Proposed Test Plans for a Study of Bleed Air Quality in Commercial Airliners

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16. Abstract

The Airliner Cabin Environment Research (ACER) Program of the National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE) has developed two research plans for an extensive study of bleed air incidents on aircraft operating in the United States. One low cost study plan would enable achievement of selected high priority objectives with minimal costs. A more comprehensive study plan is also presented that would enable a wide-ranging aircraft air quality sampling and testing program to be implemented. Important issues concerning data collection, validation, and reporting as well as business proprietary concerns still need discussion and refinement. A preliminary Work-Breakdown Schedule of the major tasks and an order of magnitude estimates of the costs associated with the two plans are provided.

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Nomenclature

AA	= Alaska Airlines
ACER	= Airline Cabin Environmental Research
AFA	= Association of Flight Attendants
AIDS	= Accident/Incident Data System
APU	= auxiliary power unit
ASHRAE	= American Society of Heating, Refrigeration and Air-Conditioning Engineers
ASIAS	= Aviation Safety Information Analysis and Sharing
ASRS	= Aviation Safety Reporting System
BRE	= Building Research Establishment
C	= Celsius
CFR	= Code of Federal Regulations
CO	= carbon monoxide
CO_2	= carbon dioxide
DOT	= Department of Transportation
EPA	= Environmental Protection Agency
FAA	= Federal Aviation Administration
FAR	= Federal Aviation Regulation
FID	= flame ionization detector
GC	= gas chromatography
HVAC	= heating, ventilating and air conditioning
H.R.	= House of Representatives
IR	= infrared
L	= liter
M	= molar
mg	= milligram (10^{-3} g)
min	= minute
mL	= milliliter (10^{-3} L)
MS	= mass spectrometry
MPa	= mega-Pascal (10^{6} Pa)
NAAQS	= National Ambient Air Quality Standards
NASA	= National Aeronautics and Space Administration
NIOSH	= National Institute of Occupational Safety and Health
NDIR	= non-dispersive infrared
O_2	= oxygen
O_3	= ozone
OSHA	= Occupational Safety and Health Agency
PEL	= permissible exposure limit
PM2.5	= particulate matter less than 2.5 X 10^{-6} m (2.5 microns) in diameter
PM10	= particulate matter less than 10 X 10^{-6} m (10 microns) in diameter
ppbv	= parts per billion by volume
ppm	= parts per million
ppmv	= parts per million by volume
RITE	= Research in the Intermodal Transport Environment
SAS	= Scandinavian Airline System
SDRs	= Service Difficulty Reports
SDRS	= Service Difficulty Reporting System
STC	= Supplemental Type Certificate
TCP	= tri-cresyl phosphate
VIPR	= Vehicle Integrated Propulsion Research (NASA Program)
VOC	= volatile organic compound
WP	= work package
$\mu g/m^3$	= 10^{-6} g per cubic meter
μL	= 10^{-6} L

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1.0 Technical Objectives

The FAA has been directed by the U.S. Congress in the "FAA Modernization and Reform Act of 2012 - H.R. 658 – Section 320" to initiate an extensive study of bleed air incidents on aircraft operating in the United States. The FAA has been specifically directed to accomplish the following:

1) Assess bleed air quality on the full range of commercial aircraft operating in the United States;
2) Identify oil-based contaminants, hydraulic fluid toxins, and other air toxins that appear in cabin air and measure the quantity and prevalence, or absence, of those toxins through a comprehensive sampling program;
3) Determine the specific amount and duration of toxic fumes present in aircraft cabins that constitute a health risk to passengers;
4) Develop a systematic reporting standard for smoke and fume events in aircraft cabins; and
5) Identify the potential health risks to individuals exposed to toxic fumes during flight.

The Airliner Cabin Environment Research (ACER) Program of the National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE) has developed two research plans (tasks, schedule, organizations and overall estimated costs) designed to achieve these objectives. Study Plan "A" will enable achievement of selected high priority objectives at minimal cost. Study Plan "B" is a more comprehensive research plan and will enable all of the objectives identified above to be addressed. The development of these plans has been a challenging undertaking due to (i) the many different organizations that must be involved, (ii) the need for highly automated, robust and reliable state-of-the art air-quality sensing technologies, and (iii) integration of the measurement technologies into the sophisticated environmental control systems of a large number of commercial airliners.

2.0 Background

In 2009 Watson conducted an internal FAA review of records to ascertain the number of bleed air contamination events within the domestic air transportation system (Watson, 2009). The FAA Aviation Safety Information Analysis and Sharing (ASIAS) system is composed of multiple databases including the Accident/Incident Data System (AIDS) and the Service Difficulty Reporting System (SDRS). The FAA review of the SDRS database covered January 1999 - November 2008 and looked for event records that noted the following identification terms: "odor, smell or fume." The search found 252 air contamination events where failures occurred in "airplane, engine or auxiliary power unit systems that may have caused tri-cresyl phosphate lubricants or phosphate ester hydraulic fluids or fuel or products of combustion of these fluids to enter the cockpit/cabin ventilation systems." Of these 252 reported incidents, 33% were due to fuel leaks, 23% were from propulsion engine oil leaks, 18% were from APU oil leaks, 13% were due to air cycle machine oil leaks and 13% were due to hydraulic fluid leaks. During this same period of time, there were 93,647,734 corresponding aircraft departures. Thus the event rate from this study is of the order of 2.7 events per million aircraft departures. Watson also noted the "trial-and-error" nature of maintenance diagnostics related to such events. In several cases, multiple events were recorded in the SDRS database for the same aircraft before the problem was properly diagnosed and then satisfactorily resolved by maintenance crews.

Murawski and Supplee (2008) reported on an examination of the AIDS and SDRS databases over an 18 month period from January 2006 through June 2007. These researchers supplemented the federal databases with additional data from aircraft flight attendant labor union records as well as publically available newspaper reports. Their search looked for records containing the following complaint terms: fume, haze, mist, odor, smell or smoke. In addition, the search also included reports of engine oil maintenance issues that did not explicitly mention an air contamination issue. (NOTE: It is unclear how these authors decided to include such records into their data set.) Murawski and Supplee concluded that 0.86 events occurred each day during the 18 month study period. With approximately 26,060 U.S. aircraft departures per day in 2006, the event rate for 2006 was estimated to be of the order of 33 events per million aircraft departures. This estimate is about an order of magnitude greater that that found by Watson (2009).

2.1 Review and Limitations of Previous Cabin Air-Quality Studies

Dickey and Wilson (1989) took air samples from an aircraft that had previous events of oil odor and found that the oil present in the cabin had not been chemically altered from the oil in the engine. In 1992, Vasak reported oil mist levels of 1.5 mg/m^3 and 1.3 mg/m^3 in the cockpit of a BAe146 cabin (Vasak, 1992).

In 1989, Malmfors (1989) studied 48 Scandinavian Airline System (SAS) flights of DC-9 and MD-80 aircraft. The sampling and monitoring equipment was contained within an ordinary briefcase. A central sampling tube was situated along the length of the briefcase and contained a temperature probe, relative humidity probe, a tyndallometer for monitoring the respirable dust concentration, a filter holder with a Teflon membrane and a cyclone to separate the coarse dust particles from the respirable particles in addition to a fan. All samplers were turned on when the aircraft left the gate and turned off when the aircraft stopped at the gate upon landing. The CO concentration was measured with a Maihak Unor 6N infrared gas analyzer which gave a low detection limit of 0.1 ppm with a range between 0-50 ppm. The CO2 concentration was also measured with an instrument based on infrared absorption and it ranged between 0-3000 ppm.

In 1990, a request was made by the Association for Flight Attendants (AFA) for NIOSH to evaluate potential employee exposures to toxic gases and/or a lack of oxygen aboard Alaska Airlines (AA) flights on McDonnell Douglas MD-80 airplanes. This request came after a number of incidents reported during passenger flights on Alaska Airlines MD-80s, during which some of the flight attendants experienced illness symptoms (including headache, dizziness, blurred vision, mental confusion, and numbness). Three NIOSH site visits were made. In the first visit data were collected from AA airlines and employee representatives and the airplane which had the highest number of incidents was visually inspected. In the second visit, NIOSH investigators conducted environmental monitoring aboard three test flights on two Alaska Airlines MD-80 700 series airplanes, under flight conditions thought to represent "worst case" and "normal" for cabin air quality. The third visit conducted additional follow up for CO monitoring on three commercial flight segments using electrochemical cells. Aircraft included MD-80 700 & 900 series along with B727 and B737. Two CO dosimeters were used side-by-side at each sampling location and the CO was continuously monitored during the flight. Total particulates were continuously monitored using optical sensors. Air samples were collected using battery-operated personal sampling pumps. Photoionization detectors (PIDs) were used to detect total VOCs and toluene. Of the 56 aircraft staffed by AA airlines, 66% of the flights were involved in at least one illness incident. B737 and MD-80-900 each had 3 incidents of which none had identifiable exposure. Seven B727 and three MD-80-900 had 2 incidents on each aircraft. An odor was reported on 24% of all 83 incident flights. VOCs averaged 1.8-3.2 ppm. Testing with magnetic resonance imaging of the head showed possible brain abnormalities for six passengers, and in three of these cases (all of whom had persistent neurologic symptoms), psychometric testing indicated cognitive or motor abnormalities. Carbon dioxide averaged between 550-1191 ppm, ozone between 0.005-0.017 ppm, and total particulates 3-26 $\mu g/m^3$.

O'Donnel et al. (1991) conducted a study on 45 flights from 7 identical aircraft of the same airline. The purpose of the study was to measure the concentration of contaminants, the temperature and the relative humidity. The study found a maximum of 2170 ppm for CO2; 4 ppm for CO; less than 0.1 ppm NO2; and 200 $\mu g/m^3$ for total particulates. No VOCs were detected. The carbon dioxide peaked mainly at the beginning and at the end of each flight. The mean temperature during all flights was around 23.4 C and the floor temperature was approximately 24 C. The relative humidity was around 18.5%.

A cabin fume incident in a BAe146 was reported in November 1999 and the resulting investigation found that one engine exhibited minor oil leakage. The engine was thoroughly tested on the ground simulating all phases of the flight from ground idle, take-off, climb, cruise, and descent. Engine bleed air samples were analyzed using EPA standard techniques using high performance liquid chromatography, gas chromatography (GC), or gas chromatography - mass spectrometry (MS). Ninety compounds were confirmed at the bleed and inlet ducts including alkanes, alkenes and aldehydes. Varying concentrations of acetone, methylene chloride, methane, ethylene, carbon dioxide, carbon monoxide, 2- and 3-methylpentane were also detected. The concentration of CO ranged between 3.9 ppm and 4.6 ppm over the entire test time duration (***, 1999).

Another study was conducted by Lee et al. (1999) which included 16 flights on Cathay Pacific aircraft from June 1996 to August 1997. Sampling methods and analysis were performed according to accepted and standardized methods (e.g., ASTM, American Conference Governmental Industrial Hygienists, American Public Health Association, and National Institute for Occupational Safety and Health). An electrochemical cell was used for 5 minutes during each flight to monitor CO levels; non-dispersive infrared NDIR sensors were used for CO2 detection; airbag/pulse fluorescence SO2 analyzer for sulphur dioxide (twice per flight); airbag/chemiluminescene NOx analyzer for nitrogen dioxide (used twice per flight); passive ozone badges or biocheck enzyme for ozone; flame ionization detectors for total hydrocarbon (twice per flight). The CO2 level exhibited higher concentrations during boarding and de-boarding than cruise due to low fresh air supplies. The average concentrations of CO2 ranged between 629 and 1,097 ppm. Ozone levels ranged from null up to 90 ppb. Carbon monoxide concentrations were between 2 and 3 ppm.

Nagda et al. reported in 2001 an ASHRAE study on bleed air quality that included 10 sectors on the following aircraft: B737, B767, and B747. Measurements indicated a maximum of 4,238 ppm of CO2, a maximum of 9 ppm of CO, a maximum of 1 ppm of ozone, a maximum of 380 $\mu g/m^3$ of particulates, and semi-VOCs were under normal detection limits.

Waters et al. (2002) conducted a study on 36 commercial transport flight segments including 11 different aircraft. The objectives of the study were to characterize cabin environmental quality parameters and to try to find a correlation between aircraft type and the environmental parameters. The study categorized the flights that were selected into three different categories depending on the total flight time as follows: short (<2 hrs), medium (2-8 hrs) and long (> 8 hrs). Six smoking flights were considered in the study. Electrochemical cells were used to monitor O3, CO and nitrogen oxides. Nondispersive infrared sensors were used for CO2 detection. GC-MS was used for monitoring VOCs and aldehydes and GC-FID (Flame Ionization Detector) was used for monitoring ethanol, aliphatic hydrocarbons and aromatic hydrocarbons. Gravimetric techniques were used for detecting inhalable particulates, total particulates, respirable particulates and nicotine. Carbon monoxide full-flight average levels were generally less than 1 ppm while the 5-minutes means were as high as 9.4 ppm. No differences between the front and rear coach locations were observed for CO exposures. Ozone gate-to-gate average levels ranged from less than 0.05 ppm to 0.24 ppm while the 5-minute mean yielded a value or 0.17 ppm (average taken from 22 flights). Toluene levels ranged from less than 0.3 to 130 ppb, limonene from 3 to 12 ppb, and ethanol from less than 0.8 to 2.4 ppm. Inhalable particulates had an average of 0.12 μg/lit over the full flight time whereas total particulates were 0.086 μg/lit. Concentrations of both total and inhalable particulates were higher in the rear of coach than the front. On the other hand, carbon dioxide concentrations had a mean during the entire flight period ranging between 874 ppm and 2328 ppm.

A study conducted by the British Building Research Establishment (BRE) in 2003 performed measurements on 7-flights using BAe146 aircraft and 6-flights on Boeing 737-300 aircraft under normal flying conditions. Over 50 volatile organic compounds (VOCs) were identified although some were typically lower during the cruise phase of the flight. The total VOCs ranged from 11-1140 $\mu g/m^3$; Maximum CO2 concentrations were 3,500 ppm and maximum CO reached 7 ppm. The study noted two sources of VOCs: passengers and the bleed air system (BRE, 2003). An article in the British Airways Cabin Crew News summarized the results of a different study conducted by the Building Research Establishment (BRE) on B757 aircraft. The article states that the concentrations of all oil compounds detected in cabin air on the B757 were each less than 100 ppb (Bagshaw, 2003).

Crew members around the world have reported neurological illness after reports of exposure to oil fumes. A recent sampling study funded by the UK-Department for Transport reported low levels of airborne tricresylphosphates (TCP, an antiwear additive added to many jet engine oils) on 23 of 100 flights involving B757, BAe146, A320 and A319 aircraft (Murawski and Michaelis, 2011). A total of 38 flights had fumes or smells as reported by at least one crew member. Out of the 552 crew members who completed a health survey at the end of each of the 100 flights, however only 4 reported a headache.

Murawski et al. (2011) reported an incident in January 2010 when the captain and the first officer on a B767 aircraft had symptoms during flight descent. These symptoms included burning chest pain and unusual fatigue. The aircraft maintenance records confirmed that engine oil had leaked into the air supply system. The captain and the first officer were later suspended from work when they failed to pass the medical test to renew their licenses (Murawski et al., 2011).

2.2 Previously Proposed European Study on Bleed Air Contamination in Aircraft

The European Union recently considered the initiation of a very large study of bleed air contamination on airliners operating within Europe. This study was called “EU MAC 3” and was planned to be part of the EU Framework 7 initiative. An industry-led consortium of 15 organizations from airframe manufacturers, airlines, suppliers, research institutes and standards development bodies proposed a comprehensive initiative to address the issue of bleed air contamination for aircraft flying in Europe. Just as this report was going to press, it was learned that EU MAC 3 was not to be funded during this year. However, efforts continue to be made by the consortium to move forward with critical parts of the work. As summarized below, the proposed European project contained four primary work packages to be accomplished over a three year period.

Work Package 1 was planned to evaluate possible sensor technologies for preventative maintenance and testing purposes with a goal of developing a system that could predict an upset condition prior to contamination levels becoming observable in the aircraft cabin. WP 1 would have developed, constructed, and certified on-board automated monitoring systems to detect the rapid (and usually transient) fume-in-cabin events. In addition, technologies to detect volcanic ash ingress were also to be evaluated.

Work Package 2 was planned to develop ground procedures for bleed-air testing of aero-engines and APUs and would have included a measurement campaign in both ground based test rigs and engines on aircraft with deliberately induced oil and lubricant contamination utilizing, in part, the monitoring systems developed in WP 1.

Work Package 3 was planned to conduct in-flight measurement research to help establish the current air quality and the extent of the bleed air contamination problem in commercial passenger aircraft through “Measurements in the Sky.” The automated systems developed in WP1 were to be deployed on a statistically significant number of aircraft and flight sectors. Data were planned to be collected on 3 airlines representing (representing both wide and standard body airplanes) over an estimated 3000 flights.

Work Package 4 was planned to prepare draft performance specifications and guidelines for European and International Standards and testing procedures – with involvement of relevant stakeholders outside of the MAC 3 consortium. WP 4 would have included toxicological evaluation of detected compounds. This required carrying out pre-normative research to develop baselines and performance specifications, and a European pre-Standard (that is both technically feasible and economically justifiable) was to be proposed.

2.3 Current RITE/ACER Research on Bleed Air Contamination Detection

A combined university/industry RITE/ACER team of Auburn University, Boeing, and Kansas State University are participating with a NASA-led project entitled Vehicle Integrated Propulsion Research (VIPR). Participants in the project are performing full scale engine tests on a wide range of sensor technologies for on-board engine health monitoring of structural and thermal performance, emissions, vibrations, acoustics, etc. VIPR's overarching goal is to develop and demonstrate smart sensor technologies that can provide early detection of impending engine maintenance issues. The test engine is a Pratt & Whitney F117-PW-100 engine on-board an Air Force C17 aircraft. This is the military version of the PW2000 engine that also powers B757 commercial aircraft.

The research goal of the RITE/ACER team in VIPR is to utilize state-of-the-art sensor technologies to sample and characterize the engine's bleed air supply under nominal and simulated oil contamination conditions for engine health monitoring. As shown in the 3D design drawing of Figure 1, jet engine oil typical of that used by commercial airlines will be injected into the test engine and the engine's bleed air supply will be routed through a series of research test stations underneath the engine for sampling and characterization. The bleed air will be evaluated by real-time sensor technologies capable of monitoring for carbon monoxide, carbon dioxide, unburned hydrocarbons as well as aerosols and particulates. In addition, samples of the bleed air will be collected and taken to laboratories for complete characterization of the entire range of possible contaminants. The engine will be operated over a range of power levels representative of ground taxi operation, take-off conditions and steady-state flight. One objective is the development of a database of thermal decomposition products for a typical aircraft engine lubricant during actual engine operation. This database will provide the industry with a "finger print" of bleed-air contamination incidents. All testing will be accomplished on the ground at NASA's Dryden Flight Research Center during July 2013.

The sensors to be tested in the VIPR program's bleed air research have been carefully selected from leading world-wide vendors. Their performance in this rugged test environment is considered to be a critical assessment for future applications on commercial aircraft during flight.

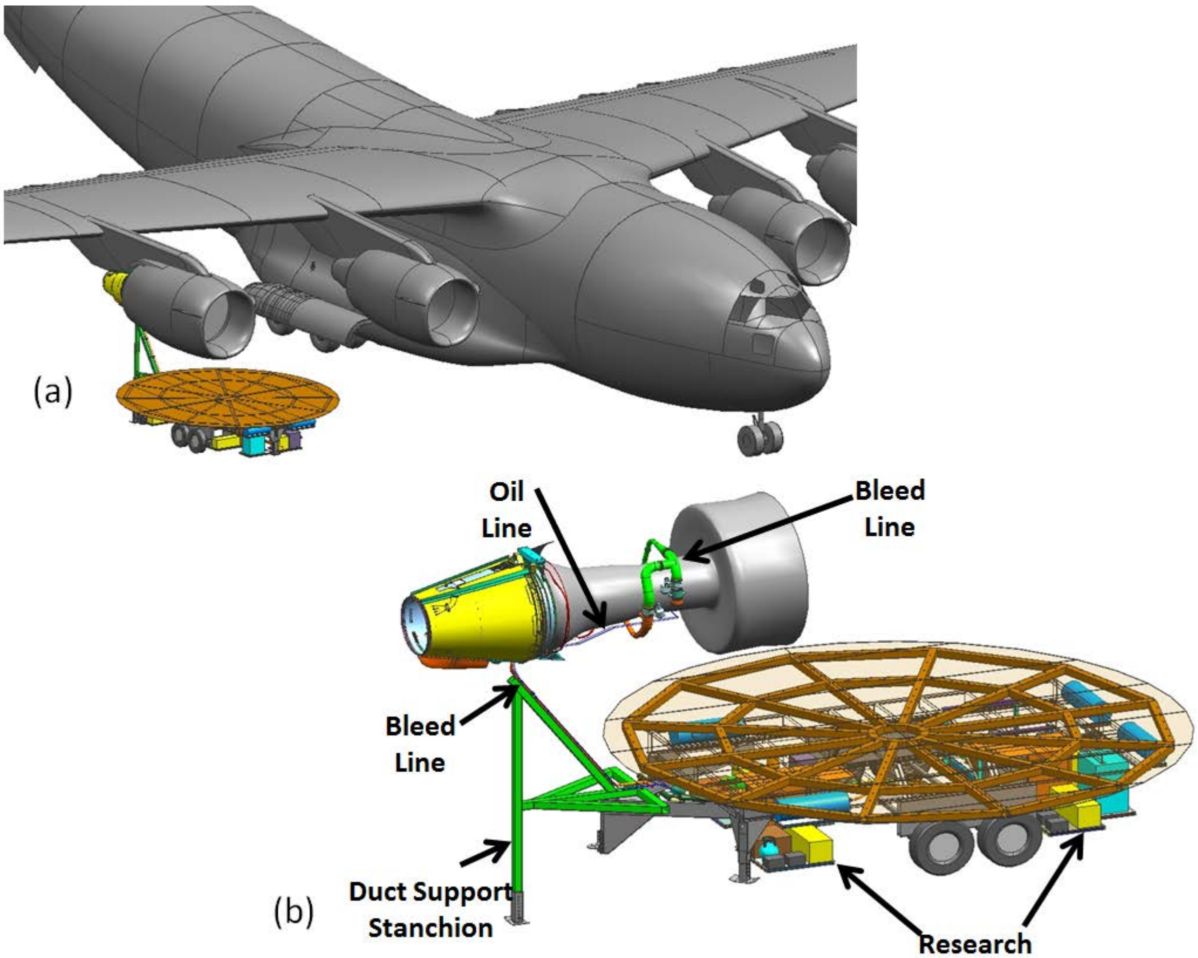
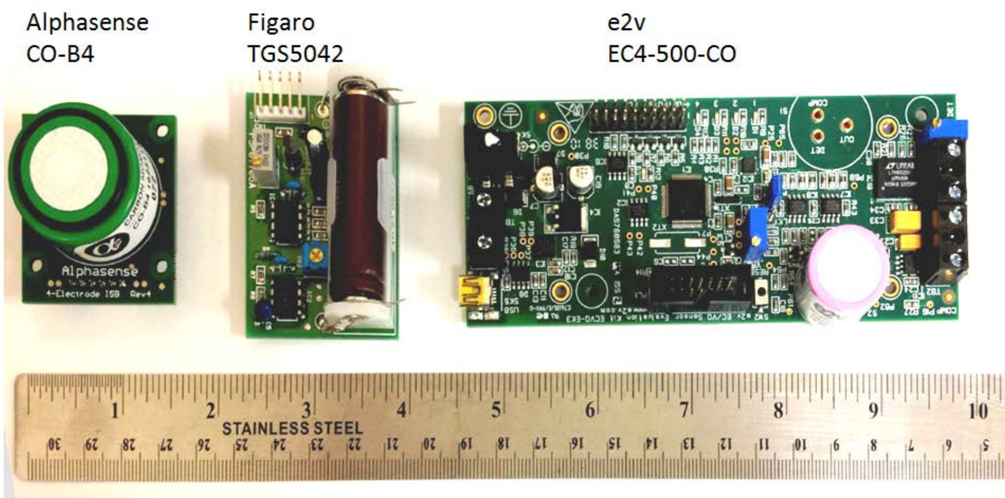


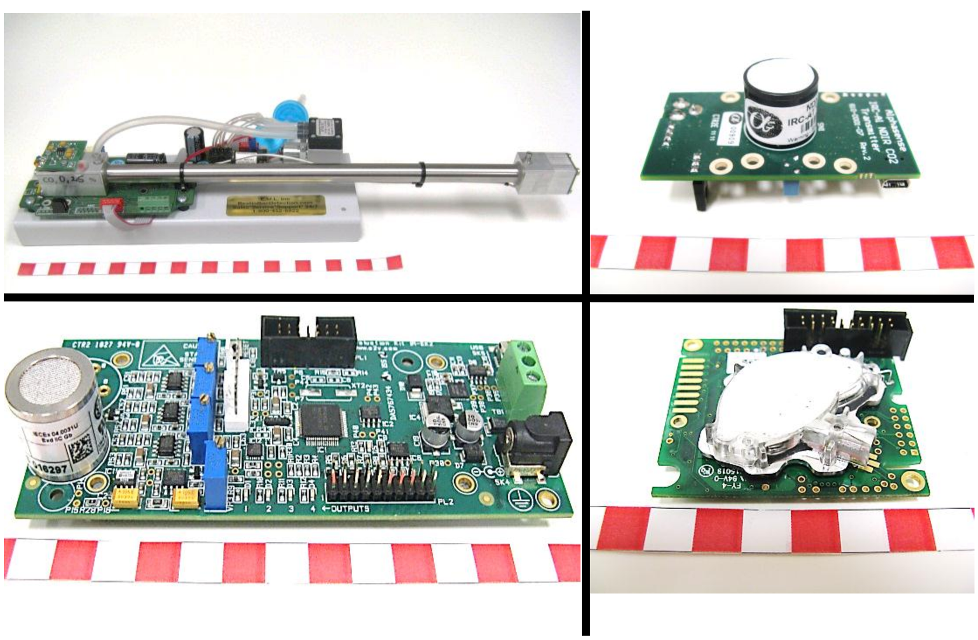
Figure 1. Schematic drawings of the ACER and Boeing Company bleed air research being performed with the NASA Vehicle Integrated Propulsion Research (VIPR) project.
(a) Relationship of the bleed air research instrumentation package to the C17.
(b) Relationship of the research instruments to the bleed air supply of the engine.

Three electrochemical carbon monoxide sensors and four non-dispersive infrared sensors by different manufacturers are being used in the NASA VIPR bleed air tests. These sensors are small and inexpensive (see Figure 2). Current research results on these state-of-the-art sensor technologies at Auburn University indicate that they are very fast and can detect small changes (i.e., 2-3 ppm) in carbon monoxide and carbon dioxide within 2-3 seconds. Since oil leakage from bearings can be either slowly varying and somewhat continuous or sporadic and quite intermittent, robust transient detection capabilities of the sensor technologies are considered to be a critical requirement for success of the planned research.

RITE/ACER's participation in the VIPR program is through RITE/ACER's "Sensors and Prognostics to Mitigate Bleed Air Contamination Events" project, commonly referred to as the Bleed Air Project. The goals of this project are well-aligned with the technical mandates of HR 658 Section 320 and will provide a necessary foundation for the Section 320 study plans discussed herein. Specific objectives of the Bleed Air Project include: 1) develop and test sensing systems and software analysis techniques that will provide sensing and measurement of air quality incidents, 2) develop validated scientific models of the kinetics of engine oil and hydraulic fluid pyrolysis, and 3) develop and test conceptual designs for potential bleed air contamination sensing and adaptable ECS techniques relevant to aircraft retrofits.



(a)



(b)

Figure 2. Commercially available air quality sensors being used in the NASA VIPR study: (a) Electrochemical CO sensors (b) nondispersive infrared CO2 sensors.

As part of this project, a bleed air simulator was developed at Kansas State University that allows air to be compressed and heated to pressures and temperatures representative of those for bleed air from aircraft engines. This simulator provides for controlled oil contamination by injecting an oil mist into the compressor inlet air. This simulator was developed for a previous project to determine the chemical signature on aircraft recirculation filters generated by oil-based air quality incidents. It is being used in the current Bleed Air Project to further characterize the chemical nature of contaminants under different pressure and temperature conditions and to determine the particulate characteristics under these conditions.

The bleed air simulator is very useful as it can be operated economically and at a variety of precisely controlled conditions. However, it is only a simulator and exhibits some limitations in its modeling of bleed air processes in actual turbine engines. The VIPR project represents the opposite extreme: ground-based tests on an actual engine. However, such tests are very expensive, costing millions of dollars to set up and conduct and only allowing measurements for a very limited set of test conditions due to costs and logistics and other programmatic constraints. To fill the void between these two extremes, an Allison 250 (T63) turbine engine (Figure 3) is being mounted on a dynamometer test stand at the KSU National Gas Machinery Laboratory. This engine is being reconfigured so controlled oil contamination can be injected into the compressor inlet and bleed air extracted at the compressor outlet. A range of bleed air conditions can be generated by controlling the load on the engine. This simulator will provide ground-based bleed air processes that are the same as in larger aircraft engines yet it can be operated at a tiny fraction of the cost of a VIPR-type experiment thus making it feasible to make many measurements over a range of bleed air conditions.

Figure 3. Allison Model 250 Turbine Engine (photo courtesy of Avon Aero)

3.0 Planned Programmatic Approach

RITE/ACER personnel have met either personally or via conference calls with representatives of the organizations shown in Table I and discussed at length the goals and objectives of the proposed bleed air quality study. The companies identified are leaders in their industries (aircraft manufacturers, operating airlines, aerospace technology) and may be willing to provide specific strategic and technical support to the proposed study plans. The potential relationships of the organizations to the study plans are listed in Table I.

Table I

Potential Strategic and Technical Participants in the Study

Company	Relationship to the Planned Study
Airbus	Major aircraft manufacturer – Provide technical advice and engineering support regarding design and installation of sensor system on Airbus aircraft, experimental protocols and procedures, interpretation of sensor data
Association of Flight Attendants	Flight attendant union – Provide technical advice regarding experimental protocols and procedures, interpretation of sensor data
Boeing	Major aircraft manufacturer – Provide technical advice and engineering support regarding design and installation of sensor system on Boeing aircraft, experimental protocols and procedures, interpretation of sensor data
Delta Air Lines	Major airline - Provide technical advice and support regarding design and installation of sensor system, experimental protocols and procedures, interpretation of sensor data
Dynetics Corporation	Technology company located in Huntsville, AL with extensive expertise in aerospace sensor systems, complex system integration, information technology including cybersecurity
Honeywell	Major aircraft environmental control system supplier – Provide technical advice and engineering support regarding design and installation of sensor system, experimental protocols and procedures, interpretation of sensor data
United Air Lines	Major airline - Provide technical advice and support regarding design and installation of sensor system, experimental protocols and procedures, interpretation of sensor data
US Airways	Major airline - Provide technical advice and support regarding design and installation of sensor system, experimental protocols and procedures, interpretation of sensor data

Our detailed discussions with these potential participants have centered on technical particulars regarding locating sensors on aircraft, identification of the pertinent contaminants to be monitored, identification of false positives, data acquisition/database development and business proprietary issues.

3.1 Overarching Requirements for the Proposed Research

3.1.1 Magnitude of a Fully Comprehensive Study

The entire list of research requirements specified in H.R. 658, Section 320 (and stated in Section 1.0 of this report) necessitates a very large research project. In particular, the requirement to "assess bleed air quality on the full range of commercial aircraft operating in the United States" implies a study that incorporates all commonly used aircraft. Table II below lists over 30 models of such aircraft. When model variants (e.g., 737-300, 737-400, etc.) are included, the number easily doubles. In fact, there are seven variants of the Boeing 737 aircraft alone and some aircraft have subvariants, for example 777-200 and 777-200ER. In addition, most aircraft models have several engine options and, for older aircraft, some may have upgraded engines. The total number of combinations that would need to be included for the "full range of aircraft" is over 100.

The infrequency of bleed air events is another factor that must be addressed for experimental planning. Even using the higher frequency of events reported by Murawski and Supplee (2008) of approximately 33 incidents per million flights, a large number of flights must be utilized in order to collect a an adequate number of measurements to quantitatively characterize the occurrence and magnitude of bleed air events. Some simple math demonstrates this challenge. If bleed air events were all similar and occurred randomly (and there is no information to indicate if they are), then perhaps a relatively small number of events would need to be captured to characterize their nature, perhaps on the order of 10 actual events. However, in order to capture 10 events, approximately 303,000 flights would need to be monitored [10 / (33/1,000,000)]. If it were desired to capture on the order of 10 events on every make, model and variant to fully characterize these events on the "full range of commercial aircraft," the number would be approximately 100 times this number or 30,300,000 flights, roughly every flight for the next 3 years! If such measurements could even be realized for $100 per flight, then the cost of such a simplistic -- but comprehensive -- study would jump to approximately $3,000,000,000, a prohibitively expensive and totally unrealistic amount.

Table II
Primary Aircraft Operated by the Major Airlines in the U.S.

	Aircraft	American Airlines	Delta Air Lines	Southwest	United Air Lines	US Airways
Regional Jets	CRJ100	-	X	-	-	-
	CRJ200	-	X	-	X	X
	CRJ700	-	X	-	X	X
	CRJ900	-	X	-	-	X
	E120	-	X	-	X	-
	E135	X	-	-	X	-
	E140	X	-	-	-	-
	E145	X	X	-	X	X
	E170	-	X	-	X	X
	E175	-	X	-	-	X
	E190	-	-	-	-	X
	DeH-8	-	-	-	-	X
	Q200	-	-	-	X	-
	Q300	-	-	-	X	-
	Q400	-	-	-	X	-
Narrow Body Jets	MD80	X				
	MD81/82/83/88	-	X	-	-	-
	MD90	-	X	-	-	-
	B737	X	X	X	X	X
	B757	X	X	-	X	X
	A319	-	X	-	X	X
	A320	-	X	-	X	X
	A321	-	-	-	-	X
Wide Body Jets	B747	-	X	-	X	-
	B767	X	X	-	X	X
	B777	X	X	-	X	-
	A300	-	-	-	-	-
	A310	-	-	-	-	-
	A330	-	X	-	-	X
	A340	-	-	-	-	X
	A350	-	-	-	-	-

A-series aircraft manufactured by Airbus (Blagnac, France)
B-series and MD-series aircraft manufactured by Boeing Commercial Airplanes (Renton, WA, USA)
CRJ-series, Q-series and DEH-8 aircraft manufactured by Bombardier Aerospace (Dorval, Quebec, Canada)
E-series aircraft manufactured by Embraer S.A. (Sao Jose dos Campos, Brazil)

Clearly, such a brute-force approach to accomplish the needed research is not feasible and a more thoughtful and selective approach is required. In developing the following plans, the FAA online database for incidents and related information was reviewed. The initial review looked at the number of air quality incidents per flight hour and it was found that the frequency varied widely amongst models and variants ranging from 0.02 incidents per 10,000 hours to nearly 7 incidents per 10,000 flight hours. The criteria used in this assessment were not the same as used by either Watson (2009) or Murawski and Supplee (2008). The intent here was to address the variation in the expected frequency of events. This wide range of event frequency arises from the statistics of small numbers. Only a few incidents, or lack thereof, on a variant with a small number of flight hours can make very big differences. Nevertheless, the range in frequency is easily one order of magnitude and may be two orders of magnitude. Additionally, a study was recently completed by Lebbin (2012) of a similar Canadian database and it is believed that these findings will be made available to the RITE/ACER and industry team.

What these statistics do <u>not</u> show is the existence of so-called “problem aircraft” i.e., individual aircraft that may have several air quality events in a relatively short period of time. Airlines have instituted careful maintenance procedures to identify the causes of air quality incidents onboard commercial airliners. Aircraft exhibiting maintenance needs are typically taken out of service and the required maintenance action accomplished. However, even after exhaustive scrutiny by maintenance personnel, the root cause of some incidents cannot be satisfactorily identified and the incident is typically labeled as “NFF - no fault found” and returned to service. Such aircraft may present an opportunity for selective application of bleed air sensing and could lead to much higher probabilities of capturing and characterizing bleed air contamination events on aircraft.

3.1.2 Enhanced Incident Reporting Standards

As noted previously, Watson (2009) found an aircraft air quality incident rate of 2.7 events per million aircraft departures while Murawski and Supplee (2008) estimated an incident rate of 33 events per million aircraft departures. The order of magnitude difference in these two incident rates may be due to under-reporting of incidents by airlines to the official Accident/Incident Data System (AIDS) and the Service Difficulty Reporting System (SDRS). Public concerns about possible under-reporting of cabin fume incidents led to the fourth directive in H.R. 658, Section 320 which requires the development of a “systematic reporting standard for smoke and fume events in aircraft cabins.”

Our discussions with airline personnel indicate that airlines have incorporated a variety of internal reporting requirements and maintenance procedures for suspected air quality incidents on aircraft. It is believed that with continued airline and union support a common reporting system can be developed that would maximize compliance and minimize business proprietary issues. Such a system would need to provide industry-wide and mutually agreed upon definitions that enable crew members, both cabin and flight crew members, to properly characterize cabin air quality incidents. For example, definitions and examples are needed that exemplify odor events (acrid, burning, oily, pungent, foul, etc.), physical/sight descriptors of incidents (smoke, haze, mist, etc.), incident duration, short term health symptoms (headache, nausea, fatigue, etc.) and other important characteristics to uniformly document and appropriately describe cabin air quality incidents.

A training module would also need to be developed to educate crew members about the potential sources of cabin air quality incidents and the seriousness of potential short term as well as long term health symptoms and effects. Crew members would also need to be trained to follow the industry standard definitions of incident descriptors (odor, sight, potential source, etc.) and comply with their airline's procedural checklist during and after suspected incidents including proper incident documentation (Murawski, 2013).

A simple online documentation form is envisioned that could be filled out by any crew member from any Internet-connected device. Participating companies and unions would need to adopt a policy that all cabin air quality incidents are to be reported using the system. The types of details regarding each incident that would need to be collected are summarized in Table III below and would need to be mutually agreed upon early in any bleed air quality study. The ability for the proposed system to be interfaced with the airlines FAA reporting requirements associated with the Accident/Incident Data System (AIDS) and the Service Difficulty Reporting System (SDRS) would have to be addressed to minimize duplication of effort. Additional issues to link incident reports with airline maintenance findings and subsequent corrective actions (while maintaining proprietary business information and privacy rights of any individuals involved) would also have to be taken into consideration. These are believed to be serious complications and their importance cannot be over emphasized.

Table III

Minimum Incident Details Needed for an Enhanced Incident Reporting System

Date
Airline
Aircraft Tail Number
Flight Number
Visible descriptors of incident
Odor descriptors on incident
Time during flight of incident occurrence
Length of incident occurrence
Suspected/confirmed source of smoke/fumes
Suspected/confirmed mechanical faults of source
Operational impact on flight/crew
Crewmember symptoms
Passenger symptoms

The research team would also need to follow up a limited number of reports with in-depth telephone/e-mail interviews of the crew and, if appropriate, maintenance personnel. The research team would also interview crew members selected randomly from the entire crew member population to assess the fraction of events that are being reported.

3.1.3 Contamination Measurements from Aircraft Bleed Air Supplies

The specific location of an instrumentation package to monitor and measure air quality will have to be determined on a case-by-case basis for each aircraft model. It is anticipated that the package would be mounted outside the cabin for reasons brought up by potential participating airlines. An accessible location upstream of the recirculation filters is envisioned. This location would provide a sampling of cabin air integrated over a substantial portion of the cabin. These measurements are needed to fully address H.R. 658, Section 320, Directives 2) "Identify oil-based contaminants, hydraulic fluid toxins, and other air toxins that appear in cabin air and measure the quantity and prevalence, or absence, of those toxins through a comprehensive sampling program;" and 3) "Determine the specific amount and duration of toxic fumes present in aircraft cabins that constitute a health risk to passengers.

However, the first directive of H.R. 658, Section 320 specifically requires the FAA to "assess the bleed air quality…" Thus, it is important to monitor and measure bleed air specifically, separate from cabin air. In addition to being mandated by H.R. 658, there are sound research reasons for direct monitoring and measurement of bleed air. Taking measurements of the bleed air supply – in addition to the cabin air – would eliminate a number of possible confounding sources of contaminants (e.g., overheated coffee pots or microwave ovens in the cabin) and eliminate the possibility of false positives from such events. This would help satisfy key concerns expressed by potential industry participants regarding false positives.

A potential location to access the bleed air supply system may be in the water system pressurization line of aircraft. This is a particularly attractive location since the temperatures of the bleed air have been reduced to ambient levels and the lower pressures and flow rates through the line should facilitate test system connection design and operation. This bleed air should also be representative of the bleed air supplied to the cabin. Additional investigation and engineering analyses of this possibility are needed.

Direct access to the bleed air supply would also enable event-based triggers to be incorporated into the sensor package to provide for air quality samples to be taken for off-line laboratory analysis later. Off-line analysis would enable analysis for a much wider range of cabin air quality contaminants and would be instrumental to identify specific amounts and duration of fumes present in aircraft cabins and evaluate potential health risks to passengers. For Plan "A" described below, it is anticipated that this direct access to the bleed air would not be feasible due to the need to respond rapidly when an appropriate aircraft (i.e., problem aircraft) is identified. Only the cabin air would be monitored for these flights. For Plan "B," monitoring of bleed air as well as the cabin air would be implemented.

The focus of bleed air supply measurements here is on those air contaminants that might arise from inadvertent malfunctions connected with the bleed air supplies from either the aircraft engine or the auxiliary power unit (APU). The principal contaminants of the aircraft bleed air supply could include (1) aerosolized droplets of jet engine or APU lubricating oil and/or (2) partially pyrolized or by-products of pyrolysis/combustion of these oils. Table IV summarizes the possible contaminants.

As noted above, RITE-ACER investigators are using electrochemical sensors to detect the presence of carbon monoxide (CO), non-dispersive infrared sensors to measure carbon dioxide (CO2), ionization detectors and light scattering diodes to detect fine aerosols and/or particulates, and catalytic bead sensors or photoionization detectors to monitor for unburned hydrocarbons. The RITE/ACER team studying bleed air contamination as part of the VIPR Program (Section 2.3 above) are utilizing the most modern and sophisticated versions of these technologies and the results of the VIPR experiments (July 2013) will help us select the specific technologies from specific vendors to utilize in this planned research.

Table IV

Summary of Potential Bleed Air Contaminants

Potential Bleed Air Contamination Event	*Probable Contaminant*
Engine oil leak producing aerosolized droplets of oil in the engine compressor	• Very fine mist of engine oil aerosols • Small amounts of carbon monoxide (CO) and carbon dioxide (CO_2)
Partially pyrolized/combusted jet engine oil	• Very fine mist of engine oil aerosols • Carbon monoxide (CO) • Carbon dioxide (CO_2) • Misc. unburned hydrocarbons • Ultrafine smoke particles
Fully pyrolized/combusted jet engine oil	• Carbon monoxide (CO) • Carbon dioxide (CO_2) • Ultrafine smoke particles

3.1.4 Ground-based Aircraft Measurements

Prior to finalizing plans and implementing measurement programs on airline revenue flights, an in-depth set of ground-based measurements on operational aircraft is needed. These ground-based measurements would provide quantification of contaminants in the cabin under controlled conditions and would provide an opportunity to evaluate the performance of planned instrumentation systems and protocols.

Ground-based experiments would be conducted on fully operational (but not necessarily flight-worthy) aircraft. Controlled amounts of engine oil or hydraulic fluid would be injected into an engine compressor and measurements taken to determine the contaminants present in both the cabin air and the bleed air supply. By using ground-based aircraft, a complete set of laboratory grade measurements as well as extensive sampling with off-site analysis could be conducted to fully develop the link between contaminants present and exposures with contamination rates and operating conditions. The measurements taken in the VIPR program, described in Section 2.3, will provide critical preliminary information to be used in devising these experiments.

Ground-based measurements would also provide a rigorous test bed for the instrumentation systems to be used during airline flights. The complete instrumentation system would be installed and operated in the same modes as envisioned for the airline flights and the resulting measurements from the systems could be compared to the known contamination inputs and measurements from the laboratory-grade instruments on-board.

Ground-based experiments are less costly than measurements on aircraft and, more importantly, controlled air quality incidents can be created as needed to fully characterize the system behavior. However, the tests are not inexpensive as fully operational aircraft are required and one or more engines must be operated throughout the tests, sometimes at high power levels. Modifications may be required to provide contamination injection into the engine and measurement access in the bleed air lines. Additionally, cleaning of the bleed air system components and, possibly, the entire cabin, will be required to restore the aircraft to its prior operating condition after the tests.

The FAA William J. Hughes Technical Center does have ground-based aircraft that would meet the needs of this portion of the plan. As to whether or not the FAA would use its own aircraft for such experiments or require use of third-party aircraft is an internal matter and is not addressed further in this plan.

3.2 Study Plan “A”

Study Plan “A” is designed to be a low-cost research plan that enables quantitative assessment of (i) the number of bleed air incidents that occur across the U.S. domestic fleet, (ii) quantitative characterization of the bleed air contaminants found during incidents on aircraft and (iii) development of a systematic reporting standard for smoke and fume events in aircraft cabins. These three goals meet several of the congressional directives contained in H.R. 658, Section 320 with the following limitations. (a) The bleed air quality would not be directly measured across the full range of commercial aircraft operating in the United States although the number of incidents would be rigorously quantified for the first time. (b) A comprehensive sampling program would not be implemented. (c) The potential health risks would not be specifically addressed, although preliminary data necessary to estimate the health risks would be provided.

Study Plan "A" attempts to capture the maximum information regarding bleed air incidents in the U.S. domestic fleet for the least cost. A key aspect of this approach is the development of a systematic reporting standard for flight crews and cabin crews to report smoke and fume events in aircraft cabins. A simple online form is envisioned that could be filled-out by any crew member from any internet connected device. The research team would follow up a limited number of reports with in-depth interviews of the crew and, if appropriate, maintenance personnel to assess how accurately the reporting described the events. The research team would also make interviews of crew members selected randomly from the entire crew member population to assess the fraction of events that were being reported. The research team would be able to add important information to the database to minimize crew reporting requirements. For example, aircraft tail number, route of flight, altitudes, etc. could all be obtained from readily available sources if the crew just reports the date, flight number, and departure city. Finally, the reporting system would need to be in place for at least one year in order to develop a useful database that could be used for characterizing the frequency of incidents, reliability of the reporting system, as well as planning for subsequent bleed air measurements on aircraft.

It is highly desirable that specific individual aircraft that are suspected of exhibiting bleed air contamination events be exploited for actual flight measurements of bleed air contamination. An applicable aircraft would be one suspected of having a problem but for which the source of the problem had not yet been identified. As noted previously, airlines identify these incidents as "No fault found." Unfortunately, preselecting such aircraft may bias the results of the study. That is, the type of bleed air contamination problem that results in an aircraft being suspect -- but one in which the problem is <u>not</u> readily identifiable and is <u>not</u> sufficiently bad to prevent the aircraft from being dispatched again -- is quite possibly the result of a non-typical bleed air contamination event that may not be characteristic of more common bleed air contamination events. Thus, the bleed air measurement activity contained in Study Plan "A" might only characterize a limited type of bleed air contamination events.

It is purely speculative at this point to estimate the number of events that would be captured with this approach. However, it appears reasonable to expect the frequency to be approximately two orders of magnitude greater than the general rate for the domestic fleet. Based upon Murawski and Supplee's 2008 estimate of 33 incidents per 1,000,000 flights, we thus might expect to detect approximately 30 incidents in 10,000 flights of "no-fault-found" aircraft. If indeed, on the order of 30 events were captured and well characterized it would go a long ways towards meeting the objectives of the mandate. The exact number of aircraft that would need to be monitored and the number of flights on each aircraft that would be monitored is speculative as well. For current planning purposes, the target is 100 flights each on 100 different aircraft (limited primarily by the logistics associated with identifying and gaining access to "no-fault-found" aircraft).

A proposed Work Breakdown Structure for Study Plan "A" is shown in Figure 4 and more detailed information of the individual tasks and timeline is shown in Table V below. It is estimated that Study Plan "A" could be accomplished for approximately $2.9 M.

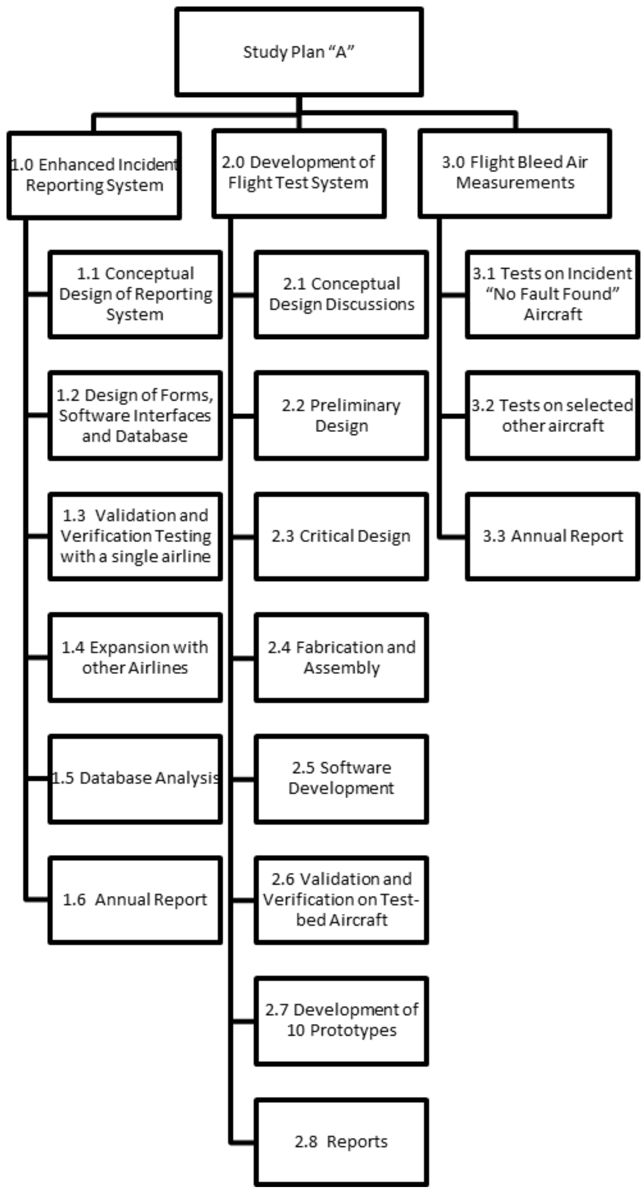


Figure 4. Planned Work Breakdown Structure of the Major Tasks of Study Plan "A."

Table V

Study Plan "A": Research Tasks and Timeline

Task 1.0 – Enhanced Incident Reporting System (Months 1-36)

- Task 1.1 Preliminary discussions with airlines to develop a common language, web-based forms and national database for describing smoke and fume events
- Task 1.2 Software, forms and database development for Incident Reporting System
- Task 1.3 Validation and verification testing of Incident Reporting Systems with a single airline
- Task 1.4 Expansion of Incident Reporting System with additional airlines
- Task 1.5 Database analysis
- Task 1.6 Annual Reporting

Task 2.0 – Development of Flight Test System (Months 1-15)

- Task 2.1 Conceptual design discussions with aircraft manufacturer and airlines (autonomous system or tie-in to aircraft system)
- Task 2.2 Preliminary design and software development
- Task 2.3 Critical design and software development
- Task 2.4 Fabrication, assembly, interfaces and test
- Task 2.5 Software development
- Task 2.6 Verification of sensor system performance (incl. stress/vibration testing, EMI tests); autonomous operation and telecommunication (through WiFi or cell-network); functional system test on test-bed aircraft
- Task 2.7 Development of 10 Prototypes
- Task 2.8 Quarterly Progress Reports and Final Technical Report

Task 3.0 – Bleed Air Contamination Measurements on Aircraft (Months 12-36)

- Task 3.1 Flight measurement campaign on "no-fault-found" aircraft
- Task 3.2 Flight measurement campaign on selected additional aircraft
  NOTE: For example ,aircraft identified as experiencing above normal levels of oil consumption .
- Task 3.3 Quarterly Progress Reports and Annual Technical report

3.3 Study Plan "B"

Study Plan "B" is designed to be a comprehensive research plan that achieves all the goals of Study Plan "A" (i.e., quantitative assessment of (i) the number of bleed air incidents that occur across the U.S. domestic fleet, (ii) quantitative characterization of the bleed air contaminants found during incidents on aircraft and (iii) development of a systematic reporting standard for smoke and fume events in aircraft cabins) along with a comprehensive bleed air flight measurement program to remove the major limitations noted in Section 3.2. Thus Study Plan "B" enables bleed air quality to be directly measured across the full range of commercial aircraft operating in the United States (although not every aircraft type or variant model would be included in the study). Study Plan "B" also includes a comprehensive sampling program and enables the potential health risks to be quantitatively evaluated.

While Study Plan "B" is designed to provide a broader characterization of bleed air contamination across the entire range of commercial aircraft in the US, for reasons explained in Section 3.1.1, it is not feasible to monitor enough flights to accurately characterize bleed air contamination events on every make, model, and variant of aircraft. A targeted approach is still required. As currently envisioned Study Plan "B" would incorporate all elements of Study Plan "A" but would extend this work to provide a broader range of bleed air contamination event characterization. There is an underlying premise in this plan that there are a relatively small number of characteristic bleed air contamination events and that these characteristic events are more or less the same across aircraft models, variants, and engines and it is only the frequency of the events that varies. An objective of this plan then is to capture enough events to be able to show some consistency, or lack thereof, across models and variants as well as to accurately characterize the range of bleed air quality events.

Maximum use will be made of the incident frequency information described in Section 3.1.1 to identify makes, models, and variants that have the highest probability of generating bleed air events. It will also be necessary to work closely with industry partners to screen and refine this list to ensure accuracy. For example, several variants of the MD-80 series historically show up as having relatively high numbers of deleterious air quality events. However, it is believed that a significant number of these events can be traced to a previous problem that has been resolved on most MD-80 aircraft (i.e., ingestion of hydraulic fluid into the APU air inlet). If participating airlines are able to identify individual problem aircraft and direct researchers to them, then the efficiency of the project can be substantially improved. If this selectivity proves not to be feasible, then the project will focus on the model variants with the highest frequencies of events.

Again, the statistics of capturing very infrequent events creates huge challenges for designing a study. If it is possible to select susceptible models and variants that have 10 times the average number of incidents per flight, then we might expect to see 33 incidents for 100,000 flights based on Murawski and Supplee's 2008 estimate. If 100,000 flights could monitored, then perhaps 33 bleed air events could be detected with extensive measurements of the contaminants along with air quality samples. This number would be in addition to the events captured on aircraft identified as "no faulty found" aircraft as described previously in Study Plan "A". If approximately 30 events could be captured on "no fault found" aircraft and another 30 events were captured on targeted aircraft, a pretty clear picture would be available concerning (i) the nature of bleed air contamination events, (ii) the variation in characteristics of those events and (iii) the consistency of the characteristics across several models and variants of aircraft.

After development costs, the per-flight cost of a highly automated bleed air monitoring system should be approximately $150 per flight. Thus monitoring 100,000 additional flights would require approximately $15M. With the previous estimate of $2.9M for Study Plan "A" and Task 4.0 Health Risks costing about $1.0M, the total estimated cost for Study Plan "B" is approximately $18.9 M. NOTE: This cost estimate does not include anticipated industry participation costs as discussed below in Section 3.5 below.

A proposed Work Breakdown Structure for Study Plan "B" is shown in Figure 5 and more detailed information of the individual tasks and timeline is shown in Table VI below.

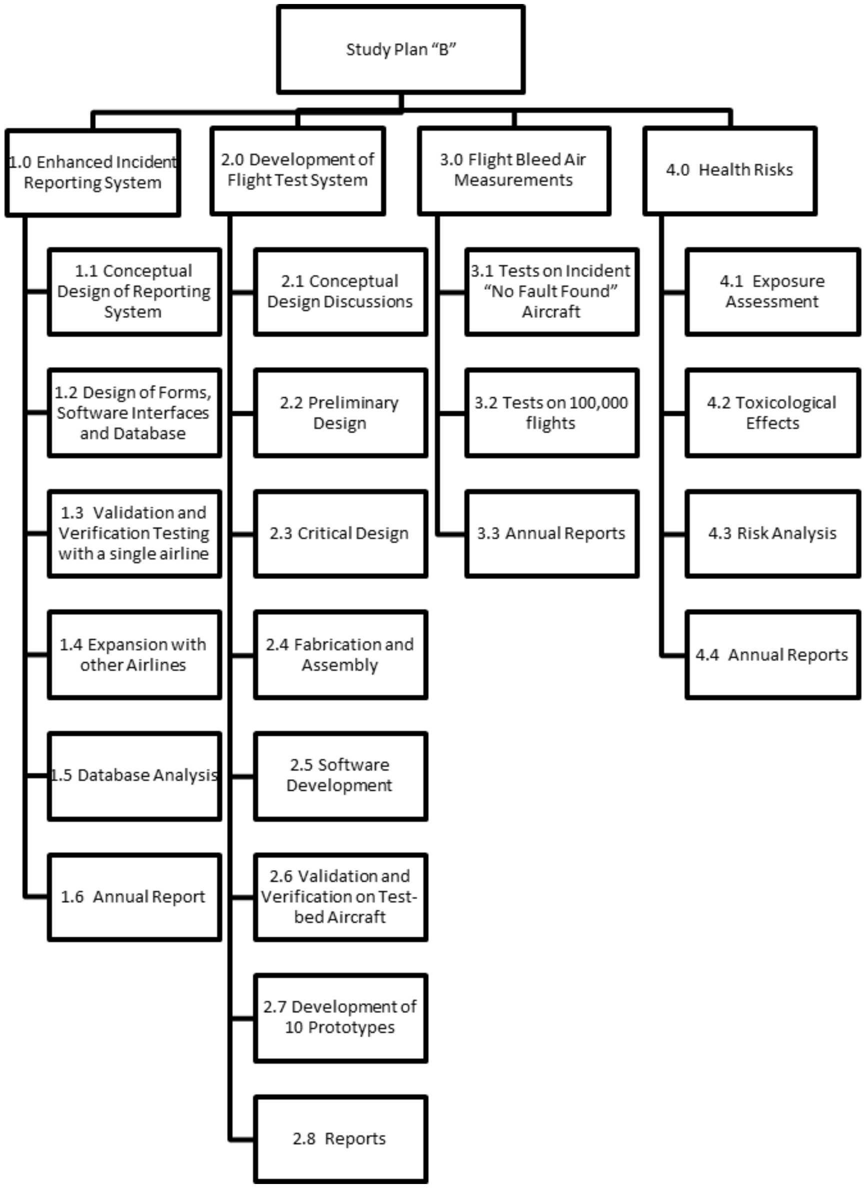


Figure 5. Planned Work Breakdown Structure of the Major Tasks of Study Plan "B."

Table VI

Study Plan "B": Research Tasks and Timeline

Task 1.0 – Enhanced Incident Reporting System (Months 1-36)
- Task 1.1 Preliminary discussions with airlines to develop a common language, web-based forms and national database for describing smoke and fume events
- Task 1.2 Software, forms and database development for Incident Reporting System
- Task 1.3 Validation and verification testing of Incident Reporting Systems with a single airline
- Task 1.4 Expansion of Incident Reporting System with additional airlines
- Task 1.5 Database analysis
- Task 1.6 Annual Reporting

Task 2.0 – Development of Flight Test System (Months 1-18)
- Task 2.1 Conceptual design discussions with aircraft manufacturer and airlines (autonomous system or tie-in to aircraft system)
- Task 2.2 Preliminary design and software development
- Task 2.3 Critical design and software development
- Task 2.4 Fabrication, assembly, interfaces and test
- Task 2.5 Software development
- Task 2.6 Verification of sensor system performance (incl. stress/vibration testing, EMI tests); autonomous operation and telecommunication (through WiFi or cell-network); functional system test on test-bed aircraft
- Task 2.7 Development of 10 Prototypes
- Task 2.8 Quarterly Progress Reports and Final Technical Report

Task 3.0 – Bleed Air Contamination Measurements on Aircraft (Months 15-48)
- Task 3.1 Flight measurement campaign on "no-fault-found" aircraft
- Task 3.2 Flight measurement campaign on selected additional aircraft
  NOTE: For example ,aircraft identified as experiencing above normal levels of oil consumption .
- Task 3.3 Quarterly Progress Reports and Annual Technical report

Phase 4.0 – Quantification of the Public Health Risks (Months 24-48)
- Task 4.1 Exposure Assessment
- Task 4.2 Evaluation of Toxicological Effects
- Task 4.3 Risk Analysis
- Task 4.4 Annual Technical Report

3.4 Industry Participation

Study Plans "A" and "B" above are both based on an assumption of full cooperation of the major US airlines in identifying aircraft to be monitored, providing timely access to aircraft for installing and removing monitoring equipment, and providing necessary information about aircraft to facilitate the development of monitoring systems and logistics. It is also based on the assumption of full cooperation of both Boeing and Airbus in providing the engineering support for designing the installation methods for the monitoring equipment in their aircraft and facilitating the necessary engineering designs and analyses for approval of those installations by the airlines and the FAA. Our preliminary discussions with key personnel from these various organizations have been fruitful and we are optimistic that excellent collaborations can occur.

Discussions with environmental control system engineers indicate that any access to bleed air, such as using the water tank pressurization line, will require a Supplemental Type Certificate (STC). Likewise, it is likely that tapping into the aircraft power lines to provide electrical power for the monitoring system will also require an STC. Thus, there is likely to be a substantial engineering support and documentation for either Study Plan. If the level of participation and cooperation anticipated during the development of these plans is not available, it is unlikely the project will be feasible and, as a minimum, the timeline would be greatly extended and costs increased.

Similarly, the development and implementation of the enhanced reporting system would require the full cooperation of airlines and crew unions in order to be successful.

As noted above for both Study Plans, the cost estimates provided in these preliminary plans do not include these industry participation costs.

3.5 General Equipment Description and Capabilities

The details of the instrument package needed are still under discussion and the development of the actual instrument package will be part of the project itself. The results of the bleed air research occurring with the NASA VIPR program and in the RITE/ACER Bleed Air project will be critical to the specific designs. However, the general requirements of the anticipated instrument package can be outlined.

It is expected that the instrument package will be operated on a given aircraft for a large number of flights depending on whether it is Study Plan “A” or “B” and the nature of the routes flown (short haul vs. transoceanic). Discussions with potential participating airlines indicate that the instrument package could be accessed periodically during that time but the system would have to operate autonomously including automatic downloading of data with no inputs from the crew or from airline maintenance personnel. The unit would have to have sufficient intelligence to sense when the aircraft is in use and the specific phase of aircraft operation (gate, taxi, flight). (The actual flight paths of all commercial aircraft flights are stored in an FAA database so that the exact location of an aircraft can be determined after the fact if a bleed air contamination event is suspected.) The test unit could not be located in the cabin where it might cause concern on the part of crew or passengers and would be vulnerable to possible tampering. It is not feasible for the unit to operate from battery power alone for such an extended time period. The unit will have to draw power from the aircraft and have battery power sufficient to maintain functionality during the times that the aircraft is not powered.

From a measurements perspective, the only way to adequately characterize a bleed air contamination event with a small and reasonably inexpensive instrument system is to also collect air samples and analyze them after-the-fact in a laboratory. However, the costs of laboratory analysis would be prohibitively expensive to sample every flight and characterize the air throughout each flight. Thus, an electronic sensor system is envisioned that detects a high probability of a bleed air event followed by triggering the operation of a simple air sampler. That is, there would be one or more sensors that would detect an anomaly in the bleed air. When such an anomaly is detected, the bleed air would be passed through an adsorption tube to collect a sample of any contaminants present. The unit would carry several adsorption tubes so that multiple samples would be collected over the course of an event to provide time resolution of the contaminant levels present. The unit would then send out an automatic notification that a possible event had occurred so that a researcher or airline maintenance personnel could remove the sample tubes as soon as feasible.

The exact sensors that will be used for the detection part of the unit have not been fully defined but several possibilities have been identified and are being tested through the NASA VIPR project (Section 2.3 above). Likely, multiple technologies would be utilized to minimize the possibility of missing a potential bleed air event. It should be noted that the requirements for this type of research sensing are not as demanding as would be expected for an in-flight warning system as is required by ASHRAE Standard 161 (2007). An occasional false indication would not be a major problem for this project as it would only result in some unnecessary time for sample retrieval and laboratory analysis. Such false positives would not disrupt flight operations. The cost of missing an event, given their expected rarity, is many times greater than the cost of a false event so the focus in designing the measurement system will be to ensure that no potential bleed air contamination event is missed.

4.0 Final Administrative Details

The Study Plans presented in this document intentionally do not contain detailed information relative to specific Organizational Roles and Responsibilities anticipated for the universities, industry and union participants in either of the two studies. Very important issues concerning data collection, validation, reporting, and intellectual property rights still need considerable discussion and refinement. Specific participation requirements will be the subject of negotiation if the FAA is issues a Request for Proposal relative to either of the study plans summarized herein. Finally, comprehensive sub-task level Work-Breakdown-Schedules along with accompanying estimated cost details and budgets associated with the phases, tasks and subtasks as well as the specific timelines and schedules will be provided as part of a response to a Request for Proposal.

5.0 Acknowledgments

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