Fuel Tank Safety
(A Balanced Approach)

2003 DER Seminar

Propulsion Break-out Session

Presented by:

Dennis Kammers
Transport Standards Staff, TAD

Overview

- **Fuel Tank Safety History**
- **SFAR 88 Findings**
- **SFAR 88 Lessons Learned**
  - A Balanced Approach
- **Summary**

Fuel Tank Safety History

	1960's-1995	1996-1999	2000-Present
Accidents (Total of 17 between 1959 and present. Key Accidents shown)	**707 Elkton MD** **747 Madrid** **737 PAL (Manila)**	**TWA 800 (New York)**	**737 Thai (Bangkok)**
Safety Approach: Ignition Sources Ignition	Prevent ignition sources (improvements to affected model after accident)	Re-examine design and maintenance to better prevent ignition sources (SFAR 88) Whole Fleet Solution	Recognition that our best efforts may not be adequate to prevent all explosions
Fuel Air Flammability	Some R&D. Not found to be practical. No requirements established.	FAA research led to inerting developments. Industry (ARAC) deemed it impractical.	Simplified system developed. Recognized that inerting is practical, and may be needed to achieve balanced solution

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Ignition Sources for Key Accidents Never Identified

- **Massive resources expended during investigations**
  - Elkton 707
  - Madrid 747
  - PAL 737
  - TWA 800 (747)
  - Thai 737
- **Exact source of ignition never determined**
  - Corrective actions based on most likely scenarios
- **All five accidents involved high flammability tanks**
- **Highlights uncertain nature of ignition source prevention safety strategy**
  - Must acknowledge unknown ignition sources will still exist

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SFAR 88 - Involvement

	Number Involved	Design Status	Maint Status
TC Holders	**TC Holders** **4 domestic *** **14 foreign** **62 TCs**	**Reviews Completed** **Corrective actions being developed, to be phased in via AD**	**Some maintenance actions via AD**
STC Holders	**22 STC Holders** **(121 STCs)**	**Reviews Ongoing** **ECD Dec 03** **Corrective actions to be via AD**	**Some maintenance actions via AD**
Domestic Fleet	**~ 5000**		**Proposal in work to change December 4, 2004 maintenance approval requirement**

* Boeing N, Boeing S, Lockheed, Maryland Air Services (F-227)

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SFAR 88 - Evolution

- SFAR 88 Initial Issue – May 2001 **(Amd. 21-78)**
  - Provide service information for **all** non-compliances
  - Use "normal AD process" to correct unsafe conditions
    - **FAA Unsafe Condition Criteria not documented**
- Amd. 21-82 – Sept. 2002
  - Added Equivalent Safety Method
    - **Permits using flammability reduction in compliance**
  - Provide service information for **only** unsafe conditions
- Harmonized Unsafe Condition Criteria Issue
  - **FAA Memo issued Feb. 2003**
- Amd. 21-83 – Dec. 2003
  - Extend STC compliance date 6 mo. (June 2003)
- **Ops Rule also amended**
  - Extend compliance date 6 mo (Dec. 2004)

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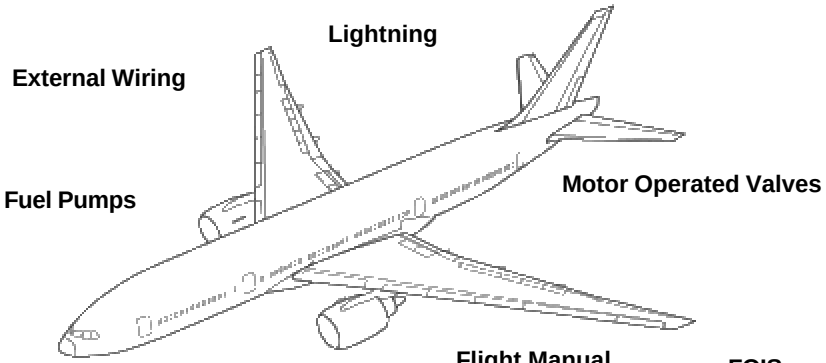
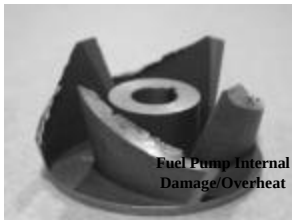
SFAR 88 - AD Process

- **SFAR 88 ignition prevention design reviews/system safety assessments**
  - Identify design issues that would not meet latest certification regulations (Amd 25-102)
  - Reviews are a "re-evaluation" of previously approved fuel systems
- **Design issues evaluated to determine if unsafe condition exists**
  - Harmonized unsafe condition criteria developed to formalized AD decision process
  - Includes flammability exposure level determination

SFAR 88 - Potential Deficiencies



Typical Ignition Sources Found



Harmonized Unsafe Condition Criteria

SFAR 88 Unsafe Condition Determination Criteria

	ELEMENT 4: Flammability Exposure Time		
	A **High Flammability Exposure Time tanks** >7% (Boeing-Seattle, Airbus-CWT)	**B** **High Flammability Exposure Time tanks driven to Low Flammability Exposure Time tanks through inerting or other means**	**C** **Low Flammability Exposure Time tanks**
ELEMENT 1: Evaluation for Single Failures	**Unsafe if:** Foreseeable Single Failures Jeopardize Safe Operation **Required Action:** All identified single failure conditions must be addressed by corrective action (i.e. AD)		
ELEMENT 2: Evaluation for Combinations of Failures	**"Compliance"** **Unsafe if:** Any noncompliance to §§25.981 (a) or (b) (Amendment 25-102) or 25.901 using guidance in AC 25.981-1 **Required Action:** It is expected that any noncompliance finding will be considered as an unsafe conditions and addressed by corrective actions (i.e. AD)	**Unsafe if:** Known Combinations of Failures Jeopardize Safe Operation **Required Action:** All known combinations of failures must be addressed by corrective action (i.e. AD).	
ELEMENT 3: Evaluation for In-Service Experience	**Unsafe if:** In-service failures exist that either a) dissipate energy into tank/create ignition sources, or b) compromise fuel tank safety protection devices **Required Action:** All of the in-service failures must be addressed by corrective action (i.e. AD)		

Major SFAR 88 Corrective Actions

Types of ADs	Safety Issue
AC pumps	**Electrical circuit protection**
Pumps in Empty Tanks	**Dry run inlet protection**
FQIS (High Flammability Tanks [1])	**Energy conducted into tank**
Other Fuel Gauging Components (Densitometer, Valve Actuators, etc.)	**Single failure – high energy**
Bonding (Lightning & Fault Current)	**Energy conducted into tank**
External Wiring	**Power short or burn through tank wall**
Maintenance	**Airworthiness Limitations**
Note: **1- Action for high flammability exposure tanks pending descision on FRS**	

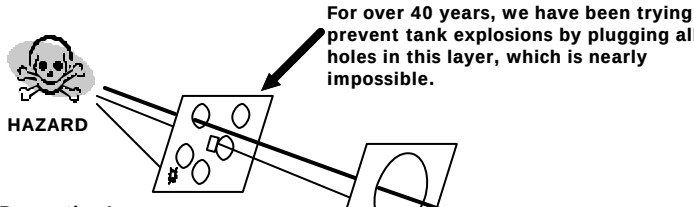
SFAR 88 - Lessons Learned

- **Goal of SFAR 88 was to preclude ignition sources**
- **Safety Assessments were very valuable**
  - Revealed unexpected ignition sources
  - Difficulty in identifying all ignition sources
    - Large number of previously unknown failures found
    - Continuing potential threat from unknown failures that we have yet to identify
- **Unrealistic to expect we can eliminate all ignition sources**
  - Ignition prevention alone is not a balanced approach

Ignition Prevention Alone

(Not Balanced Approach)

Attempting to "plug" all the holes in one layer exceeds what is realistically possible.



Ignition Prevention Layer
Holes due to:
- Design issues
- Aging systems
- Improper Maintenance, Rework, modifications, etc
-Unknown unknowns

Flammability Layer (High Flam Tank shown)
Hole due to:
- High exposure to flammable vapors

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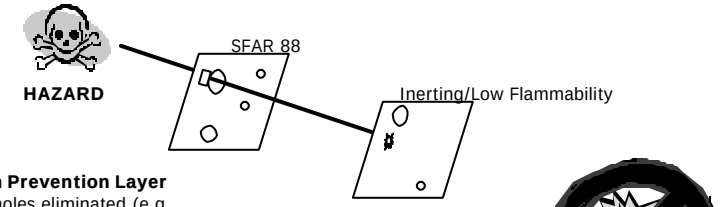
Balanced Approach with Inerting

Inerting significantly reduces hole size in flammability layer virtually eliminating future accidents.



Ignition Prevention Layer
- Some holes eliminated (e.g. design changes to preclude single failures)
- Other holes reduced in size (human factors/ maintenance issues, unknowns, etc.)

Flammability Layer
-Inerting significantly reduces holes (flammability exposure)
-Small holes remain due to system performance, dispatch relief, system reliability, etc.

ACCIDENT PREVENTED!

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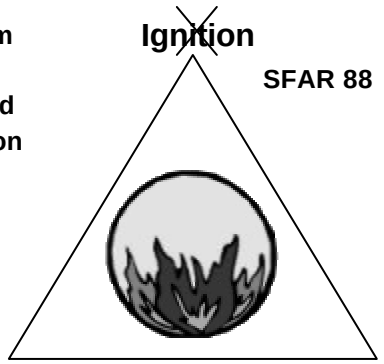
The Fire Triangle

"Prevent fuel system accidents through practical ignition and flammability reduction solutions"



Flammability Reduction System

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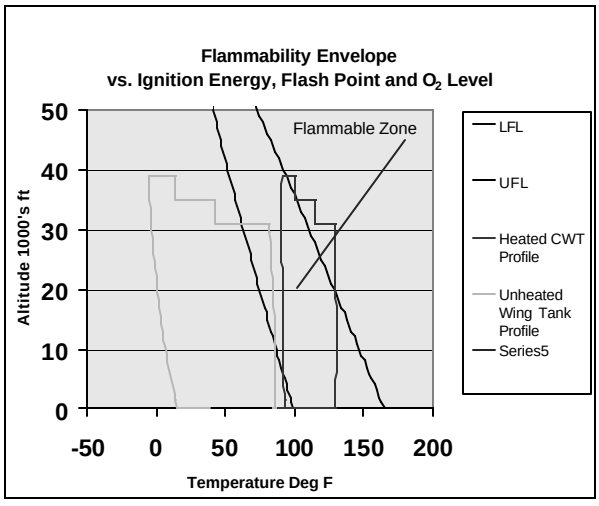
Flammability Envelope

1 Joule Spark, 21% Oxygen, 110^0 F Flash Point



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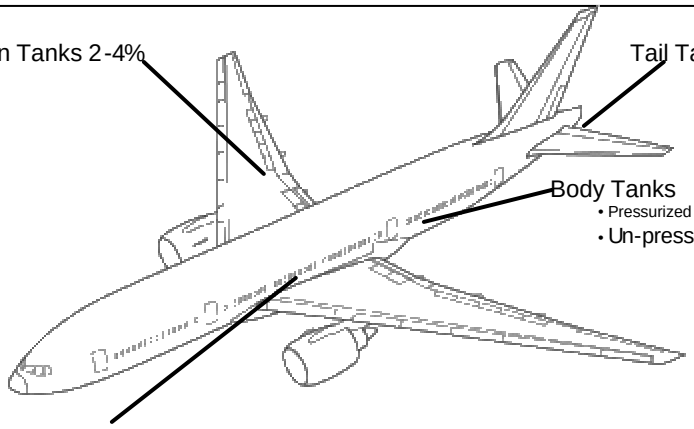
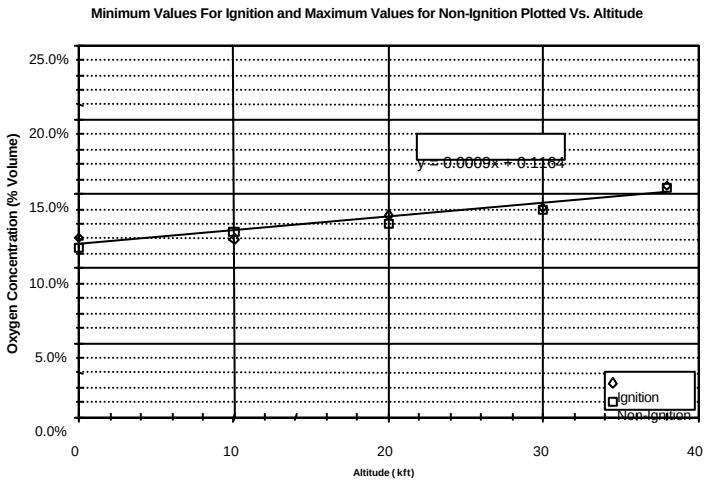
Fuel Tank Flammability Exposure



Heated Center Wing Tank 15-30%

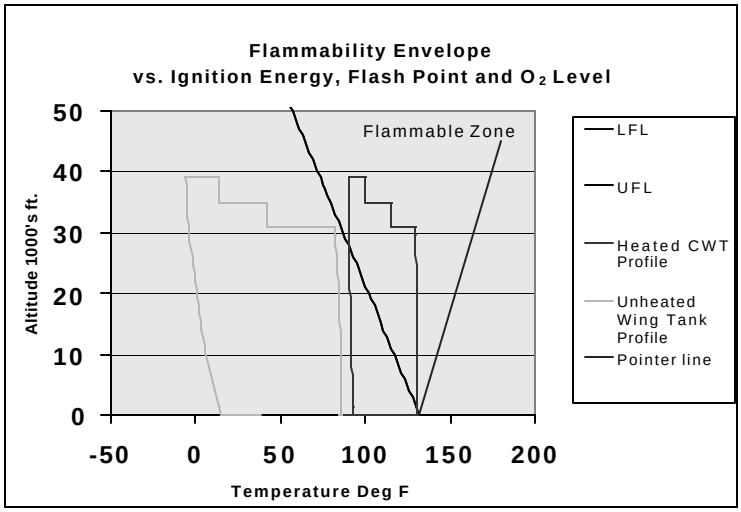
Un-heated Center Wing Tanks 4-7%

O2 Limit for Inerting System



Flammability Envelope

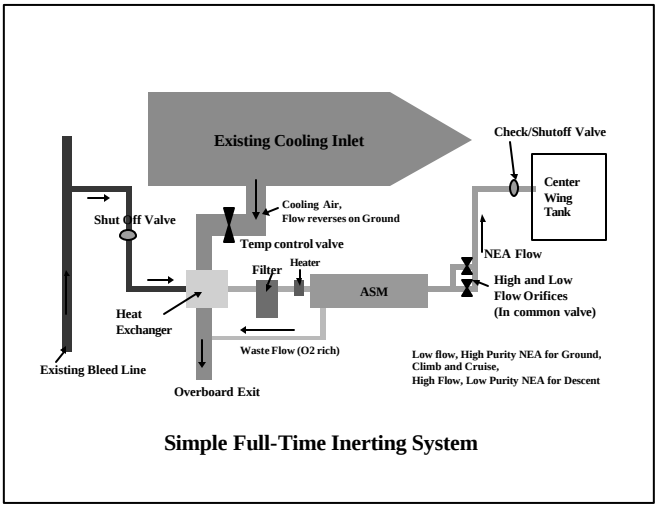
1 Joule Spark, 12% Oxygen, 110^0 F Flash Point



Inerting "Enablers"

- **9-10% O_2 not necessary for establishing "Non-Flamm"**
  - 12% O_2 for 1-20 Joule energy levels
  - 9% from combat threats
- **Engine bleed "Okay" as pressure source**
  - System compressor not necessary
- **High flamm tanks "targeted " - not <u>all</u> tanks necessary**
- **Single string system Okay**
  - Ignition prevention still necessary - first layer of protection

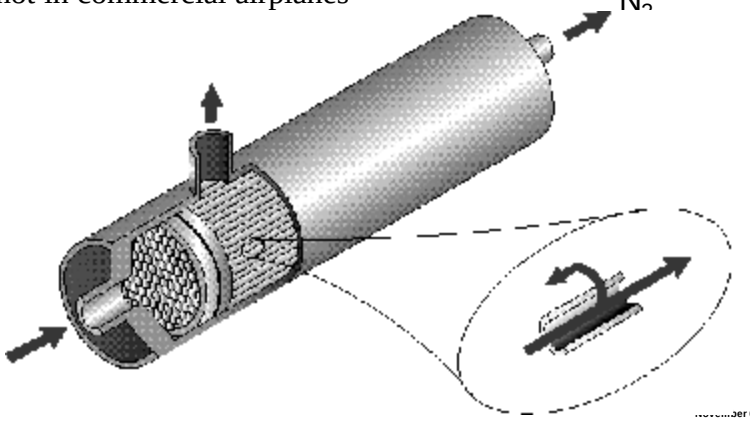
Simple Full - Time Inerting System



Simple Full-Time Inerting System

Air Separation Module Hollow Fiber Membrane Technology

- ASM used in gas generation industry 20+ years, currently not in commercial airplanes



Flammability and Inerting

- **Significant advances in understanding flammability exposure**
  - Provides insight to the vulnerability of TWA 800, and previous accidents
- **FAA research has shown that inerting systems are practical**
  - System validated by Boeing and FAA/Airbus flight testing

Fuel Tank Safety History - Summary

- **Service history and SFAR 88 has shown us that we can't eliminate all ignition sources**
  - Ignition sources for Key Accidents never identified
  - Several previously unidentified ignition sources revealed through SFAR 88 analyses
- **To achieve the desired SFAR 88 safety level, fleet-wide corrective actions requires a combination of:**
  - Actions intended to preclude ignition sources, and
  - Actions to limit the flammability exposure of the fuel tanks
- **Current status of inerting**
  - Boeing is pursuing a production cut in for the inerting system
  - Airbus is actively studying; successful flight test program
  - FAA actions/plans – No decision yet – Though actively encouraging