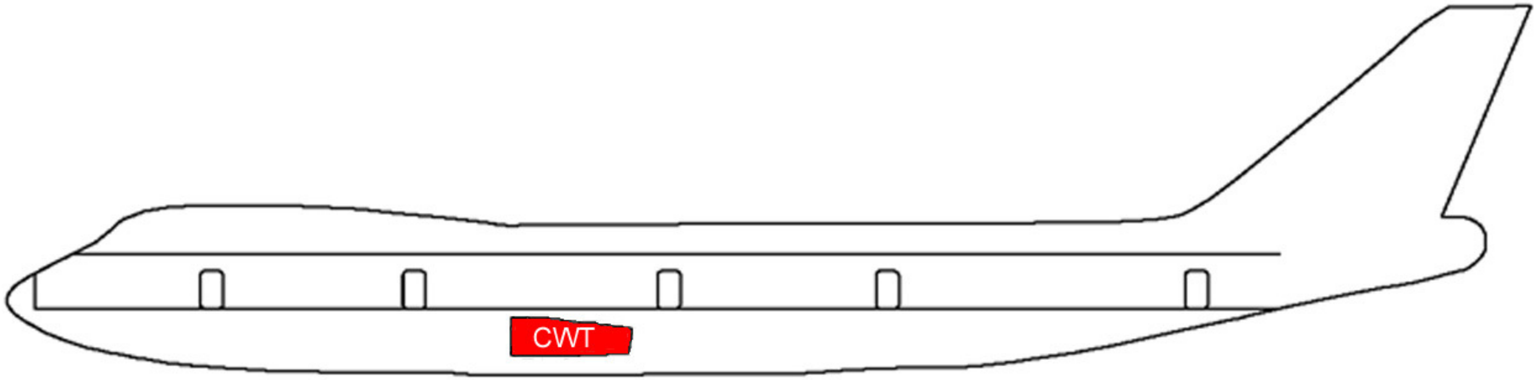

REALISTIC PROBABILITY ESTIMATES FOR DESTRUCTIVE OVERPRESSURE EVENTS IN HEATED CENTER WING TANKS OF COMMERCIAL JET AIRCRAFT

Norman Alvares, Fire Science Applications Inc., 751 Laurel St, PMB 431, San Carlos, CA 94070

Howard Lambert, Lawrence Livermore National Laboratory, Livermore, CA 94550

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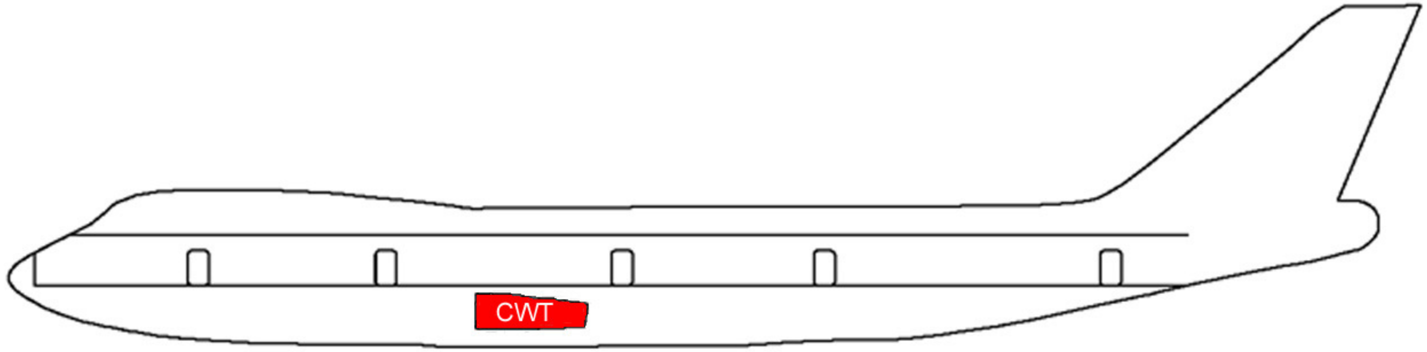
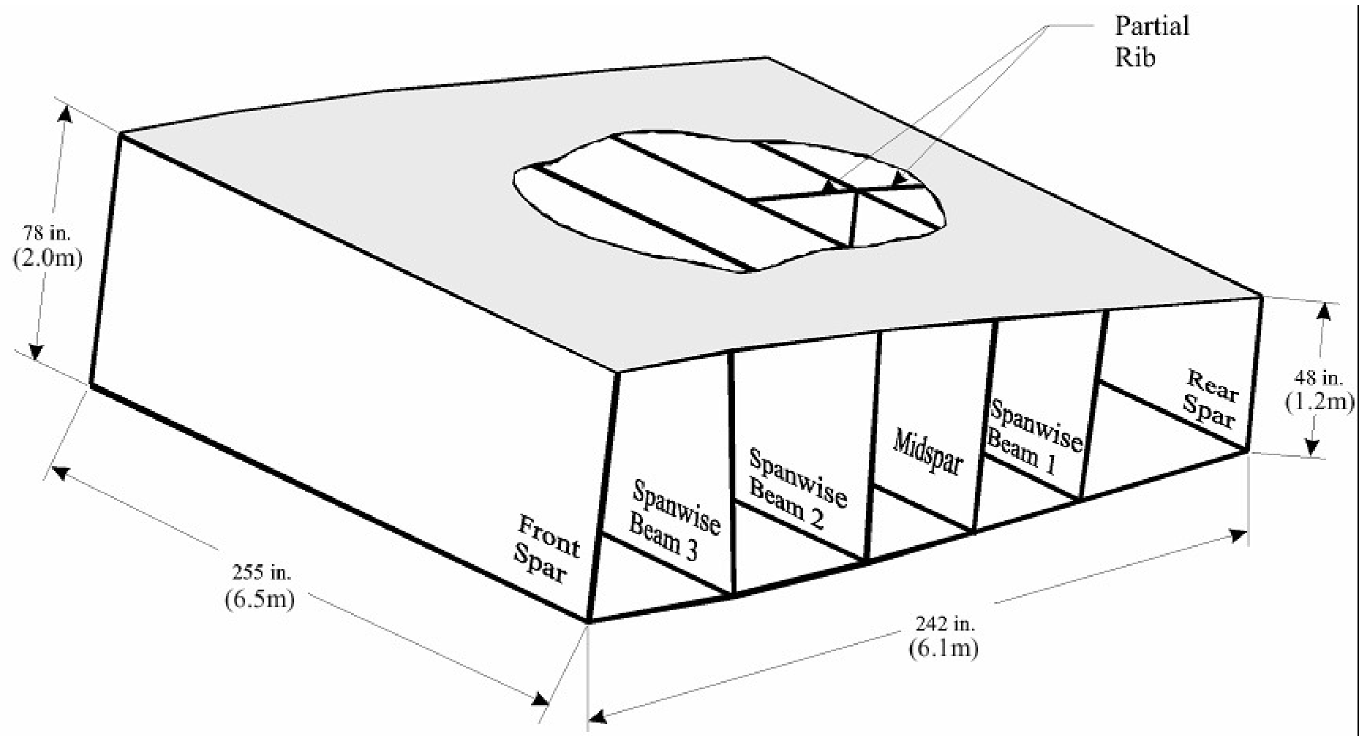
Heated Center Wing Tank





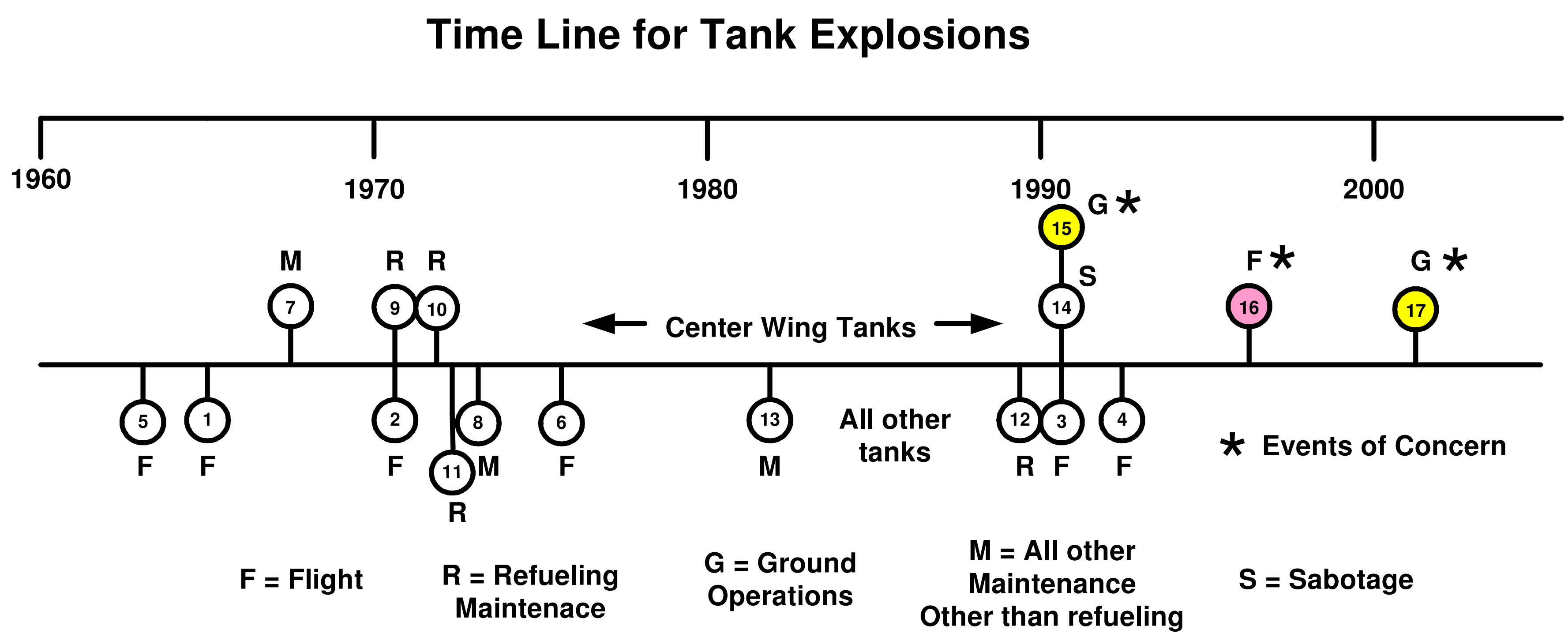
Outline of Talk

- What are “Heated” Center Wing Tanks (HCWTs) on commerical aircraft?
- How many incidents involved explosions of HCWTs?
- What is the best estimate of the explosion rate of commercial aircraft with HCWTs? Federal Aviation Administration FAA’s published in the Notice of Proposed Rule Making (NPRM) states 1 in 60 million flight hours as proposed accident rate.
- How effective are the Airworthiness Directives (ADs) issued by the FAA in reducing ignition source probabilities and hence explosion rates?
- Can FAA’s system design standard [of no more than one catastrophic loss in one billion hours (1 in 1000 million) flown] be achieved with these ADs?
- Are fuel tank atmosphere inerting devices in in-service commercial aircraft justified from a cost benefit analysis?

Background

- Three fuel tank explosions occurred in HCWTs.
- Our statistical analysis, relating the occurrence of both on-ground and in-flight HCWT explosion rate of the cumulative flight hours, gives the best estimate of explosion rate of **140 million flight hours**.
- Since TWA 800, the FAA has significantly increased the rate at which it has mandated airworthiness directives (ADs) directed at elimination of ignition sources in CWTs.
- This paper addresses effectiveness of reducing HCWT ignition source probability [when Special Federal Aviation Regulation (SFAR) 88 “Fuel Tank System Fault Tolerance Evaluation Requirements” are in effect].

Time Line for 17 tank explosions



*May 11, 1990, Manila, Philippines, Philippines Airlines Boeing 737 (on-ground)

*July 17, 1996, New York, TWA Boeing 747-100 (in-flight)

*March 3, 2001, Bangkok, Thailand, Thai Airlines Boeing 737 (on-ground)

Most likely cause of on-ground incidents is dry running fuel pump.

Common Factors HCWT explosions

- Hot day, long gate hold, air conditioning packs on and minimal fuel in the CWT being heated.
- On-ground incidents most likely caused by dry running fuel pumps.
- Cause of TWA explosion is not determined; but one potential cause is high voltage short to the low voltage system for the Fuel Quantity Indication System (FQIS) — scavenge pump not found, hence cause of explosion not conclusive.

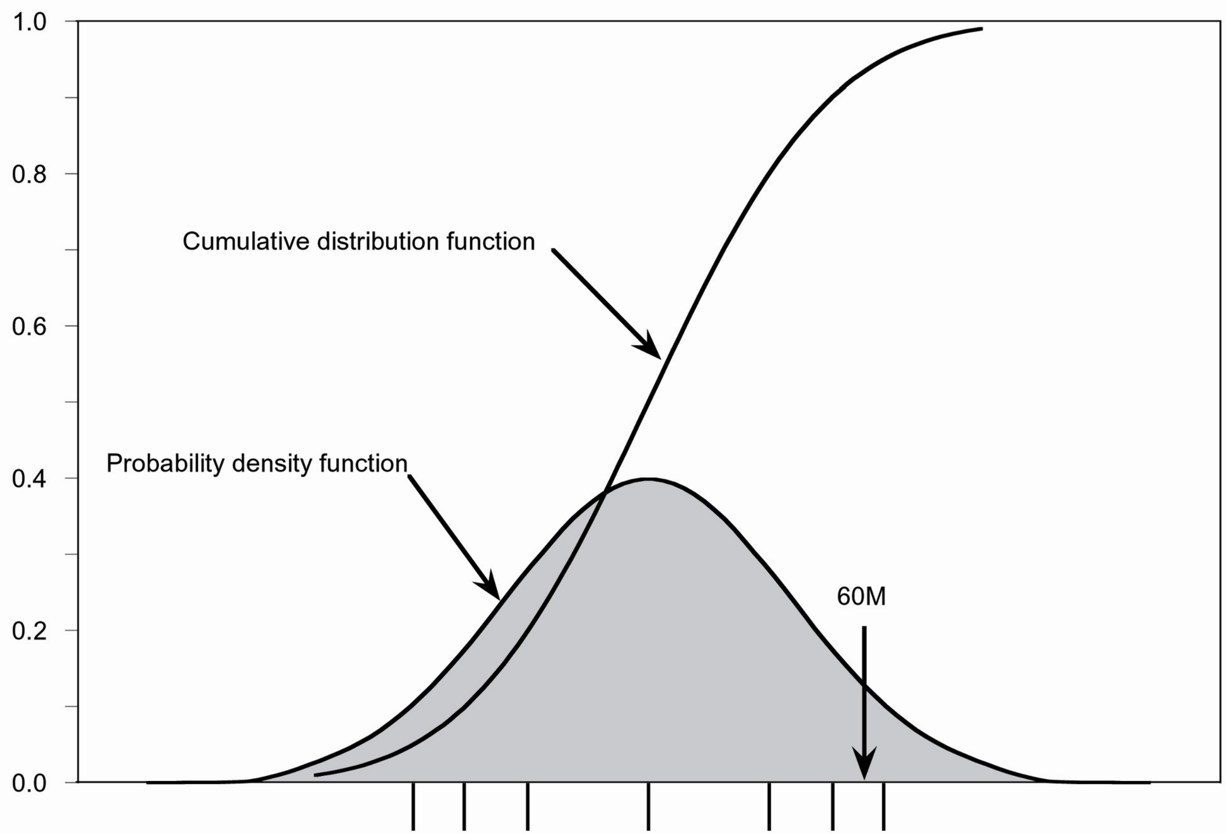
Our estimate of the mean explosion rate without SFAR 88 implementation

- 420 Million flight hours (MFH) total for aircraft with HCWTs.
- Divided by 3 HCWT explosions, this gives 1 in 140 MFH flown; (1 in 420 MFH if TWA 800 only).
- Notice of Proposed Rule Making Estimate (NPRM) is 60 million flight hours which means on the average that 7 in-flight explosions would have already occurred.
- 7% chance that the true time between explosions is less than 60 million flight hours (a statistical outlier).
- 93% chance that the estimate is greater than 60 million flight-hours.

Confidence levels for HCWT explosion rate

$$\theta = \frac{x + \frac{1}{2}z^2 + z\sqrt{\frac{x(n-x)}{n} + \frac{1}{4}z^2}}{n + z^2}$$

where x =3 the number of accidents, n is the accumulated flight-hours and z is the standard normal value that corresponds to a certain confidence level for θ

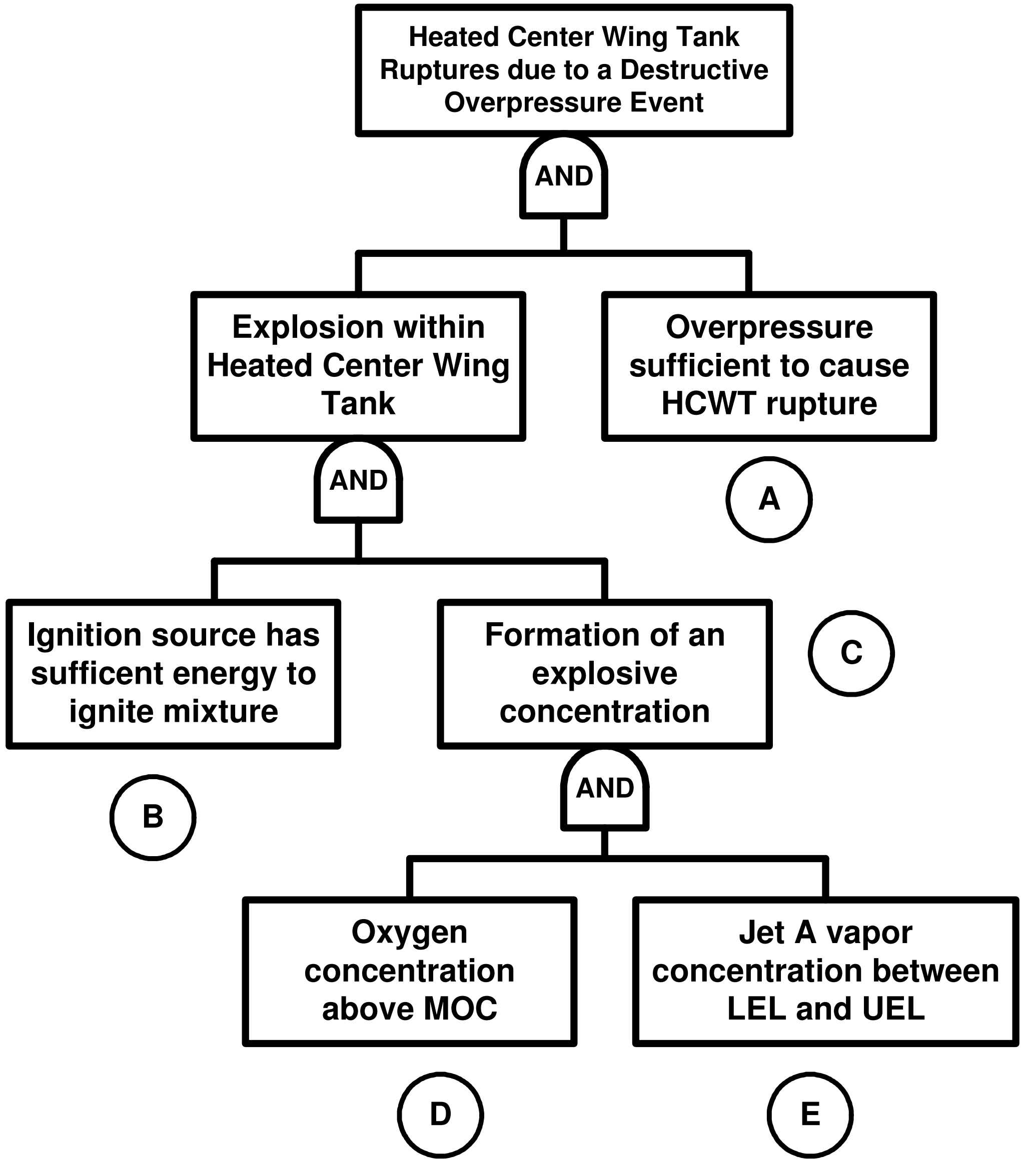


Confidence level	5%	10%	20%	50%	80%	90%	95%
ARAC Accident rate/100M hrs	0.286	0.347	0.442	0.716	1.16	1.48	1.79
ARAC Accident rate mean time between accidents in million hours	350	288	226	140	86.3	67.7	55.8

FAA tasked Sandia with developing a quantitative assessment to:

- Evaluate the overall and individual effectiveness of ADs associated with SFAR 88;
- Estimate residual risks after applying these ADs;
- Compare and evaluate independent safety assessment efforts of original equipment manufacturers (OEMs).

Generic Fault Tree for HCWT explosions



Ignition Sources listed by Sandia

(1) Fuel pumps

(2) Fuel quantity indication system (FQIS)

(3) Tubing/piping valve-solenoids

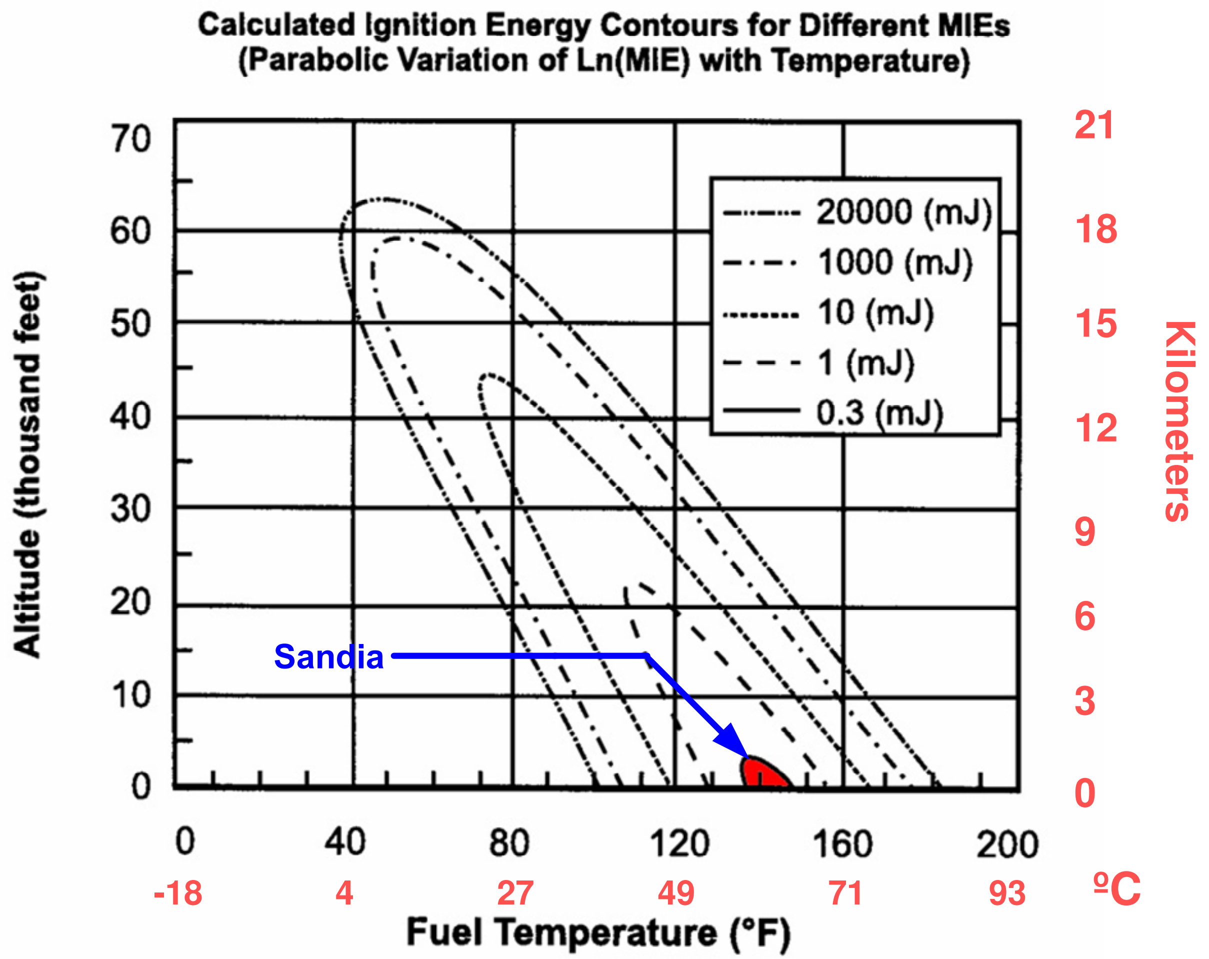
(4) Float switch/wires

(5) External threats.

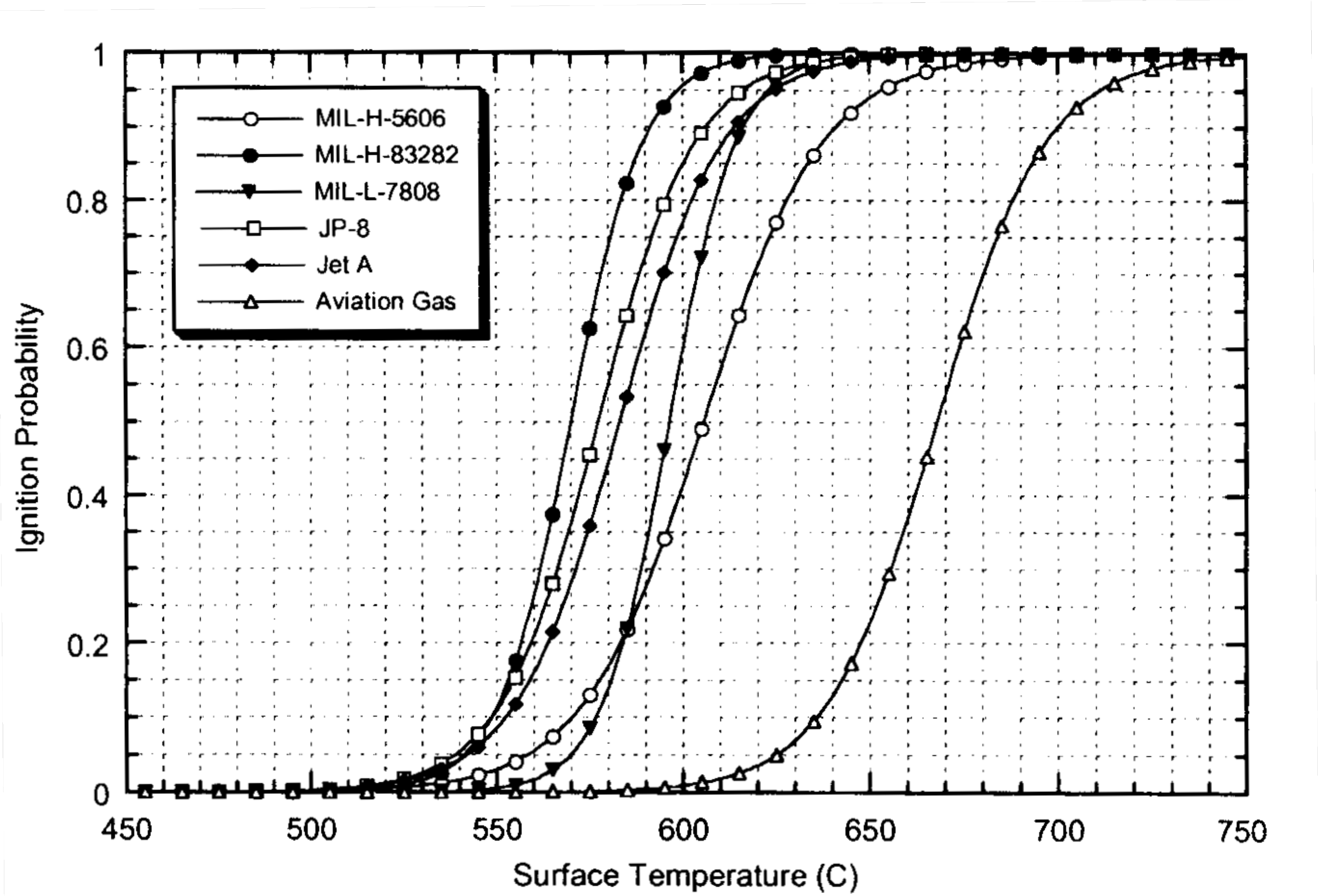
Assumptions in Sandia's Analysis

- Fuel vapor at the appropriate fuel/air ratio existed at all times.
- The surface of a HCWT component at the (threshold) temperature of 450° F (232° C) or a discharge arc of 0.2 mJ existed in the fuel tank atmosphere.
- Sandia recognized that these conditions are worst case.
- **Sandia concluded that a factor of 10 reduction in ignition source probability could be achieved by SFAR 88 implementation.**

Constant Ignition Energy Contours -- Altitude versus Fuel Temperature Plot



Ignition Probability as a Function of Surface Temperature for Aviation Fluids



Conclusions

- Best estimate for HCWT explosion rate without SFAR 88 implementation is 1:140 million flight hours.
- NPRM estimate of 1:60 million flight hours is not realistic.
- We agree with Sandia analysis of a factor of 10 reduction in ignition source probability with SFAR 88 implementation.
- Current AD's adequately address dry running fuel pump – interlocks to shut off pumps.
- We believe Sandia's analysis is conservative.
- FAA risk criteria of 1 explosion in 1000 MFH is achieved with SFAR88 implementation and negates the need, expense and potential unknown risk factors for retrofitting fuel tank atmosphere inerting devices in operating commercial aircraft.

Matrix for 17 explosions

YEAR	EVENT	AIRCRAFT	JP 4	JET A, A1	AIR-BORNE	ON GROUND	SABO-TAGE	CWT	STRUCT. FAIL B/4 FIRE	REFUEL GROUND OPS	MAIN-TENCE	LIGHT-NING	FUEL PUMPS HUMAN FACT	TAKEOFF	LAND-ING	ALTI-TUDE 10K FEET	IGN HOT SURFACE	STATIC DIS-CHARGE	ELEC-TRIC SPARK
1960																			
	5	707	X		X							X				X			
	1	707		X	X			X	X					X					
	7	727		X		X					X							X	
1970																			
	2	DC 8	X		X				X					X					
	9	727		X		X				X								X	XX
	10	727		X		X				X								X	XX
	11	DC 8	X			X				X	X							X	XX
	8	DC 8	X			X					X								X
	6	747	X		X							X				X			
1980																			
	13	DC 9	X			X							X				X		XX
	12	BEECH 400	X			X				X									X
1990																			
	3	747		X		X		X							X		X		XX
	14	727		X	X		X		X							X			
	15	737		X		X		X		X			X				X		
	16	747		X	X			X					X	X?			X		XX
	4	707		X	X			X	X					X					
2000																			
	17	737		X		X		X		X			X				X		XX
TOTAL	17 EVENTS		7	10	7	10	1	6	4	6	3	2	4	4	1	3	5	4	9

SUMMARY OF MATRIX FOR THE 17 EVENTS

- Eight events occurred in flight and ten events occurred on the ground
- Four events involved structural failure before ignition
- Two events occurred as a result of lightning strikes
- Four events occurred while un-ported fuel pumps were operating, three of which were HCWTs and involved potential human factors issues
- Seven events involved JP 4 or JP 4 - Jet A mixtures
- Ten events involved Jet A or Jet A1
- One event involved sabotage
- Six events occurred during ground base operations and/or fueling
- Three events occurred during maintenance
- None of the events JP 4 post 1990
- No events were attributed to static discharge post 1980
- One of the events occurred in a seven-passenger business jet during refueling.
- But for two events that involved charge separation during fueling, the two events evidencing lightning strikes and the event of sabotage, the initiating events have not been positively identified. However, fuel pumps appear to have the highest probability in cases where they were operating in fuel tanks containing only unusable fuel inventory.

SFAR 88 Effectiveness

- Since 1996, the FAA has significantly increased the rate at which it has promoted airworthiness directives (ADs) directed at elimination of ignition sources in CWTs. This effort includes the adoption, in 2001, of Special Federal Aviation Regulation 88 of 14 CFR part 121 (SFAR 88 “Fuel Tank System Fault Tolerance Evaluation Requirements”)
- This paper addresses SFAR 88 effectiveness in reducing HCWT ignition source probability.

Sandia's Assessment of SFAR 88 Effectiveness

The FAA commissioned Sandia National Laboratories to determine the effectiveness of airworthiness directives (ADs) under SFAR 88 that have been applied to mitigate ignition sources. This effort entailed consideration of:

1) fuel tank explosion history;

2) previous attempts at correcting ignition sources;

3) fuel tank flammability characteristics;

4) industry safety assessments and ADs that were required by SFAR 88 to identify failures and malfunctions that could create ignition sources;

5) fleet statistics and continued increase in exposure; and

6) system safety/defense in-depth concepts.