Fuel Tank Safety Enhancements of Large Transport Airplanes

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Overview

- Brief History
- SFAR 88 Ignition Prevention
- Flammability Reduction
  - Balanced Approach
- Summary
- Implementation Plan

Brief History

- Despite various efforts to reduce the risk of fuel tank explosions through other means, the fundamental safety approach remains <u>preventing the presence of ignition</u>

Brief History

- Since the 1960's, there have been FIVE key accidents involving fuel tank explosions which we now believe <u>call into question</u> this fundamental safety strategy applied to fuel systems of large commercial airplanes

Lightning Strikes – 2 Key Accidents (B707 – 1963, B747 – 1976)


Commercial Airplane Lightning Strike During Takeoff from an Airport in Japan

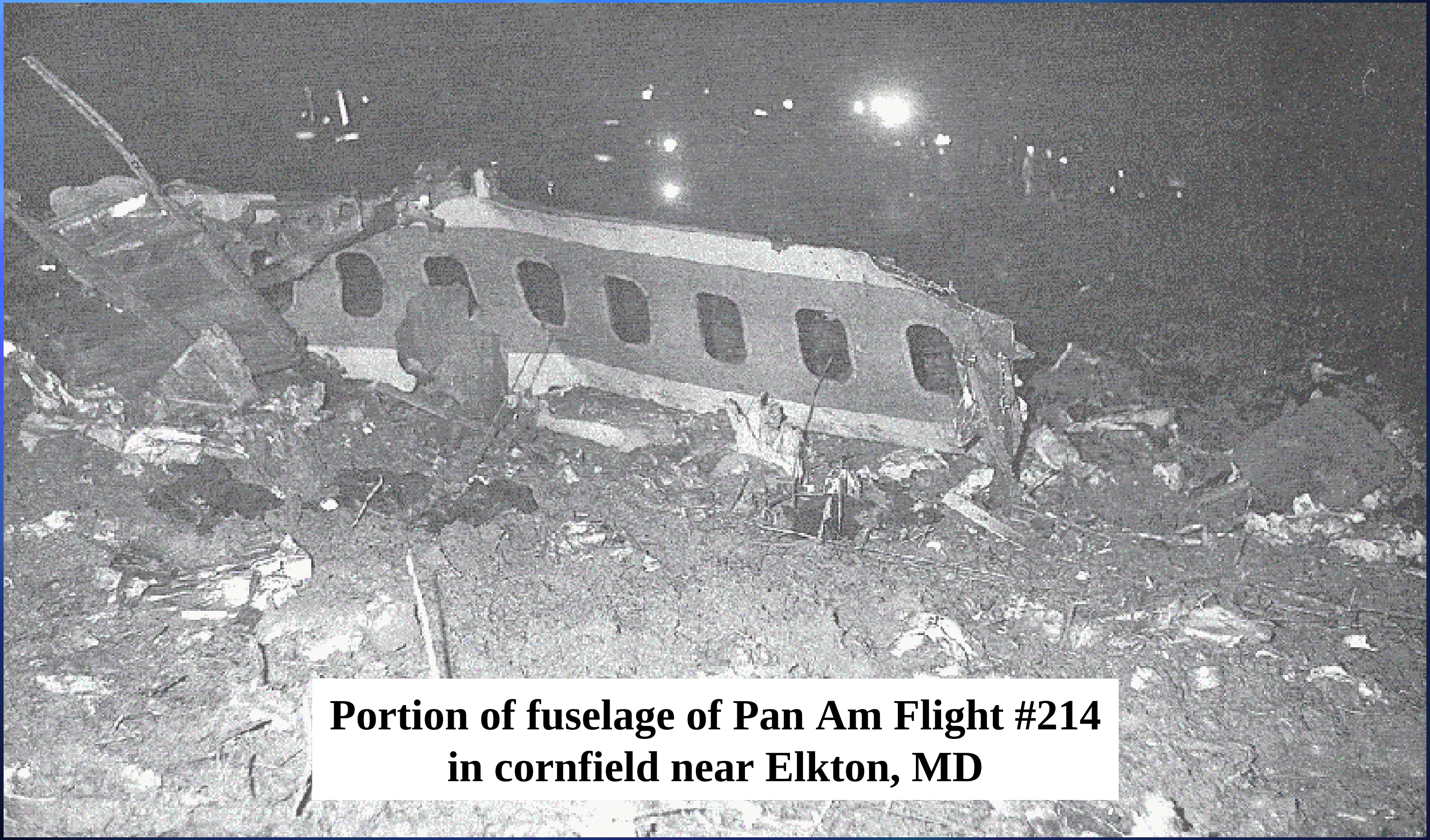
707 Elkton MD (1963)

Pan Am B707-100; N709PA

707 Elkton MD (December 8, 1963)

- While holding at 5,000 feet, left wing struck by lightning
  - Left wing exploded
  - In-flight break-up, 81 killed
- Airplane fueled with mixture of Jet A and JP-4 fuels

707 Elkton MD (1963)



747 Madrid (May 9, 1976)

- Airplane's left wing was struck by lightning while descending to 5000 ft
  - Left wing exploded
  - In-flight break-up, 17 killed
- Airplane fueled with JP-4 fuel

747 Madrid (May 9, 1976)

Madrid, B-747, 5-8104
Left Wing Reconstruction

Non-Lightning Caused Tank Explosions – 3 Key Accidents

B737 – 1090, B747 – 1996, B737 - 2001

Frayed In-Tank Wire

737 Manila (May 11, 1990)

- While pushing back from gate, empty center fuel tank exploded
  - Airplane destroyed by fire
  - 8 killed
- Airplane had been fueled with Jet A fuel

737 Manila (1990)

Philippine Air Lines, B737-300; EI-BZG

747 New York (July 17, 1996)

- While climbing through 13,000 feet, empty center tank exploded
  - In-flight break-up of airplane
  - 230 killed
- Airplane had been fueled with Jet A

747 New York (1996)

TWA (Flight 800), B747-100; N93119

737 Bangkok (March 3, 2001)

- While parked at gate, empty center tank exploded
  - Airplane destroyed by fire
  - 1 flight attendant killed
- Airplane had been fueled with Jet A fuel

737 Bangkok (2001)

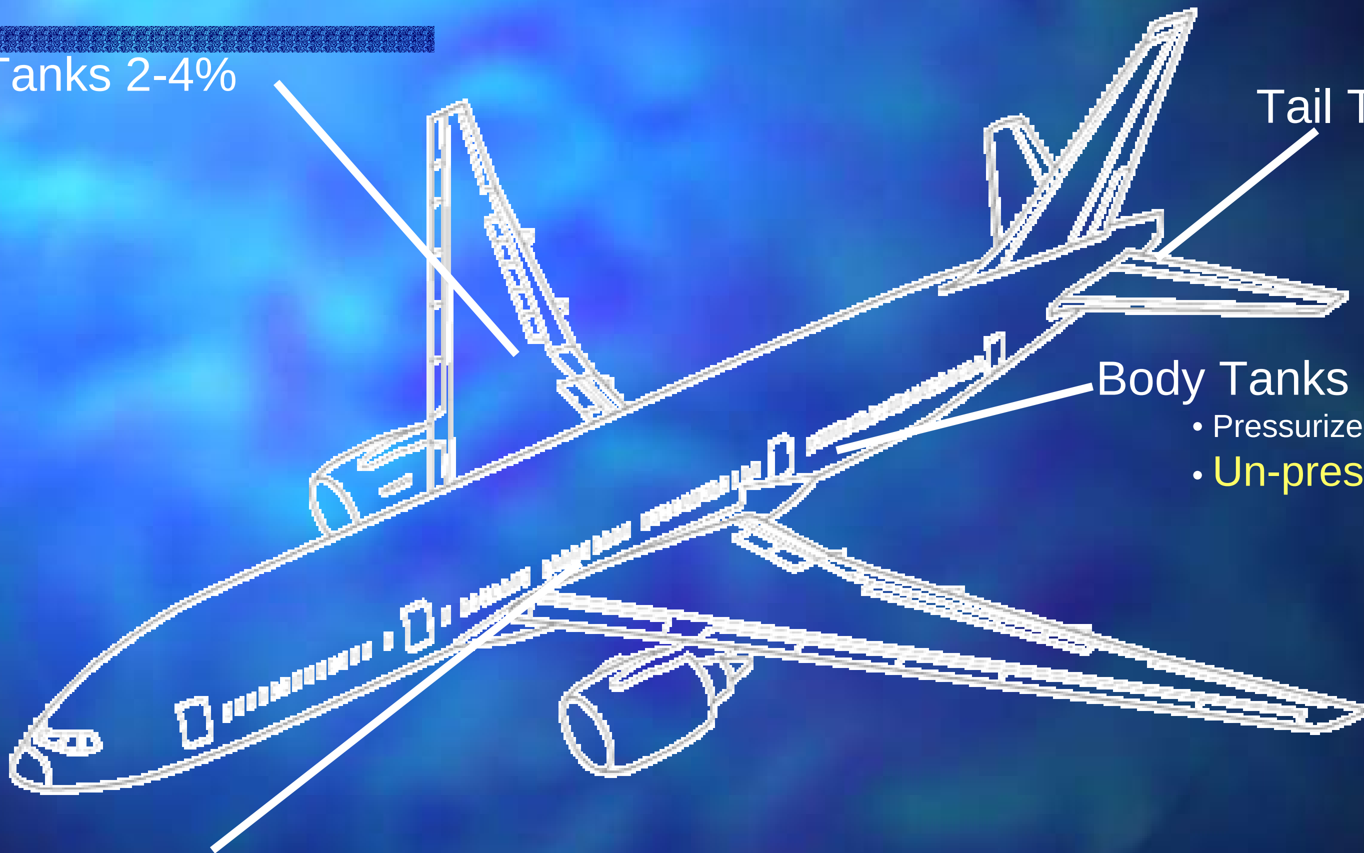
Ignition Sources for Key Accidents Never Identified

- Massive resources expended during Five investigations
  - Elkton 707 - 1963
  - Madrid 747 - 1976
  - Manila 737 - 1990
  - New York 747 - 1996
  - Bangkok 737 - 2001
- Exact source of ignition never determined
  - Corrective actions based on most likely scenarios

Ignition Sources for Key Accidents Never Identified

- All FIVE accidents involved explosions of what are now being referred to as "High Flammability" fuel tanks
  - >7% flammability exposure on a worldwide basis
- Highlights uncertain nature of ignition source prevention strategy
  - Emphasizes need for an independent layer of protection
  - "Balanced Approach" needed

Fuel Tank Flammability Exposure Typical



Center Wing Tank with Adjacent Pack Bays 15-30%,

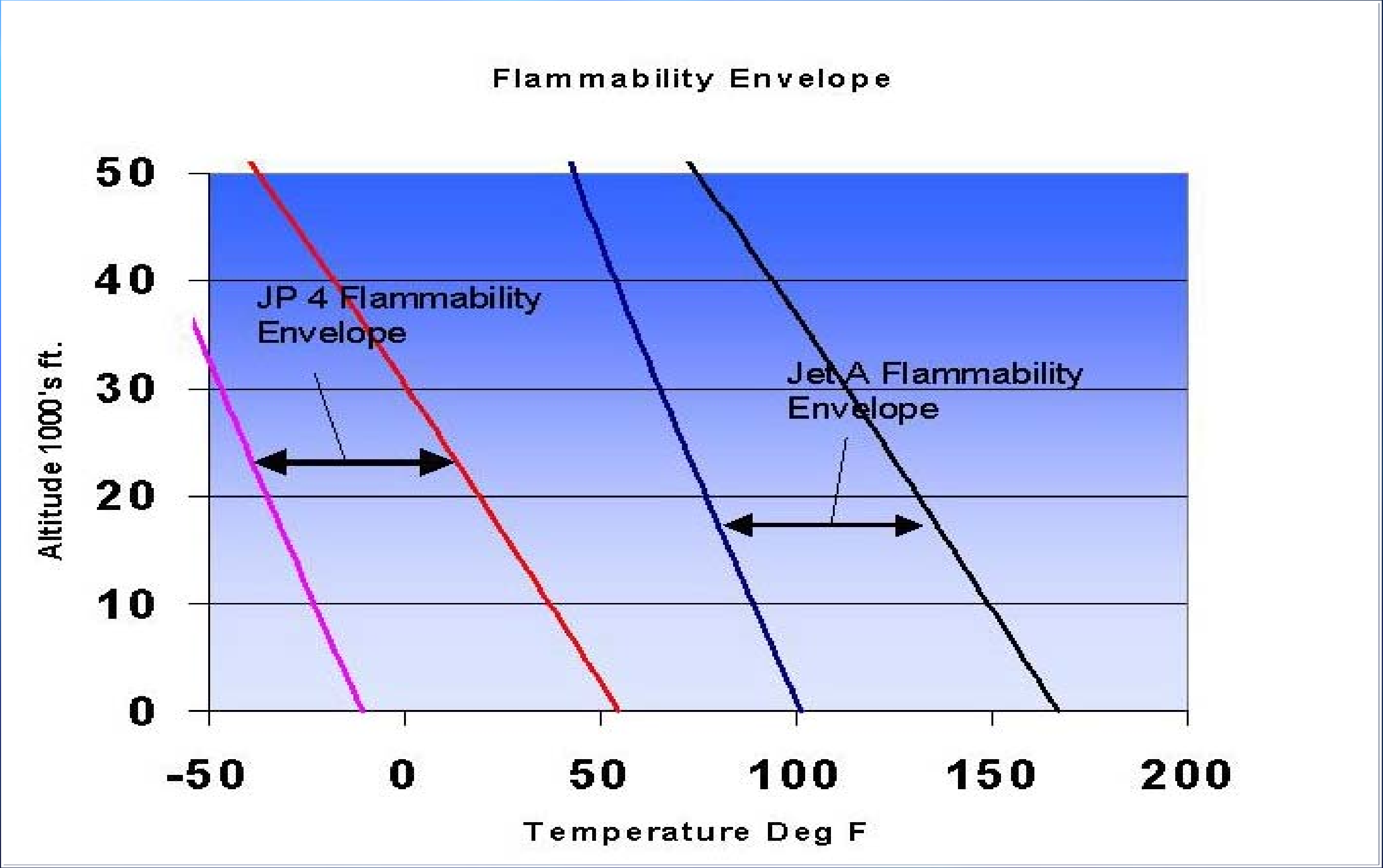
(Boeing, Airbus)

Center Wing Tanks without Pack Bays 4-7%

Fuel Types and Tank Locations have Very Different Service Histories

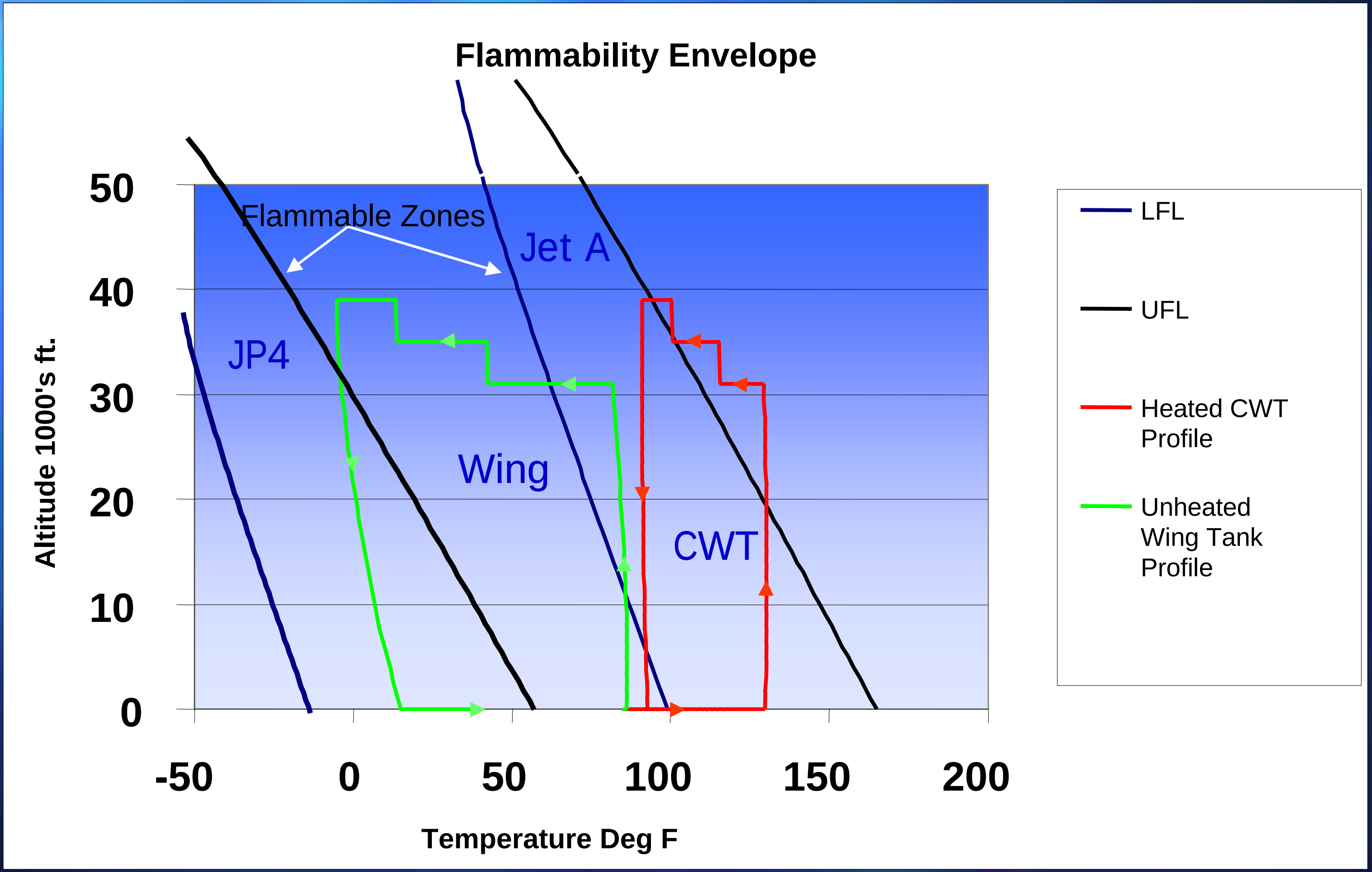
- A wing tank fueled with JP-4 has approximately the same world wide exposure to flammability as an empty heated center tank with Jet A.
- In general, wing tanks and <u>unheated</u> center wing tanks fueled with Jet A have exhibited an acceptable service history.
- Wing tanks fueled with JP-4 and empty heated center tanks fueled with Jet A have <u>not</u> had an acceptable service history.

Comparison of Flammability Envelopes JP 4 and Jet A



Flammability Envelope

1 Joule Spark, Conventional Aluminum Transport, Air Conditioning Systems Located Underneath Center Wing Tank (CWT)



Brief History - Summary

- TWA 800 brought a realization that some tanks could be flammable for a large portion of their operational time.
- U.S. NTSB “Most Wanted List”: Flammability Reduction
  - *”preclude the operation of transport category airplanes with explosive fuel-air mixtures in the fuel tank”*
  - TWA 800 recommendation

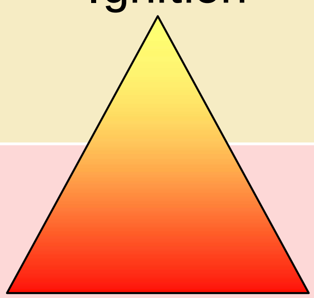
SFAR 88 Ignition Prevention

- Efforts to resolve TWA 800 led the FAA to conclude that:
  1. Many current airplanes had similar short comings in their ignition prevention approaches
  2. An additional independent layer of protection is needed to “Back-Up” the ignition prevention strategy

SFAR 88 Ignition Prevention

- In response to these findings, the FAA issued Special Federal Aviation Regulation No. 88 in June of 2001.
  - Re-examine existing commercial fleet related to ignition prevention
  - Implement safety enhancements related to the findings of these examinations

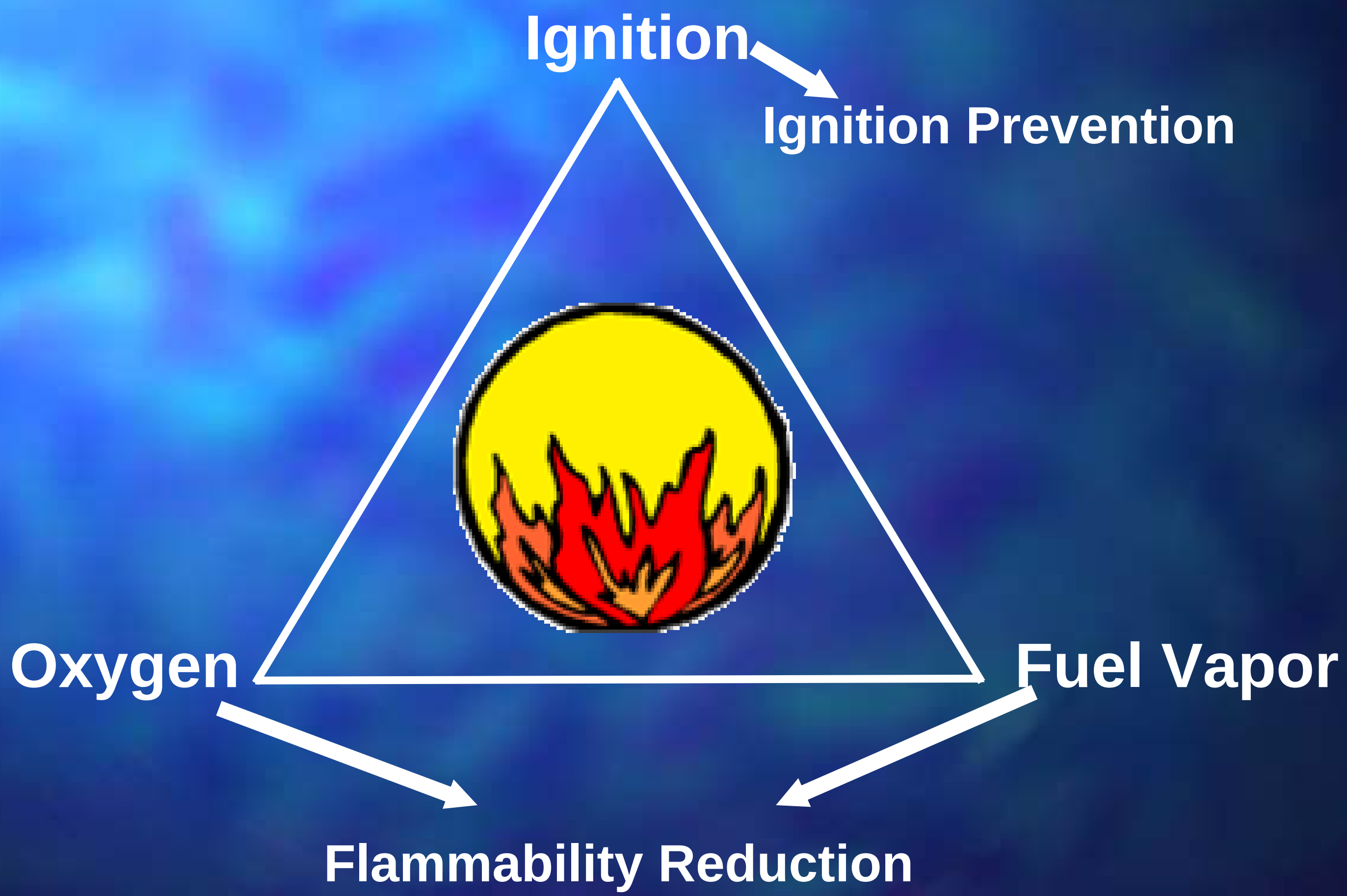
Fuel Tank Safety History
(FIVE Key Accidents)

	1960's-1990	1990-1999	2000-Present
5 Key Accidents	**707 Elkton MD** **747 Madrid** **(Lighting)**	**737 Manila** **747 New York** **(Not Lighting)**	**737 Bangkok** **(Not Lighting)**
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.**	**FAA Simplified system developed. Recognized that inerting is practical, and may be needed to achieve balanced solution**

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
  - Number of previously unknown failures found
  - Continuing threat from still unknown failures
- Unrealistic to expect we can <u>eliminate all ignition sources</u>
- Must consider flammability reduction of high flammability tanks as an integral part of system safety

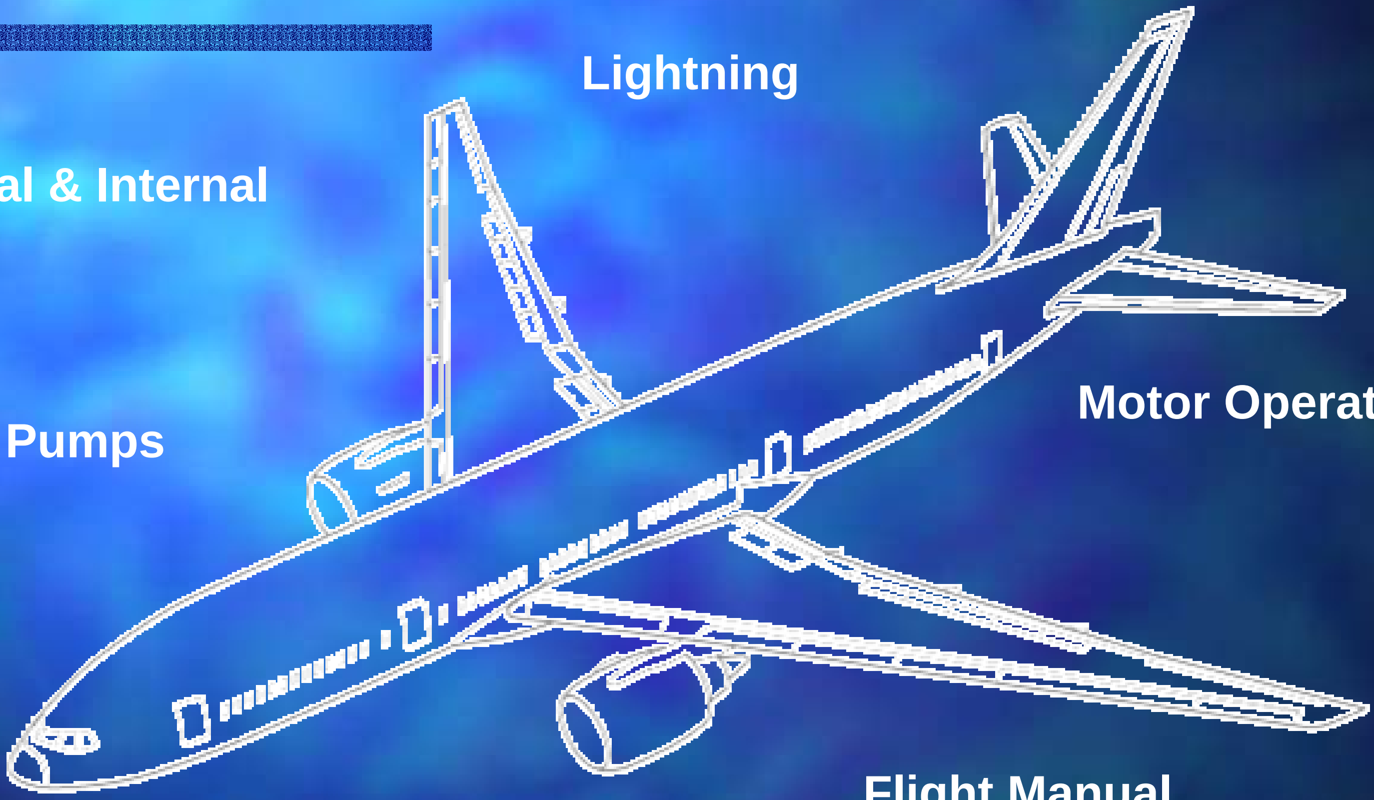
The Fire Triangle



SFAR 88 Findings

Lightning

External & Internal Wiring



Fuel Pumps

Motor Operated Valves

Flight Manual Procedures

FQIS

Recurring Maintenance

Service Experience


ARC TO LOWER WING SKIN


ARC THROUGH PUMP HOUSING


ARC THROUGH CONDUIT


Fuel Pump Internal
Damage/Overheat

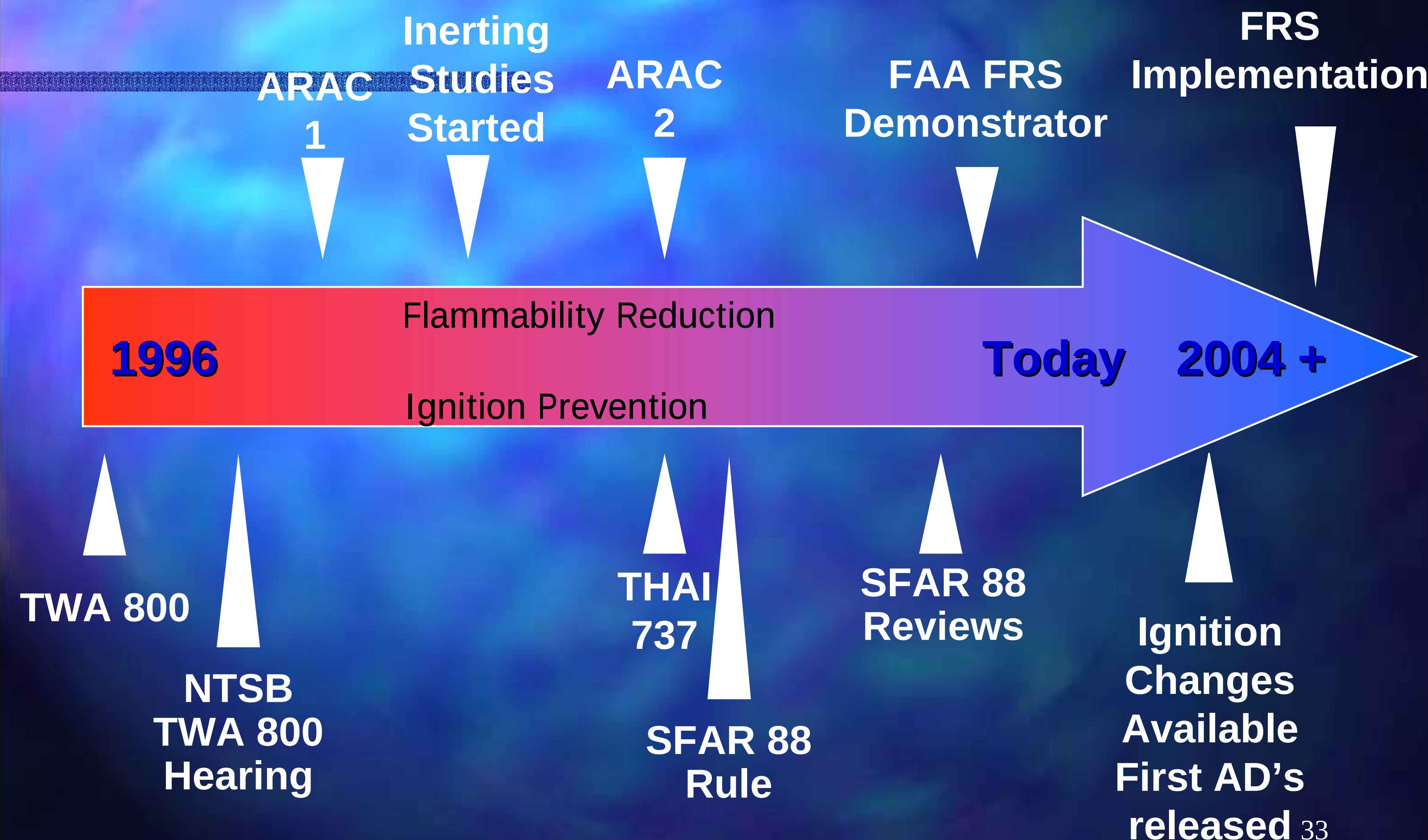
Flammability Reduction

- In 1998 and again in 2001, the FAA tasked the U.S. Aviation Rulemaking and Advisory Committee (ARAC) to explore ways to reduce flammability in fuel tank systems
  - Direct response to TWA 800

Flammability Reduction

- While both ARAC committees concluded that flammability reduction efforts would be valuable—existing technology was considered not practical for commercial aviation
  - Weight – too heavy
  - Cost – too expensive
  - Reliability – too low
- FAA continued technology R&D

Fuel Tank Safety – Recent History

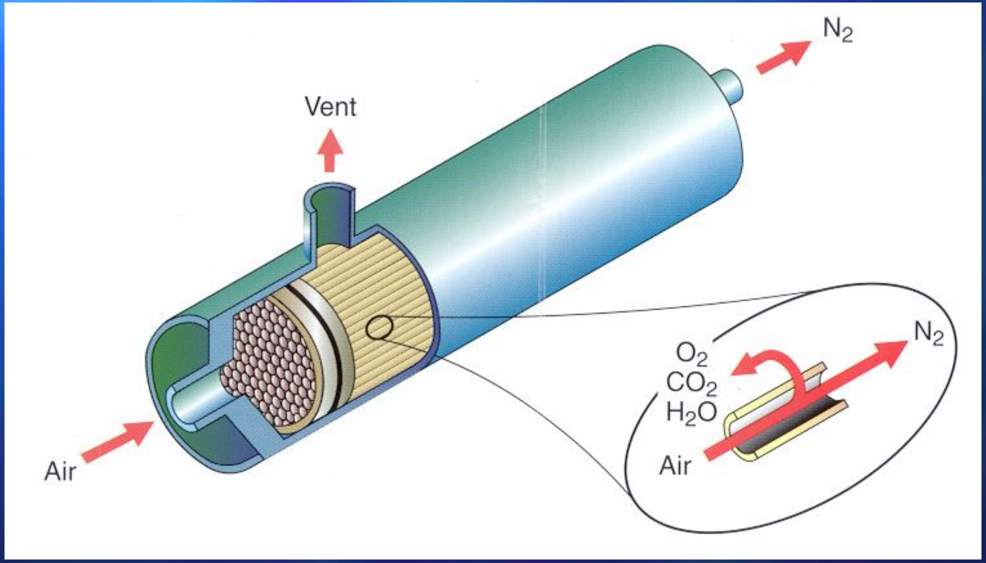


Flammability Reduction

- Main "Enablers" which made technology "Breakthrough" possible :
  1. Membrane performance at lower ΔP
  2. O_2 Concentration (9% vs. 12%)
  3. Use of simple system OK (single string)
- FAA focused testing in these areas

Breakthrough - Performance at lower ΔP

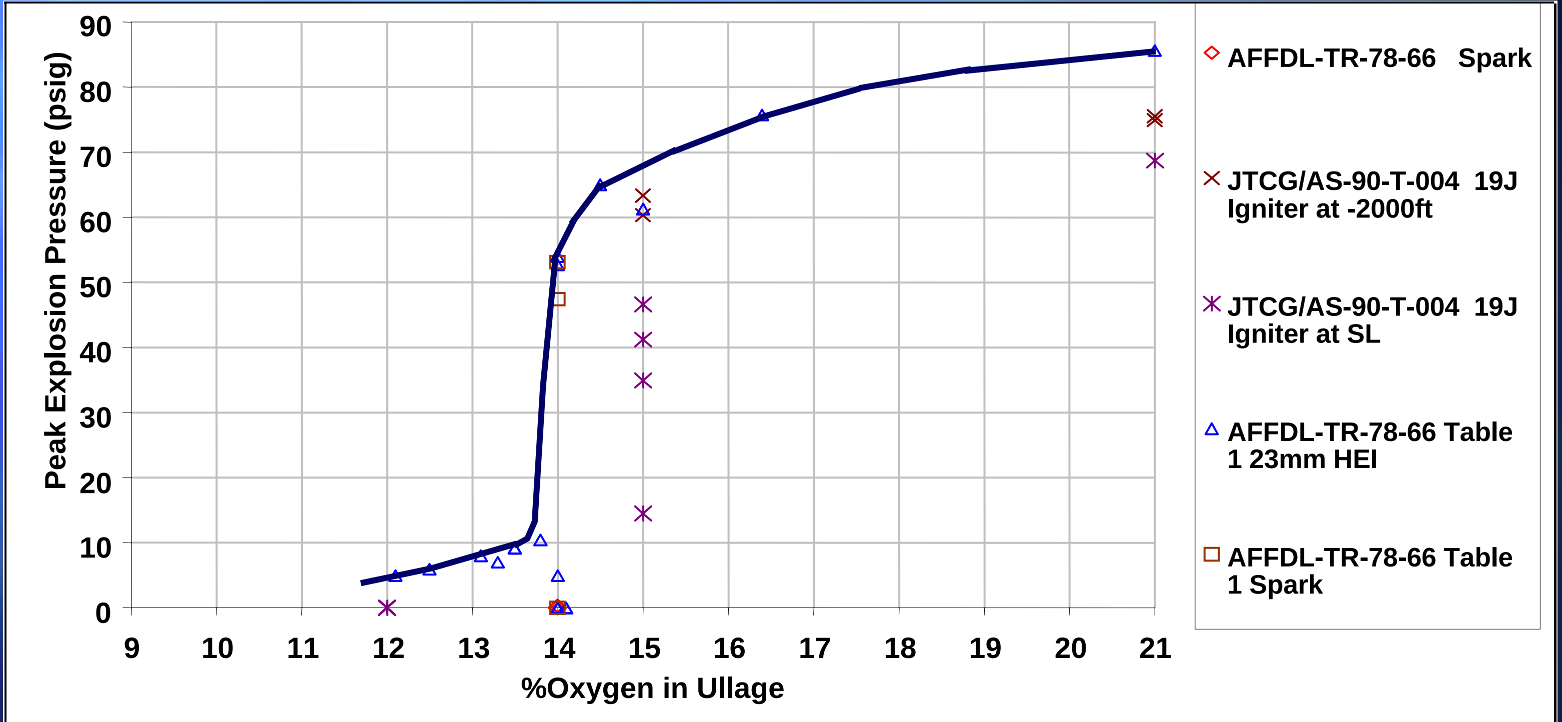
- Performance analysis and subsequent testing showed Air Separation Module technology would work at low pressures, 10 to 40 psig versus 50 to 100 psig used commercially



Breakthrough - O_2 Concentration

- Testing demonstrated that higher O_2 levels provided adequate protection
  - Adequate inerting obtained on the ground with approximately 12% O_2
    - Previous 9% O_2 levels linked to military combat threats
  - Less Nitrogen needed at altitude
    - 15.5% Oxygen adequate at 40000ft

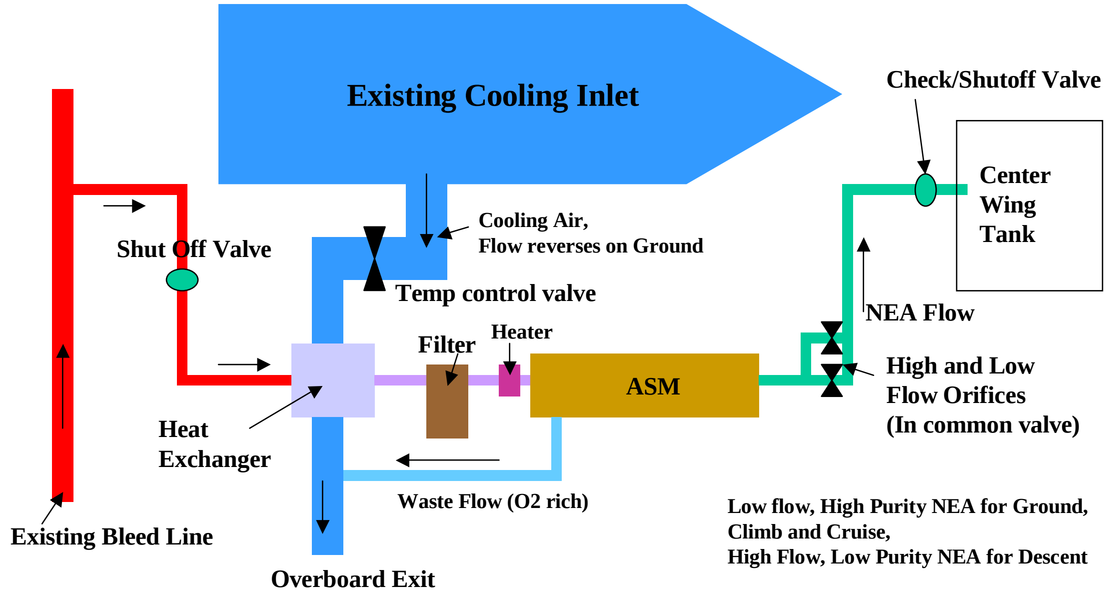
Nitrogen Inerting Test Results



Sea-Level Nitrogen Inerting Test Results

Source:Boeing Literature Review, References quoted on Chart

Breakthrough - Simple System



FAA Simple Inerting System

FAA Inerting System on 747 SP

FAA Inerting Installation on A320

Flight Testing Accomplished

- FAA R&D Testing (747SP, 737)
- Boeing 747-400 Flight Test
  - Engineering and Certification Data
- FAA/Airbus A320 Flight Test
  - FAA concept inerting system installed in A320 cargo compartment
  - Airbus gained familiarity with design concept and system performance
- Boeing 737 & 747 Certification Testing
- FAA/NASA 747 Flight Test
  - Initial flights performed in December 2003

Balanced Approach to Fuel Tank Safety

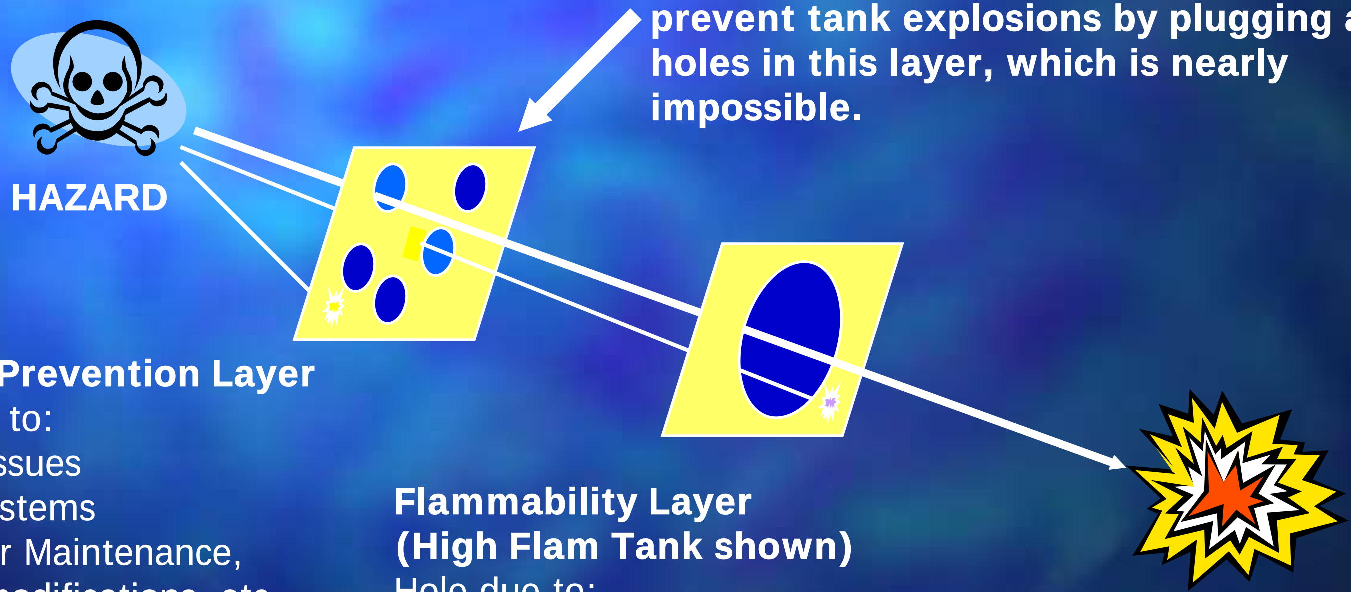
- FAA R&D has shown that Inerting is practical
- SFAR 88 addressed ignition prevention only
  - Inerting was not seen as practical at the time SFAR 88 was issued
- Balanced Approach - <u>Now Possible</u>
  - Combine ignition prevention & flammability reduction into a single solution

Ignition Prevention Alone

(Not Balanced Approach)

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

For over 40 years, we have been trying to prevent tank explosions by plugging all the holes in this layer, which is nearly impossible.

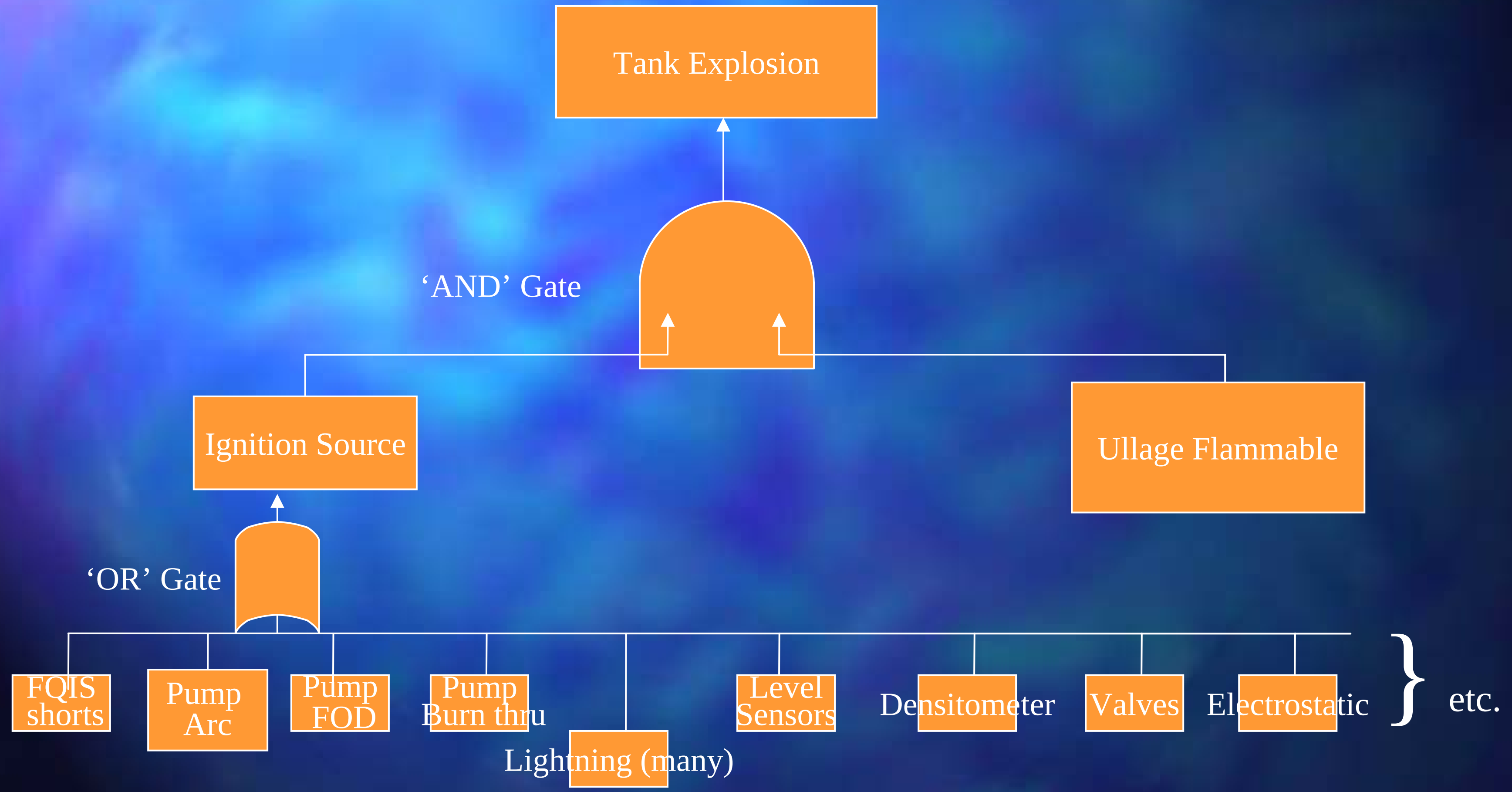


Ignition Prevention Layer
Holes due to:
- Design issues
- Aging systems
- Improper Maintenance, Rework, modifications, etc
-Unknown unknowns

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

Fault Tree: Current Fuel Tank System

Unbalanced Fault Tree



Balanced Approach with Flammability Reduction

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

ACCIDENT PREVENTED!

Reduced Flammability NPRM

- On Feb 17th 2004,

  The FAA Administrator, Marion C.Blakey, announced that the FAA was proceeding with a Notice of Proposed Rule Making (NPRM) to require reduction of flammability in high flammability tanks of U.S. commercial jet transports

Summary

- Flammability exposure is a major factor in fuel tank explosion risk
  - Simple Inerting System is now practical
- Ignition Prevention still major protection strategy
- <u>Balanced Approach</u> of Ignition Prevention and Reduced Flammability can provide a substantial improvement in fuel tank safety
- FAA is moving forward to implement a reduced flammability strategy to complement the ignition prevention strategy

Implementation Plans

- Propose production “cut-in” of flammability reduction means (FRM) on high flammability tanks (Boeing & Airbus CWTs)
- Propose retrofit of FRM on existing fleet with high flammability tanks (Boeing and Airbus CWTs)
- Propose revision to FAR 25 to include flammability limits

Federal Aviation Administration

Thank You for Your Attention