest system annual utilization rate, the small transport coming a close second due to its high daily cycles.

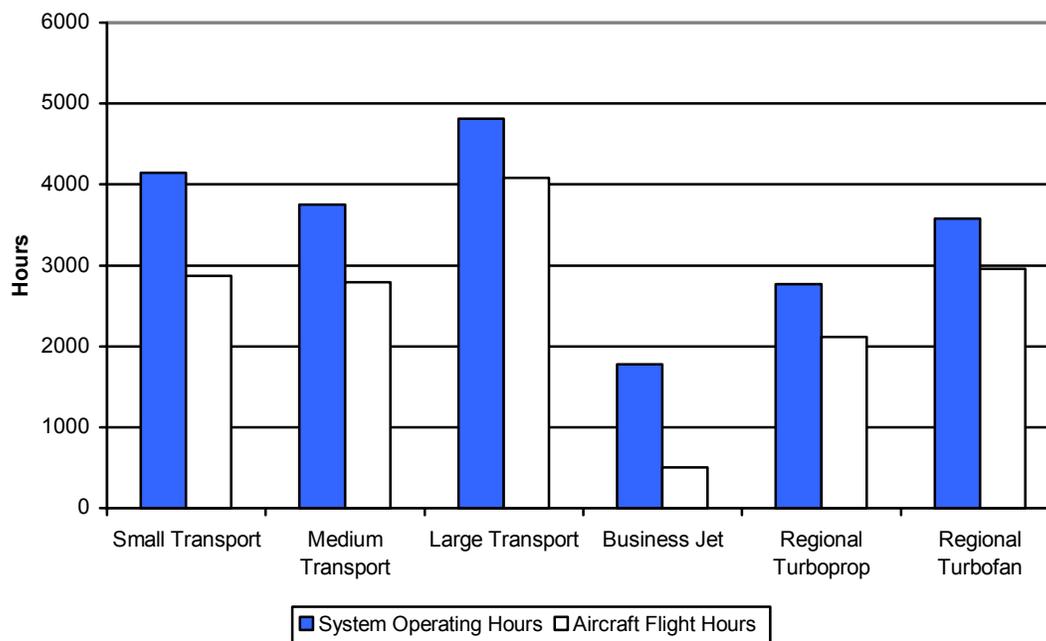


Figure 7-4. System Annual Utilization Rate

### 7.3.2 Component Reliability

To estimate the impact and related costs associated with the operation & maintenance of an OBIGGS system it was necessary to first establish a likely system reliability figure. From the system design it was possible to compile a list of components for each system. In most cases it was possible to use historical data from similar components to suggest a OBIGGS component mean time between unscheduled removal MTBUR. Where possible, more than one similar component was used.

One example of component reliability calculation was the OBIGGS shutoff valve. This valve would typically be a motorized butterfly type valve, which is to be found in many positions on different airplanes. Several similar valves were identified and using the historical component MTBUR data from more than one operator an average MTBUR figure was calculated. The OBIGGS design team suggested an MTBF of 50,000 hrs, the average MTBUR figure was in fact calculated at 38,315 hrs. This differential was expected and indeed confirmed that this method of MTBUR calculation was valid

Where insufficient historical data was available, a mean time between failure MTBF figure, set by the system design team, or a most likely figure, based on team members experience, was used.

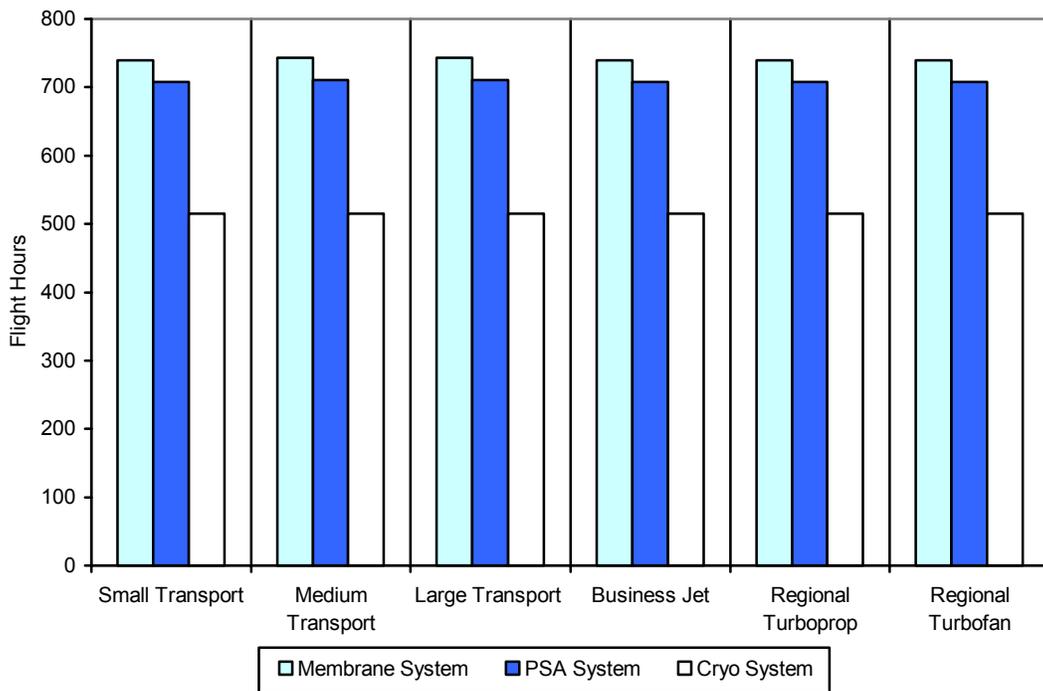
Establishing the component reliability in the form of a MTBUR figure was crucial in determining the system reliability and in enabling the Team to determine not only the component and system annual failure rate but also overall impact on airplane maintenance and operations that result from system failures.

- System Weight
- Cost to carry per airplane per year (\$)
- System Availability (driven by no of days MMEL. relief)
- Delays Per Year (Hours)
- Delay Costs Per Airplane Per Year (\$) and
- MMEL relief ranging from none to 120 days.

**7.3.3 System Reliability**

The MTBUR for the system was then determined from the individual component estimates.

An effort was made to determine the difference in MTBUR between airplane categories. Where there was sufficient component data available we found that there was little difference in MTBUR’s between the different airplane sizes. It was felt that it did not prove to be a significant factor in further calculations. Therefore with the resources available these figures were not developed further.



*Figure 7-5. System MTBUR*

**7.3.4 System Annual Failure Rate**

Using the component MTBURs and the airplane yearly utilization rate the annual failure rate for each component was calculated. The system annual failure rate was the sum of these component annual failure rates.

## Airplane Operation and Maintenance Task Team Final Report

As expected due to the increased system complexity and the maturity of the cryogenic a PSA system technology, the OBIGGS system has a much higher predicted failure rate. This calculation was crucial for many further calculations such as the system availability and the effects of different MMEL repair periods.

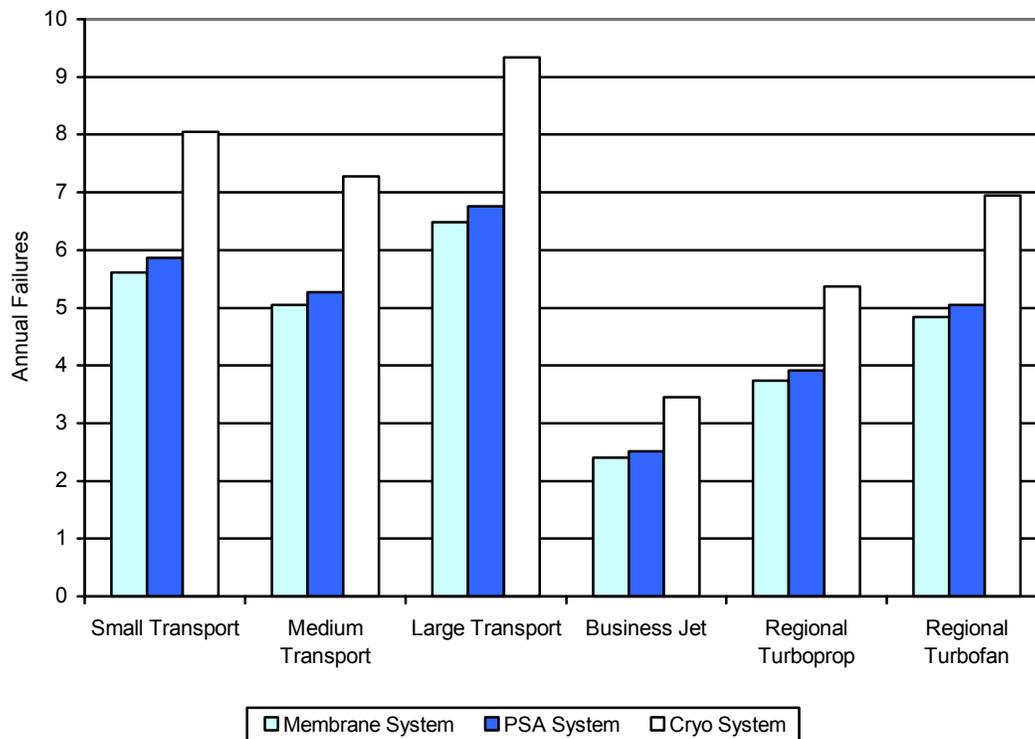


Figure 7-6. System Annual Failure Rate

### 7.3.5 Unscheduled Maintenance Labor Estimate

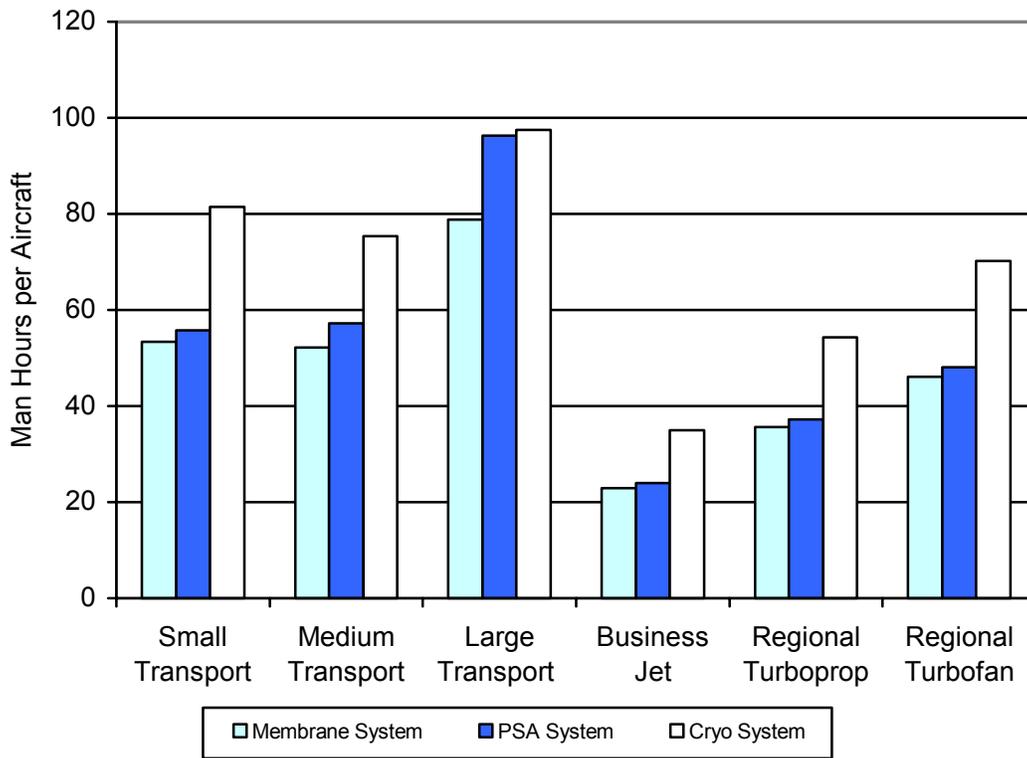
The amount of additional workload an OBIGGS system would add to an airplane maintenance requirements is a function of the annual failure rate and the component maintenance time, which in turn is a combination of the following:

- Component Removal & Replacement Time
- Component Access Time
- Trouble-Shooting Time

To calculate the labor hours per year some assumptions have been made as to the locations of the components. For example the heaviest components would be located in areas that would allow access with lifting equipment, e.g., air conditioning bay or wing to body fairing areas. Each component was individually assessed and the time to troubleshoot, access and remove and replace estimated based on similar tasks on existing airplanes.

The figures calculated refer only to the hours taken to rectify OBIGGS failures. It does not take into consideration the additional hours to maintain other airplane systems that are required to support OBIGGS (i.e. electrical or pneumatic systems) or systems effected by OBIGGS (i.e., cabin pressurization).

These figures may appear to be minimal but where an operator has many airplanes arriving and departing within a short period of time existing staffing levels may not be able to perform the rectification tasks and additional staff will need to be recruited. This additional manpower requirement is very difficult to quantify and has not been included. Therefore, the labor hour estimate is presented as an indicator of the requirement for an increased number of maintenance technicians.



*Figure 7-7. Additional Annual Labor Hours*

**7.3.6 Annual Labor Costs**

This is a product of the additional unscheduled labor hours per year and the FAA’s standard burdened labor rate for airplane maintenance technicians of \$75/ hour

The costs shown are for the additional labor hours only. Operators may have to hire additional staff to fulfill these requirements, resulting in an increased financial burden for recruitment, administration and training of the required staff.

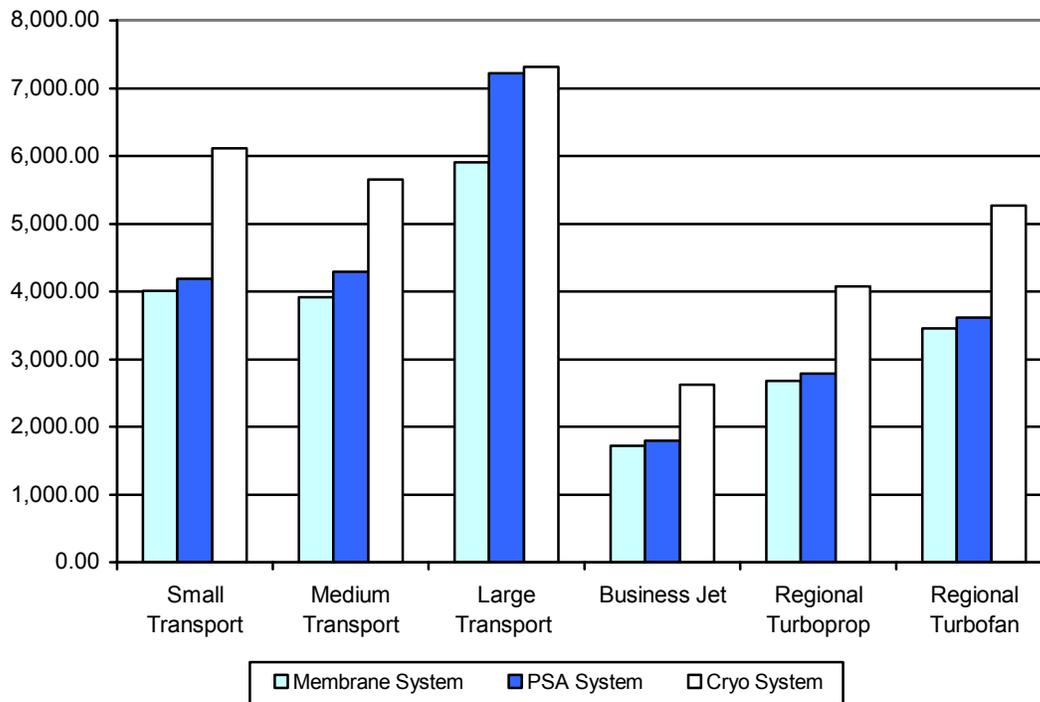


Figure 7-8. Additional Annual Labor Costs (\$)

**7.3.7 System Weight**

System weight has been calculated from the sum of the component weights specified by the design teams. The additional weight of the system installed on an airplane will not be limited to just the additional components. This estimate does not include the added weight of structural modifications to support heavy components.

Many operators are trying hard to reduce the weight of their airplanes in an effort to achieve best economy.

This system weight has been used to calculate the cost to carry per airplane per year (\$)

**7.3.8 Cost to Carry per Airplane per Year (\$)**

The cost to carry value is a figure given just to carry the additional weight of the system on an airplane for one year and represents the additional fuel burn. It is calculated from the system weight and a variable input, Cost To Carry Per lb. Per Year \$.

**7.3.9 System Availability**

System availability is a product of System Annual Failure Rate and the variable input, MMEL repair interval. For example, if the system has a failure rate of 5 times per year and has 10 days MMEL relief the worst case scenario could mean that it is inoperative for 50 days per year or 14% of the time. This would result in a system availability rate of 86%.

As mentioned earlier in this report the potential impact of three-day and ten- day MEL repair intervals were evaluated. Because system repairs are frequently accomplished in less time then the allowed per the MEL repair interval limits, assumptions were made concerning the average amount of time an inerting system would be inoperative under MEL relief. Under the two-day MEL relief repair interval it is

assumed that the average system would be inoperative for 2 days. For the ten-day MEL relief repair interval the average system would be inoperative for 7 days.

The complexity of OBIGGS and the immaturity of both the PSA & Cryogenic inerting technology result in a relatively high System annual failure rate, which drives the system availability rate down. Information from the Safety Analysis Team suggested a system availability of 97.5% is desired to ensure that the predicted benefits of the concept are ensured. On most OBIGGS systems, to achieve over 97% availability an MMEL repair interval of 1 day is required but will seriously impact airline operations.

The chart below shows a comparison of the system availability of the membrane system with one, three and 10 days relief.

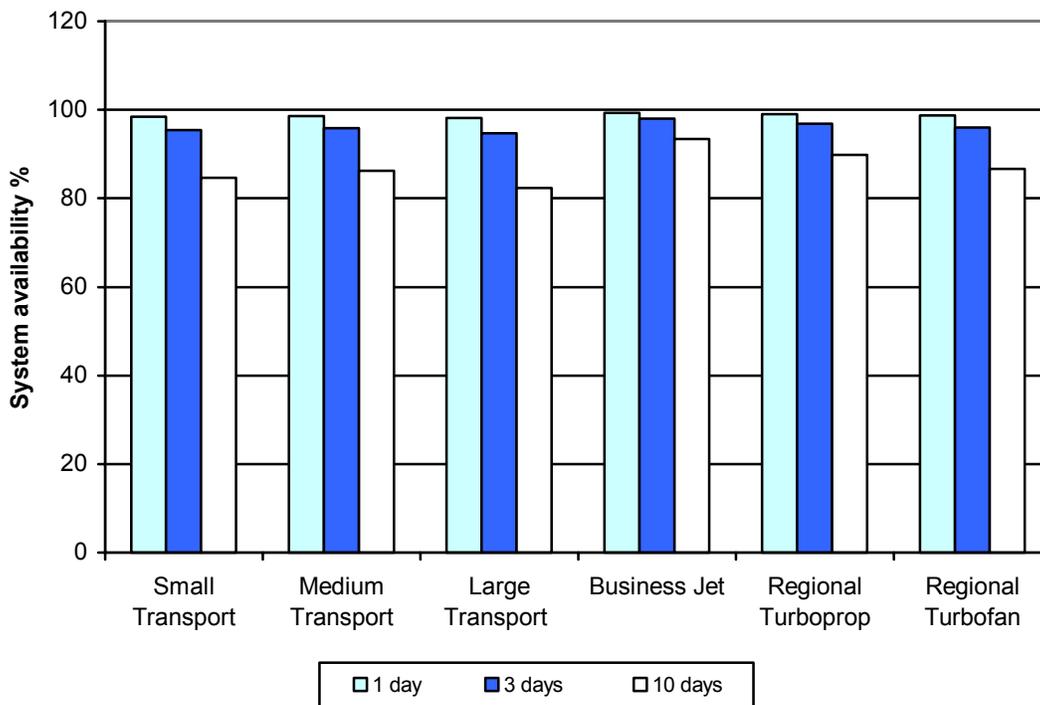


Figure 7-9. System Availability (10 Days MMEL Relief)

**7.3.10 Delays per Year (Hours)**

This figure has been arrived at by making a Delay Assumption that if an airplane has a fault in the system it will take a period of time for the mechanics to assess the situation, perform any maintenance action in accordance with the MMEL and complete any paperwork. Each airplane type has a delay assumption value which when multiplied by the component annual failure rate results in a total time delay for each component. The sum of the component delays results in the total annual system delay time, (hours).

World reliability figures are measured against delays and cancellations. Customers are often driven by such figures and operators make every effort to ensure on time departures. Such delays and cancellations not only directly effect operators with costs of customer accommodation and remuneration but loss of repeat custom and reputation are effected.

The causes of such delays and cancellations are actively pursued by operators with a view to reducing them to the minimum, adding another system to the airplanes which could effect such figures is of great importance to operators.

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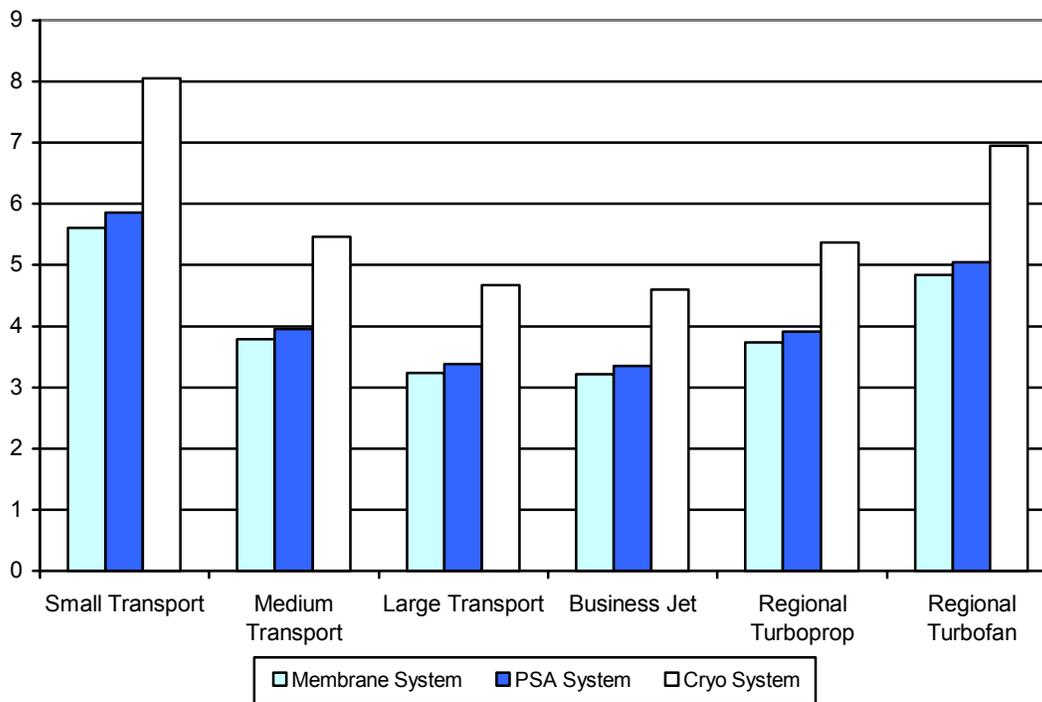


Figure 7-10. Delays per Year (Hours)

### 7.3.11 MMEL Repair Period

It was possible to estimate the financial effects of the different MMEL repair periods.

The repair periods studied include one, three and ten days relief. As previously discussed a one day repair period will result in the fleet system availability average being above 98%, three days would be 95.5% and ten days would mean a fleet system availability of 85.1%

It was necessary to presume what percentage of the annual failure rate would result in cancellations and correspondingly delays. These were judged accordingly with the different MMEL repair periods. These percentages can be seen in the chart below.

As an example: for the small transport airplane with a one day repair period 20% of the annual system failures will result in cancellations and 80% of failures will result in a delay equal to the delay assumption.

MMEL Repair Interval/ Service Cancellation			
	1 day	3 days	10 days
Small Transport	20%	5%	3%
Medium Transport	18%	4%	2%
Large Transport	15%	3%	1%
Business Jet	18%	4%	2%
Regional Turboprop	20%	5%	3%
Regional Turbofan	20%	5%	3%

Figure 7-11. MMEL Repair Interval/Service Cancellations (%)

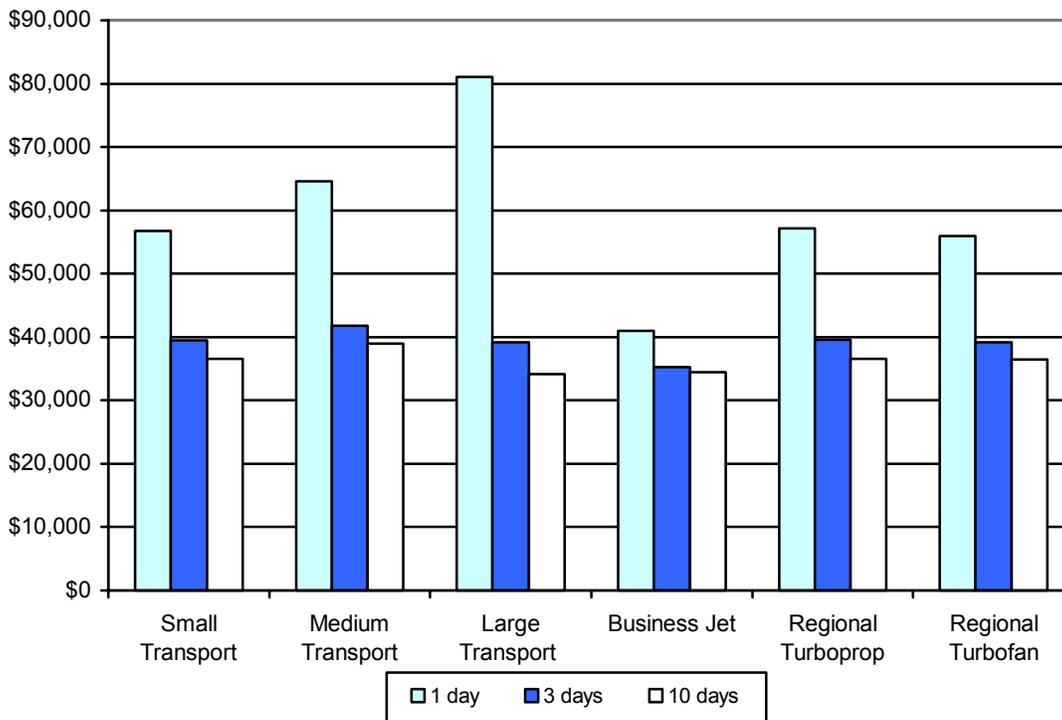
**7.3.12 Cancellation/Delay Costs**

Operators quantify cancellations and delays at rates that were deemed as propriety information but the figures used were agreed as a good representation of the costs involved and is shown in the chart below.

Cancellation / Delay Costs \$		
	Cancellation \$ per event	Delay \$ per hour
Small Transport	\$7,600	\$6,000
Medium Transport	\$20,000	\$8,490
Large Transport	\$32,600	\$10,980
Business Jet	\$7,600	\$6,000
Regional Turboprop	\$7,600	\$6,000
Regional Turbofan	\$7,600	\$6,000

*Figure 7-12. Cancellation/Delay Costs*

The following chart shows the predicted relationship between the MMEL repair period and the cancellation and delay costs for the membrane system only across the six airplane types. Where a cancellation is experienced it is presumed that half of the flights for that airplane for that day will be lost. This was felt appropriate for all airplane types except the large transport airplanes where both of the flights for that day will be lost. The figures reflect this assumption accordingly.



*Figure 7-13. Comparisons of Costs and Repair Intervals*

**7.3.13 Personnel Safety**

It is a major concern, for the operators and ground service agencies that by installing an inerting system the safety of personnel could be threatened. The danger to personnel entering confined spaces that could be contaminated with NEA is a real possibility. With an OBIGGS system that is operating all the time the airplane is in service and the possibility of the NEA atmosphere remaining in confined spaces after

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service it is a very real possibility that this system could damage or take more lives than it is intended to save. In most developed countries health and safety legislation is adhered to a lot of the time but in designing a system that reduces oxygen in some of the airplane confined spaces we could be building a trap for people to fall into.

Another major concern is the size and weight of some of the components in the various systems. These range from lightweight valves and other components to heavy compressors, heat exchangers, cryocoolers and air separation modules. These range in weight from 100 lbs. to over 225 lbs. There is a recognized need for specialist lifting equipment but the risk of damage and injury from falling heavy components would exist where it previously did not.

### **7.3.14 OBIGGS Effects on Other Airplane Systems**

The installation of an OBIGGS system on an airplane will effect the reliability and cost of operation for other airplane systems. The OBIGGS system concepts studied by this working group would add a very large additional electrical load on the airplane electrical system. The OBIGGS system also relies on the airplane pneumatic system as a supplemental air supply increasing the demand on this system. Last but not least in an attempt to reduce the size and power requirements of the OBIGGS air compressors the design team chose to take the systems supply air from the passenger cabin. This will put an additional demand on the cabin air-conditioning & pressurization systems.

#### **Electrical Power Generation**

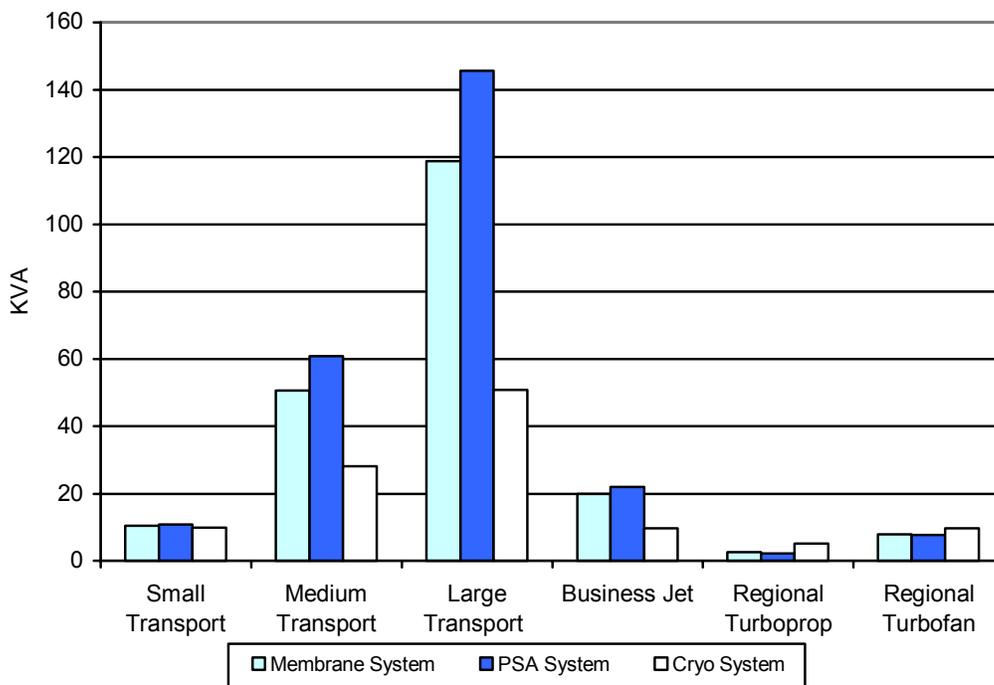
The power requirements of the OBIGGS systems may exceed the current available power.

For example, it can be seen from the chart below that the large transport airplanes will require between 115 and 145 KVA. A typical B747 Classic will produce a max continuous rate of 216 KVA of which 175 KVA is required in cruise leaving a maximum of 41 KVA. A further consideration is that this remaining power would be distributed between four power supply buses that cannot be permanently linked together.

A B747-400 can produce more power due to greater capacity generators but greater loads are required and the remaining power is again spread between power supply buses that cannot be permanently linked.

Depending on the airplane the increased power demands may require an increase to the capacity of the power generating system. The cost of increasing the electrical system capacity and the cost of maintaining a larger system were not calculated. Increasing system capacity would require larger generators, heavier wiring, and modifications to the electrical busses to handle the loads. This may not even be an option on some airplanes due to engine limitations. Needless to say these changes would be expensive and time consuming.

Increased capacity power generating systems will increase unscheduled maintenance requirements. This additional unscheduled maintenance figure has not been quantified either.



*Figure 7-14. OBIGGS Power Requirements (kVA)*

*Airplane Pressurization System*

As previously discussed in the scheduled maintenance section, extra man-hours have been added to the scheduled maintenance checks to perform a fuselage pressure decay check and accomplish repairs. Most operators’ experience that has shown that airplanes, which are currently in service, periodically require this pressure decay check in order to maintain leakage limits prescribed in airplane maintenance manuals.

Because OBIGGS take air off the cabin, operators will have to reduce the allowable cabin air leakage rate to compensate for the demand and maintain a safety margin.

Should a leak occur during operation it may not allow the OBIGGS system, which uses some cabin air pressure, to be operated and instead of allowing the airplane to continue in service until the next scheduled pressure decay check immediate rectification will be required.

These extra-unscheduled maintenance costs have not been quantified.

*Bleed Air System*

Bleed air is also used by OBIGGS systems. Where this system interfaces with OBIGGS, utilization and associated scheduled & unscheduled maintenance will be increased. This increase in unscheduled maintenance has again not been quantified.

*Stock Holding*

The amount of spare components required to be held by an operator to ensure a reliable system varies according to system reliability, number of airplanes operated and the type of operation, ETOPS etc. It was not possible to make a detailed study of the costs for all systems and airplane types but from the figures already calculated it was possible to see that a pool of spares of \$900,000 plus would be required to operate one airplane with a membrane system. This figure is a conservative estimate and does not take into account the storage, transportation, administration or capital investment costs or indeed any lease fees.

## **7.4 FLIGHT OPERATIONS**

OBIGGS provides full time inerting protection in normal operations including descent, landing and post landing incidents that might present a tank ignition hazard. The system should be designed to be fully automatic and to be automatically shed in the case of engine power, electrical, bleed source or cabin pressure failures. It is assumed that it will be monitored by the flight management systems and annunciation of failure modes will be provided to the flight crew for recording in the maintenance log. Little if any cockpit instrumentation should be provided since inerting is considered to be a safety enhancement with MEL provisions and the crew is not expected to trouble shoot it to reactivate the system or discontinue routing operations. Some basic descriptions of the inerting concept and the OBIGGS equipment, location, power sources, heat exchangers, etc. need to be provided as additional training but should be limited to need to know. "If the crew cannot affect it, don't train for it." Both flight crew and dispatch personnel will be trained as far as MEL operating rules and the airplane may need to be re-routed to a suitable repair facility. The OBIGGS system will draw power, bleed air, and incur drag from intercooler openings and the increased fuel burn costs and will result in reduced range and endurance. Some long haul and international routes could be impacted.

## **7.5 GROUND OPERATIONS**

The Onboard Gas Generating System after installation ideally would solve many of the ground base concerns and issues expressed earlier. It is the group's opinion that a continual monitoring system be installed on the flight deck to insure proper inerting is taking place during the more critical phases of the airplane route structure such as taxi and takeoff. Any anomalies should immediately put on a master caution light to alert the flight crew. The flight crew would then have the ability to shut the system down if need be. Such as the APU fire warning system on many commercial airplanes, an aural warning system should be considered while the airplane is on the ground, in the event this system malfunctions without a flight crewmember on board.

A valid concern was raised with the possibility of nitrogen entering the cabin during continuous inerting with this system. Considerations should be given to redundancy with the material used to enhance safety for passengers and crewmembers. An example would be using double wall pipe for plumping purposes, and installing nitrogen sensors in the cabin.

Maintenance training procedures fall within the above mentioned training recommendations, and would merely be tailored again to the system desired for installation.

## **8.0 HYBRID ON-BOARD INERTING SYSTEMS**

From an airplane operations and maintenance perspective there is very little difference between the full OBGI/OBIGG systems and the hybrid systems. The Airplane Operations & Maintenance Team looked at the hybrid systems but when it was determined that the system were nearly identical from this perspective, further work was discontinued. The reader may assume that the maintenance, operations and modifications impact described in the OBGIS and OBIGGS sections applies to the hybrid systems.

## **9.0 CONCLUSION**

Although the fuel tank inerting system may enhance the safety of the airplanes fuel systems, there are several areas that still need to be addressed. The following are the concerns of this task group:

- The tasking statement does not clarify if inerting systems are classified as a safety system or fuel system enhancement. The assumption that inerting systems are not required for safety of flight and are designed and maintained as such is fundamental to the conclusions of this report.
- Any inerting system would introduce additional safety risks to flight crew, passengers, and maintenance personnel. Additional safety procedures would need to be put in place to mitigate these risks.

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- If implemented, the requirement to retrofit inerting systems may place an unacceptable burden on the aircraft maintenance industry. Depending on the time scales there may not be sufficient facilities or personnel available to embody the modifications.
- The poor reliability of current on-board inerting system technology would restrict the introduction of fuel tank inerting systems on commercial aircraft. An improvement in reliability by an order of magnitude would be required to make them operationally viable.
- The implementation costs would be extremely high. Even if the inerting equipment was provided and installed for free, the cost to carry, maintenance and operational costs would exceed the benefits calculated in this document.

For all proposed inerting systems, additional maintenance labor hours will be required to maintain the system. This may require:

- The extension of the regular scheduled maintenance checks
- Additional maintenance checks
- Unscheduled unserviceability
- Contract maintenance assistance
- Additional hangar space

All of the above would lead to an increase in maintenance costs. Figures F3.3-1 through F3.3-6 in addendum F.B.1. compare the additional maintenance labor-hour estimates for each proposed system by airplane category.

### **REFERENCE**

1. Occupational Safety & Health Administration (OSHA), *Accidents Database*. UK Health & Safety Executive, Safe Work in Confined Spaces.
2. Major Phillip Parker, *USAF School of Aerospace Medicine*, Potential Health Effects of Nitrogen Inerting of Commercial Airline Fuel Systems - Dec 2000

ADDENDUM F.A.1

***MODIFICATION COST & LABOR-HOUR ESTIMATION***

to

APPENDIX F

**AIRPLANE OPERATION AND MAINTENANCE  
FINAL REPORT**

***Airplane Operation and Maintenance Task Team Final Report***

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## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

## LARGE AIRPLANE CATEGORY

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Rotable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	1300	\$ 97,500	1050	\$ 78,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>1423</b>	<b>\$ 2,129,230</b>	<b>1173</b>	<b>\$ 110,480</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD GROUND INERTING SYSTEM**

LARGE AIRPLANE CATEGORY - MEMBRANE

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2650	\$ 198,750	2200	\$ 165,000	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2773</b>	<b>\$ 2,230,480</b>	<b>2323</b>	<b>\$ 196,730</b>	<b>Per airplane</b>

**MODIFICATION COST & LABOR-HOUR ESTIMATION**  
**ON-BOARD GROUND INERTING SYSTEM**  
 LARGE AIRPLANE CATEGORY - PRESSURE SWING ADSORBITION

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2600	\$ 195,000	2150	\$ 161,250	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2723</b>	<b>\$ 2,226,730</b>	<b>2273</b>	<b>\$ 192,980</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**ON-BOARD GROUND INERTING SYSTEM**

LARGE AIRPLANE CATEGORY - CRYOGENIC

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2700	\$ 202,500	2250	\$ 168,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2823</b>	<b>\$ 2,234,230</b>	<b>2373</b>	<b>\$ 200,480</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

LARGE AIRPLANE CATEGORY - MEMBRANE

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2950	\$ 221,250	2500	\$ 187,500	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>3073</b>	<b>\$ 2,252,980</b>	<b>2623</b>	<b>\$ 219,230</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

LARGE AIRPLANE CATEGORY - PRESSURE SWING ADSORPTION

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2900	\$ 217,500	2450	\$ 183,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>3023</b>	<b>\$ 2,249,230</b>	<b>2573</b>	<b>\$ 215,480</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

LARGE AIRPLANE CATEGORY - CRYOGENIC

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	3000	\$ 225,000	2550	\$ 191,250	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane				\$ 2,000,000		\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>3123</b>	<b>\$ 2,256,730</b>	<b>2673</b>	<b>\$ 222,980</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

MEDIUM AIRPLANE CATEGORY

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	1100	\$ 82,500	1050	\$ 78,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>1223</b>	<b>\$ 114,230</b>	<b>1173</b>	<b>\$ 110,480</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD GROUND INERTING SYSTEM**

MEDIUM AIRPLANE CATEGORY - MEMBRANE

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2150	\$ 161,250	1925	\$ 144,375	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane							Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2273</b>	<b>\$ 192,980</b>	<b>2048</b>	<b>\$ 176,105</b>	<b>Per airplane</b>

**MODIFICATION COST & LABOR-HOUR ESTIMATION**  
**ON-BOARD GROUND INERTING SYSTEM**  
MEDIUM AIRPLANE CATEGORY - PRESSURE SWING ADSORPTION

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2100	\$ 157,500	1875	\$ 140,625	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane							Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2223</b>	<b>\$ 189,230</b>	<b>1998</b>	<b>\$ 172,355</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD GROUND INERTING SYSTEM**

CRYOGENIC AIRPLANE CATEGORY - CRYOGENIC

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2225	\$ 166,875	2025	\$ 151,875	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane							Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2348</b>	<b>\$ 198,605</b>	<b>2148</b>	<b>\$ 183,605</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

MEDIUM AIRPLANE CATEGORY - MEMBRANE

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2400	\$ 180,000	2175	\$ 163,125	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2523</b>	<b>\$ 211,730</b>	<b>2298</b>	<b>\$ 194,855</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

MEDIUM AIRPLANE CATEGORY - PRESSURE SWING ADSORPTION

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2350	\$ 176,250	2125	\$ 159,375	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2473</b>	<b>\$ 207,980</b>	<b>2248</b>	<b>\$ 191,105</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

MEDIUM AIRPLANE CATEGORY - CRYOGENIC

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2475	\$ 185,625	2275	\$ 170,625	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2598</b>	<b>\$ 217,355</b>	<b>2398</b>	<b>\$ 202,355</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

LARGE AIRPLANE CATEGORY

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	1200	\$ 90,000	1050	\$ 78,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>1323</b>	<b>\$ 121,730</b>	<b>1173</b>	<b>\$ 110,480</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**ON-BOARD GROUND INERTING SYSTEM**

SMALL AIRPLANE CATEGORY - MEMBRANE

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2000	\$ 150,000	1750	\$ 131,250	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane							Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2123</b>	<b>\$ 181,730</b>	<b>1873</b>	<b>\$ 162,980</b>	<b>Per airplane</b>

**MODIFICATION COST & LABOR-HOUR ESTIMATION**  
**ON-BOARD GROUND INERTING SYSTEM**  
 SMALL AIRPLANE CATEGORY - PRESSURE SWING ADSORBTION

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	1950	\$ 146,250	1700	\$ 127,500	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane							Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2073</b>	<b>\$ 177,980</b>	<b>1823</b>	<b>\$ 159,230</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD GROUND INERTING SYSTEM**

SMALL AIRPLANE CATEGORY - CRYOGENIC

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2050	\$ 153,750	1850	\$ 138,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane							Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2173</b>	<b>\$ 185,480</b>	<b>1973</b>	<b>\$ 170,480</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

SMALL AIRPLANE CATEGORY - MEMBRANE

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2200	\$ 165,000	1950	\$ 146,250	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
	16			\$ -		\$ -	Number of mechanics that follows the class.
<b>Flight Operations Engineering:</b>							
							Reviews the Engineering Project creates new W&B sheets and performance penalties
<b>Total Recurring</b>	<b>28</b>		<b>2315</b>	<b>\$ 182,650</b>	<b>2065</b>	<b>\$ 163,900</b>	<b>Per airplane</b>
<b>Reason of revision:</b>					<b>Estimated by:</b>	<b>Modification &amp; Retrofit Sub Team</b>	

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

SMALL AIRPLANE CATEGORY - PRESSURE SWING ADSORPTION

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2150	\$ 161,250	1900	\$ 142,500	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2273</b>	<b>\$ 192,980</b>	<b>2023</b>	<b>\$ 174,230</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**ON-BOARD INERTING GAS GENERATING SYSTEM**

SMALL AIRPLANE CATEGORY - CRYOGENIC

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	2250	\$ 168,750	2050	\$ 153,750	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>2373</b>	<b>\$ 200,480</b>	<b>2173</b>	<b>\$ 185,480</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

## REGIONAL TURBOFAN AIRPLANE CATEGORY

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	1100	\$ 82,500	900	\$ 67,500	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>1223</b>	<b>\$ 114,230</b>	<b>1023</b>	<b>\$ 99,230</b>	<b>Per airplane</b>

MODIFICATION COST & LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

REGIONAL TURBOFAN AIRPLANE CATEGORY (WITH BLADDER TANKS)

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	1750	\$ 131,250	1550	\$ 116,250	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>1873</b>	<b>\$ 162,980</b>	<b>1673</b>	<b>\$ 147,980</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

## REGIONAL TURBOPROP AIRPLANE CATEGORY

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75		\$ -		\$ -	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>123</b>	<b>\$ 31,730</b>	<b>123</b>	<b>\$ 31,730</b>	<b>Per airplane</b>

## MODIFICATION COST &amp; LABOR-HOUR ESTIMATION

**GROUND BASED INERTING SYSTEM**

BUSSINESS JET AIRPLANE CATEGORY

Task	Number of Persons	Rate	Special Program		D/M - Check		Description
			Man Hours	Cost	Man Hours	Cost	
<b>NON-RECURRING</b>							
<b>Engineering</b>							
Service Bulletin review	1	\$ 110	30	\$ 3,300	30	\$ 3,300	Evaluating Service Bulletin
Engineering Data	1	\$ 50	35	\$ 1,750	35	\$ 1,750	Enters the work card requirements into the data base.
Engineering Drafting	1	\$ 110	25	\$ 2,750	25	\$ 2,750	Creates the necessary drawings and figures necessary for the project.
Inventory Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering BOM and does all material provisions and allocations
Planning	1	\$ 110	20	\$ 2,200	20	\$ 2,200	Reviews the Engineering Project and provides information for accomplishment.
Maintenance Programs	1	\$ 110	35	\$ 3,850	35	\$ 3,850	Reviews the Engineering Project for effect on other projects, tasks and jobcards.
Records	1	\$ 50	10	\$ 500	10	\$ 500	Creates the necessary Project tracking numbers and maintains the records.
Quality Assurance	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Reviews the Engineering Project for Regulatory compliance.
Reliability	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Tracks and maintains the records for all the components and their trends. FAR requirement.
<b>Tech Publications</b>							
Manuals: AMM	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Aircraft Maintenance Manual
IPC	1	\$ 50	20	\$ 1,000	20	\$ 1,000	Illustrated Parts List
CMM	1	\$ 50	10	\$ 500	10	\$ 500	Component Maintenance Manual
AFM	1	\$ 50	10	\$ 500	10	\$ 500	Aircraft Flight Manual
FOM	1	\$ 50	10	\$ 500	10	\$ 500	Flight Operations Manual
SRM	1	\$ 50	10	\$ 500	10	\$ 500	Structural Repair Manual
FUELLING	1	\$ 50	15	\$ 750	15	\$ 750	Fuelling Manual
RMM	1	\$ 50	10	\$ 500	10	\$ 500	Ramp Manual
GMM	1	\$ 50	40	\$ 2,000	40	\$ 2,000	General Maintenance Manual that includes Company's Procedures
WDM	2	\$ 50	150	\$ 7,500	150	\$ 7,500	Wire Diagram Manual
Training Documentation	1	\$ 75	15	\$ 1,125	15	\$ 1,125	Making of necessary training documentation
Training Material				\$ 1,000		\$ 1,000	Material
<b>Material Control</b>							
Routable parts	1	\$ 50	43	\$ 2,125	43	\$ 2,125	Make known the Routable into the company systems
Consumable parts	1	\$ 50	25	\$ 1,250	25	\$ 1,250	Make known the Consumables into the company systems
Spares estimation	1	\$ 50	8	\$ 400	8	\$ 400	The amount of spares depending on the MTBUR
Tooling	1	\$ 50	30	\$ 1,500	30	\$ 1,500	Make known the Tooling into the company systems
<b>RECURRING</b>							
<b>Project's Estimated Time</b>							
Accomplishment	10	\$ 75	500	\$ 37,500		\$ -	See Addendum F.A.2 for detailed tasks
Engineering support	1	\$ 110	100	\$ 11,000	100	\$ 11,000	Support to hangar during modification
Kit costs							Kit costs is not included. Design Team didn't provided the data.
Kit Storage costs							No kit data available
Extra down time airplane						\$ -	Extra time airplane is on ground due to this modification. Including lost of revenue & hangar space.
<b>Training</b>							
Instructors	1	\$ 110	15	\$ 1,650	15	\$ 1,650	This is the cost for 1 training class only. A correct estimation was not feasible. Giving class + preparation time
Training Classroom				\$ 5,000		\$ 5,000	Average rent cost for classroom
Training Mechanics	16	\$ 110	8	\$ 14,080	8	\$ 14,080	Number of mechanics that follows the class.
<b>Total NON-Recurring</b>	<b>25</b>		<b>641</b>	<b>\$ 41,200</b>	<b>641</b>	<b>\$ 41,200</b>	<b>Per airplane type/ per operator</b>
<b>Total Recurring</b>	<b>28</b>		<b>623</b>	<b>\$ 69,230</b>	<b>123</b>	<b>\$ 31,730</b>	<b>Per airplane</b>

***Airplane Operation and Maintenance Task Team Final Report***

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**ADDENDUM F.A.2**

***MODIFICATION PROJECT LABOR-HOUR ESTIMATION***

**to**

**APPENDIX F**

**AIRPLANE OPERATION AND MAINTENANCE**

**FINAL REPORT**

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Airplane type:		Description:	Special Program	Heavy Check
LARGE (Boeing 747)		Ground Based Inerting Systems		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	43	0	
Mech.	Defuel and drain CW tank	4	0	
Mech.	Open, ventilate and close after modification CW tank	29	0	
Avio.	Open/close aft side of MEC	3	0	
Mech.	Remove/reinstall RH seats, carpet, floorpanels above RH cable raceway sta 1000-1265	29	0	
Avio.	Remove/reinstall floorprox,seat to seat cables and raceways RH sta 1000-1265	14	0	
Mech.	Remove/reinstall ceiling panels in fwd cargo compt. for access to cable raceways	7	0	
Mech.	Remove/install in A zone LH seats and side wall panels	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before modification	44	43	
Avio.	Install wiring between flight deck,MEC and new components located in airco. compt. 4	179	179	
Sht.mtl.	Install feed through structural provisions in CW tank aft skin at sta 1260	179	179	
Sht.mtl.	Install provisions for distribution manifold in CW tank	57	57	
Mech.	Install distribution manifold in CW tank	100	100	
Sht.mtl.	Install provisions for thermal relief valve and isolation valve installation	14	14	
Mech.	Install thermal relief valve and isolation valve	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	57	57	
Sht.mtl.	Inst. provisions for double wall pipe,witness drain etc. from fill panel to CW tank sta 1260	14	14	
Mech.	Inst. double wall pipe,witness drain etc. from fill panel to CW tank sta 1260	21	21	
Mech/Avio	Test ground based distribution system (3x)	29	29	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total labor-hours per aircraft</b>	<b>980</b>	<b>800</b>	
Mech/Avio	Inspection mechanics/avionics	132	96	
Sht.mtl.	Install heat exchanger on header assy	32	32	
	Round off/unforeseen work	157	122	
	<b>Total labor-hours including inspection</b>	<b>1300</b>	<b>1050</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
LARGE (Boeing 747)		ON-BOARD INERTING GAS GENERATING SYSTEM MEMBRANE		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	71	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	93	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	100	100	
Mech.	Remove/install several wing to body fairing panels R.H.	43	0	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	29	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin at sta.1000 R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin at sta.1000 R.H.	7	0	
Avio.	Open/close aft side of MEC	3	0	
Mech.	Remove/install in A zone LH seats and side wall panels	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before and after modification	74	69	
Avio.	Install wiring between flight deck,MEC and new components located in airco. compt. 4	286	286	
Sht.mtl.	Install provisions for filter installation in fwd. cargo compt. approx. at sta.980 RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in airco compt. 4	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Total labor-hours per aircraft	57	57	
Mech.	Inspection mechanics/avionics	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for water seperator/filter, low flow ASM and high flow ASM installation	131	131	
Mech.	Install water seperator/filter, low flow ASM and high flow ASM systems	29	29	
Avio.	Install water seperator/filter, low flow ASM and high flow ASM systems	29	29	
Mech.	Install ducting from heat exch.to water seperator/filter, low flow/high flow ASM systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for high flow valve and relief valve installation	21	21	
Mech.	Install high flow valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank at sta. 1000	179	179	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (airco compt 4 to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank sta.1000	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 7 fuel tanks	143	143	
Mech.	Install NEA gas distribution system in all 7 fuel tanks	286	286	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total labor-hours per aircraft</b>	<b>2290</b>	<b>1940</b>	
Mech/Avio	Inspection mechanics/avionics	290	220	
Sht.mtl.	Inspection sheetmetal	84	84	
	Round off/unforeseen work	286	256	
	<b>Total labor-hours including inspection</b>	<b>2950</b>	<b>2500</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
LARGE (Boeing 747)		ON-BOARD INERTING GAS GENERATING SYSTEM PRESSURE SWING ABSORPTION		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	71	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	93	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	100	100	
Mech.	Remove/install several wing to body fairing panels R.H.	43	0	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	29	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin at sta.1000 R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin at sta.1000 R.H.	7	0	
Avio.	Open/close aft side of MEC	3	0	
Mech.	Remove/install in A zone LH seats and side wall panels	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before and after modification	74	74	
Avio.	Install wiring between flight deck,MEC and new components located in airco. compt. 4	286	286	
Sht.mtl.	Install provisions for filter installation in fwd. cargo compt. approx. at sta.980 RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in airco compt. 4	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Total labor-hours per aircraft	57	57	
Mech.	Inspection mechanics/avionics	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for water seperator/filter and ASM installation	100	100	
Mech.	Install water seperator/filter and ASM systems	21	21	
Avio.	Install water seperator/filter and ASM systems	21	21	
Mech.	Install ducting from heat exch.to water seperator/filter, low flow/high flow ASM systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for high flow valve and relief valve installation	21	21	
Mech.	Install high flow valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank at sta. 1000	179	179	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (airco compt 4 to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank sta.1000	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 7 fuel tanks	143	143	
Mech.	Install NEA gas distribution system in all 7 fuel tanks	286	286	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total labor-hours per aircraft</b>	<b>2245</b>	<b>1900</b>	
Mech/Avio	Inspection mechanics/avionics	287	218	
Sht.mtl.	Inspection sheetmetal	81	81	
	Round off/unforeseen work	287	251	
	<b>Total labor-hours including inspection</b>	<b>2900</b>	<b>2450</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
LARGE (Boeing 747)		ON-BOARD INERTING GAS GENERATING SYSTEM CRYOGENIC		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	71	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	93	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	100	100	
Mech.	Remove/install several wing to body fairing panels R.H.	43	0	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	29	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin at sta.1000 R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin at sta.1000 R.H.	7	0	
Avio.	Open/close aft side of MEC	3	0	
Mech.	Remove/install in A zone LH seats and side wall panels	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before and after modification	74	74	
Avio.	Install wiring between flight deck,MEC and new components located in airco. compt. 4	286	286	
Sht.mtl.	Install provisions for filter installation in fwd. cargo compt. approx. at sta.980 RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in airco compt. 4	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Total labor-hours per aircraft	57	57	
Mech.	Inspection mechanics/avionics	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for storage syst.,cryogenic refrigerator and distillation syst.installation	171	171	
Mech.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Avio.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Mech.	Install ducting from heat exchanger to refrigerator,distillation and storage systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for modulating valve and relief valve installation	21	21	
Mech.	Install modulating valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank at sta. 1000	179	179	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (airco compt 4 to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank sta.1000	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 7 fuel tanks	143	143	
Mech.	Install NEA gas distribution system in all 7 fuel tanks	286	286	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total labor-hours per aircraft</b>	<b>2345</b>	<b>2000</b>	
Mech/Avio	Inspection mechanics/avionics	293	224	
Sht.mtl.	Inspection sheetmetal	88	88	
	Round off/unforeseen work	274	238	
	<b>Total labor-hours including inspection</b>	<b>3000</b>	<b>2550</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type: <b>MEDIUM</b> <i>(Boeing 767)</i>		Description: <b>Ground Based Inerting Systems</b>	Special Program	Heavy Check
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	14	0	
Mech.	Defuel and drain CW tank	3	0	
Mech.	Open, ventilate and close after modification CW tank	21	0	
Avio.	Open/close aft side of E/E	3	0	
Mech.	Remove/reinstall RH seats, carpet, floorpanels above RH cable raceway sta 933	29	0	
Avio.	Remove/reinstall floorprox,seat to seat cables and raceways RH sta 933	14	0	
Mech.	Remove/reinstall ceiling panels in aft cargo compt. for access to cable raceways	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before modification	44	43	
Avio.	Install wiring between flight deck, E/E and new components located in tail cone	179	157	
Sht.mtl.	Install feed through structural provisions in CW tank aft skin at sta 955	179	157	
Sht.mtl.	Install provisions for distribution manifold in CW tank	57	57	
Mech.	Install distribution manifold in CW tank	100	100	
Sht.mtl.	Install provisions for thermal relief valve and isolation valve installation	14	14	
Mech.	Install thermal relief valve and isolation valve	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	57	57	
Sht.mtl.	Inst. provisions for double wall pipe,witness drain etc. from fill panel to CW tank sta 955	14	14	
Mech.	Inst. double wall pipe,witness drain etc. from fill panel to CW tank sta 955	21	21	
Mech/Avio	Test ground based distribution system (3x)	29	29	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total manhours per aircraft</b>	<b>935</b>	<b>757</b>	
Mech/Avio	Inspection mechanics/avionics	123	56	
Sht.mtl.	Inspection sheetmetal	32	48	
	Round off/unforeseen work	110	89	
	<b>Total manhours including inspection</b>	<b>1200</b>	<b>950</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
MEDIUM (Boeing 767)		ON-BOARD INERTING GAS GENERATING SYSTEM MEMBRANE		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	29	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	43	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	43	43	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	29	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin at sta.933 R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin at sta.933 R.H.	7	0	
Avio.	Open/close aft side of E/E	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	57	57	
Avio.	Install wiring between flight deck, E/E and new components located in tail cone	257	257	
Sht.mtl.	Install provisions for filter installation in bulk cargo compt. approx. at sta.1540 RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in tail cone	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Install provisions for header/ heat exchanger installation in tail cone	57	57	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for storage syst.,cryogenic refrigerator and distillation syst.installation	129	131	
Mech.	Install storage,cryogenic refrigerator and distillation systems	29	29	
Avio.	Install storage,cryogenic refrigerator and distillation systems	29	29	
Mech.	Install ducting from heat exchanger to refrigerator,distillation and storage systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for modulating valve and relief valve installation	21	21	
Mech.	Install modulating valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank at sta. 955	143	179	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (tail cone to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank sta.955	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 3 fuel tanks	107	107	
Mech.	Install NEA gas distribution system in all 3 fuel tanks	214	214	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>1857</b>	<b>1706</b>	
Mech/Avio	Inspection mechanics/avionics	218	180	
Sht.mtl.	Inspection sheetmetal	77	81	
	Round off/unforeseen work	248	233	
	<b>Total manhours including inspection</b>	<b>2400</b>	<b>2200</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
MEDIUM (Boeing 767)		ON-BOARD INERTING GAS GENERATING SYSTEM PRESSURE SWING ABSORPTION		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	29	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	43	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	43	43	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	29	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin at sta.933 R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin at sta.933 R.H.	7	0	
Avio.	Open/close aft side of E/E	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	57	64	
Avio.	Install wiring between flight deck, E/E and new components located in tail cone	257	257	
Sht.mtl.	Install provisions for filter installation in bulk cargo compt. approx. at sta.1540 RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in tail cone	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Install provisions for header/ heat exchanger installation in tail cone	57	57	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for storage syst.,cryogenic refrigerator and distillation syst.installation	100	100	
Mech.	Install storage,cryogenic refrigerator and distillation systems	21	21	
Avio.	Install storage,cryogenic refrigerator and distillation systems	21	21	
Mech.	Install ducting from heat exchanger to refrigerator,distillation and storage systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for modulating valve and relief valve installation	21	21	
Mech.	Install modulating valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank at sta. 955	143	179	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (tail cone to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank sta.955	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 3 fuel tanks	107	107	
Mech.	Install NEA gas distribution system in all 3 fuel tanks	214	214	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>1814</b>	<b>1668</b>	
Mech/Avio	Inspection mechanics/avionics	215	179	
Sht.mtl.	Inspection sheetmetal	74	77	
	Round off/unforeseen work	247	225	
	<b>Total manhours including inspection</b>	<b>2350</b>	<b>2150</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
MEDIUM (Boeing 767)		ON-BOARD INERTING GAS GENERATING SYSTEM CRYOGENIC		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	29	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	43	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	43	43	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	29	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin at sta.933 R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin at sta.933 R.H.	7	0	
Avio.	Open/close aft side of E/E	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	57	74	
Avio.	Install wiring between flight deck, E/E and new components located in tail cone	257	257	
Sht.mtl.	Install provisions for filter installation in bulk cargo compt. approx. at sta.1540 RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in tail cone	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Install provisions for header/ heat exchanger installation in tail cone	57	57	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for storage syst.,cryogenic refrigerator and distillation syst.installation	171	171	
Mech.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Avio.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Mech.	Install ducting from heat exchanger to refrigerator,distillation and storage systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for modulating valve and relief valve installation	21	21	
Mech.	Install modulating valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank at sta. 955	143	179	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (tail cone to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank sta.955	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 3 fuel tanks	107	107	
Mech.	Install NEA gas distribution system in all 3 fuel tanks	214	214	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>1914</b>	<b>1778</b>	
Mech/Avio	Inspection mechanics/avionics	221	186	
Sht.mtl.	Inspection sheetmetal	81	85	
	Round off/unforeseen work	234	251	
	<b>Total manhours including inspection</b>	<b>2450</b>	<b>2300</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type: <b>MEDIUM</b> (MD11)		Description: <b>Ground Based Inerting Systems</b>	Special Program	Heavy Check
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	14	0	
Mech.	Defuel, drain and vent aux tank	14	0	
Mech.	Open and close after modification aux tank	7	0	
Avio.	Open/close aft side of avionics compartment	3	0	
Mech.	Remove/reinstall RH seats, carpet, floorpanels	14	0	
Avio.	Remove/reinstall floorprox,seat to seat cables and raceways RH sta 1000-1265	0	0	
Mech.	Remove/reinstall ceiling panels in fwd cargo compt. for access to cable raceways	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before modification	36	36	
Avio.	Install wiring between flight deck, avio comp and new components located in zone 114	114	114	
Sht.mtl.	Install feed through structural provisions in aux tank	143	143	
Sht.mtl.	Install provisions for distribution manifold in aux tank	50	50	
Mech.	Install distribution manifold in aux tank	86	86	
Sht.mtl.	Install provisions for thermal relief valve and isolation valve installation	14	14	
Mech.	Install thermal relief valve and isolation valve	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	57	57	
Sht.mtl.	Inst. provisions for double wall pipe,witness drain etc. from fill panel to aux tank	21	21	
Mech.	Inst. double wall pipe,witness drain etc. from fill panel to aux tank	29	29	
Mech/Avio	Test ground based distribution system (3x)	29	29	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>746</b>	<b>657</b>	
Mech/Avio	Inspection mechanics/avionics	92	96	
Sht.mtl.	Inspection sheetmetal	29	32	
	Round off/unforeseen work	133	122	
	<b>Total manhours including inspection</b>	<b>1000</b>	<b>1050</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
MEDIUM (MD11)		ON-BOARD INERTING GAS GENERATING SYSTEM MEMBRANE		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	29	0	
Mech.	Defuel, drain, purge and vent all fuel tanks	33	0	
Mech.	Open and close after modification all fuel tanks	43	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	100	100	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	14	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in cabin	14	0	
Avio.	Open/close aft side of avionics compartment	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	57	54	
Avio.	Install wiring between flight deck, avio comp and new components located in zone 114	214	214	
Sht.mtl.	Install provisions for filter installation in fwd. cargo compartment	29	29	
Mech.	Install filter assy and element	3	3	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	43	43	
Mech.	Install shut off valve and filter to shut off valve ducting	6	6	
Sht.mtl.	Install provision for compressor installation in zone 114	29	29	
Mech.	Install compressor and shut off valve to compressor ducting	9	9	
Sht.mtl.	Install provisions for bleed air items	21	21	
Sht.mtl.	Install provisions for header/ heat exchanger installation in zone 114	43	43	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	6	6	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	75	75	
Mech.	Make split in ram air duct	7	7	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	20	20	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	25	25	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for water seperator/filter, low flow ASM and high flow ASM installation	129	129	
Mech.	Install water seperator/filter, low flow ASM and high flow ASM systems	29	29	
Avio.	Install water seperator/filter, low flow ASM and high flow ASM systems	29	29	
Mech.	Install ducting from heat exch.to water seperator/filter, low flow/high flow ASM systems	14	14	
Mech.	Install HX bypass valve and ducting	4	4	
Sht.mtl.	Install provisions for high flow valve and relief valve installation	21	21	
Mech.	Install high flow valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in upper aux tank	143	143	
Sht.mtl.	Install feed through and relief valve provisions in fuselage skin (zone 114 to cabin)	71	71	
Mech.	Install ducting from relief valve to upper aux tank	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 5 fuel tanks (tail tank not included)	129	129	
Mech.	Install NEA gas distribution system in all 5 fuel tanks	257	257	
Mech/Avio	Test cryogenic distillation system (3x)	43	43	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>1869</b>	<b>1688</b>	
Mech/Avio	Inspection mechanics/avionics	222	186	
Sht.mtl.	Inspection sheetmetal	76	76	
	Round off/unforeseen work	233	201	
	<b>Total manhours including inspection</b>	<b>2400</b>	<b>2150</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
MEDIUM (MD11)		ON-BOARD INERTING GAS GENERATING SYSTEM PRESSURE SWING ABSORPTION		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	29	0	
Mech.	Defuel, drain, purge and vent all fuel tanks	33	0	
Mech.	Open and close after modification all fuel tanks	43	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	100	100	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	14	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in cabin	14	0	
Avio.	Open/close aft side of avionics compartment	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	57	57	
Avio.	Install wiring between flight deck, avio comp and new components located in zone 114	214	214	
Sht.mtl.	Install provisions for filter installation in fwd. cargo compartment	29	29	
Mech.	Install filter assy and element	3	3	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	43	43	
Mech.	Install shut off valve and filter to shut off valve ducting	6	6	
Sht.mtl.	Install provision for compressor installation in zone 114	29	29	
Mech.	Install compressor and shut off valve to compressor ducting	9	9	
Sht.mtl.	Install provisions for bleed air items	21	21	
Sht.mtl.	Install provisions for header/ heat exchanger installation in zone 114	43	43	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	6	6	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	75	75	
Mech.	Make split in ram air duct	7	7	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	20	20	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	25	25	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for water seperator/filter and ASM installation	100	100	
Mech.	Install water seperator/filter and ASM systems	21	21	
Avio.	Install water seperator/filter and ASM systems	21	21	
Mech.	Install ducting from heat exch.to water seperator/filter, low flow/high flow ASM systems	14	14	
Mech.	Install HX bypass valve and ducting	4	4	
Sht.mtl.	Install provisions for high flow valve and relief valve installation	21	21	
Mech.	Install high flow valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in upper aux tank	143	143	
Sht.mtl.	Install feed through and relief valve provisions in fuselage skin (zone 114 to cabin)	71	71	
Mech.	Install ducting from relief valve to upper aux tank	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 5 fuel tanks (tail tank not included)	129	129	
Mech.	Install NEA gas distribution system in all 5 fuel tanks	257	257	
Mech/Avio	Test cryogenic distillation system (3x)	43	43	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>1826</b>	<b>1648</b>	
Mech/Avio	Inspection mechanics/avionics	219	184	
Sht.mtl.	Inspection sheetmetal	73	73	
	Round off/unforeseen work	231	196	
	<b>Total manhours including inspection</b>	<b>2350</b>	<b>2100</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
MEDIUM (MD11)		ON-BOARD INERTING GAS GENERATING SYSTEM CRYOGENIC		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	29	0	
Mech.	Defuel, drain purge and vent all fuel tanks	33	0	
Mech.	Open and close after modification all fuel tanks	43	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	100	100	
Mech.	Remove/install several sidewall and ceiling panels in fwd. cargo compt.R.H.	14	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in cabin	14	0	
Avio.	Remove/install floor prox etc in main cabin at sta.1000 R.H.	0	0	
Avio.	Open/close aft side of avionics compartment	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	57	57	
Avio.	Install wiring between flightdeck, avionics comp and new components located in zone 114.	214	214	
Sht.mtl.	Install provisions for filter installation in fwd. cargo compartment.	29	29	
Mech.	Install filter assy and element	3	3	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	43	43	
Mech.	Install shut off valve and filter to shut off valve ducting	6	6	
Sht.mtl.	Install provision for compressor installation in zone 114	29	29	
Mech.	Install compressor and shut off valve to compressor ducting	9	9	
Sht.mtl.	Install provisions for bleed air items	21	21	
Sht.mtl.	Install provisions for header/ heat exchanger installation in zone 114	43	43	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	6	6	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	75	75	
Mech.	Make split in ram air duct	7	7	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	25	25	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	9	9	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for storage syst.,cryogenic refrigerator and distillation syst.installation	171	171	
Mech.	Install storage,cryogenic refrigerator and distillation systems	43	43	
Avio.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Mech.	Install ducting from heat exchanger to refrigerator,distillation and storage systems	17	17	
Mech.	Install HX bypass valve and ducting	4	4	
Sht.mtl.	Install provisions for modulating valve and relief valve installation	21	21	
Mech.	Install modulating valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in upper aux tank	143	143	
Sht.mtl.	Install feed through and relief valve provisions in fuselage skin (zone 114 to cabin)	71	71	
Mech.	Install ducting from relief valve to upper aux tank	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 5 fuel tanks (tail tank not included)	129	129	
Mech.	Install NEA gas distribution system in 5 fuel tanks	257	257	
Mech/Avio	Test cryogenic distillation system (3x)	43	43	
Mech/Avio	Test several systems due to partial flight deck dismantling	71	71	
	<b>Total manhours per aircraft</b>	<b>1925</b>	<b>1746</b>	
Mech/Avio	Inspection mechanics/avionics	228	192	
Sht.mtl.	Inspection sheetmetal	78	78	
	Round off/unforeseen work	269	233	
	<b>Total manhours including inspection</b>	<b>2500</b>	<b>2250</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type: <b>SMALL</b> <i>(Boeing 737)</i>		Description: <b>Ground Based Inerting Systems</b>	Special Program	Heavy Check
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	11	0	
Mech.	Defuel and drain CW tank	3	0	
Mech.	Open, ventilate and close after modification CW tank	14	0	
Avio.	Open/close aft side of E/E	3	0	
Mech.	Remove/reinstall RH seats, carpet, floorpanels above RH cable raceway	29	0	
Avio.	Remove/reinstall floorprox,seat to seat cables and raceways RH	14	0	
Mech.	Remove/reinstall ceiling panels in aft cargo compt. for access to cable raceways	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before modification	44	43	
Avio.	Install wiring between flight deck, E/E and new components located in tail cone	179	157	
Sht.mtl.	Install feed through structural provisions in CW tank aft skin	179	157	
Sht.mtl.	Install provisions for distribution manifold in CW tank	57	57	
Mech.	Install distribution manifold in CW tank	100	100	
Sht.mtl.	Install provisions for thermal relief valve and isolation valve installation	14	14	
Mech.	Install thermal relief valve and isolation valve	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	57	57	
Sht.mtl.	Inst. provisions for double wall pipe,witness drain etc. from fill panel to CW tank	14	14	
Mech.	Inst. double wall pipe,witness drain etc. from fill panel to CW tank	21	21	
Mech/Avio	Test ground based distribution system (3x)	29	29	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total manhours per aircraft</b>	<b>925</b>	<b>757</b>	
Mech/Avio	Inspection mechanics/avionics	121	96	
Sht.mtl.	Inspection sheetmetal	32	32	
	Round off/unforeseen work	122	122	
	<b>Total manhours including inspection</b>	<b>1200</b>	<b>1050</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
SMALL (Boeing 737)		ON-BOARD INERTING GAS GENERATING SYSTEM MEMBRANE		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	20	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	31	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	14	14	
Mech.	Remove/install several sidewall and ceiling panels in aft. cargo compt.R.H.	20	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin R.H.	7	0	
Avio.	Open/close aft side of E/E	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	29	29	
Avio.	Install wiring between flight deck,E/E and new components located in tail cone	214	214	
Sht.mtl.	Install provisions for filter installation in Aft cargo compt. RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in tail cone	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Install provisions for header/ heat exchanger installation in tail cone	57	57	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for water seperator/filter, low flow ASM and high flow ASM installation	129	129	
Mech.	Install water seperator/filter, low flow ASM and high flow ASM systems	29	24	
Avio.	Install water seperator/filter, low flow ASM and high flow ASM systems	29	24	
Mech.	Install ducting from heat exch.to water seperator/filter, low flow/high flow ASM systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for high flow valve and relief valve installation	21	21	
Mech.	Install high flow valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank	121	121	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (tail cone to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 3 fuel tanks	107	107	
Mech.	Install NEA gas distribution system in all 3 fuel tanks	214	214	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	64	64	
	<b>Total manhours per aircraft</b>	<b>1701</b>	<b>1531</b>	
Mech/Avio	Inspection mechanics/avionics	191	157	
Sht.mtl.	Inspection sheetmetal	75	75	
	Round off/unforeseen work	234	188	
	<b>Total manhours including inspection</b>	<b>2200</b>	<b>1950</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
SMALL (Boeing 737)		ON-BOARD INERTING GAS GENERATING SYSTEM PRESSURE SWING ABSORPTION		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	20	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	31	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	14	14	
Mech.	Remove/install several sidewall and ceiling panels in aft. cargo compt.R.H.	20	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin R.H.	7	0	
Avio.	Open/close aft side of E/E	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	36	36	
Avio.	Install wiring between flight deck, E/E and new components located in tail cone	214	214	
Sht.mtl.	Install provisions for filter installation in bulk cargo compt. RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in tail cone	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Install provisions for header/ heat exchanger installation in tail cone	57	57	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for water seperator/filter and ASM installation	93	93	
Mech.	Install water seperator/filter and ASM systems	19	19	
Avio.	Install water seperator/filter and ASM systems	19	19	
Mech.	Install ducting from heat exch.to water seperator/filter, low flow/high flow ASM systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for high flow valve and relief valve installation	21	21	
Mech.	Install high flow valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank	121	121	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (tail cone to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 3 fuel tanks	107	107	
Mech.	Install NEA gas distribution system in all 3 fuel tanks	214	214	
Mech/Avio	Test PSA system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	64	64	
	<b>Total manhours per aircraft</b>	<b>1651</b>	<b>1490</b>	
Mech/Avio	Inspection mechanics/avionics	188	156	
Sht.mtl.	Inspection sheetmetal	71	71	
	Round off/unforeseen work	240	183	
	<b>Total manhours including inspection</b>	<b>2150</b>	<b>1900</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type:		Description:	Special Program	Heavy Check
SMALL (Boeing 737)		ON-BOARD INERTING GAS GENERATING SYSTEM CRYOGENIC		
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	20	0	
Mech.	Defuel and drain all fuel tanks	14	0	
Mech.	Open, ventilate and close after modification all fuel tanks	31	0	
Mech.	Remove/install various internal fuel tank panels LH and RH for access	14	14	
Mech.	Remove/install several sidewall and ceiling panels in aft. cargo compt.R.H.	20	0	
Mech.	Remove/install several insulation blankets R.H.	14	0	
Mech.	Remove/install several seats, floorcovering and floorpanels in main cabin R.H.	21	0	
Avio.	Remove/install floor prox etc in main cabin R.H.	7	0	
Avio.	Open/close aft side of E/E	3	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	29	0	
Mech.	Clean various locations before and after modification	36	36	
Avio.	Install wiring between flight deck,E/E and new components located in tail cone	214	214	
Sht.mtl.	Install provisions for filter installation in aft cargo compt.RH	36	36	
Mech.	Install filter assy and element	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	64	64	
Mech.	Install shut off valve and filter to shut off valve ducting	7	7	
Sht.mtl.	Install provision for compressor installation in Tail Cone	36	36	
Mech.	Install compressor and shut off valve to compressor ducting	10	10	
Sht.mtl.	Install provisions for bleed air items	29	29	
Sht.mtl.	Install provisions for header/ heat exchanger installation in tail cone	57	57	
Mech.	Install header assy, bleed air items and compressor to header assy ducting	29	29	
Mech.	Install heat exchanger on header assy	7	7	
Sht.mtl.	Drill and fit new ram air inlet/outlet fairing panels	71	71	
Mech.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Avio.	Assemble and install ram air inlet/outlet panels,doors and motors	14	14	
Sht.mtl.	Install provisions for electrically driven cooling fan installation	10	10	
Avio.	Install cooling fan to ram air exit	7	7	
Sht.mtl.	Install provisions for storage syst.,cryogenic refrigerator and distillation syst.installation	171	171	
Mech.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Avio.	Install storage,cryogenic refrigerator and distillation systems	36	36	
Mech.	Install ducting from heat exchanger to refrigerator,distillation and storage systems	21	21	
Mech.	Install HX bypass valve and ducting	5	5	
Sht.mtl.	Install provisions for modulating valve and relief valve installation	21	21	
Mech.	Install modulating valve, relief valve and ducting	14	14	
Sht.mtl.	Install feed through structural provision in CW tank	121	121	
Sht.mtl.	Install feed through and shut off valve provisions in fuselage skin (tail cone to cabin)	64	64	
Mech.	Install ducting from relief valve to CW tank	14	14	
Sht.mtl.	Install provisions for NEA gas distribution ducts in all 3 fuel tanks	107	107	
Mech.	Install NEA gas distribution system in all 3 fuel tanks	214	214	
Mech/Avio	Test cryogenic distillation system (3x)	50	50	
Mech/Avio	Test several systems due to partial flight deck dismantling	64	64	
	<b>Total manhours per aircraft</b>	<b>1764</b>	<b>1603</b>	
Mech/Avio	Inspection mechanics/avionics	195	163	
Sht.mtl.	Inspection sheetmetal	79	79	
	Round off/unforeseen work	212	205	
	<b>Total manhours including inspection</b>	<b>2250</b>	<b>2050</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type: <b>SMALL</b> <i>(Boeing 737)</i>		Description: <b>Ground Based Inerting Systems</b>	Special Program	Heavy Check
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	11	0	
Mech.	Defuel and drain CW tank	3	0	
Mech.	Open, ventilate and close after modification CW tank	14	0	
Avio.	Open/close aft side of E/E	3	0	
Mech.	Remove/reinstall RH seats, carpet, floorpanels above RH cable raceway	29	0	
Avio.	Remove/reinstall floorprox,seat to seat cables and raceways RH	14	0	
Mech.	Remove/reinstall ceiling panels in aft cargo compt. for access to cable raceways	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before modification	44	43	
Avio.	Install wiring between flight deck, Avionics comp. and new components in center section	157	157	
Sht.mtl.	Install feed through structural provisions in CW tank aft skin	157	157	
Sht.mtl.	Install provisions for distribution manifold in CW tank	57	57	
Mech.	Install distribution manifold in CW tank	100	100	
Sht.mtl.	Install provisions for thermal relief valve and isolation valve installation	14	14	
Mech.	Install thermal relief valve and isolation valve	7	7	
Sht.mtl.	Modify lwr. panel for fill adaptor/components	14	14	
Mech.	Inst. double wall pipe,witness drain etc. from fill panel to CW tank	21	21	
Mech/Avio	Test ground based distribution system (3x)	29	29	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total manhours per aircraft</b>	<b>824</b>	<b>699</b>	
Mech/Avio	Inspection mechanics/avionics	116	91	
Sht.mtl.	Inspection sheetmetal	24	24	
	Round off/unforeseen work	135	85	
	<b>Total manhours including inspection</b>	<b>1100</b>	<b>900</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

Airplane type: <b>SMALL</b> <i>(Boeing 737)</i>		Description: <b>Ground Based Inerting Systems</b>	Special Program	Heavy Check
Skill	Description	labor hours	labor hours	
	<b>Accomplishment:</b>			
Mech.	Dock and undock airplane and raise and lower airplane	11	0	
Mech.	Defuel and drain CW tank	3	0	
Mech.	Open, ventilate and close after modification CW tank	14	0	
Avio.	Open/close aft side of E/E	3	0	
Mech.	Remove/reinstall RH seats, carpet, floorpanels above RH cable raceway	29	0	
Avio.	Remove/reinstall floorprox, seat to seat cables and raceways RH	14	0	
Mech.	Remove/reinstall ceiling panels in aft cargo compt. for access to cable raceways	7	0	
Avio.	Remove/install Captain seat and several panels/linings in flight deck	43	0	
Mech.	Clean various locations before modification	44	43	
Avio.	Install wiring between flight deck, Avionics comp. and new components in center section	157	157	
Mech.	Remove, install and leak-check 7 center wing bagtank cells	150	150	
Shop	Modify 7 CW bagtank cells	150	150	
Sht.mtl.	Install feed through structural provisions in CW tank aft skin	157	157	
Sht.mtl.	Install provisions for distribution manifold in CW tank	150	150	
Mech.	Install distribution manifold in CW tank	100	100	
Mech.	Modify lwr. panel for fill adaptor/components	100	100	
Sht.mtl.	Install provisions for thermal relief valve and isolation valve installation	14	14	
Mech.	Install thermal relief valve and isolation valve	7	7	
Sht.mtl.	Inst. provisions for double wall pipe, witness drain etc. from fill panel to CW tank	14	14	
Mech.	Inst. double wall pipe, witness drain etc. from fill panel to CW tank	21	21	
Mech/Avio	Test ground based distribution system (3x)	29	29	
Mech/Avio	Test several systems due to partial flight deck dismantling	100	100	
	<b>Total manhours per aircraft</b>	<b>1317</b>	<b>1192</b>	
Mech/Avio	Inspection mechanics/avionics	196	171	
Sht.mtl.	Inspection sheetmetal	34	34	
	Round off/unforeseen work	203	153	
	<b>Total manhours including inspection</b>	<b>1750</b>	<b>1550</b>	
<b>NOTE: LABOR-HOURS BASED ON MINIMUM INFORMATION !!!</b>				

**ADDENDUM F.A.3**

***MODIFICATION LABOR-HOUR ESTIMATION for  
BUSSINESS JETS***

**to  
APPENDIX F**

**AIRPLANE OPERATION AND MAINTENANCE  
FINAL REPORT**



Mark S. Reed  
Sr. Vice President  
Maintenance

April 23, 2001

RE: NPRM for Fuel System Modifications (Nitrogen Inerting)

Dear Mr. Peters,

Attached you will find several documents compiled by our Quality Control and Maintenance Scheduling departments. They expand on the information we briefly discussed during our conversation on April 18<sup>th</sup>. Hopefully, this material will improve your technical familiarity with the business-class aircraft we operate.

In the attachments you will find:

- A two page matrix showing; aircraft we operate on our air carrier certificate, whether or not they have center line fuel storage, and any potential heat sources adjacent to that fuel storage
- Simple maintenance manual references and diagrams for the systems described above
- A table showing routine fuel tank inspection intervals as well as heavy inspection intervals that would most likely be used to incorporate a major modification to the fuel tanks/system.

Executive Jet, Inc.  
4111 Bridgeway Ave.  
Columbus, OH 43219  
Tel. (614) 239-2929  
Fax (614) 239-2072  
mreed@netjets.com

One other question presented was "How long would we estimate for a modification of this scope?" Without any engineering data, I can only estimate based on experience with other system changes that I believe would be similar. A very *rough order of magnitude* estimate would be 350 to 500 man-hours, but that is highly speculative.

I hope this information helps. If we can be of any further assistance, feel free to contact us.

Sincerely,

A handwritten signature in black ink, appearing to be "M. Reed", written in a cursive style.

Mark Reed

Executive Jet is a Berkshire Hathaway Inc. company

ADDENDUM F.B.1

***SCHEDULED MAINTENANCE TASKS***  
***and***  
***ADDITIONAL LABOR-HOURS***

to  
APPENDIX F

**AIRPLANE OPERATION AND MAINTENANCE**  
**FINAL REPORT**

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## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Functional check of entire system	2C	6
Functional check of Compressor	2C	2
Inspect High Flow Check Valve	2C	1
Inspect High Flow Shut Off Valve	2C	1
Inspect Controller / control card	2C	1
Inspect Oxygen Sensor	2C	1
Remove & Replace Filters	2C	1
Remove & Replace Nitrogen check valves	2C	1
Remove & Replace Heat Exchanger	4C	6
Inspect Manifolds/Ducts	4C	4
Inspect Wiring	4C	4
Inspect Bypass Valve	4C	1
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1
Inspect Fuel Tank Check Valve	4C	1
Inspect Water separator	4C	1
Inspect Bleed Air Check Valve	4C	1
Inspect Bleed Air Shut Off Valve	4C	1
Inspect Compressor check valve	4C	1
Inspect Compressor discharge overheat switch	4C	1
Inspect Cooling fan	4C	1
Inspect Cooling fan overheat sensor	4C	1
Inspect Flow Control Orifice	4C	1
Inspect Heat Exchanger - check valve	4C	1
Inspect Over Temperature sensor	4C	1
Inspect Relief valve	4C	1
Inspect Start Contactor	4C	1
Inspect Unloading Valve	4C	1
Inspect Water separator filter	4C	1

**Figure F6.2.1-1 - OBGI Maintenance Tasks - Business Jet Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Functional check of entire system	2C	6
Functional check of Compressor	2C	2
Inspect High Flow Check Valve	2C	1
Inspect High Flow Shut Off Valve	2C	1
Inspect Controller / control card	2C	1
Inspect Oxygen Sensor	2C	1
Remove & Replace Filters	2C	1
Remove & Replace Nitrogen check valves	2C	1
Remove & Replace Heat Exchanger	4C	6
Inspect Manifolds/Ducts	4C	4
Inspect Wiring	4C	4
Inspect Bypass Valve	4C	1
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1
Inspect Fuel Tank Check Valve	4C	1
Inspect Water separator	4C	1
Inspect Bleed Air Check Valve	4C	1
Inspect Bleed Air Shut Off Valve	4C	1
Inspect Compressor check valve	4C	1
Inspect Compressor discharge overheat switch	4C	1
Inspect Cooling fan	4C	1
Inspect Cooling fan overheat sensor	4C	1
Inspect Flow Control Orifice	4C	1
Inspect Heat Exchanger - check valve	4C	1
Inspect Over Temperature sensor	4C	1
Inspect Relief valve	4C	1
Inspect Start Contactor	4C	1
Inspect Unloading Valve	4C	1
Inspect Water separator filter	4C	1

**Figure F6.2.1-3 - OBGI Maintenance Tasks - Turbofan Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Functional check of entire system	2C	6
Functional check of Compressor	2C	2
Inspect High Flow Check Valve	2C	1
Inspect High Flow Shut Off Valve	2C	1
Inspect Controller / control card	2C	1
Inspect Oxygen Sensor	2C	1
Remove & Replace Filters	2C	1
Remove & Replace Nitrogen check valves	2C	1
Remove & Replace Heat Exchanger	4C	6
Inspect Manifolds/Ducts	4C	6
Inspect Wiring	4C	6
Inspect Bypass Valve	4C	1
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1
Inspect Fuel Tank Check Valve	4C	1
Inspect Water separator	4C	1
Inspect Bleed Air Check Valve	4C	1
Inspect Bleed Air Shut Off Valve	4C	1
Inspect Compressor check valve	4C	1
Inspect Compressor discharge overheat switch	4C	1
Inspect Cooling fan	4C	1
Inspect Cooling fan overheat sensor	4C	1
Inspect Flow Control Orifice	4C	1
Inspect Heat Exchanger - check valve	4C	1
Inspect Over Temperature sensor	4C	1
Inspect Relief valve	4C	1
Inspect Start Contactor	4C	1
Inspect Unloading Valve	4C	1
Inspect Water separator filter	4C	1

**Figure F6.2.1-5 - OBGI Maintenance Tasks - Medium Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Functional check of entire system	2C	6
Functional check of Compressor	2C	2
Inspect High Flow Check Valve	2C	1
Inspect High Flow Shut Off Valve	2C	1
Inspect Controller / control card	2C	1
Inspect Oxygen Sensor	2C	1
Remove & Replace Filters	2C	1
Remove & Replace Nitrogen check valves	2C	1
Remove & Replace Heat Exchanger	4C	6
Inspect Manifolds/Ducts	4C	4
Inspect Wiring	4C	4
Inspect Bypass Valve	4C	1
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1
Inspect Fuel Tank Check Valve	4C	1
Inspect Water separator	4C	1
Inspect Bleed Air Check Valve	4C	1
Inspect Bleed Air Shut Off Valve	4C	1
Inspect Compressor check valve	4C	1
Inspect Compressor discharge overheat switch	4C	1
Inspect Cooling fan	4C	1
Inspect Cooling fan overheat sensor	4C	1
Inspect Flow Control Orifice	4C	1
Inspect Heat Exchanger - check valve	4C	1
Inspect Over Temperature sensor	4C	1
Inspect Relief valve	4C	1
Inspect Start Contactor	4C	1
Inspect Unloading Valve	4C	1
Inspect Water separator filter	4C	1

**Figure F6.2.1-2 - OBGI Maintenance Tasks - Turboprop Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Functional check of entire system	2C	6
Functional check of Compressor	2C	2
Inspect High Flow Check Valve	2C	1
Inspect High Flow Shut Off Valve	2C	1
Inspect Controller / control card	2C	1
Inspect Oxygen Sensor	2C	1
Remove & Replace Filters	2C	1
Remove & Replace Nitrogen check valves	2C	1
Remove & Replace Heat Exchanger	4C	6
Inspect Manifolds/Ducts	4C	4
Inspect Wiring	4C	4
Inspect Bypass Valve	4C	1
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1
Inspect Fuel Tank Check Valve	4C	1
Inspect Water separator	4C	1
Inspect Bleed Air Check Valve	4C	1
Inspect Bleed Air Shut Off Valve	4C	1
Inspect Compressor check valve	4C	1
Inspect Compressor discharge overheat switch	4C	1
Inspect Cooling fan	4C	1
Inspect Cooling fan overheat sensor	4C	1
Inspect Flow Control Orifice	4C	1
Inspect Heat Exchanger - check valve	4C	1
Inspect Over Temperature sensor	4C	1
Inspect Relief valve	4C	1
Inspect Start Contactor	4C	1
Inspect Unloading Valve	4C	1
Inspect Water separator filter	4C	1

**Figure F6.2.1-4 - OBGI Maintenance Tasks - Small Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Functional check of entire system	2C	6
Functional check of Compressor	2C	2
Inspect High Flow Check Valve	2C	1
Inspect High Flow Shut Off Valve	2C	1
Inspect Controller / control card	2C	1
Inspect Oxygen Sensor	2C	1
Remove & Replace Filters	2C	1
Remove & Replace Nitrogen check valves	2C	1
Remove & Replace Heat Exchanger	4C	6
Inspect Manifolds/Ducts	4C	8
Inspect Wiring	4C	8
Inspect Bypass Valve	4C	1
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1
Inspect Fuel Tank Check Valve	4C	1
Inspect Water separator	4C	1
Inspect Bleed Air Check Valve	4C	1
Inspect Bleed Air Shut Off Valve	4C	1
Inspect Compressor check valve	4C	1
Inspect Compressor discharge overheat switch	4C	1
Inspect Cooling fan	4C	1
Inspect Cooling fan overheat sensor	4C	1
Inspect Flow Control Orifice	4C	1
Inspect Heat Exchanger - check valve	4C	1
Inspect Over Temperature sensor	4C	1
Inspect Relief valve	4C	1
Inspect Start Contactor	4C	1
Inspect Unloading Valve	4C	1
Inspect Water separator filter	4C	1

**Figure F6.2.1-6 - OBGI Maintenance Tasks - Large Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Pressure/Decay Check & rectification	C	24
Functional check of Compressor	C	2
Inspect Bypass Valve	C	1
Inspect Cryo-Cooler	C	1
Inspect Distillation Column - gas valve	C	1
Inspect Distillation Column - liquid valve	C	1
Inspect Fuel Tank Check Valve	C	1
Inspect Inlet Cooler	C	1
Inspect Inlet Recuperator	C	1
Inspect Water separator	C	1
Inspect Bleed Air Check Valve	C	1
Inspect Bleed Air Shut Off Valve	C	1
Inspect Compressor check valve	C	1
Inspect Compressor discharge overheat switch	C	1
Inspect Controller / control card	C	1
Inspect Cooling fan	C	1
Inspect Cooling fan overheat sensor	C	1
Inspect Cryocooler bleed air valve	C	1
Inspect Dewar level sensor	C	1
Inspect Heat Exchanger - check valve	C	1
Inspect High Flow Sensor	C	1
Inspect Inlet shutoff valve	C	1
Inspect LNEA Dewar Cooldown Valve	C	1
Inspect Molecular sieve control valve	C	1
Inspect On / Off check valve & High flow fuse	C	1
Inspect Over Temperature sensor	C	1
Inspect Oxygen Sensor	C	1
Inspect Purge Heat Exchanger - Air Valve	C	1
Inspect Purge Heat Exchanger - Waste Valve	C	1
Inspect Relief valve	C	1
Remove & Replace Cabin Filters	C	1
Functional check of entire system	2C	6
Remove & Replace Heat Exchanger	2C	6
Remove & Replace Molecular sieves	2C	4
Inspect Distillation Column	2C	2
Remove & Replace Nitrogen check valves	2C	1
Inspect Manifolds/Ducts	4C	4
Inspect Wiring	4C	4
Inspect LNEA Dewar	4C	2
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1

Figure F7.2.1-1 - OBIGGS (Cryogenic) Maintenance Tasks - Small Transport Category

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Pressure/Decay Check & rectification	C	24
Functional check of Compressor	C	2
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Inspect Bypass Valve	C	1
Inspect Fuel Tank Check Valve	C	1
Inspect Water separator	C	1
Inspect Bleed Air Check Valve	C	1
Inspect Bleed Air Shut Off Valve	C	1
Inspect Compressor check valve	C	1
Inspect Compressor discharge overheat switch	C	1
Inspect Controller / control card	C	1
Inspect Cooling fan	C	1
Inspect Cooling fan overheat sensor	C	1
Inspect Heat Exchanger - check valve	C	1
Inspect High Flow Check Valve	C	1
Inspect High Flow Shut Off Valve	C	1
Inspect Low/High check valve	C	1
Inspect On / Off check valve & High flow fuse	C	1
Inspect Over Temperature sensor	C	1
Inspect Oxygen Sensor	C	1
Inspect Relief valve	C	1
Remove & Replace Cabin Filters	C	1
Inspect Water separator filter	C	1
Functional check of entire system	2C	8
Remove & Replace Heat Exchanger	2C	6
Remove & Replace Nitrogen check valves	2C	1
Inspect Manifolds/Ducts	4C	4
Inspect Wiring	4C	4
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1

**Figure F7.2.1-4 - OBIGGS (Membrane) Maintenance Tasks - Small Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Pressure/Decay Check & rectification	C	24
Functional check of Compressor	C	2
Inspect Bypass Valve	C	1
Inspect Cryo-Cooler	C	1
Inspect Distillation Column - gas valve	C	1
Inspect Distillation Column - liquid valve	C	1
Inspect Fuel Tank Check Valve	C	1
Inspect Inlet Cooler	C	1
Inspect Inlet Recuperator	C	1
Inspect Water separator	C	1
Inspect Bleed Air Check Valve	C	1
Inspect Bleed Air Shut Off Valve	C	1
Inspect Compressor check valve	C	1
Inspect Compressor discharge overheat switch	C	1
Inspect Controller / control card	C	1
Inspect Cooling fan	C	1
Inspect Cooling fan overheat sensor	C	1
Inspect Cryocooler bleed air valve	C	1
Inspect Dewar level sensor	C	1
Inspect Heat Exchanger - check valve	C	1
Inspect High Flow Sensor	C	1
Inspect Inlet shutoff valve	C	1
Inspect LNEA Dewar Cooldown Valve	C	1
Inspect Molecular sieve control valve	C	1
Inspect On / Off check valve & High flow fuse	C	1
Inspect Over Temperature sensor	C	1
Inspect Oxygen Sensor	C	1
Inspect Purge Heat Exchanger - Air Valve	C	1
Inspect Purge Heat Exchanger - Waste Valve	C	1
Inspect Relief valve	C	1
Remove & Replace Cabin Filters	C	1
Functional check of entire system	2C	6
Remove & Replace Heat Exchanger	2C	6
Remove & Replace Molecular sieves	2C	4
Inspect Distillation Column	2C	2
Remove & Replace Nitrogen check valves	2C	1
Inspect Manifolds/Ducts	4C	6
Inspect Wiring	4C	6
Inspect LNEA Dewar	4C	2
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1

**Figure F7.2.1-2 - OBIGGS (Cryogenic) Maintenance Tasks - Medium Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Pressure/Decay Check & rectification	C	24
Functional check of Compressor	C	2
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Inspect Bypass Valve	C	1
Inspect Fuel Tank Check Valve	C	1
Inspect Water separator	C	1
Inspect Bleed Air Check Valve	C	1
Inspect Bleed Air Shut Off Valve	C	1
Inspect Compressor check valve	C	1
Inspect Compressor discharge overheat switch	C	1
Inspect Controller / control card	C	1
Inspect Cooling fan	C	1
Inspect Cooling fan overheat sensor	C	1
Inspect Heat Exchanger - check valve	C	1
Inspect High Flow Check Valve	C	1
Inspect High Flow Shut Off Valve	C	1
Inspect Low/High check valve	C	1
Inspect On / Off check valve & High flow fuse	C	1
Inspect Over Temperature sensor	C	1
Inspect Oxygen Sensor	C	1
Inspect Relief valve	C	1
Remove & Replace Cabin Filters	C	1
Inspect Water separator filter	C	1
Functional check of entire system	2C	8
Remove & Replace Heat Exchanger	2C	6
Remove & Replace Nitrogen check valves	2C	1
Inspect Manifolds/Ducts	4C	6
Inspect Wiring	4C	6
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1

**Figure F7.2.1-5 - OBIGGS (Membrane) Maintenance Tasks - Medium Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Pressure/Decay Check & rectification	C	24
Functional check of Compressor	C	2
Inspect Bypass Valve	C	1
Inspect Cryo-Cooler	C	1
Inspect Distillation Column - gas valve	C	1
Inspect Distillation Column - liquid valve	C	1
Inspect Fuel Tank Check Valve	C	1
Inspect Inlet Cooler	C	1
Inspect Inlet Recuperator	C	1
Inspect Water separator	C	1
Inspect Bleed Air Check Valve	C	1
Inspect Bleed Air Shut Off Valve	C	1
Inspect Compressor check valve	C	1
Inspect Compressor discharge overheat switch	C	1
Inspect Controller / control card	C	1
Inspect Cooling fan	C	1
Inspect Cooling fan overheat sensor	C	1
Inspect Cryocooler bleed air valve	C	1
Inspect Dewar level sensor	C	1
Inspect Heat Exchanger - check valve	C	1
Inspect High Flow Sensor	C	1
Inspect Inlet shutoff valve	C	1
Inspect LNEA Dewar Cooldown Valve	C	1
Inspect Molecular sieve control valve	C	1
Inspect On / Off check valve & High flow fuse	C	1
Inspect Over Temperature sensor	C	1
Inspect Oxygen Sensor	C	1
Inspect Purge Heat Exchanger - Air Valve	C	1
Inspect Purge Heat Exchanger - Waste Valve	C	1
Inspect Relief valve	C	1
Remove & Replace Cabin Filters	C	1
Functional check of entire system	2C	6
Remove & Replace Heat Exchanger	2C	6
Remove & Replace Molecular sieves	2C	4
Inspect Distillation Column	2C	2
Remove & Replace Nitrogen check valves	2C	1
Inspect Manifolds/Ducts	4C	8
Inspect Wiring	4C	8
Inspect LNEA Dewar	4C	2
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1

**Figure F7.2.1-3 - OBIGGS (Cryogenic) Maintenance Tasks - Large Transport Category**

## Airplane Operation and Maintenance Task Team Final Report

Task	Interval	Labor-hours
Operational check of entire system	A	3
Pressure/Decay Check & rectification	C	24
Functional check of Compressor	C	2
Operational check of High flow ASM	C	2
Operational check of Low flow ASM	C	2
Inspect Bypass Valve	C	1
Inspect Fuel Tank Check Valve	C	1
Inspect Water separator	C	1
Inspect Bleed Air Check Valve	C	1
Inspect Bleed Air Shut Off Valve	C	1
Inspect Compressor check valve	C	1
Inspect Compressor discharge overheat switch	C	1
Inspect Controller / control card	C	1
Inspect Cooling fan	C	1
Inspect Cooling fan overheat sensor	C	1
Inspect Heat Exchanger - check valve	C	1
Inspect High Flow Check Valve	C	1
Inspect High Flow Shut Off Valve	C	1
Inspect Low/High check valve	C	1
Inspect On / Off check valve & High flow fuse	C	1
Inspect Over Temperature sensor	C	1
Inspect Oxygen Sensor	C	1
Inspect Relief valve	C	1
Remove & Replace Cabin Filters	C	1
Inspect Water separator filter	C	1
Functional check of entire system	2C	8
Remove & Replace Heat Exchanger	2C	6
Remove & Replace Nitrogen check valves	2C	1
Inspect Manifolds/Ducts	4C	8
Inspect Wiring	4C	8
Inspect Check valve Center wing	4C	1
Inspect Check valve L/H wing	4C	1
Inspect Check valve R/H wing	4C	1

**Figure F7.2.1-6 - OBIGGS (Membrane) Maintenance Tasks - Large Transport Category**

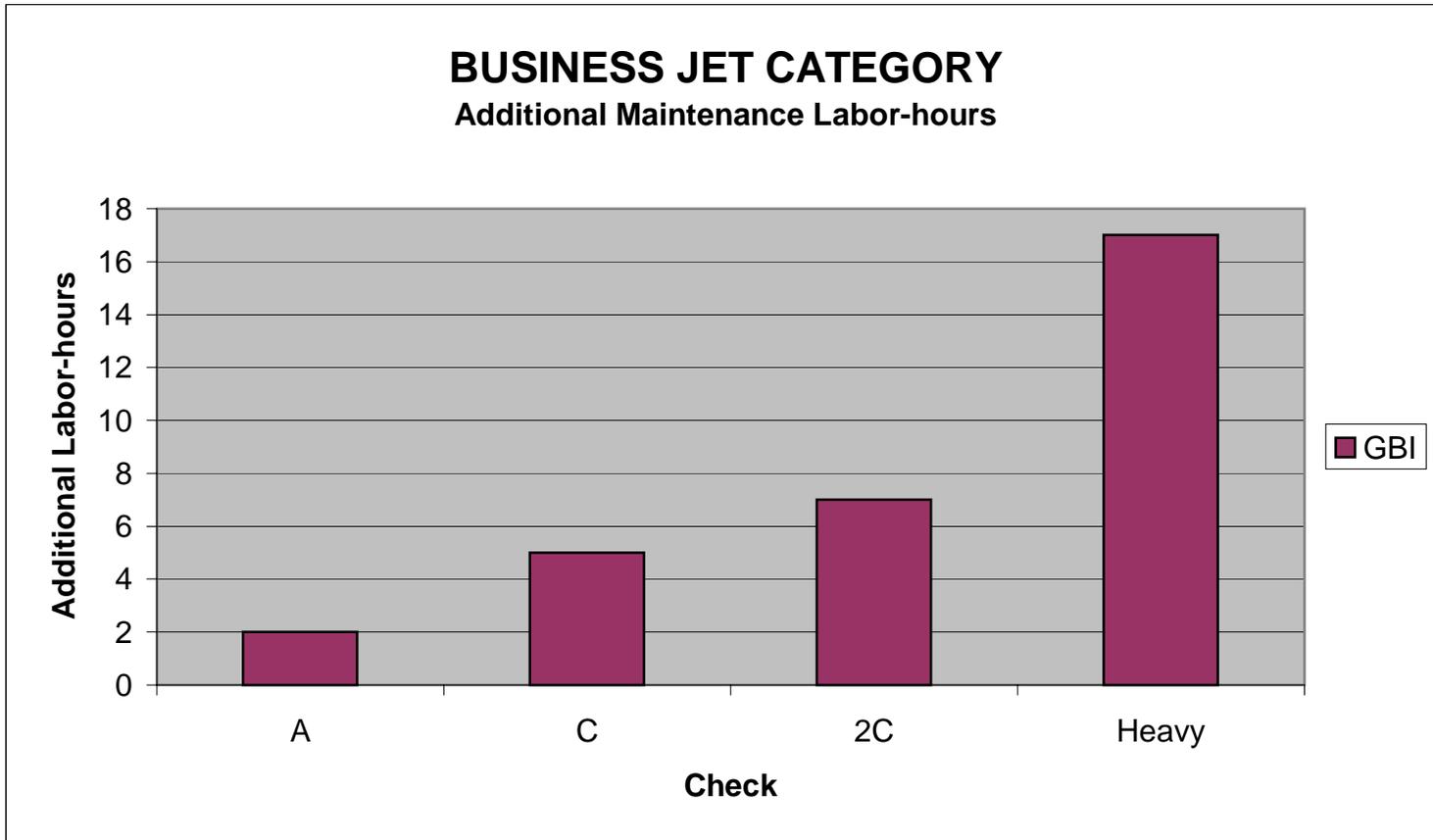


Figure F3.3-1 - Additional Maintenance Labor-hours - Business Jet Category

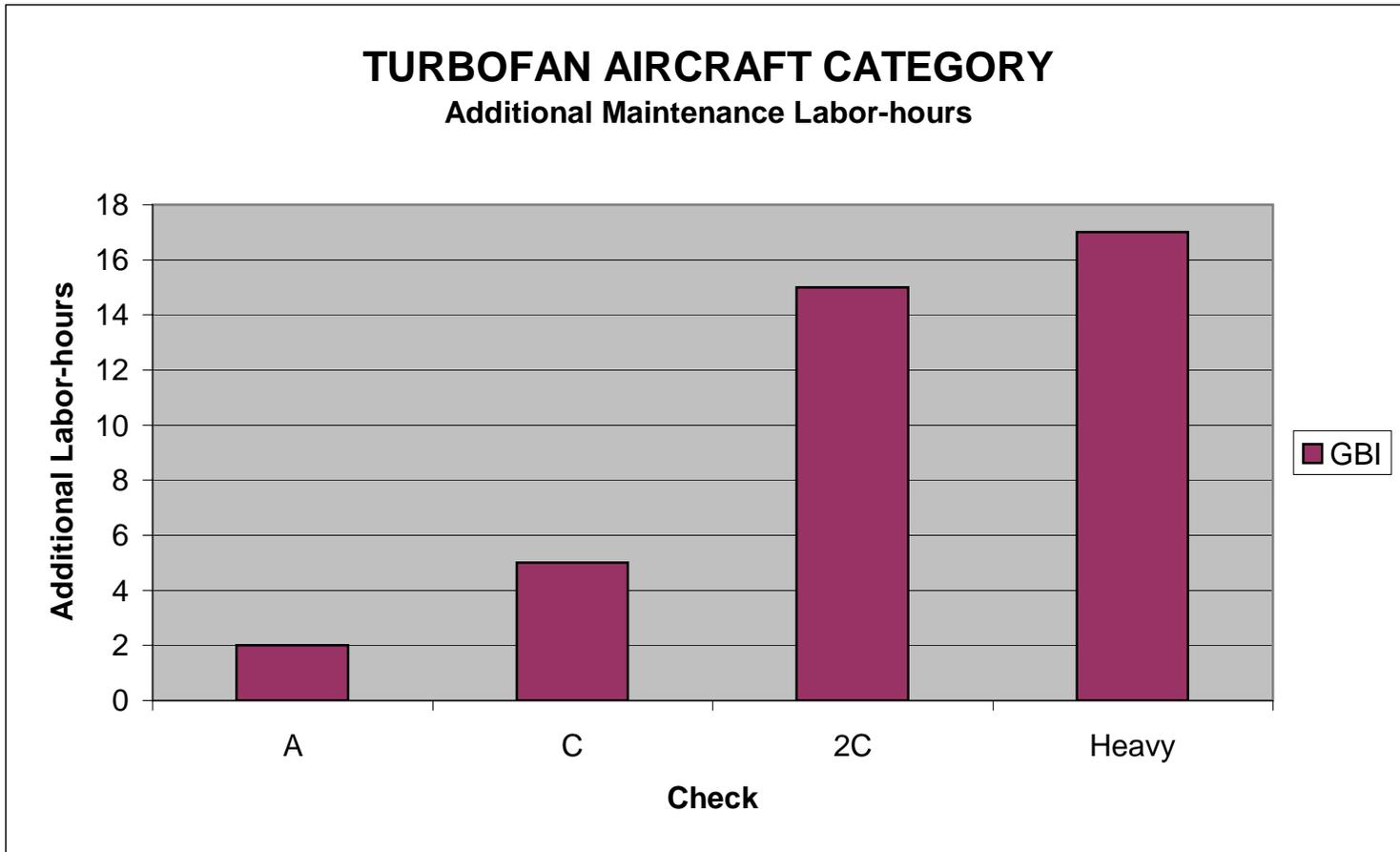


Figure F3.3-2 - Additional Maintenance Labor-hours - Turbofan Category

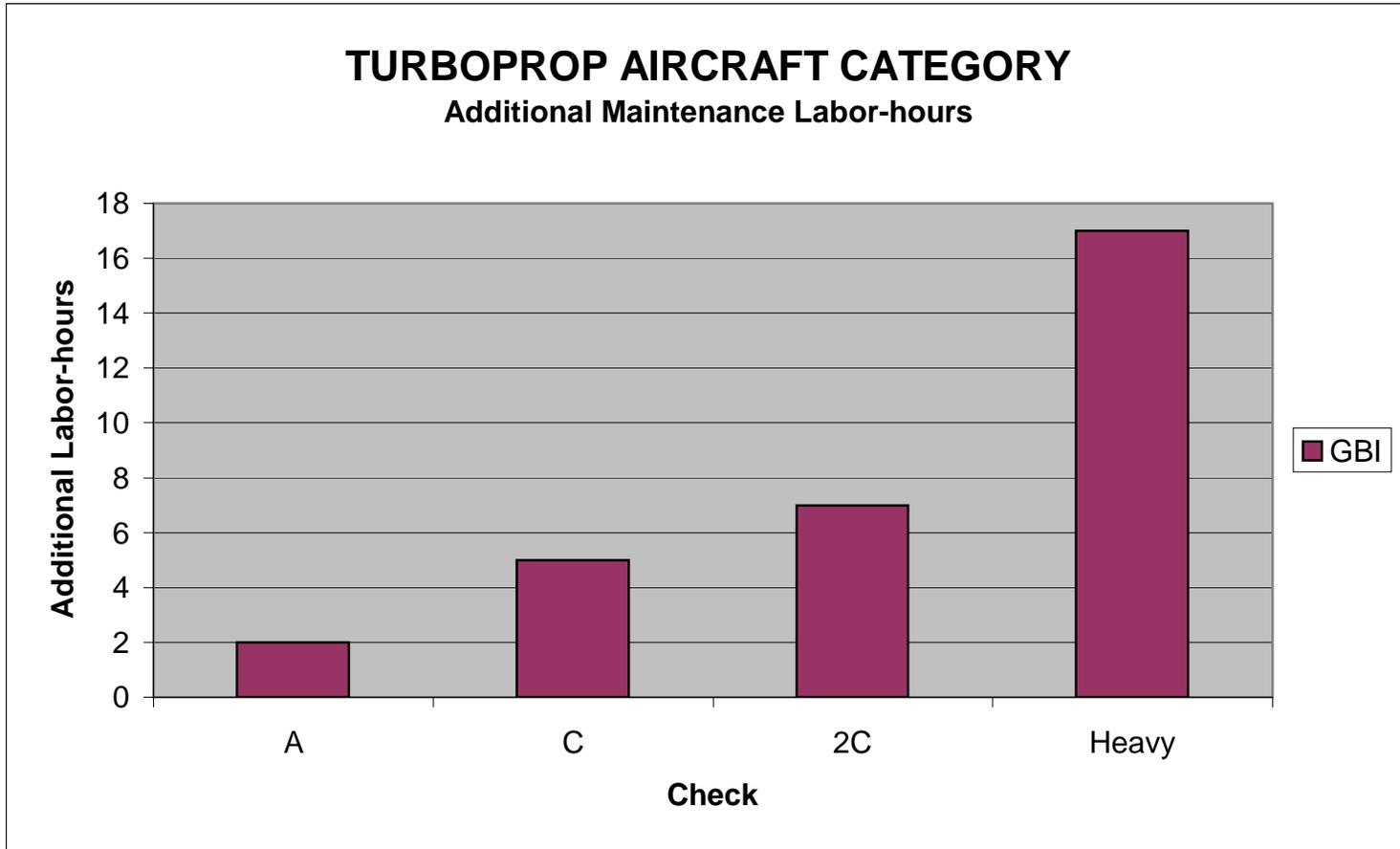


Figure F3.3-3 - Additional Maintenance Labor-hours - Turboprop Category

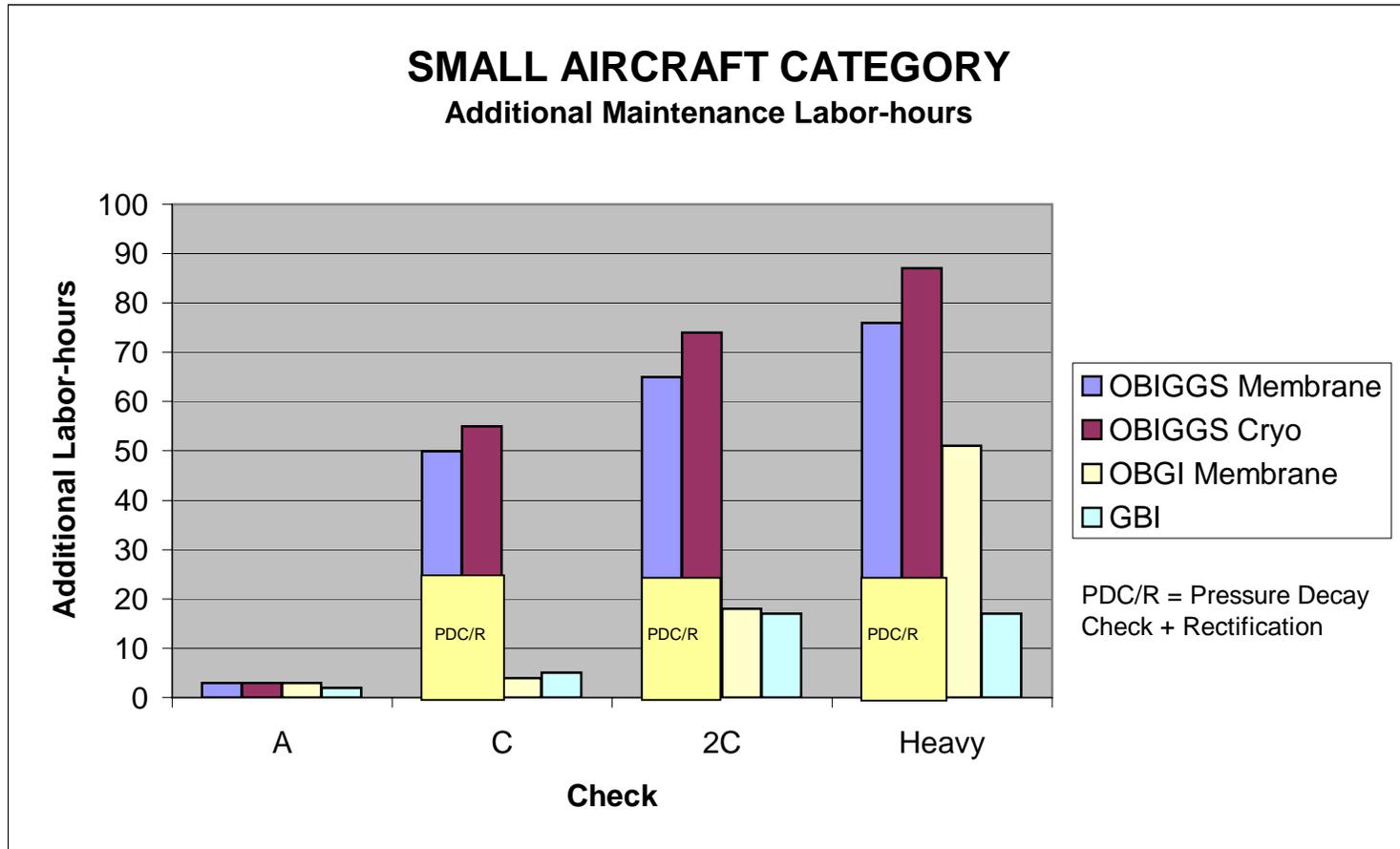


Figure F3.3-4 - Additional Maintenance Labor-hours - Small Aircraft Category

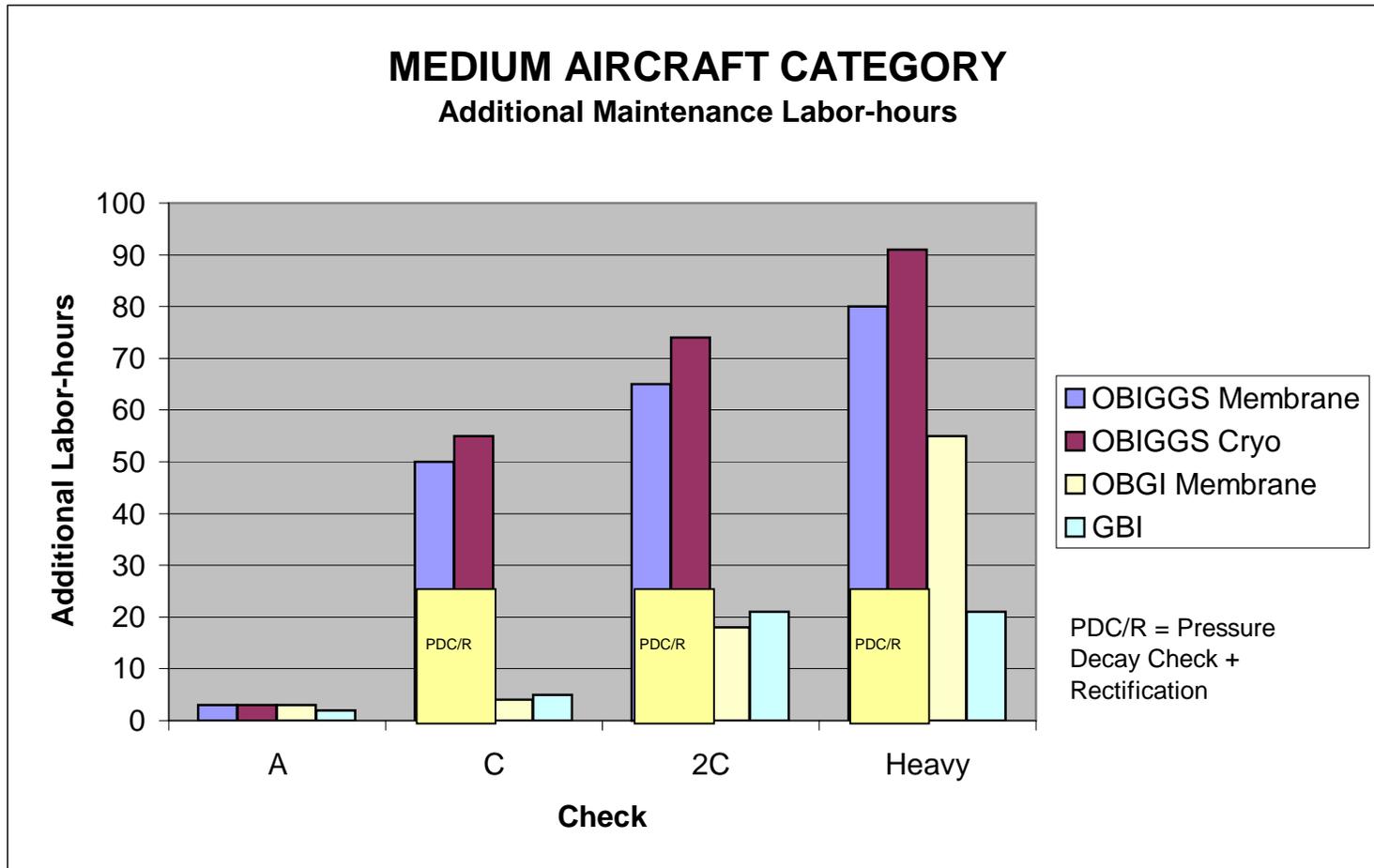


Figure F3.3-5 - Additional Maintenance Labor-hours - Medium Aircraft Category

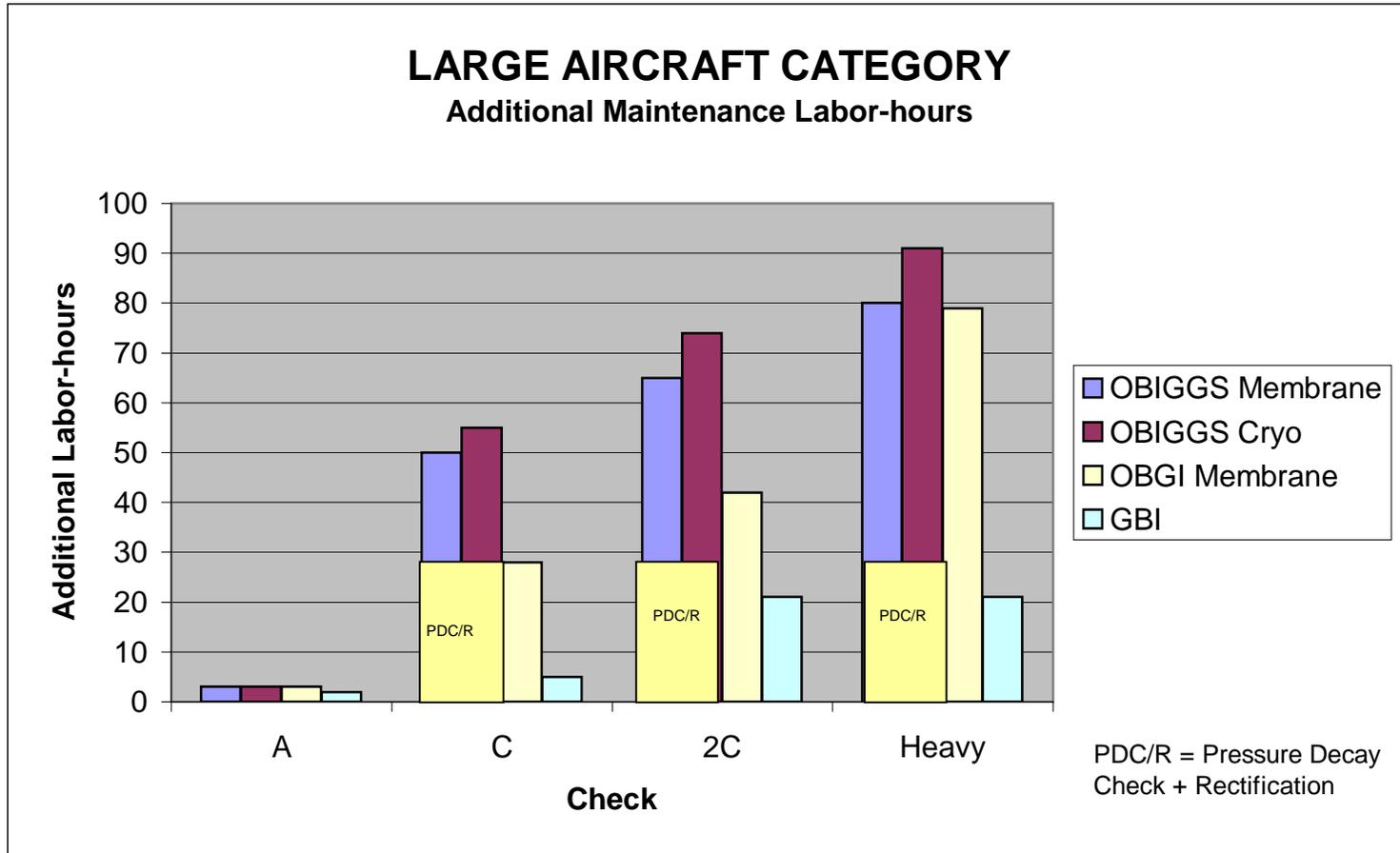


Figure F3.3-6 - Additional Maintenance Labor-hours - Large Aircraft Category

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ADDENDUM F.C.1

***UN-SCHEDULED MAINTENANCE DATA  
GROUND BASED INERTING SYSTEM***

to

APPENDIX F

**AIRPLANE OPERATION AND MAINTENANCE  
FINAL REPORT**

***Airplane Operation and Maintenance Task Team Final Report***

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**Airplane Operation and Maintenance Task Team Final Report**

**Large Transport**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year
Isolation valve (including thermal relief valve)	187,770	208,600	1	24,446	24,446	2	7	1	0.17	1.67
Non return valve	362,028	402,253	1	41,995	41,995	1	7	1	0.10	0.87
Self sealing coupling (including frangible fitting)	422,535	469,483	1	80,000	80,000	1	1	0.5	0.05	0.13
Ducting (including double wall pipe and distribution manifold)	10,000,000	10,000,000	1	80,000	80,000	2	2	1	0.05	0.26
Wiring	10,000,000	10,000,000	1	80,000	80,000	1	2	1	0.05	0.20
<b>System Totals</b>			<b>5</b>		<b>9,783</b>				<b>0.42</b>	<b>3.13</b>

**Medium Transport**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year
Isolation valve (including thermal relief valve)	187,770	208,600	1	24,446	24,446	2	6	1	0.11	1.03
Non return valve	362,028	402,253	1	41,995	41,995	1	6	1	0.07	0.53
Self sealing coupling (including frangible fitting)	422,535	469,483	1	80,000	80,000	1	1	0.5	0.03	0.09
Ducting (including double wall pipe and distribution manifold)	10,000,000	10,000,000	1	80,000	80,000	2	2	1	0.03	0.17
Wiring	10,000,000	10,000,000	1	80,000	80,000	1	2	1	0.03	0.14
<b>System Totals</b>			<b>5</b>		<b>9,783</b>				<b>0.29</b>	<b>1.96</b>

**Small Transport**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year
Isolation valve (including thermal relief valve)	187,770	208,600	1	24,446	24,446	2	6	1	0.12	1.06

**Airplane Operation and Maintenance Task Team Final Report**

Non return valve	362,028	402,253	1	41,995	41,995	1	6	1	0.07	0.55
Self sealing coupling (including frangible fitting)	422,535	469,483	1	80,000	80,000	1	1	0.5	0.04	0.09
Ducting (including double wall pipe and distribution manifold)	10,000,000	10,000,000	1	80,000	80,000	2	2	1	0.04	0.18
Wiring	10,000,000	10,000,000	1	80,000	80,000	1	2	1	0.04	0.14
<b>System Totals</b>			<b>5</b>		<b>9,783</b>				<b>0.29</b>	<b>2.02</b>

**Regional Turbofan**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year
Isolation valve (including thermal relief valve)	187,770	208,600	1	24,446	24,446	2	5	1	0.09	0.69
Non return valve	362,028	402,253	1	41,995	41,995	1	5	1	0.05	0.35
Self sealing coupling (including frangible fitting)	422,535	469,483	1	80,000	80,000	1	1	0.5	0.03	0.07
Ducting (including double wall pipe and distribution manifold)	10,000,000	10,000,000	1	80,000	80,000	2	2	1	0.03	0.13
Wiring	10,000,000	10,000,000	1	80,000	80,000	1	2	1	0.03	0.11
<b>System Totals</b>			<b>5</b>		<b>9,783</b>				<b>0.22</b>	<b>1.35</b>

**Regional Turboprop**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year
Isolation valve (including thermal relief valve)	187,770	208,600	1	24,446	24,446	2	5	1	0.12	0.97
Non return valve	362,028	402,253	1	41,995	41,995	1	5	1	0.07	0.49
Self sealing coupling (including frangible fitting)	422,535	469,483	1	80,000	80,000	1	1	0.5	0.04	0.09
Ducting (including double wall pipe and distribution manifold)	10,000,000	10,000,000	1	80,000	80,000	2	2	1	0.04	0.18
Wiring	10,000,000	10,000,000	1	80,000	80,000	1	2	1	0.04	0.15
<b>System Totals</b>			<b>5</b>		<b>9,783</b>				<b>0.30</b>	<b>1.89</b>

**Business Jet**

**Airplane Operation and Maintenance Task Team Final Report**

Component	Unit MTBMA		Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year
	Unit MTBMA	Unit MTBF								
Isolation valve (including thermal relief valve)	187,770	208,600	1	24,446	24,446	2	6	1	0.02	0.18
Non return valve	362,028	402,253	1	41,995	41,995	1	6	1	0.01	0.10
Self sealing coupling (including frangible fitting)	422,535	469,483	1	80,000	80,000	1	1	0.5	0.01	0.02
Ducting (including double wall pipe and distribution manifold)	10,000,000	10,000,000	1	80,000	80,000	2	2	1	0.01	0.03
Wiring	10,000,000	10,000,000	1	80,000	80,000	1	2	1	0.01	0.03
<b>System Totals</b>			<b>5</b>		<b>9,783</b>				<b>0.05</b>	<b>0.35</b>

***Airplane Operation and Maintenance Task Team Final Report***

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**ADDENDUM F.C.2**

***UN-SCHEDULED MAINTENANCE DATA  
ON-BOARD GROUND INERTING SYSTEM***

to

**APPENDIX F**

**AIRPLANE OPERATION AND MAINTENANCE  
FINAL REPORT**

## ***Airplane Operation and Maintenance Task Team Final Report***

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*Airplane Operation and Maintenance Task Team Final Report*

**ON-BOARD GROUND INERTING SYSTEM PARTS LIST  
DUAL FLOW MEMBRANE - Reliability Estimate Data**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Small Transport</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.03	0.09	1.72
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.24	0.72	14.37
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.05	0.10	3.00
Compressor	7,000	100,000	1	11,096	11,096	2	0.5	0.5	0.17	0.52	10.36
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.06	0.17	3.37
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.06	0.18	3.52
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.08	0.25	5.05
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.25	0.99	14.81
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.03	0.08	1.96
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.04	0.12	2.41
Temperature sensor	50,000	50,000	2	52,494	26,247	2	2	4	0.11	0.87	6.56
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.05	0.16	3.20
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.48	1.44	28.74
Air separation module	30,000	30,000	1	20,000	20,000	2	1	6	0.10	0.86	5.75
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.04	0.18	2.16
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.11	0.32	6.39
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.14	4.73	8.61
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.19	0.77	11.50
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.04	0.36	2.15
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.04	0.57	2.15
System Totals			25		960	35	44.5	44	2.30	13.48	137.79

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST  
DUAL FLOW MEMBRANE - Reliability Estimate Data**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
Medium Transport											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.03	0.08	1.26
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.16	0.48	7.19
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.07	1.50
Compressor	7,000	100,000	1	11,096	11,096	3	0.5	0.5	0.12	0.46	5.18
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.04	0.11	1.68
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.06	0.17	2.57
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.08	0.25	3.68
Heat exchanger	100,000	100,000	1	11,621	11,621	4	1	1	0.24	1.44	10.81
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.05	0.98
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.03	0.08	1.20
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.11	0.43	4.79
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.05	0.16	2.34
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.32	0.96	14.37
Air separation module	30,000	30,000	1	20,000	20,000	9	2	6	0.06	1.09	2.87
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.12	1.08
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.10	0.31	4.67
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.14	4.61	6.28
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.13	0.51	5.75
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.03	0.35	1.57
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.03	0.56	1.57
System Totals			25		960	44	44.5	42	1.81	12.28	81.35

*Airplane Operation and Maintenance Task Team Final Report*

**ON-BOARD GROUND INERTING SYSTEM PARTS LIST  
DUAL FLOW MEMBRANE - Reliability Estimate Data**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Large Transport</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.04	0.12	1.22
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.14	0.41	4.11
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.06	0.86
Compressor	7,000	100,000	1	11,096	11,096	18	2	1	0.10	2.07	2.96
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.03	0.10	0.96
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.08	0.25	2.51
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.12	0.36	3.59
Heat exchanger	100,000	100,000	1	11,621	11,621	4	1	1	0.35	2.11	10.53
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.05	0.56
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.02	0.07	0.69
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.16	0.62	4.66
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.08	0.23	2.28
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.27	0.82	8.21
Air separation module	30,000	30,000	1	20,000	20,000	18	2	6	0.05	1.42	1.64
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.10	0.62
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.15	0.45	4.55
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.20	6.73	6.12
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.11	0.44	3.29
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.05	0.51	1.53
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.05	0.82	1.53
<b>System Totals</b>			<b>25</b>		<b>960</b>	<b>68</b>	<b>46</b>	<b>42.5</b>	<b>2.08</b>	<b>17.74</b>	<b>62.41</b>

*Airplane Operation and Maintenance Task Team Final Report*

**ON-BOARD GROUND INERTING SYSTEM PARTS LIST  
DUAL FLOW MEMBRANE - Reliability Estimate Data**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Business Jet</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.01	0.02	0.30
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.05	0.14	2.74
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.01	0.02	0.57
Compressor	7,000	100,000	1	11,096	11,096	2	0.5	0.5	0.03	0.10	1.97
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.01	0.03	0.64
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.01	0.03	0.61
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.01	0.04	0.88
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.04	0.17	2.58
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.01	0.02	0.37
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.01	0.02	0.46
Temperature sensor	50,000	50,000	2	52,494	26,247	2	2	4	0.02	0.15	1.14
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.01	0.03	0.56
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.09	0.27	5.48
Air separation module	30,000	30,000	1	20,000	20,000	2	1	6	0.02	0.16	1.10
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.01	0.03	0.41
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.02	0.06	1.11
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.03	0.83	1.50
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.05	0.20	3.00
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.01	0.06	0.38
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.01	0.10	0.38
<b>System Totals</b>			<b>25</b>		<b>960</b>	<b>35</b>	<b>44.5</b>	<b>44</b>	<b>0.44</b>	<b>2.48</b>	<b>26.18</b>

*Airplane Operation and Maintenance Task Team Final Report*

**ON-BOARD GROUND INERTING SYSTEM PARTS LIST  
DUAL FLOW MEMBRANE - Reliability Estimate Data**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turboprop</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.02	0.06	1.27
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.13	0.39	7.76
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.05	1.62
Compressor	7,000	100,000	1	11,096	11,096	2	0.5	0.5	0.09	0.28	5.59
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.03	0.09	1.82
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.04	0.13	2.60
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.06	0.19	3.72
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.18	0.73	10.93
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.04	1.06
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.02	0.06	1.30
Temperature sensor	50,000	50,000	2	52,494	26,247	2	2	4	0.08	0.65	4.84
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.04	0.12	2.36
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.26	0.78	15.51
Air separation module	30,000	30,000	1	20,000	20,000	2	1	6	0.05	0.47	3.10
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.10	1.16
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.08	0.24	4.72
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.05	1.71	3.10
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.21	0.85	12.70
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.03	0.26	1.59
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.03	0.42	1.59
<b>System Totals</b>			<b>25</b>		<b>960</b>	<b>35</b>	<b>44.5</b>	<b>44</b>	<b>1.47</b>	<b>7.61</b>	<b>88.35</b>

*Airplane Operation and Maintenance Task Team Final Report*

**ON-BOARD GROUND INERTING SYSTEM PARTS LIST  
DUAL FLOW MEMBRANE - Reliability Estimate Data**

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turbofan</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.03	0.09	1.77
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.13	0.40	8.10
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.06	1.69
Compressor	7,000	100,000	1	11,096	11,096	2	0.5	0.5	0.10	0.29	5.84
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.03	0.09	1.90
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.06	0.18	3.63
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.09	0.26	5.20
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.25	1.02	15.26
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.05	1.11
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.02	0.07	1.36
Temperature sensor	50,000	50,000	2	52,494	26,247	2	2	4	0.11	0.90	6.76
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.05	0.16	3.30
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.27	0.81	16.20
Air separation module	30,000	30,000	1	20,000	20,000	2	1	6	0.05	0.49	3.24
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.10	1.22
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.11	0.33	6.59
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.15	4.88	8.87
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.30	1.18	17.74
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.04	0.37	2.22
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.04	0.59	2.22
<b>System Totals</b>			<b>25</b>		<b>960</b>	<b>35</b>	<b>44.5</b>	<b>44</b>	<b>1.90</b>	<b>12.32</b>	<b>114.20</b>

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST**

THREE-FLOW PRESSURE-SWING ADSORPTION - Reliability Estimate Data

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Small Transport</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.03	0.09	1.72
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.24	0.72	14.37
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.05	0.10	3.00
Compressor	7,000	100,000	1	11,096	11,096	2	1	0.5	0.17	0.60	10.36
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.06	0.17	3.37
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.06	0.18	3.52
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.08	0.25	5.05
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.25	0.99	14.81
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.03	0.08	1.96
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.04	0.12	2.41
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.11	0.44	6.56
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.05	0.16	3.20
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.48	1.44	28.74
Air separation module	34,000	34,000	1	15,000	15,000	2	1	6	0.13	1.15	7.67
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.04	0.18	2.16
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.11	0.32	6.39
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.14	4.73	8.61
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.29	1.15	17.21
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.04	0.36	2.15
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.04	0.57	2.15
<b>System Totals</b>			25		945	34	44	42	2.42	13.79	145.42

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST**

THREE-FLOW PRESSURE-SWING ADSORPTION - Reliability Estimate Data

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Medium Transport</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.03	0.08	1.26
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.16	0.48	7.19
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.07	1.50
Compressor	7,000	100,000	1	11,096	11,096	3	0.5	0.5	0.12	0.46	5.18
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.04	0.11	1.68
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.06	0.17	2.57
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.08	0.25	3.68
Heat exchanger	100,000	100,000	1	11,621	11,621	4	1	1	0.24	1.44	10.81
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.05	0.98
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.03	0.08	1.20
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.11	0.43	4.79
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.05	0.16	2.34
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.32	0.96	14.37
Air separation module	34,000	34,000	1	15,000	15,000	9	2	6	0.09	1.45	3.83
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.12	1.08
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.05	0.14	2.13
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.14	4.61	6.28
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.28	1.12	12.57
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.03	0.35	1.57
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.03	0.56	1.57
<b>System Totals</b>			25		945	44	44.5	42	1.92	13.08	86.59

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST**

THREE-FLOW PRESSURE-SWING ADSORPTION - Reliability Estimate Data

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Large Transport</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.04	0.12	1.22
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.14	0.41	4.11
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.06	0.86
Compressor	7,000	100,000	1	11,096	11,096	20	3	1	0.10	2.37	2.96
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.03	0.10	0.96
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.08	0.25	2.51
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.12	0.36	3.59
Heat exchanger	100,000	100,000	1	11,621	11,621	9	2	1	0.35	4.21	10.53
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.05	0.56
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.02	0.07	0.69
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.16	0.62	4.66
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.08	0.23	2.28
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.27	0.82	8.21
Air separation module	34,000	34,000	1	15,000	15,000	18	2	6	0.07	1.90	2.19
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.10	0.62
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.15	0.45	4.55
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.20	6.73	6.12
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.41	1.63	12.24
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.05	0.51	1.53
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.05	0.82	1.53
<b>System Totals</b>			25		945	75	48	42.5	2.40	21.81	71.92

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST**

THREE-FLOW PRESSURE-SWING ADSORPTION - Reliability Estimate Data

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Business Jet</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.01	0.02	0.30
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.05	0.14	2.74
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.01	0.02	0.57
Compressor	7,000	100,000	1	11,096	11,096	2	1	0.5	0.03	0.12	1.97
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.01	0.03	0.64
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.01	0.03	0.61
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.01	0.04	0.88
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.04	0.17	2.58
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.01	0.02	0.37
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.01	0.02	0.46
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.02	0.08	1.14
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.01	0.03	0.56
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.09	0.27	5.48
Air separation module	34,000	34,000	1	15,000	15,000	2	1	6	0.02	0.22	1.46
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.01	0.03	0.41
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.02	0.06	1.11
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.03	0.83	1.50
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.05	0.20	3.00
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.01	0.06	0.38
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.01	0.10	0.38
<b>System Totals</b>			25		945	34	44	42	0.44	2.48	26.54

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST**

THREE-FLOW PRESSURE-SWING ADSORPTION - Reliability Estimate Data

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turboprop</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.02	0.06	1.27
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.13	0.39	7.76
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.05	1.62
Compressor	7,000	100,000	1	11,096	11,096	2	1	0.5	0.09	0.33	5.59
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.03	0.09	1.82
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.04	0.13	2.60
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.06	0.19	3.72
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.18	0.73	10.93
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.04	1.06
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.02	0.06	1.30
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.08	0.32	4.84
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.04	0.12	2.36
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.26	0.78	15.51
Air separation module	34,000	34,000	1	15,000	15,000	2	1	6	0.07	0.62	4.14
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.10	1.16
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.08	0.24	4.72
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.11	3.49	6.35
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.21	0.85	12.70
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.03	0.26	1.59
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.03	0.42	1.59
<b>System Totals</b>			25		945	34	44	42	1.54	9.27	92.63

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**ON-BOARD GROUND INERTING SYSTEM PARTS LIST**

THREE-FLOW PRESSURE-SWING ADSORPTION - Reliability Estimate Data

Component	Unit MTBMA	Unit MTBF	Quantity /Shipset	Single Component MTBUR Calc (Hrs)	Component MTBUR Calc (System) (Hrs)	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labor Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turbofan</b>											
Cabin air filter assy	100,000	100,000	1	100,000	100,000	1	1	1	0.03	0.09	1.77
Cabin air filter element	4,000	10,000,000	1	8,000	8,000	1	1	1	0.13	0.40	8.10
Compressor unloading valve	50,000	50,000	1	38,315	38,315	1	0.5	0.5	0.03	0.06	1.69
Compressor	7,000	100,000	1	11,096	11,096	2	1	0.5	0.10	0.34	5.84
Compressor discharge check valve	100,000	100,000	1	34,119	34,119	1	0.5	1.5	0.03	0.09	1.90
Bleed shutoff valve	50,000	50,000	1	48,856	48,856	1	1	1	0.06	0.18	3.63
Bleed check valve	100,000	100,000	1	34,119	34,119	1	1	1	0.09	0.26	5.20
Heat exchanger	100,000	100,000	1	11,621	11,621	2	1	1	0.25	1.02	15.26
Cooling fan	25,000	25,000	1	58,561	58,561	1	1	0.5	0.02	0.05	1.11
Bypass valve	50,000	50,000	1	47,737	47,737	1	1	1	0.02	0.07	1.36
Temperature sensor	50,000	50,000	2	52,494	26,247	1	1	2	0.11	0.45	6.76
Water separator/filter assy	100,000	100,000	1	53,789	53,789	1	1	1	0.05	0.16	3.30
Water separator/filter element	4,000	10,000,000	1	4,000	4,000	1	1	1	0.27	0.81	16.20
Air separation module	34,000	34,000	1	15,000	15,000	2	1	6	0.07	0.65	4.32
Relief valve	50,000	50,000	1	53,306	53,306	2	1	2	0.02	0.10	1.22
Oxygen sensor	26,933	26,933	1	26,933	26,933	1	1	1	0.11	0.33	6.59
Fuel tank check valve	100,000	100,000	5	100,000	20,000	1	24	8	0.15	4.88	8.87
Controller / control card	10,000	10,000	1	10,000	10,000	1	1	2	0.30	1.18	17.74
Ducting	10,000,000	10,000,000	1	80,000	80,000	6	2	2	0.04	0.37	2.22
Wiring	10,000,000	10,000,000	1	80,000	80,000	6	2	8	0.04	0.59	2.22
<b>System Totals</b>			25		945	34	44	42	1.92	12.08	115.28

**ADDENDUM F.C.3**

***UN-SCHEDULED MAINTENANCE DATA  
ON-BOARD INERTING GAS GENERATING SYSTEM***

**to**

**APPENDIX F**

**AIRPLANE OPERATION AND MAINTENANCE  
FINAL REPORT**

***Airplane Operation and Maintenance Task Team Final Report***

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OBIGGS Data Sheet

Variable Input

	Aircraft Daily Utilization Rate - Flt Hrs	Aircraft Cycles Per Day	Minimum Turn Time Minutes	Minimum Daily Operating Hours (Includes Ground Ops Time)	Minimum Yearly Operating Hours (Includes Ground Ops Time)	Aircraft Annual Flight Hours	Aircraft pressure Check (Hours)
Small Transport	7.86	7	30	11	4146	2869	0
Medium Transport	7.65	4	45	10	3750	2792	0
Large Transport	11.18	2	60	13	4811	4081	0
Business Jet	1.37	4	60	5	1778	500	0
Regional Turboprop	5.8	7	15	8	2765	2117	0
Regional Turbofan	8.1	7	15	10	3577	2957	0

	Labour Costs \$	Delay Assumption - 1 delay = XX Minutes	Cost Per Minute Delay (\$)	Minutes delay due to extended turn time	Delay Costs \$ per hr	Cancelation Costs \$ per event	Cancelation Costs \$ per day
Small Transport	\$75	60	\$100	5	\$6,000.00	\$7,600	\$53,200
Medium Transport	\$75	45	\$142	5	\$8,490.00	\$20,000	\$70,000
Large Transport	\$75	30	\$183	5	\$10,980.00	\$32,600	\$65,200
Business Jet	\$75	60	\$100	5	\$6,000.00	\$7,600	\$26,600
Regional Turboprop	\$75	60	\$100	5	\$6,000.00	\$7,600	\$53,960
Regional Turbofan	\$75	60	\$100	5	\$6,000.00	\$7,600	\$51,680

**MMEL Relief Study**

	MMEL Repair Interval/ Service Cancellation				
	None	1 day	3 days	10 days	120 days
Small Transport	90%	20%	5%	3%	0%
Medium Transport	80%	18%	4%	2%	0%
Large Transport	70%	15%	3%	1%	0%
Business Jet	80%	18%	4%	2%	0%
Regional Turboprop	90%	20%	5%	3%	0%
Regional Turbofan	90%	20%	5%	3%	0%

	MMEL Impact No relief - Costs \$			Cancelation Costs	Delay Costs
	Membrane System	PSA System	Cryo System	\$ per day	\$ per hr
Small Transport	\$137,662.84	\$143,719.28	\$197,480.10	\$26,600	\$6,000
Medium Transport	\$164,216.51	\$171,441.17	\$235,571.87	\$35,000	\$8,490
Large Transport	\$265,267.43	\$276,937.80	\$380,531.43	\$65,200	\$10,980
Business Jet	\$66,419.23	\$69,341.33	\$95,279.72	\$13,300	\$6,000
Regional Turboprop	\$139,581.37	\$145,722.21	\$200,232.26	\$26,980	\$6,000
Regional Turbofan	\$133,825.78	\$139,713.41	\$191,975.76	\$25,840	\$6,000

	MMEL Impact 1 day relief - Costs \$			Cancelation Costs	Delay Costs
	Membrane System	PSA System	Cryo System	\$ per day	\$ per hr
Small Transport	\$56,770.49	\$59,268.10	\$81,438.41	\$26,600	\$6,000
Medium Transport	\$64,631.69	\$67,475.15	\$92,715.46	\$35,000	\$8,490
Large Transport	\$81,041.00	\$84,606.38	\$116,254.94	\$65,200	\$10,980
Business Jet	\$41,029.58	\$42,834.67	\$58,857.76	\$13,300	\$6,000
Regional Turboprop	\$57,196.83	\$59,713.19	\$82,050.00	\$26,980	\$6,000
Regional Turbofan	\$55,917.82	\$58,377.90	\$80,215.22	\$25,840	\$6,000

	MMEL Impact 3 day relief - Costs \$			Cancelation Costs	Delay Costs
	Membrane System	PSA System	Cryo System	\$ per day	\$ per hr
Small Transport	\$39,436.42	\$41,171.42	\$56,572.33	\$26,600	\$6,000
Medium Transport	\$41,823.56	\$43,663.57	\$59,996.73	\$35,000	\$8,490
Large Transport	\$39,171.36	\$40,894.69	\$56,192.10	\$65,200	\$10,980
Business Jet	\$35,296.44	\$36,849.30	\$50,633.45	\$13,300	\$6,000
Regional Turboprop	\$39,543.01	\$41,282.69	\$56,725.23	\$26,980	\$6,000
Regional Turbofan	\$39,223.25	\$40,948.87	\$56,266.54	\$25,840	\$6,000

	MMEL Impact 10 day relief - Costs \$			Cancelation Costs	Delay Costs
	Membrane System	PSA System	Cryo System	\$ per day	\$ per hr
Small Transport	\$36,547.41	\$38,155.30	\$52,427.99	\$26,600	\$6,000
Medium Transport	\$38,932.39	\$40,645.21	\$55,849.29	\$35,000	\$8,490
Large Transport	\$34,147.00	\$35,649.29	\$48,984.56	\$65,200	\$10,980
Business Jet	\$34,477.42	\$35,994.24	\$49,458.54	\$13,300	\$6,000
Regional Turboprop	\$36,600.70	\$38,210.94	\$52,504.44	\$26,980	\$6,000
Regional Turbofan	\$36,440.82	\$38,044.03	\$52,275.09	\$25,840	\$6,000

	MMEL Impact 120 day relief - Costs \$			Cancelation Costs	Delay Costs
	Membrane System	PSA System	Cryo System	\$ per day	\$ per hr
Small Transport	\$33,658.40	\$35,139.19	\$48,283.64	\$26,600	\$6,000
Medium Transport	\$35,719.97	\$37,291.46	\$51,241.02	\$35,000	\$8,490
Large Transport	\$30,797.43	\$32,152.36	\$44,179.53	\$65,200	\$10,980
Business Jet	\$33,658.40	\$35,139.19	\$48,283.64	\$13,300	\$6,000
Regional Turboprop	\$33,658.40	\$35,139.19	\$48,283.64	\$26,980	\$6,000
Regional Turbofan	\$33,658.40	\$35,139.19	\$48,283.64	\$25,840	\$6,000

	Costs per year - Membrane system only (one event per day)				
	None	1 day	3 days	10 days	120 days
Small Transport	\$137,663	\$56,770	\$39,436	\$36,547	\$33,658
Medium Transport	\$164,217	\$64,632	\$41,824	\$38,932	\$35,720
Large Transport	\$265,267	\$81,041	\$39,171	\$34,147	\$30,797
Business Jet	\$66,419	\$41,030	\$35,296	\$34,477	\$33,658
Regional Turboprop	\$139,581	\$57,197	\$39,543	\$36,601	\$33,658
Regional Turbofan	\$133,826	\$55,918	\$39,223	\$36,441	\$33,658

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**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Small Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.12	2.49
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.52	1.55	31.10
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.11	0.22	6.49
Compressor	16	7,000	100,000	1	11,096	2	0.5	0.5	0.37	1.12	22.42
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.12	0.36	7.29
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.25	5.09
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.12	0.36	7.29
Heat exchanger	14	100,000	100,000	1	11,621	2	1	1	0.36	1.43	21.41
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.07	0.18	4.25
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.09	0.26	5.21
Temperature sensor	0.15	50,000	50,000	2	26,247	2	2	4	0.16	1.26	9.48
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.08	0.23	4.63
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	1.04	3.11	62.20
Low flow air separation module	18	30,000	30,000	1	20,000	2	1	6	0.21	1.87	12.44
High flow shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.25	5.09
High flow air separation module	18	80,000	80,000	1	15,000	2	1	6	0.28	2.49	16.59
High flow check valve	1	100,000	100,000	1	41,995	1	1	1	0.10	0.30	5.92
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.08	0.39	4.67
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.15	0.46	9.24
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	1.04	34.21	62.20
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.41	1.66	24.88
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.05	0.52	3.11
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.05	0.83	3.11
<b>System Totals</b>	<b>468.15</b>			<b>28</b>	<b>739</b>	<b>39</b>	<b>47.5</b>	<b>52</b>	<b>5.61</b>	<b>53.44</b>	<b>336.58</b>

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**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Medium Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.11	1.69
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.47	1.41	21.10
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.10	0.20	4.40
Compressor	102	7,000	100,000	1	12,000	3	0.5	0.5	0.31	1.25	14.06
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.11	0.33	4.95
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.23	3.45
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.11	0.33	4.95
Heat exchanger	36	100,000	100,000	1	11,621	4	1	1	0.32	1.94	14.52
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.06	0.16	2.88
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.08	0.24	3.54
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.14	0.57	6.43
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.07	0.21	3.14
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.94	2.81	42.19
Low flow air separation module	64	30,000	30,000	1	20,000	9	2		0.19	2.06	8.44
High flow shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.23	3.45
High flow air separation module	42.5	80,000	80,000	1	15,000	9	2	6	0.25	4.25	11.25
High flow check valve	1	100,000	100,000	1	41,995	1	1	1	0.09	0.27	4.02
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.07	0.35	3.17
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.14	0.42	6.27
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.94	30.94	42.19
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.38	1.50	16.88
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.05	0.47	2.11
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.05	0.75	2.11
System Totals	646.65			28	743	55	48.5	44	5.05	51.02	227.18

**Airplane Operation and Maintenance Task Team Final Report**

**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Large Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.05	0.14	1.44
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.60	1.80	18.04
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.13	0.25	3.77
Compressor	188	7,000	100,000	1	12,000	18	2	1	0.40	8.42	12.03
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.14	0.42	4.23
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.10	0.30	2.95
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.14	0.42	4.23
Heat exchanger	58	100,000	100,000	1	11,621	4	1	1	0.41	2.48	12.42
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.08	0.21	2.46
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.10	0.30	3.02
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.18	0.73	5.50
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.09	0.27	2.68
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	1.20	3.61	36.08
Low flow air separation module	110	30,000	30,000	1	20,000	18	2	6	0.24	6.25	7.22
High flow shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.10	0.30	2.95
High flow air separation module	67	80,000	80,000	1	15,000	18	2	6	0.32	8.34	9.62
High flow check valve	1	100,000	100,000	1	41,995	1	1	1	0.11	0.34	3.44
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.09	0.45	2.71
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.18	0.54	5.36
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	1.20	39.69	36.08
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.48	1.92	14.43
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.06	0.60	1.80
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.06	0.96	1.80
System Totals	825.15			28	743	88	50	50.5	6.48	78.76	194.27

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**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Business Jet</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.02	0.05	1.07
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.22	0.67	13.33
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.05	0.09	2.78
Compressor	16	7,000	100,000	1	11,096	2	0.5	0.5	0.16	0.48	9.61
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.05	0.16	3.13
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.04	0.11	2.18
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.05	0.16	3.13
Heat exchanger	14	100,000	100,000	1	11,621	2	1	1	0.15	0.61	9.18
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.03	0.08	1.82
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.04	0.11	2.23
Temperature sensor	0.15	50,000	50,000	2	26,247	2	2	4	0.07	0.54	4.06
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.03	0.10	1.98
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.44	1.33	26.66
Low flow air separation module	18	30,000	30,000	1	20,000	2	1	6	0.09	0.80	5.33
High flow shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.04	0.11	2.18
High flow air separation module	18	80,000	80,000	1	15,000	2	1	6	0.12	1.07	7.11
High flow check valve	1	100,000	100,000	1	41,995	1	1	1	0.04	0.13	2.54
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.03	0.17	2.00
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.07	0.20	3.96
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.44	14.66	26.66
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.18	0.71	10.67
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.02	0.22	1.33
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.02	0.36	1.33
System Totals	468.15			28	739	39	47.5	52	2.40	22.91	144.29

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**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turboprop</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.03	0.08	1.66
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.35	1.04	20.74
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.07	0.14	4.33
Compressor	16	7,000	100,000	1	11,096	2	0.5	0.5	0.25	0.75	14.95
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.08	0.24	4.86
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.06	0.17	3.40
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.08	0.24	4.86
Heat exchanger	14	100,000	100,000	1	11,621	2	1	1	0.24	0.95	14.28
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.05	0.12	2.83
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.06	0.17	3.48
Temperature sensor	0.15	50,000	50,000	2	26,247	2	2	4	0.11	0.84	6.32
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.05	0.15	3.08
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.69	2.07	41.47
Low flow air separation module	18	30,000	30,000	1	20,000	2	1	6	0.14	1.24	8.29
High flow shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.06	0.17	3.40
High flow air separation module	18	80,000	80,000	1	15,000	2	1	6	0.18	1.66	11.06
High flow check valve	1	100,000	100,000	1	41,995	1	1	1	0.07	0.20	3.95
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.05	0.26	3.11
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.10	0.31	6.16
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.69	22.81	41.47
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.28	1.11	16.59
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.03	0.35	2.07
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.03	0.55	2.07
System Totals	468.15			28	739	39	47.5	52	3.74	35.63	224.44

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**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turbofan</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.11	2.15
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.45	1.34	26.83
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.09	0.19	5.60
Compressor	16	7,000	100,000	1	11,096	2	0.5	0.5	0.32	0.97	19.34
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.10	0.31	6.29
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.07	0.22	4.39
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.10	0.31	6.29
Heat exchanger	14	100,000	100,000	1	11,621	2	1	1	0.31	1.23	18.47
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.06	0.15	3.66
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.07	0.22	4.50
Temperature sensor	0.15	50,000	50,000	2	26,247	2	2	4	0.14	1.09	8.18
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.07	0.20	3.99
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.89	2.68	53.66
Low flow air separation module	18	30,000	30,000	1	20,000	2	1	6	0.18	1.61	10.73
High flow shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.07	0.22	4.39
High flow air separation module	18	80,000	80,000	1	15,000	2	1	6	0.24	2.15	14.31
High flow check valve	1	100,000	100,000	1	41,995	1	1	1	0.09	0.26	5.11
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.07	0.34	4.03
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.13	0.40	7.97
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.89	29.51	53.66
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.36	1.43	21.46
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.04	0.45	2.68
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.04	0.72	2.68
<b>System Totals</b>	<b>468.15</b>			<b>28</b>	<b>739</b>	<b>39</b>	<b>47.5</b>	<b>52</b>	<b>4.84</b>	<b>46.10</b>	<b>290.36</b>

**Airplane Operation and Maintenance Task Team Final Report**

**FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION**

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Small Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.12	2.49
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.52	1.55	31.10
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.11	0.22	6.49
Compressor	17	7,000	100,000	1	11,096	2	1	0.5	0.37	1.31	22.42
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.12	0.36	7.29
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.25	5.09
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.12	0.36	7.29
Heat exchanger	13	100,000	100,000	1	11,621	2	1	1	0.36	1.43	21.41
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.07	0.18	4.25
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.09	0.26	5.21
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.16	0.63	9.48
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.08	0.23	4.63
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	1.04	3.11	62.20
Air separation module	44	34,000	34,000	1	5,000	2	1	6	0.83	7.46	49.76
High flow valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.25	5.09
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.08	0.39	4.67
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.15	0.46	9.24
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	1.04	34.21	62.20
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.41	1.66	24.88
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.05	0.52	3.11
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.05	0.83	3.11
<b>System Totals</b>	<b>475.45</b>			<b>26</b>	<b>708</b>	<b>35</b>	<b>45</b>	<b>43</b>	<b>5.86</b>	<b>55.81</b>	<b>351.39</b>

Airplane Operation and Maintenance Task Team Final Report

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Medium Transport</b>											
Cabin air filter Assy	6	100000	100000	1	100000	1	1	1	0.03750375	0.11251125	1.68766875
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.47	1.41	21.10
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.10	0.20	4.40
Compressor	123	7,000	100,000	1	12,000	3	0.5	0.5	0.31	1.25	14.06
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.11	0.33	4.95
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.23	3.45
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.11	0.33	4.95
Heat exchanger	95	100,000	100,000	1	11,621	4	1	1	0.32	1.94	14.52
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.06	0.16	2.88
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.08	0.24	3.54
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.14	0.57	6.43
Water separator/filter Assy	10	100,000	100,000	1	53,789	1	1	1	0.07	0.21	3.14
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.94	2.81	42.19
Air separation module	156.95	34,000	34,000	1	5,000	9	2		0.75	8.25	33.75
High flow valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.23	3.45
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.07	0.35	3.17
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.14	0.42	6.27
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.94	30.94	42.19
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.38	1.50	16.88
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.05	0.47	2.11
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.05	0.75	2.11
System Totals	776.1			26	711.4175143	45	45.5	37	5.271693379	52.69053751	237.2262021

Airplane Operation and Maintenance Task Team Final Report

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Large Transport</b>											
Cabin air filter assy	6	100000	100000	1	100000	1	1	1	0.048107	0.144321	1.44321
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.60	1.80	18.04
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.13	0.25	3.77
Compressor	229	7,000	100,000	1	12,000	20	3	1	0.40	9.62	12.03
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.14	0.42	4.23
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.10	0.30	2.95
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.14	0.42	4.23
Heat exchanger	177	100,000	100,000	1	11,621	18	2	1	0.41	8.69	12.42
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.08	0.21	2.46
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.10	0.30	3.02
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.18	0.73	5.50
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.09	0.27	2.68
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	1.20	3.61	36.08
Air separation module	181	34,000	34,000	1	5,000	18	2	6	0.96	25.02	28.86
High flow valve	3	50,000	50,000	1	48,856	1	1	1	0.10	0.30	2.95
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.09	0.45	2.71
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.18	0.54	5.36
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	1.20	39.69	36.08
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.48	1.92	14.43
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.06	0.60	1.80
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.06	0.96	1.80
System Totals	988.15			26	711.4175143	85	49	43.5	6.76213321	96.24700457	202.8639963

Airplane Operation and Maintenance Task Team Final Report

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Business Jet</b>											
Cabin air filter assy	6	100000	100000	1	100000	1	1	1	0.017775	0.053325	1.0665
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.22	0.67	13.33
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.05	0.09	2.78
Compressor	17	7,000	100,000	1	11,096	2	1	0.5	0.16	0.56	9.61
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.05	0.16	3.13
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.04	0.11	2.18
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.05	0.16	3.13
Heat exchanger	13	100,000	100,000	1	11,621	2	1	1	0.15	0.61	9.18
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.03	0.08	1.82
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.04	0.11	2.23
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.07	0.27	4.06
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.03	0.10	1.98
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.44	1.33	26.66
Air separation module	44.3	34,000	34,000	1	5,000	2	1	6	0.36	3.20	21.33
High flow valve	3	50,000	50,000	1	48,856	1	1	1	0.04	0.11	2.18
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.03	0.17	2.00
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.07	0.20	3.96
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.44	14.66	26.66
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.18	0.71	10.67
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.02	0.22	1.33
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.02	0.36	1.33
System Totals	475.45			26	707.9958632	35	45	43	2.510607889	23.92410081	150.6364734

Airplane Operation and Maintenance Task Team Final Report

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turboprop</b>											
Cabin air filter Assy	6	100000	100000	1	100000	1	1	1	0.02764875	0.08294625	1.658925
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.35	1.04	20.74
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.07	0.14	4.33
Compressor	17	7,000	100,000	1	11,096	2	1	0.5	0.25	0.87	14.95
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.08	0.24	4.86
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.06	0.17	3.40
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.08	0.24	4.86
Heat exchanger	13	100,000	100,000	1	11,621	2	1	1	0.24	0.95	14.28
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.05	0.12	2.83
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.06	0.17	3.48
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.11	0.42	6.32
Water separator/filter Assy	10	100,000	100,000	1	53,789	1	1	1	0.05	0.15	3.08
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.69	2.07	41.47
Air separation module	44.3	34,000	34,000	1	5,000	2	1	6	0.55	4.98	33.18
High flow valve	3	50,000	50,000	1	48,856	1	1	1	0.06	0.17	3.40
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.05	0.26	3.11
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.10	0.31	6.16
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.69	22.81	41.47
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.28	1.11	16.59
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.03	0.35	2.07
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.03	0.55	2.07
System Totals	475.45			26	707.9958632	35	45	43	3.905213496	37.21358549	234.3128097

Airplane Operation and Maintenance Task Team Final Report

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turbofan</b>											
Cabin air filter assy	6	100000	100000	1	100000	1	1	1	0.03577	0.10731	2.1462
Cabin air filter element		4,000	10,000,000	1	8,000	1	1	1	0.45	1.34	26.83
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.09	0.19	5.60
Compressor	17	7,000	100,000	1	11,096	2	1	0.5	0.32	1.13	19.34
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.10	0.31	6.29
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.07	0.22	4.39
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.10	0.31	6.29
Heat exchanger	13	100,000	100,000	1	11,621	2	1	1	0.31	1.23	18.47
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.06	0.15	3.66
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.07	0.22	4.50
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.14	0.55	8.18
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.07	0.20	3.99
Water separator/filter element		4,000	10,000,000	1	4,000	1	1	1	0.89	2.68	53.66
Air separation module	44.3	34,000	34,000	1	5,000	2	1	6	0.72	6.44	42.92
High flow valve	3	50,000	50,000	1	48,856	1	1	1	0.07	0.22	4.39
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.07	0.34	4.03
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.13	0.40	7.97
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.89	29.51	53.66
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.36	1.43	21.46
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.04	0.45	2.68
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.04	0.72	2.68
System Totals	475.45			26	707.9958632	35	45	43	5.052289407	48.14430863	303.1373644

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Small Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.12	2.49
Cabin air filter element		4000	10,000,000	1	8,000	1	1	1	0.52	1.55	31.10
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.11	0.22	6.49
Compressor	3	7,000	100,000	1	11,096	1	0.5	0.5	0.37	0.75	22.42
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.12	0.36	7.29
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.25	5.09
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.12	0.36	7.29
Heat exchanger	0	100,000	100,000	1	11,621	1	1	1	0.36	1.07	21.41
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.07	0.18	4.25
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.09	0.26	5.21
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.16	0.63	9.48
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.08	0.23	4.63
Water separator/filter element		4000	10,000,000	1	4,000	1	1	1	1.04	3.11	62.20
Inlet shutoff valve	4	50,000	50,000	1	35,000	1	1	2	0.12	0.47	7.11
Crycooler bleed air valve	4	50,000	50,000	1	35,000	1	1	2	0.12	0.47	7.11
Flow sensor	0.1	20,000	20,000	1	20,000	1	10	2	0.21	2.70	12.44
Molecular sieve control valves	4	50,000	50,000	2	10,000	1	10	4	0.41	6.22	24.88
Molecular sieves	2.5	50,000	50,000	1	50,000	1	10	4	0.08	1.24	4.98
Purge heat exchanger	5	100,000	100,000	1	15,000	1	10	4	0.28	4.15	16.59
Purge heat exchanger valve-Air Side	4	50,000	50,000	1	35,000	1	10	4	0.12	1.78	7.11
Purge heat exchanger valve-Waste Side	4	50,000	50,000	1	35,000	1	10	4	0.12	1.78	7.11
LNEA Dewar Cooldown Valve	4	50,000	50,000	1	35,000	1	10	2	0.12	1.54	7.11
Inlet Recuperator	44	100,000	100,000	1	15,000	1	10	4	0.28	4.15	16.59
Inlet cooler	3	100,000	100,000	1	100,000	1	10	2	0.04	0.54	2.49
Cryocooler	117	8,000	8,000	1	8,000	6	2	4	0.52	6.22	31.10
LNEA Dewar	0	75,000	75,000	1	75,000	1	1	4	0.06	0.33	3.32
Dewar level sensor	0	50,000	50,000	1	50,000	1	1	2	0.08	0.33	4.98
Distillation column	6	50,000	50,000	1	50,000	1	1	4	0.08	0.50	4.98
Distillation column gas valve	4	50,000	50,000	1	35,000	1	1	2	0.12	0.47	7.11
Distillation column liquid valve	4	50,000	50,000	1	35,000	1	1	2	0.12	0.47	7.11
Temperature sensor	0.15	50,000	50,000	2	17,498	1	1	2	0.24	0.95	14.22
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.08	0.39	4.67
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.15	0.46	9.24
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	1.04	34.21	62.20
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.41	1.66	24.88
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.05	0.52	3.11
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.05	0.83	3.11
<b>System Totals</b>	<b>611</b>			<b>44</b>	<b>515</b>	<b>53</b>	<b>142.5</b>	<b>90</b>	<b>8.05</b>	<b>81.48</b>	<b>482.84</b>

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Medium Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.11	1.69
Cabin air filter element		4000	10,000,000	1	8,000	1	1	1	0.47	1.41	21.10
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.10	0.20	4.40
Compressor	14.5	7,000	100,000	1	11,096	3	0.5	0.5	0.34	1.35	15.21
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.11	0.33	4.95
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.08	0.23	3.45
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.11	0.33	4.95
Heat exchanger	0	100,000	100,000	1	11,621	4	1	1	0.32	1.94	14.52
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.06	0.16	2.88
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.08	0.24	3.54
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.14	0.57	6.43
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.07	0.21	3.14
Water separator/filter element		4000	10,000,000	1	4,000	1	1	1	0.94	2.81	42.19
Inlet shutoff valve	4	50,000	50,000	1	35,000	1	1	2	0.11	0.43	4.82
Cryocooler bleed air valve	4	50,000	50,000	1	35,000	1	1	2	0.11	0.43	4.82
Flow sensor	0.1	20,000	20,000	1	20,000	1	10	2	0.19	2.44	8.44
Molecular sieve control valves	4	50,000	50,000	2	10,000	1	10	4	0.38	5.63	16.88
Molecular sieves	2.5	50,000	50,000	1	50,000	1	10	4	0.08	1.13	3.38
Purge heat exchanger	5	100,000	100,000	1	15,000	1	10	4	0.25	3.75	11.25
Purge heat exchanger valve-Air Side	4	50,000	50,000	1	35,000	1	10	4	0.11	1.61	4.82
Purge heat exchanger valve-Waste Side	4	50,000	50,000	1	35,000	1	10	4	0.11	1.61	4.82
LINEA Dewar Cooldown Valve	4	50,000	50,000	1	35,000	1	10	2	0.11	1.39	4.82
Inlet Recuperator	82	80,000	80,000	1	15,000	1	10	4	0.25	3.75	11.25
Inlet cooler	3	100,000	100,000	1	100,000	1	10	2	0.04	0.49	1.69
Cryocooler	156	8,000	8,000	1	8,000	6	2	4	0.47	5.63	21.10
LINEA Dewar	0	75,000	75,000	1	75,000	1	1	4	0.05	0.30	2.25
Dewar level sensor	0	50,000	50,000	1	50,000	1	1	2	0.08	0.30	3.38
Distillation column	6	50,000	50,000	1	50,000	1	1	4	0.08	0.45	3.38
Distillation column gas valve	4	50,000	50,000	1	35,000	1	1	2	0.11	0.43	4.82
Distillation column liquid valve	4	50,000	50,000	1	35,000	1	1	2	0.11	0.43	4.82
Temperature sensor	0.15	50,000	50,000	2	17,498	1	1	2	0.21	0.86	9.64
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.07	0.35	3.17
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.14	0.42	6.27
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.94	30.94	42.19
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.38	1.50	16.88
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.05	0.47	2.11
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.05	0.75	2.11
<b>System Totals</b>	<b>699</b>			<b>44</b>	<b>515</b>	<b>58</b>	<b>142.5</b>	<b>90</b>	<b>7.28</b>	<b>75.34</b>	<b>327.54</b>

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Large Transport</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.05	0.14	1.44
Cabin air filter element		4000	10,000,000	1	8,000	1	1	1	0.60	1.80	18.04
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.13	0.25	3.77
Compressor	26	7,000	100,000	1	11,096	3	0.5	0.5	0.43	1.73	13.01
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.14	0.42	4.23
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.10	0.30	2.95
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.14	0.42	4.23
Heat exchanger	0	100,000	100,000	1	11,621	6	1	1	0.41	3.31	12.42
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.08	0.21	2.46
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.10	0.30	3.02
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.18	0.73	5.50
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.09	0.27	2.68
Water separator/filter element		4000	10,000,000	1	4,000	1	1	1	1.20	3.61	36.08
Inlet shutoff valve	4	50,000	50,000	1	35,000	1	1	2	0.14	0.55	4.12
Crycooler bleed air valve	4	50,000	50,000	1	35,000	1	1	2	0.14	0.55	4.12
Flow sensor	0.1	20,000	20,000	1	20,000	1	10	2	0.24	3.13	7.22
Molecular sieve control valves	4	50,000	50,000	2	10,000	1	10	4	0.48	7.22	14.43
Molecular sieves	2.5	50,000	50,000	1	50,000	1	10	4	0.10	1.44	2.89
Purge heat exchanger	5	100,000	100,000	1	15,000	1	10	4	0.32	4.81	9.62
Purge heat exchanger valve-Air Side	4	50,000	50,000	1	35,000	1	10	4	0.14	2.06	4.12
Purge heat exchanger valve-Waste Side	4	50,000	50,000	1	35,000	1	10	4	0.14	2.06	4.12
LINEA Dewar Cooldown Valve	4	50,000	50,000	1	35,000	1	10	2	0.14	1.79	4.12
Inlet Recuperator	120	60,000	60,000	1	15,000	1	10	4	0.32	4.81	9.62
Inlet cooler	3	100,000	100,000	1	100,000	1	10	2	0.05	0.63	1.44
Cryocooler	195	8,000	8,000	1	8,000	6	2	4	0.60	7.22	18.04
LINEA Dewar	0	75,000	75,000	1	75,000	1	1	4	0.06	0.38	1.92
Dewar level sensor	0	50,000	50,000	1	50,000	1	1	2	0.10	0.38	2.89
Distillation column	6	50,000	50,000	1	50,000	1	1	4	0.10	0.58	2.89
Distillation column gas valve	4	50,000	50,000	1	35,000	1	1	2	0.14	0.55	4.12
Distillation column liquid valve	4	50,000	50,000	1	35,000	1	1	2	0.14	0.55	4.12
Temperature sensor	0.15	50,000	50,000	2	17,498	1	1	2	0.27	1.10	8.25
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.09	0.45	2.71
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.18	0.54	5.36
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	1.20	39.69	36.08
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.48	1.92	14.43
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.06	0.60	1.80
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.06	0.96	1.80
<b>System Totals</b>	<b>788</b>			<b>44</b>	<b>515</b>	<b>60</b>	<b>142.5</b>	<b>90</b>	<b>9.34</b>	<b>97.47</b>	<b>280.10</b>

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Business Jet</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.02	0.05	1.07
Cabin air filter element		4000	10,000,000	1	8,000	1	1	1	0.22	0.67	13.33
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.05	0.09	2.78
Compressor	3	7,000	100,000	1	11,096	1	0.5	0.5	0.16	0.32	9.61
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.05	0.16	3.13
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.04	0.11	2.18
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.05	0.16	3.13
Heat exchanger	0	100,000	100,000	1	11,621	1	1	1	0.15	0.46	9.18
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.03	0.08	1.82
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.04	0.11	2.23
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.07	0.27	4.06
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.03	0.10	1.98
Water separator/filter element		4000	10,000,000	1	4,000	1	1	1	0.44	1.33	26.66
Inlet shutoff valve	4	50,000	50,000	1	35,000	1	1	2	0.05	0.20	3.05
Crycooler bleed air valve	4	50,000	50,000	1	35,000	1	1	2	0.05	0.20	3.05
Flow sensor	0.1	20,000	20,000	1	20,000	1	10	2	0.09	1.16	5.33
Molecular sieve control valves	4	50,000	50,000	2	10,000	1	10	4	0.18	2.67	10.67
Molecular sieves	2.5	50,000	50,000	1	50,000	1	10	4	0.04	0.53	2.13
Purge heat exchanger	5	100,000	100,000	1	15,000	1	10	4	0.12	1.78	7.11
Purge heat exchanger valve-Air Side	4	50,000	50,000	1	35,000	1	10	4	0.05	0.76	3.05
Purge heat exchanger valve-Waste Side	4	50,000	50,000	1	35,000	1	10	4	0.05	0.76	3.05
LNEA Dewar Cooldown Valve	4	50,000	50,000	1	35,000	1	10	2	0.05	0.66	3.05
Inlet Recuperator	44	100,000	100,000	1	15,000	1	10	4	0.12	1.78	7.11
Inlet cooler	3	100,000	100,000	1	100,000	1	10	2	0.02	0.23	1.07
Cryocooler	117	8,000	8,000	1	8,000	6	2	4	0.22	2.67	13.33
LNEA Dewar	0	75,000	75,000	1	75,000	1	1	4	0.02	0.14	1.42
Dewar level sensor	0	50,000	50,000	1	50,000	1	1	2	0.04	0.14	2.13
Distillation column	6	50,000	50,000	1	50,000	1	1	4	0.04	0.21	2.13
Distillation column gas valve	4	50,000	50,000	1	35,000	1	1	2	0.05	0.20	3.05
Distillation column liquid valve	4	50,000	50,000	1	35,000	1	1	2	0.05	0.20	3.05
Temperature sensor	0.15	50,000	50,000	2	17,498	1	1	2	0.10	0.41	6.10
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.03	0.17	2.00
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.07	0.20	3.96
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.44	14.66	26.66
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.18	0.71	10.67
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.02	0.22	1.33
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.02	0.36	1.33
<b>System Totals</b>	<b>611</b>			<b>44</b>	<b>515</b>	<b>53</b>	<b>142.5</b>	<b>90</b>	<b>3.45</b>	<b>34.93</b>	<b>206.98</b>

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turboprop</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.03	0.08	1.66
Cabin air filter element		4000	10,000,000	1	8,000	1	1	1	0.35	1.04	20.74
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.07	0.14	4.33
Compressor	3	7,000	100,000	1	11,096	1	0.5	0.5	0.25	0.50	14.95
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.08	0.24	4.86
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.06	0.17	3.40
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.08	0.24	4.86
Heat exchanger	0	100,000	100,000	1	11,621	1	1	1	0.24	0.71	14.28
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.05	0.12	2.83
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.06	0.17	3.48
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.11	0.42	6.32
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.05	0.15	3.08
Water separator/filter element		4000	10,000,000	1	4,000	1	1	1	0.69	2.07	41.47
Inlet shutoff valve	4	50,000	50,000	1	35,000	1	1	2	0.08	0.32	4.74
Cryocooler bleed air valve	4	50,000	50,000	1	35,000	1	1	2	0.08	0.32	4.74
Flow sensor	0.1	20,000	20,000	1	20,000	1	10	2	0.14	1.80	8.29
Molecular sieve control valves	4	50,000	50,000	2	10,000	1	10	4	0.28	4.15	16.59
Molecular sieves	2.5	50,000	50,000	1	50,000	1	10	4	0.06	0.83	3.32
Purge heat exchanger	5	100,000	100,000	1	15,000	1	10	4	0.18	2.76	11.06
Purge heat exchanger valve-Air Side	4	50,000	50,000	1	35,000	1	10	4	0.08	1.18	4.74
Purge heat exchanger valve-Waste Side	4	50,000	50,000	1	35,000	1	10	4	0.08	1.18	4.74
LINEA Dewar Cooldown Valve	4	50,000	50,000	1	35,000	1	10	2	0.08	1.03	4.74
Inlet Recuperator	44	100,000	100,000	1	15,000	1	10	4	0.18	2.76	11.06
Inlet cooler	3	100,000	100,000	1	100,000	1	10	2	0.03	0.36	1.66
Cryocooler	117	8,000	8,000	1	8,000	6	2	4	0.35	4.15	20.74
LINEA Dewar	0	75,000	75,000	1	75,000	1	1	4	0.04	0.22	2.21
Dewar level sensor	0	50,000	50,000	1	50,000	1	1	2	0.06	0.22	3.32
Distillation column	6	50,000	50,000	1	50,000	1	1	4	0.06	0.33	3.32
Distillation column gas valve	4	50,000	50,000	1	35,000	1	1	2	0.08	0.32	4.74
Distillation column liquid valve	4	50,000	50,000	1	35,000	1	1	2	0.08	0.32	4.74
Temperature sensor	0.15	50,000	50,000	2	17,498	1	1	2	0.16	0.63	9.48
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.05	0.26	3.11
Oxygen sensor	1.5	26,933	26,933	1	26,933	1	1	1	0.10	0.31	6.16
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.69	22.81	41.47
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.28	1.11	16.59
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.03	0.35	2.07
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.03	0.55	2.07
<b>System Totals</b>	<b>611</b>			<b>44</b>	<b>515</b>	<b>53</b>	<b>142.5</b>	<b>90</b>	<b>5.37</b>	<b>54.33</b>	<b>321.96</b>

FULL-TIME OBIGGS PARTS LIST  
CRYOGENIC DISTILLATION

Component	Unit weight (lbs)	Unit MTBMA	Unit MTBF	Quantity /Shipset	Component MTBUR Calc	Removal & Replacement Time Man Hours	Access Time Man Hours	Trouble-Shooting Time Man Hours	Annual Failure Rate	Labour Hours Per Year	Delays Per Year (Minutes)
<b>Regional Turbofan</b>											
Cabin air filter assy	6	100,000	100,000	1	100,000	1	1	1	0.04	0.11	2.15
Cabin air filter element		4000	10,000,000	1	8,000	1	1	1	0.45	1.34	26.83
OBIGGS shutoff valve	4	50,000	50,000	1	38,315	1	0.5	0.5	0.09	0.19	5.60
Compressor	3	7,000	100,000	1	11,096	1	0.5	0.5	0.32	0.64	19.34
Compressor discharge check valve	1	100,000	100,000	1	34,119	1	0.5	1.5	0.10	0.31	6.29
Bleed shutoff valve	3	50,000	50,000	1	48,856	1	1	1	0.07	0.22	4.39
Bleed check valve	1	100,000	100,000	1	34,119	1	1	1	0.10	0.31	6.29
Heat exchanger	0	100,000	100,000	1	11,621	1	1	1	0.31	0.92	18.47
Cooling fan	0	25,000	25,000	1	58,561	1	1	0.5	0.06	0.15	3.66
Bypass valve	3	50,000	50,000	1	47,737	1	1	1	0.07	0.22	4.50
Temperature sensor	0.15	50,000	50,000	2	26,247	1	1	2	0.14	0.55	8.18
Water separator/filter assy	10	100,000	100,000	1	53,789	1	1	1	0.07	0.20	3.99
Water separator/filter element		4000	10,000,000	1	4,000	1	1	1	0.89	2.68	53.66
Inlet shutoff valve	4	50,000	50,000	1	35,000	1	1	2	0.10	0.41	6.13
Crycooler bleed air valve	4	50,000	50,000	1	35,000	1	1	2	0.10	0.41	6.13
Flow sensor	0.1	20,000	20,000	1	20,000	1	10	2	0.18	2.33	10.73
Molecular sieve control valves	4	50,000	50,000	2	10,000	1	10	4	0.36	5.37	21.46
Molecular sieves	2.5	50,000	50,000	1	50,000	1	10	4	0.07	1.07	4.29
Purge heat exchanger	5	100,000	100,000	1	15,000	1	10	4	0.24	3.58	14.31
Purge heat exchanger valve-Air Side	4	50,000	50,000	1	35,000	1	10	4	0.10	1.53	6.13
Purge heat exchanger valve-Waste Side	4	50,000	50,000	1	35,000	1	10	4	0.10	1.53	6.13
LINEA Dewar Cooldown Valve	4	50,000	50,000	1	35,000	1	10	2	0.10	1.33	6.13
Inlet Recuperator	44	100,000	100,000	1	15,000	1	10	4	0.24	3.58	14.31
Inlet cooler	3	100,000	100,000	1	100,000	1	10	2	0.04	0.47	2.15
Cryocooler	117	8,000	8,000	1	8,000	6	2	4	0.45	5.37	26.83
LINEA Dewar	0	75,000	75,000	1	75,000	1	1	4	0.05	0.29	2.86
Dewar level sensor	0	50,000	50,000	1	50,000	1	1	2	0.07	0.29	4.29
Distillation column	6	50,000	50,000	1	50,000	1	1	4	0.07	0.43	4.29
Distillation column gas valve	4	50,000	50,000	1	35,000	1	1	2	0.10	0.41	6.13
Distillation column liquid valve	4	50,000	50,000	1	35,000	1	1	2	0.10	0.41	6.13
Temperature sensor	0.15	50,000	50,000	1	26,247	1	1	2	0.14	0.55	8.18
Relief valve	2.5	50,000	50,000	1	53,306	2	1	2	0.07	0.34	4.03
Oxygen sensor	1.5	26,933	26,933	2	17,498	1	1	1	0.20	0.61	12.27
Fuel tank check valve	0.5	100,000	100,000	5	4,000	1	24	8	0.89	29.51	53.66
Controller / control card	5.5	10,000	10,000	1	10,000	1	1	2	0.36	1.43	21.46
Ducting	345	10,000,000	10,000,000	1	80,000	6	2	2	0.04	0.45	2.68
Wiring	15	10,000,000	10,000,000	1	80,000	6	2	8	0.04	0.72	2.68
<b>System Totals</b>	<b>611</b>			<b>44</b>	<b>515</b>	<b>53</b>	<b>142.5</b>	<b>90</b>	<b>6.95</b>	<b>70.23</b>	<b>416.74</b>

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ADDENDUM F.D.1

***CONFINED SPACE ENTRY LABOR & SAFETY EQUIPMENT  
ESTIMATE***

to

APPENDIX F

**AIRPLANE OPERATION AND MAINTENANCE  
FINAL REPORT**

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**Confined Space Entry Added Labor**

System Concept	Aircraft	Inerting System Maint. Access per year	Other Maint. Access per Year	Additional M/H per entry	Annual M/H per Aircraft	Number of Aircraft	Annual Cost	
<b>Ground Based Inerting</b>	Business Jet	0.1	6	0.75	4.6	8600	\$2,950,875	
	Turboprop	0.3	6	1.5	9.5	2000	\$1,417,500	
	Turbofan	0.2	6	1.5	9.3	1000	\$697,500	
	Small Transport	0.3	6	1.5	9.4	8600	\$6,088,724	
	Medium Transport	0.3	6	1.5	9.4	1400	\$989,954	
	Large Transport	0.4	6	1.5	9.6	2000	\$1,443,853	
	<b>Total</b>							<b>\$13,588,406</b>
<b>On-Board Ground Based Inerting</b>	Membrane Business Jet	1.2	6	0.75	5.4	8600	\$3,483,000	
	Membrane Turboprop	1.8	6	1.5	11.7	2000	\$1,755,000	
	Membrane Turbofan	1.4	6	1.5	11.1	1000	\$832,500	
	Membrane Small Transport	2.2	6	1.5	12.4	8600	\$7,970,757	
	Membrane Medium Transport	1.9	6	1.5	11.9	1400	\$1,247,379	
	Membrane Large Transport	2.5	6	1.5	12.7	2000	\$1,904,119	
<b>Total</b>							<b>\$17,192,755</b>	
<b>On-Board Inert Gas Generating</b>	Membrane Business Jet	3.2	6	0.75	6.9	8600	\$4,455,238	
	Membrane Turboprop	3.7	6	1.5	14.6	2000	\$2,191,645	
	Membrane Turbofan	4.8	6	1.5	16.3	1000	\$1,219,430	
	Membrane Small Transport	5.6	6	1.5	17.4	8600	\$11,232,416	
	Membrane Medium Transport	5.0	6	1.5	16.6	1400	\$1,740,133	
	Membrane Large Transport	6.5	6	1.5	18.7	2000	\$2,807,054	
	<b>Total</b>							<b>\$23,645,917</b>
	Cryogenic Business Jet	4.6	6	0.75	8.0	8600	\$5,129,934	
	Cryogenic Turboprop	5.4	6	1.5	17.0	2000	\$2,557,357	
	Cryogenic Turbofan	6.9	6	1.5	19.4	1000	\$1,456,387	
	Cryogenic Small Transport	8.0	6	1.5	21.1	8600	\$13,590,737	
	Cryogenic Medium Transport	7.3	6	1.5	19.9	1400	\$2,091,391	
	Cryogenic Large Transport	9.3	6	1.5	23.0	2000	\$3,450,721	
	<b>Total</b>							<b>\$28,276,527</b>

**Airplane Operation and Maintenance Task Team Final Report**

**Confined Space Entry Safety Equipment Costs**

	<b>Gates</b>	<b>Maintenance Facilities</b>	<b>Gates per Kit</b>	<b>Kit Cost</b>	<b>Total Cost</b>
121 Carriers	50,000	5000	10	\$ 3,977.92	\$19,889,600
Air Freight Operations			2	\$ 3,977.92	\$9,944,800
Corporate Aircraft			2	\$ 3,977.92	\$9,944,800
<b>Total</b>					<b>\$39,779,200</b>

**Confined Space Entry Safety Equipment Quote**

<b>Quantity</b>	<b>Model</b>	<b>Description</b>	<b>Each</b>	<b>Total</b>
1	1810-3606-0011	Industrial Scientific LTX312 Monitor with LEL & Oxygen Sensors	\$ 1,096.68	\$ 1,096.68
1	1810-2251	Charger	\$ 56.01	\$ 56.01
1	1810-1238	Calibration Gas unit, oxygen & pentane	\$ 114.33	\$ 114.33
1	1810-1766	Calibration Regulator	\$ 137.20	\$ 137.20
1	EF175XX	Ram Fan Model 75 Axial Blower, Explosion proof motor, ABS Carbon filled Housing. 2500cfm	\$ 999.95	\$ 999.95
2	1225C	12" Reinforced Conductive Duct, 25 feet	\$ 651.25	\$ 1,302.50
1	DC12	12" Duct to Duct coupler	\$ 51.25	\$ 51.25
2	BG12	Carrying case, duct	\$ 75.00	\$ 150.00
1	312	12" Duct Adapter	\$ 70.00	\$ 70.00
<b>Total</b>				<b>\$ 3,977.92</b>



## Appendix G

### Estimating and Forecasting Task Team Final Report

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## **1.0 SCOPE AND DEFINITION**

The FTIHWG cost-benefit analysis includes the large, medium, and small airplane categories. The regional turboprop, regional turboprop, and business jet categories were excluded because they would have had just a small impact on the overall safety benefit, and including their costs would have significantly and disproportionately increased the cost-benefit ratio.

For each of the fuel tank inerting systems described in this report, the total cost is given over the 16-year study period (2005 through 2020). This total cost includes the initial airplane and airport modification costs plus the accumulated annual recurring costs. Airplane nonrecurring costs include engineering design for the modifications and additions to fuel system components, interfaces, instruments or displays, relocation of other equipment, wiring, tubing or ducting, and avionics software or modules. The nonrecurring engineering costs also include changes to documents (e.g., Specs, ICDs); manuals (e.g., AFM, Opts, MM); production change records; laboratory, ground, and flight tests; and FAA/JAA certification. These costs also include major-supplier parts and assemblies, tubing, wiring, ducting, Service Bulletin and kitting costs (retrofit), and special tooling for installation.

For airlines, costs include engineering and training costs, installation labor, and airplane downtime. The airplane downtime cost estimates were based on the cost to lease a comparable airplane during the retrofit period. It was assumed that 80% of the airplanes would be retrofitted during a major check and 20% were retrofitted outside of the major check cycle. For the large-airplane category, the estimated downtime was 9 days for retrofitting during a major check, and 11 days for retrofitting outside of a major check. A medium-category airplane was assumed to take 8 days during a major check and 10 days outside of a major check. For the small-category airplane, the retrofit was assumed to take 7 days during a major check and 9 days outside of a major check.

Airplane annual recurring costs include training, maintenance checks, inspections, removals, unscheduled maintenance, airplane delays. The annual weight penalty per 1,000 lb is \$165,532 for a large airplane, \$131,802 for a medium airplane, and \$62,004 for a small airplane. The cost of the weight penalty was based on values from the 1998 ARAC study.

The ground-based inerting (GBI) system costs include the costs for a fixed hydrant system and a mobile truck-based system for large- and medium-size airports. Small and foreign airports have only a mobile system. The nonrecurring airport costs include engineering design, system installation labor (including relocation of other equipment), parts and materials, and tooling. The annual recurring costs include the cost of the N<sub>2</sub> required for ullage washing, the ground service labor for inerting, and N<sub>2</sub> system maintenance, inspection, and training.

For the onboard ground inerting systems (OBGI), the airport costs included the additional ground support equipment for providing required electrical power at large and medium-sized airports. It was assumed that the airplane's APU would be used at small airports. It was assumed that the Onboard Inert Gas Generating System (OBIGGS) required no ground support equipment.

The overall airplane and airport costs for each system was calculated by multiplying the recurring and nonrecurring airplane costs by the appropriate number of airplanes. It was assumed that all airplanes built after 2007 would have the inerting system installed and that airplanes built before 2007 would require a retrofit. The airport costs were calculated by multiplying the number of large, medium, and small airports by their respective recurring and nonrecurring costs. For the US-only implementation cases, it was assumed that all B, C, and D category airports in the United States would be modified and that 158 foreign airports that are currently serviced by US operators would also be modified.

For several reasons, the airport costs estimated in this study are higher than the values listed in the FAA report DOT/FAA/AR-00/19, "The Cost of Implementing Ground Based Fuel Tank Inerting in the Commercial Fleet," dated May 2000. The FAA study only estimated the airport costs; no airplane costs were included. The FAA estimated that the airport cost of a US ground-based system for inerting heated

center wing tanks would be \$800 million US over a 10-year period starting in 2003. In contrast, this FTIHWG study estimates that the airport recurring and nonrecurring costs would be approximately \$6.8 billion US over a 16-year period.

The primary reasons for this difference in anticipated costs between the above-referenced FAA study and the ARAC study presented here is that the FTIHWG:

- Used a study period 60 percent longer than the FAA's because of the long time required to fully implement fuel tank inerting.
- Assumed higher nonrecurring airport cost primarily because it factors in higher equipment costs required to support remote airplane parking at large and medium airports.
- Included more airports in its study—whereas the FAA assumes 50 large airports and 350 small airports, this study assumes 31 large airports, 37 medium airports, and 354 small airports as well as 158 foreign airports served by US operators.
- Assumed a burdened-labor rate of \$25 per hour for ground service workers, which is nearly twice the burdened-labor rate assumed by the FAA study.
- Assumed ground-servicing hours two to three times higher, depending on airplane model, based on an underlying assumption that the worker would not leave the airplane hook-up unattended while the fuel tank was being serviced with nitrogen.
- Assumed that each airplane model would be serviced with the same amount of nitrogen, regardless of fuel load, thus requiring significantly more total nitrogen.
- Projects a 30% rise in the cost of nitrogen (from \$0.10 per 100 cubic feet to \$0.13 per 100 cubic feet) as forecast by an industrial gas company.
- Assumed 3% annual inflation in the cost of parts and labor.

The benefit values presented in this report are based on the assumption that 85% of fuel-tank-related accidents would occur in the air and the remaining 15% on the ground. Also included were the benefits of enhanced occupant survival in airplane accidents resulting from other causes, in which inerting could potentially prevent a post-crash fuel tank fire or explosion. Benefit values in this document do not reflect the confined-space hazard that wide-scale adoption of fuel tank inerting would introduce in the commercial fleet and in related ground-support areas. See section 4 for more information about benefits.

## **2.0 COST-BENEFIT ANALYSIS SUMMARY**

The following charts include the list of scenarios evaluated, the airplane and airport forecasts, standard airplane model data, accident cost data, and the cost-benefit summaries for each scenario. Note that scenarios 6, 8, and 10 have been combined with 5, 7 and 9 respectively.

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**Inerting Scenario Summary Information**

Below are all of the scenario's address in the model. Note #6, 8, and 10 have been combined with 5,7, and 9. Small Transports, PSA/Membrane Systems have been added to 13-15 to have equal coverage as the other scenario's.

<b>Scenario</b>	<b>Benefits used for Small</b>
<b>1</b> On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	
<b>2</b> On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	
<b>3</b> Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	
<b>4</b> Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	
<b>5</b> OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	From 6
<del><b>6</b> OBIGGS, All Tanks, Small Transports, PSA and Membrane Systems</del>	
<b>7</b> Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	From 8
<del><b>8</b> Hybrid OBIGGS, HCWT only, Small Transports, PSA and Membrane Systems</del>	
<b>9</b> Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	From 10
<del><b>10</b> Hybrid OBIGGS, All Tanks, Small Transports, PSA and Membrane Systems</del>	
<b>11</b> Ground Based Inerting HCWT only, All Transports	
<b>12</b> Ground Based Inerting All Fuselage Tanks, All Transports	
<b>13</b> OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems	From 6
<b>14</b> Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems	From 8
<b>15</b> Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems	From 10
<b>16</b> On-Board Liquid Nitrogen Inerting	

All Scenario dollars are in Year 2000 US\$'s

The Airplane Non-Recurring costs are divided into First-of-a-model and derivative model costs. The First-of-a-Model costs are for the design, analysis and certification for the first of an airplane type. The derivative Model costs are for the subsequent airplanes of that type.

The Recurring Airplane costs are on an annual per-airplane basis

The Airport costs based on Large, Medium or Small airports plus 4 or 2 truck Mobile unit for foreign airports if the model is US only

*Figure G-1. Scenario Information Sheet*

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Note: Actual value of the Fleet were adjusted for each scenario based on the appropriate tank mix.

Active Scenario:			Tank Mix Values for Active Scenario								Tank Mix ON/OFF(1/0):													
Scenario 16 - On-Board Liquid Nitrogen Inerting			In-Service				New				1													
			Large	Medium	Small	Regional Jet	Large	Medium	Small	Regional Jet	As provided by Alan B Hedge[SMTP:ahedge@air-econ.com] The Campbell-Hill Aviation Group, Inc.													
			100%	100%	100%	0%	100%	100%	100%	0%														
			ARAC Distribution		50-99 (Regional + Biz Jet)			100-210 (Small)			(211-400)/2 (Medium)			400-600+ (211-400)/2 (Large)										
Operator	World																							
Mission	Type	Category	Data	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Pax	Retain	xRegional Jet	1381	1383	1310	1325	1330	1349	1357	1363	1356	1348	1339	1333	1323	1317	1294	1299	1290	1280	1271	1244	1229	
		Small Transport	7506	7515	7314	7353	7406	7453	7441	7423	7393	7360	7323	7275	7242	7214	7157	7119	7082	7054	7004	6963	6930	
		Medium Transport	1088	1085	1084.5	1082	1080	1078.5	1074.5	1068.5	1065	1061.5	1055.5	1048	1039.5	1031.5	1027.5	1020.5	1010.5	996.5	981	967.5	952.5	
		Large Transport	1619	1617	1615.5	1614	1612	1609.5	1596.5	1582.5	1565	1551.5	1516.5	1466	1439.5	1419.5	1402.5	1388.5	1368.5	1351.5	1324	1301.5	1283.5	
	New	xRegional Jet	190	361	579	678	703	730	763	800	864	935	1001	1071	1143	1214	1304	1377	1467	1570	1662	1792	1918	
		Small Transport	389	865	1486	1824	2009	2220	2513	2858	3239	3674	4103	4610	5089	5576	6134	6656	7228	7792	8406	9031	9669	
		Medium Transport	61.5	126	182	241	282	327.5	383	439.5	502	565.5	642	728.5	814	885.5	966	1060	1156	1249	1357	1464	1582.5	
		Large Transport	68.5	152	232	321	389	460.5	553	648.5	757	864.5	1001	1162.5	1304	1428.5	1559	1706	1859	2004	2172	2339	2516.5	
Freighter	Retain	xRegional Jet	43	43	40	40	40	40	40	42	42	42	42	42	42	42	42	43	43	43	43	43	43	
		Small Transport	798	796	702	705	711	706	717	726	727	729	726	714	703	687	676	665	658	648	639	628	621	
		Medium Transport	306.5	316.5	312	314.5	318.5	319	320	324.5	324.5	326	326.5	326	326	326.5	327	328	327.5	326.5	325.5	324.5	323.5	
		Large Transport	344.5	354.5	350	352.5	356.5	357	359	364.5	366.5	369	371.5	373	377	378.5	382	386	388.5	390.5	391.5	387.5	390.5	
	New	xRegional Jet	0	1	9	11	14	19	22	25	30	34	38	43	49	55	60	68	74	80	90	97	106	
		Small Transport	0	32	159	204	250	300	360	437	511	567	635	711	781	866	972	1076	1200	1310	1419	1521	1643	
		Medium Transport	4.5	12	33.5	54.5	73.5	90	111.5	141.5	164.5	193	220.5	250.5	277	313	353.5	397	435	481.5	525.5	574.5	631.5	
		Large Transport	13.5	27	52.5	75.5	97.5	114	137.5	170.5	196.5	227	255.5	286.5	317	354	396.5	447	486	535.5	585.5	642.5	704.5	
<b>Grand Total</b>		13813	14686	15461	16195	16672	17173	17748	18414	19103	19847	20596	21440	22266	23108	24053	25036	26073	27112	28196	29320	30544		

Figure G-2. Airplane Forecast—World Fleet

### Estimating and Forecasting Task Team Final Report

Note: Actual value of the Fleet were adjusted for each scenario based on the appropriate tank mix.

Active Scenario:			Tank Mix Values for Active Scenario								Tank Mix ON/OFF(1/0):													
Scenario 16 - On-Board Liquid Nitrogen Inerting			In-Service				New				1													
			Large	Medium	Small	Regional Jet	Large	Medium	Small	Regional Jet	As provided by Alan B Hedge[SMTP:ahedge@air-econ.com] The Campbell-Hill Aviation Group, Inc.													
			100%	100%	100%	0%	100%	100%	100%	0%														
Operator: World - PAX Only			ARAC Distribution								50-99 (Regional + Biz Jet) 100-210 (Small) (211-400)/2 (Medium) 400-600+ (211-400)/2 (Large)													
Mission	Type	Category	Data																					
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Pax	Retain	xRegional Jet	1381	1383	1310	1325	1330	1349	1357	1363	1356	1348	1339	1333	1323	1317	1294	1299	1290	1280	1271	1244	1229	
		Small Transport	7506	7515	7314	7353	7406	7453	7441	7423	7393	7360	7323	7275	7242	7214	7157	7119	7082	7054	7004	6963	6930	
		Medium Transport	1088	1085	1084.5	1082	1080	1078.5	1074.5	1068.5	1065	1061.5	1055.5	1048	1039.5	1031.5	1027.5	1020.5	1010.5	996.5	981	967.5	952.5	
		Large Transport	1619	1617	1615.5	1614	1612	1609.5	1596.5	1582.5	1565	1551.5	1516.5	1466	1439.5	1419.5	1402.5	1388.5	1368.5	1351.5	1324	1301.5	1283.5	
	New	xRegional Jet	190	361	579	678	703	730	763	800	864	935	1001	1071	1143	1214	1304	1377	1467	1570	1662	1792	1918	
		Small Transport	389	865	1486	1824	2009	2220	2513	2858	3239	3674	4103	4610	5089	5576	6134	6656	7228	7792	8406	9031	9669	
		Medium Transport	61.5	126	182	241	282	327.5	383	439.5	502	565.5	642	728.5	814	885.5	966	1060	1156	1249	1357	1464	1582.5	
		Large Transport	68.5	152	232	321	389	460.5	553	648.5	757	864.5	1001	1162.5	1304	1428.5	1559	1706	1859	2004	2172	2339	2516.5	
Freighter	Retain	xRegional Jet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Small Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		Medium Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Large Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	New	xRegional Jet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Small Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Medium Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Large Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Grand Total			12303	13104	13803	14438	14811	15228	15681	16183	16741	17360	17981	18694	19394	20086	20844	21626	22461	23297	24177	25102	26081	

Figure G-3. Airplane Forecast—World Fleet, Passenger Only

## Estimating and Forecasting Task Team Final Report

Note: Actual value of the Fleet were adjusted for each scenario based on the appropriate tank mix.

Active Scenario:			Tank Mix Values for Active Scenario								Tank Mix ON/OFF(1/0):												
Scenario 16 - On-Board Liquid Nitrogen Inerting			In-Service				New				As provided by Alan B Hedge[SMTP:ahedge@air-econ.com] The Campbell-Hill Aviation Group, Inc.												
			Large	Medium	Small	Regional Jet	Large	Medium	Small	Regional Jet													
			100%	100%	100%	0%	100%	100%	100%	0%													
Operator: US-Operator			ARAC Distribution								50-99 (Regional + Biz Jet) 100-210 (Small) (211-400)/2 (Medium) 400-600+ (211-400)/2 (Large)												
Mission	Type	Category	Data																				
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Pax	Retain	xRegional Jet	527	525	509	511	510	509	509	508	508	507	507	504	482	446	389	389	383	378	378	365	353
		Small Transport	3384	3380	3315	3297	3280	3267	3255	3247	3234	3220	3210	3194	3178	3172	3153	3130	3100	3098	3084	3088	3095
		Medium Transport	265	263.5	261.5	262	262.5	263.5	264	264.5	265.5	265.5	262	260.5	261.5	263	265	265	264.5	266	267	267.5	267.5
		Large Transport	322	321.5	319.5	321	321.5	323.5	325	326.5	327.5	328.5	326	325.5	327.5	330	333	334	334.5	337	339	341.5	342.5
	New	xRegional Jet	111	218	325	358	360	362	369	380	389	401	415	430	444	486	532	550	578	611	635	680	720
		Small Transport	181	408	687	839	891	954	1053	1180	1320	1482	1645	1817	1996	2172	2371	2575	2791	2992	3209	3419	3623
		Medium Transport	28.5	49	59	66.5	73	78.5	89.5	97	105.5	115	128.5	144.5	155.5	167	179	195	211.5	223.5	239.5	253.5	271
		Large Transport	29.5	50	60	67.5	74	79.5	90.5	98	106.5	116	129.5	145.5	156.5	168	180	196	212.5	224.5	240.5	254.5	272
Freighter	Retain	xRegional Jet	17	17	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
		Small Transport	570	570	518	514	512	504	492	485	484	482	481	477	474	468	464	462	462	461	456	452	452
		Medium Transport	218	226.5	223	223.5	224	224	224.5	226.5	227.5	227	227.5	228.5	230	230	230.5	230.5	230	229.5	230.5	230.5	227.5
		Large Transport	225	233.5	230	230.5	231	231	231.5	234.5	236.5	236	237.5	239.5	242	242	243.5	245.5	246	246.5	249.5	250.5	249.5
	New	xRegional Jet	0	0	5	6	6	9	10	11	13	14	15	17	19	21	23	25	27	29	33	35	37
		Small Transport	0	29	106	143	180	223	271	314	361	406	452	507	557	614	675	733	800	865	940	1012	1088
		Medium Transport	3	8.5	24.5	40.5	51.5	63	76	92.5	107.5	126.5	144.5	164.5	181.5	205	226.5	254	279	307	335	363.5	400.5
		Large Transport	5	10.5	26.5	42.5	53.5	65	79	95.5	110.5	129.5	147.5	167.5	184.5	208	229.5	257	282	310	338	366.5	403.5
Grand Total			5886	6310	6683	6936	7044	7170	7353	7574	7810	8070	8342	8636	8903	9206	9508	9855	10215	10592	10988	11393	11816

Figure G-4. Airplane Forecast—U.S. Fleet

### Estimating and Forecasting Task Team Final Report

Note: Actual value of the Fleet were adjusted for each scenario based on the appropriate tank mix.

Active Scenario:			Tank Mix Values for Active Scenario								Tank Mix ON/OFF(1/0):												
Scenario 16 - On-Board Liquid Nitrogen Inerting			In-Service				New				As provided by Alan B Hedge[SMTP:ahedge@air-econ.com] The Campbell-Hill Aviation Group, Inc.												
			Large	Medium	Small	Regional Jet	Large	Medium	Small	Regional Jet													
			100%	100%	100%	0%	100%	100%	100%	0%													
Operator: US-Operator - PAX			ARAC Distribution: 50-99 (Regional + Biz Jet) 100-210 (Small) (211-400)/2 (Medium) 400-600+ (211-400)/2 (Large)																				
Mission	Type	Category	Data																				
Pax	Retain	xRegional Jet	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
		Small Transport	527	525	509	511	510	509	509	508	508	507	507	504	482	446	389	389	383	378	378	365	353
		Medium Transport	3384	3380	3315	3297	3280	3267	3255	3247	3234	3220	3210	3194	3178	3172	3153	3130	3100	3098	3084	3088	3095
		Large Transport	265	263.5	261.5	262	262.5	263.5	264	264.5	265.5	265.5	262	260.5	261.5	263	265	264.5	266	267	267.5	267.5	267.5
	New	xRegional Jet	322	321.5	319.5	321	321.5	323.5	325	326.5	327.5	328.5	326	325.5	327.5	330	333	334	334.5	337	339	341.5	342.5
		Small Transport	111	218	325	358	360	362	369	380	389	401	415	430	444	486	532	550	578	611	635	680	720
		Medium Transport	181	408	687	839	891	954	1053	1180	1320	1482	1645	1817	1996	2172	2371	2575	2791	2992	3209	3419	3623
		Large Transport	28.5	49	59	66.5	73	78.5	89.5	97	105.5	115	128.5	144.5	155.5	167	179	195	211.5	223.5	239.5	253.5	271
Freighter	Retain	xRegional Jet	29.5	50	60	67.5	74	79.5	90.5	98	106.5	116	129.5	145.5	156.5	168	180	196	212.5	224.5	240.5	254.5	272
		Small Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Medium Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Large Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	New	xRegional Jet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Small Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Medium Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Large Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Total			4848	5215	5536	5722	5772	5837	5955	6101	6256	6435	6623	6821	7001	7204	7402	7634	7875	8130	8392	8669	8944

Figure G-5. Airplane Forecast—U.S. Fleet, Passenger Only

Airport Data for Inerting Support													
<i>Note: Driven by Fleet Control Page</i>													
Operator: World													
	US Only Airports	World Airport	Current Airport Data										
Large Airport	31	85	85										
Medium Airport	37	101	101										
Small Airport	354	1014	1014										
Non US - 4 Truck Support	83		0										
Non US - 2 Truck Support	75		0										
Cum Conversion %:	14%	29%	43%	57%	71%	86%	100%	100%	100%	100%	100%	100%	100%
<b>Cum Converted Airports</b>													
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Large Airport	12	24	36	49	61	73	85	85	85	85	85	85	85
Medium Airport	14	29	43	58	72	87	101	101	101	101	101	101	101
Small Airport	145	290	435	579	724	869	1,014	1,014	1,014	1,014	1,014	1,014	1,014
Non US - 4 Truck Support	-	-	-	-	-	-	-	-	-	-	-	-	-
Non US - 2 Truck Support	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Annual Airport Conversion</b>													
Large Airport	12	12	12	12	12	12	12	-	-	-	-	-	-
Medium Airport	14	14	14	14	14	14	14	-	-	-	-	-	-
Small Airport	145	145	145	145	145	145	145	-	-	-	-	-	-
Non US - 4 Truck Support	-	-	-	-	-	-	-	-	-	-	-	-	-
Non US - 2 Truck Support	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure G-6. Airport Forecast—World and United States

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Provided by: <i>Allen Mattes[SMTP:Allen.Mattes@faa.gov]</i>											
AIRPLANE CATEGORY	LOAD FACTORS										
>300	75.00%										
210-300	73.00%										
100-209	71.00%										
REGIONAL JET	60.00%										
TURBOPROP	60.00%										
BIZJET	40.00%										
VALUE OF A FATALITY	\$2.70										
FATALITY RATE IN-FLIGHT	100.00%										
FATALITY RATE ON-THE GROUND	10.00%										
<b>LOSSES FROM AN IN-FLIGHT EXPLOSION</b>											
AIRPLANE CATEGORY		AVG. A/C SIZE	AVG. NUM. PAX	AVG. NUM. CREW	AVG. NUM. FATALITIES	OF PAX	VALUE OF A/C	VALUE OF GROUND DAMAGE	COST OF ACCIDENT INVESTIGATION		TOTAL COST OF ACCIDENT
>300		350.00	263	12	275	\$741.15	\$75.00	\$5.00	\$33.00		\$854.15
210-300		255.00	186	9	195	\$526.91	\$60.00	\$4.00	\$28.00		\$618.91
100-209		154.50	110	7	117	\$315.08	\$25.00	\$3.00	\$23.00		\$366.08
REGIONAL JET		65.00	39	5	44	\$118.80	\$17.00	\$3.00	\$20.00		\$158.80
TURBOPROP		45.00	27	4	31	\$83.70	\$9.00	\$2.00	\$15.00		\$109.70
BIZJET		11.00	4	3	7	\$19.98	\$7.00	\$1.00	\$10.00		\$37.98
<b>LOSSES FROM AN ON-THE-GROUND EXPLOSION</b>											
AIRPLANE CATEGORY		AVG. A/C SIZE	AVG. NUM. PAX	AVG. NUM. CREW	AVG. NUM. FATALITIES	VALUE OF PAX	VALUE OF A/C	VALUE OF GROUND DAMAGE	COST OF ACCIDENT INVESTIGATION		TOTAL COST OF ACCIDENT
>300		350.00	263	12	27	\$74.12	\$75.00	\$0.50	\$10.00		\$159.62
210-300		255.00	186	9	20	\$52.69	\$60.00	\$0.40	\$8.00		\$121.09
100-209		154.50	110	7	12	\$31.51	\$25.00	\$0.30	\$6.00		\$62.81
REGIONAL JET		65.00	39	5	4	\$11.88	\$17.00	\$0.20	\$4.00		\$33.08
TURBOPROP		45.00	27	4	3	\$8.37	\$9.00	\$0.10	\$3.00		\$20.47
BIZJET		11.00	4	3	1	\$2.00	\$7.00	\$0.10	\$2.00		\$11.10

Figure G-7. Accident Cost Data

Summary of Inerting Scenario Results World

Values in Millions	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting HCWT Fuselage tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	Scenario 8 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems	Scenario 10 - Ground Based Inerting HCWT only, All Tanks, All Transports	Scenario 11 - Ground Based Inerting HCWT only, All Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems	Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, PSA/Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, PSA/Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting	
Total \$ Cost with Inflation	25,321	41,901	24,415	38,349	47,601	21,476	32,969	22,973	26,203	57,021	34,569	45,797	77,735	-	-	-
NPV in 2005 of Cost	11,592	18,509	11,240	17,035	20,775	9,896	14,936	10,374	11,885	24,605	15,440	20,405	31,527	-	-	-
Total Benefits	597	1,037	591	1,032	1,202	701	1,186	668	1,109	1,202	701	1,186	1,202	-	-	-
NPV in 2005 of Benefits	219	381	217	379	441	257	435	245	407	441	257	435	441	-	-	-

Figure G-8. Cost Summary of World Fleet

**Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

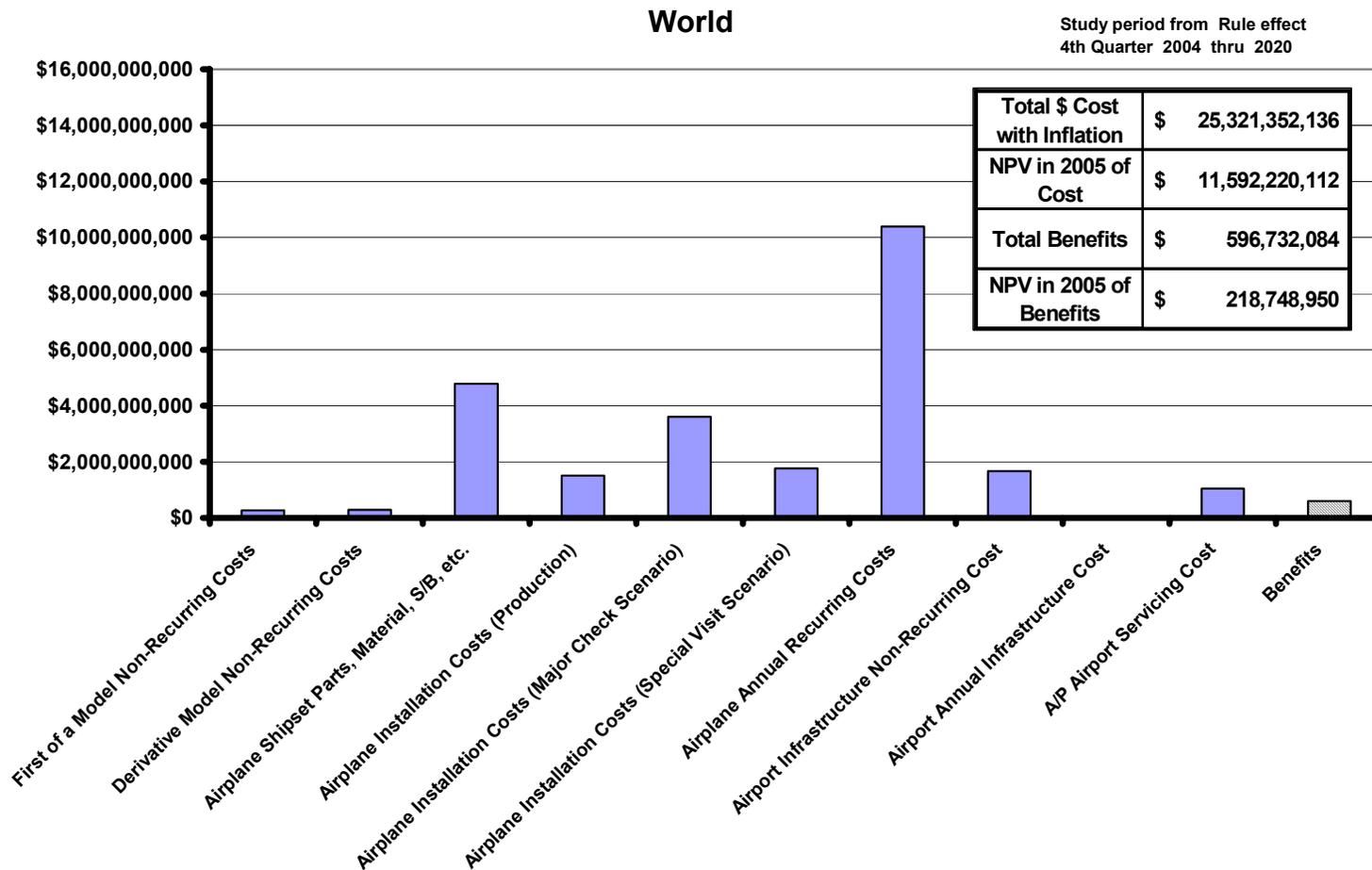


Figure G-9. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

**Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

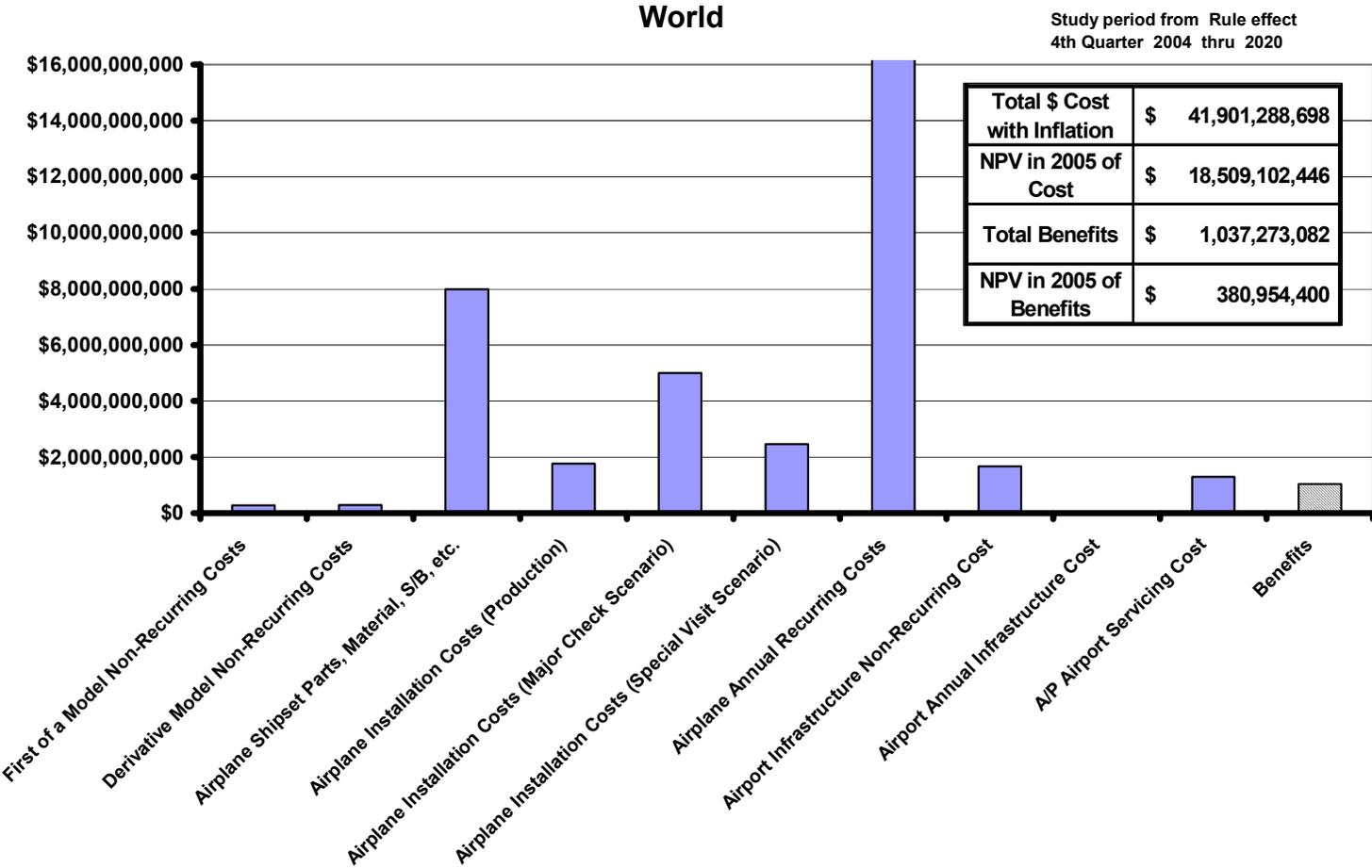


Figure G-10. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

**Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

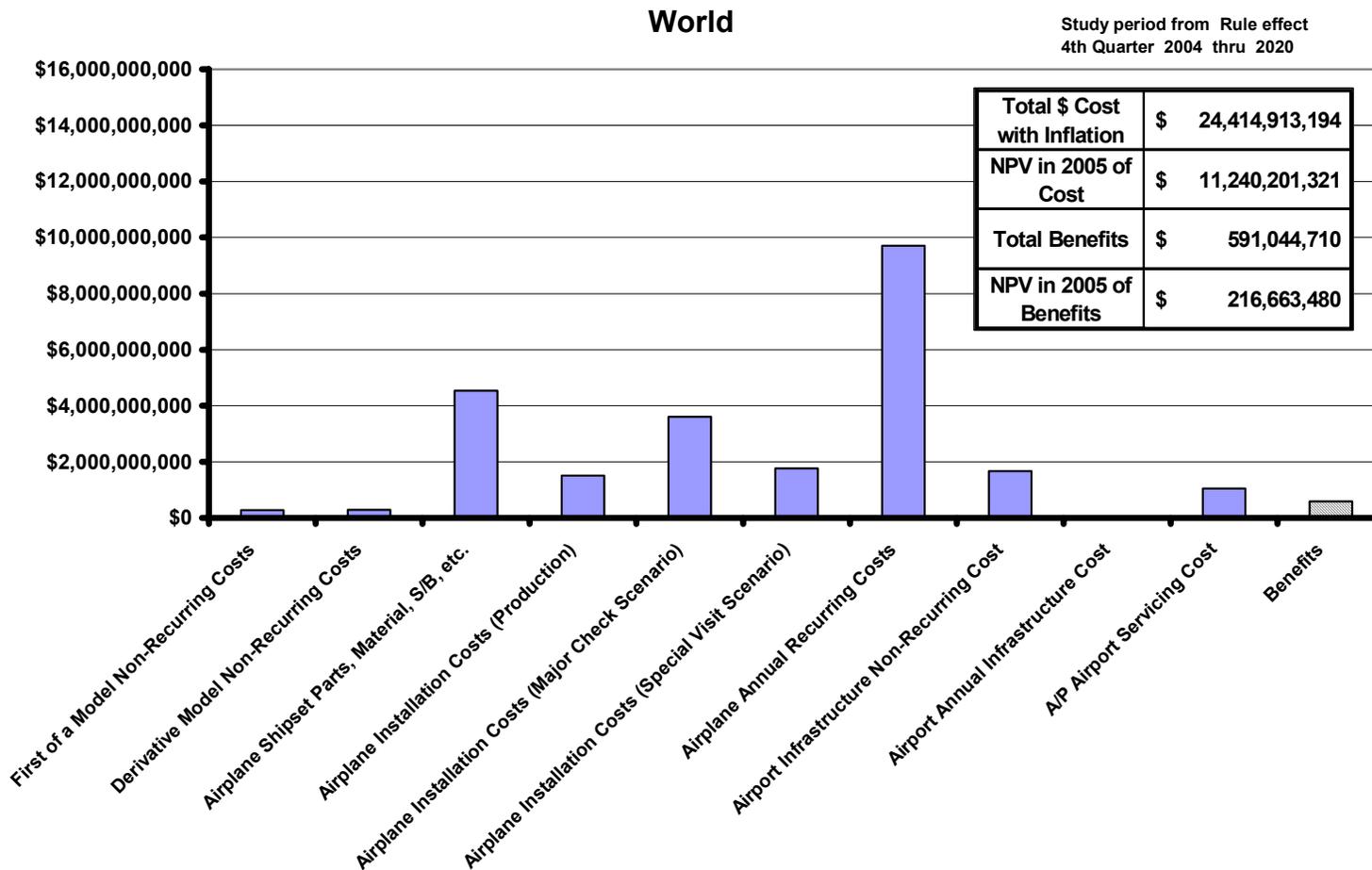


Figure G-11. Scenario 3—Hybrid Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

**Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

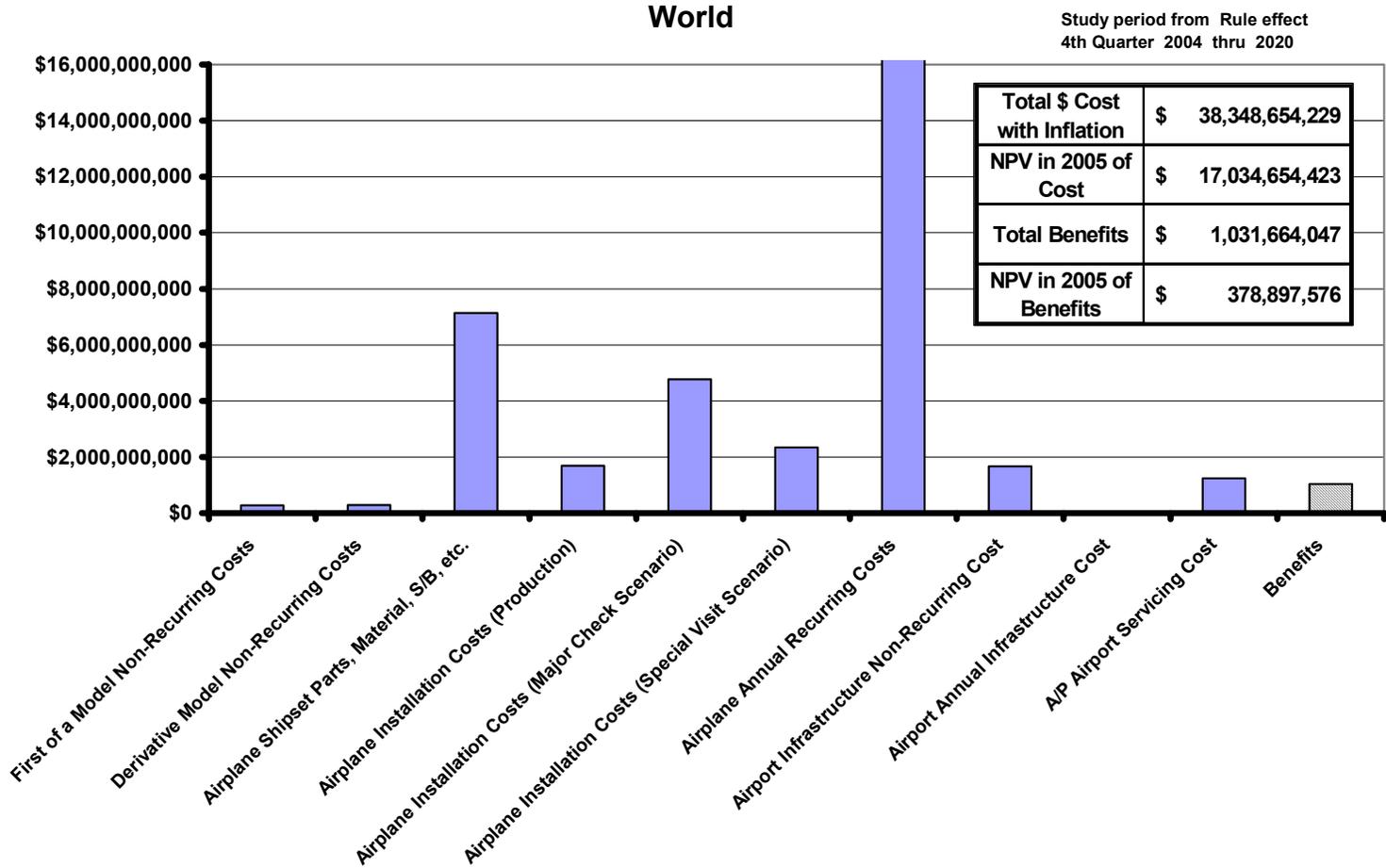


Figure G-12. Scenario 4—Hybrid Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

**Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

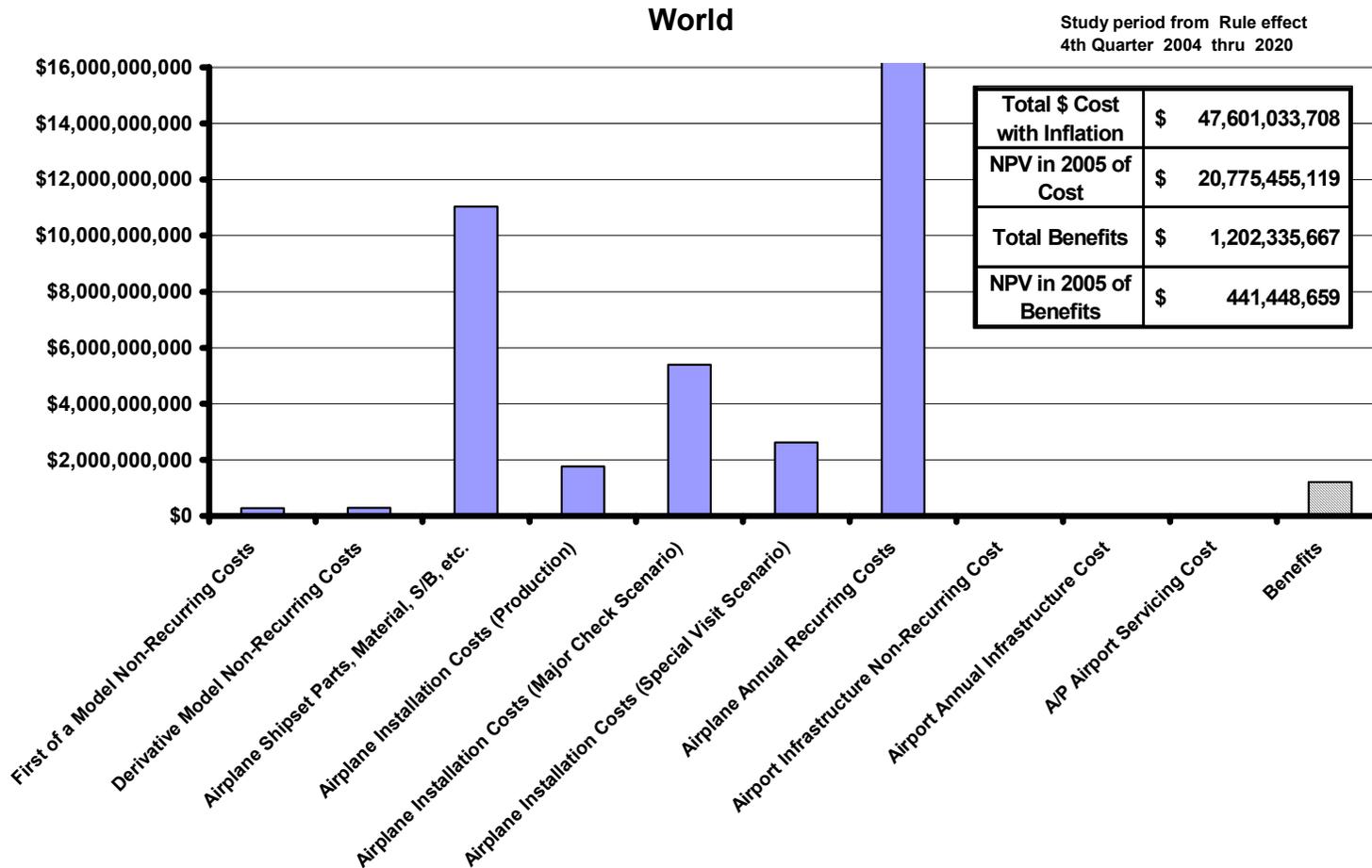


Figure G-13. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

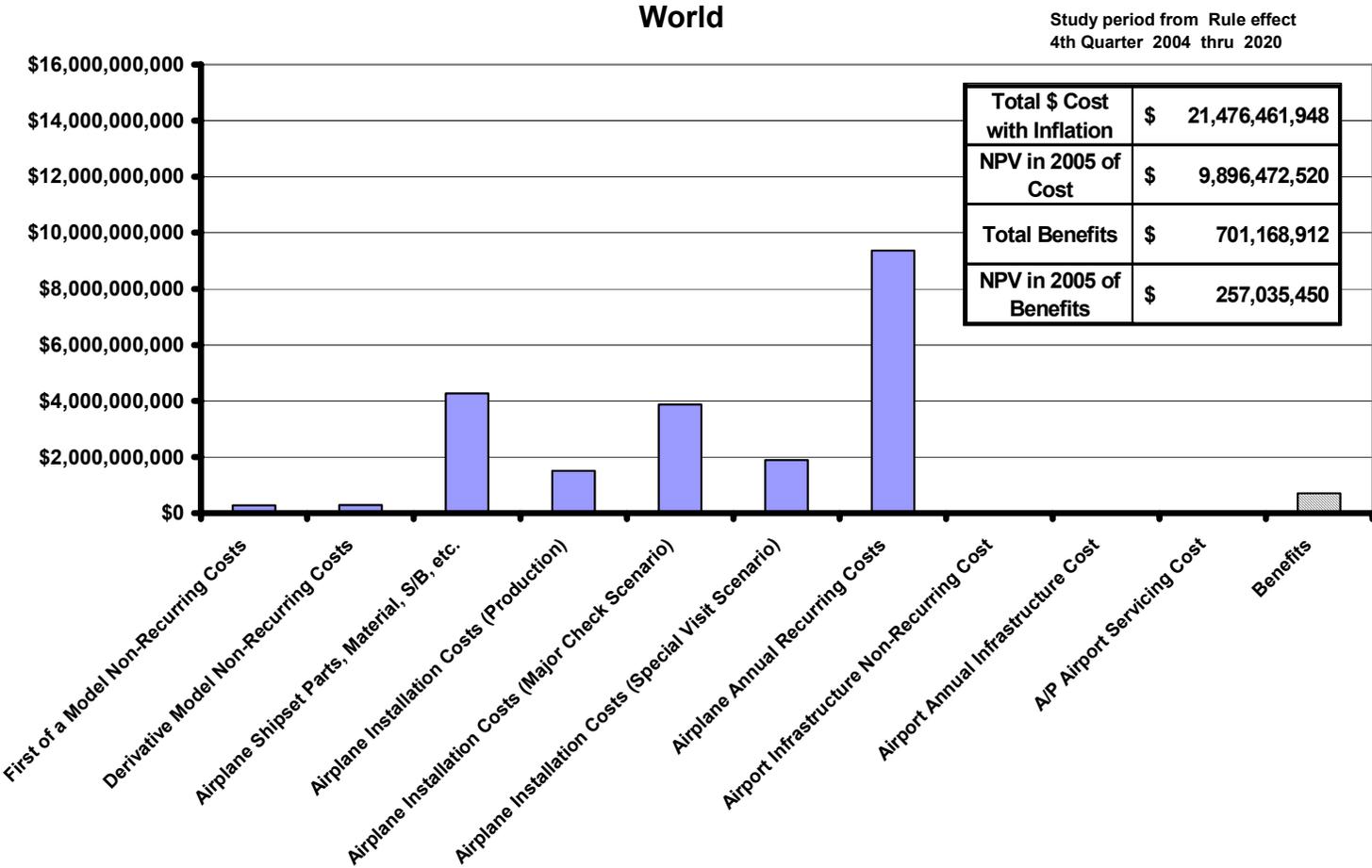


Figure G-14. Scenario 7—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

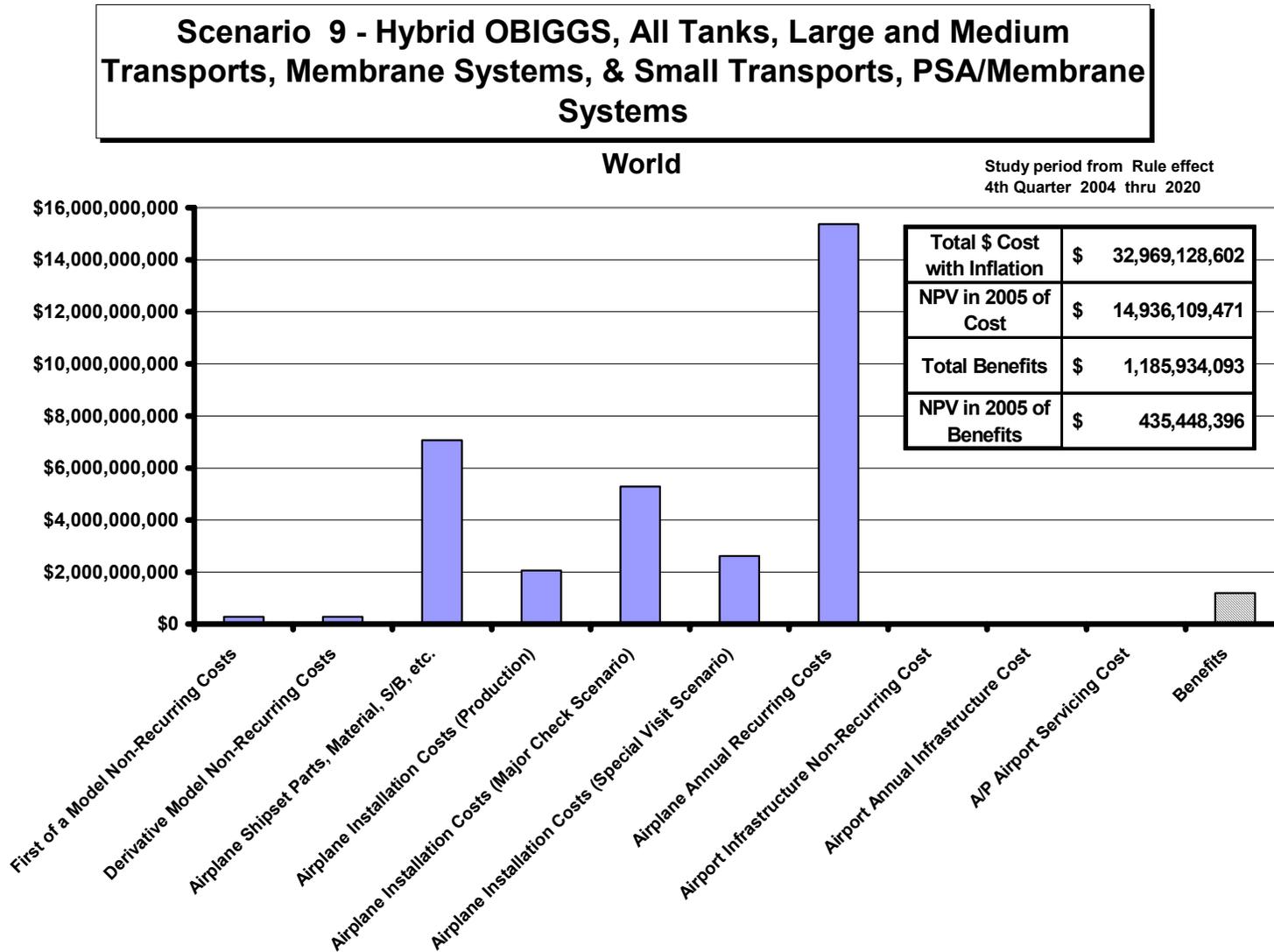


Figure G-15. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

**Scenario 11 - Ground Based Inerting HCWT only, All Transports**

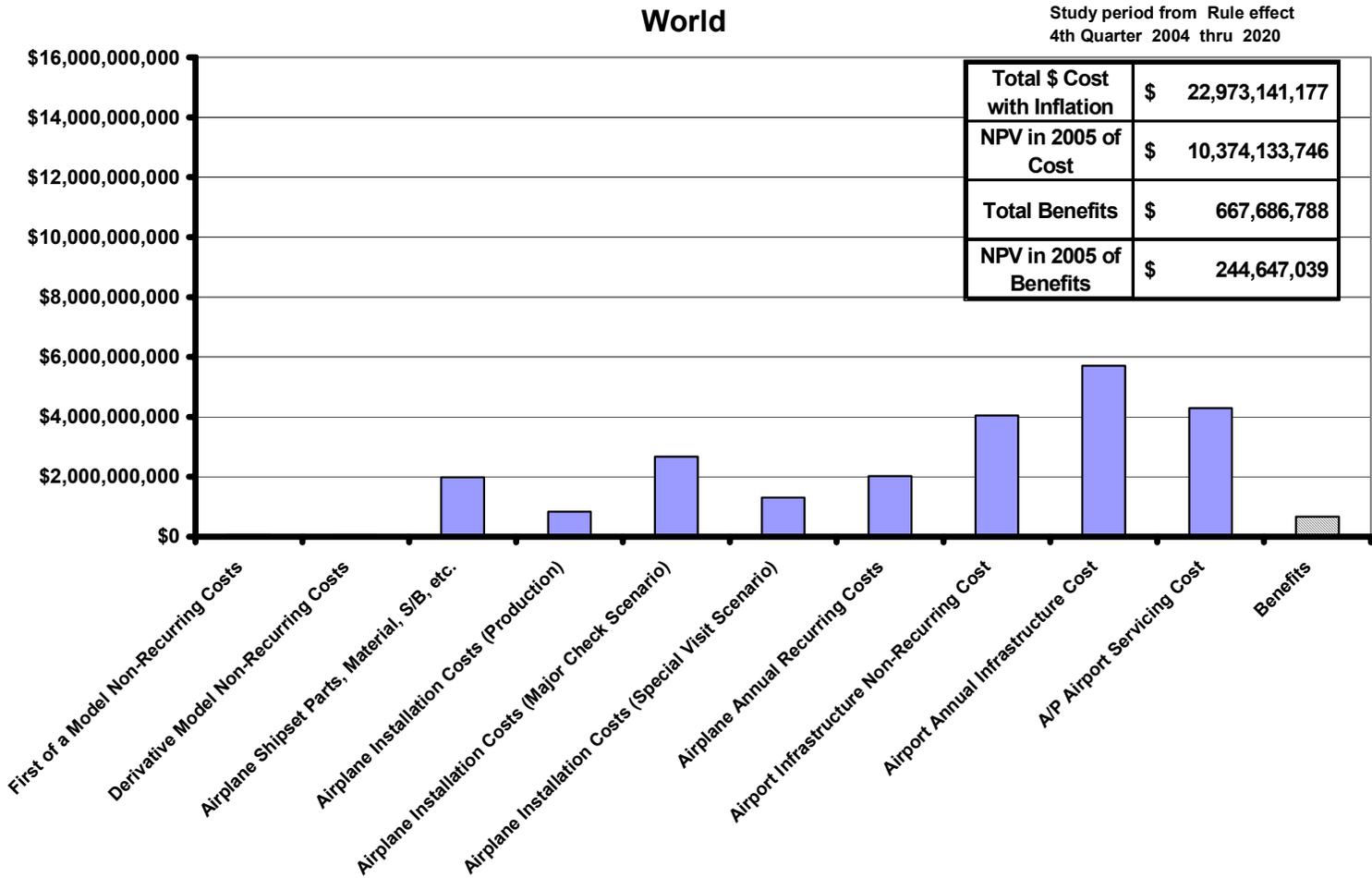


Figure G-16. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (World)

**Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports**

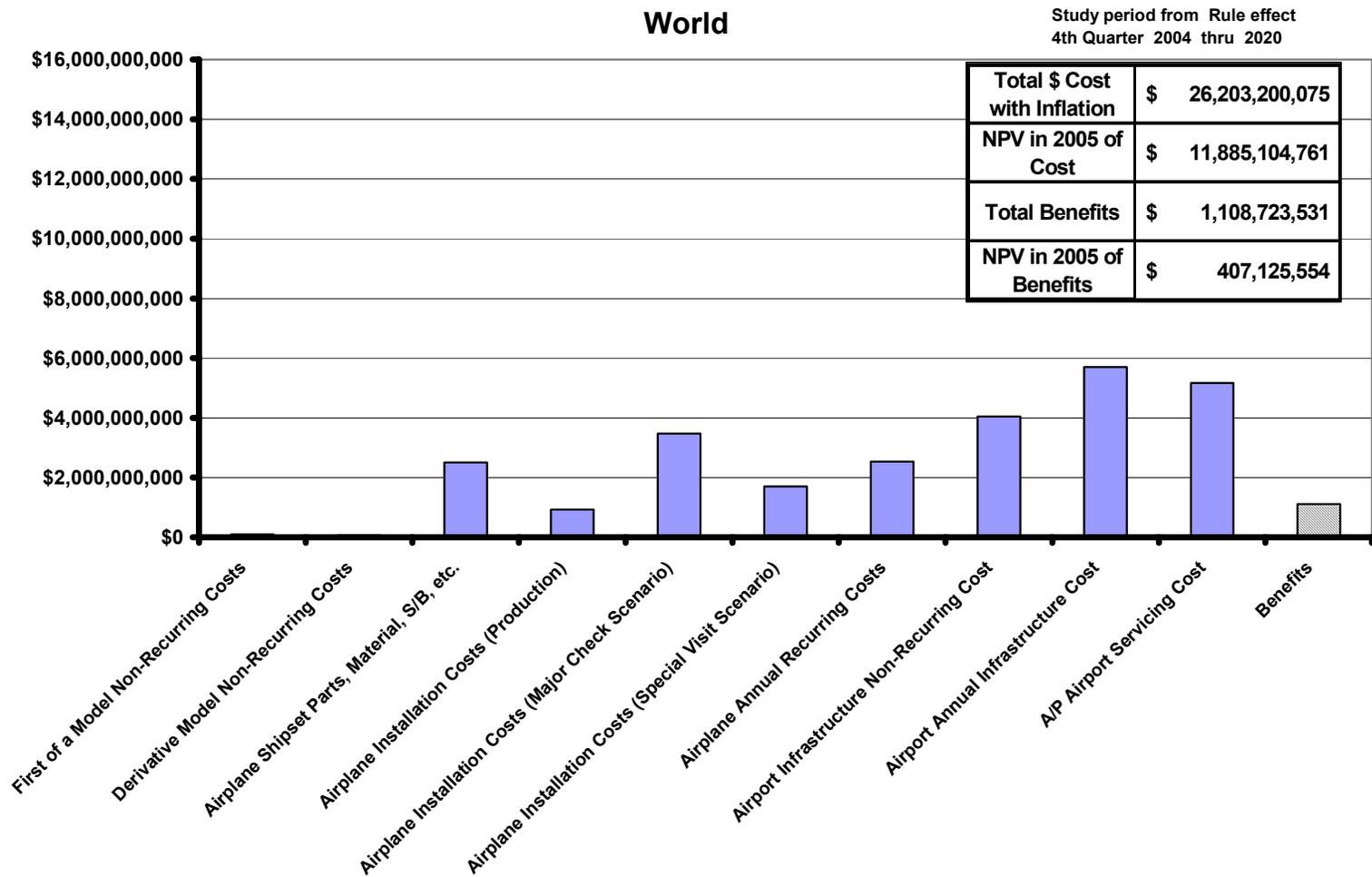


Figure G-17. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (World)

**Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

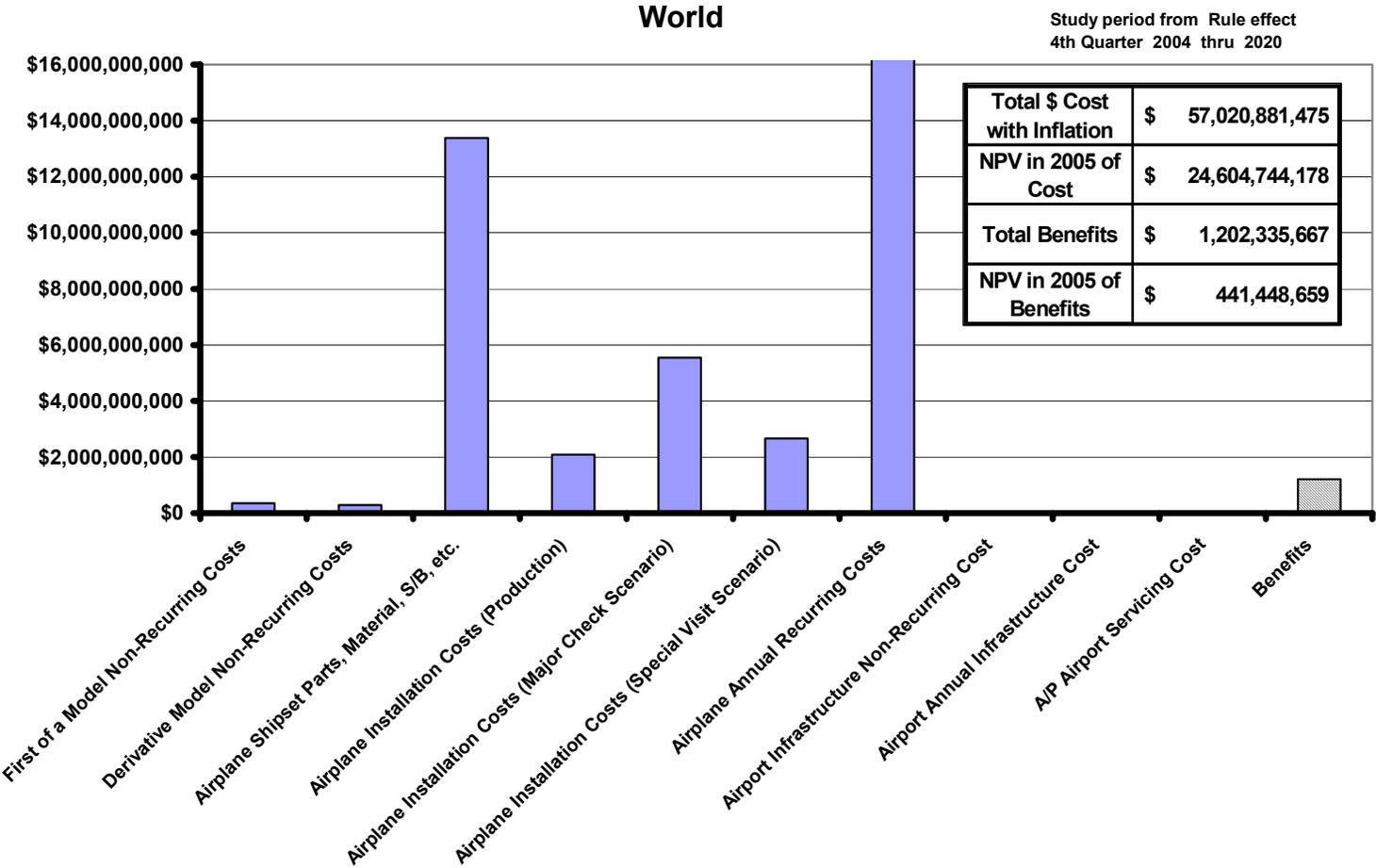


Figure G-18. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

**Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

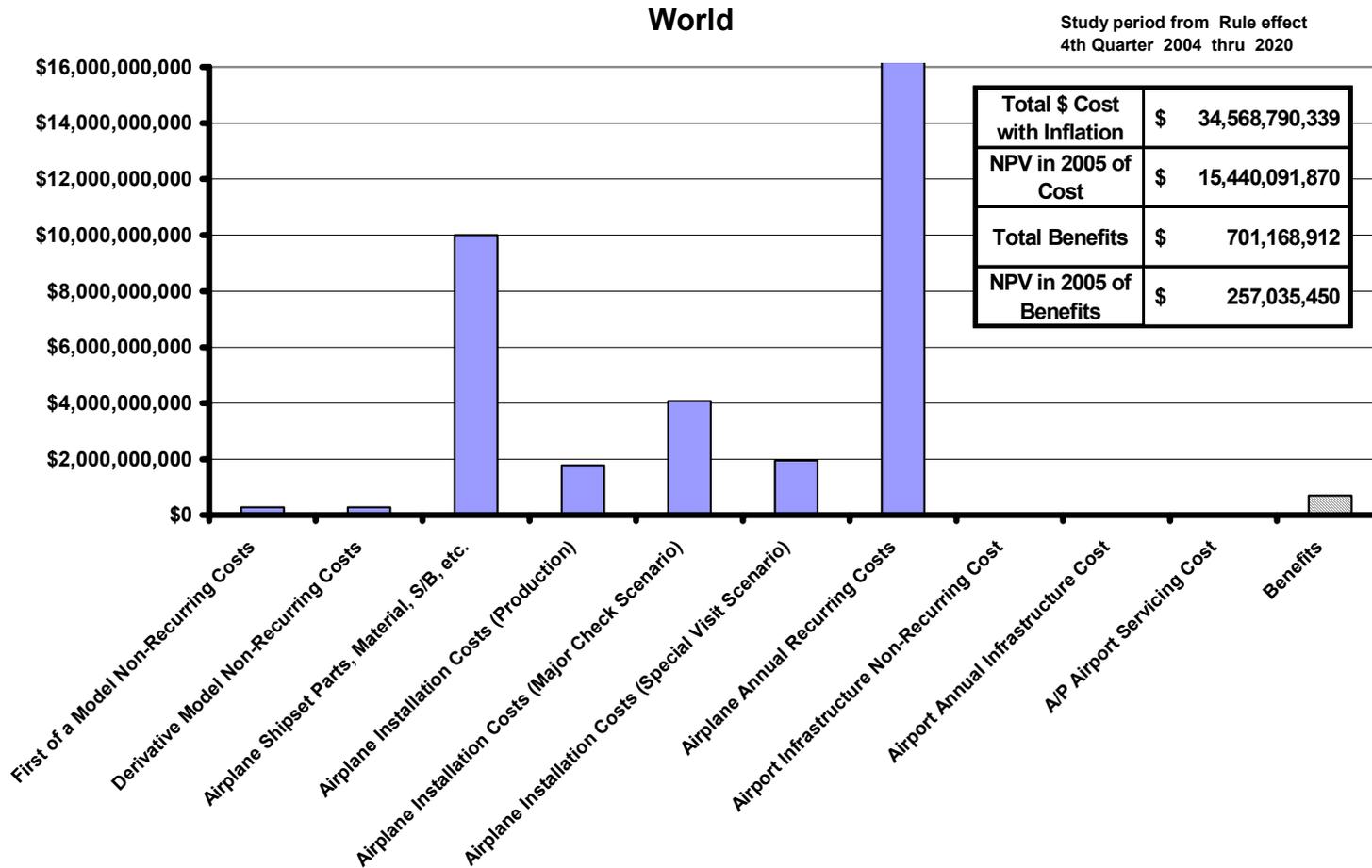


Figure G-19. Scenario 14—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

**Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

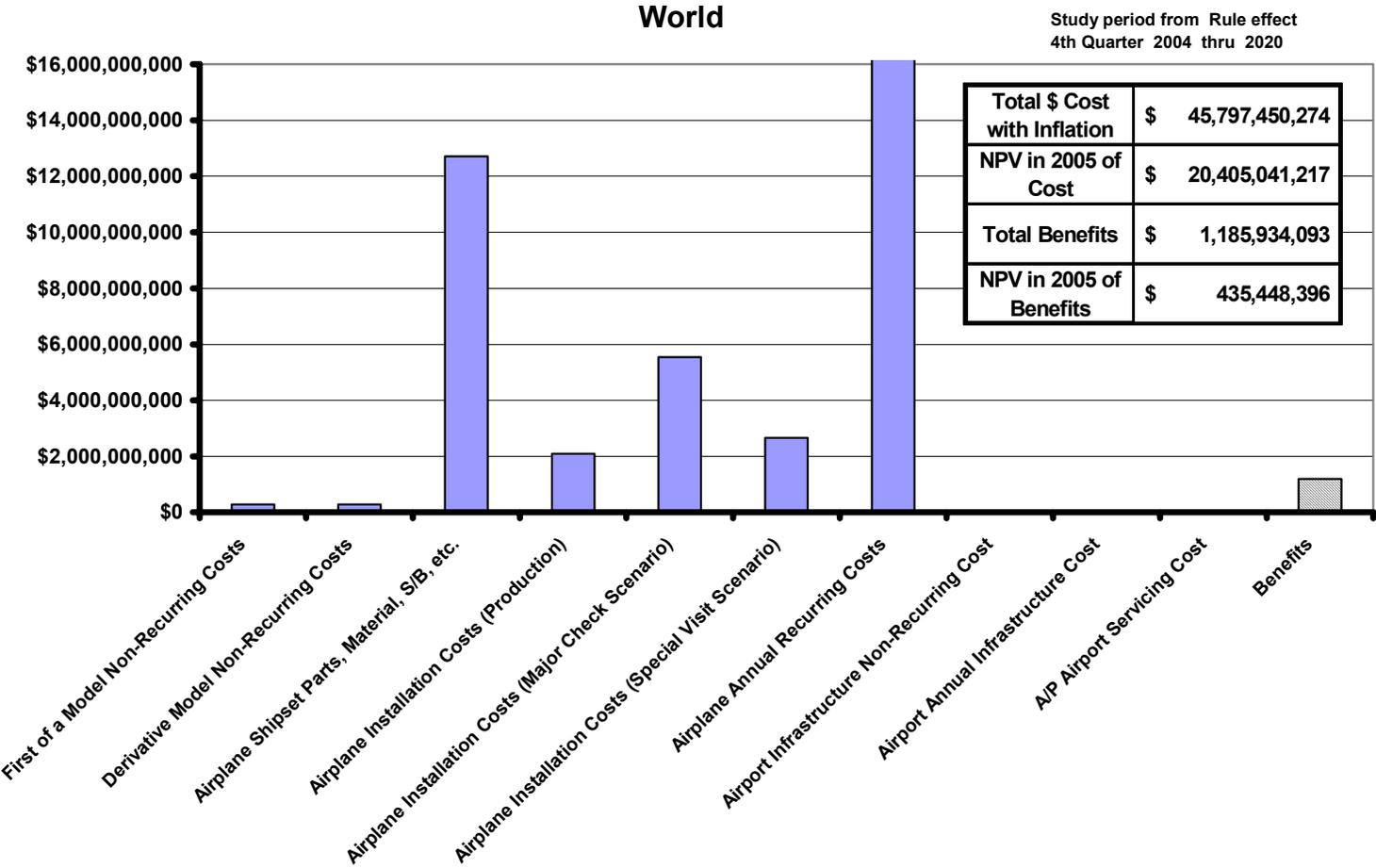


Figure G-20. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

**Scenario 16 - On-Board Liquid Nitrogen Inerting**

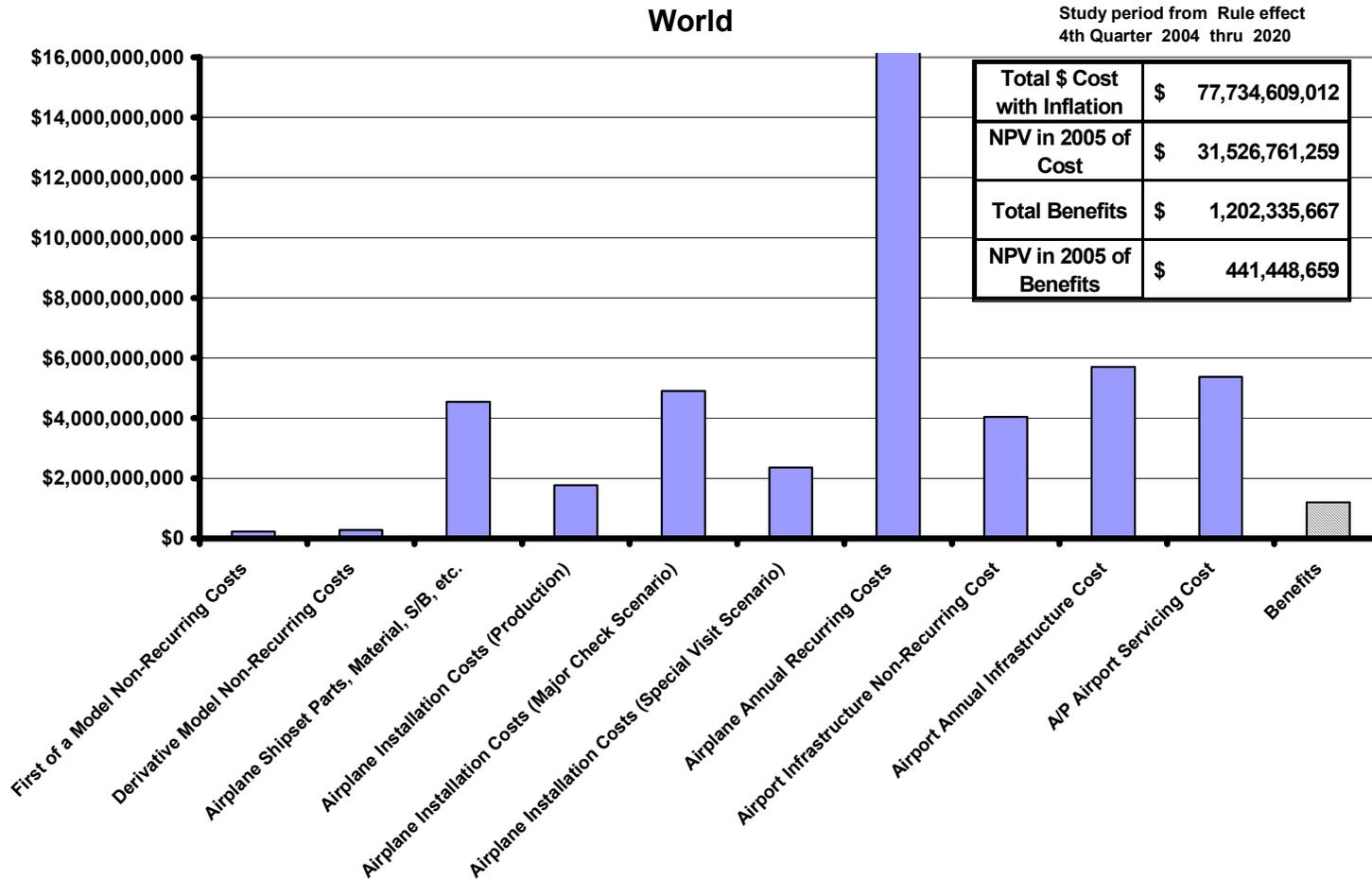


Figure G-21. Scenario 16—Onboard Liquid Nitrogen Inerting (World)

Summary of Inerting Scenario Results World - PAX Only

Values in Millions	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting HCWT Fuselage Tanks, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Tanks, All Transports	Scenario 12 - Ground Based Inerting HCWT only, All Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting			
Total \$ Cost with Inflation	21,474	34,897	20,722	32,007	39,168	18,015	27,575	21,285	24,085	47,094	28,866	38,157	65,236	-	-	-
NPV in 2005 of Cost	9,936	15,576	9,644	14,371	17,248	8,376	12,590	9,600	10,907	20,489	12,994	17,129	26,698	-	-	-
Total Benefits	597	1,037	591	1,032	1,202	701	1,186	668	1,109	1,202	701	1,186	1,202	-	-	-
NPV in 2005 of Benefits	219	381	217	379	441	257	435	245	407	441	257	435	441	-	-	-

Figure G-22. Cost Summary of World Fleet Passenger Only

**Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

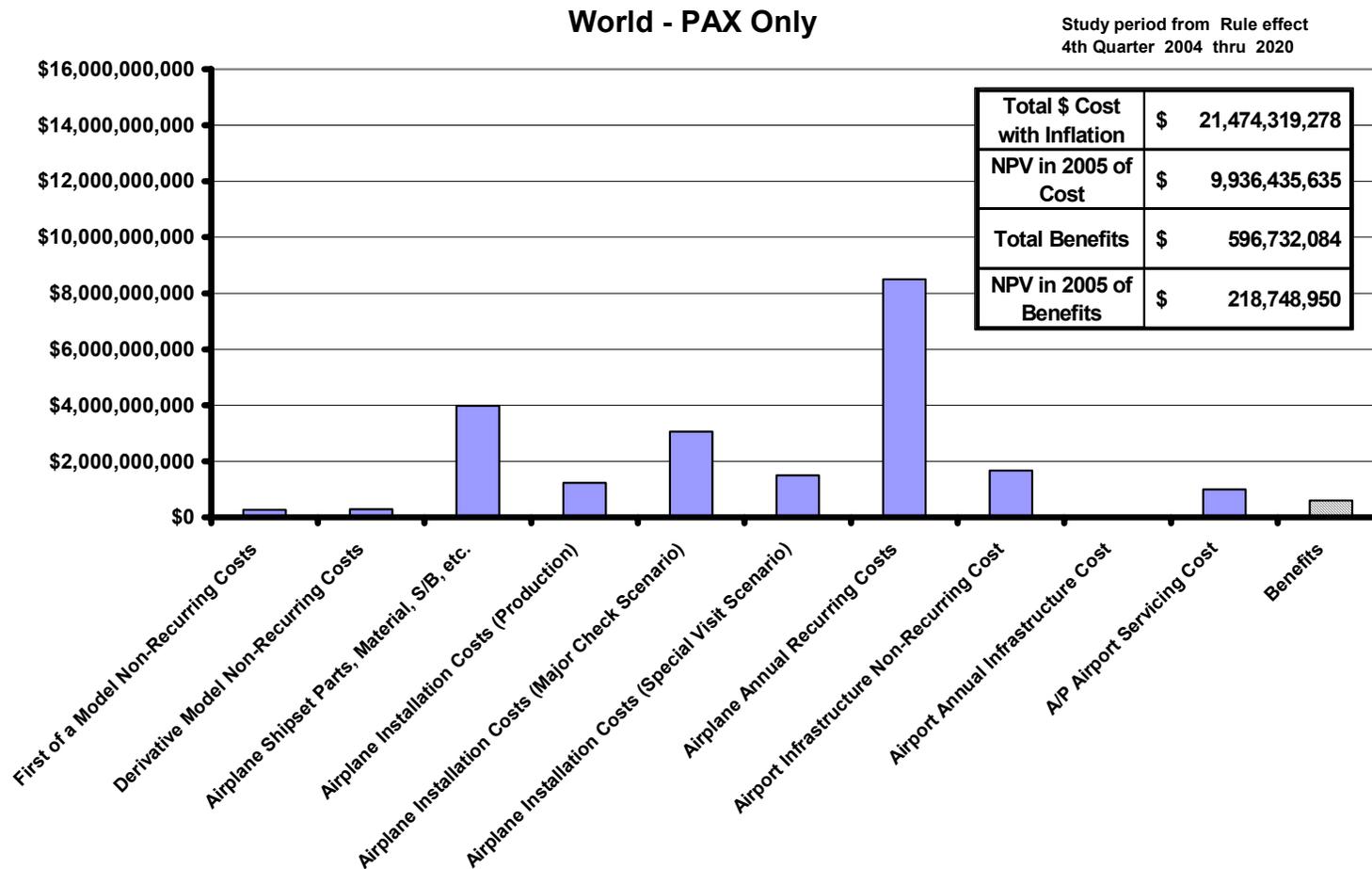


Figure G-23. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

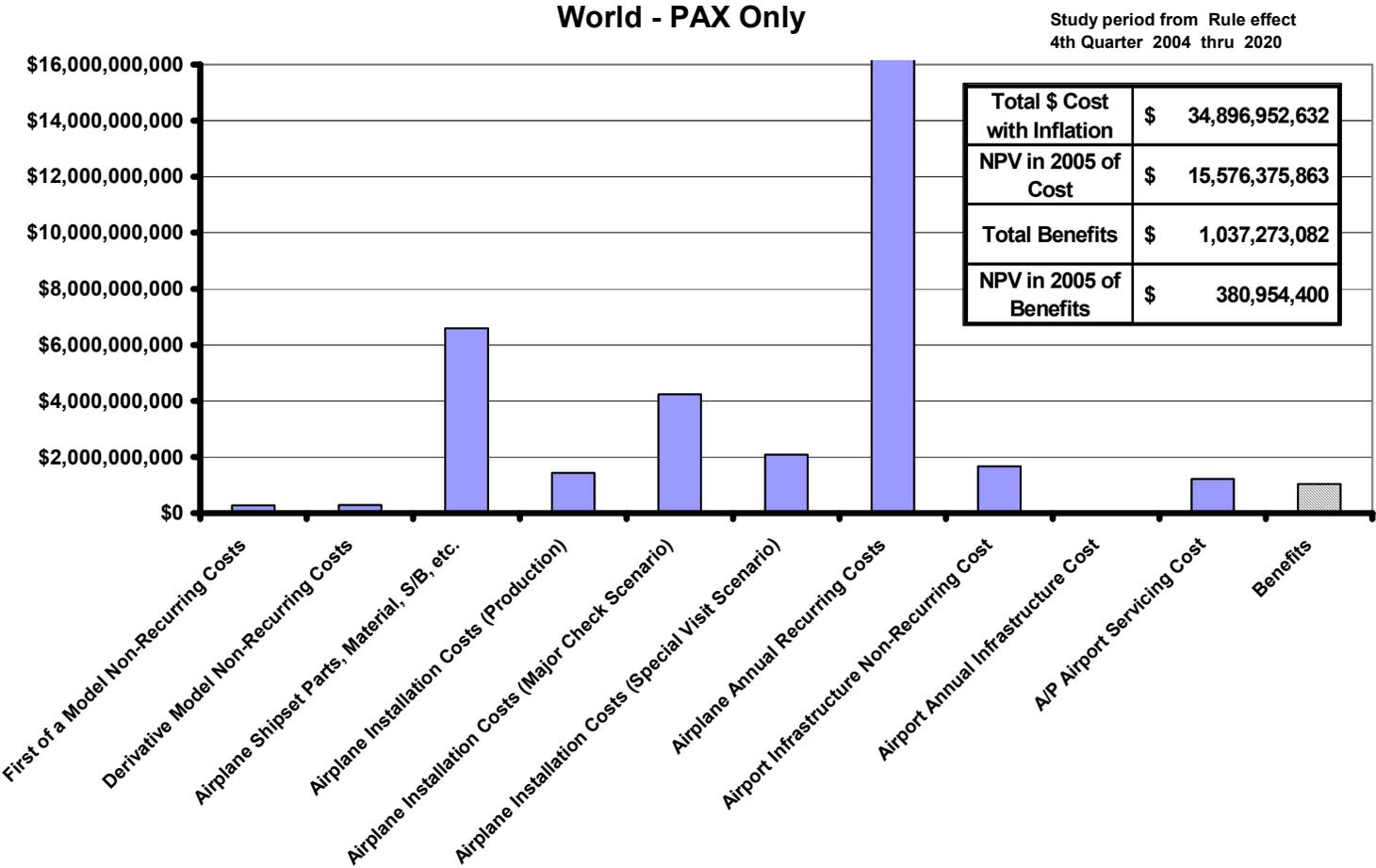


Figure G-24. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

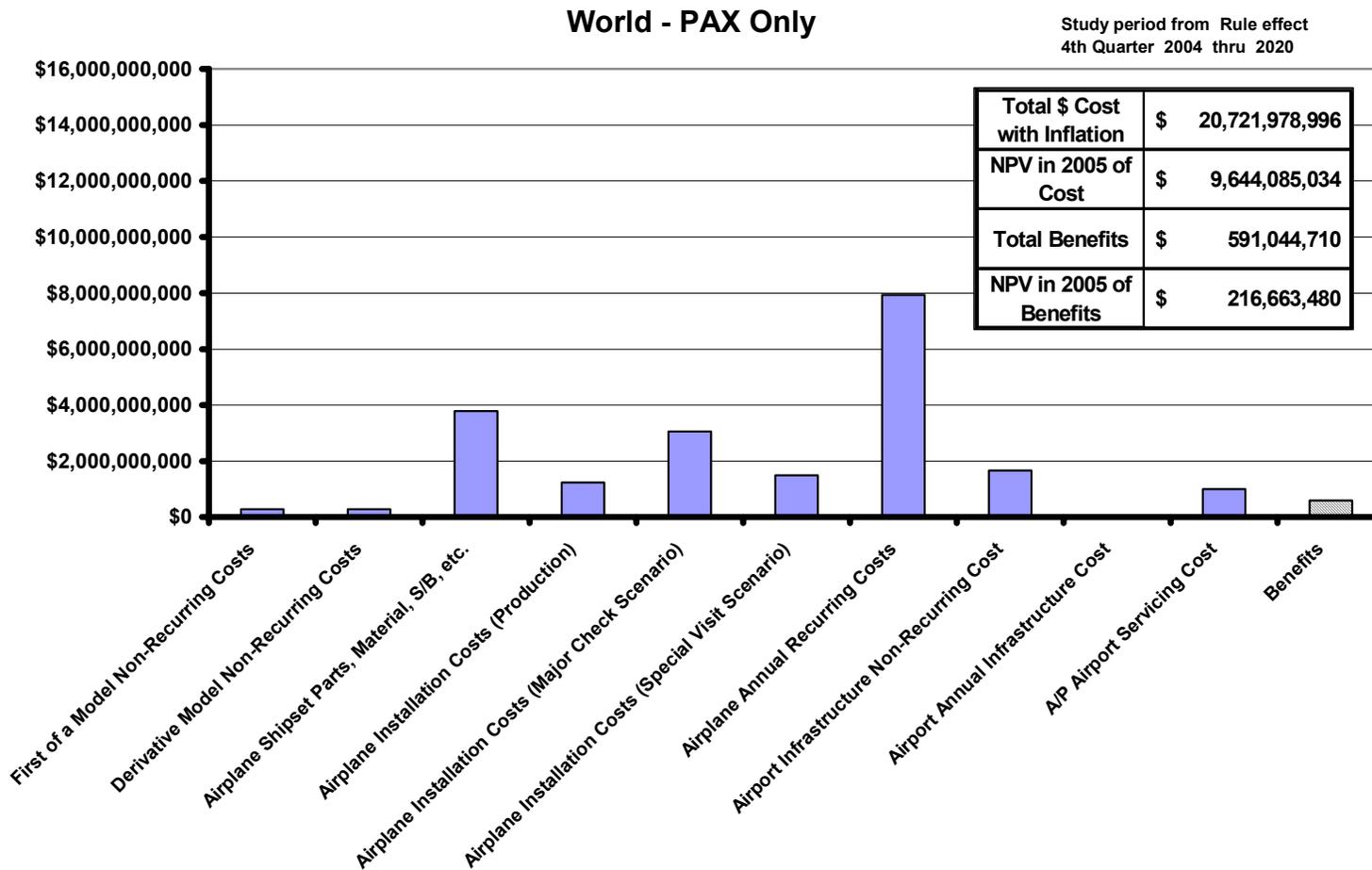


Figure G-25. Scenario 3—Hybrid Onboard Ground Inerting, HCWT Only, Large, Medium and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

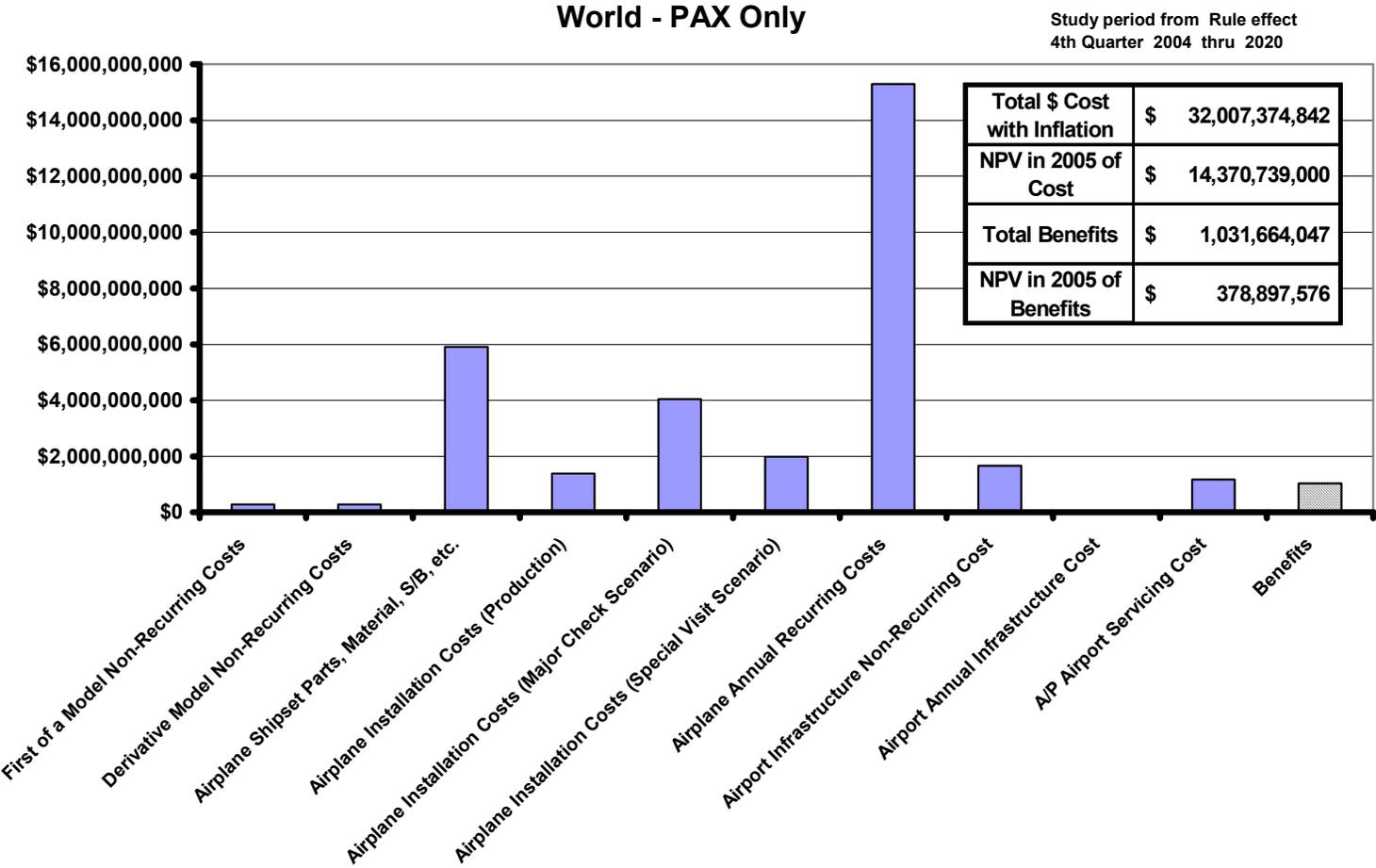


Figure G-26. Scenario 4—Hybrid Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

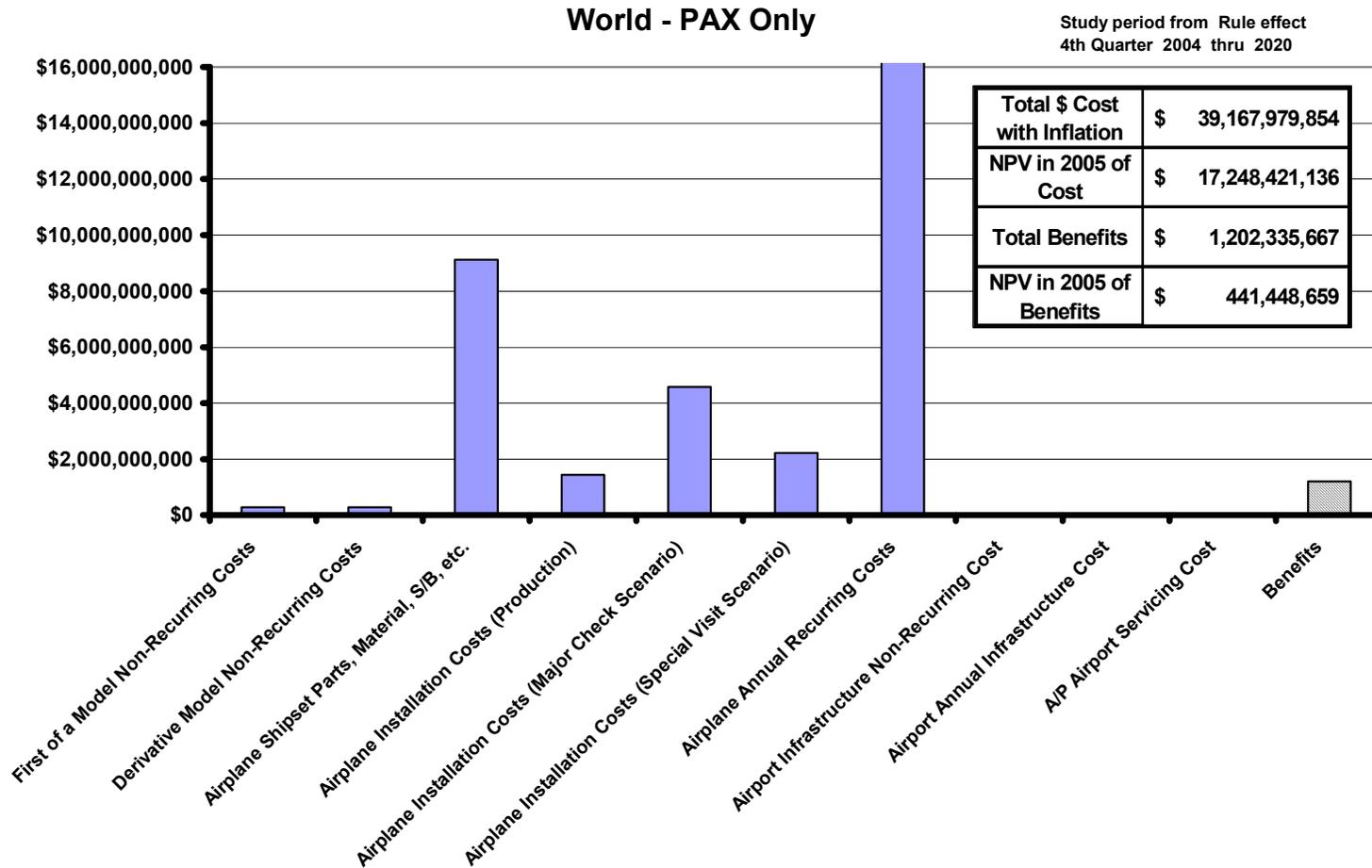


Figure G-27. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

World - PAX Only

Study period from Rule effect  
4th Quarter 2004 thru 2020

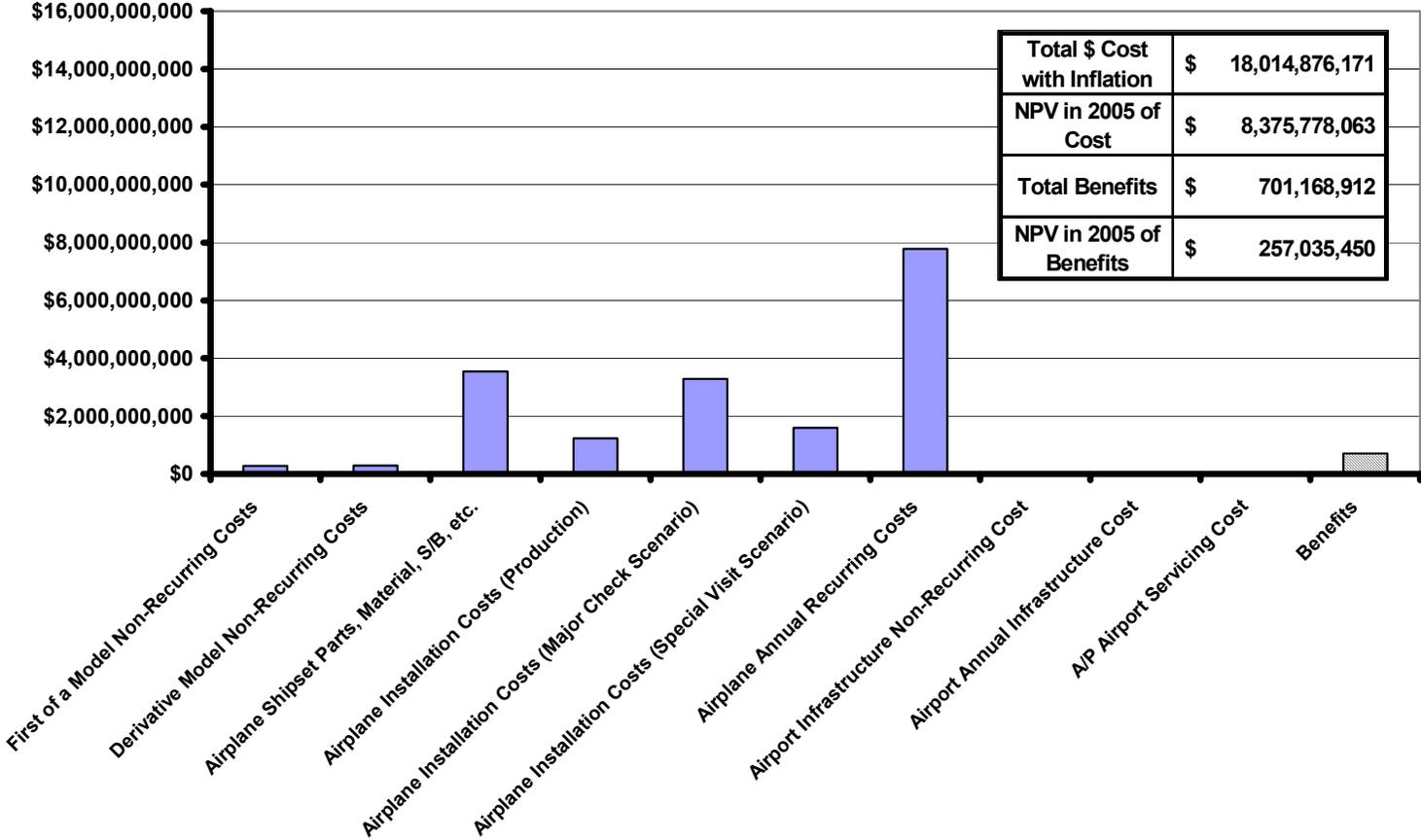


Figure G-28. Scenario 7—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

World - PAX Only

Study period from Rule effect  
4th Quarter 2004 thru 2020

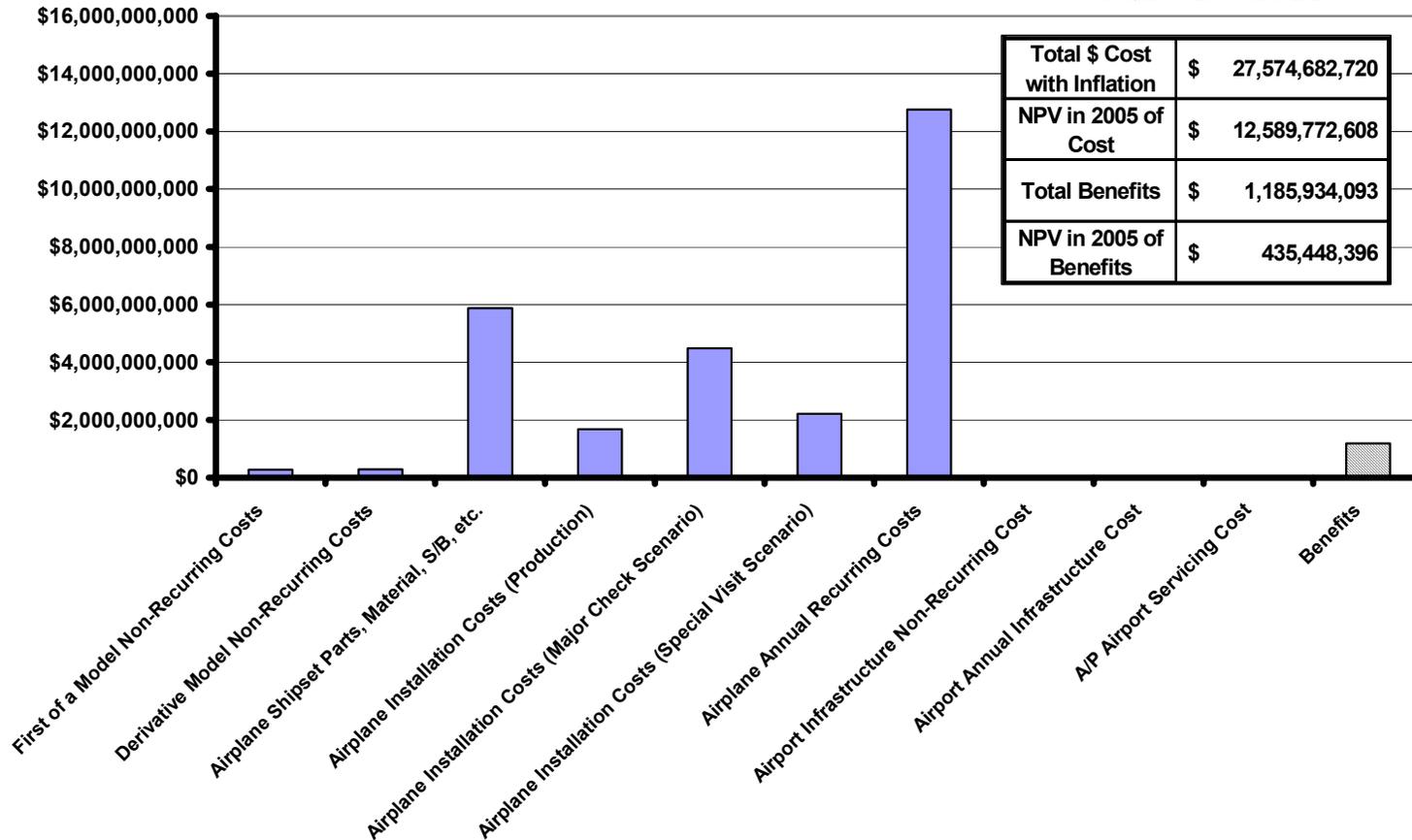


Figure G-29. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 11 - Ground Based Inerting HCWT only, All Transports**

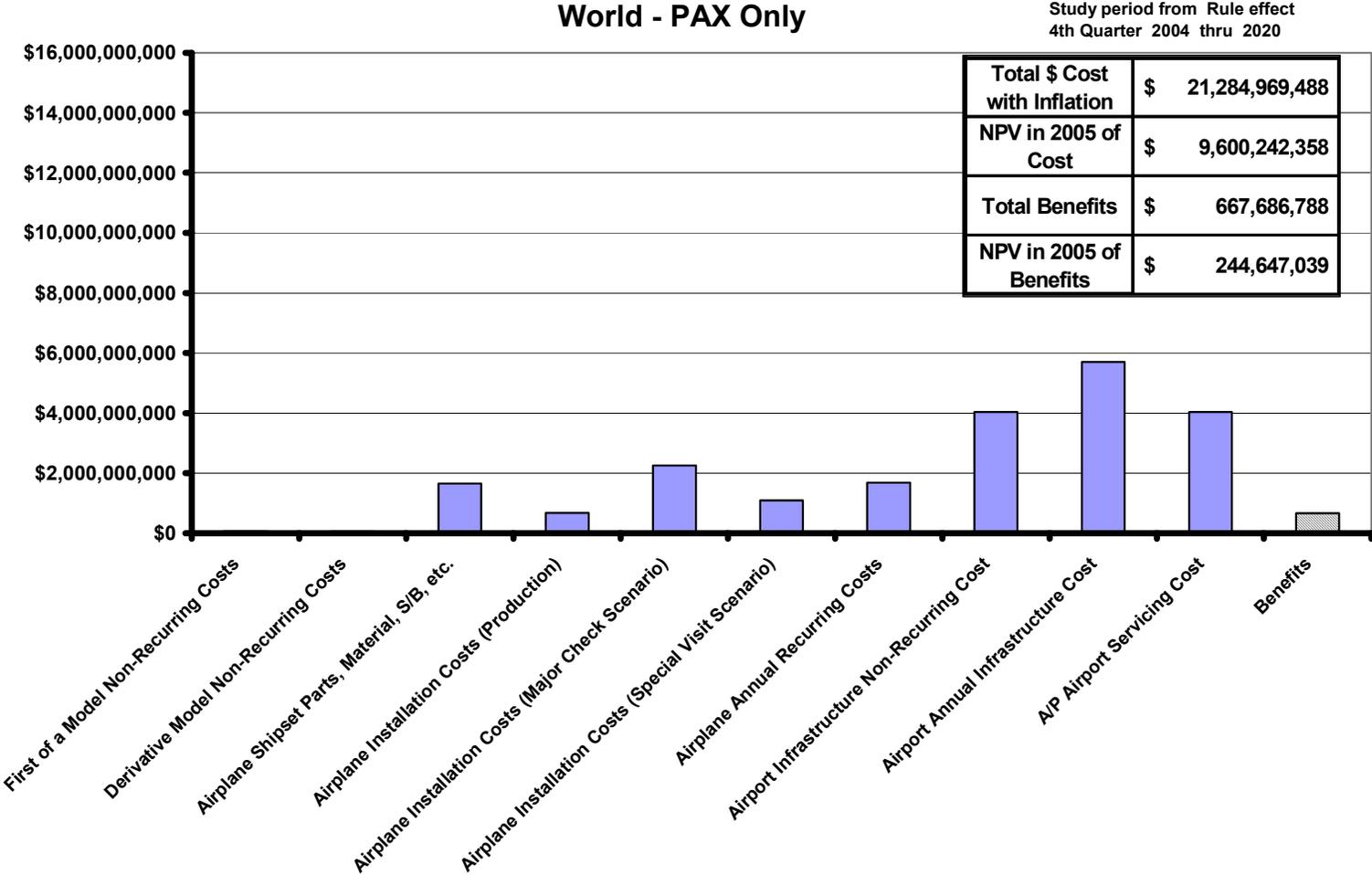


Figure G-30. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (World, Passenger Only)

**Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports**

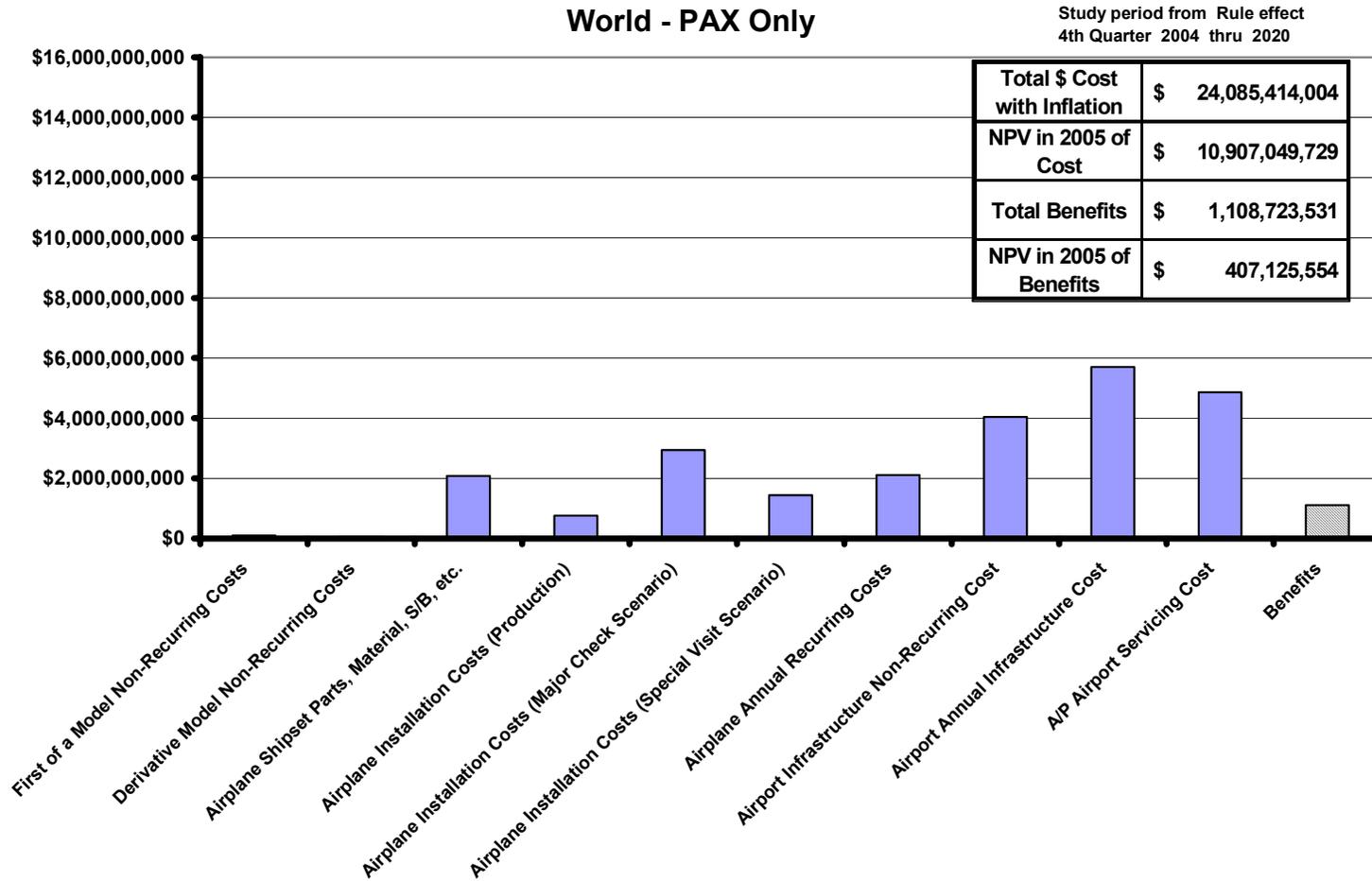


Figure G-31. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (World, Passenger Only)

**Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

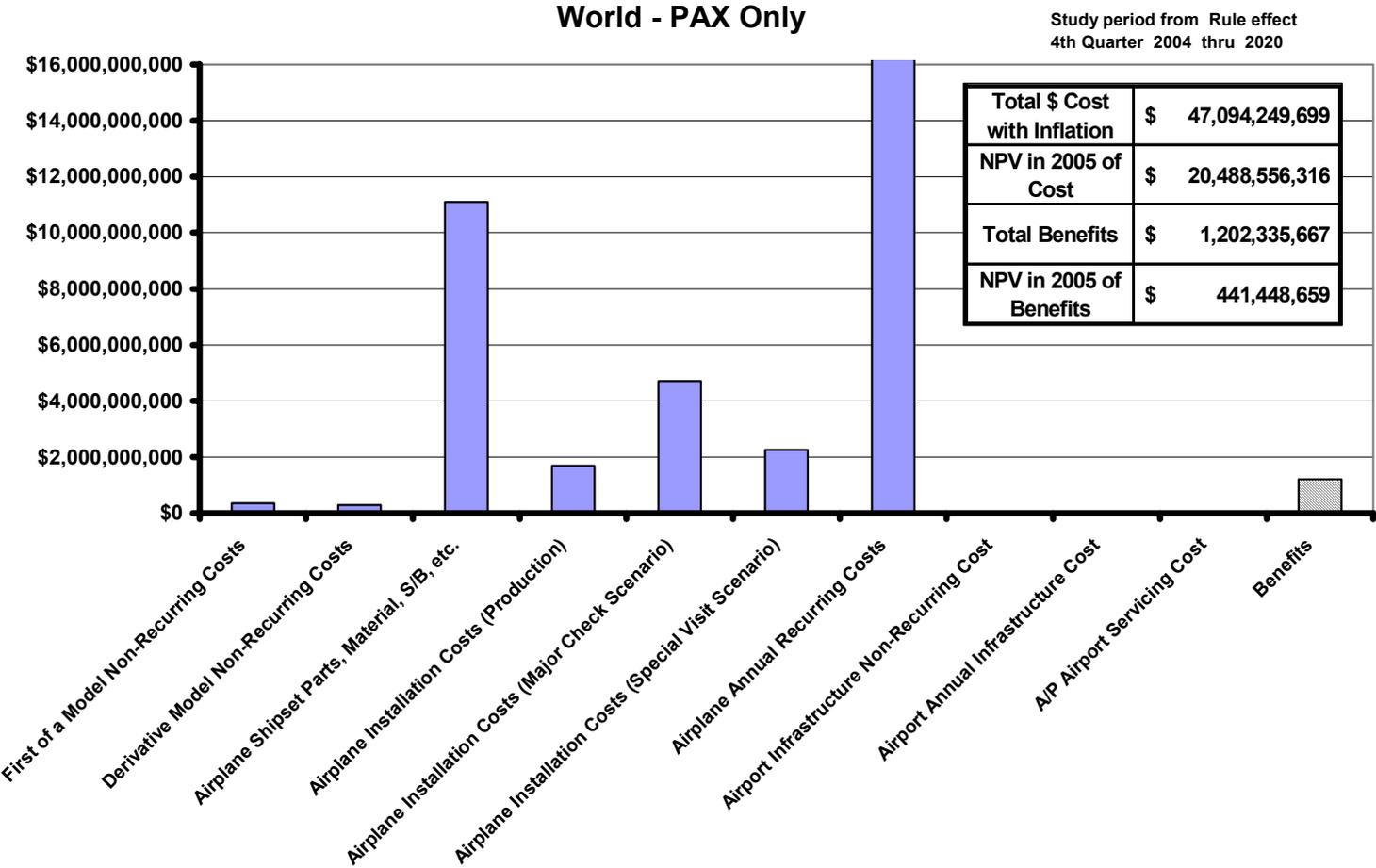


Figure G-32. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

World - PAX Only

Study period from Rule effect  
4th Quarter 2004 thru 2020

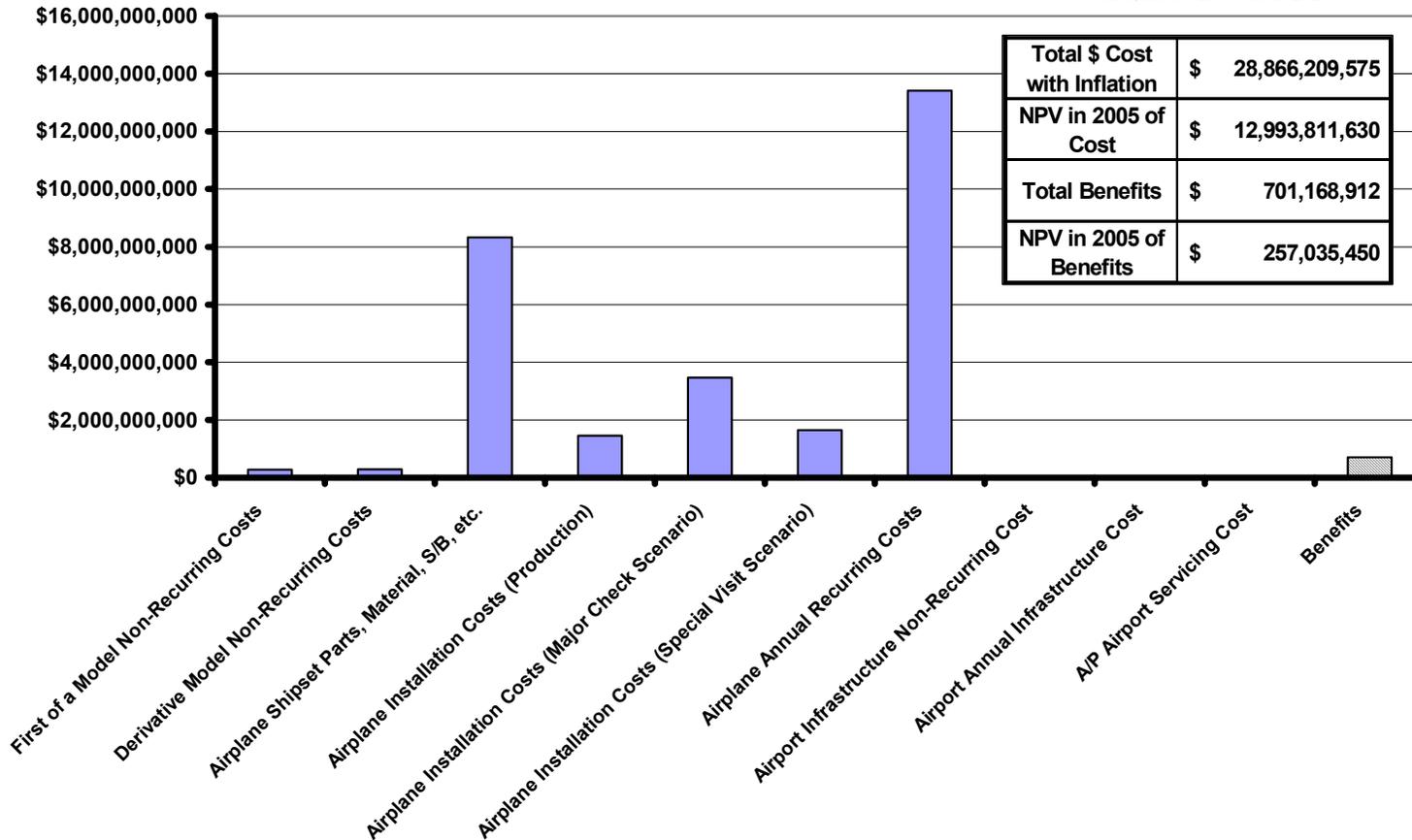


Figure G-33. Scenario 14—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

World - PAX Only

Study period from Rule effect  
4th Quarter 2004 thru 2020

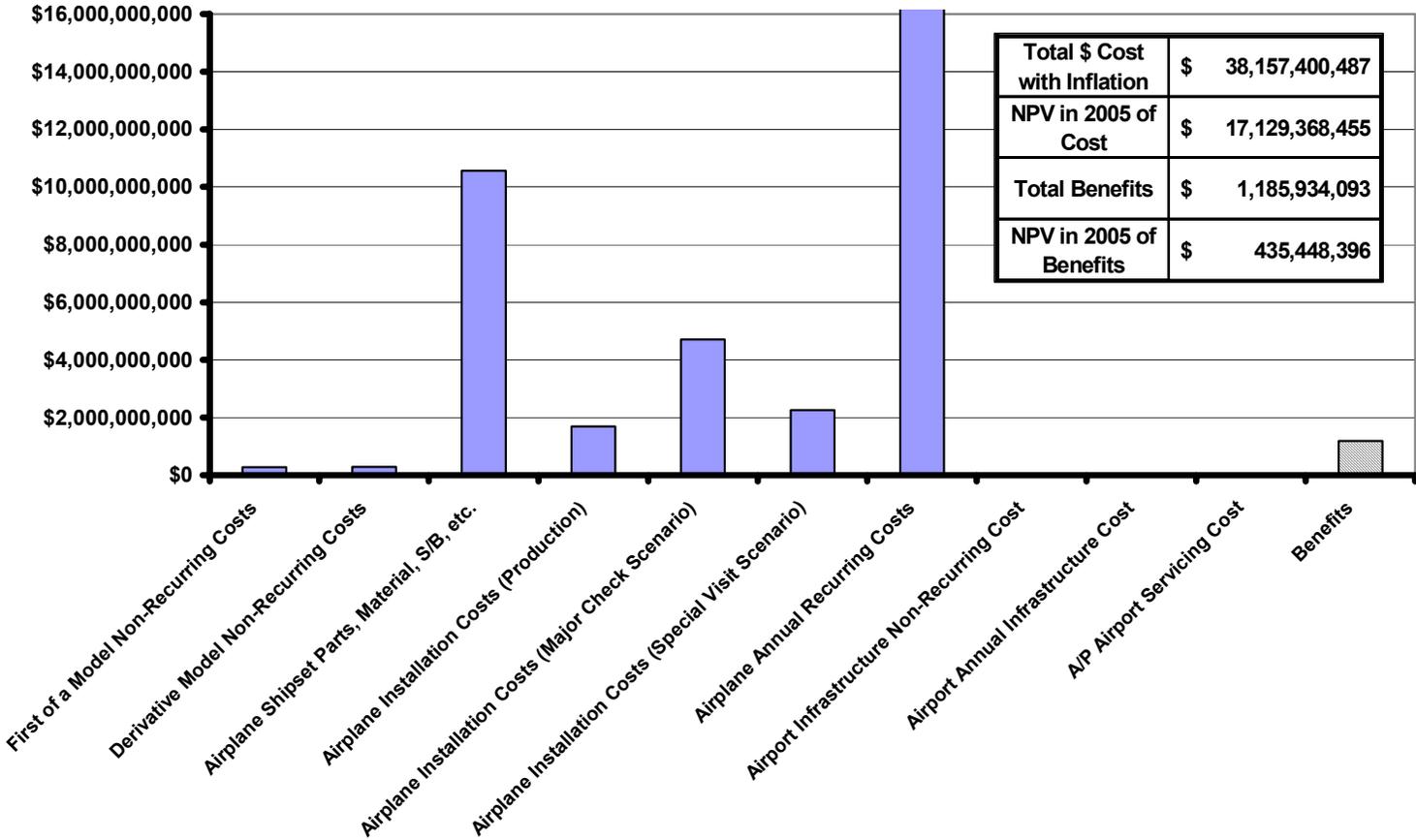


Figure G-34. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

**Scenario 16 - On-Board Liquid Nitrogen Inerting**

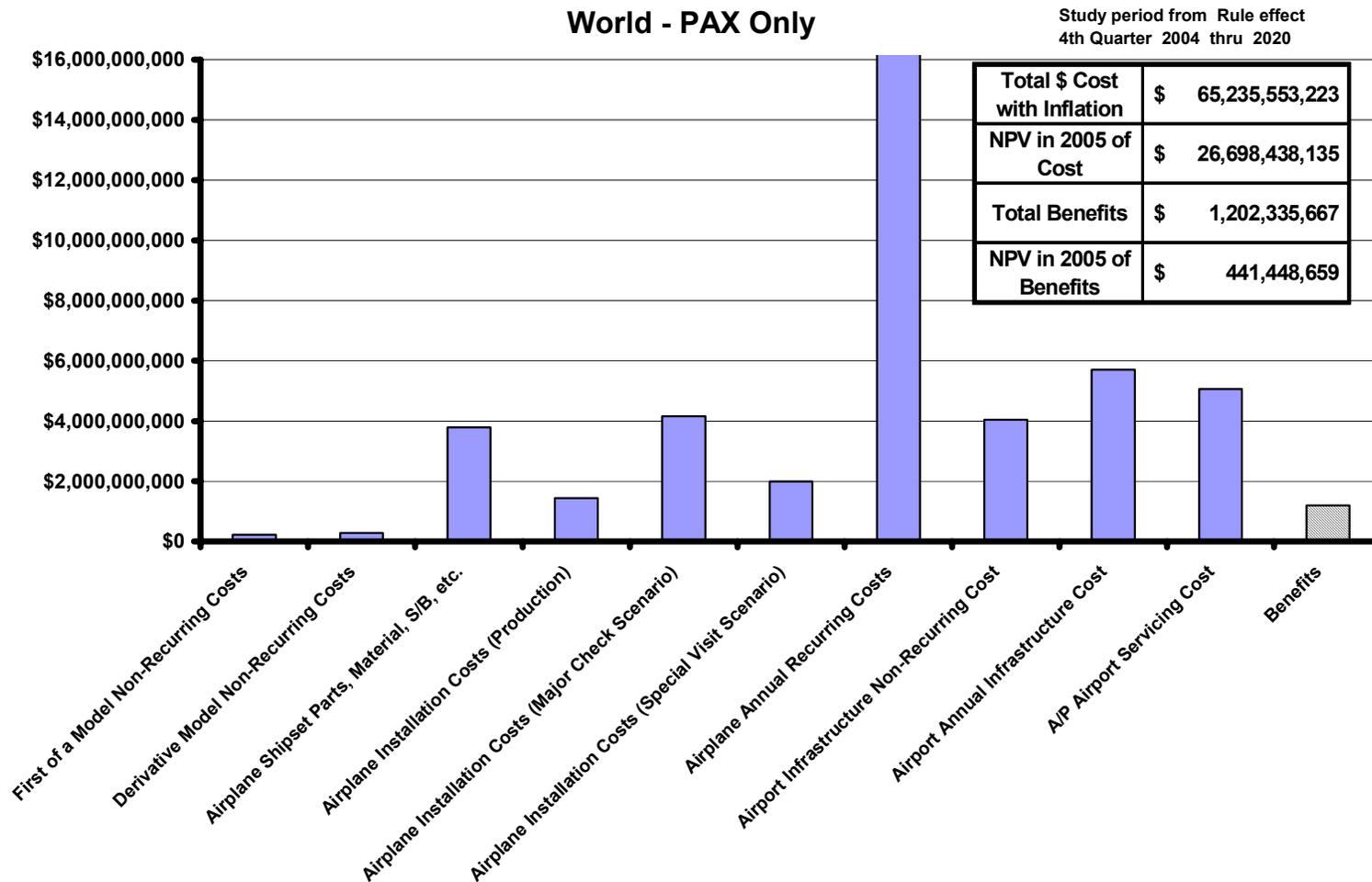


Figure G-35. Scenario 16—Onboard Liquid Nitrogen Inerting (World, Passenger Only)

Summary of Inerting Scenario Results

US-Operator

Values in Millions

	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 2 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports	Scenario 11 - Ground Based Inerting HCWT only, All Tanks, All Transports	Scenario 12 - Ground Based Inerting HCWT only, All Tanks, All Transports	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting			
Total \$ Cost with Inflation	10,082	15,367	9,744	14,203	17,047	8,606	12,680	10,429	11,588	20,924	13,586	17,414	27,692	-	-	-
NPV in 2005 of Cost	4,849	7,099	4,721	6,613	7,753	4,165	5,968	4,758	5,314	9,357	6,299	8,015	11,656	-	-	-
Total Benefits	233	434	231	432	497	274	492	258	459	497	274	492	497	-	-	-
NPV in 2005 of Benefits	86	159	85	159	183	101	181	95	169	183	101	181	183	-	-	-

Figure G-36. Cost Summary of U.S. Fleet

**Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

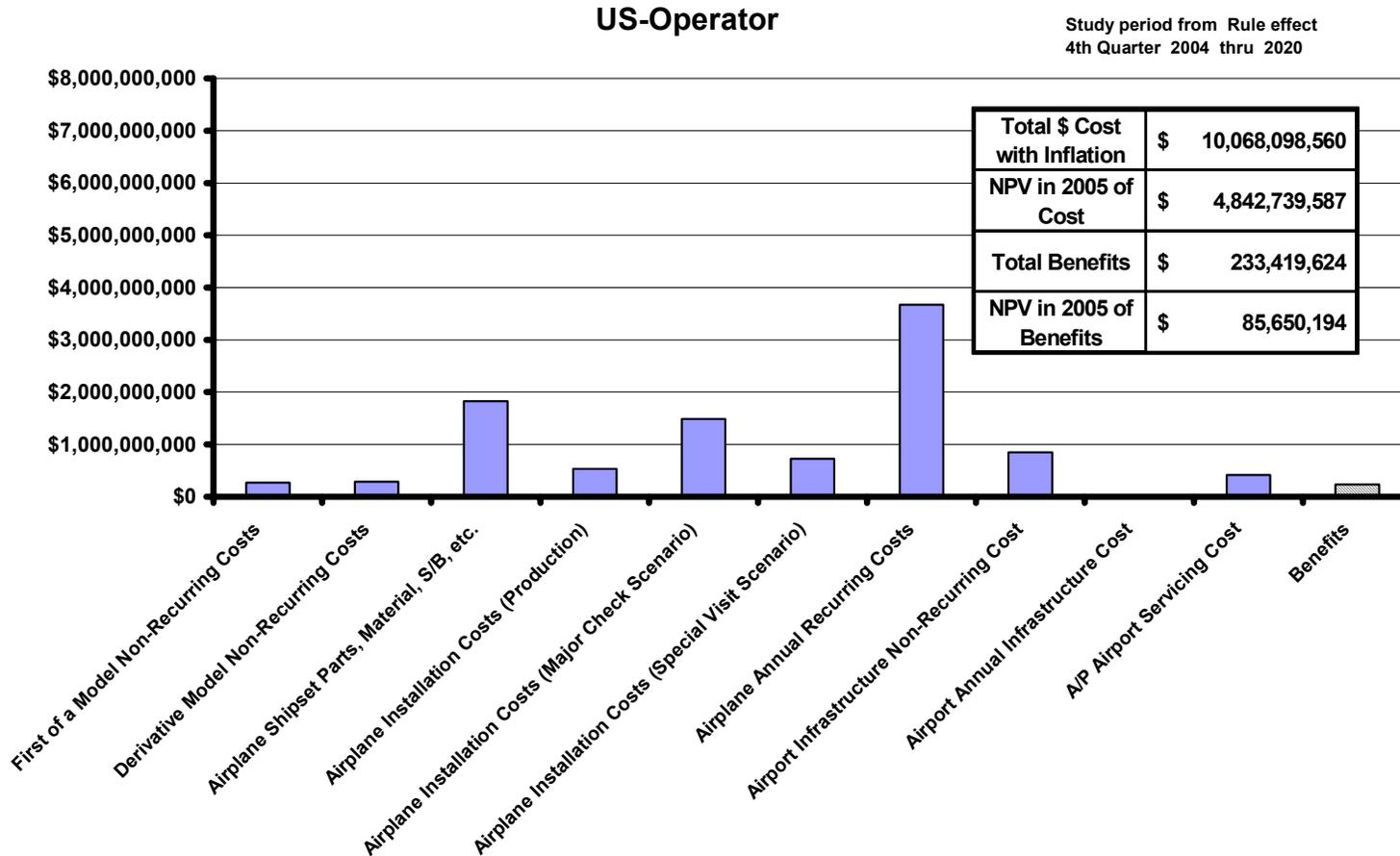


Figure G-37. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

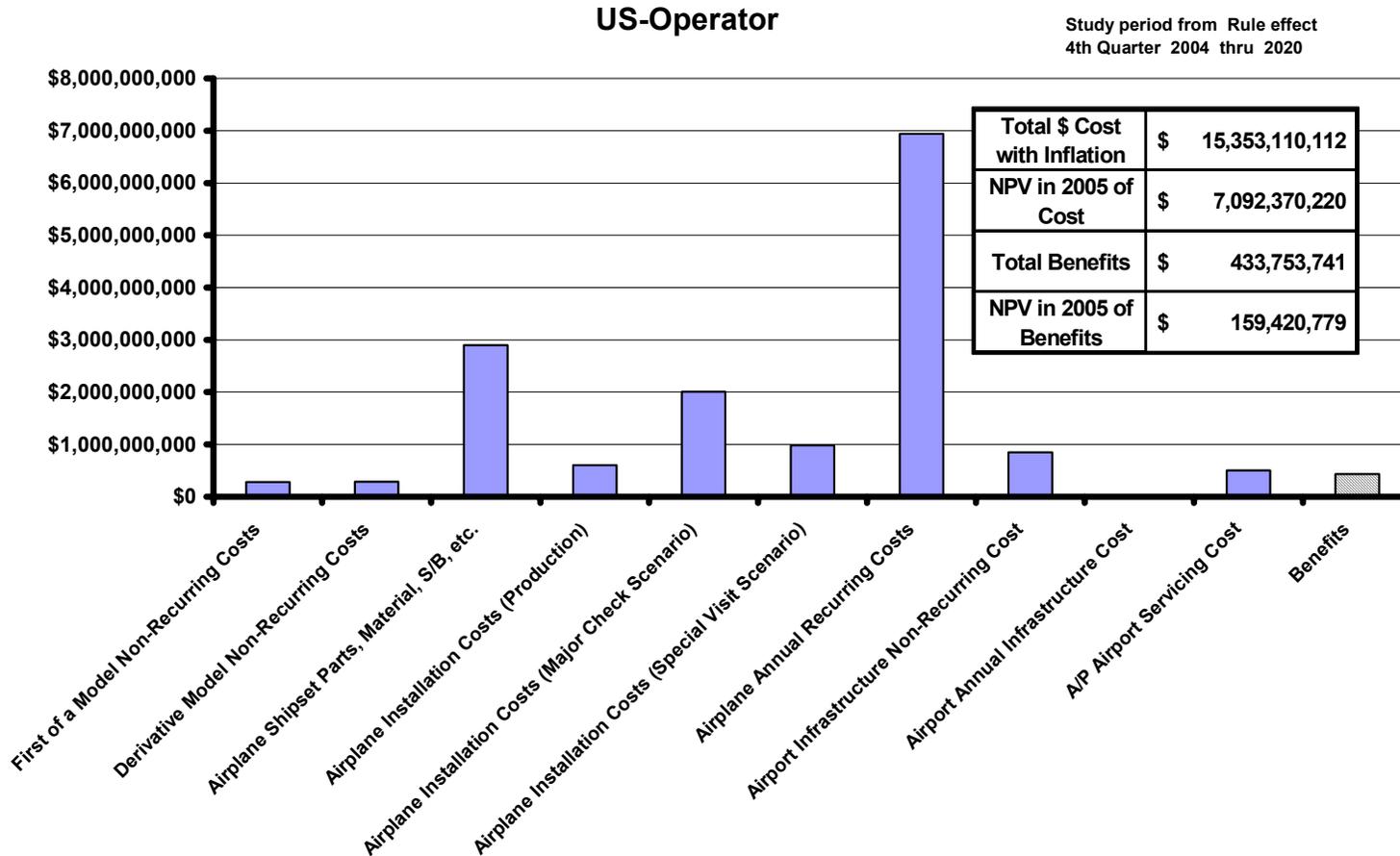


Figure G-38. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

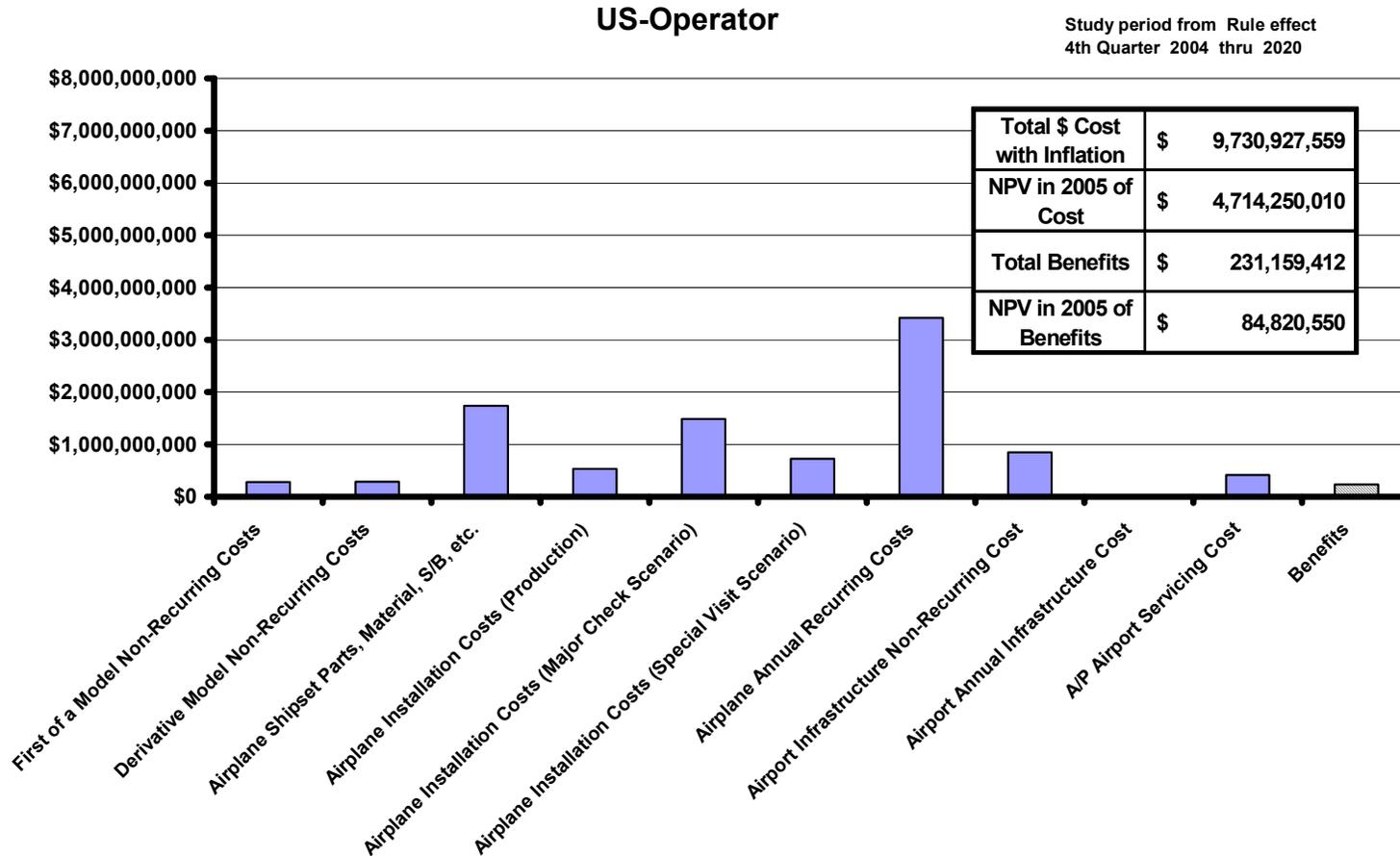


Figure G-39. Scenario 3—Hybrid Onboard Ground Inerting, HCWT Only, Large, Medium, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

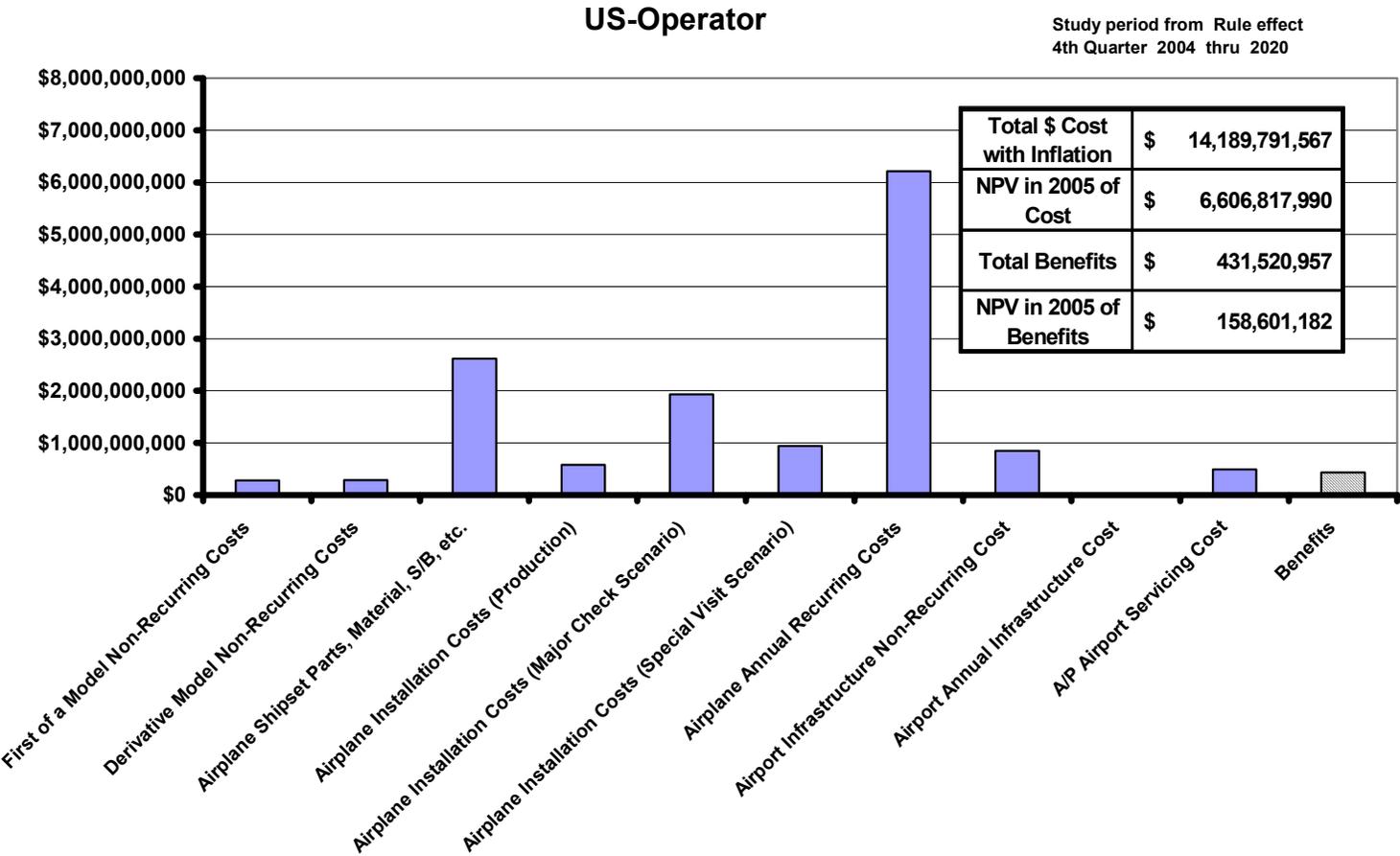


Figure G-40. Scenario 4—Hybrid Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

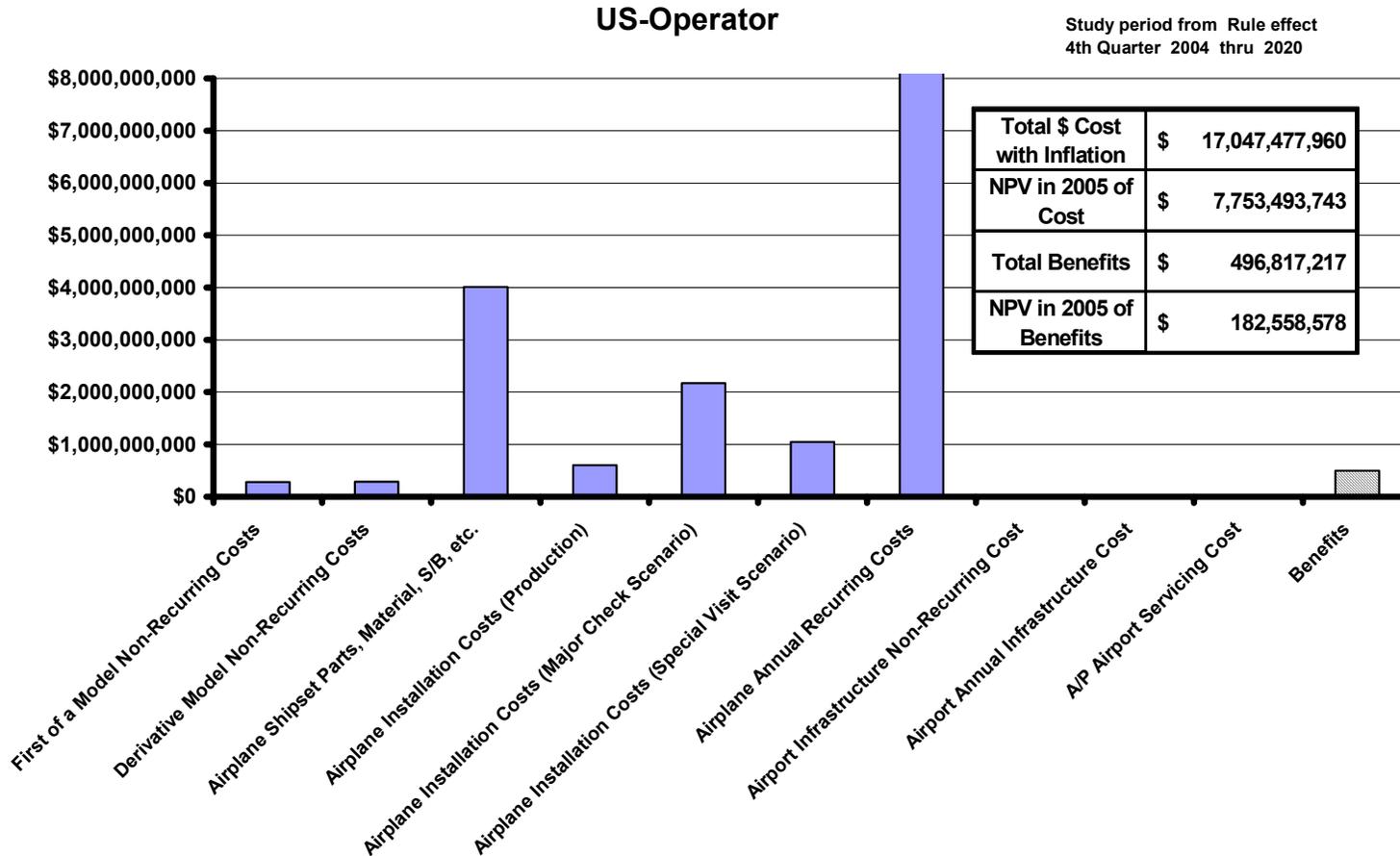


Figure G-41. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

**US-Operator**

Study period from Rule effect  
4th Quarter 2004 thru 2020

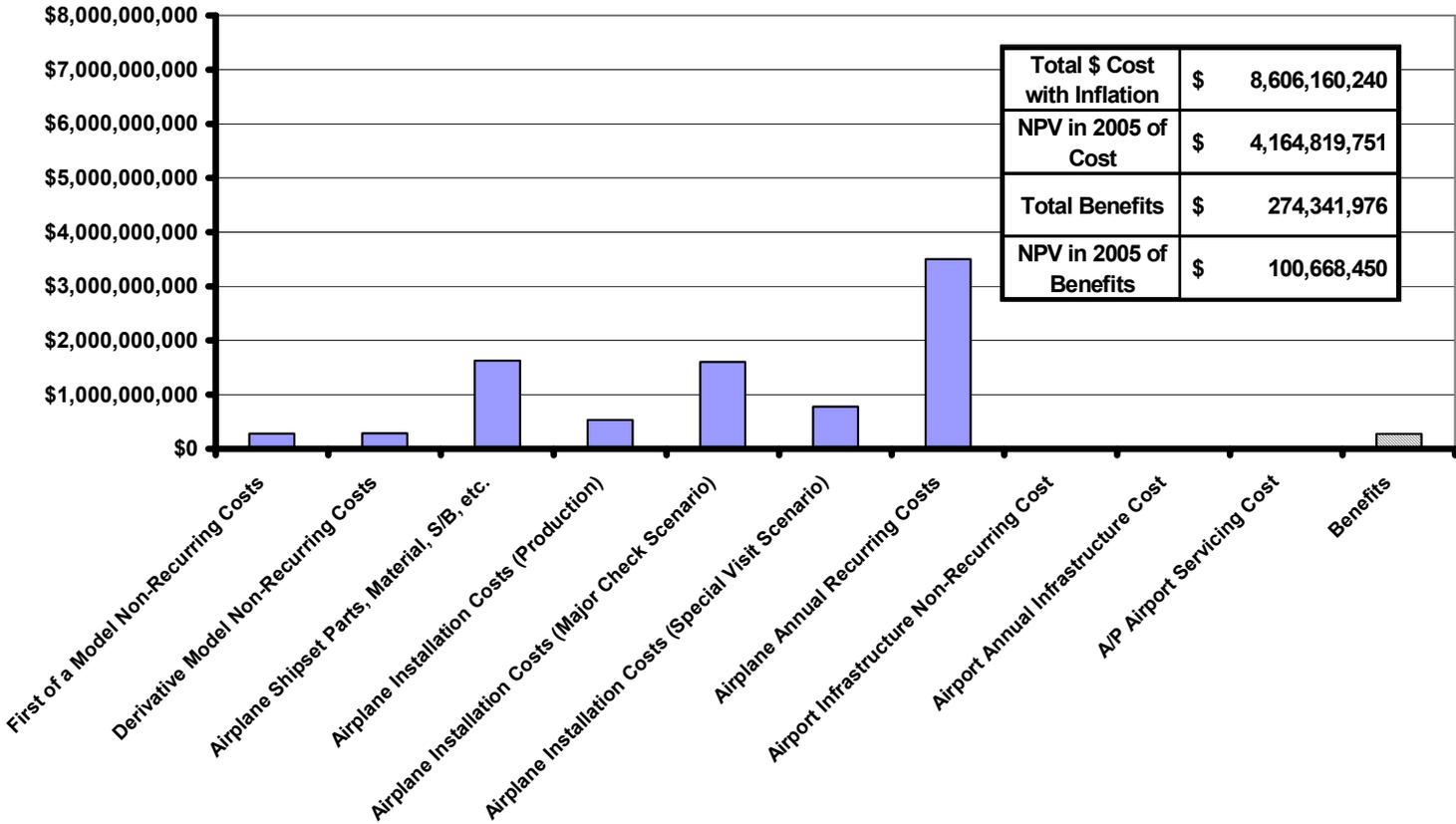


Figure G-42. Scenario 7—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium  
Transports, Membrane Systems, & Small Transports, PSA/Membrane  
Systems**

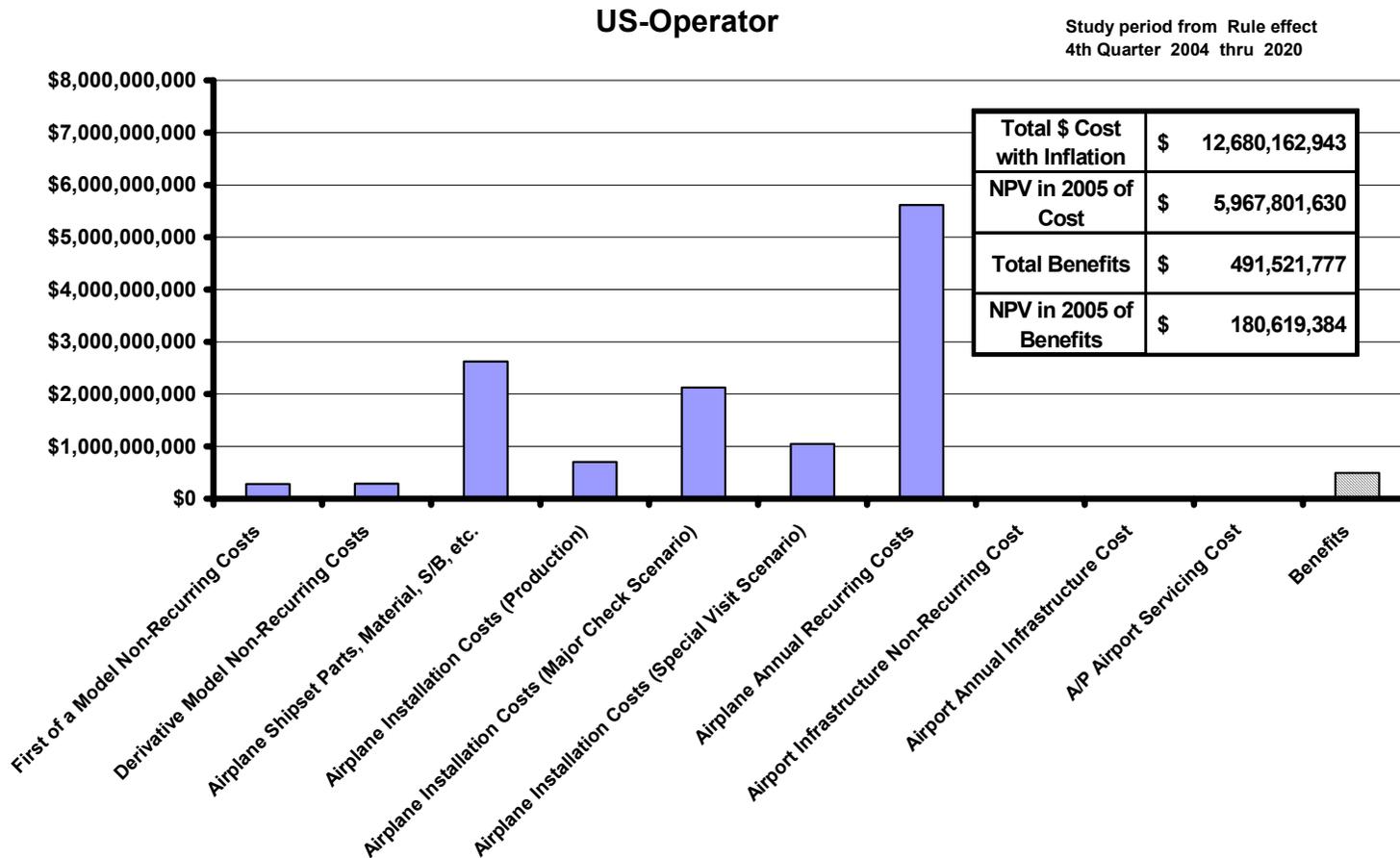


Figure G-43. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 11 - Ground Based Inerting HCWT only, All Transports**

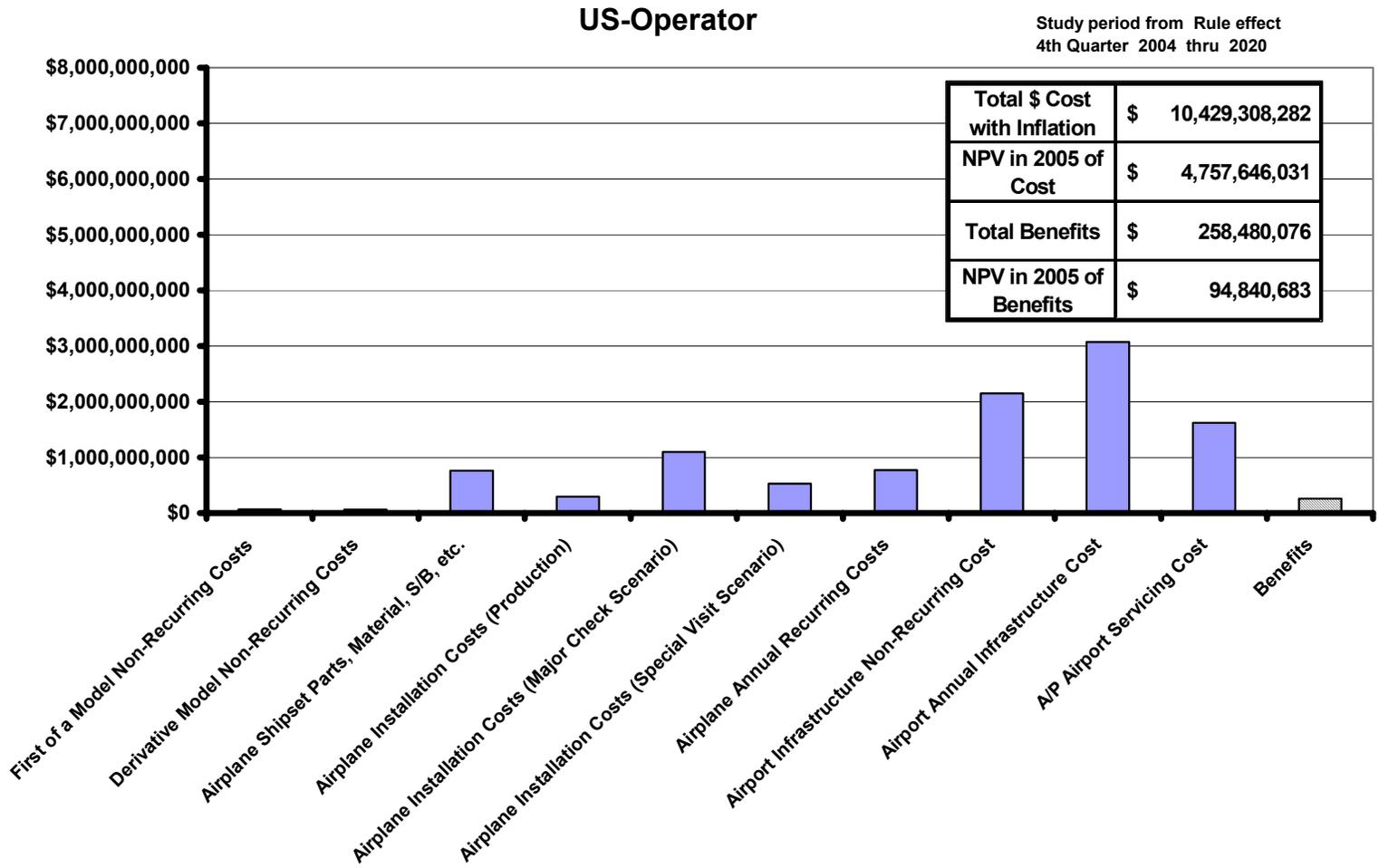


Figure G-44. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (U.S.)

**Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports**

**US-Operator**

Study period from Rule effect  
4th Quarter 2004 thru 2020

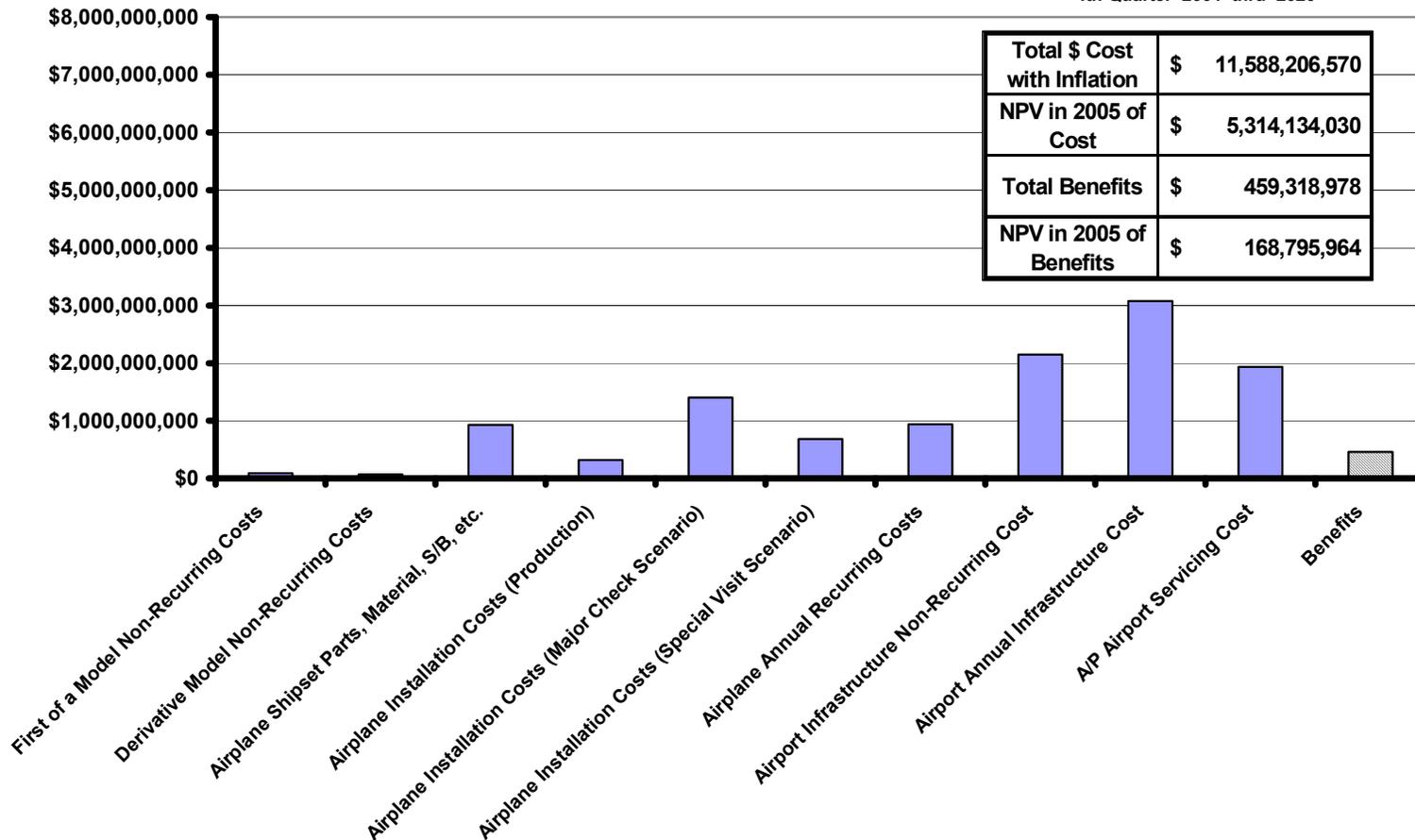


Figure G-45. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (U.S.)

**Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

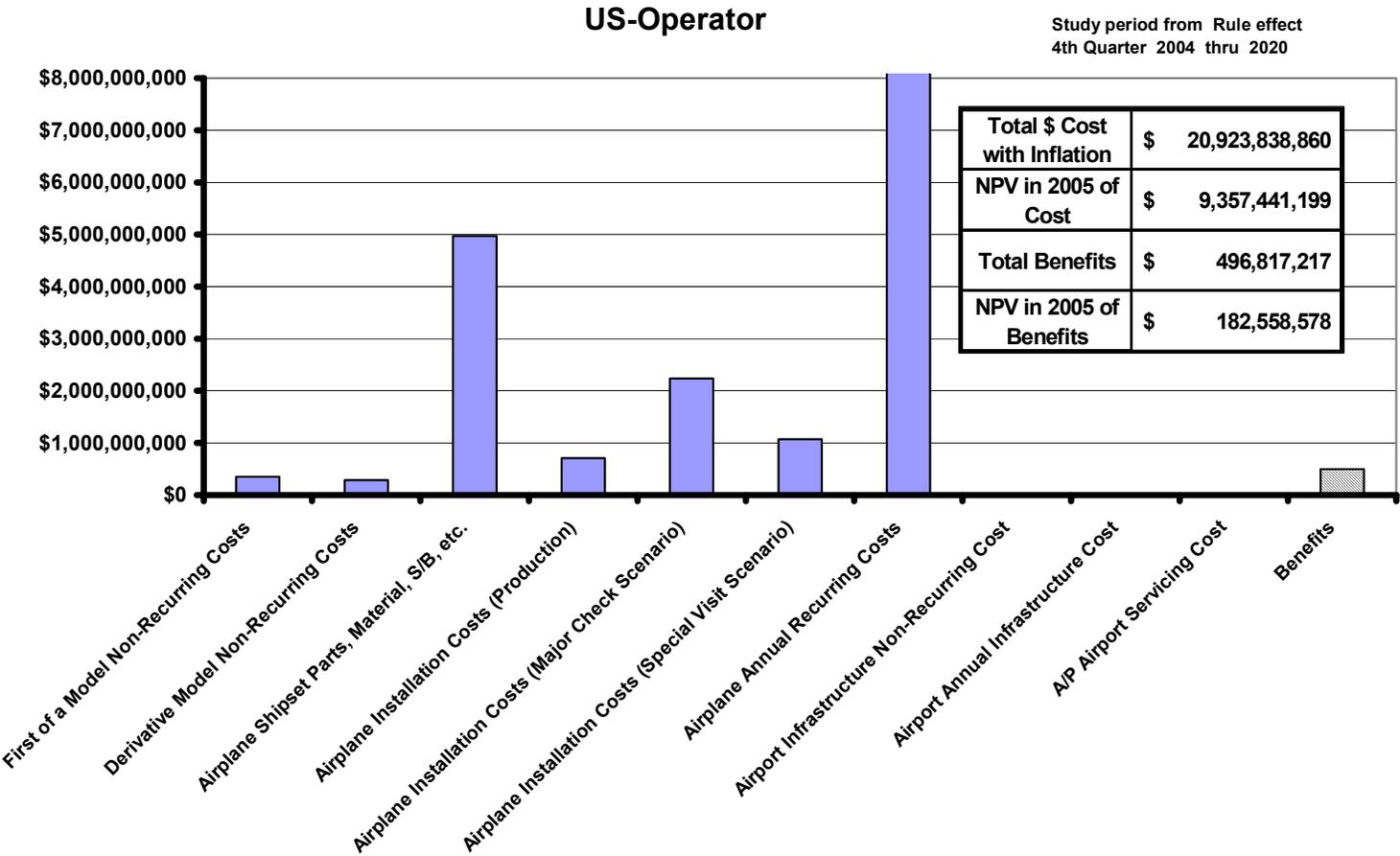


Figure G-46. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

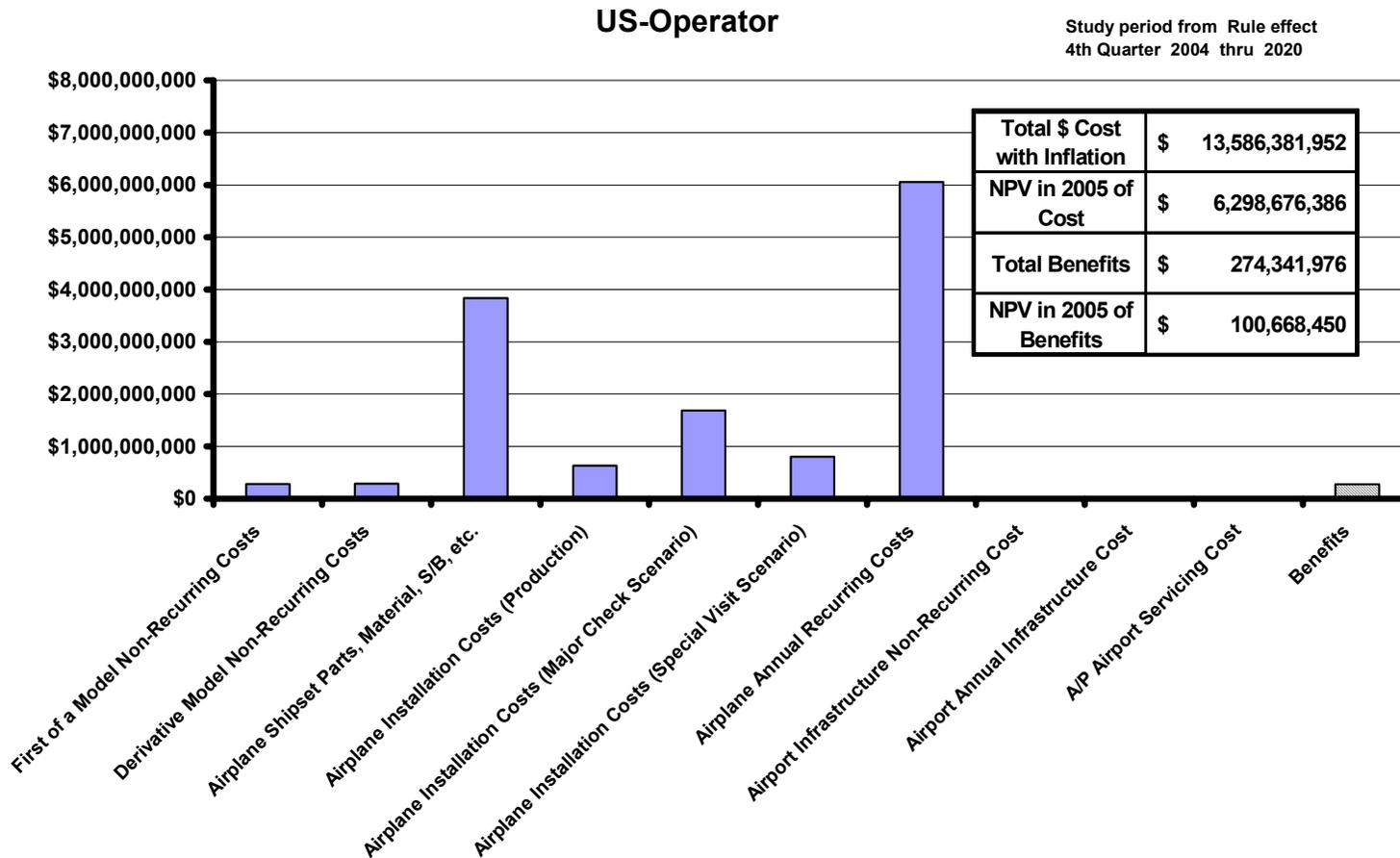


Figure G-47. Scenario 14—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

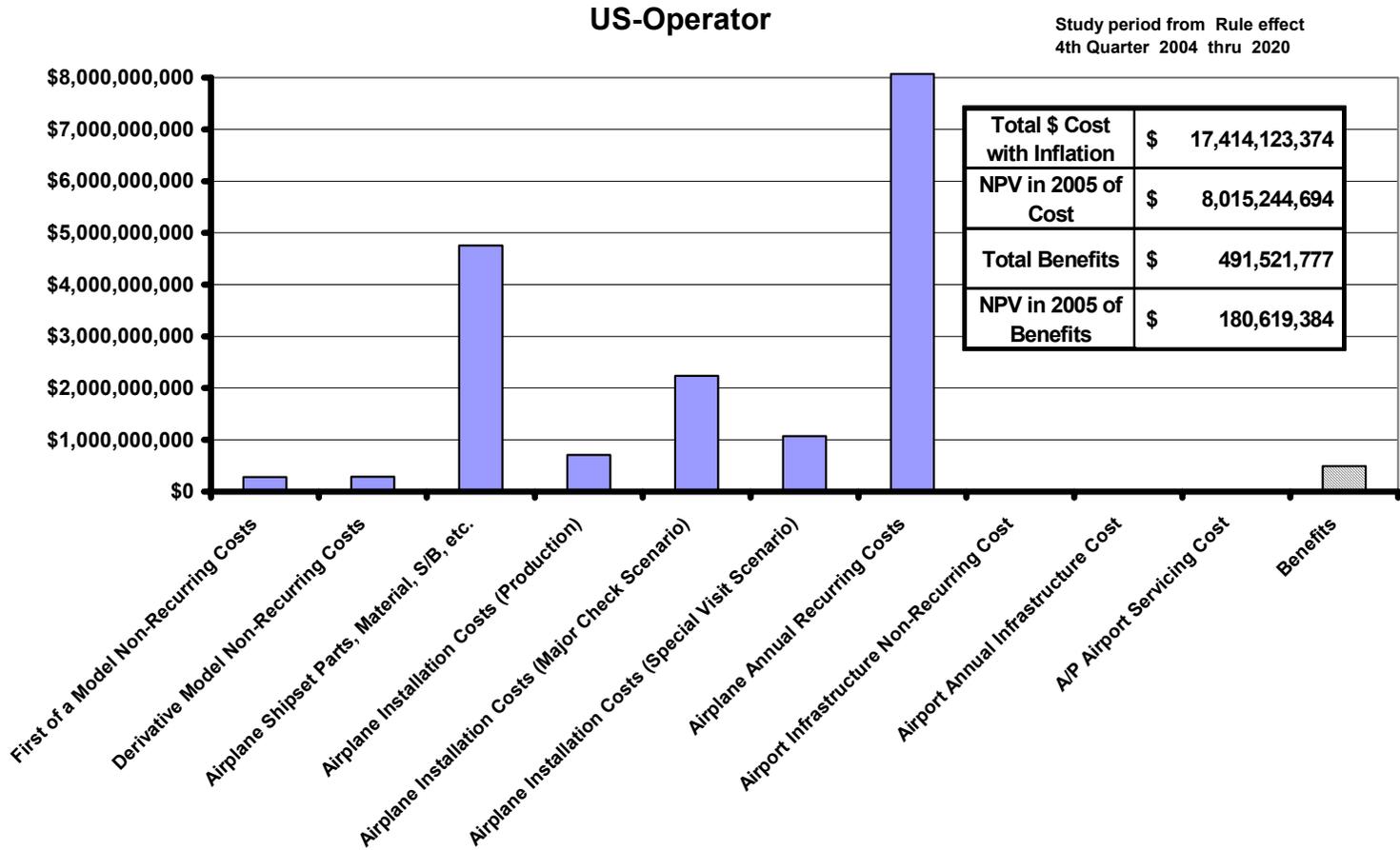


Figure G-48. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

**Scenario 16 - On-Board Liquid Nitrogen Inerting**

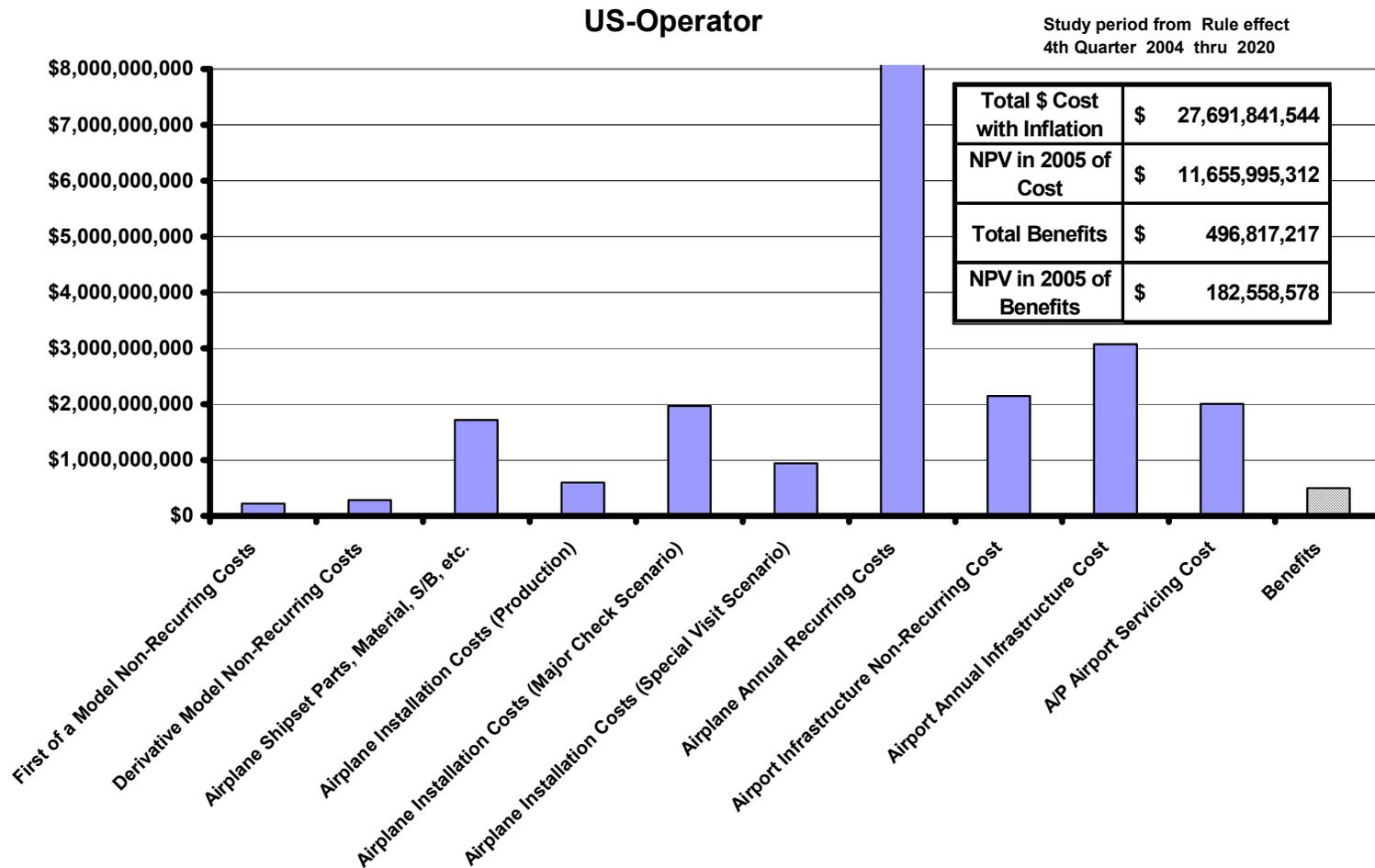


Figure G-49. Scenario 16—Onboard Liquid Nitrogen Inerting (U.S.)

Summary of Inerting Scenario Results US-Operator - PAX Only

Values in Millions

	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting HCWT Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Tanks, All Transports	Scenario 12 - Ground Based Inerting All Fuselage Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, PSA Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting			
<b>Total \$ Cost with Inflation</b>	7,588	10,898	7,352	10,149	11,675	6,349	9,194	9,321	10,207	14,550	9,868	12,474	19,817	-	-	-
<b>NPV in 2005 of Cost</b>	3,768	5,215	3,678	4,896	5,491	3,166	4,442	4,246	4,672	6,698	4,692	5,884	8,598	-	-	-
<b>Total Benefits</b>	233	434	231	432	497	274	492	258	459	497	274	492	497	-	-	-
<b>NPV in 2005 of Benefits</b>	86	159	85	159	183	101	181	95	169	183	101	181	183	-	-	-

Figure G-50. Cost Summary of U.S. Fleet, Passenger Only

**Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

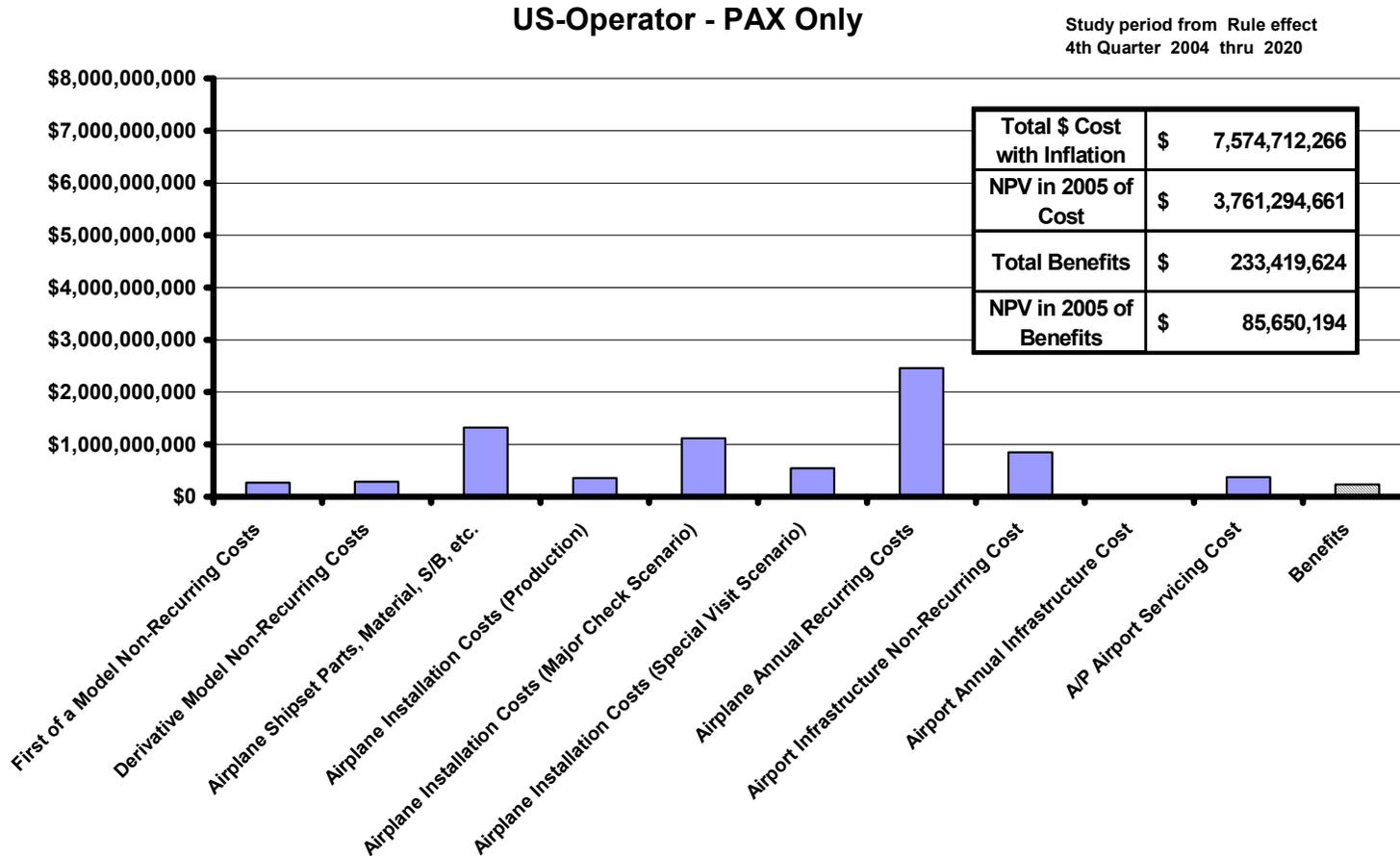


Figure G-51. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

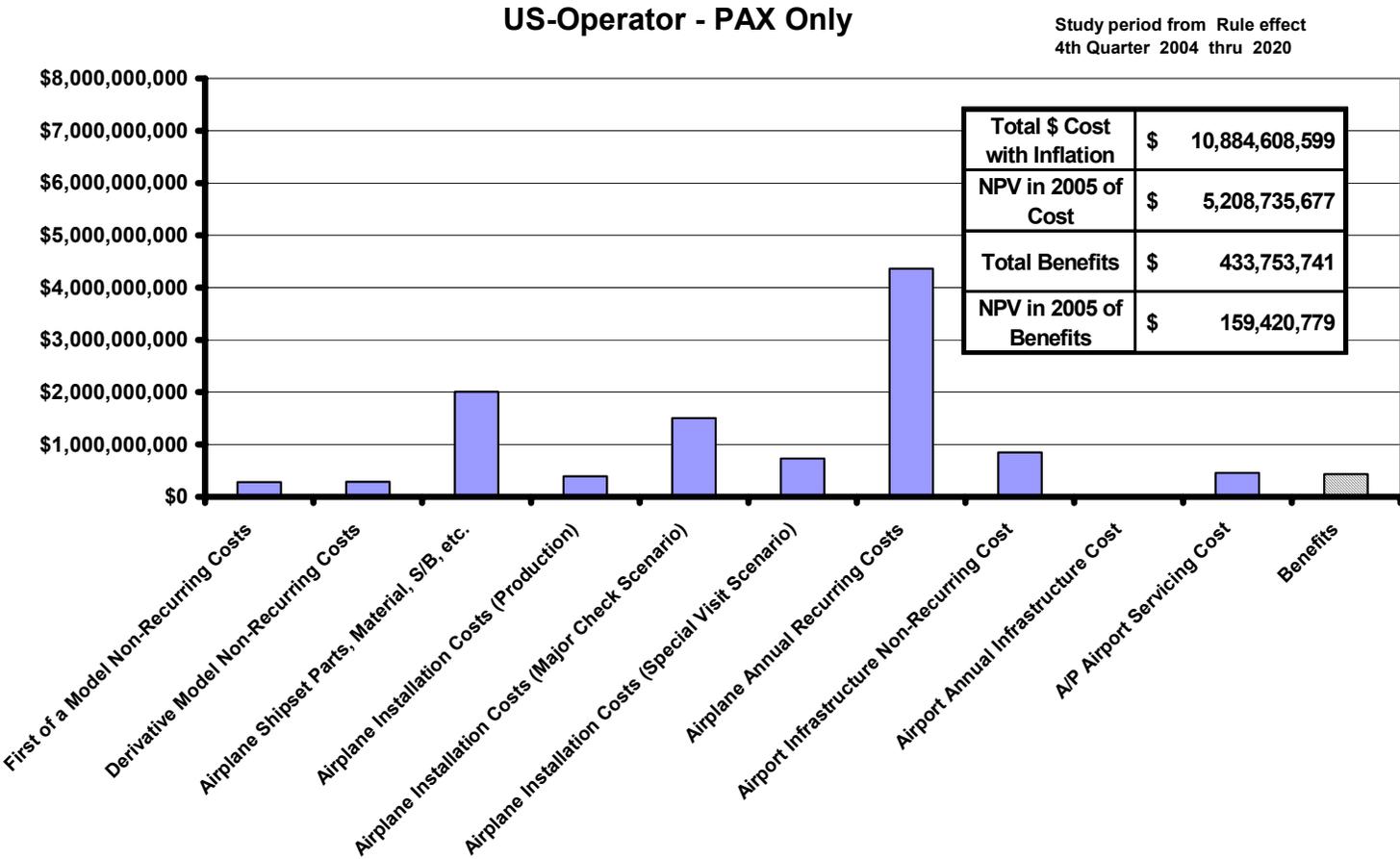


Figure G-52. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems**

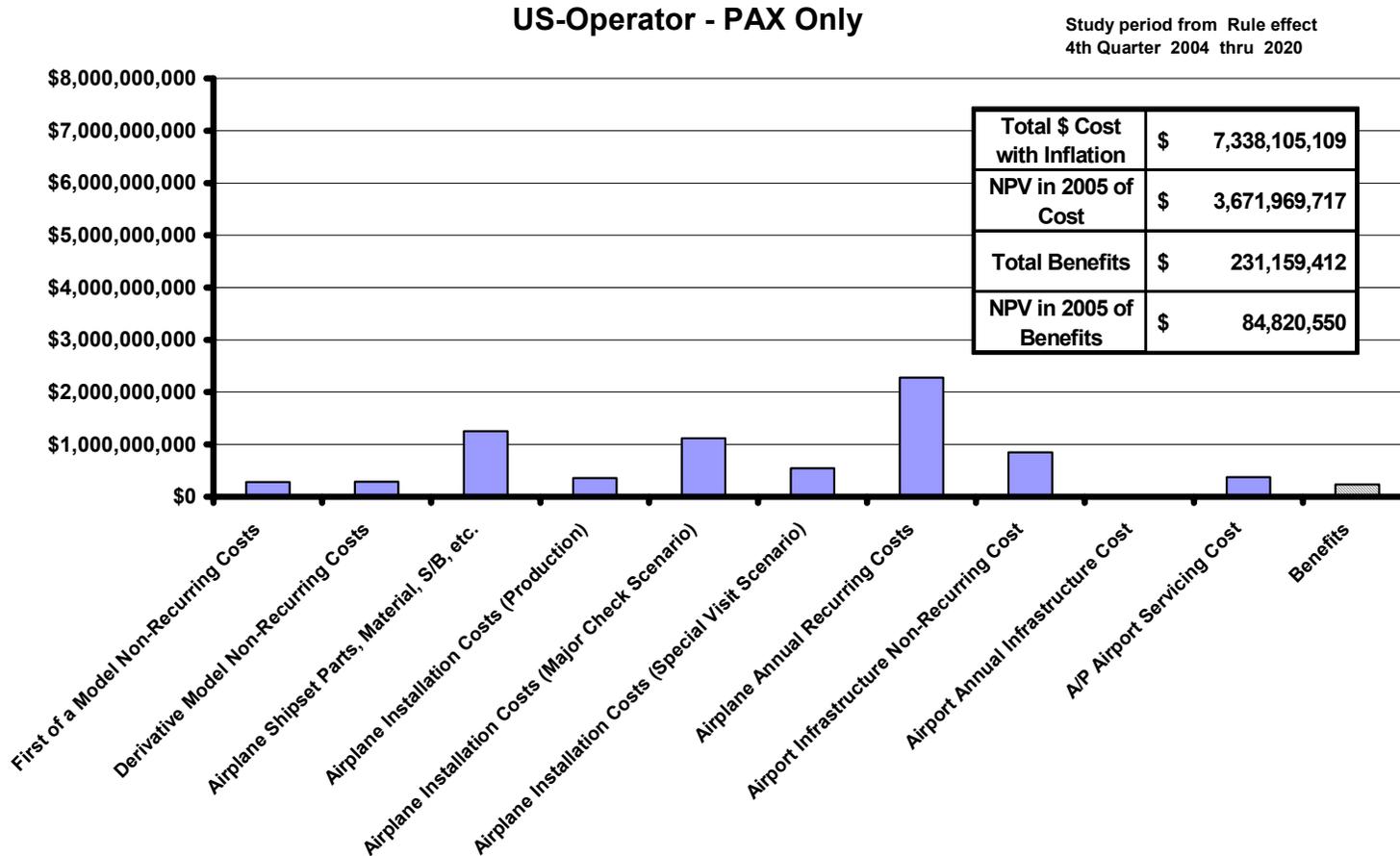


Figure G-53. Scenario 3—Hybrid Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems**

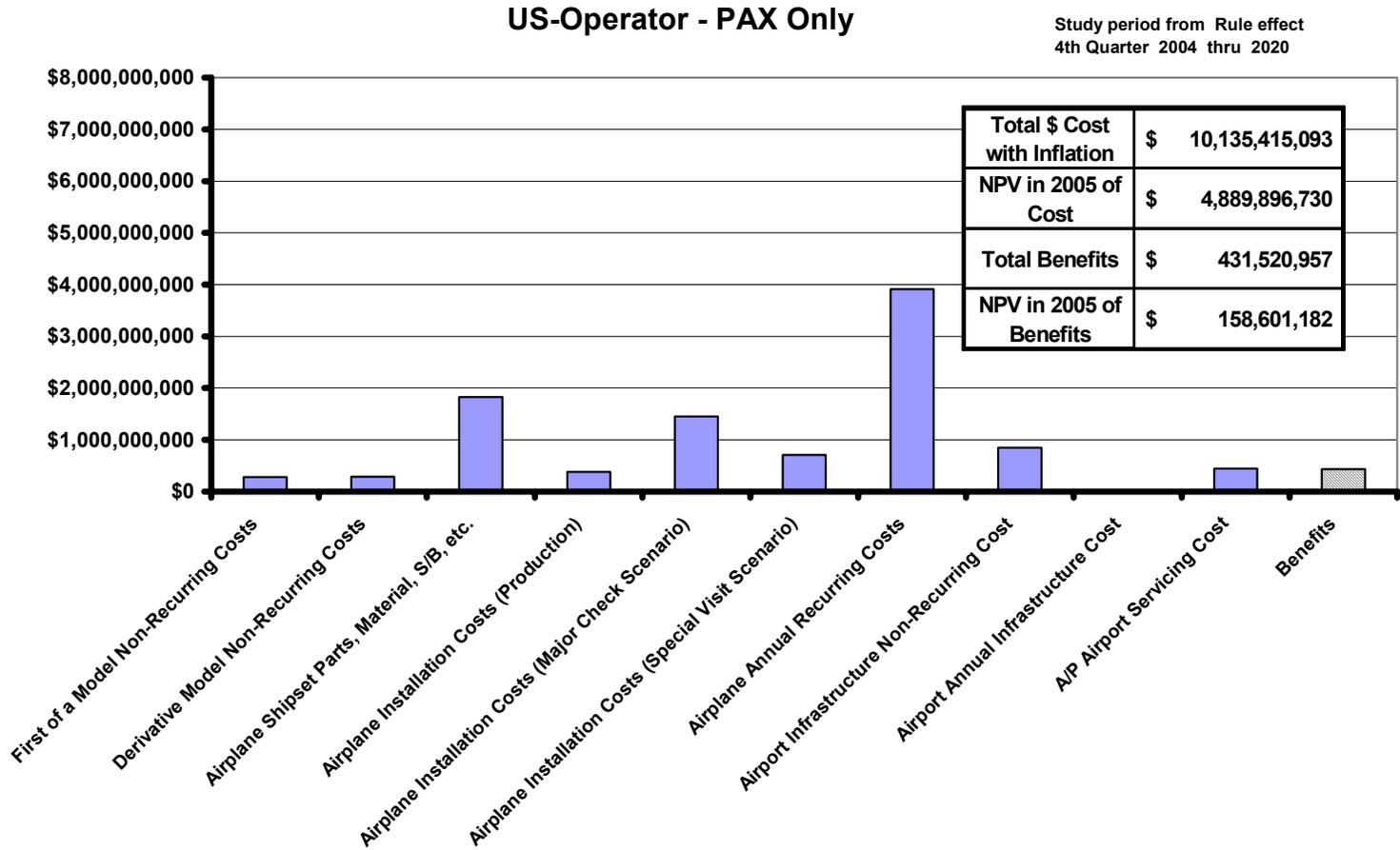


Figure G-54. Scenario 4—Hybrid Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

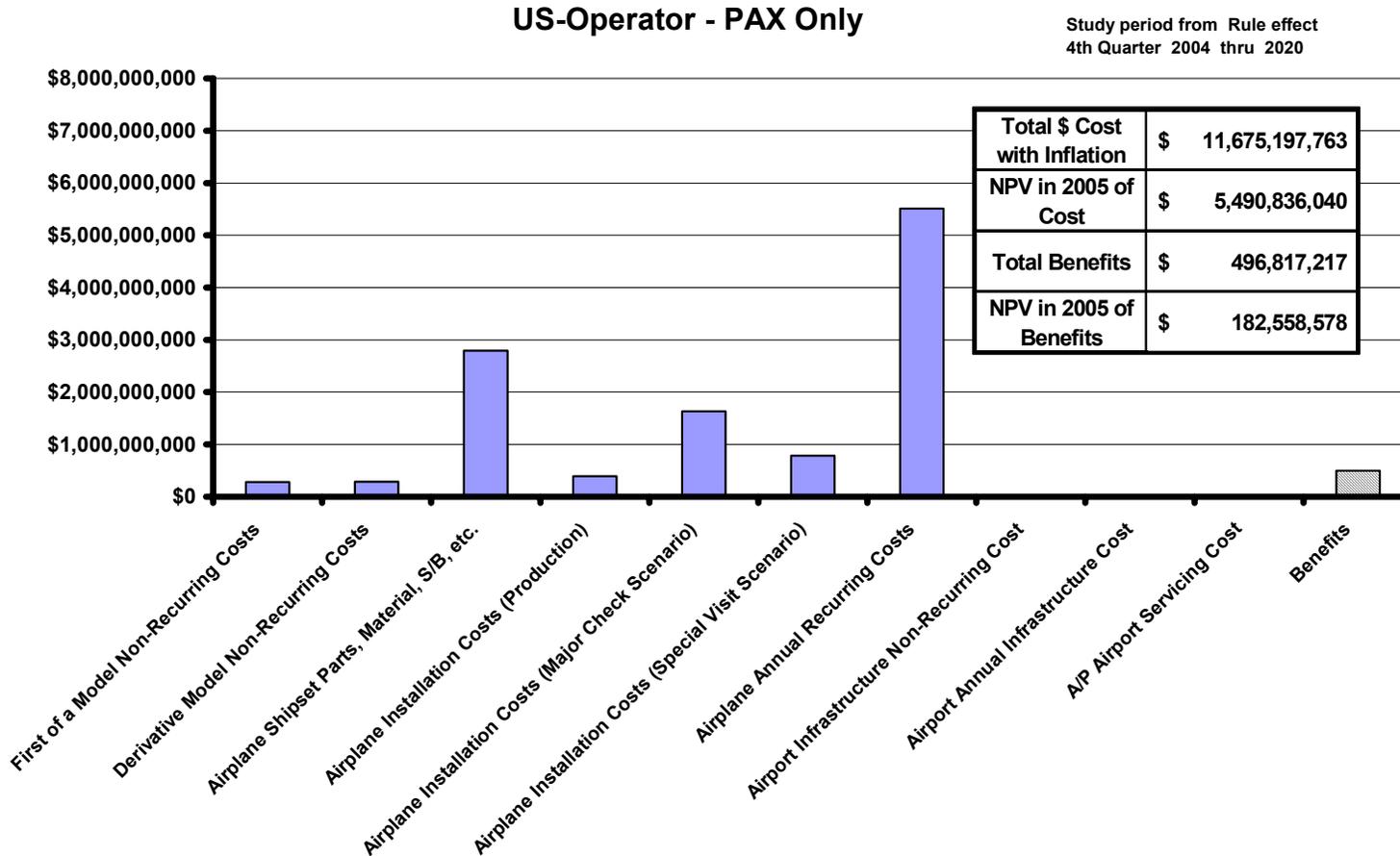


Figure G-55. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

**US-Operator - PAX Only**

Study period from Rule effect  
4th Quarter 2004 thru 2020

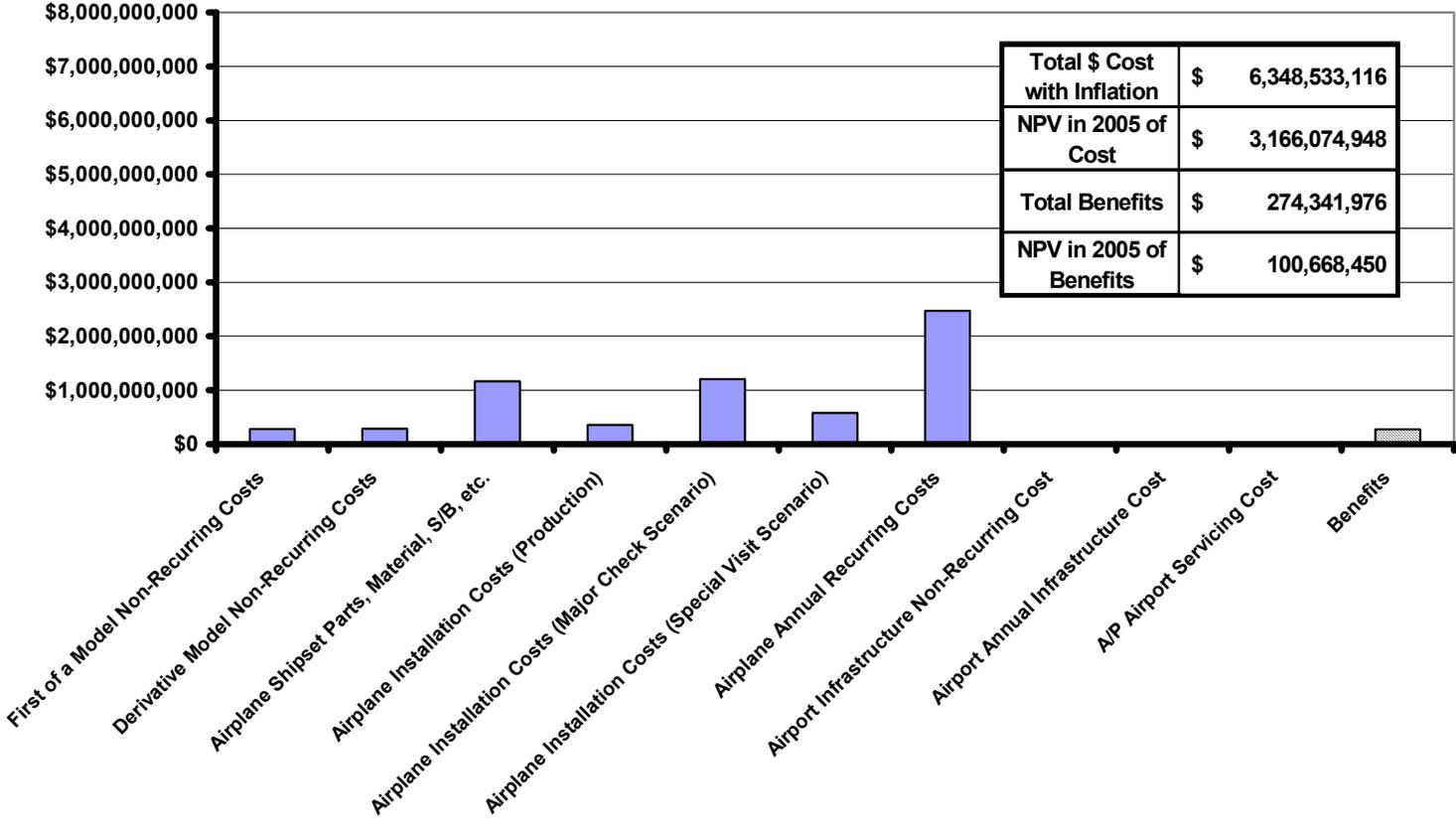


Figure G-56. Scenario 7—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems**

**US-Operator - PAX Only**

Study period from Rule effect  
4th Quarter 2004 thru 2020

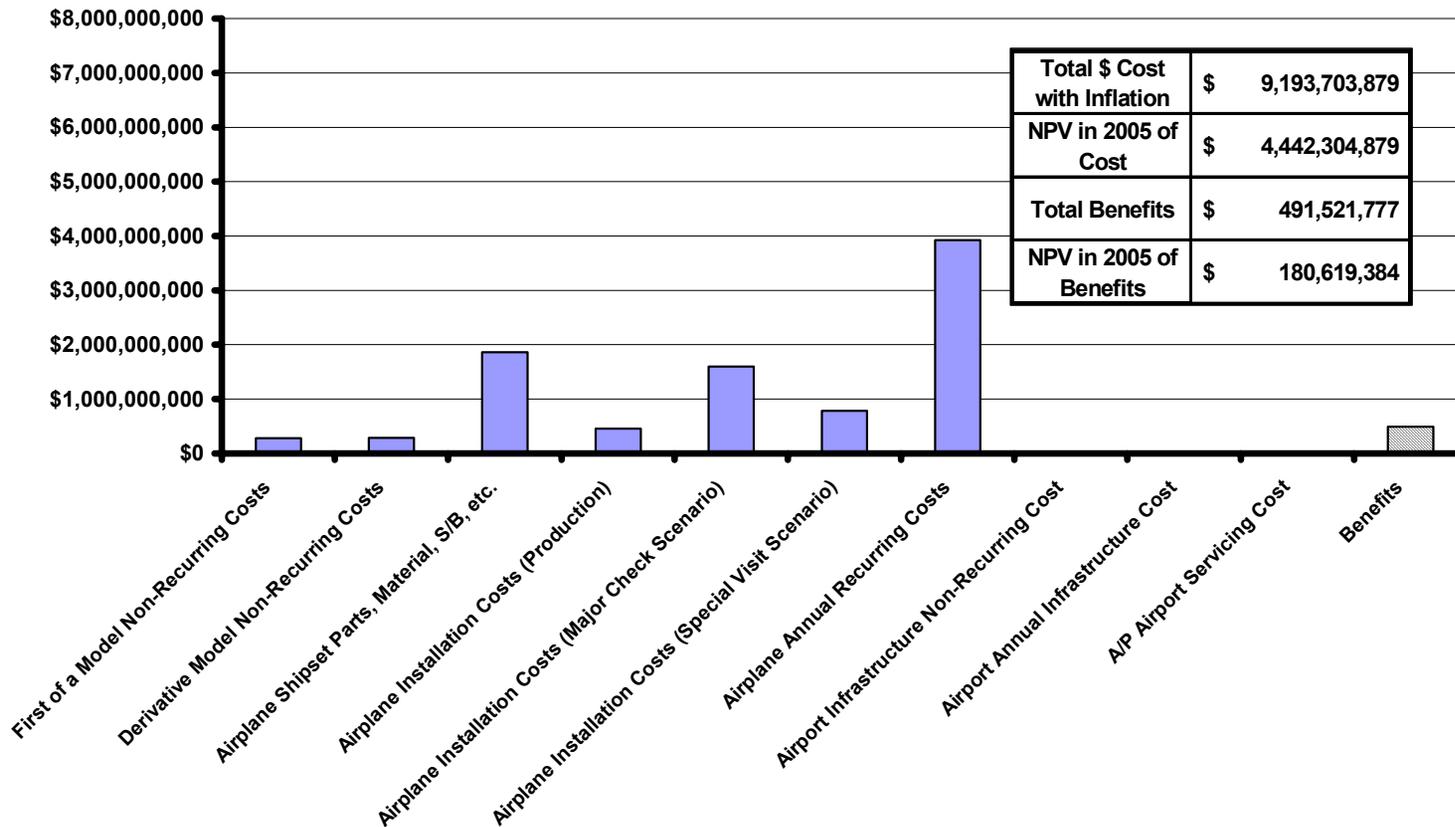


Figure G-57. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 11 - Ground Based Inerting HCWT only, All Transports**

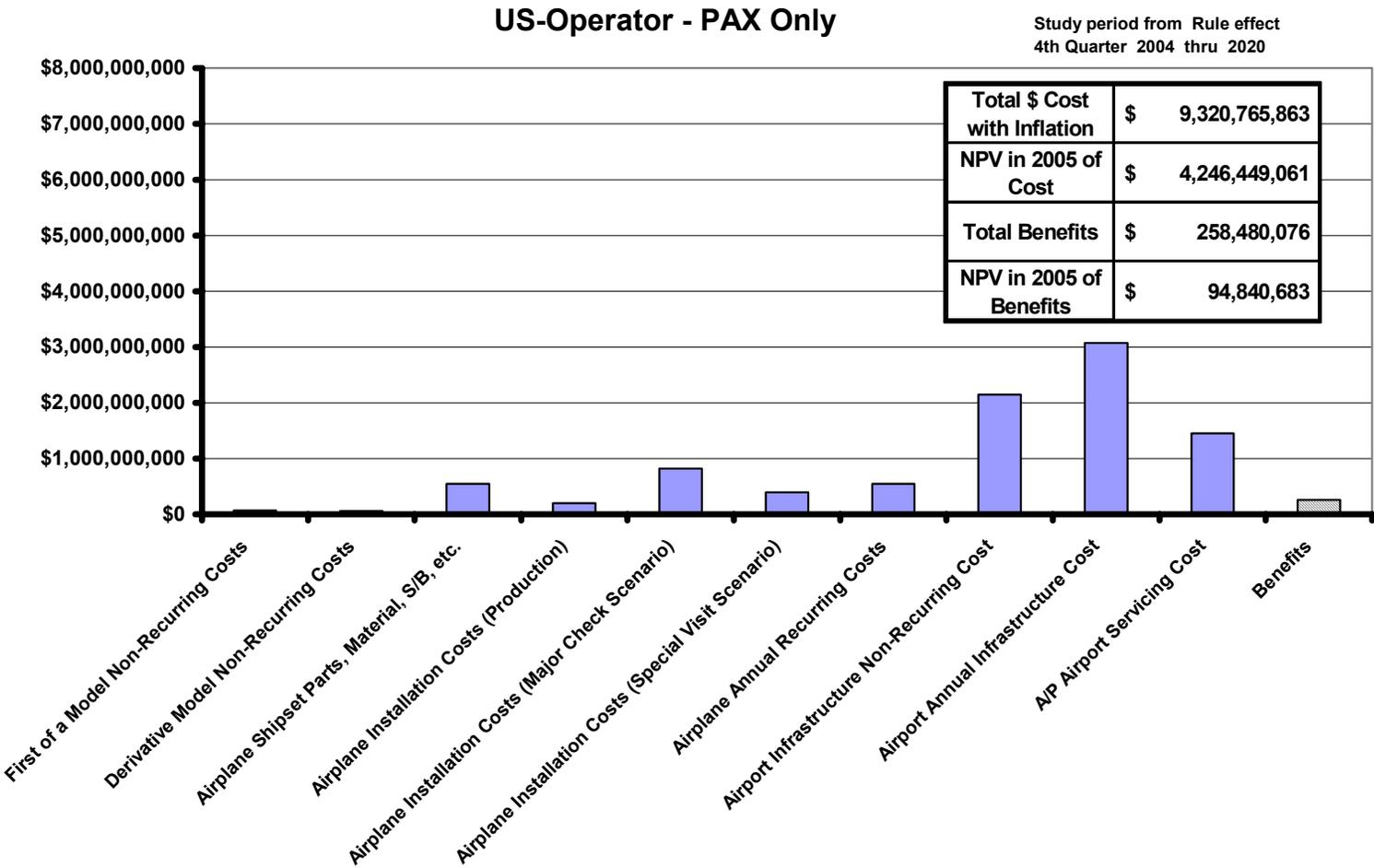


Figure G-58. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (U.S., Passenger Only)

**Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports**

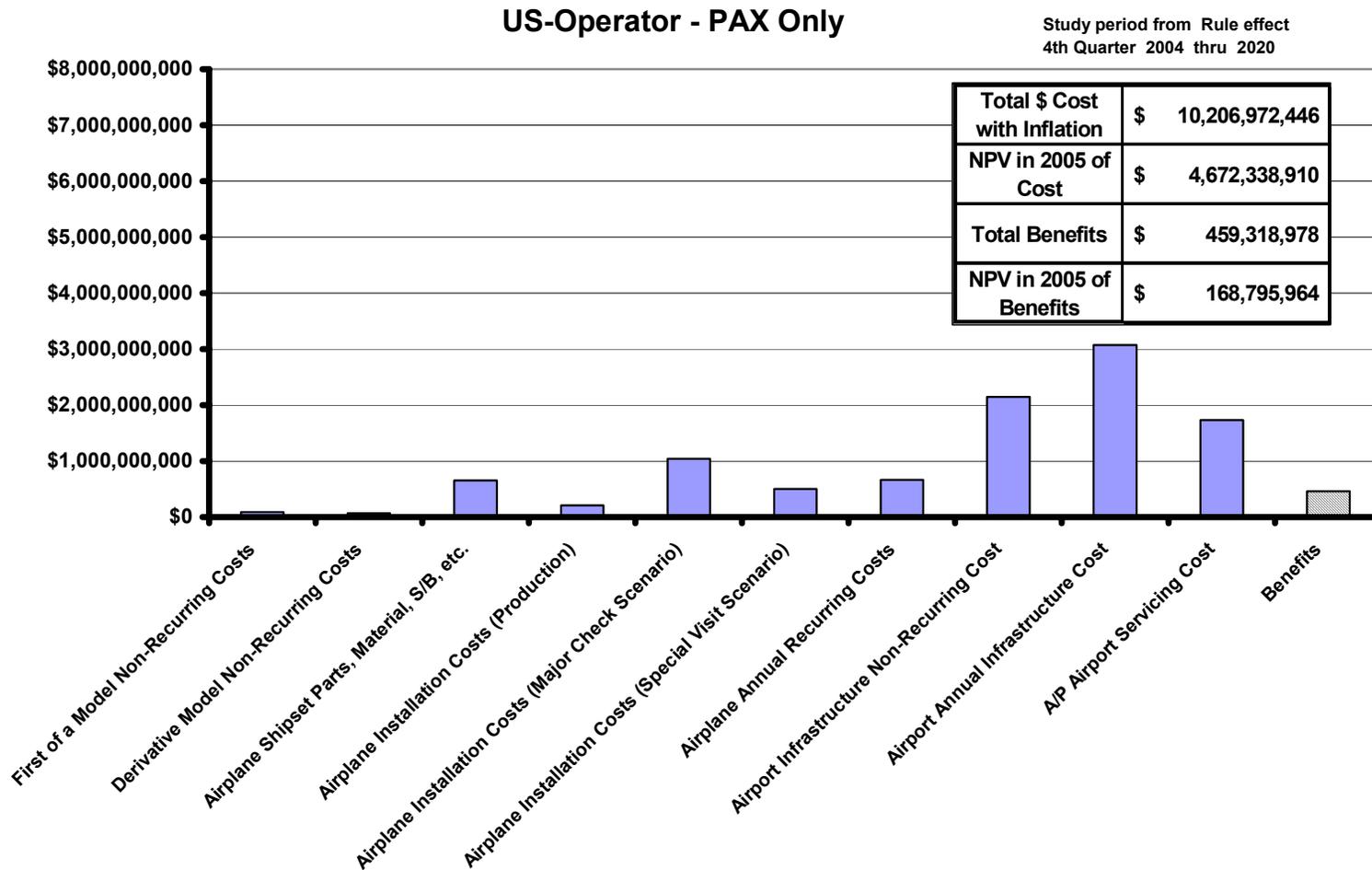


Figure G-59. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (U.S., Passenger Only)

**Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

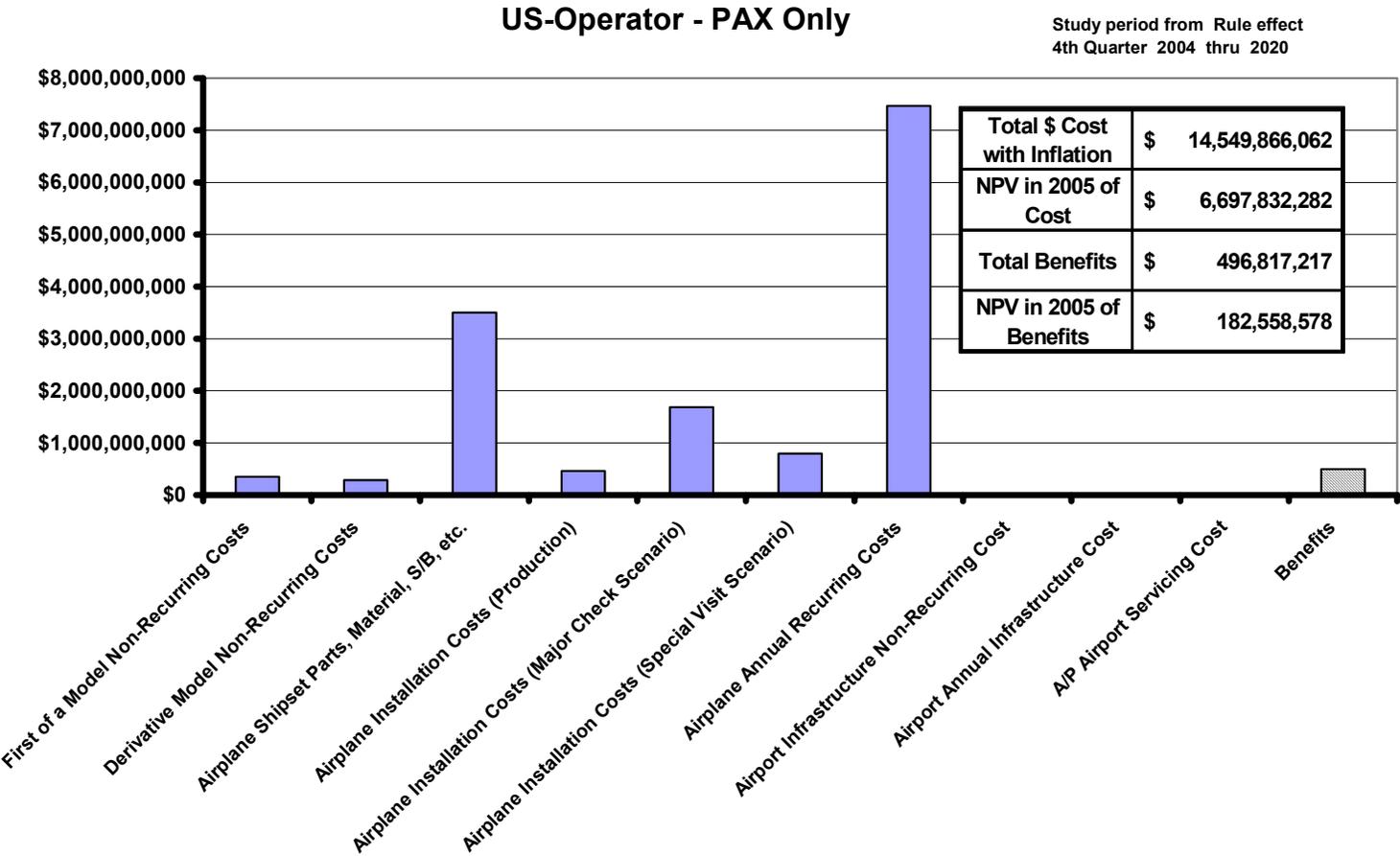


Figure G-60. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

**US-Operator - PAX Only**

Study period from Rule effect  
4th Quarter 2004 thru 2020

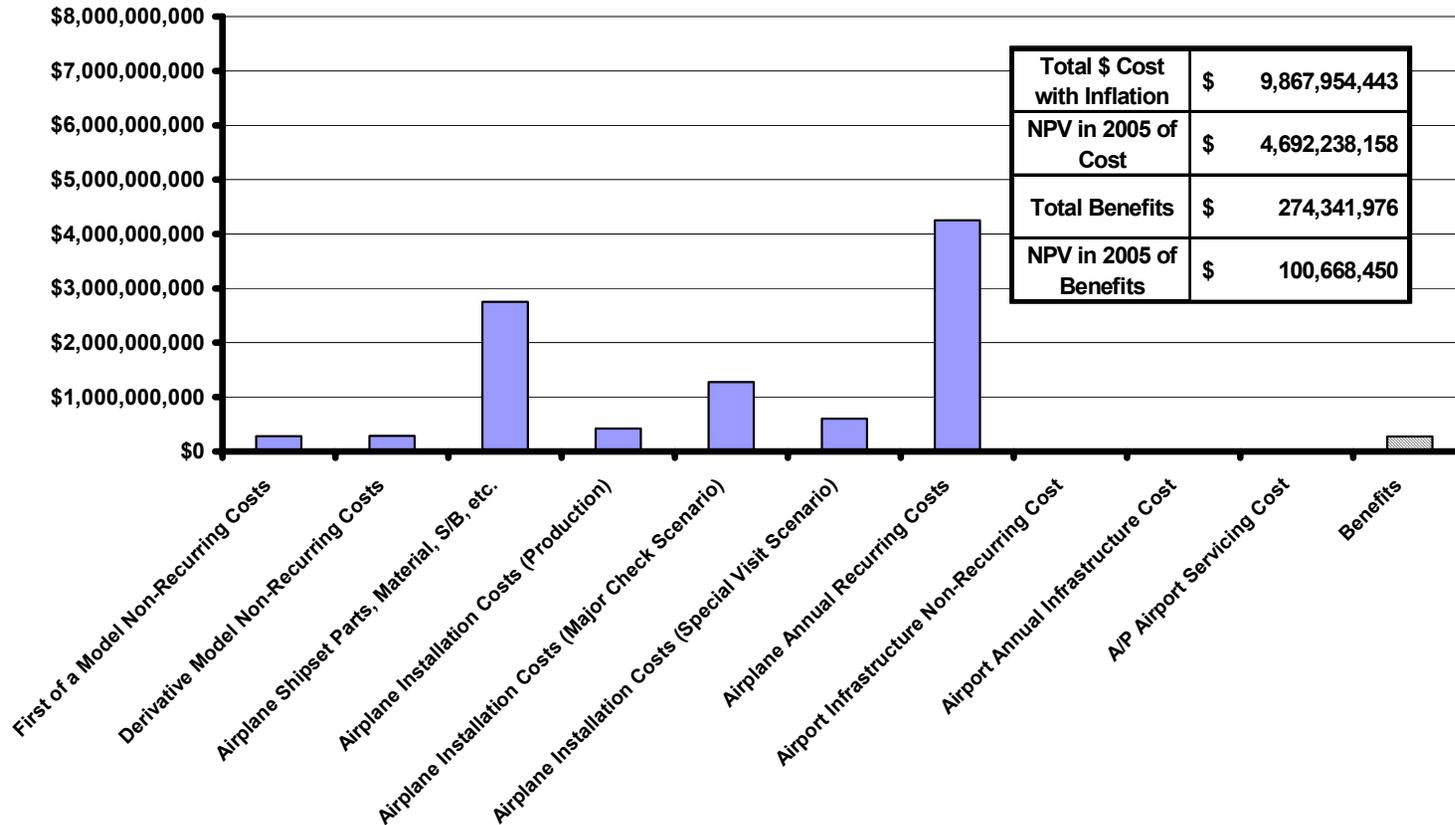


Figure G-61. Scenario 14—Hybrid OBIGGS, HCWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenics Systems, & Small Transports, PSA/Membrane Systems**

**US-Operator - PAX Only**

Study period from Rule effect  
4th Quarter 2004 thru 2020

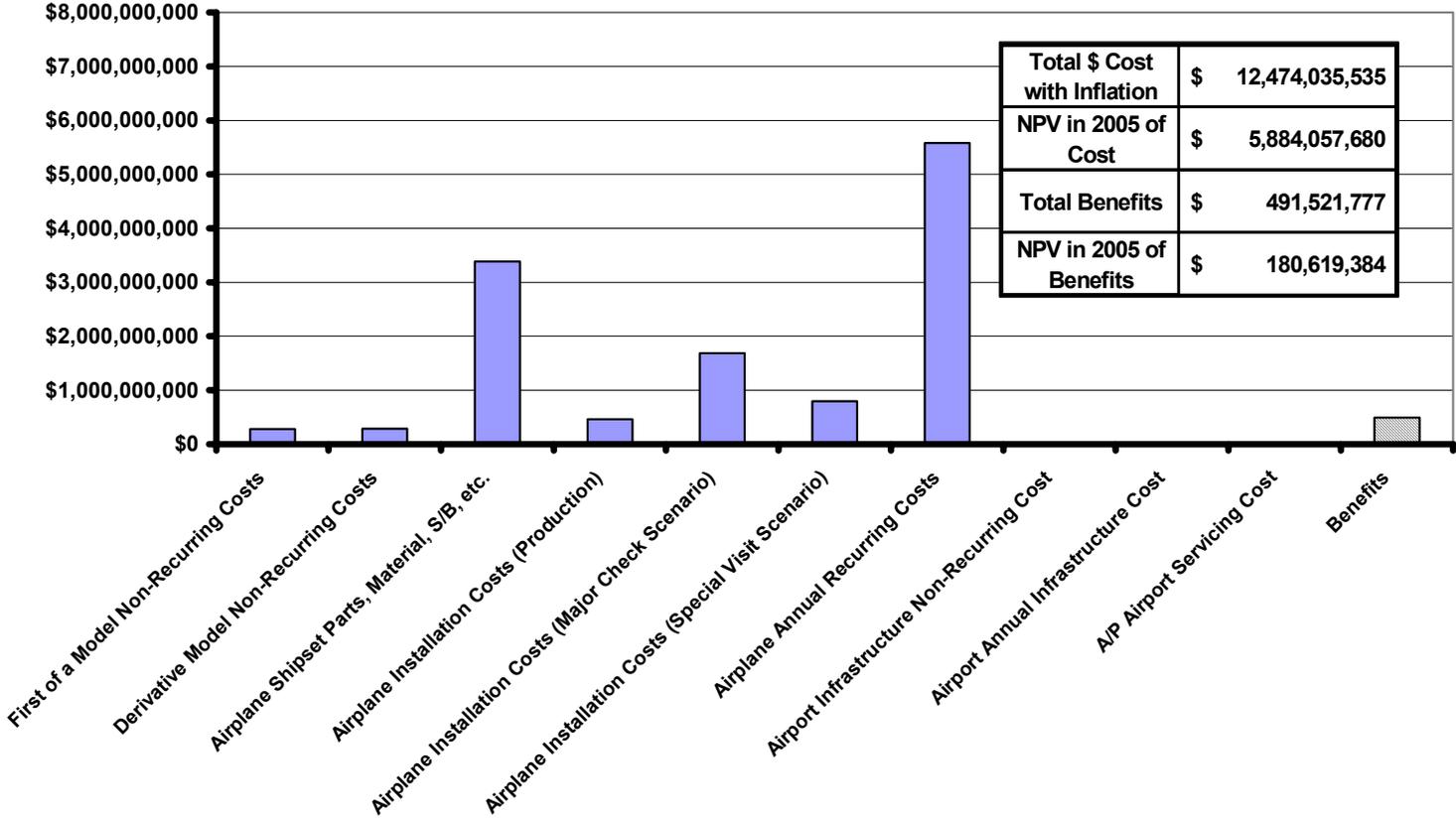


Figure G-62. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

**Scenario 16 - On-Board Liquid Nitrogen Inerting**

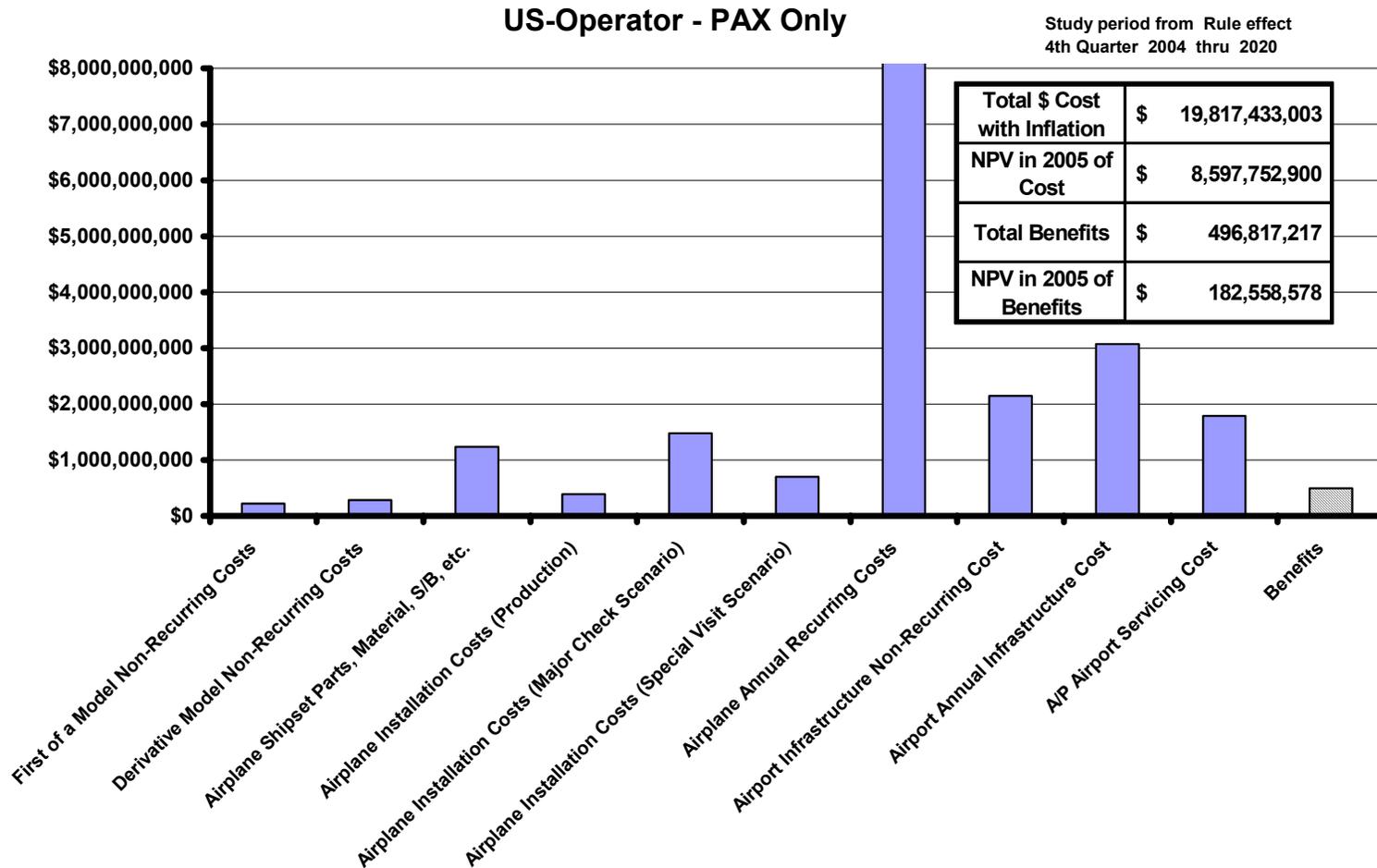


Figure G-63. Scenario 16—Onboard Liquid Nitrogen Inerting (U.S. Fleet, Passenger Only)

### **3.0 GASEOUS VERSUS LIQUID NITROGEN**

The first 15 scenarios evaluated in this study feature gaseous nitrogen systems. The 16th scenario features a liquid nitrogen system. This ARAC study focused on gaseous nitrogen generating systems rather than stored liquid nitrogen systems because gas generating systems are less expensive and less hazardous. The early inerting systems, such as that aboard the Lockheed C-5 Galaxy military transport, used stored liquid nitrogen. Those systems were heavy and relied on a large ground-support system. As technology has advanced, onboard gas-generating inerting systems like OBIGGS have become more practical. The system weight and inlet airflow and pressure to volume of nitrogen produced has vastly improved. All of the recently designed and installed nitrogen inerting systems on military aircraft have been of the OBIGGS type. A brief cost analysis of the liquid nitrogen (LN<sub>2</sub>) system is included to provide a comparison of costs relative to the other inerting systems. The safety benefits of the LN<sub>2</sub> system are assumed to be similar to OBIGGS.

The main advantage of a stored liquid nitrogen system is that it does not require aircraft bleed air or significant aircraft power to operate. However, such systems incur penalties that include higher weight than for air separation (i.e., gas generation) technology, on-board system complexity, and the need for a ground-based nitrogen supply system. The computed LN<sub>2</sub> weight is based on carrying enough LN<sub>2</sub> for three flights. The amount assumed carried reflects a proposal for a closed-loop control system that minimizes the amount of LN<sub>2</sub> required. As proposed, this system relies on oxygen sensing in the fuel tank and a control system that releases enough LN<sub>2</sub> to keep the tank inert. Ideally, this system would require only enough N<sub>2</sub> to fill the ullage once per flight.

The system described above has been sized to inert all fuel tanks on the airplane. The oxygen sensing and control system has not yet been demonstrated on a commercial airplane. The weights presented in figure G-64 are based on the FAA study “Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System,” published in 1972.

	Large airplane	Medium airplane	Small airplane
LN <sub>2</sub> weight (lb)	1,282	570	119
Storage, plumbing, controls, etc., weight (lb)	1,770	786	164
Total weight (lb)	3,052	1,356	283

*Figure G-64. Liquid Nitrogen System Weight*

Liquid nitrogen systems require the cryogenic transport and storage of nitrogen in liquid form, which boils at -195°C or -315°F. Transport, storage, and handling of LN<sub>2</sub> requires precautions to prevent severe skin burns on contact. Also, a broken bottle or distribution line may rapidly flood an enclosed area with nitrogen, causing asphyxiation. Because of the dangers and hazards associated with handling LN<sub>2</sub>, it was assumed that a mechanic, and not ground service workers, would be required to fill the airplane storage tanks.

It was assumed that the LN<sub>2</sub> would be generated and stored at each airport, so the LN<sub>2</sub> cost is the same as the gaseous N<sub>2</sub> costs. Although the airplane would be serviced once for every three flights, the cost of the labor is three times higher because it requires a mechanic instead of ground service workers. Consequently, the ground servicing costs would be about the same as for the GBI system.

It was assumed that the design, development, certification, and implementation costs for the LN<sub>2</sub> system are similar to the other systems evaluated in this study. The cost analysis for the LN<sub>2</sub> system includes only the large, medium and small airplanes. The total cost over the 16-year study period includes the initial airplane and airport modification costs and the accumulated annual recurring costs. Airplane nonrecurring costs include engineering design for the modifications and additions to fuel system components, interfaces, instruments or displays, relocation of other equipment, wiring, tubing or ducting, and avionics software or modules. The nonrecurring engineering costs also include changes to documents (e.g., Specs, ICDs); manuals (e.g., AFM, Opts, MM); production change records; laboratory, ground, and flight tests; and FAA/JAA certification. The costs also include major-supplier parts and assemblies, tubing, wiring,

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ducting, Service Bulletin and kitting costs (retrofit), and special tooling for installation. These costs were based on the costs of the GBI airplane system with the addition of an LN<sub>2</sub> storage tank and an oxygen sensing and control system. The airline recurring and nonrecurring costs were based on the installation and operating costs of an onboard system. Although the closed-loop oxygen sensing system is more complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar.



Appendix H  
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# **Safety Analysis Task Team Final Report**

## **1. INTRODUCTION**

This report describes the work carried out by the Safety Task Team to accomplish the tasks outlined below.

The objectives for the safety task team were derived from the Tasking Statement for the Fuel Tank Inerting Harmonization Working Group (FTIHWG), as published in the Federal Register on 14 July, 2000. The Tasking Statement included the following guidance:

“The threat of fuel tank explosions used in the analysis should include explosions due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, as defined in the July 1998 ARAC Fuel Tank Harmonization Working Group Report. The service history in the analysis should be further developed to include incidents involving post crash fuel tank fires. The FAA awarded a research contract to develop a database that may be useful in this endeavor. This data should be evaluated when determining what benefits may be derived from implementing ground based or on-board inerting systems. The report is titled, A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion, Report Number DOT/FAA/AR-99/73, dated December 1999.”

This task was assigned to the Safety Task Team and was further developed into the following sub-tasks:

1. Carry out a detailed analysis of previous tank explosion events documented in the 1998 ARAC Fuel Tank Harmonization Working Group Report.
2. The objective was to understand how past actions may influence future events and to determine a basis for forecasting future events.
3. Based on the service history review from item 1, develop a methodology to forecast the number of accidents that may be avoided in the future if an Inerting system were implemented.

The objective was to quantify the number of accidents avoided due to the achievable flammability reduction of each of the design concepts as applied to each of the generic airplane families under consideration.

4. Determine safety benefits associated with post impact fuel tank fire/explosion.
5. Evaluate potential new hazards created by Inerting fuel tanks.

The objective was to use a Functional Hazard Analysis to identify potential new hazards.

## **2. WORKING PRACTICES**

The Safety Task Team was comprised of five members. One was an airline specialist in flight safety investigations. One was an airline general manager in charge of aircraft systems engineering. A third was a combustion scientist. Another was a national resource specialist for fuel system design out of the aircraft certification office of the FAA. And the last member came from an airplane safety engineering background with an aircraft manufacturer.

The group held regular reviews of its progress through data exchange, through dedicated task team meetings, and through presentations and reviews of its work in front of the Working Group.

## **3 REVIEW OF SERVICE HISTORY**

The service history of the transport airplane fleet (including turbofan and turboprop airplanes) over the last 40 years was examined, and information regarding known instances of fuel tank explosion due to internal or external ignition sources (other than those caused by post-impact crash events) was assembled. Post-impact fuel tank fire/explosion events are handled separately in section 4.4.5. The starting point was the table of events contained in the 1998 Fuel Tank Harmonization Working Group Final Report as suggested by the Tasking Statement.

### **3.1 Methodology**

Attachment A contains a detailed description of each event and the findings of the investigating authority. A description of the mitigating actions taken subsequent to the event to prevent its recurrence is also included in the accident descriptions.

The 16 tank explosion events are summarized on Tables 1 and 2. They have been separated into Operational Events (i.e., those occurring on an airplane where passenger-carrying flight was intended), and Refuelling & Ground Maintenance Events. They are grouped by cause (Lightning, Engine Separation, Refuelling, Maintenance, etc.), and are then categorized by operational phase, ignition source, type of fuel tank involved, and fuel type.

Groundrules were established to guide the evaluation. First, it was determined that a forecast of future events should be based on the residual risk of recurrence of past events. In addition, the forecast should only include events for which inerting would be effective at preventing. As such it was the judgement of the team that accidents where the fuel tank was breached before the ignition would not be used to forecast future events.

In addition, the effectiveness of the actions taken subsequent to the event to prevent its recurrence were judged based on:

- Identification of the ignition source
- Confidence level that mitigating action addressed the ignition source
- Implementation level of the mitigating action/s

With these data and groundrules in place, a trend and residual risk analysis was then conducted.

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Table 1. Summary of Operational Events

		1963 Lightning Elkton 707	1976 Lightning Madrid 747	1965 UCEF/Eng sep San Fran- cisco 707	1970 Eng Sep Toronto DC-8	1990 Eng Sep New Delhi 747-200	1992 Eng Sep Marseilles 707	1989 Sabotage Bogota 727	1990 Unknown Manila 737-300	1996 Unknown New York 747
Operational Phase	Inflight	•	•	•	•	•	•	•		•
	On Ground Operations								•	
	Ground Main- tenance									
	Refuelling									
Ignition Source	Lightning	•	•							
	Overwing Fire - Inflight			•	•	•	•			
	Static Dis- charge									
	Sabotage							•		
	Unknown								•	•
Tank Type	Main (Wing) = W Center = C	W	W	W	W	W	W	C	C	C
Fuel Type		JP-4 / Jet A	JP-4 / Jet A	Jet A	JP 4	Jet A	Jet A	Jet A	Jet A	Jet A
Mitigating action taken to minimize or prevent recurrence of root cause	Airplane De- sign Change	• Flow-thru' vent; surge tank sup- pression	• Improved bonding inside tank	• Redun- dant con- trol of spar shutoff valve	• Spoiler Lockout Mechan- ism					• Flame Arrestors on Pump Inlets
	Hardware Inspection Requirements						• Mid-spar attach't repeat inspec- tion		• 12 Ser- vice Bul- letins	• 12 Ser- vice Bul- letins
	Ground Sup- port Equip- ment Change									
	Maintenance Program / Procedures Revised					•			•	•
	Operations Bulletin								•	
	Improved Airport Secu- rity							•		•
	None									
Unknown										
Recurring Event			• Different cause							•

Table 2. Summary of Refuelling and Ground Maintenance Events

		1970 Refuelling Minneapolis 727	1970 Refuelling Minneapolis 727	1973 Refuelling Toronto DC-8	1989 Refuelling Washington Beechjet 400	1967 Ground Maint. Taiwan 727	1974 Ground Maint. Travis AFB DC-8	1982 Parked Montreal DC-9
Operational Phase	Inflight							
	On Ground Operations							
	Ground Maintenance					•	•	•
	Refuelling	•	•	•	•			
Ignition Source	Lightning							
	Overwing Fire - Inflight							
	Static Discharge	•	•		•	•		
	Sabotage							
	Unknown			•			•	• Suspect dry running boost pump
Tank Type	Wing = W Rear Aux = RA Center = C Fwd Aux = FA	C	C	W	RA	C	W	FA
Fuel Type		Jet A	Jet A	JP-4 / Jet A	Jet A / JP-4	Jet A	JP-4	Jet A
Mitigating action taken to minimize or prevent recurrence of root cause	Airplane Design Change				• Installed conductive foam			
	Hardware Inspection Requirements							
	Ground Support Equipment Change		• "Anti-static" filters introduced					
	Maintenance Program / Procedures Revised			• (probable outcome)		•	•	• (probable outcome)
	Operations Bulletin							
	Improved Airport Security							
	None	•						
	Unknown							
Recurring Event		•						

### 3.2 Analysis of Previous Tank Explosion Events

As stated earlier, the starting point for the analysis was the table of events contained in the 1998 Fuel Tank Harmonization Working Group final report. The events contained in that report were based on FAA Notice on Fuel Tank Ignition Prevention Measures published in the Federal Register on April 3, 1997. The data sources used were accident and incident reports provided by investigating organizations, regulatory authorities, and original equipment manufacturers' safety-related databases. The level of details reported in the early events was sometimes limited, dependent on the event location in the world and the type of event (whether it involved an internal or external ignition source).

Late in the study for this ARAC, a fuel tank explosion in Bangkok, Thailand occurred. While it is understood that the accident investigation is ongoing, the NTSB has released information indicating the wreckage shows evidence that the heated center wing fuel tank (CWT) exploded and that the ignition

## **Safety Analysis Task Team Final Report**

source has yet to be determined. The team has not been involved in the investigation and does not wish to publish findings in advance of the investigating authority. However, this event appears to fit the guidelines set forth by the tasking statement and the team decided to include it as a statistical data point on which to base the forecast of future accidents.

From Tables 1 and 2, certain patterns and trends emerge:

- There are 8 wing tank events, and 8 involving center or fuselage tanks
- In the wing tank events, 5 out of 8 involved the use of wide-cut fuel (JP-4/Jet B)
- In the wing tank events, 5 out of 8 occurred in flight
- All the wing tank events involved external ignition sources - there are no known wing tank explosions due to internal ignition sources in approximately 900 million hours of flight operations
- There were only 2 explosions due to lightning strike, with the last event in 1976
- All the center tank events involved the use of Jet A/Jet A-1 fuel
- In the center tank events, 6 out of 8 occurred on the ground
- There are 9 operational events, and 7 refuelling and ground maintenance events

From the data, there is a difference in the respective safety levels of wing tanks and center tanks.

All the wing tank events have been due to known, external ignition sources (lightning strikes, over-wing fire, refueling, maintenance error) - there are no known internal ignition sources in over 900 million hours of operation that resulted in a tank explosion. Corrective actions to prevent recurrence of these wing tank events have been in place for many years, and have been demonstrated to be effective.

Over the years, center tanks have accumulated considerably fewer operating hours than wing tanks (for example, a B-737 has two wing tanks and one center tank, and therefore accumulates wing tank hours at twice the rate of center tank hours). Since the equipment in wing and center tanks are very similar, i.e. there are similar types and numbers of potential ignition sources, one would expect there to be significantly fewer center tank events than wing tank events. Actually the numbers of events are approximately equal. The reason is that center tanks are more flammable and potential ignition sources in wing tanks are submerged more often.

With the exception of the three most recent center tank events, and the 1989 Bogota event, the causes of all the other events have been addressed by actions designed to prevent or minimize their recurrence. The 1989 Bogota accident involved a breach of the fuel tank, which violated one of the ground rules this team established as the basis for forecasting future events.

For the three most recent center tank events the exact ignition sources have not been identified. While corrective actions to identify and minimize potential ignition sources are now being put in place, a means to reduce flammability particularly in heated center wing tanks is needed.

The team concluded that the 1990/Manila, 1996/New York, and 2001/Bangkok events should form the basis for forecasting future events.

### **3.3 Service History Conclusions**

This study identified and analyzed 16 known instances of fuel tank explosions due to internal or external ignition sources over the last 40 years of transport aircraft operations worldwide. Post impact fuel tank fire/explosion was not addressed in this section, but is addressed in section 4.4.5. The following conclusions have been drawn:

- There is a close relationship between the incidence of explosions in wing tanks and the use of wide-cut fuel.
- Wing tanks operating with Jet A type fuel have demonstrated an acceptable safety record.
- In comparison, heated center tanks and fuselage-mounted tanks are more vulnerable to explosion in the presence of ignition sources.
- The three most recent events (1990/Manila, 1996/New York, 2001/Bangkok), form the basis for forecasting future events.

**4.0 SAFETY ASSESSMENT**

**4.1 Methodology**

The safety assessments described in this section allow some comparisons to be made regarding the safety impacts of the various options relative to each other. They also provide an indication of the complexity or levels of redundancy, which such systems may require in order to meet certification requirements.

**4.2 Functional Hazard Analysis**

Since some of the inerting concepts involve technologies that currently are not fully mature or proven in a commercial airline environment, rigorous and detailed safety analyses down to component level could not be carried out with confidence. However a top-level functional hazard analysis (FHA) was performed.

This typically looks at the effects of the system not operating when required, and operating when not required, and identifies the severity of these failure conditions (using the guidance contained in Advisory Circular AC 25.1309-1A). The following functional failures were analyzed:

1. To keep the oxygen concentration inside the tank below the level which will support combustion
2. To keep the tank differential pressure within limits
3. To prevent leakage of inert gas into the passenger cabin, flight deck, or enclosed spaces that may be occupied by maintenance personnel
4. To neither endanger the occupants nor adversely affect continued safe flight as a result of failure of equipment containing high energy rotors.

The functional failures are documented below.

**Function:** (1) To keep the oxygen concentration inside the tank below the level which will support combustion

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Fails to inert when expected to.	(A) Ignition possible if ignition source present (other systems might prevent structural damage (explosion) (B) None unless ignition source present (C) None unless ignition source present	Minor	N/A	Loss of protection returns tank to pre-mod condition, i.e. only vulnerable to flammable vapor ignition if flammable atmosphere <u>and</u> ignition source present
Operates inadvertently during tank maintenance	(A) Oxygen concentration inside tank depleted (B) None (C) Asphyxiation of maintenance personnel	Hazardous	1 x 10 <sup>-7</sup> per hour	Preclude operation when fuel tanks are open.

**Function:** (2) To keep the tank differential pressure within limits

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Allows tank differential to exceed maximum positive limits	(A) Wing over-pressure deformation (B) Loss of structural integrity (C) Multiple loss of life	Catastrophic	1 x 10 <sup>-9</sup> per hour	A means, independent of the inerting system, may be required to avoid hazardous deformation.
Allows tank differential to exceed maximum negative limits	(A) Wing under-pressure deformation (B) Loss of structural integrity (C) Multiple loss of life	Catastrophic	1 x 10 <sup>-9</sup> per hour	A means, independent of the inerting system, may be required to avoid hazardous deformation.

**Function:** (3) To prevent leakage of inert gas into the passenger cabin, flight deck, or enclosed spaces that may be occupied by maintenance personnel

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Transfers inert gas into cabin or enclosed spaces	(A) Possible loss of tank inerting (B) Possible incapacitation of pilots (C) Incapacitation/death of some occupants before oxygen masks deployed	Minor Catastrophic  Hazardous	$1 \times 10^{-9}$ per hour  $1 \times 10^{-7}$ per hour	System designed to avoid introduction of hazardous quantity of Nitrogen into the cabin, flight deck or enclosed spaces.

**Function:** (4) To neither endanger the occupants nor adversely affect continued safe flight as a result of failure of equipment containing high energy rotors.

Functional Failure	Failure Condition Effect on (A) System, (B) Aircraft, (C) Occupants	Classification	Probability Requirement	Safety Design Implications
Adjacent system damage or injury to passengers	(A) Possible damage to multiple flight critical systems (B) Breach of pressure vessel (C) Injury/death of some occupants	Hazardous  Minor Hazardous	$1 \times 10^{-7}$ per hour  $1 \times 10^{-7}$ per hour	A means to contain high energy rotor failure.

### 4.3 Personnel Hazards

These hazards are documented in section 4.4 of the main body of this report and in appendix F, the Airplane Operations and Maintenance Task Team report.

### 4.4 Safety Benefit Analysis

The safety benefit forecast approach was based on the conclusions drawn from the service history review. Specifically, it was observed that the tank explosion rate is not the same for all tank types. Further it was concluded that there are similar types and numbers of potential ignition sources, so one would expect the ignition source occurrence rate to be essentially the same for all tanks. It follows then that the difference in tank (i.e., wing vs heated center wing tank) explosion rates is due to the fact that the flammability exposure is not the same for all tanks. Please refer to figure B-1 in Attachment B for the baseline flammability exposure levels predicted by a computer model developed by the FAA and refined by this ARAC. Furthermore, there are differences in the exposure to potential ignition sources. For example, on average, ignition sources in wing tanks are submerged more often than in center wing tanks.

The explosion rate for heated center wing tanks was calculated from the 3 events mentioned earlier. Explosion rates for each of the other tank types were determined based on their exposure to flammable vapors and the likelihood that the potential ignition source would not be submerged. Figure 4.4-1 shows the three events on which the analysis was based. It also shows a close correlation between heated center wing tank operating hours and events that has resulted in an approximately constant accident rate over the last 12 years.

Worldwide Cumulative Heated Center Wing Tank (HCWT)  
Operating Hours, Accidents and Rate vs. Time

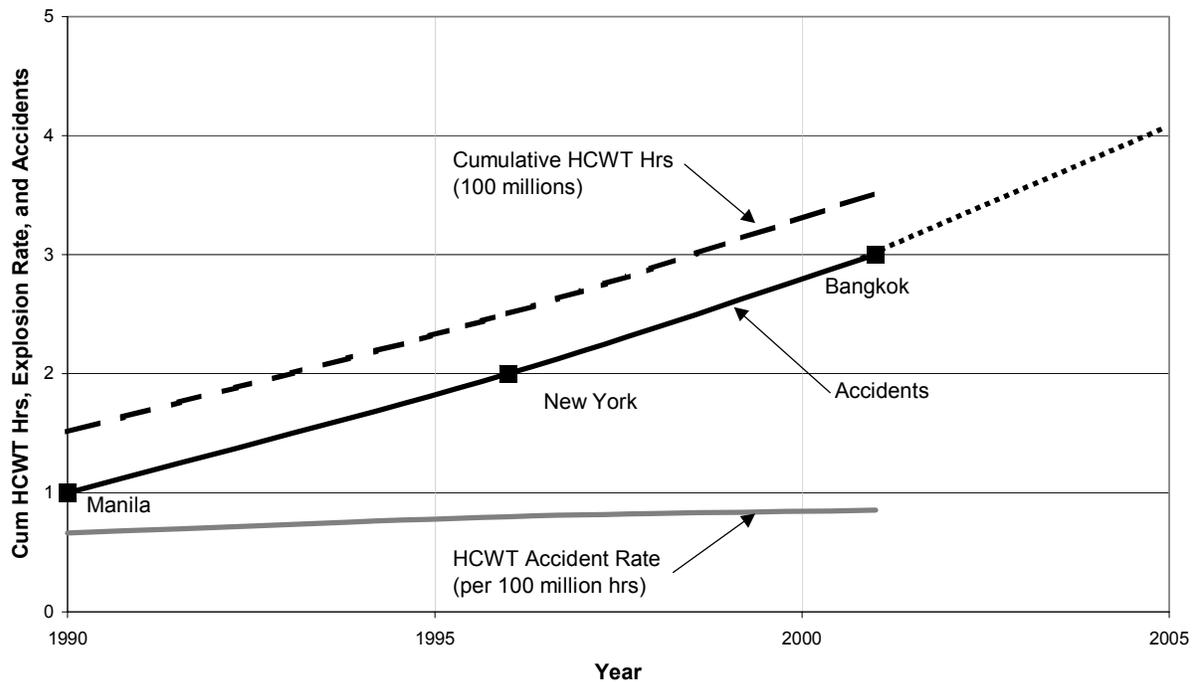


Figure 4.4-1. HCWT Operating Hours, Fuel Tank Explosion Accidents and Statistical HCWT Accident Rate

Figure 4.4-2 shows the total worldwide fuel tank accident forecast. This is the baseline accident forecast if no action were taken to preclude future events. Of the accidents forecast in Figure 4.4-2, approximately 90% are predicted to involve heated center wing tanks. Figure 4.4-3 shows the U.S. forecast, which is based the worldwide explosion rate and U.S. operated airplane operating hours (~46% of the worldwide operating hours).

In Figure 4.4-2 the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR No. 88. The 75% reduction had been estimated by the 1998 FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

## Worldwide Forecast Cumulative Accidents

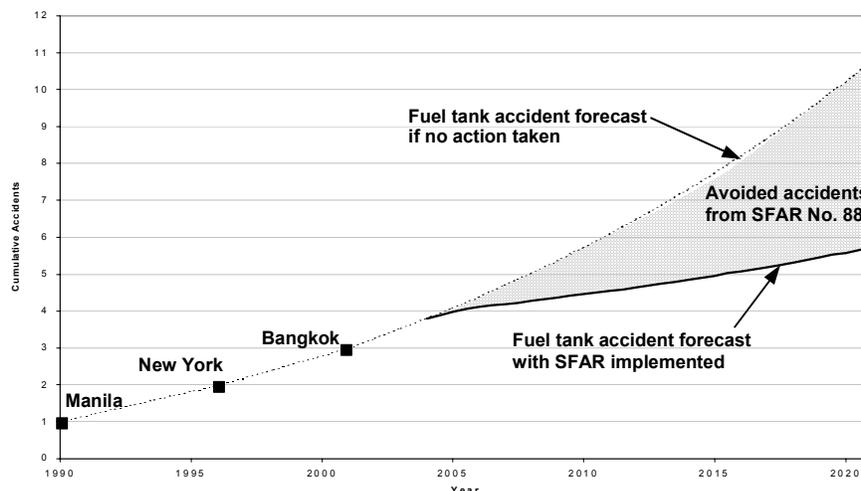


Figure 4.4-2. Worldwide Statistical Forecast Fuel Tank Explosion Accidents

## U.S. Forecast Cumulative Accidents

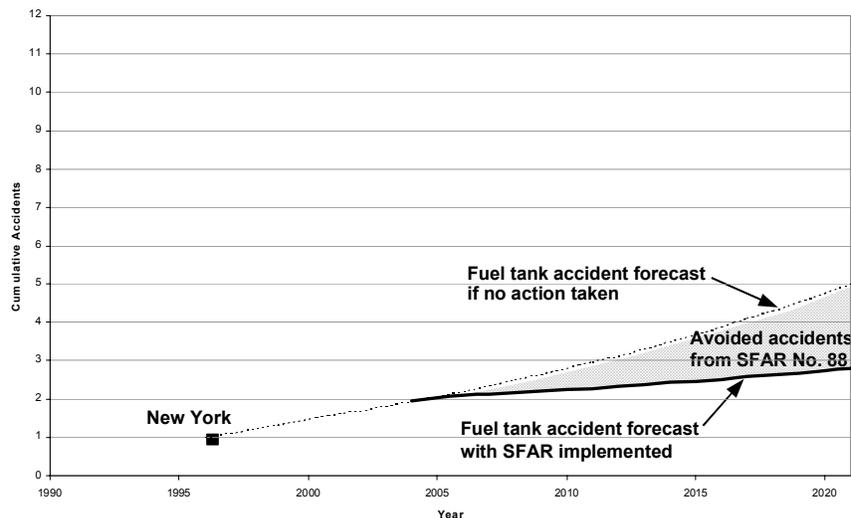


Figure 4.4-3. U.S. Statistical Forecast Fuel Tank Explosion Accidents

The observations and conclusions discussed in this section formed the basis for the baseline fuel tank explosion accident forecast.

The accidents that could be avoided due to inerting is expressed by the following equation:

$$\# \text{ Accidents Avoided} = [(P_{acc})(T_{hrs/flt hr})(H_{cum} - H_{inop})(1 - IGN_{red})]F_{lam}$$

Where:

$P_{acc}$  = Tank explosion rate (by tank type)

$T_{hrs/flt hr}$  = Tank hours per flight hour

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$H_{cum}$  = Cum hrs over study period with sys implemented

$H_{inop}$  = Cum hrs when system inop and on MEL

$IGN_{red}$  = Ignition source reduction factor (due to SFAR NO. 88)

$F_{lam}$  = Flammability reduction factor, fractional portion of risk removed due to inerting

In addition to SFAR NO. 88 effectiveness, the calculated accident rate, mix of tank types, forecast fleet growth, system availability, and achievable flammability reduction all contribute to the number of forecast avoided accidents. These parameters are given in Attachment B. Design implementation assumptions are documented in the Estimating and Forecasting Team Final Report.

## 4.4.1 Ground Based Inerting

Figure 4.4.1-1 shows the impact that ground based inerting could have on reducing future accidents over the study period. Figure 4.4.1-2 gives a breakdown by generic airplane family of the accidents that could be avoided by ground based inerting if implemented in the U.S. only. The figure also provides a multiplier to determine the breakdown of avoided accidents by generic airplane family if inerting were applied worldwide. For example there would be 4.02 times as many accidents avoided worldwide vs. the U.S. for a Large Transport. This is simply based on the operating hour ratio for each generic airplane category.

### U.S. Forecast Cumulative Accidents Ground Based Inerting

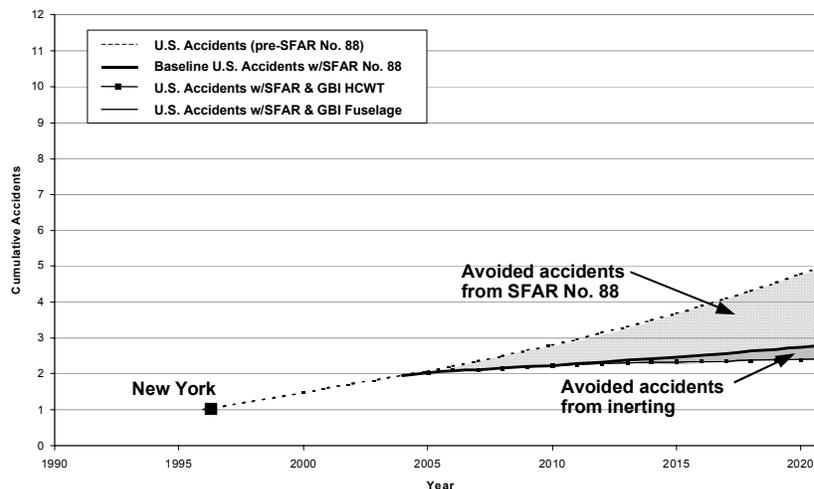


Figure 4.4.1-1. US Statistical Cumulative Accidents with Ground Based Inerting

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
U.S. Accidents Avoided by applying GBI to heated CWT only	0.06	0.04	0.28	N/A	N/A	N/A	0.38
U.S. Accidents Avoided by applying GBI to all fuselage tanks	0.06	0.04	0.29	0.00	N/A	N/A	0.39
Multiplier to Calculate Worldwide Accidents Avoided	4.02	2.31	1.92	2.25	2.48	1.28	

Figure 4.4.1-2. Accidents Avoided by Ground Based Inerting

### 4.4.2 On-Board Ground Inerting (OBGI)

Figure 4.4.2-1 shows the impact that on-board ground inerting could have on reducing future accidents over the study period. Figure 4.4.2-2 gives a breakdown by generic airplane family of the accidents that could be avoided by on-board ground inerting if implemented in the U.S. only. The figure also provides a multiplier to determine the breakdown of avoided accidents by generic airplane family if inerting were applied worldwide. For example there would be 4.02 times as many accidents avoided worldwide vs. the U.S. for a Large Transport. This is simply based on the operating hour ratio for each generic airplane category.

## U.S. Forecast Cumulative Accidents OBGI

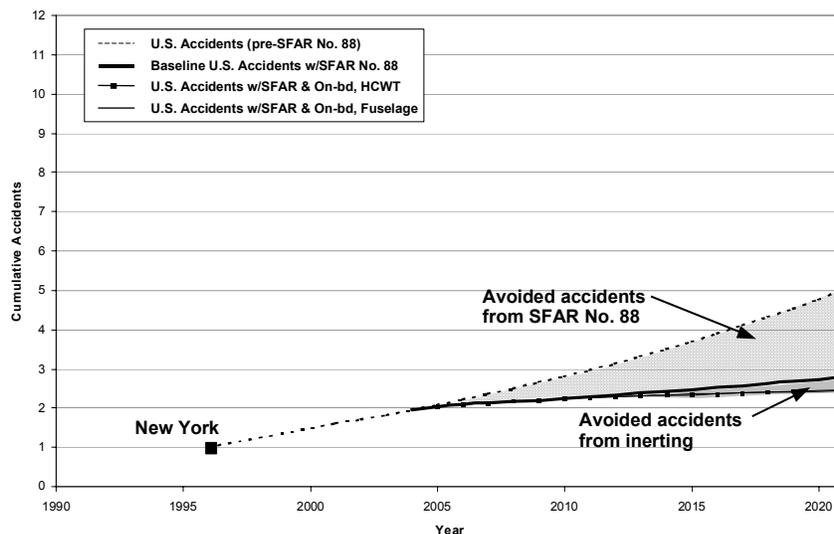


Figure 4.4.2-1. US Statistical Cumulative Accidents with On-Board Ground Inerting

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
U.S. Accidents Avoided by applying OBGI to heated CWT only	0.05	0.04	0.25	N/A	N/A	N/A	0.34
U.S. Accidents Avoided by applying OBGI to all fuselage tanks	0.06	0.04	0.26	0.00	N/A	N/A	0.35
Multiplier for Calculating Worldwide Accidents Avoided	4.02	2.31	1.92	2.25	2.48	1.28	

Figure 4.4.2-2. Accidents Avoided by On-Board Ground Inerting

### 4.4.3 On-Board Inert Gas Generating System (OBIGGS)

Figure 4.4.3-1 shows the impact that OBIGGS could have on reducing future accidents over the study period. Figure 4.4.3-2 gives a breakdown by generic airplane family of the accidents that could be avoided by OBIGGS if implemented in the U.S. only. The figure also provides a multiplier to determine the breakdown of avoided accidents by generic airplane family if inerting were applied worldwide. For example there would be 4.02 times as many accidents avoided worldwide vs. the U.S. for a Large Transport. This is simply based on the operating hour ratio for each generic airplane category.

## U.S. Forecast Cumulative Accidents OBIGGS

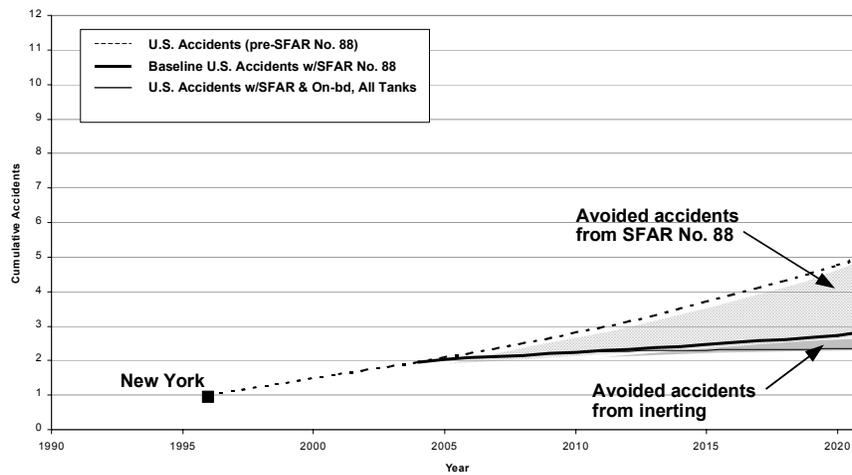


Figure 4.4.3-1. US Statistical Cumulative Accidents with OBIGGS

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
U.S. Accidents Avoided by applying OBIGGS to all tanks	0.07	0.05	0.33	N/A	N/A	N/A	0.45
Multiplier for Calculating Worldwide Accidents Avoided	4.02	2.31	1.92	2.25	2.48	1.28	

Figure 4.4.3-2. Accidents Avoided by OBIGGS

### 4.4.4 Hybrid Inert Gas Generating Systems

Figure 4.4.4-1 shows the impact that Hybrid OBIGGS could have on reducing future accidents over the study period. Figure 4.4.4-2 gives a breakdown by generic airplane family of the accidents that could be avoided by Hybrid OBIGGS if implemented in the U.S. only. The figure also provides a multiplier to determine the breakdown of avoided accidents by generic airplane family if inerting were applied worldwide. For example there would be 4.02 times as many accidents avoided worldwide vs. the U.S. for a Large Transport. This is simply based on the operating hour ratio for each generic airplane category.

## U.S. Forecast Cumulative Accidents Hybrid OBIGGS

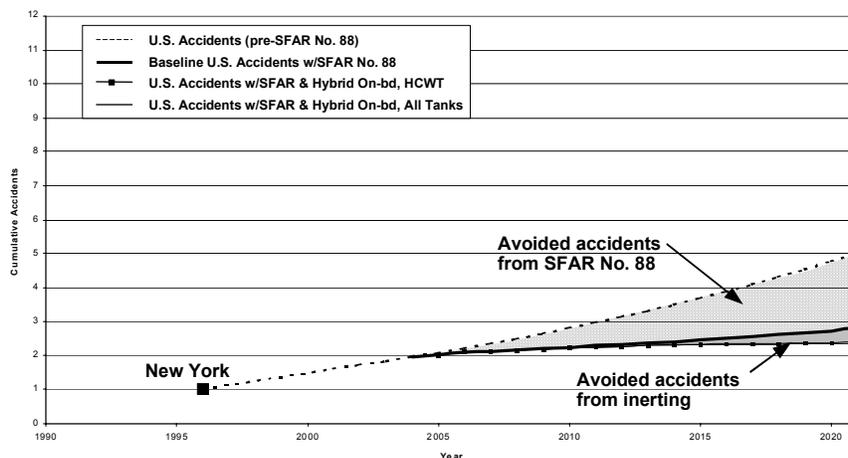


Figure 4.4.4-1. US Statistical Cumulative Accidents with Hybrid OBIGGS

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
U.S. Accidents Avoided by applying Hybrid OBIGGS to heated CWT only	0.06	0.04	0.30	N/A	N/A	N/A	0.40
U.S. Accidents Avoided by applying Hybrid OBIGGS to all tanks	0.07	0.05	0.32	0.00	N/A	N/A	0.44
Multiplier for Calculating Worldwide Accidents Avoided	4.02	2.31	1.92	2.25	2.48	1.28	

Figure 4.4.4-2. Accidents Avoided by Hybrid OBIGGS

Figure 4.4.4-3 shows the impact that Hybrid OBGI could have on reducing future accidents over the study period. Figure 4.4.4-4 gives a breakdown by generic airplane family of the accidents that could be avoided by Hybrid OBGI if implemented in the U.S. only. The figure also provides a multiplier to determine the breakdown of avoided accidents by generic airplane family if inerting were applied worldwide. For example there would be 4.02 times as many accidents avoided worldwide vs. the U.S. for a Large Transport. This is simply based on the operating hour ratio for each generic airplane category.

## U.S. Forecast Cumulative Accidents Hybrid OBGI

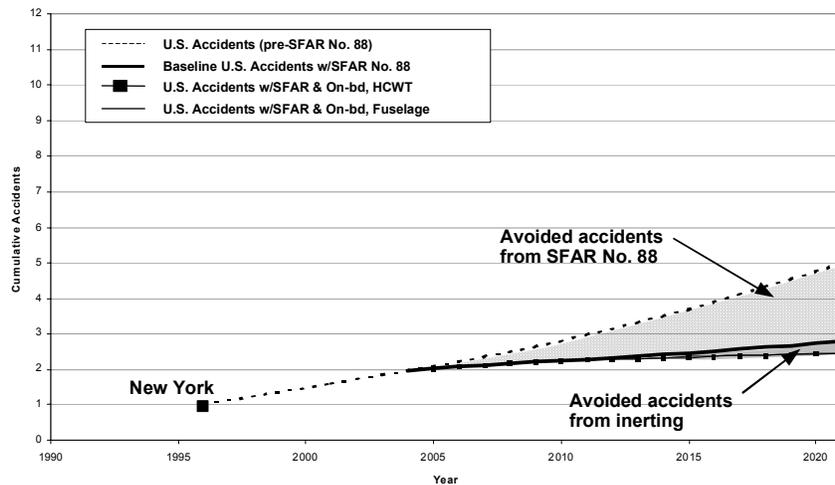


Figure 4.4.4-3. US Statistical Cumulative Accidents with Hybrid OBGI

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
U.S. Accidents Avoided by applying Hybrid OBGI to heated CWT only	0.05	0.04	0.24	N/A	N/A	N/A	0.33
U.S. Accidents Avoided by applying Hybrid OBGI to all fuselage tanks	0.06	0.04	0.25	0.00	N/A	N/A	0.35
Multiplier for Calculating Worldwide Accidents Avoided	4.02	2.31	1.92	2.25	2.48	1.28	

Figure 4.4.4-4. Accidents Avoided by Hybrid OBGI

### 4.4.5 Post Impact Fuel Tank Fire/Explosion

As suggested by the tasking statement, the safety task team evaluated the data provided by DOT/FAA/AR-99/73, "A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion." The safety team accepted the findings of this report and chose to not duplicate effort in this area. The report considered 13 survivable accidents in which a fuel tank explosion occurred, but was not the prime cause of the accident. Each of the accidents were analyzed to assess the number of lives that might be saved if nitrogen inerting systems were used. The predicted number of lives saved per year from this analysis were reported as:

Ground nitrogen inerting - center tank only	0.3
Ground nitrogen inerting - all fuel tanks	2.4
Onboard nitrogen inerting - all fuel tanks	6.0

Using this data, the forecast number of lives saved over the study period was determined. Based on the assumed annual fleet growth rates and the inerting system implementation assumptions, it is forecast that ground based inerting of the center fuel tank would save 5 lives over the study period. Similarly, onboard inerting of all fuel tanks would save 101 lives over the study period.

The report concludes:

"The predicted potential number of lives saved per year is relatively small compared to other survivability factors. One of the reasons that nitrogen inerting may not be effective, in terms of saving lives in the 13 accidents analyzed, is that in many cases fuel tanks were ruptured when the

aircraft impacted the ground. Any nitrogen in the fuel tanks is likely to have escaped with the spilled fuel. The system is only effective when the fuel tanks are not significantly ruptured."

#### 4.5 Safety Assessment Summary and Conclusions

Over the past twelve years, the fuel tank explosion rate has been essentially constant. Based on this observation, and the forecast fleet growth, the occurrence of fuel tank explosions will be more frequent in the future. Ignition source reduction activities associated with SFAR NO. 88 will provide a reduction in the fuel tank explosion rate.

Figure 4.5-1 shows the pre-SFAR No. 88 fuel tank explosion accident rate for each of the generic airplane families. Figure 4.5-2, shows how the accident rate is reduced due to the FTIHWG interpretation of the SFAR No. 88, GBI and OBIGGS benefits.

When evaluating the data in figure 4.5-1 and figure 4.5-2, it is important to understand that inerting systems offer little benefit to three (Regional Turbofan, Regional Turboprop, and Bizjet) of the six generic airplane families. This is because none have heated center wing tanks, and flammability of the wing tanks is already low. Furthermore, onboard systems were not found to be practical for these airplanes. One might expect the estimated mean time to the next accident for the OBIGGS scenario in figure 4.5-2 for example to be much longer. Indeed for airplanes equipped with OBIGGS (Large, Medium, Small Transports) it is much longer (on the order of 100 years). However, when forecasting so far into the future (and maintaining the unconstrained fleet growth assumption, see Attachment B) the Regional Turbofan, Regional Turboprop, and Bizjet's each contribute more to the forecast. Thus rather than the estimated mean time to the next accident being on the order of 100 years, it is forecast to be 51 years.

The flammability levels achieved by inerting systems can result in a significant improvement in the accident rate.

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
Accident Rate pre-SFAR No. 88	$8 \times 10^{-9}$	$8 \times 10^{-9}$	$8 \times 10^{-9}$	$6 \times 10^{-10}$	$1 \times 10^{-10}$	$4 \times 10^{-10}$	$5 \times 10^{-9}$ (weighted avg)

Figure 4.5-1. Accident Forecast Summary Information

	Pre-SFAR No. 88	With SFAR No. 88 Fully Implemented	With SFAR and GBI of Heated CWT Fully Implemented	With SFAR and OBIGGS of All Tanks Fully Implemented
Estimated Mean Time to next Accident in the US after full implementation in year 2015	4	16	36	51
Statistical Explosion Rate per operating hour for entire fleet (weighted average of all six generic airplane families)	$5 \times 10^{-9}$	$1.3 \times 10^{-9}$	$3 \times 10^{-10}$	$1.5 \times 10^{-10}$

Figure 4.5-2. Fuel Tank Explosion Accident Rate Comparison

## **ATTACHMENT A - DETAILS OF PREVIOUS TANK EXPLOSIONS**

Attachment A contains a detailed description of each event and the findings of the investigating authority, each followed by a description of the mitigating actions taken subsequent to the event to prevent its recurrence. The 16 events have been grouped initially into broad categories which characterize their circumstances, i.e. engine separation events, lightning strike events, ground maintenance events, refuelling events, “others” and those where the cause remains unknown.

### **Engine Separation Events**

1.	Date:	<b>28 June 1965</b>	Flight phase:	<b>Takeoff climb</b>
	Aircraft:	<b>Boeing 707</b>	Tank type:	<b>Main reserve tank</b>
	Location:	<b>San Francisco</b>	Fuel type:	<b>Jet A</b>

#### Summary of Event

Approximately 39 seconds after takeoff No.4 engine experienced an uncontained engine failure resulting in separation of the engine from the wing. The loss of the engine resulted in mechanical damage to the wing and a severe fire. The fire triggered a low order explosion in the No.4 reserve tank which resulted in the loss of the lower wing skin, lower stringers, and spar chord flanges. The loss of these components resulted in the loss of wing integrity which allowed the outer wing panel to fail and separate from the wing. The ensuing fire was extinguished by the closing of the main fuel shutoff valve either by the first officer or the flight engineer.

There was evidence of fire on the separated wing section, on the remaining wing around the point of separation, and on the No.4 engine. Fire was observed by ground witnesses, passengers and crew members, and photographed, in color, from the ground and by a passenger. The flight crew was alerted to the fire when an intermittent fire warning was observed while they were going through the engine shutdown procedure following the failure of the No.4 engine. The first officer then actuated the fire selector lever for the No.4 engine and discharged both fire extinguisher bottles to the engine. The fire was observed streaming from the right wing. Fuel was still streaming from the No.4 tank area after landing until the fire department plugged the hole in the bottom of the tank. The area around the fuel spill and the wing stub were foamed as a preventative measure while the passengers were disembarking from the aircraft.

#### Analysis

A disk failure resulted in an explosive failure of the No.4 engine and its separation from the wing due to high vibration and out of balance oscillation of the rotating parts of the engine. The right outer wing received so much damage to the lower load-bearing skin and associated structure that capability of the wing to sustain in-flight loads were reduced below the loads imposed, and the outer wing panel separated from the wing. Fuel from the engine fuel line was then being pumped directly into the airstream. This fuel was ignited by an undetermined source shortly after the engine separated and resulted in an explosive separation of a portion of the lower wing skin. It is believed that dangling wires from the engine separation sequence ignited the fuel. The fire was sustained by the continued supply of fuel through the engine fuel line until the flight engineer or the first officer shutoff the main fuel supply either by activating the fuel shutoff valve to the closed position or actuating the fire selector handle.

The disintegration of the third stage turbine disk cut the engine in two pieces and threw turbine debris into the wing inboard of the engine pylon. The two engine sections, each supported by only one mount on the strut, began to oscillate and separated from the wing in approximately four seconds. The strut failures were caused by the oscillation, possibly coupled with mechanical damage from flying engine parts. The engine fuel line pulled from the strut closure rib when the engine separated from the wing. Fuel was pumped through this line for an estimated 99 seconds at a rate of approximately 30,000 pounds per hour, until the fuel valve was shut off by the action of either the first officer or the flight engineer. A second

fuel source was the fuel line on the forward face of the main spar which had a loosened fitting that leaked and supplied fuel for a fire over the strut center spar between the front spar and the nacelle closure rib. A third possible flammable fluid source was the ruptured slat hydraulic line on the inboard gap cover area.

The source of the ignition cannot be determined, but the possible sources included the engine exhaust, hot turbine parts, or arcing from exposed electrical leads. The latter is the most probable source because there was an appreciable time lapse between observation of the fuel spray and ignition. The fuel sources wetted much of the upper wing surface before ignition occurred.

The fact that No.4 main tank was full of fuel probably prevented more extensive fire damage to that area of the upper wing surface because the fuel acted as a heat sink. The fire in this area reached temps ranging from approximately 870 - 1165°F, based on damage caused to the metal.

The damage to the right outboard wing section top and bottom skin and ribs could only have been caused by an over-pressure in the reserve tank. This is demonstrated particularly by the manner in which the lower skin separated from the aircraft. The entire panel was forced straight down, taking the attaching flanges of both spars with it. This is plainly the result of a low order explosion. The source of ignition for this explosion could not be determined but could have been auto-ignition, burn through, or hot surface ignition from a localized hot spot.

The final separation of the wing followed the explosion in the reserve tank. The wing separation is not believed to have been simultaneous with the explosion. The indications of yaw and vertical oscillation on the flight recorder readout and the location of the wreckage on the ground indicate that the wing section remained on the aircraft approximately 10-11 seconds after the separation of the lower skin panel.

The heat damage to the wing structure was not considered to have been a major factor in the wing failure. Rather, the loss of lower skin panel, stringer, mid spar chord flanges reduced the load carrying capability of the wing below that required to support a 1 "g" condition, thus leading to the failure.

Laboratory tests of the fuel samples taken from the six remaining fuel tanks on the aircraft revealed no significant deviation from the specification established for Jet A turbine engine fuel. It was estimated that the fuel temperature in the tanks at the time of the accident was between 70-80°F. The flammability limit of Jet A fuel was reported by the FAA to be from 90-170°F. Ambient temperature prior to the flight were recorded as 77°F.

Mitigating Actions Taken:

Airplane design change were made to incorporate redundant wiring paths to close spar and engine high pressure valves when the fuel shutoff or fire handle switch is activated. Engine assembly procedures were modified to ensure proper running clearances.

There has been no recurrence of an engine uncontained failure leading to separation of the wing since design changes.

2.	Date:	<b>July 1970</b>	Flight phase:	<b>Go-around</b>
	Aircraft:	<b>McDonnell Douglas DC-8</b>	Tank type:	<b>Wing tank</b>
	Location:	<b>Toronto</b>	Fuel type:	<b>JP-4</b>

Over the threshold of runway 32 at about 60 feet agl, the first officer deployed, instead of arming, the ground spoilers causing a rapid descent until striking the ground. The captain tried to compensate by applying full power and rotating the airplane to initiate a go-around. However, the airplane hit hard at 18 feet per second, number 4 engine separated and number 3 engine partially separated. Somewhere in the sequence of the engine separation from the wing, leaking fuel that may have been ignited by dangling wires causing some explosions. The airplane continued with go-around while trailing fuel and fire. Airplane climbed to 3,100 feet and commenced a turn for a second approach. The right wing separated above the number 3 engine, the airplane rolled over and struck the ground . The airplane crashed 2.5

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minutes following touchdown and approximately 8.5 miles from runway 32. The FAA has reported that JP-4 fuel was being used. Ambient conditions were reported as warm and sunny.

### Mitigating Action Taken:

As a result of this accident, the FAA issued an airworthiness directive (AD) requiring placard warnings against in-flight deployment of ground spoilers by DC-8 operators. Following a non-fatal accident some three years after this crash, the FAA issued another AD requiring that all aircraft of the type be fitted with spoiler locking mechanisms to prevent such an occurrence.

3.	Date:	<b>7 May 1990</b>	Flight phase:	<b>Landing</b>
	Aircraft:	<b>Boeing 747-200</b>	Tank type:	<b>No 1 wing tank</b>
	Location:	<b>New Delhi, India</b>	Fuel type:	<b>Jet A</b>

A 747-200 operating a flight from London to New Delhi landed at Delhi at 0915 local time. The flight crew reported there were no problems experienced with the No. 1 engine during the London-Delhi flight. Touchdown and engine transition to reverse thrust were reported as normal. Shortly after the engines reached full reverse, all No. 1 engine indications apparently went to zero. The flight crew was not aware of the nature or extent of the problem at this point as there was no engine fire warning. Another 747, which had landed five minutes earlier, advised the 747-200 they had a large fire on the left wing in the area of No. 1 engine. The crew reportedly pulled the No. 1 fire handle and discharged the fire extinguisher. The tower also noted the fire and alerted the aircraft and the airport fire department. The fire department was already aware of the situation and had four fire engines on the scene within two minutes of first noting the fire. The fire was reportedly extinguished within eight minutes of the first report.

All 175 passengers and 20 crew members were evacuated using the five main deck slides on the right side of the aircraft. All five slides deployed normally and were used. There were no reported injuries of anyone on board. The aircraft apparently touched down between one and two thousand feet from approach end of the runway. Weather was clear and dry with little or no wind and the temperature was 35°C. First evidence of the No. 1 engine inlet cowl contacting the runway was at three thousand feet. Spatters of molten aluminium were first noted at above five thousand feet from approach end. The aircraft stopped ten thousand feet from approach end slightly to left of center. The No. 1 engine was in a near vertical position. The engine had rotated around the mid spar attach points with the nose cowl resting on the runway and the exhaust plug and engine tail pipe jammed against the wing lower surface. The No. 1 strut upper link forward attach fuse pin was sheared. Pieces of fractured fuse pin remained in the upper link forward clevis fitting and associated strut attach lug. The aft end of the diagonal brace was detached from its associated fitting on the lower wing skin and the associated fuse pin was completely missing, and could not be found. Failure of these two strut attach points allowed the front of the engine to drop, contacting the runway. All equipment in the No. 1 strut sail boat area was destroyed by impact with strut aft bulkhead, engine exhaust pipe, tail cone and subsequent fire.

The No. 1 engine fuel supply line separated at the wiggins fitting between strut bulkhead and wing front spar. All wire bundles to the engine appeared to have been broken due to tension caused by the strut rotating to a vertical position. All leading edge flaps and leading edge fiberglass panels severely burned inboard and outboard of No. 1 strut. The outboard end of the outboard trailing edge flap was severely burned. The outboard flap track fairing was totally consumed by fire. The inboard end of the outboard aileron was severely burned. The outboard spoilers 1 and 2 and the trailing edge fiberglass panels inboard and outboard of the No. 1 strut was severely burned. The left wing tip was drooping down outboard of the No. 1 strut at about 15 degrees. There was evidence of extreme heating and warping of upper wing skin above the No. 1 strut. The upper wing skin was pulled loose from the forward and aft spar webs outboard of the No. 1 strut. Vent stringers were split open longitudinally. All upper wing skin rivets were pulled through the skin in the area of the surge tank. The lower wing skin was scorched in area of surge tank.

Analysis

In brief summary, the fuel from the ruptured fuel line and hydraulics in the strut were ignited by the hot engine and exhaust, followed by auto ignition of residual fuel in the reserve and surge tanks due to external heating. Fuel supply to the fire was terminated prior to the aircraft coming to rest and flammable wing and subsystem material continued to burn until extinguished by ground personnel.

Following forward strut pin failure and engine dropping nose down:

- Fuel is discharged at approximately 100 gpm into air stream prior to engine spar valve closure due to fuel line separation from front spar coupling. Fuel is washed under and possibly over wing and into leading edge cavity due to both forward speed of aircraft and due to thrust reverser air from engine.
- Due to engine exhaust/tailpipe being rotated up which forced diagonal brace into the hydraulic reservoirs in strut aft fairing, reservoir is crushed and 10 gallon (U.S.) hydraulic fluid is released.
- Fuel and/or hydraulic fluid is ignited on hot engine tail cone/nozzle.
- Hot engine exhaust gases and/or fuel fire heat the lower surface of reserve tank. Reserve tank is empty, but air is heated in excess of fuel AIT (auto ignition temperature). Residual undrainable fuel is approximately one U.S. gallon.
- Heated air or burning fuel vapor reaches surge tank through the reserve tank vent line. Fire initiates in surge tank due to residual fuel vapors and temperature in excess of AIT for fuel. Hot front spar at surge tank due to leading edge fire could also have been the ignition source.
- Main tank No. 1, because of fuel acting as a heat sink, remains "cool".
- Wing leading edge receives fuel spray or mist due to engine thrust reverser air or free stream air dispersion. Prior to fuel shutoff, during landing roll, fuel attaches to flap torque tubes and interior flap surfaces, and subsequently burns. Resin binding agents in fiberglass honeycomb panels will burn when fed by heat of fuel fire. Fuel was shut off prior to the end of the landing roll as evidenced by soot being confined to aft portions of strut and aft part of core cowl.

Fire damage to aft end of engine is primarily to exterior cowling and exterior surface of nozzle. Inner steel nozzle does not appear fire damaged. This is considered a consequence of external fuel or hydraulic fluid falling or spraying on aft end.

An assessment of the cause of the wing overpressure has been made. This assessment, in conjunction with visual inspection of the damage indicates that an in-tank explosion occurred which destroyed the integrity of the torque box by separating the wing panels and spars from their internal support structure. Further damage occurred after the overpressure due to inertia loads imposed during landing rollout.

The engine separation was found to be due to a maintenance error when re-assembling the components of the strut linkages.

Mitigating Action Taken

Procedural changes were implemented at the specific airline to ensure existing instructions for engine retention hardware installation were properly followed.

- |    |           |                                |               |                       |
|----|-----------|--------------------------------|---------------|-----------------------|
| 4. | Date:     | <b>31 March 1992</b>           | Flight phase: | <b>Climb</b>          |
|    | Aircraft: | <b>Boeing 707</b>              | Tank type:    | <b>No 4 wing tank</b> |
|    | Location: | <b>Near Marseilles, France</b> | Fuel type:    | <b>Jet A</b>          |

As the aircraft was climbing towards flight level 330, both right engines separated from the wing. The No.3 inboard pylon fitting fractured and subsequently released the engine under power which then

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impacted the No.4 engine causing it to separate also. The crew succeeded in controlling the aircraft and landed gear and flaps down with the right wing on fire. The aircraft rolled off the runway to the left of centerline and all crew members evacuated the aircraft safely and the firemen extinguished the fire.

The trailing edge of the wing was totally burnt in the area between both engines. The inboard and outboard flaps had completely disappeared, revealing the burnt operating mechanisms. The inboard aileron was severely damaged. Moreover, the examination of the inboard wing box identified the marks of an inner explosion on fuel tank No.4. This explosion seemed to be at the origin of significant deteriorations affecting the wing stiffness. This explosion had caused the displacement of the inner ribs of this tank. The wing stiffness was particularly damaged on the front and aft spars. Thus, it appeared that the right wing was severely damaged first because of a fire and then because of an inner explosion at the fuel tank No.4.

Note: All right wing valves, transfer and shutoff valves operated normally, when tested. The shutoff valves were found in the fully closed position and the transfer valves were found in the open position which matched the cockpit switch positions. The fuel leakage on the leading edge of the wing near engine No.3 could not have been caused by a closing failure of the shutoff valve. Damage (collateral) of the piping following the pylon detachment could be the cause of the leak. The exact location of the leak could not be detected.

During all of the descent at speeds greater than 220 kt, it is probable that the fuel leak carried on without the fuel catching fire, as the conditions for ignition (depression of the upperwing, speed....) were not achieved and the vaporized fuel was not in contact with the electrical short-circuits of the damaged cabling loom located on engine No.3 leading edge. These conditions changed during the last turn as a consequence of the semi-extension of the flaps. The speed reduced (between 220 and 190 kt), the depression on the upper wing decreased and the turbulence increased. Then, it was possible that under the effect of the electric arcs of the short-circuits quoted above, the fuel ignited, as the conditions of the kerosene-air mixture became optimal for burning. The fire was violent as the condition of the upper wing demonstrated, particularly at the trailing edge. This intense fire had destroyed the trailing edge as well as the flaps and left evidence of overheating over the whole of aft part of the right fuselage side. The air traffic controller advised that the right wing was on fire at 08:33:28 hrs and the landing touchdown occurred at 08:35:35 hrs. Consequently, the right wing fire lasted for at least two minutes.

The accident report did not provide a good rationale for the explosion in the No.4 main tank. It is believed that during the intense fire the wing structure may have weakened and fire progressed to the air-fuel mixture in the tank.

### Mitigating Action Taken

An airworthiness directive was issued to inspect the pylon/strut mid-spar fittings at 1500 hours or 600 cycles.

### **Lightning Strike Events**

5.	Date:	<b>8 December 1963</b>	Flight phase:	<b>Holding</b>
	Aircraft:	<b>Boeing 707</b>	Tank type:	<b>Wing (reserve) tank</b>
	Location:	<b>Elkton, Maryland</b>	Fuel type:	<b>Jet A / JP-4 mix</b>

The flight was in a holding pattern at 5,000 feet awaiting an instrument approach to Philadelphia airport from Baltimore, when it was struck by lightning. Immediately thereafter, the aircraft was observed to be on fire. A large portion of the left wing separated in flight and the aircraft crashed in flames near Elkton, Maryland. The probable cause was lightning induced ignition of the fuel/air mixture in the No.1 reserve fuel tank with resulting explosive disintegration of the left outer wing and loss of airplane control.

Fuel onboard at the time of the accident was approximately a 68% Jet A / 32% JP-4 by volume mix. It was estimated that fuel temperatures were 42°F in the reserve tank and 46°F in the main tanks. Considering all factors it was concluded the fuel vapors in all tanks were within the flammability limits. Multiple lightning-strike marks were found on the left wing tip. Although much effort was expended, the physical evidence failed to disclose the precise mechanism of ignition which triggered the explosion in the left reserve fuel tank.

Mitigating Action Taken

A fire suppression system was installed on some airplanes which consisted of a light-triggered fire extinguishing system in the wing surge tank. Additionally, some airplanes had a flow-through vent system installed. An FAA Advisory Circular 20-53 was developed to define lightning strike zones.

Since incorporation of the above design changes and practices, there has not been a recurrence of a lightning strike event on the 707/720 model.

6. Date:	<b>9 May 1976</b>	Flight phase:	<b>Approach</b>
Aircraft:	<b>Boeing 747-IIAF</b>	Tank type:	<b>Wing tank</b>
Location:	<b>Madrid</b>	Fuel type:	<b>Jet A / JP-4 mix</b>

The airplane was being operated as a military logistic flight to McGuire AFB with an enroute stop at Madrid, Spain. During descent for the approach at 6,000 feet, the airplane was struck by lightning which resulted in an explosion and separation of the left wing causing loss of control. Prior to the event, the crew requested ATC vectors around severe thunderstorm activity. The fuel onboard was a mixture of 58% JP-4 and 42% Jet A type.

At the time of the accident the weather was cloudy with rain and lightning, but good visibility. At least two witnesses reported seeing lightning strike the airplane. Parts from the left wing, including a section of the left wing tip, were the first found along the flight path wreckage.

Evidence of lightning strike, pitting and localized burn areas typical of lightning attachment were found on the left wing tip and on the vertical fin at the VOR antenna.

The fire centers were located in the wing tip, in the outboard end of No.1 fuel tank, and the outboard end of No.2 fuel tank. These fire centers were independent and not interconnected. There was no pattern to the fire, heat, and soot damage in the reserve tank. In the area of the No.2 tank, the fire, heat, and soot damage pattern on the inner part of the wing indicated that a fuel fire moved inboard behind the rear spar and along the trailing edge. At the wing root, the fire pattern extended fore and aft along the fuselage. The fuel for this fire obviously came from the No.2 tank from which the upper wing skin cover plank was gone.

Findings and Plausible Hypothesis

The aircraft was fueled with a mixture of JP-4 and Jet A fuels. Lightning struck the aircraft an instant before an explosion. The first wreckage on the ground contained a considerable number of parts of the left wing outboard of the No.1 engine. Damage to the wing in the area of the No.1 fuel tank is the result of a low order explosion. The ullage of the No.1 tank contained a flammable mixture of fuel and air. Pressures provided by the ignited fuel were sufficient to cause the damage. Three fires occurred in No.2 tank, No.1 tank, and the wing tip surge tank. The crushing or collapsing of the fuel tube in the No.1 tank required an application of pressure only available from an explosion. The pressure required to detach the stringers and skin from the wing were in the range of typical pressures developed by an explosion. The first deposit of wreckage formed a pattern of light objects downwind and heavy objects upwind, which is not compatible with gusting or turbulent wind conditions but is compatible with an explosion in calm or steady wind conditions. The H.F. antenna and wing tip edge were snapped off the wing by inertial loads developed by an oscillating outer wing. The loosening of the stringer/plank unit from the wing destroyed the aft wing

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box of the wing. Extreme engine oscillations developed as a result of the wing box damage. The loss of the rear box structure allowed the wing to twist torsionally and to deflect up and down about the rear spar. The first objects along the flight path were units from the inside of No.1 fuel tank. The three fire areas within the left wing contained electrical devices. The highest level of residual magnetic field was along the rear spar aft of the No.1 tank. A motor that operates a fuel valve normally mounted in this position was never found. Damage to the fuel tank access doors could only result from pressure from inside. No structural loads were applied to these doors. The 28Hz oscillations superimposed on the power line were in the area of the third harmonic of the wing oscillations (9Hz) which were attributed to engine fan rub in the early service history of the 747. The inertial damage to the extreme wing tip (H.F. antenna and coupler) could result only if the inboard section of the wing tip was still attached to inner wing. Throttle lever vibration in synchronization with the wing oscillations was observed during previous incidents. The damage to the wing tip cannot be caused by gust loads or aerodynamic loads. They were due to wing oscillations. The wing oscillations were the result of rear box failure. The deformation to rib WS 1168 was caused by pressure loads prior to its departure from the wing along with the jettison fuel line. The flight control difficulty mentioned on the CVR was probably related to the outer wing damage. The crossover vent duct for the forward outboard end of the No.1 tank was severely fire damaged, and the aft end was never recovered.

### Fuel Tank Flammability Evaluation Results

Based on these calculations of the fuel and ullage conditions, the fuel/air mixture in portions of the ullage may be such as to permit ignition at the time of a descent through 10,000 feet.

### Analysis

Consensus of the highly specialized investigation team was that an explosion occurred at or near the aft outboard corner of the No.1 Tank.

### Conclusion from the Accident Report

After analyzing all of the available evidence, it is concluded that the most probable sequence of events which culminated with multiple structural failures and separation of the wing began with an ignition of the fuel vapors in the No.1 fuel tank. The damage to the structure in the area of the tank provided positive indications of an explosion. The possibility that the explosion was a secondary result of an initial structural failure caused by excessive aerodynamic forces developed during high velocity gusts and turbulence cannot be completely dismissed; however, the evidence and the probabilities of an aircraft encountering these unique environmental conditions make this hypothesis less supportable.

### Mitigating Action Taken

A design change was incorporated that basically improved bonding (electrical grounding) where plumbing passes through the wing spar to further dissipate the voltage difference.

There has been no recurrence of a lightning strike related explosion to this model airplane or any other fleet airplane since this event in more than 246 million flights.

### **Ground Maintenance Events**

7.	Date:	<b>17 September 1967</b>	Flight phase:	<b>Ground maintenance</b>
	Aircraft:	<b>Boeing 727</b>	Tank type:	<b>Center</b>
	Location:	<b>Taiwan</b>	Fuel type:	<b>Jet A</b>

The airplane was undergoing routine scheduled maintenance of the interior of the left wing tank. Both No.1 (wing) and No.2 (cheek tank) tanks had been drained and were open. Tank No.1 had been purged and No.2 tank was to be purged. A flash fire occurred followed in a few seconds by an explosion which ruptured the integral section comprising the RH end of tank No.2. An 8 ft. by 12 ft. section of upper wing

structure was blown off. A small fire flared up in the damaged area which was quickly put out. There were 74 people in the immediate area. 16 persons were injured; five of these received serious injuries.

The precise source of ignition could not be determined. However, the following information was obtained in the ensuing investigation:

An explosion-proof light was illuminating the interior of the electronics compartment and was still functioning after the explosion. There was no evidence to indicate that it had been plugged in coincident with the event. All power was off the airplane, the ground power unit had been shutdown nearly two hours earlier, and the battery had been removed.

The lead man in charge of tank purging stated that purging with portable CO<sub>2</sub> bottles had been completed within tank No.1, and that the CO<sub>2</sub> equipment had been laid down, and that the crew had been instructed to open up the RH access door of tank No.2 before purging that tank. No checks had been made of explosive vapor concentration either internally or externally.

The tank purging procedure used is noted to be contrary to the procedure recommended in the OEM manual. One of the more severely burned mechanics, interviewed later in the hospital, was stated to have corroborated the above. The FAA personnel had come to the conclusion that tank No.2 was being purged through the LH access opening at the time. They based their assumption on the statement that the CO<sub>2</sub> equipment had just been laid down on a work stand, and that the most seriously burned mechanic was standing on a stand near the LH No.2 tank, not No.1.

It was noted that metallic parts in the CO<sub>2</sub> discharge assembly might produce a spark and also that the static electricity discharges from the fiber horn or nozzle on portable CO<sub>2</sub> bottles have been historically a cause of fuel fires.

A mechanic was filing a piece of light gage stainless steel, making a nut retainer, in a wheel well area. Another was making a layout on another piece of metal. The first man, who received burns on exposed skin areas, reported that he felt pain and ran from the area. He did not report noting the origin of the explosion.

The only ground leads specifically identified were connected to the RH landing gear, rather than to the grounding lug provided on a RH gear door, and to the rear fuselage. Whether or not ground leads were attached to the work stands, as recommended by the OEM, was not determined due to confused activities following the explosion. A large crew of workmen were reported to be cleaning (but not polishing i.e., using buffers or polishing compounds) with cans of solvent, brushes and cloths. After the explosion, several of the cans of solvent were noted to be on fire. Electrical outlets were non-explosion proof; however, none was reported as being used, at the time, except for the connection to the light in the electrical compartment.

No precautions had been taken to limit access or post warnings in the area. The FAA considers that any of the 74 men in the area might have created a spark which could have ignited fumes in the area.

#### Mitigating Action Taken

The CO<sub>2</sub> bottle flow rates were reduce and the discharge nozzles inspected and reworked. There is no known recurrence of this event for these specific causes.

8. Date:	<b>23 March 1974</b>	Flight phase:	<b>Ground maintenance</b>
Aircraft:	<b>McDonnell Douglas DC-8</b>	Tank type:	<b>Wing</b>
Location:	<b>Travis AFB, California</b>	Fuel type:	<b>JP-4</b>

Upon arrival at Travis Air Force Base from a Military Charter flight, a routine maintenance "A" check was being accomplished including maintenance action in response to the flight crew reports of inflight

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mechanical irregularities that appeared on the previous two flight legs. One of the crew log reports was an inoperative No.1 fuel boost pump.

Access to the boost pump was made through the top of the wing. This was done by removing the No.1 main fuel tank access cover, located behind and slightly outboard of the number 2 engine pylon. Affected circuit breakers for the fuel system had been opened. The tank contained approximately 3,000 pounds of JP-4 fuel. The boost pump was partially submerged in fuel. The total fuel on the aircraft was 25,000 pounds. External power from a ground power unit was connected to the aircraft.

Removal and re-installation of a different boost pump was completed. An operational check of the pump was then attempted and failed. Two of three circuit breakers for the AC three phase pump opened and no boost pressure was noted. It is noteworthy that the same two circuit breakers had opened while enroute on a prior flight leg which resulted in a log book write up "No.1 main boost pump inop". Maintenance replaced the fuel boost pump with the second pump to see if the malfunction could be cleared. Electrical power from an external power unit was reconnected after a "low fuel" warning signal was activated. Inspection of the newly installed fuel boost pump electrical connector was conducted.

At 2008 PDT an explosion occurred in the left wing center section. The upper wing surface between nos. 1 and 2 engines was blown forward and away from the airplane centerline some 250 feet from the airplane. A fire then began which engulfed the entire left wing, fuselage, and inboard right wing. Evidence from the recovered fuel boost pumps and connectors revealed no evidence of burning. The explosion resulted in hull loss, and one fatality.

The investigation also points to an external ground power unit that was supplying power to the aircraft while tank maintenance was being performed. It also mentions a flashlight which one of the mechanics on the wing had in his possession which had a broken "flasher" switch i.e. the switch that allows the user to momentarily activate the light without locking it on or off. Most of the recommendations from everyone involved focused on procedures to prevent another accident. No conclusive evidence of an ignition source was established.

### Mitigating Action Taken

The mitigation action taken for this event has yet to be determined.

### **Refuelling Events**

9.	Date:	<b>3 May 1970</b>	Flight phase:	<b>Refuelling</b>
	Aircraft:	<b>Boeing 727</b>	Tank type:	<b>Center</b>
	Location:	<b>Minneapolis</b>	Fuel type:	<b>Jet A</b>

The airplane was being refuelled using a single-point refuelling system. About 2,000 lbs of fuel had been loaded when a heavy muffled explosion occurred in the No.2 (cheek tank). A puff of gray smoke came from the LH wing tip vent. Fuelling was immediately terminated, all electrical power on the airplane was cut off, the APU was shutdown, and the aircraft was de-fuelled.

No injuries had occurred. No damage was apparent from an external check of the aircraft. The damage was largely confined to the secondary structure within the No.2 tank on the LH side of the airplane. When inspecting the tank, it was found that the structure above the top level of the fuel was heavily soot blackened. The ribs visible from the front spar access hole exhibited heavy deflection and distortion and the stringers were also damaged. Some pulled rivets were noticeable in the LH wing. The formed covers for the fuel boost pump were "hydro-pressed" down over both the RH and LH pumps, but no leaks had developed.

No faults in the electrical systems of the aircraft in and around tank No.2 were found. It is presumed, in the absence of any electrical sources, that ignition resulted from a static discharge within the No.2 tank.

Time of day was 8:28 am. Fuel temperature was 55°F. Flash point of samples was: Tank #1-118°F, Tank #2 - 120°F, Tank #3 - 110°F and the Storage tank from which the fuel was loaded was 127°F.

At the time of the event the following airplane systems were operating; the APU was operating and the LH pack was on to heat the cabin, All navigation lights on. No boost pumps were on.

The duration of the fuelling was approximately 5 minutes with the No.2 tank 31% full.

Mitigating Action Taken

No mitigating action taken since no root cause for an ignition source was found.

10.	Date:	<b>23 December 1970</b>	Flight phase:	<b>Refuelling</b>
	Aircraft:	<b>Boeing 727</b>	Tank type:	<b>Center</b>
	Location:	<b>Minneapolis</b>	Fuel type:	<b>Jet A</b>

The airplane was being refuelled using under-wing refuelling at the RH wing station. Approximately 3,000 pounds of fuel had been loaded when a muffled explosion was heard. Fuelling was immediately stopped and a minor leak was noticed coming from the area of the inboard boost pump in the LH wing. There was no fire and no injuries to any of the servicing personnel. Over-pressure damage to the aircraft's No.2 fuel tank was extensive but minor in nature.

The aircraft was being readied for its next departure. Besides the refuelling operations, other activity around the aircraft included baggage loading and de-icing operations. Some light snow was being stirred around by a wind that was blowing from the left to the right wing at 18 knots with gusts to 24 knots. The outside ambient temperature was +8°F.

After about 5 minutes of fuelling with kerosene type A (Jet A) , a harsh muffled explosion shook the aircraft with a large white cloud of smoke or vapor issuing from the LH wing root area and continuing for about 30 seconds. The outboard boost pump cavity access door was split in two with half flying across the apron and half still dangling from the opening. Fuel was leaking from the cavity area in a stream about the size of a pencil diameter. The fueller immediately dropped the "dead man" switch and closed both fuelling nozzles. The fire department was then summoned, and they hosed down the area.

Subsequent examination of the aircraft revealed minor exterior physical damage, most noticeable being the blown-off access door, collapsed and fractured number 2 tank LH fuel boost pump cavity housing, and popped rivet heads on the number 2 tank LH upper skin area. Interior physical damage was quite extensive within the number 2 fuel tank. Both the No.1 and No.3 tanks were undamaged. Evidence of soot deposits were found within the left and right hand surge tanks, the number 2 fuel tank, and at each wing tip fuel tank vent scoop area.

The investigation that followed the incident indicated that the probable cause of the explosion was delivery by the ground fuelling system of highly charged fuel into the airplane. However, the investigation was unable to pinpoint the exact source of ignition that triggered the combustion of the fuel vapor. The evidence is very strong, however, that the source of ignition was static discharge internal to the number 2 fuel tank.

Time of day was 6:18 am. Fuel temperature was 31°F. Flash point of samples was: Tank #1-119°F, Tank #2 - 118°F, Tank #3 - 124°F and the Storage tank from which the fuel was loaded was 121°F.

At the time of the event the following airplane systems were operating: APU, all navigation lights on, No.2 tank boost pumps on and all crossfeed valves open.

The duration of the fuelling was approximately 5 minutes with No.2 tank 32% full.

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### Mitigating Action Taken

The paper element filter separators in the ground refuelling equipment were replaced with filters that did not create electrostatic charging.

There has been no recurrence of a refuelling related event to this model since changes were made.

11.	Date:	<b>21 June 1973</b>	Flight phase:	<b>Refuelling</b>
	Aircraft:	<b>McDonnell Douglas DC-8</b>	Tank type:	<b>Wing</b>
	Location:	<b>Toronto</b>	Fuel type:	<b>JP-4 / Jet A mix</b>

The airplane was at the gate and a ground power unit was connected to the airplane's electrical system when a fuel tank explosion blew off pieces of the right wing top skin and spar structure. Burning fuel rapidly engulfed the right wing. The aircraft was destroyed and two ramp servicing personnel were seriously burned.

The aircraft was being fuelled with Jet B (JP-4), but examination of the left wing tanks revealed a fairly even mix of Jet A-1 and Jet B. Some Jet A-1 was already in the tanks. The ambient temperature was 76°F.

Shortly thereafter an explosion occurred in the right wing. A 20 foot long piece of wing upper skin covering the forward portion of number 3 alternate and number 4 main tank was blown high into the air and landed about 100 feet to the right of the aircraft. Flames erupted from the right wing and burning fuel was sprayed onto a man on a conveyor who leaped off toward the rear of the aircraft. This explosion was followed almost immediately by another which blew a 10 foot long piece of the upper wing skin from the aft section of the number 3 alternate tank to a position forward and to the left of the aircraft. The loss of this skin allowed the right wing to collapse, hinging from the bottom skin. Burning fuel ran from the ruptured number 4 tank and fuel manifold over the leading and trailing edges of the wing. The fuel under the right wing ran toward the front of the aircraft through the fire that now extended to the ground and he was doused with burning fuel. Both the refueller and the cargo handler were seriously burned. No passengers had boarded the aircraft. The nine crew members aboard evacuated through the loading bridge.

The findings of the Canadian Department of Transportation were that the initial explosion occurred in the number 3 alternate tank and that the fuel vapor was ignited in the wing vent system. The source of ignition of fuel vapor in the wing tank vent system could not be definitely determined, but was suspected to have originated outside the aircraft.

### Mitigating Action Taken

It is believed that no direct action was taken since it appeared that ignition of the fuel vapor had taken place outside the aircraft adjacent to the vent outlet.

12.	Date:	<b>6 June 1989</b>	Flight phase:	<b>Refuelling</b>
	Aircraft:	<b>Beechjet 400</b>	Tank type:	<b>Aux Tank</b>
	Location:	<b>Washington D.C.</b>	Fuel type:	<b>JP-4 / Jet A mix</b>

The aircraft departed early in the morning from Jackson, Mississippi enroute to New Orleans. Early in the afternoon the airplane returned to Jackson and was refuelled with JP-4. At approximately 4:00 p.m. CST the airplane departed from Jackson enroute to National Airport in Washington, DC. After arrival in Washington, the crew spent approximately one hour securing the airplane before departing for the hotel. Line service then began refuelling operations. Operations manager advised that the fuel truck was grounded to the airplane and also to the fuel ramp grounding point. Main wings were topped off first with Jet A fuel. Line personnel then began to service the aft tanks. Prior to service, there was approximately 200 pounds of fuel remaining in the tanks. After pumping five gallons into the aft tank through the aft filler port, line personnel reported hearing a hissing noise followed by a bang. Fuel surged out of the filler

opening and covered the line service personnel. At this point, refuelling was terminated and the pilots were contacted. At the time of refuelling there were thunderstorms in the area at the time of refuelling. Shortly after the refuelling operations began, heavy rain began falling in the area of the airport.

Fuel was later noted dripping from the underside of the airplane. After the cabin interior seats were removed to gain access to the aft fuel tank, it was found to be torn loose from all 14 fuselage attach points. The tank had expanded significantly from internal pressure. The forward access panels on the tank were removed for internal viewing. The inside of the tank exhibited very heavy carbon deposits throughout the tank and especially on the upper surface of the horizontal support frames within the tank. These deposits indicate some type of fire or detonation occurred inside the tank.

The investigation concluded the most probable cause was that during refuelling of the interconnected fuselage and auxiliary tanks, an electrostatic discharge occurred which resulted from charged fuel entering the aft auxiliary tank from the fuselage tank. The fuselage mounted tank had a blue foam installed in the tank to protect against rotor burst threats. The foam being used at the time was determined to have low conductivity characteristics and was able to build up an electrostatic charge which subsequently discharged in the aft tank that did not have the protective foam installed.

Mitigating Action Taken

Final action resulted in an airworthiness directive to replace the blue foam with a more conductive foam and install additional bonding and grounding to the subject fuel tank.

**Other - Parked in Hanger**

13.	Date:	<b>2 June 1982</b>	Flight phase:	<b>Parked</b>
	Aircraft:	<b>McDonnell Douglas DC-9</b>	Tank type:	<b>Fwd Aux Tank</b>
	Location:	<b>Montreal</b>	Fuel type:	<b>Jet A-1</b>

While the airplane was parked in the hangar, it is believed that a fuel boost pump located in the forward auxiliary fuel tank had been left on and overheated, causing an over-pressure in the (de-fuelled) tank, and a subsequent fire which destroyed the aircraft. Structural analysis of the auxiliary tank did not show signs of an “explosion” but did show signs of rapid over-pressure in the tank. The residual fuel in the forward auxiliary fuel tank (estimated at 2.6-3 US gallons) was insufficient for pump priming; therefore there was no motor cooling which resulted in excessive fuel vapor generation within the tank. The exact source of ignition could not be determined during the investigation but out of the four electrically operated components in the auxiliary tank, three could be ruled out as spark producing agents. These are: the fuel quantity probes and the float switch which were not energized and the fuel pressure switch which was found in good condition and its electrical wiring is installed in a metal tube. The fourth item, the transfer pump power supply harness, is the most probable source of sparks. Examination of electrical assemblies on other aircraft indicated burned sockets and pins at the pump connector. The burn marks were the result of arcing. If a faulty connector has a secondary failure at the harness pressure seal, a spark could ignite a critical fuel vapor/air mixture. Considered a serious over-pressure event.

Mitigating Action Taken

No aircraft-related action was taken since this was treated as an industrial accident rather than an event affecting airworthiness.

14.	Date:	<b>11 May 1990</b>	Flight phase:	<b>Climb</b>
	Aircraft:	<b>Boeing 727-100</b>	Tank type:	<b>Center tank</b>
	Location:	<b>Bogota, Colombia</b>	Fuel type:	<b>Jet A</b>

The airplane was climbing through 10,000 feet when an explosion occurred. Investigator reports discovered evidence of a bomb explosion. Close examination of the aircraft structure revealed evidence

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on the RH side of the passenger cabin between the emergency overwing exits. The evidence indicated the force generated by the blast compromised the structural integrity in this area causing a fuel tank rupture, fire, and inflight structural breakup of the right wing. The local ambient temperature reported at the airport was 52°F.

### **Cause Unknown**

15. Date:	<b>11 May 1990</b>	Flight phase:	<b>Parked / Push Back</b>
Aircraft:	<b>Boeing 737-300</b>	Tank type:	<b>Center tank</b>
Location:	<b>Manila, Philippines</b>	Fuel type:	<b>Jet A</b>

While being pushed back from the gate, the center tank exploded and burned. At the time of the explosion, the engines were not running and the aircraft electrical power and air-conditioning were supplied by the Auxiliary Power Unit (APU). Preliminary evidence indicates that ignition of the fuel-air mixture in the center fuel tanks was the cause of the explosion and subsequent fire. The investigation focused on the center fuel tank, which was determined to be the source of the explosion, and the possibility of an explosive or incendiary device, an external source of ignition or mechanical and/or electrical failure as a source of ignition. The investigation found no evidence of a bomb, an incendiary device, or sabotage. The investigation has yet to reveal the exact ignition source.

At the time of the accident, all the fuel boost pumps were in the “on” position. The center fuel tank had not been filled since 9th March 1990. During the pushback of the airplane the center fuel tank low pressure light illuminated, indicating that the center fuel tank had been emptied of all usable fuel. Laboratory examination of the fuel samples from the airplane and fuel storage tanks indicates that the fuel vapor in the center tank would have had a flash point of between 112 - 117°F. The ambient temperature at the time of the accident was 95°F. The fuel was estimated to be approximately 115°F based on samples of fuel drawn from other similar airplanes following the incident. It was estimated that approximately 90 pounds of fuel was in the center tank.

Of the 114 passengers and six crew members, eight were fatally injured and 30 sustained injuries.

### Mitigating Action Taken

Boeing published an all operators bulletin reminding flight crews to not operate the center boost pumps when no usable fuel was available in center tank.

16. Date:	<b>17 July 1996</b>	Flight phase:	<b>Climb</b>
Aircraft:	<b>Boeing 747-100</b>	Tank type:	<b>Center tank</b>
Location:	<b>New York</b>	Fuel type:	<b>Jet A</b>

The airplane was climbing near 13,800 feet (msl) when an inflight explosion occurred in the center wing fuel tank approximately 13 minutes after takeoff, resulting in loss of structural integrity inflight. The center wing tank was estimated to contain approximately 100 gallons of fuel. Prior to dispatch of the airplane, the air-conditioning air cycle machines, located under the center wing tank, had been operating for up to 2 hours. The center wing tank estimated fuel temperatures was 113-115°F. At the altitude and temperatures of the event, the fuel tank air/vapor mixtures were considered to be flammable. The fuel type was Jet A. There were 230 fatal injuries including the flight crew.

### Mitigating Action Taken

A series of service bulletins have been issued against the B-747 series, covering fuel pump electrical installation inspections, addition of a scavenge pump flame arrestor, and inspections and replacements of FQIS wiring and probes.

For the B-737 series (which has a similar fuel system), bulletins covering fuel tank system component and wiring inspections, and flame arrestors in the vent system are being incorporated.

**ATTACHMENT B - ANALYSIS PARAMETERS AND SUMMARY INFORMATION**

This Attachment documents the parameters used in the forecast as discussed in section 4.4

Figure B-1 provides the baseline flammability levels for each of the generic airplanes and tank types predicted using a computer model developed by the FAA and refined by this ARAC. In addition a breakdown by tank type is provided of the flammability levels after inerting.

Baseline Flammability by Tank Type	Large	Med	Small	R-Fan	R-Prp	Bizjet
Heated CWT	36.2	23.5	30.6	N/A	N/A	N/A
Unheated CWT	6.8	N/A	5.1	2.6	N/A	N/A
Aux Tank	21.8	16.7	8.8	N/A	N/A	N/A
Wing Tank	3.6	2.4	3.6	1.6	0.7	1.6
Heated CWT Flammability after inerting						
GBI	4.9	2.0	5.2	N/A	N/A	N/A
OBI	6.7	1.4	5.5	N/A	N/A	N/A
OBI, Hybrid	7.0	1.4	5.8	N/A	N/A	N/A
OBIIGGS	0.0	0.0	0.0	N/A	N/A	N/A
OBIIGGS Hybrid	0.9	0.6	0.3	N/A	N/A	N/A
Unheated CWT Flammability after inerting						
GBI	0.4	N/A	0.4	0.1	N/A	N/A
OBI	0.9	N/A	0.7	0.0	N/A	N/A
OBI, Hybrid	0.8	N/A	0.6	0.1	N/A	N/A
OBIIGGS	0.0	N/A	0.0	0.0	N/A	N/A
OBIIGGS, Hybrid	0.1	N/A	0.1	0.0	N/A	N/A
Aux Tank Flammability after inerting						
GBI	0.2	0.2	0.2	N/A	N/A	N/A
OBI	0.3	0.3	0.3	N/A	N/A	N/A
OBI, Hybrid	0.3	0.3	0.5	N/A	N/A	N/A
OBIIGGS	0.0	0.0	0.0	N/A	N/A	N/A
OBIIGGS, Hybrid	0.2	0.3	0.1	N/A	N/A	N/A
Wing Tank Flammability after inerting						
OBIIGGS	0.0	0.0	0.0	0.0	0.0	0.0
OBIIGGS, Hybrid	0.8	0.2	0.4	0.02	0.02	0.01

Figure B-1. Baseline Flammability and Flammability after inerting by tank type and design concept

Figure B-2 shows the tank mix by generic airplane family, the tank mix data was taken from the 1998 Fuel Tank Harmonization Working Group final report.

Tank/Airplane Fleet Combination	Percent of Fleet with Tank, Year 2000	Percent of Fleet with Tank, Year 2020 (Column left blank if no change from year 2000 assumed)
Heated CWT, Large Transport	64	84
Heated CWT, Medium Transport	78	88
Heated CWT, Small Transport	72	84
Heated CWT, Regional Turbofan	0	
Heated CWT, Regional Turboprop	0	
Heated CWT, Bizjet	0	
Heated or Unheated CWT, Large Transport	92	
Heated or Unheated CWT, Medium Transport	78	88
Heated or Unheated CWT, Small Transport	97	
Heated or Unheated CWT, Regional Turbofan	50	
Heated or Unheated CWT, Regional Turboprop	0	
Heated or Unheated CWT, Bizjet	0	
Wing Tank, Large Transport	100	
Wing Tank, Medium Transport	100	
Wing Tank, Small Transport	100	
Wing Tank, Regional Turbofan	100	
Wing Tank, Regional Turboprop	100	

Wing Tank, Bizjet	100	
Aux Tank, Amb Press, Large Transport	5	
Aux Tank, Amb Press, Medium Transport	0	
Aux Tank, Amb Press, Small Transport	5	
Aux Tank, Amb Press, Regional Turbofan	0	
Aux Tank, Amb Press, Regional Turboprop	0	
Aux Tank, Amb Press, Bizjet	0	

Figure B-2. Tank Type Distribution by Generic Airplane Family

Figure B-3 provide the operating hour information that formed the basis for the forecast. The data was assembled using OEM data where available. The remaining flight hour information was obtained from an independent company that records this information. Bizjet data were unavailable, but an OEM provided an estimate for Bizjet utilization.

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
Cumulative Operating Hours Through Year 2000	$1.2 \times 10^8$	$0.5 \times 10^8$	$4.2 \times 10^8$	$0.2 \times 10^8$	$2.4 \times 10^8$	$0.7 \times 10^8$	$9.2 \times 10^8$
Annual Worldwide Operating Hours, Year 2000	$7.4 \times 10^6$	$3.3 \times 10^6$	$19.4 \times 10^6$	$3.3 \times 10^6$	$14.7 \times 10^6$	$5.2 \times 10^6$	$53.3 \times 10^6$
Annual N-registered Operating Hours, Year 2000	$1.8 \times 10^6$	$1.4 \times 10^6$	$10.1 \times 10^6$	$1.5 \times 10^6$	$5.9 \times 10^6$	$4.0 \times 10^6$	$24.7 \times 10^6$

Figure B-3. Operating Hour Information

Figure B-4 gives a breakdown of the estimated pre-SFAR No. 88 accident rate based on the three most recent events. In addition the forecast worldwide-unconstrained fleet growth values are shown. These were derived from the Campbellhill World Jet Fleet Forecast (2000-2020) conducted for the Air Transport Association and were used to forecast fleet operating hours in the future. Finally, the figure shows the forecast accident breakdown by generic airplane family.

	Large	Med	Small	R-Fan	R-Prp	Bizjet	Total
Accident Rate pre-SFAR No. 88	$8 \times 10^{-9}$	$8 \times 10^{-9}$	$8 \times 10^{-9}$	$6 \times 10^{-10}$	$1 \times 10^{-10}$	$4 \times 10^{-10}$	$5 \times 10^{-9}$ (weighted avg)
Forecast Annual Fleet Growth (percent)	4.9	4.4	3.9	4.2	2.9	3.4	3.6 (weighted avg)
Forecast Worldwide Operating Hours, Year 2001 through 2020	$2.5 \times 10^8$	$1.1 \times 10^8$	$6 \times 10^8$	$1.1 \times 10^8$	$4 \times 10^8$	$1.5 \times 10^8$	$16.1 \times 10^8$
Forecast Worldwide Accidents pre-SFAR No. 88	~2	~1	~5	~0	~0	~0	~8

Figure B-4. Accident Forecast Summary Information

The tasking statement asked that the team consider that MEL relief would be available. The team assumed that if 10 day MEL relief were granted, the average repair deferral time would be 5 days. Based on the system reliability predictions made by the Airplane Operations and Maintenance Task Team, this resulted in an average system availability of 91% for onboard systems and 99.5% for ground based inerting. These were factored in to the forecast as discussed in section 4.4.



Appendix I  
Rulemaking Task Team Final Report

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# ***Rulemaking Task Team Final Report***

This report summarizes the work done by the rulemaking task team in support of the overall arac fuel tank inerting harmonization working group task.

## **1.0 RULEMAKING TEAM'S TASK**

The rulemaking team's task was defined in accordance to the FTIHWG's tasking statement. It was defined as follows:

1. To review existing regulations/advisory material/continued airworthiness instructions regarding the subject of eliminating or reducing the flammable environment in airplane fuel tank systems.
2. To prepare and coordinate within the HWG a regulatory text, for use in new rulemaking initiatives by the FAA, that would eliminate or significantly reduce the flammable environment in airplane fuel tank systems. The tasking statement stated that the recommendation proposal would be based on achieving the lowest flammability level that could be provided by [an inerting system] design that would meet FAA regulatory evaluation requirements.
3. For all system concepts recommended, develop and propose guidance material that describes the necessary analysis and/or testing that may be required to show compliance with the new regulatory text for certification and continued airworthiness.

## **2.0 METHODOLOGY USED TO ACHIEVE THE TASK**

The methodology used by the rulemaking task team to achieve the task was as follows:

### Basic Assumptions:

The rulemaking team assumed that both ground-based inerting and on-board inerting designs need to be certified and utilized. This assumption was made because the practicality of either design was unknown.

1. Determination of 14 CFR sections to be evaluated

The team determined which Title 14 of the U.S. Code of Federal Regulations (14 CFR) sections might be impacted by the two inerting-designs by examining the aircraft utilization. The team confirmed that, at a minimum, aircraft certification, aircraft maintenance and operational approval and airport facilities may be impacted. The team concluded that an assessment of the major issues affecting the 14 CFR could easily be transferred to a JAR assessment if final rulemaking was pursued.

2. Analyses of the regulatory impact on existing 14 CFR codes

The team then used the design concepts, developed by the other FTIHWG teams, to analyze the impact on the existing regulations/advisory material/continued airworthiness instructions. This analysis was done throughout the FTIHWG process in order to ensure that all design issues were accounted for in the final 14 CFR change recommendations.

3. Development of guidance material

Guidance material was developed to support the 14 CFR change proposals.

4. Flammability regulatory text proposals

Finally, regulatory text proposals that could be used by the FAA to regulate an airplane's fuel tank environment on the level of flammability reduction achieved by a practicable inerting system design concept were proposed to the Harmonization Working Group (HWG). The rulemaking team highlighted the pros and cons of each proposal, including its possible certification interpretations and its capability to allow an inerting system as an acceptable means of compliance.

5. Certification Cost Assessment

The regulatory team estimated a certification cost for both ground and on-board inerting systems. The costs were then inputted into the regulatory evaluation cost forecast.

6. HWG flammability regulatory text recommendation

The HWG was tasked to decide which proposal, if any, to recommend. The HWG's recommendation would be based on the outcome of the cost/benefit evaluation performed by the FTIHWG.

**3.0 14 CFR EVALUATION**

**3.1 DETERMINATION OF 14 CFR SECTIONS TO BE EVALUATED**

The team identified and conducted a review of the 14 CFR sections relating to aircraft certification, aircraft maintenance and operational approval and airport facilities. The 14 CFR 1-1-00 Edition as published by the U.S. Federal Aviation Administration, DOT was used as the review basis.

The European Joint Aviation Requirements (JARs) were not used as a reference basis because of the lack of JAR operational regulatory (JAR ops) expertise on the rulemaking team.

The rulemaking team concluded that the lack of JAR ops expertise and the lack of an in-depth review of the JARs did not deter the overall review objectives. The team knew that the 14 CFR and JAR part 25 aircraft certification requirements are very similar and that any differences are already documented. The team also knew that the intent of both 14 CFR and JAR operational regulations are similar. Therefore, the team decided that JAR experts could evaluate their codes, as appropriate, if a clear and concise explanation of the regulation assessment is provided.

Aircraft Certification

The rulemaking team assessed:

- 14 CFR part 21 - Aircraft -Certification Procedures for Products and Parts
- 14 CFR part 25 -Airworthiness Standards: Transport Category Airplanes

Both of these sections are utilized when certifying a Transport Category airplane and were the affected by the FAA's ignition source prevention activity (SFAR No. 88).

Other aircraft type certification standards such as 14 CFR part 23 -Airworthiness Standards: normal, utility, acrobatic and commuter category airplanes, were not assessed. The rulemaking team decided that the FAA could use the recommendations made for 14 CFR part 21 and 14 CFR part 25 to assess and to modify, if necessary, similar 14 CFR parts.

Maintenance and Operational Approval

The rulemaking team identified and assessed the following 14 CFR sections that relate to aircraft maintenance and operations:

- Part 43 - Maintenance, Preventative Maintenance, Rebuilding, and Alteration
- Part 91 - General Operating and Flight Rules
- Part 121 - Operating requirements: Domestic, flag and supplemental operations
- Part 125 - Certification and operations: Airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 or more
- Part 129 - Operations: Foreign air carriers and foreign operators of U.S.-registered aircraft engaged in common carriage

The part 43 assessment was carried out independently.

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The other parts were assessed using part 121. That is, the team assumed that any change applicable to part 121 could be read over to parts 91/125/129. This assumption was made based on FAA's ignition source prevention activity (NPRM 99-18/SFAR No. 88 effective June 6, 2001).

The team did not consider Part 135 - operating requirements: Commuter and On-Demand Operations. The rulemaking team decided that the FAA could adapt the recommendations made for 14 CFR part 91/121/125/129 to other similar 14 CFR parts.

### Airport Facilities

The rulemaking team identified and assessed 14 CFR part 139: Certification and Operations: Land Airports Serving Certain Air Carriers.

### Environment

The rulemaking team identified and assessed 14 CFR part 34, Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes. The team discussed whether to review ICAO regulations, but decided that ICAO regulations were very similar to 14 CFR part 34. Any conclusions made for 14 CFR part 34 could be used to initiate changes in other regulatory codes, e.g. ICAO, JAR.

## **3.2 ANALYSES OF THE REGULATORY IMPACT ON EXISTING 14 CFR CODES**

### **3.2.1 General Review Procedures**

The rulemaking team assessed each 14 CFR individually.

The team identified the purpose of each CFR part.

It then used engineering judgement and certification experience to conduct an evaluation of each section's regulations considering:

- both ground and on-board inerting system design concepts
- the possibility to introduce inerting systems via retroactive rulemaking (Special Federal Aviation Regulation - SFAR).

The review procedure was refined for each CFR part and is detailed in each subsection below. The procedure refinement was needed in order to ensure the completeness of the evaluation.

### **3.2.2 Review of 14 CFR Part 21**

14 CFR part 21 provides aircraft certification procedures for products and parts.

#### Review Purpose

The purpose of the rulemaking's team review was to see if any of the current certification procedures would need to be changed if inerting systems were implemented on transport category airplanes.

#### Review Procedure

The rulemaking team evaluated 14 CFR part 21 considering:

- a. Type certification / modification activities
- b. Retroactive rule action - SFAR

The group's review basis was as follows:

“For the two certification considerations above, “Do the 14 CFR part 21 regulations permit an inerting system to be certified on a transport category airplane?” If yes, then no changes should be proposed. If no, then state the change.

Because this section concerns procedures, the group decided that the conclusions reached would be equally applicable for ground and on-board inerting systems.

Review Conclusions

a. Type certification / modification activities

The current regulations are sufficient. No changes are proposed.

b. Retroactive rule action - SFAR

Any retroactive rule action initiated by the FAA would require a change to 14 CFR part 21, the Special Federal Aviation Regulations (SFAR) section.

The SFAR regulatory action would need to state the aircraft applicability and the required compliance, including the task accomplishment statement and FAR 25 rule references, the time frame for compliance and the reference to any maintenance or inspection activities.

**3.2.3 Review of 14 CFR Part 25**

14 CFR part 25 provides airworthiness standards for transport category airplanes; the standards that are used to certify an aircraft, its systems and components.

Review Purpose

The purpose of the rulemaking team's review was to:

- identify which regulations would be part of an inerting system's overall certification compliance plan
- identify if any of the existing regulations need to be modified or if any new regulations need to be created (besides the flammability rule itself) due to the uniqueness of the inerting system's design
- prepare a performance-based flammability regulatory text based on the level of flammability reduction achieved by a practicable inerting system design concept that could be recommended for incorporation into 14 CFR part 25.

Review Procedure

The rulemaking team decided to breakdown this assessment into two parts:

1. the assessment of the regulatory text that require an inerting system to be installed on an aircraft (performance-based flammability regulatory text or *flammability rule*)
2. the assessment of the rules governing the design of the inerting systems (*inerting system rule*)

Part 1 - Implementation of an inerting system via 14 CFR part 25 - Flammability rule

Prior to initiating the FTIHWG, the FAA had proposed via NPRM 99-18 a performance-based flammability regulatory proposal. The Industry made a counter-proposal to the FAA as part of the docket's comments.

The task team decided to use these two proposals as a working basis for any future regulatory text proposals.

Because these two proposals were general in nature and both allowed for an inerting system to be implemented, the team decided to conduct an evaluation of the inerting system itself in order to make sure that all certification issues were understood.

Once the FTIHWG completed its inerting systems' evaluations, then the "implementation" regulatory text (flammability rule) proposals would be revisited.

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A comprehensive discussion of how the team assessed the regulatory text that would cause the implementation of an inerting system (performance-based flammability regulatory text) is found in section entitled “Flammability Regulatory Text Evaluation and Proposal”.

### Part 2 - Inerting system design vs 14 CFR part 25

The impact of the proposed inerting systems on the 14 CFR part 25 code were determined by conducting a certification compliance evaluation of the FTIHWG’s ground based and on-board inerting design concepts.

#### 1. Identification of technical considerations

The team first identified the technical considerations that are addressed within 14 CFR part 25. Three technical considerations for the system were identified:

- safety
- design, including installation requirements
- performance

#### 2. Identification of subtopics within the identified technical considerations

These three categories were further subdivided as follows:

##### a. Safety

- Fire protection, explosion proof
- System safety analysis: FHA, FMEA
- Overpressure protection for fuel tank / airplane
- Crashworthiness
- Venting and drainage protections
- Ignition source isolation evaluation
- Physiological effects

##### b. Design, including installation requirements

- Mechanical systems: integrity of components and system integration
- Electrical systems: integrity of components and system integration
- NEA distribution capability; assurance that the design maintains an inert condition as declared.
- Influence of fuel types on the performance of the inert system
- Structural: structural integrity of components and system integration
- Retention of the fuel tank’s structural integrity (i.e. tank is not over pressurized)
- Control systems: software and hardware
- Incorporation of lessons learned, as applicable
- Line routing flexibility and support, including system layout
- Effect of rotorburst

- Identification of aircraft flight conditions excluded from the evaluation (example rapid descent)
- Assurance that other fuel system and engine functions and safety features are not significantly affected (i.e. fuel sensor indications, warning and automatic stop features, refuel sequences, tank transfers, ...)
- NEA supply specification
- Design objectives; level of redundancy
- Aircraft flammability characteristics within applicant's flight operation envelope and environmental envelope level (needed to substantiate performance considerations).

c. Performance Considerations

- Identification of the system's performance versus flight phase. The systems performance criteria were taken from the tasking statement.
  - For ground based inerting, it was assumed that the system would provide inert gas to the aircraft fuel tank(s) once the airplane reaches the gate, while the aircraft is on the ground between flights and the tanks should remain inert during taxi for takeoff, takeoff, climb and cruise.
  - For on-board ground inerting, it was assumed that the system would provide inert gas to the aircraft fuel tank(s) once the airplane reaches the gate, while the aircraft is on the ground between flights and the tanks should remain inert during taxi for takeoff, takeoff, climb and cruise.

3. Review basis

For each of the subtopics above, the team answered the following questions, once for ground based inerting - component and system level, and once for on-board inerting - component and system level:

- a. *WHY* - Identified the certification concern.
- b. *APPLICANT ACTION* - Identified the design considerations and acceptable methods of compliance that could be used to address the certification concern (of (a)).
- c. *REFERENCE* - Identified the associated 14 CFR part 25 paragraph and identified any areas where the existing paragraphs were insufficient to address the proposed design concepts.

The insufficiencies were recorded and identified as potential 14 CFR part 25 change proposals that are needed in order to accommodate fuel tank inerting systems within the existing regulatory framework.

Review Conclusions

Part 1 - Implementation of an inerting system - Flammability rule

This assessment was conducted separately. The conclusions are found in section entitled "Flammability Regulatory Text Evaluation and Proposal".

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## Part 2 - Inerting system design vs 14 CFR part 25

The review identified a total of:

- three (3) insufficiencies in 14 CFR 1-1-00 Edition
- thirty six (36) applicable paragraphs in 14 CFR 1-1-00 Edition
- three (3) new concerns unique to inerting systems

Due to the number of considerations that must be regulated within a fuel system inerting design, the team recommends that if inerting systems are to be installed on transport category airplanes, then a dedicated 14 CFR part 25 paragraph, entitled “Fuel Tank Inerting System” should be adopted. This paragraph should be worded in such a way that it can apply to both ground and on board inerting systems. A proposed wording is given below:

### Inerting System Regulatory Text Proposal

“§25.xxx Fuel Tank Inerting System

If, in order to show compliance with §25.981(c), a fuel tank inerting system is installed,

- (a) the fuel tank inerting system must not, under normal and failure conditions:
  - (i) allow any inerting agent leakage into the pressurized or personnel compartments, or confined spaces; and
  - (ii) allow overpressure of the fuel system.
- (b) The fuel tank inerting system must have:
  - (i) A connecting port such that a cross connection with any other supply line is not possible (applicable if supplied by an external inerting gas source).
  - (ii) At each inerting agent filler opening and each aircraft opening leading to direct contact with the inert gas, a placard at or near the filler cover or opening with the words “Fuel tank inerting” and the agent denomination.
  - (iii) A means to prevent the escape of hazardous quantities of fuel from the system in the case of loss of system supply pressure.
  - (iv) A shutoff or isolation means, whose failure to function is evident, that prevents undesirable system functioning and possible fuel leakage.
  - (v) A tolerance to variable inerting gas pressures or surges in the gas delivery system.
- (c) Cautions (placards) and warnings (indication system) should be provided to prevent unintentional entry into a confined space filled with a hazardous inert gas.
- (d) The characteristics and designation of the inert gas that ensure correct operation of the fuel tank inerting system shall be recorded in the operating limitations section of the Aircraft Flight Manual or equivalent.”

#### a. Insufficiencies

##### 1. Placards

First insufficiency was found in reviewing the physiological effects of inerting. Because nitrogen enriched air (NEA) is a hazardous substance, the team determined that a placard should be mandated to advise maintenance personnel of the presence of NEA. This mandate can only be enforced via a change to 14 CFR part 25.

The team recommends that the existing 14 CFR §25.1557 - “Miscellaneous markings and placards” - be used to mandate this placard. An additional paragraph (e) “fuel tank inerting systems” can be easily added. This recommendation is applicable to any type of inerting system.

Conclusion:

Add a paragraph (e) to §25.1557 to state that any opening in the aircraft leading to direct contact with NEA should have a placard or be marked with the word “nitrogen” or “NEA” at or near the opening

OR

Create a new fuel system inerting paragraph and include this concern. (see §25.xxx (b)(ii))

2. Ground Based NEA Inerting Filler Connection

Second insufficiency was found when reviewing the ground-based inerting coupling (filler connection). The team determined that the process of filling the tank with NEA could be hazardous if certain design precautions were not taken. For instance, there could be undesirable physiological effects if NEA leaked to other parts of the aircraft or undesirable electrostatic effects if fuel was pumped through NEA distribution system. The list below provides a minimum number of design precautions to be taken. These precautions are similar to those mandated within §25.973 - Fuel Tank Filler Connection.

- Ensure that NEA cannot enter into any part of the aircraft other than the tank itself
- Ensure that the refuel hose connection and the NEA gas hose connection are incapable of cross connection
- Each NEA gas cap must provide a tight seal
- If appropriate (design dependent), provide for electrically bonding the airplane to the NEA inerting ground equipment.

The above design precautions can only be assured if a change to 14 CFR part 25 is initiated.

Therefore, the team recommends that, for ground based inerting systems only, either 14 CFR part 25 §25.973 be amended to include provisions for NEA gas coupling connector or a 14 CFR part 25 paragraph be created to include the above provisions.

Conclusion:

Add a new paragraph to 14 CFR part 25 or amend §25.973 to ensure that the Ground Based NEA Inerting Filler Connection meets the same safety standards as the Fuel Tank Filler Connection and to ensure that the refuel hose and the NEA gas hose cannot be cross connected.

OR

Create a new fuel system inerting paragraph and include this concern. (see §25.xxx (b)(i))

3. Ground Based NEA Inerting - Pressurized system

The third insufficiency was found when reviewing ground based inerting components. NEA is added to the tank via a pressurized ground system. The team therefore determined that the safety precautions for introducing pressurized NEA to the aircraft would be similar to those already mandated for fuel in 14 CFR §25.979 - Pressure Fueling System. Specifically, the team examined four subparagraphs of 25.979: §25.979(a) - addresses the manifold connection, §25.979(b) - addresses the shutoff means, §25.979(c) - addresses prevention of damage to the fuel system in case of shut off valve failure and 25.979(d) - addresses the pressure fueling system structural capability.

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Similar to §25.979(a), the team determined that the ground based inerting system should have means to prevent the escape of hazardous quantities of fuel from the system (via backflow) in the case of loss of pressure to the NEA supply.

Similar to §25.979(b), the team determined that a shutoff means/isolation valve is needed to prevent undesirable system functioning and possible fuel leakage. If the applicant chooses to incorporate a mechanical shut-off means/isolation valve, then the failure to close should be evident by design. If a motorized or automatic shutoff means is incorporated then an indication is needed.

Similar to §25.979(c), the team was concerned if failure of the NEA inerting system shut off means could damage the fuel tanks. The design team stated that because it's a constant pressure flow, any failure to close would result in excess NEA being vented out.

Similar to §25.979(d), the NEA inerting system would have to be shown tolerant to variable inerting gas pressures. The safety objective should be similar to the 25.979(d) requirements. However, further research and/or experience on the system may show that other design limits are appropriate.

### Conclusion:

For ground based inerting designs only, add a new paragraph to 14 CFR part 25 or amend §25.979 to ensure that the pressurized NEA inerting system:

- (a) prevents the escape of hazardous quantities of fuel from the system (via backflow) in the case of loss of pressure to the NEA supply - §25.979(a)
- (b) shutoff means/isolation valve is incorporated to prevent undesirable system functioning and possible fuel leakage and that its failure to function is evident - §25.979(b)
- (c) not applicable - §25.979(c)
- (d) the NEA inerting system should be shown to be tolerant to variable inerting gas pressures or surges in the gas delivery system - §25.979(d)

OR

Create a new fuel system inerting paragraph and include this concern.(see §25.xxx (b)(iii), (b)(iv) and (b)(v)).

### b. Applicable paragraphs

The following 14 CFR part 25 paragraphs were found to be pertinent in showing that an inerting system (ground or on-board) is airworthy:

- §25.365 Pressurized compartment loads
- §25.729(f) Wheels and tire failure
- §25.863 Flammable fluid fire protection
- §25.901 Installation
- §25.903 Engines
- §25.954 Fuel system lightning protection
- §25.965 Fuel tank tests
- §25.975 Fuel tank vents and carburetor vapor vents
- §25.981 Fuel tank temperature
- §25.993 Fuel system lines and fittings

- §25.994 Fuel system components
- §25.1181-1207 Powerplant Fire Protection
- §25.1141 Powerplant controls: general
- §25.1301 Function and installation
- §25.1309 Equipment, systems, and installations
- §25.1316 System Lightning Protection
- §25.1353(a) Electrical Equipment and Installations
- §25.1431(c) Electrical Equipment
- §25.1438 Pressurization and pneumatic systems
- §25.1461 Equipment containing high energy rotors
- §25.1529 Instructions for Continued Airworthiness
- §25.1541 Markings and Placards: General
- §25.1581 General Aeroplane Flight Manual section

These paragraphs will be referenced within the guidance material. The utilization and the means to demonstrate compliance to each paragraph are design and applicant specific.

#### Conclusion

A minimum of thirty six (36) other 14 CFR 25 paragraphs were identified as pertinent to demonstrating the airworthiness of a fuel tank inerting system.

#### c. New Concerns

Three new issues were raised that are unique to fuel tank inerting systems and that are not found in the current 14 CFR part 25. They are:

- Hazards due to inert gas leakage
- Hazards to the fuel system
- Inert gas characteristics and specification to ensure the system integrity

#### Hazards due to inert gas leakage

NEA is considered a hazardous substance. NEA is especially hazardous because it cannot be detected by human senses (odorless and colorless) and can cause injury or death within minutes. For this reason any leakage of NEA into the pressurized or personnel compartments or confined spaces requiring maintenance must be avoided and warnings must be incorporated in case of the system's failure to retain NEA. A regulation is therefore needed to ensure that all design and procedural precautions are taken.

#### Hazards to the fuel system

Inputting inert gas into the fuel system may cause the fuel system to overpressure. This could lead to a catastrophic failure. A regulation is therefore needed to ensure that all design and procedural precautions are taken.

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## Inert Gas Characteristics and Specification

The fuel tank inerting system is designed to work with a certain type of inert gas. If another type of inert gas is used, then the system's integrity cannot be ensured. A regulation is therefore needed to ensure that the correct inert gas is used / generated for the certified system.

### **3.2.4 Review of 14 CFR Part 34**

14 CFR part 34 provides fuel venting and exhaust emission requirements for turbine engine powered airplanes.

#### Review Purpose

The purpose of the rulemaking's team review was to determine if the emissions exhausted from fuel tank vents were regulated and how.

#### Review Procedure

The rulemaking team reviewed the 14 CFR part 34 paragraphs to determine whether any paragraphs dealt with emissions emitted from fuel tank vent exhausts or from fueling trucks. If a paragraph was found, then it was to be evaluated for change or for reference in any potential guidance material. If no paragraphs were found, then this was to be documented with a possible recommendation for future evaluation.

#### Review Conclusions

The team found no 14 CFR part 34 paragraphs that regulated the pollution emitted from fuel tank vent exhausts or from fueling trucks. 14 CFR part 34 only regulates the intentional discharge of liquid fuel to the atmosphere that is drained from the nozzle manifold after the aircraft gas turbine engines are shut down.

Some members of the FTIHWG stated that there were state or county laws that forced fuel trucks to recuperate their fumes. The applicability of these regulations was outside the scope of the tasking statement and was not further evaluated.

If inerting is pursued on a large scale and fuel tank vent exhaust emissions are regulated by the U.S. Environmental Protection Agency (EPA) or equivalent, then it is recommended that the appropriate part of 14 CFR (or equivalent) be used as the vehicle to introduce any new aircraft regulatory requirements.

### **3.2.5 Review of 14 CFR Part 43**

14 CFR part 43 provides standards for maintenance, preventive maintenance, rebuilding and alterations.

#### Review Purpose

The purpose of the review was to determine whether any changes were needed to the 14 CFR part 43 standards due to the uniqueness of an inerting design.

#### Review Procedure

The rulemaking team reviewed the standards within 14 CFR part 43 to determine if any changes were needed. If a change was identified, then it was recorded. If no changes were identified, then the rulemaking team would issue a recommendation stating that the standards, as written, can accommodate inerting systems.

#### Review Conclusions

The rulemaking team determined that the 14 CFR part 43 standards did not need to be modified; today's standards can adequately accommodate an inerting system.

### **3.2.6 Review of 14 CFR Part 121 (Also Applicable to Parts 91/125/129)**

14 CFR part 121 provides standards for operating requirements of domestic, flag and supplemental operations.

#### Review Purpose

The purpose of the rulemaking team's review was to determine the changes required within 14 CFR part 121 in order to accommodate an aircraft operating with a ground based or on-board fuel tank inerting system.

The recommendations from this review can be read over to other 14 CFR parts that provide operating requirements for transport category airplanes.

#### Review Procedure

The basis for the rulemaking's team review was:

- the design concepts defined by the FTIHWG's ground based and on-board design teams
- the results obtained from the 14 CFR part 25 assessment
- regulatory precedences set by operationally similar systems, e.g. aircraft de-icing

Using the above basis, the assessment of the 14 CFR part 121 standard was conducted.

The assessment results were provided to members of the FTIHWG's maintenance team for further review. The team issued the final recommendations based on the maintenance team's inputs.

#### Review Conclusions

##### a. General

The team determined that the type of inerting design and the final decisions by the designers, airlines and operators would highly influence the type of changes needed to 14 CFR operational sections.

The group recognized that issues concerning the reviewed 14 CFR sections may go well beyond the conclusions made below. Under the FAA system, the PIC (pilot in command) is ultimately responsible for the system (i.e. FARs' 121.533, .535, .537), and not the fueler, not the airport management and not the maintenance personnel. This means that the PIC will ultimately be held responsible for:

- (a) determining whether the fuel tanks have been properly inerted prior to takeoff, independent of the system (ground or on-board)
- (b) determining whether an on-board system can, or cannot, perform its intended function (see FAR 121.563)
- (c) deciding what to do in the event of on-board or ground based failures

The PIC's responsibilities as noted in (b) and (c) imply that there must be:

- some cockpit system/indication for determining that the fuel has been inerted to the correct levels in applicable tanks and that it stays that way, i.e. there is no harmful leakage
- abnormal procedures developed based on sensors, cockpit indications and associated caution/warnings indications

The group also acknowledged that, if inerting systems were embodied, considerations on how to grant MMEL relief, per prescribed FAA procedures, needs to be further studied. The number of potential installations, the complexity of the installations and the method by which the installations are introduced all influence allowed MMEL. Based on the information presented within the ARAC FTIHWG, the

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rulemaking-team's operational specialists determined that granting of MMEL relief of any inerting system may be complex.

### **b. All Inerting Systems**

Three specific concerns that relate to all inerting systems were identified:

- (1) The requirement to have an approved operational and maintenance program
- (2) Assurance that NEA (oxygen depleted air) can not physically harm passengers and crew
- (3) Statement of when and under what conditions aircraft may need a fuel tank inerting system

#### **Approved operational and maintenance program**

The team recommends that the regulatory change be presented in a new 14 CFR 121 (or equivalent) paragraph, in a manner similar to §121.629 - Operation in Icing Conditions. In this way, all of the information can be found in one place and not dispersed between a variety of paragraphs.

The fuel tank inerting paragraph should include the following:

- Statement of the dispatch or release condition of an aircraft containing a fuel tank inerting system
- Requirement for an approved fuel tank inerting program including details:
  - of how the certificate holder determines that he/she needs to inert the aircraft fuel tanks
  - who is responsible for this decision
  - the procedures for implementing this decision
  - the specific duties and responsibilities of each operational position
  - initial and annual recurrent ground training and testing for all personnel affected
- identification of system limitations, e.g. minimum time to inert upon landing or prior to takeoff
- definition of the confined space procedures for the inerting system
- creation of communication procedures
- identification of flight crew's role at dispatch and at landing
- identification of the NEA's specifications/characteristics
- a paragraph that states under what general conditions the more specific requirements are alleviated

This proposed regulatory paragraph should include or reference specific concerns that are only relevant to ground based inerting operations or on-board inerting operations. These specifics are discussed later.

#### **NEA's Physiological effects**

Because nitrogen enriched air (oxygen depleted air) can physically harm passengers and crew in confined spaces without adequate ventilation, it is proposed to amend §121.229(c) - Location of fuel tanks - in order to state that NEA gas should be isolated from personnel compartments. The isolation should be shown for NEA gas present in both the fuel tank(s) and the inerting system equipment (pipes, valve, etc.)

The team discussed whether this was not already implicit by stating "fume proof enclosure". It was decided that because no one has ever certified an inerting system on a transport category airplane, and no one has actually analyzed the system's routings and consequences to the aircraft, that it is preferable to that NEA gas should be isolated from personnel compartments.

Conditions under which a fuel tank inerting system is installed

If the FAA decides to mandate fuel tank inerting systems, then the perceived role of this system should be stated within 14 CFR part 121 (or equivalent).

The team recommends creating a new §121.300 paragraph to state when and under what conditions aircraft may need a fuel tank inerting system. This may be accomplished by a sentence stating that a fuel tank inerting system may be installed on an aircraft as a means to meet the requirements of §25.xxxx of this chapter in effect on a given date.

An alternative recommendation is to modify §121.316 - Fuel tanks, using the same sentence concept.

Conclusion - all inerting systems

A significant amount of changes would have to be made to introduce inerting systems into transport category airplanes day to day operation. The concepts for rule basis changes have been identified. Specifics need to be developed with an appropriate group of experts using a design concept that is proposed for in-service use.

c. Ground Based Inerting System

The team's basis for regulatory changes specific to ground based inerting was established on two facts:

- Ground based inerting is a specific action that requires a specific, independent procedure.
- Ground based inerting cannot be accomplished without the complementary airport facilities

The operational program will be developed using procedures inherent to the ground based inerting design concept.

Because ground based inerting requires interface with the airport and ground personnel (the system is not contained to the aircraft), the team recommends that the new fuel tank regulatory paragraph make references to other applicable paragraphs within 14 CFR. The team proposes that 5 additional 14 CFR 121 paragraphs be modified (or concepts be included within the new fuel tank inerting paragraph):

- (1) §121.97 - Airports: Required Data : add NEA supply capability under (b)(1) Airports
- (2) §121.105 - Servicing and Maintenance Facilities: include NEA supply capability in equipment example
- (3) §121.117 - Airports: Required Data: add NEA supply capability under (b)(1) Airports
- (4) §121.123 - Servicing Maintenance Facilities: include NEA supply capability in equipment example
- (5) 121.135(b)(8) - Contents - Information Contained in the Manual: add new equipment, (b)(25), concerning inerting facilities or modify (b)(18) to add inerting to the refueling procedures

Conclusion- Ground Based Inerting:

For ground based inerting systems, an additional five other paragraphs need to be created/modified. The concepts of what these paragraphs should contain have been identified. Specific regulatory changes should be reviewed with the operational specialists using a design concept that is proposed for in-service use.

d. On-Board Inerting System

The team's basis for regulatory changes specific to on-board inerting was established considering:

- On-board inerting is a system integral to the aircraft; airport facilities are not needed
- The activation of the on-board system would be done on the aircraft (automatically or manual)

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The team did not identify any specific paragraphs for change.

The team determined that the operational program would be developed using procedures inherent to the on-board inerting design concept.

The team identified a potential MMEL impact with on-board inerting that may eventually lead to regulatory changes for pressure vessels. More aircraft everyday are affected by the loss of air from an aging pressure vessel, due to leaks, especially with the classic or aging aircraft. With air being drawn from the pressure vessel for inerting, along with a normal ongoing loss of cabin pressure, the situation exists that it will take the operation of all air conditioning packs to maintain cabin pressure. If this becomes the case, the concern is that operators will lose current MEL relief of operating or dispatching with an inoperative pack in order to assure cabin pressure as well as an operating inerting system.

If an on-board ground system is developed than the ground based and on-board recommendations should both be considered, recognizing that the airport facility requirements would be different (on-board ground - electrical source requirement; ground-based inerting - NEA supply requirement).

### Conclusion- On-Board Inerting System:

For on-board inerting systems, no additional paragraphs were identified for creation or modification. If pressure vessel air is used for inerting, regulatory changes may need to be implemented somewhere in the 14 CFR code to ensure cabin air pressure is maintained as the aircraft ages or if it is dispatched on MEL relief with an inoperative pack. On-board ground inerting system may require the regulatory modifications as described under ground based inerting, recognizing that the airport facility requirements would be different (on-board ground - electrical source requirement; ground-based inerting - NEA supply requirement). Specific regulatory changes should be reviewed with the operational specialists using a design concept that is proposed for in-service use.

#### e. Retroactive rule action

If the FAA decides to initiate any retroactive rule action, it will initiate a change to 14 CFR Part 21 - Certification Procedures for products and parts, Special Federal Aviation Regulations (SFAR) section. The SFAR will state the applicability and the required compliance, including the task accomplishment statement and FAR 25 rule references, the time frame for compliance and the reference to any maintenance or inspection activities.

FAR 121.300 will have to be updated to be in line with the SFAR rule change. The new 121 rule will have to provide provisions concerning time required to introduce the new rule, aircraft effected, operational requirements and any grandfather clauses (especially if there is a time factor linked to equipping domestic and foreign airports).

If the FAA initiates retroactive rulemaking, the team recommends that the appropriate specialists within the Aircraft Evaluation Group work as a team to write the requirements. Specific concern to the rulemaking team is the treatment of an inerting system on MMEL/MEL (master minimum equipment list)/(minimum equipment list) treatment, especially if Airworthiness Directives are issued by the design directorate because §121.628(b)(1) will have to be enforced. §121.628(b)(1) states: "The following instruments and equipment may not be included in the Minimum Equipment List: (1) instruments and equipment that are either specifically or otherwise required by the airworthiness requirements under which the airplane is type certificated and which are essential for safe operations under all operating conditions."

The group notes that the Aircraft Evaluation Group is responsible for §121.628 - Inoperable Instruments and Equipment - and not the certification and airworthiness branch.

Conclusion - retroactive rule

A retroactive rule would be initiated by FAA decision and by a simultaneous change to 14 CFR part 21 and 14 CFR part 121 (or equivalent). The retroactive rule needs to be closely coordinated within both the FAA's certification / airworthiness standard branch and the Aircraft Evaluation Group. The FAA needs to consider carefully any retroactive rule action versus its impact on the MMEL/MEL.

f. Impact on 14 CFR part 121 (or equivalent) Subpart L, N and T

The team examined the impact of introducing a fuel tank inerting system on Subpart L - Maintenance, Preventive Maintenance and Alterations, Subpart N - Training Program and Subpart T - Flight Operations.

Given the amount of knowledge that the team has on the inerting systems and their impact on aircraft operations, the team does not recommend any specific changes to Subpart L, N or T.

However, the team recognizes that there will be a need for specific training on the embodied inerting system. This training may have to be regulated within 14 CFR part 121 (or equivalent). The regulatory text would be in line with the system's complexity. For instance, specific requirements may be instituted to ensure that a person is adequately trained for ground based servicing of an aircraft with NEA, especially if the aircraft is being serviced from gas bottles, so that the wrong gas is not put into the tanks, e.g. oxygen inputted instead of NEA.

Conclusion - Impact on 14 CFR part 121 (or equivalent) Subparts L, N and T

There are no recommendations for modifications to Subparts L, N and T based on today's knowledge of the systems. The current wording is sufficient in order to ensure proper training on inerting systems. Modifications or new paragraphs may need to be introduced once an inerting system is actually proposed for in-service use.

**3.2.7 Review of 14 CFR Part 139**

14 CFR part 139 provides standards for certification and operations of land airports serving certain air carriers.

Review Purpose

The purpose of the review was to determine whether any changes were needed to the 14 CFR part 139 standards due to the airport services needed to support an inerting design.

Review Procedure

The rulemaking team reviewed the standards within 14 CFR part 139 to determine if any changes were needed. If a change was identified, then it was recorded. If no changes were identified, then the rulemaking team would issue a recommendation stating that the standards, as written, can accommodate inerting systems.

Review Conclusions

The team's review identified one change to 14 CFR part 139 standards, if ground based inerting is implemented. No changes to 14 CFR part 139 were identified if on board inerting is implemented.

The change identified concerns §139.321 paragraph(b) - Handling and Storing of Hazardous Substances and Materials. Paragraph (b) states that

“Each certificate holder shall establish and maintain standards acceptable to the Administrator for protecting against fire and explosions in storing, dispensing, and otherwise handling fuel, lubricants, and oxygen (other than articles and materials that are, or are intended to be, aircraft cargo) on the airport.

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These standards shall cover facilities, procedures, and personnel training and shall address at least the following:

- (1) Grounding and bonding.
- (2) Public protection.
- (3) Control of access to storage areas.
- (4) Fire safety in fuel farm and storage areas.
- (5) Fire safety in mobile fuelers, fueling pits, and fueling cabinets.
- (6) After January 1, 1989, training of fueling personnel in fire safety in accordance with paragraph (e) of this section.
- (7) The fire code of the public body having jurisdiction over the airport.”

If one considers NEA as the hazardous substance, then §139.321 should be modified to add a paragraph that regulates the handling of NEA. This regulation should discuss fire safety issues, as well as confined space entry and handling issues.

If one considers that hazardous substance is the flammable vapor in the aircraft fuel tanks, and that these flammable vapors are generated by the flow of fuel from a fueling operator into the tank, then an item (b)(8) can be created. Item (b)(8)’s purpose would be to ensure the airport controls the hazard presented by an aircraft fuel tank with flammable vapors. If this option is chosen, then the airport would need to ensure:

- a. A supply of NEA inert gas, in sufficient quantities, is available in order to fuel tank ullage wash all commercially operated aircraft serving the certified airport.
- b. facilities, procedures and personnel training standards in place to protect against in-tank explosion of flammable vapors of fuel tanks on commercially operated aircraft parked upon the premises of the certified airport.
- c. all commercially operated aircraft departing the certified airport has been provide the opportunity to have its fuel tank ullage washed with inert NEA gas within “x” hours of its next departure from the certified airport.

### Conclusion

If ground based inerting is pursued and the airport facilities are responsible for providing the NEA inert gas to the airport, then a revision to 14 CFR 139 is needed.

The revision can be justified in one of two ways. The first way is to regulate the safety of the public and airport when handling NEA. The second way is to regulate the hazard of the airplane and state that the airport must ensure that this hazard doesn’t exist.

The revised regulatory text should address:

- availability of NEA gas
- facility, procedures and personnel training standards
- infrastructure to ensure aircraft are inerted within a minimum time before its next departure

More specific wording was not developed because of the immaturity and impracticality of ground-based inerting.

### **3.3 DEVELOPMENT OF GUIDANCE MATERIAL FOR FUEL TANK INERTING SYSTEMS**

Upon completion of the fuel tank inerting regulatory assessment, the rulemaking team began its development of guidance material for use in designing, certifying and operating a fuel tank inerting system.

As with the regulatory evaluation, both ground based and on-board systems were considered within the development of the guidance material.

This section provides:

- the methodology used to develop the guidance material
- elements of the proposed guidance material
  - design/certifications
  - operation
- recommendations for future work

#### **3.3.1 Methodology Used to Develop the Inerting System Guidance Material**

The regulatory text change review identified four core subjects:

1. Retroactive rule - SFAR (14 CFR parts 21 and 121)
2. Design and certification (14 CFR parts 25 and 34)
3. Operation and maintenance (14 CFR parts 43, 91, 121, 125 and 129)
4. Airport Facilities (14 CFR part 139)

The rulemaking team opted to develop guidance material for two of the four subjects:

- Design and certification (14 CFR parts 25 and 34)
- Operation and maintenance (14 CFR parts 43, 91, 121, 125 and 129)

The team determined that the retroactive rule did not need associated guidance material by nature and that the FTIHWG's airport facilities team was addressing the airport facilities issues.

The team was split by expertise. The design specialists drafted the design and certification guidance material. The operational specialists drafted the operation and maintenance guidance material.

Both teams drafted the guidance material assuming that the decision had already been made to fit a fuel tank inerting system (ground or on-board) on the aircraft. (See section entitled "Flammability Regulatory Text Evaluation and Proposal" for guidance material associated to the flammability regulatory text - how to evaluate the aircraft to decide if an inerting system needs to be fitted.)

#### **3.3.2 Guidance Material - Design and Certification of a Fuel Tank Inerting System**

This section describes the objective and proposed content of guidance material associated to the design and certification of a fuel tank inerting system. The complete guidance material proposal is found in Attachment 1 of this report.

The guidance material was derived using the fuel tank inerting systems design proposals of the two FTIHWG design teams and the regulatory evaluation assessment.

The team recommends that this guidance material be refined using real fuel tank inerting design concepts that are proposed for in-service aircraft.

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### **3.3.2.1 Objective**

The objective of the team was to develop guidance material that provides information and guidance on the design, installation and certification of a NEA inerting system.

This material could then be used, if desired, to create an Advisory Circular pertaining to fuel tank inerting systems.

### **3.3.2.2 Assumptions**

The team assumed that the applicant chose to install a NEA inerting system on one or all of its aircraft's fuel tanks. The design objective of the system is to reduce or eliminate the flammable environment created in the fuel tank's fuel/air vapor ullage (means by which to show compliance to FAR/JAR 25.xxx).

The team assumed that this guidance material would be harmonized between the US Federal Aviation Administration (FAA) and Joint Aviation Authority (JAA) prior to its publication.

The team took for granted that this guidance material would not become mandatory and would not constitute a regulation. It's purpose is to provide the applicant with advice and a method of compliance that has been found acceptable to the FAA / JAA (certifying Authorities).

### **3.3.2.3 Background**

The team determined that if the guidance material is transformed into a stand-alone advisory circular, then a background section should be included as part of the advisory circular. If the guidance material is included in an existing advisory circular then the background section should be reviewed and updated as appropriate.

The team proposed a background section in its guidance material proposal, Attachment 1. This section states the conditions under which the guidance material proposal was drafted. The contents of this section may become obsolete as the subject matures.

### **3.3.2.4 Related Documents**

The team then went on to list all the documents that were known to its members and that were relevant to this fuel tank inerting design and certifications.

Five categories of documents were identified:

- a. Related 14 CFR part 25 and part 34 paragraphs
- b. Published or draft FAA Advisory Circulars
- c. Society of Automotive Engineers (SAE) documents
- d. Military specifications
- e. Other publications

The purpose of the document list is to assist designers in finding supplementary information.

If this guidance material is transformed into an advisory circular, the team recommends that this listing be double checked in order to make sure that this list is not obsolete.

### **3.3.2.5 Definitions and Abbreviations**

The team recorded all definitions and abbreviations that it felt were pertinent to a fuel-tank inerting system designer and certifier.

Some of the definitions proposed within this guidance material are supplementary to or different from those proposed by the FAA in AC 25.981-2.

### **3.3.2.6 Inerting System Design Concepts**

The team decided that the guidance material should explain the general concept of fuel tank inerting and then explain the fundamental principles behind different fuel-tank inerting design concepts. The material developed by the FTIHWG design teams was used as the basis for the design concept explanations.

The purpose of the general concept section is to explain what is fuel tank inerting and what is its effect on the fuel/air vapor environment within the fuel tank.

The purpose of the different fuel-tank inerting design-concept sections was to identify the:

1. general principles of the inerting design
2. flight phases for which the design is most likely effective
3. general impact on the aircraft design and the aircraft operation (system criteria / operational impact, including airport facilities interface)
4. specific concerning unique equipment, e.g. air separator module (ASM)

### **3.3.2.7 System Installation Considerations**

Fuel tanks become inert because of the operation of a system - the fuel tank inerting system.

The guidance material identifies some of the inerting system's installation considerations.

Specifically, the guidance material discusses design of the

- Distribution system
- Vent system
- Indications

### **3.3.2.8 Aircraft Interfaces**

The fuel tank inerting system needs to be integrated with the other aircraft systems and needs to comply with all relevant 14 CFR part 25 paragraphs.

Review of the FTIHWG's identified, the following aircraft systems that may need to interface with a fuel tank inerting design:

- Electrical
- Engine bleed air
- Cabin pressurization
- Refuel

The guidance material provides installation considerations that are specific to inerting systems.

### **3.3.2.9 Certification Plan / Compliance Demonstration**

This section of the guidance material provides general certification guidance by providing suggestion on what should be included within the fuel-tank inerting's certification plan.

The guidance material suggests that the certification plan should include:

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- a. A description of the fuel-tank's inerting design and operation
- b. A definition of the safety assessment activities and its inter-relationship with other activities within the design approval process
- c. An analysis that demonstrates the system's effectiveness and operating characteristics
- d. A test program definition where the test program is defined as ground, flight and/or laboratory testing.

The certification plan should be submitted by the applicant and approved by the Authority. The complexity of the certification plan will depend on the newness of the inerting's design, the newness of the aircraft installation and the experience of the applicant in designing and certifying.

### **3.3.2.10 Continued Airworthiness / Maintenance Considerations**

The applicant will need to define the fuel-tank inerting's continued airworthiness requirements and an associated maintenance program.

The guidance material recommends that established industry procedures are used.

The team notes, however, that this section may need to be enhanced once an actual system evaluation is performed.

### **3.3.2.11 Nitrogen Enriched Air (NEA): Precautions to Respect**

Nitrogen Enriched Air is a hazardous substance. Design precautions should be taken to avoid that any person comes in contact with NEA. Various studies have shown that improper handling of NEA or entry into a confined space without precautions can be deadly.

The guidance material states the above. The guidance material also suggests that the designer become familiar with OSHA confined space requirements. In this way the design and associated maintenance procedures can ensure that all possible precautions be built into the system to prevent bodily harm and death.

### **3.3.2.12 Environmental Impact**

The FTIHWG determined that there would be some additional hydrocarbons spewed from the fuel tank due to inerting. The quantity was not determined. The quantity would also depend on the type of inerting system installed.

The team also determined that 14 CFR part 34 does not regulate fuel tank emissions.

However, the team was not sure if particular airports or foreign airports had different emission considerations.

The purpose of this guidance material section is to alert the designer that:

- NEA inerting displaces VOCs (increases the amount of hydrocarbons put into the atmosphere)
- Possible airport restrictions may require additional vapor recuperation techniques

### **3.3.2.13 Master Minimum Equipment List (MMEL) Assessment**

The FTIHWG recommends that a fuel tank inerting system be considered for dispatch under the MMEL.

The guidance material makes this recommendation. It also states that the MMEL should be determined using standard industry procedures.

### **3.3.2.14 Final Recommendations**

The guidance material developed complements that already published in AC 25.981-2. AC 25.981-2 describes the general concept of an inerting system, where as this proposal not only discusses the general concept but specific design considerations.

If the FAA decides to encourage inerting system installations on aircraft, the team recommends that either AC 25.981-2 be expanded to include fuel-tank inerting design considerations or a specific AC entitled “Fuel Tank Inerting Design and Certification” be created.

It is recommended that any Advisory Circular be re-reviewed using an actual certified inerting design. The design considerations recommended in this guidance material are based on hypothetical designs. The lessons learned during an actual design project may assist others in designing and certifying aircraft.

### **3.3.3 Guidance Material—Operation and Maintenance of a Fuel Tank Inerting System**

This section describes the objective and proposed content of guidance material associated to the operation and maintenance of a fuel tank inerting system and to the receipt of an approved fuel tank inerting program. The complete guidance material proposal is found in Attachment 2 of this Appendix.

The guidance material was derived using the fuel tank inerting systems design proposals of the two FTIHWG design teams, the regulatory evaluation assessment and guidance material written on systems that interface with airport facilities or systems that are implemented because of environmental concerns.

The team recommends that this guidance material be refined using real fuel tank inerting design concepts that are proposed for in-service aircraft.

#### **3.3.3.1 Objective**

The objective of the team was to develop guidance material that provides:

- information and guidance on the operation and maintenance of a NEA inerting system
- guidance in obtaining approval of a fuel tank inerting program

This material could then be used, if desired, to create an Advisory Circular pertaining to fuel tank inerting systems.

#### **3.3.3.2 Assumptions**

The team assumed that the aircraft had a fuel tank inerting system (ground or on-board) installed and that the applicant (AC user) is an operator seeking to gain approval of its fuel tank inerting maintenance and operation program

The team assumed that this guidance material would be harmonized between the US Federal Aviation Administration (FAA) and Joint Aviation Authority (JAA) prior to its publication.

The team took for granted that this guidance material would not become mandatory and would not constitute a regulation. It’s purpose is to provide the applicant with advice and a method of compliance that has been found acceptable to the FAA / JAA (certifying Authorities).

#### **3.3.3.3 Background**

The team determined that if the guidance material is transformed into a stand-alone advisory circular, then a background section should be included as part of the advisory circular. The information contained in this section should be similar to the information contained in the design and certification design advisory material, with any specific information being included for relevant to operations and maintenance.

The guidance material, in Attachment 2, proposes a background section.

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### **3.3.3.4 Related Documents**

The team then went on to list all the documents that were known to its members and that were relevant to this subject.

This list should be similar to the list produced for the design and certification advisory material. Any specific maintenance or operational documents, that do not influence design changes, should be quoted.

If this guidance material is transformed into an advisory circular, the team recommends that this listing be double checked in order to make sure that this list is not obsolete.

### **3.3.3.5 Definitions and Abbreviations**

The team recorded all definitions and abbreviations that it felt were pertinent to the operation and maintenance of a fuel-tank inerting system. The definition list should be similar to the list included in the design and certification guidance material.

### **3.3.3.6 Fuel Tank Inerting Program Parts**

The team determined that any fuel tank inerting operation and maintenance program would contain six parts:

1. Management plan
2. Dispatch conditions, including any timetables
3. Operations Manual - Inerting operational procedures
4. Maintenance program - maintenance manual
5. Training
6. Health and Safety Standards

Note: Emissions: Local airport emission requirements may have to be evaluated against the possible excess of fuel tank emissions resulting from inerting. (Emissions effects will be design and aircraft dependent.)

### **3.3.3.7 Management Plan**

A management plan is a detailed description of the operational responsibilities and procedures associated with the implementation and conduct of the certificate holder's "fuel tank inerting program". The management plan may differ depending on the type of inerting system.

The purpose of the management plan is to ensure operational control (ensure proper execution of a fuel tank inerting program).

The management plan needs to be submitted and approved by the FAA. It should include:

- the name of the manager responsible for the overall fuel tank inerting program,
- this manager's organization including the individual group (task) managers, their functions and responsibilities against each applicable 14 CFR
- the specific elements covered by the plan. The elements should either be detailed within a specific document or be cross referenced to other internal documents

Specific elements for which the management organization needs to be detailed and approved are:

- a. operations
- b. maintenance

- c. aircraft servicing on ground
- d. others deemed critical to the management and operation of the fuel-tank inerting system

#### **3.3.3.8 Dispatch Conditions, Including Any Timetables**

Certain design features - aircraft (e.g. fuel tank's vent system) or fuel tank inerting system - may impose certain utilization conditions or limitations. These conditions / limitations may be related to time, outside ambient temperatures, flight phase, fuel tank loading or a set of multiple conditions.

If a limitation exists, then the certificate holder's program should define operational responsibilities and should develop procedures to instruct the flight crew, aircraft dispatchers, flight followers, and maintenance and ground personnel on the condition limitations, evaluation of these limitations and the resultant action to take. The procedures should include gate procedures, communication procedures with the ground and flight crew and coordination with ATC (air traffic control)

The limitations should be supported by the manufacturer's design data.

#### **3.3.3.9 Operations Manual—Inerting Operational Procedures**

Operational procedures associated to the fuel tank inerting system installed on the aircraft type should be approved as part of an operator's initial operational manual approval or as a revision to that manual, the Airport Handling Manual and/or the Minimum Equipment List.

Procedures most likely needing changing are flight preparation procedures and ground handling instructions.

A quality assurance program should be put into place in accordance with the management plan and applicable 14 CFR regulations.

The MEL should be developed based on the manufacturer's recommendations and the operator's operational policies and national operational requirements.

#### **3.3.3.10 Maintenance Program—Maintenance Manual**

Maintenance procedures for the fuel tank inerting system installed on the aircraft type should be approved as part of an operator's initial maintenance manual approval or as a revision to that manual.

Special emphasis should be put on the development and implementation of all procedures and precautions implemented because of inerting and in particular - handling of NEA, e.g., fuel tank purge procedures (open and confined spaces), fuel tank entry procedures and NEA handling policies.

For ground based inerting, the characteristics / specification of the NEA that will be used to inert the fuel tanks should be defined and recorded in the appropriate manuals.

For on-board inerting, particular attention should be paid to the efficiency (service life) of the air separator module (NEA producing capability), noting that NEA will not be produced if this component does not perform its intended function.

#### **3.3.3.11 Training**

Initial and recurrent ground training and testing for all affected personnel (e.g. aircraft dispatchers, ground crews, contract personnel, flight crew, etc.) need to be put in place.

The training syllabi should be adapted to each discipline and to the type of inerting system installed on the aircraft. For maintenance personnel, specific attention should be placed on the dangers of NEA and precautions to take when working in confined spaces.

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A quality assurance program should be put into place in accordance with the management plan and applicable 14 CFR regulations.

### **3.3.3.12 Health and Safety Standards**

The operator's health and safety standards should be updated to include working with NEA. Specific areas may include but are not limited to:

- NEA handling
- Emergency care procedures
- Working in confined spaces
- Identification of health risks
- Identification of protective clothing

### **3.3.3.13 Emissions**

Local airport emission requirements may have to be evaluated against the possible excess of fuel tank emissions resulting from inerting. (Emissions effects will be design and aircraft dependent.)

If the evaluation indicates there is a necessity to recover the VOCs, then procedures would have to be adopted accordingly and recorded within the management plan and the manual. Training courses would also need to incorporate these differences within the affected disciplines' course.

### **3.3.3.14 Final Recommendations**

The guidance material developed within the FTIHWG describes the steps needed to obtain approval of a fuel tank inerting Operation and Maintenance Program. There is no other known recommended guidance material or Advisory Circulars existing in the public domain.

If the FAA decides to encourage inerting system installations on aircraft, the team recommends that this guidance material be used to issue an Advisory Circular entitled "Fuel Tank Inerting Operational Program Approval".

It is recommended that any Advisory Circular be re-reviewed using an actual operation and maintenance program developed for use on a certified fuel tank inerting system. The lessons learned during the implementation of the operation and maintenance program may assist others in any future implementation exercise.

### **3.4 FLAMMABILITY REGULATORY TEXT EVALUATION AND PROPOSAL**

The rulemaking team was tasked to develop a regulatory text that could be used to regulate the fuel tank ullage environment. The FAA requested the team to develop a performance-based text where the performance criterion was defined as flammability.

The FAA's tasking statement set down the following ground rules by which the team was strictly bound:

- for the proposed regulatory text, fuel-tank inerting could be an acceptable method of compliance
- flammability was to be treated independently from fuel tank ignition prevention
- "performance-based" definition provides the applicant with a set of design requirements, not a prescriptive design requirement
- "flammability" definition - the susceptibility of the fuel/air vapor (ullage) present in a fuel tank to igniting readily or to exploding
- flammability reduction only through fuel tank inerting was to be considered by the FTIHWG, which was asked not to address or consider other methods for controlling the flammability of fuel tank ullage

#### **3.4.1 Methodology Used to Develop the Flammability Regulatory Text Recommendation**

In order to provide and substantiate a regulatory text recommendation, the team:

- identified the key parameters that could lead to controlling the fuel tank ullage environment
- identified the perceived regulatory expectations
- defined how the regulatory text may be associated to aircraft safety objectives
- proposed an outline for an evaluation standard that could be used to ensure an equivalent safety level across all product lines, including percent exposure

Regulatory text proposals were developed and evaluated (pros and cons) using the results of the above investigation.

#### **3.4.2 Parameters That Lead to Controlling Fuel Tank Ullage Environment**

The key parameters that could lead to controlling the fuel tank ullage environment were identified. This list served as the regulatory text word source. That is, in order to meet the tasking-statement's objective, the regulatory text had to be written using a variation of this word list or "parameters". The following list of "parameters" was identified:

- Flammability
- Flammable vapors
- Vapors
- Oxygen content
- Ullage
- Inerting
- Environment
- exposure

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- Minimization
- Development
- practical
- Limit
- control
- Ignition energy
- Temperature
- Center wing tank
- Heated center wing tank
- Body tank / auxiliary (“aux”) tanks / aircraft center tank (ACT)
- Wing tanks
- Trim tank / horizontal stabilizer tank
- Flight phase: ground operation (gate), taxi to take-off, take-off, climb, cruise, descent, landing, taxi into the gate

### **3.4.3 Regulatory Text Expectation**

The team agreed that the primary purpose of the flammability regulatory text was to reduce the risk of a fuel tank explosion by reducing or eliminating the flammable environment that exists in the fuel tank’s ullage space.

It was agreed that flammable environment did not pose a hazard to the aircraft in isolation. The hazard was posed only if an ignition source with sufficient energy came in contact with an ullage environment that could support combustion (fuel is in its flammable range and the oxygen content is high enough to support combustion). If one or both of the items contributing to the hazardous situation were removed then fire/explosion of the fuel tank would not occur.

Recalling the task team’s ground rules for regulatory text development, the team determined that the regulatory text should:

- Equate “flammable environment control” to demonstrating that the ullage environment can not support combustion if it comes in contact with a spark.
- Ensure that the applicant controls the environment either by demonstrating that the:
  - fuel is not in the flammable range (varies with temperature, fuel type and altitude), or
  - oxygen content is too low to support combustion

The acceptable design or procedural methods and substantiation that achieve the regulatory text’s expectations are left up to the applicant.

The effectiveness and conditions under which the design/procedures need to function/be enforced should be dictated by the aircraft’s design and overall safety features.

### **3.4.4 Regulatory Text as Associated to Aircraft Safety Objectives**

The team agreed that the regulation of fuel tank flammability could be a contributing element in preventing the aircraft “fuel tank explosion”. This conclusion was based on the circumstantial evidence

and the lack of specific cause findings in the recent fuel tank explosion accidents (see the safety section of the FTIHWG's report).

The team discussed what level of safety (per 14 CFR part 25, §25.1309) and hence redundancy should the system be required to have. This question remained unanswerable.

The tasking statement did not allow the team to examine the system as a whole versus the aircraft event "fuel tank explosion". This type of assessment would have backed out the flammability system's safety level and redundancy level because the applicant would have determined when the other features on the aircraft left the aircraft at risk. The residual risk (when and how much) would have determined the type and safety level of flammability reduction measures.

The tasking statement required that the flammability regulatory text to be independent of the other aircraft-design features. This situation did not allow other features of the aircraft to be used to set the safety and redundancy level for the system. The tasking statement provided guidance on safety level (safety enhancement) and redundancy (none). However, some group members stated that the tasking statement's assumptions were not realistic. In a "real-world" certification exercise, the applicant would either be forced to identify the "risk" condition and eliminate it or if the "risk condition" could not be identified, to design a system that ensures a flammability exposure as close to zero as possible. Both the severe design objectives and the aircraft operational reliability objectives would back out the system redundancy. In fact, most group members agreed that the system would have to be redundant to become feasible for a day-to-day transport category airplane use.

Within this discussion the team determined that any flammability regulation should ensure the "risk" condition, as defined by the accident statistics, should be assessed and found acceptable. This "risk" condition, called from now on, the "accident risk condition", was identified to be:

- aircraft operating under hot day conditions
- center wing tank empty with heat being inputted
- ground or climb phase

The group also agreed that due to uncertainty of how the accidents occurred, the "accident risk condition" should not be considered as the only risk condition. Any regulatory text and associated guidance material should ensure that similar or new-risk conditions are not created in other fuel tanks besides the center tank.

For instance an evaluation of the other tanks should be undertaken, when the fuel tank is empty or the primary potential ignition sources are uncovered (e.g. pumps). This evaluation should determine whether the fuel tank ullage enters the flammable zone and under what conditions. The design could then be altered to ensure that the risk is mitigated.

### **3.4.5 Regulatory Text Proposals**

Regulatory text proposals were developed based on discussions of the previous section and FTIHWG Terms of Reference guidelines. Each regulatory text proposal was recorded. Pros and cons of each proposal were evaluated against the conditions discussed. A representative sample of regulatory text proposals is given below. The team used these options along with the work from the other FTIHWG groups to make a final regulatory proposal to the HWG.

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### Option A

#### Section 25.981 (c) Flammable Fuel Vapors

Limit the development of flammable conditions in the fuel tanks, based on the intended fuel types, to less than X% of the expected fleet operational time defined in appendix X,

or

Provide means to mitigate the effects of an ignition of fuel vapors within the fuel tanks such that any damage caused by an ignition will not prevent continued safe flight and landing

### Pros:

- provides choices on how to control the fuel tank ullage environment
- words “limit” and “development” are performance based terms that can be interpreted within the preamble and guidance material
- an Appendix can be used to standardize the evaluation criteria
- provides an alternative means of compliance - control of aircraft structural integrity and not control of the fire triangle provided through the “or” option
- allows for a compliance interpretation so that all fuel tanks need to be studied

### Cons:

- because the X% is based on the overall average fleet operational time, the specific risk areas as defined by the accident statistics may be overlooked
- the results may vary due to a choice of mission parameters; mission parameters chosen may not resemble the actual operation of the aircraft
- due to variations in aircraft designs and missions, the derivation of a common industry standard X% may prove to be difficult
- the same design precautions may be able to be achieved by looking at a specific type of operation and not a fleet average

### Option B

#### Section 25.981 (c) Center Wing Tank Ullage Environment

- (i) under ground conditions, assess the center wing tank’s thermal characteristics to show that the development of flammable conditions is limited (or an alternative wording with the same intent - limit the development of flammable ullage)
- (ii) provide means to mitigate the effects of an ignition of fuel vapors within the fuel tanks such that any damage caused by an ignition will not prevent continued safe flight and landing.

### Pros:

- specifies the condition which is the major contributor to the risk “ground conditions”
- words “limit” and “development” are performance based terms that can be interpreted within the preamble and guidance material

- specifies the type of evaluation that needs to be done in order to take a design decision on how to manage fire triangle
- provides an alternative means of compliance - control of aircraft structural integrity and not control of the fire triangle provided through the “or” option
- states that an evaluation needs to be performed
- design objective is inherent and is not subjected to an interpretive percent value

Cons:

- does not require all fuel tanks to be assessed; too restrictive per tasking statement
- does not require an examination of the thermal characteristics under all flight phases to examine the state of the ullage environment
- The acceptable standard for “limiting” may change with time; an acceptable approach and design may not be acceptable for a future product due to a change of philosophy by an individual certifying authority

Option C

Section 25.981 Fuel tank ignition prevention

- (c) If systems adjacent to fuel tanks could cause significant heat transfer to the tanks:
  - (i) Means to reduce heating of fuel tanks by adjacent systems shall be provided; or...
  - (ii) Equivalent flammability reduction means shall be provided to offset flammability increases that would otherwise result from heating; or...
  - (iii) Means to mitigate the effects of an ignition of fuel vapors within fuel tanks shall be provided such that no damage caused by an ignition will prevent continued safe flight and landing.

Pros:

- Provides multiple options of controlling the environment and states that any one of the options are equally acceptable
- Is responsive to the issue of temperature’s effect on fuel tank ullage flammability
- Precludes the use of design methods that result in a relatively high likelihood that flammable vapors will develop in fuel tanks
- Provides a measurable design objective - flammability level in a heated tank shall be near that of an unheated tank
- “means to reduce heat” and “equivalent flammability reduction” can be described in guidance material

Cons:

- Does not meet the tasking statement because it is too specific in terms of the role of temperature within the evaluation

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### Option D

Section 25.981 Fuel tank ignition prevention

- (c) If ignition sources can develop in the fuel tanks, then
  - (i) evaluate the fuel tank ullage flammability to determine whether any type or group of tanks have flammability characteristics significantly different than the others
  - (ii) if different, then provide justification to show:
    - (a) that all practical precautions have been taken to equate the tank or tanks to within 5°C (10+°F) of the slowest cooling tank on the aircraft , or
    - (b) that the fuel tank ullage environment is made non-flammable (inert), or
    - (c) means to mitigate the effects of an ignition of fuel vapors within fuel tanks shall be provided such that no damage caused by an ignition will prevent continued safe flight and landing.

### Pros:

- states that if a tank does not have any ignition sources in the tank then the environment does not have to be considered
- requires an evaluation of all fuel tanks
- provides a performance comparison basis (tanks of the same aircraft)
- provides a flammability performance target via the cool down rate (temperature) or suppression of the flammable environment (inert)
- Implicates the notion that body tanks should be similar to wing tanks understanding that there is a physical difference between the two tank concepts

### Cons:

- Does not meet the tasking statement because it speaks about the role of ignition sources within the environmental analysis assessment
- May not be practical to apply to in-service aircraft
- Temperature delta may not be considered prescriptive

### Option E - FAR Amendment 25-102

Section 25.981(c) The fuel tank installation must include:

- (1) Means to minimize the development of flammable vapors in the fuel tanks (in the context of this rule, “minimize” means to incorporate practicable design methods to reduce the likelihood of flammable vapors), or
- (2) Means to mitigate the effects of ignition of fuel vapors within fuel tanks such that no damage caused by an ignition

### Pros:

- Word “minimize” and “development” are performance based term that can be interpreted within the preamble and guidance material
- provides an alternative means of compliance - control of aircraft structural integrity and not control of the fire triangle provided through the “or” option
- design objective is inherent and is not subjected to an interpretive percent value

- implies that all fuel tanks and all flight/ground conditions are implicated in the evaluation
- Provides multiple options of controlling the environment and states that any one of the options are equally acceptable
- States the meaning of minimize with the rule text

Cons:

- a specific Appendix imposing an evaluation method is not proposed in the regulatory text
- it is up to the applicant to show “minimization”; the guidance material and preamble will provide guidance on how to “minimize”
- “minimize” does not provide a measurable goal. It is up to the applicant and regulating authority to determine that the design is satisfactory. This may lead to inconsistent level of safety.
- The acceptable standard for minimization may change with time; an acceptable approach and design may not be acceptable for a future product due to a change of philosophy by an individual certificating authority

### **3.4.6 Conclusion**

After much deliberation, the team decided that the existing regulatory text introduced by FAR Amendment 25-102 best met the requirement of the tasking statement (Option E).

Inerting systems could be evaluated against the word practicable. That is, if the inerting system were found to be practicable then it would become the minimum standard; if not practicable then some other means of flammable reduction would become the minimum standard.

The team decided to discard the other options because it was:

- Option A: impractical to impose a numerical limitation due to the lack of an industry agreed pass/fail criteria.
- Option B: flight phase limiting; “risk” may occur in a flight phase other than ground
- Option C: primary means of compliance is through heat control; this is too restrictive for inerting and the tasking statement
- Option D: linked to ignition source control and therefore outside of the tasking statement; impractical to impose a numerical limitation due to the lack of an industry agreed pass/fail criteria

### **3.4.7 Guidance Material Associated to the Regulatory Text**

The rulemaking team agreed that the flammability regulatory text should be associated to some guidance material.

The purpose of the guidance material is to define the “standard” by which the applicant’s product is going to be evaluated and judged acceptable. It should be used to identify the design and/or procedures that are needed to ensure the safety of the aircraft design. The guidance material should not identify how to design a system. For example, the guidance material associated to this rule should not provide advice to an applicant on how to design and operate a fuel tank inerting system.

The “standard” should be subdivided into four subtopics:

1. The circumstances for conducting an assessment of flammability
2. Decision to pursue regulatory text evaluation

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3. Assessment of the flammability - the state under which the product needs to be placed in order to obtain the parameters needed to make a judgement on performance (similar to the playing field and the rules of the game.)
4. The standard itself - the basis on which the compliance decision will be based (determination of compliance)

The team agreed that an acceptable performance based rule is one in which the regulatory text and the standard are compatible and ensure an equivalent safety level across all product lines.

### Development of the “standard” limited by the tasking statement

The tasking statement limited the team’s ability to develop a flammability “standard”.

The tasking statement required the team to determine whether fuel tank inerting could be used as the practicable industry standard to show compliance to a flammability regulatory text. The FAA considered that Subtopics 1-3 were addressed by its Advisory Circular AC 25.981-2. Therefore, the rulemaking team only addressed subtopic 4.

### Development of a “standard” excluding the tasking statement instructions

Some team members felt if the FTIHWG was to endorse or create a flammability regulatory text, then all subtopics within the “standard” definition should be addressed irrespective of the tasking statement.

The team decided to discuss each subtopic and document its general concerns. These concerns could then be expanded as appropriate to the regulatory text development.

### *Circumstances For Conducting An Assessment Of Flammability*

AC 25.981-2 provides guidance in this area.

However, some team members felt that a flammability rule should not be applied to fuel tank ullage if all of the mechanical and electrical potential ignition sources were removed.

This determination could be made by developing qualitative pass/fail criteria; no credit is given for probability of failure. The design either complies with the condition “pass” or does not comply with the condition “fail”.

If the applicant passes the checklist then the flammability regulatory text is not applicable.

### *Decision to pursue regulatory text evaluation*

The team agreed that the purpose of the flammability regulatory text needed to be clearly stated within the guidance material.

The aircraft design goal (aircraft safety objective) needs to be stated. Any performance-based words - “minimized”, “limit”, etc. - need to be defined. The definition can be specified as a specific goal (X% flammability exposure) or by a design assessment associated to a pass/fail criterion.

Some team members felt that the guidance material should give credit for mitigation of ignition sources via one of two means:

1. Protection of the tank from structural and systems damage in case that ignition of fuel/vapor air mixture took.

An example of an acceptable means is the use of appropriate foam. The fuel tank is filled with a type of foam that ensures the control of the pressure rise following an ignition of the fuel/air vapor mixture.

2. Snubbing of the spark prior to its coming in contact with the flammable fuel/air vapor mixture (an ignition is not created).

### Assessment of the flammability

AC 25.981-2 provides a method to determine the average flammability exposure of a given tank.

Some team members raised concerns over whether an average flammability exposure calculation really provides the correct type of assessment needed to prevent the “accident risk”.

It was estimated that at least seven parameters needed to be assessed to determine if the “accident risk” has been mitigated. They are:

1. *Influence of outside ambient air temperature* - ISA / ISA +23°C (73.4°F) variation can be used to determine operational limitations and measure the effectiveness of any design/operational changes based on outside conditions.
2. *Effect of fuel loading on the fuel tank heat transfer characteristics* - the results can be used to show the thermodynamic influence of fuel on the overall ullage cooling behavior and resultant flammability exposure.
3. *Thermodynamic characteristics of each equipment/system* - the results can be used to identify the contribution of each equipment/system to the overall ullage characteristics. This in turn can be used to identify design changes or operational constraints (master minimum equipment list, ground operation procedures).
4. *Influence of ground operation time* - the results can be used to understand the influence of ground operation on the fuel tank ullage temperature. The results can be used to substantiate design decisions or operational procedures.
5. *Identification of hot spots* - the results can identify whether there is a local change in the flammability characteristics of the ullage.
6. *Differences/similarities between the tanks* - the results can identify whether any tank has an unusual thermodynamic characteristic as compared to the others. This reason for this difference can be evaluated and the used to determine if any design or operational actions need to be taken.
7. *Identification of the magnitude that a design is influenced by natural physical properties versus by design choices* - the results can be used to establish a comparison basis with ambient conditions. The results from the unheated configuration show the flammability exposure characteristic of the design based only on fuel loading, pressure and aerodynamic effects. The results from the heated configuration show the influence of the internal fuel system mechanical components and the adjacent systems on the flammability exposure. The comparison of heated and unheated results can be used to show the direct benefit on flammability exposure of any design or operational changes under a certain fuel loading and outside ambient air condition.

Team members agreed that probably both the average risk and specific risk were needed to ensure that all hazards were addressed within the design.

### Determination of compliance

Team members voiced concerns over the utilization of the interpretative words such as “minimize” or “limit the development”.

Experience on past projects have shown that differing opinions between the applicant and Authority of what constitutes “minimize” or “limit” has led to costly delays in some certification programs.

Industry team members encouraged the FAA and JAA to work with them as an industry group, to develop a process and associated numerical conditions by which applicable can be judged. An example of a process, is a flow chart that provides acceptable design conditions and choices on how to proceed

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depending on conditions. An example of a numerical condition is an average flammability exposure percentage or a temperature limit.

### **3.5 CERTIFICATION COST ASSESSMENT**

Below are list of activities required for certification of a fuel tank inerting means. This estimate is for one model aircraft and is not specific to a Ground Base or On-Board fuel tank inerting system. This estimate does not include design and installation of the system.

a. Qualification Testing (Assumed 4 New Parts) – 1,440 Hours Total

- 1) Review & Approve Qualification Test Procedures/Plans for New Parts (1 Man – One Month per plan)

Approximate Hours =  $1 * 160 * 4 = 640$  hours (includes conformity request)

- 2) Witness Testing (1 Man - One Month)

Approximate Hours = 160 hours

- 3) Review and Approve Qualification Test Reports (1 Man - One Month per report)

Approximate Hours =  $1 * 160 * 4 = 640$  hours

b. Lab Development/Testing – 6,500 Hours Total

- 1) We need to make sure we can distribute the gas throughout the tank and that the individual components function as a system. This requires planning, coordination, tank design & fabrication, system check out, test conduct, documentation and facility restoration.

Approximate Labor Hours = 6,100 hours

Approximate Material Cost = \$ 40,000 =  $40,000/100 = 400$  hours

***Airplane Testing - 16,049 Hours Total***

- 2) Write Engineering Work Authorization (1 Man - Two Week)

Approximate Hours =  $1 * 40 * 2 = 80$  hours

- 3) Write/Review Detailed Ground Test Plans and Flight Test Tip Sheets ( 3 Man – One Month)

Approximate Hours =  $3 * 160 = 480$  hours

- 4) Conformity Inspection/Instrumentation/Shop Support/Flight Test Support ( based on 737-NG FAA test)

**Approximate Hours = 13,765 hours**

- 5) Ground Test Portion (Ground Crew 3, Test Engineers 2, System Engineers 2, FAA Representative 1, Airplane Ground Test Hours of 68 based on 737-NG FAA test)

Approximate Hours =  $(3 + 2 + 2 + 1) * 68 = 544$  hours

a) Demonstrate Fuel Tank Inerting Procedures

b) Ensure tank remains inert during prolonged ground operations with X-Wind

- 6) Flight Test Portion (Flight Crew 2, Ground Crew 3, Test Engineers 2, System Engineers 2, FAA Representative 1, Airplane Flight Test hours of 54 based on 737-NG FAA test)

Approximate Hours =  $(2 + 3 + 2 + 2 + 1) * 54 = 540$  hours

- a) Demonstrate that Fuel Tank (s) remain inert during applicable phases of flight (taxi, takeoff, climb, cruise) with different fuel loads.

- 7) Propulsion Laboratory/Flight Test Reports (2 Man - Two Months)

Approximate Hours =  $2 * 160 * 2 = 640$  hours

- c. Certification Documents – 2880 Hours Total

- 1) Prepare and submit a Certification Plan (1 Man Month)

Approximate Hours =  $1 * 160 = 160$  hours

- 2) System Description & Analysis Report Including the System Safety Assessment (Two Man – Three Months)

Approximate Hours =  $2 * 160 * 3 = 960$  hours

- 3) Ground & Flight Test Reports (2 Man - Three Months)

Approximate Hours =  $2 * 160 * 3 = 960$  hours

- 4) FAA coordination (1 Man Month)

Approximate Hours =  $1 * 160 = 160$  hours

- 5) Support Flight Operations Evaluations Board & MSG-3 Analysis (1 Man Month)

Approximate Hours =  $1 * 160 = 160$  hours

- 6) Engine Rotor Burst Analysis Applicable only to the On-Board Inerting System (3 Man Months)

Approximate Hours =  $3 * 160 = 480$  hours

***Sum Total = 26,869 hours (approximately 6 Man – Two Years)***

**ATTACHMENT 1  
GUIDANCE MATERIAL -**

**FUEL TANK INERTING SYSTEM - DESIGN, INSTALLATION AND CERTIFICATION**

**1. Purpose**

The intent of this section is to tell the reader what is in this guidance material and how it can be used. An example of how this section could read is provided below:

“This advisory material provides information and guidance on the design, installation and certification of a NEA inerting system.

An applicant may choose to install a NEA inerting system within one or all of its aircraft’s fuel tanks in order to reduce or eliminate the flammable environment created by the fuel tank’s fuel/air vapor ullage (means by which to shown compliance to FAR/JAR 25.xxx).

The guidance provided within this advisory material is harmonized with the US Federal Aviation Administration (FAA) and Joint Aviation Authority (JAA) and is intended to provide a method of compliance that has been found acceptable. As with all AC material, it is not mandatory and does not constitute a regulation.”

**2. Background**

This section should include background material that is compatible with both the Advisory Circular that it’s published in and the regulation that it’s supporting. The background material drafted below provides the circumstances under which this guidance material was drafted. It is recommended that this section be revised upon publication of any of this material.

“Following the TWA 800 accident, both the NTSB and the FAA, questioned whether reducing or eliminating the flammable fuel tank environment could improve aircraft safety by further reducing the risk of a fuel tank explosion.

Traditionally, fuel tank explosions are prevented, by ensuring that there are no ignition sources within the flammable fuel-tank environment. Since the TWA 800 accident, the emphasis on fuel-tank ignition source prevention has increased. Both in-service and new type certificated aircraft have improved the robustness of their fuel-tank ignition source prevention designs. The FAA has issued a change to the FARs (FAR Amendments 21-78, 25-102, 91-266, 121-282, 125-36 and 129-30) in order to ensure that fuel-tank ignition sources are prevented.

However, even with the increased robustness of fuel-tank ignition source prevention, the FAA has concluded that a safety benefit may be achieved if the applicants took precautions to minimize the fuel/air flammable environment (termed the “flammable vapors”) on future airplanes.

The FAA, therefore, proposed a change to FAR 25 via NPRM 99-18 (published in Amendment 25-102) to add a requirement, §25.981(c), such that

“The fuel tank installation must include:

- (1) Means to minimize the development of flammable vapors in the fuel tanks (in the context of this rule, “minimize means to incorporate practicable design methods to reduce the likelihood of flammable vapors), *or*
- (2) Means to mitigate the effects of an ignition of fuel vapors within fuel tanks such that any damage caused by an ignition will not prevent continued safe flight and landing.”

The FAA has also published an associated guidance material (AC No. 25.981-2, entitled “Fuel Tank Flammability Minimization”) to complement FAR §25.981(c). The FAA stated that the purpose of this AC is to provide “information and guidance concerning compliance with the airworthiness standards for transport category airplanes pertaining to minimizing the formation or mitigation hazards from flammable fuel air mixtures within fuel tanks”.

Fuel tank inerting is suggested in Section 7.(a) of the AC as a means to reduce the flammable environment within a fuel tank. In fact, section 7.(a) states that “Fuel tank inerting is a highly effective means of reducing or eliminating the flammability exposure within a given fuel tank.”

When a FAA sponsored study (FAA Report DOT/FAA/AR-00/19) that fuel tank inerting was not only an efficient but economically viable solution, the FAA formed the ARAC Fuel Tank Inerting Harmonization Working Group. One of this group’s tasks was to formulate guidance material that could be used in designing an inerting system.

The guidance material presented herewith is the result of this task group. Its purpose is to provide a comprehensive guide on the considerations that an applicant should give to developing, installing and certificating a NEA inerting system.

### **3. Related Documents**

#### **Related Federal Aviation Regulations. (FAR Sections (limited to FAR 25))**

An initial review of the 14 CFR part 25 sections shows that the following paragraphs prescribe the design requirements for the substantiation and certification of a NEA inerting system as presented within the ARAC FTIHWG. This should be reviewed prior to the publication of any Advisory Material.

- 1) Paragraph that directly leads to fuel tank inerting
  - §25.981(c) Flammability minimization
- 2) new paragraph:
  - §25.xxx Fuel Tank Inerting System
  - others, if created
- 3) applicable paragraphs to fuel systems, installation, indications
  - §25.365 Pressurized compartment loads
  - §25.729(f) Wheels and tire failure
  - §25.863 Flammable fluid fire protection
  - §25.901 Installation
  - §25.903 Engines
  - §25.954 Fuel system lightning protection
  - §25.965 Fuel tank tests
  - §25.975 Fuel tank vents and carburetor vapor vents
  - §25.981 Fuel tank temperature
  - §25.993 Fuel system lines and fittings
  - §25.994 Fuel system components
  - §25.1181-1207 Powerplant Fire Protection
  - §25.1141 Powerplant controls: general
  - §25.1301 Function and installation
  - §25.1309 Equipment, systems, and installations
  - §25.1316 System Lightning Protection
  - §25.1353(a) Electrical Equipment and Installations
  - §25.1431(c) Electrical Equipment
  - §25.1438 Pressurization and pneumatic systems
  - §25.1461 Equipment containing high energy rotors
  - §25.1529 Instructions for Continued Airworthiness
  - §25.1541 Markings and Placards: General
  - §25.1581 General Aeroplane Flight Manual section

#### **Advisory Material**

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An initial review of existing FAA advisory circulars identified a number of Advisory Circulars that may be of assistance to the applicant when designing, substantiating and certification an inerting system as presented within the ARAC FTIHWG. This list would need to be updated at the time of publication of any Advisory Circular.

### 1) Existing Advisory Circulars or other standards

AC 25-8 Auxiliary Fuel System Installations, dated 5/2/86

AC 25-53A Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning, dated 4/12/85

AC 25.981-1B Fuel Tank Ignition Sources Prevention Guidelines, dated 4/18/01

AC 25.981-2 Fuel Tank Flammability Minimization, dated 4/18/01

### 2) Other Guidance Material Under Development within the FTIHWG

Guidance material - Operation and Maintenance of a Fuel Tank Inerting

### **Society of Automotive Engineers (SAE) Documents**

The following documents published by the Society of Automotive Engineers may be useful when designing, substantiating and certifying a fuel tank inerting system as presented within the ARAC FTIHWG. This list would need to be updated at the time of publication of any Advisory Circular.

- 1) SAE AIR 5128 “Electrical Bonding of Aircraft Fuel System Plumbing Systems,” (January 1997).
- 2) SAE AIR 4170, “Reticulated Polyurethane Safety Foam Explosion Suppressant Material for Fuel Systems and Dry Bays”
- 3) SAE AIR 1903 “Aircraft Inerting Systems.” (Draft)
- 4) SAE AIR 1662, “Minimization of Electrostatic Hazards in Aircraft Fuel Systems,” (October 1984).

### **Military Specifications**

The military specification reference is came from AC 25.981-2. No other published information from the military was made available to the ARAC FTIHWG. An enhanced research may be performed at the time of publication of a draft Advisory Circular.

- 1) MIL-B-83054, Baffle and Inerting Material, Aircraft Fuel Tank (March 1984)

### **Other**

Some other publications were identified as being useful when designing, substantiating and certifying an inerting system as presented within the ARAC FTIHWG. An enhanced research may be performed at the time of publication of a draft Advisory Circular.

This list may need to be expanded, as more information becomes published:

- 1) FAA Document DOT/FAA/AR-98/26, Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, June 1998. (A copy of this report can be obtained through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.fire.tc.faa.gov>)
- 2) Aviation Rulemaking Advisory Committee, Fuel Tank Harmonization Working Group, Final Report, July 1998 (a copy of this report may be obtained on line from the U.S. Department of Transportation (DOT) electronic docket, Docket No. FAA-1998-4183, at the following web site address: <http://dms.dot.gov>)

- 3) “Effects of Fuel Slosh and Vibration on the Flammability Hazards of Hydrocarbon Turbine Fuels Within Aircraft Fuel Tanks,” Technical report AFAPL-TR-70-65 (November 1970), Edwin E. Ott. (Contact Airforce Aero Propulsion Laboratory, Airforce Systems Command, Wright-Patterson Air Force Base Ohio.)
- 4) FAA Order 8110.34A, “Procedures for the Use of Fuels for Turbine Powered Aircraft,” March 1980.
- 5) FAA Document DOT/FAA/AR-99/65, “Mass Loading Effect on Fuel Vapor Concentrations in Aircraft Fuel Tank Ullage”
- 6) FAA Document DOT/FAA/AR-00/19, “The Cost of Implementing Ground Based Fuel Tank Inerting in the Commercial Fleet”, May 2000
- 7) Aviation Rulemaking Advisory Committee, Fuel Tank Inerting Harmonization Working Group, Final Report
- 8) OSHA Standard Number 1910.146 - Permit-required confined spaces subpart J, General Environmental Controls

#### **4. Definitions / Abbreviations**

The definitions and abbreviations listed hereunder are those that may be pertinent to the design and certification of a fuel tank inerting system. Some of the definitions are different than those appearing in AC 25.981-1 and/or -2 and are marked as such.

- a) ASM: Air separator module - either a passive permeable membrane system that relies on polymer membranes to separate nitrogen from air or a molecular sieve system that adsorbs oxygen from the air
- b) Center wing tank: A fuel tank located in the aircraft’s wing box but located within the fuselage of the aircraft.
- c) Flammable: Flammable, with respect to a fluid or gas, flammable means susceptible to igniting readily or to exploding. (14 CFR Part 1, Definitions).
- d) Flammability exposure: “Exposure” refers to the mission time where a combination of items in a fire triangle, required to obtain combustion, exists. The fire triangle consists of oxygen, flammable fuel, and an ignition source. If any one of these is removed, combustion will not occur.

Note: Because fuel flammability varies with fuel temperature, fuel type and fuel altitude, exposure may vary based on the heat transfer characteristics of a fuel tank. For instance, any fuel tank that presents a large surface area to the airstream could have a smaller exposure than a fuel tank within the fuselage.

- e) Flammability range: The pressure (i.e., altitude)/temperature domain where the fuel vapor/air mixture is flammable. This domain is dependent on the type of fuel used.
- f) Fuel air ratio (FAR): The ratio of the weight of fuel vapor to the weight of air in the ullage.
- g) Fuel scrubbing: Use of inerting gas to dilute the dissolved oxygen in the fuel.

Fuel scrubbing involves the injection of inert gas in a stream of fuel. The fuel is divided in multiple small streams which provides a large fuel surface area. The inert gas is mixed with these streams and absorbed by the fuel surface. This dilutes the oxygen concentration of the air already in the fuel.

To remain inert, the fuel must be placed in a tank with inert ullage. (Otherwise, it will absorb oxygen and give up nitrogen.)

Once the fuel is scrubbed and the aircraft enters its climb and early portion of the cruise flight phase, the inert gas (mostly nitrogen) will evolve out of the fuel to the ullage.

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- h) Fuel tank: An aircraft volume containing fuel. Tanks contain both liquid fuel and, in the vapor space or ullage space, a fuel vapor/air mixture, with some water vapor, depending on the relative humidity in the tank.
- i) Fuel types: Different fuels are approved for use in turbine powered airplanes. The most widely used fuel types are JET-A/JET-A1 and JET-B (JP-4), per ASTM Specification D1655-99, "Standard Specification for Aviation Turbine Fuels." The approved fuel types for a given airplane type are listed in the Airplane Flight Manual (AFM). Each fuel type has its own properties; those directly related to flammability are "flash point" and "distillation" characteristics. Property differences can occur in a given fuel type as a result of variations in the source crude oil properties and the refining process used to produce the fuel.
- j) Heated fuel tank: Fuel tanks that experience a rapid rise in temperature due to the adjacent system equipment.
- k) Inert fuel tank: Fuel tank inerting, as applied to aircraft fuel tanks, can be defined as the inclusion of a gas, in the ullage prior to ignition of the vapor, that will suppress that ignition, independent of the fuel air mixture.
- l) Inert gas: A gas that will not oxidize. In fuel tanks, the ullage is considered inert when the O<sub>2</sub> concentration is approximately 10% or less (unless future data shows otherwise), when nitrogen is used as the inert gas.
- m) Lean Fuel Vapor/Air Mixture: A fuel vapor mixture that has insufficient concentration of fuel molecules below that which will support combustion.
- n) NEA: Nitrogen enriched air - a gas with nitrogen purity of 90-98%.
- o) Operational time: The time from the start of preparing the airplane for flight, (turning on the auxiliary power unit (APU) /ground power, starting the environmental control systems etc.), through the actual flight and landing, and through the time to disembark any payload, passengers and crew.
- p) Rich Fuel Vapor/Air Mixture: A fuel vapor/air mixture that contains a concentration of fuel molecules above that which will support combustion
- q) Ullage or ullage space: The volume within the tank not occupied by liquid fuel.
- r) Ullage washing: Use of inert gas to dilute the air above the fuel (ullage).
- s) Unheated fuel tank: a fuel tank that is not heated  
(AC 25.981-2 definition - A conventional aluminum structure, integral tank of a subsonic transport wing, with minimum heat input from the aircraft systems or other fuel tanks that are heated.)
- t) Wing tank: A fuel tank located within the aircraft's wing.

Note: Generally, any tank that presents a large surface area to the airstream could be considered to have the same exposure as a wing tank. For example, fuel tanks in the horizontal or vertical stabilizer, wing-mounted pods, or externally-mounted fuselage or fairing tanks.

### **5. Inerting System Design Concepts**

Various NEA inerting system design concepts exist. Each proposed system design concept may provide a different level of flammability protection to the aircraft.

The intent of this proposed section is to provide the applicant with general information regarding the different concepts of NEA inerting systems and general level of flammability protection that can be expected from each concept.

The applicant can then use this information to assess, which, if any, NEA inerting system could be pursued for its aircraft application.

a.) General fuel tank inerting concept

This section explains what fuel tank inerting is and its effect on the fuel/air vapor environment within the fuel tank.

Fuel tank inerting, as applied to aircraft fuel tanks, can be defined as the inclusion of a gas in the ullage prior to ignition of the vapor that will suppress that ignition, independent of the fuel air mixture. The gas used can be one that simply reduces the oxygen available for combustion, such as NEA, or one that chemically interferes with the combustion process, such as Halon 1301.

This advisory material discusses only inerting systems using NEA. Therefore, the fuel tank inerting definition can be simplified to read “fuel tank inerting is the process of displacing air from the fuel tank with an inert gas (NEA) in order to decrease the probability of combustion”.

Military studies (SAE document 1903, “Aircraft Inerting Systems”) show that the oxygen content of the fuel tank ullage should be less than 9% in order to prevent fuel tank combustion after tank penetration by a high-energy incendiary (HEI) round.

For commercial applications, minimum oxygen concentration needed to prevent catastrophic fuel tank rupture may vary by tank design. Studies indicate that a 10% by volume oxygen concentration level is sufficient to prevent combustion and subsequent catastrophic consequences, in the unlikely event of an ignition source in the fuel tank.

Further research is ongoing to evaluate the effect on commercial aircraft fuel tanks, if the minimum oxygen concentration level is increased. These results may be used as a basis for new design criteria when available.

b.) Ground Based Inerting

The purpose of this section is to state:

- (1) the general principles of ground based inerting
- (2) flight phases for which ground based inerting is effective
- (3) the general impact on the aircraft design and the aircraft operation (system criteria / operational impact, including airport facilities interface)

b.1) General principles of ground based inerting

A ground based inerting system ensures ullage washing using a source of inerting gas at the airport (external to the aircraft) and a dedicated aircraft NEA distribution system.

The NEA is supplied to the fuel tanks, by an external ground source, via a dedicated line connected to the aircraft at a specific connector. The ground connection point is a type, which only allows connection to the appropriate ground equipment. It should be positioned as to minimize interference with baggage handling and other ground departure activities.

The NEA is distributed to the fuel tanks via an aircraft distribution system. The pipe that goes between the connection and the fuel tank wall should be doubled walled in order to ensure that a single failure does not release NEA into the pressurized area or an enclosed space. The manifold installed in the tank contains a series of outlets/nozzles that discharge the NEA. Initial testing done by the FAA on a B737, showed that the volume required to inert the tank ullage is approximately 1.7 times the maximum ullage space.

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The ground source supply should be controlled to ensure that the delivered pressure does not exceed the allowable value for the aircraft type being serviced. The maximum supply pressure required to avoid exceeding tank design limits differ for each aircraft design.

The typical time to inert a large transport category aircraft is estimated to be around 20 minutes.

### b.2) Flight phase for which ground based inerting is effective

The effectiveness of ground based inerting depends on the outside ambient air temperature, the amount of fuel in the tank(s), the aircraft vent system and the fuel type.

FAA sponsored testing on a B737, showed that ground based inerting may be effective during the ground, taxi, takeoff, climb and a portion of the cruise flight phase (with the possibility of retaining the effectiveness until the top of descent).

### b.3) General impact on the aircraft design and the aircraft operation

Ground based inerting system has an effect on the aircraft design, the airport facilities needed to dispatch the aircraft and the aircraft departure procedures. Ground based inerting may have an effect on the aircraft turnaround time.

The advantages of a ground based inerting system are:

- there is a minimal impact on the aircraft weight,
- system complexity limited; system is relatively simple
- aircraft system interfaces are minimized
- standard approach to supply every aircraft with a set volume of NEA (1.7 times the maximum ullage volume) can be used
- direct aircraft cost and certification cost are minimized

The disadvantage of this system is :

- complexity and cost linked to the airport facilities and infrastructure
- recurring labor costs to provide the NEA to the aircraft
- limited protection during climb and some of cruise (depends on initial fuel load)
- only inerts center wing tank..

The overall system's operational complexity will vary depending on the amount of system automatism. For example, a non-complex system's operation could consist of:

- connecting the ground supply to the aircraft
- selecting the isolation valve open
- adding an appropriate volume of NEA
- closing the isolation valve
- disconnecting the NEA supply
- filling in a control sheet to indicate that the operation has been carried out and to record the amount of NEA added. The sheet will be passed to the flight crew for confirmation that the correct quantity was loaded.

The amount of equipment added to the aircraft will again depend on the system's complexity and the number of tanks to be inerted. Some specific design features to consider are listed hereunder:

- ensure that there is no damage to the aircraft in the event of the aircraft moving while the ground equipment is still connected: consider inclusion of a self sealing coupling incorporating a frangible device
- detect for fuel leakage into the pipe: consider installing a witness drain
- isolate the tank from an external pipe: consider installing an isolation valve

- prevent backflow of the fuel in the event of loss of pressure in the NEA supply: consider incorporating a non-return valve
- relieve any pressure that may build up in the pipe due to temperature changes: consider installing a thermal relief valve
- indication of the isolation valve functioning: consider installation of a control switch and caption lamp
- ensure that a single failure does not release NEA into the pressurized area or an enclosed space: consider double walled pipes between the connection to the tanks

**Note: The ground connection coupling used in this design should be associated to an industry standard. This industry standard needs to be developed if GBI is pursued.**

Other issues that need to be considered are:

- need for dedicated ground personnel
- impact on overall ground servicing operations
- impact on the airport; infrastructure, equipment, etc.
- potential environmental issues from venting the tanks overboard

c.) On Board Ground Based Inerting (OBGI), including hybrid system

The purpose of this section is to state:

- (1) the general principles of on-board ground based inerting
- (2) flight phases for which on-board ground based inerting is effective
- (3) the general impact on the aircraft design and the aircraft operation (system criteria / operational impact, including airport facilities interface)
- (4) Air separator module

c.1) General principles of on-board ground based inerting

An on-board ground based inerting system ensures ullage washing, on the ground only, via a system that carries all equipment necessary to inert the fuel tanks on board the aircraft.

This system does not operate in-flight. This system assumes that the selected fuel tanks are inert prior to leaving the terminal gate.

NEA is produced by equipment located on the aircraft. This NEA is then fed into an aircraft distribution system similar to the GBI system.

NEA is produced by forcing air through an ASM. The air must be conditioned prior to entering the ASM - temperature / water content / purity.

The system's operational objectives, amount of NEA to be produced and delivered to the aircraft's fuel system, must be assessed for each aircraft design. For instance, assumptions such as the minimum turn around time to get the tanks inert, the air source (outside or APU), the gate operational restrictions for the APU need to be considered prior to undertaking the design.

As with GBI, the system should be designed to ensure its compatibility with the fuel tank pressure limits.

The estimated time to inert a large transport category aircraft is 60 minutes.

A hybrid OBGI system can be designed. A hybrid OBGI would only run during taxi-in and taxi-out. It provide less protections than a sized OBGI system, but would reduce the system's weight, volume, power and air consumption.

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### c.2) Flight phase for which on-board ground based inerting is effective

The effectiveness of on-board ground based inerting depends on the outside ambient air temperature, the amount of fuel in the tank(s), the aircraft vent system, the fuel type and the capacity and operating time of the system.

The effectiveness of this system is similar to that of ground based inerting (see b.(2)).

### c.3) General impact on the aircraft design and the aircraft operation

On-board ground based inerting system has an effect on the aircraft design, the airport facilities needed to dispatch the aircraft and the aircraft departure procedures. On-board ground based inerting may have an effect on the aircraft turnaround time.

The advantages of an on-board ground based inerting system are:

- it can use airport resources such as air carts or electrical carts for power
- there is no operational impact between this system and other aircraft systems;
- certification activities are simplified compared to an on-board in-flight system
- aircraft is self sufficient; it is a better solution for remote airports

The disadvantages of an on-board ground based inerting system are:

- the size and the weight of the system
- the cost linked to the airport facilities (less than for ground based inerting)
- hull/skin penetration necessary for the compressor's ram air inlet and exhaust, as well as for the heat exchangers
- affect on engine/aircraft performance
- increased electrical power usage at the gate; requires a dedicated power source
- compressor and cooling fan noise
- increase in maintenance exclusion zones on ground
- provides limited protection during climb and some of cruise (depending on initial fuel load)
- poor reliability

The overall system's operational complexity will vary depending on the amount of system automatism. For example, a typical OBG system, that is not redundant, not cross-vented, has no warm up times for the ASMs and does not affect turn around time, could consist of:

- providing air to the system via an electrically driving air compressor (or alternative bleed air source)
- conditioning the air to enter into the ASMs - temperature, water content, purity
- producing the nitrogen via an ASM
- controlling the O<sub>2</sub> content
- distributing the NEA to the aircraft fuel tanks
- the operational control of the system, start and shutoff of the system, could be performed semi-automatically
- a recording system to state that the NEA has been added to the aircraft fuel tanks should be envisaged

The amount of equipment added to the aircraft will again depend on the system's complexity and the number of tanks to be inerted. Some specific design features to consider are listed hereunder:

#### compressor:

- containment features or location chosen so as to mitigate the effects of uncontained rotating equipment failure
- thermal cut-out features or ice / FOD prevention features to prevent motor overheating

- spark or flame arrestors incorporated in the compressor inlet and exits to avoid generation and propagation of sparks

ducts / vents:

- external temperature elements to automatically shutoff the system when an overheat is detected
- double walled ducting to limit the chance of NEA leakage into the pressurized section of the aircraft
- ventilation to avoid built up of NEA
- oxygen rich vents located away from fuel sources so as to not create a fire hazard
- bonding the tubing of the distribution system to prevent the creation of static electricity at high velocity flow rates of NEA

valves / sensors:

- pressure relief system to avoid fuel tank overpressure
- temperature monitoring sensors to avoid hot air being pumped into fuel tanks and increasing the risk of fuel tank explosion

general:

- development of confined entry space procedures
- air monitoring system (O2 level)
- system to ensure hot gas is not input into the tanks
- features to prevent icing of components, especially the ASM or water separator/filter
- indication system providing information on how system is operating

Other issues that need to be considered are:

- air inlet and exhaust for compressor and heat exchangers require hull/skin penetration
- potential risk from oxygen by-product
- appropriate space on the aircraft needed to fit the equipment
- potential environmental issues from venting the tanks overboard

c.4) Air separator module

The air separator module is a line replaceable unit and should be easily accessible by maintenance personnel.

The choice of ASM is up to the system designer.

One choice may be a passive permeable membrane system that relies on polymer membranes to separate nitrogen from air.

A second choice may be a molecular sieve system that adsorbs oxygen from the air.

Considerations that should be taken within the design choice are:

- Durability
- Sensitivity to hydrocarbon contamination
- Sensitivity to water contamination

d.) On-Board Inert Gas Generating System (OBIGGS) including Hybrid System

The purpose of this section is to state:

- (1) the general principles of on-board inert gas generating system
- (2) flight phases for which on-board inert gas generating system is effective

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- (3) the general impact on the aircraft design and the aircraft operation (system criteria / operational impact, including airport facilities interface)
- (4) Air separator module

### d.1) General principles of on-board inert gas generating system

An on-board inert gas generating system, OBIGGS, generates and distributes inert gas to selected fuel tanks at all times during the flight.

The OBIGGS design definition should be compatible with the system operational objectives (flammability exposure level).

Full time operation: This type of OBIGGS system is recommended for applicants that want to stay inert throughout the flight envelope. The system design is generally driven by the aircraft descent and descent rate because the system tries to produce enough inert gas to equalize the fuel tanks and to prevent ambient air from entering the fuel tank. This type of design keeps the system inert at all times.

Hybrid system - Intermittent or low-flow operation: This type of OBIGGS system is recommended when some small exposure time is permitted and when the system size is a concern. The system selectively applies inerting to certain tanks during a specific portion of the aircraft profile. For example, this system would typically not need to be sized for descent due to the minimal exposure time of the descent (compared to the takeoff, climb and cruise) or because the fuel and ullage in the tank may have cooled off during flight.

The distribution of the NEA is via an aircraft distribution system, similar to that both the GBI and OBI system.

The NEA is produced by forcing conditioned (temperature / water content / purity) air through an ASM. The air source is the aircraft - either aircraft cabin air or bleed air.

OBIGGS is not operated on the ground so it has no effect on turn around time. OBIGGS is not operated on the ground because it is continuously topping up the tanks.

As with all inerting systems, the OBIGGS system should be designed to ensure its compatibility with the fuel tank pressure limits. For OBIGGS, if cabin air is used as the source, particular attention needs to be paid to the aircraft pressurization requirements.

### d.2) Flight phase for which on-board ground based inerting is effective

A full time OBIGGS system is effective during all flight phases.

A hybrid system (an intermittent or low flow system) is effective during a selected number of flight phases. The system designer chooses these flight phases.

### d.3) General impact on the aircraft design and the aircraft operation

OBIGGS has an affect on the entire aircraft design. It does not have an affect on the aircraft turn around time because it is continually topping up the tanks throughout the flight.

OBIGGS is sized to inert during normal ground and typical flight operations. Normal operations include normal takeoff, climb, cruise, descent, landing and ground operations. Emergency descent is not a normal operation. The driving case for the design is normal descent.

The advantages of an OBIGGS system are:

- All fuel tanks are inerted through all phases of flight
- Aircraft is self sufficient; it can be used at all airports
- Reduced corrosion and condensation in the fuel tanks

The disadvantages of an OBIGGS system are:

- The size and weight of the system
- Engine / aircraft performance are affected
- Hull/skin penetration necessary for the compressor's ram air inlet and exhaust, as well as for heat exchangers
- Drag penalties from heat exchanger ram inlet, exit and ASM waste exit
- Potential interference with cabin re-pressurization during descent
- If air is drawn from the cabin, cabin air distribution patterns may be affected
- Compressor and cooling fan noise
- Decreased thrust recovery from the outflow valve
- High pressure ratio compressor

The overall system's operational complexity will vary depending on the amount of system automatism. For example, a typical OBIGGS system, that is not redundant, not cross-vented, does not effect turn around time, uses bleed air as its source during climb and cruise and cabin air as its source during descent, and is not operated between flights could consist of :

- Providing air to the system via the aircraft cabin or bleed air source via an electrically driven compressor (6:1 for large and medium transport, 4:1 for all others)
- Conditioning the air to enter the ASM - temperature, water content, purity
- Producing NEA via an ASM
- Controlling the O2 content and pressure prior to NEA entering the fuel tanks
- Distributing the NEA to the aircraft fuel tanks
- The operational control of the system, start and shutoff of the system, could be performed automatically with a manual override in case of system failure
- A method to ensure that NEA is being added to the aircraft fuel tanks should be envisaged

The amount of equipment added to the aircraft will depend on the system's complexity and the number of tanks to be inerted. Some specific design features to consider are listed here under:

compressor:

- containment features or location chosen so as to mitigate the effects of uncontained rotating equipment failure
- thermal cut-out features or ice / FOD prevention features to prevent motor overheat
- spark or flame arrestors incorporated in the compressor inlet and exits to avoid generation and propagation of sparks

ducts / vents:

- external temperature elements to automatically shutoff the system when an overheat is detected
- double walled ducting to limit the chance of NEA leakage into the pressurized section of the aircraft
- ventilation to avoid built up of NEA
- oxygen rich vents located away from fuel sources so as to not create a fire hazard
- bonding the tubing of the distribution system to prevent the creation of static electricity at high velocity flow rates of NEA

valves / sensors:

- pressure relief system to avoid fuel tank overpressure

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- temperature monitoring sensors to avoid hot air being pumped into fuel tanks and increasing the risk of fuel tank explosion
- rapid shutoff of the shutoff valve by a high flow fuse or similar equipment, near the fuselage penetration, in order to prevent loss of cabin pressurization

### general:

- development of confined entry space procedures
- air monitoring system (O<sub>2</sub> level)
- system to ensure hot gas is not input into the tanks
- features to prevent icing of components, especially the ASM or water separator/filter
- indication system providing information on how system is operating

Other issues that need to be considered are:

- air inlet and exhaust for compressor and heat exchangers require hull/skin penetration
- potential risk from oxygen by-product
- appropriate space on the aircraft needed to fit the equipment
- potential environmental issues from venting the tanks overboard

### d.4) Air separator module

The air separator module is a line replaceable unit and should be easily accessible by maintenance personnel.

The choice of ASM is up to the system designer.

One choice may be a passive permeable membrane system that relies on polymer membranes to separate nitrogen from air.

A second choice may be a molecular sieve system that adsorbs oxygen from the air.

Considerations that should be taken within the design choice are:

- Durability
- Sensitivity to hydrocarbon contamination
- Sensitivity to water contamination

## **6. Certification Plan / Compliance Demonstration**

Any inerting system is an integral part of the fuel system. A certification plan needs to be developed in order to demonstrate the airworthiness of the system itself, including its compatibility with the surrounding systems (fuel, air, ...)

This section provides general certification guidance by providing suggestions on what could be included within the certification plan.

### a.) Description:

Describe the fuel-tank inerting system design and operation.

The design description should include a description of the type of inerting system chosen, a system schematic, its interface with other aircraft systems including the cockpit, its interface with external services (for instances it needs NEA supplied from a source outside the aircraft).

The operational description should include the flight phases for which the system will be operated.

b.) Safety Assessment:

The applicant should define the safety assessment activities and their interrelationship with other activities within the design approval process.

FAR/JAR 25.1309 and its associated guidance material should be used as the basis of the assessment.

Compliance with FAR 25.901(c) should be demonstrated.

The analysis should identify any maintenance and or flight crew indications and procedures required to maintain aircraft safety as a result of fuel-tank inerting system installation.

c.) Analysis:

Analysis can be used to demonstrate the systems effectiveness and operating characteristics.

The first analysis is the flammability exposure analysis. If the applicant wishes to establish the benefit that the fuel tank inerting system has then the analysis should be done with and without the system installed.

The second type of analysis concerns the system operating characteristics. The analysis may be used to show the predicted effectiveness of the system. Its impact on other aircraft systems and its behavior under critical flight or electrical loading conditions should be evaluated.

A similarity analysis may be done to show the correct functioning of comparable systems or components.

d.) Testing: ground test, flight test and laboratory test

Ground / Flight Testing

A ground and/or flight test program should be established based on the newness of the design concept.

A flight and/or ground test program can be used to demonstrate that the fuel tank inerting system, including the NEA distribution system, is functioning as intended.

Laboratory Testing

Laboratory testing should be used, as required, for component test qualification.

e.) Compliance reports

The type of compliance reports should be provided within the certification plan.

Examples of the types of reports that may be provided are:

- System description and analysis
- System safety analysis
- Ground and flight analysis
- Component qualification reports

**7. System installation considerations**

Fuel tanks become inert because of the system operation. If the system is not installed and maintained correctly it can become in and of itself a hazard to the aircraft.

The fuel tank inerting system produces (OBGI and OBIGGS) and distributes NEA to one or more fuel tanks and vents the displaced fuel tank ullage overboard.

a.) Distribution system

The NEA distribution system is both external and internal to the fuel tank(s). Its purpose is to deliver NEA to the tanks.

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### *External to the tank*

Because NEA is a hazardous substance, design precautions should be taken to avoid and to detect NEA leakage. Design precautions such as double walled pipes, isolation-valves, seals between interfaces and leak detection devices should be considered within the design. The distribution piping should be routed through the non-pressurized portion of the bulkhead in order to minimize the risk of leakage into the cabin.

### *Internal to the tank*

Distribution system should be constructed in order to ensure a homogenous distribution of NEA throughout the tank. Appropriate precautions should be taken to ensure that the tank is not over-pressurized and that fuel does not contaminate the NEA distribution system. The distribution system should be bonded such that static electricity at high velocity flow rates of NEA does not create an ignition source.

#### b.) Vent system

The fuel tank vent system affects the efficiency of the inerting system.

#### *Open vent system*

Virtually all commercial vent-systems are designed to allow ambient air to flow into the tanks due to pressure differences between the tank and ambient.

The inert gas will freely flow out of the vent system. The system design should therefore be sized to accommodate for this loss. For OBIGGS systems, because the tanks are being kept inert all the time, the flow of the inert gas must be sufficient to limit the increase of oxygen content in the ullage due to ambient air influx.

#### *Open, cross-vent flow*

Some aircraft types vent the fuel tanks to multiple vent boxes (cross vent flow). This vent arrangement may permit a crosswind to ventilate the tanks with ambient air on the ground and/or in-flight. (FAA flight testing on a B737 showed that this type of system did not retain the NEA under ground based inerting conditions.) The effect of this type of vent should be tested.

#### *Closed vent*

Some military aircraft close the vent system with specialized check valves in order to retain inert gas in the fuel tanks. The check valves require a differential pressure to open. This feature adds a level of complexity to the vent system.

If this type of system is used, structural stresses on the wing structure should be carefully analyzed and be accounted for in the basic design. A fuel tank with an open vent will normally have some positive (expanding) or negative (contracting) pressures occurring during climb and descent until the ambient air equalizes with the pressure inside the tank. A closed-vent system exaggerates this effect by requiring the air at the high-pressure area to overcome the check valve's spring.

In a similar manner, a closed-vent system may increase the structural stress due to overflowing fuel from a fuel tank. For example, a fill valve may fail to close allowing a fuel tank to overflow into the vent system. Two-phase flow can develop when this overflow is combined with air pressure being expelled from other tanks. The addition of the backpressure from the check valve's spring will add to the total pressure within the fuel tank.

A check valve that fails closed may cause the fuel tank structure to experience high loads. For example, a check valve that failed closed on the ground would prevent air from exiting during climb resulting in a large pressure attempting to expand the fuel tank structure. A check valve that failed closed in flight

would prevent air from entering the tank during descent resulting in the ambient air attempting to crush the tank structure. Redundant check valves would alleviate these stresses.

In addition, if the fuel tank is directly supplying an engine a vacuum will develop within the tank as fuel is consumed unless air can replace the fuel. Redundant check valves would avoid the possibility of engine flameout.

In addition to redundant check valves, a tank pressure indication for the flight crew should be considered. Upon indication, the crew could reduce the climb or descent rate or level off to minimize the structural stress.

c.) Indications: cockpit, maintenance

Indications should be provided such that the user of the inerting system knows the system's condition (operational status). The type of indication should be compatible with the inerting system's design and complexity.

The user of the system should be able to know whether the system is:

- on or off,
- pressurized
- malfunctioning

For automatic systems, a manual override could be considered.

Because the inerting system is considered an added level of protection above that provided by the design features of the ignition system, it is defined by the FAA (AC 25.981-2) as a "safety enhancing" system and is not considered an "essential system". This means that no in-flight indication to the flight crew or any associated flight crew procedures would be needed (except possible if the automatic shutoff of the system fails) for enroute failure of the inerting system.

## **8. Aircraft Interfaces**

The fuel tank inerting system needs to be integrated with the other aircraft systems and need to comply with all relevant 14 CFR part 25 paragraphs.

The fuel tank inerting systems considered within the ARAC FTIHWG showed the systems interface with, at a minimum, the electrical, air and refuel systems. The systems also affect structure and rotorburst considerations.

This section details design considerations for electrical, air and refuel systems.

### Electrical system

Inerting systems can place large demands on the electrical system so it is imperative that this be taken into account during the design phase. At a minimum, an onboard system that generates inert gas will require power for a controller, control valves, heat exchanger fans, and sensors. Some designs will require power for precooler fans, additional control valves, and compressors. The power requirements may be upwards of 30 KVA or more depending on aircraft fuel tank size, number of tanks to be inerted, and the desired level of exposure.

For ground operation of the inerting equipment, ground electrical service plugs should be reviewed to ensure they have adequate capacity for the electrical power requirement. The ground service bus should also be reviewed for adequate capacity to handle the inerting system as well as the other systems that are typically operating during ground servicing. In addition, the capacity of the ground power supply should be considered to avoid overload.

For in-flight operation of the inerting equipment, in addition to the items mentioned for ground operation, consideration should be given to emergency power conditions. For example, many aircraft implement

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“load-shedding” which removes power from nonessential equipment in the event of generator failure. The inerting equipment should not jeopardize safe flight so system designers should consider “shedding” this equipment. Design items that should be included in this evaluation are: fleet-level exposure to a non-inert, flammable fuel tank; availability of power from the remaining generator(s) when one generator becomes inoperative; cost effectiveness of upgrading the power system to larger generator capacity; and cost effectiveness of “shedding” other nonessential equipment.

### *Engine bleed air system*

Onboard systems that separate nitrogen from air require a source for that air. Some aircraft will elect to use engine or APU bleed air as the source.

Membrane and PSA separators generally require fuel vapor and oil to be separated from the bleed air prior to entering the separator. Water and water vapor will also adversely affect PSA separators, requiring a water separator for removal.

Environmental control systems and potable water systems also rely on bleed air for operation. The environmental control system regulates its demand for bleed air. A regulator failure can cause pressure surges in the system, which may adversely affect the inerting system. Sufficient analysis and testing should be performed to ensure the interaction between the environmental and inerting systems (and other systems drawing bleed air) don't pose a safety hazard to the aircraft or engines in the event of component failures.

### *Cabin pressurization system*

Some aircraft may supply the air separators by compressing cabin air in lieu of, or in addition to, the engine bleed air supply. Another option is to compress engine bleed air when it's available and use compressed cabin air at other times.

### *Filters*

The air separator module will benefit from an air filter to keep out small particles. The compressor may require a filter to keep large particles from jamming the rotor possibly causing a rotor hazard or flammability hazard.

### *Water separator*

PSA modules are sensitive to moisture and will need to be dried once wetted. This can adversely affect system performance and should be avoided by the addition of a water separator upstream of the module(s).

### *Isolation valve and high-flow fuse*

An isolation valve, or another means to shutoff flow, will prevent system operation during failure conditions. For example, when one of the air conditioning packs has failed and the air supply to the cabin is just sufficient for the passengers, the inerting system must be shutoff. In addition, a duct rupture downstream of the valve could quickly evacuate the cabin. This can be prevented by incorporating a “high flow” fuse that closes when the air flow exceeds the needs of the inerting system.

### *Redundant check valves (to avoid fuel fumes in cabin)*

The inerting system couples the cabin and fuel tanks with a system of plumbing. FAR 25.967(e) requires the cabin to be separated from fuel tanks via a fume proof and fuel proof enclosure. Typically redundant check valves in series are employed in plumbing systems to prevent fumes or fuel from entering the cabin.

### *Refuel systems*

Inerting systems operated on ground should be compatible with the refuel system, so as to avoid overpressure of the fuel tanks and to not interfere with the gauging system and the shutoff system.

If ground based inerting is used, the ground connection coupling should be to the defined industry standard.

### **9. Continued Airworthiness/Maintenance Considerations**

The inerting system is part of the aircraft installation and therefore should meet the requirements of FAR §25.1529.

Because nitrogen is a hazardous substance, maintenance procedures should be defined in order to meet OSHA confined space requirements (OSHA No. 1910.146). Placards and environmental monitoring systems should be put in place in order to minimize the risk to the maintenance personnel.

The appropriate warning information should be included in the Maintenance Manuals. Particular attention should be paid to the ventilation systems.

### **10. Nitrogen Enriched Air (NEA): Precautions to Respect**

Nitrogen and other inert gases are not normally dangerous but when used in confined spaces they can quickly create oxygen deficient atmosphere that can be deadly. Nitrogen is especially hazardous because it cannot be detected by human senses and can cause injury and death within minutes. In the US at least 21 people have died in 18 separate accidents between 1990 to 1996 involving the use of nitrogen in confined spaces, even with strict health and safety procedures in place. On the average, work in confined spaces kills 15 people every year in the UK across a wide range of industries, from those involving complex plant through to simple storage vessels. In addition, a number of people are seriously injured. Those killed include not only people working in the confined space but those who try to rescue them without proper training.

The health risk to ground and maintenance personnel servicing the aircraft employing nitrogen inerting technology is present not only in the fuel tanks themselves but in the location of the nitrogen generating equipment. Wherever possible such equipment should be located outside the pressure hull, however, this is not possible on the majority of production aircraft. Therefore, it will be necessary to ensure that safety system and procedures are in place to protect the aircraft and personnel working in and around them.

More detail concerning confined spaces can be found in reference 8.

### **11. Evaluation of the Effects on Emissions**

Inerting with NEA causes additional VOCs (volatile organic compounds) to be displaced from the fuel tank. The increase in VOCs depends on the tank size and the amount ullage space (fuel quantity present in the tank).

Today, there are no 14 CFR regulations controlling fuel tank vent exhaust. However, some airports with the US and foreign airports may have local restriction on VOCs.

If these restrictions exist, then an assessment of the VOC content may need to be initiated along with a vapor recuperation system.

### **12. Master Minimum Equipment Assessment**

The FAA state in AC 25.981-2 that an inerting system is not a flight critical system and that airplanes may be dispatched with the system inoperative for short periods of time, provided the overall exposure to flammable vapors, including dispatch with the system inoperative, meets its flammability requirements.

The standard industry method should therefore be used to propose MMEL relief, along with a proposal stating the conditions under which the system can be inoperative

**ATTACHMENT 2  
GUIDANCE MATERIAL - FUEL TANK INERTING SYSTEM - OPERATION AND  
MAINTENANCE**

**Purpose**

The purpose of this guidance material is to provide advice in obtaining approval of a fuel tank inerting program.

A fuel tank inerting program is only needed if a fuel tank inerting system is installed on an aircraft.

**Background**

This guidance material was created by the FTIHWG as part of its operational regulatory assessment of fuel tank inerting systems. A fuel inerting system is installed to render the fuel tank environment non-flammable.

The background section should be expanded if this guidance material is ever made into an Advisory Circular.

**Related Material**

List other applicable ACs and industry standards including health and safety standards.

The FARs that would be referenced here would depend on the type of inerting system certified on the aircraft.

The references in the design guidance material could be used as applicable.

Other references to add, if determined applicable at the time of the Advisory Circular publication are:

- 3.1 (National Fire Protection Agency)NFPA 410 chapter 4 Aircraft Fuel Maintenance
- 3.2 OSHA Standard Number 1910.146 - Permit-required confined spaces subpart J, General Environmental Controls
- 3.3 Confined Space by Eric LeBreton - Canadian Transport Emergency Centre , Canutec Web site

**Definitions**

The type of definitions may be the same as those listed in the design guidance material. Specific definitions related to the operation of a NEA inerting system may be added based on an actual system design..

- a). ASM: Air separator module - either a passive permeable membrane system that relies on polymer membranes to separate nitrogen from air or a molecular sieve system that adsorbs oxygen from the air
- b). Center wing tank: A fuel tank located in the aircraft's wing box but located within the fuselage of the aircraft.
- c). Flammable: Flammable, with respect to a fluid or gas, flammable means susceptible to igniting readily or to exploding. (14 CFR Part 1, Definitions).
- d). Flammability exposure: "Exposure" refers to the mission time where a combination of items in a fire triangle, required to obtain combustion, exists. The fire triangle consists of oxygen, flammable fuel, and an ignition source. If any one of these is removed, combustion will not occur.

Note: Because fuel flammability varies with fuel temperature, fuel type and fuel altitude, exposure may vary based on the heat transfer characteristics of a fuel tank. For instance, any fuel tank that presents a large surface area to the airstream could have a smaller exposure than a fuel tank within the fuselage.

- e). Flammability range: The pressure (i.e., altitude)/temperature domain where the fuel vapor/air mixture is flammable. This domain is dependent on the type of fuel used.
- f). Fuel air ratio (FAR): The ratio of the weight of fuel vapor to the weight of air in the ullage.
- g). Fuel tank: An aircraft volume containing fuel. Tanks contain both liquid fuel and, in the vapor space or ullage space, a fuel vapor/air mixture, with some water vapor, depending on the relative humidity in the tank.
- h). Fuel types: Different fuels are approved for use in turbine powered airplanes. The most widely used fuel types are JET-A/JET-A1 and JET-B (JP-4), per ASTM Specification D1655-99, "Standard Specification for Aviation Turbine Fuels." The approved fuel types for a given airplane type are listed in the Airplane Flight Manual (AFM). Each fuel type has its own properties; those directly related to flammability are "flash point" and "distillation" characteristics. Property differences can occur in a given fuel type as a result of variations in the source crude oil properties and the refining process used to produce the fuel.
- i). Heated fuel tank: Fuel tanks that experience a rapid rise in temperature due to the adjacent system equipment.
- j). Inert fuel tank: Fuel tank inerting, as applied to aircraft fuel tanks, can be defined as the inclusion of a gas, in the ullage prior to ignition of the vapor, that will suppress that ignition, independent of the fuel air mixture.
- k). Inert gas: A gas that will not oxidize. In fuel tanks, the ullage is considered inert when the O<sub>2</sub> concentration is approximately 10% or less (unless future data shows otherwise), when nitrogen is used as the inert gas.
- l). Lean Fuel Vapor/Air Mixture: A fuel vapor mixture that has insufficient concentration of fuel molecules below that which will support combustion.
- m). NEA: Nitrogen enriched air - a gas with nitrogen purity of 90-98%.
- n). Operational time: The time from the start of preparing the airplane for flight, (turning on the auxiliary power unit (APU) /ground power, starting the environmental control systems etc.), through the actual flight and landing, and through the time to disembark any payload, passengers and crew.
- o). Rich Fuel Vapor/Air Mixture: A fuel vapor/air mixture that contains a concentration of fuel molecules above that which will support combustion
- p). Ullage or ullage space: The volume within the tank not occupied by liquid fuel.
- q). Ullage washing: Use of inert gas to dilute the air above the fuel (ullage).
- r). Unheated fuel tank: a fuel tank that is not heated  
(AC 25.981-2 definition - A conventional aluminum structure, integral tank of a subsonic transport wing, with minimum heat input from the aircraft systems or other fuel tanks that are heated.)
- s). Wing tank: A fuel tank located within the aircraft's wing.  
Note: Generally, any tank that presents a large surface area to the airstream could be considered to have the same exposure as a wing tank. For example, fuel tanks in the horizontal or vertical stabilizer, wing-mounted pods, or externally-mounted fuselage or fairing tanks.

### **Fuel Tank Inerting Program Elements**

- a.) Management plan: a detailed description of the operational responsibilities and procedures associated with the implementation and conduct of the certificate holder's "fuel tank inerting program".

Note: the management plan may differ depending on the type of inerting system.

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- b.) Establishment of inerting timetables/dispatch conditions: (design dependent) a set of timetables associated to the effectiveness of the inerting process. These timetables may need to associate inerting with arrival or departure time, ambient air temperature, etc.. For GBI there may be a “validity time”. Associated limitations need to be defined, provided and used by the certificate holder’s personnel.
- c.) Establishment of inerting operational procedures: Aircraft inerting procedures and responsibilities need to be defined - aircraft arrival, dispatch, maintenance
- d.) Establishment of maintenance program: a maintenance program and associated precautions
- e.) Training: Initial and recurrent ground training and testing for all affected personnel (e.g. aircraft dispatchers, ground crews, contract personnel, flight crew, etc.) need to be put in place. The type of training will be system dependent (GBI / OBIGGS)
- f.) Health and Safety Standards: Health and safety standards will need to be revised to include the use of nitrogen.

Note: Emissions: Local airport emission requirements may have to be evaluated against the possible excess of fuel tank vent emissions (VoCs) resulting from inerting. (Emission effects will be design and aircraft dependent.)

### **Management plan**

Purpose of the plan is to ensure that operational control (ensure proper execution of a fuel tank inerting program).

The plan needs to be submitted and approved by the FAA. The plan includes :

- the manager responsible for the overall fuel tank inerting program,
- this manager’s organization including the individual group (task) managers, their functions and responsibilities against each applicable FAR
- the specific elements covered by the plan. The elements should either be detailed within a specific document or be cross referenced to other internal documents

Specific elements for which the management organization needs to be detailed and approved are:

#### a) Operations:

The management position responsible for ensuring that all elements of the inerting program are developed, integrated and coordinated needs to be identified. This person is responsible for ensuring that the plan and program are circulated and implemented throughout the organization to those people who have duties, responsibilities and functions to accomplish within the overall program plan. The plan should consider the following:

- for each airport where fuel tanks will be inerted, determine who will be responsible for operational procedures linked to inerting
- specify the functions, duties, responsibilities, instructions and procedures to be used by flight crew members, air dispatchers and management dispatch personnel for safely accomplishing inerting (ground procedures) and dispatching an aircraft with an inert fuel tank(s)
- if inerting is linked to a “validity time”, then define a detailed procedure to re-perform the fuel tank inerting and re-dispatch the aircraft. Coordination with the ATC, ground operation personnel, flight crewmembers, dispatchers or flight followers, contract personnel and management personnel should be detailed. Consideration of whether GBI can be done with passengers on board needs to be accounted for in the final plan.

- Ensure oversight of the program

b) Maintenance:

Identify who is responsible for ensuring that enough trained and qualified personnel, as well as adequate facilities and equipment are available at each airport where fuel tank inerting operations are expected. The management plan should:

- ensure that all necessary maintenance elements of management plan and fuel tank inerting program have been developed (in accordance with the aircraft type and manufacturers recommendations), integrated and coordinated.
- Detail the duties, responsibilities and function of this plan and ensure that this has been circulated and implemented by the persons assigned to perform the specific duties.
- Ensure management oversight of the program
- Incorporate a detailed description of the maintenance portion of the fuel tank inerting program in the certificate holder's manuals for use and guidance of maintenance, ground, flight crew, contract and management personnel.

c) Aircraft Servicing on Ground

The interface of fuel tank inerting procedure with the other pre-departure activities needs to be detailed and diffused. Management of activities such as refueling, baggage/cargo loading, catering services, toilet servicing, etc. need to be integrated and coordinated with the fuel tank inerting activity.

Precautions, including the dangers of what could happen if these precautions are not respected, that need to be taken by persons providing these other interface services should be developed, diffused and implemented.

**Establishment of inerting timetables/dispatch conditions**

Certain design features - fuel tank and vent system or the inerting system - may have certain limitations. The limitations may be related to time, outside ambient temperatures or fuel tank loading.

These limitations are design dependent and will be defined by the OEM. Not all designs will have limitation conditions!

Operational procedures should be established in order to ensure that these limitations are respected.

If one of these limitations exists, then the certificate holder's program should define operational responsibilities and should develop procedures to instruct the flight crew, aircraft dispatchers, flight followers, and maintenance and ground personnel on the condition limitations, evaluation of these limitations and the resultant action to take. The procedures should include gate procedures, communication procedures with the ground and flight crew and coordination with ACT.

The limitations should be supported by the manufacturer's design data.

a) "Validity Time"

For ground based inerting, the effect of inerting may be time limited; that is the fuel tank ullage may only stay inert for a certain period of time.

For on board inerting, the inerting system may have to be started a certain minimum time prior to dispatch. If its operation is interrupted (or stopped), then the effect of inerting may be time limited

The "validity time" clock starts from the time the inerting process is completed and stops when the aircraft pushes back from the gate.

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Procedures to determine the action if the “validity time” is exceeded shall be detailed and defined in the certificate holder’s program.

### b) Outside Air Temperature

Fuel tanks may only have to be inerted when the ambient temperature is above a certain limit. This limit is dependent on the fuel tank design and shall be provided by the manufacturer.

A procedure, and the associated responsibility definition, should be put into place to define when inerting is needed based solely on outside air temperature. The procedure should define the effect of the increase/decrease of temperature with time of day and the projected weather forecast.

### c) Fuel Tank Loading

Fuel tank inerting may only be needed if the fuel tank is being dispatched not full. This limit is dependent on the fuel tank design and shall be provided by the manufacturer.

A procedure, and the associated responsibility definition, should be put into place to define when inerting is needed based solely on fuel tank loading.

### d) Multiple conditions

A multiple set of conditions may need to exist in order to forego fuel tank inerting. The manufacturer shall define these conditions.

A procedure, and the associated responsibility definition, should be put into place to define when inerting is needed. Particular attention should be paid to the decision criteria used and the communication of the decision.

## **Operations Manual**

### a) General

Operational procedures regarding the fuel tank inerting system install on the aircraft type should be approved as part of an operator’s initial operational manual approval or as a revision to that manual.

A quality assurance program should be put into place in accordance with the management plan and applicable FAR regulations.

### b) Operating Procedures

Specific attention should be paid to the impact that fuel tank inerting has on the flight preparation instructions and the ground handling instructions. Each aircraft manufacturer (or fuel tank inerting system supplier) should provide the operator with system operating instructions / recommendations. These instructions may vary depending on the type of fuel tank inerting system installed.

Flight preparation procedures may be impacted, if the operator needs to determine whether or not the fuel tank needs to be inerted. The decision criteria, developed under section 7.0, should be used, as appropriate.

Ground handling instructions should include,

- Safety precautions to be taken when inerting (GBI)
- Changes that inerting brings to current procedures or precautions, such as fuel mixing precautions
- Embarking and disembarking passengers while the fuel tanks are being inerted
- Crew procedures that will ensure the proper precautions are taken to avoid NEA vapors from entering the cabin while passengers and/or flight crew are on board. (Manufacturer recommendation - design dependent.)

- Safety precaution on the ramp - identification of areas that should be avoided by passengers/flight crew embarking / disembarking /inspecting the airplane due to the presence of NEA
- Start-up procedure (OBIGGS)
- Communication instructions

It is noted that the Airport Handling Manual may need to be updated due to the presence of an inerting system.

The operator may opt to create a dedicated fuel-tank inerting section within its ground handling procedure section of the operating manual. The management plan (section 6.0), the timetable/dispatch conditions (section 7.0), fuel tank inerting procedures, communication procedures and cockpit preparation procedures could be discussed within this dedicated section.

### c) Minimum Equipment List (MEL)

The presence of a fuel tank inerting system may impact the operator's MEL.

As with other systems, the MEL for a fuel tank inerting system should be developed based on the manufacturer's recommendations and the operator's operational policies and national operational requirements.

The MEL determination will be made considering that an acceptable level of safety is maintained with this system non-operational. Specific compensating factors, which may allow the acceptable level to be maintained are: appropriate operating limitations, transfer of the function to another system, alternative means to produce a similar effect.

The Technical Log will be used to record when and why the aircraft's fuel tank inerting system is dispatched on MEL. Any operational limitations should also be noted. The rectification of this MEL item should also be recorded in the Technical Log and include the details of the rectification as well as a statement that the MEL item has been removed.

## Maintenance Manual

### a) General

Maintenance procedures for the fuel tank inerting system installed on the aircraft type should be approved as part of an operator's initial maintenance manual approval or as a revision to that manual.

A quality assurance program should be put into place in accordance with the management plan and applicable FAR regulations.

### b) NEA Handling Policies

Special emphasis should be put on the development and implementation of all procedures and precautions implemented because of inerting and in particular - handling of NEA. This includes:

- Fuel tank purge procedures - open and confined spaces
- Fuel tank entry procedures
- Precautions around fuel tank vents
- Precautions around NEA supply trucks
- Recuperation of fuel tank vent gas (recuperation of VoCs)
- Special clothing or protection gear
- emergency care in case of asphyxiation by NEA

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- NEA handling procedures

### c) NEA specifications / characteristics

GBI - The characteristics / specification of the NEA that will be used to inert the fuel tanks should be defined and recorded in the appropriate manuals.

OBIGGS - Particular attention should be paid to the efficiency (service life) of the air separator module (nitrogen producing capability), noting that nitrogen will not be produced if this component does not perform its intended function.

### **Training Requirements**

All persons involved in the maintenance, dispatch and operation of the aircraft need to receive initial and recurrent training on the functioning, operation and procedures associated to the fuel tank inerting system, as well as the danger of nitrogen if these procedures are not respected. These persons are:

- Flight crew
- Dispatcher
- Ground personnel
- Contractor
- Maintenance personnel

The training syllabi should be adapted to each discipline and to the type of inerting system installed on the aircraft. However, each course should include:

- A description of the inerting system, including its purpose
- The benefits and potential dangers of the system
- Hazards and handling of NEA
- A description of the management plan and communication process - overall process of who is involved and the specific role of the discipline being trained
  - The specific requirements of the program and the duties, responsibilities and functions detailed in the program
- Emergency care procedures if nitrogen asphyxiation occurs
- A test or qualification examine

For maintenance personnel, specific attention should be placed on the dangers of nitrogen and precautions to take when working in confined spaces.

The operator should ensure that its initial and recurrent training program for each discipline is described in detail and documented in the company's training requirements.

### **Health and Safety Standards**

The operator's health and safety standards should be updated to include working with NEA. Specific areas may include but are not limited to:

- NEA handling
- Emergency care procedures

- Working in confined spaces
- Identification of health risks
- Identification of protective clothing

**Emissions**

Certain countries may have national regulations concerning the amount of VOCs released into the atmosphere.

Each operator must assess the environmental impact using the manufacturer emissions estimation and the national environmental regulation.

The result of this assessment may lead to the mandatory recovery of the VOCs or the prohibition of fuel tank inerting within the national airspace. If this happens ground or flight procedures would have to be adopted accordingly and recorded within the management plan and the manual. Training courses would also need to incorporate these differences within the affected disciplines' course.



# Aviation Rulemaking Advisory Committee Fuel Tank Inerting Harmonization Working Group

Submitted jointly by:

AEA, AECMA, AIA,  
Air Liquide, ALPA, API, ATA,  
FAA, IAM, JAA, and NADA/F

## Team Reports

February 2002



Association of European Airlines

*NATIONAL AIR DISASTER  
ALLIANCE/FOUNDATION*



European Association  
of Aerospace Industries



Air Transport Association of America





U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

**Transport Airplane Directorate  
Aircraft Certification Service**

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June 29, 2001

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Dear Brad and Sean:

As the FAA member of the Fuel Tank Inerting Harmonization Working Group (FTIHWG), I request that the following two changes be made to the FTIHWG report. First, insert the following paragraph in Section 1.1, Overview of the Executive Summary, of the report. This paragraph documents the previously stated FAA concerns with the assumptions and resulting conclusions in the report.

"The FAA, as a member of the FTIHWG, disagrees with certain assumptions and has questions on other assumptions used in this study. The assumptions used in the study are critical to the cost estimates provided for the fuel tank inerting options studied. Therefore, the FAA has some reservations as to the accuracy of the Working Group's conclusions expressed in this report. Those conclusions produced inerting system cost estimates in the tens of billions of U.S. dollars with relatively minor benefits from inerting for the fifteen year study period. The FAA's questions can only be answered following a full review of the data in the appendices to this report. As stated in the Task, the FAA will use the data in the report and results of independent FAA research and development programs in evaluating if a practical means of inerting fuel tanks can be found for the in-

service fleet, new production airplanes, and new airplane designs. The FAA has provided an attachment to the report with an expanded explanation of the most significant issues."

Second, insert the attached summary of the FAA concerns as an appendix or attachment to the report. I understand from my conversations with Brad Moravec on June 27, 2001, when I told him I would send this request, that a number of the reports had been printed for submittal to the Executive Committee of the Aviation Rulemaking Advisory Committee (ARAC) for their review and approval prior to issuing the report. However, I request that these changes be included in the report before it is sent to the Executive Committee. I regret submitting these changes at this late time in the process, but because the report was only finalized over the last few days I was unable to complete the FAA organizational review of the summary sections of the report any earlier. The FAA will review the full report, including the data and justifications for the assumptions that are contained in the appendices, after we receive our complete copy of the report.

If you need to discuss this further, please contact me at 425-227-2689.

Sincerely,

*Original signed  
by G. Michael Collins*

G. Michael Collins,  
FAA Representative,  
Fuel Tank Inerting Harmonization Working Group

Attachment

## Fuel Tank Inerting Harmonization Working Group

### FAA Concerns with Assumptions and Conclusions

**Summary:** The FAA, as a member of the FTIHWG, disagrees with certain assumptions and has questions on other assumptions used in this study. The assumptions used in the study are critical to the cost estimates provided for the fuel tank inerting options studied. Therefore, the FAA has some reservations as to the accuracy of the Working Group's conclusions expressed in this report. Those conclusions produced inerting system cost estimates in the tens of billions of U.S. dollars with relatively minor benefits from inerting for the fifteen-year study period. The FAA's questions can only be answered following a full review of the data in the appendices to this report. As stated in the Task, the FAA will use the data in the report and results of independent FAA research and development programs in evaluating if a practical means of inerting fuel tanks can be found for the in-service fleet, new production airplanes, and new airplane designs. This attachment to the report provides an explanation of the most significant issues.

#### **Significant FAA Disagreements:**

- Ground Based Inerting, Dedicated Personnel Not Required: The FAA disagrees that the person who would perform the inerting tasks needs to be a dedicated person or remain present and observe the entire inerting process after connecting the nitrogen enriched air (NEA) hose to the airplane connection, opening valves and starting the inerting of the tank(s). This is in conflict with the conclusion of the FAA/industry team contained in FAA report DOT/FAA/AR-00/19, *The Cost of Implementing Ground-Based Fuel Tank Commercial Fleet*, dated May 2000. In addition, the safeguards included in the design concepts developed by the task team preclude the need for dedicated personnel to observe the process. The use of dedicated personnel has a very significant contribution to the total estimated cost for ground-based inerting presented in the report.
- Ground Based Inerting, Technician (Mechanic) not required: The FAA disagrees that a technician (mechanic) is required, even for some start-up period, to perform the tasks required to inert the fuel tanks
- Special Federal Aviation Regulation (SFAR) No. 88, Predicted Accidents Avoided: The report assumes that the SFAR would prevent 75 per cent of future fuel tank accidents. This assumption has a very significant affect on the predicted benefits for fuel tank inerting shown in this report. The 75 per cent prediction is not supported by any data or by the FAA Final Regulatory Evaluation that was included in the final rule that issued the SFAR (docket number FAA-1999-6411, published in the Federal Register on May 7, 2001). When performing that final regulatory evaluation, in response to comments received to the notice and further analysis, the FAA determined that such a prediction has no acceptable mathematical basis. In addition, the ignition source in the three most recent fuel tank explosions (1990 Philippine Airlines, 1996 TWA 800, and 2001 Thai Airways) has not been determined. The SFAR, and any resulting required modifications, could eliminate possible failures and malfunctions that have been identified since the TWA 800 accident that can cause an ignition source, and this will provide a needed improvement in the safety of fuel tanks. However, even if all those potential ignition sources were eliminated as a

## Fuel Tank Inerting Harmonization Working Group

### FAA Concerns with Assumptions and Conclusions

result of the SFAR, there is no way to positively determine if that action would have prevented those accidents. This is very important in the FAA's overall program to prevent future fuel tank explosions. That is the reason for the FAA's determination that it will take both eliminating potential ignition sources and eliminating or significantly reducing the exposure of fuel tanks to flammable fuel/air mixtures to provide an acceptable level of safety.

- Hazard to Passengers and Crew from Inerting Systems: The FAA disagrees that nitrogen enriched air (NEA) or oxygen enriched air produced by the membrane separation technology used in the study creates a hazard for passengers and crew of the affected airplanes (on-board or ground-based designs). The design concepts used in the study included features to preclude leakage of either NEA or the oxygen enriched air byproduct of the inerting systems from entering (pressurized) areas of the cabin that would be occupied by passengers and flight crew members. In addition, existing Federal Aviation Requirements would prevent obtaining FAA approval of any inerting system design that would prevent a hazard to passengers or flight crews.
- Hazard to Maintenance Personnel from Inerting Systems: The FAA disagrees that nitrogen enriched air (NEA) or oxygen enriched air produced by the membrane separation technology used in the study creates a significant hazard for maintenance personnel working on or near the affected airplanes (on-board or ground-based designs). The design concepts used in the study included features to preclude leakage of either NEA or the oxygen enriched air byproduct of the inerting systems from entering (pressurized) areas of the cabin that would be occupied by maintenance personnel. Regarding hazards to maintenance personnel when entering confined spaces where inerting equipment may be located or fuel tanks after they have been inerted, confined space entry requirements established by industry and required the U.S. Occupational Safety and Health Administration for areas with potential to have oxygen depleted atmosphere would prevent injury to maintenance personnel. The oxygen-enriched air discharged from the membranes, as a byproduct, does not have a high enough oxygen concentration to create a fire hazard.

#### **Significant FAA Questions:**

- Incorporation of Modifications Resulting from SFAR No. 88: The report assumes all modifications that would be required as a result of the SFAR design review would be incorporated throughout the fleet by 2006. This assumption has a very significant affect on the predicted benefits for fuel tank inerting used in forming the conclusions in this report and it may be overly optimistic. The SFAR requires that affected type certificate holders and supplemental type certificate holders perform a safety review of their fuel tank systems and determine if their designs meet the latest requirements for precluding fuel tank ignition sources. If it does not meet those requirements, they must develop all design changes necessary to meet those requirements. The results of the design review are to be submitted to the FAA in a report by December 6, 2002. (If they can not develop all the design changes by the compliance date, they can be granted an extension of time to develop those design changes if certain conditions are

## Fuel Tank Inerting Harmonization Working Group

### FAA Concerns with Assumptions and Conclusions

met.) The FAA will then review the reports and the design changes. If the FAA determines that modifications are required to existing airplanes, the FAA would issue proposals for airworthiness directives (ADs) that would require that the airplanes be modified by some future date. The time allowed in the final ADs to modify in-service airplanes would depend on the complexity of the modifications. The FAA questions the ability of the industry to develop all the required modifications and then modify all the in-service airplanes in the three-year period following the compliance date for the SFAR, especially considering the industries history of waiting to begin modifying in-service airplanes until after the FAA has issued final rule ADs requiring the modifications.

- Inerting Implementation Schedule: The schedule for implementing fuel tank inerting in the fleet shows no affect on safety until beyond 2010. The full affect is not shown until 2015, when all modifications are completed. This is shown for both ground-based inerting and on-board inerting designs. The data in the report also shows that inerting would be more effective in preventing fuel tank explosions than even the 75 % predicted effectiveness for SFAR 88 used in the report. Therefore, improving the implementation schedule for inerting combined with a more realistic schedule for incorporating modifications resulting from the SFAR would greatly improve the cost-benefit ratio for inerting.

# Aviation Rulemaking Advisory Committee

## Fuel Tank Inerting Harmonization Working Group



August 7, 2001

Mr. G. Michael Collins,  
FAA Representative,  
Fuel Tank Inerting Harmonization Working Group  
Transport Airplane Directorate  
Aircraft Certification Services  
1601 Lind Avenue, S.W.  
Renton, Washington 98055

Reference: Letter dated June 29, 2001, to Mr. Bradford A. Moravec and Mr. Sean B. O'Callaghan.

Dear Mr. Collins,

As co-chairman of the ARAC Fuel Tank Inerting Harmonization Working Group we have agreed not to revise the final ARAC working group report as requested in your referenced letter. The Working Group had previously discussed the questions raised by this letter and we believed we had general consensus on these issues. These issues are also addressed at length in the final report.

The goal of the Working Group was to gain consensus on study assumptions and conclusions. According to the ARAC operating procedures, "General consensus means that, although there may be disagreement among the members of the group, the group has heard, recognized, acknowledged, and reconciled the concerns or objections to the general acceptability of the group. Although not every member fully agrees in the context and principle, all members support the overall position of the group and agree not to object to the proposed recommendation." At last working group meetings in June, we believed we had general consensus from all of the Working Group members.

The members of the Working Group represented a range of interests from the US and Europe, including airplane manufacturers, airlines, airports, industrial gas companies, pilots, machinists, regulators, and public interest. These groups participated in the study because they support government and industry efforts to improve fuel tank safety. The working group recognized that overstating costs or technical issues could result in a missed opportunity to improve fuel tank safety. On the other hand, understating the costs or other issues could result in recommending a method of improving fuel tank safety that is technically infeasible, takes too long to implement, or is so costly that it is scrapped before any benefits are realized. In this case, the opportunity to introduce practical fuel tank safety improvements could be delayed.

For these reasons, every attempt was made to accurately represent the technical requirements, safety benefits, regulatory matters and estimated costs. Your letter points out assumptions that you believe overstate the cost and risk and understate the benefits. We do not believe this is the case as we have outlined below and documented in the final report. The discussion below repeats sections from your letter followed by our comments, shown in Italics.

## **Discussion:**

### **FAA Statement:**

**Summary:** The FAA, as a member of the FTIHWG, disagrees with certain assumptions and has questions on other assumptions used in this study. The assumptions used in the study are critical to the cost estimates provided for the fuel tank inerting options studied. Therefore, the FAA has some reservations as to the accuracy of the Working Group's conclusions expressed in this report. Those conclusions produced inerting system cost estimates in the tens of billions of U.S. dollars with relatively minor benefits from inerting for the fifteen year study period. The FAA's questions can only be answered following a full review of the data in the appendices to this report. As stated in the Task, the FAA will use the data in the report and results of independent FAA research and development programs in evaluating if a practical means of inerting fuel tanks can be found for the in-service fleet, new production airplanes, and new airplane designs. This attachment to the report provides an explanation of the most significant issues.

### **Significant FAA Disagreements:**

Ground Based Inerting, Dedicated Personnel Not Required: The FAA disagrees that the person who would perform the inerting tasks needs to be a dedicated person or remain present and observe the entire inerting process after connecting the nitrogen enriched air (NEA) hose to the airplane connection, opening valves and starting the inerting of the tank(s). This is in conflict with the conclusion of the FAA/industry team contained in FAA report DOT/FAA/AR-00/19, *The Cost of Implementing Ground-Based Fuel Tank Commercial Fleet*, dated May 2000. In addition, the safeguards included in the design concepts developed by the task team preclude the need for dedicated personnel to observe the process. The use of dedicated personnel has a very significant contribution to the total estimated cost for ground based inerting presented in the report.

### ***Response:***

*The assumption that a ground service person would attend to the complete fuel tank inerting process was discussed many times in our working group meetings and Telecons. Section 5.4.5 of the final report outlines the tasks performed by the ground service person and reasons a dedicated person is required. To summarize, a dedicated person is required to: a) verify the inerting process was completed correctly and accurately reported to the flight crew; b) ensure that the inerting process is done in a coordinated and timely manner to avoid conflicts with other ground service activity and minimize the potential for flight delays; and c) ensure that the inerting process is done by a properly trained person to prevent injuries and airplane damage. For the inerting operations that*

*are accomplished by a mobile system, the vehicle driver would also be the one responsible for inerting the fuel tank. In this case, there would be no point in leaving the vehicle. Large and medium sized airports would have some mobile inerting to service remotely parked airplanes. Small airports, which constitute approximately 85% of the airports in the study, would only have mobile inerting.*

*With regards to the significance of this assumption to the overall estimated cost, by assuming that none of the inerting is performed by a dedicated ground service person, (i.e. accounting only for the labor to connect and disconnect the inerting system) the cost reduction is less than 5% of the total cost over the study period.*

**FAA Statement:**

Ground Based Inerting, Technician (Mechanic) not required: The FAA disagrees that a technician (mechanic) is required, even for some start-up period, to perform the tasks required to inert the fuel tanks.

***Response:***

*In section 4.5.4, the Operations and Maintenance experts on the study recommended that the inerting process be performed by a skilled mechanic until the inerting systems were automated and reliable. The intention is to ensure the process is done correctly and avoid possible injury or damage to the airplane. Nevertheless, the additional cost of using a mechanic for the start-up period was not included in the cost-benefit study.*

**FAA Statement:**

Special Federal Aviation Regulation (SFAR) No. 88, Predicted Accidents Avoided: The report assumes that the SFAR would prevent 75 per cent of future fuel tank accidents. This assumption has a very significant affect on the predicted benefits for fuel tank inerting shown in this report. The 75 per cent prediction is not supported by any data or by the FAA Final Regulatory Evaluation that was included in the final rule that issued the SFAR (docket number FAA-1999-6411, published in the Federal Register on May 7, 2001). When performing that final regulatory evaluation, in response to comments received to the notice and further analysis, the FAA determined that such a prediction has no acceptable mathematical basis. In addition, the ignition source in the three most recent fuel tank explosions (1990 Philippine Airlines, 1996 TWA 800, and 2001 Thai Airways) has not been determined. The SFAR, and any resulting required modifications, could eliminate possible failures and malfunctions that have been identified since the TWA 800 accident that can cause an ignition source, and this will provide a needed improvement in the safety of fuel tanks. However, even if all those potential ignition sources were eliminated as a result of the SFAR, there is no way to positively determine if that action would have prevented those accidents. This is very important in the FAA's overall program to prevent future fuel tank explosions. That is the reason for the FAA's determination that it will take both eliminating potential ignition sources and eliminating

or significantly reducing the exposure of fuel tanks to flammable fuel/air mixtures to provide an acceptable level of safety.

***Response:***

*The 1998 ARAC study estimated that the fuel system improvements and improved maintenance practices expected from the proposed SFAR rules would reduce the fuel tank accident rate by 75%. There were no changes to the final SFAR rule that would reduce the expected SFAR benefits. The consensus of the Working group was that accounting for a 75% ignition source reduction was an appropriate assumption.*

*While the FAA final version of the SFAR does not state a specific reduction in ignition sources, it does state “the FAA believes that the rule will significantly reduce the risk of a future accident”. Considering extent of the fuel system improvements that are likely to be required to comply with SFAR 88, the majority of the working group believed that the benefit from SFAR 88 should be included, and the consensus was to use the 75% previously estimated.*

**FAA Statement:**

Hazard to Passengers and Crew from Inerting Systems: The FAA disagrees that nitrogen enriched air (NEA) or oxygen enriched air produced by the membrane separation technology used in the study creates a hazard for passengers and crew of the affected airplanes (on-board or ground-based designs). The design concepts used in the study included features to preclude leakage of either NEA or the oxygen enriched air byproduct of the inerting systems from entering (pressurized) areas of the cabin that would be occupied by passengers and flight crew members. In addition, existing Federal Aviation Requirements would prevent obtaining FAA approval of any inerting system design that would prevent a hazard to passengers or flight crews.

***Response:***

*As discussed in section 4.4 of the final report, high concentrations of nitrogen can cause death in seconds. All known design, operation and maintenance measures would be taken to prevent hazards to the passenger and flight crew. However, because of the uniqueness of some of these inerting systems to commercial aviation, all hazards can not be completely ruled out. This is why the working group recommended that this issue be studied further. The cost-benefit analysis did not include inerting accidents.*

**FAA Statement:**

Hazard to Maintenance Personnel from Inerting Systems: The FAA disagrees that nitrogen enriched air (NEA) or oxygen enriched air produced by the membrane separation technology used in the study creates a significant hazard for maintenance personnel working on or near the affected airplanes (on-board or ground-based designs). The design concepts used in the study included features to preclude leakage of either

NEA or the oxygen enriched air byproduct of the inerting systems from entering (pressurized) areas of the cabin that would be occupied by maintenance personnel. Regarding hazards to maintenance personnel when entering confined spaces where inerting equipment may be located or fuel tanks after they have been inerted, confined space entry requirements established by industry and required the U.S. Occupational Safety and Health Administration for areas with potential to have oxygen depleted atmosphere would prevent injury to maintenance personnel. The oxygen-enriched air discharged from the membranes, as a byproduct, does not have a high enough oxygen concentration to create a fire hazard.

***Response:***

*Again, as discussed in section 4.4 of the report, high concentrations of nitrogen can cause death in seconds. All known design, operation and maintenance measures would be taken to prevent hazards to the passenger and flight crew. However, because of the uniqueness of some of these inerting systems to commercial aviation, all hazards can not be completely ruled out. This is why the working group recommended that this issue be studied further. The cost-benefit analysis did not include inerting accidents.*

**FAA Statement:**

**Significant FAA Questions:**

Incorporation of Modifications Resulting from SFAR No. 88: The report assumes all modifications that would be required as a result of the SFAR design review would be incorporated throughout the fleet by 2006. This assumption has a very significant affect on the predicted benefits for fuel tank inerting used in forming the conclusions in this report and it may be overly optimistic. The SFAR requires that affected type certificate holders and supplemental type certificate holders perform a safety review of their fuel tank systems and determine if their designs meet the latest requirements for precluding fuel tank ignition sources. If it does not meet those requirements, they must develop all design changes necessary to meet those requirements. The results of the design review are to be submitted to the FAA in a report by December 6, 2002. (If they can not develop all the design changes by the compliance date, they can be granted an extension of time to develop those design changes if certain conditions are met.) The FAA will then review the reports and the design changes. If the FAA determines that modifications are required to existing airplanes, the FAA would issue proposals for airworthiness directives (ADs) that would require that the airplanes be modified by some future date. The time allowed in the final ADs to modify in-service airplanes would depend on the complexity of the modifications. The FAA questions the ability of the industry to develop all the required modifications and then modify all the in-service airplanes in the three year period following the compliance date for the SFAR, especially considering the industries history of waiting to begin modifying in-service airplanes until after the FAA has issued final rule ADs requiring the modifications.

***Response:***

*The cost-benefit analysis assumed SFAR changes would be fully implemented by 2007 (not 2006). The benefits of SFAR are based on expected design improvements and improved maintenance practices. The final SFAR rule requires operators include these improved maintenance practices by June 2003. Although maintenance practices will have an immediate improvement in fuel tank safety, no benefits were assumed until 2007. The final SFAR rule requires that TC and STC holders develop any design improvements required to meet the new rules by December 6, 2002. It was assumed that the design changes would take approximately 4 years to implement. There may be delays in implementing the design improvements either because TC/STC holders cannot complete their design development by December 6, 2002 or the operators need more than 4 years to install the design changes. As shown in figure 1-3, as long as these design improvements are implemented by 2010, there would be almost no change to the accident rate and consequently, the cost-benefit analysis.*

**FAA Statement:**

Inerting Implementation Schedule: The schedule for implementing fuel tank inerting in the fleet shows no affect on safety until beyond 2010. The full affect is not shown until 2015, when all modifications are completed. This is shown for both ground-based inerting and on-board inerting designs. The data in the report also shows that inerting would be more effective in preventing fuel tank explosions than even the 75 % predicted effectiveness for SFAR 88 used in the report. Therefore, improving the implementation schedule for inerting combined with a more realistic schedule for incorporating modifications resulting from the SFAR would greatly improve the cost-benefit ratio for inerting.

***Response:***

*For the purpose of a cost-benefit analysis, the working group assumed that the earliest the FAA could promulgate an inerting rule would be 2005. This is an optimistic assumption because of the complexities of the rule changes required, especially for a world-wide implementation. The working group assumed that airplane manufactures could create designs for 107 major and derivative airplane models within three years. This is a very optimistic assumption because of the number of airplane models and the uniqueness of these inerting systems to commercial aviation. The working group assumed that operators would need 7 years to fully implement the inerting systems. This is based on installing the system during a scheduled heavy check. To address airplanes with heated center wing tanks, this would require retrofitting approximately 1800 airplanes per year. All three of these assumptions are optimistic. Any increase in the time required to fully implement the inerting system would decrease the benefits.*

## *Summary*

*Every attempt was made to accurately represent the technical requirements, safety benefits, regulatory matters and estimated costs. Your letter points out assumptions that you believe overstate the cost and risk and understate the benefits. As we have outlined above and documented in the final report, we do not believe this is the case. In fact, we made several optimistic assumptions that reduced the estimated cost of implementing an inerting system and decreased the time it will take to implement it. These assumptions include:*

- 1) unlimited resources, such as engineers, mechanics, hangers, parts, or facilities*
- 2) no increase in the average airplane turn-time at the gate*
- 3) allowing MMEL dispatch of an inoperative inerting system*
- 4) no growth in the number airports*
- 5) modification of only 100 passenger and above airplanes*
- 6) no airplane or airport equipment depreciation or replacement*
- 7) 15% of the future fuel tank accidents occur on the ground (currently the rate is 67%)*

*If any of these assumptions proves to be mistaken, the costs may be higher or the implementation time may be longer. The assumptions made for the cost-benefit analysis attempted to balance the risk of over or under estimating the costs.*

We expect the FAA to fully review the final report once it is submitted by the ARAC Executive Committee. We hope you find that the final report adequately addresses the questions raised in your letter.

Sincerely,

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Bradford A. Moravec  
Co-Chairman  
ARAC Fuel Tank Inerting  
Harmonization Working Group

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Sean B. O'Callaghan  
Co-Chairman  
ARAC Fuel Tank Inerting  
Harmonization Working Group

## **FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

### **Question No. 1**

During the August 8, 2001, presentation to the ARAC Executive Committee, the FTIHWG Co-Chairs described the results of a recently completed Sensitivity Study that was based on varying the assumptions in the report's cost-benefit study. The specific inputs that were varied, the amount they were varied, and the results of the sensitivity study should be included in the text of the report - perhaps a table listing all of these would help to simplify and clarify the analysis. Further, any changes requested by Executive Committee members should also be included. It is suggested that these be placed in the Executive Summary as Section 1.2.

#### **Response:**

The Working Group agreed the entire document will not be reprinted with the changes because of the time and cost involved. The Ex-Com comments and the sensitivity analysis will be included in an addendum to the Executive Summary and limited changes will be made to the Executive Summary text.

### **Question No. 2**

The Executive Summary states the FTIHWG did not recommend any new regulatory text. Recommending regulatory text was part of the tasking statement. When asked about this during the August 8 Executive Committee meeting, one of the FTIHWG co-chairs stated there are recommendations in the text of the report for the FAA to consider if FAA should propose fuel tank flammability regulations based on fuel tank inerting. The Executive Summary should be revised to inform the reader where those recommendations can be found in the report.

#### **Response:**

The following text will be included here, as part of the addendum to the executive summary:

"The FAA Tasking Statement for this ARAC FTIHWG study required that this Working Group "prepare a report to the FAA that provides recommended regulatory text for new rulemaking and the data needed for the FAA to evaluate the options for implementing new regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new production, and new type design transport category airplanes. Although the Working Group did not recommend new rulemaking, the Working Group did conduct an evaluation of existing regulations, advisory material and continued airworthiness instructions concerning the elimination or reduction of the flammable environment in the airplane using a nitrogen inerting system. The Working Group found that 14 CFR Part 25 and

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

14 CFR Parts 91, 121, 125, 129 and 139 would be significantly impacted by the introduction of a fuel tank inerting system and that the 14 CFR changes were linked to the inerting system concept. For this reason, the Working Group recommended that a dedicated paragraph, "Fuel Tank Inerting System" / "Operation of Fuel Tank Inerting System", be incorporated in each effected 14 CFR part and that associated guidance material should be developed. The Working Group then developed preliminary regulatory and guidance material proposals, as requested by the FAA. The Working Group recommended that these proposals be refined if and when a practicable inerting system is developed and integrated on a certified aircraft. Specific details concerning regulatory and guidance material development is found in Section 12.0."

### **Question No. 3**

The tasking statement required the Fuel Tank Inerting Harmonization Working Group "prepare a report to the FAA that provides recommended regulatory text for new rulemaking and the data needed for the FAA to evaluate the options for implementing new regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new production, and new type design transport category airplanes." The report discusses the results of the cost-benefit study performed by the FTIHWG, but it does not contain all the data required under the task. Although the appendices to the report, the Team Reports, include aggregate cost estimates and much of the supporting data, they do not provide all of the data used to support those aggregate estimates. Specifically, there is no explanation of the basis for the estimated engineering hours for the certification costs, no description of the components and their individual costs for the major supplier parts and the major assemblies cost categories, and the costs involved in the service bulletin and parts kit estimates are not adequately explained. Assumptions used as the basis for each of the economic assessments in the document should be summarized at the front of each section, so the FAA and the public can easily understand the basis for the assessment.

### **Response:**

Because of time and resource constraints the Working Group was not able to amend each section of the final report with the cost assumptions.

The certification detailed cost breakdown and the associated assumptions are found in Appendix I. The supplier part and major assembly costs are listed in Appendix D, (On-Board Design). The airport costs are included in Appendix E and the airline operation, maintenance and installation costs are included Appendix F. To develop a more detailed cost assessment, the Working Group recommends that the FAA work with airplane and equipment manufacturers to evaluate the costs on specific airplane models.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 4

The estimated costs appear to include service bulletin and parts kits costs for airplanes modified during production (new production airplanes) as well as retrofit of in-service airplanes. Why would each individual (future) new production airplane require a service bulletin and a kit of parts? Why would the parts cost be at the same level as the costs for a retrofit of an in-service airplane? The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

### **Response:**

It is assumed that the writer's question addresses the standard format used in Figures G9-G63. The FTIHWG agrees that a Service Bulletin would not be issued for in-production or future production airplanes. However, the costs associated with activities such as certification, engineering drawings, records and technical publications, warranty and customer support, parts receiving and inspection, inventory planning, tooling, materials and supplier parts costs are required for either a production change or a Service Bulletin. For a production installation, it was assumed that the cost savings from not drafting a Service Bulletin is offset by the additional costs of the manufacturing planning, production illustrations and engineering support to the shop, system checks and inspections required for a production incorporation. It was also assumed that the component and material costs were the same for the new, production and in-service generic category airplanes. This assumption simplified the economic calculations. The FTIHWG does not believe it is valid to reduce the Sensitivity Analysis based on these factors mentioned in this question.

### Question No. 5

The Economic and Forecasting team used a spreadsheet to calculate the estimated costs of the inerting systems provided in the report. This spreadsheet needs to part of the report so it is available to both the FAA and the public.

### **Response**

A public version of the spreadsheet will be given to the FAA to include with the final report. The spreadsheet allows the user to vary cost and benefit values, fleet sizes, and other parameters and compare the results against the baseline values.

## **FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

### **Question No. 6**

The report states neither the bleed air nor the electrical energy available on in-service airplane designs is adequate to power an on-board fuel tank inerting system. The lack of available bleed air led to the requirement for an air compressor on all on-board designs. However, there are no data in the report to support this conclusion. For bleed air, supporting data should include bleed air available from the engines and bleed air requirements. For electrical energy available, supporting data should include consideration of load shedding priorities. For both bleed air and electrical energy, supporting data should show during which flight and ground conditions the availability is limited.

### **Response:**

The Working Group's conclusion that in-service and current production airplanes lack the bleed and electrical power to meet the demands of on on-board inerting system was based solely on statements made by representatives of airframe manufactures and operators during the Working Group discussions. No data was presented to the Working Group to support these conclusions. The study evaluated six generic airplane sizes. Engine bleed and electrical power is airplane specific information. Airplanes are designed and certificated to supply the required bleed and electrical power under normal and certain failure conditions. On some airplanes, combinations of these conditions, such as engine idle, hot day temperatures or engine-out operation require all of the available engine bleed or electrical power. The Working Group assumed that additional bleed and electrical power demands could degrade functions such as anti-icing capability, cabin pressure or temperature control or air-driven pump performance. The actual effects of additional bleed and power extraction required to supply on-board fuel tank inerting systems should be evaluated further by the FAA on an airplane model-by-model basis.

### **Question No. 7**

The FAA has been evaluating a fuel tank inerting/cargo compartment fire suppression system based on a single on-board nitrogen generating system. This was discussed during the FTIHWG team meetings and also several at public research and development meetings that included representatives of the aerospace industry. Evaluation of this combined system was not part of the tasking statement and the on-board task team chose not to voluntarily evaluate it as part of the work performed in this study. However, such a system would eliminate a significant amount of weight from existing airplanes by removing the existing (long duration) Halon based cargo compartment fire suppression system used to keep cargo compartment fires from re-igniting after a cargo compartment fire has been put out by another Halon "knock-down" system. What would the affect be on a new airplane design if the weight of such an inerting system were offset by not requiring the installation of a long

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

duration Halon cargo compartment fire suppression system? The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

**Response:**

Although a single fuel tank inerting/cargo compartment fire suppression system was discussed conceptually, no information, design, analytical, application or test data was presented to the FTIHWG on such a system. The FTIHWG did not have the time or resources to combine the two system designs and conduct trades studies to optimize the system design. Also, the fuel tank inerting sensitivity analysis spreadsheet lacks the data to perform a combined system cost calculation. The Working Group believes that in a new airplane design, it is possible some synergy of design may be achieved by incorporating a combined system. The FAA should further study this concept.

### **Question No. 8**

The fuel tank volume used for the generic large transport airplane, which is the basis for the cost study of inerting large transports, is larger than the actual fuel tank volume of most in-service large transport airplanes. This results in a higher cost estimate for inerting large transport airplanes than would be calculated if the actual mix of in-service fuel tank volumes were used in the cost study. Appendix D of the report does provide parametric sizing curves to determine equipment requirements based on selecting a fuel tank size and airplane turnaround time which will enable determining equipment sizes for actual in-service tank. However, the Executive Summary of the report should acknowledge this limitation on the cost data presented in the report.

**Response:**

The question makes a point that the generalized aircraft used in the study could overstate the large fuel tank volumes thus overstating the costs of providing nitrogen for inerting this class of airplane. The Team acknowledges that the use of generic airplanes will overstate or understate the costs and benefits of airplanes within each of the six generic categories. The working group agreed to use the same generic airplane categories that were used by the 1998 ARAC fuel tank study. Errors from using the generic airplanes are small and tend to compensate each other. This information will be included in the revised Executive Summary.

### **Question No. 9**

Section 1.9 of the FTIHWG report estimates that 24 to 81 lives may be lost as a result of nitrogen inerting of fuel tanks over the 2005 - 2020 study period. The text implies these lives would be lost as a result of exposure to inert (oxygen depleted) atmosphere inside fuel tanks during

## **FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

fuel tank system maintenance. Occupational Safety and Health Administration (OSHA) requirements and fuel service industry practices for preparing fuel tanks for maintenance require ventilating the tank with air until the oxygen level is above a minimum limit value and the hydrocarbon concentration is well below the lower explosive limit. In addition maintenance personnel are already required to wear oxygen and hydrocarbon concentration detectors with alarms when entering fuel tanks. Therefore, the statements in the report about increased deaths as a result of fuel tank inerting should be removed from the Executive Summary and the costs for additional confined space training and safety equipment should not be included in the report or the Sensitivity Analysis.

### **Response:**

The FTIHWG reached general consensus that that it should acknowledge the hazards associated with nitrogen inerting systems and the need for further study in the Executive Summary. As stated in the first sentence of paragraph 2 of Section 1.9, “The FTIHWG lacks the expertise to assess these risks with confidence”. However, the available historical data does suggest that, despite the best intentions, procedures and regulations, accidental fatalities do happen. As already indicated, since the FTIHWG do not consider themselves sufficiently expert to evaluate the impact, and the cost associated with these estimated fatalities were not included in any of the statistics used to generate the study costs or the costs in the Sensitivity Analysis. The costs for additional training and equipment were listed in Appendix F but were not included in the cost estimates or sensitivity analysis.

### **Question No. 10**

Appendix G, page G-1, states the airplane weight penalty costs are based on the 1998 (FTHWG) ARAC study. The cost factor driving these estimates are estimates of the number of flights that would face distance and weight limitations because these earlier systems were much heavier than the systems described in the 2001 FTIHWG report. Those estimated losses were, in turn, built into the fuel cost estimate. A more appropriate value for the lower weights of the inerting design concepts presented in the 2001 FTIHWG report was to be used in the Sensitivity Analysis. This lower weight penalty cost should be part of the documentation of the Sensitivity Analysis. The table below compares the weight penalty used in the report and the Sensitivity Analysis.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

Generic Airplane Size	\$ Per 1,000 lb.	Sensitivity Analysis
Large (Generic) Transport	\$165,532	25.5 gal/lb.
Medium (Generic) Transport	\$131,802	26.5 gal/lb.
Small (Generic) Transport	\$62,004	7.4 gal/lb.

**Response:**

The question addresses weight penalties in the sensitivity analyses. It will be included here as part of the addendum to the Executive Summary.

**Question No. 11**

The report estimates the airplane turnaround time for each generic airplane category. Appendix F (page F-27) of the report then bases the mean time between failure (MTBF) calculations using a much longer turnaround. This creates an unrealistically high rate of failures and generates high estimated maintenance cost. The Sensitivity Analysis should use MTBF calculations based on the same turnaround times used in the equipment sizing analysis.

**Response:**

This question pertains to the on-board ground system sizing and usage. The minimum turn times used in the study were determined using actual operating data obtained from the operators. Operators all have a minimum amount of time required to turn an aircraft between flights for each aircraft type in their operation. This "minimum" turn time is used in developing their operations flight schedules. Some operators regularly schedule their flights using minimum turn times. Others simply use the "minimum" turn time as a benchmark to make sure that sufficient time is included in their schedules to turn the aircraft. Early in this study the Working Group concluded that the inerting process must not increase the aircraft turn times because of significant impact on airport infrastructure and airline operations. As a result, the minimum turn times for each aircraft category were determined and used as a design parameter in system sizing to ensure that the inerting system could inert the fuel tanks within the minimum turn time.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

However, not all flights are turned in the minimum turn times. It was assumed that the on-board ground system would operate during the time the airplane was at the gate. To accurately determine the system reliability the average operating time was used based on an average turn time. To estimate the operating time for a system based on the minimum turn time which was a lower limit design parameter would severely underestimate the average system operating time and therefore the operating costs. However, an automatic shut-off feature could be added to the control system of the on-board ground systems to minimize their running time.

In addition, this question assumes that operating time is the only factor effecting the MTBUR and MTBF of a component. In fact depending on the type of component operating cycles and exposure to environmental factors can have a larger influence on component MTBF. It is true that operating time is a significant factor in the MTBF for a motor or compressor. But it is also true that operating cycles and exposure to environmental factors have a much larger effect on components such as valves, seals, ducting, wiring etc. Because turn time is not a factor on the full OBIGGS systems we have looked at the sensitivity of the reliability data for the GBI and OBG systems. The OBG system has three components that would be significantly effected by decreasing the operating time. Those components would be the compressor, the cooling fan, and the air separation module. Decreasing the operating time for these components by 50% would double their MTBF. However, it would only increase the System MTBF by ~9%, from 960 hrs to 1038 hrs. A similar benefit would be realized in the corresponding System Annual Failure rates and Unscheduled Labor Hours to maintain the systems. The reliability of all of the components in the Ground Based Inerting system are primarily effected by component cycles not operating time and therefore changing the operating time would have little or no effect on system MTBF.

### **Question No. 12**

The cost estimate is based on modification of a portion of the in-service fleet performed during scheduled heavy ('D') checks and another portion of the fleet modified by taking the airplanes out of service dedicated for "non-scheduled" modification. The report should justify the need for modifications outside the scheduled heavy check time period. The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

### **Response:**

After evaluating the scope of the modifications, the Maintenance and Operations team concluded that, most operators would not be able to schedule incorporation of the inerting systems during an airplane's regular heavy maintenance visit. Because it is very expensive to have aircraft out of service for any amount of time, airlines put a lot of effort into carefully planning the work package. The goal is to maximize the efficiency of the work package and use of the facilities thereby minimizing the time out of service. In part, this means utilizing enough technicians to accomplish the most concurrent work possible without having one task interfere with another. An evaluation of the modification

## **FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

work package by the Maintenance & Operations Task Team determined that incorporation of the modification into a heavy check work package would result in a significant extension to the length of the check. The amount of time between aircraft heavy checks is driven by calendar days and flying time. Once the aircraft runs out of time it must be taken out of service until the heavy check can be accomplished. Most operators' heavy check facilities are tightly scheduled and a significant increase in the length of the check would force the operator to contract out heavy checks or ground the aircraft. With the scope of this modification, it is likely that many operators would opt to avoid disrupting the efficiency of the heavy check line by accomplishing the modification in dedicated modification lines or by contracting the modifications out to other maintenance facilities. This eliminates the risk of grounding multiple aircraft by backing up a "heavy check" maintenance facility line.

### **Question No. 13**

When modified during a scheduled heavy check, the report states the airline will be required to extend the time for the inerting modification by 7 to 9 additional days even for a ground based inerting manifold installation. The reason given is the airline can not perform other maintenance on the airplane when modifying the fuel tank. A more detailed justification for this reason should be provided. A large portion of the installation is work performed outside the tank. Also, work can be performed on the aircraft during fuel tank modifications provided it is done in accordance with the lockout, tag-out procedures in place. The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

### **Response:**

As discussed earlier, it is very expensive to have aircraft out of service for any amount of time, therefore airlines typically put a lot of effort into carefully planning the check work package. The goal is to maximize the efficiency of the work package and use of the facilities thereby minimizing the time out of service. In part, this means utilizing enough technicians to accomplish the most concurrent work possible without having one task interfere with another. The work package labor estimates included in Appendix F-A1 & F-A2 were developed by experienced aircraft maintenance program planners with the goal of maximizing work flow to minimize the aircraft out of service time. Many considerations were taken into account including access requirements for all concurrent tasks, electrical power requirements, safety regulations, etc. Wherever possible, modification tasks would be scheduled concurrently with other work. However, in many cases space and resource requirements for one task will interfere with another task in the same area and therefore they cannot be accomplished concurrently.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### **Question No. 14**

The FTIHWG should evaluate using a simplified inert gas distribution manifold with ports in only two or three bays. This concept has been shown on recent scale model testing at the FAA Technical Center to inert the fuel tank even more efficiently (less nitrogen required) than the more complicated manifold design used in the report. The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

#### **Response:**

Since the scale model test results were not available to the HWG at the time their evaluations were completed regarding inerting systems, it was not possible to include these scale model tests manifold system. In addition, none of the HWG participants have any knowledge of the test results or their relevance and therefore cannot estimate its impact in the Sensitivity Analysis. The HWG believes once the full-scale testing and analysis results are available for use, the applicability and/or impact on the Sensitivity Analysis should be studied at that time.

### **Question No. 15**

The ground based inerting section of the report does not provide a need for installing any indication or activation system in the cockpit; however, the cost for installation of the ground based inerting system includes installation of cockpit instrumentation. The costs associated with installing cockpit instrumentation or activation should be eliminated to further streamline the installation and maintenance costs. This would reduce the installation time significantly from the over 1000 hours stated in the report. The Sensitivity Analysis should reduce the installation and parts costs from that used in the report based a system with no cockpit indication of activation system.

#### **Response:**

The parts cost did not include a flight deck indication system. The installation costs could be reduced by 43 hours per airplane.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 16

Does the estimated cost to incorporate inerting on new production airplanes include a reduction in labor installation time as more and more of these systems are installed on airplanes after the first one (learning curve improvements)? The Sensitivity Analysis should reduce the installation costs from that used in the report based on learning curve improvements.

#### **Response:**

It was recognized that the initial inerting system installations would require more labor hours. The estimate for production incorporation represents a mature installation value. This mature value gives a good average over the production life of the airplane.

### Question No. 17

The report states that some airports have placed restrictions on running APUs, but the report does not provide substantiation of this statement. This resulted in the requirement to include an air compressor in the on-board inerting designs. The report should substantiate this statement and list the airports that restrict the operation of APUs. The list should identify which are U.S. airports and non-U.S. airports.

#### **Response:**

An air compressor was chosen because bleed air was not available during the phases of flight when inert gas was needed to supply the fuel tanks. The reasons are described in the Onboard Design Team report (Appendix D) where each of the systems is described. APU noise restrictions were discussed but this was not the primary reason for including an air compressor in the design.

### Question No. 18

The report does not identify separate costs to implement fuel tank inerting concepts on in-service, new production and new airplane designs. Include costs for each category of airplane in the Executive Summary for both the basic report and the Sensitivity Analysis.

#### **Response:**

The cost summary charts in the report combine the costs and benefits for in-service, production and new airplane designs. As an example, two scenarios are included below to show the results for separate categories airplanes. Figures 1-3 show the costs and benefits for scenario 7.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

Figure 1 is the combined cost of new and existing airplanes. Figure 2 is the combined retrofit cost of the fleet only. Figure 3 is the combined cost of new airplanes only. Figure 4 is the combined cost of new and existing airplanes. Figure 5 is the combined cost for retrofit of the existing fleet only. Figure 6 is the combined cost of new airplanes only.

### **Question No. 19**

The SFAR requires development of design changes to correct any design deficiencies identified by the analysis. These changes may be mandated into the existing fleet through the normal airworthiness directive rulemaking process. In the Sensitivity Analysis, what would be the affect on the estimated benefit of fuel tank inerting if inerting were required to be implemented before implementation of any modifications that may result from the design reviews required by SFAR 88?

#### **Response:**

The analysis required to answer the above question would require significant additional resources, time and effort by the FTIHWG. These resources are not available to the FTIHWG and consequently the additional evaluation cannot be accomplished.

### **Question No. 20**

The analysis does not include any benefit for preventing future accidents that could be caused by sabotage, such as a small bomb. The National Transportation Safety Board (NTSB) recommended the FAA consider developing airplane modifications such as fuel tank inerting (safety recommendation A-96-174) in a letter to the FAA dated December 13, 1996. In that letter, the NTSB cited a November 17, 1989, Avianca Flight 203 airplane crash as being caused by small bomb that could be prevented by fuel tank inerting. As stated in the letter, a small bomb was placed under a passenger seat above a center wing tank (CWT). The letter states "the bomb explosion did not compromise the structural integrity of the airplane; however, the explosion punctured the CWT and ignited the fuel-air vapors in the ullage, resulting in the destruction of the airplane." The Sensitivity Analysis should include calculated benefits of inerting based on including prevention the accident referenced above in the service history analysis.

## **FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

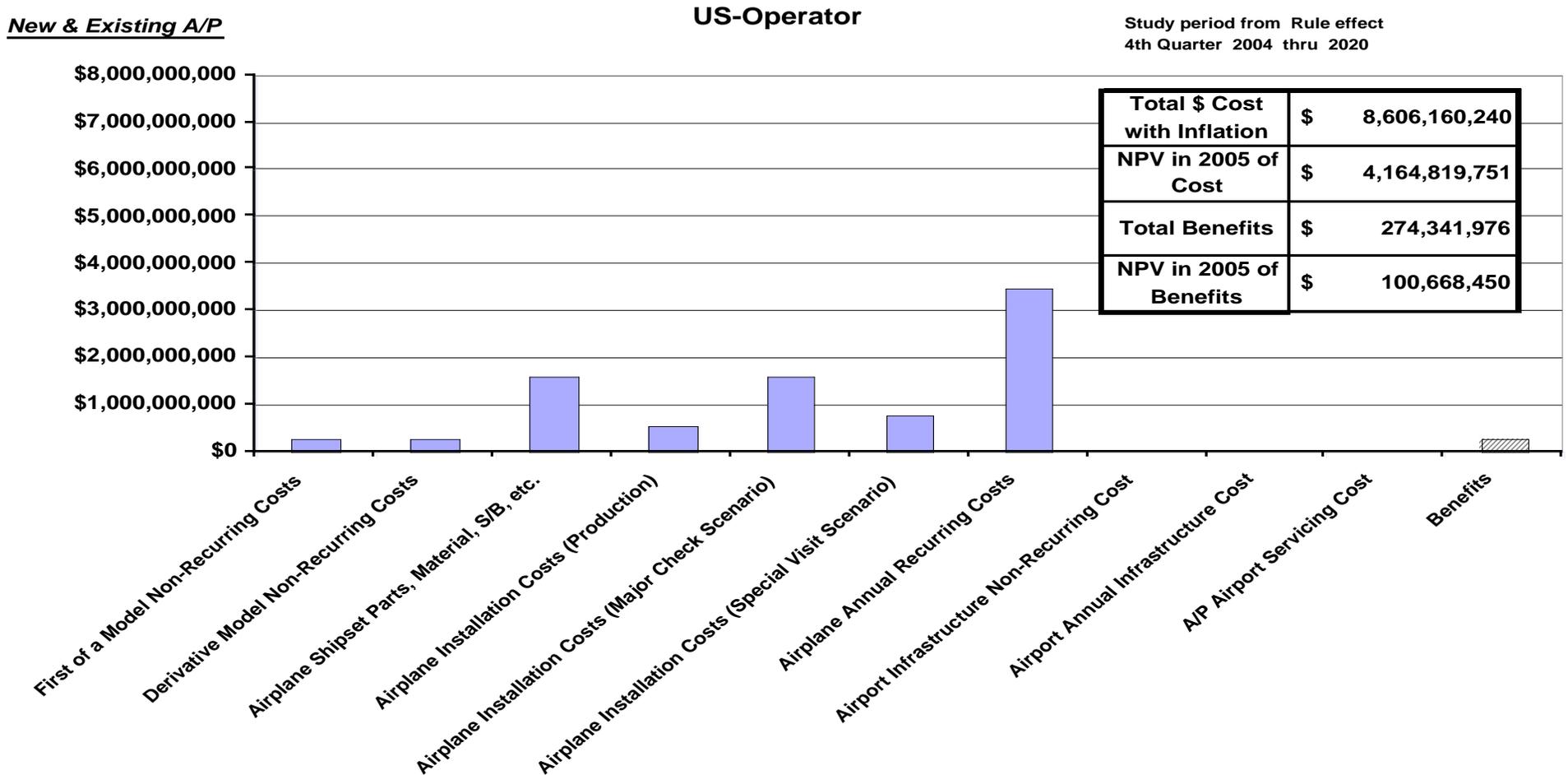
### **Response:**

The FTIHWG acknowledges that inerting may offer some benefit in preventing fuel tank explosions caused by small explosive devices that would not otherwise result in a catastrophe. However, those benefits could not be quantified because of uncertainties related to secondary ignition sources and the loss of nitrogen following breach of the fuel tank. If the FAA and/or NTSB has information that resolves the uncertainties discussed above, the FAA has the option to include that accident in their regulatory evaluation process.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Figure 1

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium  
Transports, Membrane Systems, & Small Transports, PSA/Membrane  
Systems**



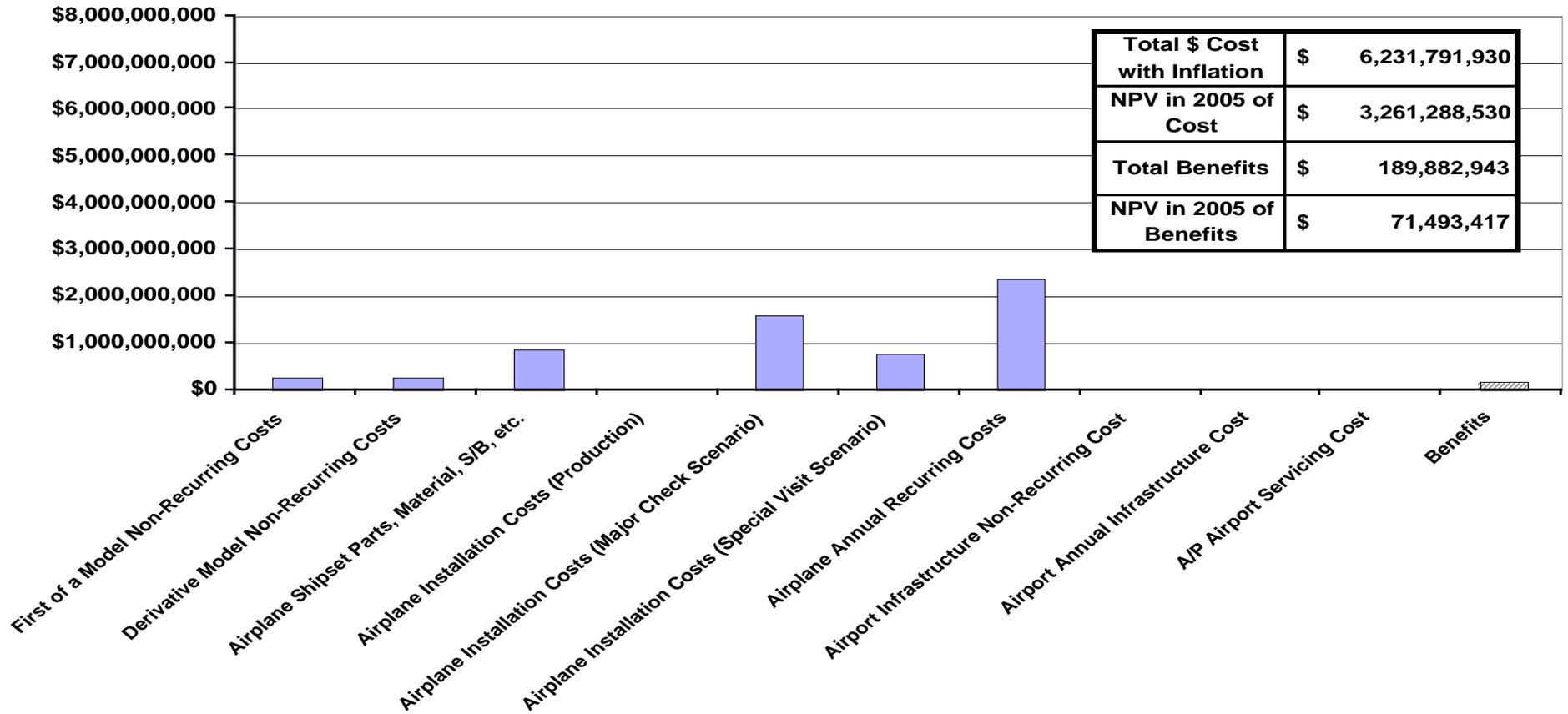
## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report Figure 2

### Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems

Retro of Fleet only

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

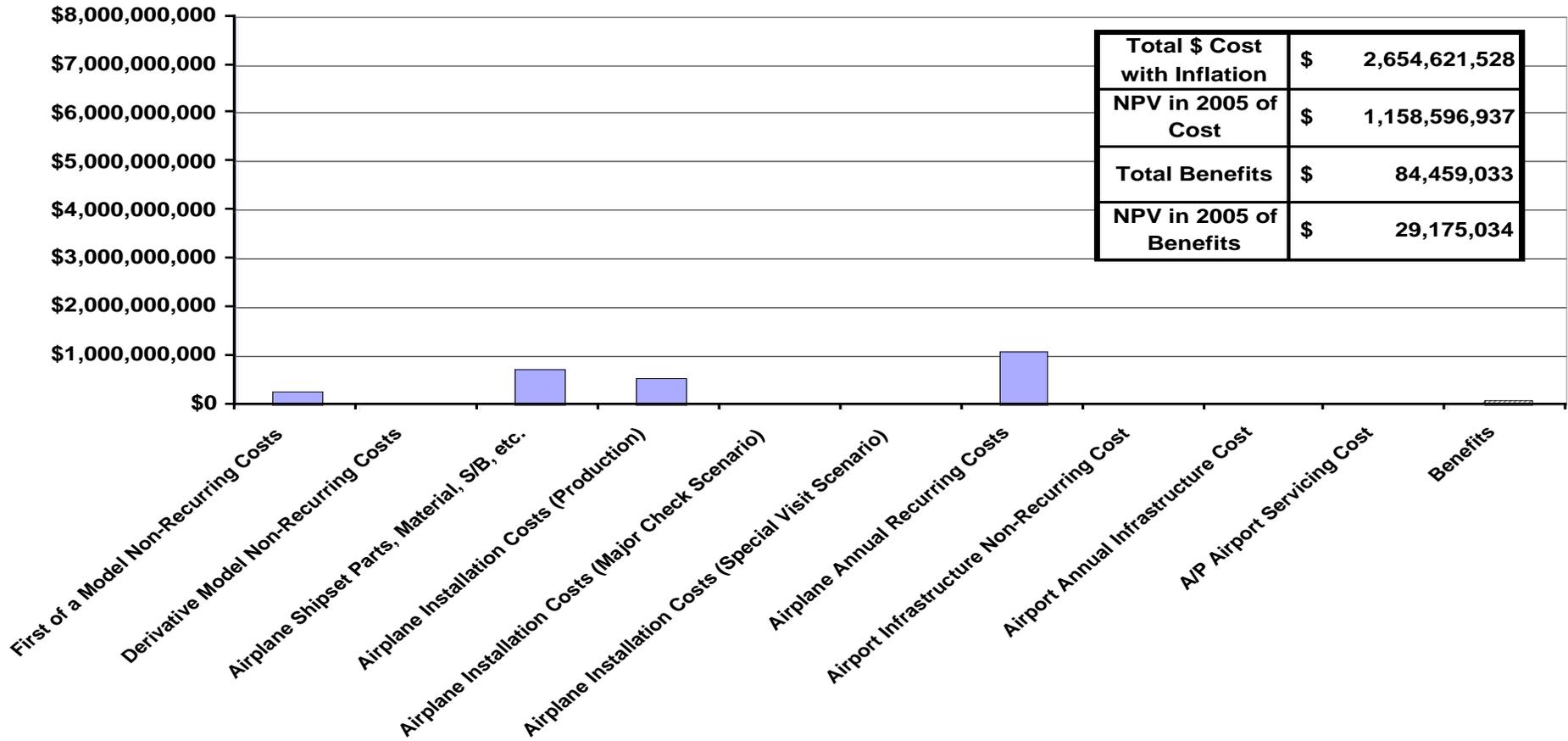
### Figure 3

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium  
Transports, Membrane Systems, & Small Transports, PSA/Membrane  
Systems**

New A/P Only

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

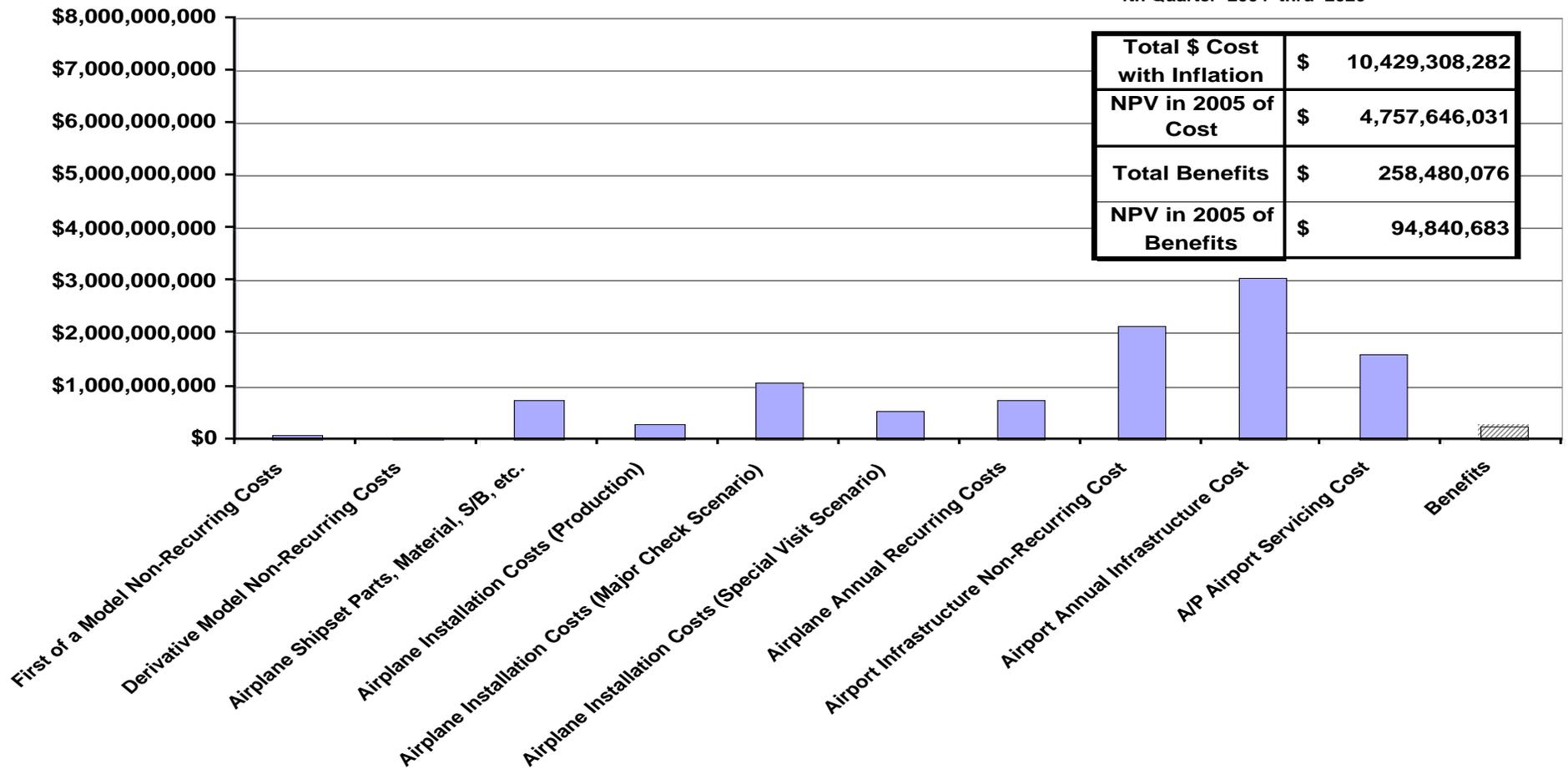
### Figure 4

#### Scenario 11 - Ground Based Inerting HCWT only, All Transports

New & Existing A/P

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

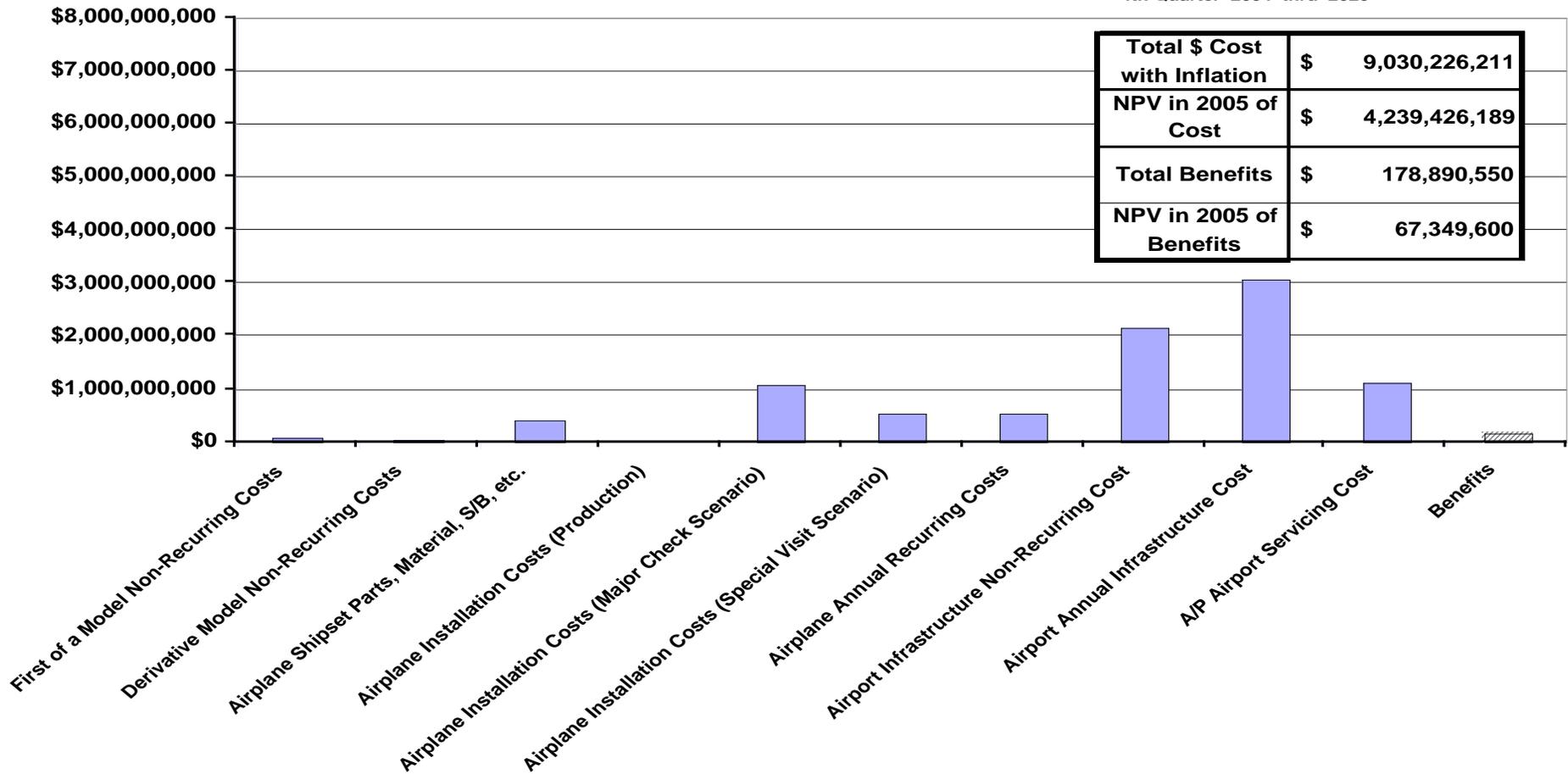
### Figure 5

#### Scenario 11 - Ground Based Inerting HCWT only, All Transports

Retro of Fleet only

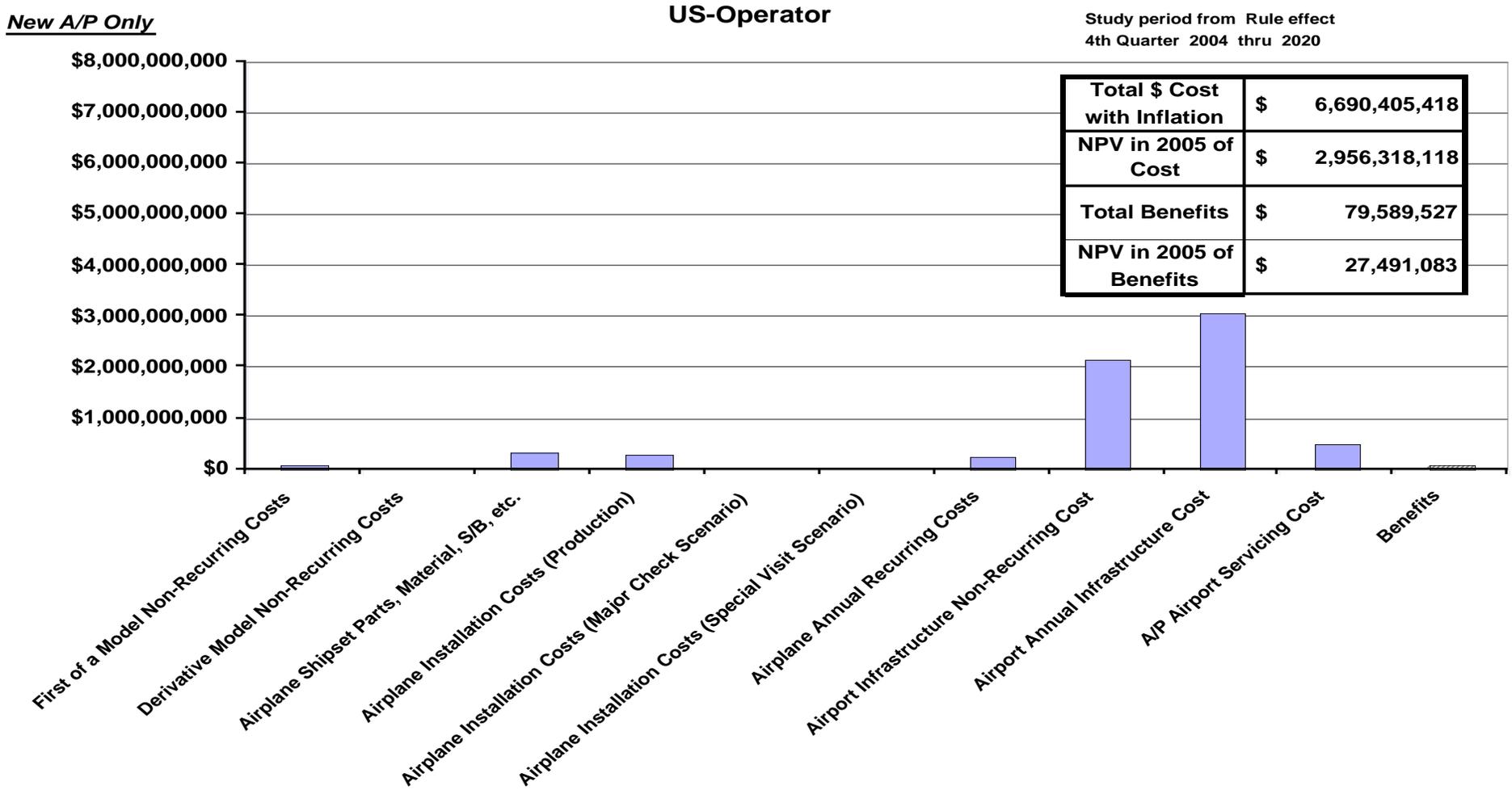
US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report Figure 6

**Scenario 11 - Ground Based Inerting HCWT only, All Transports**



# Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

Section/Page Number

Comment/Question

**Page 1-7, par. 2**

**As there was no consensus of a key assumption that a 75% reduction in the accident rate should be used based on SFAR #88, the report should identify who the majority and minority are on this important point and the majority and minority should articulate their reasons for agreeing or disagreeing with this assumption.**

**Response:**

At the Working Group meeting held prior to release of the final Report to the Executive Committee there was general consensus on the assumption to use a 75% reduction in the accident rate based on SFAR 88. General consensus is defined in the ARAC operating procedures as:

“General Consensus means that, although there may be disagreement among the members of the group, the group has heard, recognized, acknowledged, and reconciled the concerns or objections to the general acceptability of the group. Although not every member fully agrees in context and principle, all members support the overall position of the group and agree not to object to the proposed recommendation.”

The ground rules also provide for confidentiality during the voting process.

Additionally, a sensitivity analysis was conducted after the final report was completed to evaluate the range of opinion on the reduction in the accident rate due to SFAR 88. This sensitivity analysis was presented at the Executive Committee meeting August 8, 2001 and has been added to the Executive Summary.

**Page 1-8**

**Why is there such a great difference in avoided fatalities for Ground Based Inerting versus On Board systems (OBIGGS) 132 vs. 253?**

**Response:**

Ground Based Inerting (GBI) was designed to inert the Center Wing Tank only, while the Onboard Inert Gas Generating System (OBIGGS) was designed to inert all fuel tanks. Because OBIGGS keeps all the tanks inert through all flight phases, it is more effective at preventing fatalities from explosion occurring on the ground and in-flight (152 for OBIGGS vs. 127 for GBI). For the same reasons, OBIGGS is also more effective at preventing fatalities associated with post-crash fires (101 for OBIGGS vs. 5 for GBI).

# Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

Page 1-9

Please explain why the cost benefit analysis ratio for Hybrid OBIGGS (HCWT only) option would not change as follows based on the following assumptions:

**If no improvement assumed from SFAR 88**

**10:1**

If there were no improvement due to SFAR 88, the cost-benefit ratio for Scenario 7 (Hybrid OBIGGS -HCWT only) would be approximately 10:1. The range of opinion within the Working Group was 25% to 90% SFAR 88 effectiveness.

**Plus if reliability is 50% better than 20 year old systems**

**5:1**

The system reliability used in this study is already more than 50% better than 20-year-old systems designs.

**Plus if investment cost is amortized over 30 years instead of expensed over 1-10 years**

**1:1**

For the most systems, the capital costs were only about 30% of the total cost. They were expensed in the year in which they were incurred throughout the 16 year study period, not just years 1-10.

Most of the capital equipment would need to be replaced within 30 years. Once the replacement costs are accounted for, amortizing over 30 years would not reduce the total cost.

**Plus if pain and suffering and potential punitive damage awards are assumed at \$2 million per victim**

**1:2**

The study used \$2.7 million per accident victim.

**Plus if inflation adjustment for benefits is 7% per year**

**1:3**

Inflation would affect both the costs as well as the benefits. Increasing the inflation would not change the cost-benefit ratio.

## **Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

**Page 3-2**

**How can a major assumption involving reduction of accident risk be justified based on reduction of ignition sources if the ignition sources of the past three accidents “have not been identified”?**

**Response:**

It was the general consensus of the FTIHWG that the ignition source reduction assumption of 75% was reasonable. Further, a sensitivity analysis was done and the assumption was varied from 25% to 90% as discussed at the last Ex-Com meeting on August 8, 2001. The results of the sensitivity analysis will be included in the revised executive summary in the final report.

**Figure 11-4**

**Please state the assumption and explain the calculations by which the Net Present Value NPV were performed for Costs and Benefits for each option.**

**Response:**

This question asked for explanations of the calculations of Net Present Value for costs and benefits. The Team concluded that the explanation provided on page 11-1 under METHODOLOGY was intended to answer this question for the reader. Basically, the benefits were estimated for the year in which they were expected to accrue, and likewise the costs. Both costs and benefits were inflated from current year values by 3% per year. To get the net present value, these costs were discounted by 10% per year to the year 2005.

**Figure 5-17**

**Why are the Benefits different here than in Figure 11-4, \$168 million vs. \$95 million NPV in 2005 Benefits?**

**Response:**

This question seeks to clarify a discrepancy between Figures (Scenario 11-Ground Based Inerting, HCWT Only. All Transports, [US Passenger only] 5-17 and 11-4 (Cost Summary-Worldwide Fleet, Passenger Planes). The team concluded that the questioner might have misinterpreted the figure labeling in the report. Figure 5-17 on the upper half of page 5-18 depicts Scenario 11 (Ground Based Inerting, HCWT Only. All Transports, [US Passenger only]), which indicates for U.S. operators only an NPV of about \$95 million for the benefits. This corresponds to Figure 11-5, Cost Summary-U.S. Fleet, Passenger Planes Only, not 11-4 (Cost Summary-Worldwide Fleet, Passenger Planes) at the bottom of page 11-6 which indicates \$95 million NPV for benefits of Scenario 11, U.S. operators only.

## **Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

### **Figure 7-14 Scenario 1**

**Was inflation included in Total Benefits? If so how?**

**Response:**

The question related to how inflation was factored into the calculations. As set forth above, inflation was assumed to be 3% per year for both benefits and costs.

### **Page 8-6 Component Reliability**

**How reliable is this component reliability estimate?**

**What about new equipment and 1998 Report by the Fuel Tank Harmonization Working Group's estimates which show much lower operation and maintenance costs?**

**Response:**

The reliability estimate for the common components, i.e. valves, fans, wiring, etc., was based on data for similar components used in similar applications on commercial aircraft. Therefore, the reliability estimate should be very good.

In-service commercial aircraft reliability data for components unique to inerting systems was not readily available. Therefore data was obtained for equipment currently being used in various applications. For example, the inerting equipment suppliers estimated reliability data for membrane technology based on equipment being used in industrial and military applications.

As another example, in-service data was not available for the compressor, therefore the reliability estimate was made by a detailed component level analysis. Component reliabilities (motor stator, bearings etc) were taken from databases built on in-service data.

The operation and maintenance costs for the 1998 Report did not have the benefit of a review by maintenance experts as this ARAC does. The 1998 Report costs were ROM costs and the team recognized that all of the costs involved were not captured in time for that report.

The information was not available at the time of publication for public release from the Air Force.

### **Page 12-1 How was "practicality" defined?**

**This is a key term but I do not see a definition.**

**Response:**

When assessing the practicality of the inerting systems the following considerations were included:

- Safety benefit versus added hazards and costs
- Technology (system/equipment) maturity

## **Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

- Compatibility with other aircraft systems (integration)
- Weight impact: loss of seating capacity ; impact on aircraft performance
- Reliability: dispatch, in-flight (ability to reach destination), equipment replacement
- Maintainability: ease and interval
- Infrastructure to ensure system operation: airport facilities, fluid (i.e. NEA), etc.
- Compliance with FAR's

### **Page 13-1 Safety Assessment items 2 and 4 How? and How Much?**

Item 2: "Ignition source reduction activities associated with SFAR no. 88 are expected to provide a reduction in the fuel tank explosion rate."

#### **Response:**

The general consensus of the FTIHWG was that ignition source reduction assumption of 75% was reasonable. Further, a sensitivity analysis was done and the assumption was varied from 25% to 90% as discussed at the last Ex-Com meeting on August 8, 2001. While every effort is being made to fully comply with SFAR no. 88 it is recognized that the risk of having an ignition source present can never be fully eliminated and the SFAR effectiveness assumption recognizes that.

Item 4: "The flammability exposure levels achieved by inerting systems can result in an improvement in the accident rate."

#### **Response:**

As discussed in the report inerting can substantially reduce fuel tank flammability, as a result the risk of explosion is also reduced. The fuel tank explosion accident rate for the entire fleet (weighted average of all six generic airplanes) is currently  $\sim 5 \times 10^{-9}$  per hour. With SFAR no. 88 fully implemented at 75% effectiveness, the fuel tank explosion accident rate is forecast to drop to  $\sim 1.3 \times 10^{-9}$  per hour. If GBI were implemented, the fuel tank explosion accident rate is forecast to drop to  $\sim 3 \times 10^{-10}$  per hour. If an Onboard Inert Gas Generating system were implemented, the fuel tank explosion accident rate is forecast to be  $\sim 1.5 \times 10^{-10}$  per hour.

### **Page 13-1 Ground Based Inerting item 5 Please explain why.**

The question has to do with:

"Because an OBGIS runs only on the ground, interference with other airplane systems would be minimized and the certification process should be simpler."

## **Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

**Response:**

Systems that must operate properly per their function and not interfere with any other equipment required. Normally this is accomplished with ground and flight tests, which the FAA may deem necessary after each retrofit installation.

A system that operates only on the ground, and is shut off prior to flight, can be shown to not interfere with any other equipment required for flight. Once certified not to interfere, only ground operational tests would be required to show proper operation. This saves time and money as shown in this report.

**Page 13-1 Ground-Based Inerting,  
Item 1 Why?**

The questions refers to:

“ Installing the airplane portion of a GBI system does not require any new technology to be developed. However, retrofit GBI systems will be extremely difficult and will require an evaluation of each airplane category model to determine if a retrofit installation is practical. “

**Response:**

The retrofit manifold will need to be designed to avoid interference with already installed systems such as vent systems, FQIS probes/sensors/wiring, refuel manifolds, and cross-feed manifolds. The design will thus require more internal support brackets on ribs and stringers to accommodate the non-optimum routing.

Structure penetrations of major structure items (i.e. spars and ribs) are expected to be required. The feasibility of introducing these penetrations in the structure will be dependent upon the structure design philosophy applied to the particular aircraft model, and in the in-service history of a particular aircraft (i.e. have previous repairs already been carried out due to previous in service events).

Specific aircraft type design modifications, such as reinforcing plates to ensure the strength of the existing parts are not compromised, would be necessary. This will increase the amount of drilling/machining necessary inside the tank. To carry out these operations special drilling fixtures will be required, particularly in areas of tight access due to the proximity of stiffeners on the ribs, spars and skins. The location of the GBI manifold will be near the top of the tank to avoid impeding access to the tank for maintenance and to minimize fuel submergence during GBI.

It was assumed that it would be possible to avoid removing the majority of the existing fuel system installation to install the new manifold. However, special protective tooling is likely to be required for the FQIS electrical harnesses to ensure they are not inadvertently damaged during drilling/ installation activity. The cost of replacing an FQIS harness is major, and was not assumed as part of the retrofit GBI installation.

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Modifications to existing vent systems to preclude cross venting would be necessary for a large portion of the fleet. The design changes to accomplish this have not been developed, and require careful consideration to assure these modifications do not introduce new safety issues.

All of the above factors, would contribute to the difficulty and costs associated with retrofitting a GBI system installation.

Subsequent to the ARAC task team effort and final report, the FAA has accomplished testing that suggests the distribution of nitrogen to each tank bay may not be necessary. The distribution system details would be designed for each aircraft with the objective of minimizing the impact. Methods to economize are a part of detailed design. However, it is also appropriate to note that savings during detailed design are often offset or exceeded by complications not accounted for in preliminary design studies similar to that done for this ARAC.

### **Item 2: Why not part of fuelling operation**

This question refers to:

The availability of airport supply systems to supply NEA at each terminal gate and remote parking area is a serious problem that needs to be resolved before GBI can be implemented.

*Section 10.17 of the report Para 10.3.2.3 also covers this issue.*

### **Response:**

The Terms of Reference requested that the system inert the fuel tank at arrival. Depending on the fuel load and aircraft size inerting may be completed before, at the same time, or after refueling. If directly linked to the refuel there would be a knock on effect to refueling other aircraft since the refuel truck for example would have to wait until both operations were completed. The location of the connection for the NEA on the aircraft will be near the center tank. Aircraft refuel connections are typically outboard of the engine or between the engines. To minimize the impact on the ground operation of the aircraft the ground based on-board system has been designed so that it can be performed at any time.

Due to the physical separation of the two connections it will not be possible to observe or monitor each connection without walking between each one. In the event of an interruption of one of the servicing operations increased delay would result since to trouble shoot one system would require the other operation to be suspended.

### **Page 13-2 Airport Facilities Item 4 Aren't there systems that capture VOC?**

Item 4 states:

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“Significant volumes of VOC were released during both processes, regardless of inert gas used. This increase in VOC emissions should be investigated and resolved to avoid any serious potential health, environmental, and safety issues.”

**Response:**

Vapor recovery systems are not presently installed or required on airplane or fuel handling systems handling Jet-A type fuel. If the increase of hydrocarbon emissions caused by GBI becomes a subject for regulatory action this may require modification to the aircraft vent system and a means of vapor recovery at each fueling position. The costs of this were not included in the study.

The natural occurring VOC release from jet fuel is relatively minor due to its low vapor pressure and is therefore generally exempt from capture. The two operations referred to in this statement – aircraft fuel tank ullage washing and fuel scrubbing (displacing entrained oxygen with NEA) introduces the physical removal of normally stable light end components from the jet fuel.

Preliminary laboratory tests conducted on both processes, using various inert gases, indicates that not only is there a significant VOC volume increase but also the driving off of other components that normally remain entrained within the fuel. The release of these other components tends to form unacceptable concentrations of otherwise non-lethal hazardous material when in their natural state. Therefore, the Working Group recommended that additional investigation into this matter be carried out before implementation of a NEA inerting process for today’s transport category aircraft.

**Page 13-2 Onboard Inert Gas Generating System,  
Item 4 What airlines are you referring to?**

Item 4 states,

“ The weight of an installed OBIGGS is significant; for example, for a large transport category airplane, the OBIGGS weighs between 1,120 and 1,600 lb.”

**Response:**

The study used the same six generic aircraft that were specified for the 1998 ARAC FTIHWG study. These are representative of the fleet without being specific to one manufacturer. The “large” aircraft have a 350 or greater passenger capacity.

**13-2 Onboard Inert Gas Generating System,  
Item 6, 8 What is the basis for this? Was the reliability number used for current systems or 20 year old military systems?**

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This question refers to:

“ Item 6: Current technology components of an OBIGGS have demonstrated low reliability.”

**Item 8:** NEA membrane air separation systems that have improved efficiency and performance, and lower nonrecurring costs would be a necessary part of a practical membrane-type OBIGGS.”

**Response:**

Items 6 and 8 refer to different aspects of OBIGGS systems. Item 6 refers to the C-17 system, which does not have sufficient reliability for use in commercial aircraft service. The lessons learned from this system were applied to the inerting concepts in this report in order to avoid the low reliability components. No other system currently exists with the capacity to inert transport aircraft fuel tanks so the inerting equipment suppliers must project reliability estimates for the conceptual systems presented in this report.

Item 8 refers to the latest technology in production from suppliers of inert-gas generating equipment and has nothing to do with reliability, but rather feasibility. This equipment must produce more nitrogen from less supply air to be feasible. The suppliers have indicated that R&D efforts are being undertaken to improve the efficiency but improvements will only occur with a “scientific breakthrough”.

Reliability was based on existing components and supplier projections as presented in the response to question 8-6.

**Page 13-3 Airplane O & M, Item 4**

**Why is 0.7% to 0.1% down time necessary?**

Item 4 refers to the reliability of inerting systems, it states:

“The current reliability of inerting system technology is unacceptable from a maintenance and operational viewpoint and requires an order of magnitude improvement to make them operationally viable.”

**Response:**

Improvements in reliability are necessary to ensure that the inerting system does not cause a significant decrease in overall dispatch reliability. A significant decrease in dispatch reliability would lead to a systemic effect on airplane utilization.

**Page 13-3 Estimating and Forecasting, Item 3**

**Why aren't these systems practical?**

Item 3 states:

“Of the design concepts studied, the one with the lowest cost-benefit ratio was the GBI and the hybrid OBIGGS concept applicable to heated CWTs only.”

## **Aviation Consumer Action Project (ACAP) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

### **Response:**

The general consensus of the Working Group was that fuel tank inerting will take many years to implement and will have an enormous operational impact, with costs that far exceed the benefits. Based upon these factors, the consensus was that these inerting systems were not practical at this time.

When assessing the practicality of the inerting systems the following considerations were included:

- Safety benefit versus added hazards and costs
- Technology (system/equipment) maturity
- Compatibility with other aircraft systems (integration)
- Weight impact: loss of seating capacity; impact on aircraft performance
- Reliability: dispatch, in-flight (ability to reach destination), equipment replacement
- Maintainability: ease and interval
- Infrastructure to ensure system operation: airport facilities, fluid (i.e. NEA), etc.
- Compliance with FAR's

### **General Questions**

- 1) **What is the basis for concluding that fuel tank inerting is not practical based solely of the WG's cost benefit analysis?**

### **Response:**

The general consensus of the Working Group was that fuel tank inerting will take many years to implement and will have an enormous operational impact, with costs that far exceed the benefits as calculated in accordance with the standard Department of Transportation formula.

Based upon these factors, the consensus was that these inerting systems were not practical at this time.

The cost-benefit analysis is a part of the regulatory evaluation process. The terms of reference required that any recommended inerting system meet regulatory evaluation criteria. When assessing the practicality of the inerting systems the working group also considered:

- Safety benefit versus added hazards
- Technology (system/equipment) maturity
- Compatibility with other aircraft systems (integration)
- Weight impact: loss of seating capacity ; impact on aircraft performance
- Reliability: dispatch, in-flight (ability to reach destination), equipment replacement
- Maintainability: ease and interval

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- Infrastructure to ensure system operation: airport facilities, fluid (i.e. NEA), etc.
- Compliance with FAR's

**2) Who are the economists who crunched the numbers for the cost benefit analysis and what are their affiliations and qualifications?**

Allen A. Mattes, a senior economist for the FAA, in the office of Aviation Policy and Plans, Aircraft Regulatory Branch, supported the Economic and Forecasting team. He provided guidance for setting up the cost benefit analysis. The task teams provided the data used in the analysis. A working group member supported each task team.

**3) Who are the members of the WG, their affiliations and professional qualifications?**

**Response:**

The ARAC Working Group members, listed below, were chosen from resumes submitted to the FAA. The FAA and the Chairman of the ARAC Executive Committee selected the members of the Working Group. The Working Group members were selected for two reasons: they had the skills, background, and capabilities to fully address the Terms of Reference and they represented a balanced range of industry opinions. The Working Group and task teams included designers and manufacturers of inerting systems.

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<b>Name</b>	<b>Representing</b>	<b>Company</b>
Brad Moravec	Aerospace Industries Association (AIA)	The Boeing Company
Sean O'Callaghan	Association of European Airlines (AEA)	British Airways
G. Michael Collins	Federal Aviation Administration (FAA)	FAA, Transport Airplane Directorate
Laurent Gruz	Joint Aviation Authorities (JAA)	Direction Générale de l'Aviation Civile (France) (DGAC)
Anne Jany	European Association of Aerospace Industries (AECMA)	Airbus
James Hurd (Alternate)	Public Interest Groups	National Air Disaster Alliance / Foundation (NADA / F)
C. William Kauffman	Public Interest Groups	National Air Disaster Alliance / Foundation (NADA / F)
Charlie Osonitsch	Small Transport Aircraft Manufacturer	Gulfstream Aerospace
Karl Beers	Inert Gas Equipment Manufacturing	Air Liquide - MEDAL
Brian Sutton	Airline Pilots Association International (ALPA)	TWA /American
Frank O'Neill	Air Transport Association (ATA)	United Airlines
Jay Hiles	International Association of Machinists (IAM)	US Airways
David Lotterer	Regional Airline Association (RAA)	RAA
Ted Campbell	American Petroleum Inst.(API)	Texaco

4) **What are the views of the designers and manufacturers of the fuel tank inerting systems on the conclusions and cost benefit analysis of the WG?**

**Response:**

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The Working Group and task teams included members who are designers and manufacturers of fuel tank inerting systems. The Working Group reached general consensus on the conclusions and recommendations.

**5) Did you consult with any economists who do not have a vested interest in the outcome of the FAA's adoption of fuel tank inerting? If so who?**

**Response:**

The FAA economist, who is impartial, was the only one on the study.

**6) What is the per ticket cost of the various fuel tank inerting options?  
Isn't it true that the total cost of fuel tank inerting is about 1/6% of airline revenue according to your calculations?**

**Response:**

The net cost per flight, averaged over the large, medium and small generic airplanes, ranges from \$72 (hybrid OBIGGS) to \$128 (Full OBIGGS). Over the portion of the study period where inerting would be used (2008-2020), the net cost per ticket would be \$0.45 to \$0.98. It was assumed that this cost would be applied to all tickets regardless of whether an inerting system was installed or not.

The FAA may be able to provide this airline revenue data; it was not used in our calculations.

**7) Why have you not developed regulatory text as required by the tasking statement?  
How many lawyers (regulatory and air crash tort) were on the WG? What were their affiliations and expertise?**

**Response:**

Chapter 12 and Appendix I provide comprehensive regulatory text. No lawyers were assigned to the Working Group because the tasking requested only "recommended" regulatory text. The FAA does not assign lawyers for drafting "recommended" regulatory text.

**8) Where is the analysis for your recommendation that new aircraft designs could substantially reduce risk and cost of preventing fuel tank explosions?**

**Response:**

This question pertains to the Co-Chairmen's recommendation that the FAA and Industry study means other than inerting to reduce fuel tank flammability. In general, the FAA's fuel tank flammability model was used to evaluate the effects of ground cart cooling, improved insulation between the Center Wing Tank and adjacent heat sources, and improved fuel scavenging.

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***Co-Chair Recommendations***

**Examples of alternative flammability reductions methods  
using the ARAC fleet-wide flammability exposure model**  
Percent Exposure of Airplane Types

Airplane Configuration	LARGE	MEDIUM	SMALL
Baseline	36.2	23.5	30.6
Duct Insulation	26.3	19.9	23.9
Ground Cart Cooling	26.7	16.9	20.2
Duct Insulation & Ground Carts	18.5	12.3	16.2
Reduced Residual Fuel	33.5	20.0	27.4
Duct Insulation with Reduced Residual Fuel	23.8	16.3	22.7
Ground Cart Cooling with Reduced Residual Fuel	23.4	13.1	19.2
Duct Insul & Grd Carts w/ Reduced Residual Fuel	15.9	10.0	15.2

**Conclusion:** The flammability model results show that a combination of hardware and procedure changes may lower fuel tank flammability exposure by more than half.

**9) How has the views and experience of military aviation that has used fuel tank inerting been used by the WG?**

**Response:**

The task teams included participants from the US Navy and industry engineers who have worked on military inerting systems. Their efforts were used extensively in preparing this report.

**10) Isn't it true that a \$3 Billion annual cost equates to a per flight cost of 16 cents over 20 years and 33 cents over 10 years?**

**Response:**

The net cost per flight, averaged over the large, medium and small generic airplanes, ranges from \$72 (hybrid OBIGGS) to \$128 (Full OBIGGS). Over the portion of the study period where inerting would be used (2008-2020), the net cost per ticket would be \$0.45 to \$0.98. It was assumed that this cost would be applied to all tickets regardless of whether an inerting system was installed or not.

**11) What is the legal basis for the position that cost benefit analysis is the only or main factor for the FAA to determine whether or not to require fuel tank inerting?**

**Response:**

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The cost-benefit analysis is not the only or main factor for the FAA to use to determine whether or not to propose a rule. Under the Sept. 30, 1993, Executive Order #12866, a Federal agency must perform a cost-benefit analysis when proposing a rule. However, the Federal agency should select the approach that would maximize net benefits (including potential economic, safety, and other impacts). The cost-benefit analysis is only one of several factors affecting an Agency's decision to propose or not to propose. In other words, there is no legal requirement that a positive net benefit is a requirement for a Federal agency to issue a proposed regulation.

**12) Did you consider the indirect costs to the industry of lower revenue caused by accidents, the investigation and litigation costs?**

**Response:**

The benefits included DOT's latest estimate of the amount society would pay to prevent a potential fatality (\$2.7 million), the value of the destroyed airplane, value of ground damage and accident investigation.

**13) Did you consider the non-economic costs of human pain, misery and suffering caused by failing to prevent accidents that are preventable with currently available technology?**

**Response:**

The benefits included DOT's latest estimate of the amount society would pay to prevent a potential fatality.

Allen Mattes input:

The benefits included the DOT's latest estimate of the amount society would pay to prevent a potential fatality. This value, which is periodically revised to account for inflation, is based on a survey performed by the Urban Institute ([The Cost of Highway Crashes](#), June 1991) of studies that have estimated the amounts society is willing to pay for reduced risk of fatalities. The willingness to pay approach attempts to value an average of all the benefits arising from the prevention of a fatality.

**14) Did you consider the overall costs to the US economy of a policy that authorizes airlines and manufacturers to not fix a known hazard to air travelers, especially if it leads to series of preventable accidents killing hundreds of air travelers? The Comet syndrome? The potential bankruptcy of airlines (ie Pan Am after Pan Am 103)? The potential liability of the US government and industry officials for such policies leading to many preventable deaths? The professional reputations of those involved in promoting such policies? The morality of recommending a policy that will knowingly cause a horrible death for hundreds of air travelers?**

**Response:**

The qualified benefits of accident prevention are discussed in chapter 11 of the report. They include DOT's latest estimate of the amount society would pay to prevent a potential fatality (\$2.7 million), the

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value of the destroyed airplane, value of ground damage and accident investigation

**15) Are there not other cost benefit analyses available to WG members that show much lower costs and higher benefits?**

**Response:**

Yes, other cost-benefit analyses used by the Working Group include the 1998 ARAC study and the FAA's Ground Based Inerting Study (DOT/FAA/AR-00/19). Although the studies are not directly comparable, data from both these studies were used.

**16) Have the Industry members of the WG met privately to pre-determine or decide their strategy to oppose fuel tank inerting a biased cost benefit analysis?**

**Response:**

No, the WG is not aware of any privately held meetings. The ARAC process was used to develop an industry consensus on the response to the Tasking Statement.

**17) What instructions or pressures have been brought to bear on WG members by their superiors to come up with a negative recommendation on fuel tank inerting?**

**Response:**

The Working Group recommended that the FAA and industry continue research and development on inerting systems. This should not be considered a negative recommendation. Additionally, the Working Group is not aware of any members that were pressured to take a position they did not agree with.

# National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

## Question 1

1.) Within the report as submitted there are significant omissions which must be addressed:

- a) A literature survey is required in order to identify all significant documents pertaining to fuel tank flammability, explosions, and ignition sources.

### **Response:**

Bill Kauffman, a Working Group member and Ex. Com. member, has provided a list of references:

#1. AAR, File# 1-0015, 3 March 65, CAB, Boeing 707-121, N709 PA, Pan American World Airways, Inc, near Elkton MD, 8 Dec, 1963.

#2. FAA-RD-72-53, The Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System, Aug. 1972, final report, DOT, FAA.

#3. The Boeing Co, Code Ident. No D226-20582-1, Vol. 1 of 4, Center Wing Tank Fuel Heating Study, release date 14 March, 1980.

#4. Transport Fuel Flammability Conference, Washington DC, 7-9 Oct., 1997, FAA/SAE, Proceedings.

#5. FAA Notice of Public Comment, 3 April, 1997, NTSB Recommendations Relating to TWA Flight 800

#6. AAR-00/03, NTSB, In Flight Breakup Over the Atlantic Ocean of Transworld Flight 800, Boeing 747-131, N93119, near East Moriches, NY, 17 July, 1996.

The FTIHWG web site lists the following reference material:

ARAC Tasking Record, dated July, 2000

Terms of Reference, dated July, 2000

FAR Part 25 – Fuel System, dated March 17, 1977

Thermal Modeling to Predict Fuel Tank Flammability, dated 10/07/97

Fuel System In-Tank Design Philosophy on Boeing Aircraft, dated 10/07/97

Fuel System In-Tank Design Philosophy on Airbus Aircraft, dated 10/07/97

1998 ARAC FTHWG Final Report, dated 1998

Fleet Statistics, dated 4/17/98

Airplane Standard Worksheets and Charts, dated 4/17/98

Explosion of JET A Vapor by J.E. Shepherd, dated 10/7/97

Ivor Thomas's Presentation at FAA Technical Center, dated 10/18/00

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Performance of a DC-9 Liquid Nitrogen System, dated August, 1972  
Ivor Thomas's Thermal Model, dated 12/01/00, 1/12/01, 3/14/01  
The Cost of Implementing Ground-Based Fuel Tank Inerting in the Commercial Fleet, dated May, 2000  
A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion, dated December, 1999  
A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, dated June, 1998  
Evaluate the Effectiveness of Ground-Based Fuel Tank Inerting During Airplane Ground and Flight Operations (Boeing 737 Test Plan), dated Feb. 11, 2002  
Airport Survey – Buffalo, dated 1/4/01  
Airport Survey – LAX, dated 1/4/01

- b) An identification must be made of those individuals and their associated organizations that participated in the writing of the report and their specific contribution.

**Response:**

The ARAC Working Group members were chosen from resumes submitted to the FAA. The FAA and members of the Chairman of the ARAC Executive Committee met and selected the members of the Working Group. The selected candidates were determined to be capable of addressing all aspects in the Terms of Reference. There were selected for two reasons: they had the skills, background, and capabilities to fully address the task and they represented a balanced range of industry opinions.

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Name	Representing	Company	Contribution
Brad Moravec	Aerospace Industries Association (AIA)	The Boeing Company	Economic and Forecasting Team
Sean O'Callaghan	Association of European Airlines (AEA)	British Airways	Airline Operations and Maintenance Team and Safety Team
G. Michael Collins	Federal Aviation Administration (FAA)	FAA, Transport Airplane Directorate	Rulemaking Team
Laurent Gruz	Joint Aviation Authorities (JAA)	Direction Générale de l'Aviation Civile (France) (DGAC)	Rulemaking Team
Anne Jany	European Association of Aerospace Industries (AECMA)	Airbus	Rulemaking Team
James Hurd (Alternate)	Public Interest Groups	National Air Disaster Alliance / Foundation (NADA / F)	At Large
C. William Kauffman	Public Interest Groups	National Air Disaster Alliance / Foundation (NADA / F)	At Large
Charlie Osonitsch	Small Transport Aircraft Manufacturer	Gulfstream Aerospace	Airplane Design Team
Karl Beers	Inert Gas Equipment Manufacturers	Air Liquide - MEDAL	Airplane Design Team
Brian Sutton	Airline Pilots Association International (ALPA)	TWA	Airline Operations and Maintenance Team
Frank O'Neill	Air Transport Association (ATA)	United Airlines	Airport Facility Team
Jay Hiles	International Association of Machinists (IAM)	US Airways	Airline Operations and Maintenance Team
David Lotterer	Regional Airline Association (RAA)	RAA	At large
Ted Campbell	American Petroleum Inst.(API)	Texaco	Airport Facility Team

- c) Under the analysis of benefits, no consideration was given to the adverse impact upon ticket sales after next fuel tank explosion, the cost of family breakups which invariably result when a family member is lost in an air disaster, and the payment of considerable punitive damages by the air transport industry which will result after the next fuel tank explosion. The final version of this report does put the industry on notice regarding a known dangerous but fixable situation. On 17 August, 01, \$480M in damages were awarded against Cessna Aircraft Co. regarding an alleged known defect concerning the failure of seat positioning locks.

## **National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

**Response:**

The Tasking Statement required that we evaluate designs based on the FAA's regulatory evaluation methodology, the items listed above fall outside the scope of the evaluation. The Working Group used FAA's methodology and the best cost and benefit data available. If other data or new methods become available then analysis should be reevaluated.

- d) A survey of the performance parameters of existing operational inerting systems, particularly on military aircraft (C-5, C-17, F-22, Osprey) where weight, space, and power penalties are especially severe, should be provided and discussed.

**Response:**

List of performance parameters sent by Bill Kauffman to Greg H on 12/6

At this time, the Air Force and Navy are in the approval process for the release of data.

We have members who are familiar with the systems participating on the team.

### **Question 2**

The question of appropriateness for doing a cost/benefit analysis must be addressed. In three other situations involving the substantial loss of life this seems not to have been an issue: 1) In the Our Lady of Angels, Chicago IL, 1958 school fire resulting in 110 dead an immediate sprinkler and call box installation was initiated and completed within 2 years for all Chicago schools. B) More recently for the past several years Ford Explorer rollovers, presumably initiated by defective tires, have resulted in over 200 deaths. An expenditure of approximately \$4B has been made, by only two corporations, as a result of recalls to correct this problem. C) Additionally, at present there is a massive recall of faulty fire sprinkler heads by one manufacturer. It has not been noted that a CBA has been done in order to justify the recall. In a California automobile fuel tank fire case, enormous damages were awarded to the injured in a jury trial as General Motors had reportedly decided that the \$8 cost per vehicle required for fuel system redesign and manufacture was not cost effective compared to damages that would be awarded in a trial. In a ruling in the recently completed term, the US Supreme Court judged unanimously in a USEPA related case that only public health (safety?) could be considered and not cost regarding new clean air standards.

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**Response:**

The Tasking Statement required that we evaluate designs based on the FAA's regulatory evaluation requirements, the items listed above fall outside the scope of the required evaluation. The above general comments are outside of the ARAC Fuel Tank Inerting Harmonization Working Group's Tasking Statement issued by the FAA and will not be answered by this Working Group.

The benefits included the DOT's latest estimate of the amount society would pay to prevent a potential fatality. This value, which is periodically revised to account for inflation, is based on a survey performed by the Urban Institute ([The Cost of Highway Crashes](#), June 1991) of studies that have estimated the amounts society is willing to pay for reduced risk of fatalities. The willingness to pay approach attempts to value an average of all the benefits arising from the prevention of a fatality.

**Question 3**

No discussion is provided concerning the failure of the strategy to control ignition sources only for the prevention of fuel air explosions (FAE). For FAE where the governing physics is best described by the explosion pentagon – fuel, air, ignition source (these three are considered to be the fire triangle), mixing the fuel and air, and confinement. Experience in other industries (process, coal mining, and grain and feed) has shown that while the control of ignition sources may decrease the number of incidents it does not eliminate them. These industries have also adopted the strategy to control fuel, and the combined effect has been to almost totally eliminate fuel air explosions. Considering that in the three most recent aircraft fuel tank explosions in which the ignition sources have not been identified it is undoubtedly not realistic to assign any numerical value to the possible future effect of SFAR88. Actually, some scenarios could be devised giving negative values for its effect.

**Response:**

To address the issue of SFAR 88 effectiveness in preventing future accidents, the Working Group considered three effectiveness values in the sensitivity analysis, 25%, 75% and 90%. There are a limited number of potential ignition sources in the fuel system. SFAR 88 will address all of these potential sources.

## **National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

With today's technology level, the Working Group could not recommend an inerting system that met the FAA's evaluation requirements. However, the Working Group recommended further research in order to develop a practical inerting system.

### **Question 4**

The projected cost of fuel tank inerting as estimated recently (July 98, ARAC1, \$4B; May 2000, FAA, \$1.6B; August 2001, ARAC2, \$10.4B) varies too widely to provide any confidence. It far exceeds the rate of inflation. New technology driven by such a market opportunity would have a significant impact upon lowering the cost. (The cost of PC's has been significantly lowered by technology and demand.) Additionally, substantial infrastructure costs will be borne by the nitrogen supply contractors as is the case with aviation fuel. Liquid nitrogen systems seem to offer significant cost advantages, but they have been neglected. At the April 01 Ex Com meeting, it was recommended explicitly to the Working Group that cryogenic nitrogen systems be considered. Manipulation and slight annotation of the information presented in the report allows the CBR to be lowered to a value of 4.0. Normalization of the costs by other parameters such as passenger flight miles, segments, tickets, etc. makes it almost inconsequential - \$0.25 to \$1.25. The cost indicated for a future incident of \$480M is at least low by a factor of two. TWA 800 estimates were around \$1B.

### **Response:**

The three studies mentioned above all used different evaluation periods and other economic assumptions. The 1998 ARAC study and the FAA's study used 10-year evaluation periods. This study used a 16-year evaluation period. Although a longer evaluation period gives a higher total cost it produces a lower cost-benefit ratio. These differences are explained in Appendix G.

As requested by the Executive Committee, a liquid nitrogen system was evaluated and included in Appendix G. The Working Group is not aware of the calculations that lower the Cost-Benefit Ratio to of any of the proposed systems to 4.0. The Working Group would welcome any cost savings suggestions.

## **National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

The loss of life is typically the largest component of the overall cost of a catastrophic accident. This cost was determined based on the number of passengers onboard as given in Figure 4-4, and the accidents avoided as given in Figure 4-5. Note that roughly 1 accident is forecast to be avoided, however, that accident is divided between the Large, Medium and Small transports based on their relative risk. The Small transport has the largest forecast fraction of avoided accidents, and has the smallest passenger payload of the three transports. Although the total cost of the TWA 800 accident was not available to the Working Group, some of the known costs were used in this study.

The FAA's evaluation methodology compares the costs and benefits of proposed rulemaking. Although the cost per ticket is one way to scale the total costs, it is not part of the evaluation methodology.

### **Question 5**

All known gas turbine transport aircraft fuel tank explosion incidents should be listed. It is anticipated that this number can be as big as 34. The 17 used by the Working Group may be noted as well as the reasons for their inclusion as well as the exclusion of others.

#### **Response:**

All known fuel tank explosion accidents were included in the study. The tasking statement required that the set of accidents defined in the 1998 Fuel Tank Harmonization Working Group Final Report be used by the FTIHWG. There were 16 accidents in that set and a 17th (the Bangkok accident) was added. These accidents represent those involving internal or external ignition sources (other than those associated with ground fire explosion). In addition the tasking statement required that the benefits associated with ground fire explosion be evaluated. The tasking statement suggested DOT/FAA/AR-99/73, "A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion" be used as a reference. That report included analysis of an additional 13 accidents. So, a total of 30 accidents were included in the analysis.

### **Question 6**

Fuel tank explosions are a single point failure – an energy release of sufficient magnitude into a combustible fuel air mixture. In aviation such a scenario is not acceptable. Inerting of the vapor mixture is a highly specific totally directed fix for this dangerous condition. The nitrogen inerting of fuel tanks is noted to be 100% effective in eliminating fuel vapor air explosions within aircraft fuel tanks. Should aircraft with such a defect continue to be certified?

## **National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

### **Response:**

Aircraft fuel systems are designed to preclude single point failures and multiple failures, which would result in an ignition source. Multiple failures are typically necessary for scenarios that would result in an ignition source in a fuel tank. It should also be noted that changes have been introduced since 1996, and other changes will result from SFAR88, that will increase the number of failures necessary for an ignition source to enter a fuel tank.

Also as stated in reply to question 2 and 3, the finding that the inerting technology did not provide benefits that are reasonably justified by the costs, does not mean flammability reduction should be abandoned. It was recommended by the Working Group that other methods of flammability reduction be considered further. For airplanes that apply for type certification after June 6, 2001, the new requirements of CFR 14 Part 25.981(c) will apply.

### **Question 7**

A risk analysis relating to the different types of aircraft needs to be conducted so as to propose an intelligent implementation of an inerting program – begin with the high-risk aircraft, ignore the low risk aircraft.

### **Response:**

Agreed, however the analysis necessary to answer the above question would require significant additional resources, time and effort by the FTIHWG. The FAA should consider this as part of any potential rulemaking.

### **Question 8**

All methods that would decrease fuel tank flammability need to be examined and evaluated, especially those that may be quickly and cheaply implemented: like suppression, expanded metal mesh, and JP-5 fuel. Such was briefly introduced at the end of the Ex Com, 8 August 01, presentation.

### **Response:**

## **National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report**

Agreed. The tasking of this Working Group was limited to the study of inerting systems. Nevertheless, alternatives to inerting, which were evaluated as part of the 1998 ARAC study, should be studied further.

### **Question 9**

The NTSB supports fuel tank inerting. On 8 August, 01, Carol Carmody, acting chair, expressed her disappointment that the Working Group used CBA to recommend that fuel tank inerting not be implemented. On 23 August, 2000, the past chair, Jim Hall, noted that “it is imperative at long last, the aviation community move with dispatch to remove flammable fuel/air mixtures from the fuel tanks of transport category aircraft” as

recommended to the FAA by the CAB on 17 December, 1963 as a result of the Pan Am flight 214 disaster. Do the NTSB and CAB have privileged expertise or data that would allow them to arrive at a different conclusion from the Working Group?

#### **Response:**

NTSB specialists participated as observers; any information from the NTSB would be welcomed

The Cost-Benefit analysis is a step in the rulemaking evaluation process. The Working Group could not recommend new rulemaking because inerting systems designed with today’s technology would not meet the evaluation requirements. The working group recommended further research with the expectation that new technology would produce a practical system.

### **Question 10**

OSHA data for nitrogen asphyxiation in the workplace for 13 years (1984-1996) gives 61 accidental deaths resulting in an average of 4.69 deaths per year. It should be noted that the great majority of the situations did not involve the level of training and technology that is employed in the air transportation industry. This data should be adjusted on the estimated percentage of national nitrogen consumption to be used for fuel tank inerting.

#### **Response:**

The FTIHWG lacked the time and expertise to assess these risks with confidence. However, the FTIHWG felt it was important to bind the risk. To do this, a simple extrapolation of available Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) data was used. Based on 1980-1989 NIOSH data, the confined space accident rate is between 0.20 (for the

## **National Air Disaster Alliance/Foundation (NADA/F) Questions and Comments Through ARAC**

### **Ex-Com on the June 2001 FTIHWG Final Report**

transportation industry) and 0.68 (for the Oil and Gas industry) per 100 thousand employees. Of these, 43% were due to "Hazardous Atmosphere - O<sub>2</sub> deficiency." Assuming that these were all inert gas related (Argon, Nitrogen, CO<sub>2</sub>, etc) would result in a confined space asphyxiation rate of 0.086 to 0.292 per 100 thousand employees. According to OSHA, there were 1.2431 million US airline employees in 1999. This would suggest the US airline industry could expect 1.07 to 3.6 fatalities per year. However, in 1993 OSHA implemented more rigorous confined space permit rules and estimated those rules would reduce fatalities by 85% in the US. Assuming these rules are as effective as initially estimated reduces the US airline industry fatalities per year to 0.16 to 0.54. The US accounts for approximately 46% of worldwide airplane operations, and it was assumed that an OSHA equivalent confined space regulation did not exist in the rest of the world. That results in a non-US airline industry fatality rate of 1.26 to 4.23. The range then for the total worldwide airline industry fatality rate is 1.42 to 4.77

fatalities per year due to confined space asphyxiation from Nitrogen. Based on the assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that a total of 24 to 81 lives may be lost over the study period due to this risk. The FTIHWG did not have participation from OSHA or NIOSH. It is recommended that those agencies evaluate this risk based on current data before implementing inerting on a global scale.

# American Association of Airport Executives Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

## Question 1

Throughout this report it is recognized that there is a potential hazard to ground service and airport personnel associated with the use of nitrogen in Ground Based Inerting (GBI) and it is difficult to assess the actual risk; text pages 16, 20 and 45

{ 4.4}. Despite identifying the risk, there was no mention of any ARFF requirements that airports might need to consider. New ARFF requirements could mandate specialized equipment and additional manpower, a major cost to airports. In addition there may be building and fire code requirements that need to be addressed regarding the storage of nitrogen on airports or within a terminal facility (pg 74 {6.4}).

### **Response:**

Time and manpower did not allow for a study of all the collateral issues associated with the proposed GBI concept such as airport safety and airport fire department responsibilities. Since building and fire codes can vary between local jurisdictions, it would have been difficult to identify all the potential problems. There would have to be a thorough risk assessment carried out as it would pertain to confined spaces entry, ground NEA saturation, proximity of equipment to the terminals, etc. The Airport Facilities Task Team identified these potential hazards so they may be properly addressed in advance of any decision to implement the GBI concept.

## **Question 2**

There are concerns expressed about the environmental impact and health and safety implications regarding the release of "...volatile organic compounds into the atmosphere" (pg. 61 {5.4.5}) and using nitrogen-enriched air (NEA) in GBI. Exhibit E also indicates that further environmental study would be required to better address this impact on airports. Addressing this environmental impact could be costly to airports and could impact the overall cost-benefit analysis.

### **Response:**

Environmental Impact Considerations of GBI – The AFTT completely agrees with the statement noted. This was a major issue with the concept of nitrogen saturating the fuel. As related in the final report, there are existing environmental pressures being exerted on today's airports. As such, the impact of adding an incremental known pollution source will require further research and evaluation. Again lack of time, resources and lack of readily available environmental baseline data prohibited the team from performing a thorough evaluation of all the issues and costs related to this.

## American Association of Airport Executives Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### **Question 3**

During the presentation as well as in the report (pg 177{11.2}) the term “Airport cost...” was used when talking about ground support equipment and hydrant systems. A distinction must be made that indicates that these are actually **airline** costs at airports.

### **Response:**

The term “airport cost” was used to differentiate between the facility costs and the direct aircraft related costs of GBI. Because facility improvement and use agreements will vary from airport to airport, it was beyond the scope of the task team to identify who will be responsible for each of the costs.

### **Question 4**

There is language that seems to propose a regulatory change to 14CFR Part 139 that will require the airport operator to be responsible for the safety associated with ground based inerting (pg 187{12.3} and pg 190{12.5.2}). Why is this being proposed? Currently all fueling or such aircraft related operations are the responsibility of the airline.

### **Response:**

The FTIHWG tasking statement directed the Group to propose regulatory language where it believed it was appropriate to do so. Referring to Part 139.321 “Handling and Storing of Hazardous Substances and Materials, the AFTT believed that the requirements set forth in this paragraph were applicable to the storage distribution and handling of NEA. If GBI becomes a requirement, the availability or lack of the necessary facilities could possibly impact the certification of the airport.

### **Question 5**

The report indicates that there could be delays associated with ground-based inerting (pg 60{5.4.4}). Were the costs of delays and the subsequent congestion associated with GBI factored into the cost-benefit analysis?

### **Response:**

The maintenance costs for the delays were included, but the systemic costs (increased number of terminals, airplanes, personnel, etc) were not.



**AIR LINE PILOTS ASSOCIATION, INTERNATIONAL**

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FAX 703-689-4370

April 12, 2002

Mr. Anthony Fazio  
Director, Office of Rulemaking, ARM-1  
Federal Aviation Administration  
800 Independence Avenue, SW  
Washington, DC 20591

Dear Mr. Fazio: *Tony*

On behalf of the Air Line Pilots Association, I would like to comment on the recently submitted report of the Fuel Tank Inerting Harmonization Working Group.

We appreciated the opportunity to participate on this working group. We firmly believe that fuel tank inerting is a technically feasible technique that will help preclude fuel tank explosions in the future. We have concerns about the cost benefit analysis assumptions that were used by the working group. We feel using the predetermined DOT figure of \$2.7 million per human life lost is unreasonably low.

The Working Group report identifies many recommendations by the membership to continue fuel tank inerting research to improve the efficiency of the systems. At the ARAC Executive Committee meeting that received the working group report last month, it was indicated that work on developing a viable fuel tank inerting process is continuing. Future design/production aircraft could be modified on the drawing board to be compatible with the demands of an inerting system.

We certainly support this work and want to see it continue.

Sincerely yours,

William W. Edmunds, Jr.  
Senior Human Performance Specialist



## **MEDAL**

Karl S. Beers  
Air Liquide – MEDAL, L.P.  
305 Water St.  
Newport, DE 19804

12 April, 2002

Mr. Anthony Fazio  
US Department of Transportation  
Federal Aviation Administration  
800 Independence Ave. SW  
ARM -1 Room 810  
Washington, DC. 20591

RE: Letter to FAA Docket relating to an observation on the FTIHWG report.

Dear Mr. Fazio:

I am sending this letter to point out a concern I have with the Fuel Tank Inerting Harmonization Working Group Final report. Before I get into the details of my concern I would like to make it absolutely clear that this note is not a dissenting opinion of the report contents, but rather documentation of an note on the report's conclusions and recommendations from the prospective a member of the Fuel Tank Inerting Harmonization Working Group.

When I submitted my resume for consideration to be part of the Fuel Tank Inerting Harmonization Working Group, I was honored to be part of this activity and selected as part of the FTIHWG. The primary reason I wanted to become involved was to be part of a study that had the potential to make recommendations to the aviation industry that could dramatiially improve the safety of fuel tanks by inerting. I felt that with Air Liquide's background in nitrogen generating technologies and our experience in fuel tank inerting on military aircraft, we had a lot to offer the working group in completing its task.

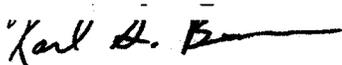
It is true that at the completion of the work and the submission of the working group report there was general consences of the working group members as defined by the ARAC operating procededures. While we may not have agreed with every detail of the report

conclusions and recommendations, all of our concerns were acknowledged by the other members of the working group and addressed as best they could. It was clear from the work completed and data gathered by the various sub-task teams that the cost of inerting the commercial aircraft fleet over the study period would exceed the benefit as calculated in our report.

Now that the FAA has the working group report and its recommendations it is clear that a decision has to be made on flammability requirements for the fuel tanks on the existing commercial fleet aircraft. I would like to point out to you an issue I noticed in the inerting cost model which is inconsistent with the report conclusions. The CY2005 NPV cost benefit ratio calculated by the model for scenario 7, OBIGGS Hybrid HCWT only for the US Passenger fleet, is 41 :1. The report recommendations indicate that the FAA, NASA, and the industry should pursue technological advancements to decrease the size, weight, performance, and reliability/maintainability of inerting systems while reducing their cost. If scenario 7 was re-run with the cost of the systems at zero and the cost to carry the weight and maintain the inerting system also at zero, the cost / benefit ratio only reduces to 18 :1. It is clear that through research improving the systems will make them better for the aviation industry if the FAA were to impart a rule where inerting were to be used for flammability management, however no amount of research will make the systems cost, weight, and maintenance requirements go to zero which does not entirely support the working group recommendations.

From my experience of being on the working group it is clear that the FAA has a difficult decision to make about the flammability of the existing aircraft fleet. I urge the FAA to strongly consider fuel tank inerting as a viable technology that will offer a significant improvement to the safety of the commercial aircraft fleet. Please include this letter into the docket along with the FTIHWG report and do not hesitate to contact me if you have any questions regarding this letter.

Regards,



Karl S. Beers

TO: FAA Office of Rulemaking

FROM: Paul Hudson, Aviation Consumer Action Project  
Member, FAA Aviation Rulemaking Advisory Committee, Executive  
Committee

DATE: April 12, 2002

RE: Comments on Fuel Tank Inerting Harmonization Working Group  
Final Report dated February 2002

The final report as did a prior report in 1998 unanimously found that (a) there is a substantial risk of explosion in airliner fuel tanks (center fuel tanks with adjacent heat sources representing about 90% of airliners were estimated to be in explosive condition 30% of the time in 1998 and 33% in 2001), (b) that fuel tank inerting provides clear safety benefits, and (c) that hundreds of lives would be saved otherwise who would be lost in air disasters caused by fuel tank explosions. Both reports admit that fuel tank inerting is technically feasible with variety of technologies. Such technologies have been used in military aviation for many years, but are not required or used in commercial aviation.

In addition to ACAP I am advised that EXCOM member NADA/F, several members of the Working Group and the manufacturers of various fuel tank inerting systems strongly disagree with the recommendation of the Working Group that fuel tank inerting should not required by the FAA but merely be the subject of further study and instead endorse the following ACAP recommendation:

ACAP recommends that the FAA promptly issue a regulation requiring that all commercial airliners certified to operate in the United States reduce the potential for fuel tank explosions to no more than 1% of their operating time as measured by FAA testing and recorded measurements of temperature and oxygen and fuel content of fuel tanks during operation. The Working Group failed to produce the regulatory language that was part of its tasking. This regulation should be phased in over the next three years so that industry may have time to adjust and select the most cost effective technologies to meet

the minimum 1% performance standard. The FAA should pre-approve systems that meet this standard but permit unapproved systems to also qualify by meeting stringent performance tests and monitoring. Most wing tanks currently operate in explosive condition 1% to 5% of their operating time. Such a standard is performance based, technology neutral and would cost far less to comply with than the alternatives. ACAP will submit a rulemaking petition in the next few weeks setting forth proposed regulatory language for consideration by the FAA.

There is strong disagreement on the cost benefit analyses, which range from 53: 1 to 1 : 3 depending on the assumptions used.

The finding of the working committee that the cost of mandating fuel tank inerting exceeds its benefits is deeply flawed. Flaws in the Working Group cost benefit analysis include (a) failure to account for increased risk of terrorist bombings of airliners, especially since the 9/11 attacks, (b) the unsubstantiated and unwarranted assumption that existing or proposed improvements (SFAR no. 88) will reduce the risk of fuel tank explosions by 75%, (c) the unrealistically low value placed on the benefit to society of one lost life in air travel based on a dated study of traffic fatalities, (d) the failure to properly account for lost revenue to the industry caused by public fear of flying after preventable air disasters and the cumulative loss of revenue to the travel and tourism industry caused by loss of public confidence in the safety of air travel and the low public tolerance for mass transportation disasters, (e) the risk of high punitive damage awards against aircraft manufacturers and airlines for willful failure to correct known safety design defects (e.g. adjacent heat sources to center fuel tanks producing explosive air fuel mixtures of over 140 degrees F.), (f) the lack of an economist with recognized credentials in cost benefit analysis to perform its study, (g) the high labor costs generated by assuming dedicated ground based inerting crews and a long time frame for fueling operations, and (h) the high failure rate assumed for aircraft based systems.

In accordance with the decision of the EXCOM and the minutes of the March 13, 2002 meeting dated March 18, 2002, it is respectfully requested that these comments be

included with the cover letter from the EXCOM chairman conveying the Working Group Report to the FAA as well as in the public record and available on line.

***NATIONAL AIR DISASTER ALLIANCE / FOUNDATION***

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**Dissenting Opinion:**

**FAA ARAC Fuel Tank Inerting Harmonization Working Group (FTIHWG)**

**Submitted by James H. Hurd, FTIHWG Member, TWA 800, and  
NATIONAL AIR DISASTER ALLIANCE/FOUNDATION Board Member.**

Submitted March 13, 2002 at the FAA Aviation Rulemaking Advisory Committee (ARAC) Executive Committee (ExComm) Meeting.

**Subject to revisions as a result of additional information from the Working Group.**

FTIHWG Participants, Technical Research and Writing by the following:

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**Introduction**

September 2000 an FAA Aviation Rulemaking Advisory Committee (ARAC) was formed in order to provide advice to the FAA about implementing fuel tank inerting (FTI) into center wing tanks (CWT). Their Final Report was issued in June 2001 and submitted to the FAA ARAC Executive Committee (ExComm) in August 2001. Clarifications were requested by the Committee and these will be submitted to the Committee in March 2002. **Both the report and the clarifications are found to be deficient as described in detail below.** It should be noted that this is a second effort to address the fuel tank explosibility issue.

In 1998 the FAA initiated an ARAC study regarding fuel tank inerting in the ullage (empty space with vapors) portion of center wing tanks (CWT). This study was a result of the TWA 800 crash and the National Transportation Safety Board (NTSB) recommendations. This study lasted approximately six months. The findings were that more studies and technology were required and that the cost benefit analysis was not within FAA guidelines.

An explosive mixture of fuel vapors and air will form in the ullage volume of aircraft fuel tanks. A subsequent presence of an active ignition source resulted in a damaging explosion such as the most recent known examples:

- a Boeing 737, Bangkok, Thailand, 2001;
- a Boeing 747, New York, New York, 1996; TWA 800, and
- a Boeing 737, Manila, Philippines, 1990.

Lowering the oxygen content in this ullage volume with nitrogen will prevent these explosions and increase flight safety. A mechanism, which absolutely eliminates the possibility of these fuel tank explosions, is to **reduce the oxygen concentration within the fuel tanks, by increasing the nitrogen content. Any ignition source is then ineffective.**

It should be noted that fuel tank inerting is supported by members of the National Transportation Safety Board (NTSB) and continues to be posted as one of their top ten "Most Wanted" safety improvements. On 8 August 2001, Carol Carmody, acting chair, expressed her disappointment that the FAA (FTIHWG) Working Group relied on cost benefit ratio (CBR) as a basis in recommending that fuel tank inerting not be implemented.

On 23 August 2000, the past NTSB chair, Jim Hall, noted that:

*"It is imperative at long last, that the aviation community move with dispatch to remove flammable fuel/air mixtures from the fuel tanks of transport category aircraft as recommended to the FAA by the CAB on 17 December 1963 as a result of the Pan Am flight 214 disaster."*

It is expected that the NTSB can provide to the FAA their information, which supports the inerting of fuel tanks.

The FAA has compiled a list of **27 incidents of fuel tank ignitions**, including fatal explosions from commercial and military flights. See Page 12 of this report for the compilation. It is possible that there are additional incidents or disasters that were not accurately investigated.

Captain Tim Murphy reminded ALPA at its Safety Meeting in August 2001,  
*"Not all plane crashes are investigated, worldwide."*

Significant criticism of the concept of cost benefit analysis or ratio is justified, and quantitative data may be chosen which significantly affects these calculations. **It is possible to argue that an immediate program should be initiated in order to inert aircraft fuel tanks, and thus effectively eliminate this explosion danger.**

**Cost/Benefit Analysis**

The 1998 FTIHWG report stated a cost of \$5B to \$20B over a 15-year period, and the 2001 FTIHWG report stated a cost of \$20B to \$35B over a 15-year period, with no satisfactory explanation for the inconsistencies of their cost benefit analysis. *NADA/F* believes that technical research could demonstrate that lower costs can be achieved with all the scenarios.

- Based upon information available and discussed at the FTIHWG, a normalized charge (cost to the passenger) could be as low as \$.25 per passenger per flight delivered.
- Cost of nitrogen, which is 100% effective in preventing an ignition, could be a charge of \$8.25 for the nitrogen, plus a service charge of \$100 per aircraft per flight.

The basic concept of cost/benefit ratio (CBR) or cost/benefit analysis (CBA) seems to be fatally flawed. The numerical value can be made very large by having a large numerator or small denominator or very small by having a small numerator or large denominator. Having the quantity of the order of unity does not seem to resolve much. More often than not the financial quantities in the Working Group’s report are at best estimates, or at worst sheer speculation. Also, some of the assumptions used to justify figures are flawed as explained below.

Within the June 2001 report there are numerous CBR calculations which give the results that the cost of nitrogen fuel tank inerting are greater than the benefits produced. For some of these calculations it is possible to make straightforward comments affecting their validity and/or changing the results to produce a more favorable situation for the implementation of nitrogen fuel tank inerting.

**Comments on ARAC FTIHWG 2001 Final Report Dated 6/01/02**

1. Pg. 1-7 ¶ 1.8 → Evaluation timeline assumes that it will take 36 months to certify a design and 84 additional months (7 years) to modify the fleet. Figure 1 is a rough cash flow diagram during the evaluation period. The non-recurring costs associated with inerting are realized between 2005 and 2015. Based on pg. 1-8 ¶ 1.8, there is only one expected accident that could be avoided in the 16-year evaluation period. This is due to the fact that no benefit could be realized before the system is implemented. It is suggested that the sensitivity analysis include an earlier implementation date, and/or a longer total time frame.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Event	Reg. Published			Design Cert							All go					
Cost	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Benefit																↑

Figure 1 – ROM Cash Flows of Cost and Benefit Over Study Period

2. A major assumption that the recently enacted SFAR 88 (Special Federal Aviation Regulation) would reduce accident rates by 75% is not supported by any evidence. Note that no source of ignition has been pinpointed for any of the three most recent explosions. To assume that 75% of these type of accidents can be avoided by inspecting just one of the possible sources is not credible. Further, it has been suggested that this type of manual inspection of wiring harnesses more likely would result in damage of brittle insulation and may increase the likelihood of accidents by creating ignition sources.
3. Page 1-8 2nd ¶ Indicates that only 1 airplane accident would be avoided in the 16-year study. Note that full inerting system capabilities would only be on line for 6 of those 16 years. (See Page 12 for an FAA list of the 27 incidents of fuel tank ignition, including 13 during the last twenty years.)
4. Page 1-8 4th ¶ Says 132 deaths avoided for GBI (Ground Based Inerting) and 253 for OBIGSS (Onboard Inert Gas generating System) over the 16-year evaluation period, which is 6 years of system functionality. The benefit over 16 years of operation would be 352 for GBI and 675 for OBIGGS.
5. Accident rates are based on only 3 data points, and therefore do not create a statistically significant pattern. Therefore these rates must represent a fairly low confidence interval. It is suggested that the sensitivity analysis include a range of accident rates that represent higher levels of confidence intervals.
6. Page 1-9 Figure 1-5. Again the benefit interval is only 6 years projected over a 16-year time frame the ratios vary from 14:1 to 20:1.
7. Page 2-2 ¶ 2.b → “Various means of supplying nitrogen (i.e., liquid. . .)” The report does not cover liquid nitrogen supplies. (Note that “i.e.” stands for “that is”, which indicates that they were to specifically look at liquid nitrogen).
8. Page 4-8 ¶ 4.5 → “it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss. . .” These assumptions are not factually or statistically based. The sensitivity analysis should allow for large variation in these estimates. Refer to number 4 above. Over a 16-year period the lives saved are 352 for GBI and 675 for OBIGGS. If we allow that in 100% of explosions there is a total loss, then the numbers become 407 and 780.

	Benefit (\$US billion)	Adjustment for 16 years of benefit	Adjustment for total loss	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	0.245	0.653	0.755	10.37	13.7:1
OBGI (HCWT only)	0.219	0.584	0.675	11.6	17.2:1
Hybrid OBIGGS (HCWT only)	0.257	0.685	0.792	9.9	12.5:1
OBIGGS (all tanks)	0.441	1.176	1.359	20.78	15.3:1

9. If we include the factors from item 8 in the sensitivity analysis, the most favorable scenarios become:

	Scenario from 8/8 Summary Pg#	Benefit (\$US billion)	Adjustment for 16 years of benefit	Adjustment for total loss	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	37	0.281	0.749	0.866	4.196	4.8:1
Hybrid OBIGGS (HCWT only)	43	0.3	0.800	0.925	3.68	4.0:1

10. Page 6-14 → Inclusion of Capital costs may be redundant. It is likely that the operator of the system will absorb those costs, and recoup them via operating costs.

11. Page 11-1 Is the “willingness to pay” value of human life escalated in the out years? If not, then there is another skew in the data. The “willingness to pay” benefit is discounted back to 2005 at 7%. If no escalation was assumed, then the benefits are understated by that 7% discount. Since most of the benefits are in the out years, there is a significant impact. If the adjustments for escalation of benefit are included that changes the most favorable scenario.

12. A major domestic airline disclosed that the actual costs used by the airlines to account for loss of life vary between \$2.7M and \$4.0M based upon the demographics of the airlines route structure.

13. Page G-2, last sentence before Section 2.0 → States “See section 4 for more information about benefits.” No section 4 is included in this report. Please provide missing or removed information.

**Numerous examples may be cited of improvements being made within society to increase safety without performing a CBR analysis.**

(a) In the Our Lady of Angels, Chicago IL, 1958 school fire resulting in 97 dead, an immediate sprinkler and call box installation was initiated and completed within two years for *all* Chicago schools.

(b) More recently, for the past several years Ford Explorer automotive rollovers, presumably initiated by defective tires, have resulted in over 200 deaths. An expenditure of approximately \$4B has been made by only two corporations as a result of the initial recalls to correct this problem and a second recall valued at \$41.5M has also most recently occurred.

(c) The Ford Motor Company also has an additional problem and is spending nearly \$3B to replace millions of flawed ignition modules. These faulty systems resulted in 11 deaths and 31 injuries.

(d) Additionally, at present there is a massive recall of faulty fire sprinkler heads produced by one manufacturer, Central Sprinkler: the Omega model for residential use, and the GB model for commercial use. It has not been noted that a CBR has been done in order to justify the recall.

In an inverse situation a CBR was calculated by General Motors regarding the safety of fuel systems in automobile crashes. In a recent California jury trial verdict enormous damages, nearly \$4B, were awarded to the injured as General Motors had reportedly decided that the \$8 cost per vehicle required for fuel system redesign and manufacture was not cost effective compared to damages which would be awarded in any subsequent trials.

Finally, the U.S. Supreme Court has in the last term spoke on the issue of CBR. They judged unanimously in an U.S. EPA (Environmental Protection Agency) related case that only public health (substitute the closely related word safety) could be considered and not cost regarding new clean air standards.

### **Benefit Analysis**

As currently structured the benefits chiefly accrue from the figure of \$2.7M which is described by the DOT (Department of Transportation) as the amount "*which U.S. society is willing to spend on increased safety in order to prevent a death.*" It should be stressed that the *NATIONAL AIR DISASTER ALLIANCE/FOUNDATION* does not agree with the DOT economists who have defined \$2.7M as the cost of a life lost in an air crash, or the maximum amount of "*willingness to pay*" for aviation safety and security. History has shown that the American people have *NOT* found this an acceptable amount.

The current very adverse response by the thousands of families suffering from the loss of family members due to the events of September 11th, 2001, and to the provisions of the "Air Transportation Safety and Systems Stabilization Act," also indicate that this is a very inadequate amount.

Page 4, #8, of this document, references Page 4-8 ¶ 4.5 of the FTIHWG 2001 Final Report: "*it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in-flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss. . .*"

This statement indicates that 90% of the passengers in a ground explosion would be survivors, and potential burn victims. The September 11<sup>th</sup> burn victims, helped by medical technology of 2002, will have medical bills greatly in excess of \$2.7M per person, plus personal care, compensation for their pain and suffering, and have special needs that we cannot imagine. Indeed, juries and judicial rulings and settlements for air crash survivors, especially burn victims, have been ten times greater than \$2.7M and more. No one would trade places with them for any amount of money, and society wants these victims compensated so that they receive the full support that they need. Industry should be willing to finance higher costs to prevent on board fires and explosions. When the money and technology are there, and have been there for 30 years, the industry should do everything possible to prevent fire and explosions on airplanes.

During a meeting between FAA rulemaking authorities and *NATIONAL AIR DISASTER ALLIANCE/FOUNDATION* members on 28 September 2001, it was indicated by the FAA that this benefit restriction was too limited and that the concept of benefits should be expanded. Such additional benefits should consider the costs of family breakups, which invariably results when a family member is lost. The U.S. government indicates that it has great respect and support for the concept of a small business. A political and legal environment is developed for such to thrive. The family is an ideal example of a small business, and post-air crash conditions should be favorable for the survival of this business.

As the events of September 11th have shown, and as will be applicable to other crashes, air disasters can have other enormous secondary economic effects which need to enter into the benefits calculations. There is the loss of passenger revenue due to fleet grounding and the reluctance of individuals to travel by air. The airlines first response is to lower fares (and profits) when passenger traffic decreases and people do not want to fly. There is decreased use of hotels, restaurants, rental cars, theaters, and all other items related to travel. There may be extensive property loss as a result of an air crash as well as an extensive loss of jobs.

Some quantitative data may be connected to the four airplane crashes on September 11th, which show that the benefits of increased safety have been significantly underestimated in the past.

- \$2T Stock market losses may be estimated (from Milken Review)
- \$15B in air transport losses, or more, **and still growing**
- \$90B for property losses and interrupted business at the Pentagon and New York City (NYC) (per Swiss Reinsurance Co.) OR
- \$105B NYC losses estimated through June 2003 for lost revenue, damage and rebuilding (source NYC Comptroller, and Congressional aids)
- \$30B for the first five months of the War on Terror abroad (recent news)
- \$140B Projected Federal Stimulus Package to prop up the U.S. economy (not including global losses) ("Newsweek," 10/1/01).
- 32 Boeing airplanes for which struggling airlines might not be able to take delivery ("Wall St Journal" 10/9/01)
- \$0 Financial compensation for some airline executives. Pay cuts and job insecurity industry-wide.
- 1.8M jobs lost in the U.S. by the end of 2002, all as a result of the September 11th aviation disasters.
- No cost estimates for an aviation disaster at a nuclear power facility (Milken Review)

At present, the job loss in the aviation industry alone worldwide stands at 400,000, including an estimated 30,000 job loss for Boeing alone. The cost of the TWA 800 crash is currently estimated to be approximately \$1B. The cost of Swissair 111 is estimated at possibly \$2B, and the airline is no longer in business. The Libyan government has reportedly offered a \$6B settlement with regard to PanAm 103, plus the costs of damages since 1988, and the airline failed to stay in business. A potential casualty of unknown magnitude is the collapse of the insurance and reinsurance market as a result of the aviation disaster losses.

The airline industry is at crisis worldwide, and much needs to be done to re-build faith in the industry. *NADA/F* urges government and the industry to evaluate safety and security recommendations first on their merits to re-build confidence in the aviation industry. The

American people are not accepting known fatal flaws and safety and security contracted to the lowest cost bidder.

At the 28 September 01 meeting at the FAA with *NADA/F*, the economist stated that he had not imagined multiple accidents in a single day. We cannot afford for the industry to ignore that possibility ever again.

As a result of the next such aviation disaster punitive damages of unknown amounts may be awarded to families suffering the loss of members. On 17 August 01, \$400+M in damages were awarded against Cessna Aircraft Co. regarding an alleged known defect concerning the failure of seat positioning locks.

The information above would indicate that the dollar amount attributed to benefits could and should be increased significantly, thus substantially decreasing the figure for the CBR.

**The June 2001 ARAC Final Report does put the air transport industry on notice that there is a known single point failure mechanism which will produce a catastrophic fuel tank explosion. The report also indicates that the nitrogen inerting of fuel tank ullage is 100% effective in eliminating fuel vapor/air explosions within aircraft fuel tanks. A known hazardous condition may be eliminated.**

In other scenarios, where nitrogen-generating systems are considered, the small amount of information which is available in the unclassified world would seem to indicate that current military technology, if available for use, could also lower the cost estimates. The military has been using fuel tank inerting for over 30 years, and their classified information could be helpful.

### **Ignition Source Control**

#### **Benefits Attributed to SFAR 88 (Special Federal Aviation Regulation)**

*The FTIHWG determined that the benefit of ullage inerting should be reduced to reflect the benefits offered by new procedures defined by SFAR 88. The SFAR was released as the Working Group was assessing the benefits of inerting, and these benefits were discounted considerably (75%) based on the assumption that the process defined in the SFAR would yield significant benefits.*

"The 75% reduction had been estimated by the 1998 FTIHWG." [*FTIHWG Final Report Pg. H-9*]

The benefits offered by SFAR 88 are difficult to quantify, because many of the ignition sources for fuel tank explosions have not been identified as noted by the FAA [**Federal Register May 7, 2001 pg. 23127**]

"As noted, the FAA has not quantified the potential benefits from this final rule because there is uncertainty about the actual ignition sources in the two fuel tanks..."

Further the regulatory text in SFAR 88 calls for reducing the exposure to flammable mixtures. From §25.981(c):

"The fuel tank installation must include either--

1. Means to minimize the development of flammable vapors in the fuel tanks (in the context of this rule, "minimize" means to incorporate practicable design methods to reduce the likelihood of flammable vapors); or
2. Means to mitigate the effects of an ignition of fuel vapors within fuel tanks such that no damage caused by an ignition will prevent continued safe flight and landing."

The FTIHWG assumed a 75% reduction in fuel tank explosions resulting from the implementation of SFAR 88, however, has this included the reduction of flammability exposure specified in the regulatory text for SFAR 88?

A **fuel/air explosion** (FAE) occurs when five items come together:

- fuel,
- oxidizer (oxygen),
- ignition source,
- confinement, and
- vapor phase fuel/oxidizer mixing.

The first three are commonly known as the fire triangle while all are known as the explosion pentagon. For the latter situation the removal of any one item precludes an explosion, but the attempted control of only one component, such as ignition sources, is a risky strategy. It may decrease the number of incidents, but it will not eliminate them. Experiences in other industries such as the process, coal mining, and grain and feed have shown that it is necessary also to control the fuel in order to eliminate fuel/air explosions.

**It is exceedingly difficult to have two failures at the same time** — ignition sources and combustible fuel/air mixture. Such a strategy was adopted by another segment of the transportation industry, maritime petroleum shipping, where the scrubbing of tankage led to an electrostatic ignition source for the fuel vapor/air mixtures. An analysis of the problem led to the use of stack gases as an oxidizer diluent within the empty tanks.

**Nonconventional ignition sources** have become of increased concern.

- Silver components within the fuel tank through chemical reactions occurring in the presence of low sulfur fuel can produce conducting paths leading to short circuits.
- On 26 November 1989 an Avianca B-727-100 crashed shortly after takeoff from Bogota, Columbia as a result of the detonation of an explosive device placed in a seat on the starboard side of the passenger cabin, which in turn ignited fuel vapors in an empty fuel tank.

- On 22 December 2001, an American Airlines 767-300, Flight 63, traveling from Paris, France to Miami FL, was diverted to Boston MA. A passenger sitting in a port side window seat slightly aft of the wing trailing edge had attempted to detonate an explosive device which had been hidden in his shoes. Had the initiation attempt been successful and had he been located above the center wing tank he may have ignited, with fatal results, the fuel vapors in the center wing tank.
- January 1995 responding to a routine fire alarm in a Manila apartment building, firemen and investigators uncovered a bomb-making factory with electronic timers and terrorist plans regarding near-future transpacific flights. The timers matched those used to explode a bomb on a Philippines airline flight of a few weeks earlier, which killed one passenger and forced an emergency landing. The eleven long haul flights, all with intermediate stops on a single day, designated as imminent targets involved mainly those of United and American Airlines, the same airlines targeted for September 11th. The explosive technique of operation Bojinka of placing a small bomb within the cabin certainly could have been enhanced by locating it over the center wing tank and detonating it later into the flight when its liquid fuel had mostly been consumed.

As with the case of the Avianca and American Airlines flights, SFAR88 would not have decreased the likelihood of these intentional ignition sources.

In the process, coal mining, and grain and feed industries unanticipated/unexpected ignition sources led to the failure to eliminate explosions by the control of ignition sources exclusively. It will be the same situation regarding SFAR88. It is thus impossible to definitively quantize its effect and not to implement a second backup strategy such as nitrogen fuel tank inerting.

### **Related Safety Issues**

It is not realistic to try to inert the fuel tanks in all aircraft at all locations within the global aviation network at the same time. A risk and consequence analysis needs to be performed relating to the different types of aircraft so as to propose an intelligent implementation of an inerting program.

Logic would dictate that one would begin with the high risk, heated center wing tank (HWCT) aircraft currently in production or to be put into production. Those to be neglected would be ones of smaller capacity near the end of their airframe life. Geographically, the initiation would occur at airports with the largest passenger traffic and last implementation would be those with little passenger traffic.

Any cost associated with the implementation of fuel tank nitrogen inerting must be normalized in a rational fashion. This is not an enormous one-time expense which will be paid for by the air transport industry. Just like any other expense it will be passed on to the passengers.

1. Based upon information available to and discussed by the Working Group, such a normalized charge could be as low as \$0.25 per passenger per flight delivered.
2. There could be a charge of \$8.25 for the nitrogen plus a service charge of approximately \$100 per aircraft per flight.

- Even now, when fuel prices are at an all time low, the airlines are authorized to charge a fuel surcharge for each ticket of \$18.60 one way, and \$37.20 round trip. The surcharge was added when the price of Jet A fuel was at a maximum, and may still be charged to the customer.
- Passenger Facility Charges (PFC's) can be a maximum of \$4 (plus tax) per airport, with a maximum of \$20 (plus tax) per ticket, and the PFC's continue to increase.
- The domestic transportation tax is 7.5% per ticket, and billions have accumulated in the federal Aviation Trust Fund.
- The new security tax is \$2.50 one way and \$5 round trip, or with multiple segments can be \$10 round trip per ticket.
- The International Transportation Tax used to be \$3 per round trip ticket, and now round trip international taxes can be \$200+ per ticket. International ticket taxes continue to increase in the number of taxes, and the amount of the tax, or service charge, or user fee.

**Such an expense of \$.25 per passenger per flight, or \$100+ for nitrogen, per airplane, per flight is literally peanuts in comparison to the cost of the ticket, taxes, and service charges. Since September 11<sup>th</sup> passengers have not complained about the security tax, and have expressed that they are willing to pay for higher levels of safety and security.**

### **Conclusions**

The combustible fuel vapor and air mixture which appears in the ullage of HCWT's (heated center wing tanks) during a certain period of flight time, 33%, represents a safety risk. Nitrogen inerting eliminates this risk for a very minimal cost. The modification of the air transport system to implement this procedure may be done in a very intelligent, controlled manner. As the events of September 11th have shown, air crashes have many unforeseen consequences, and the air travel system has shown itself to have limited elasticity. The next HCWT explosion may well have extensive foreseen and unforeseen consequences. **A measured, determined introduction of the nitrogen fuel tank inerting technology is imperative beginning immediately in order to enhance aviation safety.**

The following is the FAA compiled list of incidents of fuel tank ignitions from the Federal Register: April 3, 1997 (volume 62, Number 64) Page 16013-16041

[www.epa.gov/fedrgstr/EPA-GENERAL/1997/April/Day-03/g8495.htm](http://www.epa.gov/fedrgstr/EPA-GENERAL/1997/April/Day-03/g8495.htm)

**Commercial Fuel Tank Explosions:**

	Model	Operator/Location	Year	Fatal	Hull loss
1	B707	OSO	1959	4	Yes
2	B707	Elkton	1963	81	Yes
3	B707	San Francisco	1965	0	Yes
4	B727	Southern Air Transport, Taiwan	1964	1	No
5	B727	Minneapolis	1968	0	No
6	B727	Minneapolis	1971	0	No
7	DC-8	Toronto Canada	July 1970	106	Yes
8	DC-8	Travis AFB	1974	1	Yes
9	DC-9	Air Canada	1982	0	Yes
10	Beechjet 400	Jackson MS	June 1989	0	No
11	B727	Avianca	1989	107	Yes
12	B737	Philippine Airlines	1990	8	Yes
13	B747	TWA 800	July 1996	230	Yes
14	B737	Thai Airlines	2001	1	Yes

**Military Non-Combat Fuel Tank Explosions:**

1	B52	Loring AFB Maine	July 1970	0	Yes
2	B707	USAF Spain	June 1971	Yes	Yes
3	B52H	Minor ND AFB	Nov. 1975	0	Yes
4	B747	Iranian Fuel Tanker	1976	7	Yes
5	KC135Q	Plattsburg AFB NY	Feb. 1980	Not Noted	Yes
6	B52G	Robins AFB Georgia	Aug. 1980	Yes	Yes
7	KC135A	Near Chicago	March 1982	Yes	Yes
8	B52G	Grand Forks AFB ND	Jan. 1983	Not Noted	Yes
9	KC135A	Altus AFB OK	Feb. 1987	Yes	Yes
10	B52H	Swayer AFB MI	Dec. 1988	Yes	Yes
11	KC135A	Loring AFB Maine	Sept. 1989	Yes	Yes
12	KC135A	Loring AFB Maine	Oct. 1989	Yes	Yes
13	KC135R	Mitchell Field, Milwaukee WI	Dec. 1993	Yes	Yes

**Total 27**

Updated: March 11, 2002

## Glossary

### Basic Inerting design systems:

**GBI**            **Ground Based Inerting** – A system using ground-based nitrogen gas supply equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to unheated wing tanks. The affected fuel tanks would be inerted once the airplane reaches the gate and is on the ground between flights.

**OBGI**            **Onboard Ground-Inerting** – An onboard system that uses nitrogen gas generating equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to an unheated wing tank. The affected fuel tanks will be inerted while the airplane is on the ground between flights.

**OBIGGS**        **Onboard Inert Gas Generating System** – A system that uses onboard nitrogen gas generating equipment to inert all the fuel system's tanks so that they remain inert throughout normal ground and typical flight operations.

**Derivative combinations of OBGI and OBIGGS** were also studied, and were described as “hybrid systems.”

ARAC	Aviation Rulemaking Advisory Committees
CBA	Cost Benefit Analysis
CBR	Cost Benefit Ratios
FTIHWG	Fuel Tank Inerting Harmonization Working Group
SFAR	Special Federal Aviation Regulation

**The following Comments for Liquid Nitrogen On-Board Storage and Cost Benefit Analysis are being submitted on behalf of those who contributed Technical Research and Writing to the dissent.**

Comments on ARAC Final Report  
**CBA for Liquid Nitrogen On-board Storage**

In the June 2001 ARAC FTIHWG Final Report sixteen different scenarios are considered in order to assess the cost. In scenario sixteen what could be one of the most promising concepts, an onboard cryogenic (liquid) nitrogen system, is considered as a result of a request made by the ARAC Executive Committee at its April 2001 meeting to the Working Group. The CBR as calculated by the Working Group is not favorable. However, alternative calculations presented below are much more favorable.

The term "*practicable design methods*" may have been interpreted by the FTIHWG to exclude the inerting concepts (Scenario 1 to 16) reviewed and deemed not be cost effective. However, the analysis of Scenario 16 appears to be incomplete and inaccurate. Their CBA was based on a number of assumptions, which are detailed in the Estimating and Forecasting team's final report in Section 3. The following assumptions are under question:

- (1) "*Gas generating systems are less expensive and less hazardous*"
- (2) "*The computed LN<sub>2</sub> weight is based on carrying enough LN<sub>2</sub> for three flights*"
- (3) "*The system described above has been sized to inert all fuel tanks on the airplane*"
- (4) "*Weight in Figure G-64 based on FAA study "Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System" (1972)*"
- (5) "*A mechanic; not a ground service worker is required to fill the airplane storage tanks.*"
- (6) "*All nitrogen needed would be generated at the airport*"
- (7) "*All retrofit costs based on the costs of the GBI airplane system.*"
- (8) "*Although the closed-loop oxygen sensing system is more complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar*"

Many of the assumptions made either do not apply or should be restated to reflect the realities of the system proposed at the ExComm meeting of April 2001.

A concept has been developed using liquid nitrogen to generate gaseous nitrogen with purity in excess of 99.9% to maintain a non-flammable ullage in airplane fuel tanks. The primary advantage of liquid nitrogen storage is the ability to convert a large volume of nitrogen gas from a substantially smaller volume of liquid. The ratio of gas volume to liquid volume for nitrogen is 696:1. The system concept employs a liquid nitrogen (LN<sub>2</sub>) storage vessel or dewar, which is designed for use on aircraft. The LN<sub>2</sub> is vaporized to nitrogen gas and delivered through a simple manifold to the ullage of the aircraft fuel tank. The pressure in the dewar is controlled at a low pressure by a pressure-reducing valve. In the event of over-pressure or failure of the primary relief valve, a safety device (rupture disk) opens to vent nitrogen gas outside the aircraft beyond. The flow of nitrogen gas is controlled by the ullage flammability, which determined by the combination of oxygen concentration and ullage temperature. This method of control limits

nitrogen usage to only the portions of the flight profile that require inerting to mitigate flammability. Measurement of oxygen concentration is the only means available to determine with certainty that the ullage is inert. While adding to the complexity of the overall system, an oxygen sensor ensures effectiveness of any inerting system, while conserving nitrogen. The internal pressure of the dewar (less than 5 psi) is adequate to deliver the nitrogen through the control valves, to the ullage manifold. The design uses very little power, due to the use of dewar pressure for delivery of the nitrogen gas. The only power required for this design is for the solenoid valve and instrumentation, approximately 1 kW.

### **Assumptions (from FTIHWG Final Report)**

#### **(1) "Gas generating systems are less expensive and less hazardous than liquid nitrogen based systems"**

The nitrogen gas generating systems evaluated by the FTIHWG all required a complex array of compressors, heat exchangers, filters, valves, water separators and air separation modules or distillation columns. The cost of equipment for each system is in excess of \$180K. In addition, connections to a bleed air source as well as substantial power requirements lead to very high installation costs. The liquid nitrogen based system offers a significant reduction in the number and complexity of components. The cost of equipment as proposed is to be included in a service fee charged by the inerting service provider. For a moment, make a comparison between cryogenic nitrogen and aviation fuel. We do not load crude petroleum on the aircraft for onboard refining into jet fuel. The refinery would weigh too much and consume too much power!

Installation costs are expected to be paid by the same parties as for the other 15 Scenarios, however, these costs must be substantially lower as the only connections required are for the ullage manifold, the vent and the electrical system (instrumentation only). While it is understood that costs in categories (e.g. engineering, setup) are similar, the cost for hardware and installation for the liquid nitrogen based system will be considerably lower than the others considered. The assumption made by the Estimating and Forecasting team is inaccurate. The same process of estimating costs (e.g., figure F-A2, etc.) must be made for the liquid nitrogen based on-board design as for the others.

The asphyxiation hazard attributed to nitrogen inerting is taken very seriously by the industrial gases industry, and any system offered would unquestionably be assessed for the risks. Beyond well-structured safety procedures and training, safety interlocks can be included in the design without adding significantly to the complexity of the system. Interlocks provide protection even when operators and maintenance personnel ignore safety procedures. Normal airline maintenance procedures for accessing enclosed spaces (i.e. fuel tanks) require the area to be purged to remove hydrocarbon vapors. This process is likely enough to mitigate the risk of asphyxiation; however, the oxygen concentration can be checked easily before entry. The oxygen sensors included with the inerting system can control a latch to prohibit access when the oxygen level is too low. In addition, inexpensive (approx. \$300) hand held oxygen sensors can be used to increase the level of safety. This design and these procedures are very common in industry today.

**(2) "The computed LN2 weight is based on carrying enough LN2 for three flights"**

The design of the liquid nitrogen system can provide for adequate storage for three flights, however, this may be necessary only for medium sized aircraft, which often have quick turn times and several trips per day. In contrast, large aircraft have longer turn times, and often only fly one trip per day. Some sizes specified by the FTIHWG are considerably larger than necessary. For example, the weight of LN2 specified in their analysis (1,282 lbs.) generates enough nitrogen gas to inert the equivalent of over 131,000 gallons of ullage space. In light of turn times associated with large aircraft, and length of flights, is it necessary to carry so much nitrogen? The FTIHWG should consider whether it is necessary to require capacity for three flights across all airframe sizes.

**(3) "The system described above has been sized to inert all fuel tanks on the airplane"**

The Tasking Statement [Federal Register: July 14, 2000 (Volume 65, Number 136)] states that *"The system shall inert all fuel tanks with an on-board nitrogen gas generating system..."*. This is inconsistent with the requirements for Ground Based Inerting, which states that *"The system shall inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank..."*. Please clarify the differentiation in requirements for the two modes of inerting.

(4) "Weight in Figure G-64 based on FAA study "Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System" (1972)"

The FTIHWG's report referenced data from a report that is 30 years old. Advances in storage of liquid nitrogen may have had a favorable impact on the weights and costs associated with liquid nitrogen storage. Based on equipment available today, the weights were updated and are reflected in Figure G-64 (re-stated) below. Limiting the amount of liquid nitrogen stored on-board may also offer the benefit of reducing the size and weight, and to a lesser extent, the fuel penalty. A 100-gallon Dewar carries enough liquid nitrogen to inert over 69,000 gallons of ullage space. The vessel weighs only 475 lbs. Additional components include pressure-reducing valves, pressure relief valve, solenoid valve, oxygen analyzer, thermocouples and piping are anticipated to weigh no more than 100 additional lbs. The weight of the distribution manifold specified in the Ground Based Inerting Team's report (Pg. C-26, Figure 13.0-1) is 54 lbs. **The FTIHWG should redress their estimates of weights associated with liquid nitrogen based on-board inerting designs evaluated as Scenario 16 (Pg. G-66).** The following table represents revised estimates of weights shown on Figure G-64:

	Large Airplane			Medium Airplane			Small Airplane		
	Cu-Ft N <sub>2</sub>	Weight	Gal	Cu-Ft N <sub>2</sub>	Weight	Gal	Cu-Ft N <sub>2</sub>	Weight	Gal
LN <sub>2</sub>	9,311	675	100	4,655	338	50	2,328	169	25
Storage, controls, wt		575			375			300	
Plumbing		54			34			22	
<b>Total</b>		<b>1,304</b>			<b>747</b>			<b>491</b>	

Figure G-64 (re-stated) Liquid Nitrogen System Weight (all fuel tanks)

**(5) "A mechanic; not a ground service worker is required to fill the airplane storage tanks."**

A nitrogen service contractor can conduct the process of filling the airplane storage tanks. Two methods of executing this process are foreseen:

(a) Fill on-board LN<sub>2</sub> storage tanks located through a unique external connection located on the airframe (similar to the process fueling the aircraft)

(b) Replace empty vessels with full vessels, which have been filled and tested off-line by nitrogen supply contractor.

It is proposed that the service provided by the nitrogen supply contractor include:

- Supply and maintain liquid nitrogen storage vessels along with ancillary components; including valves, instrumentation, and pressure regulators.
- Fill vessels with liquid nitrogen as required.
- Design, test, and certify liquid nitrogen inerting package excluding fuel tank distribution manifold.

This can be offered on a fee basis, requiring no investment in equipment. The fee includes all items defined above with little or no initial capital investment. Anticipated cost for the service is less than \$200 per turnaround, which occurs once every two to three flights.

In **Item A** above, the design of the on-board inerting system utilizing liquid nitrogen requires a connection from the LN<sub>2</sub> storage vessel to a unique, frangible fitting located outside the airframe, in a location accessible to the ground based nitrogen service contractor. A design similar to the proposed by the Ground Based Inerting Design team could be adapted easily for cryogenic service. The nitrogen contractor would utilize operators trained in the delivery of liquid nitrogen and airport operations to transfer liquid nitrogen from their storage vehicle to the on-board vessel. A similar process is safely conducted hundreds of times a day for a wide range of industries, albeit not in an airport environment.

The vessel will be filled at a local liquid nitrogen manufacturing facility located near the airport facility.

In **Item B**, it is foreseen that the storage vessel will be an integrated, removable system including all valves and instrumentation, excluding the oxygen analyzer. The nitrogen contractor will be

responsible for maintaining and testing the equipment as well filling them in their facility located near the airport. Vessels requiring replacement will be removed from the airplane and replaced with a filled unit that has been tested. The process of changing liquid nitrogen vessels will be conducted by personnel trained in safe handling of cryogenic equipment; specifically for the airline industry.

Changing cylinders has an added advantage of ensuring that the inerting system is operational prior to a flight. The procedure will include a full check of the storage system at the nitrogen contractor's facility; therefore not affecting turn times. The failure rate of this design will be extremely low. In the rare event of failures, replacements will always be on hand, as the equipment becomes standard ground equipment. The design of the inerting system is such that the change can be made quickly, safely and dependably. Special mounting and connection hardware will be used to ensure this.

**The FTIHWG should re-calculate the costs of inerting when inerting service is provided at a cost of \$200 per use every two flights, three flights.**

**(6) "All nitrogen needed would be generated at the airport"**

There are a number of manufacturers of liquid nitrogen serving industries throughout the world. A network of Air Separation Units (ASU) separate air into its three main components: nitrogen, oxygen, and argon using a distillation process. At ASU's a subsequent process called *liquefaction* converts the gases to liquid for more efficient storage. As a liquid, nitrogen and the other industrial gases can be transported to customers within a 200-mile radius cost effectively. When the delivery truck arrives, the liquid nitrogen is transferred to the customer's storage tank. It is extremely rare for customers to need to generate liquid nitrogen on their facility. Only when the quantities are extremely large, does it make sense to generate liquid on site. Typical ASU's serve hundreds of customers over a wide geography. Even the largest airports will not use enough liquid nitrogen to economically justify a dedicated ASU. Existing liquid nitrogen manufacturing capacity is anticipated to be adequate to serve airport needs in the U.S.

There is a wide-ranging network of industrial gas distributors who store liquid nitrogen, oxygen argon and others to serve industries like welding. Liquid nitrogen is available virtually anywhere in the United States; either through manufacturers or distributors. **Appendix C** illustrates the network of liquid nitrogen, oxygen and argon throughout the United States. The distributor network is not shown.

The proposed solution does not require liquid nitrogen to necessarily be present at every airport facility. Since the design provides inerting for multiple flights, servicing can be scheduled by airlines at a select number of airports (e.g. Hub airports) to minimize the overall cost of implementation. In addition, the process can be scheduled during slow periods, for example overnight to further reduce the impact of inerting. **The FTIHWG should consider the use of on hand nitrogen production facilities for the supply of liquid nitrogen and determine the cost under that circumstance.**

**(7) "All retrofit costs based on the costs of the GBI airplane system"**

It is not necessary to replicate the GBI design for the liquid nitrogen based design. If **Item 5A** were used, the GBI design could easily be adapted to facilitate liquid nitrogen delivery to the on-board storage vessel. However, **Item 5B** requires no external connection to facilitate delivery of liquid nitrogen. In this case, the cost of adding an external connection along with associated fittings, valves and monitors will not be required.

The design of the manifold should be redressed in light of the results of the FAA tests on a scale model (DOT/FAA/AR-01/6). Results from testing at the Technical Center indicate that the manifold design may be greatly simplified, reducing engineering expense and weight, with equivalent results to the GBI Design team's proposed design.

**(8) "Although the closed-loop oxygen sensing system is more complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar"**

Oxygen sensors provide the only reliable means of confirming whether ullage is inert. The designs offered by the on-board and ground based design teams do not offer oxygen sensors. The consequences of this decision include over-compensating for lack of information by purging with substantially more nitrogen than required. Beyond unnecessary nitrogen cost and time spent with the inerting process, this solution increases emissions of hydrocarbons by a factor of at least three; though often more than that when full CW tanks are involved.

Inclusion of an oxygen analyzer in the design considerably reduces the volume and time needed to maintain an inert ullage. The system will use oxygen and temperature information to determine flammability, and deliver nitrogen gas only when the conditions warrant nitrogen to limit flammability.

A design using liquid nitrogen storage would be far less complex than any OBIGGS system proposed, simply due to the fact that integration into an aircraft's power systems and bleed air are not required with the liquid nitrogen design. With the removable vessel option (Item 5A), maintenance procedures will be conducted off the aircraft, and procedures associated with inerting can be conducted every two to three flights in a process slightly more complex than baggage handling.

The FTIHWG should assess the benefit offered by oxygen analyzers with the on-board inerting system in contrast to the cost of complexity.

The FTIHWG should also conduct a comparable analysis of the liquid nitrogen based on-board inerting concept.

As both food and fuel are furnished by independent contractors to the air carriers it would seem reasonable that nitrogen should also be furnished in this manner at a substantially lower cost than is calculated in the final report.

This one example shows that the dollar amount associated with costs may be lowered, thus decreasing the value of the CBR. And, this scenario is of special interest in that it burdens the aircraft only with the weight and volume of the inerting material which is produced and delivered by those expert in the process.

## Appendix A

### An Alternative to OBIGGS

A solution has been developed for on-board inerting that directly addresses the issues raised by the FTIHG's final report. In the report, the FTIHG recognizes the safety benefit of on-board inerting in comparison to ground based inerting. The recommendation specifies that alternative technologies should be assessed which offer the safety benefits, but at lower cost and power consumption. One alternative offered to the FTIHG, but not given serious consideration was the use of liquid nitrogen dewars for storage on board, with an automatic distribution system tied into the fuel tank's ullage. There are a number of benefits offered by such a design, which were not made clear in the FTIHG's report:

- Substantial improvement in reliability over OBIGGS, which requires rotating equipment including a compressor.
- Substantial reduction in power requirements
- Ability to service a range of flow requirements
- Employment of higher purity nitrogen, therefore, about half the flow requirement
- Control of ullage based on flammability as oxygen sensors are included in the design
- Ability to redirect nitrogen flow for cabin fire suppression

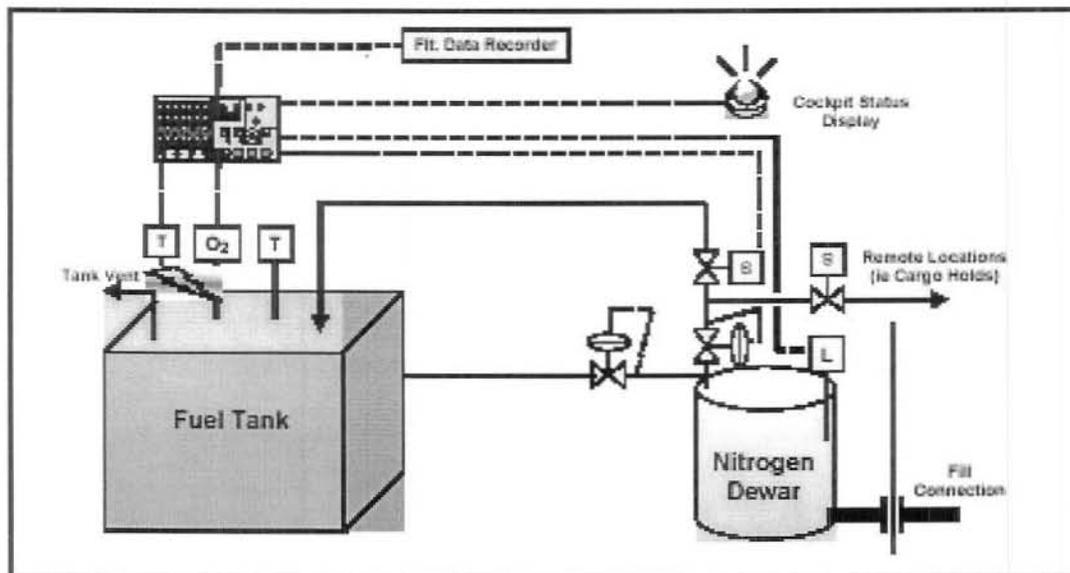
The power required to generate on-board nitrogen utilizing all of the three OBIGGS designs considered is unacceptable for today's fleet according to the final report from the FTIHG. It is well established that a significant amount of power is required for all modes of nitrogen generation, including pressure swing adsorption, air separating membranes and cryogenic distillation. While the concept of generating nitrogen on demand is appealing to the airline industry, the reality exists that this comes at a cost; specifically limited power resources on aircraft.

All modes of air separation require compressors to raise the pressure of the air being separated. In the case of pressure swing adsorption, differences in pressure are used to enable sieve material to separate nitrogen from air, then release impurities; specifically oxygen during lower pressure cycles. Pressure is required in membrane systems to drive oxygen and other impurities through the polymeric membrane material allowing higher purity nitrogen to pass through the air separation modules ASM. Finally, cryogenic distillation requires very high pressure to generate the high expansion rate required to cool air to cryogenic temperatures required for separation.

In all three cases, compressors are required to drive the separation process. Compressors have two serious issues associated with them as spelled out in the FTTHWG's report; reliability and power.

Liquid nitrogen used on-board, does not carry these burdens. As indicated above, manufacture of liquid nitrogen does require a considerable amount of power; in fact more than what is required for the three technologies discussed above. The differentiating factor, however, is that the power does not need to be provided on the aircraft.

Liquid nitrogen is supplied to a wide range of industries through a network of Air Separation Units (ASU) spread throughout North America and the rest of the world. Once made, liquid nitrogen can be stored in specially insulated vessels for weeks at a time. Thousands of businesses have their nitrogen delivered as a liquid and store it in these vessels so they can use the liquid or vaporized nitrogen gas as needed. The same concept is practical for the airline industry; albeit with special considerations.



Liquid nitrogen has a purity of 99.997% , therefore the amount of nitrogen required for inerting is reduced substantially. The OBIGGS systems discussed in the FTTHWG report generate nitrogen with a purity of 95% . The volume of nitrogen required using lower purity nitrogen is about 75% higher than would be required for liquid nitrogen. It is argued that the cost of inerting with higher purity nitrogen is lower than for lower purity (see "The Effect of Nitrogen Purity on Ulage Washing" below).

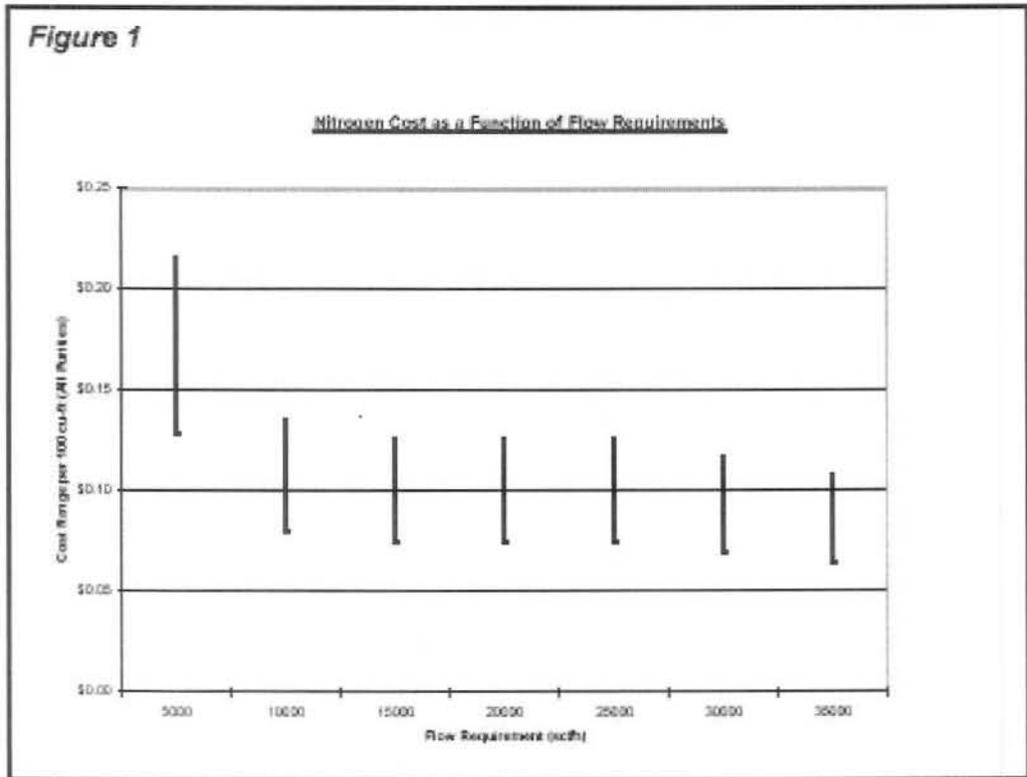
## Appendix B

### The Effect of Nitrogen Purity on Ullage Washing

Nitrogen generators can deliver a wide range of flow and purity. As a general rule, the unit cost for nitrogen decreases as the flow requirements increase and the unit cost increases as the purity increases. The cost of nitrogen is also sensitive to energy costs and atmospheric conditions. It is normally assumed that the added cost of higher purity nitrogen (98 to 99% N<sub>2</sub>) is cost prohibitive compared to the less expensive nitrogen in the 95 to 96% purity range. Analysis of nitrogen costs over a range on purity has found that the opposite is true. When the total cost of inerting is considered, higher purity nitrogen provides lower cost ullage washing, while reducing the time required to inert and reducing fuel vapor emissions resulting from the process. The following represents the results of the analysis which was derived from purge calculations and a matrix of nitrogen costs.

*Figure 1* represents the range of costs for nitrogen generated on site (either membrane or PSA) as a function of the average flow requirement in std cu-ft/hr. The curves illustrate that the unit cost for nitrogen (\$ per 100 cu-ft) steadily decreases as the average flow requirements increase. The curve only represents a trend, which is affected by the selection of equipment and the usage pattern. Equipment offered by industrial gas suppliers cover a range of flows. The efficiency of the equipment can vary depending on which part of the operating curve the equipment is operating. The most economic selection of nitrogen generating equipment can be made by the industrial gas manufacturers, and are typically offered as leased equipment.

The prices cover a wide range, due to variations in equipment cost, and purity. The prices shown below assume a cost of \$.075 per kW-hr. Higher or lower electrical rates will affect the cost. The costs represented above do not include liquid nitrogen.

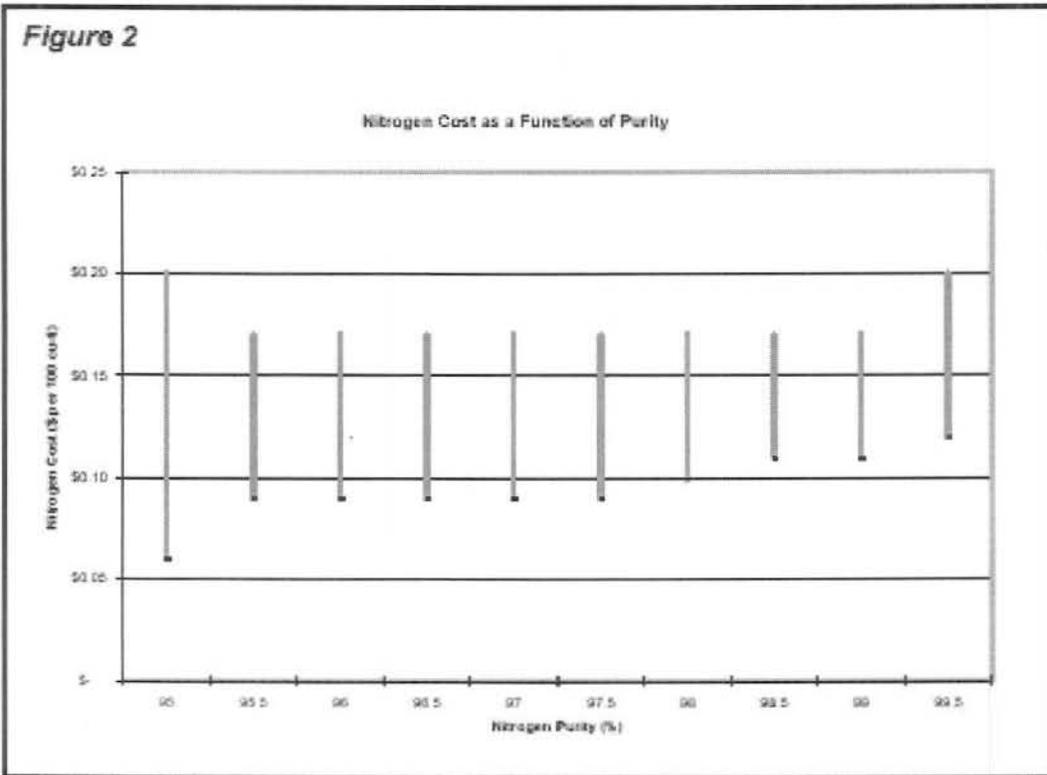


**Figure 1. Nitrogen Cost as a Function of Flow Requirements**

*Figure 2* shows the effect that purity has on nitrogen cost. For every purity value, a range of costs is shown to reflect flow requirements as well as equipment lease costs. It can be seen that the cost of nitrogen increases as the purity level increases. To generate nitrogen of higher purity, either larger equipment is required or the energy requirements are higher due to the demands of the higher purity cycles. Often the same generating equipment can produce nitrogen at a range of purity levels at a sacrifice of energy or capacity. The unit cost for nitrogen is affected in either case.

The value of nitrogen in inerting applications increases considerably as purity increases. There is a significant reduction in the nitrogen volume requirement for high purity compared to low purity nitrogen. Inerting flow is often expressed as volume of inerting nitrogen required for a given ullage volume (V/V) or the number of equivalent ullage volumes of nitrogen required to inert the ullage. The definition of inert varies considerably from application to application. For ullage washing, 8% O<sub>2</sub> is the target concentration.

Test data have indicated that the risk of flammability for Jet-A fuel is insignificant below 10% O<sub>2</sub>. As a practical matter, the Ground Based Design team has determined that the target O<sub>2</sub> concentration for ground based inerting is 8%. As there is a delay between the inerting process and takeoff, 8% ensures that the ullage will remain inert throughout the initial stages of the flight cycle.



**Figure 2 Nitrogen Cost as a Function of Purity**

The theoretical volume of gas required to inert the ullage will be a function of the ullage O<sub>2</sub> concentration prior to inerting, the target O<sub>2</sub> concentration and the O<sub>2</sub> concentration of the nitrogen used to inert.

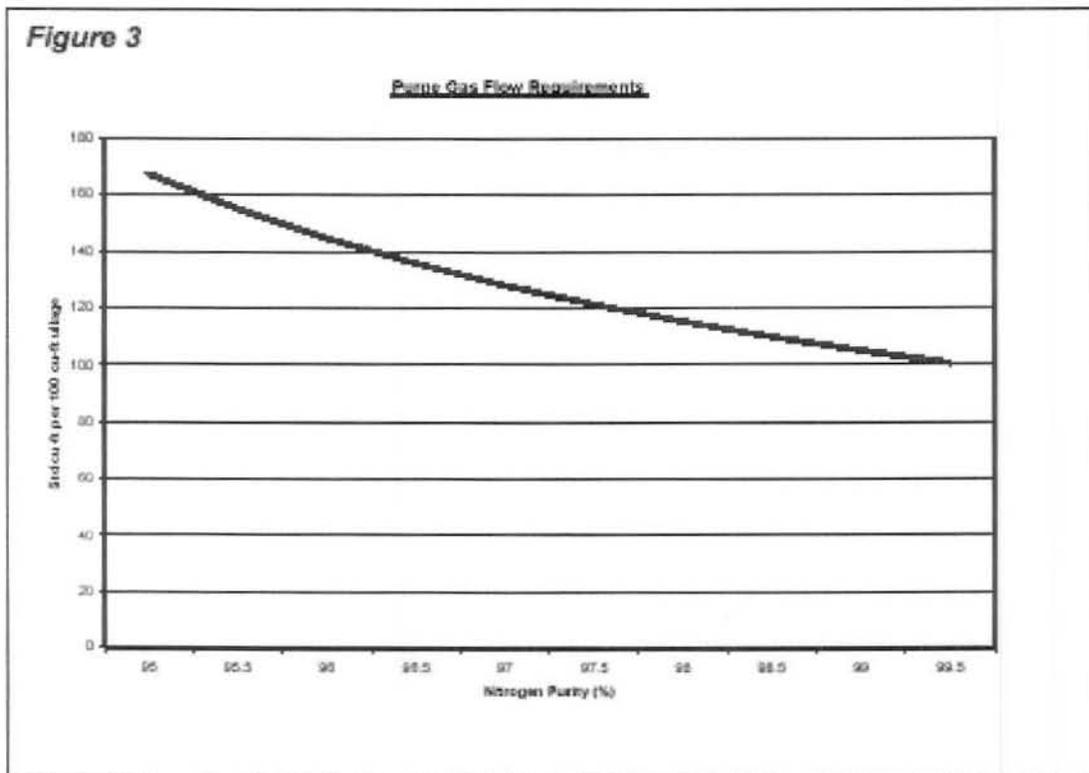
The relationship between nitrogen purity and volume required is represented by a logarithmic curve. The following formula is used:

$$n = \ln\left(\frac{C_o - C_p}{C_t - C_p}\right)$$

where

- n = number of ullage volumes of N<sub>2</sub> required for purge
- C<sub>o</sub> = Initial Oxygen concentration in ullage (%)
- C<sub>t</sub> = Final (or target) Oxygen concentration in ullage (%)
- C<sub>p</sub> = Oxygen concentration of purge gas (%)

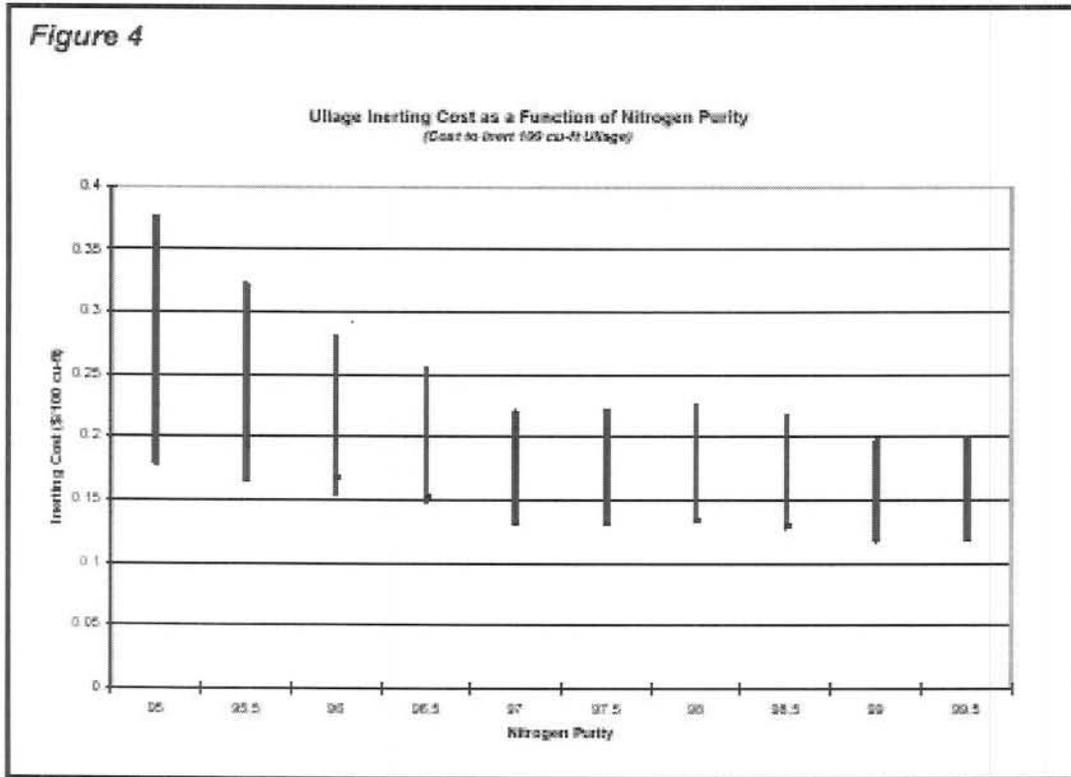
*Figure 3* represents the relationship between purge gas purity and the equivalent ullage volume in standard cu-ft required to reduce the O<sub>2</sub> concentration from 21% to 8% for an ullage of 100 std cu-ft



**Figure 3 Purge Gas Flow Requirements**

The curve shows that when the purge gas is 95% approximately 170 cu-ft of purge gas is required to inert a 100 cu-ft ullage. On the other extreme, only 100 cu-ft is required to inert the same ullage to 8% using nitrogen with a purity of 99.5%. This represents a 41% reduction in purge gas volume required. The added benefit of higher purity nitrogen offsets the added cost as *Figure 4* illustrates. The curve represents the theoretical volume requirement assuming efficient mixing of the inerting gas with the ullage. Typically, the efficiency of the inerting process is less than perfect and is affected adversely by such factors as geometry, purge nozzle configuration and location and the vent location. As a general rule, actual purge gas requirements can be expected to exceed the theoretical volumes.

It is shown in *Figure 4* that the cost of inerting actually decreases as the purity of nitrogen is increased. Comparing the minimum costs shown for each purity, the cost to inert a 100 cu-ft ullage with 95% nitrogen is \$0.18 versus \$0.12 when nitrogen of 99% purity is used. The difference in cost is attributed to the significant reduction in nitrogen required. The plot represented in *Figure 4* was created by multiplying the required volume of nitrogen required (from *Figure 3*) by the cost per cu-ft (from *Figure 2*).



**Figure 4 Ullage Inerting Cost as a Function of Nitrogen Purity**  
(Cost to Inert 100 cu-ft Ullage)

For a given flow rate, higher purity nitrogen has the added benefit of reducing the amount of time required to inert an ullage space. The family of curves shown in Figure 5 shows the effect nitrogen purity has on the time required to inert. Each curve represents inerting time as a function of purity. The time to inert was determined using the Ground Based Design team's equipment design basis of 251 scfm. Three curves are used to represent the classifications of aircraft identified by the ARAC to represent the groups of aircraft subject to the inerting procedure.

The first aircraft group, identified as "Commuter" represents the average fuel tank size for commuter aircraft. In this case, the average fuel tank is 3,000 gallons for an equivalent tank volume of 401 cu-ft. The inerting time using 95% nitrogen is 3 minutes, 24 seconds. Using 99% purity, the inerting time is 2 minutes, 6 seconds.

The next curve represents inerting time for the group identified as "Medium Transport" or "Single Aisle" Aircraft. For this group, the average tank size was assumed to be 10,000 gallons or 1,337 cu-ft. The inerting time ranges from 8 minutes 57 seconds using 95% nitrogen to a low of 5 minutes, 36 seconds using 99% nitrogen.

Finally, the "Large Transport" or "Wide Body" aircraft class has an average fuel tank capacity of 25,000 gallons or 3342 cu-ft. The range of times required for inerting goes from 22 minutes 23 seconds using 95% purity nitrogen to 14 minutes, 2 seconds using 99% nitrogen.

The value of reducing the amount of time required to inert fuel tanks has not been quantified, however, the Ground Based Inerting Design team included among its assumptions that the process will not affect turn time. The design for aircraft accommodates the flow rates specified in this document. To reduce the volume of nitrogen required for inerting, and thus the time required nitrogen purity could be increased from the originally proposed 95% to 99%. The benefits are threefold; lower cost, reduced time to inert and reduced emissions.

In addition, the volume and time can be further reduced by inerting only the ullage. The curves above assume inerting with a volume equivalent to the volume of an empty fuel tank. This greatly simplifies the process, and decreases the likelihood that errors can be made. In many cases, however, nitrogen is wasted, the process takes considerably longer than necessary, and fuel vapor emissions are increased substantially.

Properly inerting the fuel tank to address only the volume of the ullage can be done if the oxygen concentration of the ullage is measured. Oxygen analyzers added to the fuel tank or at the fuel tank's vent can provide a reasonable estimate of the oxygen concentration in the fuel tank. Knowing the oxygen concentration can significantly reduce the nitrogen requirement, and in addition provide a direct measurement of the effects of inerting.

The overall cost of inerting fuel tank ullage is driven by a number of factors including the flow rate, purity, method of supply, nitrogen cost and ullage volume. The analysis of this matrix of data has determined that higher purity nitrogen provides the most cost effective purge gas. Nitrogen can be generated at airport facilities at the full range (95 to 99%) of purity analyzed using membrane generators or Pressure Swing Adsorption (PSA) generators. The design for the distribution manifold and supporting components specified for retrofit of aircraft will limit the flow rate and pressure available for the inerting process. As turn time and cost become more critical, there are alternatives to optimize the process including higher purity nitrogen and oxygen measurement.

Figure 5

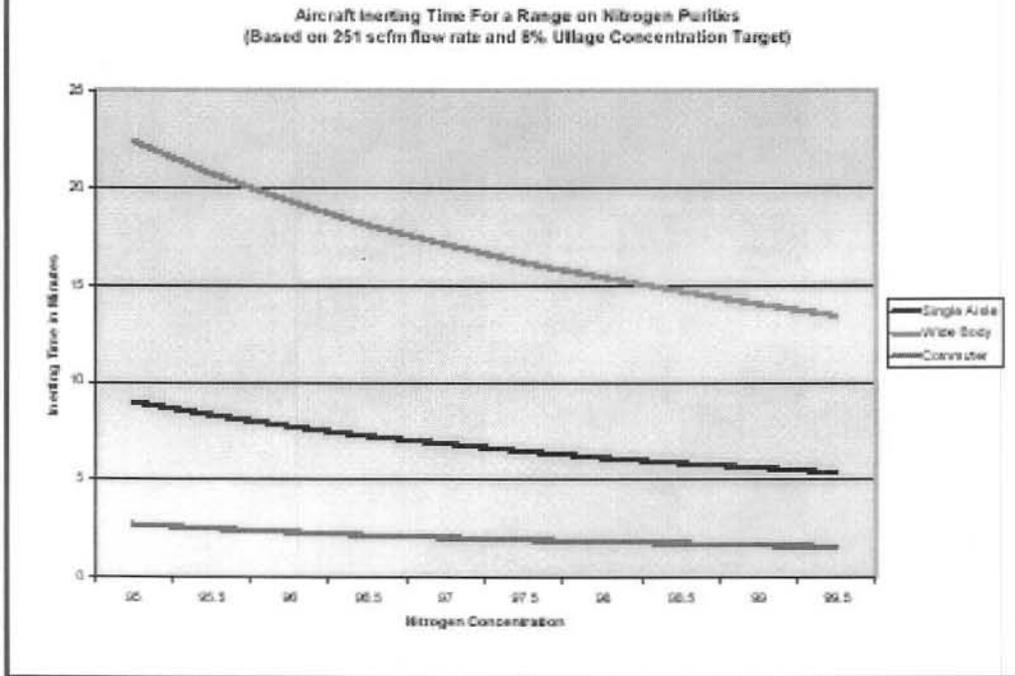


Figure 5 Aircraft Inerting Time For a Range on Nitrogen Purities  
(Based on 251 scfm flow rate and 8% Ullage Concentration Target)

Appendix C

**ASU Plant Locations for all Industrial Gases Companies USA**



**Comments Submitted for the Public Record Concerning the Team Reports,  
February 2002, of the ARAC Fuel Tank Inerting Harmonization Working Group,  
Submitted to the ARAC ExComm on 13 March 2002**

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**EXECUTIVE SUMMARY**

A combustible fuel vapor/air mixture may exist under certain conditions in the ullage volumes of aircraft fuel tanks. On occasion this mixture may be accidentally ignited by the presence of an unanticipated ignition source with disastrous consequences. According to NTSB statistics, seventeen civil aircraft have been destroyed in the last 35 years. Lowering the oxygen content in this ullage volume with nitrogen will prevent these explosions and increase flight safety. Significant criticism of the concept of cost benefit analysis or ratio is justified and quantitative data may be chosen which significantly affects these calculations. It is possible to argue that an immediate program should be initiated in order to inert aircraft fuel tanks, and thus effectively eliminate this explosion danger.

**Introduction**

An explosive mixture of fuel vapors and air may form in the ullage volume of aircraft fuel tanks. A subsequent presence of an active ignition source results in a damaging explosion such as the most recent examples: a Boeing 737, Bangkok, Thailand, 2001; a Boeing 747, New York, New York, 1996; and a Boeing 737, Manila, Philippines, 1990. A comprehensive listing of fuel tank explosions is given in the Final Report, 1998, of the First Fuel Tank Inerting Working Group (see below). A mechanism which absolutely eliminates the possibility of these fuel tank explosions is to reduce the oxygen concentration within the fuel tanks by increasing the nitrogen content. *Any* ignition source is then ineffective.

In September 2000 an Aviation Rulemaking Advisory Committee first met in order to provide advice to the FAA on this subject matter. Their Final Report was issued in June 2001 and submitted to the FAA ARAC Executive Committee in August 2001. Clarifications were requested by the Ex Comm, and these will be submitted to the Ex Comm in March 2002. Both the report and the clarifications are found to be deficient by the authors of this dissent as described in detail below. It should be noted that this is a second effort to address the fuel tank explosibility issue.

In 1998 the FAA initiated an ARAC study regarding fuel tank inerting in the ullage portion of center wing tanks. This study was a result of the TWA 800 crash and the NTSB recommendations. This study lasted approximately six months. The findings were that more studies and technology were required and that the cost benefit analysis was not within FAA guidelines. The complete 1998 FTIHWG Final Report may be found at < [www.fire.tc.faa.gov](http://www.fire.tc.faa.gov) >under the heading of reports and on page 7.

It should be noted that fuel tank inerting is supported by members of the National Transportation Safety Board and continues to be posted as one of their top ten “Most Wanted” safety improvements. On 8 August 2001, Carol Carmody, acting chair, expressed her disappointment that the Working Group relied on cost benefit ratio, CBR, as a basis in recommending that fuel tank inerting not be implemented. On 23 August 2000, the past chair, Jim Hall, noted that “it is imperative at long last, the aviation community move with dispatch to remove flammable fuel/air mixtures from the fuel tanks of transport category aircraft” as recommended to the FAA by the CAB on 17 December 1963 as a result of the Pan Am flight 214 disaster. It is expected that the NTSB can provide to the FAA their information which supports the inerting of aircraft fuel tanks.

### **Cost/Benefit Analysis**

The basic concept of cost/benefit ratio, CBR, or cost/benefit analysis, CBA, seems to be fatally flawed. The numerical value can be made very large by having a large numerator or small denominator or very small by having a small numerator or large denominator. Having the quantity of the order of unity does not seem to resolve much. More often than not the financial quantities in the Working Group’s report are at best estimates, or at worst sheer speculation. Also, some of the assumptions used to justify figures are flawed as explained below.

Within the June 2001 report there are numerous CBR calculations which give the results that the cost of nitrogen fuel tank inerting are greater than the benefits produced. For some of these calculations it is possible to make straightforward comments affecting their validity and/or changing the results to produce a more favorable situation for the implementation of nitrogen fuel tank inerting.

### **Comments on ARAC FTIHWG 2001 Final Report Dated 6/01**

1. Pg 1-7 ¶ 1.8 → Evaluation timeline assumes that it will take 36 months to certify a design and 84 additional months to modify the fleet. Figure 1 is a rough cash flow diagram during the evaluation period. The non-recurring costs associated with inerting are realized between 2005 and 2015. Based on pg 1-8 ¶ 1.8, there is only one expected accident that could be avoided in the study period. This is due to the fact that no benefit could be realized before the system is implemented. It is suggested that the sensitivity analysis include an earlier implementation date, and/or a longer total time frame.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Event	Reg Published			Design Cert							All go					
Cost	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Benefit																↑

Figure 1 – ROM Cash Flows of Cost and Benefit Over Study Period

2. A major assumption that the recently enacted SFAR 88 would reduce accident rates by 75% is not supported by any evidence. Note that no source of ignition has been pinpointed for any of the three most recent explosions. To assume that 75% of these type of accidents can be avoided by inspecting just one of the possible sources is not credible. Further, it has been suggested that this type of manual inspection of wiring harnesses more likely would result in damage of brittle insulation and may increase the likelihood of accidents by creating ignition sources.
3. Page 1-8 2<sup>nd</sup> ¶ Indicates that only 1 airplane accident would be avoided in the 16 year study. Note that full inerting system capabilities would only be on line for 6 of those 16 years.
4. Page 1-8 4<sup>th</sup> ¶ Says 132 deaths avoided for GBI and 253 for OBIGSS over the 16 year evaluation period, which is 6 years of system functionality. The benefit over 16 years of operation would be 352 for GBI and 675 for OBIGGS.
5. Accident rates are based on only 3 data points, and therefore do not create a statistically significant pattern. Therefore these rates must represent a fairly low confidence interval. It is suggested that the sensitivity analysis include a range of accident rates that represent higher levels of confidence intervals.
6. Page 1-9 Figure 1-5. Again the benefit interval is only 6 years projected over a 16 year time frame the ratios vary from 14:1 to 20:1.
7. Page 2-2 ¶ 2.b → “Various means of supplying nitrogen (i.e., liquid. . .)” The report does not cover liquid nitrogen supplies. (Note that “i.e.” stands for “that is”, which indicates that they were to specifically look at liquid nitrogen).
8. Page 4-8 ¶ 4.5 → “it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss. . .” These assumptions are not factually or statistically based. The sensitivity analysis should allow for large variation in these estimates. Refer to number 4 above. Over a 16 year period the lives saved are 352 for GBI and 675 for OBIGGS. If we allow that in 100% of explosions there is a total loss, then the numbers become 407 and 780.

	Benefit (\$US billion)	Adjustment for 16 years of benefit	Adjustment for total loss	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	0.245	0.653	0.755	10.37	13.7:1
OBGI (HCWT only)	0.219	0.584	0.675	11.6	17.2:1
Hybrid OBIGGS (HCWT only)	0.257	0.685	0.792	9.9	12.5:1
OBIGGS (all tanks)	0.441	1.176	1.359	20.78	15.3:1

9. If we include the factors from item 8 in the sensitivity analysis, the most favorable scenarios become:

	Scenario from 8/8 Summary Pg#	Benefit (\$US billion)	Adjustment for 16 years of benefit	Adjustment for total loss	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	37	0.281	0.749	0.866	4.196	4.8:1
Hybrid OBIGGS (HCWT only)	43	0.3	0.800	0.925	3.68	4.0:1

10. Page 6-14 → Inclusion of Capital costs may be redundant. It is likely that the operator of the system will absorb those costs, and recoup them via operating costs.
11. Page 11-1 Is the “willingness to pay” value of human life escalated in the out years? If not, then there is another skew in the data. The “willingness to pay” benefit is discounted back to 2005 at 7%. If no escalation was assumed, then the benefits are understated by that 7% discount. Since most of the benefits are in the out years, there is a significant impact. If the adjustments for escalation of benefit are included then the most favorable scenarios become:

	Scenario from 8/8 Summary Pg#	Benefit (\$US billion) Adjusted in Item 9	Adjustment for 7% Discount / Inflation	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	37	0.866	2.557	4.196	1.6:1
Hybrid OBIGGS (HCWT only)	43	0.925	2.731	3.68	1.3:1

12. A major domestic airline disclosed that the actual costs used by the airlines to account for loss of life vary between \$2.7 M and \$4.0 M based upon the demographics of the airlines route structure. The most favorable scenarios become:

	Scenario from 8/8 Summary Pg#	Benefit (\$US billion) Adjusted in Item 11	Adjustment for \$4M/Life	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	37	2.557	3.788	4.196	1.1:1
Hybrid OBIGGS (HCWT only)	43	2.731	4.046	3.68	0.9:1

13. Page G-2, last sentence before Section 2.0 → States “See section 4 for more information about benefits.” No section 4 is included in this report. Please provide missing or removed information.

Numerous examples may be cited of improvements being made within society to increase safety without performing a CBR analysis.

(a) In the Our Lady of Angels, Chicago IL, 1958 school fire resulting in 93 dead, according to the NFPA, an immediate sprinkler and call box installation was initiated and completed within two years for *all* Chicago schools.

(b) More recently, for the past several years Ford Explorer automotive rollovers, presumably initiated by defective tires, have resulted in over 200 deaths. An expenditure of approximately \$4B has been made by only two corporations as a result of the initial recalls to correct this problem and a second recall valued at \$41.5M has also most recently occurred.

(c) The Ford Motor Company also has an additional problem and is spending nearly \$3B to replace millions of flawed ignition modules. These faulty systems resulted in 11 deaths and 31 injuries.

(d) Additionally, at present there is a massive recall of faulty fire sprinkler heads produced by one manufacturer, Central Sprinkler: the Omega model for residential use, and the GB model for commercial use. It has not been noted that a CBR has been done in order to justify the recall.

In an inverse situation a CBR was calculated by General Motors regarding the safety of fuel systems in automobile crashes. In a recent California jury trial verdict enormous damages, nearly \$4B, were awarded to the injured as General Motors had reportedly decided that the \$8 cost per vehicle required for fuel system redesign and manufacture was not cost effective compared to damages which would be awarded in any subsequent trials.

Finally, the U.S. Supreme Court has in the last term spoke on the issue of CBR. They judged unanimously in a U.S. EPA related case that only public health (substitute the closely related word safety) could be considered and not cost regarding new clean air standards.

### **Benefit Analysis**

As currently structured the benefits chiefly accrue from the figure of \$2.7M which is described as the amount which U.S. society is willing to spend on increased safety in order to prevent a death. However, the current very adverse response by families suffering from the loss of members due to the events of 11 September 01 to the provisions of the “Air Transportation Safety and Systems Stabilization Act,” would indicate that this is a very inadequate amount. During a meeting between FAA rulemaking authorities and National Air Disaster Alliance/Foundation members on 28 September 2001, it was indicated by the FAA that this

benefit restriction was too limited and that the concept of benefits should be expanded. Such additional benefits should consider the costs of family breakups which invariably results when a family members is lost. The U.S. government indicates that it has great respect and support for the concept of a small business. A political and legal environment is developed for such to thrive. The family is an ideal example of a small business and post-air crash conditions should be favorable for the survival of this business. As the events of 11 September 01 have shown, and as will be applicable to other crashes, air disasters can have other enormous secondary economic effects which need to enter into the benefits calculations. There is the loss of passenger revenue due to fleet grounding and the reluctance of individuals to travel by air. There is decreased use of hotels, restaurants, rental cars, theaters, and all other items related to travel. There may be extensive property loss as a result of an air crash as well as an extensive loss of jobs. Some quantitative data may be connected to the four airplane crashes on 11 September 01 which show that the benefits of increased safety have been significantly underestimated in the past. Stock market losses may be estimated at approximately \$3T and air transport losses may range as high as \$15B. Property losses are expected to be \$40B. At the end of 2002 it is estimated that 1.8M U.S. jobs will be lost as a result of the 11 September 01 events. At present, the job loss in the aviation industry alone world-wide stands at 400K. The cost of the TWA 800 crash is currently estimated to be approximately \$1B and the Libyan government has reportedly offered a \$6B settlement with regard to PanAm 103. A potential casualty of unknown magnitude is the collapse of the insurance and reinsurance market as a result of the aviation disaster losses.

The June 2001 ARAC Final Report does put the air transport industry on notice that there is a known single point failure mechanism which will produce a catastrophic fuel tank explosion. The report also indicates that the nitrogen inerting of fuel tank ullage is 100% effective in eliminating fuel vapor/air explosions within aircraft fuel tanks. A known hazardous condition may be eliminated. As a result of the next such aviation disaster punitive damages of unknown amounts may be awarded to families suffering the loss of members. On 17 August 01, \$480M in damages were awarded against Cessna Aircraft Co. regarding an alleged known defect concerning the failure of seat positioning locks.

The information above would indicate that the dollar amount attributed to benefits could and should be increased significantly, thus substantially decreasing the figure for the CBR.

### **Cost Analysis**

In the June 2001 ARAC Final Report sixteen different scenarios are considered in order to assess the cost of inerting. In scenario sixteen, which should be one of the most promising concepts, an onboard cryogenic (liquid) nitrogen system, is considered as a result of a request made by the ARAC Executive Committee at its April 2001 meeting to the Working Group. The CBR as calculated by the Working Group for this concept is not favorable. However, alternative calculations presented below are much more favorable. It would be anticipated that such a reanalysis could be done for each scenario.

## **Comments on ARAC Final Report CBA for Liquid Nitrogen On-board Storage Scenario**

The term "*practicable design methods*" may have been interpreted by the FTIHWG to exclude the inerting concepts (Scenario 1 to 16) reviewed and deemed not be cost effective. However, *the analysis of Scenario 16 appears to be incomplete and inaccurate*. Their CBA was based on a number of assumptions, which are detailed in the Estimating and Forecasting team's final report in Section 3. The following assumptions are under question:

- (1) "*Gas generating systems are less expensive and less hazardous*"
- (2) "*The computed LN<sub>2</sub> weight is based on carrying enough LN<sub>2</sub> for three flights*"
- (3) "*The system described above has been sized to inert all fuel tanks on the airplane*"
- (4) "*Weight in Figure G-64 is based on FAA study "Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System" (1972)*"
- (5) "*A mechanic, not a ground service worker is required to fill the airplane storage tanks.*"
- (6) "*All nitrogen needed would be generated at the airport*"
- (7) "*All retrofit costs are based on the costs of the GBI airplane system.*"
- (8) "*Although the closed-loop oxygen sensing system is less complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar*"

Many of the assumptions made either do not apply or should be restated to reflect the realities of the system proposed at the Ex Comm meeting of April 2001.

A concept has been developed using liquid nitrogen to generate gaseous nitrogen with purity in excess of 99.9% to maintain a non-flammable ullage in airplane fuel tanks. The primary advantage of liquid nitrogen storage is the ability to convert a large volume of nitrogen gas from a substantially smaller volume of liquid. The ratio of gas volume to liquid volume for nitrogen is 696:1. The system concept employs a liquid nitrogen (LN<sub>2</sub>) storage vessel or dewar, which is designed for use on aircraft. The LN<sub>2</sub> is vaporized to nitrogen gas and delivered through a simple manifold to the ullage of the aircraft fuel tank. The pressure in the dewar is controlled at a low pressure by a pressure-reducing valve. In the event of over-pressure or failure of the primary relief valve, a safety device (rupture disk) opens to vent nitrogen gas outside the aircraft and beyond. The flow of nitrogen gas is controlled by the ullage flammability, which is determined by the combination of oxygen concentration and ullage temperature. This method of control limits nitrogen usage to only the portions of the flight profile that require inerting to mitigate flammability. Measurement of oxygen concentration is the only means available to determine with certainty that the ullage is inert. While adding to the complexity of the overall system, an oxygen sensor ensures effectiveness of any inerting system, while conserving nitrogen. The internal pressure of the dewar (less than 5 psi) is adequate to deliver the nitrogen through the control valves, to the ullage manifold. The design uses very little power, due to the use of dewar pressure for delivery of the nitrogen gas. The only power required for this design is for the solenoid valve and instrumentation, approximately 1 kW.

#### **Assumptions (from FTIHWG Final Report)**

- (1) "Gas generating systems are less expensive and less hazardous than liquid nitrogen based systems"**

The nitrogen gas generating systems evaluated by the FTIHWG all required a complex array of compressors, heat exchangers, filters, valves, water separators and air separation modules or distillation columns. The cost of equipment for each system is in excess of \$180K. In addition, connections to a bleed air source as well as substantial power requirements lead to very high installation costs. The liquid nitrogen based system offers a significant reduction in the number and complexity of components. The cost of equipment as proposed is to be included in a service fee charged by the inerting service provider. For a moment, make a comparison between cryogenic nitrogen and aviation fuel. We do not load crude petroleum on the aircraft for onboard refining into jet fuel. The refinery would weigh too much and consume too much power!

Installation costs are expected to be paid by the same parties as for the other 15 Scenarios, however, these costs must be substantially lower as the only connections required are for the ullage manifold, the vent and the electrical system (instrumentation only). While it is understood that costs in categories (e.g. engineering, setup) are similar, the cost for hardware and installation for the liquid nitrogen based system will be considerably lower than the others considered. The assumption made by the Estimating and Forecasting team is inaccurate. **The same process of estimating costs (e.g., figure F-A2, etc.) must be made for the liquid nitrogen based on-board design as for the others.**

The asphyxiation hazard attributed to nitrogen inerting is taken very seriously by the industrial gases industry, and any system offered would unquestionably be assessed for the risks. Beyond well-structured safety procedures and training, safety interlocks can be included in the design without adding significantly to the complexity of the system. Interlocks provide protection even when operators and maintenance personnel ignore safety procedures. Normal airline maintenance procedures for accessing enclosed spaces (i.e. fuel tanks) require the area to be purged to remove hydrocarbon vapors. This process is likely enough to mitigate the risk of asphyxiation; however, the oxygen concentration can be checked easily before entry. The oxygen sensors included with the inerting system can control a latch to prohibit access when the oxygen level is too low. In addition, inexpensive (approx. \$300) hand held oxygen sensors can be used to increase the level of safety. This design and these procedures are very common in industry today.

## **(2) "The computed LN2 weight is based on carrying enough LN2 for three flights"**

The design of the liquid nitrogen system can provide for adequate storage for three flights, however, this may be necessary only for medium sized aircraft, which often have quick turn times and several trips per day. In contrast, large aircraft have longer turn times, and often only fly one trip per day. Some sizes specified by the FTIHWG are considerably larger than necessary. For example, the weight of LN2 specified in their analysis (1,282 lbs.) generates enough nitrogen gas to inert the equivalent of over 131,000 gallons of ullage space (almost three completely empty 747 tanks). In light of turn times associated with large aircraft, and length of flights, is it necessary to carry so much nitrogen? **The FTIHWG should consider whether it is necessary to require capacity for three flights across all airframe sizes.**

## **(3) "The system described above has been sized to inert all fuel tanks on the airplane"**

The Tasking Statement [Federal Register: July 14, 2000 (Volume 65, Number 136)] states that "The system shall inert all fuel tanks with an on-board nitrogen gas generating system...". This is inconsistent with the requirements for Ground Based Inerting, which states that *"The system shall inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank..."*. **Please clarify the differentiation in requirements for the two modes of inerting.**

**(4) "Weight in Figure G-64 is based on FAA study "Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System" (1972)"**

The FTIHWG's report referenced data from a report that is 30 years old. Advances in storage of liquid nitrogen may have had a favorable impact on the weights and costs associated with liquid nitrogen storage. Based on equipment available today, the weights were updated and are reflected in Figure G-64 (re-stated) below. Limiting the amount of liquid nitrogen stored on-board may also offer the benefit of reducing the size and weight, and to a lesser extent, the fuel penalty. A 100-gallon Dewar carries enough liquid nitrogen to inert over 69,000 gallons of ullage space. The vessel weighs only 475 lbs. Additional components include pressure-reducing valves, pressure relief valve, solenoid valve, oxygen analyzer, thermocouples and piping are anticipated to weigh no more than 100 additional lbs. The weight of the distribution manifold specified in the Ground Based Inerting Team's report (Pg C-26, Figure 13.0-1) is 54 lbs. **The FTIHWG should redress their estimates of weights associated with liquid nitrogen based on-board inerting designs evaluated as Scenario 16 (Pg G-66).** The following table represents revised estimates of weights shown on Figure G-64:

	Large Airplane			Medium Airplane			Small Airplane		
	Cu-Ft N <sub>2</sub>	Weight	Gal	Cu-Ft N <sub>2</sub>	Weight	Gal	Cu-Ft N <sub>2</sub>	Weight	Gal
LN <sub>2</sub>	9,311	675	100	4,655	338	50	2,328	169	25
Storage, controls, wt		575			375			300	
Plumbing		54			34			22	
<b>Total</b>		<b>1,304</b>			<b>747</b>			<b>491</b>	

Figure G-64 (re-stated) Liquid Nitrogen System Weight (all fuel tanks)

**(5) "A mechanic, not a ground service worker is required to fill the airplane storage tanks."**

A nitrogen service contractor can conduct the process of filling the airplane storage tanks. Two methods of executing this process are foreseen:

(a) Fill on-board LN<sub>2</sub> storage tanks located on the aircraft through a unique external connection located on the airframe (similar to the process fueling the aircraft).

(b) Replace empty vessels with full vessels, which have been filled and tested off-line by nitrogen supply contractor.

It is proposed that the service provided by the nitrogen supply contractor include:

- Supply and maintain liquid nitrogen storage vessels along with ancillary components; including valves, instrumentation, and pressure regulators.
- Fill vessels with liquid nitrogen as required.
- Design, test, and certify liquid nitrogen inerting package excluding fuel tank distribution manifold.

This can be offered on a fee basis, requiring no investment in equipment. The fee includes all items defined above with little or no initial capital investment. Anticipated cost for the service is less than \$200 per turnaround, which occurs once every two to three flights.

In **Item a** above, the design of the on-board inerting system utilizing liquid nitrogen requires a connection from the LN<sub>2</sub> storage vessel to a unique, frangible fitting located outside the airframe, in a location accessible to the ground based nitrogen service contractor. A design similar to the proposed by the Ground Based Inerting Design team could be adapted easily for cryogenic service. The nitrogen contractor would utilize operators trained in the delivery of liquid nitrogen and airport operations to transfer liquid nitrogen from their storage vehicle to the on-board vessel. A similar process is safely conducted hundreds of times a day for a wide range of industries, albeit not in an airport environment.

The vessel will be filled at a local liquid nitrogen manufacturing facility located near the airport facility.

In **Item b**, it is foreseen that the storage vessel will be an integrated, removable system including all valves and instrumentation, excluding the oxygen analyzer. The nitrogen contractor will be responsible for maintaining and testing the equipment as well filling them in their facility located near the airport. Vessels requiring replacement will be removed from the airplane and replaced with a filled unit that has been tested. The process of changing liquid nitrogen vessels will be conducted by personnel trained in safe handling of cryogenic equipment, specifically for the airline industry.

Changing cylinders has an added advantage of ensuring that the inerting system is operational prior to a flight. The procedure will include a full check of the storage system at the nitrogen contractor's facility, therefore not affecting turn times. The failure rate of this design will be extremely low. In the rare event of failures, replacements will always be on hand, as the equipment becomes standard ground equipment. The design of the inerting system is such that the change can be made quickly, safely and dependably. Special mounting and connection hardware will be used to ensure this.

**The FTIHWG should re-calculate the costs of inerting when inerting service is provided at a cost of \$200 per use every two to three flights.**

**(6) "All nitrogen needed would be generated at the airport"**

There are a number of manufacturers of liquid nitrogen serving industries throughout the world. A network of Air Separation Units (ASU) separate air into its three main components: nitrogen, oxygen, and argon using a distillation process. At ASU's a subsequent process called *liquefaction* converts the gases to liquid for more efficient storage. As a liquid, nitrogen and the other industrial gases can be transported to customers within a 200-mile radius cost effectively. When the delivery truck arrives, the liquid nitrogen is transferred to the customer's storage tank. It is extremely rare for customers to need to generate liquid nitrogen on their facility. Only when the quantities are extremely large, does it make sense to generate liquid on site. Typical ASU's serve hundreds of customers over a wide geography. Even the largest airports will not use enough liquid nitrogen to economically justify a dedicated ASU. Existing liquid nitrogen manufacturing capacity is anticipated to be adequate to serve airport needs in the U.S.

There is a wide-ranging network of industrial gas distributors who store liquid nitrogen, oxygen argon and others to serve industries like welding. Liquid nitrogen is available virtually anywhere in the United States; either through manufacturers or distributors. **Appendix C** illustrates the network of liquid nitrogen, oxygen and argon throughout the United States. The distributor network is not shown.

The proposed solution does not require liquid nitrogen to necessarily be present at every airport facility. Since the design provides inerting for multiple flights, servicing can be scheduled by airlines at a select number of airports (e.g. Hub airports) to minimize the overall cost of implementation. In addition, the process can be scheduled during slow periods, for example overnight to further reduce the impact of inerting. **The FTIHWG should consider the use of on-hand nitrogen production facilities for the supply of liquid nitrogen and determine the cost under that circumstance.**

**(7) "All retrofit costs are based on the costs of the GBI airplane system"**

It is not necessary to replicate the GBI design for the liquid nitrogen based design. If **Item 5a** were used, the GBI design could easily be adapted to facilitate liquid nitrogen delivery to the on-board storage vessel. However, **Item 5b** requires no external connection to facilitate delivery of liquid nitrogen. In this case, the cost of adding an external connection along with associated fittings, valves and monitors will not be required.

**The design of the manifold should be redressed in light of the results of the FAA tests on a scale model (DOT/FAA/AR-01/6).** Results from testing at the Technical Center indicate that the manifold design may be greatly simplified, reducing engineering expense and weight, with equivalent results to the GBI Design team's proposed design.

**(8) "Although the closed-loop oxygen sensing system is less complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar"**

Oxygen sensors provide the only reliable means of confirming whether ullage is inert. The designs offered by the on-board and ground based design teams do not offer oxygen sensors. The consequences of this decision include over-compensating for lack of information by purging with substantially more nitrogen than required. Beyond unnecessary nitrogen cost and time spent with

the inerting process, this solution increases emissions of hydrocarbons by a factor of at least three; though often more than that when full CW tanks are involved.

Inclusion of an oxygen analyzer in the design considerably reduces the volume and time needed to maintain an inert ullage. The system will use oxygen and temperature information to determine flammability, and deliver nitrogen gas only when the conditions warrant nitrogen to limit flammability.

A design using liquid nitrogen storage would be far less complex than any OBIGGS system proposed, simply due to the fact that integration into an aircraft's power systems and bleed air are not required with the liquid nitrogen design. With the removable vessel option (Item 5A), maintenance procedures will be conducted off the aircraft, and procedures associated with inerting can be conducted every two to three flights in a process slightly more complex than baggage handling.

**The FTIHWG should assess the benefit offered by oxygen analyzers with the on-board inerting system in contrast to the cost of complexity.**

**The FTIHWG should also conduct a comparable analysis of the liquid nitrogen based on-board inerting concept.**

As both food and fuel are furnished by independent contractors to the air carriers it would seem reasonable that nitrogen should also be furnished in this manner at a substantially lower cost than is calculated in the final report.

This one example of a careful analysis of a scenario shows that the dollar amount associated with costs may be lowered, thus decreasing the value of the CBR. And, this scenario is of special interest in that it burdens the aircraft only with the weight and volume of the inerting material which is produced and delivered by those expert in the process.

In the other scenarios, where nitrogen-generating systems are considered, the small amount of information which is available in the unclassified world would seem to indicate that current military technology, if available for use, could also lower the cost estimates.

## **Ignition Source Control**

### **Benefits Attributed to SFAR 88**

The FTIHWG determined that the benefit of ullage inerting should be reduced to reflect the benefits offered by new procedures defined by SFAR 88. The SFAR was released as the Working Group was assessing the benefits of inerting, and these benefits were discounted considerably (75%) based on the assumption that the process defined in the SFAR would yield significant benefits.

*"The 75% reduction had been estimated by the 1998 FTIHWG."* [FTIHWG Final Report Pg. H-9]

The benefits offered by SFAR 88 are difficult to quantify, because many of the ignition sources for fuel tank explosions have not been identified as noted by the FAA [Federal Register May 7, 2001 pg 23127]

"As noted, the FAA has not quantified the potential benefits from this final rule because there is uncertainty about the actual ignition sources in the two fuel tanks..."

Further the regulatory text in SFAR 88 calls for reducing the exposure to flammable mixtures. From §25.981(c):

"The fuel tank installation must include either--

1. Means to minimize the development of flammable vapors in the fuel tanks(in the context of this rule, "minimize" means to incorporate practicable design methods to reduce the likelihood of flammable vapors); or
2. Means to mitigate the effects of an ignition of fuel vapors within fuel tanks such that no damage caused by an ignition will prevent continued safe flight and landing."

The FTIHWG assumed a 75% reduction in fuel tank explosions resulting from the implementation of SFAR 88, however, has this included the reduction of flammability exposure specified in the regulatory text for SFAR 88?

A fuel/air explosion (FAE) occurs when five items come together: fuel, oxidizer, ignition source, confinement, and vapor phase fuel/oxidizer mixing. The first three are commonly known as the fire triangle while all are known as the explosion pentagon. For the latter situation the removal of any one item precludes an explosion, but the attempted control of only one component, such as ignition sources, is a risky strategy. It may decrease the number of incidents, but it will not eliminate them. Experiences in other industries such as the process, coal mining, and grain and feed have shown that it is necessary also to control the fuel in order to eliminate fuel/air explosions. It is exceedingly difficult to have two failures at the same time — ignition sources and combustible fuel/air mixture. Such a strategy was adopted by another segment of the transportation industry, maritime petroleum shipping, where the scrubbing of tankage led to an electrostatic ignition source for the fuel vapor/air mixtures. An analysis of the problem led to the use of stack gases as an oxidizer diluent within the empty tanks.

Recently, two nonconventional ignition sources have become of increased concern. Silver components within the fuel tank through chemical reactions occurring in the presence of low sulfur fuel can produce conducting paths leading to short circuits. And, on 26 November 1989 an Avianca B-727-100 crashed shortly after takeoff from Bogota, Columbia as a result of the detonation of an explosive device placed in a seat on the starboard side of the passenger cabin, which in turn ignited fuel vapors in an empty fuel tank. Additionally, on 22 December 2001, an American Airlines 767-300, Flight 63, traveling from Paris, France to Miami FL, was diverted to Boston MA. A passenger sitting in a port side window seat slightly aft of the wing trailing edge had attempted to detonate an explosive device which had been hidden in his shoes. Had the

initiation attempt been successful and had he been located above the center wing tank he may have ignited, with fatal results, the fuel vapors in the center wing tank. Finally, in January 1995 responding to a routine fire alarm in a Manila apartment building, firemen and investigators uncovered a bomb-making factory with electronic timers and terrorist plans regarding near-future transpacific flights. The timers matched those used to explode a bomb on a Philippines airline flight of a few weeks earlier, which killed one passenger and forced an emergency landing. The eleven long haul flights, all with intermediate stops on a single day, designated as imminent targets involved mainly those of United and American Airlines — the same ones targeted for 11 September 2001. The explosive technique of operation Bojinka of placing a small bomb within the cabin certainly could have been enhanced by locating it over the center wing tank and detonating it later into the flight when its liquid fuel had mostly been consumed. As with the case of the Avianca and American Airlines flights, SFAR88 would not have decreased the likelihood of these intentional ignition sources.

In the process, coal mining, and grain and feed industries unanticipated/unexpected ignition sources led to the failure to eliminate explosions by the control of ignition sources exclusively. It will be the same situation regarding SFAR88. It is thus impossible to definitively quantize its effect and not to implement a second backup strategy such as nitrogen fuel tank inerting.

### **Related Safety Issues**

It is not realistic to try to inert the fuel tanks in all aircraft at all locations within the global aviation network at the same time. A risk and consequence analysis needs to be performed relating to the different types of aircraft so as to propose an intelligent implementation of an inerting program. Logic would dictate that one would begin with the high risk, heated center wing tank (HWCT) aircraft currently in production or to be put into production. Those to be neglected would be ones of smaller capacity near the end of their airframe life. Geographically, the initiation would occur at airports with the largest passenger traffic and last implementation would be those with little passenger traffic.

Fuel tank nitrogen inerting, as recognized by SFAR88, is not *the* only way to *lower* the risk of fuel tank explosions. All methods which would decrease fuel tank flammability need to be examined and evaluated, especially those which may be quickly and cheaply implemented such as: suppression systems, expanded metal mesh, JP-5 type fuels, the loading of additional chilled fuel, scrapping of older aircraft with questionable electrical system problems, using external cooling systems during ground holds, ventilation of the heat exchanger bays, etc.

Any cost associated with the implementation of fuel tank nitrogen inerting must be normalized in a rational fashion. This is not an enormous one-time expense which will be paid for by the air transport industry. Just like any other expense it will be passed on to the passengers. Even now, when fuel prices are at an all time low the fuel surcharge which was added when the price of Jet A was at a maximum is still being charged to the customer. Based upon information available to and discussed by the Working Group, such a normalized charge could be as low as \$0.25 per passenger per flight delivered, or \$8.25 for the nitrogen plus a service charge of approximately

\$100 per aircraft per flight. Such an expense is literally peanuts and may be compared with other charges such as facility, \$5 per passenger, or security, \$10 per passenger maximum.

### **Conclusions**

The combustible fuel vapor and air mixture which appears in the ullage of HCWT's during a certain period of flight time, 33%, represents a safety risk. Nitrogen inerting eliminates this risk for a very minimal cost. The modification of the air transport system to implement this procedure may be done in a very intelligent, controlled manner. As the events of 11 September 2001 have shown, air crashes have many unforeseen consequences, and the air travel system has shown itself to have limited elasticity. The next HCWT explosion may well have extensive foreseen and unforeseen consequences. A measured, determined introduction of the nitrogen fuel tank inerting technology is imperative beginning immediately in order to enhance aviation safety.

## Appendix A

### An Alternative to OBIGGS

A solution has been developed for on-board inerting that directly addresses the issues raised by the FTIHWG's final report. In the report, the FTIHWG recognizes the safety benefit of on-board inerting in comparison to ground based inerting. The recommendation specifies that alternative technologies should be assessed which offer the safety benefits, but at lower cost and power consumption. One alternative offered to the FTIHWG, but not given serious consideration was the use of liquid nitrogen dewars for storage on board, with an automatic distribution system tied into the fuel tank's ullage. There are a number of benefits offered by such a design, which were not made clear in the FTIHWG's report:

- Substantial improvement in reliability over OBIGGS, which requires rotating equipment including a compressor.
- Substantial reduction in power requirements.
- Ability to service a range of flow requirements.
- Employment of higher purity nitrogen, therefore, about half the flow requirement.
- Control of ullage based on flammability as oxygen sensors are included in the design.
- Ability to redirect nitrogen flow for cabin fire suppression.

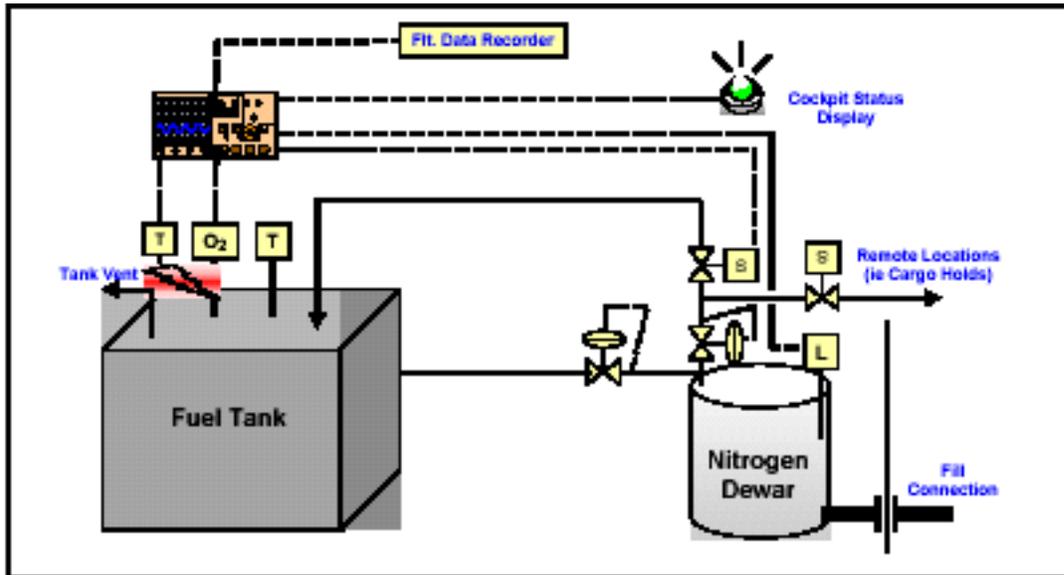
The power required to generate on-board nitrogen utilizing all of the three OBIGGS designs considered is unacceptable for today's fleet according the final report from the FTIHWG. It is well established that a significant amount of power is required for all modes of nitrogen generation, including pressure swing adsorption, air separating membranes and cryogenic distillation. While the concept of generating nitrogen on demand is appealing to the airline industry, the reality exists that this comes at a cost, specifically limited power resources on aircraft.

All modes of air separation require compressors to raise the pressure of the air being separated. In the case of pressure swing adsorption, differences in pressure are used to enable sieve material to separate nitrogen from air, then release impurities; specifically oxygen during lower pressure cycles. Pressure is required in membrane systems to drive oxygen and other impurities through the polymeric membrane material allowing higher purity nitrogen to pass though the air separation modules, ASM. Finally, cryogenic distillation requires very high pressure to generate the high expansion rate required to cool air to cryogenic temperatures required for separation.

In all three cases, compressors are required to drive the separation process. Compressors have two serious issues associated with them as spelled out in the FTIHWG's report; reliability and power.

Liquid nitrogen used on-board, does not carry these burdens. As indicated above, manufacture of liquid nitrogen does require a considerable amount of power; in fact more than what is required for the three technologies discussed above. The differentiating factor, however, is that the power does not need to be provided on the aircraft.

Liquid nitrogen is supplied to a wide range of industries through a network of Air Separation Units (ASU) spread throughout North America and the rest of the world. Once made, liquid nitrogen can be stored in specially insulated vessels for weeks at a time. Thousands of businesses have their nitrogen delivered as a liquid and store it in these vessels so they can use the liquid or vaporized nitrogen gas as needed. The same concept is practical for the airline industry; albeit with special considerations.



Liquid nitrogen has a purity of 99.997%, therefore the amount of nitrogen required for inerting is reduced substantially. The OBIGGS systems discussed in the FTIHWG report generate nitrogen with a purity of 95%. The volume of nitrogen required using lower purity nitrogen is about 75% higher than would be required for liquid nitrogen. It is argued that the cost of inerting with higher purity nitrogen is lower than for lower purity (see *"The Effect of Nitrogen Purity on Ullage Washing"* below).

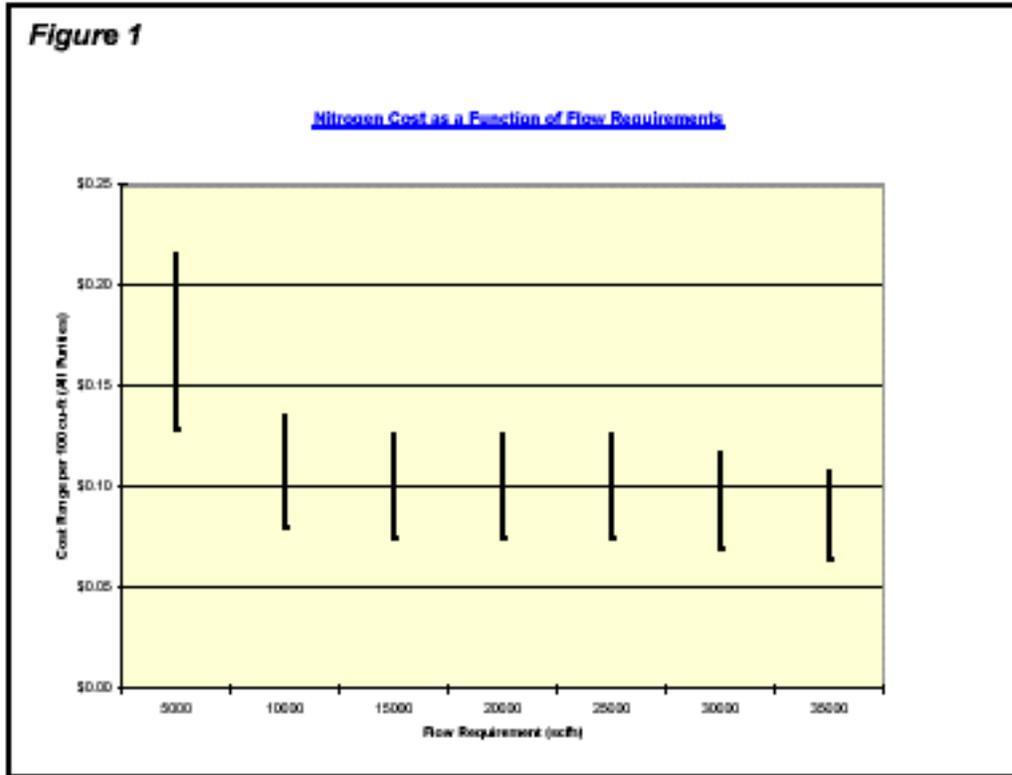
## Appendix B

### The Effect of Nitrogen Purity on Ullage Washing

Nitrogen generators can deliver a wide range of flow and purity. As a general rule, the unit cost for nitrogen decreases as the flow requirements increase and the unit cost increases as the purity increases. The cost of nitrogen is also sensitive to energy costs and atmospheric conditions. It is normally assumed that the added cost of higher purity nitrogen (98 to 99% N<sub>2</sub>) is cost prohibitive compared to the less expensive nitrogen in the 95 to 96% purity range. Analysis of nitrogen costs over a range on purity has found that the opposite is true. When the total cost of inerting is considered, higher purity nitrogen provides lower cost ullage washing, while reducing the time required to inert and reducing fuel vapor emissions resulting from the process. The following represents the results of the analysis which was derived from purge calculations and a matrix of nitrogen costs.

*Figure 1* represents the range of costs for nitrogen generated on site (either membrane or PSA) as a function of the average flow requirement in std cu-ft/hr. The curves illustrate that the unit cost for nitrogen (\$ per 100 cu-ft) steadily decreases as the average flow requirements increase. The curve only represents a trend, which is affected by the selection of equipment and the usage pattern. Equipment offered by industrial gas suppliers cover a range of flows. The efficiency of the equipment can vary depending on which part of the operating curve the equipment is operating. The most economic selection of nitrogen generating equipment can be made by the industrial gas manufacturers, and are typically offered as leased equipment.

The prices cover a wide range, due to variations in equipment cost, and purity. The prices shown below assume a cost of \$.075 per kW-hr. Higher or lower electrical rates will affect the cost. The costs represented above do not include liquid nitrogen.

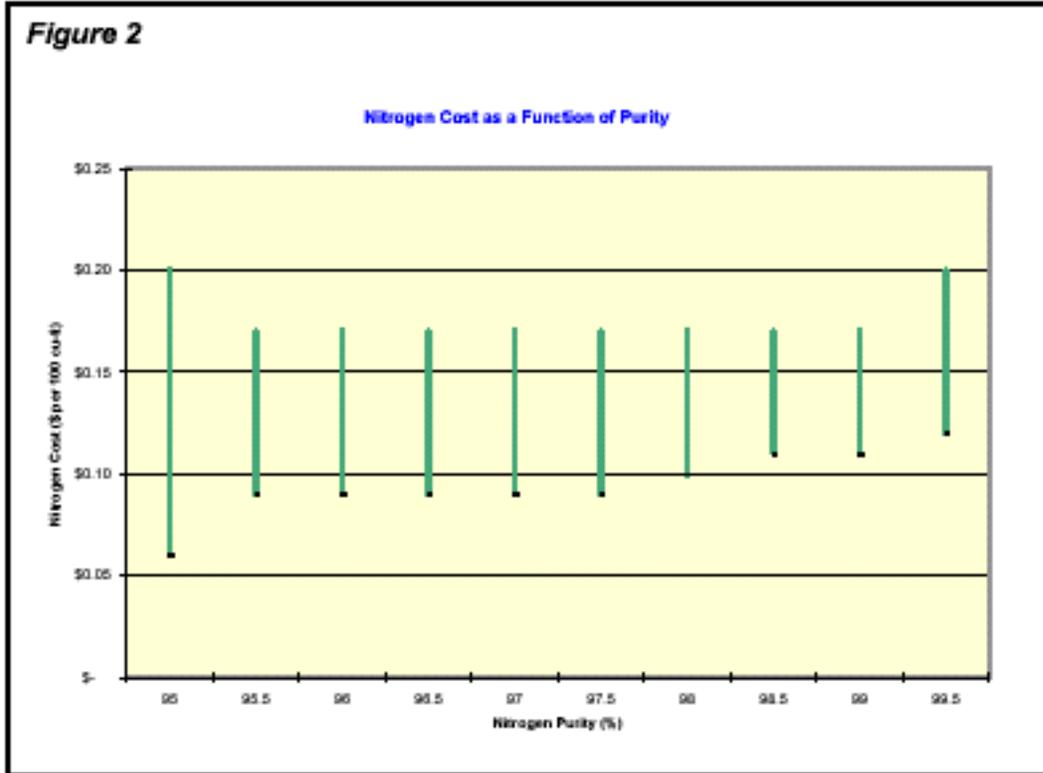


**Figure 1. Nitrogen Cost as a Function of Flow Requirements**

*Figure 2* shows the effect that purity has on nitrogen cost. For every purity value, a range of costs is shown to reflect flow requirements as well as equipment lease costs. It can be seen that the cost of nitrogen increases as the purity level increases. To generate nitrogen of higher purity, either larger equipment is required or the energy requirements are higher due to the demands of the higher purity cycles. Often the same generating equipment can produce nitrogen at a range of purity levels at a sacrifice of energy or capacity. The unit cost for nitrogen is affected in either case.

The value of nitrogen in inerting applications increases considerably as purity increases. There is a significant reduction in the nitrogen volume requirement for high purity compared to low purity nitrogen. Inerting flow is often expressed as volume of inerting nitrogen required for a given ullage volume (V/V) or the number of equivalent ullage volumes of nitrogen required to inert the ullage. The definition of inert varies considerably from application to application. For ullage washing, 8% O<sub>2</sub> is the target concentration.

Test data have indicated that the risk of flammability for Jet-A fuel is insignificant below 10% O<sub>2</sub>. As a practical matter, the Ground Based Design team has determined that the target O<sub>2</sub> concentration for ground based inerting is 8%. As there is a delay between the inerting process and takeoff, 8% ensures that the ullage will remain inert throughout the initial stages of the flight cycle.



**Figure 2 Nitrogen Cost as a Function of Purity**

The theoretical volume of gas required to inert the ullage will be a function of the ullage O<sub>2</sub> concentration prior to inerting, the target O<sub>2</sub> concentration and the O<sub>2</sub> concentration of the nitrogen used to inert.

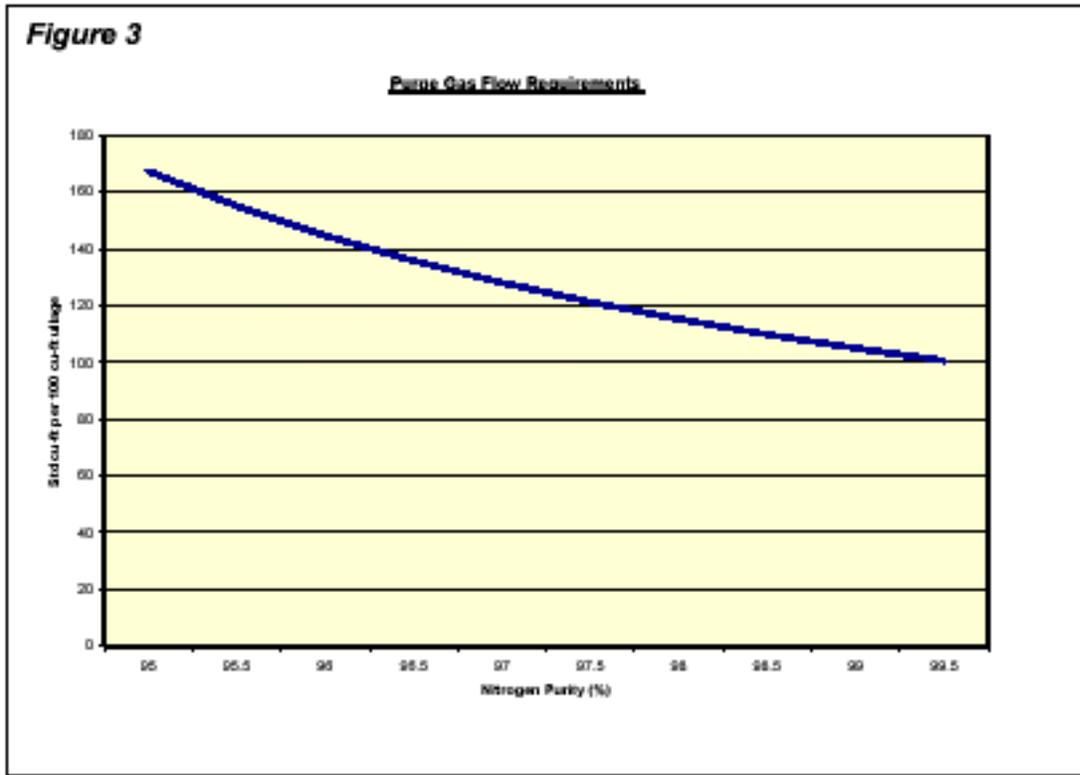
The relationship between nitrogen purity and volume required is represented by a logarithmic curve. The following formula is used:

$$n = \ln\left(\frac{C_o - C_p}{C_t - C_p}\right)$$

where:

- n = number of ullage volumes of N<sub>2</sub> required for purge
- C<sub>o</sub> = Initial Oxygen concentration in ullage (%)
- C<sub>t</sub> = Final (or target) Oxygen concentration in ullage (%)
- C<sub>p</sub> = Oxygen concentration of purge gas (%)

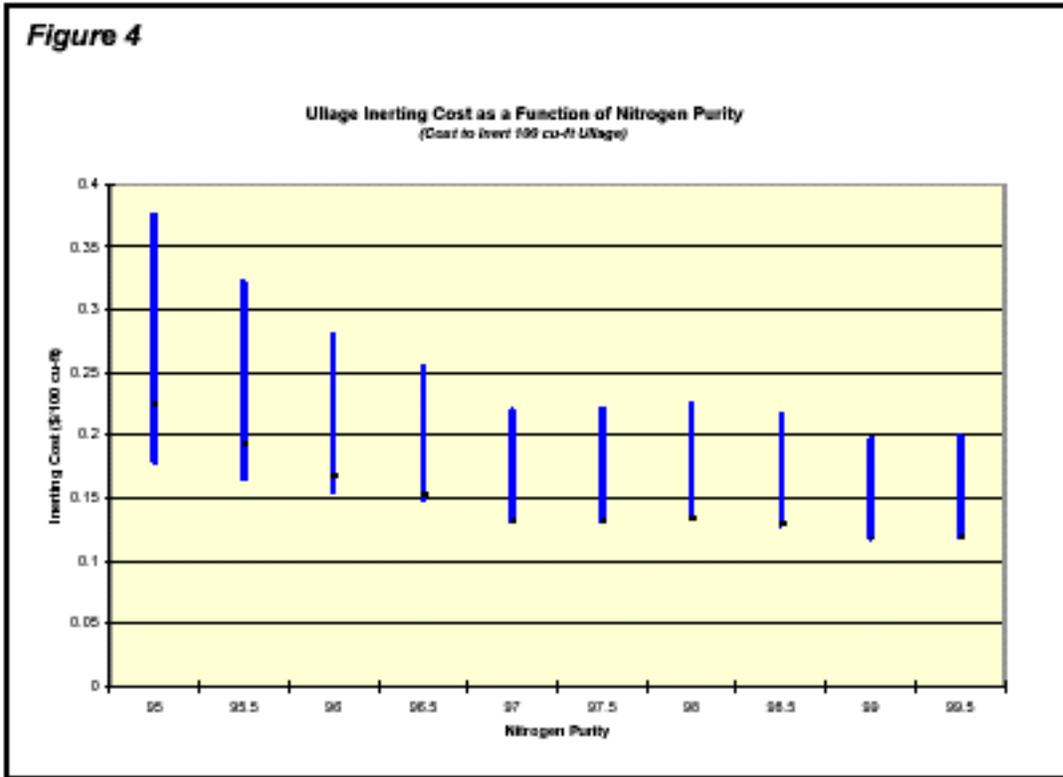
**Figure 3** represents the relationship between purge gas purity and the equivalent ullage volume in standard cu-ft required to reduce the O<sub>2</sub> concentration from 21% to 8% for an ullage of 100 std cu-ft



**Figure 3 Purge Gas Flow Requirements**

The curve shows that when the purge gas is 95% N<sub>2</sub>, approximately 170 cu-ft of purge gas is required to inert a 100 cu-ft ullage. On the other extreme, only 100 cu-ft is required to inert the same ullage to 8% using nitrogen with a purity of 99.5%. This represents a 41% reduction in purge gas volume required. The added benefit of higher purity nitrogen offsets the added cost as **Figure 4** illustrates. The curve represents the theoretical volume requirement assuming efficient mixing of the inerting gas with the ullage. Typically, the efficiency of the inerting process is less than perfect and is affected adversely by such factors as geometry, purge nozzle configuration and location and the vent location. As a general rule, actual purge gas requirements can be expected to exceed the theoretical volumes.

It is shown in **Figure 4** that the cost of inerting actually decreases as the purity of nitrogen is increased. Comparing the minimum costs shown for each purity, the cost to inert a 100 cu-ft ullage with 95% nitrogen is \$0.18 versus \$0.12 when nitrogen of 99% purity is used. The difference in cost is attributed to the significant reduction in nitrogen required. The plot represented in **Figure 4** was created by multiplying the required volume of nitrogen required (from **Figure 3**) by the cost per cu-ft (from **Figure 2**).



**Figure 4 Ullage Inerting Cost as a Function of Nitrogen Purity**  
*(Cost to Inert 100 cu-ft Ullage)*

For a given flow rate, higher purity nitrogen has the added benefit of reducing the amount of time required to inert an ullage space. The family of curves shown in Figure 5 shows the effect nitrogen purity has the time required to inert. Each curve represents inerting time as a function of purity. The time to inert was determined using the Ground Based Design team's equipment design basis of 251 scfm. Three curves are used to represent the classifications of aircraft identified by the ARAC to represent the groups of aircraft subject to the inerting procedure.

The first aircraft group, identified as "Commuter" represents the average fuel tank size for commuter aircraft. In this case, the average fuel tank is 3,000 gallons for an equivalent tank volume of 401 cu-ft. The inerting time using 95% nitrogen is 3 minutes, 24 seconds. Using 99% purity, the inerting time is 2 minutes, 6 seconds.

The next curve represents inerting time for the group identified as "Medium Transport" or "Single Aisle" Aircraft. For this group, the average tank size was assumed to be 10,000 gallons or 1,337 cu-ft. The inerting time ranges from 8 minutes 57 seconds using 95% nitrogen to a low of 5 minutes, 36 seconds using 99% nitrogen.

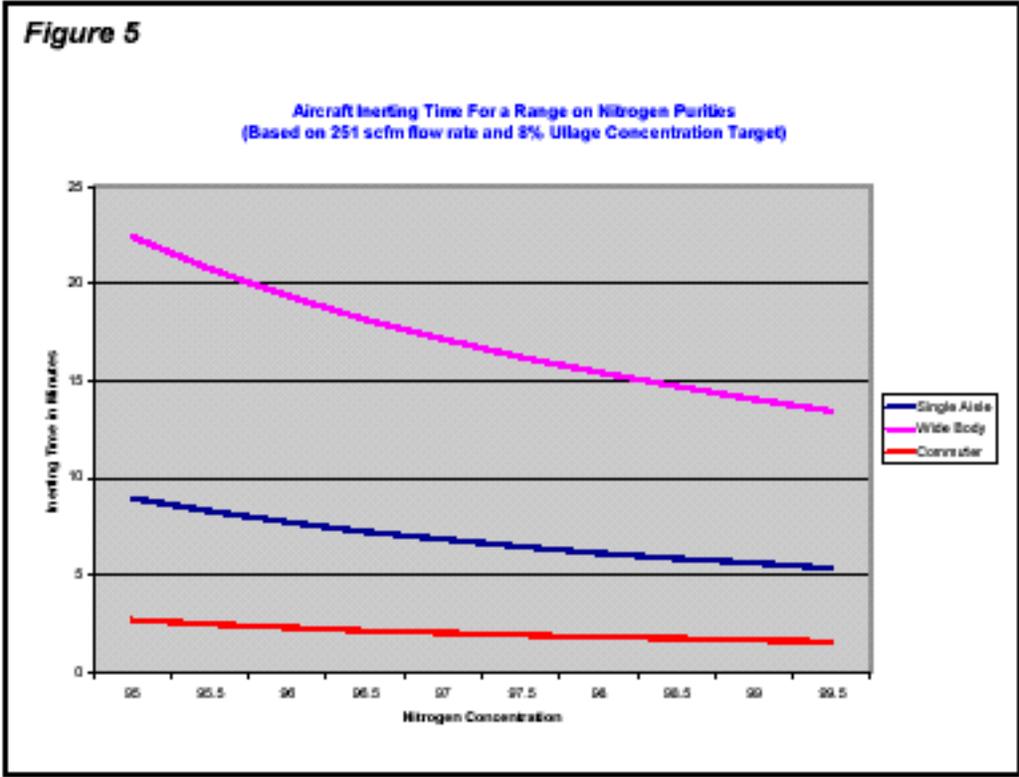
Finally, the "Large Transport" or "Wide Body" aircraft class has an average fuel tank capacity of 25,000 gallons or 3342 cu-ft. The range of times required for inerting goes from 22 minutes 23 seconds using 95% purity nitrogen to 14 minutes, 2 seconds using 99% nitrogen.

The value of reducing the amount of time required to inert fuel tanks has not been quantified, however, the Ground Based Inerting Design team included among its assumptions that the process will not affect turn time. The design for aircraft accommodates the flow rates specified in this document. To reduce the volume of nitrogen required for inerting, and thus the time required nitrogen purity could be increased from the originally proposed 95% to 99%. The benefits are threefold; lower cost, reduced time to inert and reduced emissions.

In addition, the volume and time can be further reduced by inerting only the ullage. The curves above assume inerting with a volume equivalent to the volume of an empty fuel tank. This greatly simplifies the process, and decreases the likelihood that errors can be made. In many cases, however, nitrogen is wasted, the process takes considerably longer than necessary, and fuel vapor emissions are increased substantially.

Properly inerting the fuel tank to address only the volume of the ullage can be done if the oxygen concentration of the ullage is measured. Oxygen analyzers added to the fuel tank or at the fuel tank's vent can provide a reasonable estimate of the oxygen concentration in the fuel tank. Knowing the oxygen concentration can significantly reduce the nitrogen requirement, and in addition provide a direct measurement of the effects of inerting.

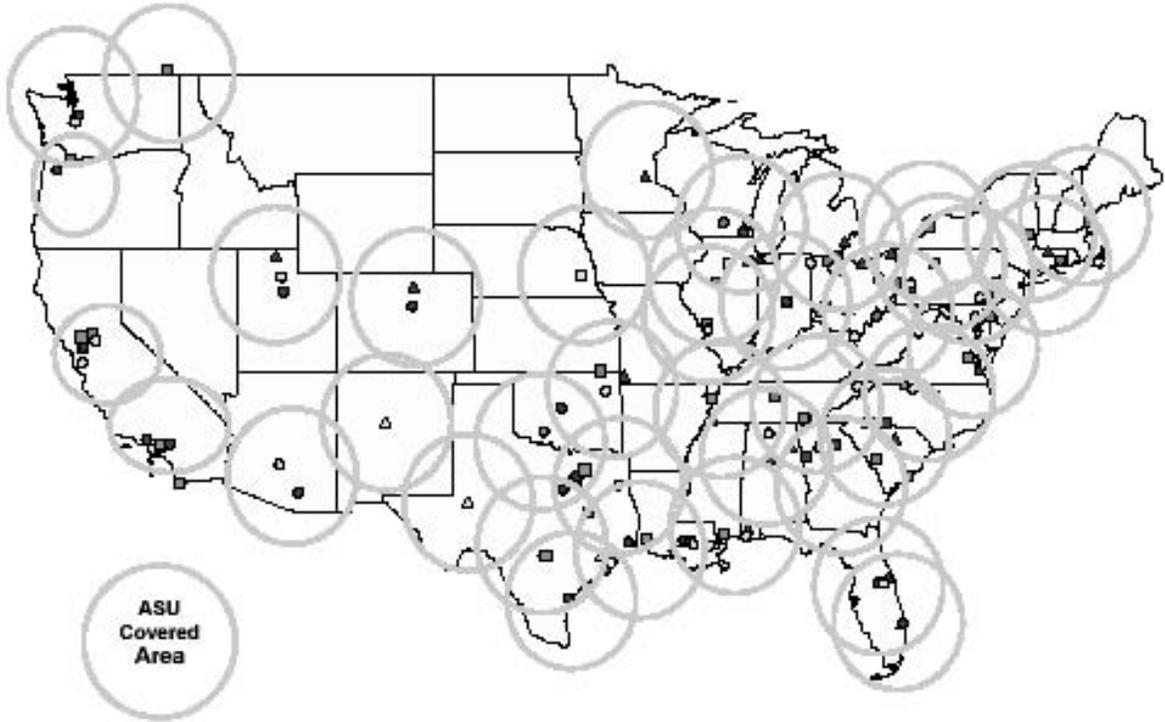
The overall cost of inerting fuel tank ullage is driven by a number of factors including the flow rate, purity, method of supply, nitrogen cost and ullage volume. The analysis of this matrix of data has determined that higher purity nitrogen provides the most cost effective purge gas. Nitrogen can be generated at airport facilities at the full range (95 to 99%) of purity analyzed using membrane generators or Pressure Swing Adsorption (PSA) generators. The design for the distribution manifold and supporting components specified for retrofit of aircraft will limit the flow rate and pressure available for the inerting process. As turn time and cost become more critical, there are alternatives to optimize the process including higher purity nitrogen and oxygen measurement.



**Figure 5 Aircraft Inerting Time For a Range on Nitrogen Purities**  
(Based on 251 scfm flow rate and 8% Ullage Concentration Target)

## Appendix C

### ASU Plant Locations for all Industrial Gases Companies USA



**RE; Letter to Docket**

Comments from ALPA representative on working group

February 3, 2002

To all concerned:

Due to the controversy surrounding the overall conclusions of this working group, I feel it is necessary to better explain my reasoning for reaching general consensus with the group. First of all, considering the fact that on a daily basis we are traveling on these aircraft transporting family, friends, and countless thousands of others who have trusted their lives to us, there is no safety measure in which I would meet with opposition. Inerting is without a doubt an excellent method which is technically possible, to help prevent fuel tank explosions in the years to come. However, in addition to determining whether or not inerting was possible, we were also tasked to determine if it could be implemented in a financially responsible manner utilizing an assigned cost benefit model. Unfortunately, as the body of the report indicates, it became painstakingly clear that the costs were going to far exceed the benefit as it was directed to be calculated. The problem, in my opinion, was the ground rules in which we were given to work. We were free to calculate costs in a manner we deemed to be the most realistic in our best professional opinions. However, the benefit calculation was basically set forth using the predetermined DOT figure of 2.7 million dollars per human life lost. Although I feel this figure is pathetically low, considering the many long-term aspects involved, it does represent the value society has deemed to be reasonable.

Although the cost side of the equation may vary greatly in either direction according to many variables, it does represent our reasonable best guess utilizing some of the most experienced individuals in the industry. If you would take the time to read the report in full, you would find many recommendations to continue research into inerting to improve the efficiency of the systems. In my opinion, the onboard systems on future design and future production airplanes show great potential. Due to the time constraints of our study, we were basically limited to one design, which would be used on all aircraft. In reality, future design/future production aircraft could be modified on the drawing board to be compatible with the demands of an inerting system. This could greatly alleviate both the installation and maintenance costs of the on board system we studied.

I urge the FAA to take these factors into consideration, especially with regard to the benefit side of the equation. Please understand that this working group simply operated within the ground rules in which we were tasked. Unfortunately, unless society mandates a change in the way we value human life; our budget will always fall far short of what is required to fund this excellent safety enhancement.

Sincerely,

Brian H. Sutton  
Airline Pilots Association  
TWA-LLC Boeing 767 First Officer



**INTERNATIONAL ASSOCIATION OF MACHINISTS AND AEROSPACE WORKERS**

**District 141-M OFFICE OF Flight Safety**

**US Airways, Inc. Pittsburgh International Airport,**

**Hangar 3 Pit D305 Pittsburgh, PA. 15231**

**Phone (412) 472-7829 Fax (412) 472-4620**

Mr. John J. Hiles

IAMAW & DISTRICT 141-M

Greater Pittsburgh International Airport

US Airways Hangar #3 Pit D305

Pittsburgh, PA. 15231

March 29, 2002

**CERTIFIED MAIL RETURN RECEIPT REQUESTED**

Mr. Anthony Fazio

US Department of Transportation

Federal Aviation Administration

800 Independence Ave. SW

ARM -1 Room 810

Washington, DC. 20591

RE: Letter to FAA Docket relating to FTIHWG activity

Dear Mr. Fazio:

To help clarify the concerns of my colleagues on how and why a consensus and / or general consensus was reached, I would like to submit the following comments and recommendations to the FAA for further review. These comments should not only help explain how I personally reasoned with the general consensus as a working group member, but also to provide personal recommendations for future fuel tank inerting studies. Please don't consider this as a dissenting opinion because it is not, as I along with the IAMAW believe fuel tank inerting is a great method of reducing fuel tank explosions in years to come. This is generated more from a personal observation more than anything, and should help to clarify the above mentioned concerns and future recommendations.

When I was approached to be the International Association of Machinists and Aerospace Workers (IAMAW) Representative on the Fuel Tank Inerting Harmonization Working Group (FTIHWG), I jumped at the opportunity. I jumped at the opportunity because one of my primary responsibilities is to look out for our airplane maintainers in this industry, along with promoting and enhancing the safety of commercial airplane flight with respect to the mechanical side of the house. I also felt I had a great deal to offer considering I had over 20 years of experience maintaining commercial aircraft Domestically and Internationally prior to my present position with the IAMAW. I also participated because the IAMAW was elated that the government was looking at new ways to improve airplane fuel tank safety using inerting techniques. I later found out that was a common denominator to many in the group, who I might add accomplished this additional work along with their normal work duties.

It didn't take long to realize that once we as the Working Group were assembled, up and running, together we had jointly put together a fairly large group of exceptionally experienced people in separate task teams to assist us with this monumental task. It is my opinion that given the

time guidelines provided by the FAA, the study assumptions and conclusions provided to us by these different groups was impressive to say the least. A wide range of professionals and probably some of the most experienced in the industry represented numerous groups not only from the USA, but also from Europe. These industry professionals should be commended for a job well done given the guidelines they had to follow, but unfortunately to the best of my knowledge that has yet to happen!

Near the end of this project, the Working Group had numerous conference calls and meetings to try and gain consensus on the conclusions and assumptions provided to us by the task teams. Although every HWG member did not fully agree with the initial guidelines, including myself, compounded by the provided data from the task teams as time went along, it was understood that all of the Working Group members concerns would be discussed in detail. This was so we could comfortably reach a fair and equitable conclusion for ultimately a group general consensus (worst case scenario as far as I was concerned).

I will add that many hours were spent discussing numerous concerns from the HWG in many cities across the US and abroad. In what I thought was to be our final working group meeting in Seattle, June of 2001, it was understood and agreed to by all HWG members, that when the meeting did officially close we would have a general consensus by every member concerning all the issues discussed.

During this time of discussion, it became clear that because of the cost benefit guidelines given to us by the FAA, we would by long odds exceed the benefits outlined by the directions provided to us by the FAA. Given these guidelines required the working group to make reasonable, but professional assumptions with several of the issues discussed. Unfortunately, no matter how many reasonable assumptions were made, it became clear that no matter how you looked at it, the cost was going to far exceed the benefit!

Due to the time constraints of this study, proprietary issues, lack of current data other than using data from the previous 1998 Fuel Tank Inerting ARAC, along with the DOT lost human life figure, (which I personally believe to be pitiful), didn't leave much choice but to side with a general consensus if we were to play by the rules. As mentioned earlier, it is unfortunate that assumptions had to be made to come to certain conclusions. In defense of this, these assumptions in my opinion were very optimistic, as the full report indicates. It is my belief that these assumptions actually helped to reduce the cost of implementing an inerting system while decreasing the implementation time, all the while knowing every attempt and effort was made to represent the safety benefits, technical requirements, regulatory issues, operational issues and associated costs.

After the August 2001 Ex-Com meeting where the final report was presented, many questions were generated from certain ex-com members and public interest groups to the HWG. I would like to add that even though many of these questions were in my opinion way outside the guidelines set force in the TOR, and also the scope of our assignment, we as a working group addressed and answered every question to the best of our abilities.

As somewhat painstaking as this is to say, it is my professional opinion that the FAA keep this working group together to continue with the recommendations set forth within the report. This group now has the knowledge and understanding to get directly to work without muddying through two separate Fuel Tank Inerting ARAC studies before getting started.

I would also recommend that since we now have two fuel tank inerting studies using non – specific airplanes referred to as generic airplanes in the reports, the time has come to start using actual aircraft (i.e. Boeing, Airbus, Gulfstream). It is also our recommendation that the FAA take a long look at the human life figure, and re-evaluate the 2.7 million dollar figure (recently increased slightly to 3.1 million) generated from the 1991 highway accident loss of life study. By doing so the cost benefit could then be modified to show the more realistic costs for current, in service, production and new airplane designs.

It is also our opinion that while employees of the FAA were very helpful during the working group meetings, it is our recommendation that the FAA be available for direction and advice, but that they not have an actual seat on future working groups. Lets get to the bottom of this once and for all and take a hard look at real in service airplanes, with realistic time and cost guidelines. We also believe that the FAA should produce a rule as soon as possible for all future design commercial aircraft, where as all future designs should be implemented with at least the basics to have fuel tank inerting capabilities. It is our belief that the reports to date provide enough data to start this process in motion.

I urge the FAA to continue with this worth while project and strongly consider the above mentioned concerns and recommendations, along with any others you may receive. I also ask that the FAA due it in as timely a manner as possible considering the length of time disclosed in the report to fully implement any type of future fuel tank inerting. Please include this letter into the docket relating to the recent activities for public record on Fuel Tank Inerting. A hard copy has been sent via US mail.

Sincerely,

John J. Hiles

Permanent FAA Committee

IAMAW

Cc: All Exec Comm

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 1

During the August 8, 2001, presentation to the ARAC Executive Committee, the FTIHWG Co-Chairs described the results of a recently completed Sensitivity Study that was based on varying the assumptions in the report's cost-benefit study. The specific inputs that were varied, the amount they were varied, and the results of the sensitivity study should be included in the text of the report - perhaps a table listing all of these would help to simplify and clarify the analysis. Further, any changes requested by Executive Committee members should also be included. It is suggested that these be placed in the Executive Summary as Section 1.2.

#### **Response:**

The Working Group agreed the entire document will not be reprinted with the changes because of the time and cost involved. The Ex-Com comments and the sensitivity analysis will be included in an addendum to the Executive Summary and limited changes will be made to the Executive Summary text.

### Question No. 2

The Executive Summary states the FTIHWG did not recommend any new regulatory text. Recommending regulatory text was part of the tasking statement. When asked about this during the August 8 Executive Committee meeting, one of the FTIHWG co-chairs stated there are recommendations in the text of the report for the FAA to consider if FAA should propose fuel tank flammability regulations based on fuel tank inerting. The Executive Summary should be revised to inform the reader where those recommendations can be found in the report.

#### **Response:**

The following text will be included here, as part of the addendum to the executive summary:  
"The FAA Tasking Statement for this ARAC FTIHWG study required that this Working Group "prepare a report to the FAA that provides recommended regulatory text for new rulemaking and the data needed for the FAA to evaluate the options for implementing new regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new production, and new type design transport category airplanes. Although the Working Group did not recommend new rulemaking, the Working Group did conduct an evaluation of existing regulations, advisory material and continued airworthiness instructions concerning the elimination or reduction of the flammable environment in the airplane using a nitrogen inerting system. The Working Group found that 14 CFR Part 25 and 14 CFR Parts 91, 121, 125, 129 and 139 would be significantly impacted by the introduction of a fuel tank inerting system and that the 14 CFR changes were linked to the inerting system concept. For this reason, the Working Group recommended that a dedicated paragraph, "Fuel Tank Inerting System" / "Operation of Fuel Tank Inerting System", be incorporated in each effected 14 CFR part and that associated guidance material should be developed. The Working Group then developed preliminary regulatory and guidance material proposals, as requested by the FAA. The Working Group recommended that these proposals be refined if and when a practicable inerting system is developed and integrated on a certified aircraft. Specific details concerning regulatory and guidance material development is found in Section 12.0."

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 3

The tasking statement required the Fuel Tank Inerting Harmonization Working Group "prepare a report to the FAA that provides recommended regulatory text for new rulemaking and the data needed for the FAA to evaluate the options for implementing new regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new production, and new type design transport category airplanes." The report discusses the results of the cost-benefit study performed by the FTIHWG, but it does not contain all the data required under the task. Although the appendices to the report, the Team Reports, include aggregate cost estimates and much of the supporting data, they do not provide all of the data used to support those aggregate estimates. Specifically, there is no explanation of the basis for the estimated engineering hours for the certification costs, no description of the components and their individual costs for the major supplier parts and the major assemblies cost categories, and the costs involved in the service bulletin and parts kit estimates are not adequately explained. Assumptions used as the basis for each of the economic assessments in the document should be summarized at the front of each section, so the FAA and the public can easily understand the basis for the assessment.

#### **Response:**

Because of time and resource constraints the Working Group was not able to amend each section of the final report with the cost assumptions.

The certification detailed cost breakdown and the associated assumptions are found in Appendix I. The supplier part and major assembly costs are listed in Appendix D, (On-Board Design). The airport costs are included in Appendix E and the airline operation, maintenance and installation costs are included Appendix F. To develop a more detailed cost assessment, the Working Group recommends that the FAA work with airplane and equipment manufacturers to evaluate the costs on specific airplane models.

### Question No. 4

The estimated costs appear to include service bulletin and parts kits costs for airplanes modified during production (new production airplanes) as well as retrofit of in-service airplanes. Why would each individual (future) new production airplane require a service bulletin and a kit of parts? Why would the parts cost be at the same level as the costs for a retrofit of an in-service airplane? The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

#### **Response:**

It is assumed that the writer's question addresses the standard format used in Figures G9-G63. The FTIHWG agrees that a Service Bulletin would not be issued for in-production or future production airplanes. However, the costs associated with activities such as certification, engineering drawings, records and technical publications, warranty and customer support, parts receiving and inspection, inventory planning, tooling, materials and supplier parts costs are required for either a production change or a Service Bulletin. For a production installation, it was assumed that the cost savings from not drafting a Service Bulletin is offset by the additional costs of the manufacturing planning, production illustrations and engineering support to the shop, system checks

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

and inspections required for a production incorporation. It was also assumed that the component and material costs were the same for the new, production and in-service generic category airplanes. This assumption simplified the economic calculations. The FTIHWG does not believe it is valid to reduce the Sensitivity Analysis based on these factors mentioned in this question.

### Question No. 5

The Economic and Forecasting team used a spreadsheet to calculate the estimated costs of the inerting systems provided in the report. This spreadsheet needs to part of the report so it is available to both the FAA and the public.

#### **Response**

A public version of the spreadsheet will be given to the FAA to include with the final report. The spreadsheet allows the user to vary cost and benefit values, fleet sizes, and other parameters and compare the results against the baseline values.

### Question No. 6

The report states neither the bleed air nor the electrical energy available on in-service airplane designs is adequate to power an on-board fuel tank inerting system. The lack of available bleed air led to the requirement for an air compressor on all on-board designs. However, there are no data in the report to support this conclusion. For bleed air, supporting data should include bleed air available from the engines and bleed air requirements. For electrical energy available, supporting data should include consideration of load shedding priorities. For both bleed air and electrical energy, supporting data should show during which flight and ground conditions the availability is limited.

#### **Response:**

The Working Group's conclusion that in-service and current production airplanes lack the bleed and electrical power to meet the demands of an on-board inerting system was based solely on statements made by representatives of airframe manufactures and operators during the Working Group discussions. No data was presented to the Working Group to support these conclusions. The study evaluated six generic airplane sizes. Engine bleed and electrical power is airplane specific information. Airplanes are designed and certificated to supply the required bleed and electrical power under normal and certain failure conditions. On some airplanes, combinations of these conditions, such as engine idle, hot day temperatures or engine-out operation require all of the available engine bleed or electrical power. The Working Group assumed that additional bleed and electrical power demands could degrade functions such as anti-icing capability, cabin pressure or temperature control or air-driven pump performance. The actual effects of additional bleed and power extraction required to supply on board fuel tank inerting systems should be evaluated further by the FAA on an airplane model-by-model basis.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 7

The FAA has been evaluating a fuel tank inerting/cargo compartment fire suppression system based on a single on-board nitrogen generating system. This was discussed during the FTIHWG team meetings and also several public research and development meetings that included representatives of the aerospace industry. Evaluation of this combined system was not part of the tasking statement and the on-board task team chose not to voluntarily evaluate it as part of the work performed in this study. However, such a system would eliminate a significant amount of weight from existing airplanes by removing the existing (long duration) Halon based cargo compartment fire suppression system used to keep cargo compartment fires from re-igniting after a cargo compartment fire has been put out by another Halon "knock-down" system. What would the affect be on a new airplane design if the weight of such an inerting system were offset by not requiring the installation of a long duration Halon cargo compartment fire suppression system? The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

#### **Response:**

Although a single fuel tank inerting/cargo compartment fire suppression system was discussed conceptually, no information, design, analytical, application or test data was presented to the FTIHWG on such a system. The FTIHWG did not have the time or resources to combine the two system designs and conduct trades studies to optimize the system design. Also, the fuel tank inerting sensitivity analysis spreadsheet lacks the data to perform a combined system cost calculation. The Working Group believes that in a new airplane design, it is possible some synergy of design may be achieved by incorporating a combined system. The FAA should further study this concept.

### Question No. 8

The fuel tank volume used for the generic large transport airplane, which is the basis for the cost study of inerting large transports, is larger than the actual fuel tank volume of most in-service large transport airplanes. This results in a higher cost estimate for inerting large transport airplanes than would be calculated if the actual mix of in-service fuel tank volumes were used in the cost study. Appendix D of the report does provides parametric sizing curves to determine equipment requirements based on selecting a fuel tank size and airplane turnaround time which will enable determining equipment sizes for actual in-service tank. However, the Executive Summary of the report should acknowledge this limitation on the cost data presented in the report.

#### **Response:**

The question makes a point that the generalized aircraft used in the study could overstate the large fuel tank volumes thus overstating the costs of providing nitrogen for inerting this class of airplane. The Team acknowledges that the use of generic airplanes will overstate or understate the costs and benefits of airplanes within each of the six generic categories. The working group agreed to use the same generic airplanes categories that were used by the 1998 ARAC fuel tank study. Errors from using the generic airplanes are small and tend to compensate each other. This information will be included in the revised Executive Summary.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 9

Section 1.9 of the FTIHWG report estimates that 24 to 81 lives may be lost as a result of nitrogen inerting of fuel tanks over the 2005 - 2020 study period. The text implies these lives would be lost as a result of exposure to inert (oxygen depleted) atmosphere inside fuel tanks during fuel tank system maintenance. Occupational Safety and Health Administration (OSHA) requirements and fuel service industry practices for preparing fuel tanks for maintenance require ventilating the tank with air until the oxygen level is above a minimum limit value and the hydrocarbon concentration is well below the lower explosive limit. In addition maintenance personnel are already required to wear oxygen and hydrocarbon concentration detectors with alarms when entering fuel tanks. Therefore, the statements in the report about increased deaths as a result of fuel tank inerting should be removed from the Executive Summary and the costs for additional confined space training and safety equipment should not be included in the report or the Sensitivity Analysis.

### **Response:**

The FTIHWG reached general consensus that it should acknowledge the hazards associated with nitrogen inerting systems and the need for further study in the Executive Summary. As stated in the first sentence of paragraph 2 of Section 1.9, "The FTIHWG lacks the expertise to assess these risks with confidence". However, the available historical data does suggest that, despite the best intentions, procedures and regulations, accidental fatalities do happen. As already indicated, since the FTIHWG do not consider themselves sufficiently expert to evaluate the impact, and the cost associated with these estimated fatalities were not included in any of the statistics used to generate the study costs or the costs in the Sensitivity Analysis. The costs for additional training and equipment were listed in Appendix F but were not included in the cost estimates or sensitivity analysis.

### Question No. 10

Appendix G, page G-1, states the airplane weight penalty costs are based on the 1998 (FTIHWG) ARAC study. The cost factor driving these estimates are estimates of the number of flights that would face distance and weight limitations because these earlier systems were much heavier than the systems described in the 2001 FTIHWG report. Those estimated losses were, in turn, built into the fuel cost estimate. A more appropriate value for the lower weights of the inerting design concepts presented in the 2001 FTIHWG report was to be used in the Sensitivity Analysis. This lower weight penalty cost should be part of the documentation of the Sensitivity Analysis. The table below compares the weight penalty used in the report and the Sensitivity Analysis.

<b>Generic Airplane Size</b>	<b>\$ Per 1,000 lb.</b>	<b>Sensitivity Analysis</b>
Large (Generic) Transport	\$165,532	25.5 gal/lb.
Medium (Generic) Transport	\$131,802	26.5 gal/lb.
Small (Generic) Transport	\$62,004	7.4 gal/lb.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Response:

The question addresses weight penalties in the sensitivity analyses. It will be included here as part of the addendum to the Executive Summary.

### Question No. 11

The report estimates the airplane turnaround time for each generic airplane category. Appendix F (page F-27) the report then bases the mean time between failure (MTBF) calculations using a much longer turnaround. This creates an unrealistically high rate of failures and generates high estimated maintenance cost. The Sensitivity Analysis should use MTBF calculations based on the same turnaround times used in the equipment sizing analysis.

### Response:

This question pertains to the on-board ground system sizing and usage. The minimum turn times used in the study were determined using actual operating data obtained from the operators. Operators all have a minimum amount of time required to turn an aircraft between flights for each aircraft type in their operation. This "minimum" turn time is used in developing their operations flight schedules. Some operators regularly schedule their flights using minimum turn times. Others simply use the "minimum" turn time as a benchmark to make sure that sufficient time is included in their schedules to turn the aircraft. Early in this study the Working Group concluded that the inerting process must not increase the aircraft turn times because of significant impact on airport infrastructure and airline operations. As a result, the minimum turn times for each aircraft category were determined and used as a design parameter in system sizing to ensure that the inerting system could inert the fuel tanks within the minimum turn time.

However, not all flights are turned in the minimum turn times. It was assumed that the on-board ground system would operate during the time the airplane was at the gate. To accurately determine the system reliability the average operating time was used based on an average turn time. To estimate the operating time for a system based on the minimum turn time which was a lower limit design parameter would severely underestimate the average system operating time and therefore the operating costs. However, an automatic shut-off feature could be added to the control system of the on-board ground systems to minimize their running time.

In addition, this question assumes that operating time is the only factor effecting the MTBUR and MTBF of a component. In fact depending on the type of component operating cycles and exposure to environmental factors can have a larger influence on component MTBF. It is true that operating time is a significant factor in the MTBF for a motor or compressor. But it is also true that operating cycles and exposure to environmental factors have a much larger effect on components such as valves, seals, ducting, wiring etc. Because turn time is not a factor on the full OBIGGS systems we have looked at the sensitivity of the reliability data for the GBI and OBC systems. The OBC system has three components that would be significantly effected by decreasing the operating time. Those components would be the compressor, the cooling fan, and the air separation module. Decreasing the operating time for these components by 50% would double their MTBF. However, it would only increase the System MTBF by ~9%, from 960 hrs to 1038 hrs. A similar benefit would be realized in the corresponding System Annual Failure rates and Unscheduled Labor Hours to maintain the systems. The reliability of all of the components in the Ground Based Inerting system are primarily effected by component

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

cycles not operating time and therefore changing the operating time would have little or no effect on system MTBF.

### Question No. 12

The cost estimate is based on modification of a portion of the in-service fleet performed during scheduled heavy ('D') checks and another portion of the fleet modified by taking the airplanes out of service dedicated for "non-scheduled" modification. The report should justify the need for modifications outside the scheduled heavy check time period. The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

#### **Response:**

After evaluating the scope of the modifications, the Maintenance and Operations team concluded that most operators would not be able to schedule incorporation of the inerting systems during an airplane's regular heavy maintenance visit. Because it is very expensive to have aircraft out of service for any amount of time, airlines put a lot of effort into carefully planning the work package. The goal is to maximize the efficiency of the work package and use of the facilities thereby minimizing the time out of service. In part, this means utilizing enough technicians to accomplish the most concurrent work possible without having one task interfere with another. An evaluation of the modification work package by the Maintenance & Operations Task Team determined that incorporation of the modification into a heavy check work package would result in a significant extension to the length of the check. The amount of time between aircraft heavy checks is driven by calendar days and flying time. Once the aircraft runs out of time it must be taken out of service until the heavy check can be accomplished. Most operators' heavy check facilities are tightly scheduled and a significant increase in the length of the check would force the operator to contract out heavy checks or ground the aircraft. With the scope of this modification, it is likely that many operators would opt to avoid disrupting the efficiency of the heavy check line by accomplishing the modification in dedicated modification lines or by contracting the modification out to other maintenance facilities. This eliminates the risk of grounding multiple aircraft by backing up a "heavy check" maintenance facility line.

### Question No. 13

When modified during a scheduled heavy check, the report states the airline will be required to extend the time for the inerting modification by 7 to 9 additional days even for a ground based inerting manifold installation. The reason given is the airline can not perform other maintenance on the airplane when modifying the fuel tank. A more detailed justification for this reason should be provided. A large portion of the installation is work performed outside the tank. Also, work can be performed on the aircraft during fuel tank modifications provided it is done in accordance with the lockout, tag-out procedures in place. The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

#### **Response:**

As discussed earlier, it is very expensive to have aircraft out of service for any amount of time, therefore airlines typically put a lot of effort into carefully planning the check work package. The goal is to maximize the

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

efficiency of the work package and use of the facilities thereby minimizing the time out of service. In part, this means utilizing enough technicians to accomplish the most concurrent work possible without having one task interfere with another. The work package labor estimates included in Appendix F-A1 & F-A2 were developed by experienced aircraft maintenance program planners with the goal of maximizing work flow to minimize the aircraft out of service time. Many considerations were taken into account including access requirements for all concurrent tasks, electrical power requirements, safety regulations, etc. Wherever possible, modification tasks would be scheduled concurrently with other work. However, in many cases space and resource requirements for one task will interfere with another task in the same area and therefore they cannot be accomplished concurrently.

### **Question No. 14**

The FTIHWG should evaluate using a simplified inert gas distribution manifold with ports in only two or three bays. This concept has been shown on recent scale model testing at the FAA Technical Center to inert the fuel tank even more efficiently (less nitrogen required) than the more complicated manifold design used in the report. The Sensitivity Analysis should reduce the installation costs from that used in the report based on this issue.

#### **Response:**

Since the scale model test results were not available to the HWG at the time their evaluations were completed regarding inerting systems, it was not possible to include these scale model tests manifold system. In addition, none of the HWG participants have any knowledge of the test results or their relevance and therefore cannot estimate its impact in the Sensitivity Analysis. The HWG believes once the full-scale testing and analysis results are available for use, the applicability and/or impact on the Sensitivity Analysis should be studied at that time.

### **Question No. 15**

The ground based inerting section of the report does not provide a need for installing any indication or activation system in the cockpit; however, the cost for installation of the ground based inerting system includes installation of cockpit instrumentation. The costs associated with installing cockpit instrumentation or activation should be eliminated to further streamline the installation and maintenance costs. This would reduce the installation time significantly from the over 1000 hours stated in the report. The Sensitivity Analysis should reduce the installation and parts costs from that used in the report based a system with no cockpit indication of activation system.

#### **Response:**

The parts cost did not include a flight deck indication system. The installation costs could be reduced by 43 hours per airplane.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 16

Does the estimated cost to incorporate inerting on new production airplanes include a reduction in labor installation time as more and more of these systems are installed on airplanes after the first one (learning curve improvements)? The Sensitivity Analysis should reduce the installation costs from that used in the report based on learning curve improvements.

#### **Response:**

It was recognized that the initial inerting system installations would require more labor hours. The estimate for production incorporation represents a mature installation value. This mature value gives a good average over the production life of the airplane.

### Question No. 17

The report states that some airports have placed restrictions on running APUs, but the report does not provide substantiation of this statement. This resulted in the requirement to include an air compressor in the on-board inerting designs. The report should substantiate this statement and list the airports that restrict the operation of APUs. The list should identify which are U.S. airports and non-U.S. airports.

#### **Response:**

An air compressor was chosen because bleed air was not available during the phases of flight when inert gas was needed to supply the fuel tanks. The reasons are described in the Onboard Design Team report (Appendix D) where each of the systems is described. APU noise restrictions were discussed but this was not the primary reason for including an air compressor in the design.

### Question No. 18

The report does not identify separate costs to implement fuel tank inerting concepts on in-service, new production and new airplane designs. Include costs for each category of airplane in the Executive Summary for both the basic report and the Sensitivity Analysis.

#### **Response:**

The cost summary charts in the report combine the costs and benefits for in-service, production and new airplane designs. As an example, two scenarios are included below to show the results for separate categories airplanes. Figures 1-3 show the costs and benefits for scenario 7. Figure 1 is the combined cost of new and existing airplanes. Figure 2 is the combined retrofit cost of the fleet only. Figure 3 is the combined cost of new airplane only. Figure 4 is the combined cost of new and existing airplanes. Figure 5 is the combined cost for retrofit of the existing fleet only. Figure 6 is the combined cost of new airplanes only.

## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question No. 19

The SFAR requires development of design changes to correct any design deficiencies identified by the analysis. These changes may be mandated into the existing fleet through the normal airworthiness directive rulemaking process. In the Sensitivity Analysis, what would be the affect on the estimated benefit of fuel tank inerting if inerting were required to be implemented before implementation of any modifications that may result from the design reviews required by SFAR 88?

#### **Response:**

The analysis required to answer the above question would require significant additional resources, time and effort by the FTIHWG. These resources are not available to the FTIHWG and consequently the additional evaluation cannot be accomplished.

### Question No. 20

The analysis does not include any benefit for preventing future accidents that could be caused by sabotage, such as a small bomb. The National Transportation Safety Board (NTSB) recommended the FAA consider developing airplane modifications such as fuel tank inerting (safety recommendation A-96-174) in a letter to the FAA dated December 13, 1996. In that letter, the NTSB cited a November 17, 1989, Avianca Flight 203 airplane crash as being caused by small bomb that could be prevented by fuel tank inerting. As stated in the letter, a small bomb was placed under a passenger seat above a center wing tank (CWT). The letter states "the bomb explosion did not compromise the structural integrity of the airplane; however, the explosion punctured the CWT and ignited the fuel-air vapors in the ullage, resulting in the destruction of the airplane." The Sensitivity Analysis should include calculated benefits of inerting based on including prevention the accident referenced above in the service history analysis.

#### **Response:**

The FTIHWG acknowledges that inerting may offer some benefit in preventing fuel tank explosions caused by small explosive devices that would not otherwise result in a catastrophe. However, those benefits could not be quantified because of uncertainties related to secondary ignition sources and the loss of nitrogen following breach of the fuel tank. If the FAA and/or NTSB has information that resolves the uncertainties discussed above the FAA has the option to include that accident in their regulatory evaluation process.

**FAA Questions and Comments Through ARAC  
Ex-Com on the June 2001 FTIHWG Final Report**

**FAA Questions and Comments Through ARAC  
Ex-Com on the June 2001 FTIHWG Final Report**

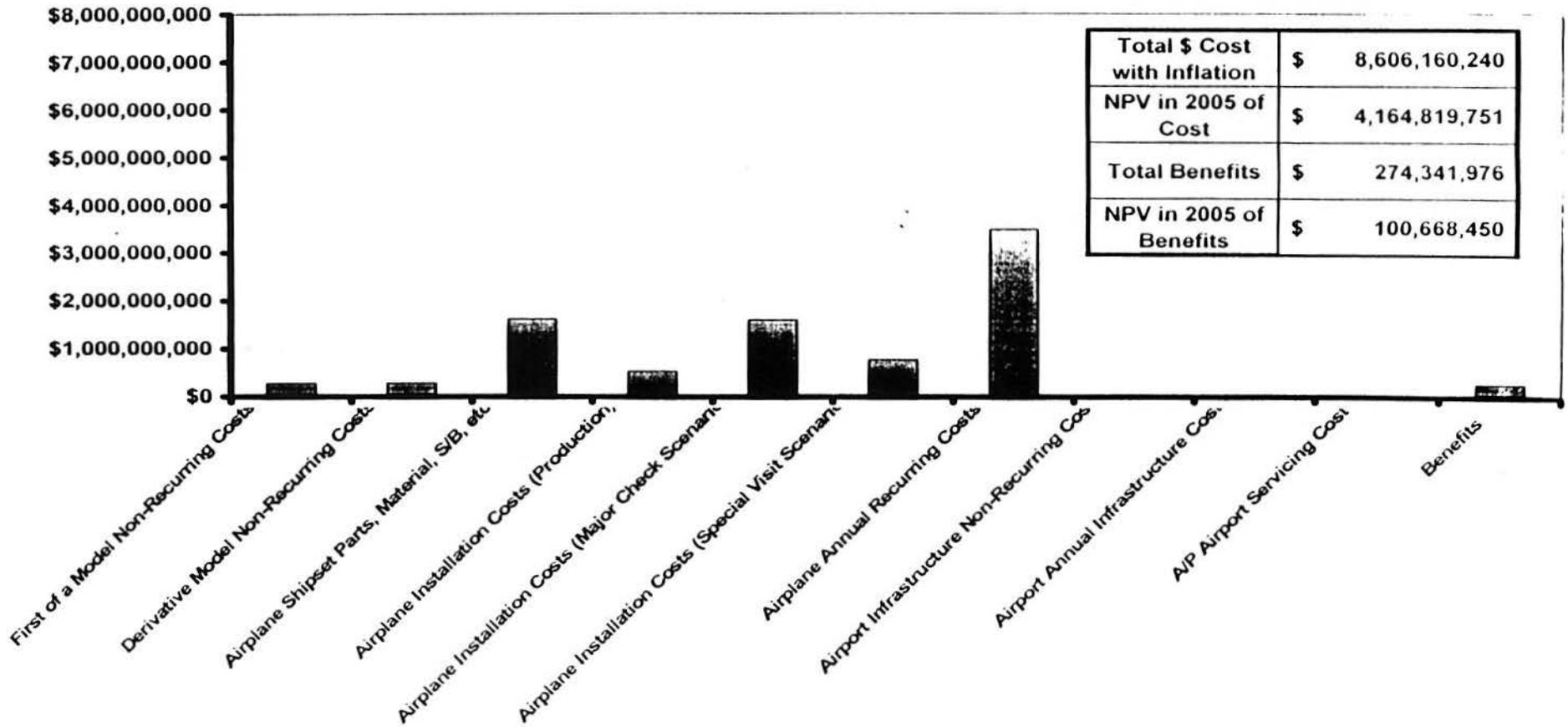
**Figure 1**

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium  
Transports, Membrane Systems, & Small Transports, PSA/Membrane  
Systems**

New & Existing A/P

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



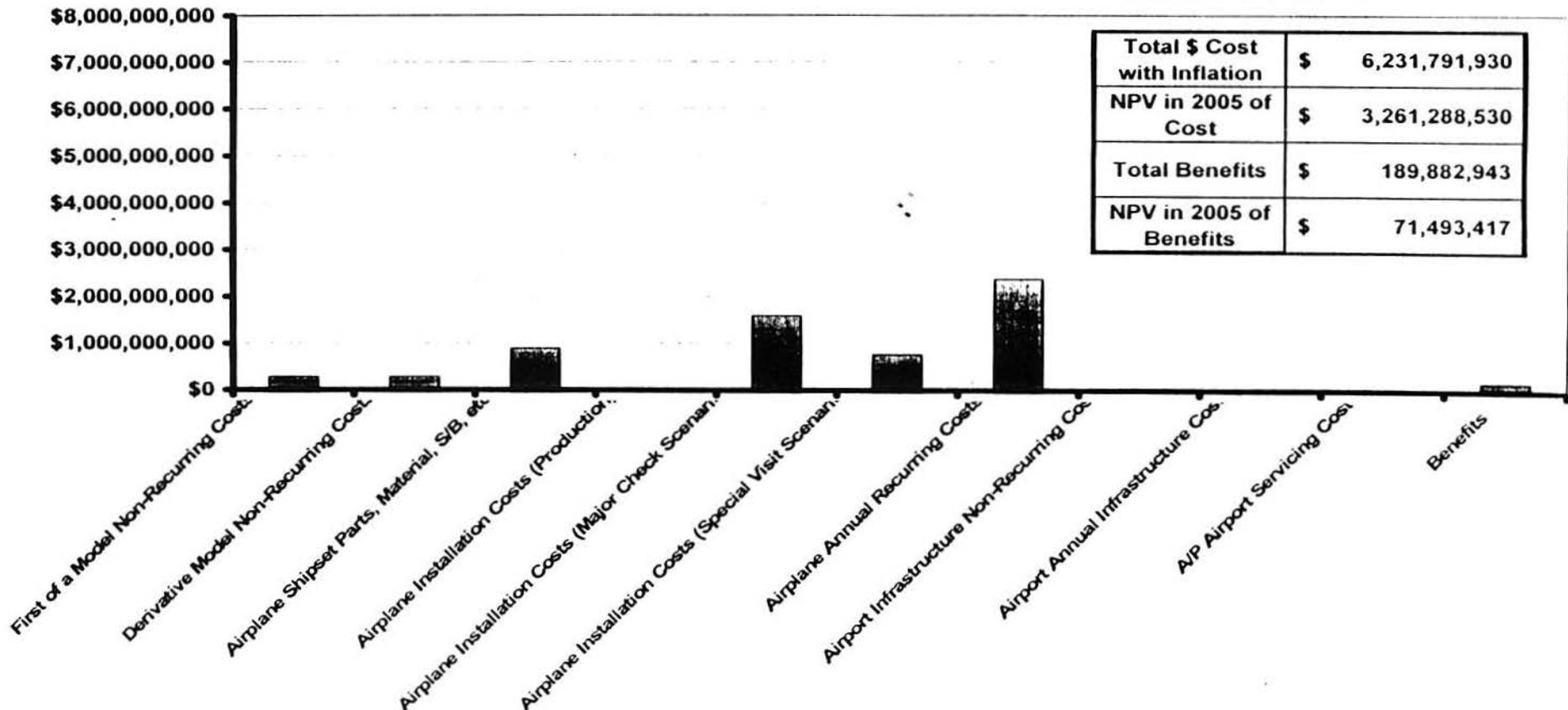
## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report Figure 2

### Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems

Retro of Fleet only

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

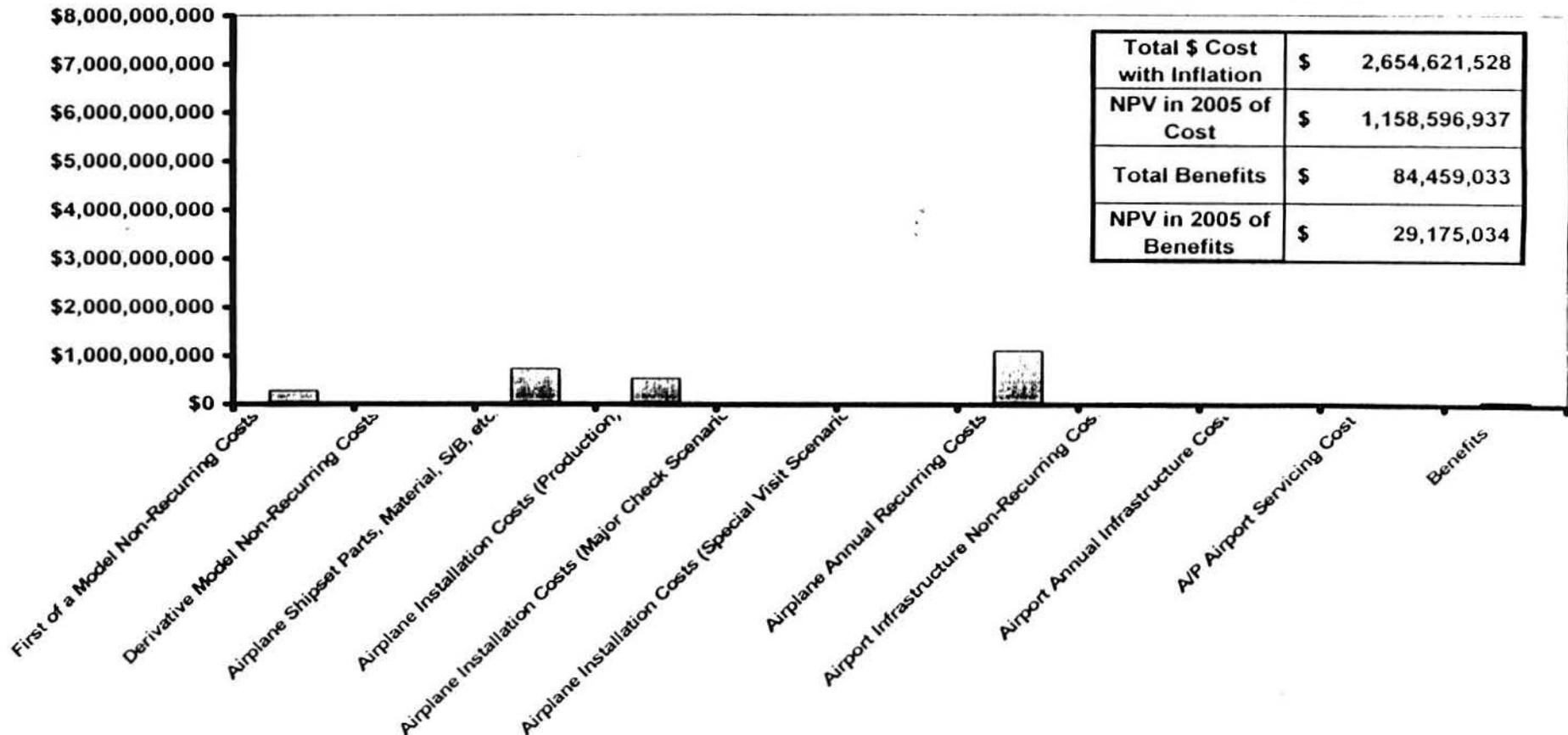
### Figure 3

**Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium  
Transports, Membrane Systems, & Small Transports, PSA/Membrane  
Systems**

New A/P Only

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

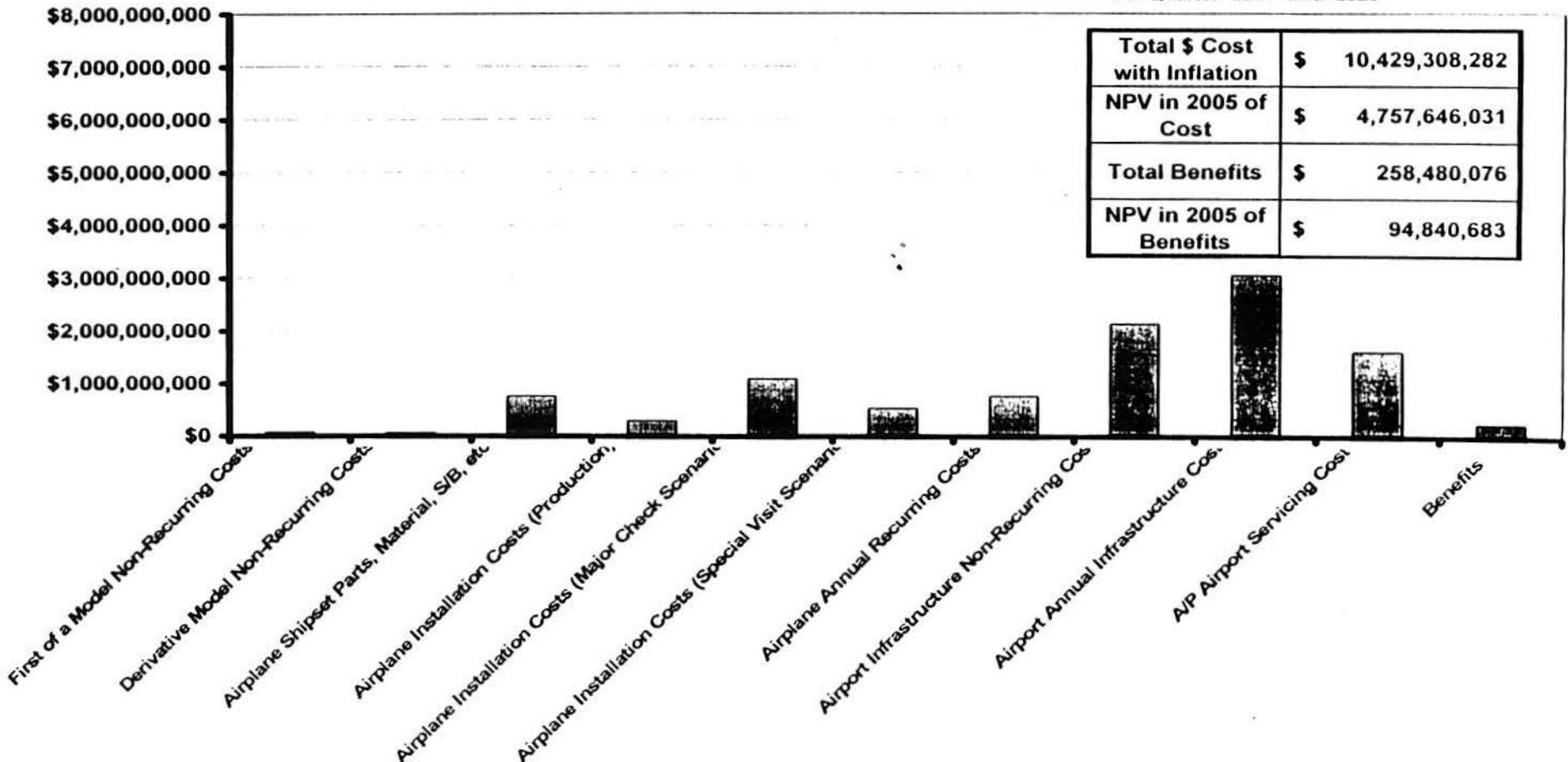
Figure 4

### Scenario 11 - Ground Based Inerting HCWT only, All Transports

New & Existing A/P

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



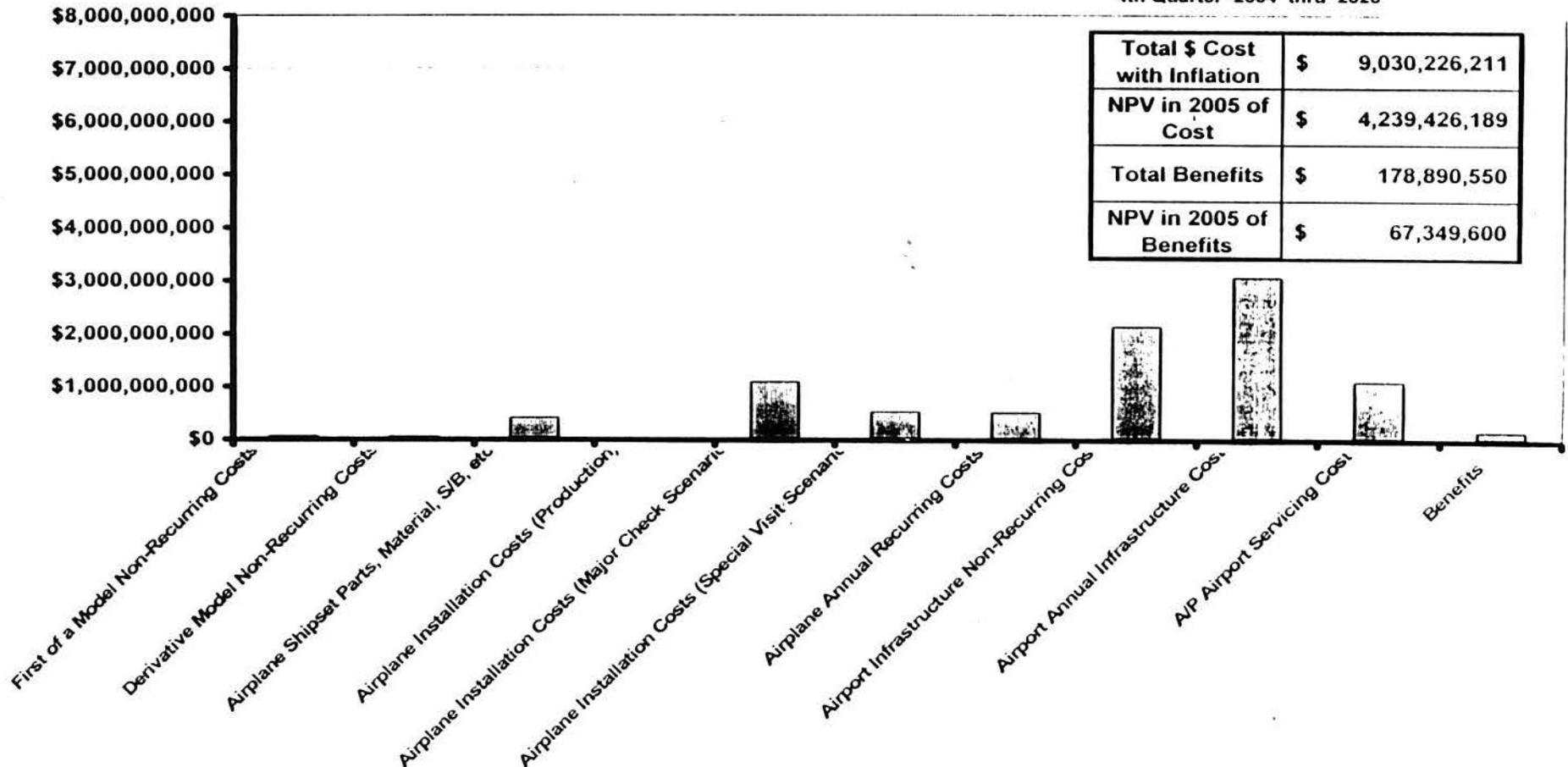
## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report Figure 5

### Scenario 11 - Ground Based Inerting HCWT only, All Transports

*Retro of Fleet only*

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



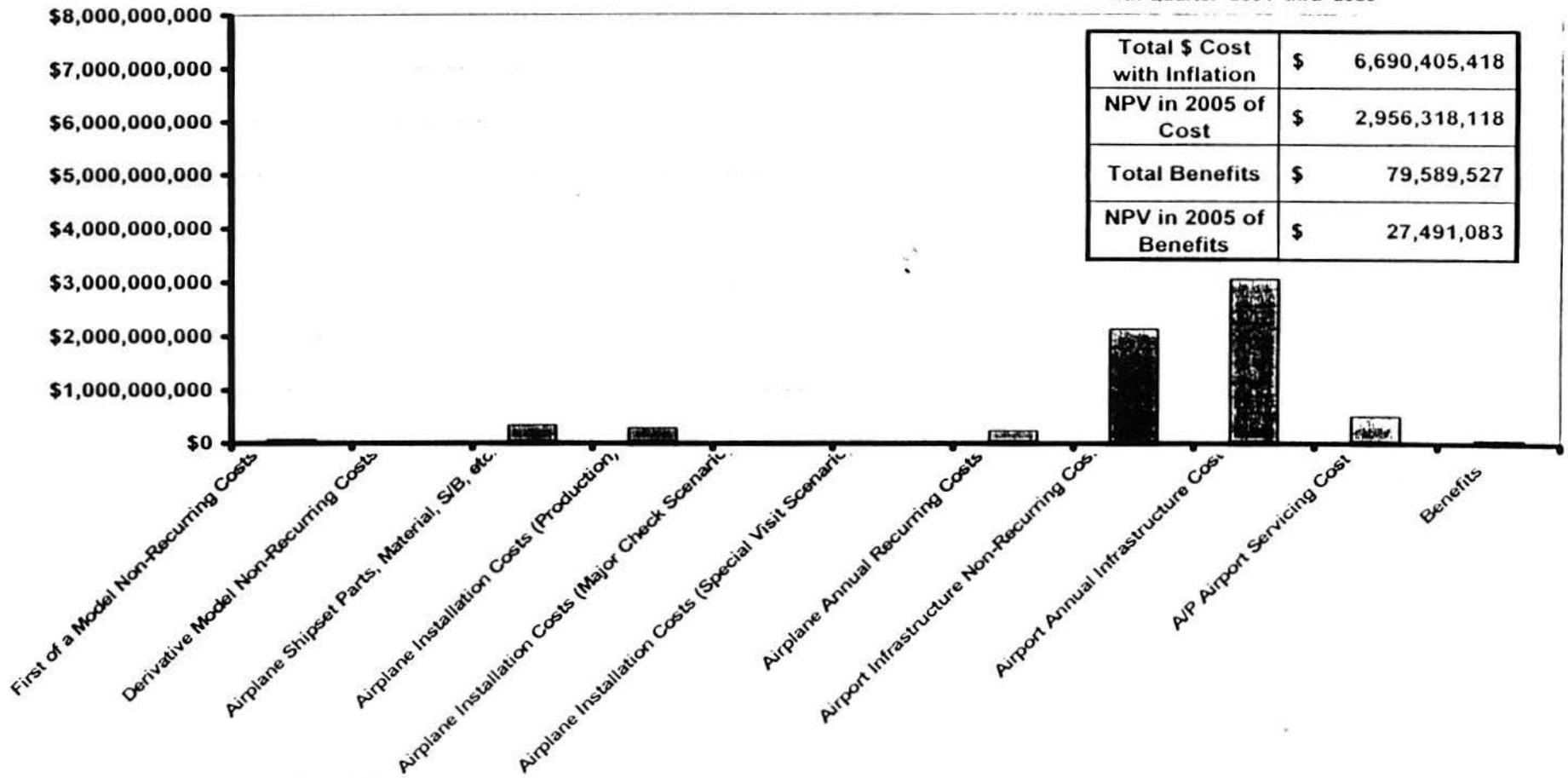
## FAA Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report Figure 6

### Scenario 11 - Ground Based Inerting HCWT only, All Transports

New A/P Only

US-Operator

Study period from Rule effect  
4th Quarter 2004 thru 2020



**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

Section/Page Number

Comment/Question

Page 1-7, par. 2

As there was no consensus of a key assumption that a 75% reduction in the accident rate should be used based on SFAR #88, the report should identify who the majority and minority are on this important point and the majority and minority should articulate their reasons for agreeing or disagreeing with this assumption.

**Response:**

At the Working Group meeting held prior to release of the final Report to the Executive Committee there was general consensus on the assumption to use a 75% reduction in the accident rate based on SFAR 88. General consensus is defined in the ARAC operating procedures as:

“General Consensus means that, although there may be disagreement among the members of the group, the group has heard, recognized, acknowledged, and reconciled the concerns or objections to the general acceptability of the group. Although not every member fully agrees in context and principle, all members support the overall position of the group and agree not to object to the proposed recommendation.”

The ground rules also provide for confidentiality during the voting process.

Additionally, a sensitivity analysis was conducted after the final report was completed to evaluate the range of opinion on the reduction in the accident rate due to SFAR 88. This sensitivity analysis was presented at the Executive Committee meeting August 8, 2001 and has been added to the Executive Summary.

Page 1-8

**Why is there such a great difference in avoided fatalities for Ground Based Inerting versus On Board systems (OBIGGS) 132 vs. 253?**

**Response:**

Ground Based Inerting (GBI) was designed to inert the Center Wing Tank only, while the Onboard Inert Gas Generating System (OBIGGS) was designed to inert all fuel tanks. Because OBIGGS keeps all the tanks inert through all flight phases, it is more effective at preventing fatalities from explosion occurring on the ground and in-flight (152 for OBIGGS vs. 127 for GBI). For the same reasons, OBIGGS is also more effective at preventing fatalities associated with post-crash fires (101 for OBIGGS vs. 5 for GBI).

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

Page 1-9

Please explain why the cost benefit analysis ratio for Hybrid OBIGGS (HCWT only) option would not change as follows based on the following assumptions:

**If no improvement assumed from SFAR 88** **10:1**

If there were no improvement due to SFAR 88, the cost-benefit ratio for Scenario 7 (Hybrid OBIGGS -HCWT only) would be approximately 10:1. The range of opinion within the Working Group was 25% to 90% SFAR 88 effectiveness.

**Plus if reliability is 50% better than 20 year old systems** **5:1**

The system reliability used in this study is already more than 50% better than 20-year-old systems designs.

**Plus if investment cost is amortized over 30 years instead of expensed over 1-10 years**

**1:1**

For the most systems, the capital costs were only about 30% of the total cost. They were expensed in the year in which they were incurred throughout the 16 year study period, not just years 1-10.

Most of the capital equipment would need to be replaced within 30 years. Once the replacement costs are accounted for, amortizing over 30 years would not reduce the total cost.

**Plus if pain and suffering and potential punitive damage awards are assumed at \$2 million per victim** **1:2**

The study used \$2.7 million per accident victim.

**Plus if inflation adjustment for benefits is 7% per year** **1:3**

Inflation would affect both the costs as well as the benefits. Increasing the inflation would not change the cost-benefit ratio.

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

**Page 3-2**

**How can a major assumption involving reduction of accident risk be justified based on reduction of ignition sources if the ignition sources of the past three accidents “have not been identified”?**

**Response:**

It was the general consensus of the FTIHWG that the ignition source reduction assumption of 75% was reasonable. Further, a sensitivity analysis was done and the assumption was varied from 25% to 90% as discussed at the last Ex-Com meeting on August 8, 2001. The results of the sensitivity analysis will be included in the revised executive summary in the final report.

**Figure 11-4**

**Please state the assumption and explain the calculations by which the Net Present Value NPV were performed for Costs and Benefits for each option.**

**Response:**

This question asked for explanations of the calculations of Net Present Value for costs and benefits. The Team concluded that the explanation provided on page 11-1 under METHODOLOGY was intended to answer this question for the reader. Basically, the benefits were estimated for the year in which they were expected to accrue, and likewise the costs. Both costs and benefits were inflated from current year values by 3% per year. To get the net present value, these costs were discounted by 10% per year to the year 2005.

**Figure 5-17**

**Why are the Benefits different here than in Figure 11-4, \$168 million vs. \$95 million NPV in 2005 Benefits?**

**Response:**

This question seeks to clarify a discrepancy between Figures (Scenario 11-Ground Based Inerting, HCWT Only. All Transports, [US Passenger only] 5-17 and 11-4 (Cost Summary-Worldwide Fleet, Passenger Planes). The team concluded that the questioner might have misinterpreted the figure labeling in the report. Figure 5-17 on the upper half of page 5-18 depicts Scenario 11 (Ground Based Inerting, HCWT Only. All Transports, [US Passenger only]), which indicates for U.S. operators only an NPV of about \$95 million for the benefits. This corresponds to Figure 11-5, Cost Summary-U.S. Fleet, Passenger Planes Only, not 11-4 (Cost Summary-Worldwide Fleet, Passenger Planes) at the bottom of page 11-6 which indicates \$95 million NPV for benefits of Scenario 11, U.S. operators only.

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

**Figure 7-14 Scenario 1**

**Was inflation included in Total Benefits? If so how?**

**Response:**

The question related to how inflation was factored into the calculations. As set forth above, inflation was assumed to be 3% per year for both benefits and costs.

**Page 8-6 Component Reliability**

**How reliable is this component reliability estimate?**

**What about new equipment and 1998 Report by the Fuel Tank Harmonization Working Group's estimates which show much lower operation and maintenance costs?**

**Response:**

The reliability estimate for the common components, i.e. valves, fans, wiring, etc., was based on data for similar components used in similar applications on commercial aircraft. Therefore, the reliability estimate should be very good.

In-service commercial aircraft reliability data for components unique to inerting systems was not readily available. Therefore data was obtained for equipment currently being used in various applications. For example, the inerting equipment suppliers estimated reliability data for membrane technology based on equipment being used in industrial and military applications.

As another example, in-service data was not available for the compressor, therefore the reliability estimate was made by a detailed component level analysis. Component reliabilities (motor stator, bearings etc) were taken from databases built on in-service data.

The operation and maintenance costs for the 1998 Report did not have the benefit of a review by maintenance experts as this ARAC does. The 1998 Report costs were ROM costs and the team recognized that all of the costs involved were not captured in time for that report.

The information was not available at the time of publication for public release from the Air Force.

**Page 12-1 How was "practicality" defined?**

**This is a key term but I do not see a definition.**

**Response:**

When assessing the practicality of the inerting systems the following considerations were included:

- Safety benefit versus added hazards and costs
- Technology (system/equipment) maturity

## ACAP (Paul Hudson)

### Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

- Compatibility with other aircraft systems (integration)
- Weight impact: loss of seating capacity ; impact on aircraft performance
- Reliability: dispatch, in-flight (ability to reach destination), equipment replacement
- Maintainability: ease and interval
- Infrastructure to ensure system operation: airport facilities, fluid (i.e. NEA), etc.
- Compliance with FAR's

#### Page 13-1 Safety Assessment items 2 and 4 How? and How Much?

Item 2: "Ignition source reduction activities associated with SFAR no. 88 are expected to provide a reduction in the fuel tank explosion rate."

#### Response:

The general consensus of the FTIHWG was that ignition source reduction assumption of 75% was reasonable. Further, a sensitivity analysis was done and the assumption was varied from 25% to 90% as discussed at the last Ex-Com meeting on August 8, 2001. While every effort is being made to fully comply with SFAR no. 88 it is recognized that the risk of having an ignition source present can never be fully eliminated and the SFAR effectiveness assumption recognizes that.

Item 4: "The flammability exposure levels achieved by inerting systems can result in an improvement in the accident rate."

#### Response:

As discussed in the report inerting can substantially reduce fuel tank flammability, as a result the risk of explosion is also reduced. The fuel tank explosion accident rate for the entire fleet (weighted average of all six generic airplanes) is currently  $\sim 5 \times 10^{-9}$  per hour. With SFAR no. 88 fully implemented at 75% effectiveness, the fuel tank explosion accident rate is forecast to drop to  $\sim 1.3 \times 10^{-9}$  per hour. If GBI were implemented, the fuel tank explosion accident rate is forecast to drop to  $\sim 3 \times 10^{-10}$  per hour. If an Onboard Inert Gas Generating system were implemented, the fuel tank explosion accident rate is forecast to be  $\sim 1.5 \times 10^{-10}$  per hour.

#### Page 13-1 Ground Based Inerting item 5 Please explain why.

The question has to do with:

"Because an OBGIS runs only on the ground, interference with other airplane systems would be minimized and the certification process should be simpler."

## ACAP (Paul Hudson)

# Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Response:

Systems that must operate properly per their function and not interfere with any other equipment required. Normally this is accomplished with ground and flight tests, which the FAA may deem necessary after each retrofit installation.

A system that operates only on the ground, and is shut off prior to flight, can be shown to not interfere with any other equipment required for flight. Once certified not to interfere, only ground operational tests would be required to show proper operation. This saves time and money as shown in this report.

### Page 13-1 Ground-Based Inerting, Item 1 Why?

The questions refers to:

“ Installing the airplane portion of a GBI system does not require any new technology to be developed. However, retrofit GBI systems will be extremely difficult and will require an evaluation of each airplane category model to determine if a retrofit installation is practical. “

### Response:

The retrofit manifold will need to be designed to avoid interference with already installed systems such as vent systems, FQIS probes/sensors/wiring, refuel manifolds, and cross-feed manifolds. The design will thus require more internal support brackets on ribs and stringers to accommodate the non-optimum routing.

Structure penetrations of major structure items (i.e. spars and ribs) are expected to be required. The feasibility of introducing these penetrations in the structure will be dependent upon the structure design philosophy applied to the particular aircraft model, and in the in-service history of a particular aircraft (i.e. have previous repairs already been carried out due to previous in service events).

Specific aircraft type design modifications, such as reinforcing plates to ensure the strength of the existing parts are not compromised, would be necessary. This will increase the amount of drilling/machining necessary inside the tank. To carry out these operations special drilling fixtures will be required, particularly in areas of tight access due to the proximity of stiffeners on the ribs, spars and skins. The location of the GBI manifold will be near the top of the tank to avoid impeding access to the tank for maintenance and to minimize fuel submergence during GBI.

It was assumed that it would be possible to avoid removing the majority of the existing fuel system installation to install the new manifold. However, special protective tooling is likely to be required for the FQIS electrical harnesses to ensure they are not inadvertently damaged during drilling/ installation activity. The cost of replacing an FQIS harness is major, and was not assumed as part of the retrofit GBI installation.

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
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Modifications to existing vent systems to preclude cross venting would be necessary for a large portion of the fleet. The design changes to accomplish this have not been developed, and require careful consideration to assure these modifications do not introduce new safety issues.

All of the above factors, would contribute to the difficulty and costs associated with retrofitting a GBI system installation.

Subsequent to the ARAC task team effort and final report, the FAA has accomplished testing that suggests the distribution of nitrogen to each tank bay may not be necessary. The distribution system details would be designed for each aircraft with the objective of minimizing the impact. Methods to economize are a part of detailed design. However, it is also appropriate to note that savings during detailed design are often offset or exceeded by complications not accounted for in preliminary design studies similar to that done for this ARAC.

**Item 2: Why not part of fuelling operation**

This question refers to:

The availability of airport supply systems to supply NEA at each terminal gate and remote parking area is a serious problem that needs to be resolved before GBI can be implemented.

*Section 10.17 of the report Para 10.3.2.3 also covers this issue.*

**Response:**

The Terms of Reference requested that the system inert the fuel tank at arrival. Depending on the fuel load and aircraft size inerting may be completed before, at the same time, or after refueling. If directly linked to the refuel there would be a knock on effect to refueling other aircraft since the refuel truck for example would have to wait until both operations were completed. The location of the connection for the NEA on the aircraft will be near the center tank. Aircraft refuel connections are typically outboard of the engine or between the engines. To minimize the impact on the ground operation of the aircraft the ground based on-board system has been designed so that it can be performed at any time.

Due to the physical separation of the two connections it will not be possible to observe or monitor each connection without walking between each one. In the event of an interruption of one of the servicing operations increased delay would result since to trouble shoot one system would require the other operation to be suspended.

**Page 13-2 Airport Facilities Item 4**  
**Aren't there systems that capture VOC?**

Item 4 states:

12/27/01

**ACAP (Paul Hudson)**

**Questions and Comments Through ARAC  
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“Significant volumes of VOC were released during both processes, regardless of inert gas used. This increase in VOC emissions should be investigated and resolved to avoid any serious potential health, environmental, and safety issues.”

**Response:**

Vapor recovery systems are not presently installed or required on airplane or fuel handling systems handling Jet-A type fuel. If the increase of hydrocarbon emissions caused by GBI becomes a subject for regulatory action this may require modification to the aircraft vent system and a means of vapor recovery at each fueling position. The costs of this were not included in the study.

The natural occurring VOC release from jet fuel is relatively minor due to its low vapor pressure and is therefore generally exempt from capture. The two operations referred to in this statement – aircraft fuel tank ullage washing and fuel scrubbing (displacing entrained oxygen with NEA) introduces the physical removal of normally stable light end components from the jet fuel.

Preliminary laboratory tests conducted on both processes, using various inert gases, indicates that not only is there a significant VOC volume increase but also the driving off of other components that normally remain entrained within the fuel. The release of these other components tends to form unacceptable concentrations of otherwise non-lethal hazardous material when in their natural state. Therefore, the Working Group recommended that additional investigation into this matter be carried out before implementation of a NEA inerting process for today’s transport category aircraft.

**Page 13-2 Onboard Inert Gas Generating System,  
Item 4 What airliners are you referring to?**

Item 4 states,

“ The weight of an installed OBIGGS is significant; for example, for a large transport category airplane, the OBIGGS weighs between 1,120 and 1,600 lb.”

**Response:**

The study used the same six generic aircraft that were specified for the 1998 ARAC FTHWG study. These are representative of the fleet without being specific to one manufacturer. The “large” aircraft have a 350 or greater passenger capacity.

**13-2 Onboard Inert Gas Generating System,  
Item 6, 8 What is the basis for this? Was the reliability number used for current systems or 20 year old military systems?**

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

This question refers to:

“Item 6: Current technology components of an OBIGGS have demonstrated low reliability.”

**Item 8:** NEA membrane air separation systems that have improved efficiency and performance, and lower nonrecurring costs would be a necessary part of a practical membrane-type OBIGGS.”

**Response:**

Items 6 and 8 refer to different aspects of OBIGGS systems. Item 6 refers to the C-17 system, which does not have sufficient reliability for use in commercial aircraft service. The lessons learned from this system were applied to the inerting concepts in this report in order to avoid the low reliability components. No other system currently exists with the capacity to inert transport aircraft fuel tanks so the inerting equipment suppliers must project reliability estimates for the conceptual systems presented in this report.

Item 8 refers to the latest technology in production from suppliers of inert-gas generating equipment and has nothing to do with reliability, but rather feasibility. This equipment must produce more nitrogen from less supply air to be feasible. The suppliers have indicated that R&D efforts are being undertaken to improve the efficiency but improvements will only occur with a “scientific breakthrough”.

Reliability was based on existing components and supplier projections as presented in the response to question 8-6.

**Page 13-3 Airplane O & M, Item 4**

**Why is 0.7% to 0.1% down time necessary?**

Item 4 refers to the reliability of inerting systems, it states:

“The current reliability of inerting system technology is unacceptable from a maintenance and operational viewpoint and requires an order of magnitude improvement to make them operationally viable.”

**Response:**

Improvements in reliability are necessary to ensure that the inerting system does not cause a significant decrease in overall dispatch reliability. A significant decrease in dispatch reliability would lead to a systemic effect on airplane utilization.

**Page 13-3 Estimating and Forecasting, Item 3**

**Why aren't these systems practical?**

Item 3 states:

“Of the design concepts studied, the one with the lowest cost-benefit ratio was the GBI and the hybrid OBIGGS concept applicable to heated CWTs only.”

## ACAP (Paul Hudson)

# Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

**Response:**

The general consensus of the Working Group was that fuel tank inerting will take many years to implement and will have an enormous operational impact, with costs that far exceed the benefits. Based upon these factors, the consensus was that these inerting systems were not practical at this time.

When assessing the practicality of the inerting systems the following considerations were included:

- Safety benefit versus added hazards and costs
- Technology (system/equipment) maturity
- Compatibility with other aircraft systems (integration)
- Weight impact: loss of seating capacity; impact on aircraft performance
- Reliability: dispatch, in-flight (ability to reach destination), equipment replacement
- Maintainability: ease and interval
- Infrastructure to ensure system operation: airport facilities, fluid (i.e. NEA), etc.
- Compliance with FAR's

### General Questions

- 1) **What is the basis for concluding that fuel tank inerting is not practical based solely of the WG's cost benefit analysis?**

**Response:**

The general consensus of the Working Group was that fuel tank inerting will take many years to implement and will have an enormous operational impact, with costs that far exceed the benefits as calculated in accordance with the standard Department of Transportation formula.

Based upon these factors, the consensus was that these inerting systems were not practical at this time.

The cost-benefit analysis is a part of the regulatory evaluation process. The terms of reference required that any recommended inerting system meet regulatory evaluation criteria. When assessing the practicality of the inerting systems the working group also considered:

- Safety benefit versus added hazards
- Technology (system/equipment) maturity
- Compatibility with other aircraft systems (integration)
- Weight impact: loss of seating capacity ; impact on aircraft performance
- Reliability: dispatch, in-flight (ability to reach destination), equipment replacement
- Maintainability: ease and interval

## ACAP (Paul Hudson)

### Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

- Infrastructure to ensure system operation: airport facilities, fluid (i.e. NEA), etc.
- Compliance with FAR's

#### 2) Who are the economists who crunched the numbers for the cost benefit analysis and what are their affiliations and qualifications?

Allen A. Mattes, a senior economist for the FAA, in the office of Aviation Policy and Plans, Aircraft Regulatory Branch, supported the Economic and Forecasting team. He provided guidance for setting up the cost benefit analysis. The task teams provided the data used in the analysis. A working group member supported each task team.

#### 3) Who are the members of the WG, their affiliations and professional qualifications?

##### **Response:**

The ARAC Working Group members, listed below, were chosen from resumes submitted to the FAA. The FAA and the Chairman of the ARAC Executive Committee selected the members of the Working Group. The Working Group members were selected for two reasons: they had the skills, background, and capabilities to fully address the Terms of Reference and they represented a balanced range of industry opinions. The Working Group and task teams included designers and manufacturers of inerting systems.

**ACAP (Paul Hudson)**

**Questions and Comments Through ARAC**

**Ex-Com on the June 2001 FTIHWG Final Report**

Name	Representing	Company
Brad Moravec	Aerospace Industries Association (AIA)	The Boeing Company
Sean O'Callaghan	Association of European Airlines (AEA)	British Airways
G. Michael Collins	Federal Aviation Administration (FAA)	FAA, Transport Airplane Directorate
Laurent Gruz	Joint Aviation Authorities (JAA)	Direction Générale de l'Aviation Civile (France) (DGAC)
Anne Jany	European Association of Aerospace Industries (AECMA)	Airbus
James Hurd (Alternate)	Public Interest Groups	National Air Disaster Alliance / Foundation (NADA / F)
C. William Kauffman	Public Interest Groups	National Air Disaster Alliance / Foundation (NADA / F)
Charlie Osonitsch	Small Transport Aircraft Manufacturer	Gulfstream Aerospace
Karl Beers	Inert Gas Equipment Manufacturing	Air Liquide - MEDAL
Brian Sutton	Airline Pilots Association International (ALPA)	TWA /American
Frank O'Neill	Air Transport Association (ATA)	United Airlines
Jay Hiles	International Association of Machinists (IAM)	US Airways
David Lotterer	Regional Airline Association (RAA)	RAA
Ted Campbell	American Petroleum Inst.(API)	Texaco

4) What are the views of the designers and manufacturers of the fuel tank inerting systems on the conclusions and cost benefit analysis of the WG?

Response:

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

The Working Group and task teams included members who are designers and manufacturers of fuel tank inerting systems. The Working Group reached general consensus on the conclusions and recommendations.

**5) Did you consult with any economists who do not have a vested interest in the outcome of the FAA's adoption of fuel tank inerting? If so who?**

**Response:**

The FAA economist, who is impartial, was the only one on the study.

**6) What is the per ticket cost of the various fuel tank inerting options? Isn't it true that the total cost of fuel tank inerting is about 1/6% of airline revenue according to your calculations?**

**Response:**

These calculations are not part of the regulatory evaluation. However, the data is available in the report to make cost estimates on a per ticket, per flight or total revenue basis.

**7) Why have you not developed regulatory text as required by the tasking statement? How many lawyers (regulatory and air crash tort) were on the WG? What were their affiliations and expertise?**

**Response:**

Chapter 12 and Appendix I provide comprehensive regulatory text. No lawyers were assigned to the Working Group because the tasking requested only "recommended" regulatory text. The FAA does not assign lawyers for drafting "recommended" regulatory text.

**8) Where is the analysis for your recommendation that new aircraft designs could substantially reduce risk and cost of preventing fuel tank explosions?**

**Response:**

This question pertains to the Co-Chairmen's recommendation that the FAA and Industry study means other than inerting to reduce fuel tank flammability. In general, the FAA's fuel tank flammability model was used to evaluate the effects of ground cart cooling, improved insulation between the Center Wing Tank and adjacent heat sources, and improved fuel scavenging.

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

*Co-Chair Recommendations*

**Examples of alternative flammability reductions methods  
using the ARAC fleet-wide flammability exposure model**  
Percent Exposure of Airplane Types

Airplane Configuration	LARGE	MEDIUM	SMALL
Baseline	36.2	23.5	30.6
Duct Insulation	26.3	19.9	23.9
Ground Cart Cooling	26.7	16.9	20.2
Duct Insulation & Ground Carts	18.5	12.3	16.2
Reduced Residual Fuel	33.5	20.0	27.4
Duct Insulation with Reduced Residual Fuel	23.8	16.3	22.7
Ground Cart Cooling with Reduced Residual Fuel	23.4	13.1	19.2
Duct Insul & Grd Carts w/ Reduced Residual Fuel	15.9	10.0	15.2

**Conclusion:** The flammability model results show that a combination of hardware and procedure changes may lower fuel tank flammability exposure by more than half.

**9) How has the views and experience of military aviation that has used fuel tank inerting been used by the WG?**

**Response:**

The task teams included participants from the US Navy and industry engineers who have worked on military inerting systems. Their efforts were used extensively in preparing this report.

**10) Isn't it true that a \$3 Billion annual cost equates to a per flight cost of 16 cents over 20 years and 33 cents over 10 years?**

**Response:**

Corrine will ask John Hellman about per flight cost.

**11) What is the legal basis for the position that cost benefit analysis is the only or main factor for the FAA to determine whether or not to require fuel tank inerting?**

**Response:**

The cost-benefit analysis is not the only or main factor for the FAA to use to determine whether or not to propose a rule. Under the Sept. 30, 1993, Executive Order #12866, a Federal agency must perform a

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

cost-benefit analysis when proposing a rule. However, the Federal agency should select the approach that would maximize net benefits (including potential economic, safety, and other impacts). The cost-benefit analysis is only one of several factors affecting an Agency's decision to propose or not to propose. In other words, there is no legal requirement that a positive net benefit is a requirement for a Federal agency to issue a proposed regulation.

**12) Did you consider the indirect costs to the industry of lower revenue caused by accidents, the investigation and litigation costs?**

**Response:**

The benefits included DOT's latest estimate of the amount society would pay to prevent a potential fatality (\$2.7 million), the value of the destroyed airplane, value of ground damage and accident investigation.

**13) Did you consider the non-economic costs of human pain, misery and suffering caused by failing to prevent accidents that are preventable with currently available technology?**

**Response:**

The benefits included DOT's latest estimate of the amount society would pay to prevent a potential fatality.

Allen Mattes input:

The benefits included the DOT's latest estimate of the amount society would pay to prevent a potential fatality. This value, which is periodically revised to account for inflation, is based on a survey performed by the Urban Institute (The Cost of Highway Crashes, June 1991) of studies that have estimated the amounts society is willing to pay for reduced risk of fatalities. The willingness to pay approach attempts to value an average of all the benefits arising from the prevention of a fatality.

**14) Did you consider the overall costs to the US economy of a policy that authorizes airlines and manufacturers to not fix a known hazard to air travelers, especially if it leads to series of preventable accidents killing hundreds of air travelers? The Comet syndrome? The potential bankruptcy of airlines (ie Pan Am after Pan Am 103)? The potential liability of the US government and industry officials for such policies leading to many preventable deaths? The professional reputations of those involved in promoting such policies? The morality of recommending a policy that will knowingly cause a horrible death for hundreds of air travelers?**

**Response:**

The qualified benefits of accident prevention are discussed in chapter 11 of the report. They include DOT's latest estimate of the amount society would pay to prevent a potential fatality (\$2.7 million), the value of the destroyed airplane, value of ground damage and accident investigation

**ACAP (Paul Hudson)**  
**Questions and Comments Through ARAC**  
**Ex-Com on the June 2001 FTIHWG Final Report**

**15) Are there not other cost benefit analyses available to WG members that show much lower costs and higher benefits?**

**Response:**

Yes, other cost-benefit analyses used by the Working Group include the 1998 ARAC study and the FAA's Ground Based Inerting Study (DOT/FAA/AR-00/19). Although the studies are not directly comparable, data from both these studies were used.

**16) Have the Industry members of the WG met privately to pre-determine or decide their strategy to oppose fuel tank inerting a biased cost benefit analysis?**

**Response:**

No, the WG is not aware of any privately held meetings. The ARAC process was used to develop an industry consensus on the response to the Tasking Statement.

**17) What instructions or pressures have been brought to bear on WG members by their superiors to come up with a negative recommendation on fuel tank inerting?**

**Response:**

The Working Group recommended that the FAA and industry continue research and development on inerting systems. This should not be considered a negative recommendation. Additionally, the Working Group is not aware of any members that were pressured to take a position they did not agree with.

## Redhead Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question 1

Throughout this report it is recognized that there is a potential hazard to ground service and airport personnel associated with the use of nitrogen in Ground Based Inerting (GBI) and it is difficult to assess the actual risk; text pages 16, 20 and 45

{ 4.4}. Despite identifying the risk, there was no mention of any ARFF requirements that airports might need to consider. New ARFF requirements could mandate specialized equipment and additional manpower, a major cost to airports. In addition there may be building and fire code requirements that need to be addressed regarding the storage of nitrogen on airports or within a terminal facility (pg 74 {6.4}).

### **Response:**

Time and manpower did not allow for a study of all the collateral issues associated with the proposed GBI concept such as airport safety and airport fire department responsibilities. Since building and fire codes can vary between local jurisdictions, it would have been difficult to identify all the potential problems. There would have to be a thorough risk assessment carried out as it would pertain to confined spaces entry, ground NEA saturation, proximity of equipment to the terminals, etc. The Airport Facilities Task Team identified these potential hazards so they may be properly addressed in advance of any decision to implement the GBI concept.

### **Question 2**

There are concerns expressed about the environmental impact and health and safety implications regarding the release of "...volatile organic compounds into the atmosphere" (pg. 61 {5.4.5}) and using nitrogen-enriched air (NEA) in GBI. Exhibit E also indicates that further environmental study would be required to better address this impact on airports. Addressing this environmental impact could be costly to airports and could impact the overall cost-benefit analysis.

### **Response:**

Environmental Impact Considerations of GBI – The AFTT completely agrees with the statement noted. This was a major issue with the concept of nitrogen saturating the fuel. As related in the final report, there are existing environmental pressures being exerted on today's airports. As such, the impact of adding an incremental known pollution source will require further research and evaluation. Again lack of time, resources and lack of readily available environmental baseline data prohibited the team from performing a thorough evaluation of all the issues and costs related to this.

## Redhead Questions and Comments Through ARAC Ex-Com on the June 2001 FTIHWG Final Report

### Question 3

During the presentation as well as in the report (pg 177{11.2}) the term “Airport cost...” was used when talking about ground support equipment and hydrant systems. A distinction must be made that indicates that these are actually **airline** costs at airports.

#### Response:

The term “airport cost” was used to differentiate between the facility costs and the direct aircraft related costs of GBI. Because facility improvement and use agreements will vary from airport to airport, it was beyond the scope of the task team to identify who will be responsible for each of the costs.

### Question 4

There is language that seems to propose a regulatory change to 14CFR Part 139 that will require the airport operator to be responsible for the safety associated with ground based inerting (pg 187{12.3} and pg 190{12.5.2}). Why is this being proposed? Currently all fueling or such aircraft related operations are the responsibility of the airline.

#### Response:

The FTIHWG tasking statement directed the Group to propose regulatory language where it believed it was appropriate to do so. Referring to Part 139.321 “Handling and Storing of Hazardous Substances and Materials, the AFTT believed that the requirements set forth in this paragraph were applicable to the storage distribution and handling of NEA. If GBI becomes a requirement, the availability or lack of the necessary facilities could possibly impact the certification of the airport.

### Question 5

The report indicates that there could be delays associated with ground-based inerting (pg 60{5.4.4}). Were the costs of delays and the subsequent congestion associated with GBI factored into the cost-benefit analysis?

#### Response:

The maintenance costs for the delays were included, but the systemic costs (increased number of terminals, airplanes, personnel, etc) were not.



**AIR LINE PILOTS ASSOCIATION, INTERNATIONAL**

535 HERNDON PARKWAY □ P.O. BOX 1169 □ HERNDON, VIRGINIA 20172-1169 □ 703-689-2270  
FAX 703-689-4370

April 12, 2002

Mr. Anthony Fazio  
Director, Office of Rulemaking, ARM-1  
Federal Aviation Administration  
800 Independence Avenue, SW  
Washington, DC 20591

Dear Mr. <sup>Tony</sup>Fazio:

On behalf of the Air Line Pilots Association, I would like to comment on the recently submitted report of the Fuel Tank Inerting Harmonization Working Group.

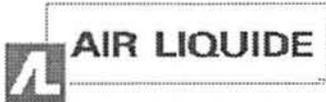
We appreciated the opportunity to participate on this working group. We firmly believe that fuel tank inerting is a technically feasible technique that will help preclude fuel tank explosions in the future. We have concerns about the cost benefit analysis assumptions that were used by the working group. We feel using the predetermined DOT figure of \$2.7 million per human life lost is unreasonably low.

The Working Group report identifies many recommendations by the membership to continue fuel tank inerting research to improve the efficiency of the systems. At the ARAC Executive Committee meeting that received the working group report last month, it was indicated that work on developing a viable fuel tank inerting process is continuing. Future design/production aircraft could be modified on the drawing board to be compatible with the demands of an inerting system.

We certainly support this work and want to see it continue.

Sincerely yours,

William W. Edmunds, Jr.  
Senior Human Performance Specialist



## **MEDAL**

Karl S. Beers  
Air Liquide – MEDAL, L.P.  
305 Water St.  
Newport, DE 19804

12 April, 2002

Mr. Anthony Fazio  
US Department of Transportation  
Federal Aviation Administration  
800 Independence Ave. SW  
ARM –I Room 810  
Washington, DC. 20591

RE: Letter to FAA Docket relating to an observation on the FTIHWG report.

Dear Mr. Fazio:

I am sending this letter to point out a concern I have with the Fuel Tank Inerting Harmonization Working Group Final report. Before I get into the details of my concern I would like to make it absolutely clear that this note is not a dissenting opinion of the report contents, but rather documentation of an note on the report's conclusions and recommendations from the prospective a member of the Fuel Tank Inerting Harmonization Working Group.

When I submitted my resume for consideration to be part of the Fuel Tank Inerting Harmonization Working Group, I was honored to be part of this activity and selected as part of the FTIHWG. The primary reason I wanted to become involved was to be part of a study that had the potential to make recommendations to the aviation industry that could dramatically improve the safety of fuel tanks by inerting. I felt that with Air Liquide's background in nitrogen generating technologies and our experience in fuel tank inerting on military aircraft, we had a lot to offer the working group in completing its task.

It is true that at the completion of the work and the submission of the working group report there was general consences of the working group members as defined by the ARAC operating procedures. While we may not have agreed with every detail of the report

conclusions and recommendations, all of our concerns were acknowledged by the other members of the working group and addressed as best they could. It was clear from the work completed and data gathered by the various sub-task teams that the cost of inerting the commercial aircraft fleet over the study period would exceed the benefit as calculated in our report.

Now that the FAA has the working group report and its recommendations it is clear that a decision has to be made on flammability requirements for the fuel tanks on the existing commercial fleet aircraft. I would like to point out to you an issue I noticed in the inerting cost model which is inconsistent with the report conclusions. The CY2005 NPV cost benefit ratio calculated by the model for scenario 7, OBIGGS Hybrid HCWT only for the US Passenger fleet, is 41 :1. The report recommendations indicate that the FAA, NASA, and the industry should pursue technological advancements to decrease the size, weight, performance, and reliability/maintainability of inerting systems while reducing their cost. If scenario 7 was re-run with the cost of the systems at zero and the cost to carry the weight and maintain the inerting system also at zero, the cost / benefit ratio only reduces to 18 :1. It is clear that through research improving the systems will make them better for the aviation industry if the FAA were to impart a rule where inerting were to be used for flammability management, however no amount of research will make the systems cost, weight, and maintenance requirements go to zero which does not entirely support the working group recommendations.

From my experience of being on the working group it is clear that the FAA has a difficult decision to make about the flammability of the existing aircraft fleet. I urge the FAA to strongly consider fuel tank inerting as a viable technology that will offer a significant improvement to the safety of the commercial aircraft fleet. Please include this letter into the docket along with the FTIHWG report and do not hesitate to contact me if you have any questions regarding this letter.

Regards,



Karl S. Beers

TO: FAA Office of Rulemaking

FROM: Paul Hudson, Aviation Consumer Action Project  
Member, FAA Aviation Rulemaking Advisory Committee, Executive  
Committee

DATE: April 12, 2002

RE: Comments on Fuel Tank Inerting Harmonization Working Group  
Final Report dated February 2002

The final report as did a prior report in 1998 unanimously found that (a) there is a substantial risk of explosion in airliner fuel tanks (center fuel tanks with adjacent heat sources representing about 90% of airliners were estimated to be in explosive condition 30% of the time in 1998 and 33% in 2001), (b) that fuel tank inerting provides clear safety benefits, and (c) that hundreds of lives would be saved otherwise who would be lost in air disasters caused by fuel tank explosions. Both reports admit that fuel tank inerting is technically feasible with variety of technologies. Such technologies have been used in military aviation for many years, but are not required or used in commercial aviation.

In addition to ACAP I am advised that EXCOM member NADA/F, several members of the Working Group and the manufacturers of various fuel tank inerting systems strongly disagree with the recommendation of the Working Group that fuel tank inerting should not required by the FAA but merely be the subject of further study and instead endorse the following ACAP recommendation:

ACAP recommends that the FAA promptly issue a regulation requiring that all commercial airliners certified to operate in the United States reduce the potential for fuel tank explosions to no more than 1% of their operating time as measured by FAA testing and recorded measurements of temperature and oxygen and fuel content of fuel tanks during operation. The Working Group failed to produce the regulatory language that was part of its tasking. This regulation should be phased in over the next three years so that industry may have time to adjust and select the most cost effective technologies to meet

the minimum 1% performance standard. The FAA should pre-approve systems that meet this standard but permit unapproved systems to also qualify by meeting stringent performance tests and monitoring. Most wing tanks currently operate in explosive condition 1% to 5% of their operating time. Such a standard is performance based, technology neutral and would cost far less to comply with than the alternatives. ACAP will submit a rulemaking petition in the next few weeks setting forth proposed regulatory language for consideration by the FAA.

There is strong disagreement on the cost benefit analyses, which range from 53: 1 to 1 : 3 depending on the assumptions used.

The finding of the working committee that the cost of mandating fuel tank inerting exceeds its benefits is deeply flawed. Flaws in the Working Group cost benefit analysis include (a) failure to account for increased risk of terrorist bombings of airliners, especially since the 9/11 attacks, (b) the unsubstantiated and unwarranted assumption that existing or proposed improvements (SFAR no. 88) will reduce the risk of fuel tank explosions by 75%, (c) the unrealistically low value placed on the benefit to society of one lost life in air travel based on a dated study of traffic fatalities, (d) the failure to properly account for lost revenue to the industry caused by public fear of flying after preventable air disasters and the cumulative loss of revenue to the travel and tourism industry caused by loss of public confidence in the safety of air travel and the low public tolerance for mass transportation disasters, (e) the risk of high punitive damage awards against aircraft manufacturers and airlines for willful failure to correct known safety design defects (e.g. adjacent heat sources to center fuel tanks producing explosive air fuel mixtures of over 140 degrees F.), (f) the lack of an economist with recognized credentials in cost benefit analysis to perform its study, (g) the high labor costs generated by assuming dedicated ground based inerting crews and a long time frame for fueling operations, and (h) the high failure rate assumed for aircraft based systems.

In accordance with the decision of the EXCOM and the minutes of the March 13, 2002 meeting dated March 18, 2002, it is respectfully requested that these comments be

included with the cover letter from the EXCOM chairman conveying the Working Group Report to the FAA as well as in the public record and available on line.

***NATIONAL AIR DISASTER ALLIANCE / FOUNDATION***

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**Dissenting Opinion:**

**FAA ARAC Fuel Tank Inerting Harmonization Working Group (FTIHWG)**

**Submitted by James H. Hurd, NATIONAL AIR DISASTER ALLIANCE/FOUNDATION FAA ARAC Executive Committee Representative, FTIHWG Member, TWA 800, and NATIONAL AIR DISASTER ALLIANCE/FOUNDATION Board Member.**

Submitted March 13, 2002 at the FAA Aviation Rulemaking Advisory Committee (ARAC) Executive Committee (ExComm) Meeting.

FTIHWG Participants, Technical Research and Writing by the following:

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Gail Dunham, NADA/F President, [GADunham@aol.com](mailto:GADunham@aol.com) (215) 793-9224

The following is submitted to be included as a Dissent Addendum with the FTIHWG Final Report as accepted by the ExComm on March 13, 2002. NADA/F does not consider the recommendations in the FTIHWG Report to be valid. This dissent includes all of the technical data as presented by the NADA/F representatives.

Introduction

September 2000 an FAA Aviation Rulemaking Advisory Committee (ARAC) was formed in order to provide advice to the FAA about implementing fuel tank inerting (FTI) into centerwing tanks (CWT). Their Final Report was issued in June 2001 and submitted to the FAA ARAC Executive Committee (ExComm) in August 2001. Clarifications were requested by the Committee and these will be submitted to the Committee in March 2002. Both the report and the clarifications are found to be deficient as described in detail below. It should be noted that this is a second effort to address the fuel tank explosibility issue.

In 1998 the FAA initiated an ARAC study regarding fuel tank inerting in the ullage (empty space with vapors) portion of center wing tanks (CWT). This study was a result of the TWA 800 crash and the National Transportation Safety Board (NTSB) recommendations. This study lasted approximately six months. The findings were that more studies and technology were required and that the cost benefit analysis was not within FAA guidelines.

An explosive mixture of fuel vapors and air will form in the ullage volume of aircraft fuel tanks. A subsequent presence of an active ignition source resulted in a damaging explosion such as the most recent known examples:

- a Boeing 737, Bangkok, Thailand, 2001;
- a Boeing 747, New York, New York, 1996; TWA 800, and
- a Boeing 737, Manila, Philippines, 1990.

Lowering the oxygen content in this ullage volume with nitrogen will prevent these explosions and increase flight safety. A mechanism, which absolutely eliminates the possibility of these fuel tank explosions, is to **reduce the oxygen concentration within the fuel tanks, by increasing the nitrogen content. Any ignition source is then ineffective.**

It should be noted that fuel tank inerting is supported by members of the National Transportation Safety Board (NTSB) and continues to be posted as one of their top ten "Most Wanted" safety improvements. On 8 August 2001, Carol Camody, acting chair, expressed her disappointment that the FAA (FHWG) Working Group relied on cost benefit ratio (CBR) as a basis in recommending that fuel tank inerting not be implemented.

On 23 August 2000, the past NTSB chair, Jim Hall, noted that:

"It is imperative at long last, that the aviation community move with dispatch to remove flammable fuel/air mixtures from the fuel tanks of transport category aircraft as recommended to the FAA by the CAB on 17 December 1963 as a result of the Pan Am flight 214 disaster."

It is expected that the NTSB can provide to the FAA their information, which supports the inerting of fuel tanks.

The FAA has compiled a list of **27 incidents of fuel tank ignitions**, including fatal explosions from commercial and military flights. See Page 12 of this report for the compilation. It is possible that there are additional incidents or disasters that were not accurately investigated.

Captain Tim Murphy reminded ALPA at its Safety Meeting in August 2001, "*Not all plane crashes are investigated, worldwide.*"

Significant criticism of the concept of cost benefit analysis or ratio is justified, and quantitative data may be chosen which significantly affects these calculations. It is possible to argue that an immediate program should be initiated in order to inert aircraft fuel tanks, and thus effectively eliminate this explosion danger.

Cost/Benefit Analysis

The 1998 FTIHWG report stated a cost of \$5B to \$20B over a 15-year period, and the 2001 FTIHWG report stated a cost of \$20B to \$35B over a 15-year period, with no satisfactory explanation for the inconsistencies of their cost benefit analysis. NADA/F believes that technical research could demonstrate that lower costs can be achieved with all the scenarios listed in the report.

- Based upon information available and discussed at the FTIHWG, a normalized charge (cost to the passenger) could be as low as \$ .25 (cents) per passenger per flight delivered.
- Cost of nitrogen, which is 100% effective in preventing an ignition, could be a charge of \$8.25 for the nitrogen, plus a service charge of \$100 per aircraft per flight.

The basic concept of cost/benefit ratio (CBR) or cost/benefit analysis (CBA) seems to be fatally flawed. The numerical value can be made very large by having a large numerator or small denominator or very small by having a small numerator or large denominator. Having the quantity of the order of unity does not seem to resolve much. More often than not the financial quantities in the Working Group's report are at best estimates, or at worst sheer speculation. Also, some of the assumptions used to justify figures are flawed as explained below.

Within the June 2001 report there are numerous CBR calculations which give the results that the cost of nitrogen fuel tank inerting are greater than the benefits produced. For some of these calculations it is possible to make straightforward comments affecting their validity and/or changing the results to produce a more favorable situation for the implementation of nitrogen fuel tank inerting.

**Comments on ARAC FTIHWG 2001 Final Report Dated 6/01/02**

1. Pg. 1-7 ¶ 1.8 → Evaluation timeline assumes that it will take 36 months to certify a design and 84 additional months (7 years) to modify the fleet. Figure 1 is a rough cash flow diagram during the evaluation period. The non-recurring costs associated with inerting are realized between 2005 and 2015. Based on pg. 1-8 ¶ 1.8, there is only one expected accident that could be avoided in the 16-year evaluation period. This is due to the fact that no benefit could be realized before the system is implemented. It is suggested that the sensitivity analysis include an earlier implementation date, and/or a longer total time frame.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Event	Reg. Published			Design Cert							All go					
Cost	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Benefit																↑

Figure 1 – ROM Cash Flows of Cost and Benefit Over Study Period

2. A major assumption that the recently enacted SFAR 88 (Special Federal Aviation Regulation) would reduce accident rates by 75% is not supported by any evidence. Note that no source of ignition has been pinpointed for any of the three most recent explosions. To assume that 75% of these type of accidents can be avoided by inspecting just one of the possible sources is not credible. Further, it has been suggested that this type of manual inspection of wiring harnesses more likely would result in damage of brittle insulation and may increase the likelihood of accidents by creating ignition sources.
3. Page 1-8 2nd ¶ Indicates that only 1 airplane accident would be avoided in the 16-year study. Note that full inerting system capabilities would only be on line for 6 of those 16 years. *(See Page 12 for an FAA list of the 27 incidents of fuel tank ignition, including 13 during the last twenty years.)*
4. Page 1-8 4th ¶ Says 132 deaths avoided for GBI (Ground Based Inerting) and 253 for OBIGSS (Onboard Inert Gas generating System) over the 16-year evaluation period, which is 6 years of system functionality. The benefit over 16 years of operation would be 352 for GBI and 675 for OBIGGS.
5. Accident rates are based on only 3 data points, and therefore do not create a statistically significant pattern. Therefore these rates must represent a fairly low confidence interval. It is suggested that the sensitivity analysis include a range of accident rates that represent higher levels of confidence intervals.
6. Page 1-9 Figure 1-5. Again the benefit interval is only 6 years projected over a 16-year time frame the ratios vary from 14:1 to 20:1.
7. Page 2-2 ¶ 2.b → “Various means of supplying nitrogen (i.e., liquid. . .)” The report does not cover liquid nitrogen supplies. (Note that “i.e.” stands for “that is”, which indicates that they were to specifically look at liquid nitrogen).
8. Page 4-8 ¶ 4.5 → “it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss. . .” These assumptions are not factually or statistically based. The sensitivity analysis should allow for large variation in these estimates. Refer to number 4 above. Over a 16-year period the lives saved are 352 for GBI and 675 for OBIGGS. If we allow that in 100% of explosions there is a total loss, then the numbers become 407 and 780.

	Benefit (\$US billion)	Adjustment for 16 years of benefit	Adjustment for total loss	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	0.245	0.653	0.755	10.37	13.7:1
OBGI (HCWT only)	0.219	0.584	0.675	11.6	17.2:1
Hybrid OBIGGS (HCWT only)	0.257	0.685	0.792	9.9	12.5:1
OBIGGS (all tanks)	0.441	1.176	1.359	20.78	15.3:1

9. If we include the factors from item 8 in the sensitivity analysis, the most favorable scenarios become:

	Scenario from 8/8 Summary Pg#	Benefit (\$US billion)	Adjustment for 16 years of benefit	Adjustment for total loss	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	37	0.281	0.749	0.866	4.196	4.8:1
Hybrid OBIGGS (HCWT only)	43	0.3	0.800	0.925	3.68	4.0:1

10. Page 6-14 → Inclusion of Capital costs may be redundant. It is likely that the operator of the system will absorb those costs, and recoup them via operating costs.

11. Page 11-1 Is the “willingness to pay” value of human life escalated in the out years? If not, then there is another skew in the data. The “willingness to pay” benefit is discounted back to 2005 at 7%. If no escalation was assumed, then the benefits are understated by that 7% discount. Since most of the benefits are in the out years, there is a significant impact. If the adjustments for escalation of benefit are included that changes the most favorable scenario.

	Scenario from Summary Pg#	Benefit (\$US billion) Adjusted in Item	Adjustment for 7% Discount Inflation	Cost billion	Cost-Ratio
GBI (HCWT)	37	0.86	2.55	4.19	1.6:
Hybrid OBIGGS (HCWT)	43	0.92	2.73	3.68	1.3:

12. A major domestic airline disclosed that the actual costs used by the airlines to account for loss of life vary between \$2.7M and \$4.0M based upon the demographics of the airlines route structure. The most favorable scenarios become:

	Scenario from 8/8 Summary Pg#	Benefit (\$US billion) Adjusted in Item 11	Adjustment for \$4M/Life	Cost (\$US billion)	Cost-Benefit Ratio
GBI (HCWT only)	37	2.557	3.788	4.196	1.1:1
Hybrid OBIGGS (HCWT only)	43	2.731	4.046	3.68	0.9:1

13. Page G-2, last sentence before Section 2.0 → States “See section 4 for more information about benefits.” No section 4 is included in this report. Please provide missing or removed information.

Num erous exam ples m ay be cited of im provem ents being m ade w ithin society to increase safety w ithout perform ing a CBR analysis.

(a) In the Our Lady of Angels, Chicago IL, 1958 school fire resulting in 97 dead, an immediate sprinkler and call box installation was initiated and completed within two years for *all* Chicago schools.

(b) M ore recently, for the past several years Ford Explorer autom otive rollovers, presum ably initiated by defective tires, have resulted in over 200 deaths. An expenditure of approxim ately \$4B has been made by only two corporations as a result of the initial recalls to correct this problem and a second recall valued at \$41.5M has also m ost recently occurred.

(c) The Ford M otor Com pany also has an additional problem and is spending nearly \$3B to replace m illions of flaw ed ignition m odules. These faulty system s resulted in 11 deaths and 31 injuries.

(d) A dditionally, at present there is a m assive recall of faulty fire sprinkler heads produced by one m anufacturer, Central Sprinkler: the O m ega m odel for residential use, and the G B m odel for com m ercial use. It has not been noted that a CBR has been done in order to justify the recall.

In an inverse situation a CBR was calculated by General M otors regarding the safety of fuel system s in autom obile crashes. In a recent California jury trial verdict enormous dam ages, nearly \$4B , were awarded to the injured as General M otors had reportedly decided that the \$8 cost per vehicle required for fuel system redesign and manufacture was not cost effective com pared to dam ages which w ould be awarded in any subsequent trials.

Finally, the U S. Suprem e Court has in the last term spoke on the issue of CBR . They judged unan im ously in an U S. EPA (Environmental Protection Agency) related case that only public health (substitute the closely related w ord safety) could be considered and not cost regarding new clean air standards.

### Benefit Analysis

As currently structured the benefits chiefly accrue from the figure of \$2.7M which is described by the DOT (Department of Transportation) as the amount "which U S. society is willing to spend on increased safety in order to prevent a death." It should be stressed that the NATIONAL AIR DISASTER ALLIANCE/FOUNDATION does not agree w ith the DOT econom ists who have defined \$2.7M as the cost of a life lost in an air crash, or the m axim um amount of "w illingness to pay" for aviation safety and security. H istory has show n that the Am erican people have NOT found this an acceptable amount.

The current very adverse response by the thousands of fam ilies suffering from the loss of fam ily members due to the events of September 11th, 2001, and to the provisions of the "Air Transportation Safety and System s Stabilization Act," also indicate that this is a very inadequate amount.

Page 4, #8, of this document, references Page 4-8 ¶ 4.5 of the FTIHW G 2001 Final Report:

"it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in-flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss. . ."

This statement indicates that 90% of the passengers in a ground explosion would be survivors, and potential burn victims. The September 11<sup>th</sup> burn victims, helped by medical technology of 2002, will have medical bills greatly in excess of \$2.7M per person, plus personal care, compensation for their pain and suffering, and have special needs that we cannot imagine. Indeed, juries, judicial rulings, and settlements for air crash survivors with severe injuries, especially burn victims, have been ten times greater than \$2.7M and more. No one would trade places with them for any amount of money, and society wants these victims compensated so that they receive the full support that they need. Industry should be willing to finance higher costs to prevent on board fires and explosions. When the money and technology are there, and have been there for 30 years, the industry should do everything possible to prevent fire and explosions on airplanes.

During a meeting between FAA rulemaking authorities and NATIONAL AIR DISASTER ALLIANCE/FOUNDATION members on 28 September 2001, it was indicated by the FAA that this benefit restriction was too limited and that the concept of benefits should be expanded. Such additional benefits should consider the costs of family breakups, which invariably results when a family member is lost. The U.S. government indicates that it has great respect and support for the concept of a small business. A political and legal environment is developed for such to thrive. The family is an ideal example of a small business, and post-air crash conditions should be favorable for the survival of this business.

As the events of September 11th have shown, and as will be applicable to other crashes, air disasters can have other enormous secondary economic effects which need to enter into the benefits calculations. There is the loss of passenger revenue due to fleet grounding and the reluctance of individuals to travel by air. The airlines first response is to lower fares (and profits) when passenger traffic decreases and people do not want to fly. There is decreased use of hotels, restaurants, rental cars, theaters, and all other items related to travel. There may be extensive property loss as a result of an air crash as well as an extensive loss of jobs.

Some quantitative data may be connected to the four airplane crashes on September 11th, which show that the benefits of increased safety have been significantly underestimated in the past.

- \$2T Stock market losses may be estimated (from Milken Review)
- \$15B in air transport losses, or more, and still growing
- \$90B for property losses and interrupted business at the Pentagon and New York City (NYC) (per Swiss Reinsurance Co.) OR
- \$105B NYC losses estimated through June 2003 for lost revenue, damage and rebuilding (source NYC Comptroller, and Congressional aids)
- \$30B for the first five months of the Waron Terror abroad (recent news)
- \$140B Projected Federal Stimulus Package to prop up the U.S. economy (not including global losses) ("Newsweek," 10/1/01).
- 32 Boeing airplanes for which struggling airlines might not be able to take delivery ("WallStreetJournal" 10/9/01)

- \$0 Financial compensation for some airline executives. Pay cuts and job insecurity industry-wide.
- 1.8M jobs lost in the U.S. by the end of 2002, all as a result of the September 11th aviation disasters.
- No cost estimates for an aviation disaster at a nuclear power facility (Milken Review)

At present, the job loss in the aviation industry alone worldwide stands at 400,000, including an estimated 30,000 job loss for Boeing alone. The cost of the TWA 800 crash is currently estimated to be approximately \$1B. The cost of Swissair 111 is estimated at possibly \$2B, and the airline is no longer in business. The Libyan government has reportedly offered a \$6B settlement with regard to PanAm 103, plus the costs of damages since 1988, and the airline failed to stay in business. A potential casualty of unknown magnitude is the collapse of the insurance and reinsurance market as a result of the aviation disaster losses.

The airline industry is at crisis worldwide, and much needs to be done to re-build faith in the industry. NADA/F urges government and the industry to evaluate safety and security recommendations first on their merits to re-build confidence in the aviation industry. The American people are not accepting known fatal flaws and safety and security contracted to the lowest cost bidder.

At the 28 September 01 meeting at the FAA with NADA/F, the economist stated that he had not imagined multiple accidents in a single day. We cannot afford for the industry to ignore that possibility ever again.

As a result of the next such aviation disaster punitive damages of unknown amounts may be awarded to families suffering the loss of members. On 17 August 01, \$400+M in damages were awarded against Cessna Aircraft Co. regarding an alleged known defect concerning the failure of seat positioning locks.

The information above would indicate that the dollar amount attributed to benefits could and should be increased significantly, thus substantially decreasing the figure for the CBR.

The June 2001 ARAC Final Report does put the air transport industry on notice that there is a known single point failure mechanism which will produce a catastrophic fuel tank explosion. The report also indicates that the nitrogen inerting of fuel tank ullage is 100% effective in eliminating fuel vapor/air explosions within aircraft fuel tanks. A known hazardous condition may be eliminated.

In other scenarios, where nitrogen-generating systems are considered, the small amount of information which is available in the unclassified world would seem to indicate that current military technology, if available for use, could also lower the cost estimates. The military has been using fuel tank inerting for over 30 years, and their classified information could be helpful.

## Ignition Source Control

Benefits Attributed to SFAR 88 (Special Federal Aviation Regulation)

The FTIHWG determined that the benefit of ullage inerting should be reduced to reflect the benefits offered by new procedures defined by SFAR 88. The SFAR was released as the Working Group was assessing the benefits of inerting, and these benefits were discounted considerably (75%) based on the assumption that the process defined in the SFAR would yield significant benefits.

"The 75% reduction had been estimated by the 1998 FTIHWG." [FTIHWG Final Report Pg. H-9]

The benefits offered by SFAR 88 are difficult to quantify, because many of the ignition sources for fuel tank explosions have not been identified as noted by the FAA [**Federal Register May 7, 2001 pg. 23127**]

"As noted, the FAA has not quantified the potential benefits from this final rule because there is uncertainty about the actual ignition sources in the two fuel tanks..."

Further the regulatory text in **SFAR 88** calls for reducing the exposure to flammable mixtures. From **§25.981(c)**:

"The fuel tank installation must include either--

1. Means to minimize the development of flammable vapors in the fuel tanks (in the context of this rule, "minimize" means to incorporate practicable design methods to reduce the likelihood of flammable vapors); or
2. Means to mitigate the effects of an ignition of fuel vapors within fuel tanks such that no damage caused by an ignition will prevent continued safe flight and landing."

The FTIHWG assumed a 75% reduction in fuel tank explosions resulting from the implementation of SFAR 88, however, has this included the reduction of flammability exposure specified in the regulatory text for SFAR 88?

A fuel/air explosion (FAE) occurs when five items come together:

- fuel,
- oxidizer (oxygen),
- ignition source,
- confinement, and
- vapor phase fuel/oxidizer mixing.

The first three are commonly known as the fire triangle while all are known as the explosion pentagon. For the latter situation the removal of any one item precludes an explosion, but the attempted control of only one component, such as ignition sources, is a risky strategy. It may decrease the number of incidents, but it will not eliminate them. Experiences in other industries such as the process, coal mining, and grain and feed have shown that it is necessary also to control the fuel in order to eliminate fuel/air explosions.

It is exceedingly difficult to have two failures at the same time – ignition sources and combustible fuel/air mixture. Such a strategy was adopted by another segment of the transportation industry, maritime petroleum shipping, where the scrubbing of tankage led to an electrostatic ignition source for the fuel vapor/air mixtures. An analysis of the problem led to the use of stack gases as an oxidizer diluent within the empty tanks.

Non-conventional ignition sources have become of increased concern.

- Silver components within the fuel tank can produce conducting paths leading to short circuits through chemical reactions occurring in the presence of low sulfur fuel.
- On 26 November 1989 an Avianca B-727-100 crashed shortly after takeoff from Bogotá, Columbia as a result of the detonation of an explosive device placed in a seat on the starboard side of the passenger cabin, which in turn ignited fuel vapors in an empty fuel tank.
- On 22 December 2001, an American Airlines 767-300, Flight 63, traveling from Paris, France to Miami FL, was diverted to Boston MA. A passenger sitting in a port side window seat slightly aft of the wing trailing edge had attempted to detonate an explosive device which had been hidden in his shoes. Had the initiation attempt been successful and had he been located above the center wing tank he may have ignited, with fatal results, the fuel vapors in the center wing tank.
- In January 1995, responding to a routine fire alarm in a Manila apartment building, firemen and investigators uncovered a bomb-making factory with electronic timers and terrorist plans regarding near-future transpacific flights. The timers matched those used to explode a bomb on a Philippines Airline flight a few weeks earlier, which killed one passenger and forced an emergency landing. The eleven long haul flights, all with intermediate stops on a single day, designated as imminent targets involved mainly those of United and American Airlines, the same airlines targeted for September 11th. The explosive technique of operation Bojinka of placing a small bomb within the cabin certainly could have been enhanced by locating it over the center wing tank and detonating it later into the flight when its liquid fuel had mostly been consumed.

As with the case of the Avianca and American Airlines flights, SFAR 88 would not have decreased the likelihood of these intentional ignition sources.

In the process, coal mining, and grain and feed industries unanticipated/unexpected ignition sources led to the failure to eliminate explosions by the control of ignition sources exclusively. It will be the same situation regarding SFAR 88. It is thus impossible to definitively quantize its effect and not to implement a second backup strategy such as nitrogen fuel tank inerting.

#### Related Safety Issues

It is not realistic to try to inert the fuel tanks in all aircraft at all locations within the global aviation network at the same time. A risk and consequence analysis needs to be performed relating to the different types of aircraft so as to propose an intelligent implementation of an inerting program.

Logic would dictate that one would begin with the high-risk, heated center wing tank (HCWT) aircraft currently in production or to be put into production. Those to be neglected would be ones of smaller capacity near the end of their airframe life. Geographically, the initiation would occur first at airports with the largest passenger traffic. The last implementations would be at those airports with little passenger traffic.

Any cost associated with the implementation of fuel tank nitrogen inerting must be normalized in a rational fashion. This is not an enormous one-time expense which will be paid for by the air transport industry. Just like any other expense it will be passed on to the passengers.

1. Based upon information available to and discussed by the Working Group, such a normalized charge could be as low as \$0.25 per passenger per flight delivered.
  2. There could be a charge of \$8.25 for the nitrogen plus a service charge of approximately \$100 per aircraft per flight.
- Even now, when fuel prices are at an all time low, the airlines are authorized to charge a fuel surcharge for each ticket of \$18.60 one way, and \$37.20 round trip. The surcharge was added when the price of Jet A fuel was at a maximum, and may still be charged to the customer.
  - Passenger Facility Charges (PFC's) can be a maximum of \$4 (plus tax) per airport, with a maximum of \$20 (plus tax) per ticket, and the PFC's continue to increase.
  - The domestic transportation tax is 7.5% per ticket, and billions have accumulated in the federal Aviation Trust Fund.
  - The new security tax is \$2.50 one way and \$5 round trip, or with multiple segments can be \$10 round trip per ticket.
  - The International Transportation Tax used to be \$3 per round trip ticket, and now round trip international taxes can be \$200+ per ticket. International ticket taxes continue to increase in the number of taxes, and the amount of the tax, or service charge, or user fee.

Such an expense of \$0.25 per passenger per flight, or \$100+ for nitrogen, per airplane, per flight is literally peanuts in comparison to the cost of the ticket, taxes, and service charges. Since September 11<sup>th</sup> passengers have not complained about the security tax, and have expressed that they are willing to pay for higher levels of safety and security.

### Conclusions

The combustible fuel vapor and air mixture which appears in the ullage of HCWT's (heated center wing tanks) during a certain period of flight time, 33%, represents a safety risk. Nitrogen inerting eliminates this risk for a very minimal cost. The modification of the air transport system to implement this procedure may be done in a very intelligent, controlled manner. As the events of September 11th have shown, air crashes have many unforeseen consequences, and the air travel system has shown itself to have limited elasticity. The next HCWT explosion may well have extensive foreseen and unforeseen consequences. A measured, determined introduction of the nitrogen fuel tank inerting technology is imperative beginning immediately in order to enhance aviation safety.

**The following is the FAA compiled list of incidents of fuel tank ignitions from the Federal Register: April 3, 1997 (volume 62, Number 64) Page 16013-16041**

[www.epa.gov/fedrgrstr/EPA-GENERAL/1997/April/Day-03/g8495.htm](http://www.epa.gov/fedrgrstr/EPA-GENERAL/1997/April/Day-03/g8495.htm)

**Commercial Fuel Tank Explosions:**

	<b>Model</b>	<b>Operator/Location</b>	<b>Year</b>	<b>Fatal</b>	<b>Hull loss</b>
1	B707	OSO	1959	4	Yes
2	B707	Elkton	1963	81	Yes
3	B707	San Francisco	1965	0	Yes
4	B727	Southern Air Transport, Taiwan	1964	1	No
5	B727	Minneapolis	1968	0	No
6	B727	Minneapolis	1971	0	No
7	DC-8	Toronto Canada	July 1970	106	Yes
8	DC-8	Travis AFB	1974	1	Yes
9	DC-9	Air Canada	1982	0	Yes
10	Beechjet 400	Jackson MS	June 1989	0	No
11	B727	Avianca	1989	107	Yes
12	B737	Philippine Airlines	1990	8	Yes
13	B747	TWA 800	July 1996	230	Yes
14	B737	Thai Airlines	2001	1	Yes

**Military Non-Combat Fuel Tank Explosions:**

1	B52	Loring AFB Maine	July 1970	0	Yes
2	B707	USAF Spain	June 1971	Yes	Yes
3	B52H	Minor ND AFB	Nov. 1975	0	Yes
4	B747	Iranian Fuel Tanker	1976	7	Yes
5	KC135Q	Plattsburg AFB NY	Feb. 1980	Not Noted	Yes
6	B52G	Robins AFB Georgia	Aug. 1980	Yes	Yes
7	KC135A	Near Chicago	March 1982	Yes	Yes
8	B52G	Grand Forks AFB ND	Jan. 1983	Not Noted	Yes
9	KC135A	Altus AFB OK	Feb. 1987	Yes	Yes
10	B52H	Sawyer AFB MI	Dec. 1988	Yes	Yes
11	KC135A	Loring AFB Maine	Sept. 1989	Yes	Yes
12	KC135A	Loring AFB Maine	Oct. 1989	Yes	Yes
13	KC135R	Mitchell Field, Milwaukee WI	Dec. 1993	Yes	Yes

Total 27

Updated: March 11, 2002

## Glossary

### Basic Inerting design systems:

**GBI**      **Ground Based Inerting** – A system using ground-based nitrogen gas supply equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to unheated wing tanks. The affected fuel tanks would be inerted once the airplane reaches the gate and is on the ground between flights.

**OBGI**      **Onboard Ground-Inerting** – An onboard system that uses nitrogen gas generating equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to an unheated wing tank. The affected fuel tanks will be inerted while the airplane is on the ground between flights.

**OBIGGS**      **Onboard Inert Gas Generating System** – A system that uses onboard nitrogen gas generating equipment to inert all the fuel system's tanks so that they remain inert throughout normal ground and typical flight operations.

**Derivative combinations of OBGI and OBIGGS** were also studied, and were described as “**hybrid systems.**”

ARAC	Aviation Rulemaking Advisory Committees
CBA	Cost Benefit Analysis
CBR	Cost Benefit Ratios
FTIHWG	Fuel Tank Inerting Harmonization Working Group
SFAR	Special Federal Aviation Regulation

**The following Comments for Liquid Nitrogen On-Board Storage and Cost Benefit Analysis are being submitted on behalf of those who contributed Technical Research and Writing to the dissent.**

Comments on ARAC Final Report  
**CBA for Liquid Nitrogen On-board Storage**

In the June 2001 ARAC FTIHWG Final Report sixteen different scenarios are considered in order to assess the cost. In scenario sixteen what could be one of the most promising concepts, an onboard cryogenic (liquid) nitrogen system, is considered as a result of a request made by the ARAC Executive Committee at its April 2001 meeting to the Working Group. The CBR as calculated by the Working Group is not favorable. However, alternative calculations presented below are much more favorable.

The term "*practicable design methods*" may have been interpreted by the FTIHWG to exclude the inerting concepts (Scenario 1 to 16) reviewed and deemed not to be cost effective. However, the analysis of Scenario 16 appears to be incomplete and inaccurate. Their CBA was based on a number of assumptions, which are detailed in the Estimating and Forecasting team's final report in Section 3. The following assumptions are under question:

- (1) "*Gas generating systems are less expensive and less hazardous*"
- (2) "*The computed LN<sub>2</sub> weight is based on carrying enough LN<sub>2</sub> for three flights*"
- (3) "*The system described above has been sized to inert all fuel tanks on the airplane*"
- (4) "*Weight in Figure G-64 based on FAA study "Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System" (1972)*"
- (5) "*A mechanic; not a ground service worker is required to fill the airplane storage tanks.*"
- (6) "*All nitrogen needed would be generated at the airport*"
- (7) "*All retrofit costs based on the costs of the GBI airplane system.*"
- (8) "*Although the closed-loop oxygen sensing system is more complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar*"

Many of the assumptions made either do not apply or should be restated to reflect the realities of the system proposed at the ExComm meeting of April 2001.

A concept has been developed using liquid nitrogen to generate gaseous nitrogen with purity in excess of 99.9% to maintain a non-flammable ullage in airplane fuel tanks. The primary advantage of liquid nitrogen storage is the ability to convert a large volume of nitrogen gas from a substantially smaller volume of liquid. The ratio of gas volume to liquid volume for nitrogen is 696:1. The system concept employs a liquid nitrogen (LN<sub>2</sub>) storage vessel or dewar, which is designed for use on aircraft. The LN<sub>2</sub> is vaporized to nitrogen gas and delivered through a simple manifold to the ullage of the aircraft fuel tank. The pressure in the dewar is controlled at a low pressure by a pressure-reducing valve. In the event of over-pressure or failure of the primary relief valve, a safety device (rupture disk) opens to vent nitrogen gas outside the aircraft beyond. The flow of nitrogen gas is controlled by the ullage flammability, which is determined by the combination of oxygen concentration and ullage temperature. This method of control limits

nitrogen usage to only the portions of the flight profile that require inerting to mitigate flammability. Measurement of oxygen concentration is the only means available to determine with certainty that the ullage is inert. While adding to the complexity of the overall system, an oxygen sensor ensures effectiveness of any inerting system, while conserving nitrogen. The internal pressure of the dewar (less than 5 psi) is adequate to deliver the nitrogen through the control valves, to the ullage manifold. The design uses very little power, due to the use of dewar pressure for delivery of the nitrogen gas. The only power required for this design is for the solenoid valve and instrumentation, approximately 1 kW.

### **Assumptions (from FTIHWG Final Report)**

#### **(1) "Gas generating systems are less expensive and less hazardous than liquid nitrogen based systems"**

The nitrogen gas generating systems evaluated by the FTIHWG all required a complex array of compressors, heat exchangers, filters, valves, water separators and air separation modules or distillation columns. The cost of equipment for each system is in excess of \$180K. In addition, connections to a bleed air source as well as substantial power requirements lead to very high installation costs. The liquid nitrogen based system offers a significant reduction in the number and complexity of components. The cost of equipment as proposed is to be included in a service fee charged by the inerting service provider. For a moment, make a comparison between cryogenic nitrogen and aviation fuel. We do not load crude petroleum on the aircraft for onboard refining into jet fuel. The refinery would weigh too much and consume too much power!

Installation costs are expected to be paid by the same parties as for the other 15 Scenarios, however, these costs must be substantially lower as the only connections required are for the ullage manifold, the vent and the electrical system (instrumentation only). While it is understood that costs in categories (e.g. engineering, setup) are similar, the cost for hardware and installation for the liquid nitrogen based system will be considerably lower than the others considered. The assumption made by the Estimating and Forecasting team is inaccurate. The same process of estimating costs (e.g., figure F-A2, etc.) must be made for the liquid nitrogen based on-board design as for the others.

The asphyxiation hazard attributed to nitrogen inerting is taken very seriously by the industrial gases industry, and any system offered would unquestionably be assessed for the risks. Beyond well-structured safety procedures and training, safety interlocks can be included in the design without adding significantly to the complexity of the system. Interlocks provide protection even when operators and maintenance personnel ignore safety procedures. Normal airline maintenance procedures for accessing enclosed spaces (i.e. fuel tanks) require the area to be purged to remove hydrocarbon vapors. This process is likely enough to mitigate the risk of asphyxiation; however, the oxygen concentration can be checked easily before entry. The oxygen sensors included with the inerting system can control a latch to prohibit access when the oxygen level is too low. In addition, inexpensive (approx. \$300) hand held oxygen sensors can be used to increase the level of safety. This design and these procedures are very common in industry today.

**(2) "The computed LN2 weight is based on carrying enough LN2 for three flights"**

The design of the liquid nitrogen system can provide for adequate storage for three flights, however, this may be necessary only for medium sized aircraft, which often have quick turn times and several trips per day. In contrast, large aircraft have longer turn times, and often only fly one trip per day. Some sizes specified by the FTIHWG are considerably larger than necessary. For example, the weight of LN2 specified in their analysis (1,282 lbs.) generates enough nitrogen gas to inert the equivalent of over 131,000 gallons of ullage space. In light of turn times associated with large aircraft, and length of flights, is it necessary to carry so much nitrogen? The FTIHWG should consider whether it is necessary to require capacity for three flights across all airframe sizes.

**(3) "The system described above has been sized to inert all fuel tanks on the airplane"**

The Tasking Statement [Federal Register: July 14, 2000 (Volume 65, Number 136)] states that *"The system shall inert all fuel tanks with an on-board nitrogen gas generating system..."*. This is inconsistent with the requirements for Ground Based Inerting, which states that *"The system shall inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank..."*. Please clarify the differentiation in requirements for the two modes of inerting.

**(4) "Weight in Figure G-64 based on FAA study "Performance of a DC-9 Aircraft Liquid Nitrogen Fuel Tank Inerting System" (1972)"**

The FTIHWG's report referenced data from a report that is 30 years old. Advances in storage of liquid nitrogen may have had a favorable impact on the weights and costs associated with liquid nitrogen storage. Based on equipment available today, the weights were updated and are reflected in Figure G-64 (re-stated) below. Limiting the amount of liquid nitrogen stored on-board may also offer the benefit of reducing the size and weight, and to a lesser extent, the fuel penalty. A 100-gallon Dewar carries enough liquid nitrogen to inert over 69,000 gallons of ullage space. The vessel weighs only 475 lbs. Additional components include pressure-reducing valves, pressure relief valve, solenoid valve, oxygen analyzer, thermocouples and piping are anticipated to weigh no more than 100 additional lbs. The weight of the distribution manifold specified in the Ground Based Inerting Team's report (Pg. C-26, Figure 13.0-1) is 54 lbs. The FTIHWG should redress their estimates of weights associated with liquid nitrogen based on-board inerting designs evaluated as Scenario 16 (Pg. G-66). The following table represents revised estimates of weights shown on Figure G-64:

	Large Airplane			Medium Airplane			Small Airplane		
	Cu-Ft N <sub>2</sub>	Weight	Gal	Cu-Ft N <sub>2</sub>	Weight	Gal	Cu-Ft N <sub>2</sub>	Weight	Gal
LN <sub>2</sub>	9,311	675	100	4,655	338	50	2,328	169	25
Storage, controls, wt		575			375			300	
Plumbing		54			34			22	
<b>Total</b>		<b>1,304</b>			<b>747</b>			<b>491</b>	

Figure G-64 (re-stated) Liquid Nitrogen System Weight (all fuel tanks)

**(5) "A mechanic; not a ground service worker is required to fill the airplane storage tanks."**

A nitrogen service contractor can conduct the process of filling the airplane storage tanks. Two methods of executing this process are foreseen:

(a) Fill on-board LN<sub>2</sub> storage tanks located through a unique external connection located on the airframe (similar to the process fueling the aircraft)

(b) Replace empty vessels with full vessels, which have been filled and tested off-line by nitrogen supply contractor.

It is proposed that the service provided by the nitrogen supply contractor include:

- Supply and maintain liquid nitrogen storage vessels along with ancillary components; including valves, instrumentation, and pressure regulators.
- Fill vessels with liquid nitrogen as required.
- Design, test, and certify liquid nitrogen inerting package excluding fuel tank distribution manifold.

This can be offered on a fee basis, requiring no investment in equipment. The fee includes all items defined above with little or no initial capital investment. Anticipated cost for the service is less than \$200 per turnaround, which occurs once every two to three flights.

In **Item A** above, the design of the on-board inerting system utilizing liquid nitrogen requires a connection from the LN<sub>2</sub> storage vessel to a unique, frangible fitting located outside the airframe, in a location accessible to the ground based nitrogen service contractor. A design similar to the proposed by the Ground Based Inerting Design team could be adapted easily for cryogenic service. The nitrogen contractor would utilize operators trained in the delivery of liquid nitrogen and airport operations to transfer liquid nitrogen from their storage vehicle to the on-board vessel. A similar process is safely conducted hundreds of times a day for a wide range of industries, albeit not in an airport environment.

The vessel will be filled at a local liquid nitrogen manufacturing facility located near the airport facility.

In **Item B**, it is foreseen that the storage vessel will be an integrated, removable system including all valves and instrumentation, excluding the oxygen analyzer. The nitrogen contractor will be

responsible for maintaining and testing the equipment as well filling them in their facility located near the airport. Vessels requiring replacement will be removed from the airplane and replaced with a filled unit that has been tested. The process of changing liquid nitrogen vessels will be conducted by personnel trained in safe handling of cryogenic equipment; specifically for the airline industry.

Changing cylinders has an added advantage of ensuring that the inerting system is operational prior to a flight. The procedure will include a full check of the storage system at the nitrogen contractor's facility; therefore not affecting turn times. The failure rate of this design will be extremely low. In the rare event of failures, replacements will always be on hand, as the equipment becomes standard ground equipment. The design of the inerting system is such that the change can be made quickly, safely and dependably. Special mounting and connection hardware will be used to ensure this.

**The FTIHWG should re-calculate the costs of inerting when inerting service is provided at a cost of \$200 per use every two flights, three flights.**

**(6) "All nitrogen needed would be generated at the airport"**

There are a number of manufacturers of liquid nitrogen serving industries throughout the world. A network of Air Separation Units (ASU) separate air into its three main components: nitrogen, oxygen, and argon using a distillation process. At ASU's a subsequent process called *liquefaction* converts the gases to liquid for more efficient storage. As a liquid, nitrogen and the other industrial gases can be transported to customers within a 200-mile radius cost effectively. When the delivery truck arrives, the liquid nitrogen is transferred to the customer's storage tank. It is extremely rare for customers to need to generate liquid nitrogen on their facility. Only when the quantities are extremely large, does it make sense to generate liquid on site. Typical ASU's serve hundreds of customers over a wide geography. Even the largest airports will not use enough liquid nitrogen to economically justify a dedicated ASU. Existing liquid nitrogen manufacturing capacity is anticipated to be adequate to serve airport needs in the U.S.

There is a wide-ranging network of industrial gas distributors who store liquid nitrogen, oxygen argon and others to serve industries like welding. Liquid nitrogen is available virtually anywhere in the United States; either through manufacturers or distributors. **Appendix C** illustrates the network of liquid nitrogen, oxygen and argon throughout the United States. The distributor network is not shown.

The proposed solution does not require liquid nitrogen to necessarily be present at every airport facility. Since the design provides inerting for multiple flights, servicing can be scheduled by airlines at a select number of airports (e.g. Hub airports) to minimize the overall cost of implementation. In addition, the process can be scheduled during slow periods, for example overnight to further reduce the impact of inerting. **The FTIHWG should consider the use of on hand nitrogen production facilities for the supply of liquid nitrogen and determine the cost under that circumstance.**

**(7) "All retrofit costs based on the costs of the GBI airplane system"**

It is not necessary to replicate the GBI design for the liquid nitrogen based design. If **Item 5A** were used, the GBI design could easily be adapted to facilitate liquid nitrogen delivery to the on-board storage vessel. However, **Item 5B** requires no external connection to facilitate delivery of liquid nitrogen. In this case, the cost of adding an external connection along with associated fittings, valves and monitors will not be required.

The design of the manifold should be redressed in light of the results of the FAA tests on a scale model (DOT/FAA/AR-01/6). Results from testing at the Technical Center indicate that the manifold design may be greatly simplified, reducing engineering expense and weight, with equivalent results to the GBI Design team's proposed design.

**(8) "Although the closed-loop oxygen sensing system is more complex than an OBIGGS, it was assumed the maintenance and delay costs would be similar"**

Oxygen sensors provide the only reliable means of confirming whether ullage is inert. The designs offered by the on-board and ground based design teams do not offer oxygen sensors. The consequences of this decision include over-compensating for lack of information by purging with substantially more nitrogen than required. Beyond unnecessary nitrogen cost and time spent with the inerting process, this solution increases emissions of hydrocarbons by a factor of at least three; though often more than that when full CW tanks are involved.

Inclusion of an oxygen analyzer in the design considerably reduces the volume and time needed to maintain an inert ullage. The system will use oxygen and temperature information to determine flammability, and deliver nitrogen gas only when the conditions warrant nitrogen to limit flammability.

A design using liquid nitrogen storage would be far less complex than any OBIGGS system proposed, simply due to the fact that integration into an aircraft's power systems and bleed air are not required with the liquid nitrogen design. With the removable vessel option (Item 5A), maintenance procedures will be conducted off the aircraft, and procedures associated with inerting can be conducted every two to three flights in a process slightly more complex than baggage handling.

The FTIHWG should assess the benefit offered by oxygen analyzers with the on-board inerting system in contrast to the cost of complexity.

The FTIHWG should also conduct a comparable analysis of the liquid nitrogen based on-board inerting concept.

As both food and fuel are furnished by independent contractors to the air carriers it would seem reasonable that nitrogen should also be furnished in this manner at a substantially lower cost than is calculated in the final report.

This one example shows that the dollar amount associated with costs may be lowered, thus decreasing the value of the CBR. And, this scenario is of special interest in that it burdens the aircraft only with the weight and volume of the inerting material which is produced and delivered by those expert in the process.

## Appendix A

### An Alternative to OBIGGS

A solution has been developed for on-board inerting that directly addresses the issues raised by the FTIHWG's final report. In the report, the FTIHWG recognizes the safety benefit of on-board inerting in comparison to ground based inerting. The recommendation specifies that alternative technologies should be assessed which offer the safety benefits, but at lower cost and power consumption. One alternative offered to the FTIHWG, but not given serious consideration was the use of liquid nitrogen dewars for storage on board, with an automatic distribution system tied into the fuel tank's ullage. There are a number of benefits offered by such a design, which were not made clear in the FTIHWG's report:

- Substantial improvement in reliability over OBIGGS, which requires rotating equipment including a compressor.
- Substantial reduction in power requirements
- Ability to service a range of flow requirements
- Employment of higher purity nitrogen, therefore, about half the flow requirement
- Control of ullage based on flammability as oxygen sensors are included in the design
- Ability to redirect nitrogen flow for cabin fire suppression

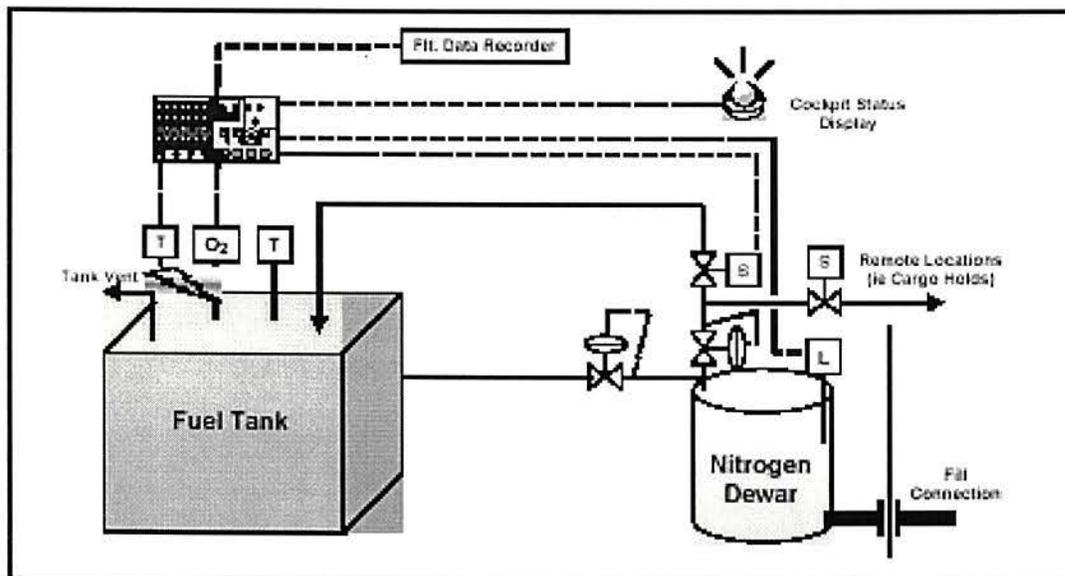
The power required to generate on-board nitrogen utilizing all of the three OBIGGS designs considered is unacceptable for today's fleet according the final report from the FTIHWG. It is well established that a significant amount of power is required for all modes of nitrogen generation, including pressure swing adsorption, air separating membranes and cryogenic distillation. While the concept of generating nitrogen on demand is appealing to the airline industry, the reality exists that this comes at a cost; specifically limited power resources on aircraft.

All modes of air separation require compressors to raise the pressure of the air being separated. In the case of pressure swing adsorption, differences in pressure are used to enable sieve material to separate nitrogen from air, then release impurities; specifically oxygen during lower pressure cycles. Pressure is required in membrane systems to drive oxygen and other impurities through the polymeric membrane material allowing higher purity nitrogen to pass through the air separation modules ASM. Finally, cryogenic distillation requires very high pressure to generate the high expansion rate required to cool air to cryogenic temperatures required for separation.

In all three cases, compressors are required to drive the separation process. Compressors have two serious issues associated with them as spelled out in the FTIHWG's report; reliability and power.

Liquid nitrogen used on-board, does not carry these burdens. As indicated above, manufacture of liquid nitrogen does require a considerable amount of power; in fact more than what is required for the three technologies discussed above. The differentiating factor, however, is that the power does not need to be provided on the aircraft.

Liquid nitrogen is supplied to a wide range of industries through a network of Air Separation Units (ASU) spread throughout North America and the rest of the world. Once made, liquid nitrogen can be stored in specially insulated vessels for weeks at a time. Thousands of businesses have their nitrogen delivered as a liquid and store it in these vessels so they can use the liquid or vaporized nitrogen gas as needed. The same concept is practical for the airline industry; albeit with special considerations.



Liquid nitrogen has a purity of 99.997% , therefore the amount of nitrogen required for inerting is reduced substantially. The OBIGGS systems discussed in the FTIHWG report generate nitrogen with a purity of 95% . The volume of nitrogen required using lower purity nitrogen is about 75% higher than would be required for liquid nitrogen. It is argued that the cost of inerting with higher purity nitrogen is lower than for lower purity (see "The Effect of Nitrogen Purity on Usage Washing" below).

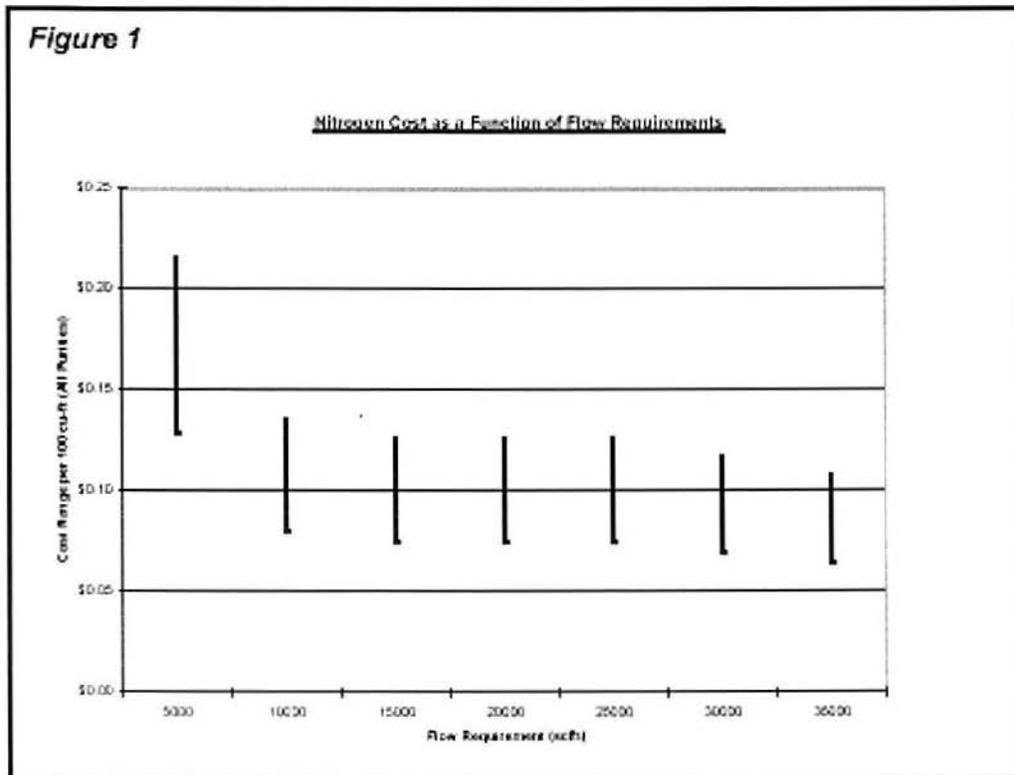
## Appendix B

### The Effect of Nitrogen Purity on Ullage Washing

Nitrogen generators can deliver a wide range of flow and purity. As a general rule, the unit cost for nitrogen decreases as the flow requirements increase and the unit cost increases as the purity increases. The cost of nitrogen is also sensitive to energy costs and atmospheric conditions. It is normally assumed that the added cost of higher purity nitrogen (98 to 99% N<sub>2</sub>) is cost prohibitive compared to the less expensive nitrogen in the 95 to 96% purity range. Analysis of nitrogen costs over a range on purity has found that the opposite is true. When the total cost of inerting is considered, higher purity nitrogen provides lower cost ullage washing, while reducing the time required to inert and reducing fuel vapor emissions resulting from the process. The following represents the results of the analysis which was derived from purge calculations and a matrix of nitrogen costs.

*Figure 1* represents the range of costs for nitrogen generated on site (either membrane or PSA) as a function of the average flow requirement in std cu-ft/hr. The curves illustrate that the unit cost for nitrogen (\$ per 100 cu-ft) steadily decreases as the average flow requirements increase. The curve only represents a trend, which is affected by the selection of equipment and the usage pattern. Equipment offered by industrial gas suppliers cover a range of flows. The efficiency of the equipment can vary depending on which part of the operating curve the equipment is operating. The most economic selection of nitrogen generating equipment can be made by the industrial gas manufacturers, and are typically offered as leased equipment.

The prices cover a wide range, due to variations in equipment cost, and purity. The prices shown below assume a cost of \$.075 per kW-hr. Higher or lower electrical rates will affect the cost. The costs represented above do not include liquid nitrogen.

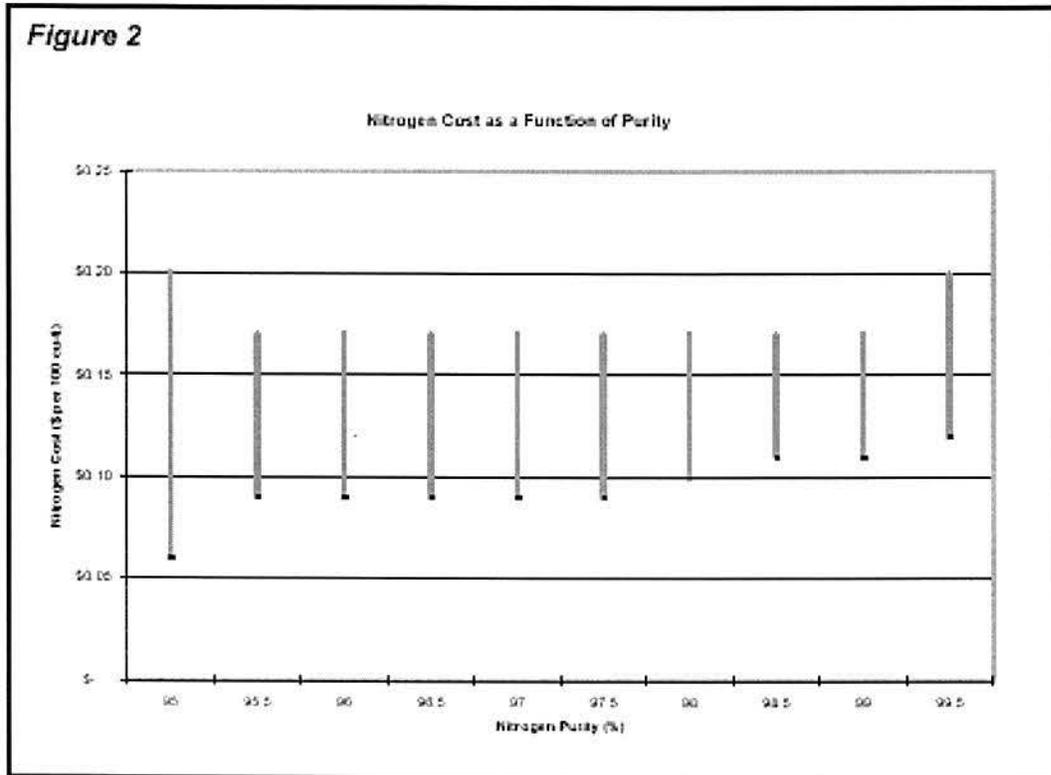


**Figure 1. Nitrogen Cost as a Function of Flow Requirements**

*Figure 2* shows the effect that purity has on nitrogen cost. For every purity value, a range of costs is shown to reflect flow requirements as well as equipment lease costs. It can be seen that the cost of nitrogen increases as the purity level increases. To generate nitrogen of higher purity, either larger equipment is required or the energy requirements are higher due to the demands of the higher purity cycles. Often the same generating equipment can produce nitrogen at a range of purity levels at a sacrifice of energy or capacity. The unit cost for nitrogen is affected in either case.

The value of nitrogen in inerting applications increases considerably as purity increases. There is a significant reduction in the nitrogen volume requirement for high purity compared to low purity nitrogen. Inerting flow is often expressed as volume of inerting nitrogen required for a given ullage volume (V/V) or the number of equivalent ullage volumes of nitrogen required to inert the ullage. The definition of inert varies considerably from application to application. For ullage washing, 8% O<sub>2</sub> is the target concentration.

Test data have indicated that the risk of flammability for Jet-A fuel is insignificant below 10% O<sub>2</sub>. As a practical matter, the Ground Based Design team has determined that the target O<sub>2</sub> concentration for ground based inerting is 8%. As there is a delay between the inerting process and takeoff, 8% ensures that the ullage will remain inert throughout the initial stages of the flight cycle.



**Figure 2** Nitrogen Cost as a Function of Purity

The theoretical volume of gas required to inert the ullage will be a function of the ullage O<sub>2</sub> concentration prior to inerting, the target O<sub>2</sub> concentration and the O<sub>2</sub> concentration of the nitrogen used to inert.

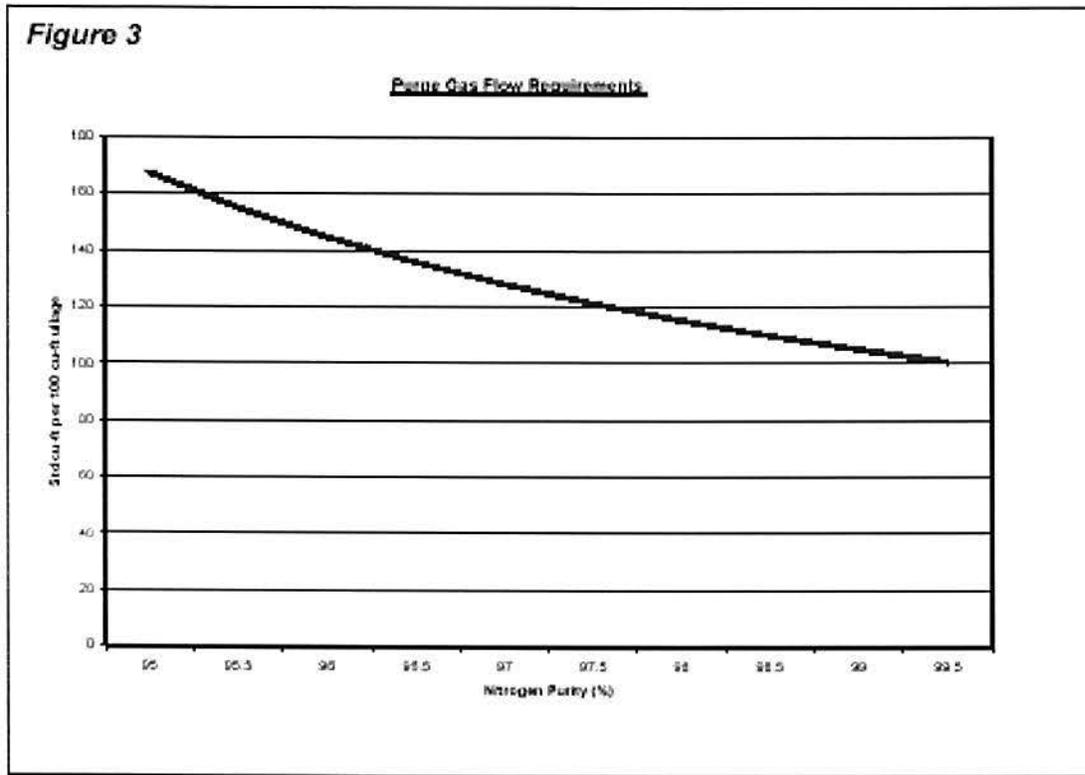
The relationship between nitrogen purity and volume required is represented by a logarithmic curve. The following formula is used:

$$n = \ln\left(\frac{C_o - C_p}{C_t - C_p}\right)$$

where

- n = number of ullage volumes of N<sub>2</sub> required for purge
- C<sub>o</sub> = Initial Oxygen concentration in ullage (%)
- C<sub>t</sub> = Final (or target) Oxygen concentration in ullage (%)
- C<sub>p</sub> = Oxygen concentration of purge gas (%)

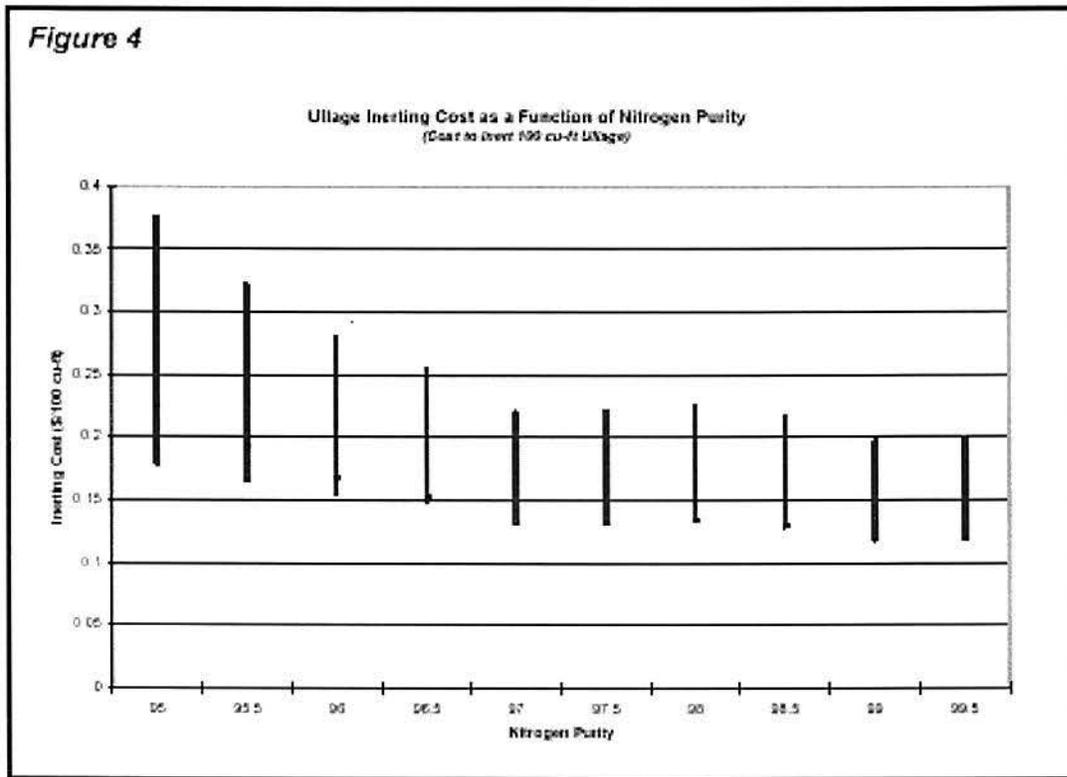
*Figure 3* represents the relationship between purge gas purity and the equivalent ullage volume in standard cu-ft required to reduce the O<sub>2</sub> concentration from 21% to 8% for an ullage of 100 std cu-ft



**Figure 3 Purge Gas Flow Requirements**

The curve shows that when the purge gas is 95% approximately 170 cu-ft of purge gas is required to inert a 100 cu-ft ullage. On the other extreme, only 100 cu-ft is required to inert the same ullage to 8% using nitrogen with a purity of 99.5%. This represents a 41% reduction in purge gas volume required. The added benefit of higher purity nitrogen offsets the added cost as *Figure 4* illustrates. The curve represents the theoretical volume requirement assuming efficient mixing of the inerting gas with the ullage. Typically, the efficiency of the inerting process is less than perfect and is affected adversely by such factors as geometry, purge nozzle configuration and location and the vent location. As a general rule, actual purge gas requirements can be expected to exceed the theoretical volumes.

It is shown in *Figure 4* that the cost of inerting actually decreases as the purity of nitrogen is increased. Comparing the minimum costs shown for each purity, the cost to inert a 100 cu-ft ullage with 95% nitrogen is \$0.18 versus \$0.12 when nitrogen of 99% purity is used. The difference in cost is attributed to the significant reduction in nitrogen required. The plot represented in *Figure 4* was created by multiplying the required volume of nitrogen required (from *Figure 3*) by the cost per cu-ft (from *Figure 2*).



**Figure 4 Ullage Inerting Cost as a Function of Nitrogen Purity  
(Cost to Inert 100 cu-ft Ullage)**

For a given flow rate, higher purity nitrogen has the added benefit of reducing the amount of time required to inert an ullage space. The family of curves shown in Figure 5 shows the effect nitrogen purity has the time required to inert. Each curve represents inerting time as a function of purity. The time to inert was determined using the Ground Based Design team's equipment design basis of 251 scfm. Three curves are used to represent the classifications of aircraft identified by the ARAC to represent the groups of aircraft subject to the inerting procedure.

The first aircraft group, identified as "Commuter" represents the average fuel tank size for commuter aircraft. In this case, the average fuel tank is 3,000 gallons for an equivalent tank volume of 401 cu-ft. The inerting time using 95% nitrogen is 3 minutes, 24 seconds. Using 99% purity, the inerting time is 2 minutes, 6 seconds.

The next curve represents inerting time for the group identified as "Medium Transport" or "Single Aisle" Aircraft. For this group, the average tank size was assumed to be 10,000 gallons or 1,337 cu-ft. The inerting time ranges from 8 minutes 57 seconds using 95% nitrogen to a low of 5 minutes, 36 seconds using 99% nitrogen.

Finally, the "Large Transport" or "Wide Body" aircraft class has an average fuel tank capacity of 25,000 gallons or 3342 cu-ft. The range of times required for inerting goes from 22 minutes 23 seconds using 95% purity nitrogen to 14 minutes, 2 seconds using 99% nitrogen.

The value of reducing the amount of time required to inert fuel tanks has not been quantified, however, the Ground Based Inerting Design team included among its assumptions that the process will not affect turn time. The design for aircraft accommodates the flow rates specified in this document. To reduce the volume of nitrogen required for inerting, and thus the time required nitrogen purity could be increased from the originally proposed 95% to 99%. The benefits are threefold; lower cost, reduced time to inert and reduced emissions.

In addition, the volume and time can be further reduced by inerting only the ullage. The curves above assume inerting with a volume equivalent to the volume of an empty fuel tank. This greatly simplifies the process, and decreases the likelihood that errors can be made. In many cases, however, nitrogen is wasted, the process takes considerably longer than necessary, and fuel vapor emissions are increased substantially.

Properly inerting the fuel tank to address only the volume of the ullage can be done if the oxygen concentration of the ullage is measured. Oxygen analyzers added to the fuel tank or at the fuel tank's vent can provide a reasonable estimate of the oxygen concentration in the fuel tank. Knowing the oxygen concentration can significantly reduce the nitrogen requirement, and in addition provide a direct measurement of the effects of inerting.

The overall cost of inerting fuel tank ullage is driven by a number of factors including the flow rate, purity, method of supply, nitrogen cost and ullage volume. The analysis of this matrix of data has determined that higher purity nitrogen provides the most cost effective purge gas. Nitrogen can be generated at airport facilities at the full range (95 to 99%) of purity analyzed using membrane generators or Pressure Swing Adsorption (PSA) generators. The design for the distribution manifold and supporting components specified for retrofit of aircraft will limit the flow rate and pressure available for the inerting process. As turn time and cost become more critical, there are alternatives to optimize the process including higher purity nitrogen and oxygen measurement.

Figure 5

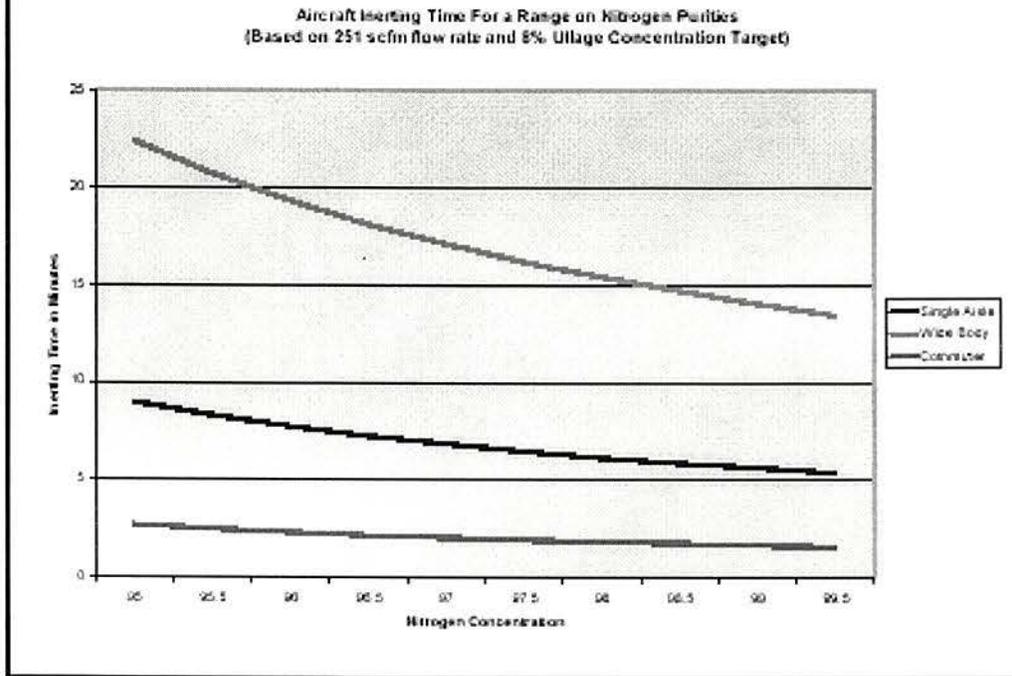


Figure 5 Aircraft Inerting Time For a Range on Nitrogen Purities  
(Based on 251 scfm flow rate and 8% Ullage Concentration Target)

Appendix C

**ASU Plant Locations for all Industrial Gases Companies USA**



>Bill Kauffman, ARAC Working Group on Fuel Tank Inerting, and Member ARAC  
>Executive Committee

>

>Tom O'Mara, Alternate to ARAC Executive Committee.

>

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>We accept the facts of the ARAC report on the dangers of "exploding" center  
>fuel tanks, as discovered by NTSB during their investigation of three  
>aviation disasters. However, we do not agree with the recommendation that  
>FAA do nothing because deploying a proven fix to this fixable fatal flaw is  
>"too expensive."

>

>The danger posed by "flammable vapor/air mixtures in center fuel tanks" is a  
>"single point" threat to passenger and crew safety - a known danger that  
>fuel tank inerting which acts like a wet blanket on ignition points in and  
>around the center fuel tanks on Boeing 737 and 747 can eliminate.

>

>We do not believe Congress, DOT, The White House, or Passengers expect FAA  
>to simply ignore a "single point" threat to air safety with a "proven fix"  
>to a danger first identified by the CAB in 1963 - some 38-years ago.

>

>Parker Hannifin demonstrated its fuel tank inerting technology in 1967. The  
>Military deployed it, but commercial aviation did not. Now, 38-years and at  
>least 3 total hull losses later, an industry led ARAC recommends FAA "do  
>nothing" because a "proven fix" is, in their opinion, "too expensive."

>

>We find a "do not deploy" recommendation absolutely unacceptable, as  
>irresponsible as that of a doctor who would ignore an operable brain tumor  
>on a patient's X-ray because the patient's HMO does not want to pay for a  
>proven, though expensive, life saving brain operation.

>

>If FAA accepts this "do nothing" recommendation, the agency forces hundreds  
>of passengers and crew to board exploding aircraft such as the Boeing 737  
>and Boeing 747. Should passengers be herded onto aircraft that have a  
>fixable fatal flaw? We think not.

>

>A "do nothing" decision is as a violation of Congress's mandate to FAA as a  
>safety and safety only agency. In our view it would be unconscionable for

>FAA to "do nothing" and ignore a proven "fix" that can keep Boeing 737 and  
>747 models from exploding on the runway or in the air.

>

>We agree that FAA has a legal right to ignore the evidence gathered by NTSB  
>from three hull losses caused by "center fuel tank explosions" since 1990.

>However, we do not believe the agency has a moral right to ignore the death  
>of hundreds when a Philippine Airlines operated Boeing 737 exploded on the  
>runway in 1990, a TWA operated Boeing 747 exploded over Long Island Sound,  
>New York in 1996, and a Thailand Air operated Boeing 737 exploded on the  
>ground in 2001.

>

>Have more planes been lost due to the ignition of "flammable air/ vapor from  
>jet fuel" than the three mentioned in the ARAC report? Could be. Consider  
>the state of plane crash investigations worldwide.

>

>Captain Tim Murphy of the International Air Line Pilots Association told an  
>ALPA Safety Conference in Washington, D.C., on August 15, 2001:

>

>"Some accidents are not investigated at all. Some countries don't have the  
>ability or the will to investigate. We have two-tiered safety in the world:  
>JAA-FAA and the rest of the world. This is not good. We are pushing one  
>safety standard, worldwide. It's an uphill battle in many parts of the  
>world, including Africa where Air Traffic Control is one pilot telling  
>another pilot his position."

>

>Should FAA ignore 40 years of scientific proof that flammable vapors in  
>center fuel tanks threaten the lives of millions of passengers and crew? We  
>do not think so.

>

>Did Congress intend FAA to ignore "fixable fatal flaws with proven fixes"  
>when Congress made FAA a "safety and safety" only agency in 1996? We do not  
>think so.

>

>Indeed, we believe the record supports our perception of the FAA as an  
>independent, safety and safety only agency.

>

>For example, FAA has deployed many "fixes" to fixable fatal flaws on  
>commercial aircraft that cost billions of dollars since 1996 with  
>Airworthiness Directives. The agency has ordered fixes with and without  
>"consensus," with and without the ARAC process.  
> FAA, as we understand it, is tasked by Congress to build safer skies on  
>solid foundation of objective science, not on a slippery slope of cost  
>benefit analysis.

>

>A vote to take "no action" would mean the following.

>

>ü FAA is ignoring a single point failure that has destroyed three aircraft  
>over 11 years with a proven fix, that FAA is ignoring a design failure on  
>commercial aircraft - the Boeing 737 and 747 models, specifically.

>

>ü FAA is dismissing 40 years of evidence gathered by CAB and NTSB crash  
>investigators. This includes the 1963 warning of the CAB about the danger of  
>"flammable air/vapor mixtures" in fuel tanks, and the objection by NTSB  
>Chair Carol Carmody to the do nothing recommendation of the ARAC Working  
>Group on Fuel Tank Inerting.

>

>ü FAA is ignoring the evidence gathered by NTSB from 3 aviation disasters  
>over an 11-year period- two Boeing 737 and one Boeing 747 - possibly more.

>

>ü FAA is ignoring scientific evidence that explains how "flammable air/vapor  
>mixtures" can cause Boeing 737 and 747 models to explode when unprotected  
>ignition sources - fray wires, for example - ignite flammable vapor/air  
>mixtures from expended jet fuel in poorly vented center fuel tanks.

>

>ü FAA is ignoring its mission as a safety and safety only agency as  
>outlined by Congress in 1996, and as envisioned by passengers.

>

>ü FAA is pinning its safety decisions on "cost benefit analysis" a very  
>slippery slope, and a slope the agency has ignored when the danger to the  
>public was great enough. The threat of exploding center fuel tanks on two  
>of the most popular commercial planes - the Boeing 737 and 747 - is, in our  
>view, sufficiently grave to put objections based solely on cost benefit  
>analysis on the sidelines.

>

>

> Cost Benefit Analysis:

>

>The majority of ARAC members who recommend no action be taken hang their  
>argument on one peg: "It's too expensive."

>

>They argue costs outweigh benefits to passengers, preferring to let this  
>"fatal flaw" hang, like the legendary sword of Damocles, over the heads of  
>passengers and crew on Boeing 737 and 747 aircraft.

>

>The "take no action" folks claim the cost for deployment of fuel tank  
>inerting is too high, \$10 to \$20 Billion. They offer no fix for planes  
>manufactured in the future, even though the evidence points to a "design  
>flaw" with lethal consequences for every passenger and crew member on a  
>commercial aircraft with a center fuel tank, and a venting system that does  
>not work on a variety of commercial jet transports.

>  
>Ten to Twenty Billion Dollars sounds like a lot of money. It is. We can't  
>argue that \$10 or \$20 Billion is chump change. It's a lot of money. On this  
>point we agree.  
>  
>Does Aviation have pay cash for this fix? No.  
>  
>Rather, we suggest the purchase of Fuel Tank Inerting, like the purchase of  
>an expensive home, can be paid for a little bit at a time, without unduly  
>burdening passengers, or breaking the financial back of airlines.  
>  
>For example, passengers could pay for this "fix" with a few pennies per  
>ticket over 20 years - as low as \$.23 center per ticket, according to  
>recently retired NTSB Crash investigator, Dr. Bernie Loeb. ( need  
>confirmation of the number from Loeb - Bill Kauffman know him and should be  
>able to confirm this fact.)  
>  
>Is \$.23 a cost per ticket "too expensive" for safer Boeing 737, 747, and  
>other aircraft in the 21st Century? Is \$1 or \$5 per ticket "too much" when  
>passengers get the benefit of a "fix" that can keep center fuel tanks from  
>exploding under them? We don't think so.  
>  
>We would remind FAA that safe planes are supposed to be built on sound  
>engineering. Companies like Airbus and Boeing are expected to "engineer out"  
>fatal flaws. The issue of "airworthiness" in Commercial Aviation - as far as  
>we can discern from conversations with Aviation folks as well as passengers  
>and legislators - does not rest on Dollars and Cents or Pounds and pence,  
>but on sound science. Cost benefit analysis is too spongy a foundation on  
>which to build safer planes, safer highways, safer cars, or safer schools.  
>  
>A couple of examples illustrate why cost benefit analysis should be  
>discarded when public safety is on the line.  
>  
>Chicago, 1958.  
>  
>A fire broke out at Our Lady of The Angels grammar school, on the West Side  
>of Chicago, on an otherwise normal school day. When the smoke cleared one  
>hundred ten children and teachers were dead.  
>Did politicians or expert panels recommend Chicago do nothing to make  
>schools safer because a "fix" might upset some cost benefit analysis box  
>score? No!  
>  
>Chicago hired the best and brightest in fire prevention. They listened to  
>their explanation of this tragic fire. They asked for a plan to prevent such  
>a tragedy from ever repeating itself in their city. Then, Chicago deployed

>their recommendation. Money did not deter the people of Chicago from making  
>their schools as safe as proven technology could make them.

>

>Back in 1958, no one in Chicago argued:

>" We can't fix this "fixable fatal flaw" in our schools. It's too expensive  
>to protect our children from fires. We prefer to bury a hundred or so  
>youngsters, every once in awhile. Fires are predictable. We choose to ignore  
>them. We'd rather have low taxes than safe schools. Our children are  
>expendable."

>

>Instead, Chicago added sprinkler systems and a fire alarm box at every  
>school, in less than 2-years. Cities around the country followed Chicago's  
>example. Fire codes were revised in many towns and cities. The risk of fire  
>to the lives of America's school children was recognized as "fixable" and  
>"proven fixes" were deployed. Lives were not given a "dollar value" but  
>recognized as "priceless."

>

>Two questions:

>

>Should FAA follow the logic of Chicago when faced with a "fixable fatal  
>flaw" on commercial jets with center fuel tanks operating in U.S. Skies?

>

>Should FAA deploy proven fixes or should FAA let planeloads of passengers  
>die in predictable, foreseeable, and preventable aviation disasters?

>

>Detroit, 2001.

>

>Ford Motor Company fixed " a fixable fatal flaw" on its Explorer model SUV  
>after fewer than 200 drivers and passengers died because of rear tire "blow  
>outs," on three continents. Ford replaced ALL tires on ALL Explorers at a  
>cost of \$3 Billion. However, the cost was not part of the carmakers  
>decision of " to fix or not to fix."

>

>Ford's CEO told Congress, " We are doing the right thing for our  
>customers."

>

>Firestone has allocated approximately \$1 Billion to replace questionable  
>tires, and closed the plant that was the biggest source of this "fixable  
>fatal flaw" for their tires.

>

>Congress held hearings on the Ford/ Firestone danger. When the evidence was  
>in - even though some argued it was fuzzy - Congress pushed Ford and  
>Firestone to "fix this fixable fatal flaw" as quickly as possible. Car  
>safety was not subject to cost/ benefit analysis for D.C. lawmakers. Safe  
>cars and Safe schools drove Chicago and Detroit to act after fewer than 200

>lives had been lost, and a fix was available.

>

>In conclusion, we do not believe cost benefit analysis should be the driving  
>force behind the design and manufacture of safer planes. Cost benefit  
>analysis should not motivate FAA to deploy proven "fixes" to "fixable fatal  
>flaws" on commercial aircraft.

>

>Other facts that need further venting, greater emphasis in the reports on  
>Fuel Tank Inerting of 1998 and 2001 include the following.

>

>Ø The danger posed by flammable air/vapor was known to aviation in  
>1963, possibly earlier.

>

>NTSB Chairman Hall made the following statement at the probable cause  
>hearing in the loss of TWA 800 on July 17, 1996:

>"I recently came across the following quotation: ' It is recommended that  
>every effort be expended to arrive at a practical means by which flammable  
>air/vapor mixtures are eliminated in fuel tanks.' This was presented by our  
>predecessor agency the Civil Aeronautics Board on December 17, 1963,  
>following the crash of Pan American flight 214 near Elkton, Maryland."

>

>Ø In 1967, Parker Hannifin created a fuel tank inerting system that could  
>render flammable air/ vapor mixtures from expended jet fuel harmless.

>

>As every camper knows, " You can't start a fire with wet matches." The same  
>is true for flammable vapor/air mixtures in center fuel tanks, when a fuel  
>tank inerting system is operational. The Military deployed this technology  
>in the 1960s. Commercial aircraft manufacturers said, "No."

>

>Why did aviation say, "No."? Apparently, the fix was too expensive, too  
>inconvenient, and too troublesome for plane manufacturers back then.

>

>However, if Regulators of commercial aviation had the same attitude that  
>Chicago Politicians and Parents had after Our Lady of Angels burned, or  
>displayed the same willingness to fix a fixable fatal flaw that Ford  
>exhibited in 2001, at least two Boeing 737s and one Boeing 747 would not  
>have exploded between 1990 and 2001.

>

>Ø Several changes in aviation operations and regulations have worked against  
>timely deployment of fuel tank inerting and other "fixes."

>

>FAA was folded into the Department of Transportation in 1968. Ten years  
>later, President Jimmy Carter agreed with Congress and De-Regulated  
>Aviation. The goals of De-Regulation: increase competition, save passengers  
>money without a decrease in safety. Did passengers save money? Yes.

>Passengers have saved \$19 Billion, according to some estimates, in 21 years  
>since De-Regulation. Was there more competition? Yes. Was safety  
>compromised? Yes.  
>  
>Ø Two casualties of competition and De-Regulation deserve special mention.  
>  
>(1) PanAm shrank from a giant to a pigmy after PanAm 103 was blown out of  
>the skies over Lockerbie, Scotland, by terrorists in 1988.  
>  
>Why did passengers shun PanAm after the PanAm 103 loss?  
>  
>Passengers stopped using the carrier when they learned PanAm had collected  
>fees to strengthen security, but spent the bulk of security fees on  
>non-security items. Indeed, many have come to the conclusion that the "fee  
>for security sur-charge" was a sham, an inventive way to get more cash into  
>corporate coffers with little benefit for passengers. Certainly there is no  
>evidence that PanAm security at Frankfurt, Germany, was improved as a result  
>of this "security fee per ticket" charge.  
>  
>(2) ValuJet is now known as AirTran.  
>  
>The airline is considerably downsized from it's glory days, when Secretary  
>of Transportations told the American people that ValuJet is a "a perfectly  
>safe airline." The Secretary made these remarks near the crash site of  
>ValuJet flight 592 - the DC-9 had crashed into the Florida Everglades over  
>Mother's Day weekend in 1996, killing 110.  
>  
>It turned out that ValuJet put hazardous materials in the cargo hold, and  
>the cargo hold did not have fire detection or fire suppression technology.  
>Why was ValuJet flight 592 unprotected from fire in the cargo hold?  
>FAA ignored a 1988 NTSB recommendation that the agency deploy this "proven"  
>life saving technology. FAA took no action when aviation balked at the  
>expense and inconvenience they would suffer if FAA ordered the deployment of  
>this " proven fix" to a "fixable fatal flaw."  
>  
>A year after the loss of ValuJet flight 592 - one year after the Congress  
>made FAA a "safety and safety only" agency - FAA told the aviation industry  
>to deploy "fire detection and fire suppression systems" by March 19, 2001,  
>or park planes that were still "unfixed."  
>  
>Our Recommendation:  
>  
>FAA must protect the flying public from exploding center fuel tanks. It must  
>deploy the proven technology that can "fix" this "fixable fatal flaw" as  
>soon as possible. The "fix" is available. The "fix" is proven to work. Fuel

>Tank Inerting is not a "Fix" that FAA should ignore. Thirty years of "no  
>action" is enough. No more planes should be left in the dangerous conditions  
>that caused the loss of a Boeing 737 at Manila in 1990, a Boeing 747 over  
>Long Island in 1996, and a Boeing 737 at Bangkok in 2001.  
>  
>Congress would condemn a Defense Department that sent soldiers into battle  
>with blanks, instead of live ammunition, just as Congress would condemn Ford  
>or Firestone if they refused to "fix" the fixable fatal flaw on its SUV and  
>all terrain tires. Surely, Congress will not praise an FAA or Boeing if  
>they fail to deploy a "proven fix" that is available for deployment.  
>  
>Passengers have waited 40-years for FAA to "fix" this "fixable fatal flaw"  
>on popular model aircraft such as the Boeing 737 and Boeing 747. FAA should  
>not force American citizens or tourists to board planes that are less safe  
>than available technology can make them. American citizens, tourists, pilots  
>and flight attendants should not have to wait any longer for FAA to fix this  
>fixable fatal flaw. Losing three planes - maybe more - should be enough to  
>motivate FAA to act.  
>  
>In this case, there is no excuse for a " We'll wait until more planes  
>explode" decision at FAA. The danger posed by "flammable air/ vapor  
>mixtures" in center fuel tanks should not linger any longer. It is time for  
>action.  
>  
>Questions:  
>  
>What if TWA 800 had exploded on the ground at JFK in 1996 instead of over  
>Long Island Sound, New York? What would Congress, DOT, or The White House  
>tell FAA to do when the images of a burned-out 747 hull appeared on the  
>nightly newscasts for weeks, possibly months as The Discover Channel, MSNBC  
>Investigates, Rivera Live, etc. debated the story?  
>  
>What if - and it's a likely scenario - TWA 800 had exploded while attached  
>to the JFK terminal?  
>  
>What if 3 or 4 planes blew up - so-called collateral damage - their  
>explosion triggered by a TWA 800 explosion on the ground at JFK?  
>  
>We suggest Congress, DOT, and The White House would have demanded the speedy  
>deployment of fuel tank inerting in 1996 if TWA 800 had blown apart on the  
>JKF tarmac.  
>  
>We recommend the FAA do the following:  
>  
>1) Explore the use of J-Jet fuel as an interim step to make planes with

>center fuel tanks safer.

>

>J-fuel is less combustible than other jet fuels. The U. S. Navy uses it  
>because many of its aircraft are used on carriers and the fuel is kept in a  
>confined space. J-fuel is used on Air Force One, Two, Three, and Four. The  
>use of J-Fuel can greatly reduce the danger facing passengers on older  
>planes while fuel tank inerting technology is deployed. If J-fuel is used  
>to make President George W. Bush safer, it should be used to make those who  
>vote safer as well.

>

>2) FAA should require fuel tank inerting systems installed on ALL planes  
>with center fuel tanks manufactured after December 31, 2002, if these planes  
>intend to operate in U.S. skies.

>3) FAA should require fuel tank inerting installed on ALL planes with center  
>fuel tanks that intend to operate in U. S. Airspace by a time certain - say,  
>four years.

>

>4) FAA should ban commercial aircraft with center fuel tanks from U.S. skies  
>if they do not have fuel tank inerting technology installed within four  
>years.

>

>We suggest 4 years because that was the ruling of FAA in the summer of 1997  
>when the agency required the deployment of fire suppression and fire  
>detection systems in the cargo holds of passenger aircraft by March 19,  
>2001.

>

>5) We recommend that the U. S. House and Senate Transportation and Aviation  
>Sub-Committees hold televised public hearings Fuel Tank Inerting and  
>Aviation Safety Standards in the fall of 2001.

>

>The goal of these Congressional Hearings: craft a treaty that will give  
>passengers One Standard of Safety, worldwide, which Captain Tim Murphy and  
>the International Federation of Airline Pilots Association believe is  
>needed.

>Finally, we recommend the FAA petition Congress for the right to add a \$5  
>surcharge on every airline ticket.

>

>The monies would be deposited into a "Fix Trust Fund." Funds from this "FIX  
>fund" could help prevent aircraft prone to exploding center fuel tanks -  
>especially geriatric plane with worn out, frayed, and split wiring - from  
>exploding on the ground or in the air. Passengers, in effect, buy the safer  
>skies that industry is reluctant to fund.

>

>We recommend Ralph Nader, Jim Hall, Jim Burnett, or Mary Schiavo be  
>appointed as Trustee of the Fix Fund. In this way, passengers could be sure

>their Fix Fund deposits, unlike their Aviation Trust Fund deposits now grown  
>to \$14 Billion, will be used to fix fixable fatal flaws rather than pretty  
>up the nation's books.

>

>A "Fix Fund" can make air travel safer sooner rather than later, and stop  
>the aviation industry from whining "its too expensive" to fix a danger that  
>has a proven fix.

>

>August 20, 2001

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## FAA Action

FAA Action: NPRM: Reduction of Fuel Tank Flammability in Transport Category Airplanes – [FAA-2005-22997](#), and Proposed Advisory Circular 25.981-2A, Fuel Tank Flammability in the [Regulatory and Guidance Library](#)



U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# Advisory Circular

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**Subject:** FUEL TANK FLAMMABILITY  
REDUCTION MEANS

**Date:** 9/19/08

**AC No.** 25.981-2A

**Initiated by:** ANM-112

**1. Purpose.** This advisory circular (AC) provides information and guidance on compliance with the airworthiness standards for transport category airplanes about limiting the time a fuel tank may be flammable or mitigation of hazards from flammable fuel air mixtures within fuel tanks. This guidance is applicable to transport category airplanes for which a new, amended, or supplemental type certificate is requested, and for which Amendment 25-125 applies. It is also applicable to certain existing design approval holders and certain pending applications for new type certificates, supplemental type certificates and amended type certificates where required by §§ 26.33, 26.35, 26.37, and 26.39, contained in a subpart D to Title 14, Code of Federal Regulations (CFR) part 26, “Fuel Tank Flammability.” Guidance on compliance with the associated requirements for operators of affected airplanes that must comply with requirements in 14 CFR parts 121, 125 and 129, to incorporate flammability reduction or ignition mitigation means by specified dates, will be contained in a separate document.

**2. Applicability.**

a. This guidance provided in this document is for design approval applicants and holders, airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) transport category airplane type certification engineers and their designees.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in demonstrating compliance with the relevant regulations. On the other hand, if we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation or design changes as a basis for finding compliance.

c. This material does not change, create any additional, authorize changes in, or permit deviations from, regulatory requirements.

**3. Cancellation.** Advisory Circular (AC) 25.981-2, Fuel Tank Flammability Minimization, dated 4/18/01, is cancelled.

**4. Related Documents.**

a. Federal Aviation Regulations. The applicable sections of part 25 that prescribe the design requirements for the substantiation and certification about prevention of ignition sources within the fuel tanks of transport category airplanes include:

- § 25.863 Flammable fluid fire protection.
- § 25.901 Installation.
- § 25.954 Fuel system lightning protection.
- § 25.981 Fuel tank ignition prevention.

b. Advisory Circulars (AC). You can get the following FAA ACs from the U.S. Department of Transportation, Subsequent Distribution Office, M-30, Ardmore East Business Center, 3341 Q 75<sup>th</sup> Avenue, Landover, MD 20785, or on the internet at: <http://www.airweb.faa.gov/rgl>.

- (1) AC 25-8 Auxiliary Fuel System Installations.
- (2) AC 20-53B Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Caused by Lightning.
- (3) AC 25.981-1B Fuel Tank Ignition Source Prevention Guidelines.
- (4) AC 120-27 Aircraft Weight and Balance Control.
- (5) AC 26-1 Part 26, Continued Airworthiness and Safety Improvements
- (6) AC 25-26 Development of Standard Wiring Practices Documentation

c. Society of Automotive Engineers (SAE) Documents. You can get the following documents from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096.

- (1) SAE AIR 5128, “Electrical Bonding of Aircraft Fuel System Plumbing Systems” (January 1997).
- (2) SAE AIR 4170A, “Reticulated Polyurethane Safety Foam Explosion Suppressant Material for Fuel Systems and Dry Bays” (November 1998).

(3) SAE AIR 1662, "Minimization of Electrostatic Hazards in Aircraft Fuel Systems" (October 1984).

d. Military Specifications (MIL).

(1) MIL-B-83054, Baffle and Inerting Material, Aircraft Fuel Tank (March 1984). (Note: this reference provides an extensive list of military specifications about the use of polyurethane foam.) You can get a copy of this document from the Department of Defense, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, or on the internet at <http://assist.daps.dla.mil/online/start/>.

e. Other.

(1) FAA Document DOT/FAA/AR-98/26, "A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks" (June 1998). (You can get a copy of this report from the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.fire.tc.faa.gov/pdf/ar98-26.pdf>.)

(2) Aviation Rulemaking Advisory Committee (ARAC), Fuel Tank Harmonization Working Group, Final Report (July 1998). You can get a copy of this report at the following web site address: <http://www.regulations.gov>, by inserting the associated docket number (Docket No. FAA-1998-4183) into the advanced docket search function. You can also get a copy of this report at the following web site address: <http://www.fire.tc.faa.gov/systems/fuel tank/papers.stm>.

(3) "Effects of Fuel Slosh and Vibration on the Flammability Hazards of Hydrocarbon Turbine Fuels Within Aircraft Fuel Tanks," Technical Report AFAPL-TR-70-65 (November 1970), Edwin E. Ott. Contact the Air Force Aero Propulsion Laboratory, Airforce Systems Command, Wright-Patterson Air Force Base Ohio.

(4) FAA Document DOT/FAA/AR-99/65, "Mass Loading Effects on Fuel Vapor Concentrations in an Aircraft Fuel Tank Ullage." You can get a copy of this report from the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.fire.tc.faa.gov/pdf/tn99-65.pdf>.

(5) FAA Document DOT/FAA/AR-00/19, "The Cost of Implementing Ground-Based Fuel Tank Inerting in the Commercial Fleet." DOT/FAA/AR-00/19 (May 2000). You can get a copy of this report from the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.fire.tc.faa.gov/pdf/00-19.pdf>.

(6) FAA Document DOT/FAA/AR-01/6, "Inerting of a Vented Aircraft Fuel Tank Test Article with Nitrogen Enriched Air" (December 2000). You can get a copy of

this report from the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.fire.tc.faa.gov/pdf/01-6.pdf>.

(7) “The Effectiveness of Ullage Nitrogen-Inerting Systems against 30-mm High-Explosive Incendiary Projectiles,” China Lake Naval Weapons Center, J. Hardy Tyson and John F. Barnes, May 1991. You can get a copy of this report at the following web site address: <http://www.regulations.gov>, by inserting the docket number associated with this AC (FAA-2005-22997) into the advanced docket search function.

(8) FAA Document DOT/FAA/AR-TN02/79, “Limiting Oxygen Concentrations Required to Inert Jet Fuel Vapors Existing at Reduced Fuel Tank Pressures” (April 2003). You can get a copy of this report from the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.fire.tc.faa.gov/pdf/TN02-79.pdf>.

(9) FAA Special Condition, “Boeing Model 747-100/200B/200F/200C/SR/SP/100B/300/100B SUD/400/400D/400F Airplanes; Flammability Reduction Means (Fuel Tank Inerting),” Docket No. NM270; Special Conditions No. 25-285-SC. You can get a copy of these special conditions at the following web site address: <http://www.regulations.gov>, by inserting the docket number associated with this AC (FAA-2005-22997) into the advanced docket search function.

(10) FAA Document DOT/FAA/AR-07/30, “Jet A Volatility Survey,” July 2007. A copy of this report is available through the National Technical Information Service (NTIS), Springfield, Virginia 22161, or at the following web site address: <http://www.tc.faa.gov/its/worldpac/techrpt/ar0730.pdf>.

(11) FAA Document DOT/FAA/AR-05/8, “Fuel Tank Flammability Assessment Method User’s Manual” (May 2008), web site address: <http://www.fire.tc.faa.gov/systems/fuel tank/FTFAM.stm>

(12) FAA Document DOT/FAA/AR-04/41, “Evaluation of Fuel Tank Flammability and the FAA Inerting System on the NASA 747 SCA” (December 2004), web site address: <http://www.fire.tc.faa.gov/pdf/04-41.pdf>.

(13) Aviation Rulemaking Advisory Committee (ARAC), Fuel Tank Inerting Harmonization Working Group, Final Report (February 2002). You can get a copy of this report at the following web site address: <http://www.regulations.gov>, by inserting the associated docket number (U.S. Department of Transportation (DOT) electronic dockets, Docket No. FAA-2005-22997) into the advanced docket search function. You can also get a copy of this report, at the following web site address: [http://www.faa.gov/regulations\\_policies/rulemaking/committees/arac/media/ec/EC\\_FT\\_T2.pdf](http://www.faa.gov/regulations_policies/rulemaking/committees/arac/media/ec/EC_FT_T2.pdf)

(14) FAA Order 8110.104, Responsibilities and Requirements for Implementing Part 26 Safety Initiatives, Effective Date 12/3/07, You can get FAA Orders from the

U.S. Department of Transportation, Subsequent Distribution Office, M-30, Ardmore East Business Center, 3341 Q 75<sup>th</sup> Avenue, Landover, MD 20785, or available on the internet at: <http://www.airweb.faa.gov/rgl>.

(15) FAA Memo No. ANM-08-113-001, Policy Statement on Clarification of Maximum Payload Capacity Definition in Design Approval Holder Rules, dated September 12, 2008. You can get a copy on the internet at: <http://www.airweb.faa.gov/rgl>.

## 5. Definitions.

a. Auxiliary Fuel Tank is a tank installed to make additional fuel available for increasing the flight range of that airplane. The term “auxiliary” means that the tank is secondary to the airplane’s main fuel tanks, i.e., the functions of the main tanks are immediately available and operate without immediate supervision by the flightcrew in the event of failure or inadvertent depletion of fuel in an auxiliary tank. Auxiliary tanks are usually intended to be emptied of usable fuel during flight and have been installed in various locations including center wing structure, horizontal stabilizers, wings and cargo compartments. Therefore, auxiliary fuel tanks are “normally emptied” fuel tanks as defined below.

b. Main Fuel Tank is defined in § 25.981(b)(3)(iii) as “a fuel tank that feeds fuel directly into one or more engines and holds required fuel reserves continually throughout each flight.” The functions of the main tanks are immediately available and operate without immediate supervision by the flightcrew in the event of failure or inadvertent depletion of fuel in an auxiliary tank. Generally, main tanks are those dedicated to the feed of the engines during engine feed isolation.

c. Normally Emptied, with respect to fuel tanks, is defined in § 26.31(b) as “a fuel tank other than a Main Fuel Tank.” Main Fuel Tank is defined in § 25.981(b), and expanded above.

d. Bulk Average Fuel Temperature is defined in paragraph N25.2(a) of appendix N to part 25 as “the average fuel temperature within the fuel tank, or different sections of the tank if the tank is subdivided by baffles or compartments.”

e. Center Wing Tank (CWT) is a fuel tank located partially or entirely in the center of an airplane's wing box.

f. Design Approval Holder (DAH) is defined in AC 26-1 as the holder of any design approval, including type certificate, amended type certificate, supplemental type certificate, amended supplemental type certificate, parts manufacturer approval, Technical Standard Order (TSO) authorization, letter of TSO design approval, and field approvals. The definition in AC 26-1 adds that in particular contexts, the term DAH may also refer to applicants for design approvals. In the context of this AC, the term DAH applies to applicants for new design approvals and for changes to existing designs, and it

applies to holders of design approvals and applicants for design approvals affected by part 26, subpart D.

g. Flammable, with respect to a fluid or gas, means susceptible to igniting readily or to exploding (14 CFR part 1, Definitions). A non-flammable ullage is one where the fuel-air vapor is too lean or too rich to burn or is inert as defined below. As defined in paragraph N25.2(c) of appendix N to part 25, “a fuel tank that is not inert is considered flammable when the bulk average fuel temperature within the tank is within the flammable range for the fuel type being used. For any fuel tank that is subdivided into sections by baffles or compartments, the tank is considered flammable when the bulk average fuel temperature within any section of the tank, that is not inert, is within the flammable range for the fuel type being used.

h. Fleet Average Flammability Exposure is defined in paragraph 25.2(e) of appendix N to part 25 as “the percentage of the flammability exposure evaluation time (FEET) each fuel tank ullage is flammable for a fleet of an airplane type operating over the range of flight lengths in a world-wide range of environmental conditions and fuel properties as defined in this appendix” (appendix N to part 25). Section 25.981(b)(3)(ii) explains this term “means the percent of time each fuel tank ullage is flammable for a fleet of an airplane type operating over the range of flight lengths.” Fleet average flammability exposure is the total time the tank is flammable divided by the total FEET.

i. Flammability Exposure Evaluation Time (FEET) is defined in paragraph N25.2(b) of appendix N to part 25 as “the time from the start of preparing the airplane for flight, through the flight and landing, until all payload is unloaded and all passengers and crew have disembarked. In the Monte Carlo program, the flight time is randomly selected from the Flight Length Distribution (Table 2), the pre-flight times are provided as a function of the flight time, and the post-flight time is a constant 30 minutes.” Table 2 referenced in this definition is Table 2 of appendix N to part 25.

j. Flammability Envelope is the pressure (i.e., altitude)/temperature domain where the fuel vapor/air mixture is flammable. This flammability envelope is defined in appendix N to part 25, by the upper flammability limit (UFL) and the lower flammability limit (LFL). These flammability limits are dependent on the type of fuel used and vary for different fuel batches that meet the fuel specification. For Jet-A fuels the variation of flash points that are to be used in the analysis are defined in appendix N to part 25. Appendix N also defines the LFL and UFL as a function of altitude and fuel flash point. The flammability envelope for the fuel is defined by the UFL and LFL as follows:

(1) LFL at sea level is the flash point temperature of the fuel at sea level minus 10 degrees F. LFL decreases from sea level value with increasing altitude at a rate of 1 degree F per 808 feet.

(2) UFL at sea level is the flash point temperature of the fuel at sea level plus 63.5 degrees F. UFL decreases from the sea level value with increasing altitude at a rate of 1 degree F per 512 feet.

k. Flammability Reduction Means (FRM) is any system intended to meet the flammability exposure criteria in appendix M to part 25.

l. Flash Point of a flammable fluid is defined in paragraph N25.2(d) of appendix N to part 25 as “the lowest temperature at which the application of a flame to a heated sample causes the vapor to ignite momentarily, or “flash.” The flash point of a fuel is determined using the standardized test method(s) permitted by the fuel specification. Table 1 of appendix N to part 25, provides the Gaussian (or “normal”) distribution for the flash point of the standard (Jet-A) fuel to be used in the analysis.

m. Fuel Types approved for use for a given airplane type are listed in the Airplane Flight Manual (AFM) and the type certificate data sheet. Each fuel type has its own properties; those directly related to flammability are “flash point” and “distillation” characteristics. Property differences can occur in different batches of a given fuel type because of variations in the properties of the source crude oil and the refining process used to produce the fuel. The most widely used fuel types are JET-A or JET-A1, per ASTM International Specification D1655, “Standard Specification for Aviation Turbine Fuels.” Older airplanes have been approved for use of JET-B (JP-4), per ASTM Specification D6615, “Specification for Jet B Wide-Cut Aviation Turbine Fuel.”

n. Gaussian Distribution is defined in paragraph N25.2(f) of appendix N to part 25 as “another name for the normal distribution, a symmetrical frequency distribution having a precise mathematical formula relating the mean and standard deviation of the samples. Gaussian distributions yield bell-shaped frequency curves having a preponderance of values around the mean with progressively fewer observations as the curve extends outward.”

o. Hazardous Atmosphere is defined in paragraph N25.2(g) of appendix N to part 25 as “an atmosphere that may expose maintenance personnel, passengers or flightcrew to the risk of death, incapacitation, impairment of ability to self-rescue (that is, escape unaided from a confined space), injury, or acute illness.”

p. Inert is defined in paragraph N25.2(h) of appendix N to part 25. It states “the tank is considered inert when the bulk average oxygen concentration within each compartment of the tank is 12 percent or less from sea level up to 10,000 feet altitude, then linearly increasing from 12 percent at 10,000 feet to 14.5 percent at 40,000 feet altitude, and extrapolated linearly above that altitude.”

q. Inerting is defined in paragraph N25.2(i) as “a process where a noncombustible gas is introduced into the ullage of a fuel tank so that the ullage becomes non-flammable.”

r. Lean Fuel Vapor/Air Mixture is a fuel vapor/air mixture that contains a concentration of fuel molecules below that which will support combustion.

s. Monte Carlo Analysis is defined in paragraph N25.2(j) of appendix N to part 25 as “the analytical method that is specified in this appendix (appendix N to part 25) as the compliance means for assessing the fleet average flammability exposure time for a fuel tank.” Paragraph N25.3(a) requires analysis be performed in accordance with the methods and procedures defined in the User’s Manual referenced in paragraph 4e(11) of this AC.

t. Oxygen evolution is defined in paragraph N25.2(k) of appendix N to part 25. It “occurs when oxygen dissolved in the fuel is released into the ullage as the pressure and temperature in the fuel tank are reduced.”

u. Rich Fuel Vapor/Air Mixture is a fuel vapor/air mixture that contains a concentration of fuel molecules above that which will support combustion.

v. Warm Day Case is that portion of the Monte Carlo Analysis during ground or takeoff/climb phases of flights that begin with a sea level ground ambient temperature of 80 degrees F (standard day plus 21 degrees F) or above, from the flammability analysis done for overall ground operations or warm day takeoff/climb phases.

w. Standard Deviation is defined in paragraph N25.2(l) of appendix N to part 25 as “a statistical measure of the dispersion or variation in a distribution, equal to the square root of the arithmetic mean of the squares of the deviations from the arithmetic means.”

x. Transport Effects is defined in paragraph N25.2(m) of appendix N to part 25 as “the change in fuel vapor concentration in a fuel tank caused by low fuel conditions and fuel condensation and vaporization.” The change caused by low fuel conditions is also referred to as “mass loading” (see paragraph 4(e)(4)).

y. Ullage is defined in paragraph N25.2(n) of appendix N to part 25 as “the volume within the fuel tank not occupied by liquid fuel.”

z. Equivalent Conventional Unheated Aluminum Wing Tank is defined in § 25.981(b)(3)(i) as “an integral tank in a unheated semi-monocoque aluminum wing of a subsonic airplane that is equivalent in aerodynamic performance, structural capability, fuel tank capacity and tank configuration to the designed wing.”

aa. Body Tank is a fuel tank installed entirely inside the fuselage of an airplane in a compartment with no tank surface exposed to outside air flow during flight, e.g., an auxiliary fuel tank installed in the cargo compartment of an airplane. See paragraph 4e(11), “Fuel Tank Flammability Assessment Method User’s Manual.”

## **6. Regulatory Background.**

a. Amendment 25-11 to part 25 introduced the requirements of § 25.981 about limiting temperatures in fuel tanks to prevent ignition of fuel vapors in the fuel tanks from hot surfaces. Advisory Circular 25.981-1A, which was issued in 1972 (now

canceled), provided guidance that included failure modes that should be considered when determining compliance with the fuel tank surface temperature requirements defined in § 25.981.

b. Other sections of part 25 require prevention of ignition sources from lightning (§ 25.954) and from failures in the fuel tank system (§§ 25.901 and 25.1309). Sections 25.901 and 25.1309 set forth the provisions to evaluate the fuel tank system and show that “no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane....” However, service history has shown that ignition sources have developed in airplane fuel tanks because of external ignition sources, and internal ignition sources resulting from unforeseen failure modes, manufacturing and maintenance errors or factors that were not considered at the time of original certification of the airplane.

c. Section 25.981, as amended by Amendment 25-102, was adopted to provide improved standards for preventing ignition sources within fuel tanks and minimizing the exposure to operation of transport category airplanes with flammable vapors in the fuel tanks. Under Amendment 25-102, the title of § 25.981 was revised to “Fuel tank ignition prevention,” and paragraphs (a) and (b) were revised to address the prevention of ignition sources within the fuel tanks. Guidance on these paragraphs is provided in AC 25.981-1B, Fuel Tank Ignition Source Prevention Guidelines (or latest revision). Amendment 25-102 also added a new paragraph (c), which requires minimization of the formation of flammable vapors in the fuel tanks, or mitigation of any hazards if ignition does occur. This provision was included in § 25.981(c), which was intended to require design practices that reduce exposure to operation with flammable vapors in transport category airplane fuel tanks to the lowest practical level.

**7. Current Requirements.** The Fuel Tank Flammability Reduction (FTFR) rule titled “Reduction of Fuel Tank Flammability in Transport Category Airplanes” is effective as of September 19, 2008. The 2008 FTFR rule included an amendment to part 25 fuel tank flammability requirements, part 26 (Continued Airworthiness and Safety Improvements for Transport Category Airplanes) by adding a new subpart D, Fuel Tank Flammability, and amendments to certain operational rules associated with the subpart D requirements. This AC provides guidance for § 25.981, as amended by Amendment 25-125, and the continuous airworthiness requirements of part 26, subpart D. These rules apply to new certification and to certain existing type design approval holders (DAH). The 2008 FTFR also included operational requirements related to the part 26, subpart D, requirements. Guidance for affected operators will be issued later. The following table summarizes the amendments and the applicability of each amendment. Because of the complexity of these requirements, you should refer to the specific regulations for complete details.

**TABLE 1**

**Summary of Regulatory Changes that were made by the 2008 Fuel Tank  
Flammability Reduction rule**

<b>Summary of Rules</b>		
<b>14 CFR</b>	<b>Description of Requirement</b>	<b>Applies To</b>
§ 25.5 Incorporation by Reference	Incorporates the Fuel Tank Flammability Users's Manual by reference	
§ 25.981, Fuel Tank Explosion Prevention	Paragraph (a) provides ignition prevention requirements; (b) specifies flammability exposure limits for different fuel tank types and mandates use of fuel tank flammability assessment method; (c) provides the option of using Ignition Mitigation Means (IMM) instead of meeting the paragraph (b) flammability limits; and (d) contains requirements for airworthiness limitation items (ALI), including critical design configuration control limitations (CDCCL), for ignition prevention means, IMM or FRM.	Applicants for TCs for transport category airplanes and design changes to those certificates.
Appendix M, Fuel Tank System Flammability Reduction Means	Establishes performance, reliability and reporting requirements for flammability reduction means (FRM).	Applicants for approval of FRM.
Appendix N, Fuel Tank Flammability Exposure and Reliability Analysis	Defines the fuel tank flammability exposure analysis model (Monte Carlo) including definitions, input variables and data tables that must be used in the analysis.	Any person required to perform flammability exposure analysis.
<b>Part 26 Continued Airworthiness and Safety Improvements for Transport Category Airplanes</b>		
§ 26.5 Applicability Table	Provides an overview of the applicability of part 26. It provides guidance in identifying what sections apply to various types of entities. The specific applicability of each subpart and section is specified in the regulatory text. Subpart D addresses fuel tank flammability.	Applicants for TCs, and changes to those TCs for transport category airplanes. Manufacturers of certain airplane models.
Part 26, subpart D	Fuel Tank Flammability.	TCs, and design changes to those TCs for transport category airplanes. Manufacturers of certain airplane models.



	<p>2008, requires impact assessment of fuel tanks and other STCs, on IMM or FRM developed by TC holder to determine if any ALI has been violated by March 21, 2011, or before certification, whichever is later.</p> <p>Applicants for any pending and future fuel tank that is normally empty must comply with the requirements of § 25.981, Amendment 25-125.</p> <p>Require development of service instructions to correct designs that compromise ALI defined by TC holder by March 19, 2012 or before certification, whichever is later.</p>	carrying airplanes.
§ 26.37, Pending type certification projects: Fuel tank flammability	Requires compliance with § 25.981, Amendment 25-125, if the application was made on or after June 6, 2001.	Pending certification projects for large transport category passenger-carrying airplanes.
§ 26.39, Newly produced airplanes: Fuel tank flammability	Requires fuel tanks on affected airplanes (produced under FAA production certificates) for which application is made for original certificates of airworthiness or for export airworthiness approval after September 20, 2010, meet the flammability requirements as stated above for § 26.33.	Certain Boeing airplane models, both passenger carrying and cargo.

b. Section 25.981 together with appendices M and N to part 25 and the Fuel Tank Flammability User's Manual incorporated by reference (see § 25.5), Amendment 25-125, provide flammability limits and the method for determining the flammability of fuel tanks. The flammability limits for fuel tanks that are normally emptied and have any portion of the tank located within the fuselage contour must meet the 3 percent average and 3 percent warm day flammability exposure limits in appendix M to part 25, as required by § 25.981(b)(2). Section 25.981(b) limits the flammability exposure of all other fuel tanks to either 3 percent average, or that of a fuel tank within the wing of the airplane model being evaluated, whichever is greater. If the wing is not a conventional unheated aluminum wing, § 25.981(b) requires the analysis be based on that of an assumed Equivalent Conventional Unheated Aluminum Wing Tank. If a flammability reduction means (FRM), such as nitrogen inerting, is used, additional reliability requirements are provided in appendix M to part 25. Appendix N specifies the requirements for conducting the flammability exposure analysis required to show compliance to § 25.981 and appendix M. Appendix N provides the ability to perform a qualitative analysis for fuel tanks installed in aluminum wings provided it substantiates the fuel tank is a conventional unheated wing tank. Section 25.981(c) retains the option

of using ignition mitigation means (IMM), for example reticulated polyurethane foam, to address fuel tank flammability requirements of § 25.981. It also extends the existing requirements for development of critical design configuration control limitations (CDCCL) for ignition prevention, that were formerly in paragraph (b), to any FRM or IMM and places the amended requirement in § 25.981(d).

c. The amendment also includes continued airworthiness and safety improvement requirements that are contained in a new subpart D to part 26. The new subpart D includes §§ 26.33, 26.35, 26.37 and 26.39. These sections specify different compliance requirements for the affected DAHs. The affected airplanes include those with a seating capacity of 30 passengers or more, or a payload of 7500 pounds or more. Appendix 1 of this AC provides a list of affected models, and Appendix 3 of this AC provides guidance on compliance with these requirements. The intent of § 25.981(b) is to require that the exposure to the formation or presence of flammable vapors is limited to specific values for fuel tanks located within the wing and fuselage contour. The flammability limits for the specific tank type are summarized in the following table:

**TABLE 2****Summary of Flammability Limits for the Specific Tank Type**

Airplanes Affected	Category of Action (Cert. Projects Include TCs, ATCs, & STCs)	Applicable Regulations	Fleet Flammability Exposure (Percent Exposure Time)	
			Normally Emptied & Any Portion Inside Fuselage	All Other Fuel Tanks
All part 25 transports	Future applications for new TCs	§ 25.981(b)		
Turbine powered large transports with  Max Pass $\geq$ 30  or  Max Payload $\geq$ 7500 Lb <b>(* See note)</b> See appendix 1 for list of airplane models			Appendix M	3 percent or equal to conventional unheated aluminum wing tank, whichever is greater
	Pending TC applied on or after June 6, 2001	§ 26.37	(Flam $\leq$ 3% Plus 3% warm day limit)	
	Pending or Future STC or ATC for normally emptied tanks	§ 26.35(d)(2)		
	Future STC or ATC If changes existing fuel tank capacity	§ 26.35(d)(3)	If Flam $>$ 7%, Do appendix M	Flammability $\leq$ 7%
	Production cut-in (After September 19, 2010)	§ 26.39 (Boeing) & Ops Rules (Airbus)	Reduce flammability to: $\leq$ 3% average and $\leq$ 3% warm day limit	
Fleet retrofit	§ 26.33(c) & Ops Rules			

\* Applies to transport category, passenger carrying airplanes for which the state of manufacture issued the original certificate of airworthiness or export airworthiness approval on or after January 1, 1992. Section 26.39 production cut-in applies to both cargo and passenger airplanes.

## 8. Compliance Demonstration.

a. Showing Compliance with § 25.981(b) or (c). Section 25.981 provides two options for addressing the hazards associated with fuel tank flammability:

- Controlling fuel tank flammability to specified levels, and
- Mitigating the hazards if ignition of the fuel vapors occurs.

(1) The first means, as provided in § 25.981(b), shows that the flammability of a fuel tank does not exceed the limits defined in the regulation. When this method of compliance is used, a flammability analysis is required to establish the flammability of the fuel tank, and incorporation of an FRM in any fuel tank to reduce the flammability of any tank that exceeds the applicable flammability limit. Guidance for determining the flammability of a fuel tank is provided in paragraph 10 of this AC. Guidance for incorporating an FRM, including pressurization of a fuel tank, temperature control of a fuel tank, limiting fuel properties and fuel tank inerting, are provided in paragraph 9 of this AC.

(2) Compliance with § 25.981(b) is not required if the hazards of ignition of fuel vapors are mitigated by use of an Ignition Mitigation Means (IMM) meeting the requirements of § 25.981(c). Guidance for demonstrating compliance using IMM is provided in paragraph 12 of this AC. Examples of IMM include filling the tank with polyurethane foam, metallic foils, demonstrating the structure can withstand an explosion, or explosion suppression systems. Since IMM mitigates the effects of ignition so that it is not hazardous, there is no requirement to determine the fuel tank flammability, if this method is used to demonstrate compliance.

b. Showing Compliance with § 25.981(d). Appendix 2 of this AC includes guidance for establishing CDCCL relating to FRM or IMM for the fuel tank system.

c. Showing Compliance with §§ 26.33 and 26.35. Specific guidance for compliance with the continued operational safety requirements contained in part 26, subpart D is provided in appendix 3 of this AC.

## 9. General Considerations – Fuel Tank Flammability.

a. Formation of Flammable Vapors. The critical considerations in controlling exposure to operation with flammable mixtures in the tank include the control of formation of flammable vapors and/or oxygen concentration. Factors influencing the formation of flammable vapors include fuel type and properties, fuel temperature, pressure in the tank, and any design feature that significantly increases the potential for fuel mists to be created. The time a fuel tank is flammable determined by the Monte Carlo analysis is based upon the assumption that design features needed to prevent spraying and misting of fuel in the tank have been incorporated into the design so these factors are not considered. Rather, the fuel properties and temperature and pressure in the fuel tank are used to determine when the fuel tank is flammable. General design practices that affect the overall flammability risk are described below. Airplane designs submitted for FAA evaluation will be evaluated against these practices.

### b. Design Practices to Minimize Flammability Exposure.

(1) Misting and sloshing. The flammability of fuel vapors in a fuel tank can be dramatically influenced by agitation, sloshing, spraying, or misting of fuel. These processes increase the surface area of the fuel allowing more fuel vapors to evolve from the fuel, which results in a higher concentration of fuel molecules in the ullage space. Design practices that reduce the potential for fuel agitation, sloshing, spraying and misting should be incorporated into the design so that flammability is minimized. Examples of proven design practices include installation of sufficient baffling in the tanks to reduce sloshing, and returning any fuel used to cool fuel pumps to the bottom of the tank. Section 6 of SAE Document AIR 1662 describes recommended design practices for minimizing hazards associated with electrostatic charging in fuel tanks. Several of these practices relate to minimizing the formation of flammable vapors, including:

(a) Introducing fuel at low velocity near the bottom of fuel tanks so that the inlet is covered early in the refueling or fuel transfer process.

(b) Directing the fuel flow onto a grounded conducting surface to reduce electrostatic charge build-up.

(c) Using a balanced distribution system to make sure that all fuel tank bays are filled to equal levels to assist in reducing fuel velocity (this minimizes charge relaxation time and mist formation).

These practices greatly reduce the presence of fuel mist that will broaden the flammability range of the fuel at the lean end and cause flammable vapors at temperatures well below the flash point. Appendix N to part 25, paragraph N25.4(3)(ii), defines the flammability envelope that must be used for the flammability exposure analysis. The flammability envelope is a function of the flash point of the fuel selected by the Monte Carlo flammability assessment methodology defined in paragraph 4e(11) of

this AC. This determination if the fuel tank is flammable is based upon the assumption that design precautions described in this paragraph have been implemented.

(2) Fuel temperature is one of the key factors that determine fuel tank flammability in unpressurized fuel tanks approved for use with common Jet A type fuels. The most effective methods for controlling fuel tank temperature may differ between different fuel tanks, according to their exposure to the risk. For instance, fuel tanks located in conventional unheated aluminum wings of subsonic transport category airplanes, with little or no heat input from airplane systems or from other adjacent fuel tanks that have large surface areas that allow cooling of the fuel, have been analyzed and shown to meet the intent of the regulation. Fuel tanks located within the fuselage contours or other tanks located within the wing that do not cool require more design attention. For example, auxiliary fuel tanks located in the cargo compartment or pressurized areas, tanks located in the center wing box, horizontal stabilizer tanks, tanks with small surface areas exposed to airflow, and tanks made from materials that act as insulators, may have less ability to reject heat to ambient air, both on the ground and in flight, and may be subject to heat sources from equipment located nearby in the fuselage such as the air conditioning packs that supply cool air to the cabin. For fuel tanks that, because of installation location and/or other factors, do not meet the applicable flammability limits, an FRM or IMM is needed to comply.

(3) Fuel types. The proposal for fuels for an airplane type is submitted to the FAA by the applicant for approval, and once approved the fuels are shown in the AFM. The definitions of LFL and UFL define the fuel temperature at which a fuel tank can be expected to be flammable. From the definitions, it can easily be seen that fuel flash point is key. Currently, Jet-A and Jet-A1 are the predominant fuels used in commercial aviation. Because of this, wing tanks are commonly not flammable as the fuel temperature is typically below the LFL. However, the heat input to any tank can push tanks fueled with Jet-A/A1 into the flammable range. A fuel such as JP-4 has the reverse effect. The flash point is below normal ambient temperatures during ground operations, resulting in more flammability exposure for typical wing tanks and less for tanks that are insulated from outside air, such as CWT. The higher temperature tanks are less flammable because the fuel temperature is above the UFL more of the time, resulting in an over-rich condition.

(a) Appendix N to part 25 defines a typical transport category airplane fuel based upon a survey of fuels drawn from operating airplanes as shown in paragraph 4e(10) of this AC. The fuels include Jet A/A1 flash point distribution and also lower flash point fuels commonly used in China and Russia. This distribution is also included in appendix N to part 25 and the Monte Carlo analysis in the paragraph 4d(11) of this AC. For consistency across applicants, and for simplicity, each applicant is required to apply the distribution defined in appendix N unless the FAA finds that this distribution is not representative of the fuels that could be expected to be used on the particular airplane being evaluated.

(b) If the use of low flash point fuels, such as JP-4, is proposed as an approved fuel, the fuel properties defined in the User's Manual may not provide a representative flammability exposure analysis. Use of JP-4 type fuels on a typical transport category airplane may significantly increase operational exposure to flammable vapors. Therefore, modification of the flammability analysis and incorporation of additional flammability reduction capability, such as improved FRM performance, may be required to mitigate the increased exposure created by continuous use of such fuels.

(4) Fuel tank ullage sweeping is the introduction of air into a fuel tank and dumping the fuel vapor overboard to reduce the concentration of fuel vapors in the ullage. This means would result in significant emission of fuel vapors into the atmosphere and would likely not meet emissions standards, unless these vapors were removed prior to dumping the air into the atmosphere. Ullage sweeping would not likely have a significant effect on the bulk average fuel temperature of the affected fuel tank and it would not decrease the oxygen content of the ullage. Therefore, it would not provide a significant reduction in the flammability exposure as determined by the flammability assessment method required by part 25, appendix N.

(5) Controlling oxygen concentration. The accepted level for tank inerting used by the military is to reduce the oxygen concentration in the tank ullage to less than 9 percent. This is the standard established in the 1950s for a zero flammability risk design because ignition sources (hostile munitions) are a likely event in military missions. The standard precludes "cool flame" ignition, where the pressure rise is relatively low. The actual oxygen concentration needed to prevent a catastrophic fuel tank rupture during an ignition event per FAA testing (reference 4(e)(8)), and military live fire testing using incendiary rounds (reference 4 (e)(7)), is higher. The higher the oxygen concentration, the higher the pressure that is developed in the fuel tank during a combustion event. Therefore, the applicant may establish the acceptable oxygen concentration based upon evaluation of the structural capability and maximum peak pressure of the fuel tank. The oxygen concentration defined in the definitions paragraph of this AC is an acceptable benchmark for transport category airplane fuel tanks inerted with nitrogen, without additional substantiation. The oxygen concentration limit was established using nitrogen enriched air to displace oxygen. The allowable oxygen concentration varies with the type of inerting gas used. If another inerting gas such as carbon dioxide is used the applicant must substantiate the allowable oxygen concentration needed to show compliance.

c. STC and amended TC applicants for design changes to install a Normally Emptied fuel tank must comply with § 25.981 at Amendment 25-125. The guidance in this AC primarily addresses means of compliance with the new tank itself. However, these applicants must also comply with all applicable CDCCLs established by the TC holder.

## 10. Determining Fuel Tank Flammability.

a. Acceptable Means of Determining the Flammability Exposure. There are two means of establishing the flammability of a fuel tank. The method that is acceptable depends upon the flammability level that the tank is required to meet. Paragraph N25.1(a) of appendix N to part 25 allows for using a qualitative method if it substantiates the fuel tank is a conventional unheated aluminum wing tank. The criteria listed below describe the characteristics of conventional unheated aluminum wing tanks. For all other fuel tanks, the Monte Carlo Model defined in paragraph 4e(11) of this AC must be used as required by appendix N.

### (1) Qualitative flammability assessment.

(a) A conventional unheated aluminum wing tank is a conventional aluminum structure, integral tank of a subsonic transport airplane wing, with minimal heating from airplane systems or other fuel tanks and cooled by ambient airflow during flight. Heat sources that have the potential for significantly increasing the flammability exposure of a fuel tank would preclude the tank from being considered “unheated.” Examples of such heat sources that may have this effect are heat exchangers, adjacent heated fuel tanks, transfer of fuel from a warmer tank, and adjacent air conditioning equipment. Thermal anti-ice systems and thermal anti-ice blankets typically do not significantly increase flammability of fuel tanks. For these tanks, a qualitative assessment showing equivalency to the unheated aluminum wing fuel tank may be acceptable when considered with the following:

- 1 A description of the airplane configuration, (including subsonic, wing construction, etc.),
- 2 A listing of any heat sources in or adjacent to the fuel tank,
- 3 The type of fuel approved for the airplane,
- 4 The tank operating pressure relative to ambient static pressure,
- 5 The tank is uninsulated and made of aluminum, and
- 6 The tank has a large aerodynamic surface area exposed to outside air to transfer heat from the tank.

(b) Fuel tanks with an aerodynamic surface area to volume ratio (surface area/volume) greater than 1.0 have been shown to meet these criteria. Fuel tanks with a ratio less than 1 are not considered conventional unheated aluminum wing tanks. The aerodynamic surface area includes the area of the integral aluminum wing fuel tank that is exposed to outside air. It does not include any portion of a fuel tank that is shielded from free stream airflow, such as the front and rear spar, or an area under a fairing or wing thermal blanket.

(c) Wing tanks that do not meet the criteria above for use of the qualitative method must use the Monte Carlo analysis (ref. appendix N). For example, if a fuel tank were made of composites, the applicant would need to show compliance using one of the two alternatives provided in § 25.981(b) for wing tanks. One alternative would require the applicant to conduct an assessment of the fleet average flammability exposure for an equivalent conventional unheated aluminum wing tank meeting the criteria above, on the airplane type for which approval is sought. This would establish the maximum allowable flammability level for the actual composite wing fuel tanks. The second alternative provided in § 25.981(b) is to conduct an assessment of the actual composite wing tanks and demonstrate the fleet average flammability exposure of any tanks does not exceed three percent.

(2) Monte Carlo Analysis. When the compliance demonstration requires demonstrating a fuel tank meets a specific fuel tank flammability or the tank does not meet the qualitative assessment criteria previously discussed, both § 25.981(b)(1) and paragraph N25.3(a) of appendix N to part 25 require the flammability assessment be conducted in accordance with the methods and procedures in the FAA document, “Fuel Tank Flammability Assessment Method User’s Manual,” (User’s Manual) dated May 2008, which is incorporated by reference in § 25.5 for § 25.981 and Appendix N. This document may be obtained from the following web site: (<http://www.fire.tc.faa.gov/systems/fuel tank/FTFAM.stm>). Section 25.5 includes a provision permitting use of later FAA versions of the User’s Manual when FAA publishes a notice of the change in the Federal Register.

(a) This analytical method is based upon predicting the fleet average flammability exposure, and the warm day fleet average flammability exposure as applicable, to operation with flammable fuel air vapors in the fuel tank. The fuel tank flammability exposure for the tank being evaluated is calculated for the specific fleet of airplanes of interest for which approval is sought using certain standardized parameters for all airplane models and certain airplane model specific parameters. The flammability exposure calculated by the analysis is then compared to the flammability limits defined in the regulations to determine compliance. The analysis method is therefore a standardized analysis method.

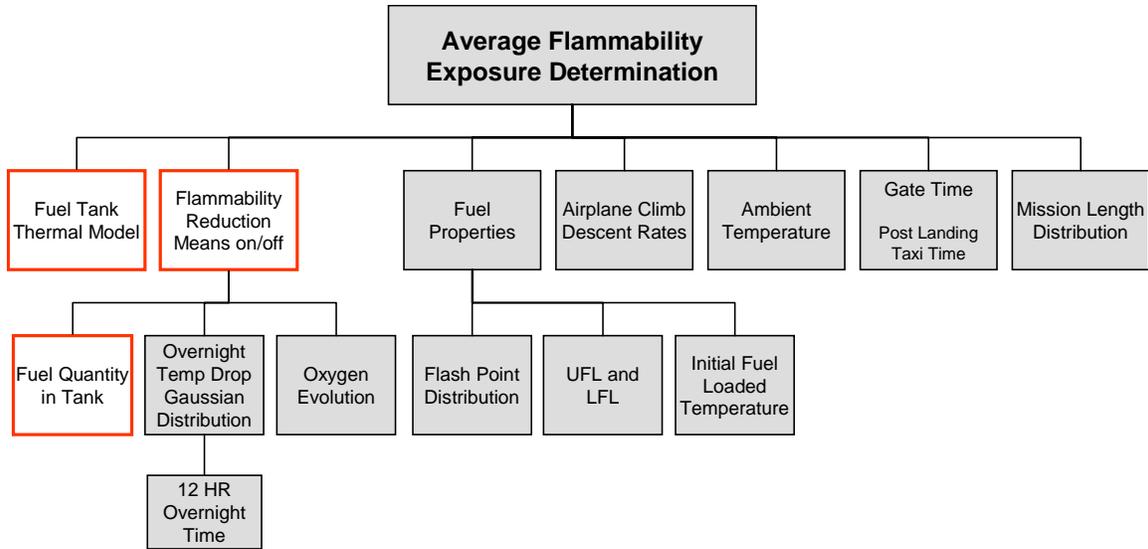
(b) The fuel flash point at a given temperature and pressure is used to determine when the ullage in the tank is flammable. When the fuel temperature at a given altitude is in the range between the LFL and the UFL, the ullage is assumed to instantaneously become flammable. When using a Monte Carlo analysis, that transition is considered to occur instantaneously as pressure and temperature changes. The Monte Carlo Model is based on the assumption that any fuel being loaded during refuel is at ambient outside temperature when determining flammability exposure. Appendix N to part 25 defines the fuel properties used in the Monte Carlo Model. This includes the fuel flash point distribution and the flammability envelope of the fuel that is required to be used for the analysis.

(c) Appendix N to part 25 requires the flammability exposure be determined independently for each fuel tank. For fuel tanks that are subdivided by baffles or compartments, N25.3(a) requires an analysis be performed for each section of the tank. Alternatively, if the applicant can show that one section of the tank always has higher flammability exposure than any other section, the applicant may perform the analysis only of that one section. Within each tank where barriers or walls prevent mixing of the fuel/air mixtures, separate volumes or compartments should be treated independently to determine the worst case flammability exposure for that tank because of temperature variations within different portions of the tank. If FRM based upon inerting is used, oxygen concentration in those compartments of the tank can differ significantly from other compartments in the tank (such as an airplane model that has a center wing box that extends out into the wing, or a compartment in a fuel tank where vent inlets may create differences in temperature or oxygen concentration (if an FRM based on inerting is used)).

(d) It is possible for the critical compartment to change from one compartment of the tank to another compartment during different portions of the flight. In this case, the flammability of the individual compartments would need to be determined throughout the flight and the times when any compartment of the tank is flammable would be included in the overall average flammability calculation.

(e) If a fuel tank is determined to exceed the applicable flammability requirements, the holder may control fuel tank flammability by incorporation of an FRM or IMM. Guidance for FRM is provided in paragraph 11 of this AC.

(3) Developing inputs to the Monte Carlo Model. The Monte Carlo Model, which randomly generates values for uncertain variables over and over, is used to simulate a process where the variables are random within defined distributions. The results of a large number of cases can then be used to approximate the results of the real world conditions. Appendix N to part 25 provides standard distributions and values that must be used when determining fuel tank flammability. Figure 1 shows the parameters that are used by the Monte Carlo Model to determine fuel tank flammability. The outlined, non-shaded boxes identify inputs that are dependent on the fuel tank design and operation and on the FRM design. The shaded boxes identify parameters that are fixed in the Monte Carlo Model.



**FIGURE 1**

### Monte Carlo Parameters to Determine Fuel Tank Flammability

(4) Monte Carlo Parameters. The fuel tank thermal model and fuel quantity in the fuel tank are user inputs needed to determine the fuel tank flammability for a fuel tank without an FRM. The performance of an FRM must also be provided by the user if an FRM is installed. User inputs to the Monte Carlo Model and standardized parameters include the following as defined in appendix N to part 25 and in the User's Manual (defined in paragraph 4e(11) of this AC):

(a) Standardized parameters used in the Monte Carlo Model.

1 Cruise ambient temperature, N25.3(b)(1), N25.4 and Table 1 of appendix N.

2 Ground ambient temperature, N25.3(b)(2), N25.4 and Table 1 of appendix N.

3 Fuel flash point, N25.3(b)(3), N25.4 and Table 1 of appendix N.

4 Flight length distribution, in conjunction with the airplane utilization information submitted under Airplane specific inputs below.

5 Airplane climb and descent profiles (paragraph N25.3(b)(5) requires the applicant use the climb and descent profiles defined in the User's Manual.

6 Preflight and post flight gate times; the preflight times are provided as a function of the flight time by the Monte Carlo Model in the User's Manual and the post-flight time is a constant 30 minutes, both as defined by N25.2(b).

7 Oxygen evolution rate (included in model when FRM used, based upon User's Manual as required by N25.3(d)(5)).

8 Overnight temperature change (when FRM is added).

(b) Airplane specific inputs: The airplane specific inputs should reflect the most severe airplane operating conditions or configuration with respect to fuel tank flammability exposure.

1 Airplane cruise altitude.

2 Fuel tank quantities. As discussed in the User's Manual, the FAA Monte Carlo Model has a feature that allows the user to input times when the tank is full and empty so that the fuel quantity in the tank can be modeled. The model assumes a constant rate of fuel use between the specified tank full and empty times and does not account for unique fuel management techniques such as fuel transfer systems that may be incorporated for purposes such as center of gravity (C.G.) management. If fuel quantity affects fuel tank flammability, inputs to the Monte Carlo analysis may need to be modified by the user if the standard model does not provide a realistic representation of the actual fuel quantity within the fuel tank or compartment of the fuel tank throughout each of the flights being evaluated. Input values for this data must be obtained from ground and flight test data or the FAA approved fuel management procedures in the AFM.

3 Airplane cruise mach number.

4 Airplane maximum range. This parameter should be determined assuming a payload equivalent to a load factor of 75 percent for a typical two class passenger configuration for the airplane model, using year-around average passenger weights and standard average baggage and carry-on weights per AC 120-27, "Aircraft Weight and Balance Control," standard day atmosphere, zero wind, long range cruise speed and domestic or international reserves as would apply to the typical operation of the airplane.

5 Fuel tank thermal characteristics. If fuel temperature affects fuel tank flammability, the rule requires that inputs to the Monte Carlo analysis be provided that represent the actual bulk average fuel temperature within the critical compartment of the fuel tank throughout each of the flights being evaluated. For fuel tanks that are subdivided by baffles or compartments, bulk average fuel temperature inputs should be developed for each section of the tank. The temperature in any compartment that results in the highest flammability at any given time should be used in the tank flammability analysis. If one compartment in the tank always has the highest flammability exposure, the temperature in that compartment should be used in the analysis. The rule requires that input values for these data be obtained from ground and flight test data or a thermal model of the tank that has been validated by ground and flight test data. The thermal input data should reflect the most severe airplane operating conditions or configuration.

For example, for fuel tanks located near heat sources such as the airplane environmental conditioning system (ECS), also called air conditioning packs (packs), the maximum allowable number of packs should be running during test and modeling conditions.

6 Maximum airplane operating temperature limit as defined by any limitations in the AFM. This value is obtained from the flight manual for the specific airplane type.

7 Airplane Utilization. The rule requires that the applicant provide data supporting the number of flights per day and the number of hours per flight for the specific airplane model under evaluation. If there is no existing airplane fleet data to support the airplane being evaluated, the applicant must provide substantiation that the number of flights per day and the number of hours per flight for that airplane model is consistent with the existing fleet data they propose to use.

(aa) Fuel tank thermal model. A computer simulation, validated by flight test data, is one way to provide inputs for the model that simulates the thermal behavior of the tank throughout the airplane operating envelope. This model must be provided by the applicant based on the particular characteristics of the particular fuel tank that is being evaluated. The applicant may use the thermal modeling tool incorporated into the Monte Carlo Model if flight test data show that this modeling technique provides conservative prediction of fuel tank temperatures. The Monte Carlo Model includes a feature to use exponential time constants to define the heating and cooling characteristics of a fuel tank. This feature has the capability to input 6 different constants for various conditions that may be present on typical aluminum fuel tanks. While this feature is one method of modeling the fuel tank thermal characteristics so that fuel tank temperatures can be predicted, it is not an acceptable method of modeling the fuel tank if it does not provide accurate results. It may be necessary for the applicant to develop a separate fuel tank temperature model that accurately predicts fuel tank temperatures. Appendix 4 of this AC provides further guidance regarding developing a validated fuel tank thermal model for use in showing compliance for fuel tanks. This guidance will be helpful for use in developing a thermal model for a fuel tank with an FRM.

(bb) Simplified fuel tank thermal model. To simplify the certification process and avoid the need to develop a fuel tank thermal model, if an applicant so chooses, it is acceptable to determine the flammability exposure of a tank with an inerting system added by assuming the fuel temperature is otherwise always between the LFL and UFL.

(cc) Body fuel tank thermal model. If the tank is located entirely inside the fuselage of the airplane in a compartment and no tank surface is exposed to outside air flow during flight, e.g., an auxiliary fuel tank installed in the cargo compartment of an airplane, it is considered a "Body Tank." For these fuel tanks, the Monte Carlo model defined in paragraph 4e(11) allows the calculated temperatures of the fuel tank to be controlled by the temperature of the compartment in which the fuel tanks is installed.

b. Fuel Tank FRM Model. If FRM is used, the rule requires an FAA-approved Monte Carlo Model be used to show compliance with the flammability requirements of § 25.981 and appendix M of part 25. The program must determine the time periods during each flight phase when the fuel tank or compartment with the FRM would be flammable. The following factors must be considered in establishing these time periods:

(1) Any time periods throughout the FEET and under the full range of expected operating conditions, when the FRM is operating properly but fails to maintain a non-flammable fuel tank because of the effects of the fuel tank vent system or other causes.

(2) The effect of any inerting system may be included in this analysis. The applicant should present a description of the system including its control logic, and data to substantiate its performance at lowering the ullage oxygen content to below the inert level defined in appendix N to this part to comply with the applicable average flammability level. Where the system does not provide continuous protection such as a ground based inerting system as described in paragraph 4e(5) of this AC, the degradation of the ullage inerting level with time, altitude, oxygen evolution from the fuel, air inhalation with fuel use or altitude reduction, and possible effects from vent system operation must be addressed.

c. Compliance Report. The results of the analysis described above, together with substantiation data for the assumptions used in the analysis, including test data validating the thermal analysis used, would be included in the compliance report presented to the FAA. If the tank in question requires a demonstration of equivalence, an analysis of a real or hypothetical unheated wing tank on the same airplane must also be presented.

d. Documentation and Validation of Monte Carlo Model. As discussed earlier in paragraph 10, modifications to the Monte Carlo model are limited to the additional features needed to model an FRM, tank thermal characteristics, and fuel management. All modifications to the model's code must be thoroughly documented and validated both through detailed analysis and flight test. The compliance report should include a summary section that lists all modifications.

**11. Flammability Reduction Means.** The available methods of limiting exposure to operation with a flammable ullage space in the tank include preventing the formation of flammable vapors and/or controlling the oxygen concentration. Factors that directly influence the formation of flammable vapors include the fuel type properties, fuel temperature, pressure within the fuel tank, and any design feature that increases the potential for fuel mists to be created. Design precautions described earlier within this AC to limit misting or sloshing of fuel within a fuel tank should be taken.

Demonstrating compliance when an FRM is used requires modification to the Monte Carlo Model to include a simulation of the FRM performance. The simulation must determine the times during the flight when the FRM is effective at maintaining a non-

flammable fuel tank. Factors that need to be considered when developing the simulation are discussed within this section.

a. **Managing Heat Transfer to the Fuel Tank.** In general, heat sources should not be located in or near fuel tanks, and heating from other sources, such as hydraulic heat exchangers or rejection of heat from engine systems, should be avoided unless features are incorporated to maintain fuel tank flammability equivalent to an unheated wing fuel tank. Locating heat-producing systems away from the tanks should be considered. If this is not a practical solution, installation of an FRM using thermal control may be another option. Possible technical solutions include the use of thermal insulation blankets, and/or providing ventilation and/or dedicated cooling to remove excess heat from the fuel tank or areas adjacent to the tank.

b. **Cooling/Ventilation of Fuel Tanks.** If the fuel tank is located in an area of the airplane where little or no cooling occurs, such as the center wing box, certain horizontal stabilizers, or auxiliary fuel tanks located in the cargo compartment, ventilation or dedicated cooling may also be an effective means of demonstrating compliance. The cooling/ventilation means should be effective under all operating conditions, including ground and flight operation, considered necessary to achieve the desired goal of showing the tank flammability is equivalent to the unheated wing tanks. Adequate cooling/ventilation may be provided for certain airplane types by means such as installation of an air gap in spaces adjacent to fuel tanks and utilizing cold air source during ground operation to cool the tank, and the use of ram air inlets for in-flight operation to transfer heat from the tank. Other means (e.g., bleeding cool air from the ECS packs into the air gap) may also be effective at providing adequate cooling/ventilation of the tank.

c. **Controlling Fuel Tank Pressure.** The flammability of the fuel tank is affected by the pressure in the tank. Typical transport category airplane fuel tanks are vented to the atmosphere and operate at or slightly above local ambient pressure. Fuel tanks located within the wing typically operate with a pressure equal to the local static pressure unless features are incorporated to increase the fuel tank operating pressure. Designs have been developed that use pressurization of the wing fuel tanks as a means to transfer fuel. Pressurization of the fuel tanks also provides reduced flammability. Manufacturers have also incorporated National Advisory Committee for Aeronautics (NACA) scoops on the vent outlets of some airplane fuel tank systems to enhance engine suction feed performance. The pressure recovery factor of these scoops varies but in general is in the range of .4 to .6. Therefore fuel tank pressure during flight may be between .5 to 1.25 psi above local static pressure. The increase in tank pressure results in a reduction in fuel tank flammability.

Many recently designed auxiliary fuel tanks, located in pressurized cargo compartments, incorporate structural features that allow utilization of pneumatic pressure to transfer fuel from the fuel tank to the airplane fuel tank system. These tanks typically are designed to operate at the airplane cabin pressure which is normally equivalent to approximately 8000 feet pressure altitude. This results in a significant reduction in fuel

tank flammability. Controlling fuel tank pressure is one means of reducing fuel tank flammability. The Body Tank model in the Monte Carlo Model defined in paragraph 4e(11) of this AC has features that allow the user to input a pressure differential relative to ambient pressure so that fuel tank flammability under these conditions can be evaluated.

d. Fuel Tank Ullage Sweeping. A positive ventilation system has been studied to be used to “sweep” the ullage of flammable fuel vapor/air mixtures at a rate that keeps the ullage lean when the fuel temperature and pressure in the tank would otherwise define the tank as being flammable. It is discussed in the ARAC Fuel Tank Harmonization Working Group Final Report in paragraph 4e(2) of this AC. The rule requires that the fuel tank flammability be determined based upon the Monte Carlo analysis, which determines if the fuel tank ullage is flammable based on the fuel temperature and fuel tank altitude (or pressure altitude).

e. Higher Flash Point Fuels. One method of reducing fuel tank flammability is to restrict the fuel type specified in the AFM to higher flash point fuels (e.g., JP-5, 140 degrees F flash point). This method, in combination with other means, may be effective at reducing the exposure. However, as discussed in the ARAC Fuel Tank Harmonization Working Group Final Report in paragraph 4e(2) of this AC, this approach is not considered to be practical at this time. If this method were considered, the applicant would need to request FAA approval for use of a fuel type with a different flash point when conducting the flammability assessment than that required by appendix N to part 25.

f. Oxygen Concentration.

(1) Fuel Tank Inerting. Fuel tank inerting is a highly effective means of reducing or eliminating the flammability exposure within a given tank. This method eliminates flammable vapors by displacing oxygen from the ullage space of the tank with inert gas (reducing the oxygen concentration below the level that would support combustion of flammable vapors). The military has used this method to prevent fuel tank explosions of combat airplanes. While system requirements for commercial applications are different, the development of technology for separation of nitrogen gas from air has allowed the size and weight of inerting systems to be significantly reduced for commercial applications. Additional size and weight reductions may be achieved by new approaches such as catalytic conversion of fuel vapors in fuel tanks to produce carbon dioxide for use as the inert gas that is under development.

(2) Recent technology developments have made it possible to develop inerting systems that use optimized air sources that are part of the initial airplane design. These systems are capable of inerting a fuel tank during normal airplane operating conditions. Older technology airplanes that have limited bleed air sources are less efficient and it may not be practical to provide an inerting system that inerts the tank throughout the flight envelope. On these airplanes a flammability assessment based upon the time the

inerting system is effective, as well as consideration of the fuel tank flammability, may be part of the overall compliance demonstration.

(3) The applicant may show that inerting is only needed for certain missions, for example during warmer days when the fuel ullage would be flammable, or parts of a particular flight to lower the fuel tank vapor/air mixture average exposure to a level that meets the flammability limit. Inerting may be achieved by supplying inert gas from on-board storage bottles, holding either gas or liquid inerting agent, on board inert gas generation systems (OBIGGS), or from a ground storage system if the tank is inerted only on the ground. Nitrogen is currently the inert gas of choice for inerting fuel tanks and the requirements in the § 25.981 address the requirements for use of nitrogen based inerting systems. Use of other gases, such as carbon dioxide, to inert a fuel tank would include many of the same considerations for markings and maintenance procedures. However there may be other considerations that need to be addressed in the certification plan, such as gas absorbed by the fuel and the effect of the gas absorbed on the fuel system performance, such as suction feed performance.

(4) FRM designs that reduce the oxygen concentration to very low levels during cruise and increase the flow of nitrogen enriched air (NEA) into the fuel tank during decent have been found to optimize the design. One nitrogen inerting system designed for retrofit into airplanes with limited air sources has a dual flow mode that takes into consideration the performance of the air separation modules (see paragraph 4e(12) of this AC). During cruise the system operates at low flow mode where high nitrogen concentration NEA is introduced into the fuel tank to lower the oxygen concentration to very low levels. During decent the system is operated in high flow mode where the flow rate of NEA is increased. At high flow rates the nitrogen concentration of the NEA is lower.

(5) Oxygen Level. The accepted practice for tank inerting used by the military for a nitrogen based system is to reduce the oxygen concentration in the tank ullage to less than 9 percent. Data obtained from military testing that was conducted in 1991 (see paragraph 4e(7) of this AC), as well as FAA testing (see paragraph 4e(8) of this AC), shows that 12 percent oxygen concentration at sea level, will provide sufficient protection for transport category airplanes when using nitrogen based systems. As stated in the definitions paragraph of this AC, a fuel tank is considered to be inert when the bulk average oxygen concentration within each compartment of the fuel tank is 12 percent or less from sea level up to 10,000 feet altitude, then linearly increasing from 12 percent at 10,000 feet to 14.5 percent at 40,000 feet altitude, and extrapolated linearly above that altitude.

g. Oxygen Evolution. Fuel loaded on the airplane from sources vented to the atmosphere contains dissolved oxygen. Systems added to inert fuel tanks must take into account the dissolved and entrained oxygen in the fuel when loaded onto the airplane. The applicant can either design the system to allow and compensate for the evolution of the oxygen or include provisions to remove or “scrub” the oxygen from the fuel during refueling. The effect of oxygen that may rapidly evolve from the fuel during pressure reduction conditions, such as during climb, must be accounted for in the Monte Carlo

Model. Section 4.3 of the User's Manual discusses how oxygen evolution should be treated in the Monte Carlo analysis when an FRM using inerting is developed.

**NOTE:** An FAA ground and flight test program evaluated the effectiveness of inerting a center wing fuel tank with a ground based nitrogen enriched air supply without a closed vent system. The testing included measuring the effects of oxygen evolution. The results of the test program are contained in FAA Report, Ground and Flight Testing of a Boeing 737 Center Wing Fuel Tank Inerted with Nitrogen Enriched Air, Report # DOT/FAA/AR-01/63, (July 2001). The report is available on the internet at <http://www.fire.tc.faa.gov/pdf/01-63.pdf>.

h. Overnight Temperature Change. As the airplane sits overnight, the temperature will change accompanied by an associated density change of the fuel tank ullage. Usually, the change in temperature is downward from the last flight of the day to the first flight the next day. The result is that the fuel tank will "breathe in" additional air as the ullage density increases. The applicant must take this effect into consideration. Appendix N defines the required distribution the applicant must use in a Monte Carlo analysis to determine the change in temperature. The starting temperature is the temperature of the ullage at the end of the last flight as determined by the validated thermal model. The ending temperature is the ambient outside temperature before the next flight after an overnight temperature change. The applicant must substantiate the number of flights per day for a particular airplane and apply the overnight temperature change effect once "per day" in the FRM module developed by the applicant for the Monte Carlo analysis. Some airplane operations (such as executive jets) result in routine operations with consecutive days of overnight temperature changes that may cause the oxygen concentration in the fuel tanks to be elevated so the tank is no longer inert. The effects of consecutive overnight temperature changes on FRM performance should be provided by the DAH in the airplane operating and maintenance instructions.

i. Other Considerations Related to Oxygen. The applicant should consider any other environmental conditions or airplane system that may have an effect on the oxygen concentration within the fuel tank in question. Some existing fuel tank vent systems are designed to vent to both wing tips. For a fuel tank that may be vented to both sides of the airplane, the applicant must consider the effects of pressure differences across the wing and the resulting cross flow through the tank. Differential pressures created during maneuvers, between the vents located near each wing tip result in significant flow of air through the fuel tank and can result in adverse effects on an FRM that is based upon limiting oxygen concentrations. Installation of check features, such as a lightly loaded check valve in the vent system, or limiting the venting to one vent outlet have been shown to limit cross-flow. Any changes to an existing airplane vent system must meet the associated regulations (e.g., §§ 25.975 and 25.979). For example, one factor that needs to be considered is possible increases in fuel tank bottom pressures during refueling conditions due to any additional pressure losses resulting from modifications to the vent system. When inerting is used as the means of compliance, the inert gas distribution system must be shown to be effective in all compartments of a fuel tank. The

design may be optimized by incorporation of features to maintain even distribution of the inerting gas.

j. Compliance Demonstration. Flight test demonstration and analysis will be required to demonstrate the effectiveness of the inerting system (see appendix 5 for information on measurement of oxygen concentrations in airplane fuel tanks). The demonstration should include critical conditions and demonstration that the inerting system reduces the oxygen concentration in the tank to an acceptable level, without leaving pockets of oxygen concentrations above the maximum level within the tank. Where the applicant uses inerting as one part of an overall method to reduce flammability (for example inerting in combination with tank temperature control), the applicant should demonstrate the effectiveness of each part of the overall method independently, as well as in combination to show overall effectiveness at meeting the flammability requirements.

(1) The amount of flight testing that is acceptable for showing compliance depends upon the proposed method of compliance. For example, an applicant may choose to develop an FRM performance model and then substantiate by airplane testing that the model accurately predicts the system performance. An applicant may also choose to define the critical points in the airplane operating envelope and then conduct flight test conditions at the critical points to show compliance.

(2) For an inerting-based FRM that is effective at preventing fuel tank flammability during normal airplane operating conditions, the demonstration that would be needed may be limited to providing substantiation that the distribution system is effective at inerting all sections of the tank, that the system provides adequate flow, and that the reliability of the system meets the overall requirements.

(3) In addition, the applicant must substantiate that the added system meets the installation requirements of part 25.

k. System Reliability Considerations.

(1) The overall time the fuel tank is flammable cannot exceed 3 percent of the Flammability Exposure Evaluation Time (FEET), which is the total time, including both ground and flight time, considered in the flammability assessment defined in appendix N. As a portion of this 3 percent, if flammability reduction means (FRM) are used, each of the following time periods cannot exceed 1.8 percent of the FEET: (a) when any FRM is operational but the fuel tank is not inert and the tank is flammable; and (b) when any FRM is inoperative and the tank is flammable.

(2) Master Minimum Equipment List (MMEL) Interval. Inerting systems designed as a flammability reduction means are considered part of a balanced fuel tank safety approach together with design features incorporated to prevent ignition sources in fuel tanks. These FRM are not considered flight critical and airplanes may be eligible for dispatch under the MMEL with the FRM inoperative. The FAA Flight Operations Evaluation Board (FOEB) will establish the MMEL dispatch relief interval for the FRM

based on data submitted by the applicant to the FAA. This value should reflect the value the applicant uses in the reliability analysis and the requirements of appendix N25.3(d)(2), which states that if dispatch with the system inoperative under the MMEL is requested, the time period assumed in the reliability analysis must be 60 flight hours for a 10-day MMEL dispatch limit unless an alternative period has been approved by the Administrator. The FOEB may accept a system reliability analysis using the Monte Carlo Model. As shown in section 3.2 of the User's Manual, inputs needed to conduct an analysis include, mean time between failures (MTBF) of the FRM, average time to restore the system function after it is placed on the Minimum Equipment List (MEL), and the number of flights before a failed FRM would be detected. These inputs are discussed in more detail in the User's Manual.

(3) Reliability Reporting. The regulation requires that the applicant demonstrate effective means to ensure collection of FRM reliability data so that the effects of component failures can be assessed on an on-going basis. The reporting requirement is contained in appendix M, paragraph M25.5, and applies to applicants and DAH.

(4) The rule requires the TC or STC holder to provide the FAA with summaries of the FRM reliability data in compliance with appendix M to part 25 on a quarterly basis for the first five years after the FRM is installed and operational. After that time, continued quarterly reporting requirements may be replaced with other reliability tracking methods approved by the FAA Oversight Office. The requirement for quarterly reports may be eliminated if the FAA determines that the reliability of the FRM meets, and will continue to meet, the requirements of the rule.

(5) Operators are not required to report FRM reliability information. Type certificate holders are required to gather the needed data and may use existing reporting systems that are currently used for airplane maintenance, reliability, and warranty claims to gather the data from operators using existing business arrangements between the TC holders and the airlines.

(6) The reliability report should include information regarding overall system dispatch reliability, including identification of the component that caused the failure of the system, and the number of days on average the system was placed on the MMEL. The report should be submitted to the FAA Oversight Office by a letter on a quarterly basis as required by the regulation.

#### 1. Indications.

(1) Since inerting systems are considered a safety enhancing system, similar to a flight data recorder, no indication to the flightcrew of the flammability of the fuel tank, and associated flightcrew procedures for fuel tank flammability or oxygen concentration are specifically required by the regulation. The need to provide indication of the FRM status will depend on the particular FRM design. Various design methods may be used to make sure an FRM meets the reliability and performance requirements. These may

include a combination of system integrity monitoring and indication, redundancy of components, and maintenance actions. A combination of maintenance indication or maintenance check procedures could be used to limit exposure to latent failures within the system, or high inherent reliability may be used to make sure the system will meet the fuel tank flammability exposure requirements.

(2) The need for FRM indications and the frequency of checking system performance (maintenance intervals) must be determined as part of the FRM fuel tank flammability exposure analysis. The determination of a proper maintenance interval and procedure will follow completion of the certification testing and demonstration of the system's reliability and performance prior to certification or as part of the FAA review process for airplanes manufactured under existing TC or auxiliary fuel tanks under existing STC.

(3) Appropriate maintenance level indications and limitations should be placed in the MMEL to maintain the reliability of the inerting system to the level required by the regulations. For example, maintenance level messages would likely be needed to meet the reliability requirements for an FRM to show when the system is not functioning properly so the inoperative interval that goes into the reliability analysis can be limited to short periods. Installation of an oxygen sensor to measure the oxygen concentration, and appropriate maintenance messages may be needed to meet reliability requirements or may be a desirable feature that may eliminate the need for frequent maintenance checks.

m. Inerting System Safety Considerations.

(1) For inerting systems that generate NEA on board, the waste gas may create additional fire hazards or change the hazards within certain areas of the airplane. Therefore, these effects should be considered a potential hazard to the airplane. By the very nature of the process of separating nitrogen from air, the waste gas will be of a higher concentration of oxygen than normal air. Since higher concentrations of oxygen may lead to a greater likelihood of ignition, given the availability of fuel vapor and a spark, safety assessment and special precautions may be required.

(2) Inerting systems that use combustion or catalytic processes to produce inerting gas typically operate at elevated temperatures that may introduce hazards into the airplane design. These systems must be located and designed such that they comply with airplane fire protection regulations, such as § 25.863, etc.

(3) Special maintenance procedures may be required to meet the reliability and performance requirements for fuel tanks that utilize nitrogen inerting. Maintenance actions that require entry into a fuel tank that contains inert gas or an area adjacent to an inerted fuel tank may be hazardous if appropriate safety precautions are not utilized. The fuel tank should be ventilated and appropriate air source provided. Appropriate warning information should be included in the maintenance manuals and placards placed at fuel tank entry points warning maintenance personnel.

(4) Confined spaces are compartments or enclosures with limited openings for entry and exit, not intended for continuous human occupancy, and only suitable for temporary work such as inspections, maintenance, or repairs. A fuel tank has potential hazards that include toxic chemicals, insufficient oxygen with a concentration that is below 19.5 percent or excess oxygen that is above 23.5 percent, and a flammable gas, vapor, or mist in excess of 10 percent of its LFL. (Reference U.S. Department of Labor Occupational Safety & Health Administration (OSHA), 29 CFR §1910.146(b)). Specific procedures must be in place that identify, control, or eliminate these hazards prior to maintenance personnel entering into fuel tanks.

(5) A large percentage of the work involved in properly inspecting and modifying airplane fuel tanks and their associated systems must be done in the interior of the tanks. Performing the necessary tasks requires inspection and maintenance personnel to physically enter the tank, where environmental hazards exist. These hazards exist in any fuel tank (regardless of whether a nitrogen inerting system is installed) and include fire and explosion, toxic and irritating chemicals, oxygen deficiency, and the confinement to the fuel tank itself. To prevent related injuries, operator and repair station maintenance organizations have developed specific procedures for identifying, controlling, or eliminating the hazards of fuel-tank entry. In addition, government agencies have adopted safety requirements for use when entering fuel tanks and other confined spaces. These same procedures along with additional markings would be applied to the reduced oxygen environment likely to be present in and adjacent to an inerted fuel tank.

(6) Confined and Adjacent Space Markings. The addition of a system that utilizes inerting to reduce the flammability of a fuel tank may result in reduced oxygen concentrations due to leakage of the inert gas in locations in the airplane where service personnel would not expect it.

(7) A worker is considered to have entered a confined space just by putting his or her head across the plane of the opening. If the confined space contains high concentrations of inert gases, workers who are simply working near the opening may be at risk. These gases may be under pressure because of the design of the inerting system, and any hazards associated with working in adjacent spaces near the opening, should be identified in the marking of the opening to the confined space.

(8) Introduction of NEA within the fuel tanks creates additional risks because of the possibility of NEA leaking into compartments adjacent to the fuel tanks. Lack of oxygen in these areas could be hazardous to maintenance personnel, and in some cases could affect the passengers, or flightcrew. Existing certification requirements address these hazards. Appendix M25.3(c) requires markings to emphasize the potential hazards associated with confined spaces and areas where a hazardous atmosphere could be present as a result of the addition of FRM. That paragraph requires that the access doors and panels to the fuel tanks with FRMs and to any other enclosed areas that could contain hazardous atmosphere under either normal conditions or failure conditions be permanently stenciled, marked, or placarded to warn of hazards.

(9) Fuel tanks are confined spaces and contain high concentrations of fuel vapors that must be exhausted from the fuel tank before entry. Other precautions such as measurement of oxygen concentrations before entering a fuel tank are already required.

(10) Designs currently being implemented locate the FRM in the fairing below the center wing fuel tank. Access to these areas is obtained by opening doors or removing panels which allow some ventilation of the spaces adjacent to the FRM. Leakage of NEA into areas adjacent to the FRM equipment or tanks may create a hazard for maintenance personnel. Confined space hazards in the areas adjacent to the fuel tanks should be assumed unless it can be shown that adequate ventilation is provided so air quality for maintenance personnel is assured. Unless the design eliminates this hazard, markings should be provided to warn service personnel of possible hazards associated with the reduced oxygen concentrations in the areas adjacent to the FRM. Appropriate markings would be required for all inerted fuel tanks, tanks adjacent to inerted fuel tanks and all fuel tanks connected to the inerted tanks via plumbing. The plumbing includes, but is not limited to, plumbing for the vent system, fuel feed system, refuel system, transfer system and cross-feed system. The markings should also be stenciled on the external upper and lower surfaces of the inerted tank adjacent to any openings to ensure maintenance personnel understand the possible hazards of fuel vapors and lack of oxygen in and adjacent to the fuel tank.

(11) Markings/placards. The regulation requires that if an inerting system is installed on an airplane, the access doors and panels to the fuel tank(s) and any other enclosed areas that could contain hazardous atmosphere under either normal conditions or failure conditions must be permanently stenciled, marked, or placarded to warn of hazards. These placards would be considered CDCCL and should be included in the required markings section of the maintenance instructions.

The following is an example of wording that may be used:

- Low oxygen content possible during nitrogen generation system operation.
- Obey employer safety procedures.
- Failure to obey may cause injury.

I



**FIGURE 2**

**Low Oxygen Level Placard**



**FIGURE 3**

**Confined Space Placard**

## **12. Ignition Mitigation Means (IMM).**

The following are acceptable means to mitigate the effects of an explosion.

a. One means to meet § 25.981 is to protect a tank from structural and systems damage that could prevent continued safe flight and landing of the airplane. This alternative recognizes that an applicant may choose to accept a high flammability exposure in a given tank and to provide additional protection to extinguish or suppress an explosion in a tank if an ignition occurs.

b. The use of appropriate foams to fill the fuel tank and thereby control the pressure rise following an ignition of the fuel vapor/air mixture has been demonstrated to be effective by the United States Air Force (USAF) and other military forces. Foams are in use on several civilian transport category airplane types. Detailed design information regarding use of reticulated polyurethane safety foam for explosion suppression is provided in the report referenced in paragraph 4d(1) of this AC. The applicant may use such a foam installation to satisfy the requirement of § 25.981. The foam type should be demonstrated to be effective in suppressing explosions to a level where structural and system damage is prevented. The applicant should:

(1) Provide data on the foam, including material, pore size, and intended method for installing the foam in the tank.

(2) Address the potential for, and the effects of, degradation of the foam, from any environmental effects and long term aging, on both the airplane and engine fuel systems. If the foam has a limited useful life, particular installation requirements, or other features that are essential for the IMM to perform its intended function, they should be defined as CDCCLs.

(3) Address the effects of the foam installation on fuel system performance, including engine feed, venting, unusable fuel, sump capacity, expansion space capacity, fueling, and defueling, including the effect of the foam on electrostatic buildup in the tank.

(4) Address the effect of the foam installation on the airplane fuel system, as well as the auxiliary power unit (APU) and engine fuel systems, and develop maintenance procedures to ensure the foam is correctly installed, both initially and when reinstalled, if removed for access to the tank.

/s/ Ali Bahrami

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**APPENDIX 1****LIST OF § 26.33(a) AFFECTED MODELS/FAA OVERSIGHT OFFICES****TABLE 1-1****Section 26.33(a) Applicable Airplane Models**

The following list represents the airplane models determined to meet the applicability criteria of § 26.33(a). This list only represents our best determination at this time and may not be complete. Design approval holders are responsible for identifying all of their airplane models meeting the applicability criteria.

<u>Aerospatiale</u>	ATR 42, ATR 72
:	:
<u>Airbus:</u>	A300, A310, A318, A319, A320, A321, A330, A340, A380
<u>BAE:</u>	BAe-146, BAe Jetstream 4100, ATP, Avro 146
<u>Boeing:</u>	717, 737, 747, 757, 767, 777, MD-80, MD-90, MD-11
<u>Bombardier:</u>	CL-600-2B19 (CRJ-100/200/440), CL-600-2C10 (CRJ-700), CL-600-2D15, CL-600-2D24 (CRJ-900), DHC-8
<u>CASA:</u>	CN-235, C-295
<u>Dornier:</u>	328-100, 328-300
<u>Embraer:</u>	EMB-120, EMB-135, EMB-145, ERJ-170, ERJ-190
<u>Fokker:</u>	F.27 Mk 50, F.28 Mk 0070 and Mk 0100
<u>Saab:</u>	340 (or SF-340), 2000

**TABLE 1-2****FAA Oversight Offices**

Airplane manufacturer	FAA Oversight Office
Aerospatiale	Transport Airplane Directorate, International Branch, ANM-116
Airbus	Transport Airplane Directorate, International Branch, ANM-116
BAE	Transport Airplane Directorate, International Branch, ANM-116
Boeing	Seattle Aircraft Certification Office
Bombardier	New York Aircraft Certification Office
CASA	Transport Airplane Directorate, International Branch, ANM-116
deHavilland	New York Aircraft Certification Office
Dornier	Transport Airplane Directorate, International Branch, ANM-116
Embraer	Transport Airplane Directorate, International Branch, ANM-116
Fokker	Transport Airplane Directorate, International Branch, ANM-116
Lockheed	Atlanta Aircraft Certification Office
McDonnell-Douglas	Los Angeles Aircraft Certification Office
SAAB	Transport Airplane Directorate, International Branch, ANM-116

**APPENDIX 2****DEVELOPING CRITICAL DESIGN CONFIGURATION CONTROL  
LIMITATIONS - FUEL TANK FLAMMABILITY**

1. Introduction. This appendix provides guidance for developing Critical Design Configuration Control Limitations (CDCCL) for fuel tank systems to prevent the fuel tank from exceeding the applicable flammability exposure limits established in the 2008 Fuel Tank Flammability Reduction (FTFR) rule. Guidance for developing CDCCLs to maintain ignition prevention features is located in AC 25.981-1B, Fuel Tank Ignition Source Prevention Guidelines, or the latest revision.

2. Definitions.

a. Aircraft Maintenance Manual (AMM). A manual developed by the manufacturer of a particular airplane that contains information necessary for the continued airworthiness of that airplane.

b. Airworthiness Limitation Item (ALI). Mandatory maintenance of the fuel system that can include CDCCL, inspections, or other procedures determined necessary to ensure, with respect to this AC, the fuel tank flammability exposure does not increase above the certification limits as a result of maintenance actions, repairs, or alterations throughout the operational life of the airplane.

c. Component Maintenance Manual (CMM). A manual developed by a manufacturer that contains information necessary for the continued airworthiness of a particular component.

d. Critical Design Configuration Control Limitations (CDCCL). A limitation requirement to preserve a critical design feature of a flammability reduction system or of the fuel system design that is necessary for the design to meet the performance standards of § 25.981 throughout the life of the airplane model. The purpose of the CDCCL is to provide instructions to retain the critical features during configuration changes that may be caused by alterations, repairs, or maintenance actions.

e. Instructions for Continued Airworthiness (ICA). The information documented in accordance with 14 CFR 25.1529 and 14 CFR part 25, appendix H that includes the applicable methods, inspections, processes, procedures, and airworthiness limitations required to keep the airplane airworthy throughout its operational life.

3. Discussion.

a. Critical Design Configuration Control Limitations include those features of the design that must be present and maintained to achieve the safety level intended by § 25.981 for the operational life of the airplane. Changes to the airplane, such as installing a fuel re-circulation system, hydraulic heat exchanger in the fuel tank, or a heat source adjacent to the fuel tank, may affect fuel tank flammability exposure. A CDCCL would be necessary in this example to prohibit the addition of heat to the fuel tank.

Another example of a CDCCL might be limits on operation with certain fuel types such as JP-4. The CDCCL would also control or prohibit the kinds of modifications to airplanes, like modifications that affect the vent system of a fuel tank that has an FRM installed or the addition of auxiliary fuel tanks that vent into a fuel tank that has an FRM installed, that could adversely change the flammability exposure of fuel tanks to which it may be connected. All fuel tanks subject to the requirements of Amendment 25-125, even those in airplanes that do not have high flammability fuel tanks, will need to have CDCCL defined so that future modifications do not increase the flammability above the regulatory limit. Under part 26, CDCCL must also be provided for fuel tanks required to be modified by FRM or IMM. The application of CDCCL under the FTFR rule is similar to the requirements already applied to fuel tank ignition source prevention in Amendment 25-102 to § 25.981.

b. The FTFR also includes the requirement that visible means identifying CDCCL be present. This is required to prevent alterations to critical features of the system. As the visible identifications are critical to the FRM or IMM system, they are also considered to be CDCCL. Any tampering or removal would be in violation of the CDCCL. These CDCCLs, inspections, or other procedures would be documented as airworthiness limitations in the ICA.

c. The CDCCLs for fuel tank flammability include any information necessary to maintain those design features that have been determined by analysis of the fuel tank system (e.g., fault tree analysis, failure modes and effects analysis) as needed to maintain the performance of the FRM or IMM, or maintain the fuel tank flammability within the limits established by the applicable regulations. AC 25-981-1B (or latest revision) contains additional guidance on how to perform the analysis for ignition prevention CDCCLs. CDCCLs are intended to preclude the occurrence of any maintenance or inspection task or procedure that could result in a failure, malfunction, or defect that would compromise the intended function of the critical part, component or design feature that ensures the fuel tank flammability exposure does not exceed the regulatory limits. This information is essential to ensure that maintenance, repairs, or alterations do not unintentionally violate the integrity of the original type design of the fuel tank system. CDCCLs may be required that define the critical features, such as:

- Flammability exposure of the unheated aluminum wing tank, and associated cooling rate,
- Limits on heat input such as adding heat blankets or additional hydraulic heat exchangers,
- Limits on how an auxiliary fuel tank is integrated with an existing airplane fuel tank system, such as limiting venting into a tank with FRM based upon inerting or transferring warm fuel from the auxiliary tank,
- Limits on airplane systems such as minimum quantity of engine bleed air flow or electricity that is required to supply power to an FRM,
- Limits on use of high volatility fuels such as JP-4,
- Quantity of engine bleed air flow that is used for inerting,

- Limits on penetrations of the fuel tank,
- Limits on any changes to fuel management that may affect FRM,
- Limits on changes to any placards or means used to visibly identify critical design features of the fuel tank system that must not be compromised for the operational life of the airplane,
- Life limits on parts such as polyurethane foam used as an IMM, and the air separation modules used in an inerting system.

d. Airworthiness limitations are part of the ICA. Design approval holders (DAH) need to make available to affected parties pertinent changes to the ICAs. (The term “make available” is used in the same sense that it is used in § 21.50.) The rule is not intended to alter or interfere with the existing commercial relationships between TC holders and these other persons. The FAA anticipates that DAHs would be able to be reasonably compensated for developing these documents, as they are under current practice.

e. The rule requires creation of an Airworthiness Limitations Section (ALS), unless previously established. The ALS is required by current part 25 and includes those items that have mandatory inspection or replacement times related to fuel systems and structure. The ALS is included in the ICA, approved as part of type certification, and distributed with an airplane on delivery. In this way the ALS is visible to all who need it and who would be required to comply with it under §§ 121.917, 125.509 and 129.117. For those airplanes that currently do not have an ALS, the rule requires an ALS only for fuel tank safety related limits. This rule does not require that the ALS for these airplanes include the other requirements for an ALS established under Amendment 25-54 to part 25, or a later amendment. For those DAH or applicants with airplanes certified to Amendment 25-54 or later, the existing ALS would be revised to include the fuel tank system ALI.

f. The ICA developed by the DAH using the guidance in this advisory circular must be approved by the responsible FAA Oversight Office. Those approved instructions are required by related operational rules to be used by operators to develop and propose changes in their maintenance programs and incorporate design changes needed to maintain the fuel tank flammability within the approved limits and to ensure continued airworthiness of certain features of the FRM and IMM for the operational life of the airplane. These changes to the maintenance programs must be reviewed and approved by the operator’s designated FAA inspector or Principal Inspector.

#### 4. Development of Critical Design Configuration Control Limitations.

a. The CDCCLs, which are a type of Airworthiness Limitation, are the primary means of managing and controlling the configuration of the FRM, IMM or design features that affect the flammability of any fuel tank that does not require an FRM or IMM. In the context of this AC, CDCCLs provide limitation requirements for configuration management to preserve the integrity of certain critical flammability features of the fuel tank system design. These critical features are essential to ensure fuel

tank flammability does not increase above limits defined in the regulations as a result of configuration changes caused by maintenance action, repair, or alteration of those critical features. While initial inspections may be necessary to ensure that a CDCCL has not been compromised (e.g., because of aging, wear, maintenance, alterations, etc.), they are not intended to require repetitive inspections. Rather the intent of the CDCCL is to ensure that all affected maintenance personnel are aware of the need to make sure the configuration identified by the CDCCL is preserved for the operational life of the airplane.

b. The DAH may determine that the CDCCLs are applicable at the individual part level or at the component level. In the context of this guidance, components are assembled from parts. Design approval holders may elect to identify a CDCCL that applies to the component for the purposes of reducing tracking of ALIs that may apply to individual parts of the component. If the component level is used, the design approval holder is responsible for revising the CMM instructions to identify all of the critical features of the component design for approval by the FAA Oversight Office.

c. To identify the parts or components to which the CDCCLs are applicable, the DAH must first conduct a configuration assessment of the fuel tank system design. The purpose is to identify any foreseeable maintenance or inspection actions or other causes that could compromise the configuration of a critical feature of the fuel tank system. In the context of this guidance, foreseeable causes are those that have occurred in service in the past or those that engineering judgment predicts could compromise the critical feature of a part or component of a fuel tank system. The DAH must develop maintenance and inspection instructions to prevent those foreseeable changes to the design configuration of the critical ignition source prevention features.

d. **Airworthiness Limitations Section Content.** The ALIs should include the following:

- The Limitation Statements shown below,
- A brief description of the flammability reduction, ignition mitigation means features,
- The flammability issue associated with inadvertent changes to the configuration of each of those design features, and
- The reference to maintenance instructions, if applicable, and other information in manuals (such as airplane maintenance, standard wire practices manual, etc.,) that have been revised or created to advise affected personnel of the CDCCLs.

e. **Limitation Statement:** The Critical Design Configuration Control Limitation statements are as follows:

LIMITATIONS.

- (1) The critical features of the parts or components identified in the CDCCLs must be maintained in a configuration identical to an approved type design for the airplane.
  - (2) Any repairs or overhauls to the critical features of the parts or components that are identified must be maintained in accordance with the design approval holder's maintenance manual or with other acceptable repair or overhaul specifications and parts approved by the FAA Oversight Office specifically for that part or component.
  - (3) In cases where the critical features of a component are specified, any test equipment or tooling utilized to repair or overhaul the component must be in accordance with the CMM or otherwise comply with 14 CFR 43.13(a) and be substantiated and documented as equivalent.
5. Identification and Awareness of CDCCLs.
- a. The DAH should list the parts components or features to which the CDCCLs are applicable for a particular airplane in the service information (e.g., maintenance planning document or special certification item document) documenting the CDCCL. This is the mechanism for identifying critical features and requiring their control. To ensure that the operator introducing a modification or the mechanic is aware of the need to consider these critical features, it will be necessary to insert cross-references in certain documents to comply with the CDCCLs.
    - (1) The DAH should identify a task with WARNING or CAUTION notes for a component or part that has a critical design feature in the AMM. The operator should incorporate acceptable procedures to ensure compliance with the CDCCLs.
    - (2) The DAH should include information in standard practices manuals to ensure the CDCCL information is provided to those making modifications or maintaining the type design. (see AC 25-26, Development of Standard Wiring Practices Documentation (11/14/07) for guidance on preparation of these manuals).
    - (3) The DAH should identify the appropriate CMM. In addition, the design approval holder should ensure that a statement is inserted into both the CMM and the Airplane Maintenance Manual that the component is controlled by the CDCCL and, therefore, that it may be repaired or overhauled only in accordance with the CMM or other acceptable maintenance procedures and parts approved by the FAA Aircraft Certification Office.
    - (4) These documents should include a statement that the part, component or design feature component is controlled by the CDCCL and, therefore, that it may be

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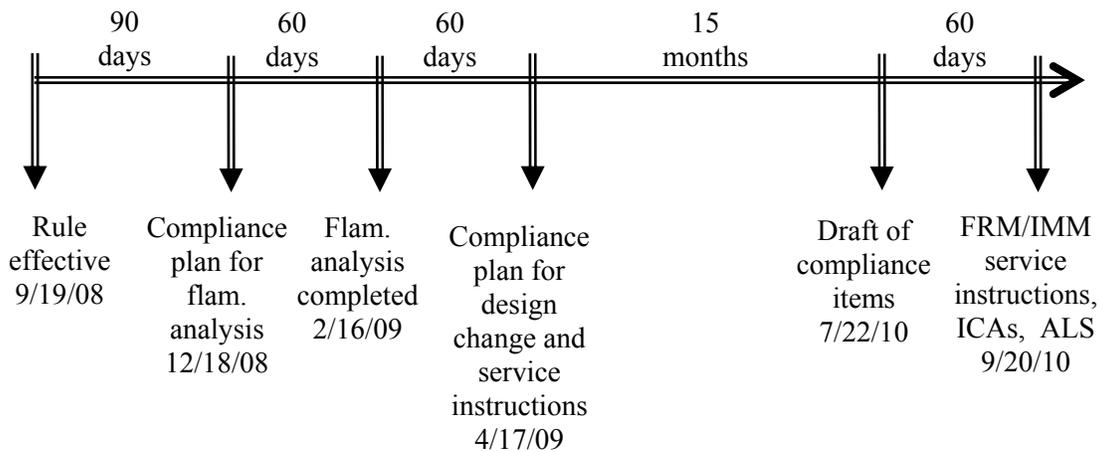
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Appendix 2

repaired or overhauled only in accordance with the CMM or other acceptable maintenance procedures approved by the FAA Oversight Office.

**APPENDIX 3**

**COMPLIANCE WITH PART 26, SUBPART D, SECTIONS 26.33 AND 26.35**

1. Section 26.33 Holders of type certificates: Fuel tank flammability. This section requires TC holders of certain large transport category airplanes described below to analyze the flammability exposure of all their affected airplanes' fuel tanks and develop service instructions for those tanks that exceed limits defined in the rule. For example, a TC holder of an affected airplane with any fuel tank that is determined by the analysis to have high flammability exposure (over 7 percent) is required to develop service instructions for IMM or FRM to reduce the flammability exposure of the fuel tank. If the fuel tank is normally emptied and any portion of the fuel tank is located within the fuselage contour, § 26.33(c)(1)(i) requires the FRM meet the flammability exposure criteria of appendix M of part 25. For all other fuel tanks with a flammability exposure over 7 percent, § 26.33(c)(1)(ii) requires the FRM meet the flammability criteria of appendix M except instead of complying with paragraph M25.1 of the appendix the fleet average flammability exposure may not exceed 7 percent. The affected TC holders would also be required to submit compliance plans for the flammability analysis and the development of service instructions for an FRM or IMM. The due dates for items required by this regulation are as follows:



**FIGURE 3-1**

**Compliance Timeline for TC Holders (§ 26.33)**

a. Applicability. Section 26.33(a) states that this rule applies to “*U.S. type certificated transport category, turbine-powered airplanes, other than those designed solely for all-cargo operations, for which the State of Manufacture issued the original certificate of airworthiness or export airworthiness approval on or after January 1, 1992, that, as a result of original type certification or later increase in capacity have:*

- (1) *A maximum type-certificated passenger capacity of 30 or more, or*
- (2) *A maximum payload capacity of 7,500 pounds or more.”*

(1) The reference to the originally certificated capacity, or later increase in capacity, is intended to address two situations:

(a) In the past, some designers and operators have gotten design change approval for a slightly lower capacity to avoid applying requirements mandated only for airplanes over specified capacities. By referencing the capacity resulting from original certification, this rule removes this possible means of avoiding compliance.

(b) It is also possible that an airplane design could be originally certified with a capacity slightly lower than the minimum specified in this section, but through later design changes, the capacity could be increased above this minimum. The reference to later increases in capacity ensures that, if this occurs, the design would have to meet the requirements of this section.

(2) *Maximum payload capacity* is defined in 14 CFR 119.3, Definitions. Also see the reference in paragraph 4e(15) of this AC.

(3) Foreign Type Certificate Holders. This paragraph applies not only to domestic TC holders, but also to foreign TC holders. In this sense, this section is different from most type certification programs, where foreign applicants typically work with their responsible certification authority, and the FAA relies, to some degree, upon that authority’s findings of compliance under bilateral agreements. Since this rulemaking is not harmonized in all cases, the FAA will initially retain the authority to make all the necessary compliance determinations, and where appropriate, may request certain compliance determinations by the appropriate foreign authorities using procedures developed under the bilateral agreements. The compliance planning provisions of this section (discussed later) are equally important for domestic and foreign TC holders and applicants, and we will work with the foreign authorities to ensure that their TC holders and applicants perform the planning necessary to comply with the requirements of this section.

b. Flammability Determination and Service Instructions.

(1) Flammability Analysis. Section 26.33(b) requires holders of TCs for large transport category airplanes to submit a flammability exposure analysis for approval by the FAA oversight office by December 18, 2008. Section 26.33(b)(2) provides an

exception to the flammability analysis requirement for fuel tanks for which the TC holder has notified the FAA that it will provide design changes and service instructions for an FRM or IMM meeting the requirements of § 26.33(c).

(2) Model Variations and Derivatives.

(a) Section 26.33(b) specifies that the flammability analysis must include *“all fuel tanks defined in the type design, as well as all design variations approved under the type certificate that affect flammability exposure.”* Design variations that may affect fuel tank flammability could include changing the fuel tank volume or usable fuel capacity, changes in the fuel management procedures, engine changes that might affect parameters such as airplane climb rate or bleed air available if needed by an FRM. Other examples of configuration differences that may affect fuel tank flammability exposure are provided in the discussion of § 26.35. It would also include all modifications and changes mandated by airworthiness directives (AD) that affect fuel tank flammability exposure as of the effective date of the rule. These ADs would only be those issued against any configurations developed by TC holders. This would include any ADs issued against modifications defined by a third party STC installed on affected airplanes. The result would be a configuration that is clearly understood by both industry and the FAA.

(b) An example of a design variation is an airplane certificated with the same model and series designation that could have different maximum takeoff gross weights, changes in fuel tank configuration or engine type or thrust, equipment installations, or passenger versus all-cargo carrying capabilities. Derivatives, in most cases, are those model airplanes that historically incorporate significant design changes from the original approved type design. In general, these derivative models would have to comply with later airworthiness standards for those areas incorporating the significant design changes. The derivative models are listed on the same TC data sheet with the original certificated model. Various segments of industry have also defined these changes as “variants.” For the purpose of this regulation, we consider the terms “derivatives” and “variants” to be synonymous.

(3) Service Instructions and Service Bulletins. If the flammability exposure analysis shows that the average exposure for any fuel tank exceeds 7 percent, § 26.33(c) requires the TC holder to develop design changes and service instructions for either FRM or IMM. Modifications incorporated into existing airplanes, including safety related changes (design and/or maintenance) that are mandated by AD, are typically made by operators using service instructions developed by the TC holders. These service instructions are commonly referred to as service bulletins. In this regulation, service instructions must contain sufficient information for the operator to incorporate the design change and any associated procedures and airworthiness limitations. They may include specific step-by-step procedures and information needed by the operator, such as parts lists, drawings, etc. Therefore, the paragraph requires TC holders to develop and submit for approval by the FAA, not just data defining a proposed design change, but a package of complete information that includes all of the information necessary to enable an operator to comply with the operational rules, discussed later. This information should

be formatted and completed to a point similar to what would be submitted to the FAA if the FAA were to be issuing a mandatory action.

(4) Flammability Levels.

(a) The guidance in this paragraph applies to the new FRM or IMM requirements of § 25.981(b) and (c), and appendix M, to existing fuel tanks that exceed 7 percent average flammability exposure. For any fuel tank that is normally emptied and exceeds 7 percent average flammability exposure, if any portion of the tank is located in the fuselage contour, the rule requires TC holders to develop IMM or FRM that reduces the flammability exposure to 3 percent average flammability exposure and 3 percent warm day requirements of appendix M. The warm day requirement would limit the average flammability exposure of the tank for each of the ground, takeoff and climb phases of the airplane operation during warm days to 3 percent average flammability exposure. The flammability exposure limit for these particular tanks has been established in consideration of the service experience that shows these tanks to have a higher risk for fuel tank explosion than other tanks. For all other fuel tanks located in other portions of the airplane (for example, the wing and empennage), the proposal would require TC holders to develop IMM or FRM that reduces the flammability exposure below 7 percent and apply the requirements for an FRM of subparagraph M25.2, M25.3, M25.4 of appendix M if an FRM is selected as the means of compliance. This rule is not expected to result in the need for FRM or IMM in any fuel tanks located in the wings of airplanes in the existing fleet because previous assessments estimate these tanks have flammability exposure below 7 percent. However, the analysis required by this rule may reveal some fuel tanks located within the wing that exceed 7 percent.

(b) The definition of tanks that are normally emptied and auxiliary fuel tanks used in this section are the same as that discussed in the preamble to the flammability reduction rulemaking associated with this AC.

c. Compliance Times.

(1) Section 26.33(d) requires submitting for approval by the FAA oversight office the design changes and service instructions required by § 26.33(c) by September 20, 2010.

(2) The compliance times stated in this section are also used as the basis for the compliance dates for introduction of these systems into the operators' fleets under parts 121, 125, and 129. Extension of the compliance dates for development of the service instructions by the certificate holders would either reduce the amount of time available to operators or delay full deployment of these safety improvements. Incorporation of FRM or IMM will likely require access inside the fuel tanks. Typically fuel tanks are only accessed during heavy maintenance checks that are done on a schedule established during development of the maintenance program. The compliance dates for the operational rules were established to allow a majority of the modifications to be done during these heavy maintenance checks. Introduction of FRM or IMM outside of normally scheduled

maintenance would increase the cost to the operators because extra tank entry and airplane down time would be needed.

d. Critical Design Configuration Control Limitations.

(1) Section 26.33(e) requires that for fuel tanks equipped with FRM or IMM, holders of TCs affected by this section must establish airworthiness limitations consisting of CDCCL, inspections, or other procedures. The purpose of these limitations is, for tanks equipped with FRM, to prevent increasing the flammability exposure of the tanks above that permitted under § 26.33 and, for tanks equipped with IMM, to prevent degradation of the performance of the IMM installed in accordance with this section. Appendix 2 of this AC provides additional guidance regarding development of CDCCL. For example, certain fuel tanks may rely on natural cooling or use of certain fuel types to meet the flammability levels required by the rule. Therefore, CDCCL may be required that define the critical features, such as—

- flammability exposure of the unheated aluminum wing tank,
- cooling rate,
- limits on heat input,
- limits on use of high volatility fuels such as JP-4,
- quantity of engine bleed air flow that is used for inerting,
- limits on penetrations of the fuel tank,
- limits on any changes to fuel management that may affect FRM,
- limits on changes to any placards or means used to visibly identify critical design features of the fuel tank system that must not be compromised for the operational life of the airplane.

(2) Instructions for Continued Airworthiness. As discussed below, airworthiness limitations, such as those in this section, are part of the ICA. Section 21.50 requires that TC holders make changes to the ICA available to persons required to comply with them. As used throughout this notice, the term “make available” is used in the same sense that it is used in § 21.50.

e. Airworthiness Limitations.

(1) Section 26.33(f) requires creation of an ALS, unless previously established. The ALS is required by current part 25 and includes those items that have mandatory inspection or replacement times related to fuel systems and structure. The ALS is included in the ICA, approved as part of certification, and distributed with an airplane on delivery. In this way the ALS is visible to all who need it and who would be required to comply with it under §§ 121.1117, 125.509 and 129.117 of this rule. The current part 25 ALS and ICA requirements apply only to airplane types originally certified after Amendment 25-54 (adopted in 1981) and were developed for structural considerations. As a result, they are not applicable to many current airplanes and do not currently contain information for other systems.

(2) For those TC holders of airplanes that currently do not have an ALS, the regulation only requires establishing an ALS to include fuel tank safety related limits. This would not require that the ALS for these airplanes include the other requirements for an ALS established under Amendment 25-54 to part 25, or a later amendment. For those TC holders or applicants with airplanes certified to Amendment 25-54 or later, the existing ALS would be revised to include the fuel tank system ALI.

f. Compliance Planning.

(1) Historically, the FAA has worked together with the TC holders when safety issues arise to identify solutions and actions that need to be taken. Some of the safety issues that have been addressed by this process include those involving aging aircraft structure, thrust reversers, cargo doors, and wing icing protection. In some cases service instructions have not been developed in a timely manner. While some manufacturers have addressed these safety issues and developed service instructions, others have not applied the resources necessary to develop service instructions in a timely manner. This has caused delay in the adoption of corrective action(s). The compliance planning requirements of § 26.33(g) and (h) are intended to provide TC holders and the FAA with assurance that they understand what means of compliance is acceptable and have taken necessary actions, including assigning sufficient resources, to achieve compliance with this section. This paragraph is based substantially on “The FAA and Industry Guide to Product Certification,” which describes a process for developing project-specific certification plans for type certification programs. This Guide may be found in the docket. This planning requirement would not apply to future applicants for TC because, as described in the Guide, this type of planning routinely occurs at the beginning of the certification process. (Additional information is available in the Order referenced in paragraph 4e(14).)

(2) The Guide recognizes the importance of ongoing communication and cooperation between applicants and the FAA. Section 26.33, while regulatory in nature, is intended to encourage establishment of the same type of relationship in the process of complying with this section.

(a) Compliance Plan for Flammability Exposure Analysis. Section 26.33(g) requires submittal of a compliance plan within 90 days after September 19, 2008, for the flammability exposure analysis required by this section. The intent of the proposal is to promote early planning and communication between the certificate holders and the FAA. The affected design approval holders would be required to submit a compliance plan that addresses the following:

1 A proposed schedule, identifying all major milestones, for meeting the flammability analysis compliance date of this rule or a determination that compliance with § 26.33(b) of this section is not required because design changes and service instructions for FRM or IMM will be developed and made available as required by § 26.33.

2 If required, a proposed means of performing a flammability exposure analysis.

(b) Compliance Plan for Design Changes and Service Instructions.

1 Section 26.33(h) requires that each holder of a TC required to comply with § 26.33(c) must submit to the FAA oversight office a compliance plan for their project within 210 days after September 19, 2008. In addition to items corresponding to those required for the compliance plan in § 26.33(g), this plan requires--

(aa) A proposal for submitting a draft of all compliance items required by § 26.33(d), (e) and (f) for review by the FAA oversight office not less than 60 days before the compliance times specified in the rules, and

(bb) A proposed means of compliance with this section, identifying all required deliverables, including all compliance items and all data to be developed to substantiate compliance. If the TC holder has already initiated compliance, the FAA oversight office will review the results of those efforts to ensure that the results are acceptable.

(cc) A proposal for how the approved service information and any necessary modification parts will be made available to affected persons.

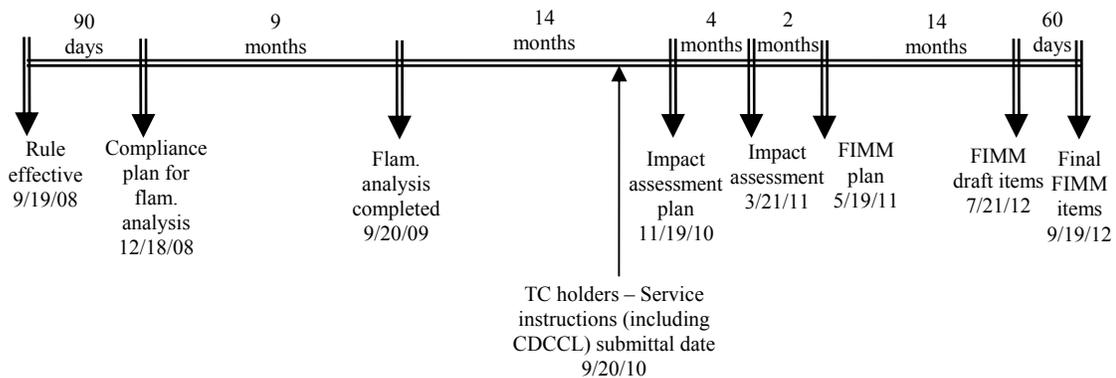
2 This section is intended to ensure that affected persons and the FAA have a common understanding and agreement of what is necessary to achieve compliance with this section. Integral to the compliance plan will be the inclusion of procedures to allow the FAA to monitor progress toward compliance. These aspects of the plan will help ensure that the expected outcomes will be acceptable and on time. The schedule for the availability of the service information and any required parts is critical to the affected operators ability to schedule the modification of their airplanes and make changes to their maintenance or inspection programs in accordance with the operational rules. We would expect each TC holder to work with the FAA oversight office to develop a plan to create the required service instructions within the specified time. The plan should include periodic reviews with the FAA office.

3 The success of this fuel tank safety initiative hinges upon the timely development of service instructions and production incorporation of FRM or IMM by the affected certificate holders. If service instructions are not available when required, operators will not be able to begin incorporation of the FRM or IMM into their fleet as their airplanes undergo normally scheduled maintenance checks. Delay in availability of the service instructions could result in the need for operators to do unscheduled maintenance to comply with the operational requirements, resulting in significant unnecessary cost.

g. Section 26.33(j) requires that affected type certificate holders implement the compliance plans, as approved under that section. It allows for revisions to the plans, if

approved, but such revisions would still have to result in compliance by the specified compliance dates.

2. Section 26.35 Changes to type certificates affecting fuel tank flammability: This section addresses changes to TCs, including installing auxiliary fuel tanks, changes in the capacity of fuel tanks, and changes that may increase the fuel tank flammability exposure of an existing fuel tank that is required by § 26.33(c) to incorporate either a FRM or IMM. An auxiliary fuel tank installed by STC or field approval may result in adverse effects on any FRM or IMM developed by the TC holder as required by § 26.33. This section requires those affected to conduct a flammability exposure analysis of their design, an impact assessment to determine any adverse impact their design may have on tanks for which CDCCL are required, and development of design changes to address adverse changes in flammability exposure. The dates for demonstrating compliance are shown as follow:



**FIGURE 3-2**

**Compliance Timeline for Holders and Applicants of Changes to Certificates (§ 26.35)**

a. Applicability. Paragraph 26.35 (a) states that this section applies to holders and applicants for approvals of the following design changes to any airplane subject to § 26.33(a):

- For holders of STCs or field approvals issued before September 19, 2008, and for applicants for STCs or amendments to TCs applied for before September 19, 2008, if the approval was not issued before

September 19, 2008, this section applies to installation of a Normally Emptied fuel tank.

- For applicants for STCs or amendments to TCs applied for on or after September 19, 2008, this section applies to installation of a Normally Emptied fuel tank, changes to fuel tank capacity, and changes that may increase the flammability exposure of an existing fuel tank for which FRM or IMM is required by § 26.33 (c).

(1) Existing STCs and Field Approvals. For existing STCs and field approvals, this proposal excludes design changes other than for Normally Emptied fuel tank installations. (Field approvals are no longer issued for fuel tank installations.) The meaning of “Normally Emptied” fuel tank is explained earlier in the discussion of § 25.981 and in paragraph 5 of this AC. As discussed in the background section of the preamble to the flammability rulemaking associated with this AC, SFAR 88 included review of all changes to the airplane that could result in the development of ignition sources. We reviewed the fuel system related STCs in the fleet and did not identify any changes that would significantly increase fuel tank flammability. Therefore we have determined that application of this rule to current STC holders, other than those relating to auxiliary fuel tank installations, would not improve fuel tank safety.

(2) Pending Applications for STCs and TC Amendments to TCs. Except for applications that are pending as of September 19, 2008, for installation of Normally Emptied fuel tanks, pending applications for design change approvals were excluded from the final rule. Under § 26.35(d)(2), applicants with pending applications for design changes to install Normally Emptied fuel tanks must comply with § 25.981 at Amendment 25-125.

(3) Future Applicants for STCs or TC amendments.

(a) Auxiliary Fuel Tanks Installed Under STC or amendment to TC. The regulation applies to design changes for which application is made on or after September 19, 2008, to install auxiliary fuel tanks on large transport category airplanes subject to the part 26 rule. The applicability list is included in appendix 1 to this AC. These design changes must be shown to comply with § 25.981, as discussed previously in this AC. For example, the center wing box structure on some versions of certain airplane models did not originally carry fuel, but later models of the airplane may include fuel in these areas. This would be considered to be a change to add a new fuel tank, and compliance with § 25.981 would be required.

(b) Design Changes Affecting Fuel Tank Capacity. An applicant may propose to change the size of sections to an existing fuel wing tank or change the useable fuel capacity in an existing tank. Both increases and decreases in fuel tank capacity must be addressed. Under § 26.35(d)(3), these applicants must comply with the requirements of § 26.33. For example, the applicant must perform a flammability exposure analysis for the modified tank and, if the exposure exceeds 7 percent, the applicant must include FRM or IMM, as required by § 26.33.

(c) Design Changes that May Increase Fuel Tank Flammability Exposure of Tanks for which FRM or IMM are Required. Examples of design changes that may increase fuel tank flammability exposure include installation of hydraulic or electronics system heat exchangers in a fuel tank, installation of heater blankets on the wing, modification of the fuel management that results in changes in fuel tank flammability, installation of a fuel re-circulation system that transfers heat from the engine to the fuel tank, or changes to the flight manual to use lower flash point fuels such as JP-4 or Russian or Chinese fuels. As discussed below, applicants for these types of design changes must perform an impact assessment and, if applicable CDCCL are compromised, develop flammability impact mitigation means.

b. Compliance Times. Section 26.35(b) establishes a timeframe in which the affected persons must submit for approval (to the FAA oversight office) a flammability exposure analysis for their design changes. The rule includes a 12-month timeframe to complete the analysis for existing STCs. Any applicant whose STC or TC amendment is not approved within 12 months after September 19, 2008, would have to complete the analysis before approval.

c. Flammability Analysis.

(1) Supplemental type certificate holders or applicants affected by this section would need to conduct a flammability analysis using the method defined in appendix N of the rule. A number of inputs are required to conduct this analysis. Airplane specific data, such as flight length distributions or airplane climb rate, may not be readily available from the original TC holder. We intend the STC holders to obtain the information by working with the operators of airplanes that have their STC installed. Applicants would need to work with prospective customers. Operators have business agreements with the original TC holders and access to information they obtained when they purchased the airplane. Conservative assumptions or business agreements with the original TC holders are other possible methods of gathering airplane type specific data needed for the analysis.

(2) The flammability analysis required by this § 26.35(b) is intended to identify applications for fuel tank installations that would require incorporation of FRM or IMM or that may increase the flammability exposure of such tanks. As discussed in the preamble to this rule, for existing fuel tank STCs, the flammability analysis is needed to determine if future action should be taken to address auxiliary fuel tanks installed under STCs or field approvals. Additional analysis after obtaining the CDCCL from the TC holder and developing any FIMM, is necessary to demonstrate that the final configuration complies with the applicable flammability analysis requirements and does not violate the CDCCL defined by the original TC holder.

(3) For design changes that may increase the flammability of fuel tanks equipped with FRM or IMM for which compliance with applicable CDCCL must be shown, the purpose of the requirement to perform flammability analyses is to ensure that

the change does not increase flammability exposure in ways that were not anticipated when the CDCCL were developed. If an applicant can show that the design would have no such effect, it may be possible to avoid performance of a full analysis per appendix N through substantiating an equivalent level of safety finding.

d. Impact Assessment.

(1) Section 26.35 requires affected persons<sup>1</sup> to submit for approval (to the FAA oversight office) an impact assessment of the fuel tank system, as modified by their design change. The purpose of this requirement is to identify any features of the modification to the original type design that may violate the critical design configuration control limitations developed by the original TC holder under § 26.33(d). For example, if an FRM that utilizes inerting were incorporated into an airplane, a CDCCL would likely be developed that would limit venting of air into the fuel tank because it could introduce oxygen into the tank, resulting in a flammable vapor space. In this case the STC holder would need to assess its design and identify any violation of the CDCCL identified for the FRM. Results from the analysis would be provided to the FAA in the form of a report or summary letter.

(2) Holders of STCs and field approvals for fuel tanks designed to be normally emptied on airplane models listed in Table 3-1 have to submit the safety assessment by March 21, 2011. This date is six months after the TC holder is required to establish their CDCCLs. Applicants for STCs and for amendments to type certificates whose design changes are not approved within that six-month period would have to submit the assessment before approval of the change. Once the CDCCLs are approved, the TC holder is required to make them available to other affected persons, including those subject to this section.

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<sup>1</sup> This refers to STC holders for auxiliary fuel tanks as of September 19, 2008, and future applicants for design changes that may increase flammability exposure of tanks for which FRM or IMM are required.

**TABLE 3-1**  
**AFFECTED AIRPLANE MODELS**

Model – Boeing
747 Series
737 Series
777 Series
767 Series
757 Series
Model – Airbus
A318, A319, A320, A321 Series
A300, A310 Series
A330, A340 Series

e. Development of Service Instructions. Section 26.35(d) requires development of design changes and service instructions as stated in § 26.35 (d)(1), (d)(2) and (d)(3).

(1) Section 26.35(d)(1) affects persons required to prepare impact assessments, described in the previous paragraph. It includes requirements that apply if the impact assessment shows that a design change compromises any CDCCL applicable to any airplane on which the change is eligible for installation. The holder or applicant would have to develop a means, referred to as a Flammability Impact Mitigation Means (FIMM), to comply with all applicable CDCCLs. FIMM could include either additional design changes or limitations or other procedures. If FIMM are necessary, the applicant or holder would also have to show that their design change, as modified by the FIMM, would still meet the other requirements of this section. For example, § 26.35(d) requires that the flammability analysis for an existing auxiliary fuel tank, as modified by FIMM, would have to be accomplished per § 26.35(b). This paragraph is necessary to ensure that the safety improvements in this rule are not degraded by later design changes.

(2) Section 26.35(d)(2) requires applicants for STCs and amended TCs for installation of a Normally Emptied tank, to meet the requirements of § 25.981 in effect on September 19, 2008 if—

- (a) the application is made before September 19, 2008 and the approval was not issued before September 19, 2008, or
- (b) the application was made on or after September 19, 2008,

(3) Section 26.35(d)(3) requires applicants for a STC or an amendment to a type certificate made on or after September 19, 2008, that changes the capacity of an

existing tank to comply with the requirements of § 26.33, Holders of type certificates: Fuel tank flammability, as discussed in paragraph 1 of this appendix.

(4) Various methods described in this AC are available for meeting the flammability exposure requirements. The exact modifications needed to comply depend upon specific details of the particular design and choices made by the designers. The most likely solutions include inerting, cooling of the tank, installation of polyurethane foam and pressurizing the tank similar to other tanks that use air pressure for fuel transfer.

f. Compliance Times for Design Changes and Service Instructions. Section 26.35(e) establishes timeframes in which holders of STCs and field approvals and applicants for STCs and amendments to TCs must comply with the requirements of § 26.35(d). Supplemental type certificate holders and holders of field approvals would be required to comply by September 19, 2012, which is 24 months after the TC holder compliance date for § 26.33(c). Applicants for STCs and amendments to TCs whose applications are pending on September 19, 2008, would have to comply before the FAA would issue their approval.

g. Compliance Planning. Section 26.35(f) requires compliance plans for the actions required by this section. Compliance planning is discussed earlier in this appendix with guidance for § 26.33. Because STC holders and applicants would need the TC holders' CDCCLs to comply with paragraphs (c) and (d) of this section, the compliance times for submitting those plans provide adequate time after the TC holders are required to comply with § 26.33. The compliance planning dates are given in Table 2 of § 26.35(f), which is shown below.

h. Section 26.35(g) requires that affected holders and applicants implement the compliance plans, as approved under that section. It allows for revisions to the plans, if approved, but such revisions would still have to result in compliance by the specified compliance dates.

**TABLE 3-2**

**COMPLIANCE PLANNING DATES**

	Flammability Exposure Analysis Plan	Impact Assessment Plan	Design Changes and Service Instructions Plan
STC and Field Approval Holders	December 18, 2008	November 19, 2010	May 19, 2011

## APPENDIX 4

### CONSIDERATIONS FOR FUEL TANK THERMAL MODELS

1. The type of thermal model that is needed to show compliance will depend upon the method of compliance selected for the different requirements. For fuel tanks shown to have equivalent flammability to that of an unheated aluminum wing fuel tank, a fuel tank thermal model may not be needed if the qualitative flammability assessment method defined in paragraph 11 of this AC is used. For other tanks where specific flammability levels must be shown, thermal modeling will be needed if fuel temperature affects fuel tank flammability. This appendix provides guidance for validating the thermal modeling of a fuel tank. It is based on using in the Monte Carlo Model defined by the User's Manual (defined in paragraph 4e(11) of this AC). As stated in paragraph 4.1 of the User's Manual, if flight test data or a detailed analysis of the fuel tank's thermal behavior shows that this method cannot yield an accurate representation of the actual fuel tank's fuel temperature profile, then modification of the thermal model code in the Monte Carlo model is necessary.

2. Validating fuel tank thermal coefficients, "Tau," for use in the Monte Carlo Model.

a. When a fuel tank is heated or cooled by a change in air temperature, the response of the fuel temperature is to increase or decrease, respectively, following an exponential decay law. On the ground, air temperature is considered to be ambient temperature at the airplane location, and in flight it will be the Total Air Temperature (TAT) experienced by the airplane. This exponential trend is driven by the temperature difference between the fuel and TAT, and the response of the mass of the fuel and tank. It can be represented by the system exponential decay time constant Tau, and an equilibrium temperature that the fuel temperature will eventually reach. The equilibrium temperature for a totally unheated tank will be very close to the air temperature, and can be expressed as a temperature difference from ambient temperature on the ground and TAT in flight. For this method, the temperature difference will be called Delta T.

b. By taking data from a flight test, the values for Tau and Delta T can be approximated as a function of fuel load and air temperature. This method requires recording fuel tank temperatures and TAT at regular intervals during critical operational ground and flight test conditions so that the fuel tank thermal characteristics can be established.

3. Compliance Testing. Testing should include ground and flight conditions with variable fuel quantities, and any heat transfer from airplane generated sources to the fuel tank at the critical conditions. The Monte Carlo Model includes the capability to use 6 different Tau values, and sufficient testing to confirm the validity of each of the values used in the model should be done. In addition, the thermal characteristics of the critical

portion of the fuel tank relative to formation of flammable vapors should be used in the Monte Carlo Model and validated by the testing. Baffling incorporated into most fuel tanks results in segmented volumes that may significantly affect heat transfer and, therefore, the flammability within the tank volume. If barriers or walls result in separate volumes within the tank and prevent mixing of the fuel and/or vapors in the tank, then each of these volumes should be evaluated independently to determine the worst case exposure for that tank. The validation may include a qualitative assessment of the heat sources (warm fuel transfer, hydraulic heat exchanges, fuel return lines, ECS packs, etc.) and thermal characteristics of different portions of the fuel tank to substantiate critical location for the test evaluation of the Taus.

a. Temperature Measurement. The location of test instrumentation should consider tank configuration and operational factors to determine which locations in the fuel tank require evaluation. The fuel temperature should be measured at critical locations in the tank for each of the critical fuel loading conditions. If an FRM that limits ullage oxygen concentration is included in the design, test instrumentation should be located in critical locations of the ullage to support analysis of the ullage density changes and its effect on ullage oxygen concentration. The locations of fuel and ullage test temperature sensors should take into consideration any structural barriers or baffles that may divide the tank into regions that may have different thermal characteristics.

b. Test Conditions. The applicant should conduct sufficient ground and/or flight testing that simulates the actual operation of the airplane type so that a validated fuel tank thermal model can be developed that will accurately model the fuel tank. Fuel tank temperatures should be measured so that the change in bulk average fuel temperature in each affected tank on the ground and in-flight versus time can be determined. The minimum number of test conditions needed to validate the thermal modeling of the fuel tank will depend upon the number of variables that may affect the fuel tank temperature. For example, a minimum of two test flights would be required, one representative of a short mission for the airplane and one representative of a long mission for a typical CWT design so that variability in mission length, gate time and fuel quantities could be addressed. The short mission should include at least 30 minutes of ground operation prior to flight, and the long mission at least 90 minutes of ground operation prior to flight. For the entire mission (i.e., from the start-up of airplane systems to completion of the flight), temperatures should be recorded in the test tank(s) at locations to represent the bulk fuel temperature in each separate section of the test tank(s) unless a qualitative assessment shows that fewer locations can be justified. For this discussion, TAT is used to represent ambient temperature on the ground and TAT in flight. The fuel temperature and TAT should be recorded at least once per minute. The test program should be designed to address the fuel tank thermal response as a function of day type including testing on warm days to understand the fuel tank thermal response when the tank is most likely to be flammable.

4. Example of a Flight Test. The sample flight test shown below is an illustration of how to demonstrate that the bulk average fuel temperature modeling used in the Monte Carlo Model, based upon use of Time Constant Tau, is acceptable for the particular tank

under evaluation. The flight test shown is for a hypothetical aluminum wing tank on a long-range airplane. The data includes operational time before and after the flight as required by the method. The fuel temperature is recorded every minute and the bulk average fuel tank temperature is then determined from the test data. (Data at 10 minute intervals is shown for the example, to save space.) The Tau value is estimated for a full tank and decreased as the fuel is burned off in flight. Using the value of Tau, the tank bulk average fuel temperatures can be estimated using the exponential decay equation, (the term "Fuel Temp" in the equations is an abbreviation for "bulk average fuel temperature"):

$$(\text{Fuel Temp change in time } t)/(\text{Fuel Temp}-\text{TAT})= 1-e^{(-t/\text{Tau})}$$

This can also be written as:

$$\text{Fuel Temp change in time } t = (\text{Fuel Temp}-\text{TAT}) \times (1-e^{(-t/\text{Tau})})$$

The resultant estimated fuel temperature is then compared to the actual and the Tau values corrected until a satisfactory match is obtained. This can be done manually or using a computer solver approach. If there is no heating of the tank, the Tau values can be obtained directly. If there is significant heating of the tank, the equilibrium temperature can be found by increasing the value for TAT to (TAT + Delta T), where Delta T is the tank equilibrium temperature offset from TAT. In this case, both the values for Tau and Delta T must be found for the tank. The Tau used in the Monte Carlo Model should be shown to predict fuel tank temperatures with an error of less than 3 degrees for a period of time not to exceed 5 minutes. If the accuracy does not meet this level, the applicant may choose to use a Tau that is adjusted so that the predicted temperature would be higher and produce a conservative flammability level or propose an alternative method of modeling fuel tank temperatures.

<b>TABLE 4-1</b>										
<b>Example of Wing Fuel Tank Flight Test Results (Part 1 of 2)</b>										
Shown at 10 minute increments for this example to save space. Should be recorded at 1 minute intervals							Delta T	Estimated Tau	Predicted Temp based on Tau value	Tank Temperature Error
Time	OAT	Mach Number	TAT	Altitude	Fuel Load	Fuel Temp	Fuel Temp TAT			Actual vs. Predicted
Min	Deg. F.		Deg. F,	Ft.	%	Deg. F.	Deg. F.			Deg F.
0	80	0.00	80.0	0	100	80.0	0.0	149.8	80.0	0.0
10	80	0.00	80.0	0	100	80.0	0.0	149.8	80.0	0.0
20	80	0.00	80.0	0	100	80.0	0.0	149.8	80.0	0.0
30	80	0.00	80.0	0	100	80.0	0.0	149.8	80.0	0.0
40	80	0.00	80.0	0	100	80.0	0.0	149.8	80.0	0.0
50	80	0.00	80.0	0	100	80.0	0.0	149.8	80.0	0.0
60	80	0.00	85.9	0	100	80.0	-5.8	149.8	80.0	0.0
70	42.5	0.43	58.2	8750	100	79.5	21.2	149.8	79.4	0.0
80	5	0.57	32.7	17500	100	77.4	44.6	149.8	77.1	-0.2
90	-32.5	0.71	8.5	26250	100	73.9	65.4	149.8	73.4	-0.5
100	-70	0.86	-18.7	35000	100	69.2	87.8	149.8	68.3	-0.8
110	-70	0.86	-18.7	35000	100	63.8	82.5	149.8	62.7	-1.2
120	-70	0.86	-18.7	35000	100	58.8	77.4	149.8	57.3	-1.4
130	-70	0.86	-18.7	35000	100	53.9	72.6	149.8	52.4	-1.6
140	-70	0.86	-18.7	35000	100	49.4	68.1	149.8	47.7	-1.7
150	-70	0.86	-18.7	35000	100	45.1	63.8	149.8	43.3	-1.8
160	-70	0.86	-18.7	35000	100	41.0	59.7	149.8	39.2	-1.8
170	-70	0.86	-18.7	35000	100	37.2	55.9	149.8	35.4	-1.8
180	-70	0.86	-18.7	35000	100	33.6	52.3	149.8	31.8	-1.8
190	-70	0.86	-18.7	35000	100	30.2	48.9	149.8	28.5	-1.7
200	-70	0.86	-18.7	35000	100	26.9	45.6	149.8	25.3	-1.6
210	-70	0.86	-18.7	35000	98	23.7	42.4	146.9	22.4	-1.3
220	-70	0.86	-18.7	35000	94	20.7	39.3	142.2	19.6	-1.1
230	-70	0.86	-18.7	35000	90	17.7	36.4	137.5	16.9	-0.8

<b>TABLE 4-1 (Continued)</b>										
<b>Example of Wing Fuel Tank Flight Test Results (Part 2 of 2)</b>										
Shown at 10 minute increments for this example to save space Should be recorded at 1 minute intervals							Delta T	Estimated Tau	Predicted Temp based on Tau value	Tank Temperature Error
Time	OAT	Mach Number	TAT	Altitude	Fuel Load	Fuel Temp	Fuel Temp- TAT			Actual vs. Predicted
Min	Deg. F.		Deg F.	Ft.	%	Deg F.	Deg F.			Deg F.
240	-70	0.86	-18.7	35000	87	14.9	33.6	132.8	14.3	-0.6
250	-70	0.86	-18.7	35000	83	12.2	30.9	128.1	11.9	-0.4
260	-70	0.86	-18.7	35000	79	9.7	28.3	123.4	9.5	-0.1
270	-70	0.86	-18.7	35000	76	7.2	25.9	118.7	7.3	0.1
280	-70	0.86	-18.7	35000	72	4.9	23.6	114.0	5.2	0.3
290	-70	0.86	-18.7	35000	68	2.7	21.3	109.3	3.2	0.5
300	-70	0.86	-18.7	35000	65	0.6	19.3	104.6	1.3	0.7
310	-70	0.86	-18.7	35000	61	-1.4	17.3	99.9	-0.4	1.0
320	-70	0.86	-18.7	35000	57	-3.3	15.4	95.2	-2.1	1.2
330	-70	0.86	-18.7	35000	54	-5.0	13.7	90.5	-3.7	1.3
340	-70	0.86	-18.7	35000	50	-6.6	12.0	85.8	-5.1	1.5
350	-70	0.86	-18.7	35000	46	-8.2	10.5	81.1	-6.4	1.7
360	-70	0.86	-18.7	35000	43	-9.6	9.1	76.4	-7.7	1.9
370	-70	0.86	-18.7	35000	39	-10.9	7.8	71.7	-8.8	2.1
380	-70	0.86	-18.7	35000	35	-12.1	6.6	67.0	-9.8	2.2
390	-70	0.86	-18.7	35000	31	-13.2	5.5	62.3	-10.7	2.4
400	-70	0.86	-18.7	35000	28	-14.1	4.5	57.6	-11.6	2.6
410	-70	0.86	-18.7	35000	24	-15.0	3.7	52.9	-12.3	2.7
420	-70	0.86	-18.7	35000	20	-15.8	2.9	48.2	-12.9	2.9
430	-70	0.86	-9.8	33906	17	-16.2	-6.5	43.5	-13.3	3.0
440	-20	0.67	22.1	22969	17	-10.4	-32.5	38.8	-8.1	2.3
450	30	0.48	55.6	12031	16	2.4	-53.2	34.1	4.0	1.7
460	80	0.28	80.0	1094	15	20.8	-59.2	29.9	23.5	2.7
470	80	0.00	80.0	0	15	36.2	-43.8	29.9	40.0	3.8
480	80	0.00	80.0	0	15	47.6	-32.4	29.9	52.3	4.7
490	80	0.00	80.0	0	15	56.0	-24.0	29.9	61.4	5.3

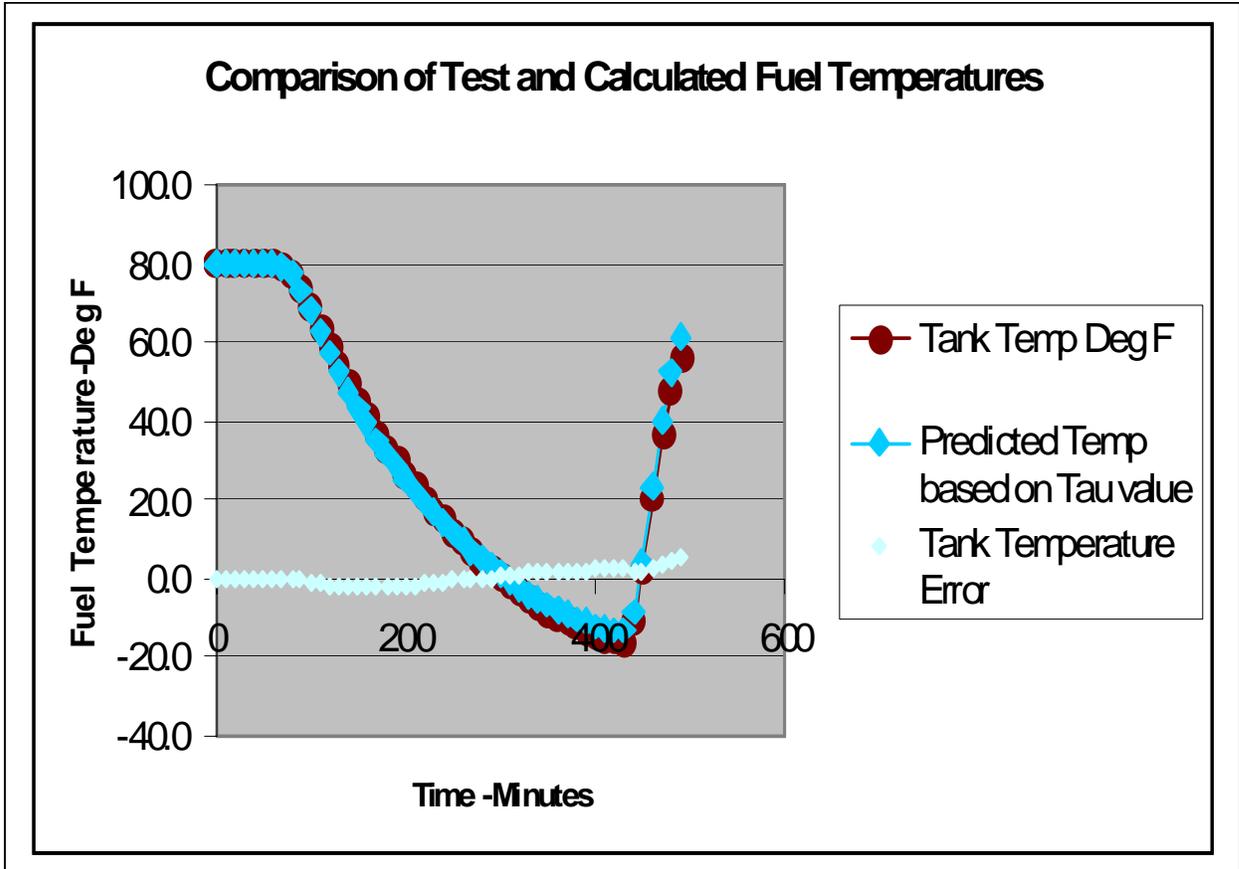


FIGURE 4-1

**Comparison of Test and Calculated Fuel Temperatures**

5. Compliance Reporting. In order to show the fuel tank temperature modeling is acceptable using this method, the compliance report should include plots of the flight test data, as well as the predicted fuel tank temperatures and the associated error between the predicted temperature and those measured during the flight test.

## APPENDIX 5

### MEASUREMENT OF OXYGEN CONCENTRATION IN AIRPLANE FUEL TANKS

#### 1. Introduction.

##### a. Background on Oxygen.

(1) Oxygen is the element most associated with life on our planet. It has an atomic number of 16 and is classified as an oxidizer, which means it reacts readily with other elements and is key to many reactions taking place. Oxygen is essential to every living thing. Air is a mixture made of 99.9 percent oxygen and nitrogen existing primarily on the molecular level in a single bond with itself, thus we use the chemistry term  $O_2$  when describing oxygen and  $N_2$  when describing nitrogen.

(2) Measuring oxygen in a given environment is accomplished by exposing a gas sample to a sensor designed to give feedback for a changing amount of oxygen in the sample. The various sensing technologies rely on one of several different natural properties of oxygen to change the voltage in a circuit, or more directly, the number of counts on an A/D converter. Virtually all oxygen sensors do not sense the volume percentage of oxygen in a sample, but rather, the partial pressure of oxygen in the gas sample in question. The analyzer is then calibrated for volume percent oxygen given a fixed sample pressure, flow, and temperature.

##### b. Types of Oxygen Sensors.

(1) Most sensing technologies work on some type of chemical reaction. A galvanic cell is a sensor containing a small amount of a liquid solution that reacts with oxygen, retained within a permeable membrane. The gas sample is exposed to the sensor membrane and oxygen from the sample enters or leaves the sensor solution to create equilibrium. The solution in these sensors is separated by an anode and cathode. A fixed current source changes the voltage across the anode and cathode given a changing amount of oxygen in the sensor solution (see Reference 1 of paragraph 4 of this appendix). This voltage can be converted to a fixed output with a voltage divider and some linearizing circuitry. Some sensors simply have a piece of chemical compound (i.e., zirconium oxide) reacting between two electrodes. When a gas sample is exposed to the quantity of compound, the oxygen in the sample reacts with the compound and changes the voltage across the electrodes (see Reference 2 of paragraph 4 of this appendix).

(2) Virtually all sensors have a finite life, due to the fact that the reactants and solutions degrade and dilute over time. It is possible to measure oxygen with a truly non-consumable sensor. One commercially available oxygen analyzer uses the principals of paramagnetism of oxygen to measure the volume concentration of oxygen. Because

oxygen becomes magnetic when exposed to a magnetic field and the other constituents of air (nitrogen, carbon dioxide, and water vapor) do not, it is possible to make a detector that is sensitive to the amount of paramagnetic oxygen in an otherwise diamagnetic mixture of gases. In the case of the Rosemount 755R paramagnetic oxygen analyzer, a dumbbell-shaped, nitrogen-filled, hollow glass sensing body, wrapped with a single platinum wire, is suspended on a platinum/nickel alloy ribbon. When the sensing body is surrounded by a gas sample, “magnetic buoyancy” occurs creating a torque on the dumbbell. The current required to counteract the torque and restore the dumbbell to its null position is directly proportional to the amount of paramagnetic gas (oxygen) in the sample (see Reference 3 of paragraph 4 of this appendix).

(3) Some sensors do not require a dedicated gas sample to be removed from the environment to be measured, and thus can be used in situ, or literally in place. Some of these sensors work on the fluorescence properties of light, which change with partial pressure of oxygen in a given environment. These sensors detect changing fluorescence properties (intensity, time decay, etc.) of the light reflected from a coherent source using a spectrometer (see Reference 4 of paragraph 4 of this appendix). This measurement method is best applied in a controlled environment as the process is very sensitive to changes in temperature and pressure and all in situ methods impose unique calibration problems. In general, sensors that are reacting with oxygen make poor in situ sensors due to their propensity to consume oxygen in the general area of the measurement causing a type of sensor drift during measurements of quiescent environments.

2. Choosing a Measurement Method. To choose a measurement method several considerations must be made. The quantity of data as well as the number of gas sample locations required will determine the method of acquiring oxygen concentration for a flight test. The primary methods of measuring the oxygen concentration in a fuel tank ullage applied to date are continuous sampling, in situ measurements, and discrete sample measurements. Each primary method of measurement has an analyzer/sensor technology that is best applied given the measurement requirements. Each sensor and analyzer combination will have specific gas sample requirements. In the case of in situ measurements, sensitive sensors and fiber optic cables may need special protection. Discrete (individual) measurements made during any test always require the carefully choreographed and documented actions of test personnel during the test. This can lead to problems with post-test analysis of the data if information becomes lost or mishandled. Virtually all instrumentation has an effect on the environment being measured. Regardless of the method used to measure oxygen concentration, care should be taken to minimize the sampling system impact on the ullage oxygen concentration. Ullage samples drawn from the fuel tank for measurement should be returned if possible to the tank in locations that minimize the effect of the samples taken for measurement. The analysis presented for compliance should include the effect of the instrumentation on the results.

a. Continuous Sampling. The ideal measurement of oxygen concentration in a fuel tank environment is instantaneous and continuous. This, however, is not very practical as

some finite time is required to sample ullage gas and excite a particular sensor. By keeping gas sample lines short and small (diameter), while maintaining a relatively high sample flow rate, a gas sample system with a relatively short response time can be developed. Traditional sensors generally have a response time between 500 ms and 5 seconds, depending upon the technology applied.

(1) Flow Through Sensor System.

(a) One such method of continuous sampling was developed and applied by the FAA using flow through galvanic cells and a pressure regulated sample train. The sample train uses a powerful pump to draw a gas sample from the ullage sample location in question, through a forward pressure regulator, which regulates the pressure on the input of the sample train to a vacuum pressure lower than the lowest expected pressure in the sample environment (2.73 psia or 141 Torr @ 40,000 feet). The gas sample is then pumped up to a pressure to that just above sea level (14.7 psia or 760 Torr), allowing the gas sample to flow through a flow meter, the galvanic sensor, and then a check valve. Lastly, the gas sample passes through a pressure controller that regulates the back pressure to a fixed value that can be maintained throughout the flight cycle. This pressure is critical to maintaining the calibration of the analyzer with the galvanic cell sensor. The gas sample can then be returned to the ullage to allow for a minimal effect on the sample environment.

(b) Calibration of this measurement methodology is accomplished easily by having a selector valve in the sample train before the input pressure regulator. The sample train is completely pressure regulated, providing calibration gas to the system input, allowing time for the system to stabilize, and adjusting the analyzer gain allows for calibration. It is best to check for adherence of your oxygen measurement system to a wide variety of calibration gases at least once before and after a test program. This is accomplished by calibrating in the traditional manner, and then checking several other calibration gases with different oxygen concentrations within the measurement range of the testing.

(c) When applying this measurement method to an airplane flight test, care must be taken to preclude liquid fuel or vapors from entering the cabin from the fuel tank gas sample lines. Traditionally, all sample lines are double walled and the shroud (outer wall) space is vented overboard to the exterior of the cabin. Leak checks of both the line and shroud prior to testing are essential. The measurement system sample volume should be isolated from the fuel tank with flash arrestors in the event of a failure that creates an ignition within the measurement system itself. Most oxygen sensors operate on very low power; however, complete isolation of the sensor, and other sources of energy within the sample system, from the fuel tank is essential in the event of a failure that could create a reaction within any portion of the flammable sampling system.

(d) The sampling of liquid fuel should be precluded by use of float valves on the ends of each sample tube in the fuel tank. Also, in the event of a failure that allowed liquid fuel into the sample lines, fuel should be prevented from entering the

measurement system with either an automatic float shut-off switch or a warning system that allows for the operator to shut-down the sample system. The measurement system itself should also be shrouded and ventilated to allow for protection of the cabin environment in the case of a sample train leak. During ground operation, when natural suction is not available from the cabin exterior, the measurement system housing should also be continuously purged.

(e) A complete description of the galvanic cell continuous sample system applied by the FAA for the purposes of studying in-flight fuel tank inerting is given in Reference 5 from section 4 of this appendix.

## (2) Flow-by Sensor System.

(a) Some sensors react significantly with the sample, and therefore may not be appropriate for returning the sample to the tank. A method of applying this type of sensor to a fuel tank environment is to create a volume flow sample train similar to the one described in the previous section. A small amount of this sample is then removed from the loop, in the positive pressure portion of the flow train, allowed to flow through the reacting sensor in question, and then deposited overboard. Minimizing the flow to the sensor helps minimize the effect of the consumed sample and creates a safer environment should the reaction of the ullage sample with the sensor become hazardous. It may be necessary to remove flammable fuel tank vapors from the sample gas to safely apply some sensors for measuring ullage gas.

(b) Calibration of this measurement methodology is accomplished easily by having a selector valve in front of the sensor housing, outside of the primary sample loop. Care must be taken to ensure that the calibration gases flow through the sensor at same pressure and flow rate as the flow by sample. The flow-by sensor should stabilize quickly, allowing for adjustment of the analyzer gain. Again, it is best to check for adherence of your oxygen measurement system to a wide variety of calibrations gases at least once before and after a test program.

(c) Ensuring safety of a flow-by sensor installation is done much in the same manner as described in the previous section. Special care may need to be taken to ensure the reaction between the sensor and the ullage gas sample remains completely benign to the measurement system and the aircraft in general. It is for this reason that high energy sensors have not been applied to in-flight measurement applications. Whatever installation is chosen, careful analysis and application is required, within the confines of the regulations, to minimize risk in accordance with the individual program plan developed.

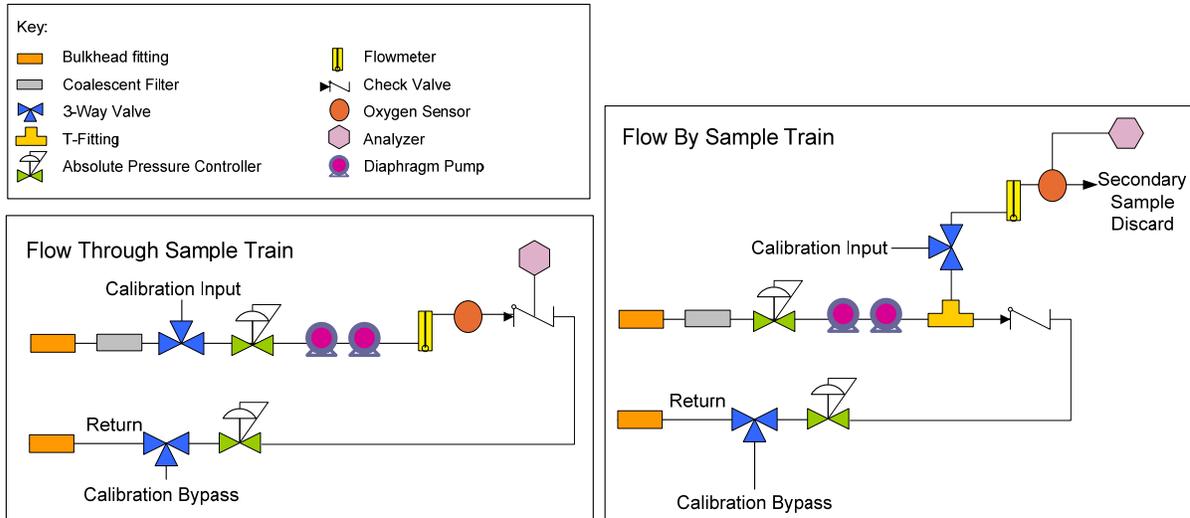


FIGURE 5-1

### Block Diagrams of Flow Through and Flow Bypass Sample Systems

#### b. In Situ Measurements.

(1) Application of in situ sensors for measuring fuel tank ullage oxygen concentration has been applied and observed by the FAA on a limited basis. However, recent advances in application of these sensor technologies make them a viable option for future in-flight oxygen concentration measurement in a fuel tank ullage. Optical methods such as fluorescence quenching are attractive to apply to measurements in fuel tanks due to the intrinsically safe nature of the energy required for the sensor, and in situ methods in general alleviate the need to remove flammable ullage gas from the fuel tank for sampling.

(2) Each in situ sensor will have its own unique installation issues due to the sensor size and shape, as well as any environmental limitations such as temperature. Routing of any fiber optic cables will need to be within the requirements for the cable.

(3) The main difficulty with applying in situ sensors is the need to calibrate the sensor in place. This is not practical on a daily basis in an airplane fuel tank. This is complicated by the fact that optical methods generally have a very nonlinear response and need to be calibrated for a changing ullage temperature. In previous applications of fluorescence quenching sensors, the calibration was done in a controlled environment using multiple gases at multiple temperatures. The system was then installed in the tank and each channel was then “normalized” to a baseline intensity using air at some middle calibration temperature. This proved to be problematic given the variable of the baseline intensity of the different channels between the lab and airplane.

(4) To alleviate this, a sleeve assembly could be fabricated for the sensor that allows the sensor to be immersed in calibration gas through the sleeve, deposited from the outside of the fuel tank, to allow for daily checking of the calibration for several

gases. At the very least, the sensors would need to be validated at a single point before every flight. This has been accomplished in the past by having the inert gas generation system create a fixed oxygen concentration gas for an extended period of time. This will eventually stabilize the tank at a single oxygen concentration and temperature to allow for validation of each sensor in the tank. It is easy to see that this could quickly become expensive and time consuming if the calibration had to be checked multiple times and/or with multiple gases on a daily basis.

(5) Safety requirements for equipment located within a fuel tank such as in situ measurement systems are already established in the existing § 25.981 and related sections (See AC 25.981-1B (or latest revision)). These safety requirements establish limitations on power required for instruments installed and places limitations on materials for use in fuel tanks. Part 25 addresses analysis of failure modes in general (§ 25.1309) and sets general installation requirements (subpart F). The power required for any sensor installed in a fuel tank needs to be calculated to be less than the minimum ignition energy prescribed by the FAA for fuel tank installations. Any cables that need to be installed should be routed in accordance with standard industry practices within the requirements of all airworthiness regulations. Each individual installation needs to be analyzed and evaluated for risk within the confines of the regulations and agreed upon by all project stakeholders.

c. Discrete Sampling. Although not desirable, it is possible to evaluate the capability of a particular inerting system to allow for protection of a given fuel tank without acquiring continuous oxygen concentration data throughout a complete flight cycle. This may be because of advances in ullage oxygen concentration modeling or because of the existence of a large quantity of previously acquired data for a similar inerting system and application. Regardless, collection of discrete samples at several critical times for a few different ullage locations can provide a complete picture of capability of an inerting system to maintain an inert ullage in a specified fuel tank during a flight cycle for some applications. Discrete methods may provide a cost advantage over continuous sampling measurements and can be considerably less complex if large quantities of gas samples are not required. The primary methods of acquiring discrete samples are through vacuum bottle sampling or through single point calibration and sampling.

(1) Vacuum Bottle Sampling.

(a) One method of acquiring discrete ullage gas samples at various times is by the use of vacuum sample bottles, which are previously cleaned, evacuated, and hermetically sealed. Vacuum bottles are generally used by plumbing several bottles in series. Each bottle has an individual hand operated valve to let in a gas sample, to the desired sample line, which is located within the ullage of the fuel tank in question. Each vacuum sample bottle in the series will provide a single, discrete gas sample in time at that particular ullage sample location. A vacuum sample bottle generally has a second vacuum bottle adjacent to it which is deployed (valve opened) before deploying the

actual vacuum sample bottle. This is done to “update” the sample line with a fresh ullage gas sample before opening the sample bottle to acquire the gas sample.

(b) Each sample location will have an associated series of vacuum sample bottles, depending upon the number of samples required and the individual test setup. Typically these bottles are analyzed after completion of the test for oxygen content and whatever additional gas analysis is desired, by a laboratory that specializes in this kind of gas sample. It is critical to have a simple, well documented, plan for gas sampling to ensure that test personnel acquire the required gas samples at the appropriate time and allow for adequate documentation. As is always the case with human/test interaction, a series of procedures and checks are required to minimize the possibility of human error.



**FIGURE 5-2**

**Vacuum Bottle Sample System Installed on an NTSB Test Aircraft**

(c) The primary safety concerns with a vacuum bottle sample system are similar to those for a continuous sample system. All sample lines penetrating the pressurized bulkhead should be leak checked and shrouded to preclude the possibility of ullage gas or fuel entering the cabin. Additionally, each sample bottle series should be housed in a shroud which is ventilated overboard to the cabin exterior. The advantage of analyzing the gas samples after the flight test is that no additional safety features are required to protect the aircraft fuel tank from the potential ignition source of a sensor or associated gas sample regulation equipment.

## (2) Single Point Calibration and Sampling.

(a) It is possible to use an analyzer and sample train to obtain discrete oxygen concentration measurements during a flight test. This can be accomplished by rapidly calibrating an analyzer sensor with a calibration sample gas, and then exposing the sensor to the desired ullage gas sample. This method would probably only be effective for measuring the oxygen concentration at times and tank locations with a relatively stable pressure, temperature, and oxygen concentration within the fuel tank ullage.

(b) All of the safety considerations associated with single point calibration and sample methods are identical to those of continuous sampling methods. For this reason alone, it may not be desirable to apply this methodology to a flight test scenario. Most of the cost and complexity of a gas sample system installation for a flight test environment is attributable to the safety features (sample line shrouds, box ventilation system, and system safety analysis). To apply these methods and not install the additional equipment to continuously sample, at a relatively small cost and complexity, does not seem cost effective. Again, every installation and application needs to be analyzed for certification requirements, data ranges, and program risk, within the confines of the regulations, to ensure a successful, cost effective flight test.

3. Selections of Sample Locations. The primary consideration when selecting the location and number of gas sample ports is the physical geometry of the fuel tanks, as well as the compartmentalization of the fuel tank. The two types of fuel tanks considered are single bay tanks and multiple bay tanks.

### a. Single Bay Fuel Tanks.

(1) Single bay fuel tanks have a single volume, broken up only by structural members, which do not impede the flow of gases inside the tank. It is possible to select a single gas sample location that is representative of the entire ullage average oxygen concentration, but without prior measurements during similar inerting testing or extensive computation calculations, it is difficult to ensure a single measurement location is representative of the entire ullage. For fuel tanks where air enters the fuel tank during descent, a continuous measurement of ullage oxygen concentration during a specified aircraft descent profile is essential to determining the level of protection afforded the tank by the inerting system and is the best measure of the sizing of inerting system for the specified fuel tank. The critical sampling location would typically be located near where outside air enters the tank. Therefore if a single sampling location is proposed, substantiation that the selected sampling location will provide oxygen measurements that demonstrate the tank is inert must be provided.

(2) Measurements too close to the airplane vent (air deposit) or the NEA deposit nozzle can provide a biased measure of the average ullage oxygen concentration. It is possible that during the mixing of NEA and vent air into the tank, brief pockets of

high or low oxygen concentration ullage gas may exist within the ullage. Without compartmentalized bay walls, these pockets will be transient and difficult to identify. Mixing can be problematic in the vertical direction (between the top and bottom of the tank), particularly when considering low flow rates of air or NEA entering a tall thin fuel tank. If a fuel tank has associated radiant heat on the bottom (heated CWT), this problematic mixing will be small in nature and short lived.

(3) At the end of every test the aircraft fuel tank ullage will have a measured average ullage oxygen concentration after the aircraft has come to a complete stop and the inerting system has been shut off. By continued examination of this average over a period of 20-60 minutes during the operation of the aircraft air cycle machines (bottom heat), good vertical mixing can be validated. Any change in the average ullage oxygen concentration after the test is complete, with no additional air or NEA is entering the tank, can only be caused by changing oxygen concentration readings due to the mixing of the resulting ullage constituency. Again, without prior knowledge, the only way to ensure the inerting system is appropriate for the aircraft fuel tank is by the continuous measure of oxygen concentration at several strategic locations within the ullage during an appropriate descent flight test.

b. Multiple Bay Fuel Tanks.

(1) Multiple bay tanks are fuel tanks broken into several smaller volumes by solid or nearly solid web structures. These structures can be somewhat limited in their partitioning with large openings and extensive gaps between the web and the tank structure as is the case with many wing fuel tanks. These web structures can also be very solid in nature, with the only large openings being doors removed during maintenance and small web gaps for equalizing fuel and ullage gas, making a very compartmentalized tank.

(2) Fuel tanks with relatively open partitions may only require a few gas sample locations across many bays to allow for the accurate measurement of the overall fuel tank ullage average. Previous research highlighting inert gas distribution behavior during ground inerting may be beneficial to determining the number and location of gas sample ports. However this is not a guarantee of good air redistribution given the different nature of the NEA deposit and the vent opening. In the end, several more oxygen concentration sample locations may be necessary to allow for validation of inert gas distribution and ullage gas mixing during certain flight tests. These additional sample locations can be utilized when the mixing of the tank needs to be examined or validated using oxygen measurement channels redundant at that time.

(3) In the case of very compartmentalized fuel tanks, inert gas distribution may be problematic, depending on the sizing of the inerting system and the NEA deposit scheme selected. This generally requires at least one gas sample in each compartment, with long thin compartments perhaps requiring two gas sample locations. Bays that have a large vertical height, while still remaining relatively thin, may require an additional sample port at the bottom of the bay. Again, any differences in the oxygen concentration

of the top and bottom of an ullage compartment will be transient in nature, but the knowledge of this behavior may allow for an explanation of an unusual measurement obtained and could allow for the validation of fuel tank inerting models being utilized.

4. References.

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2. Doebelin, E., Measurement Systems Application and Design, McGraw-Hill, 1990, pages 729-730.
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5. Burns, Michael and Cavage, William M., "A Description and Analysis of the FAA Onboard Oxygen Analysis System," FAA report DOT/FAA/AR-TN03/52, June 2003.



# Federal Register

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**Monday,  
July 21, 2008**

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**Part III**

## **Department of Transportation**

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**Federal Aviation Administration  
14 CFR Parts 25, 26, 121 et al.  
Reduction of Fuel Tank Flammability in  
Transport Category Airplanes; Final Rule**

**DEPARTMENT OF TRANSPORTATION****Federal Aviation Administration****14 CFR Parts 25, 26, 121, 125, and 129**

[Docket No. FAA-2005-22997; Amendment Nos. 25-125, 26-2, 121-340, 125-55, and 129-46]

RIN 2120-A123

**Reduction of Fuel Tank Flammability in Transport Category Airplanes**

**AGENCY:** Federal Aviation Administration (FAA), DOT.

**ACTION:** Final rule, request for comments.

**SUMMARY:** This final rule amends FAA regulations that require operators and manufacturers of transport category airplanes to take steps that, in combination with other required actions, should greatly reduce the chances of a catastrophic fuel tank explosion. The final rule does not direct the adoption of specific inerting technology either by manufacturers or operators, but establishes a performance-based set of requirements that set acceptable flammability exposure values in tanks most prone to explosion or require the installation of an ignition mitigation means in an affected fuel tank. Technology now provides a variety of commercially feasible methods to accomplish these vital safety objectives.

**DATES:** These amendments become September 19, 2008. Send your comments by January 20, 2009. The incorporation by reference of the document listed in the rule is approved by the Director of the Federal Register as of September 19, 2008.

**FOR FURTHER INFORMATION CONTACT:** If you have technical questions about this action, contact Michael E. Dostert, FAA, Propulsion/Mechanical Systems Branch, ANM-112, Transport Airplane Directorate, Aircraft Certification Service, 1601 Lind Avenue, SW., Renton, Washington 98057-3356; telephone (425) 227-2132, facsimile (425) 227-1320; e-mail: [mike.dostert@faa.gov](mailto:mike.dostert@faa.gov). Direct any legal questions to Doug Anderson, ANM-7, FAA, Office of Regional Counsel, 1601 Lind Avenue, SW, Renton, WA 98057-3356; telephone (425) 227-2166; facsimile (425) 227-1007, e-mail [Douglas.Anderson@faa.gov](mailto:Douglas.Anderson@faa.gov).

**SUPPLEMENTARY INFORMATION:** Later in this preamble under the ADDITIONAL INFORMATION section, we discuss how you can comment on a certain portion of this final rule and how we will handle your comments. Included in

this discussion is related information about the docket, privacy, and the handling of proprietary or confidential business information. We also discuss how you can get a copy of this final rule and related rulemaking documents.

**Authority for Rulemaking**

The FAA's authority to issue rules regarding aviation safety is found in Title 49 of the United States Code. Subtitle I, Section 106 describes the authority of the FAA Administrator. Subtitle VII, Aviation Programs, describes in more detail the scope of the agency's authority.

This rulemaking is promulgated under the authority described in Subtitle VII, Part A, Subpart III, Section 44701, "General requirements." Under that section, the FAA is charged with promoting safe flight of civil aircraft in air commerce by prescribing minimum standards required in the interest of safety for the design and performance of aircraft; regulations and minimum standards in the interest of aviation safety for inspecting, servicing, and overhauling aircraft; and regulations for other practices, methods, and procedures the Administrator finds necessary for safety in air commerce. This regulation is within the scope of that authority because it prescribes

- New safety standards for the design of transport category airplanes, and
- New requirements necessary for safety for the design, production, operation and maintenance of those airplanes, and for other practices, methods, and procedures related to those airplanes.

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## I. Executive Summary

### A. Statement of the Problem

Fuel tank explosions have been a constant threat with serious aviation safety implications for many years. Since 1960, 18 airplanes have been damaged or destroyed as the result of a fuel tank explosion. Two of the more recent explosions—one involving a Boeing 747 (Trans World Airways (TWA) Flight 800) off Long Island, New York in 1996 and the other, a Boeing 727 terrorist-initiated explosion (Avianca Flight 203) in Bogotá, Columbia in 1989<sup>1</sup>—occurred during flight and led to catastrophic losses (including the deaths of 337 individuals). Two other recent explosions on airplanes operated by Philippine Airlines and Thai Airlines occurred on the ground (resulting in

nine fatalities).<sup>2</sup> While the accident investigations of the TWA, Philippine Airlines and Thai Airlines accidents failed to identify the ignition source that caused the explosion, the investigations found several similarities. In each instance:

1. The weather was warm, with an outside air temperature over 80 °F;
2. The explosion occurred on the ground or soon after takeoff; and
3. The explosion involved empty or nearly empty tanks that contained residual fuel from the previous fueling.

Additionally, investigators were able to conclude that the center wing fuel tank in all three airplanes contained flammable vapors in the ullage (that portion of the fuel tank not occupied by liquid fuel) when the fuel tanks exploded. This was also the case with the Avianca airplane.

A system designed to reduce the likelihood of a fuel tank fire, or mitigate the effects of a fire should one occur, would have prevented these four fuel tank explosions.

A statistical evaluation of these accidents has led the FAA to project that, unless remedial measures are taken, four more United States (U.S.) registered transport category airplanes will likely be destroyed by a fuel tank explosion in the next 35 years. Although we cannot forecast precisely when these accidents will occur, computer modeling that has been an accurate predictor in the past indicates these events are virtually certain to occur. We believe at least three of these explosions are preventable by the adoption of a comprehensive safety regime to reduce both the incidence of ignition sources developing and the likelihood of the fuel tank containing flammable fuel vapors.

### B. Reducing the Chance of Ignition

To address the first part of this comprehensive safety regime, we have taken several steps to reduce the chances of ignition. Since 1996, we have imposed numerous airworthiness requirements (including airworthiness directives or “ADs”) directed at the elimination of fuel tank ignition sources. Special Federal Aviation Regulation No. 88 of 14 Code of Federal Regulations (CFR) part 21 (SFAR 88; 66 FR 23086, May 7, 2001) requires the detection and correction of potential system failures that can cause ignition. Although these measures should prevent some of the four forecast explosions, our review of the current

transport category airplane designs of all major manufacturers has shown that unanticipated failures and maintenance errors will continue to generate unexpected ignition sources. Since manufacturers completed their SFAR 88 ignition prevention reviews, we have had reports of potential ignition sources (including unsafe conditions) that were not identified in the SFAR 88 reviews. For example:

- We issued AD 2006–06–14 to require the inspection of fuel quantity indicating probes within the fuel tanks of Airbus A320 airplanes to prevent an ignition source due to sparks that could be created following a lightning strike. This failure mode was not identified as a possible ignition source in the SFAR 88 analysis presented to the FAA.

- We issued AD 2006–12–02 following a report of an improperly installed screw inside the fuel pump housings of A320 airplanes that could loosen and fall into the pump’s electrical windings. This could create a spark and ignite fuel vapors in the pump. The ignited vapors could then exit the fuel pump housing, enter the fuel tank through the hole created when the screw fell out of the housing, and cause a fuel tank explosion. This failure mode was not identified as a possible ignition source in the SFAR 88 analysis presented to the FAA.

- We received an in-service report on a Boeing 777 that was operated for over 30 days with an open vent hole between the center wing fuel tank and the wheel well of the airplane. During maintenance, a vent hole cover used to facilitate venting of the tank was inadvertently left off. This was not discovered until a flight occurred where the tank was fueled to a level where the fuel spilled from the tank into the wheel well during pitching up of the airplane for takeoff. Since the airplane brakes routinely exceed temperatures that could ignite fuel vapors and the wheels are retracted into the wheel well, the open vent port could have allowed ignition of fuel vapors in the center tank and a fuel tank explosion. This type of maintenance error was also not identified as providing a possible ignition source during the SFAR 88 safety reviews.

- On May 5, 2006, an explosion occurred in the wing fuel tank of a Boeing 727 in Bangalore, India, while the airplane was on the ground. This event occurred after a modification to include special Teflon sleeving and recurring inspections had been implemented to prevent possible arcing of the fuel pump wires to metallic conduits located in the fuel tank. Initial information indicates that the identified

<sup>1</sup> Although it was determined that a terrorist’s bomb had caused the explosion of the center tank in the Bogotá accident, the NTSB determined the “bomb explosion did not compromise the structural integrity of the airplane; however, the explosion punctured the [center wing tank] and ignited the fuel-air vapors in the ullage, resulting in destruction of the airplane.”

<sup>2</sup> Philippine Airlines Boeing 737 accident in Manila in 1990, and a Thai Airlines Boeing 737 accident in Bangkok in 2001.

AD action was inadequate to prevent the formation of an ignition source in the fuel tank and that the change intended to improve safety caused premature wear of the sleeving and an unsafe condition. Premature wear of Teflon sleeving on the Boeing 737 has also been reported, resulting in AD action to modify the design and replace the existing sleeving. This failure mode was not identified as a possible ignition source in the SFAR 88 analysis presented to the FAA.

- We also received a report that during a recent certification program test, an ignition source developed in the fuel pumps causing pump failure. These pumps had been designed to meet the most stringent requirements of SFAR 88 and Amendment 25–102 to 14 CFR 25.981 (issued concurrently with SFAR 88), yet the pump failed in a manner that allowed a capacitor to arc to the pump enclosure and create an ignition source. The applicant has since conducted a design review that has resulted in numerous modifications to the pump's design.

- Following the TWA 800 accident, the risk of uncontrolled fire adjacent to the fuel tanks causing a fuel tank explosion was identified as an unsafe condition. In 2006, we issued a MD–80 AD (AD 2006–15–15) to prevent worn insulation on wires from arcing at the auxiliary hydraulic pump, which could result in a fire in the wheel well of the airplane. The AD required inspections to validate the pump wire integrity as well as incorporating sleeving on portions of the wires. In April 2008, we received reports of improper means of compliance being used regarding the requirements of AD 2006–15–15. Human error in completing the procedures required by the AD resulted in airplanes being operated without the needed safety improvements.

Based on the above examples, we have concluded that we are unlikely to identify and eradicate all possible sources of ignition.

### *C. Reducing the Likelihood of an Explosion After Ignition*

To ensure safety, therefore, we must also focus on the environment that permits combustion to occur in the first place. Many transport category airplanes are designed with heated center wing tanks in which the fuel vapors are flammable for significant portions of their operating time. This final rule addresses the risk of a fuel tank explosion by reducing the likelihood that fuel tank vapors will explode when an ignition source is introduced into the tank.

Technology now exists that can prevent ignition of flammable fuel vapors by reducing their oxygen concentration below the level that will support combustion. By making the vapors “inert,” we can significantly reduce the likelihood of an explosion when a fire source is introduced to the fuel tank. FAA-developed prototype onboard fuel tank inerting systems have been successfully flight tested on Airbus A320 and Boeing 747 and 737 airplanes. We have also approved inerting systems for the Boeing 747 and 737 airplanes, and two airplanes of each model type have performed as expected during airline in-service evaluations. Boeing plans to install these systems on all new production airplanes.

Given that ignition sources will develop, the chances of a fuel tank explosion naturally correlate with the exposure of the tank to flammable vapors. The requirements in this final rule mitigate the effects of such flammability exposure and limit it to acceptable levels by mandating the installation of either a Flammability Reduction Means (FRM) or an Ignition Mitigation Means (IMM).<sup>3</sup> In either case, the technology has to adhere to performance and reliability standards that are set by us and contained in Appendices M and N to Title 14 Code of Federal Regulations (CFR) part 25.

This final rule amends the existing airworthiness standards contained in 14 CFR 25.981 to require all future type certificate (TC) applicants for transport category airplanes to reduce fuel tank flammability exposure to acceptable levels. It also amends 14 CFR part 26 “Continued Airworthiness and Safety Improvements”<sup>4</sup> to require TC holders to develop FRM or IMM for many large turbine-powered transport category airplanes with high-risk fuel tanks. Finally, it amends 14 CFR parts 121, 125 and 129 to require operators of these airplanes to incorporate the approved FRM or IMM into the fleet and to keep them operational. We estimate that approximately 2,700 existing Airbus and Boeing airplanes operating in the United States as well as about 2,300 newly manufactured airplanes that enter U.S. airline passenger service will be affected. Fuel tank system designs in

<sup>3</sup> FRM consist of systems or features installed to reduce or control fuel tank flammability to acceptable levels. IMM is based upon mitigating the effects of a fuel vapor ignition in a fuel tank so that an explosion does not occur. Polyurethane foam installed in a fuel tank is one form of an IMM. See AC 25.981–2 for additional information.

<sup>4</sup> Part 26 was added to the Code of Federal Regulations to include all requirements for Continued Operational Safety. See Docket number FAA–2004–18379 for more information on this subject.

several pending type-certification applications, including the Boeing 787<sup>5</sup> and Airbus A350, also have to meet these requirements.

We acknowledge that these requirements are costly and have adopted these steps only after spending several years researching the most cost-effective ways to prevent fuel tank explosions in cooperation with engineers and other experts from the affected industry. Those efforts have resulted in the development of fuel-inerting technology that is vastly cheaper than originally thought.

In contrast, the loss of a single, fully loaded large passenger airplane in flight, such as a Boeing 747 or Airbus A380, would result in death and destruction causing societal loss of at least \$1.2 billion (based on costs of prior calamities). We estimate that compliance with this new rule will prevent between one and two accidents of some type (for analytical purposes we assume the accidents would involve “average” airplanes with “average” passenger loads) over 35 years.<sup>6</sup> In addition to the direct costs of such an accident, we now recognize that, in the post-9/11 aviation environment, the public could initially assume that an in-flight fuel tank explosion is the result of terrorist actions. This could cause a substantial immediate disruption of flights, similar to what occurred in Britain on August 10, 2006, due to the discovery of a terrorist plot.<sup>7</sup> This could have an immediate and substantial adverse economic effect on the aviation industry as a whole.

The FAA's safety philosophy is to address aviation safety threats whenever practicable solutions are found, especially when dealing with intractable and catastrophic risks like fuel tank explosions that are virtually certain to

<sup>5</sup> This airplane model already includes a FRM in its design that the applicant intends to show will meet today's final rule, so no additional modifications will be required.

<sup>6</sup> Although Boeing has committed to installing compliant FRM in all future production airplanes, regardless of this rule, operators could deactivate the systems unless this rulemaking is adopted. The final regulatory evaluation includes the costs and benefits of these actions for newly produced Boeing and Airbus airplanes.

<sup>7</sup> Flight schedules in Britain were significantly disrupted due to flight cancellation of all flights into Heathrow Airport and 30 percent of all short-haul flights out of Heathrow Airport for one day (according to Secretary of State for Transport Douglas Alexander). The day after the event, the crowds and lines that log-jammed British airports the day before were largely gone, he said. British Airways stated that it cancelled 1,280 flights between August 10–17 due to the discovery of the terror plot and subsequent security measures. EasyJet said it was forced to cancel 469 flights because of the disruption caused by the terror alert. Ryanair said it cancelled a total of 265 flights.

occur. Thus, now that solutions are reasonably cost effective, we have determined that it is necessary for safety and in the public's best interest to adopt these requirements.

## II. Background

### A. Summary of the NPRM

On November 23, 2005, the FAA published in the **Federal Register** the Notice of Proposed Rulemaking (NPRM) entitled "Reduction of Fuel Tank Flammability in Transport Category Airplanes" (70 FR 70922). This NPRM is the basis for this final rule.

In the NPRM, we proposed steps to be taken by manufacturers and operators of transport category airplanes to significantly reduce the chances of a catastrophic fuel tank explosion. The proposal followed seven years of intensive research by the FAA and industry into technologies designed to make fuel tanks effectively inert. Inerting reduces the amount of oxygen in the fuel tank vapor space so that combustion cannot take place if there is an ignition source. Although the NPRM did not specifically direct the adoption of inerting technology, it did propose a performance-based set of requirements for reducing fuel tank flammability to an acceptably safe level.

We proposed regulatory changes to require manufacturers and operators to reduce the average fuel tank flammability exposure in affected fleets. The main premise of the proposal was that a balanced approach to fuel tank safety was needed that provides both prevention of ignition sources and reduction of flammability of the fuel tanks. While the focus of the NPRM was on airplanes used in passenger operations, we requested comments on whether the new requirements should also be applied to all-cargo airplanes.

We also proposed changes to expand the coverage of part 25 by making manufacturers generally responsible for the development of service information and safety improvements (including design changes) where needed to ensure the continued airworthiness of previously certificated airplanes. This change was proposed to ensure that operators would be able to obtain service instructions for making necessary safety improvements in a timely manner.

As to fuel tank flammability specifically, we proposed to require manufacturers, including holders of certain airplane TCs and of auxiliary fuel tank supplemental type certificates (STCs), to conduct a flammability exposure analysis of their fuel tanks. We proposed a new Appendix L (now

Appendix N) to part 25 that provides a method for calculating overall and warm day fuel tank flammability exposure. Where the required analyses indicated that the fuel tank has an average flammability exposure below 7 percent, we anticipate no changes would be required. However, for the other fuel tanks, manufacturers would be required to develop design modifications to support a retrofit of the airplane fuel tanks. Under the NPRM, the average flammability exposure of any affected wing tank would have to be reduced to no more than 7 percent. In addition, for any normally emptied fuel tank (including auxiliary fuel tanks) located in whole or in part in the fuselage, flammability exposure was to be reduced to 3 percent, both for the overall fleet average and for operations on warm days.

We also proposed to set more stringent safety levels for certain critically located fuel tanks in most new type designs, while maintaining the current, general standard under § 25.981 for all other fuel tanks. The expectation was that the design of most normally emptied and auxiliary tanks located in whole or in part in the fuselage of transport category airplanes would need to incorporate some form of FRM or IMM.

In Appendix M to part 25, we proposed to adopt detailed specifications for all FRM, if they were used to meet the flammability exposure limitations. These additional requirements were designed to ensure the effectiveness and reliability of FRM, mandate reporting of performance metrics, and provide warnings of possible hazards in and around fuel tanks.

We also proposed that TC holders for specific airplane models with high flammability exposure fuel tanks be required to develop design changes and service instructions to facilitate operators' installation of IMM or FRM. Manufacturers of these airplanes would also have to incorporate these design changes in airplanes produced in the future. In addition, design approval holders (TC and STC holders) and applicants would have to develop airworthiness limitations to ensure that maintenance actions and future modifications do not increase flammability exposure above the limits specified in the proposal. These design approval holders would have to submit binding compliance plans by a specified date, and these plans would be closely monitored by the design approval holders' FAA Oversight Offices to ensure timely compliance.

Lastly, the proposal would require affected operators to incorporate FRM or IMM for high-risk fuel tanks in their existing fleet of affected airplane models. The proposal would have applied to operators of airplanes under parts 91, 125, 121, and 129. Operators would also have to revise their maintenance and inspection programs to incorporate the airworthiness limitations developed under the NPRM. We also proposed strict retrofit deadlines, which were premised on prompt compliance by manufacturers with their compliance plans.

The NPRM contains the background and rationale for this rulemaking and, except where we have made revisions in this final rule, should be referred to for that information.

### B. Related Activities

On November 28, 2005, the FAA published a Notice of Availability of Proposed Advisory Circular (AC) 25.981-2A, Fuel Tank Flammability, and request for comments in the **Federal Register** (70 FR 71365). The notice announced the availability of a proposed AC that would set forth an acceptable means, but not the only means, of demonstrating compliance with the provisions of the airworthiness standards set forth in the NPRM. On March 21, 2006, the FAA published a notice that extended the comment period as a result of an extension of the NPRM's comment period to May 8, 2006 (71 FR 14281).

### C. Differences Between the NPRM and the Final Rule

As a result of the comments received and our own continued review of the proposals in the NPRM, we have made several changes to the proposed regulatory text. The majority of these changes will be discussed in the "Discussion of the Final Rule" section below. The following is a summary of the main differences between the NPRM and this final rule.

1. *Design Approval Holders.* The design approval holder (DAH) requirements proposed in the NPRM as subpart I of part 25 are now contained in new part 26. This was done to harmonize with the regulatory structure of other international airworthiness authorities. We also revised the applicability for the retrofit requirement so the DAH requirements do not apply to airplanes manufactured before 1992. The effect of this change is that DAHs will not have to develop FRM or IMM for many older airplane models that do not have significant remaining useful life in passenger operations. We revised the compliance times for DAHs to

develop and make available service instructions for FRM or IMM by replacing specific compliance dates with a compliance time of 24 months after the effective date of this rule for all affected airplane models. We have also made some changes, discussed later, to the compliance planning sections of the DAH requirements.

2. *Auxiliary Fuel Tanks.* We have learned that few auxiliary fuel tanks installed under STCs and field approvals remain in service, and we need to obtain additional information to decide whether the risks from these tanks justify retrofit requirements. Therefore, we have removed the requirements for an FRM or IMM retrofit for these tanks.

3. *Impact Assessments.* We limited the requirement for impact assessments for auxiliary fuel tanks to airplanes with high flammability tanks for which an FRM is required (i.e., Heated Center Wing Tank airplanes).

4. *All-Cargo Airplanes.* We retained the proposal to exclude all-cargo airplanes from the requirement to retrofit high flammability tanks with FRM or IMM. However, we added a requirement that when any airplane that has an FRM or IMM is converted from passenger use to all-cargo use, these safety features must remain operational. We also added a requirement that newly manufactured all-cargo airplanes must meet the same requirements as newly manufactured passenger airplanes. We revised § 25.981 to remove the exclusion of all-cargo airplanes so that any newly certificated transport category airplane, regardless of the type of operation, must meet the same safety standards.

5. *Part 91 Operators.* The proposed rule would have applied to operators under part 91, which is limited to private use operations. However, the final rule does not include part 91 requirements.

6. *Retrofit Requirements for Operators.* We have added a provision for air carrier operators that allows a one year extension in the compliance time to retrofit of their affected fleets if they revise their operations specifications and manuals to use ground conditioned air<sup>8</sup> when it is available. Instead of requiring retrofit for all airplanes with high flammability fuel tanks, we revised the operating rules to prohibit operation of these airplanes in passenger service after 2016 unless an FRM or IMM is installed. This approach gives operators the option of converting these airplanes to all-cargo service. We also prohibit the

operation of airplanes with high flammability fuel tanks produced after 2009 unless they are equipped with FRM or IMM. This requirement parallels the proposed production cut-in requirement, but also applies to foreign manufactured airplanes. Finally, instead of requiring retrofit of high flammability auxiliary fuel tanks, we prohibit installation of auxiliary fuel tanks after 2016 unless they comply with the new requirements of § 25.981.

### III. Discussion of the Final Rule

#### A. Summary of Comments

The FAA received over 100 comment letters to the proposed rule and guidance material. These letters covered a wide spectrum of topics and range of responses to the rulemaking package, which will be discussed more fully below. While there was much support for the general intent of the rule changes and the guidance material, there were several requests for changes and for clarification.

#### B. Necessity of Rule

##### 1. Estimates/Conclusions Supporting Need for Rule

In the NPRM and its supporting documents, we noted several estimates and conclusions that we used to determine the necessity and content of this rule. We received comments on the following assumptions:

- The historical accident rate for heated center wing tank (HCWT) airplanes is 1 accident per 60 million hours of flight (before implementing corrective actions following TWA 800).
- That SFAR 88 and other corrective actions would prevent 50 percent of future fuel tank explosions.
- That Boeing and Airbus airplanes have an equal risk of an explosion.
- That a HCWT, depending upon the airplane model and its mode of operation, is explosive 12 to 24 percent of the time.
- That the rate of accidents directly correlates to flammability exposure.

Based on the comments received, we have changed the historical accident rate estimate to 1 accident per 100 million hours. This change does not affect our conclusion that the historical accident rate for HCWT airplanes supports the need for this rule. As for the other estimates and conclusions, we have not changed these in the final rule.

##### a. Historical (pre-TWA 800) Accident Rate

Airbus, the Air Transport Association (ATA), Alaska Airlines (Alaska), the Association of Asia Pacific Airlines (AAPA), the Association of European

Airlines (AEA), Boeing, Cathay Pacific Airways (Cathay), Delta Air Lines (Delta) and FedEx stated that the historical accident rate of 1 accident every 60 million fleet operating hours was too high. Most of these commenters recommended a rate of 1 accident per 140 million hours. Their proposed rate is based on the number of accidents and the total fleet hours for heated center wing tank (HCWT) airplanes through 2005 (3 accidents over 430 million hours). Several of these commenters also noted that this rate is closer to the conservative estimate in the MITRE Corporation's assessment of the FAA's accident prediction/avoidance model (1 accident every 160 million hours).<sup>9</sup>

Boeing proposed a rate of 1 accident every 100 million hours. Boeing's analysis also started with the number of accidents and the total fleet hours for HCWT airplanes through 2005. However, Boeing recognized that some of the improvement since 2001 may be attributable to the FAA/industry focus on ignition prevention and concluded that the rate of 1 accident every 100 million hours more accurately represents the pre-TWA 800 rate.

FedEx stated that, from a historical basis, 140 million hours would be a correct mean time between accidents. However, FedEx noted that a more conservative estimate closer to 100 million hours would still be acceptable.

In a related comment, ATA questioned our use of flight hours as the measure of exposure to risk. ATA noted that two of the historical accidents did not occur in flight. Therefore, flight hours may understate exposure and overstate risk. ATA concluded that these accidents support the use of block hours or some other measure that accounts for time on the ground (and would lower the accident rate by about 16 percent).

We agree that the accident rate used in the NPRM was too high and needs adjustment. While the rate of 1 accident every 140 million hours is correct if you only use the total fleet hours for HCWT airplanes through 2005, it fails to consider the beneficial effects of FAA/industry action following the TWA 800 accident. Since that accident, we have issued many ADs to address specific findings of unsafe conditions that could produce fuel tank ignition sources. In addition, the Fuel Tank Safety Rule, of which SFAR 88 was a part, was issued in 2001 to establish a systematic process for identifying and eliminating ignition

<sup>8</sup> "Ground conditioned air" is temperature controlled air used to ventilate the airplane cabin while the airplane is parked between flights.

<sup>9</sup> The Mitre assessment of the FAA accident prediction methodology is included as Appendix H of the Initial Regulatory Evaluation and is available in the docket for this rulemaking (Document Number FAA-2005-22997-3).

sources. Many of the improvements resulting from these actions have been implemented in the transport airplane fleet, and the improved safety record since TWA 800 is largely attributable to them. While the commenters acknowledge that these actions have been effective at preventing future accidents, most of them failed to reduce their proposed historical rate accordingly to address these benefits. In contrast, Boeing's recommended rate considers the benefits of these actions (which we calculate covers about 170 million hours).

We believe that an accident rate of 1 per 100 million hours is an accurate calculation of the historical accident rate before implementation of post-TWA 800 ignition prevention actions. Therefore, we used this rate in developing this final rule and its supporting documents. However, this change does not affect our conclusion that the historical accident rate for HCWT airplanes supports the need for this rule. We continue to believe that the risk of an accident is too high.

Several commenters referred to the rate in the MITRE Corporation's report (1 accident every 160 million hours). This rate includes operations of airplanes without HCWT. Recommendations resulting from MITRE's review included a suggestion that only fleet hours from airplanes with HCWT be used in the accident prediction model. We agreed with this recommendation and have adjusted the accident rate accordingly.

Finally, we do not agree with ATA's conclusion that the use of flight hours to predict future accidents results in an overstated risk. Both the past accident rate and the future predicted number of accidents were based upon the number of flight hours of airplanes with high flammability fuel tanks, and in both cases the number of flight hours does not include ground time. The ratio of flight time to ground time is unlikely to change significantly in the future because the average flight length and the amount of time spent on the ground before and after each flight are unlikely to change significantly. Therefore, whether past and future accident rates are stated in terms of flight time only or flight time plus ground time, the projected future accident rates would predict the same number of accidents over any given time period.

#### b. SFAR 88 Effectiveness Rate

In the NPRM and its supporting documents, we estimated that SFAR 88 would prevent 50 percent of future fuel tank explosions (although we also conducted a sensitivity analysis using

effectiveness rates of 25 and 75 percent). ATA stated that the 50 percent effectiveness rate was without basis or explanation and recommended a rate of 90 percent. Airbus recommended an effectiveness rate in the range of 75 to 90 percent. If these higher rates are used, ATA and Airbus noted the safety benefits of the proposed rule are insufficient to justify the costs, and they requested that we withdraw the NPRM.

Predicting the effectiveness of ignition prevention actions is challenging, since many ignition sources are the result of human error, which cannot be precisely predicted or quantitatively evaluated. Despite extensive efforts by the FAA and industry to prevent ignition sources, we continue to learn of new ignition sources. Some of these ignition sources are attributable to failures on the part of engineering organizations to identify potential ignition sources and provide design changes to prevent them. Others are attributable to actions by production, maintenance, and other operational personnel, who inadvertently compromise wiring and equipment producing ignition sources. Regardless of the causes, we believe that ignition prevention actions, while necessary, are insufficient to eliminate ignition sources.

Based on the recently discovered ignition sources discussed earlier, we continue to believe that an assumed effectiveness rate of 50 percent is reasonable and appropriate. In its study on SFAR 88 effectiveness, Sandia National Laboratories concluded that our estimate of 50 percent was reasonable, and the value of 75 percent effectiveness assumed in the initial Aviation Rulemaking Advisory Committee (ARAC) report was overly optimistic. While the report of the ARAC Fuel Tank Inerting Harmonization Working Group<sup>10</sup> initially assumed an effectiveness of 75 percent, the report was later amended to use a range of effectiveness between 25 to 75 percent because of the uncertainty in predicting the effectiveness.

Finally, since ATA did not submit any data to substantiate that a higher effectiveness rate is more reasonable, we believe the post-SFAR 88 service experience supports the use of a range of effectiveness between 25 to 75 percent and a median value of 50 percent.

#### c. Boeing and Airbus Airplanes Have an Equal Risk of an Explosion

We concluded that all airplanes with HCWT had similar levels of fuel tank

flammability and the associated increase in the likelihood of a fuel tank explosion. We based the SFAR 88 effectiveness estimates on the HCWT fleet as a whole. We did not differentiate among airplane models based upon design differences that could affect the likelihood of an ignition source forming.

AEA, Airbus, Frontier Airlines (Frontier), the Air Safety Group UK, Singapore Airlines (Singapore), BAE Systems (BAE), TDG Aerospace (TDG) disagreed with this proposal and argued that the risk of an explosion is lower for Airbus airplanes. These commenters noted that fuel tank designs for those airplanes that experienced a fuel tank explosion are at least a decade older than Airbus' designs. Airbus argued that its airplanes use newer technology and design philosophies that have incorporated the lessons learned from prior designs. BAE and two individuals suggested that we address fuel tank flammability by issuing ADs to address specific design shortfalls in the two airplane types that have experienced fuel tank explosions (i.e., the Boeing 737 and 747 series airplanes).

While we did note differences between the designs and technologies used by Boeing and Airbus, we concluded that the risk of an explosion was equal for Boeing and Airbus airplanes based on similarities in their fuel tank designs and service history. We found that both manufacturers have similar problematic fuel tank design features. For example, air conditioning equipment is located below the center wing tank in both manufacturers' designs (and HCWT have flammability exposure well above that of a conventional unheated aluminum wing tank). Likewise both manufacturers locate fuel gauging systems with capacitance measuring probes inside the fuel tank, and associated wiring to the probes enters the fuel tank from outside. These wires are co-routed with high-energy wiring to other airplane systems that have sufficient energy to cause an ignition source inside the fuel tanks. Finally, high-energy electrical fuel pumps are located within the fuel tanks and are fuel-cooled and manufactured by the same component suppliers. Arcing of the pump could cause a spark inside the fuel tank or could create a hole at the pump connector, causing a fuel leak and an uncontrolled fire outside of the tank.

As for the service history and design reviews of Airbus airplanes, we found numerous situations that indicate a risk of an explosion similar to those aboard Boeing airplanes, including:

- The electrical bonding straps used on Airbus airplanes have been reported

<sup>10</sup> Document Number FAA-22997-6 in the docket for this rulemaking.

to degrade due to corrosion; the bonding jumpers used by Boeing are made of a different material that does not corrode.

- All fuel pumps on Boeing airplanes are being modified to incorporate ground fault power interrupters, whereas only pumps that can arc directly into the fuel tank ullage are being modified to incorporate ground fault power interrupters on Airbus airplanes.

- The safety assessments conducted by both manufacturers resulted in very similar numbers of ignition sources that required modifications to their airplanes.

- After the SFAR 88 assessments were completed, we learned that fuel quantity indicating probes within the fuel tanks of Airbus A320 airplanes could be an ignition source due to sparks that could be created following a lightning strike. This resulted in the issuance of AD 2006–06–14.

- After the SFAR 88 assessments were completed, we learned that the improper installation of a screw inside the fuel pumps of Airbus A320 airplanes could result in the screw loosening and falling into the pump electrical windings. This could create a spark and ignite vapors in the pump that could exit the fuel pump housing into the fuel tank through the hole created when the screw fell out of the housing. This resulted in the issuance of AD 2006–12–02.

The recent discovery of the ignition sources in Airbus A320 airplanes is evidence that unforeseen failures will occur in the future that can result in ignition sources on Airbus airplanes. The Airbus fleet has significantly fewer flight hours than Boeing airplanes and, as the Airbus airplanes age, we expect to see more unforeseen failures. Therefore, based on design similarities and service history, we see no reason to differentiate between Airbus and Boeing airplanes. This rule requires all affected manufacturers to determine the fuel tank flammability exposure of their airplanes by assessing them against performance-based requirements that specify a flammability exposure that we have determined provides an acceptable level of safety. Additional action is only required for those airplanes that do not meet the required level of fuel tank flammability safety.

#### d. ARAC Flammability Exposure Data

Airbus and AEA both commented that the ARAC flammability exposure data cited in the NPRM are incorrect and need to be reduced based on updated data developed by both Boeing and Airbus. They said this reduction is important since the lower data reduce

the level of safety improvement that can be achieved by this rule from the FAA's intended "order of magnitude" (factor of 10) to a safety improvement in the range of only a factor of 7.7 to 2.7, depending on the model used. Airbus also objected to our conclusion that a HCWT, depending upon the airplane model and its mode of operation, is explosive 12 to 24 percent of the time. Airbus requested that this be corrected to reflect the latest industry estimates for Airbus products (i.e., 8 to 12 percent) and 16 to 18 percent for other manufacturers.

We acknowledge that the flammability exposure data cited in the NPRM may not reflect current values. However, Boeing and Airbus submitted those data to us as part of the SFAR 88 reviews. While we agree with Airbus that more recent information has indicated lower flammability for HCWTs, we do not agree that the more recent values should be used since the manufacturers have not submitted a validated analysis using the revised flammability assessment techniques (as defined in § 25.981) to support its figures. Changes to the method for calculating fuel tank flammability, such as airplane ground times used in the Monte Carlo analysis required by Appendix N may result in additional variations in flammability calculations. Since flammability reduction was first considered by the aviation industry, the flammability values quoted by airplane manufacturers have varied considerably. These variations were the result of the method used to calculate the flammability of the fuel tanks and more accurate fuel tank temperature data based upon flight tests. For example, the first ARAC determined values ranged from 10 to 50 percent for generic airplanes equipped with HCWT. After the conclusion of this activity, Airbus was quoted in *Air Safety Week* as stating the A310 HCWT having a flammability exposure of 4 percent. In 2001, as part of the SFAR 88 compliance, Airbus submitted flammability values to the European Aviation Safety Agency (EASA) and to us that ranged between 12 and 23 percent.

We recognize that as methods for measuring fuel tank flammability are refined, it is likely that calculated flammability exposure will also change. These refinements also apply to the conventional unheated aluminum wing tanks that ARAC used as the baseline for determining an acceptable exposure. We now know that the exposure of these tanks is considerably lower than originally estimated by ARAC. However, none of this new information changes the findings of ARAC that HCWTs have significantly higher risk of fuel tank

explosions, or that the reduction in flammability exposure would be on the order of a factor of 10. Therefore, we do not believe that these refinements change the overall conclusion that certain fuel tanks that are affected by this rule have significantly higher flammability exposure than conventional unheated aluminum wing tanks. No change has been made to the final rule as a result of these comments.

#### e. Accidents Directly Correlate to Flammability Exposure

Airbus did not agree with the assumption that the rate of accidents directly correlates to flammability exposure. Airbus contended that the risk of ignition source development must also be considered when evaluating the benefits of flammability reduction.

We agree with Airbus that the overall risk of a fuel tank explosion includes both the potential for an ignition source and the likelihood that the fuel tank will be flammable when an ignition source occurs. There may be differences in the likelihood of an ignition source occurring between different airplane types, but these differences would be very difficult to quantify. We have no statistically significant, validated data that could be used to establish rates of development of ignition sources for different airplane types. As discussed in the Sandia report, there is a wide variation in the predicted rate of ignition sources developing in fuel tanks and there is no industry agreement on the rate that should be used for individual airplane designs. In addition, recent service history shows there have been a number of ignition sources that have developed following the TWA 800 accident in both Airbus and Boeing airplane models.

Given this lack of data and consensus on ignition source risks, we continue to believe that correlating accident rates with flammability exposure is the most appropriate analytical approach.

#### 2. Additional Research Needed

Airbus, AAPA, AEA, EASA, Iberia Maintenance and Engineering (Iberia), Singapore and Virgin Atlantic Airways (Virgin) stated that this rulemaking is premature because the risks of additional fuel tank explosions are not adequately defined. These commenters argued that additional research is necessary to better understand flammability, SFAR 88 effectiveness and the risks of additional explosions. In a related comment, the International Federation Victims of Aviation Accident (IFVAA) stated that additional research should be performed to identify

technology that would completely eliminate, not just reduce, fuel tank flammability.

We think it would be a mistake to delay this rule to conduct additional research. Service history and the recent occurrences of ignition sources described earlier demonstrate that the risk of future explosions remains significant. In addition, we believe that additional research would not provide any useful information that would change our finding that flammability reduction, in combination with the SFAR 88 measures, is needed to prevent such explosions. As for IFVAA's comment, we consider existing flammability reduction means highly effective and sufficient to reduce the risk of fuel tank explosions to an acceptable level. While further research might identify even better solutions, the resulting delay would deprive the public of the benefits of these currently available safety improvements.

### 3. Consistent Safety Level With Other Systems

Airbus commented that SFAR 88 improvements, together with the current rate of occurrence, put fuel tank safety on the order of one accident for every billion flight hours (i.e.  $10^{-9}$  accidents per flight hour) which is consistent with safety objectives of other critical airplane systems.<sup>11</sup> Airbus argued that this rule requires fuel tanks to go to a higher level of safety than other critical systems and that this is inconsistent with the overall risk.

Application of existing safety standards to prevent ignition sources that are similar to those applied to other systems has not resulted in an acceptable level of safety, and we have determined that limiting fuel tank flammability is also needed. Fuel tank explosions are unacceptably occurring at a rate greater than  $10^{-9}$  per flight hour and the recent events described above show that unanticipated failures continue to result in ignition sources within airplane fuel tanks. To protect the flying public, we have developed a "fail safe" policy for fuel tank safety that includes both ignition prevention and flammability reduction to reduce fuel tank explosion risk to an acceptable level.

### 4. Human Errors

AEA stated that human errors are not new and should not be used to justify this rule. AEA pointed out that TC

holders are obliged to consider human error during airplane design to mitigate errors. In addition, continuing airworthiness instructions (e.g., maintenance manuals) highlight safety considerations where necessary. AEA also contended that, in the 17 accidents cited by the FAA in the NPRM, there is no evidence that any were caused by the introduction of an ignition source through human error. Finally, AEA noted that human errors will always be a factor in aviation safety, particularly when introducing added complexity such as an inerting system.

We agree with AEA that human errors are not a new phenomenon and that the introduction of new systems on airplanes can have unintended consequences resulting from human error. We also believe the safety benefits of FRM or IMM is warranted. Service history shows the current regulations do not provide an adequate mitigation of human errors for fuel tank systems. Ignition sources continue to occur even though designers have conducted analyses that concluded ignition sources would not occur. Earlier in this document, we discussed numerous ignition sources that have recently developed in airplanes that had previously been shown by safety assessments to have features that would prevent ignition sources from developing. These ignition sources were caused by errors in defining assumptions in safety assessments, as well as in the design, manufacture and maintenance of these airplanes. These events show that an additional layer of protection (in the form of FRM or IMM) is needed to prevent future fuel tank explosions.

### 5. Explosion Risk Analysis

American Trans Air commented that the assumptions made in the explosion risk analysis were erroneous and not within the range of reasonable values. American Trans Air recommended that a completely new analysis of the fuel tank explosion risk be undertaken. This new analysis should utilize widely accepted assumptions, including taking into account:

- The history of particular type designs.
- The actual ignition risk potential (i.e., potential ignition sources not in the ullage are either exempted, or substantially discounted in the analysis).
- Actual ignition energies, applying these energies to the potential ignition sources.
- The definitions and assumptions of fuel-air vapor mixtures that have been

further derived and applied on an individual type design basis.

We agree with the commenter that the assumed fuel air vapor mixture should be based upon the individual fuel tank design, and we included variations in the pressure and temperature of the fuel when developing the fuel tank flammability model. This factor is already accounted for in the Monte Carlo method defined in Appendix N. As for the other assumptions offered by American Trans Air, they cannot be used in an analysis, because there is a wide variation in the possible values.

### 6. Special Certification Review Process vs. Rulemaking

American Trans Air commented that if an analysis identifies type designs still found to have unacceptable risk after all SFAR 88 alterations have been executed, an appropriate response to address the remaining at-risk type designs may be the use of the special certification review process. American Trans Air noted that there appears to be wide variability in the risk between type designs, and concluded that generalized rulemaking is inappropriate at this time.

We do not agree that we should address each type design with unacceptable flammability risk by special certification review and then by an appropriate AD. Through careful study, we have determined that the flammability risk on many airplanes is too high. To address this risk, we have created an objective design standard by which all airplanes can be measured. If airplanes currently meet this design standard, no action will be required. The TC holder for those airplanes that do not meet it will have to make only those changes that bring that airplane model into compliance. We have determined that the uncertainty involved in the elimination of ignition sources requires reduced flammability to acceptably reduced tank explosion risk, and the most effective and efficient way to address this issue is through the rulemaking process.

### 7. Flammability Reduction Means (FRM) Effectiveness

In the NPRM, we said lowering the flammability exposure of the affected fuel tanks in the existing fleet and limiting the permissible level of flammability on new production airplanes would result in an overall reduction in the flammability potential of these airplanes of approximately 95 percent. Airbus and AEA commented that we overstated the potential benefits of flammability reduction measures by a factor between 4 and 7. They said we used a factor of 20 (95 percent) for the

<sup>11</sup> This is the quantitative probability measure (one in one billion) of an event that is "extremely improbable" as that term is used in § 25.1309 and other part 25 airworthiness standards. See AC 25.1309.

reduction in flammability exposure achieved by reducing the flammability of HCWT to 3 percent or less. They said the subsequent reduction in flammability will be in the order of a factor of three to five and not a factor of 20. Therefore, the number of accidents prevented would consequentially be less than projected by the FAA. Airbus also said the FAA appears not to have considered the effectiveness of the FRM itself, which it said is in the order of 67 to 87 percent by latest industry estimates. Therefore, Airbus suggests that the Initial Regulatory Evaluation (IRE) is incomplete and should be revised to include this key parameter.

The 95 percent value used in the NPRM was not based on the ratio of fuel tank fleet average flammability exposure before and after implementing the requirements of this rule. It was derived by qualitatively evaluating the effectiveness of an FRM in preventing fuel tank explosions that would not be prevented by ignition prevention measures.

When an FRM is installed on a fuel tank, it must meet both the 3 percent fleet average flammability exposure and also the 3 percent warm day (specific risk) flammability exposure requirements.<sup>12</sup> For the warm day requirement, the flammability exposure must be below 3 percent during ground and takeoff/climb conditions for those days above 80 degrees F when the FRM is operational. These are the conditions when fuel tanks tend to have the highest flammability exposure and when the accidents discussed earlier occurred.

The combination of the warm day requirement and the fleet average flammability requirement results in an FRM with overall flammability reduction benefits that are significantly higher than those estimated by the commenters. Since the NPRM was issued, we have reviewed and approved FRM designs and have found the performance exceeds the certification limits. When the FRM is operating, the fuel tanks are rarely flammable. So, the major risk of fuel tank flammability occurs when the system is inoperative and this time is limited to a maximum of 1.8 percent of the Flammability

<sup>12</sup> The overall time the fuel tank is flammable cannot exceed 3 percent of the Flammability Exposure Evaluation Time (FEET), which is the total time, including both ground and flight time, considered in the flammability assessment defined in proposed Appendix N. As a portion of this 3 percent, if flammability reduction means (FRM) are used, each of the following time periods cannot exceed 1.8 percent of the FEET: (1) When any FRM is operational but the fuel tank is not inert and the tank is flammable; and (2) when any FRM is inoperative and the tank is flammable.

Exposure Evaluation Time (FEET). Historically, designers provide a safety margin in the design so that the design limits are never exceeded, so we would expect the flammability to be below this level.

Another consideration in using a 95 percent effectiveness measure is the safety improvement noted during warm days. Without any FRM, a HCWT is flammable about 50 percent of the time during climb. Meeting both the 3 percent warm day requirement and the 3 percent reliability requirement results in a flammability exposure of the tank of less than half of one percent during climb. For an airplane with an initial warm day flammability of 50 percent, this is a 99 percent reduction in the flammability during climb. We, therefore, used the 95 percent effectiveness for flammability reduction in the risk model for the final regulatory evaluation.

### C. Applicability

#### 1. Airplanes With Fewer Than 30 Seats

The proposed DAH requirements would apply (with some exclusions) to transport category turbine-powered airplanes approved for a passenger capacity of 30 or more persons or a maximum payload capacity of 7,500 pounds or more. The UK Air Safety Group disagreed with the proposed rule's limited applicability because the design of fuel tank systems is similar for both large and small airplanes. Therefore, it argued that the potential explosion hazard is equal. The commenter also noted that EASA's CS-25 regulation for Fuel Tank Ignition Prevention does not make any distinction based on the number of passenger seats.

We did not include smaller part 25 airplanes in the DAH requirements of this final rule because those airplanes generally do not have high flammability tanks. While some parts of their fuel tank system designs are similar to those of larger airplanes, we do not agree that the overall architecture and the risk of a fuel tank explosion are equal. Data submitted by manufacturers of smaller part 25 airplanes as part of the SFAR 88 analysis show that their airplanes typically do not have fuel tanks located within the fuselage contour, and would not be considered high flammability fuel tanks. In most cases, cool fuel from the wing tanks is drawn into the center wing box, so the overall flammability is low. In addition, these tanks are not normally emptied, reducing the amount of ullage.

Based on these facts, the benefits of including these smaller airplanes in all

of the requirements of this rule are minimal and do not warrant the cost. However, we do agree that the part 25 requirements applicable to new type designs should be the same for all transport category airplanes, regardless of size. The cost to design and produce a new airplane to meet the flammability requirements is significantly less than that for existing airplanes since the designers can optimize the performance of the FRM or IMM and integrate it into the airplane design to minimize costs. Therefore, § 25.981 of this rule applies to all transport category airplanes regardless of size.

#### 2. Part 91 and 125 Operators

The NPRM proposed that operators under parts 91, 121, 125, and 129 incorporate FRM or IMM and keep it operational on their affected airplanes. The AEA and Airbus asked that parts 91 and 125 operations be excluded and cited corporate use airplanes as an example of operations where the cost would far exceed the benefit. According to AEA and Airbus, the cost/benefit analysis for these airplanes, when operated under part 91 or part 125, would produce results similar to those for all-cargo airplanes (which are excluded from the retrofit requirements of this rule).

We recognize a distinction between part 91 and part 125 operations, in that part 91 does not allow commercial operations for compensation or hire, while part 125 does allow such operations, as long as the operator does not "hold out" to the public that they are available for such operations (in which case they would be required to operate as an air carrier). For example, many business jets are operated under part 91 if the operator does not receive compensation for transporting passengers (e.g., a corporate jet transporting the corporation's employees). On the other hand, charter companies frequently operate under part 125 to transport sports teams and other groups for compensation.

While we recognize that private owners and operators may choose to assume the risk of possible fuel tank explosions, we see no reason why persons flying on commercial charter flights should be exposed to a greater risk of a fuel tank explosion than passengers flying on airplanes operated under parts 121 and 129. Commercial charter passengers are in no better position to recognize and accept the risk of a fuel tank explosion than are air carrier passengers. Additionally, the risk and likelihood of a fuel tank explosion are potentially commensurate with that of the same airplane model operated

under parts 121 and 129. Therefore, the final rule has been revised to exclude part 91 operations, but does not exclude part 125 operations. However, because of the significant safety benefits of this rule, we encourage part 91 operators to install FRM on their airplanes, and not to remove it if it is already installed.

### 3. All-Cargo Airplanes

In response to our request for comments on the proposed exclusion of all-cargo airplanes from this rulemaking, we received numerous comments both supporting and opposing the exclusion. Airbus, the Cargo Airline Association (CAA), FedEx, ATA, ABX Air (ABX), United Parcel Service (UPS), and National Air Carrier Association (NACA) agreed that all-cargo airplanes should be excluded from this rulemaking. The CAA argued that the risks are lower for cargo carriers due to several factors:

a. Cargo operations are predominately night operations with lower outside ambient temperatures (making fuel tanks less likely to be flammable).

b. Cargo operators do not typically run air conditioning packs prior to takeoff as many passenger operators do.

c. The CAA members typically operate one to two round trips each day, which is a lower utilization rate than most passenger airplanes.

The CAA stated that costs to various airline industry segments should be considered when proposing any new regulation. The CAA supported establishing a safety baseline which allows different operations to meet the baseline in different ways. Based on the factors articulated above, the CAA maintained the cost/benefit analysis does not justify its application to cargo airplanes.

FedEx commented that there is a finite amount of safety dollars and it is important to use them effectively. As the cost/benefit analysis does not justify inclusion of all-cargo airplanes, FedEx claimed it is not permissible to include them under FAA rulemaking authority. ATA stated that the proposed rule should not apply to all-cargo airplanes, other than the design rules proposed to prevent modifications that could increase the flammability exposure of a fuel tank. ABX agreed with ATA, and noted that the ignition prevention measures of SFAR 88 provide an acceptable level of safety for these airplanes. Finally, Airbus and UPS based their support for our proposal to exclude cargo airplanes on the reasons stated in the NPRM.

On the other hand, the National Transportation Safety Board (NTSB), the Independent Pilots Association (IPA),

the Air Line Pilots Association (ALPA), the EASA, the Coalition of Airline Pilots Association (CAPA), Singapore and the National Air Traffic Controllers Association (NATCA) do not agree that all-cargo airplanes should be excluded from this rulemaking. While the NTSB, IPA and NATCA acknowledged that cargo airplanes typically carry fewer people, they pointed out that these airplanes regularly use airports in densely populated areas where an accident could have a catastrophic effect for people on the ground. The NTSB and IPA also cited a recent DC-8 cargo fire accident where an inerting system might have prevented or substantially reduced the magnitude of the fire, and a C-5A accident at Dover Air Force Base where the presence of an inerting system may have been the reason many lives were saved.

The IPA also stated that there should be one level of safety for all part 25 airplanes, and noted that all-cargo airplanes are typically older (which makes them more susceptible to ignition sources within the tank). In addition, ADs are being issued on even the newer models to restrict operations for flammability/ignition concerns.

ALPA commented that all-cargo airplanes should not be excluded from critical safety improvements simply because there are fewer fatalities in a typical crash. ALPA recommended that we apply a firm deadline for the manufacturers to complete a flammability analysis on all-cargo airplanes compared to the passenger versions of the same airplane model.

EASA did not agree with introducing a new distinction among part 25 products. In EASA's view, the justification for excluding all-cargo airplanes has yet to be substantiated. CAPA thought the logic of excluding all-cargo airplanes could be extended to each individual operator or to all airplanes with differing passenger capacities. For example, CAPA questioned whether, if operator "A" had many more Boeing 737 airplanes than operator "B", would we require Operator "A" to use FRM while Operator "B" would not have to. CAPA stated that this same type of flawed logic is being applied to all-cargo airplanes. In its opinion, the value of pilot lives should not depend on what is in the back of the airplane. Finally, NATCA commented that confidence in flying would be diminished if there were a cargo airplane accident, and we should not set a precedent that sets a different safety standard based on the intended operation of the airplane.

Boeing stated that its safety philosophy is to not differentiate

between passenger and cargo airplanes in managing fleet-wide airplane risk and therefore, did not exclude airplanes designed solely for cargo operations in their proposed revision to § 25.981(b).

After reviewing these comments, we have decided that we will not require existing all-cargo airplanes to meet the retrofit requirements in this final rule. We did not receive any data on the costs, benefits or risks for all-cargo airplanes in response to our request in the NPRM, and we do not have any new data to justify requiring retrofit of FRM or IMM on the current fleet of all-cargo airplanes. We will continue to gather additional data regarding these factors and may initiate further rulemaking action if the flammability of these airplanes is found to be excessive.

However, we will require compliance with the requirements of this final rule for (i) future designs; (ii) the conversion of any passenger airplane with an FRM or IMM to all-cargo use; and (iii) future production of all-cargo airplanes. We agree with NATCA and other commenters with respect to removing the exclusion from § 25.981 of airplanes designed solely for all-cargo operations. The airworthiness standards of part 25 do not impose different requirements depending on the intended use of the airplane. 49 U.S.C. 44701 requires that we adopt such minimum airworthiness standards as are necessary, and historically we have recognized that those minimum standards should be the same for all transport category airplanes, regardless of their intended use. There are practical reasons for this approach, since the intended use can change quickly based on business considerations unrelated to safety. Therefore, we agree that the proposed new design standards in part 25 should not distinguish between all-cargo and passenger airplanes.

The rationale for including a production cut-in for all-cargo airplanes is based upon the long-term goal of fleet-wide reduction in flammability exposure to eliminate the likelihood of fuel tank explosions. In addition to the immediate effects of an accident, we believe a fuel tank explosion on an all-cargo airplane could have a significant impact on the aviation industry due to public sensitivity to terrorist actions. The cost of installing FRM in new production airplanes is less than the cost of to retrofit airplanes, because the installation can be efficiently integrated into the production process. In most cases, this integration will be done for the passenger version of the same airplane, so additional engineering work will be minimal. The benefits of production cut-in are also higher than

for retrofit since the new airplane has a longer life and reduced flammability will provide safety benefits for the life of the airplane.

As for conversion airplanes, when older airplanes can no longer be operated competitively in passenger service, it is common for them to be converted to all-cargo service. Since many passenger airplanes will have FRM or IMM already installed as a result of this rule, operators may be inclined to deactivate or remove the FRM or IMM to reduce operational costs, if these airplanes are converted to all-cargo airplanes in the future. We do not believe it would be in the public interest to allow previously installed systems to be deactivated because the capital cost to install the systems would already have been incurred, and the safety benefits of retaining the system would outweigh any cost savings that might result from deactivating them. Accordingly, we have revised the operational rules to prohibit deactivation or removal of FRM or IMM under this scenario.

The regulatory evaluation for this final rule has been revised to address these factors and concludes that imposing these requirements on all-cargo airplanes is cost effective for new designs and newly produced all-cargo airplanes. Prohibiting deactivation of FRM or IMM on converted airplanes is also cost effective.

#### 4. Specific Airplane Models

Proposed § 25.1815(j) listed specific airplane models that would be excluded from the requirements of proposed § 25.1815 (now § 26.33). These are airplane models that, because of their advanced age and small numbers, would likely make compliance economically impractical. In the NPRM, we asked for comments on other airplane models that may present unique compliance challenges and should be excluded from the requirements of this rule. In response to this request, we received several comments requesting that additional specific airplane models be excluded from this rule. Given the number of models identified, we have decided it makes more sense to “grandfather” all models manufactured before a certain date. Based on these comments, we have changed the applicability of the design approval holder requirements in proposed § 25.1815(a) (now § 26.33(a)) from those airplanes type certificated after January 1, 1958 to those airplanes produced on or after January 1, 1992.

a. Out-of-Production/Low Service Life Remaining Models

Boeing and Airbus recommended that the rule only apply to airplane models and auxiliary tanks currently in production, or recently out-of-production, that have significant numbers in service and will continue in service well beyond the date when 100 percent compliance is achieved. Based on this standard, Boeing submitted a list of airplane models and auxiliary tanks to add to the excluded models in proposed § 25.1815(j), including the DC-8, DC-9, DC-10, MD-80, MD-90, MD-11, Boeing 707, 720, 727, 737-100/-200, 747-100/-200/-300 and associated derivatives, and 737-300/-400/-500 (auxiliary tanks only). Airbus requested that the Airbus A300/A310 series airplanes be added to the list based on this standard.

We acknowledge that there is no reason to require design approval holders (DAHs) to develop design changes for airplanes that will be retired before FRM or IMM installation is required by this rule. Conducting the flammability assessments and developing design modifications for those airplanes would require significant engineering resources. More importantly, these airplanes would not benefit from the development of FRM or IMM, since they would be retired or converted to cargo operations before the installation of these systems is required. Therefore, we have limited the applicability of the DAH requirements in the final rule (proposed § 25.1815(a), now § 26.33(a)) to airplanes produced on or after January 1, 1992.

The youngest of the airplanes produced before then would be more than 25 years old by the time operators would be required to modify them. We agree with the commenters that the vast majority of these airplanes would either be retired or converted to cargo service before they reach that age. This is consistent with current practice. This limitation has the effect of excluding the Boeing 707, 727, 737-100/200 and 747-100/200/300; the McDonnell Douglas DC-8, DC-9, DC-10, and KC-10/KDC-10; and the Lockheed L-1011. Airplanes of the other models that Boeing, Airbus and ATA requested be excluded have been produced on or after January 1, 1992. For airplanes produced on or after January 1, 1992, the remaining life and likelihood of their continued operation in passenger service is sufficient to require compliance with the requirements of this rule.

To clearly differentiate between airplanes produced before and after this date, we changed proposed § 25.1815(a)

(now § 26.33(a)) to refer to the date when “the State of Manufacture issued the original certificate of airworthiness or export airworthiness approval.” This information is readily available to the TC holders who applied for these approvals. We also added a provision to proposed § 25.1815(d) (now § 26.33(d)) to require the service information describing FRM or IMM to identify the airplanes that must be modified under this rule. This will make it readily apparent to operators which of their airplanes are subject to the retrofit requirements.

For airplanes with high flammability tanks produced before 1992, instead of requiring operators to retrofit these airplanes, we have added a provision in the operational rules prohibiting passenger operations of these airplanes after the date by which an operator’s airplanes that are subject to the retrofit requirement must be retrofitted.<sup>13</sup> This enables operators to convert these airplanes to cargo service rather than to retrofit them. If operators of these airplanes choose to operate them in passenger service past this date, they could contract with the DAH or a STC vendor to develop an FRM or IMM to meet the safety requirements of this rule. Without this provision, the exclusion of airplanes produced before 1992 could have the unintended consequence of encouraging operators to continue to operate these airplanes with high flammability tanks in passenger service, since the retrofit and operating costs of FRM or IMM would not have to be incurred.

These changes to the DAH and operational rules have the effect of making the applicability of these requirements different. The DAH requirements now only apply to airplanes produced on or after January 1, 1992, but the operational rules still apply to all airplanes meeting the applicability criteria proposed in the NPRM.<sup>14</sup> Therefore, we have revised the applicability provisions of the operational rule sections to incorporate these criteria, rather than referencing the applicability of the DAH rules.

As for Boeing’s request to exempt certain auxiliary fuel tanks, as discussed

<sup>13</sup> As discussed later, we are also adding a provision that allows operators under parts 121 and 129 to extend the compliance date by one year based on use of ground conditioned air. Operators using this extension will be able to operate these pre-1992 airplanes in passenger service until they are required to have all of their post-1991 airplanes retrofitted.

<sup>14</sup> With certain listed exceptions, transport category turbine-powered airplanes type certificated after January 1, 1958, with a maximum passenger capacity of 30 or more or a maximum payload capacity of 7,500 pounds or more.

later in more detail, we have retained the requirement to conduct flammability assessments and impact assessments for auxiliary fuel tanks. However, we have delayed any action to require retrofit of IMM or FRM for auxiliary fuel tanks installed under STCs and field approvals until additional information can be gathered. We agree with Boeing that any auxiliary fuel tank installed in pre-1992 airplane models should also be excluded from the need to conduct flammability assessments, since we have determined we would not take action against any tank in these airplane models due to their advanced age.

#### b. Limited U.S. Inventory Models

Airbus requested that airplanes having a limited U.S. inventory be excluded from this rule, because the operators of these airplanes would shoulder a disproportionate impact of non-recurring engineering expenses needed to design and develop FRM systems. Under this standard, Airbus asked that the A330-200 (only 11 N-registered airplanes) and the A340 (no N-registered airplanes) be added to proposed § 25.1818(j). We cannot agree with the Airbus suggested approach. We have no way to predict future market conditions in the United States for the A330-200 and A340 model airplanes. Airbus continues to sell these models and lessors continue to offer them for lease. Based on market conditions, U.S. operators may add these models to their fleets in larger numbers and we see no reason why persons flying on these airplanes should be exposed to a greater risk of a fuel tank explosion. Therefore, we are not excluding these airplane models from the requirements of this final rule.

#### c. Airbus A321

Airbus and ATA suggested the A321 should be excluded because this model does not have fuel pumps in the center wing tank, reducing the risk of a fuel tank explosion. The lack of fuel pumps does not adequately mitigate the risk of an explosion. There are numerous potential ignition sources inside fuel tanks that can result from failure of various components, including the fuel quantity indication system, motor driven valves, fuel level sensors, and electrical bonds. In addition, heating of the fuel tank walls by external heat sources introduces a concern that the hot surface could ignite the vapors in the tank. The justification provided for excluding this model (because the center tank does not have motor driven pumps located in the tank) does not address the overall fuel tank safety issue and would only have merit if fuel pump

failures were the only potential ignition sources. Therefore, we are not excluding this airplane model from the requirements of this final rule.

#### d. Airplanes With Low Flammability Tanks

The proposed retrofit limit for an acceptable fleet-wide average flammability exposure was 7 percent. We determined that fuel tanks having a flammability exposure greater than 7 percent are high flammability tanks that present a greater risk for fuel tank explosion. American Trans Air commented that, we stated in the NPRM that some airplanes have center tanks with a fleet average flammability exposure that does not exceed 7 percent, including “the Lockheed L-1011, and Boeing MD-11, DC10, MD80, and Boeing 727, and Fokker F28 MK100.” American Trans Air stated that this implies that we have information in our possession indicating that these airplane models already meet the proposed flammability limits, and asked that we add these models to the list of excluded airplanes in proposed § 25.1815(j) (now § 26.33).<sup>15</sup>

The statement quoted by American Trans Air from the NPRM was based on previous flammability assessments provided to us for SFAR 88 compliance. These assessments were based upon simplified assessment methods. For airplanes produced after January 1, 1992, we have retained the requirement to conduct flammability assessments on these airplanes to ensure that the earlier assessments are correct and that design changes for these tanks are not necessary. Once the assessment has been made, a manufacturer or operator may not need to make any change to the airplane. This is because the flammability risk assessment may disclose a level of risk below the threshold required for modification. As discussed earlier, we are allowing a qualitative assessment for conventional unheated aluminum wing tanks, which will substantially reduce the burden for completing the flammability assessments.

#### 5. Wing Tanks

##### a. General

Proposed § 25.981 does not apply the same flammability standard to all fuel tanks, and requires lower flammability

limits for “fuel tanks that are normally emptied and located within the fuselage contour.” The NTSB expressed concern that wing fuel tanks have exploded, and noted that its safety recommendations were not limited to:

- (1) Certain types of fuel tanks,
- (2) Tanks with specific types of exposure, or
- (3) Tanks with explosive risks that vary or lessen over time.

The NTSB stated that we should take action to prevent all tanks from having flammable fuel-air mixtures in the ullage. The NATCA agreed, and stated that, to achieve an acceptable level of safety, the requirements of § 25.981 that apply to new airplanes should establish the same flammability standard for all fuel tanks regardless of location. The NATCA supported this suggestion by referencing the ARAC accident summaries that showed 8 out of 17 fuel tank explosions have involved wing tanks. The ALPA also expressed concern that certain wing designs and system installations may result in internal heating of the wing structure and ultimately the wing fuel tanks. The ALPA stated that we must insist that those specific installations fall under the requirements of this rule and that no unsafe flammability exposure exist in those wing tanks.

In contrast, Embraer, Bombardier Aerospace (Bombardier), and American Trans Air opposed incorporation of new flammability standards for conventional wing tanks. Embraer stated the benefits would be negligible and would not justify the costs. Embraer maintained that service history provides ample evidence that conventionally designed wing tanks inherently provide sufficient protection from fuel tank ignition when conventional fuels are used and that the current requirements are adequate. American Trans Air commented that many twin engine airplane type designs utilize a common fuel system operational concept that results in low exposure to high energy ignition sources in the main wing tanks. This exposure is further reduced in airplanes operated in extended-range twin-engine operations (ETOPS) service, due to the increased fuel reserves required in these operations.

The service history of conventional unheated aluminum wing tanks that contain Jet A fuel indicates that there would be little safety benefit by further limiting the flammability of these tanks. While NATCA and the NTSB expressed concern because accidents have occurred in wing fuel tanks, they did not differentiate service experience based on fuel type used (JP-4 versus Jet

<sup>15</sup> As we discussed above, we have limited the applicability of the DAH requirements in § 26.33 to airplane models produced on or after January 1, 1992. This date excludes the Boeing Model 727, DC-10 and the Lockheed L-1011. The other airplane models mentioned by the commenter have airplanes produced after 1991 and would be covered by this rule.

A). Our review of the nine<sup>16</sup> wing tank ignition events shows that 5 of the 9 airplanes were using JP-4 fuel and this type fuel is no longer used except on an emergency basis in the U.S. Three of the remaining four events were caused by external heating of the wing by engine fires, and the remaining event occurred on the ground during maintenance. To date, there have been no fuel tank explosions in conventional unheated aluminum wing tanks fueled with Jet A fuel that have resulted in any fatalities. The flammability characteristics of JP-4 fuel results in the fuel tanks being flammable a significant portion of the time when an airplane is in flight. This is not the case for wing tanks containing Jet A fuel. Therefore, a conventional unheated aluminum wing tank (that quickly cools in an airplane model approved for Jet A fuel) would not require FRM or IMM.

As proposed, § 25.981(b) maintained the intended flammability standards for wing tanks that were introduced in 2001, as part of Amendment 25-102 to part 25.<sup>17</sup> The proposed text clarified the existing term “means to minimize the development of flammable vapors” by including references to a conventional unheated aluminum wing tank, or 3 percent average flammability. Therefore, no new flammability standards are introduced for conventional wing tanks. Fuel tanks manufactured from materials other than aluminum, or that have unique features that would not allow cooling of the fuel tank (such as a small surface area exposed to the air stream) or that are heated (such as by having warm fuel transferred from another tank) may need FRM to comply with the previously issued requirements.

#### b. Use of Composite Materials

Airbus pointed to the industry trend towards the use of composite materials, which tend to have a lower heat transfer coefficient than aluminum. These materials act as insulators, slowing down any heating or cooling effects. Therefore, new TC designs using composite structures will have a natural flammability exposure greater than an equivalent conventional unheated aluminum wing tank, and designers will be forced to implement FRM. The NATCA noted that, with increased use

of composites in wing designs, the assumption that wing tanks cool adequately may be incorrect.

We agree that composite materials may act as an insulator that will not allow fuel tank cooling, resulting in increased flammability. Limiting fuel tank flammability using FRM may be needed to meet the flammability exposure of a “conventional unheated aluminum wing tank” that is required by § 25.981. Airbus’s suggestion that it is impractical for the rule to mandate the use of inerting for wing fuel tanks on airplanes with composite fuel tanks is not supported by recent events. While this rule is performance based and means other than inerting could be used, inerting has been found to be one means that is both technically feasible and economically viable. For example, the Boeing 787 will have wing fuel tanks constructed of composites, and FRM using nitrogen has been incorporated into the design to reduce the fuel tank flammability below that of a conventional aluminum wing tank.

### 6. Auxiliary Fuel Tanks

#### a. Definition

In the NPRM, we described auxiliary fuel tanks as tanks that are installed to permit airplanes to fly for longer periods of time by increasing the amount of available fuel. The proposed rule defined an auxiliary fuel tank as one that is normally emptied and has been installed pursuant to an STC or field approval to make additional fuel available. We also stated that auxiliary fuel tanks are “aftermarket” installations not contemplated by the original manufacturer of the airplane.

Airbus and AEA suggested the definition of auxiliary fuel tank should be clarified. They recommended that we use the generally accepted definition that is in AC 25.981-2. Boeing also requested that the definition of an auxiliary fuel tank be revised to more generally state that it is a fuel tank added to an airplane to increase range instead of referencing it as one installed pursuant to an STC or field approval. Boeing noted that an airplane might be delivered with an Original Equipment Manufacturer designed, manufactured and type certified auxiliary fuel tank.

Changes to the regulatory text in proposed subpart I (now part 26) resulted in eliminating the need for this definition in the final rule. Therefore, we have deleted the definition of auxiliary fuel tank from proposed § 25.1803(a) (now § 26.31(a)) and will maintain the definition in AC 25.981-2.

#### b. Existing Auxiliary Tanks

Boeing, Airbus, AEA, and ATA commented that older auxiliary fuel tanks should be exempt from the requirements of this rule since the benefits would be small compared to the cost of the retrofits. Boeing stated by the year 2016, most of the airplanes with auxiliary tanks installed during production would be over 30 years old. Future service life is generally thought to be minimal for these older airplanes. Boeing also commented, based upon feedback received from some operators, that these operators would deactivate their auxiliary fuel tanks rather than install FRM or IMM. The ATA added that the favorable service history (no operational accidents caused by auxiliary tank overpressures or explosions), operating environment (minimal exposure to flammable conditions), and proximity to retirement for many of these tanks makes it unnecessary to include auxiliary tanks in the applicability of this rule. Finally, Embraer commented that only auxiliary fuel tanks located close to heat sources and lacking free stream cooling require the special attention that the rule proposes.

As discussed previously, we changed the language in proposed § 25.1815 (now § 26.33), which applies to TC holders, to limit its applicability to airplanes produced on or after January 1, 1992, and this would include any auxiliary fuel tanks installed by the original TC holder. Since § 26.35 (formerly § 25.1817) applies only to design changes to airplanes subject to § 26.33, this change from the NPRM has the effect of excluding most of the older auxiliary tank designs installed by STC or field approval, which were approved for installation on airplanes no longer subject to this rule.

For those auxiliary tanks approved under STCs or field approvals (if any) that are still covered under the rule, we believe that most of these tanks transfer fuel by pressurizing the tank with cabin air. The increased pressure results in reduced flammability that could be considered an FRM if the minimum flammability performance requirements are met. However, we have limited data on the number of these tanks currently in operation and their age. We currently do not have adequate information on the flammability exposure or the number and the type of auxiliary fuel tanks installed under STCs or field approvals to determine whether to subject them to the requirements of this final rule. Based upon these limited data, we cannot predict the number of high flammability auxiliary fuel tanks that

<sup>16</sup> As discussed previously, on May 6, 2006, a ninth wing tank ignition event occurred.

<sup>17</sup> As discussed in the NPRM, Amendment 25-102 revised § 25.981 to require that fuel tank flammability exposure be “minimized.” As explained in the preamble to that final rule, the objective of this requirement is to reduce the flammability exposure to that of an unheated aluminum wing tank.

will be in service in 2016 or the number of airplanes with auxiliary fuel tanks installed by STC or field approvals that could still be operational for some period of time past the year 2016.

While no conclusive evidence has been presented, the commenters have raised issues worthy of further study. To prevent delaying the safety benefits of compliance with this rule, we have elected to defer the portion of this rulemaking that would have required development and installation of an FRM or IMM for auxiliary fuel tanks installed by STC or field approvals for further study. We have removed these proposed requirements from both the DAH and operational rules.

To assess the possible safety benefits and costs more accurately, we are requesting further comments regarding information needed to determine if future action should be taken to address auxiliary fuel tanks installed by STC or field approvals. The rule retains the requirements for STC holders to conduct a flammability assessment of auxiliary fuel tank designs, to conduct an impact assessment of the auxiliary tank on any FRM or IMM, and to develop the modifications for any adverse impact that is found. These requirements are still necessary both to assess the need for further rulemaking and to prevent increasing the flammability exposure of tanks into which the auxiliary tanks feed fuel. This could potentially defeat the purpose of requiring reduced flammability for these tanks. To limit the scope and cost of the requirement to perform impact assessments, this requirement only applies to auxiliary tanks approved for installation on Boeing and Airbus airplanes that we currently are aware will be required to have FRM or IMM installed.

#### c. Future Installation of Auxiliary Tanks

While we are foregoing action to require retrofit of existing auxiliary fuel tanks, we recognize that this decision could allow installation of currently approved auxiliary fuel tanks indefinitely, even if their flammability exposure exceeds those allowed under this rule. Therefore, we have added a new paragraph to the operational rule sections<sup>18</sup> in this final rule to prohibit installation of any auxiliary tank after the retrofit compliance date (nine years after the effective date) unless we have certified that the tank complies with § 25.981, as amended by this rule.

#### d. Request for Comments

As discussed previously, we have concluded that additional information is needed before we can determine whether it would be cost effective to apply the requirements of this final rule to auxiliary fuel tanks installed under STCs or field approvals. The FAA, therefore, requests additional comments addressing the following specific questions:

1. Which airplanes produced on or after January 1, 1992, with 30 passengers or more or a payload of 7500 pounds, have auxiliary fuel tanks installed by STC or field approval?

2. What are the U.S. registration tail numbers of the airplanes with the tanks installed?

3. How many of these tanks are installed in airplanes used in all-cargo operations?

4. What is the STC holder's name and what are the STC numbers for these tanks?

5. How many of these tanks are installed under the Form 337 field approval process?

6. Are the tanks operational or deactivated?

7. How many engineering hours would be required to develop an FRM or IMM for these tanks?

8. How much would the parts cost for an FRM or IMM for these tanks?

9. What would the labor costs be for installing an FRM or IMM in these tanks?

10. How many days would it take to install an FRM or IMM in the affected airplane?

11. If the FAA required operators to install FRM or IMM, would those operators modify those tanks accordingly, or would they comply by simply deactivating those tanks? Please be model-specific for both passenger and all-cargo airplanes, if possible.

12. What would be the economic consequences to the operator of deactivating an auxiliary fuel tank?

Comments should be submitted to Docket No. FAA-2005-22997 by January 20, 2009. Comments may be submitted to the docket using any of the means listed in the **ADDRESSES** section later in the document.

#### 7. Existing Horizontal Stabilizer Fuel Tanks

In the NPRM, we stated that horizontal stabilizer fuel tanks are fuel tanks that may be required to be retrofitted with FRM or IMM. We understood that these tanks may not cool rapidly, since a large portion of the fuel tank surface is located within the fuselage contour. Airbus stated that they

do not believe the rule should apply to horizontal stabilizer fuel tanks, because these types of fuel tanks are low flammability and, if these tanks are treated as high flammability, the rule would impose significant additional costs to install FRM or IMM for these tanks. Therefore, Airbus concluded that we should either review these additional engineering complications and associated costs (particularly with respect to retrofit) or apply the same requirements to these tanks as those proposed for wing tanks not in the fuselage contour.

The retrofit requirement of this rule only applies to fuel tanks that have an average flammability exposure above 7 percent. To the extent the risk analysis indicates a particular fuel tank actually is a low risk tank, no further requirements would apply. Some horizontal stabilizers, including those made by Airbus, are manufactured from composite material that acts as an insulator. These tanks may also be used to maintain airplane center of gravity, so warmer fuel may be transferred into them during flight. These features may result in flammability exposure that exceeds the 7 percent limit that is used to establish whether retrofit of an FRM or IMM is required. Tanks constructed of composites may also exceed the flammability exposure established for new designs in § 25.981(b).

The analysis required by this rule will establish the flammability exposure and determine the need for an FRM or IMM in horizontal stabilizer fuel tanks. If fuel tanks located within the horizontal stabilizer are not high flammability tanks, then no FRM or IMM would be needed and no additional cost would be incurred for retrofit. However, if an FRM or IMM is required because the tank is determined to be high flammability, it should be possible, using standard design methods, to address the technical issues. For example, the pressure drop mentioned by Airbus can be addressed by using a properly sized and designed FRM so that adequate nitrogen can be supplied to any affected tank. This can be done using available technology and with costs that are consistent with those for other tanks considered in the regulatory evaluation. Airbus provided no technical justification for its assertion to the contrary.

#### 8. Foreign Persons/Air Carriers Operating U.S. Registered Airplanes

Airbus, EASA, and the UK Civil Aviation Authority (UKCAA) requested a change to the wording of proposed § 129.117(a). This change would clarify that the applicability of this rule is

<sup>18</sup> §§ 121.1117(n), 125.509(n), and 129.117(n).

limited to foreign persons and foreign air carriers operating U.S. registered transport category, turbine powered airplanes for which development of an IMM, FRM or Flammability Impact Mitigation Means (FIMM) is required under proposed §§ 25.1815, 25.1817 or 25.1819 (now §§ 26.33, 26.35, and 26.37). Their understanding is that the paragraph is not intended to apply to airplanes registered outside of the United States.

As provided in §§ 129.1(b) and 129.101(a), the commenters are correct that § 129.117 would not apply to aircraft registered outside the United States. To clarify our intent, we have revised § 129.117(a) to include the words "U.S. registered."

#### 9. Airplanes Operated Under § 121.153

In the proposed rule, the FAA requested comments on whether categories of airplane operations other than all-cargo operations should be excluded. In response to our request, AEA and Airbus noted that § 121.153 permits the operation, by U.S. airlines, of airplanes registered in another International Civil Aviation Organization (ICAO) member states under specified circumstances. They said that, while history shows that the use of the § 121.153 provisions is relatively rare, it can provide important flexibility when unusual circumstances dictate the urgent need of replacement airplanes for U.S. carriers. Given the small effect of excluding airplanes leased under the provisions of § 121.153 from any requirements of the proposed rule, the commenters recommend that they be excluded from applicability provisions of the proposed rule. Otherwise, they said, if compliance with the proposed retrofit requirements are applied as proposed, § 121.153 would preclude this practice for airplanes that have not been retrofitted with FRM. These commenters argued that this result would present a burden to both U.S. operators (who would lose the flexibility provided by § 121.153) and non-U.S. operators (for whom the value of their unmodified airplanes would be reduced).

Section 121.153(c) does not relate to a "category of operation," such as all-cargo operations. Rather, it permits certificate holders to operate foreign registered airplanes for any type of operation, as long as the airplanes meet all applicable regulations. Allowing the operation of foreign registered airplanes that do not comply with this rule would be contrary to the intent of both § 121.153(c) and this rulemaking. It would also subject a certificate holder's passengers to differing levels of safety

based on the registry of the airplane. This is not acceptable and we did not make the change proposed by the commenters in the final rule. However, as discussed later in more detail, we are working with foreign authorities to establish harmonized flammability reduction standards. If we achieve that objective, the "burdens" suggested by the commenters would disappear.

#### 10. International Aspects of Production Requirements

The AEA and Airbus disagreed with the proposed requirement to incorporate FRM or IMM into all new production airplanes. They stated that existing procedures for exporting airplanes from the United States allow the importing country to accept specific non-compliances on the export certificate of airworthiness. The AEA also asked for clarification of the discussion of FAA authority over airplanes produced outside the United States. Likewise, Embraer asked that the requirement to incorporate FRM or IMM into all new production airplanes be dropped from the proposal. Embraer pointed out that foreign regulatory authorities do not currently have certification standards for FRM or IMM, so Embraer is unclear how airplanes with such systems would be approved by the importing country. The ATA questioned the FAA contention (by context) that the proposed rulemaking has no international (ICAO) implications. It asked for the proposal to be reviewed by relevant international law experts for compatibility with the principles of sovereignty and authority in ICAO International Standards and Recommended Practices, Annex 8 to the Convention on International Civil Aviation, Airworthiness of Aircraft.

As discussed in the NPRM, we intend for the proposed new production requirements to apply to any manufacturer over which the FAA has jurisdiction under ICAO Annex 8. For this reason, we used the same language as Annex 8 to define the applicability of those requirements. Under that annex (and under this rule), we have jurisdiction over organizations to which we issue production approvals, including production certificates. This may include organizations that accomplish final assembly outside the United States. While no affected U.S. production certificate holders currently accomplish final assembly outside the United States, it is possible that they might in the future. For example, if Boeing were to perform final assembly of a future version of the Boeing 737 in another country, those airplanes would still be subject to the production cut-in

requirements of this final rule as long as Boeing produces them under Boeing's U.S. production certificate.

Regarding the comment that current procedures allow the importing country to accept specific non-compliances on the export certificate of airworthiness, the commenters are referring to the waiver provisions of § 21.327(e)(4). The non-compliances referenced in that section relate to the requirements for issuance of an export airworthiness approval.<sup>19</sup> The production cut-in requirement of this rule is unrelated to those requirements. Rather, it requires that affected airplanes produced under U.S. production approvals must conform to an approved type design that meets the fuel tank flammability requirements of this rule. Therefore, while a foreign authority may be able to waive the requirements for issuing airworthiness approvals, it does not have the authority under ICAO Annex 8 to override our requirements, imposed as the State of Manufacture, for our production approval holders.

Finally, in addition to meeting the requirements of this rule, any airplane produced for export would also have to meet all other requirements applicable to the production certificate holder (such as the requirement to maintain its quality control system in accordance with its FAA approval). These requirements cannot be waived under the provisions of § 21.327(e)(4). Therefore, we are not aware of any basis for a foreign authority to object to our requirement for production cut-in. Of course, once the airplane is placed into operation by a foreign operator, the operator would have to comply with the requirements of its authority for operation and maintenance of the airplane, which may or may not include requirements relating to fuel tank flammability. As discussed later in more detail, we are currently working with foreign authorities to harmonize our requirements with theirs.

#### *D. Requirements for Manufacturers and Holders of Type Certificates, Supplemental Type Certificates and Field Approvals*

##### 1. General Comments About Design Approval Holder (DAH) Requirements

We received a number of general comments responding to the concept of DAH requirements rather than to the DAH requirements in this specific

<sup>19</sup> For example, § 21.327(e)(4) references § 21.329, which in turn references § 21.183 for the requirements for a standard U.S. airworthiness certificate. For new airplanes, § 21.183 requires that the product conform to its approved type design and is in condition for safe operation.

rulemaking. We responded to these types of comments in the comment disposition document accompanying our policy statement titled "Safety—A Shared Responsibility—New Direction for Addressing Airworthiness Issues for Transport Airplanes." Both were published in the **Federal Register** on July 12, 2005 (70 FR 40168 AND 70 FR 40166, respectively). We received similar comments on our NPRM on Enhanced Airworthiness Program for Airplane Systems (70 FR 58508, October 6, 2005, RIN 2120–A131). As a result, we will not respond to such comments again here.

## 2. Flammability Exposure Requirements for New Airplane Designs

As proposed, the rule requires those airplanes incorporating FRM to limit the fleet average flammability exposure to 3 percent, and to limit warm day exposure to 3 percent, for all normally emptied fuel tanks located, in whole or in part, in the fuselage. All other fuel tanks can either meet the 3 percent average flammability exposure limitation or have a flammability exposure that is not higher than the exposure in a conventional unheated aluminum wing tank that is cooled by exposure to ambient temperatures during flight.

### a. General Comments About Applicability to New Production Airplanes

The NACA and its member airlines fully support the requirement for incorporation of either an FRM or IMM to provide fuel tank inerting for all new production airplanes, including those that already have an approved TC or STC. Airbus, AEA, AAPA, and EASA also commented that installation of FRM during an airplane manufacturing process may be appropriate. The EASA expressed its support for production cut-in and plans to amend its rules to a harmonized approach that requires production incorporation.

As we stated in the NPRM, "The safety objective of these proposed rules is to have the required modifications installed and operational at the earliest opportunity."<sup>20</sup> For U.S.-manufactured airplanes, we proposed to meet this objective by requiring affected production approval holders to incorporate these changes by the compliance date for developing FRM or IMM service information. Recognizing that we do not have similar authority over affected foreign manufacturers, we did not propose a similar requirement for them. However, as noted by the commenters, our safety objective still

applies to those airplanes, and it is equally feasible for FRM or IMM to be incorporated on new foreign-manufactured airplanes after the necessary design changes are developed. Further, as stated by EASA, it has agreed to harmonize requirements for new production airplanes. Including FRM or IMM in production is more efficient and less costly than retrofitting these airplanes, which is also required under the NPRM.

Based on these factors, we had assumed that FRM or IMM would be incorporated on all airplanes produced by both domestic and foreign manufacturers after designs were developed within two years after the effective date of this final rule. Given the reluctance of foreign manufacturers to commit to developing these design changes within the prescribed period (as discussed later), we now recognize that an operational requirement is needed to effectuate our intent. Accordingly, operators may not operate affected airplanes produced after September 20, 2010 unless they are equipped with FRM or IMM. Because we had intended that all airplanes delivered after these design changes had been developed would include these safety improvements, this requirement is a logical outgrowth of the NPRM.

### b. Flammability Analysis Using the Monte Carlo Method

For all fuel tanks, an analysis must be performed to determine whether the fuel tank, as originally designed, meets the fleet average flammability exposure limits discussed above. To determine the flammability exposure of fuel tanks, the ARAC used a specific methodology incorporating a Monte Carlo analysis.<sup>21</sup> As proposed, any analysis of a fuel tank must be performed in accordance with this methodology (as detailed in proposed appendix L, now appendix N, and in the draft FAA document, Fuel Tank Flammability Assessment Method User's Manual).<sup>22</sup> We considered approving alternative methodologies in lieu of Appendix N, but we found that no other alternative considered all factors that influence fuel tank

<sup>21</sup> This methodology determines the fuel tank flammability exposure for numerous simulated airplane flights during which various parameters such as ambient temperature, flight length, fuel flash point are randomly selected. The results of these simulations are averaged together to determine the fleet average fuel tank flammability exposure.

<sup>22</sup> As indicated in the proposed Appendix L (now Appendix N), we are incorporating the User's Manual by reference into the final rule. This was incorporated by reference in the final rule by creating a new § 25.5.

flammability exposure (which is the safety objective of this rule).

The ATA proposed upgrading the Monte Carlo method or developing a similar method that would be used to evaluate airplane risk of a fuel tank explosion. The method proposed by ATA would include not only fuel tank flammability, but also the risk of ignition sources developing in a fuel tank based upon the specific airplane design.

The Monte Carlo method is intended to be used to determine fuel tank flammability alone, not the overall likelihood of a fuel tank explosion. While the ATA's suggestion is intriguing, we do not believe there is presently a method of accurately predicting the risk of an ignition source developing in a fuel tank. With this final rule, we are implementing a balanced approach to prevent fuel tank explosions: By addressing both ignition prevention (as defined in the requirements of § 25.981(a) and SFAR 88) and flammability reduction (as defined in this rule). Compliance with both standards ensures that fuel tank explosion risk is acceptable.

The EASA also expressed concerns about the proposed methodology since it is complex and allows variations in fuel tank flammability to be introduced by variations in the input parameters used in the analysis. Although EASA welcomed the improvements to the Monte Carlo method proposed in the NPRM that set the majority of the input parameters, EASA expressed concern that the method does not adequately address heat transfer and the assumptions retained do not allow proper quantification of the exposure.

We share the concern expressed by EASA that, unless properly controlled, variation in the DAH input parameters used in the flammability assessment could result in significant differences between various DAHs. Fuel tank thermal modeling, including heat transfer, is the one major variable parameter provided by the user. Appendix N25.3(e) requires that substantiating data for the fuel tank thermal model, along with other input parameters, be submitted with the analysis. Therefore, we believe that Appendix N does adequately address heat transfer and provides a method that allows for proper quantification of flammability exposure.

Finally, Parker Hannifin Corporation noted an error in the Monte Carlo computer code that mistakenly added the time prior to flight and utilized the flight time constants rather than ground time constants in certain calculations. This error could produce two counter-

<sup>20</sup> 70 FR at 70940.

acting effects. In some circumstances, it could produce higher flammability exposure when the tank-full time constant is used longer than actually required. In other circumstances, it tends to reduce the flammability exposure by using the tank empty-time constant earlier than actually warranted. Overall this has the net effect of slightly underestimating the actual fuel tank flammability exposure so assessments using the revised computer code would produce slightly higher flammability values. We addressed this error in the final rule and the computer code is now correct.

#### c. Definition of "Normally Emptied Tank"

As defined in proposed § 25.1803(d) (now § 26.31(b)), "normally emptied tank" refers to a fuel tank that is emptied of fuel during the course of a flight and, therefore, can contain a substantial vapor space during a significant portion of the airplane operating time. Boeing requested that the definition for "normally emptied" be removed. Boeing based this request on the fact that heat input to the tank and the heat rejection rate (i.e., the rate of heat transfer from the tank) play more of a factor in a tank's flammability than whether it is normally emptied.

While we acknowledge that the heat input to the fuel tank and heat rejection from the tank are major factors in fuel tank flammability, the reason we are concerned about tanks that are normally emptied is not related to their flammability. As stated in the preamble to the NPRM, normally emptied fuel tanks can contain a substantial fuel vapor space that could expose potential ignition sources to the fuel vapor for an extended period of time. Fuel in tanks that are not normally emptied covers potential ignition sources more often than fuel in normally emptied tanks. This prevents ignition sources from igniting fuel vapors in the tank. Therefore, normally emptied fuel tanks have a higher likelihood of exposing flammable vapor to ignition sources than tanks that are not normally emptied. This rule specifically differentiates between fuel tanks that are normally emptied and other fuel tanks by requiring reduced fuel tank flammability because of the increased risk of an explosion in normally emptied tanks.

#### d. Fixed Numerical Standard

For new airplane designs, we requested comments on whether the reference to a conventional unheated aluminum wing tank or a fixed numerical standard for the requirements

of § 25.981(b) would be more workable and effective. The safety objective of a "conventional unheated aluminum wing tank" is consistent with the ARAC recommendation and § 25.981(c) (amendment 102). However, it does not provide a numerical standard to apply in future type certification programs. In certain cases, the compliance demonstration would be simplified if a fixed numerical standard were provided in the regulation, because there would be no analysis needed to establish the flammability exposure of a conventional unheated aluminum wing tank that is the alternative flammability exposure. We believe this approach has implementation advantages and should achieve the safety level intended by the ARAC recommendation and the current approach in § 25.981(c) (amendment 102).

Transport Canada, Boeing, Airbus, and ATA agreed that including a fixed numerical standard was preferred. Several of them suggested that we needed to provide further justification for the selection of a 3 percent fixed value and proposed different numerical values. These commenters did not agree with the inclusion of a variable standard of equivalence to a conventional unheated aluminum wing tank.

Airbus stated that a numerical value within the level recommended by ARAC (i.e., 7 percent) would be more practical and potentially safer than a flammability equivalency to a hypothetical wing fuel tank. While the 3 percent limit should be considered an acceptable goal if FRM is used, Airbus suggested that for fuel tanks that have a base flammability exposure less than 7 percent, there should not be a requirement to use FRM. The existing minimization of heat sources, as required by EASA, should be adequate. Airbus concluded that establishing a standard of 7 percent for fuel tank flammability exposure would ensure that FRM would provide a significant benefit (at least a 50 percent reduction in flammability) and remove the potential to actually reduce the overall safety as a result of increased ignition risk potential due to hazards associated with adding new FRM or IMM to the airplanes.

These commenters did not provide any compelling reasons to change the proposed 3 percent average flammability exposure or to eliminate the provision for showing equivalence to a conventional unheated aluminum wing tank. The reason for including the fixed 3 percent flammability exposure is to simplify the compliance demonstration. The reason for allowing for equivalence to a conventional

unheated aluminum wing tank is to give flexibility to designers who are willing to perform the required evaluations. The proposal from the ARAC and other commenters to increase the flammability exposure value to 7 percent would allow a significant increase in fuel tank flammability over that permitted by § 25.981. The fleet of airplanes that ARAC determined had achieved an acceptable level of safety was made up of airplanes with conventional unheated aluminum wing tanks with flammability exposures that varied from very low levels of around 1.5 percent for outboard wing fuel tanks to the highest values below 6 percent for some larger inboard wing tanks. These numerical values would all be lower if calculated today, consistent with the lower values now calculated by manufacturers for HCWTs.

Therefore, in this final rule, we adopted a flammability standard that includes showing a fuel tank is equivalent to a conventional unheated aluminum wing tank or 3 percent, whichever is greater. For purposes of this final rule, a conventional unheated aluminum wing tank is a conventional aluminum structure, integral tank of a subsonic transport airplane wing, with minimal heating from airplane systems or other fuel tanks and cooled by ambient airflow during flight. Heat sources that have the potential for significantly increasing the flammability exposure of a fuel tank would preclude the tank from being considered "unheated." Examples of such heat sources that may have this effect are heat exchangers, adjacent heated fuel tanks, transfer of fuel from a warmer tank, and adjacent air conditioning equipment. Thermal anti-ice systems and thermal anti-ice blankets typically do not significantly increase flammability of fuel tanks.

#### e. Tanks Located Within the Fuselage Contour

Boeing disagreed with the distinction in proposed § 25.981 between tanks located within the fuselage contour that are normally emptied and other tanks. Boeing suggested that main tanks and tanks not partially within the fuselage do not represent all the tanks with low flammability exposure and acceptable safety records. Boeing stated that on the other hand it is possible to design a main or wing tank with exceptional heat sources and/or minimal cooling. It is also possible to design a normally emptied tank that is partially within the contour of the fuselage which is low flammability (3 percent or less).

Bombardier did not understand the justification for introducing a maximum

3 percent fuel tank flammability exposure for wing tanks with a portion of the tank located within the fuselage. Bombardier stated that there is an inconsistency in requiring wing tanks to have flammability exposure of between 2 percent and 5 percent, while requiring fuselage tanks to be below 3 percent. Bombardier concluded that keeping all tanks below a 7 percent flammability exposure level should be considered acceptable, and recommended that tanks with less than 7 percent flammability exposure not be required to have FRM.

The distinction in flammability exposures in the rule between tanks located within the fuselage contour that are normally emptied and other tanks was made because the former generally have an increased risk of explosion. The location within the fuselage typically results in little or no cooling of the tank and, in some cases, actually heats the tank. Tanks that are normally emptied operate much of the time empty. Therefore, components that could be potential ignition sources are exposed to the tank ullage. We agree with Boeing on the possibility that fuel tanks located in the wing can be high flammability if the tank is heated or does not cool due to tank design features. However, the rule limits fuel tank flammability in these tanks to 3 percent or equivalent to a conventional unheated aluminum wing tank, addressing that risk.

For fuel tanks located outside the fuselage contour, § 25.981, as amended by this final rule, retains the flammability limits 3 percent or equivalent to a conventional unheated aluminum wing tank. Only if any portion of the fuel tank is located within the fuselage contour, and if the tank is normally emptied, is it required to meet the 3 percent average and 3 percent warm day requirement. If an applicant chooses to locate a portion of a main fuel tank inside the fuselage, the rule requires that the fuel tank meet the same standard as a main fuel tank located solely outside of the fuselage contour (i.e., 3 percent or equivalent to a conventional unheated aluminum wing tank wing).

Since existing airplane types with main fuel tanks that go from the wing into the fuselage are not normally emptied, FRM or IMM is required for these tanks only if the tank flammability exposure exceeds 7 percent (proposed § 25.1815 (now § 26.33)). For future designs using similar architecture, these types of designs would need to show that the main tank that extends into the fuselage meets the standard of equivalent to a conventional unheated aluminum wing tank or 3 percent.

#### f. Compliance Demonstration

Boeing, Airbus, and BAE requested that applicants be allowed to use design review to determine that an aluminum fuel tank is equivalent to the low flammability standard fuel tank as defined by ARAC. This would be in lieu of a detailed Monte Carlo based flammability analysis. The BAE stated that performing a cumbersome and expensive Monte Carlo analysis for metallic wing tanks of conventional design is unnecessary and adds no value. For other types of tanks, or wing tanks with a substantial heat input, BAE believes the use of alternative analytical methods may be appropriate and suggested a qualitative assessment of the design and the installation should be adequate to determine whether a given tank has a low flammability exposure. Finally, BAE recommended a simple set of objective criteria be allowed for establishing fuel tank flammability in these tanks.

Boeing requested that we:

- Revise proposed § 25.981(b) to allow a simplified flammability analysis for fuel tanks shown by design review to be a Conventional Unheated Aluminum Wing Tank.
- Delete proposed § 25.981(b)(1) and (b)(2), which reference Appendixes N and M for the flammability analysis methodology and flammability exposure criteria, respectively.
- Revise the definition of conventional unheated aluminum wing tanks to consider allowing some minimal heat sources (i.e., hydraulic systems) and significant cooling which results in low flammability exposure and a satisfactory level of safety.

We agree with the commenters' assertion that a simplified qualitative flammability analysis for conventional unheated aluminum wing tanks is appropriate and have modified Appendix N to permit this. Our intent is to limit the quantitative analysis for aluminum wing tanks with unique or unconventional designs that are heated or designed such that minimal cooling occurs. For example, a quantitative flammability analysis would be necessary for a wing tank that has a relatively small surface area, thereby minimizing surface cooling effects, a composite tank or a tank that has equipment inducing heat into the fuel tank greater than a small amount.

We have also added guidance to AC 25.981-2 that describes how to conduct a qualitative analysis to establish equivalency to a conventional unheated aluminum wing tank. This guidance provides examples of allowable heat sources and cooling characteristics for a

fuel tank to be considered a "conventional unheated aluminum wing tank," so that the safety standard established by the ARAC definition for a conventional unheated aluminum wing tank is maintained. For compliance with § 25.981(d), the guidance also includes a discussion of how Critical Design Configuration Control Limitations (CDCCL) would need to be developed to define any critical features of the fuel tank design needed to limit the flammability to that of a conventional unheated aluminum wing tank.

As for Boeing's specific changes to § 25.981, we do not agree that § 25.981(b)(1) and (b)(2) should be deleted because Appendix N provides necessary definitions and methods for establishing Fleet Average Flammability Exposure and Appendix M establishes performance standards for FRM. These appendices, and the references to them in § 25.981(b)(1) and (b)(2), are necessary to achieve the safety objectives of this rulemaking. We have not adopted Boeing's suggestion to modify the definition of "Equivalent Conventional Unheated Aluminum Wing." However, we do agree with the comment to allow some minimal heating of tanks such as that from a hydraulic heat exchanger that does minimal heating. We have revised the term "Conventional Unheated Aluminum Wing" used in § 25.981 to "Conventional Unheated Aluminum Wing Tank" to clarify that the flammability of the fuel tank is the standard. Since some minimal degree of heating typically occurs in many of these tanks, this change recognizes that such minimal heating is permissible.

#### g. Heat Sources Located in or Near Fuel Tanks

Transport Canada and the UK Air Safety Group suggested we prohibit the placement of heat sources within or near fuel tanks. Transport Canada questioned why we would allow such an undesirable design practice to continue. The UK Air Safety Group contended the NPRM failed to address the contribution of high fuel tank temperature to fuel tank explosions. The commenter noted that the Boeing 737 and 747 have air conditioning units that raise the fuel tanks' temperature well above the outside ambient temperature because these units are located beneath the center fuel tanks.

We agree with the commenters' underlying concern about controlling fuel tank temperature. While locating heat sources in or near fuel tanks increases the tanks' flammability, specifically prohibiting this design

practice may not be the most efficient and effective way to address the problem. This rule is performance-based and is seeking innovative design solutions which could permit locating heat sources near or in fuel tanks. For example, designers may wish to develop an FRM based upon managing the fuel tank temperature by transferring heat between tanks. These designs may provide flammability exposures well below that of a tank that complied with the proposal made by the commenters. Risk is directly proportionate to the flammability exposure of a tank. Therefore, we have developed a flammability performance standard that is independent of the design details of a tank installation.

#### h. Effects of Systems Failures on Flammability

The CAPA requested that we ensure the effects of any system failures that might increase the fuel tank flammability above the acceptable limit be considered and properly evaluated prior to issuing the final rule.

The flammability analysis required by § 25.981 includes a requirement to show that flammability exposure does not exceed minimum levels. It also requires that the overall flammability exposure analysis includes consideration of system failures when demonstrating that the FRM meets the reliability requirements of this rule. In addition, the analysis required by § 25.981(d) that determines the CDCCL and airworthiness limitations includes consideration of possible critical design features that must be maintained and may not be altered to assure the flammability limits are achieved. We have provided additional guidance and clarification in AC 25.981-2 regarding reliability assessments and establishing CDCCL and airworthiness limitations for FRM and IMM. Accordingly, we believe the commenter's concerns are already addressed by the proposed language, and no change was made to the final rule.

#### i. Move Flammability Exposure Method to Advisory Circular

The EASA, Transport Canada, Boeing, and Bombardier commented that the Monte Carlo method should not be defined in the rule as the method for determining fuel tank flammability. Instead, it would be more appropriately included in advisory material.

We do not agree with these commenters. The Monte Carlo method is specified in the rule to ensure standardization of the methodology for determining fuel tank flammability across all airplane models so a uniform

level of safety is achieved. Advisory circulars (ACs) provide guidance for methods, procedures, or practices that are acceptable to us for complying with regulations. ACs are only one means of demonstrating compliance, and we cannot require their use. Specifying Monte Carlo analysis in an AC could result in numerous methodologies and input parameters being used to determine flammability exposure, and we believe that this could result in differing flammability exposures in the fleet that may allow some fuel tanks to have greater flammability than intended by the rule. To ensure that all DAHs reach comparable conclusions from their assessments, it is necessary to require that they use the same methodology. This can only be accomplished through the rulemaking process.

However, to accommodate minor revisions that would not appreciably affect analytical results, we have included a provision in Appendix N25.1(c) permitting use of alternative methods if approved by the FAA. This is similar to the flexibility provided in § 25.853 for alternative test methods to those defined in Appendix F of part 25.

#### 3. Flammability Exposure Requirements for Current Airplane Designs

Proposed § 25.1821 (now § 26.39) contains the fuel tank flammability safety requirements for newly produced airplanes. Paragraph (b) sets forth the criteria that, when met by any fuel tank, requires that fuel tank to have an FRM or IMM meeting the new requirements of § 25.981. Paragraph (c) contains the requirements for all other fuel tanks that exceed a Fleet Average Flammability Exposure of 7 percent.

##### a. Same Standards for New and Current Airplane Designs

Boeing asked that we revise proposed § 25.1821(b) to state "any fuel tank not shown by design review to be a Conventional Unheated Aluminum Wing Tank, must meet the requirements of § 25.981 in effect on [effective date of final rule]." In conjunction with this change, paragraph (c) would be deleted. Boeing stated that new production airplanes should meet the same requirements as new airplane designs, since the criteria for tanks at risk should be a function of heating and cooling, not whether the fuel tank is normally emptied and located partially within the fuselage.

We do not agree with Boeing. As discussed earlier, tanks that are normally emptied and located at least partially within the fuselage are generally more susceptible to explosion

because of both increased ullage and operating at higher temperatures. We have determined that the 7 percent flammability exposure limit recommended by ARAC is an adequate standard to determine which fuel tanks in newly produced airplanes need an FRM or IMM. If the fleet average flammability exposure is above 7 percent for fuel tanks normally emptied and located within the fuselage contour, these fuel tanks will be required to be flammable no more than 3 percent on average and 3 percent for warm day operations. We expect that the vast majority of large transport category airplanes will have a fleet average flammability exposure above 7 percent for these specific fuel tanks and will be required to comply with § 25.981 for production airplanes affected by the DAH requirement.

Other tanks on newly produced airplanes also may not exceed the 7 percent flammability exposure limit, but the final rule would allow reduction to that level by various methods of FRM described in AC 25.981-2 that would not necessarily require the added complexity and cost of a nitrogen inerting based FRM. We believe this requirement is sufficient to provide an acceptable level of safety for current production airplanes because these tanks have significantly lower risk of fuel tank explosions, as demonstrated by their service history. Therefore, we do not believe the safety improvements from redesign of these tanks to meet the new requirements of § 25.981 are sufficient to justify the resulting costs.

##### b. 7 Percent Exposure Flammability Questioned

In the NPRM, we stated that fuel tanks that have a flammability exposure higher than 7 percent are unduly dangerous. American Trans Air commented that this statement is arbitrary, based on flawed analysis, and cannot be supported. Bombardier expressed its opinion that the NPRM and its supporting data did not adequately substantiate the declared 7 percent exposure. Although Bombardier considered that achieving 7 percent exposure is feasible with reasonable design precautions, Bombardier stated that this is not an acceptable reason for creating a standard. Bombardier also quoted information shared among the airline industry and authorities that heated tanks may vary between 8 percent to as high as 40 percent in flammability exposure.

Boeing did not agree with the proposed flammability requirements for newly produced airplanes, because fuel tanks other than those located within

the fuselage contour that are normally emptied would be allowed to have flammability of up to 7 percent. Boeing commented that this flammability is more than twice that of what is allowed for similar tanks in new designs. Boeing noted that the first ARAC determination that 7 percent flammability exposure is acceptable was based on the original coarse ARAC flammability analysis which determined that unheated tanks had a flammability level of approximately 5 percent. Two percent was added for potential variation resulting in the 7 percent proposal. Boeing pointed out that the Monte Carlo analysis has been significantly refined since the first ARAC report, and the estimated flammability exposure of 5 percent (7 percent with potential variation) has been reduced to be in the range of 3 percent (4 percent with potential variation) or less for the same fuel tanks.

We have determined that the 7 percent or less fleet average flammability exposure recommended by ARAC is an adequate value that can be used to identify those airplane models that need to be retrofitted with an FRM or IMM. The fuel tank flammability limits established for newly produced airplanes (subject to the production cut-in requirements) are the same as those for retrofit of the existing fleet (proposed § 25.1815 (now § 26.33)). We determined this flammability exposure achieves the desired safety benefits, since currently produced airplanes generally have conventional unheated aluminum wing tanks, the tanks ARAC determined to have adequate safety level, with flammability exposures below 7 percent.

We agree with Boeing that newly produced airplanes should not be allowed to have fuel tank flammability that is twice that of new designs, and this is not what we intended. The intent of this rule is to apply its safety improvements to the fuel tanks that have been shown to have an increased risk of explosion, not to require modifications to conventional unheated aluminum wing tanks, or other fuel tanks that have significantly lower flammability. Data we have available for currently produced airplanes indicate the flammability of tanks located outside the fuselage contour have flammability below 7 percent and further reduction in flammability exposure as recommended by Boeing would add significant cost to the rule, since a number of fuel tanks would be required to have an FRM or IMM to meet the suggested flammability values of 3 to 4 percent.

Recognizing that, based on the applicability criteria of proposed § 25.1821(a) (now § 26.39), this section only applies to current production Boeing models. We have revised paragraph (a) to specifically identify those models. As discussed previously, we have also added a requirement to the operational rules that operators must meet these requirements for any airplane subject to this rule that is produced more than two years after the effective date.

#### 4. Continued Airworthiness and Safety Improvements

##### a. 7 Percent Standard Should Apply to All Tanks

Boeing requested that § 25.1815(c)(1) be modified to state that, for fuel tanks with flammability exposure exceeding 7 percent that require an FRM, “a means must be provided to reduce the fuel tank flammability exposure to meet the criteria of Appendix M of this part.” In addition, Boeing recommended that we delete § 25.1815(c)(1)(i) and (ii). Boeing stated that any fuel tank that has significant heat loads, regardless of the location on the airplane, should meet the requirements of Appendix M if an FRM is selected as the design modification.

We do not concur with Boeing’s comment that the flammability requirements of Appendix M should apply to any fuel tank that exceeds 7 percent average flammability. As discussed previously, the reason we are adopting more stringent requirements for fuel tanks that are normally emptied and located within the fuselage contour is that those tanks both have higher flammability exposure and are more likely to have ullage exposed to ignition sources. For other fuel tanks where the fleet average flammability exposure exceeds 7 percent, the requirements of Appendix M apply with the exception that the flammability requirements of M25.1(a) and (b) are replaced by the requirement that fleet average flammability exposure must not exceed 7 percent. We believe this is acceptable for these tanks on existing airplanes. Since most of these tanks are not “normally emptied,” the risk that flammable vapors will be exposed to ignition sources is generally much lower.

##### b. Compliance Planning

Airbus requested that the compliance planning requirements contained in § 25.1815 be removed because they are unnecessary. Airbus believes the only important compliance date is the final date for DAHs to submit the data and

documents necessary to support operator compliance. Airbus commented that the compliance plan requirements in §§ 25.1815(g), (h) and (i) add constraints on the manufacturer with no safety benefit. Airbus stated these documents should not be subject to a requirement with respect to the DAH documentation delivery date. However, if the delivery dates for these documents are mandated, Airbus requested that they be expressed in the format of a duration tied to the date of approval of the previous submittal.

Boeing recommended we remove the § 25.1815(g)(3) requirement to identify deviations to methods of compliance identified in FAA advisory material, because the proposed means of compliance should not be compared to other means. Instead, they should be evaluated on their own merits.

While we understand the commenters’ concerns, these documents will provide assurance that the required flammability exposure analyses and, if applicable, proposed design changes, are being addressed in a timely fashion. As stated in the NPRM, the resolution of fuel tank safety issues needs to be handled in a “uniform and expeditious” manner. Providing compliance times based on the dates of our previous approvals would result in various compliance times, depending upon whether DAHs’ submissions are acceptable. It would have the undesirable effect of providing more time for those manufacturers submitting deficient documents.

Compliance planning will promote communication between the affected manufacturer and us. It will also provide sufficient time to discuss any concerns with respect to how the affected manufacturer proposes to analyze fleet average flammability exposure or certify design changes. Compliance planning will also help to ensure that the affected manufacturer is able to meet the required compliance times of the rule for accomplishing the submittal of the flammability exposure analysis, design changes, and service instructions, if applicable (proposed § 25.1815 (now § 26.33) and proposed § 25.1817 (now § 26.35)). We intend to closely monitor compliance status and take appropriate action, if necessary.

However, we do acknowledge that some provisions of proposed § 25.1815(g), (h) and (i) could be removed without adversely affecting our ability to facilitate TC holder compliance. Specifically, proposed paragraph (g)(3) would require TC holders to identify intended means of compliance that differ from those described in FAA advisory materials.

While this is still a desirable element of any compliance plan, we now believe that an explicit requirement is unnecessary and it is not included in the final rule. As with normal type certification planning, we expect that TC holders will identify differences and fully discuss them with the FAA Oversight Office early in the compliance period to ensure that these differences will ultimately not jeopardize full and timely compliance. Because we believe that timely review and approval is beneficial and will save both DAH and FAA resources, the advisory material will recommend that if the DAH proposes a compliance means differing from that described in the advisory material, the DAH should provide a detailed explanation of how it will demonstrate compliance with this section. The FAA Oversight Office will evaluate these differences on their merits, and not by comparison with FAA advisory material.

Similarly, proposed § 25.1815(i) contains provisions that would have authorized the FAA Oversight Office to identify deficiencies in a compliance plan, or the TC holder's implementation of the plan, and require specified corrective actions to remedy those deficiencies. While we anticipate that this process will still occur in the event of potential non-compliance, we have concluded that it is unnecessary to adopt explicit requirements to correct deficiencies and have removed them from the final rule. Ultimately, TC holders are responsible for submitting compliant FRM or IMM by the date specified. This section retains the requirements to submit a compliance plan and to implement the approved plan. If the FAA Oversight Office determines that the TC holder is at risk of not submitting compliant FRM or IMM by the compliance date because of deficiencies in either the compliance plan or the TC holder's implementation of the plan, the FAA Oversight Office will document the deficiencies and request TC holder corrective action. Failure to implement proper corrective action under these circumstances, while not constituting a separate violation, will be considered in determining appropriate enforcement action if the TC holder ultimately fails to meet the requirements of this section.

Finally, we realized that the rule text could more clearly state our intent to allow DAHs flexibility to modify their approved plan if necessary. Accordingly, we changed proposed § 25.1815 (now § 26.33(i)) to read: "Each affected type certificate holder must implement the compliance plans, or later revisions, \* \* \*

#### c. Changes to Type Certificates Affecting Flammability

Proposed § 25.1817 (now § 26.35) addressed changes to TCs that could affect fuel tank flammability. This section proposed to require that a flammability exposure analysis be accomplished in accordance with Appendix N for all affected fuel tanks installed under an STC, amended TC, or field approval within 12 months after the effective date of the final rule. An impact assessment that identifies any features of the design change that compromise any CDCCL applicable to any airplane with high flammability tanks for which CDCCL are required must also be submitted to the FAA Oversight Office. This section also proposed a requirement to develop service instructions to correct designs that compromise airworthiness limitations, defined by the TC holder under proposed § 25.1815 (now § 26.33), within 48 months after the final rule's effective date.

Airbus proposed we restrict the application of any proposed changes to § 25.981 to new TCs and significant design changes (i.e., new fuel tanks). For minor design changes such as relocating a fuel level sensor or a small increase in tank capacity, the TC holder should only be required to show no degradation in the flammability under the criteria proposed by § 25.1815. Airbus stated that the cross-reference between what is in the preamble and § 25.1815, and what is required by § 25.1817, is misleading.

We agree with Airbus, and have revised proposed § 25.1817 (now § 26.35) to require compliance with the new § 25.981 only for new fuel tanks. Other design changes that increase capacity of existing fuel tanks must comply with § 26.33. Design changes that affect the flammability exposure of existing tanks equipped with FRM or IMM must comply with CDCCLs for those tanks. This will ensure that these design changes do not degrade the level of safety required by this rule.

#### d. Combine §§ 25.1815 and 25.1817

Boeing requested that we combine proposed §§ 25.1815 and 25.1817 into one section. We do not agree with this suggestion, since it would not achieve the goals of this rulemaking. As proposed, §§ 25.1815 (now § 26.33) and 25.1817 (now § 26.35) would apply to different entities. Section 25.1815 (now § 26.33) would apply to TC holders of transport category airplanes, and § 25.1817 (now § 26.35) to auxiliary tank STC holders and future applicants for design changes. The STC holders have distinctly different compliance dates

because information such as CDCCL developed by the DAHs under proposed § 25.1815 (now § 26.33) is needed before the STC holders can comply with proposed § 25.1817 (now § 26.35). Separate sections provide a clear statement of the requirements for each situation so affected persons can more easily understand what is needed to comply with the rules applicable to them. Therefore, the final rule retains the language as proposed with no change.

#### e. Pending Type Certification Projects

Proposed § 25.1819 contains the requirements for pending TC projects. As proposed, this section contains different requirements for those transport category airplanes based on whether the application was made before or on/after June 6, 2001 (the effective date of Amendment 25-102). Boeing requested that this section be deleted because it saw no reason to differentiate among designs based on the date of application.

We partially agree with Boeing and have revised this section. In the final rule, any pending certification projects that have not received type certification by the effective date of this rule will be required to meet the requirements of § 25.981, as amended by this rule. Since there are no longer any ongoing TC projects where the application was received prior to June 6, 2001, there is no reason for this distinction and we have removed proposed § 25.1819(c). However, we have received applications for type certification projects after June 6, 2001, that are still pending (e.g., the Boeing 787 and Airbus A350), and we have determined that a specific requirement in § 25.1819 is needed to address these projects. We do not believe this section should be completely deleted, as requested, because these projects (and future design changes to these airplanes), would not otherwise be required to comply with § 25.981, as amended by this final rule. The change to the rule will maintain the requirement that pending projects meet the same flammability standards as required for new type certificates and that applicants develop CDCCL as proposed in the NPRM.

#### f. Type Certificates Applied for on or After June 6, 2001

Proposed § 25.1819(d) (now § 26.37(b)) requires that if an application for type certification was made on or after June 6, 2001, the requirements of § 25.981 of this rule apply. Section 25.981 requires, in part, that the fleet average flammability exposure of a fuel

tank not exceed 3 percent or that of a conventional unheated aluminum wing tank.

Airbus objected to the setting of a 3 percent flammability limit for all fuel tanks for a pending type certification, if the application was made on or after June 6, 2001. Airbus agreed that a 3 percent flammability limit could be considered as an acceptable goal when FRM is used. However, for fuel tanks that have a base flammability exposure less than 7 percent, there should not be a requirement to impose FRM, and the existing minimization of heat sources should be considered adequate. If initial flammability is between 3 and 7 percent, the safety benefit to reduce it to 3 percent through the use of FRM is not justified, when considering the introduction of new failure conditions, and operational and ownership costs of an FRM.

Airbus apparently misunderstood the effect of the proposed requirements of § 25.1819 (now § 26.37) for TCs for which application was made on or after June 6, 2001. The following is provided to clarify the requirements of the rule and address the concern expressed by Airbus. The flammability requirements for an airplane for which application was made on or after June 6, 2001, would include § 25.981 at Amendment 25–102 for all tanks except normally emptied tanks located within the fuselage contour. As stated earlier in this preamble, the rule text has been changed to clarify that the flammability exposure is equivalent to a conventional unheated aluminum wing tank or 3 percent, at the applicant's option. This flammability exposure is unchanged from Amendment 25–102, which would not have permitted a flammability exposure of 7 percent. This rule adds a new requirement for fuel tanks located within the fuselage contour that are normally emptied. Normally emptied tanks located within the fuselage must meet the 3 percent average and the 3 percent warm day flammability limits defined in Appendix M, which is the same flammability requirement being applied to these types of fuel tanks on existing airplanes.

#### g. Design Change to Add a Normally Emptied or Auxiliary Fuel Tank

As proposed, § 25.1819(e) would require that any future design change to a TC for which the application is pending when this rule is adopted and that—

- Adds an auxiliary fuel tank, or
- Adds a fuel tank designed to be normally emptied, or
- Increases fuel tank capacity, or

- May increase the flammability exposure of an existing fuel tank must meet the requirements of § 25.981, as amended by this rule. Boeing asked that this paragraph be deleted because it is specifically for “pending” type certification projects and, by definition, there is no existing type certificate to change. If the intent of proposed § 25.1819 (now § 26.37) is to define requirements for projects in work at the time of the final rule, then Boeing suggested there is no need for this section. Any change after the new production compliance date would have to meet the new production requirements (§ 25.1821).

Proposed § 25.1819(e) specifically targets potential future changes to certain long-term, pending type certification programs. Under proposed § 25.1819(c), these programs would not be required to comply with § 25.981, as amended by this rule. Our intent was that, although the original TC would not have to comply with the current requirements, any later changes would have to comply. Since we issued the NPRM, all of these projects have been certified, so there are no pending projects for which this paragraph is needed. Therefore, we have removed it from the final rule.

#### E. Flammability Exposure Requirements for Airplane Operators

The proposed operating rules would prohibit the operation of certain transport category airplanes operated under parts 91, 121, 125, and 129 beyond specified compliance dates, unless the operator of those airplanes has incorporated approved IMM, FRM or FIMM modifications and associated airworthiness limitations for the affected fuel tanks. The proposed rules would not apply to airplanes used only in all-cargo or part 135 operations. Finally, the proposed operating rules would also create new subparts that pertain to the support of continued airworthiness and safety improvements.

##### 1. General Comments About Applicability to Existing Airplanes

Airbus, AEA and AAPA believe the retrofit requirement is not cost effective. Our analysis showed that the benefit/cost ratio of the production cut-in and retrofit requirements are similar. This was our rationale for adopting the combined approach of production cut-in and retrofit. However, these commenters believe the 7 percent discount rate used in our cost/benefit analysis is too high and is responsible for the determination that cost/benefit ratios are similar between the production cut-in and retrofit. We infer from their comments

that they believe that 3 percent is a more realistic number and supports their contention that retrofit is not justified. The commenters note that an EASA analysis concluded that the retrofit was not justified. A major concern was that the bulk of the retrofit costs (present value terms) will be incurred in about 1/3 of the time (7 years) required for the forward fit costs (22 years). They believe that the cash outlay to retrofit in such a short time, coupled with the small safety benefit, is not justified when compared with the cost/benefit of the production cut-in. They also stated that the high cost of the retrofit over such a short period would place financial stress on an industry that is already financially constrained. In contrast, the cost of production incorporation of FRM in new airplanes will be borne by airlines that are prepared to accept the cost of new airplanes with the FRM included in the “sticker price.”

Except as discussed previously regarding the exclusion of part 91 operations, we continue to believe that a retrofit requirement is justified. As discussed in the NPRM and earlier in this preamble, the risk of fuel tank explosions on the current fleet of airplanes with high flammability tanks is still significant because, despite our efforts to eliminate ignition sources, they continue to occur. At the same time, we have made a number of changes to the proposed requirements to reduce their cost and improve their cost-effectiveness. As discussed later in this preamble, the final regulatory evaluation (FRE) has been revised to include the benefits of preventing lost revenue to the industry as a whole if another fuel tank explosion were to occur. When these benefits are included, variations in the discount rate do not alter the conclusion that this rule is reasonably cost-effective.

The compliance time for the retrofit requirement allows for incorporation of design modifications over a seven-year period. Operators can spread the costs over this time period. We have also included a provision in the operational rules (discussed later) that allows operators an extension of up to one year after the 50 percent and 100 percent retrofit deadlines for full fleet incorporation of the design modifications if the operator includes requirements in their operations specifications to use ground conditioned air when available. For 50 percent of an operator's fleet, this would allow retrofit to be completed by September 21, 2015 rather than September 19, 2014. Similarly, for 100 percent of an operator's fleet, this would allow retrofit to be completed by

September 19, 2018 rather than September 19, 2017. This provision provides a reduction in the costs to operators because it allows an additional year to install an FRM or IMM. We also adjusted the applicability of the rule so that older airplanes that were produced prior to 1992, which will be nearing the end of their useful life in passenger service, will not be subject to the phase-in-requirement of the rule. The DAH-supported design modifications will only be required on airplanes with significant remaining useful life in passenger service so the benefits of the rule are optimized.

As for the comments on the standard discount rate, the rate that is mandated by the Office of Management and Budget when conducting regulatory evaluations is 7 percent. The Initial Regulatory Evaluation included a sensitivity study where variations in the discount rate (using 3 and 7 percent) were considered. Variations in the discount rate affect both the cost and the benefits of the rulemaking. Thus, using a discount rate of 3 percent (as they recommend) increases the benefits of the rulemaking, because the value of averted future accidents would also have a higher present value.

## 2. Authority to Operate With an Inoperative FRM, IMM or FIMM

In the NPRM, we requested public comment on the proposal to allow the current Flight Operations Evaluation Board (FOEB) process to establish the Master Minimum Equipment List (MMEL) interval for the FRM or IMM rather than requiring a specific maximum fixed time interval that the FRM can be inoperative. Airbus, Boeing, ATA, AEA and British Airways supported the rule as proposed and generally agreed the FOEB is the appropriate vehicle to establish the approved MMEL interval for inoperative FRM. In contrast, Smith's Aero commented that FRM must be considered a flight critical system, without MMEL relief for the performance of the system to meet the overall intended safety level stated by the FAA in the NPRM. Finally, Frontier asked how long an airplane could be operated with an inoperative FRM system.

As stated in the NPRM, the intent of the rule is to provide an additional layer of protection from having a fuel tank explosion if an ignition source occurs inside a fuel tank. While the FRM system is needed to maintain the safety of a fleet of airplanes, it is not considered flight critical for every flight, since the ignition prevention means required by § 25.981 requires robust fail-

safe features that provide an adequate level of safety during short periods of time when the FRM is inoperative under the MMEL (no greater than 1.8 percent of the operating time). We agree with the commenters that "FRM designers" should make the design goals for the MMEL relief intervals available and notify the FOEB of their recommendation. The allowable MMEL interval is design dependent and cannot be defined by us until a design is presented and the interval is justified by the system reliability analysis and the FOEB.

Frontier also asked whether en route weather conditions would be a factor with the MEL. At this time, en route weather conditions are not part of the consideration for operation under the operator's MEL. This is one of the considerations in the Monte Carlo assessment, so operation under an operator's MEL during warm days would not be an additional consideration for the MMEL.

## 3. Availability of Spare Parts

Frontier asked if we had given proper consideration to the fact that there will most likely be an initial spare parts shortage. The compliance time for fleet-wide retrofit of FRM or IMM is nine years after the effective date of this final rule, with 50 percent compliance required within 6 years. Therefore, the manufacturers of components should have the capability to produce needed spares and no shortage of parts is anticipated. We have not included a consideration of parts shortages when establishing the MMEL interval.

## 4. Requirement That Center Fuel Tank Be Inert Before First Flight of the Day

Frontier requested information on whether the final rule would require that the center fuel tank be inert before the first flight of the day and, if so, if the Auxiliary Power Unit is inoperative, could the inerting system then be inoperative until after main engine start. The final rule does not directly address the operational details of the FRM. These will be determined based on the DAH's design and any operating limitations that may be necessary to meet the performance standards of this final rule.

## F. Appendix M—FRM Specifications

Appendix M to part 25 contains detailed specifications for all FRMs if they are used to meet the flammability exposure limitations. These specifications are designed to ensure the performance and reliability of FRMs. We received several comments on

Appendix M and have made changes to the rule based on some of them.

### 1. Fleet Average Flammability Exposure Level

Paragraph M25.1(a) requires that the Fleet Average Flammability Exposure of each fuel tank may not exceed 3 percent of the Flammability Exposure Evaluation Time. As discussed previously, as a portion of this 3 percent, if flammability reduction means (FRM) are used, each of the following time periods cannot exceed 1.8 percent of the FEET: (1) When any FRM is operational but the fuel tank is not inert and the tank is flammable; and (2) when any FRM is inoperative and the tank is flammable. Boeing requested a change to this paragraph to clarify that, for both the operational and inoperative requirements, only time periods when the fuel tank is in a flammable state are counted toward each 1.8 percent flammability exposure limit.

We agree that the method of determining these times needs clarification and we have revised paragraph M25.1(a) as requested by Boeing.

### 2. Inclusion of Ground and Takeoff/Climb Phases of Flight

Paragraph M25.1(b) requires that ground, takeoff and climb phases of flight be included in the fuel tank fleet average flammability exposure analysis. Boeing asked that paragraph M25.1(b) be reworded to exclude a specific reference to the takeoff flight phase. Boeing's justification was that there is no benefit in conducting a separate flammability analysis for the takeoff phase of flight since it is a very short duration. Boeing recommended the takeoff phase be included with the climb phase of flight. Boeing also suggested the rule clarify that the transition from ground to climb phase for this analysis occurs at weight off wheels.

We agree with Boeing and have revised paragraph M25.1(b) in the final rule to remove consideration of the takeoff phase of flight as a separate requirement. These two phases are now required to be considered in combination using the term "takeoff/climb" phase. In addition, we added a sentence to paragraph M25.1(b)(2) stating that the transition from ground to takeoff/climb phase for this analysis occurs at weight off wheels.

### 3. Clarification of Sea Level Ground Ambient Temperature

Paragraph M25.1(b)(1) requires that the fuel tank fleet average flammability

exposure analysis, as defined in Appendix N, “must use the subset of flights starting with a sea level ground ambient temperature of 80°F. (standard day plus 21°F. atmosphere) or more, from the flammability exposure analysis done for overall performance.” An individual commenter requested that we define the term “more” in this statement. We agree that this requirement needs clarification and, in the final rule, paragraph M25.1(b)(1), we replaced the word “more” with the word “above.” We also replaced the word “starting” with “that begin.”

#### 4. Deletion of Proposed Paragraph M25.2 (Showing Compliance)

Paragraph M25.2 establishes the means for showing compliance with fuel tank flammability requirements. Boeing requested the contents of paragraph M25.2 be moved to Advisory Circular 25.981-2A as it defines a method of compliance and, as such, should be located in an AC.

As discussed previously, ACs provide guidance for methods, procedures, or practices that are acceptable to us for complying with regulations. ACs are only one means of demonstrating compliance, and we cannot require their use. The compliance means in paragraph M25.2 is regulatory in nature to ensure that applicants are providing the data necessary to validate the parameters used in their calculations for fuel tank fleet average flammability exposure (as required by paragraph M25.1), and to substantiate that their system meets these requirements during normal airplane operations for any combination of airplane configuration (as required by paragraph M25.2(b)). We have made no change as a result of this comment.

#### 5. Deletion of “Fuel Type” From List of Requirements in Proposed Paragraph M25.2(b)

Boeing also requested that paragraph M25.2(b) be revised to remove “fuel type” from the list of requirements and add “or other relevant airplane system configuration” to it. Boeing stated the items listed in paragraph M25.2(b) affect the performance of a FRM system that is supplied by engine bleed air, and fuel type does not affect bleed system pressure. We agree with Boeing and have revised this paragraph in the final rule.

#### 6. Latent Failures

Paragraph M25.3(a) requires that reliability indications be provided to identify latent failures of the FRM. These indications are needed to ensure appropriate actions can be taken to

maintain the FRM’s reliability. An individual commenter asked that we define what is meant by “reliability indications” in paragraph M25.3.

In this context, reliability indications are normally computer messages or lights that identify whether components are functioning properly. Reliability indications are likely to be needed for the FRM to meet the reliability requirements in the rule. The type of indications needed will depend on the design and the outcome of the reliability analysis. If a nitrogen inerting FRM were to be developed with no indication of system failures, the system would have significant exposure to long-term operation with latent failures. Maintenance indications would likely be needed so that the minimum reliability of the system could meet the rule.

Boeing requested that paragraph M25.3 be deleted or modified to remove the term “latent.” This would be consistent with the special conditions issued for the Boeing 737 and 747 flammability reduction systems. In addition, the term “latent” would not be applicable if an indication is provided. An individual commenter agreed, stating that latent failures are not detectable and, hence, cannot be indicated. Embraer commented that both paragraphs M25.3(a) and (b) should be deleted because a literal interpretation would require any latent failure to be detected and indicated. This contradicts the NPRM’s preamble, which states that the designer is allowed to make a trade-off between system failure probability and failure detection/annunciation to show compliance with the system performance requirements. In addition, Embraer maintained that paragraph M25.3(a) is already addressed and should not be repeated here because the requirement for failure detection is inherent in the flammability exposure requirement and in the 1.8 percent limit on system failure contribution to flammability exposure.

On a related topic, Airbus and Embraer commented that the proposed rule is too restrictive and mandates an excessive amount of indication and monitoring. Airbus indicated that the proposed text appears to assume the adoption of an active system to reduce flammability and this may not necessarily be appropriate if a passive system were to be used. Some means of verifying that the passive means is fully functional could be required, but it may be inherent in the design and therefore, no specific action would be required except to ensure that other airplane modifications do not adversely affect the fuel tank flammability.

The FAA agrees with these commenters and has modified paragraph M25.3(a) in the final rule.

This change makes it clear that the intent of the rule is to require only those indications needed to assure any FRM meets the minimum reliability requirements of the rule. The preamble to the NPRM provided a detailed explanation of the intent of these requirements. The need for indications is determined from the system reliability assessment that requires a minimum reliability for any FRM. The type of indications that may be needed to meet the reliability requirements depends upon the details of the design and the outcome of the system reliability analysis. Various design methods may be used to make sure an FRM meets the reliability and performance requirements in this rule. For example, if an FRM based upon nitrogen inerting is developed and no indication of system failures is provided, the system would have significant exposure to long-term operation with latent failures. Maintenance indications would likely be needed so that the minimum reliability of the system could meet the rule. Other designs may use active or passive cooling means for flammability reduction. For these systems, the level of indication required would depend upon the reliability of the cooling system components.

The need for FRM indications and the frequency of checking system performance (maintenance intervals) must be determined based on the results of the FRM fuel tank fleet average flammability exposure analysis. The determination of a proper maintenance interval and procedure will follow completion of the certification testing and the reliability analysis used to establish the system complies with the performance requirements.

#### 7. Identification of Airworthiness Limitations

Paragraph M25.4(a) requires that if FRM is used to comply with paragraph M25.1, airworthiness limitations must be identified for all maintenance or inspection tasks required to identify failures of components within the FRM that are needed to meet paragraph M25.1. Boeing requested that paragraph M25.4(a) be modified to require only airworthiness limitations be identified for “significant” maintenance or inspection tasks. Boeing stated that it is overly restrictive to require that all maintenance tasks be identified as airworthiness limitations. It argued that applicants should be granted the flexibility to identify significant tasks as

airworthiness limitations and other non-significant tasks as maintenance significant items.

We agree with Boeing that we should not require that all maintenance tasks for FRM be identified as airworthiness limitations. Airworthiness limitations for the FRM system are only required for those FRM components that, in the event of failure, would affect the ability of the fuel tank to meet the Fleet Average Flammability Exposure specified in paragraph M25.1. We regard any task that is necessary to meet this objective as "significant." We recognize that manufacturers are also required to provide other maintenance information for the FRM as part of the instructions for continued airworthiness required by § 25.1529.

#### 8. Catastrophic Failure Modes

EASA noted that Appendix M significantly differs from the harmonized special conditions it used for certifying FRM on some specific airplane models. EASA asked that we explicitly state that catastrophic results must not occur from any single failure or combination of failures not shown to be extremely improbable (for the FRM system) as required in the noted special conditions. We agree that possible catastrophic failure modes of the FRM must be shown to meet the requested standard. However, we do not agree that EASA's change is needed since the regulatory intent is already addressed by other regulations that apply to FRM. For example, the general requirements of § 25.901 that apply to all Subpart E regulations apply to an FRM certificated to meet § 25.981 and Appendix M. Therefore, we did not make any change to Appendix M based on EASA's comment.

#### 9. Reliability Reporting

Paragraph M25.5 requires the applicant to demonstrate an effective means to ensure collection of FRM reliability data and to provide a report to the FAA. We requested comments on the proposal to require DAHs to submit a quarterly report on FRM reliability for 5 years. We consider these reports necessary to determine whether the predicted reliability for these systems is accurate, and to enable us to initiate necessary corrective actions if they are not. We intend for DAHs to gather the needed data from operators using existing reporting systems that are currently used for airplane maintenance, reliability, and warranty claims. The operators would provide this information through existing or new business arrangements between the DAHs and the operators.

The AEA and ATA questioned this reliability reporting process. They stated the current reporting systems may not be equipped to accommodate this new data requirement without additional burden and cost. Airbus also stated the reporting requirement is unclear and without sufficient detail to enable them to fully comment. The AEA and Airbus also contend that the reporting requirement places operators in a position of having an obligation to report this information to the DAHs where such an obligation did not previously exist. They suggested that we not rely on technicalities and recognize the new obligation being imposed on the operators. Finally, Transport Canada commented that the rule appears to require extensive data collecting and reporting and requested more details be provided regarding what this data will be used for.

The purpose of collecting reliability data is to ensure that failures of the system are reviewed and corrected. In this manner, system reliability is enhanced and FRM malfunctions will become very infrequent. The reporting requirement will also provide data necessary to validate that the reliability of the FRM achieved in service meets the values used in the fleet average flammability exposure and reliability analyses so that the actual flammability reduction in service airplanes will achieve the safety goals of this rulemaking.

The reliability reporting requirements in paragraph M25.5 would not add an additional burden or cost to the operators. We also continue to believe that this rule does not directly impose reporting requirements on operators. These reporting requirements are placed upon the DAH, not the operator. The NPRM and proposed AC 25.981-2B provided a description of the level of complexity that was intended in the quarterly reporting requirements. Furthermore, they do not specify that a new reporting system be created. The current reporting system could be used to gather the data and it could then be provided to the DAHs through normal business agreements. The DAH is required to make arrangements to collect sufficient data and provide a report to us. Reporting would be necessary only for a representative sampling of airplanes, as determined by the manufacturer in its compliance plan. Airlines routinely collect and store reliability data from airplane systems for a variety of reasons, such as engine and airplane system reliability data collected for Extended Twin Operations, warranty claims and maintenance planning, and

in many cases they report these data to DAHs.

Therefore, DAHs should be able to readily obtain these data through normal business practices. As a practical matter, DAHs will be monitoring the performance of these systems, just as they monitor other systems, both for warranty and liability reasons. Operators will be providing this information to DAHs as normal business practice to obtain DAH support in correcting any problems that occur. Our expectation is that the DAHs' compliance plans will simply state that DAHs will compile this information into periodic reports (which they would normally do for their own use anyway) and provide them to the FAA. No change has been made to the final rule as a result of these comments.

Bombardier requested that paragraph M25.5(b) be revised to allow non-U.S. manufacturers to submit their reports to their national authorities rather than the FAA. While we acknowledge that submitting a report to a foreign manufacturer's national authority might simplify the paperwork exchange, at this time other authorities have not agreed to harmonize with this rule. Therefore, there are no corresponding regulations that would require the submittal of reliability reports to these authorities or to ensure that we will see these reports. We have revised the requirement to allow for FAA approval of alternative reporting procedures, which would include reporting to other authorities with harmonized requirements. The rule also provides that, after the first five years of reporting, if the demonstrated reliability of the FRM meets and will continue to meet the reliability requirements in paragraph M25.1 (not to exceed 1.8 percent of the FEET), other reliability tracking methods could be proposed to us for approval, or possibly reporting could be eliminated.

Boeing requested that M25.5(b) be revised to allow the applicant to suggest alternative methods of reporting and submit the report to us on a yearly basis instead of a quarterly basis. It asserted that a one-year reporting requirement will allow for more statistically significant data to be collected for new systems. We agree that a quarterly requirement may be unduly burdensome, but we believe that a yearly requirement is too long to enable us to initiate timely corrective action to address reliability problems. Therefore, we have modified paragraph M25.5(b) in the final rule to extend the reporting to once every 6 months for the first five years after service introduction of the FRM. This reporting period should

allow adequate time to gather data to establish the performance of the FRM and for any needed corrective actions to be taken if the performance of the FRM falls below minimum levels.

Boeing also requested changes be made to allow applicants that have established reporting methods to suggest these as alternative methods of meeting the reporting requirements. We believe the current wording allows the DAH the latitude to develop a reporting system and request FAA approval based upon their business arrangements with operators so long as the reporting system provides sufficient data to the FAA to determine the reliability of the FRM. Allowing the use of alternative reporting methods could lead to disparate reports among manufacturers, making FAA oversight difficult.

### G. Appendix N—Fuel Tank Flammability Exposure and Reliability Analysis

#### 1. General

Appendix N to part 25 provides the requirements for conducting the analyses for fleet average fuel tank flammability exposure required to meet § 25.981(b) and Appendix M and to comply with part 26 requirements. Appendix N contains the method for calculating overall and warm day fuel tank flammability exposure values needed to show that the affected airplane's tanks comply with the proposed limitations on flammability exposure.

#### 2. Definitions

Paragraph N25.2 provides specific definitions associated with flammability and analysis terminology used in Appendix N. We received comments requesting clarification on five of these definitions:

a. *Ullage*: Boeing suggested this definition should ensure that all of the ullage space is considered (not just the fuel volume), and we agree. In the final rule, this definition has been revised to clarify that the total ullage space must be considered.

b. *Flammability Exposure Evaluation Time (FEET)*: An individual commenter wanted to understand when the evaluation time begins and ends for airplanes using ground conditioned air with the auxiliary power unit (APU)/ground power unit (GPU) operating or electrical power that is connected to the airplane. The evaluation time would begin as soon as the airplane is prepared for flight, regardless of whether an APU or electrical ground power is used. The time would end as soon as the airplane has landed and passengers and crew

have disembarked and payload has been unloaded. In passenger operations where numerous flights may occur each day, this definition would result in all the time between flights also being part of the FEET. The only exception would be the time at the end of the last flight of the day to the point in the next morning when the airplane is being readied for flight. This is consistent with the definition for FEET given in paragraph N25.2(b).

c. *Bulk Average Fuel Temperature*: An individual commenter suggested the definition include the means for determining "bulk average fuel temperature." As we stated in the preamble to the NPRM, the determination of whether the ullage in the fuel tank is flammable is based on the temperature of the fuel in the tank or compartment of interest. This is derived from a fuel tank thermal model, the atmospheric pressure in the tank, and the properties of the fuel. The thermal model is comprised of temperature data acquired from various locations within the fuel tank. In order to express the fuel temperature of the tank as a whole in the fuel tank fleet flammability exposure analysis, a weighted average by volume should be calculated at each point in time since the temperature may vary across the tank or compartments of the tank depending upon the volume of that area. We will provide additional guidance on how to determine Bulk Average Fuel Temperature in AC 25.981–2A.

d. *Flash Point*: An individual commenter asked what the term "heated sample" meant in this definition. The standardized methods for determining flash point are ASTM D 56 and ASTM 3828. Both methods place a sample of fuel in a closed cup and heat it at a constant rate. A small flame is introduced into the cup, and the lowest temperature at which ignition is observed is referred to as the flash point. The heated sample is the fuel that is placed in the closed cup when conducting this test.

e. *Inerting*: An individual commenter requested that fuel removal from the ullage mixture be included as an acceptable inerting method. We do not agree with this request. The definition of inerting is based upon oxygen concentration, not fuel content of the ullage. The Monte Carlo method uses the bulk fuel temperature to determine fuel tank flammability, and does not consider transport effects or tank ventilation. However, if an applicant wishes to consider methods for removing fuel from the ullage mixture, it could request a finding of equivalent safety under the provisions of § 21.21.

To be equivalent, such a method would have to be shown to provide at least the same level of safety as an FRM meeting the performance requirements of Appendix M.

#### 3. Input Parameters

Paragraph N25.3(c) provides the parameters that are specific to a particular airplane model under evaluation that must be provided as inputs to the Monte Carlo analysis. Boeing had two comments on these parameters.

First, Boeing requested we add a new parameter to paragraph N25.3(c) for airplane utilization. This parameter would require the applicant to provide data supporting the number of flights per day and the number of hours per flight from existing fleet data. Boeing stated that this information is necessary to determine when to apply the diurnal effect that is required by paragraph N25.4(c) based upon the number of flights per day. The number of hours per flight will also provide validation of the mean hours per flight generated by the Monte Carlo analysis.

We agree with Boeing's comment and the final rule includes a new paragraph N25.3(c)(7) for airplane utilization that addresses this comment. Boeing's second comment was a request that the statement "or for the section of the tank having the highest flammability exposure" be removed from paragraph N25.3(c)(5). As proposed, paragraph N25.3(c)(5) requires that, for any fuel tank that is subdivided by baffles or compartments, the bulk average fuel temperature inputs must be provided either for each section of the tank or for the section of the tank having the highest flammability exposure. Boeing stated that every region in a fuel tank should be considered in order to establish the total flammability exposure of the tank. If the bulk temperature input only consisted of a section of the fuel tank having the highest flammability exposure, Boeing argued that the total flammability of the tank would not be accurately accounted for because the analysis would not consider regions that were less flammable.

Any fuel tank that is compartmentalized or subdivided into sections by baffles is "flammable" under the definition for Appendix N (N25.2(c)) when the bulk average fuel temperature within any section of the tank that is not inert is within the flammable range for the fuel type being used. We agree with Boeing that the clause "or for the section for the tank having the highest flammability exposure" in paragraph N25(c)(3) causes confusion, and we

have revised paragraph N25.3(c)(5) as requested.

We are providing guidance in AC 25.981-2 on the need to conduct the flammability analysis for each bay or compartment and then sum the time any portion of the tank is flammable in the flammability analysis.

#### 4. Verification of "Flash Point Temperature"

An individual commenter requested verification of the flash point temperature (120 °F) that is used in Table 1 of Appendix N. We have defined in Table 1 of Appendix N a "mean fuel flash point temperature" based upon worldwide survey data that was collected from 1998 through 1999. The Monte Carlo analysis varies the flash point based upon the distribution of possible flash point temperatures for the fuel, similar to what would be expected for a fleet of airplanes where fuels from various refineries and locations are used.

#### H. Critical Design Configuration Control Limitations (CDCCLs)

Past experience has shown that critical features of airplane designs have inadvertently been changed when maintenance actions or alterations to airplanes have been made. For example, critical wiring that was intended to be separated from other wiring to prevent possible unsafe conditions has been modified so new or rerouted wiring was co-routed with the critical wires. These instances revealed the need for airplane designers to identify safety critical features, in this case wiring separations, and for these features to be marked so that maintenance personnel are aware of the critical features.

We proposed adding fuel tank flammability related design features to the existing fuel tank ignition source CDCCL requirements in § 25.981(d) (formerly paragraph (b)). This section requires CDCCL, inspections, or other procedures as necessary, to prevent increasing the flammability exposure of tanks above that permitted by the amended § 25.981(b) and to prevent degradation of the performance and reliability of any means provided for compliance with paragraphs 25.981(a), (b) or (c). We also proposed adding fuel tank flammability to the existing requirements to place visible means of identifying critical features of the design in areas of the airplane where foreseeable maintenance actions, repairs or alterations could compromise the CDCCL. Similar provisions were proposed in § 25.1815(e) for existing type certificates.

#### 1. Remove Requirement

Boeing, Embraer and Bombardier requested that we remove the requirement to establish CDCCLs to prevent the increase of flammability in the fuel tanks and to prevent degradation of the performance and reliability of the FRM. They stated that it is not practical or effective to try to control flammability through the use of CDCCLs. Instead, they argued that the certification process should be used to establish the design's flammability exposure. Bombardier also pointed out that the type certification data sheet is the appropriate means to capture limitations (e.g., fuel type, fuel temperature) that would affect flammability.

The intent of the CDCCL requirement is to define the critical features of the design that could be unintentionally altered in a way that could cause a reduction in fuel tank safety. In the case of IMM or FRM, maintenance or alterations to the airplane could significantly affect fuel tank flammability and the performance of these systems. Since the heating or cooling rate of a fuel tank could be a critical feature, placing a heat exchanger or other heat source in or near the tank or changing the cooling rate by transferring warm fuel to the tank are examples of changes that could result in a significant increase in fuel tank flammability.

The commenters did not provide any substantiating information as to why they believe it is not practical or effective to use CDCCLs to control fuel tank flammability. Our experience with applying the CDCCL concept to fuel tank ignition sources has shown it to be both practical and effective. Locating this information on the TC data sheet, as suggested by Bombardier, would not provide the information to individuals, such as maintenance personnel, who could be responsible for inadvertently changing the system. Accordingly, we do not believe this suggestion would be effective. In contrast, as airworthiness limitations, CDCCLs are clearly defined as maintenance requirements that are routinely complied with by maintenance personnel and that are enforceable under the operational rules (e.g., § 91.403(c)). The intent of applying the CDCCL concept to FRM and IMM is to provide a common location within the maintenance instructions where information on fuel tank safety related critical features are located. Therefore, we have retained the requirement in § 25.981(d) to identify CDCCLs for FRM and IMM.

On a related issue, paragraph (h) of each of the proposed operational rules would have required operators to comply with the CDCCLs. In the NPRM, we inadvertently omitted reference to § 25.981 as one of the sources of requirements for these CDCCLs. Therefore, we have added these references to the final rule. This change is simply clarifying, since operators are required to comply with airworthiness limitations under existing regulations.

#### 2. Clarification on Responsibility for Later Modifications

As proposed, § 25.1817(d) (now § 26.35(d)) would require that modifications made to an airplane comply with any CDCCL applicable to that airplane. The AEA questioned whether this paragraph would require the TC holder or STC applicant applying for a design change to achieve a flammability exposure level equal to or better than that existing on the unmodified airplanes, or if the TC holder or STC applicant will be held to the flammability exposure limits specified in the rule.

The proposed requirement for TC holders to develop CDCCL is contained in proposed § 25.1815(e) (now § 26.33(d)). It would require CDCCL "to prevent increasing the flammability exposure of the tanks above that permitted under this section and to prevent degradation of the performance of any means provided under paragraph (c)(1) or (c)(2)<sup>23</sup> of this section." The AEA has identified an ambiguity and potential conflict in this quoted provision. Specifically, if a TC holder develops FRM whose performance exceeds that required by proposed § 25.1815(c)(1), it is not clear whether the CDCCL would have to maintain the flammability exposure provided by the FRM or whether the rule would allow an increase in flammability exposure up to that permitted (i.e., 3 percent or equivalent to a conventional unheated aluminum wing tank, along with the "warm day" requirement).

To eliminate this ambiguity, we have deleted the reference to paragraph (c)(1) in the quoted provision. This revision has the effect of requiring CDCCL for FRM that allow increasing flammability up to that permitted by the rule, but retains the requirement that degradation of performance of IMM is not permitted. Since IMM may be installed on high flammability tanks, degradation of IMM could have serious safety consequences and would not be consistent with the intent of the rule.

<sup>23</sup> Paragraphs (c)(1) and (c)(2) provide for FRM and IMM, respectively.

We note that TC holders may be inclined to develop overly stringent CDCCL for FRM that could potentially make it impossible for holders of auxiliary fuel tank STCs to meet them. This would force operators to deactivate these tanks. This over-stringency would not be consistent with this rule's intent, which is to minimize the burden on operators, consistent with achieving the safety objectives of this rule. This issue is discussed in more detail in AC 25.981-2B.

Proposed § 25.981(d) contained the same ambiguity by requiring CDCCL to prevent degradation of performance and reliability of any means provided according to paragraph (b) of that section (FRM). We have made a similar change to paragraph (d) to allow degradation of FRM as long as the airplane still meets the standard required by paragraph (b).

### 3. Limit CDCCLs to Fuel Tanks That Require FRM or IMM

Boeing requested that proposed § 25.1815(e) (now § 26.33(e)) be modified to only require CDCCLs that are necessary to prevent the increase of fuel tank flammability for fuel tanks that require an FRM or IMM. Boeing stated that development of CDCCLs for other fuel tanks is not practical, nor is there history to show that changes to the fuel tanks of airplanes in service significantly increase flammability in the tanks. Boeing also requested that the requirement to make critical features of the design visibly identifiable only apply to areas where it is practical to do so.

For existing designs subject to proposed § 25.1815(e) (now § 26.33(e)), we agree with Boeing, and have limited the applicability of the requirement to develop CDCCL to those tanks for which FRM or IMM are required. We recognize that there are many existing modifications that may affect the flammability exposure of existing fuel tanks. We agree with Boeing that, for main tanks and other tanks not incorporating FRM or IMM, it is impractical to impose CDCCLs on these tanks that may result in significant compliance problems for affected operators. For tanks equipped with FRM or IMM, however, we believe CDCCLs are necessary to prevent degradation of these systems below acceptable levels of performance.

We also agree with Boeing that, in many instances, it may not always be practical to mark critical features relating to controlling fuel tank flammability and the proposed rule should be modified to allow the applicant to justify why markings are

not needed. We have modified the next to last sentence in § 26.33(e) accordingly.

This change will allow acceptance of designs without markings when the applicant can show that such markings would be impracticable. We intend for applicants to identify any CDCCL that are required and to provide justification for why the marking would be impracticable. Like all CDCCLs, these would still be documented as airworthiness limitations in the instructions for continued airworthiness.

### 4. STC Holders May Not Have Data to Comply

The AEA and Airbus challenged our statement in the NPRM that operators have access to information that may be needed by STC and field approval holders to perform flammability and impact assessments. The commenters noted that such information is highly proprietary and is rarely provided to operators. AEA added that contractual agreements to obtain TC holder information are difficult, if not impossible, to obtain.

For many years, the FAA and other regulatory authorities (including EASA) have routinely required manufacturers to make available information that they consider proprietary when we determine providing this information is necessary for aviation safety. For example, most ADs reference information that would otherwise be proprietary in the form of service bulletins, which manufacturers are required to make available to operators. Similarly, § 21.50 requires manufacturers to make available instructions for continued airworthiness, which manufacturers would also typically consider proprietary.

In existing § 25.981(b), we required DAHs to define and make available CDCCL to prevent the unintended creation of ignition sources as a result of maintenance or airplane modifications. In proposed § 25.981(e), we required the identification of critical features of a design that cannot be altered without consideration of the effects on safety. As discussed previously in this section, the final rule includes a new requirement for CDCCLs affecting fuel tank flammability.

Some of the data that STC and field approval holders may need are already normally provided to operators in the airplane flight manual, including fuel management information and airplane climb rates. For other necessary data, such as fuel tank thermal characteristics, we believe that the

market will promote business agreements where TC holders will make their data available to customers willing to pay for the data. Airbus or other TC holders may make a business decision not to support their customers and provide these data. In these cases, it may be necessary for the operator or STC applicant to acquire the data from other sources. Another option is for applicants to provide a Monte Carlo analysis based on conservative inputs for parameters where no data are available. For example, an applicant could provide thermal characteristics data that are conservative so that detailed testing and confirmation of data from flight testing of an airplane would not be required. Finally, if these approaches are not practical, the information needed to conduct the Monte Carlo analysis could be obtained from in-service airplanes.<sup>24</sup>

### *I. Methods of Mitigating the Likelihood of a Fuel Tank Explosion*

#### 1. Alternatives to Inerting

In the IRE, we selected the use of onboard nitrogen inerting to assess the costs of reducing fuel tank flammability. By doing this, several commenters thought we were mandating fuel tank inerting as the only acceptable means of compliance. ATA and Bombardier commented that the proposal is not a performance-based rule, since it "effectively prescribes the use of fuel tank inerting." ATA also stated that they were not aware of any existing or emerging FRM or IMM that would meet the proposed performance-based requirements other than inerting. Frontier Airlines questioned why we focused on FRM and IMM as methods of compliance when the FAA concluded that other solutions were better and more practical.

This rule does not mandate fuel tank inerting as the only acceptable means of compliance. Rather, it establishes performance-based requirements that allow applicants to choose the FRM or IMM that best suits their particular airplane design, so long as it meets the performance requirements of this final rule. While the Initial Regulatory Evaluation is based upon the use of inerting, this technology was chosen because it is considered the most cost-

<sup>24</sup> Most of the STCs that could be affected by this rulemaking are auxiliary fuel tanks that use pressurized air to transfer fuel. In these cases, the inputs needed for the Monte Carlo assessment are simplified because the fuel tank pressure is controlled to provide fuel transfer, and the temperature changes of the fuel tank are limited because the fuel tank is located in the cargo compartment.

effective based upon extensive review by industry experts on the ARAC.

Technology now provides a variety of commercially feasible methods to accomplish the vital safety objectives addressed by this rule. Advisory Circular 25.981-2 discusses a number of technologies other than fuel tank inerting that can be used for demonstrating compliance. For example, many auxiliary tank manufacturers are considering pressurizing the fuel tanks to reduce flammability, and many military airplanes use IMM consisting of polyurethane foam. One recent applicant has proposed FRM incorporating pressurization of the fuel tanks and a fuel recirculation system that circulates fuel to the outboard wing to cool the fuel. Therefore, we believe that other technologies are available.

ATA commented that we should consider convening an industry study group to re-examine the potential of higher flash point fuel as a possible alternative method for reducing flammability and overall airplane level risk. ATA noted that refineries may now be capable of producing higher flash point fuels in the near term in sufficient quantity for commercial aviation use. In addition, Boeing advised ATA that a 10 °F elevation in the flash point standard for Jet A could effect a reduction in flammability exposure rates approximately equivalent to the proposed FRM. While ATA acknowledged the likelihood is not high that this approach would provide a more cost-effective solution than FRM, particularly in the long term, it deserves reconsideration. The UK Air Safety Group, through one of its members, agreed with ATA and suggested the use of higher flash point fuels (such as JP-5) should be investigated as a possible solution.

While we welcome the potential for using various forms of FRM, we do not believe delaying implementation of the rule is in the public's interest. The FAA and industry participated in ARAC activities that provided economic analysis of existing technologies, including inerting and mandatory use of higher flash point fuels. At that time, inerting was found to be a more cost-effective means of showing compliance with the performance-based FRM rule. In contrast, as shown in the ARAC report,<sup>25</sup> using higher flash point fuels was not the most practical means of achieving the desired safety level because of the higher cost of these fuels.

If technology and refining capabilities have advanced to the point where higher flash point fuels are available in quantity at a competitive cost, the industry may use that means to show compliance, and this means is discussed in the proposed AC 25.981-2.

Flammability assessments with a specified minimum fuel flash point, in conjunction with airplane flight manual limitations requiring use of such fuel, could be used as a means of compliance with this rule. Since the rule is performance-based and does not mandate any particular solution, industry may find innovative ways to show compliance to standards.

## 2. Inerting Systems Could Create Ignition Sources

Transport Canada expressed concern that adding inerting systems to fuel tanks may create ignition sources and result in additional heating of in-fuselage tanks. It argued the solution may inadvertently increase flammability exposure. Transport Canada recommended the FRM be designed to ensure its reliable operation and minimal maintenance. The UK Air Safety Group, through one of its members, also expressed this concern. The commenter suggested that inerting systems could actually compromise the fuel tank system, that insulation could impede inspections of equipment and structure, and that ventilation could cause performance penalties.

We acknowledge the commenters' concerns that installing FRM could introduce negative safety consequences. However, these potential consequences do not outweigh the safety benefits of flammability reduction. As with all safety equipment, the FRM must comply with the existing applicable airworthiness standards that are intended to prevent system failures from having a negative safety impact. In addition, we have introduced new requirements in this rule to address the possible negative safety impact of using an onboard nitrogen inerting system. Compliance with these combined requirements should produce systems that are reliable, maintainable, and meet the flammability requirements of this rule.

## 3. Instruments to Monitor Inerting Systems

ATEXA recommended that when a nitrogen dilution system is used, the airplane should be equipped with instruments to verify that the system is functioning as expected. These instruments should record data continuously so the pilot can control the oxygen concentration in the tanks

within prescribed limits on the ground, before take-off, and at landing. This data should also be recorded in the flight data recorder so that, should another accident happen, the cause/origin could be identified.

As we stated before, this rule is performance based and allows designers the ability to be innovative. The need for indications and controls is design dependent, and the blanket requirement recommended by ATEXA could be overly stringent. DAHs may choose to provide flight crew indications of FRM status, or they may propose an automated FRM with built-in test to verify proper operation. It would be inappropriate for the rule to mandate specific design features.

As for the suggestion to record data, adding additional parameters to the FDR would be cost-prohibitive. Furthermore, we do not consider this necessary because the functioning of any FRM or IMM would likely not have any direct bearing on determining the cause of an accident. The flammability exposure of the fuel tank is not actually an indicator that a tank has exploded and the determination that a fuel tank explosion caused an accident could be made using physical evidence.

In a related comment, the Shaw Aerospace team (Shaw) commented that failure monitoring of system operation is inadequate. As proposed, the system relies totally on the built-in test to detect when the tanks are not inert due to a failure rather than direct measurement of the fuel tank oxygen concentration to determine if the tank is flammable. Shaw cited factors such as oxygen evolution from the fuel as the airplane climbs and local areas of high oxygen in the tanks because of lack of adequate nitrogen distribution as sources of flammability that will not be detected by monitoring the performance of the FRM, rather than measuring the oxygen concentration in the tank. Shaw stated that if the oxygen concentration in the fuel tank ullage is not monitored and periodically sampled, it would be difficult to prove the effectiveness of the system.

From the Shaw team's comments, we infer that Shaw believes the monitoring requirements should be modified to require ullage sampling to ensure that the tank remains non-flammable. We do not agree that a change to the proposed regulation is needed. Compliance methods are discussed in AC 25.981-2. Applicants may choose to measure fuel tank oxygen concentration directly or infer the concentration through system performance capability and monitoring. Appendix M25.2 requires that localized higher concentrations of oxygen that

<sup>25</sup> Document Number FAA-22997-7 in the docket for this rulemaking.

might result from inadequate distribution of nitrogen, as well as the possible effects of oxygen evolution from the fuel, be addressed in the compliance demonstration.

#### 4. Risk of Nitrogen Asphyxiation

If fuel tank inerting is used to reduce the flammability exposure of a fuel tank, several commenters noted that the introduction of nitrogen enriched air within the fuel tank, and possibly in compartments adjacent to the tank, could create additional risk because of the lack of oxygen in these areas. They believe the risk to maintenance personnel from nitrogen asphyxiation may exceed any safety benefit that fuel tank inerting may provide. To support their position, these commenters cited the Fuel Tank Inerting Harmonization Working Group's (FTIHWG) 2002 Final Report (24–81 lives could be lost between 2005–2020 due to asphyxiation while servicing transport airplanes) and other industrial accident data showing that oxygen depleted atmospheres account for significant loss of life. The commenters are concerned that we have failed to consider this potential loss of life that will result from this rule.

We acknowledge that special precautions are needed for worker entry into confined spaces where fuel vapors or nitrogen enriched air may be present. The standard practice of U.S. industry today is to comply with existing Occupational Safety and Health Administration (OSHA) requirements. These requirements have resulted in ventilating fuel tanks with air and measuring the oxygen concentration before entry into a fuel tank. In addition, persons entering a fuel tank must wear respirators as well as oxygen monitors to alert them should the oxygen concentration be insufficient.

The introduction of nitrogen into a fuel tank does not change the existing requirements for personnel to enter a fuel tank. No new training or changes to fuel tank entry procedures should be needed as a result of this rule. Since there are already specific OSHA requirements for fuel tanks that would prevent any fatalities, any loss of life would be due to non-compliance with OSHA regulations, not this rulemaking. Despite these existing OSHA requirements and the protections they afford, we have added new requirements for markings to notify workers at all access points and areas of the airplane where lack of oxygen could be a hazard. For these reasons, we have not included costs for loss of life due to asphyxiation in the final regulatory evaluation for this rulemaking.

We are also not persuaded by the commenters' reference to the FTIHWG 2002 Final Report. The predicted number of fatalities in that report is based upon application of data from every possible cause of nitrogen asphyxiation that is included in data collected between 1980 and 1989 by the U.S. National Institute of Occupational Safety and Health. The data quotes a total number of fatalities for all causes, including cases such as bottled nitrogen being hooked up to oxygen systems at a nursing home. This bulletin is not based upon data that can easily be applied to the aviation industry and does not provide any data that could be used to predict a rate of fatalities for the specific circumstances relating to airplane fuel tank safety. In addition, we do not think it is appropriate to extrapolate the data from the bulletin without taking into account existing OSHA requirements used in the aviation industry or that the placards required by this rule will heighten awareness to the risks associated with entering fuel tanks.

#### 5. Warning Placards

This rule attempts to reduce the risk of nitrogen asphyxiation by requiring markings on the access doors and panels to the fuel tanks with FRMs, and to any other enclosed areas that could contain hazardous atmosphere. These markings will warn maintenance personnel of the possible presence of a potentially hazardous atmosphere. Bombardier commented that the use of placards and the exact wording proposed is too prescriptive. Bombardier recommended the rule require a general warning, with guidance defining methods of compliance placed in the corresponding AC 25.981–2.

The requirement for placards is based upon methods used throughout aviation and other industries where safety warnings are needed to protect workers from possible harm. Locating the requirements in the regulation rather than in advisory material provides appropriate level of regulatory review of this safety critical information and will result in standardizing the means of warning maintenance personnel. Applicants may apply for a finding of equivalent safety should they wish to propose an alternative means of achieving the level of safety provided by the placard requirement in the rule.

#### 6. Definition of "Inert"

A fuel tank is considered inert when the bulk average oxygen concentration within each compartment of the tank is 12 percent or less from sea level up to 10,000 feet altitude, then linearly increasing from 12 percent at 10,000 feet

to 14.5 percent at 40,000 feet altitude, and extrapolated linearly above that altitude.

Several commenters, including Airbus, AAPA, AEA and Blaze Tech, questioned whether an allowable oxygen concentration of 12 percent would inert a fuel tank. They pointed to comments in an FAA research document stating that "(f)urther experiments to examine the trend of peak pressure rise as a function of both altitude and oxygen concentration are needed." The commenters stated that this is an indication that the 12 percent oxygen concentration limit would not prevent the ignition of fuel vapors from rupturing an airplane fuel tank and that further work is necessary before accepting the 12 percent value. American Trans Air and ATEXA noted that the chemical process industry, as quoted by the French National Institute for Research and Security (INRS, 2004), uses a safety factor of 0.5 for industrial volumes on non-homogenous fuels, and operators must strive to maintain a maximum oxygen content of 5 percent for inerting purposes. Based on this, American Trans Air and ATEXA stated that the 12 percent limit would not be safe.

In 1997, we initiated research activity to determine a maximum oxygen concentration level at which civilian transport category airplane fuel tanks would be inert from ignition sources resulting from airplane system failures and malfunctions. Our testing determined that a maximum value of 12 percent was adequate at sea level. The 12 percent value was initially based on the limited energy sources associated with an electrical arc or thermal sparks that could be generated by airplane system failures and lightning on typical transport airplanes and was not intended to include events such as explosives or hostile fire.<sup>26</sup> As a result of this research, we learned that the quantity of nitrogen needed to inert commercial airplane fuel tanks was less than previously believed. An effective FRM can now be smaller and less complex than earlier systems that were designed to meet the more stringent military standards intended to prevent ignition from high energy battle damage.

The 12 percent value is further substantiated by the results of live fire testing conducted by China Lake Naval Weapons Center that showed a 12 percent oxygen concentration prevents

<sup>26</sup> These test results are available on our Web site: <http://www.fire.tc.faa.gov/pdf/tn02-79.pdf> as FAA Technical Note "Limiting Oxygen Concentrations Required to Inert Jet Fuel Vapors Existing at Reduced Fuel Tank Pressures," report number DOT/FAA/AR-TN02/79.

ignition, even when high energy incendiary rounds were used that had ignition energies well in excess of any source anticipated to occur on a commercial airplane. These data show that 12 percent oxygen concentration for commercial airplanes achieves a comparable level of protection against catastrophic fuel tank explosions as the traditional 9 percent value used by the military for combat airplanes. The suggestion that the oxygen concentration should be limited to 5 percent is impractical for commercial airplanes since a significantly larger flammability reduction system would be needed and, based upon these test results, there would be no appreciable improvement in airplane safety.

Finally, the quoted FAA comment that additional testing is needed was taken out of context. The recommendation for additional testing referred to conditions when the oxygen concentration was between 1 to 1.5 percent greater than the limit of 12 percent. Testing at these higher oxygen concentration values was not extensive since the focus of the testing was to establish the limiting oxygen concentration where ignition was not possible. Our report's suggestion that additional experiments are needed was not an indication that the 12 percent limit was inadequate—quite the opposite. In fact, the next sentence of the report confirms the importance of the study's validation of the 12 percent limit: "The results contained in this report should be useful in the design, sizing, and optimization of future airplanes inerting systems and add to the overall knowledge base of jet fuel flammability characteristics."<sup>27</sup>

#### 7. Use of Carbon Dioxide

An individual commenter stated that inerting a fuel tank with carbon dioxide may introduce new concerns because of the solubility of this gas in fuel and the possible effects on fuel system operation. This commenter also wanted to know what the acceptable level of oxygen would be to consider the fuel tank ullage inert when this gas was used.

We acknowledge the use of carbon dioxide for inerting may require special considerations for fuel feed system performance. The subject of inerting with carbon dioxide is addressed in AC 25.981-2 and we have revised it to highlight these concerns. As for the commenter's specific question about oxygen concentration in the fuel tank,

the acceptable level of oxygen is the same as if nitrogen is used.

#### 8. Environmental Impact of FRM

The UK Air Safety Group, Phyre Tech and one individual questioned the environmental impact of using FRM to displace air and fuel vapor from the fuel tanks into the surrounding environment. These commenters expressed concern about increased hydrocarbon emissions into the atmosphere.

The IRE did not include an environmental assessment or analysis because we determined the environmental impact of a FRM or IMM to be negligible. Their installation will not affect the amount of fuel vapors and hydrocarbon emissions that are discharged from fuel tanks during refueling. Currently, fuel tank designs vent fuel vapors and hydrocarbon emissions into the atmosphere when air is exhausted from the fuel tanks during refueling and flight. Data from recent flight tests of a Boeing 737 equipped with a nitrogen-based FRM showed that installation of FRM and related design changes actually reduce the amount of hydrocarbons vented from the tanks during flight.<sup>28</sup> In those test flights, the data indicated that pressure differences from one wing tip to the other wing tip, where the two airplane fuel tank vent outlets are located, resulted in cross flow of air through the fuel tanks including the center wing tank for the original vent configuration. This occurred often in flight and periodically on the ground when any crosswinds were present. As a result, fuel vapors were exhausted from the fuel tanks into the atmosphere. Any air that entered the fuel tank diluted the nitrogen concentration in the tank such that the fuel tank vent outlets needed to be modified to prevent cross flow of air through the vent system. Modification of the vent system resulted in reduced hydrocarbon discharge to the atmosphere.

#### 9. Current FRMs Fail To Meet Requirements

Transport Canada noted that an FRM must meet not only the requirements in this rule, but also the relevant other sections within part 25, in particular § 25.1309. Transport Canada stated that current FRM designs would not meet § 25.1309 because of a lack of system redundancy, a lack of appropriate system performance monitoring and indication, and the allowance of MMEL relief.

<sup>28</sup>Data from flight testing on the Boeing 737 (DOT/FAA/AR-01/63, "Ground and Flight Testing of a Boeing 737 Center Wing Fuel Tank Inerted With Nitrogen-Enriched Air," dated August 2001).

We do not agree that existing FRM systems do not meet all the relevant sections of part 25, including § 25.1309. We approved the FRM systems for the Boeing 747-400 and 737NG series airplanes in August 2005, and December 2006, respectively, as showing compliance with all the applicable part 25 regulations. This approval was validated by EASA shortly thereafter. While the commenter is correct that these systems lack redundancy, and limited dispatch with the systems inoperative is allowed under the MMEL, these systems are supplementary safety systems that are intended to work in combination with the ignition prevention features required by § 25.981 to prevent future fuel tank explosions.

#### 10. FRM Based on Immature Technology

Airbus had numerous objections regarding our description of the prototype hybrid onboard inert gas generation system (OBIGGS) that was tested on an Airbus A320 in 2003. Airbus objected to the OBIGGS being called a "prototype." Instead, Airbus would characterize the OBIGGS as "laboratory demonstration equipment." Airbus (and AEA) commented that the OBIGGS was not in an advanced state of development and would require extensive development before it reached a level of maturity suitable for certification and operation. Airbus also stated that we have not identified to Airbus an existing regulation that would require Airbus to develop an FRM, and Airbus is not committed to any such development program. British Airways also expressed concerns that the proposed systems have not been fully tested or developed and operators may find themselves required to install a system that is not yet fully certified.

We acknowledge that the development and certification of a production and retrofit FRM would require significant engineering and development. While the FRM equipment (i.e., FAA-developed prototype OBIGGS) installed and flown on an Airbus airplane had not been certified, an FRM system similar in concept was designed, tested, and certified on Boeing 737 and 747 series airplanes within two years of the Airbus demonstration flights. This certification demonstrates that the technology is mature, and that our proposed two-year compliance is reasonable and achievable. The harmonized certification requirements for the Boeing 737 and 747 FRM, which were nearly identical to those proposed in the NPRM, were published as Special Conditions in 2005 for public comment.

<sup>27</sup> Document FAA-22997-14, Executive Summary.

This provided the public, including Airbus, with detailed information needed to develop an FRM. In addition, much of the hardware and components needed for an FRM have been developed by aerospace manufacturers and this developmental work should reduce the time needed for Airbus to develop a system.

During development of the NPRM, Airbus provided us with a cost analysis for an FRM that included the cost of engineering, components and operation of the system. We trust that the cost information was based upon initial engineering assessments of FRM and contact with component vendors. We concur with Airbus that, prior to this final rule, there was no regulation that would require a flammability reduction means to be developed and installed. However, since the NPRM was published, two Boeing 737 and two Boeing 747 airplanes have been delivered with operational FRM based upon nitrogen inerting technology. These systems have performed very well and provide an indication that the technology is mature for application to commercial aviation. In addition, in its March 5, 2007, letter, Airbus confirmed information it shared with FAA in November 2006, that Airbus is proceeding with the development of an FRM (Docket No. 22997-149).

#### *J. Compliance Dates*

The Families of TWA Flight 800 Association, Inc., as well as several members of the public, commented that the compliance times are too long and should be shortened. While we understand the commenters' frustration with the proposed compliance times, the schedules chosen are based on the industry's ability to respond to this rule. Each DAH, operator, and after-market modifier will have to follow a series of steps to make appropriate assessments and develop designs and installation plans. Designing FRM for each affected airplane model will require engineering resources; allowing less than 24 months for developing the design changes is not practical and could result in unintended reduction in airplane safety because of increased likelihood of design errors. Accelerating the retrofit schedule could significantly increase the cost of the program due to the need to introduce FRM into operators' fleets during lengthy out-of-sequence maintenance visits. We believe that the schedules chosen correctly balance the risk of a fuel tank explosion during the compliance period with the industry implementation capability.

#### 1. Part 26 Design Approval Holder Compliance Dates

##### a. Submitting the Flammability Exposure Analysis

Boeing requested that proposed § 25.1815(b)(1) (now § 26.33(b)(1)) be revised to remove the compliance time (i.e., 150 days after the effective date of the rule) for TC holders to submit the flammability exposure analysis for affected airplane fuel tanks. Boeing stated that a large amount of test data is required to develop the analysis and, as such, a compliance time of 150 days would be inadequate. They believe this requirement is primarily for program planning purposes and that the compliance time in Table 1 of proposed § 25.1815(d) is appropriate for that purpose.

Embraer and Bombardier similarly commented that the 150-day compliance time for submitting the flammability analysis is inadequate. The basis for their comment was that validation of fuel tank thermal models will require developing new flammability tools and flight testing, which will require additional time. Embraer proposed a 24-month compliance time, and Bombardier proposed a 12-month compliance time.

We believe the proposed compliance time is adequate. It will ensure that the flammability exposure analyses are completed for every affected fuel tank in a timeframe we consider acceptable because of the reduced amount of work required for conventional unheated aluminum wing tanks. These analyses will determine if FRM is required for a given fuel tank, and the timeliness of completing the analysis is needed to meet the design and implementation schedule. As discussed earlier, we have revised proposed § 25.1815(b)(2) (now § 26.33(b)(2)(i)) of the final rule to allow TC holders to avoid performing the flammability analysis for particular tanks by stating in their compliance plans that they will treat the tank as high flammability and develop FRM or IMM, as required. In addition, no flammability analysis will likely be required to determine the flammability of the center wing tanks of Boeing and Airbus models, since we have determined from their comments that these models exceed the 7 percent limit. We have also significantly reduced the complexity of fuel tank thermal analyses that will be required by the industry because we modified the analysis requirements to allow a qualitative flammability assessment for conventional unheated aluminum wing tanks. No flight testing would be needed

to gather data for conventional unheated aluminum wing tanks.

For the remaining tanks for which a flammability assessment is needed, the DAHs have been aware of the need to address fuel tank flammability and have conducted testing of airplanes to develop fuel tank thermal models. Therefore, additional time should not be needed to develop fuel tank thermal modeling for the majority of fuel tanks in the fleet. We believe 150 days is sufficient to complete the required analyses, and have made no change to the compliance time in the final rule.

##### b. Submitting a Compliance Plan for Developing Design Changes and Service Instructions

Under proposed § 25.1815(h), each holder of an existing TC would need to submit to the FAA Oversight Office a compliance plan for developing design changes and service instructions within 210 days of the effective date of the rule, which equals 60 days after the compliance date for submitting the flammability analysis. Embraer and Bombardier claimed developing a compliance plan within 60 days of submitting the flammability analysis was impractical. They based their objections on the fact that Boeing and Airbus, who are specifically cited in the NPRM, were already preparing for compliance prior to publication of the NPRM. They claimed that those DAHs not cited in the NPRM are not doing advanced preparation and will need extra time.

While Airbus acknowledged that 210 days is a reasonable timeframe, Airbus was concerned about how this timeframe would accommodate delays caused by our review. For example, if the TC holder delivers a flammability analysis which indicates a value under 7 percent, and, after review, the FAA identifies failings resulting in a value above 7 percent, the TC holder would then have significantly less time to draw up any potential compliance plan. Airbus stated that, in such cases, it could be unreasonable for us to require the TC holder to comply within 210 days. Therefore, Airbus suggested that we consider removing the fixed time period of 210 days and allow 60 days after the FAA and TC holder have agreed that the correct result is greater than 7 percent. It noted the requirements on operators of such airplanes should also be adjusted by a similar time.

We do not agree with this suggestion. Airbus provided comments to the NPRM that its airplane models have HCWT with flammability that ranges between 9 and 16 percent. Boeing has

previously provided a statement to the FAA in response to SFAR 88 evaluations that all of its airplane models with HCWT are above the 7 percent value that determines when an FRM or IMM is needed. Based upon this information we have determined that all Boeing and Airbus models specifically listed in proposed § 25.1815 (now § 26.33) have center wing fuel tanks that will require an FRM or IMM. Since the analysis needed to determine whether the affected tanks would require an FRM or IMM is already completed, Airbus and Boeing can begin developing compliance plans for design changes immediately after publication of this final rule. Similarly, if Embraer and Bombardier believe their tanks may be high flammability, they should also begin developing compliance plans for design changes immediately after publication of this final rule.

#### c. Service Instruction Submittal Dates

Airbus and Boeing recommended that the compliance dates for each airplane model shown in § 25.1815(d), Table 1, be replaced by a specific time period for all airplanes in the table. Boeing suggested the same two-year compliance period be applied to all affected models to allow adequate time to complete design development, validation and certification of flammability reduction systems, and development and validation of service bulletins. Boeing stated that this two-year period would provide the required timing for airline coordination and parts procurement flow time needed to support the beginning of the retrofit period. Airbus suggested 36 months is required to develop the system design and that an additional 6 months should be provided to allow for an in-service evaluation of the FRM so that any problems with the design could be identified and corrected before implementation into the fleet by the operating rules. Embraer requested a compliance time of 48 months to develop the design change. Cathay similarly commented that, while Boeing is making advanced preparations, Airbus is not. Cathay also requested that the compliance time be extended to support a more "realistic" FRM development schedule. Cathay also commented that the FAA states "the proposed compliance date is based on the premise that the NPRM was to be issued in 2005." The new compliance dates need to be revised to reflect delays in issuing the final rule. Bombardier felt that 24 months for the design changes should only commence once the authorities have accepted the design change plan.

We agree with the commenters that a fixed time for all airplane models should be established. We have determined that a 24-month compliance time for DAH development of the IMM or FRM is adequate for each of the DAHs to complete the task. Since we have determined from the comments that the Airbus and Boeing models listed in Table 1 in the NPRM require FRM or IMM, no flammability analysis is needed before design development begins. The full 24-month time can, therefore, be used by Airbus and Boeing to develop the design and service instructions for our approval.

In addition, Airbus and Boeing have had significant notification of this rulemaking. In February 17, 2004, we made a public announcement of our plans to develop and publish a proposal to require both retrofit and production incorporation of FRM or IMM. The NPRM was issued in November, 2005, and the rulemaking processing time has provided extensive time to develop designs as well as work with suppliers to discuss cost and schedule issues. Special conditions for the Boeing 737 and 747 were published by the FAA and EASA that provided performance standards for FRM in 2005. Many of the components in nitrogen based FRM systems are similar or identical to components used in military applications or pneumatic systems on commercial airplanes. The air separation modules used in these systems are based on technology currently used extensively in other industries. Therefore, we believe Airbus's request to increase the development and certification time from 24 months to 42 months, and Embraer's request for 48 months, are excessive, and we are confident that 24 months provides adequate time for design and service instruction development. Extending this compliance time would delay the operators' installation of these important safety improvements. Therefore, we have not revised the final rule as requested.

#### 2. Operator Fleet Retrofit Compliance Dates

In proposed §§ 91.1509, 121.1117, 125.509 and 129.117, we included a Table 1 that contained the interim and final compliance dates for operators to complete the installations of IMM, FRM or FIMM required by those sections. Table 1 proposed unique compliance dates for those affected Boeing and Airbus models with high flammability fuel tanks. These dates were selected based upon the availability of service instructions and the risk associated with each airplane model.

#### a. Removal of Unique Compliance Dates for Affected Airplane Models

Boeing stated that, assuming the FAA concludes that retrofit is justified, the compliance time should be 7 years from the date that service instructions are available for all airplane models. Boeing maintained there is no justification for requiring unique compliance times tied to airplane models and recommended deleting Table 1.

We agree and have removed Table 1 from the final rule. This table has been replaced with a standardized compliance date for all affected airplanes. As explained below, the new compliance time for all models is 9 years from the effective date of this rule. We did not link the operators' compliance time to our approval of the service instructions because the length of time it will take us to approve the submission will depend upon the quality of the submission. While the compliance planning provisions are intended to ensure that the submissions are approvable, whether they have that effect is within the control of the DAHs.

#### b. Increase Compliance Times From 7 to 10 Years

The ATA asked that the compliance times be increased from 7 to 10 years after manufacturers develop the necessary design changes. ATA argued that the accident rate is such that there is little risk of catastrophic in-flight fuel tank explosion during that period. A 10-year compliance time would allow all operators to incorporate the FRM in heavy maintenance visits instead of only 85 percent of them.

We partially agree with ATA. As discussed previously, we are providing a compliance time of 24 months for all affected manufacturers to develop necessary design changes. We have adjusted the compliance times in the operational rules to allow 6 years after the effective date for compliance by 50 percent of an operator's fleet, and 9 years for full implementation, i.e., we are retaining the compliance time of 7 years after the design changes are developed. The compliance period of 7 years for operators to incorporate the design modifications into each fleet was selected to allow the vast majority of the FRM or IMM to be incorporated during airplane heavy checks and to achieve the safety level expected by the public.

Nevertheless, as ATA noted, 15 percent of the airplanes may need to incorporate FRM at a time other than during a heavy check. To address this concern and reduce the costs of this rule, we have revised the operational requirements of parts 121 and 129 to

allow a one-year extension for retrofit if the operator elects to use ground conditioned air for all airplanes with high flammability tanks (i.e., Boeing and Airbus models) for “actual gate times” exceeding 30 minutes when ground air is available at the gate and operational and the ambient temperature exceeds 60 degrees F. This approach responds to requests for more time to retrofit while providing compensating risk reduction by use of ground conditioned air, which reduces flammability for airplanes on the ground. We are not including this extension provision in part 125, because these airplanes are typically not parked at gates where ground conditioned air is available. Also, these operators typically only operate one or very few airplanes subject to this rule, so they will not encounter the difficulties that ATA identified in scheduling large fleets of airplanes for modifications.

For purposes of this provision, “actual gate time” is time when the airplane is parked at a gate for servicing and passenger egress and ingress. If scheduled gate time is 30 minutes or less, but departure is delayed so that airplane is parked for more than 30 minutes, use of ground air is required for any period longer than 30 minutes. This ensures that heating of tanks (and resulting increased flammability) is limited. “Available” means installed at the gate. “Operational” means working, so that an operator is not in violation simply because ground conditioned air is out of service for maintenance. Ambient temperature is the official temperature at the airport as provided by the U.S. National Weather Service or worldwide METAR<sup>29</sup> weather report system. This provision requires revision of operator’s operations specifications and relevant manuals to ensure that the commitment to use of ground air is fully implemented and enforceable. In the near future we will be issuing guidance

<sup>29</sup>METAR (from the French, “message d’observation météorologique régulière pour l’aviation”) is a format for reporting weather information. METAR means “aviation routine weather report” and is predominantly used by pilots in fulfillment of a part of a pre-flight weather briefing, and by meteorologists, who use aggregated METAR information to assist in weather forecasting.

METAR reports usually come from airports. Typically, reports are generated once an hour; however, if conditions change significantly, they may be updated in special reports called SPECI’s. Some reports are encoded by an Automated Surface Observing System located at airports, military bases and other sites. Some locations still use augmented observations, which are recorded by digital sensors and encoded via software, but are reviewed by certified weather observers or forecasters prior to being transmitted. Observations may also be taken by trained observers or forecasters who manually observe and encode their observations prior to their being transmitted. Source: Wikipedia, August 2007.

on compliance with the conditions for this extension.

#### c. Interim Compliance Dates

We proposed interim compliance dates for operators to incorporate any FRM or IMM into 50 percent of their affected high flammability airplanes within their fleet. Boeing requested we revise §§ 91.1509(d)(1), 121.1117(d)(1), 125.509(d)(1), and 129.117(d)(1) to state: “IMM, FRM or FIMM, if required by §§ 25.1815, 25.1817, or 25.1819 of this chapter, that are approved by the FAA Oversight Office, are installed in at least 50 percent of the operator’s fleet within 4 years from the date service instructions are available. This does not apply for certificate holders with only one airplane in the fleet.”

Boeing stated that newly delivered airplanes should be included in the operator’s “fleet” for purposes of Table 1. Boeing also commented that Table 1 should not be split by individual airplane model, but should include all airplanes in a given operator’s current fleet. The recommended revision to 50 percent of the operator’s fleet should also specify if this is 50 percent of their fleet operating on the compliance date, 50 percent of their fleet that is operating at the beginning of the compliance period, or 50 percent of their fleet that will be operating at the end of the compliance period.

We agree that additional clarification is needed on the definition of “50 percent of fleet.” We intended that the 50 percent figure be based on all airplanes that are required to be modified under this rule and that are being operated by an operator 6 years after the effective date of this rule. Any airplanes transferred or purchased with high flammability fuel tanks, would be included in the operator’s “fleet.” Since newly delivered airplanes are not required to be modified, they are not included as part of the 50 percent of the fleet to meet this requirement.

#### K. Cost/Benefit Analysis

As noted in the Regulatory Evaluation Summary, specific comments on the quantitative costs and benefits estimates are more completely discussed in the FRE. In this section, we only address general economic issues that were addressed by the comments.

##### 1. Security Benefits

In the NPRM, we noted that the potential benefits from preventing terrorist-initiated accidents were excluded from consideration in both the ARAC reports and the IRE. While the proposed FRM requirements were not primarily intended to address terrorist-

initiated explosions, we invited public comment on possible additional security benefits that inerting fuel tanks may provide. In response to this request, we received several comments, including the following:

- The NTSB and several individuals supported including benefits from prevented consequences of terrorist action in the FRE and suggested we should complete a cost/benefit analysis of inerting all fuel tanks to address terrorist threats. The NTSB noted that, although not intended for missile defense or entirely effective as such, flammability reduction systems could mitigate the results of shrapnel entering fuel tanks during a terrorist act. Therefore, the NTSB recommended that the cost-benefit analysis for the final rule should include estimates of potential missile attacks on airplanes. In addition, these commenters also supported including possible benefits from preventing terrorist actions caused by bombs exploding in the airplane.

- CAPA stated that the United States is at a heightened risk of terrorist attacks. CAPA noted the aviation industry affects nearly 9 percent of the U.S. Gross Domestic Product, and suggested that terrorists will undoubtedly seek ways to attack the aviation infrastructure. CAPA recommended that we should complete a cost benefit analysis of inerting all fuel tanks and make recommendations to the Department of Homeland Security and aviation industry.

- NATCA commented that there would be an adverse effect on the public’s confidence in flying if another fuel tank explosion occurred.

- Airbus and AEA stated that, in theory, there may be some benefit to improving security by installing FRM on airplanes. However, they noted that we have no basis for estimating the amount of that benefit and they do not believe it to be substantial.

- ATA and FedEx objected to the FAA’s including the Avianca 727 accident in its justification of this rule. They stated that this accident, which resulted from a small bomb placed above the center wing fuel tank on the previous flight, would not have been prevented by the requirements of this rule.

Based upon the comments received and our review of historical evidence, we have not quantified any potential benefits from an FRM system preventing a fuel tank explosion caused by a terrorist missile or an on-board bomb.

We have also not quantified the potential benefits from a fuel tank explosion being misinterpreted as a terrorist-caused event because such an

outcome is too speculative to include in the main body of the analysis. However, we have provided a quantified estimate of the possible benefits from preventing this misinterpretation in Appendix A of the FRE.

However, some of the public will cancel or curtail their air travel after they discover that the in-flight accident was caused by an airplane electrical or mechanical malfunction. An in-flight explosion is a catastrophic accident. There is a long history that air travel declines for two to three months after a major catastrophic accident. We use a study by Wong and Yen, "Impact of Flight Accidents on Passenger Traffic Volume of the Airlines in Taiwan", in the *Journal of Eastern Asia Society for Transportation Studies*, vol. 5, October 2003, to provide an estimate of the potential demand losses from a fuel tank explosion.

## 2. Likelihood of Future Explosions in Flight

The IRE assumed that all future accidents caused by fuel tank explosions will occur in flight. This assumption was based upon an evaluation of the flammability exposure times for various flight phases that showed the majority of the time fuel tanks are flammable is during flight. The method used by us in the IRE to estimate the likelihood of future explosions occurring in flight or on the ground was based upon an earlier version of the Monte Carlo model, "Fuel Tank Flammability Assessment Method User's Manual, DOT/FAA/AR-05/8." This earlier model used ground times of 30, 60 and 90 minutes for short, medium, and long-range airplanes. Using this model, we determined 90 percent of the flammability exposure time occurred during flight. We then simplified the IRE by assuming all future accidents would occur in flight.

Our review of recent fleet data collected from in-service airplanes indicates that ground times are longer than used in the earlier version of the Monte Carlo model. This results in a higher percentage of the flammability exposure time being when an airplane is on the ground. In addition, the historical accident rate of one accident out of three occurring in flight is based upon a limited number of events and is not a valid sample size for establishing the future accident rate. Since ignition sources may occur at any time during ground or flight operations, the ARAC fuel tank study concluded that the likelihood of future fuel tank explosions correlates to the flammability exposure of a fuel tank. We agree with this conclusion.

MyTravel Airlines, AEA, Alaska Airlines, ATA, and Airbus stated that, the probabilities of an in-flight explosion and an on-the-ground explosion is the simple extrapolation of the three events; that is, there is a 33.33 percent probability of an in-flight explosion and a 66.67 percent probability of an on-the-ground explosion. Boeing commented that its engineering analysis indicated an 80 percent probability of an in-flight explosion and a 20 percent probability of an on-the-ground explosion and supported its recommendation with a recent flammability assessment using a revised Monte Carlo model. Boeing also recommended that a sensitivity analysis be included in the regulatory evaluation varying the number of in-flight events by values of 33 percent or 50 percent. In the GRA, Incorporated appendix to the ATA comment, they noted that using plausible assumptions in FAA's model, a better estimate of the percentage of time that a tank is flammable would be 78 percent in the air.

We believe that the appropriate method to evaluate the future risk is through a flammability assessment rather than observations of an infrequently occurring event. As a result, we agree with the Boeing analysis and disagree with the ATA and Airbus analyses and revise our risk analysis so that there is an 80 percent probability that an explosion will occur in flight and a 20 percent probability that it will occur on the ground.

Finally, we do not agree with Boeing's recommendation to include in the FRE an assessment of the sensitivity of varying the ground versus flight accidents between 30 and 50 percent. The IRE already included variations in many factors that affect the predicted cost and benefits and adding another sensitivity factor would not provide useful data for determining the need for this rule.

## 3. Costs to Society of Future Accidents

Several commenters said the cost of future accidents used in the IRE did not include all the costs to society. They said the IRE excluded the costs of investigating the accident, cleanup at the accident scene, replacement and retraining of flight crew, and any design change needed to correct failures of parts or systems on the airplane. They added that an accident would also cause a loss of confidence in the aviation industry leading to the public reducing their airline travel. They requested these additional costs be included in the final rule.

We agree with some of these comments and, as previously discussed, we include quantitative estimates of the potential benefits from the loss of confidence in aviation transport. We disagree that we did not include accident investigation and clean-up costs because the IRE contained a specific \$8 million cost for the accident investigation. Although it may occur that design changes will need to be made, these changes would be done via rulemaking or AD and the costs for those specific changes would be estimated when proposed.

## 4. Value of a Prevented Fatality

AEA and ATA stated that the value of a prevented fatality should be 3 million dollars. AEA stated there is no basis for using a higher value.

Different government entities use different estimates of the value of a prevented fatality. For example, the Environmental Protection Agency uses a value of \$7 million and the Department of Transportation has historically used a value of \$3 million (which we used in the IRE). There are several different values that have been reported in economic literature and there is no one value on which there is universal or near-universal agreement. The Office of Management and Budget allows agencies to evaluate their cost-benefit analyses using alternative values for a prevented fatality in order to evaluate how sensitive the analytic results are to the assumed values. Therefore, we believe that varying the value to show the range of reasonable effects is appropriate and we have included values of \$3 million, \$5.5 million, and \$8 million to provide a better understanding of the sensitivity of the evaluation to changes in this baseline assumption.

## 5. Cost Savings if Transient Suppression Units (TSUs) Are Not Required

The NTSB determined that the probable cause of the TWA Flight 800 explosion was ignition of the flammable fuel/air mixture in the center wing fuel tank. Although the ignition source could not be determined with certainty, the NTSB determined that the most likely source was a short circuit outside of the center wing tank that allowed excessive voltage to enter the tank through electrical wiring associated with the fuel quantity indication system (FQIS). We issued ADs mandating separation of the FQIS wiring that enters the fuel tank from high power wires and circuits on the classic Boeing 737 and 747 airplanes after the TWA 800 accident, and this resulted in installation of TSUs as an

alternative method of compliance with the ADs.

In the NPRM for this rulemaking, we requested public comment on the possible cost savings that would occur if airlines were not required to install transient suppression units (TSUs) on the fuel quantity gauging systems of the high flammability fuel tanks that would need FRM to comply with this rule. We received the following responses:

- Several commenters stated that we need to clarify the requirements for design changes resulting from SFAR 88, since they believed no additional changes to incorporate TSU would be needed for their fleet.

- According to ATA, the cost avoidances would be minor, compared to the impact of the ignition-prevention ADs and pending SFAR 88 maintenance upgrades.

- AEA stated that TSUs will not be removed, so there is no cost savings. If the TSUs were removed, additional costs would be incurred for certification, service bulletins, manpower, and hangar space.

- Airbus and My Travel Airways commented that they anticipate no significant savings since only a fraction of the fleet is designed with a need for these devices, and the cost of these devices is small, compared to the cost of flammability reduction systems.

- Transport Canada commented that ignition prevention should not be traded off against flammability reduction. Both should be required.

- Qantas stated that, if these devices could be removed from its existing fleet, it would realize a significant cost savings in operations and maintenance. Qantas also said that the cost of these devices is minimal compared to the installation of an FRM, but if the FQIS requires replacement of the fuel gauging system to make the devices effective, it would be similar in cost to an FRM. However, Qantas noted that an FRM may produce a weight penalty such that a FQIS replacement would still be preferred.

Prior to this rule, the findings from the analysis required by SFAR 88 showed that most transport category airplanes with high flammability fuel tanks needed TSUs to prevent electrical energy from airplane wiring from entering the fuel tanks in the event of a latent failure in combination with a single failure. Since this rule requires FRM or IMM to mitigate an unsafe condition by converting these fuel tanks into low flammability fuel tanks, TSUs will no longer be needed. Therefore, we believe it is appropriate to include this as a cost avoidance of this rule. However, based on the comments that

installing these TSUs will impose a minimal cost, we did not estimate a cost offset for those airplanes that would have been required to have TSUs installed but are no longer required to do so under this rule.

#### 6. Corrections About Boeing Statements

Boeing stated that the IRE has several statements that should be corrected in the final version. First, Boeing will not provide engineering analyses via service bulletins or provide initial aid to large airlines and independent third party repair stations. Boeing asked that these statements be deleted. Boeing also indicated that it will follow the regulatory requirements for providing service information. Finally, Boeing pointed out that the IRE improperly references STCs where it should be referencing amended TCs.

We agree with Boeing and have revised these issues in the FRE accordingly.

#### 7. 757 Size Category

Boeing noted that the Model 757 was classified as a small airplane in the IRE and suggested that it be included in the medium category. Boeing based this on the fact that the Model 757's fuel tank volume and airplane performance is similar to that of other airplanes categorized as medium-sized by ARAC.

We agree and have included the Boeing 757 in the medium category and have adjusted the weight and cost estimates accordingly.

#### 8. Number of Future Older In-Service Airplanes Overestimated

Alaska Airlines commented that the IRE overestimated the number of older in-service airplanes in future years, which artificially increases the benefits of the FRM retrofit requirements. Alaska Airlines asserted that industry projects a higher proportion of newer airplanes versus older airplanes for the projected benefit period.

The fleet mix in the IRE was based upon our fleet forecast. Therefore, the number of newer airplanes reflected the official FAA fleet projections. In the FRE, we have updated the fleet mix data using the most recent *FAA Aerospace Forecasts Fiscal Years 2006–2017*. This forecast projects higher retirement rates than those forecasted in the *FAA Aerospace Forecasts Fiscal Years 2004–2015*, which we used in the IRE.

#### 9. Revisions to the FRM Kit Costs

ATA, AEA, AAPA, Federal Express, Airbus, and Boeing suggest that we revise the price of the FRM components because the original ARAC estimates had not been fully developed and tested

and, subsequent to this additional development, the FRM kit costs are higher.

Boeing has provided new kit costs for its various models, which are revised from its previous component costs. We agree with Boeing and use them in the FRE for production airplanes.

However, United/Shaw Aero Devices/Air Liquide have recently developed an FTI system to retrofit in airplanes and they have reported kit costs. As they have a patent for the system and operational prototypes, we use the United/Shaw Aero Devices/Air Liquide retrofitting kit costs in this analysis.

#### 10. Revisions to the Labor Time To Retrofit FRM Components

Several commenters reported that the labor hours to retrofit an airplane used in the IRE were too low. In its discussions with the airlines, Boeing provided an estimated number of labor hours to retrofit its kits by model. The ATA reviewed these estimated hours and commented that its expected labor hours were approximated 25 percent to 40 percent higher than the preliminary numbers provided by Boeing. Qantas reported that the retrofitting labor hours are 50 percent greater than those in the service bulletins.

However, the United/Shaw Aero Devices/Air Liquide retrofitting kit is different from the retrofitting kit on which the ATA based its reported hours. As a result, just as we use the United/Shaw Aero Devices/Air Liquide retrofitting kit costs, we also use their labor hour estimates to install their system.

However, the labor hours to retrofit these kits will decline over time due to mechanics becoming more familiar with the installation procedures. T.P. Wright found that an 80 percent learning efficiency has been a common occurrence in airplane production. We assume that this 80 percent learning efficiency also applies to retrofitting operations.

#### 11. Retrofitting Costs per Airplane

Cathay Pacific and the AAPA commented that the per airplane retrofitting costs reported by EASA for an Airbus airplane would be between \$600,000 to about \$1 million (converting Euros into Dollars). Airbus provided similar comments.

In combining the United/Shaw Aero Devices/Air Liquide kit costs and their labor hours costs, we calculate that the per airplane retrofitting costs will initially be \$110,000 to \$250,000. Over time, these costs will decline by \$10,000 to \$17,000 per airplane.

#### 12. Percentage of Retrofits Completed During a Heavy Check

Airbus commented that the average time between heavy checks is 10 to 12 years. Thus, 85 percent of the retrofits could not be completed within the proposed 8 year time-frame.

We disagree. Our experience has been that the vast majority of airplanes in commercial passenger service in the United States have some form of a heavy check no later than every 8 years.

The AEA commented that 60 percent of the retrofits would be completed during a heavy check while ATA commented that 85 percent would be completed during a heavy check. In the IRE, we had used 85 percent.

We agree with the ATA comment and use the 85 percent value in the FRE. Operators who choose to take advantage of the extension allowed by use of ground conditioned air will be able to complete the retrofits of an even higher percentage of their fleet during heavy checks.

#### 13. Number of Additional Days of Out-of-Service Time To Complete a Retrofit

The ATA commented that retrofitting FRM during a heavy check would add two days of out-of-service time, AEA commented that it would add two to three days, while Airbus commented that the airlines had told EASA that it would add one day.

In the IRE, we had used two days. We agree with ATA and use two days in the FRE for the out-of-service time if the retrofit is performed during a heavy check.

Airbus commented that retrofitting FRM during a medium check would add 5 days while it would add seven days if completed during a special maintenance visit. In the IRE, we had used four days out-of-service for a retrofit performed during a special maintenance visit based on the ARAC report. Airbus provided no justification for its disagreement with the ARAC conclusion. As we received no comments other than the Airbus comment on this topic, we disagree with Airbus and use four days out-of-service for a special maintenance visit.

#### 14. Economic Losses From an Out-of-Service Day

Airbus and the ATA commented that the losses to an airline from an out-of-service day should be based on the airplane on ground economic loss or the loss in net operating revenue, not a prorated monthly lease rate as used in the IRE.

We disagree. While it is true that the loss to air carrier A is greater than the

prorated monthly lease rate, most potential air travelers will use alternative air carrier B if air carrier A takes an airplane out of service for a short time. Consequently, alternative air carrier B receives an economic benefit that is not captured by only focusing on the air carrier airplane that is out of service. The FAA's responsibility is to cost the potential loss to the aviation system, not individual air carriers at specific points in time. This is particularly apparent when alternative air carrier B will need to remove an airplane from service and air carrier B's air travelers will use air carrier A that will receive an economic benefit that is not captured by focusing solely on the loss to air carrier B at that specific point in time.

Airbus commented that the FRM cost for its products is underestimated by a factor of two to three. Based upon review of all comments, including those based upon a certificated FRM provided by Boeing, we believe the FAA cost estimates should be revised by a factor of 1.6 and we have adjusted the regulatory evaluation accordingly. We applied the revised retrofitted airplane costs for the certificated FRM systems to all similarly-sized airplane models because we determined that the fuel tank inerting systems will be similar for both manufacturers.

#### 15. Updated FRM Weight Data

Boeing provided updated weight data for the flammability reduction systems that have been or are being developed for its airplane models. Boeing stated that the final weights for the Boeing 747-400 and 737-NG systems are known since the designs have been certified. Boeing estimated the weight for the Boeing 777 system. As for the Boeing 757 and 767 systems, preliminary designs indicate these systems will be similar and Boeing estimated the weights based upon comparison to the other models. Boeing also provided updated estimates for average annual flight hours for Boeing airplanes.

We have revised the weight and annual flight hour data in the FRE for production airplanes based on Boeing's updated information. We also used this updated data for similarly sized Airbus airplane models.

United/Shaw Aero Devices/Air Liquide reported that their retrofitting kits weigh less than the Boeing kits. We used United/Shaw Aero Devices/Air Liquide kit weights for the retrofitted airplanes.

#### 16. Updated Fuel Consumption Data

Boeing also provided revised annual fuel consumption due to the FRM weight and increased bleed flow and ram drag. A GRA, Incorporated report that surveyed several air carriers provided current air carrier fuel consumption per pound of additional weight.

For the annual fuel consumption due to the FRM weight, we have used the GRA values from the air carriers because we believe the air carriers will be more accurate in reflecting their actual usage over a variety of flight mission lengths and conditions than the Boeing engineers would be. We used the Boeing estimates of the additional fuel consumption for increased bleed air flow and ram drag in the FRE. We used these rates for both production and retrofitted airplanes because United/Shaw Aero Devices/Air Liquide did not provide independent estimated rates for their kits.

#### 17. Updated Fuel Cost Data

Several commenters reported that the \$1 per gallon aviation fuel cost used in the IRE no longer reflected the economic reality. For a cost per gallon, Frontier suggested \$2.11, ATA suggested \$1.50, Qantas suggested \$2.00, and Airbus suggested \$1.50.

We agree that the per gallon price of aviation fuel has increased. Based on our *FAA Aerospace Forecasts Fiscal Years 2008-2025*, we determined that the average future price per gallon will be \$2.01. Although this fuel price is based on the most recently published FAA forecast, we recognize that, given the current record high oil prices, this estimate may underestimate the long term aviation fuel cost.

#### 18. Cost of Inspections

Air Safety Group, UK commented that the NPRM does not include any costs associated with the impact of FRM inspections on flight delays and cancellations. The commenter recommended that the cost/benefit analysis be revised to take a more realistic account of these additional operational costs. Boeing's comments included revised estimates of these costs.

With respect to flight delays and cancellations due to these inspections, the DAH requirements allow placing a nonfunctional FRM or IMM on the MEL provided the overall system performance meets the minimum criteria. We agree with the revised costs from Boeing on the costs of delays and cancellations in the FRE and used them for both production and retrofitted airplanes.

### 19. Inspection and Maintenance Labor Hours

Boeing commented that the annual labor hours for inerting system inspection and maintenance time should be revised to 6 hours for Boeing passenger and all-cargo airplanes. Boeing cited design features and related fault indication systems that will eliminate the need for scheduled maintenance performance checks on the inerting systems. Boeing also reported that unscheduled delays will only occur for failures that require locking the NGS Shutoff Valve closed.

We agree with Boeing's estimates for both production and retrofitted airplanes and use them in the FRE.

### 20. Daily Check

ATA commented that its estimates for inerting system operational and maintenance costs are much higher than those used by the FAA. ATA stated that 15 maintenance minutes per airplane per day will be required and this was not accounted for by the FAA.

We infer from ATA's comment that ATA believes that our estimated maintenance costs should be revised to include a 15 minute daily check of the FRM. The inerting system certified by the FAA (and validated by EASA) for the Boeing Model 737NG and 747-400 airplanes did not include a daily check. Specific features of the design, in conjunction with indication systems, removed the need for a daily check. We anticipate that Airbus's design will be similar in that the electronic centralized airplane monitor will be utilized for FRM status. This would impose no greater burden on operators than the FRM systems that have been certified to date. As a result, we have not included costs associated to a 15 minute daily check of the FRM in the FRE.

### 21. Spare Parts Costs

Boeing asked that the inerting system spare parts costs be revised based on its updated costs from suppliers. Boeing estimated that the air separator/filter capacity and life is directly related to the environment in which the airplane is operated. Boeing added that its filter installation includes monitoring for excessive pressure drop that is used to determine when the filter needs to be replaced. Finally, Boeing noted that its expected filter maintenance interval is greater than one year for average environmental conditions.

We agree with the cost information provided by Boeing and used the new cost for the filter element replacement in the FRE. While we acknowledge the filters will be replaced when the

pressure across the filter is excessive, Boeing did not provide an expected average filter replacement interval. In general, air separator/filters are expected to last between 1 and 3 years, depending upon the conditions under which the airplane is flown. An annual filter element replacement is a worst case situation. As a result, in the FRE, we use an average filter element replacement interval of every 2 years.

### 22. Air Separation Module (ASM) Replacement

Boeing asked the FAA to revise the cost of ASMs that would need to be purchased for replacing modules when they reach their design life. The IRE contained estimates ranging from \$5,275 to \$28,814. Boeing stated the revised costs range from \$30,520 to \$151,000. As United/Shaw Aero Devices/Air Liquide did not provide an estimate for this cost component, we applied the Boeing estimate to retrofitted airplanes.

Boeing also requested that the ASM replacement costs be evaluated based upon data provided in a table for average annual utilization by Boeing airplane model. Boeing believed this data is more realistic of model specific fleet utilization. While the IRE assumed an average utilization rate of 3,000 flight hours, Boeing's current data for different models range from 3,000 to 4,250 flight hours for passenger carrying airplanes and 1,000 to 4,250 for all-cargo airplanes. Finally, Boeing stated that the design life goal for the ASM remains 27,000 hours. FedEx commented that a manufacturer had told them that the ASMs will need to be replaced every few years.

We agree with Boeing that the design goal of an ASM replacement every 27,000 flight hours will be reached and we use that interval for the ASM replacement frequencies in this Regulatory Evaluation.

#### L. Miscellaneous

##### 1. Harmonization

Several commenters (Boeing, Transport Canada, Alitalia, AAPA, Virgin, Cathay) expressed the need for harmonization of FAA requirements with those of other national aviation authorities. These commenters noted that harmonization with the other major regulatory agencies would benefit the industry and encourage a broader dialogue. We agree that harmonization of the fuel tank flammability safety requirements is usually desirable. Prior to and throughout the development of this rule, we used several avenues to involve other foreign regulatory authorities and industry, including:

- Aviation Rulemaking Advisory Committee (ARAC) working groups comprised of representatives of foreign regulatory authorities and industry and other interested parties were used to review issues and provide recommendations for developing and harmonizing this rule. EASA, Transport Canada and the Brazilian CTA participated in these working groups, which conducted extensive studies of fuel tank safety. These studies included a review of the fleet history as well as evaluating the various options for improving airplane safety through flammability reduction. One working group was created to review fuel tank flammability and methods to reduce flammability in the tanks. This then led to the creation of a second working group that exclusively reviewed fuel tank inerting. The recommendations from these working groups became part of the basis for this proposed rule. The recommendations from the two fuel tank safety ARAC studies guided our rulemaking proposal and this final rule.

- We also participated in an industry and regulatory authority group assembled by EASA to review fuel tank flammability safety and produce an EASA Regulatory Impact Assessment (RIA). This RIA is available on EASA's Web site at ([www.easa.eu.int/doc/Events/fuel tanksafety\\_24062005/easa\\_fuel tanksafety\\_24062005\\_qa\\_summary.pdf](http://www.easa.eu.int/doc/Events/fuel tanksafety_24062005/easa_fuel tanksafety_24062005_qa_summary.pdf)).

EASA's RIA recommended production incorporation of FRM on newly produced airplanes that have high flammability tanks and EASA has indicated that it plans to propose an amendment to their regulations applying to new transport airplane designs in CS-25. We anticipate harmonization of these requirements. However, EASA has not yet determined that FRM retrofit should be required.<sup>30</sup> We believe the fleet operation projections show that the risk of an explosion occurring on existing airplanes and newly produced airplanes is similar. This safety issue needs to be addressed, despite the lack of harmonization, and we have included a FRM retrofit requirement in this final rule.

While we remain committed to the goal of harmonization, our primary objective in this rulemaking is to improve aviation safety. When we determine that the need exists for a certain regulation, and the other regulatory agencies find that a more stringent or lenient requirement is appropriate, we review their findings

<sup>30</sup>EASA has commissioned a study to reconsider the desirability of a retrofit requirement.

and will revise our regulation if our regulatory goals are met, an equivalent level of safety is achieved, and any additional burden imposed on the industry is justified. This is the approach we have taken in drafting this rule.

2. Part 25 Safety Targets

AEA commented that part 25 is missing safety targets and recommended the final rule include a specific target for both ignition and flammability reduction. This target could be achieved by ignition source prevention in combination with flammability reduction. AEA proposed the target be the same as for any other catastrophic event in transport category airplanes: 10<sup>-9</sup> per flight hour.

We do not agree with AEA's proposal to include a safety target in part 25. As discussed previously, because ignition sources are caused by human error and other unpredictable factors, it is impossible to assign an accurate probability value to them. Therefore, § 25.981 is based on a balanced approach for preventing fuel tank explosions. This section provides both ignition prevention plus an additional safety improvement by controlling fuel tank flammability exposure to an acceptable level. Today's rule adds

requirements for fuel tanks located in the fuselage contour and extend the mitigation into the fleet of existing airplanes.

IV. Rulemaking Analyses and Notices

Paperwork Reduction Act

As required by the Paperwork Reduction Act of 1995 (44 U.S.C. 3507(d)), the FAA submitted a copy of the new (or amended) information collection requirement(s) in this final rule to the Office of Management and Budget for its review. OMB approved the collection of this information and assigned OMB Control Number 2120-0710.

This rule supports the information needs of the FAA in approving design approval holder and operator compliance with the rule. The likely respondents to this proposed information requirement are the design approval holders such as Boeing, Airbus and several auxiliary fuel tank manufacturers as well as operators. The rule requires the certificate holders to submit a report to the FAA twice each year for a period up to 5 years. Operators who choose to use ground air conditioning would be required to provide a one time statement of their intent to use this option. The burden would consist of the work necessary for:

- DAH to develop flammability analysis reports and the service instructions for installation of IMM or FRM.
- DAH to develop changes and incorporate a maintenance plan into the existing maintenance programs.
- DAH to provide bi-annual reliability reports for FRM for the first 5 years of operation.
- Operators to provide notification to the FAA of their intent to use ground air conditioning.
- Operators to record the results of the installation and maintenance activities.

The largest paperwork burden will be a one-time effort (spread over 3 years) associated with the Design approval holders (TC and STC holders) to develop design changes. Operators will also need to update their maintenance programs, including maintenance manuals, to include the design changes. The basis for these estimates is the industry Aviation Rulemaking Advisory Committee report, which provided hours for each of the 3 major areas of paperwork. Based on an aerospace engineer total compensation rate of \$110 an hour, the total burden will be as follows:

Documents required to show compliance with the final rule	Hours	Total cost (in millions of \$2007)
Application to FAA for Amended TC or STC .....	405,000	44.550
Documents (Specifications, ICDs, etc.) .....	30,900	3.399
Revisions to Manuals (Flight Manuals, Operations, and Maintenance) for FRM Systems .....	29,500	3.245
<b>Total .....</b>	<b>465,400</b>	<b>51.194</b>

As these recordkeeping costs will be spread out evenly over the three years, the yearly burden will be \$17.065 million and involve 155,133 hours.

After this initial 3-year period, this rulemaking would result in an annual recordkeeping and reporting burden of 4,000 hours. This burden is based on five (5) design approval holders submitting 40 total reports per year requiring an average of 100 hours to complete each report. All records that will be generated to verify the installation, to record any fuel tank system inerting failures, and to record any maintenance would use forms currently required by the FAA.

The FAA computed the annual recordkeeping (Total Pages) burden by analyzing the necessary paperwork requirements needed to satisfy each process of the rule.

An agency may not collect or sponsor the collection of information, nor may it impose an information collection requirement unless it displays a currently valid Office of Management and Budget (OMB) control number.

International Compatibility

In keeping with U.S. obligations under the Convention on International Civil Aviation, it is FAA policy to comply with International Civil Aviation Organization (ICAO) Standards and Recommended Practices to the maximum extent practicable. The FAA has determined that there are no ICAO Standards and Recommended Practices that correspond to these proposed regulations.

Regulatory Evaluation Summary

Regulatory Evaluation, Regulatory Flexibility Determination, International Trade Assessment, and Unfunded Mandates Assessment

Changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 (Pub. L. 96-354) requires agencies to analyze the economic impact of regulatory changes on small entities. Third, the Trade Agreements Act (Pub. L. 96-39) prohibits agencies from setting standards that create unnecessary obstacles to the foreign commerce of the United States. In developing U.S. standards, this Trade

Act requires agencies to consider international standards and, where appropriate, that they be the basis of U.S. standards. Fourth, the Unfunded Mandates Reform Act of 1995 (Pub. L. 104-4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of \$100 million or more annually (adjusted for inflation with base year of 1995). This portion of the preamble summarizes the FAA's analysis of the economic impacts of this final rule. We suggest readers seeking greater detail read the full regulatory evaluation, a copy of which we have placed in the docket for this rulemaking.

In conducting these analyses, the FAA has determined that this final rule: (1) Has benefits that justify its costs, (2) is an economically "significant regulatory action" as defined in section 3(f) of Executive Order 12866, (3) is "significant" as defined in DOT's Regulatory Policies and Procedures; (4) will have a significant economic impact on a substantial number of small entities; (5) will not create unnecessary obstacles to the foreign commerce of the United States; and (6) will impose an unfunded mandate on state, local, or tribal governments, or on the private sector by exceeding the previously identified threshold. These analyses are summarized as follows.

Aviation Industry Affected

The rule affects Boeing, Airbus, and operators of certain Boeing and Airbus airplanes that have heated center wing tanks (HCWTs).<sup>31</sup>

Disposition of Comments

There were many comments on the Initial Regulatory Evaluation (IRE) associated with FRM. We accepted many of these comments. However, the volume and the technical nature of these comments require a more detailed response than is possible in this summary. As a result, the complete disposition of the economic comments and their effects on the economic analysis are contained in the complete Final Regulatory Evaluation, which is filed separately.

Period of Analysis and Affected Airplanes

The period of analysis begins in 2008 and concludes in 2042. We used a 10-year time period (2008-2017) to calculate the equipment installation costs for airplanes affected by the final rule. The end of the analysis period of 2042 captures the full operative lives of the 2009-2017 production airplanes.

The airplanes affected by the final rule include passenger airplanes with HCWTs manufactured prior to the 2009 production cut-in date. These airplanes will need to be retrofitted with FRM by 2017. In addition, these affected airplanes also include all production passenger and cargo airplanes with HCWTs that will be manufactured between 2009 and 2017 (except the B-787 and A380 that will be

manufactured with FRM. Cargo airplanes manufactured before 2009 and cargo airplanes that have been or will be converted from passenger airplanes (conversion cargo airplanes) are not included unless FRM was installed while the airplane was used in passenger service.

Airplanes have an average 25-year life expectancy. Thus, the 2009 production airplanes will be retired in 2033 and the last of the production airplanes in this analysis (those produced in 2017) will be out of service by 2042. Similarly, all of the pre-2009 existing airplanes requiring retrofitting will be retired by 2033 (the 2008 production airplanes will be the last year of production airplanes will not have FRM installed as original equipment). Thus, the maintenance and fuel costs will begin in 2009 and continue to 2042 for production airplanes and will begin in 2010 and continue to 2033 for retrofitted airplanes.

During the analysis period the final rule will affect an estimated 5,110 airplanes, 5,022 retrofitted and production passenger airplanes (2,732 retrofitted and 2,290 production) and 88 production cargo airplanes (see Table 1). These airplanes will fly 370 million hours, 364 million for passenger airplanes and 6 million for production cargo. Of the 364 million passenger airplane flight hours, 303 million will be flown by airplanes with FRM and 61 million will be flown by airplanes without FRM. The airplanes without FRM will be those manufactured prior to 2009 until they are retired or retrofitted between 2008 and 2017.

TABLE 1.—SUMMARY OF THE TOTAL NUMBERS OF AIRPLANES AND FLIGHT HOURS AFFECTED BY THE RULE

Airplane category	Airplanes	Flight hours (millions)
PASSENGER PRODUCTION .....	2,290	199
RETROFITTED WITH FRM .....	2,732	105
NO FRM .....		61
TOTAL PASSENGER .....	5,022	364
CARGO PRODUCTION .....	88	6
TOTAL .....	5,110	370

Risk of a HCWT Explosion

If there were no final rule and no SFAR 88, engineering analysis indicates that there would be 1 explosion for every 100 million HCWT airplane flight hours. Air carrier passenger airplanes would incur 3.64 explosions of which production airplanes would incur 1.99

explosions and retrofitted airplanes would incur 1.65 explosions. Of the retrofitted airplanes, 1.04 would occur to airplanes with FRM and 0.61 would occur to airplanes without FRM. Production cargo airplanes would incur 0.06 explosions. As, obviously, fractions of accidents do not occur, we describe

the cumulative probability of the number of accidents in fractions of an accident for analytic purposes. For example, engineering analysis would project that the first accident would occur in 2012, the second one in 2019, the third one in 2026, and the final 0.64 of an accident in 2035. However, care

<sup>31</sup> The following airplane models are not included as HCWT airplanes: B-717; B-727; certain B-767

and B-777 models, A-321, A-330-200 and A380. In addition, the B-787 is not included because it

needs FRM to comply with its existing Part 25 certification requirements.

should be taken in assuming that these rare events will necessarily occur in the forecasted year. As an illustration, in a 1,000 Monte Carlo simulation trials, 3 accidents occurred 233 times out of the 1000 trials. For those 3-accident cases, two accidents happened in the same year 25 times.

#### Number of HCWT Explosions Potentially Affected by the Rule

Our Monte Carlo analysis indicates that we cannot statistically reject the hypothesis that SFAR 88 is 50 percent effective in preventing these accidents. This analysis, in combination with the service history since the implementation of SFAR 88, indicates that a 50 percent SFAR 88 effectiveness rate is appropriate, but we conducted a sensitivity analysis using two other possible SFAR 88 effectiveness rates of 25 percent and 75 percent in the Final Regulatory Evaluation. Using a 50 percent SFAR 88 effectiveness rate, in the absence of this final rule, we calculate that there would be 1.82 HCWT air carrier passenger airplane explosions occurring to the HCWT airplanes during the time period of the analysis. As it will take time to install FRM, 77 percent of the flight hours will be flown by airplanes with FRM while 23 percent of the flight hours will be flown by airplanes without FRM. Thus, 1.52 air carrier passenger airplane HCWT explosions will be prevented by the rule and 0.3 HCWT explosions could occur to airplanes without FRM.

#### Percentage of In-Flight Explosions

Our engineering analysis determined that eighty percent of the accidents would occur in flight and twenty percent would occur on the ground.

#### Benefits

There are two types of benefits from preventing an airplane explosion. Direct safety benefits arise from preventing the resulting fatalities and property losses. Secondly, demand benefits arise from preventing the aviation demand losses resulting from the reduction in demand to fly, which will be a consequence of a loss of public confidence in commercial aviation safety following an airplane explosion. Further, the explosion that results from an electrical charge is indistinguishable (until the accident is investigated) from an explosion caused by a terrorist bomb. This uncertainty about the explosion cause may result in costly governmental and industry reactions to a perceived terrorist plot. However, the benefits preventing such a potential reaction is too speculative to provide a definitive quantitative benefit estimate, although

we have quantified a possible estimate in Appendix A of the Regulatory Evaluation.

#### Quantified Demand Benefits

As discussed in the economic literature, there is a direct, immediate, but temporary decrease in air travel in the aftermath of a catastrophic air carrier passenger airplane explosion. We estimate the loss to the aviation industry to be \$292 million from such an accident.

#### Quantified Direct Benefits

##### Direct Benefits From Preventing a HCWT Explosion—Assumptions and Values

- Final rule is published on January 1, 2008.
- Discount rate is 7 percent.
- Passenger airplanes would be retrofitted between 2010 and 2017.
- No airplane scheduled to be retired before 2018 will be retrofitted.
- Passenger airplanes have a 25-year service life.
- With no SFAR 88 and no FRM rule, a heated center wing tank (HCWT) airplane will have a fuel tank explosion every 100 million flight hours.
- Special Federal Air Regulation (SFAR) 88 will prevent half of the future explosions.
- Boeing and Airbus HCWT airplanes have equal explosion risks.
- 80 percent of the accidents will be catastrophic in-flight accidents; with an average of 142 fatalities for a passenger airplane and 2 fatalities for a cargo airplane.
- 20 percent of the accidents will occur on-the-ground with an average of 14 fatalities for a passenger airplane and no fatalities for a cargo airplane.
- The airplane is destroyed in an HCWT explosion.
- The value of a prevented fatality is \$5.5 million.

##### Direct Benefits From Preventing a HCWT Explosion—Results

- The average undiscounted direct benefits from preventing an air carrier passenger airplane in-flight HCWT explosion will be \$841 million, with a range of \$628 million to \$2.2 billion.
- The average undiscounted direct benefits from preventing an air carrier passenger airplane on-the-ground HCWT explosion will be \$115 million, with a range of \$77 million to \$320 million.
- The average undiscounted direct benefits from preventing an air carrier passenger airplane HCWT explosion weighted by an 80 percent probability of an in-flight accident and a 20 percent

probability of an on-the-ground accident will be \$696 million.

- The average undiscounted direct benefits from preventing an air carrier cargo airplane HCWT explosion will be \$77 million.

#### Total Benefits

Of great concern to the FAA is that a practical solution now exists for a real threat of an aviation catastrophe. Even though these are low probability accidents, they are high consequence accidents. For example, if a single in-flight catastrophic accident with 190 occupants (235 seats) is prevented by 2012, the present value of the benefits will be greater than the present value of the costs. Using a \$5.5 million value for a prevented fatality, the benefits from preventing an in-flight explosion range of \$625 million to \$750 million for a B-737 or an A-320 family airplane to \$1.0 billion to \$2.15 billion for all other affected airplanes. The mean of the estimated benefits from preventing an in-flight explosion (weighted by the number of flight hours for each type of affected airplane model) are \$840 million.

Thus, the undiscounted total weighted average benefit from preventing an in-flight explosion is \$1.130 billion. Adjusting this value for the 20 percent of the accidents that will occur on the ground produces an undiscounted average benefit of about \$1 billion.

We calculated that the present value of the weighted average benefits from preventing the 1.5 accidents would be \$657 million.

#### Compliance Cost Assumptions and Values

The compliance costs are based on installing a fuel tank inerting (FTI) system because that is the only FRM system that has been developed. If a future FRM system is developed that competes with FTI then we have likely overestimated the compliance costs.

- Fully burdened aviation engineer labor rate is \$110 an hour.
- Fully burdened aviation mechanic labor rate is \$80 an hour.
- One-time engineering costs to develop STCs or modified TCs are between \$2.2 million to \$5.7 million a model.
- Retrofitting kits cost from \$77,000 (B-737 and A-320 Family), \$120,000–\$164,000 (B-757, B-767, and A-300/310), to \$165,000–\$192,000 (all other airplanes).
- Initial retrofitting labor costs in 2010 will range from \$24,000 to \$70,000.

- There is a retrofitting labor learning curve of 30 percent such that the retrofitting labor hours (and costs) will be approximately 70 percent of the 2010 labor hours in 2013 and 49 percent of the 2010 labor hours by 2017.
- Retrofitting kit and labor costs in 2010 will range from \$100,000 for the B-737 and A-320 Family and \$148,000 to \$203,000 (for all other airplanes).
- Out-of-Service Losses (Associated with a retrofit during a routine "D" check) are \$10,000 to \$28,000.
- Out-of-Service Losses (Associated with a retrofit during a special maintenance session) are \$30,000 to \$84,000.
- The same reduction in hours out-of-service for labor hours will apply to the number of out-of-service hours.
- Retrofitting kits weigh 84 pounds (for the B-737 and the A-320 family), 117 pounds to 150 pounds (for the B-757, B-767, and A-300/310), and 182 pounds to 215 pounds for the B-747, B-777, and A-330/340).
- Retrofitted airplane increased annual fuel burn from weight, bleed air intake, and ram drag is 2,000–2,500 gallons (B-737) to 4,000 gallons (A-320

- Family) to 4,400 to 6,500 gallons (everything else).
- Production airplane FTI kit costs are \$92,000 (B-737 and A-320) to \$186,000–\$205,000 (for all other airplanes).
- Production airplane labor installation costs are \$6,500–\$8,000.
- Production kit and labor costs in 2009 will be \$100,000 for the B-737 and A-320 Family) and \$195,000 to \$212,500 (for all other airplanes).
- Production airplane FTI weight is 105 pounds (B-737 and A-30 Family) to 250–300 pounds (for all other airplanes).
- Production airplane increased annual fuel burn from weight, bleed air intake, and ram drag is 2,900 gallons (B-737) to 4,600 gallons (A-320 Family) to 6,300 to 7,100 gallons (everything else).
- Cost of aviation fuel is \$2.01 per gallon.
- Additional scheduled and unscheduled maintenance, delays, and water separator/filter replacement costs are \$3,250 to \$5,150.
- Annual operating costs are between \$10,000 (B-737) to \$15,000 (A-320 Family) to \$17,500–\$20,000 (for all other airplanes).

- Air separation module (ASM) replaced every 27,000 flight hours.
  - ASM replacement cost is \$45,000 (B-737 and A-320 Family) to \$135,000–\$153,000 (for all other airplanes).
- Weighted average compliance costs (excluding the engineering costs) are:
- Retrofitted Passenger Airplanes:* \$213,000 (\$135,000 for retrofit and \$78,000 for operational). *Range:* \$144,000 to \$395,000.
- Production Passenger Airplanes:* \$177,000 (\$68,000 for installation and \$109,000 for operational). *Range:* \$156,000 to 410,000.

**Total Compliance Costs**

As shown in Table 2, the present value of the total compliance costs is \$1.012 billion, of which \$975 million will be incurred by air carrier passenger airplane operators, and \$37 million will be incurred by air carrier production cargo airplanes.

Of the air carrier passenger airplane present value costs of \$975 million, operators of retrofitted airplanes will incur \$436 million (43 percent) while operators of production airplanes will incur \$539 million (57 percent).

**TABLE 2.—COMPLIANCE COSTS BY TYPE OF OPERATION AND TYPE OF AIRPLANE**  
[In millions of 2007 dollars]

Operator	Total costs		
	Undiscounted	Present value (7%)	Present value (3%)
<b>AIR CARRIER PASSENGER:</b>			
RETROFITTED .....	\$839	\$436	\$623
PRODUCTION .....	1,237	539	825
AUXILIARY FUEL TANKS .....	<1	<1	<1
<b>TOTAL .....</b>	<b>2,076</b>	<b>975</b>	<b>1,448</b>
<b>AIR CARRIER CARGO:</b>			
PRODUCTION .....	100	37	63
<b>TOTAL .....</b>	<b>100</b>	<b>37</b>	<b>63</b>
<b>GRAND TOTAL .....</b>	<b>2,176</b>	<b>1,012</b>	<b>1,511</b>

As shown in Table 3, 54 percent of the present value costs (at 7 percent) for retrofitted air carrier passenger airplanes are from the engineering and one-time

equipment installation costs while these costs are 47 percent for production airplanes. Similarly, 46 percent of the present value costs for retrofitted

airplanes are due to additional fuel, operational, and ASM (air separation module) costs while these costs are 53 percent for production airplanes.

**TABLE 3.—COMPLIANCE COSTS FOR AIR CARRIER PASSENGER AIRPLANES**  
[In millions of 2007 dollars]

Cost category	Total costs		
	Undiscounted	Present value (7%)	Present value (3%)
<b>RETROFITTED:</b>			
ENGINEERING .....	\$19	\$16	\$18
INSTALLATION .....	346	220	283
INVENTORY .....	9	6	7
FUEL .....	215	93	149
OPERATIONAL .....	113	49	77

TABLE 3.—COMPLIANCE COSTS FOR AIR CARRIER PASSENGER AIRPLANES—Continued  
[In millions of 2007 dollars]

Cost category	Total costs		
	Undiscounted	Present value (7%)	Present value (3%)
ASM REPLACEMENT .....	137	52	89
TOTAL .....	839	436	623
PRODUCTION:			
ENGINEERING .....	107	100	103
INSTALLATION .....	230	152	191
INVENTORY .....	7	4	5
FUEL .....	459	149	272
OPERATIONAL .....	197	63	116
ASM REPLACEMENT .....	237	71	138
TOTAL .....	1,237	539	825
GRAND TOTAL .....	2,076	975	1,448

Benefit Cost Analysis

As previously described, these are low probability, high consequence accidents. If a single in-flight catastrophic accident with 190 occupants (a 235 seat airplane) were to be prevented by 2012, the present value of the benefits will be greater than the

present value of the costs. Further, as shown in the Regulatory Evaluation in Appendix IV-7, there is a 26 percent probability that the final rule present value benefits will be greater than its present value costs.

As shown in Table 4, using the weighted average benefits at a 7 percent

discount rate, the net benefit losses for the final rule would be \$355 million, of which production passenger airplanes would account for \$151 million, retrofitted passenger airplanes would account for \$167 million and production cargo airplanes would account for \$37 million.

TABLE 4.—PRESENT VALUE OF THE RULE BENEFITS AND COSTS  
[In millions of 2007 dollars]

Type of operation	Present value (7%)		
	Benefits	Costs	Net benefits
PASSENGER:			
RETROFITTED .....	\$271	\$438	(\$167)
PRODUCTION .....	386	537	(151)
TOTAL .....	657	975	(318)
PRODUCTION CARGO .....	<1	37	(37)
GRAND TOTAL .....	657	1,012	(355)

Sensitivity Analysis of the Rule Costs and Benefits

Table 5 provides a sensitivity analysis for the final rule that, using the weighted by flight hours average benefit value, varies the discount rate (7 and 3

percent), the value of preventing a statistical fatality (\$3 million, \$5.5 million, and \$8 million), and the SFAR 88 effectiveness rate (25, 50, and 75 percent). As is shown, the quantified benefits are greater than the costs when the SFAR 88 effectiveness rate is 25

percent for: (1) An \$8 million value of a prevented fatality and; (2) a \$5.5 million value of a prevented fatality using a 3 percent discount rate. Net benefits numbers in parentheses are negative.

TABLE 5.—PRESENT VALUES OF THE BENEFITS AND COSTS FOR ALL AFFECTED AIRPLANES BY DISCOUNT RATE, VALUE OF A PREVENTED FATALITY, AND SFAR 88 EFFECTIVENESS RATE  
[In millions of 2007 dollars]

Discount rate	Value of fatality	SFAR 88 effectiveness (percent)	Present values		
			Benefits	Costs	Net benefits
7% .....	\$5.5	50	\$657	\$1,012	(\$355)
7% .....	3	50	469	1,012	(543)
7% .....	8	50	828	1,012	(184)
7% .....	5.5	25	989	1,012	(23)
7% .....	3	25	704	1,012	(308)

TABLE 5.—PRESENT VALUES OF THE BENEFITS AND COSTS FOR ALL AFFECTED AIRPLANES BY DISCOUNT RATE, VALUE OF A PREVENTED FATALITY, AND SFAR 88 EFFECTIVENESS RATE—Continued

[In millions of 2007 dollars]

Discount rate	Value of fatality	SFAR 88 effectiveness (percent)	Present values		
			Benefits	Costs	Net benefits
7% .....	8	25	1,242	1,012	230
7% .....	5.5	75	330	1,012	(682)
7% .....	3	75	235	1,012	(777)
7% .....	8	75	414	1,012	(598)
3% .....	5.5	50	1,141	1,509	(368)
3% .....	3	50	842	1,509	(667)
3% .....	8	50	1,434	1,509	(75)
3% .....	5.5	25	1,658	1,509	149
3% .....	3	25	1,263	1,509	(246)
3% .....	8	25	2,151	1,509	642
3% .....	5.5	75	517	1,509	(992)
3% .....	3	75	421	1,509	(1,088)
3% .....	8	75	717	1,509	(792)

#### Differences Between the Initial Regulatory Evaluation (IRE) and Final Regulatory Evaluation (FRE) Assumptions and Unit Values

In the IRE, we had estimated that the present value of the proposed rule's direct benefits would be \$495 million and that the present value of the proposed rule's costs would be \$808 million. Table 6 provides a summary of the important differences in the assumptions and the unit values between those in the IRE and those used

in this FRE. The significant benefits increases are due to the quantification of the demand benefits and the use of \$5.5 million for the value of a prevented fatality. In the final rule the benefits and costs were both substantially increased by the inclusion of Boeing production airplanes (except the B-787). In the NPRM analysis we assumed Boeing would voluntarily comply for its production airplanes; we did not assume this for the final rule analysis. The benefits and costs were both

decreased by the shorter period of analysis. The significant cost increases are due to the increases in the production FTI kit costs, their annual additional fuel consumption due to the FTI weights and the bleed air and ram drag effects, the increased price of aviation fuel, and the air separation module (ASM) replacement costs (there will be 1 ASM replacement for most retrofitted airplanes and 2 ASM replacements for most production airplanes).

TABLE 6.—DIFFERENCES IN THE ASSUMPTIONS/VALUES IN THE IRE AND IN THE FRE

Assumptions/values	FRE	IRE
Time Period of Analysis .....	2009–2042 .....	2006–2055.
Accident Rate .....	1 Every 100 Million HCWT Flight Hours .....	1 Every 60 Million HCWT Flight Hours.
Number of Flight Hours .....	370 Million Total .....	460 Million.
	364 Million Passenger.	
	6 Million Production Cargo..	
Number of Accidents .....	3.7 Total .....	7.67.
	3.64 Passenger.	
	0.06 Cargo.	
Percentage of In-Flight Accidents .....	80% .....	100%.
Base Year for Dollars .....	2007 .....	2004.
Reduction in Air Travel Demand .....	\$292 Million (annual real growth rate of 3%) .....	Qualitatively large.
Value of a Prevented Fatality .....	\$5.5 Million .....	\$3 Million.
Average Number of In-Flight Fatalities .....	142 .....	142.
Average Number of On-the-Ground Fatalities .....	14 .....	8.
Average Accident Value for an In-Flight Explosion (Passenger Airplane).	\$841 Million .....	\$505 Million.
Average Accident Value for an On-the-Ground Explosion (Passenger Airplane).	\$115 Million .....	Not Estimated.
Weighted Average Accident Value (Passenger Airplane)	\$696 Million .....	\$505 Million.
Weighted Average Accident Value (Production Cargo Airplane).	\$77 Million .....	\$75 Million.
Hourly Labor Rates .....	Engineer \$110 .....	Engineer \$115.
	Mechanic \$80 .....	Mechanic \$75.
Total Number of Retrofits .....	Passenger 2,732 .....	Passenger 3,328.
	Boeing 1,780 .....	Boeing 2,327.
	Airbus 952 .....	Airbus 1,001.
Retrofitting Kit Costs .....	Small \$77,000 .....	Small \$105,000.
	Medium \$120,000–\$164,000 .....	Medium \$135,000.
	Large \$175,000–\$192,000 .....	Large \$179,000.
Retrofitting Labor Costs (Scheduled Maintenance) .....	\$24,000–\$28,000 .....	\$30,000–\$35,000.

TABLE 6.—DIFFERENCES IN THE ASSUMPTIONS/VALUES IN THE IRE AND IN THE FRE—Continued

Assumptions/values	FRE	IRE
Number of Out-of-Service Days (Scheduled Maintenance).	2	2.
Out-of-Service Costs (Scheduled Maintenance)	Small \$10,000 Medium \$22,000 Large \$28,000	Small \$9,000. Medium \$14,000. Large \$13,000.
Retrofitting Costs (Scheduled Maintenance)	Small \$110,000 Medium \$165,000–\$215,000 Large \$214,000–\$229,000	Small \$135,000. Medium \$170,000. Large \$214,000.
Retrofitting Labor Costs (Dedicated Visit)	\$62,000–\$70,000	\$40,000–\$45,000.
Number of Out-of-Service Days (Dedicated Visit)	6	4.
Out-of-Service Costs (Dedicated Visit)	Small \$30,000 Medium \$66,000 Large \$84,000	Small \$19,000. Medium \$56,000. Large \$53,000.
Retrofitting Costs (Dedicated Visit)	Small \$137,000 Medium \$211,000–\$264,000 Large \$289,000–\$311,000	Small \$163,000. Medium \$234,000. Large \$276,000.
Fuel Cost per Gallon	\$2.01	\$1.00.
Retrofitting FTI Weight	Small 84 lbs Medium 117–150 lbs Large 182–215 lbs	Small 95 lbs. Medium 148 lbs. Large 218 lbs.
Annual Retrofitted Passenger Airplane Fuel Consumption (Weight, Bleed Air, and Ram Drag).	Small 2,500–4,000 Gals Medium 3,000–4,125 Gals Large 4,500–6,550 Gals	Small 1,500–3,900. Medium 2,900. Large 4,800.
Annual Retrofitted Passenger Airplane Fuel Cost	Small \$5,250–\$8,000 Medium \$6,000–\$8,300 Large \$9,000–\$13,150	Small \$1,500–\$3,900. Medium \$2,900. Large \$4,800.
Total Number of Production Passenger Airplanes	Total 2,290 (2009–2017) Boeing 1,268 Airbus 1,022	Total 3,274 (2008–2030). Boeing 0. Airbus 2,650.
Total Number of Production (No Conversion) Cargo Airplanes.	Total 88 (2009–2017) Boeing 66 Airbus 22	Total 624 (2008–2030). Boeing 0. Airbus 624 (includes Conversion).
Production Kit Costs	Small \$92,000 Medium \$186,000 Large \$205,000	Small \$83,000. Medium \$107,000. Large \$137,000.
Production Labor Costs	\$6,500–\$8,000	\$7,000–\$8,000.
Unit Production Costs	Small \$98,000 Medium \$194,000 Large \$213,000	Small \$90,000. Medium \$115,000. Large \$145,000.
Production FTI Weight	Small 105 lbs Medium 280 lbs Large 300 lbs	Small 95 lbs. Medium 148 lbs. Large 218 lbs.
Annual Production Passenger Airplane Fuel Consumption (Weight, Bleed Air, and Ram Drag).	Small 2,300–4,625 Gals Medium 5,600–6,725 Gals Large 6,850–8,600 Gals	Small 1,500–3,900. Medium 2,900. Large 4,800.
Annual Production Passenger Airplane Fuel Cost	Small \$3,850–\$7,625 Medium \$9,250–\$11,100 Large \$11,300–\$14,300	Small \$1,500–\$3,900. Medium \$2,900. Large \$4,800.
Maintenance	\$3,250–\$5,150	\$5,900–\$7,500.
ASM Replacement Cost (Every 9 Years)	Small \$30,500–\$45,000 Medium \$135,000 Large \$153,000	Small \$5,275. Medium \$18,761. Large \$28,814.

Costs and Benefits of Alternatives to the Final Rule

As shown in Table 7, we evaluated the baseline costs and weighted average benefits for the 8 alternatives to the final rule using a value of \$5.5 million for a prevented fatality, a 7 percent discount rate, and a 50 percent SFAR 88 effectiveness rate. These expected benefits are based on a rare event mean

probability. The date when an avoided accident occurs has a significant impact on the expected benefits.

- ALTERNATIVE 1. Cover only air carrier passenger airplanes
- ALTERNATIVE 2. Exclude auxiliary fuel tanks
- ALTERNATIVE 3. Cover only air carrier retrofitted passenger airplanes
- ALTERNATIVE 4. Cover only air carrier production passenger airplanes

ALTERNATIVE 5. Cover only air carrier production passenger and cargo airplanes

ALTERNATIVE 6. Final rule plus part 91 airplanes

ALTERNATIVE 7. Final rule plus conversion cargo airplanes

ALTERNATIVE 8. Final rule plus conversion and retrofitted cargo airplanes

TABLE 7.—BENEFITS AND COST SUMMARIES FOR 8 ALTERNATIVES TO THE FINAL RULE USING A \$5.5 MILLION VALUE FOR A PREVENTED FATALITY, A 7 PERCENT DISCOUNT RATE, AND A 50 PERCENT SFAR 88 EFFECTIVENESS RATE  
[In millions of 2007 dollars]

Option	Present value (7%)		Net benefits
	Benefits	Costs	
FINAL RULE .....	\$657	\$1,012	(\$355)
ALTERNATIVES:			
1. Cover Only Part 121 Passenger Airplanes (excludes Part 121 cargo and Part 91) .....	657	975	(318)
2. Cover Only Part 121 Passenger Airplanes but No Auxiliary Tanks .....	657	975	(318)
3. Cover Only Part 121 Retrofitted Passenger Airplanes (excludes All Production Passenger, all Cargo, and Part 91 Airplanes) .....	271	438	(167)
4. Cover Only Part 121 Production Passenger Airplanes .....	386	537	(151)
5. Cover Only Part 121 Production Passenger and Cargo Airplanes .....	386	574	(188)
6. Final Rule Plus Part 91 Airplanes .....	657	1,026	(369)
7. Final Rule Plus Conversion Cargo Airplanes .....	657	1,109	(452)
8. Final Rule Plus Conversion and Retrofitted Cargo Airplanes .....	657	1,229	(572)

Another way to analyze these alternatives is to evaluate them on an incremental cost per life saved; i.e., a cost-effectiveness analysis. For this rule, the effectiveness metric is the number of expected prevented fuel tank explosions, which is then converted into the present value of the number of fatalities prevented. The mid-point of the time-frame in which an accident would happen is 2022 for production airplanes and 2019 for retrofitted airplanes. For all other airplanes, the mid-point would be about 50 years from today, or 2060. In Table 8, the first column lists the specific types of airplanes that could have FRM installed. The second column reports the number of fuel tank explosions that FRM would prevent using an SFAR 88 effectiveness

rate of 50 percent. The third column provides the present value of the total costs to install FRM on those airplanes minus the present value of the destroyed airplane and minus the demand benefits weighted by the number of flight hours. The passenger airplane hull value is \$50, which gives present values of \$19 million for production airplanes and \$24 million for retrofitted airplanes. The present value of the demand benefits would be \$100 million for retrofitted airplanes and \$151 million for production airplanes. The fourth column takes the number of prevented explosions and divides it into the costs to calculate the present value of the cost to prevent one explosion. The fifth column provides the number of fatalities that would be

prevented if FRM were installed on the airplane assuming that 80 percent of the explosions would be in-flight and 20 percent would be on the ground. These numbers are then adjusted by the discount rate to reflect the present value of the fatalities for production and retrofitted passenger airplanes. The final column supplies the average present value of the cost for that option to prevent one fatality. As shown in Table 8, the two most cost-effective options would be to install FRM on production passenger airplanes and on existing passenger airplanes. The final rule contains all of the options except conversion cargo airplanes and retrofitted cargo airplanes.

TABLE 8.—INCREMENTAL COST EFFECTIVENESS ANALYSIS OF THE INDIVIDUAL ALTERNATIVES USING A PRESENT VALUE ANALYSIS WITH A 7 PERCENT DISCOUNT RATE AND A 50 PERCENT SFAR 88 EFFECTIVENESS RATE  
[Total costs in millions of 2007 dollars]

Options	Number of explosions prevented	PV	PV	Average No. of fatalities	PV
		Costs—hull and demand loss	Cost to prevent one accident		Cost to prevent 1 statistical fatality
Production Passenger Airplanes .....	1.00	\$367	\$367	46	\$8.000
Production Cargo Airplanes .....	0.0385	37	961	.055	17,473.000
Production Part 91 Airplanes .....	0.00082	2	2,439	.249	9,785.000
Retrofitted Passenger Airplanes .....	0.52	314	604	56	11.000
Conversion Cargo Airplanes .....	0.095	83	874	.055	15,891.000
Retrofitted Cargo Airplanes .....	0.064	110	1,719	.055	31,255.000
Retrofitted Part 91 Airplanes .....	0.0194	12	6,186	.249	24,843.000
Final Rule .....	1.5585	741	475	49	10.000

Conclusion

When modeling discrete rare events such as fuel tank explosions, it is important to understand and evaluate the distribution around the mean value rather than to rely only on a single point estimated value. This variability analysis indicates there is a substantial

(23 percent) probability that the quantified benefits will be greater than the costs. The Federal Aviation Administration believes that the correct public policy choice is to eliminate the substantial probability of a high consequence fuel tank explosion accident by proceeding with the final rule.

Regulatory Flexibility Analysis Introduction and Purpose of This Analysis

The Regulatory Flexibility Act of 1980 (Pub. L. 96-354) (RFA) establishes “as a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and of

applicable statutes, to fit regulatory and informational requirements to the scale of the businesses, organizations, and governmental jurisdictions subject to regulation. To achieve this principle, agencies are required to solicit and consider flexible regulatory proposals and to explain the rationale for their actions to assure that such proposals are given serious consideration." The RFA covers a wide-range of small entities, including small businesses, not-for-profit organizations, and small governmental jurisdictions.

Agencies must perform a review to determine whether a rule will have a significant economic impact on a substantial number of small entities. If the agency determines that it will, the agency must prepare a regulatory flexibility analysis as described in the RFA.

We believe that this final rule will have a significant economic impact on a substantial number of small entities. The purpose of this analysis is to provide the reasoning underlying the FAA determination. The FAA has determined that:

- There will not be a significant impact on a substantial number of manufacturers.
- There will be a significant impact on a substantial number of small operators.

To make this determination in this final rule, we perform a Regulatory Flexibility Analysis (RFA). Under Section 63(b) of the RFA, the analysis must address:

- Description of reasons the agency is considering the action.
- Statement of the legal basis and objectives for the rule.
- Significant issues raised during public comment.
- Description of the recordkeeping and other compliance requirements of the rule.
- All federal rules that may duplicate, overlap, or conflict with the rule.
- Description and an estimated number of small entities.
- Economic impact.
- Describe the alternatives considered.

#### Description of Reasons the Agency Is Considering the Action

Fuel tank explosions have been a threat with serious aviation safety implications for many years. The explosion of TWA Flight 800 (a Boeing 747) off Long Island, New York in 1996 occurred in-flight with the loss of all 230 on board. Two other explosions on airplanes operated by Philippine Airlines and Thai Airlines occurred on the ground (resulting in nine fatalities).

While the accident investigations of the TWA, Philippine Airlines, and Thai Airlines accidents failed to identify the ignition source that caused the explosion, the investigations found several similarities

The requirements contained in this final rule will reduce the likelihood of fuel tank fires, and mitigate the effects of a fire if one occurs.

#### Statement of the Legal Basis and Objectives for the Rule

The FAA's authority to issue rules regarding aviation safety is found in Title 49 of the United States Code. Subtitle I, Section 106 describes the authority of the FAA Administrator. Subtitle VII, Aviation Programs, describes in more detail the scope of the agency's authority.

This rulemaking is promulgated under the authority described in Subtitle VII, Part A, Subpart III, Section 44701, "General requirements." Under that section, the FAA is charged with promoting safe flight of civil aircraft in air commerce by prescribing minimum standards required in the interest of safety for the design and performance of aircraft; regulations and minimum standards in the interest of aviation safety for inspecting, servicing, and overhauling aircraft; and regulations for other practices, methods, and procedures the Administrator finds necessary for safety in air commerce. This regulation is within the scope of that authority because it prescribes:

- New safety standards for the design of transport category airplanes, and
- New requirements necessary for safety for the design, production, operation and maintenance of those airplanes, and for other practices, methods, and procedures related to those airplanes.

Accordingly, this final rule amends Title 14 of the Code of Federal Regulations and address deficiencies in current regulations regarding airplane designs of the current and future fleet. The rule will require transport category airplanes to minimize flammability of fuel tanks.

#### Significant Issues Raised During Public Comment

Individuals and companies commented that they will incur costs as a result of the requirements contained in the rule. The National Air Carrier Association (NACA) supports FRM being applied to production passenger airplanes. They oppose applying FRM to existing passenger airplanes and to any cargo airplanes. Their primary concerns were that the cost of retrofitting passenger airplanes was too high for the

potential benefits and they believe that cargo airplanes were not at risk. They did not provide specific cost estimates. The Regional Airline Association (RAA) opposes any FRM requirement, although only one of their member airlines has airplanes that will be affected by the final rule.

#### Description of the Recordkeeping and Other Compliance Requirements of the Rule

We expect no more than minimal new reporting and recordkeeping compliant requirements to result from this rule. The rule will require additional entries in existing required maintenance records to account for either the additional maintenance requirements or the installation of nitrogen-inerting systems and the addition of insulation between heat-generating equipment and fuel tanks.

#### All Federal Rules That May Duplicate, Overlap, or Conflict With the Rule

SFAR 88 was enacted to ensure no ignition sources exist in the fuel tanks. After that rule was promulgated and the manufacturers' safety analyses were submitted to the regulatory authorities, we continued to find ignition sources that had not been revealed in the safety analyses. Thus, SFAR 88 cannot eliminate all future ignition sources. This rule is designed to work in conjunction with SFAR 88 to prevent future HCWT explosions. We are unaware that the rule will overlap, duplicate or conflict with any other existing Federal Rules.

#### Description and an Estimated Number of Small Entities

The FAA uses the size standards from the Small Business Administration for Air Transportation and Aircraft Manufacturing specifying companies having less than 1,500 employees as small entities. Boeing is the sole U.S. manufacturer affected by this final rule. As Boeing has more than 1,500 employees and is not considered a small entity, there will not be a significant impact on a substantial number of manufacturers.

We identified a total of 15 U.S. operators who will be affected by this final rule and qualify as small businesses because they have fewer than 1,500 employees. These 15 entities operate a total of 214 airplanes. Once the firms were classified as small entities, we gathered information on their annual revenues.

We obtained the small entities' fleets using data from FAA Flight Standards and BACK Associates Fleet Database. The number of employees and revenues

were obtained from the U.S. Department of Transportation Form 41 filings, BTS Office of Airline Information, Hoovers Online, and Thomas Gale Business and Company Resource Center.

**Economic Impact**

To assess the cost impact to small business part 121 airlines, we estimated the present value retrofit cost for the affected aircraft in the small entities fleet. Table 8 summarizes the cost to retrofit per airplane and the associated model types.

**TABLE 8.—RETROFIT COST BY AIRPLANE MODEL**

Model	Present value cost
<b>Retrofit Cost Per Model:</b>	
B-737—Classic .....	\$137,000
B-737—NG .....	121,000
B-757 .....	211,000
B-767 .....	264,000
B747—100/100/300 .....	289,000
B-747—400 .....	289,000
B-777 .....	311,000
A-320 Family .....	137,000
A-330 .....	311,000

We estimated each operator's compliance cost by multiplying the average retrofit cost per airplane by the

total number of each type of airplane the operator currently has. Then we measured the economic impact on small entities by dividing the firms' total estimated present value compliance cost by its annual revenue. We believe that if the retrofit cost exceeds 2% of a firm's annual revenue, then there is a significant economic impact. As shown in the following table, the present value of the retrofitting costs is estimated to be greater than two percent of annual revenues for three small operators. Thus, as the rule will have a significant economic impact on three small operators we determined this final rule will have a significant impact on a substantial number of small entities.

**TABLE 9.—TOTAL RETROFITTING COSTS AND THEIR PERCENTAGE OF ANNUAL REVENUES FOR THE AFFECTED SMALL OPERATORS**

Airplane model	Small entity operator	Number of affected aircraft	Cost	Annual revenue	Cost as a percent of revenue
BOEING 737-700 .....	ALOHA AIRLINES .....	2	\$242,000	.....	.....
BOEING 737-700 .....	ALOHA AIRLINES .....	5	605,000	.....	.....
BOEING 737-700 .....	ALOHA AIRLINES .....	1	121,000	.....	.....
<b>Total</b> .....	.....	.....	<b>968,000</b>	<b>\$300,601,582</b>	<b>0.32</b>
BOEING 737-300 .....	ATA AIRLINES .....	3	411,000	.....	.....
BOEING 737-800 .....	ATA AIRLINES .....	11	1,331,000	.....	.....
BOEING 737-800 .....	ATA AIRLINES .....	1	121,000	.....	.....
BOEING 757-200 .....	ATA AIRLINES .....	4	1,055,000	.....	.....
BOEING 757-200 .....	ATA AIRLINES .....	2	422,000	.....	.....
BOEING 757-300 .....	ATA AIRLINES .....	4	844,000	.....	.....
<b>Total</b> .....	.....	.....	<b>4,184,000</b>	<b>330,177,135</b>	<b>1.27</b>
BOEING 757-200 .....	EOS AIRLINES .....	3	633,000	1,084,907	58.350
AIRBUS A318-100 .....	FRONTIER AIRLINES [CO-USA] .....	8	1,096,000	.....	.....
AIRBUS A319-100 .....	FRONTIER AIRLINES [CO-USA] .....	39	5,343,000	.....	.....
AIRBUS A319-100 .....	FRONTIER AIRLINES [CO-USA] .....	10	1,370,000	.....	.....
<b>Total</b> .....	.....	.....	<b>7,809,000</b>	<b>1,130,837,682</b>	<b>0.69</b>
BOEING 767-300 .....	HAWAIIAN AIRLINES .....	4	1,056,000	.....	.....
BOEING 767-300 .....	HAWAIIAN AIRLINES .....	8	2,112,000	.....	.....
BOEING 767-300 .....	HAWAIIAN AIRLINES .....	3	792,000	.....	.....
BOEING 767-300 .....	HAWAIIAN AIRLINES .....	3	792,000	.....	.....
<b>Total</b> .....	.....	.....	<b>4,752,000</b>	<b>881,599,398</b>	<b>0.54</b>
BOEING 767-200 .....	MAXJET AIRWAYS .....	1	264,000	.....	.....
BOEING 767-200 .....	MAXJET AIRWAYS .....	1	264,000	.....	.....
BOEING 767-200 .....	MAXJET AIRWAYS .....	1	264,000	.....	.....
<b>Total</b> .....	.....	.....	<b>792,000</b>	<b>2,422,199</b>	<b>32.70</b>
BOEING 737-400 .....	MIAMI AIR INTERNATIONAL .....	2	274,000	.....	.....
BOEING 737-800 .....	MIAMI AIR INTERNATIONAL .....	3	363,000	.....	.....
BOEING 737-800 .....	MIAMI AIR INTERNATIONAL .....	1	121,000	.....	.....
BOEING 737-800 .....	MIAMI AIR INTERNATIONAL .....	1	121,000	.....	.....
BOEING 737-800 .....	MIAMI AIR INTERNATIONAL .....	2	121,000	.....	.....
<b>Total</b> .....	.....	.....	<b>1,000,000</b>	<b>73,403,477</b>	<b>1.36</b>
BOEING 757-200 .....	PRIMARIS AIRLINES .....	1	211,000	19,403,658	1.09
BOEING 737-300 .....	RYAN INTERNATIONAL AIRLINES .....	1	137,000	.....	.....
BOEING 737-400 .....	RYAN INTERNATIONAL AIRLINES .....	1	137,000	.....	.....
BOEING 737-800 .....	RYAN INTERNATIONAL AIRLINES .....	2	242,000	.....	.....
BOEING 737-800 .....	RYAN INTERNATIONAL AIRLINES .....	1	121,000	.....	.....

TABLE 9.—TOTAL RETROFITTING COSTS AND THEIR PERCENTAGE OF ANNUAL REVENUES FOR THE AFFECTED SMALL OPERATORS—Continued

Airplane model	Small entity operator	Number of affected aircraft	Cost	Annual revenue	Cost as a percent of revenue
BOEING 737–800 .....	RYAN INTERNATIONAL AIRLINES ...	1	121,000 .....	.....	.....
BOEING 757–200 .....	RYAN INTERNATIONAL AIRLINES ...	1	211,000 .....	.....	.....
BOEING 757–200 .....	RYAN INTERNATIONAL AIRLINES ...	1	211,000 .....	.....	.....
BOEING 757–200 .....	RYAN INTERNATIONAL AIRLINES ...	2	422,000 .....	.....	.....
Total .....	.....	.....	1,602,000	101,560,750	1.58
AIRBUS A319–100 .....	SPIRIT AIRLINES [USA] .....	30	4,100,000 .....	.....	.....
AIRBUS A321–100 .....	SPIRIT AIRLINES [USA] .....	6	822,000 .....	.....	.....
Total .....	.....	.....	4,922,000	540,426,363	0.91
BOEING 737–800 .....	SUN COUNTRY AIRLINES .....	2	242,000 .....	.....	.....
BOEING 737–800 .....	SUN COUNTRY AIRLINES .....	6	726,000 .....	.....	.....
BOEING 737–800 .....	SUN COUNTRY AIRLINES .....	2	242,000 .....	.....	.....
BOEING 737–800 .....	SUN COUNTRY AIRLINES .....	3	363,000 .....	.....	.....
Total .....	.....	.....	1,573,000	225,789,595	0.70
AIRBUS A320–100 .....	USA 3000 AIRLINES .....	1	137,000 .....	.....	.....
AIRBUS A320–100 .....	USA 3000 AIRLINES .....	1	137,000 .....	.....	.....
AIRBUS A320–100 .....	USA 3000 AIRLINES .....	9	1,233,000 .....	.....	.....
Total .....	.....	.....	1,507,000	132,077,603	1.14
B–737–429 .....	CASINO EXPRESS .....	1	137,000 .....	.....	.....
B–737–46B .....	CASINO EXPRESS .....	1	137,000 .....	.....	.....
B–737–4S3 .....	CASINO EXPRESS .....	1	137,000 .....	.....	.....
B–737–8Q8 .....	CASINO EXPRESS .....	2	242,000 .....	.....	.....
B–737–8Q8 .....	CASINO EXPRESS .....	1	121,000 .....	.....	.....
B–737–86N .....	CASINO EXPRESS .....	1	121,000 .....	.....	.....
Total .....	.....	.....	895,000	34,178,453	2.62
B–737–3Y0 .....	PACE AIRLINES .....	1	137,000 .....	.....	.....
B–757–256 .....	PACE AIRLINES .....	1	137,000 .....	.....	.....
B–757–236 .....	PACE AIRLINES .....	1	137,000 .....	.....	.....
Total .....	.....	.....	411,000	40,411,353	1.02

Describe the Alternatives Considered

- As described in the Analysis of Alternatives section, we evaluated the following 8 alternatives to the final rule.
- ALTERNATIVE 1. Cover only air carrier passenger airplanes
  - ALTERNATIVE 2. Exclude auxiliary fuel tanks
  - ALTERNATIVE 3. Cover only air carrier retrofitted passenger airplanes
  - ALTERNATIVE 4. Cover only air carrier production passenger airplanes
  - ALTERNATIVE 5. Cover only air carrier production passenger and cargo airplanes
  - ALTERNATIVE 6. Final rule plus part 91 airplanes
  - ALTERNATIVE 7. Final rule plus conversion cargo airplanes
  - ALTERNATIVE 8. Final rule plus conversion and retrofitted cargo airplanes

Our conclusion was that the final rule provided the best balance of cost and

benefits for the United States society. Whether an airplane is flown by a small entity or by a large entity, the risk is largely the same. Consequently, we determined that the final rule should apply to all passenger airplanes and to production cargo airplanes.

Regulatory Flexibility Analysis Summary

As the rule will have a significant economic impact on three small operators, we determined this final rule will have a significant impact on a substantial number of small entities.

International Trade Analysis

The Trade Agreements Act of 1979 (Pub. L. 96–39), as amended by the Uruguay Round Agreements Act (Pub. L. 103–465), prohibits Federal agencies from establishing any standards or engaging in related activities that create unnecessary obstacles to the foreign commerce of the United States.

Pursuant to these Acts, the establishment of standards are not considered unnecessary obstacles to the foreign commerce of the United States, when the standards have a legitimate domestic objective, such as the protection of safety, and when the standards do not operate in a manner that excludes imports that meet this objective. The statute also requires consideration of international standards and, where appropriate, that they be the basis for U.S. standards. The FAA notes the purpose of this rule is to ensure the safety of the American public. We have assessed the effects of this rule to ensure that it does not exclude imports that meet this objective. As a result, this rule is not considered as creating unnecessary obstacles to foreign commerce.

Unfunded Mandates Act

Title II of the Unfunded Mandates Reform Act of 1995 (Pub. L. 104–4)

requires each Federal agency to prepare a written statement assessing the effects of any Federal mandate in a proposed or final agency rule that may result in an expenditure of \$100 million or more (adjusted annually for inflation with the base year 1995) in any one year by State, local, and tribal governments, in the aggregate, or by the private sector; such a mandate is deemed to be a "significant regulatory action." The FAA currently uses an inflation-adjusted value of \$136.1 million in lieu of \$100 million.

There will be 3 years (2015, 2016, and 2017) in which the undiscounted costs will be greater than \$136.1 million. Consequently, in Table 7 of the regulatory evaluation summary, we evaluated the costs and benefits of 8 alternatives to the final rule.

#### *Executive Order 13132, Federalism*

The FAA has analyzed this rule under the principles and criteria of Executive Order 13132, Federalism. We determined that this action will not have a substantial direct effect on the States, on the relationship between the national Government and the States, or on the distribution of power and responsibilities among the various levels of government, and therefore will not have federalism implications.

#### *Regulations Affecting Intrastate Aviation in Alaska*

Section 1205 of the FAA Reauthorization Act of 1996 (110 Stat. 3213) requires the Administrator, when modifying regulations in title 14 of the CFR in manner affecting intrastate aviation in Alaska, to consider the extent to which Alaska is not served by transportation modes other than aviation, and to establish such regulatory distinctions, as he or she considers appropriate. Because this rule applies to the certification of future designs of transport category airplanes and their subsequent operation, it could affect intrastate aviation in Alaska. Nevertheless, the FAA has determined that it is inappropriate to relieve intrastate aviation interests in Alaska from the requirements of today's rule because of the safety objective served by this rule.

#### *Environmental Analysis*

FAA Order 1050.1E identifies FAA actions that are categorically excluded from preparation of an environmental assessment or environmental impact statement under the National Environmental Policy Act in the absence of extraordinary circumstances. The FAA has determined this rulemaking action qualifies for the categorical exclusion identified in

paragraph 312f and involves no extraordinary circumstances.

#### *Regulations that Significantly Affect Energy Supply, Distribution, or Use*

The FAA has analyzed this rule under Executive Order 13211, Actions Concerning Regulations that Significantly Affect Energy Supply, Distribution, or Use (May 18, 2001). We have determined that it is not a "significant energy action" under the executive order because the rule is not likely to have a significant adverse effect on the supply, distribution, or use of energy.

#### **Submission of Comments**

##### *Request for Comments*

Comments should be submitted to Docket No. FAA-2005-22997 by January 20, 2009. Comments may be submitted to the docket using any of the means listed in the Addresses section below.

We will file in the docket all comments we receive, as well as a report summarizing each substantive public contact with FAA personnel concerning this rulemaking. The docket is available for public inspection before and after the comment closing date.

*Privacy Act:* We will post all comments we receive, without change, to <http://www.regulations.gov>, including any personal information you provide. Using the search function of our docket Web site, anyone can find and read the comments received into any of our dockets, including the name of the individual sending the comment (or signing the comment for an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the **Federal Register** published on April 11, 2000 (65 FR 19477-78) or you may visit <http://DocketsInfo.dot.gov>.

##### *Proprietary or Confidential Business Information*

Do not file in the docket information that you consider to be proprietary or confidential business information. Send or deliver this information directly to the person identified in the **FOR FURTHER INFORMATION CONTACT** section of this document. You must mark the information that you consider proprietary or confidential. If you send the information on a disk or CD ROM, mark the outside of the disk or CD ROM and also identify electronically within the disk or CD ROM the specific information that is proprietary or confidential.

Under 14 CFR 11.35(b), when we are aware of proprietary information filed

with a comment, we do not place it in the docket. We hold it in a separate file to which the public does not have access, and we place a note in the docket that we have received it. If we receive a request to examine or copy this information, we treat it as any other request under the Freedom of Information Act (5 U.S.C. 552). We process such a request under the DOT procedures found in 49 CFR part 7.

**ADDRESSES:** You may send comments identified by Docket Number FAA-2004-22997 using any of the following methods:

- *Federal eRulemaking Portal:* Go to <http://www.regulations.gov> and follow the online instructions for sending your comments electronically.

- *Mail:* Send comments to Docket Operations, M-30, U.S. Department of Transportation, 1200 New Jersey Avenue, SE., West Building Ground Floor, Room W12-140, Washington, DC 20590-0001.

- *Fax:* Fax comments to the Docket Operations at 202-493-2251.

- *Hand Delivery or Courier:* Bring comments to Docket Operations in Room W12-140 of the West Building Ground Floor at 1200 New Jersey Avenue, SE., Washington, DC, between 9 a.m. and 5 p.m., Monday through Friday, except Federal holidays.

*Docket:* To read background documents or comments received, go to <http://www.regulations.gov> at any time or to Room W12-140 of the West Building Ground Floor at 1200 New Jersey Avenue, SE., Washington, DC, between 9 a.m. and 5 p.m., Monday through Friday, except Federal holidays.

#### **Availability of Rulemaking Documents**

You can get an electronic copy using the Internet by:

- (1) Searching the Federal eRulemaking Portal (<http://www.regulations.gov>);
- (2) Visiting the Federal Regulations and Policies Web page at [http://www.faa.gov/regulations\\_policies/](http://www.faa.gov/regulations_policies/); or
- (3) Accessing the Government Printing Office's web page at <http://www.gpoaccess.gov/fr/index.html>.

You can also get a copy by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM-1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267-9680. Make sure to identify the docket number, or amendment number of this rulemaking.

#### **Small Business Regulatory Enforcement Fairness Act**

The Small Business Regulatory Enforcement Fairness Act (SFREFA) of 1996 requires FAA to comply with

small entity requests for information or advice about compliance with statutes and regulations within its jurisdiction. If you are a small entity and you have a question regarding this document, you may contact its local FAA official, or the person listed under **FOR FURTHER INFORMATION CONTACT**. You can find out more about SBREFA on the Internet at [http://www.faa.gov/regulations\\_policies/rulemaking/sbre\\_act/](http://www.faa.gov/regulations_policies/rulemaking/sbre_act/).

#### List of Subjects

##### 14 CFR part 25

Aircraft, Aviation safety, Incorporation by reference, Reporting and recordkeeping requirements.

##### 14 CFR part 26

Aircraft, Aviation safety, Continued airworthiness.

##### 14 CFR part 121

Air carriers, Aircraft, Aviation safety, Reporting and recordkeeping requirements, Safety, Transportation.

##### 14 CFR part 125

Aircraft, Aviation safety, Reporting and recordkeeping requirements.

##### 14 CFR part 129

Air carriers, Aircraft, Aviation safety, Reporting and recordkeeping requirements, Security measures.

#### V. The Amendment

■ In consideration of the foregoing, the Federal Aviation Administration amends Chapter 1 of Title 14, Code of Federal Regulations (CFR) parts 25, 26, 121, 125, and 129, as follows:

#### PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

■ 1. The authority citation for part 25 continues to read as follows:

**Authority:** 49 U.S.C. 106(g), 40113, 44701, 44702 and 44704.

■ 2. Part 25 is amended by adding a new § 25.5 to read as follows:

##### § 25.5 Incorporations by reference.

(a) The materials listed in this section are incorporated by reference in the corresponding sections noted. These incorporations by reference were approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. These materials are incorporated as they exist on the date of the approval, and notice of any change in these materials will be published in the **Federal Register**. The materials are available for purchase at the corresponding addresses noted below, and all are available for

inspection at the National Archives and Records Administration (NARA), and at FAA, Transport Airplane Directorate, Aircraft Certification Service, 1601 Lind Avenue, SW., Renton, Washington 98057-3356. For information on the availability of this material at NARA, call 202-741-6030, or go to: [http://www.archives.gov/federal\\_register/code\\_of\\_federal\\_regulations/ibr\\_locations.html](http://www.archives.gov/federal_register/code_of_federal_regulations/ibr_locations.html).

(b) The following materials are available for purchase from the following address: The National Technical Information Services (NTIS), Springfield, Virginia 22166.

(1) Fuel Tank Flammability Assessment Method User's Manual, dated May 2008, document number DOT/FAA/AR-05/8, IBR approved for § 25.981 and Appendix N. It can also be obtained at the following Web site: <http://www.fire.tc.faa.gov/systems/fueltank/FTFAM.stm>.

(2) [Reserved]

■ 3. Amend § 25.981 by revising paragraphs (b) and (c) and adding a new paragraph (d) to read as follows:

##### § 25.981 Fuel tank explosion prevention.

\* \* \* \* \*

(b) Except as provided in paragraphs (b)(2) and (c) of this section, no fuel tank Fleet Average Flammability Exposure on an airplane may exceed three percent of the Flammability Exposure Evaluation Time (FEET) as defined in Appendix N of this part, or that of a fuel tank within the wing of the airplane model being evaluated, whichever is greater. If the wing is not a conventional unheated aluminum wing, the analysis must be based on an assumed Equivalent Conventional Unheated Aluminum Wing Tank.

(1) Fleet Average Flammability Exposure is determined in accordance with Appendix N of this part. The assessment must be done in accordance with the methods and procedures set forth in the Fuel Tank Flammability Assessment Method User's Manual, dated May 2008, document number DOT/FAA/AR-05/8 (incorporated by reference, see § 25.5).

(2) Any fuel tank other than a main fuel tank on an airplane must meet the flammability exposure criteria of Appendix M to this part if any portion of the tank is located within the fuselage contour.

(3) As used in this paragraph,

(i) *Equivalent Conventional Unheated Aluminum Wing Tank* is an integral tank in an unheated semi-monocoque aluminum wing of a subsonic airplane that is equivalent in aerodynamic performance, structural capability, fuel

tank capacity and tank configuration to the designed wing.

(ii) *Fleet Average Flammability Exposure* is defined in Appendix N to this part and means the percentage of time each fuel tank ullage is flammable for a fleet of an airplane type operating over the range of flight lengths.

(iii) *Main Fuel Tank* means a fuel tank that feeds fuel directly into one or more engines and holds required fuel reserves continually throughout each flight.

(c) Paragraph (b) of this section does not apply to a fuel tank if means are provided to mitigate the effects of an ignition of fuel vapors within that fuel tank such that no damage caused by an ignition will prevent continued safe flight and landing.

(d) Critical design configuration control limitations (CDCCL), inspections, or other procedures must be established, as necessary, to prevent development of ignition sources within the fuel tank system pursuant to paragraph (a) of this section, to prevent increasing the flammability exposure of the tanks above that permitted under paragraph (b) of this section, and to prevent degradation of the performance and reliability of any means provided according to paragraphs (a) or (c) of this section. These CDCCL, inspections, and procedures must be included in the Airworthiness Limitations section of the instructions for continued airworthiness required by § 25.1529. Visible means of identifying critical features of the design must be placed in areas of the airplane where foreseeable maintenance actions, repairs, or alterations may compromise the critical design configuration control limitations (e.g., color-coding of wire to identify separation limitation). These visible means must also be identified as CDCCL.

■ 4. Part 25 is amended by adding a new APPENDIX M to read as follows:

#### APPENDIX M TO PART 25—FUEL TANK SYSTEM FLAMMABILITY REDUCTION MEANS

M25.1 *Fuel tank flammability exposure requirements.*

(a) The Fleet Average Flammability Exposure of each fuel tank, as determined in accordance with Appendix N of this part, may not exceed 3 percent of the Flammability Exposure Evaluation Time (FEET), as defined in Appendix N of this part. As a portion of this 3 percent, if flammability reduction means (FRM) are used, each of the following time periods may not exceed 1.8 percent of the FEET:

(1) When any FRM is operational but the fuel tank is not inert and the tank is flammable; and

(2) When any FRM is inoperative and the tank is flammable.

(b) The Fleet Average Flammability Exposure, as defined in Appendix N of this

part, of each fuel tank may not exceed 3 percent of the portion of the FEET occurring during either ground or takeoff/climb phases of flight during warm days. The analysis must consider the following conditions.

(1) The analysis must use the subset of those flights that begin with a sea level ground ambient temperature of 80° F (standard day plus 21° F atmosphere) or above, from the flammability exposure analysis done for overall performance.

(2) For the ground and takeoff/climb phases of flight, the average flammability exposure must be calculated by dividing the time during the specific flight phase the fuel tank is flammable by the total time of the specific flight phase.

(3) Compliance with this paragraph may be shown using only those flights for which the airplane is dispatched with the flammability reduction means operational.

#### M25.2 *Showing compliance.*

(a) The applicant must provide data from analysis, ground testing, and flight testing, or any combination of these, that:

(1) Validate the parameters used in the analysis required by paragraph M25.1 of this appendix;

(2) Substantiate that the FRM is effective at limiting flammability exposure in all compartments of each tank for which the FRM is used to show compliance with paragraph M25.1 of this appendix; and

(3) Describe the circumstances under which the FRM would not be operated during each phase of flight.

(b) The applicant must validate that the FRM meets the requirements of paragraph M25.1 of this appendix with any airplane or engine configuration affecting the performance of the FRM for which approval is sought.

#### M25.3 *Reliability indications and maintenance access.*

(a) Reliability indications must be provided to identify failures of the FRM that would otherwise be latent and whose identification is necessary to ensure the fuel tank with an FRM meets the fleet average flammability exposure requirements listed in paragraph M25.1 of this appendix, including when the FRM is inoperative.

(b) Sufficient accessibility to FRM reliability indications must be provided for maintenance personnel or the flightcrew.

(c) The access doors and panels to the fuel tanks with FRMs (including any tanks that communicate with a tank via a vent system), and to any other confined spaces or enclosed areas that could contain hazardous atmosphere under normal conditions or failure conditions, must be permanently stenciled, marked, or placarded to warn maintenance personnel of the possible presence of a potentially hazardous atmosphere.

#### M25.4 *Airworthiness limitations and procedures.*

(a) If FRM is used to comply with paragraph M25.1 of this appendix, Airworthiness Limitations must be identified for all maintenance or inspection tasks required to identify failures of components within the FRM that are needed to meet paragraph M25.1 of this appendix.

(b) Maintenance procedures must be developed to identify any hazards to be

considered during maintenance of the FRM. These procedures must be included in the instructions for continued airworthiness (ICA).

#### M25.5 *Reliability reporting.*

The effects of airplane component failures on FRM reliability must be assessed on an on-going basis. The applicant/holder must do the following:

(a) Demonstrate effective means to ensure collection of FRM reliability data. The means must provide data affecting FRM reliability, such as component failures.

(b) Unless alternative reporting procedures are approved by the FAA Oversight Office, as defined in part 26 of this subchapter, provide a report to the FAA every six months for the first five years after service introduction. After that period, continued reporting every six months may be replaced with other reliability tracking methods found acceptable to the FAA or eliminated if it is established that the reliability of the FRM meets, and will continue to meet, the exposure requirements of paragraph M25.1 of this appendix.

(c) Develop service instructions or revise the applicable airplane manual, according to a schedule approved by the FAA Oversight Office, as defined in part 26 of this subchapter, to correct any failures of the FRM that occur in service that could increase any fuel tank's Fleet Average Flammability Exposure to more than that required by paragraph M25.1 of this appendix.

■ 5. Part 25 is amended by adding a new APPENDIX N to read as follows:

### APPENDIX N TO PART 25—FUEL TANK FLAMMABILITY EXPOSURE AND RELIABILITY ANALYSIS

#### N25.1 *General.*

(a) This appendix specifies the requirements for conducting fuel tank fleet average flammability exposure analyses required to meet § 25.981(b) and Appendix M of this part. For fuel tanks installed in aluminum wings, a qualitative assessment is sufficient if it substantiates that the tank is a conventional unheated wing tank.

(b) This appendix defines parameters affecting fuel tank flammability that must be used in performing the analysis. These include parameters that affect all airplanes within the fleet, such as a statistical distribution of ambient temperature, fuel flash point, flight lengths, and airplane descent rate. Demonstration of compliance also requires application of factors specific to the airplane model being evaluated. Factors that need to be included are maximum range, cruise mach number, typical altitude where the airplane begins initial cruise phase of flight, fuel temperature during both ground and flight times, and the performance of a flammability reduction means (FRM) if installed.

(c) The following definitions, input variables, and data tables must be used in the program to determine fleet average flammability exposure for a specific airplane model.

#### N25.2 *Definitions.*

(a) *Bulk Average Fuel Temperature* means the average fuel temperature within the fuel tank or different sections of the tank if the

tank is subdivided by baffles or compartments.

(b) *Flammability Exposure Evaluation Time (FEET)*. The time from the start of preparing the airplane for flight, through the flight and landing, until all payload is unloaded, and all passengers and crew have disembarked. In the Monte Carlo program, the flight time is randomly selected from the Flight Length Distribution (Table 2), the pre-flight times are provided as a function of the flight time, and the post-flight time is a constant 30 minutes.

(c) *Flammable*. With respect to a fluid or gas, flammable means susceptible to igniting readily or to exploding (14 CFR Part 1, Definitions). A non-flammable ullage is one where the fuel-air vapor is too lean or too rich to burn or is inert as defined below. For the purposes of this appendix, a fuel tank that is not inert is considered flammable when the bulk average fuel temperature within the tank is within the flammable range for the fuel type being used. For any fuel tank that is subdivided into sections by baffles or compartments, the tank is considered flammable when the bulk average fuel temperature within any section of the tank, that is not inert, is within the flammable range for the fuel type being used.

(d) *Flash Point*. The flash point of a flammable fluid means the lowest temperature at which the application of a flame to a heated sample causes the vapor to ignite momentarily, or "flash." Table 1 of this appendix provides the flash point for the standard fuel to be used in the analysis.

(e) *Fleet average flammability exposure* is the percentage of the flammability exposure evaluation time (FEET) each fuel tank ullage is flammable for a fleet of an airplane type operating over the range of flight lengths in a world-wide range of environmental conditions and fuel properties as defined in this appendix.

(f) *Gaussian Distribution* is another name for the normal distribution, a symmetrical frequency distribution having a precise mathematical formula relating the mean and standard deviation of the samples. Gaussian distributions yield bell-shaped frequency curves having a preponderance of values around the mean with progressively fewer observations as the curve extends outward.

(g) *Hazardous atmosphere*. An atmosphere that may expose maintenance personnel, passengers or flight crew to the risk of death, incapacitation, impairment of ability to self-rescue (that is, escape unaided from a confined space), injury, or acute illness.

(h) *Inert*. For the purpose of this appendix, the tank is considered inert when the bulk average oxygen concentration within each compartment of the tank is 12 percent or less from sea level up to 10,000 feet altitude, then linearly increasing from 12 percent at 10,000 feet to 14.5 percent at 40,000 feet altitude, and extrapolated linearly above that altitude.

(i) *Inerting*. A process where a noncombustible gas is introduced into the ullage of a fuel tank so that the ullage becomes non-flammable.

(j) *Monte Carlo Analysis*. The analytical method that is specified in this appendix as the compliance means for assessing the fleet average flammability exposure time for a fuel tank.

(k) *Oxygen evolution* occurs when oxygen dissolved in the fuel is released into the ullage as the pressure and temperature in the fuel tank are reduced.

(l) *Standard deviation* is a statistical measure of the dispersion or variation in a distribution, equal to the square root of the arithmetic mean of the squares of the deviations from the arithmetic means.

(m) *Transport Effects*. For purposes of this appendix, transport effects are the change in fuel vapor concentration in a fuel tank caused by low fuel conditions and fuel condensation and vaporization.

(n) *Ullage*. The volume within the fuel tank not occupied by liquid fuel.

#### N25.3 Fuel tank flammability exposure analysis.

(a) A flammability exposure analysis must be conducted for the fuel tank under evaluation to determine fleet average flammability exposure for the airplane and fuel types under evaluation. For fuel tanks that are subdivided by baffles or compartments, an analysis must be performed either for each section of the tank, or for the section of the tank having the highest flammability exposure. Consideration of transport effects is not allowed in the analysis. The analysis must be done in accordance with the methods and procedures set forth in the Fuel Tank Flammability Assessment Method User's Manual, dated May 2008, document number DOT/FAA/AR-05/8 (incorporated by reference, see § 25.5). The parameters specified in sections N25.3(b) and (c) of this appendix must be used in the fuel tank flammability exposure "Monte Carlo" analysis.

(b) The following parameters are defined in the Monte Carlo analysis and provided in paragraph N25.4 of this appendix:

(1) Cruise Ambient Temperature, as defined in this appendix.

(2) Ground Ambient Temperature, as defined in this appendix.

(3) Fuel Flash Point, as defined in this appendix.

(4) Flight Length Distribution, as defined in Table 2 of this appendix.

(5) Airplane Climb and Descent Profiles, as defined in the Fuel Tank Flammability Assessment Method User's Manual, dated May 2008, document number DOT/FAA/AR-05/8 (incorporated by reference in § 25.5).

(c) Parameters that are specific to the particular airplane model under evaluation that must be provided as inputs to the Monte Carlo analysis are:

(1) Airplane cruise altitude.

(2) Fuel tank quantities. If fuel quantity affects fuel tank flammability, inputs to the Monte Carlo analysis must be provided that represent the actual fuel quantity within the fuel tank or compartment of the fuel tank throughout each of the flights being evaluated. Input values for this data must be obtained from ground and flight test data or the approved FAA fuel management procedures.

(3) Airplane cruise mach number.

(4) Airplane maximum range.

(5) Fuel tank thermal characteristics. If fuel temperature affects fuel tank flammability, inputs to the Monte Carlo analysis must be provided that represent the actual bulk

average fuel temperature within the fuel tank at each point in time throughout each of the flights being evaluated. For fuel tanks that are subdivided by baffles or compartments, bulk average fuel temperature inputs must be provided for each section of the tank. Input values for these data must be obtained from ground and flight test data or a thermal model of the tank that has been validated by ground and flight test data.

(6) Maximum airplane operating temperature limit, as defined by any limitations in the airplane flight manual.

(7) Airplane Utilization. The applicant must provide data supporting the number of flights per day and the number of hours per flight for the specific airplane model under evaluation. If there is no existing airplane fleet data to support the airplane being evaluated, the applicant must provide substantiation that the number of flights per day and the number of hours per flight for that airplane model is consistent with the existing fleet data they propose to use.

(d) *Fuel Tank FRM Model*. If FRM is used, an FAA approved Monte Carlo program must be used to show compliance with the flammability requirements of § 25.981 and Appendix M of this part. The program must determine the time periods during each flight phase when the fuel tank or compartment with the FRM would be flammable. The following factors must be considered in establishing these time periods:

(1) Any time periods throughout the flammability exposure evaluation time and under the full range of expected operating conditions, when the FRM is operating properly but fails to maintain a non-flammable fuel tank because of the effects of the fuel tank vent system or other causes,

(2) If dispatch with the system inoperative under the Master Minimum Equipment List (MMEL) is requested, the time period assumed in the reliability analysis (60 flight hours must be used for a 10-day MMEL dispatch limit unless an alternative period has been approved by the Administrator),

(3) Frequency and duration of time periods of FRM inoperability, substantiated by test or analysis acceptable to the FAA, caused by latent or known failures, including airplane system shut-downs and failures that could cause the FRM to shut down or become inoperative.

(4) Effects of failures of the FRM that could increase the flammability exposure of the fuel tank.

(5) If an FRM is used that is affected by oxygen concentrations in the fuel tank, the time periods when oxygen evolution from the fuel results in the fuel tank or compartment exceeding the inert level. The applicant must include any times when oxygen evolution from the fuel in the tank or compartment under evaluation would result in a flammable fuel tank. The oxygen evolution rate that must be used is defined in the Fuel Tank Flammability Assessment Method User's Manual, dated May 2008, document number DOT/FAA/AR-05/8 (incorporated by reference in § 25.5).

(6) If an inerting system FRM is used, the effects of any air that may enter the fuel tank following the last flight of the day due to changes in ambient temperature, as defined

in Table 4, during a 12-hour overnight period.

(e) The applicant must submit to the FAA Oversight Office for approval the fuel tank flammability analysis, including the airplane-specific parameters identified under paragraph N25.3(c) of this appendix and any deviations from the parameters identified in paragraph N25.3(b) of this appendix that affect flammability exposure, substantiating data, and any airworthiness limitations and other conditions assumed in the analysis.

#### N25.4 Variables and data tables.

The following data must be used when conducting a flammability exposure analysis to determine the fleet average flammability exposure. Variables used to calculate fleet flammability exposure must include atmospheric ambient temperatures, flight length, flammability exposure evaluation time, fuel flash point, thermal characteristics of the fuel tank, overnight temperature drop, and oxygen evolution from the fuel into the ullage.

(a) Atmospheric Ambient Temperatures and Fuel Properties.

(1) In order to predict flammability exposure during a given flight, the variation of ground ambient temperatures, cruise ambient temperatures, and a method to compute the transition from ground to cruise and back again must be used. The variation of the ground and cruise ambient temperatures and the flash point of the fuel is defined by a Gaussian curve, given by the 50 percent value and a  $\pm 1$ -standard deviation value.

(2) Ambient Temperature: Under the program, the ground and cruise ambient temperatures are linked by a set of assumptions on the atmosphere. The temperature varies with altitude following the International Standard Atmosphere (ISA) rate of change from the ground ambient temperature until the cruise temperature for the flight is reached. Above this altitude, the ambient temperature is fixed at the cruise ambient temperature. This results in a variation in the upper atmospheric temperature. For cold days, an inversion is applied up to 10,000 feet, and then the ISA rate of change is used.

(3) Fuel properties:

(i) For Jet A fuel, the variation of flash point of the fuel is defined by a Gaussian curve, given by the 50 percent value and a  $\pm 1$ -standard deviation, as shown in Table 1 of this appendix.

(ii) The flammability envelope of the fuel that must be used for the flammability exposure analysis is a function of the flash point of the fuel selected by the Monte Carlo for a given flight. The flammability envelope for the fuel is defined by the upper flammability limit (UFL) and lower flammability limit (LFL) as follows:

(A) LFL at sea level = flash point temperature of the fuel at sea level minus 10 ° F. LFL decreases from sea level value with increasing altitude at a rate of 1 ° F per 808 feet.

(B) UFL at sea level = flash point temperature of the fuel at sea level plus 63.5 ° F. UFL decreases from the sea level value with increasing altitude at a rate of 1 ° F per 512 feet.



TABLE 2.—FLIGHT LENGTH DISTRIBUTION—Continued

Flight length (NM)		Airplane maximum range—nautical miles (NM)									
From	To	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
9400	9600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
9600	9800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
9800	10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

(c) Overnight Temperature Drop. For airplanes on which FRM is installed, the overnight temperature drop for this appendix is defined using:

(1) A temperature at the beginning of the overnight period that equals the landing temperature of the previous flight that is a random value based on a Gaussian distribution; and

(2) An overnight temperature drop that is a random value based on a Gaussian distribution.

(3) For any flight that will end with an overnight ground period (one flight per day out of an average number of flights per day, depending on utilization of the particular airplane model being evaluated), the landing outside air temperature (OAT) is to be chosen as a random value from the following Gaussian curve:

TABLE 3.—LANDING OUTSIDE AIR TEMPERATURE

Parameter	Landing outside air temperature °F
Mean Temperature .....	58.68
negative 1 std dev .....	20.55
positive 1 std dev .....	13.21

(4) The outside ambient air temperature (OAT) overnight temperature drop is to be chosen as a random value from the following Gaussian curve:

TABLE 4.—OUTSIDE AIR TEMPERATURE (OAT) DROP

Parameter	OAT drop temperature °F
Mean Temp .....	12.0
1 std dev .....	6.0

(d) Number of Simulated Flights Required in Analysis. In order for the Monte Carlo analysis to be valid for showing compliance with the fleet average and warm day flammability exposure requirements, the applicant must run the analysis for a minimum number of flights to ensure that the fleet average and warm day flammability exposure for the fuel tank under evaluation meets the applicable flammability limits defined in Table 5 of this appendix.

TABLE 5.—FLAMMABILITY EXPOSURE LIMIT

Minimum number of flights in Monte Carlo analysis	Maximum acceptable Monte Carlo average fuel tank flammability exposure (percent) to meet 3 percent requirements	Maximum acceptable Monte Carlo average fuel tank flammability exposure (percent) to meet 7 percent part 26 requirements
10,000 .....	2.91	6.79
100,000 .....	2.98	6.96
1,000,000 .....	3.00	7.00

**PART 26—CONTINUED  
AIRWORTHINESS AND SAFETY  
IMPROVEMENTS FOR TRANSPORT  
CATEGORY AIRPLANES**

■ 6. The authority citation for part 26 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702 and 44704.

■ 7. Revise § 26.5 to read as follows:

**§ 26.5 Applicability Table.**

Table 1 of this section provides an overview of the applicability of this

part. It provides guidance in identifying what sections apply to various types of entities. The specific applicability of each subpart and section is specified in the regulatory text.

TABLE 1.—APPLICABILITY OF PART 26 RULES

Effective date of rule	Applicable sections		
	Subpart B EAPAS/ FTS	Subpart D fuel tank flammability	Subpart E damage tolerance data
	December 10, 2007	September 19, 2008	January 11, 2008
Existing <sup>1</sup> TC Holders .....	26.11	26.33	26.43, 26.45, 26.49
Pending <sup>1</sup> TC Applicants .....	26.11	26.37	26.43, 26.45
Existing <sup>1</sup> STC Holders .....	N/A	26.35	26.47, 26.49
Pending <sup>1</sup> STC/ATC Applicants .....	26.11	26.35	26.45, 26.47, 26.49
Future <sup>2</sup> STC/ATC Applicants .....	26.11	26.35	26.45, 26.47, 26.49
Manufacturers .....	N/A	26.39	N/A

<sup>1</sup> As of the effective date of the identified rule.

<sup>2</sup> Application made after the effective date of the identified rule.

■ 8. Amend part 26 by adding a new subpart D to read as follows:

**Subpart D—FUEL TANK FLAMMABILITY**

**General**

Sec.

26.31 Definitions.

26.33 Holders of type certificates: Fuel tank flammability.

26.35 Changes to type certificates affecting fuel tank flammability.

26.37 Pending type certification projects: Fuel tank flammability.

26.39 Newly produced airplanes: Fuel tank flammability.

**Subpart D—Fuel Tank Flammability**

**General**

**§ 26.31 Definitions.**

For purposes of this subpart—

(a) *Fleet Average Flammability Exposure* has the meaning defined in Appendix N of part 25 of this chapter.

(b) *Normally Emptied* means a fuel tank other than a Main Fuel Tank. Main Fuel Tank is defined in 14 CFR 25.981(b).

**§ 26.33 Holders of type certificates: Fuel tank flammability.**

(a) *Applicability.* This section applies to U.S. type certificated transport category, turbine-powered airplanes, other than those designed solely for all-cargo operations, for which the State of Manufacture issued the original certificate of airworthiness or export airworthiness approval on or after January 1, 1992, that, as a result of original type certification or later increase in capacity have:

(1) A maximum type-certificated passenger capacity of 30 or more, or

(2) A maximum payload capacity of 7,500 pounds or more.

(b) *Flammability Exposure Analysis.*

(1) *General.* Within 150 days after September 19, 2008, holders of type certificates must submit for approval to the FAA Oversight Office a flammability exposure analysis of all fuel tanks defined in the type design, as well as all design variations approved under the type certificate that affect flammability exposure. This analysis must be conducted in accordance with Appendix N of part 25 of this chapter.

(2) *Exception.* This paragraph (b) does not apply to—

(i) Fuel tanks for which the type certificate holder has notified the FAA under paragraph (g) of this section that it will provide design changes and service instructions for Flammability Reduction Means or an Ignition Mitigation Means (IMM) meeting the requirements of paragraph (c) of this section.

(ii) Fuel tanks substantiated to be conventional unheated aluminum wing tanks.

(c) *Design Changes.* For fuel tanks with a Fleet Average Flammability Exposure exceeding 7 percent, one of the following design changes must be made.

(1) *Flammability Reduction Means (FRM).* A means must be provided to reduce the fuel tank flammability.

(i) Fuel tanks that are designed to be Normally Emptied must meet the flammability exposure criteria of Appendix M of part 25 of this chapter if any portion of the tank is located within the fuselage contour.

(ii) For all other fuel tanks, the FRM must meet all of the requirements of Appendix M of part 25 of this chapter, except, instead of complying with paragraph M25.1 of this appendix, the Fleet Average Flammability Exposure may not exceed 7 percent.

(2) *Ignition Mitigation Means (IMM).* A means must be provided to mitigate the effects of an ignition of fuel vapors within the fuel tank such that no damage caused by an ignition will prevent continued safe flight and landing.

(d) *Service Instructions.* No later than September 20, 2010, holders of type certificates required by paragraph (c) of this section to make design changes must meet the requirements specified in either paragraph (d)(1) or (d)(2) of this section. The required service instructions must identify each airplane subject to the applicability provisions of paragraph (a) of this section.

(1) *FRM.* The type certificate holder must submit for approval by the FAA Oversight Office design changes and service instructions for installation of fuel tank flammability reduction means (FRM) meeting the criteria of paragraph (c) of this section.

(2) *IMM.* The type certificate holder must submit for approval by the FAA Oversight Office design changes and service instructions for installation of fuel tank IMM that comply with 14 CFR 25.981(c) in effect on September 19, 2008.

(e) *Instructions for Continued Airworthiness (ICA).* No later than September 20, 2010, holders of type certificates required by paragraph (c) of this section to make design changes must submit for approval by the FAA Oversight Office, critical design configuration control limitations (CDCCL), inspections, or other procedures to prevent increasing the flammability exposure of any tanks equipped with FRM above that permitted under paragraph (c)(1) of this section and to prevent degradation of

the performance of any IMM provided under paragraph (c)(2) of this section. These CDCCL, inspections, and procedures must be included in the Airworthiness Limitations Section (ALS) of the ICA required by 14 CFR 25.1529 or paragraph (f) of this section. Unless shown to be impracticable, visible means to identify critical features of the design must be placed in areas of the airplane where foreseeable maintenance actions, repairs, or alterations may compromise the critical design configuration limitations. These visible means must also be identified as a CDCCL.

(f) *Airworthiness Limitations.* Unless previously accomplished, no later than September 20, 2010, holders of type certificates affected by this section must establish an ALS of the maintenance manual or ICA for each airplane configuration evaluated under paragraph (b)(1) of this section and submit it to the FAA Oversight Office for approval. The ALS must include a section that contains the CDCCL, inspections, or other procedures developed under paragraph (e) of this section.

(g) *Compliance Plan for Flammability Exposure Analysis.* Within 90 days after September 19, 2008, each holder of a type certificate required to comply with paragraph (b) of this section must submit to the FAA Oversight Office a compliance plan consisting of the following:

(1) A proposed project schedule for submitting the required analysis, or a determination that compliance with paragraph (b) of this section is not required because design changes and service instructions for FRM or IMM will be developed and made available as required by this section.

(2) A proposed means of compliance with paragraph (b) of this section, if applicable.

(h) *Compliance Plan for Design Changes and Service Instructions.* Within 210 days after September 19, 2008, each holder of a type certificate required to comply with paragraph (d) of this section must submit to the FAA Oversight Office a compliance plan consisting of the following:

(1) A proposed project schedule, identifying all major milestones, for meeting the compliance dates specified in paragraphs (d), (e) and (f) of this section.

(2) A proposed means of compliance with paragraphs (d), (e) and (f) of this section.

(3) A proposal for submitting a draft of all compliance items required by paragraphs (d), (e) and (f) of this section for review by the FAA Oversight Office

not less than 60 days before the compliance times specified in those paragraphs.

(4) A proposal for how the approved service information and any necessary modification parts will be made available to affected persons.

(i) Each affected type certificate holder must implement the compliance plans, or later revisions, as approved under paragraph (g) and (h) of this section.

**§ 26.35 Changes to type certificates affecting fuel tank flammability.**

(a) *Applicability.* This section applies to holders and applicants for approvals of the following design changes to any airplane subject to 14 CFR 26.33(a):

(1) Any fuel tank designed to be Normally Emptied if the fuel tank installation was approved pursuant to a supplemental type certificate or a field approval before September 19, 2008;

(2) Any fuel tank designed to be Normally Emptied if an application for a supplemental type certificate or an amendment to a type certificate was made before September 19, 2008 and if the approval was not issued before September 19, 2008; and

(3) If an application for a supplemental type certificate or an amendment to a type certificate is made on or September 19, 2008, any of the following design changes:

(i) Installation of a fuel tank designed to be Normally Emptied,

(ii) Changes to existing fuel tank capacity, or

(iii) Changes that may increase the flammability exposure of an existing fuel tank for which FRM or IMM is required by § 26.33(c).

(b) *Flammability Exposure Analysis—*

(1) *General.* By the times specified in paragraphs (b)(1)(i) and (b)(1)(ii) of this section, each person subject to this section must submit for approval a flammability exposure analysis of the auxiliary fuel tanks or other affected fuel tanks, as defined in the type design, to the FAA Oversight Office. This analysis must be conducted in accordance with Appendix N of part 25 of this chapter.

(i) Holders of supplemental type certificates and field approvals: Within 12 months of September 19, 2008,

(ii) Applicants for supplemental type certificates and for amendments to type certificates: Within 12 months after September 19, 2008, or before the certificate is issued, whichever occurs later.

(2) *Exception.* This paragraph does not apply to—

(i) Fuel tanks for which the type certificate holder, supplemental type certificate holder, or field approval holder has notified the FAA under paragraph (f) of this section that it will provide design changes and service instructions for an IMM meeting the requirements of § 25.981(c) in effect September 19, 2008; and

(ii) Fuel tanks substantiated to be conventional unheated aluminum wing tanks.

(c) *Impact Assessment.* By the times specified in paragraphs (c)(1) and (c)(2) of this section, each person subject to paragraph (a)(1) of this section holding an approval for installation of a Normally Emptied fuel tank on an airplane model listed in Table 1 of this section, and each person subject to paragraph (a)(3)(iii) of this section, must submit for approval to the FAA Oversight Office an assessment of the fuel tank system, as modified by their design change. The assessment must identify any features of the design change that compromise any critical design configuration control limitation (CDCCL) applicable to any airplane on which the design change is eligible for installation.

(1) Holders of supplemental type certificates and field approvals: Before March 21, 2011.

(2) Applicants for supplemental type certificates and for amendments to type certificates: Before March 21, 2011 or before the certificate is issued, whichever occurs later.

TABLE 1

Model—Boeing
747 Series
737 Series
777 Series
767 Series
757 Series
Model—Airbus
A318, A319, A320, A321 Series
A300, A310 Series
A330, A340 Series

(d) *Design Changes and Service Instructions.* By the times specified in paragraph (e) of this section, each person subject to this section must meet the requirements of paragraphs (d)(1) or (d)(2) of this section, as applicable.

(1) For holders and applicants subject to paragraph (a)(1) or (a)(3)(iii) of this section, if the assessment required by paragraph (c) of this section identifies any features of the design change that compromise any CDCCL applicable to

any airplane on which the design change is eligible for installation, the holder or applicant must submit for approval by the FAA Oversight Office design changes and service instructions for Flammability Impact Mitigation Means (FIMM) that would bring the design change into compliance with the CDCCL. Any fuel tank modified as required by this paragraph must also be evaluated as required by paragraph (b) of this section.

(2) Applicants subject to paragraph (a)(2), or (a)(3)(i) of this section must comply with the requirements of 14 CFR 25.981, in effect on September 19, 2008.

(3) Applicants subject to paragraph (a)(3)(ii) of this section must comply with the requirements of 14 CFR 26.33.

(e) *Compliance Times for Design Changes and Service Instructions.* The following persons subject to this section must comply with the requirements of paragraph (d) of this section at the specified times.

(1) Holders of supplemental type certificates and field approvals: Before September 19, 2012.

(2) Applicants for supplemental type certificates and for amendments to type certificates: Before September 19, 2012, or before the certificate is issued, whichever occurs later.

(f) *Compliance Planning.* By the applicable date specified in Table 2 of this section, each person subject to paragraph (a)(1) of this section must submit for approval by the FAA Oversight Office compliance plans for the flammability exposure analysis required by paragraph (b) of this section, the impact assessment required by paragraph (c) of this section, and the design changes and service instructions required by paragraph (d) of this section. Each person's compliance plans must include the following:

(1) A proposed project schedule for submitting the required analysis or impact assessment.

(2) A proposed means of compliance with paragraph (d) of this section.

(3) For the requirements of paragraph (d) of this section, a proposal for submitting a draft of all design changes, if any are required, and Airworthiness Limitations (including CDCCLs) for review by the FAA Oversight Office not less than 60 days before the compliance time specified in paragraph (e) of this section.

(4) For the requirements of paragraph (d) of this section, a proposal for how the approved service information and any necessary modification parts will be made available to affected persons.

TABLE 2.—COMPLIANCE PLANNING DATES

	Flammability exposure analysis plan	Impact assessment plan	Design changes and service instructions plan
STC and Field Approval Holders ...	December 18, 2008 .....	November 19, 2010 .....	May 19, 2011.

(g) Each person subject to this section must implement the compliance plans, or later revisions, as approved under paragraph (f) of this section.

**§ 26.37 Pending type certification projects: Fuel tank flammability.**

(a) *Applicability.* This section applies to any new type certificate for a transport category airplane, if the application was made before September 19, 2008, and if the certificate was not issued September 19, 2008. This section applies only if the airplane would have—

- (1) A maximum type-certificated passenger capacity of 30 or more, or
- (2) A maximum payload capacity of 7,500 pounds or more.

(b) If the application was made on or after June 6, 2001, the requirements of 14 CFR 25.981 in effect on September 19, 2008, apply.

**§ 26.39 Newly produced airplanes: Fuel tank flammability.**

(a) *Applicability:* This section applies to Boeing model airplanes specified in Table 1 of this section, including passenger and cargo versions of each model, when application is made for original certificates of airworthiness or export airworthiness approvals after September 20, 2010.

TABLE 1

Model—Boeing
747 Series
737 Series
777 Series
767 Series

(b) Any fuel tank meeting all of the criteria stated in paragraphs (b)(1), (b)(2) and (b)(3) of this section must have flammability reduction means (FRM) or ignition mitigation means (IMM) that meet the requirements of 14 CFR 25.981 in effect on September 19, 2008.

- (1) The fuel tank is Normally Emptied.
- (2) Any portion of the fuel tank is located within the fuselage contour.
- (3) The fuel tank exceeds a Fleet Average Flammability Exposure of 7 percent.

(c) All other fuel tanks that exceed an Fleet Average Flammability Exposure of 7 percent must have an IMM that meets 14 CFR 25.981(d) in effect on September

19, 2008, or an FRM that meets all of the requirements of Appendix M to this part, except instead of complying with paragraph M25.1 of that appendix, the Fleet Average Flammability Exposure may not exceed 7 percent.

**PART 121—OPERATING REQUIREMENTS: DOMESTIC, FLAG, AND SUPPLEMENTAL OPERATIONS**

■ 9. The authority citation for part 121 continues to read as follows:

**Authority:** 49 U.S.C. 106(g), 40113, 40119, 41706, 44101, 44701–44702, 44705, 44709–44711, 44713, 44716–44717, 44722, 44901, 44903–44904, 44012, 46105, 46301.

■ 10. Amend part 121 by adding a new § 121.1117, to read as follows:

**§ 121.1117 Flammability reduction means.**

(a) *Applicability.* Except as provided in paragraph (o) of this section, this section applies to transport category, turbine-powered airplanes with a type certificate issued after January 1, 1958, that, as a result of original type certification or later increase in capacity have:

- (1) A maximum type-certificated passenger capacity of 30 or more, or
- (2) A maximum payload capacity of 7,500 pounds or more.

(b) *New Production Airplanes.* Except in accordance with § 121.628, no certificate holder may operate an airplane identified in Table 1 of this section (including all-cargo airplanes) for which the State of Manufacture issued the original certificate of airworthiness or export airworthiness approval after September 20, 2010 unless an Ignition Mitigation Means (IMM) or Flammability Reduction Means (FRM) meeting the requirements of § 26.33 of this chapter is operational.

TABLE 1

Model—Boeing	Model—Airbus
747 Series	A318, A319, A320, A321 Series
737 Series	A330, A340 Series
777 Series	
767 Series	

(c) *Auxiliary Fuel Tanks.* After the applicable date stated in paragraph (e) of this section, no certificate holder may operate any airplane subject to § 26.33 of this chapter that has an Auxiliary

Fuel Tank installed pursuant to a field approval, unless the following requirements are met:

(1) The certificate holder complies with 14 CFR 26.35 by the applicable date stated in that section.

(2) The certificate holder installs Flammability Impact Mitigation Means (FIMM), if applicable, that is approved by the FAA Oversight Office.

(3) Except in accordance with § 121.628, the FIMM, if applicable, is operational.

(d) *Retrofit.* Except as provided in paragraphs (j), (k), and (l) of this section, after the dates specified in paragraph (e) of this section, no certificate holder may operate an airplane to which this section applies unless the requirements of paragraphs (d)(1) and (d)(2) of this section are met.

(1) IMM, FRM or FIMM, if required by §§ 26.33, 26.35, or 26.37 of this chapter, that are approved by the FAA Oversight Office, are installed within the compliance times specified in paragraph (e) of this section.

(2) Except in accordance with § 121.628, the IMM, FRM or FIMM, as applicable, are operational.

(e) *Compliance Times.* Except as provided in paragraphs (k) and (l) of this section, the installations required by paragraph (d) of this section must be accomplished no later than the applicable dates specified in paragraph (e)(1), (e)(2), or (e)(3) of this section.

(1) Fifty percent of each certificate holder's fleet identified in paragraph (d)(1) of this section must be modified no later than September 19, 2014.

(2) One hundred percent of each certificate holder's fleet identified in paragraph (d)(1) of this section must be modified no later than September 19, 2017.

(3) For those certificate holders that have only one airplane of a model identified in Table 1 of this section, the airplane must be modified no later than September 19, 2017.

(f) *Compliance After Installation.* Except in accordance with § 121.628, no certificate holder may—

(1) Operate an airplane on which IMM or FRM has been installed before the dates specified in paragraph (e) of this section unless the IMM or FRM is operational, or

(2) Deactivate or remove an IMM or FRM once installed unless it is replaced

by a means that complies with paragraph (d) of this section.

(g) *Maintenance Program Revisions.* No certificate holder may operate an airplane for which airworthiness limitations have been approved by the FAA Oversight Office in accordance with §§ 26.33, 26.35, or 26.37 of this chapter after the airplane is modified in accordance with paragraph (d) of this section unless the maintenance program for that airplane is revised to include those applicable airworthiness limitations.

(h) After the maintenance program is revised as required by paragraph (g) of this section, before returning an airplane to service after any alteration for which airworthiness limitations are required by §§ 25.981, 26.33, or 26.37 of this chapter, the certificate holder must revise the maintenance program for the airplane to include those airworthiness limitations.

(i) The maintenance program changes identified in paragraphs (g) and (h) of this section must be submitted to the operator's Principal Maintenance Inspector responsible for review and approval prior to incorporation.

(j) The requirements of paragraph (d) of this section do not apply to airplanes operated in all-cargo service, but those airplanes are subject to paragraph (f) of this section.

(k) The compliance dates specified in paragraph (e) of this section may be extended by one year, provided that—

(1) No later than December 18, 2008, the certificate holder notifies its assigned Flight Standards Office or Principal Inspector that it intends to comply with this paragraph;

(2) No later than March 18, 2009, the certificate holder applies for an amendment to its operations specification in accordance with § 119.51 of this chapter and revises the manual required by § 121.133 to include a requirement for the airplane models specified in Table 2 of this section to use ground air conditioning systems for actual gate times of more than 30 minutes, when available at the gate and operational, whenever the ambient temperature exceeds 60 degrees Fahrenheit; and

(3) Thereafter, the certificate holder uses ground air conditioning systems as described in paragraph (k)(2) of this section on each airplane subject to the extension.

TABLE 2

Model—Boeing	Model—Airbus
747 Series	A318, A319, A320, A321 Series

TABLE 2—Continued

Model—Boeing	Model—Airbus
737 Series 777 Series 767 Series 757 Series	A300, A310 Series A330, A340 Series

(l) For any certificate holder for which the operating certificate is issued after September 19, 2008, the compliance date specified in paragraph (e) of this section may be extended by one year, provided that the certificate holder meets the requirements of paragraph (k)(2) of this section when its initial operations specifications are issued and, thereafter, uses ground air conditioning systems as described in paragraph (k)(2) of this section on each airplane subject to the extension.

(m) After the date by which any person is required by this section to modify 100 percent of the affected fleet, no certificate holder may operate in passenger service any airplane model specified in Table 2 of this section unless the airplane has been modified to comply with § 26.33(c) of this chapter.

(n) No certificate holder may operate any airplane on which an auxiliary fuel tank is installed after September 19, 2017 unless the FAA has certified the tank as compliant with § 25.981 of this chapter, in effect on September 19, 2008.

(o) *Exclusions.* The requirements of this section do not apply to the following airplane models:

- (1) Convair CV-240, 340, 440, including turbine powered conversions.
- (2) Lockheed L-188 Electra.
- (3) Vickers Armstrong Viscount.
- (4) Douglas DC-3, including turbine powered conversions.
- (5) Bombardier CL-44.
- (6) Mitsubishi YS-11.
- (7) BAC 1-11.
- (8) Concorde.
- (9) deHavilland D.H. 106 Comet 4C.
- (10) VFW—Vereinigte Flugtechnische VFW-614.
- (11) Illyushin Aviation IL 96T.
- (12) Vickers Armstrong Viscount.
- (13) Bristol Aircraft Britannia 305.
- (14) Handley Page Handley Page Herald Type 300.
- (15) Avions Marcel Dassault—Breguet Aviation Mercure 100C.
- (16) Airbus Caravelle.
- (17) Fokker F-27/Fairchild Hiller FH-227.
- (18) Lockheed L-300.

**PART 125—CERTIFICATION AND OPERATIONS; AIRPLANES HAVING A SEATING CAPACITY OF 20 OR MORE PASSENGERS OR A MAXIMUM PAYLOAD CAPACITY OF 6,000 POUNDS OR MORE; AND RULES GOVERNING PERSONS ON BOARD SUCH AIRCRAFT**

■ 11. The authority citation for part 125 continues to read as follows:

**Authority:** 49 U.S.C. 106(g), 40113, 44701-44702, 44705, 44710-44711, 44713, 44716-44717, 44722.

■ 12. Amend part 125 by adding a new § 125.509 to read as follows:

**§ 125.509 Flammability reduction means.**

(a) *Applicability.* Except as provided in paragraph (m) of this section, this section applies to transport category, turbine-powered airplanes with a type certificate issued after January 1, 1958, that, as a result of original type certification or later increase in capacity have:

- (1) A maximum type-certificated passenger capacity of 30 or more, or
- (2) A maximum payload capacity of 7,500 pounds or more.

(b) *New Production Airplanes.* Except in accordance with § 125.201, no person may operate an airplane identified in Table 1 of this section (including all-cargo airplanes) for which the State of Manufacture issued the original certificate of airworthiness or export airworthiness approval after September 20, 2010 unless an Ignition Mitigation Means (IMM) or Flammability Reduction Means (FRM) meeting the requirements of § 26.33 of this chapter is operational.

TABLE 1

Model—Boeing	Model—Airbus
747 Series	A318, A319, A320, A321 Series
737 Series 777 Series 767 Series	A330, A340 Series

(c) *Auxiliary Fuel Tanks.* After the applicable date stated in paragraph (e) of this section, no person may operate any airplane subject to § 26.33 of this chapter that has an Auxiliary Fuel Tank installed pursuant to a field approval, unless the following requirements are met:

(1) The person complies with 14 CFR 26.35 by the applicable date stated in that section.

(2) The person installs Flammability Impact Mitigation Means (FIMM), if applicable, that is approved by the FAA Oversight Office.

(3) Except in accordance with § 125.201, the FIMM, if applicable, are operational.

(d) *Retrofit.* Except as provided in paragraph (j) of this section, after the dates specified in paragraph (e) of this section, no person may operate an airplane to which this section applies unless the requirements of paragraphs (d)(1) and (d)(2) of this section are met.

(1) Ignition Mitigation Means (IMM), Flammability Reduction Means (FRM), or FIMM, if required by §§ 26.33, 26.35, or 26.37 of this chapter, that are approved by the FAA Oversight Office, are installed within the compliance times specified in paragraph (e) of this section.

(2) Except in accordance with § 125.201 of this part, the IMM, FRM or FIMM, as applicable, are operational.

(e) *Compliance Times.* The installations required by paragraph (d) of this section must be accomplished no later than the applicable dates specified in paragraph (e)(1), (e)(2) or (e)(3) of this section.

(1) Fifty percent of each person's fleet of airplanes subject to paragraph (d)(1) of this section must be modified no later than September 19, 2014.

(2) One hundred percent of each person's fleet of airplanes subject to paragraph (d)(1) of this section must be modified no later than September 19, 2017.

(3) For those persons that have only one airplane of a model identified in Table 1 of this section, the airplane must be modified no later than September 19, 2017.

(f) *Compliance after Installation.* Except in accordance with § 125.201, no person may—

(1) Operate an airplane on which IMM or FRM has been installed before the dates specified in paragraph (e) of this section unless the IMM or FRM is operational, or

(2) Deactivate or remove an IMM or FRM once installed unless it is replaced by a means that complies with paragraph (d) of this section.

(g) *Inspection Program Revisions.* No person may operate an airplane for which airworthiness limitations have been approved by the FAA Oversight Office in accordance with §§ 26.33, 26.35, or 26.37 of this chapter after the airplane is modified in accordance with paragraph (d) of this section unless the inspection program for that airplane is revised to include those applicable airworthiness limitations.

(h) After the inspection program is revised as required by paragraph (g) of this section, before returning an airplane to service after any alteration for which airworthiness limitations are required

by §§ 25.981, 26.33, 26.35, or 26.37 of this chapter, the person must revise the inspection program for the airplane to include those airworthiness limitations.

(i) The inspection program changes identified in paragraphs (g) and (h) of this section must be submitted to the operator's assigned Flight Standards Office responsible for review and approval prior to incorporation.

(j) The requirements of paragraph (d) of this section do not apply to airplanes operated in all-cargo service, but those airplanes are subject to paragraph (f) of this section.

(k) After the date by which any person is required by this section to modify 100 percent of the affected fleet, no person may operate in passenger service any airplane model specified in Table 2 of this section unless the airplane has been modified to comply with § 26.33(c) of this chapter.

(l) No person may operate any airplane on which an auxiliary fuel tank is installed after September 19, 2017 unless the FAA has certified the tank as compliant with § 25.981 of this chapter, in effect on September 19, 2008.

(m) *Exclusions.* The requirements of this section do not apply to the following airplane models:

- (1) Convair CV-240, 340, 440, including turbine powered conversions.
- (2) Lockheed L-188 Electra.
- (3) Vickers Armstrong Viscount.
- (4) Douglas DC-3, including turbine powered conversions.
- (5) Bombardier CL-44.
- (6) Mitsubishi YS-11.
- (7) BAC 1-11.
- (8) Concorde.
- (9) deHavilland D.H. 106 Comet 4C.
- (10) VFW—Vereinigte Flugtechnische VFW-614.
- (11) Ilyushin Aviation IL 96T.
- (12) Vickers Armstrong Viscount.
- (13) Bristol Aircraft Britannia 305.
- (14) Handley Page Handley Page Herald Type 300.
- (15) Avions Marcel Dassault—Breguet Aviation Mercure 100C.
- (16) Airbus Caravelle.
- (17) Fokker F-27/Fairchild Hiller FH-227.
- (18) Lockheed L-300.

**PART 129—OPERATIONS: FOREIGN AIR CARRIERS AND FOREIGN OPERATORS OF U.S.-REGISTERED AIRCRAFT ENGAGED IN COMMON CARRIAGE**

■ 13. The authority citation for part 129 continues to read as follows:

**Authority:** 49 U.S.C. 1372, 49113, 440119, 44101, 44701-44702, 447-5, 44709-44711, 44713, 44716-44717, 44722, 44901-44904, 44906, 44912, 44105, Pub. L. 107-71 sec. 104.

■ 14. Amend part 129 by adding a new § 129.117 to read as follows:

**§ 129.117 Flammability reduction means.**

(a) *Applicability.* Except as provided in paragraph (o) of this section, this section applies to U.S.-registered transport category, turbine-powered airplanes with a type certificate issued after January 1, 1958, that as a result of original type certification or later increase in capacity have:

- (1) A maximum type-certificated passenger capacity of 30 or more, or
- (2) A maximum payload capacity of 7,500 pounds or more.

(b) *New Production Airplanes.* Except in accordance with § 129.14, no foreign air carrier or foreign person may operate an airplane identified in Table 1 of this section (including all-cargo airplanes) for which application is made for original certificate of airworthiness or export airworthiness approval after September 20, 2010 unless an Ignition Mitigation Means (IMM) or Flammability Reduction Means (FRM) meeting the requirements of § 26.33 of this chapter is operational.

TABLE 1

Model—Boeing	Model—Airbus
747 Series	A318, A319, A320, A321 Series
737 Series 777 Series 767 Series	A330, A340 Series

(c) *Auxiliary Fuel Tanks.* After the applicable date stated in paragraph (e) of this section, no foreign air carrier or foreign person may operate any airplane subject § 26.33 of this chapter that has an Auxiliary Fuel Tank installed pursuant to a field approval, unless the following requirements are met:

(1) The foreign air carrier or foreign person complies with 14 CFR 26.35 by the applicable date stated in that section.

(2) The foreign air carrier or foreign person installs Flammability Impact Mitigation Means (FIMM), if applicable, that are approved by the FAA Oversight Office.

(3) Except in accordance with § 129.14, the FIMM, if applicable, are operational.

(d) *Retrofit.* After the dates specified in paragraphs (j), (k), and (l) of this section, after the dates specified in paragraph (e) of this section, no foreign air carrier or foreign person may operate an airplane to which this section applies unless the requirements of paragraphs (d)(1) and (d)(2) of this section are met.

(1) IMM, FRM or FIMM, if required by §§ 26.33, 26.35, or 26.37 of this chapter,

that are approved by the FAA Oversight Office, are installed within the compliance times specified in paragraph (e) of this section.

(2) Except in accordance with § 129.14, the IMM, FRM or FIMM, as applicable, are operational.

(e) *Compliance Times.* Except as provided in paragraphs (k) and (l) of this section, the installations required by paragraph (d) of this section must be accomplished no later than the applicable dates specified in paragraph (e)(1) or (e)(2) of this section.

(1) Fifty percent of each foreign air carrier or foreign person's fleet identified in paragraph (d)(1) of this section must be modified no later than September 19, 2014.

(2) One hundred percent of each foreign air carrier or foreign person's fleet of airplanes subject to paragraph (d)(1) or this section must be modified no later than September 19, 2017.

(3) For those foreign air carriers or foreign persons that have only one airplane for a model identified in Table 1, the airplane must be modified no later than September 19, 2017.

(f) *Compliance after Installation.* Except in accordance with § 129.14, no person may—

(1) Operate an airplane on which IMM or FRM has been installed before the dates specified in paragraph (e) of this section unless the IMM or FRM is operational.

(2) Deactivate or remove an IMM or FRM once installed unless it is replaced by a means that complies with paragraph (d) of this section.

(g) *Maintenance Program Revisions.* No foreign air carrier or foreign person may operate an airplane for which airworthiness limitations have been approved by the FAA Oversight Office in accordance with §§ 26.33, 26.35, or 26.37 of this chapter after the airplane is modified in accordance with paragraph (d) of this section unless the maintenance program for that airplane is revised to include those applicable airworthiness limitations.

(h) After the maintenance program is revised as required by paragraph (g) of this section, before returning an airplane to service after any alteration for which airworthiness limitations are required by §§ 25.981, 26.33, 26.35, or 26.37 of this chapter, the foreign person or foreign air carrier must revise the maintenance program for the airplane to include those airworthiness limitations.

(i) The maintenance program changes identified in paragraphs (g) and (h) of this section must be submitted to the operator's assigned Flight Standards Office or Principal Inspector for review and approval prior to incorporation.

(j) The requirements of paragraph (d) of this section do not apply to airplanes operated in all-cargo service, but those airplanes are subject to paragraph (f) of this section.

(k) The compliance dates specified in paragraph (e) of this section may be extended by one year, provided that—

(1) No later than December 18, 2008, the foreign air carrier or foreign person notifies its assigned Flight Standards Office or Principal Inspector that it intends to comply with this paragraph;

(2) No later than March 18, 2009, the foreign air carrier or foreign person applies for an amendment to its operations specifications in accordance with § 129.11 to include a requirement for the airplane models specified in Table 2 of this section to use ground air conditioning systems for actual gate times of more than 30 minutes, when available at the gate and operational, whenever the ambient temperature exceeds 60 degrees Fahrenheit; and

(3) Thereafter, the certificate holder uses ground air conditioning systems as described in paragraph (k)(2) of this section on each airplane subject to the extension.

TABLE 2

Model—Boeing	Model—Airbus
747 Series	A318, A319, A320, A321 Series
737 Series	A300, A310 Series
777 Series	A330, A340 Series
767 Series	
757 Series	

(l) For any foreign air carrier or foreign person for which the operating certificate is issued after September 19, 2008, the compliance date specified in paragraph (e) of this section may be extended by one year, provided that the foreign air carrier or foreign person meets the requirements of paragraph (k)(2) of this section when its initial operations specifications are issued and, thereafter, uses ground air conditioning systems as described in paragraph (k)(2) of this section on each airplane subject to the extension.

(m) After the date by which any person is required by this section to modify 100 percent of the affected fleet, no person may operate in passenger service any airplane model specified in Table 2 of this section unless the airplane has been modified to comply with § 26.33(c) of this chapter.

TABLE 3

Model—Boeing	Model—Airbus
747 Series	A318, A319, A320, A321 Series
737 Series	A300, A310 Series
777 Series	A330, A340 Series
767 Series	
757 Series	
707/720 Series	

(n) No foreign air carrier or foreign person may operate any airplane on which an auxiliary fuel tank is installed after September 19, 2017 unless the FAA has certified the tank as compliant with § 25.981 of this chapter, in effect on September 19, 2008.

(o) *Exclusions.* The requirements of this section do not apply to the following airplane models:

- (1) Convair CV-240, 340, 440, including turbine powered conversions.
- (2) Lockheed L-188 Electra.
- (3) Vickers Armstrong Viscount.
- (4) Douglas DC-3, including turbine powered conversions.
- (5) Bombardier CL-44.
- (6) Mitsubishi YS-11.
- (7) BAC 1-11.
- (8) Concorde.
- (9) deHavilland D.H. 106 Comet 4C.
- (10) VFW—Vereinigte Flugtechnische VFW-614.
- (11) Ilyushin Aviation IL 96T.
- (12) Vickers Armstrong Viscount.
- (13) Bristol Aircraft Britannia 305.
- (14) Handley Page Handley Page Herald Type 300.
- (15) Avions Marcel Dassault—Breguet Aviation Mercure 100C.
- (16) Airbus Caravelle.
- (17) Fokker F-27/Fairchild Hiller FH-227.
- (18) Lockheed L-300.

Issued in Washington, DC, on July 9, 2008.

**Robert A. Sturgell,**

*Acting Administrator.*

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