AEM 617

Fuel Systems

Aircraft Fuel Systems

Avgas: Aviation Gasoline (see ASTM D910-11) Piston Engines

The most common is 100LL ("One hundred low lead" or "hundred low lead")

The # represents the octane rating.

Low lead is only relative to other older products. (as 100 with 1 g/L) 100LL has 0.5 g/L of tetraethyl lead

Some fuel grades have 2 #s. (Ex: 80/87.) The 1st number represents the typical octane rating (aka aviation lean). The 2nd number represents an aviation rich octane rating. Aircraft engines have the capability to vary the mixture; a rich mixture is less susceptible to detonation (i.e. higher octane). 100LL is 130 w/ rich mixtures.

Each fuel grade is dyed a specific color. These colors did not scan properly.

100LL is blue ← common

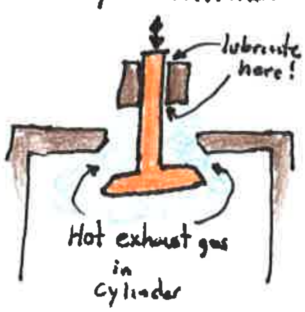
80/87 is red ← very rare now

115/145 is purple ← Reno, NV why? air-racers w/ high compression WW2 engines

Q: Why is there lead in fuel?

A: Lubrication: of valves in a high temperature burning environment.

Teledyne-Continental "Current aircraft engines feature valve gear components which are designed for compatibility with the leaded ASTM D910 fuels. In such fuels, the lead acts as a lubricant, coating the contact areas between the valve guide, and seat. The use of unleaded auto fuels with engines designed for leaded fuels can result in excessive exhaust valve seat wear due to the lack of lead. The result can be remarkable, with cylinder performance deterioration to unacceptable levels in under 10 hours."



Properties:

Density: $6.01\ \frac{lbf}{U.S.\,gal}$ at 59°F to $6.41\ \frac{lbf}{U.S.\,gal}$ at −40°F

Freeze: $T < -58°C \approx -72°F$

Conductivity: $< 450\ \frac{pS}{m}$

Jet Fuel: (ASTM D1655) Turbine Engines + Diesel Piston Engines

The most common ~~is~~ are Jet A. (civilian) and since the 90s JP-8 (military).

Similar in properties to Kerosene (i.e. lighter less viscous than diesel)

Color is "straw colored" This color did not scan properly.

3 main civilian types:

- Jet A: freezes at -40°F ← common
- Jet A1: freezes at -53°F
- Jet B: freezes at -76°F ← mixture of 30% Kerosene + 70% gasoline ~~diesel~~.

Cold, eh?

Several military types

- JP 8: similar to Jet A (MIL-DTL 83133)
- JP 5: Navy version of JP8 with a higher flashpoint for carrier safety.
- JP 4: Older jet fuel (phased out in 1970s to 1990s)

The exotics:

- JP 7: SR71 fuel w/ a very high flashpoint (140°F)
  Trivia: additive to apparently reduce radar signature of exhaust!

Properties

Density: 6.4 – 7.0 lbs/gal

Unfortunately, different refineries can produce jet fuel with different densities. Plus, the density changes with temperature.

TWA 800 B 747 1996

Aircraft destroyed in crash off the coast of Long Island NY after takeoff from JFK.

An unusual flight path and multiple fireballs contributed to speculation of ....

The NTSB report says: "An explosion of the center wing fuel tank (CWT), resulting from the ignition of the flammable fuel/air mixture in the tank. The source of ignition enery for the explosion could not be determined with certainty, but, of the sources evaluated by the investigation, the most likely was a short circuit outside of the CWT that allowed excessive voltage to enter it through electrical wiring associated with the fuel quantity indication system.

Contributing factors to the accident were the design and certification concepts that fuel tank explosions could be prevented solely by precluding all ignition sources and the design and certification of the Boeing 747 with heat sources located beneath the CWT with no means to reduce the heat transferred into the CWT or to render the fuel vapor in the tank nonflammable.

Visual translation

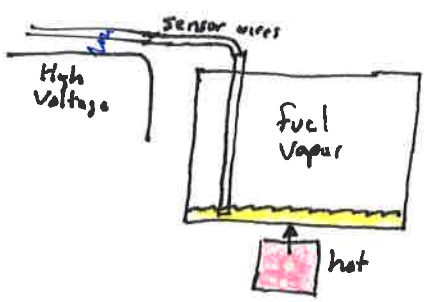
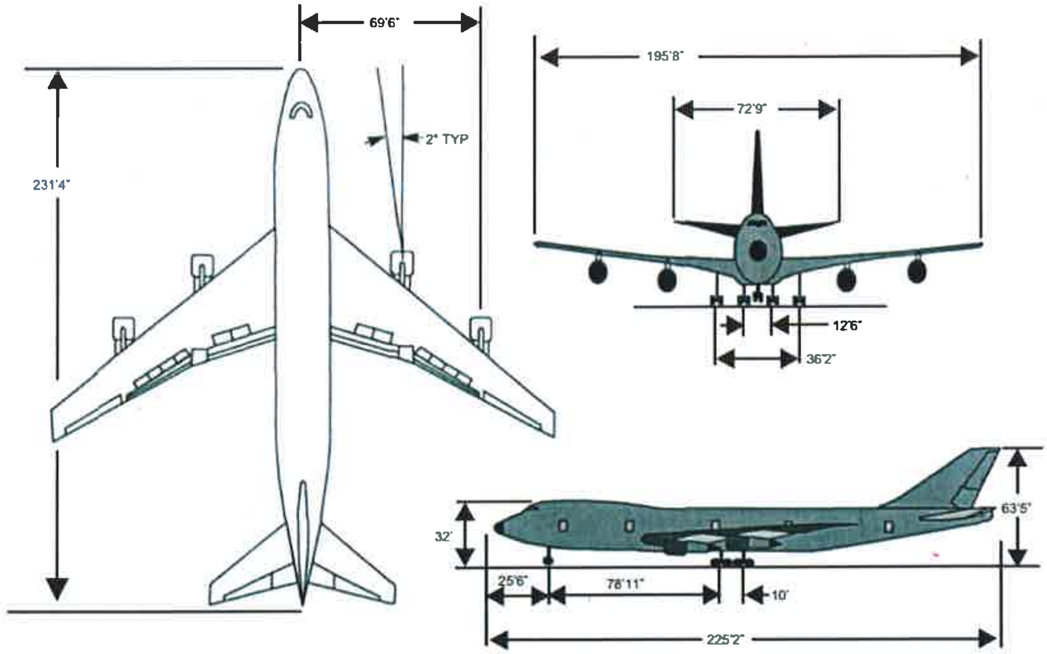


Image sources: NTSB Report



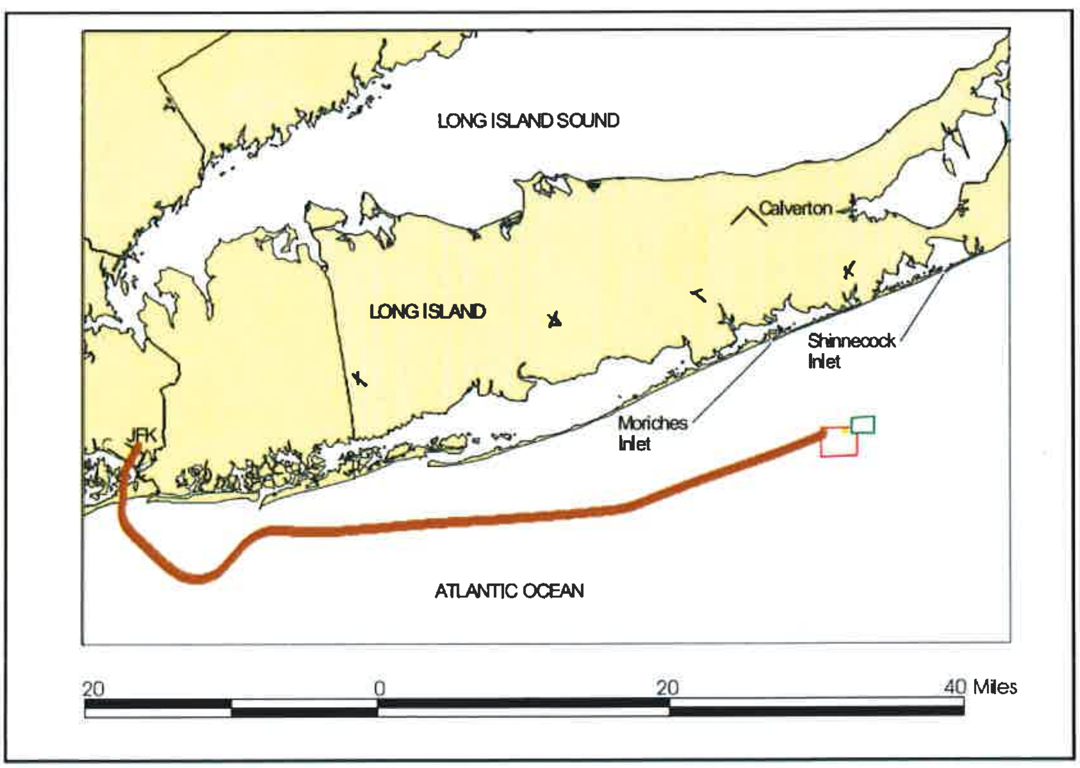


Figure 21. The wreckage location relative to the airplaine's flightpath, JFK, and Long Island.

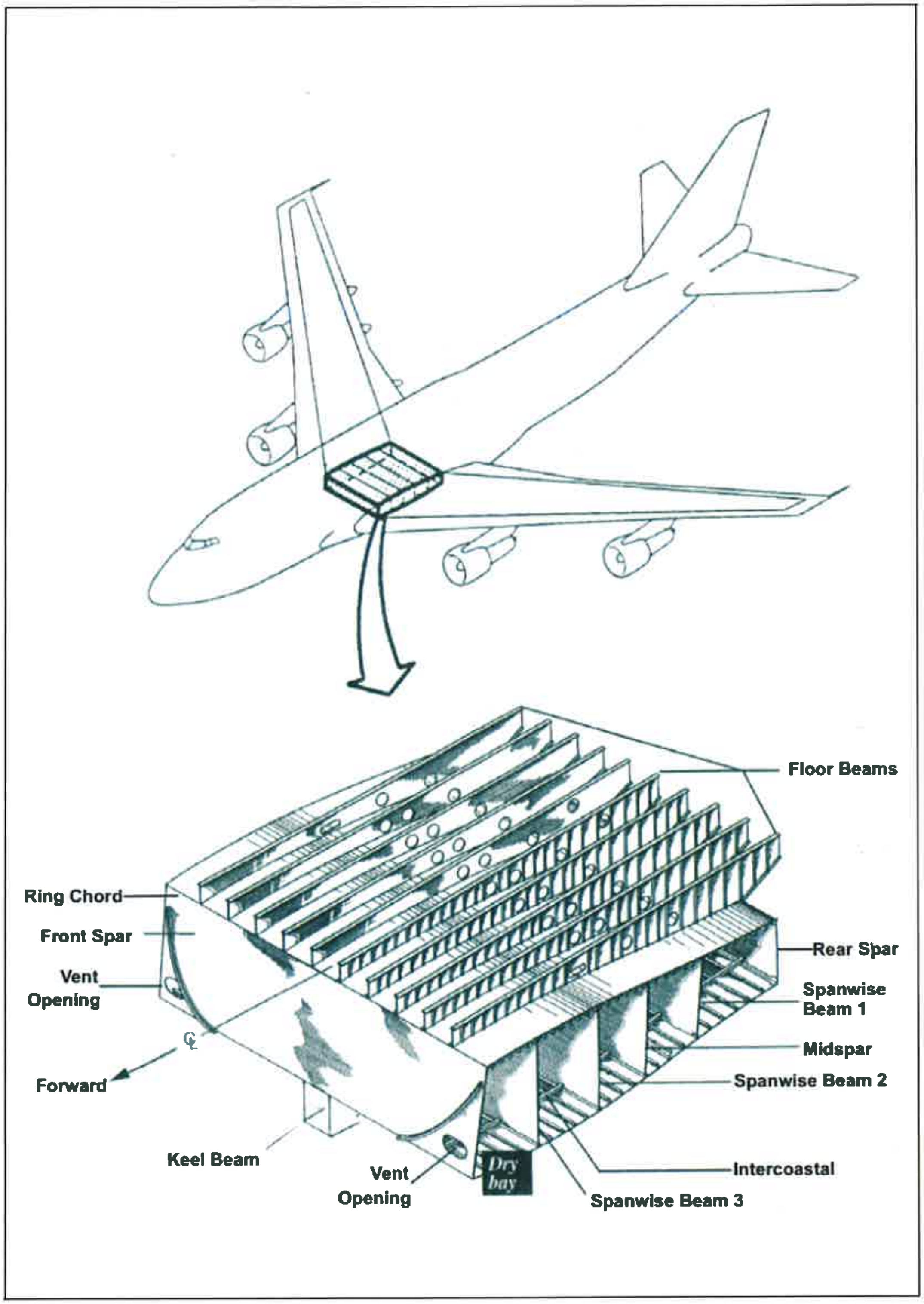


Figure 4a. A cross-section of the 747-100 wing center section.

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[31] The compartment between SWB3 and the front spar was originally equipped with a bladder cell for water and plumbing to inject that water into the engines to increase engine thrust on takeoff. When the original engines were replaced with higher thrust engines, water for water injection was not needed, and the compartment between SWB3 and the front spar was converted to a dry bay. The accident airplane's water system had been deactivated, and the bladder cell and plumbing had been removed. In some later models of the 747 and in the military (E-4B) version, this dry bay has been modified to carry fuel.

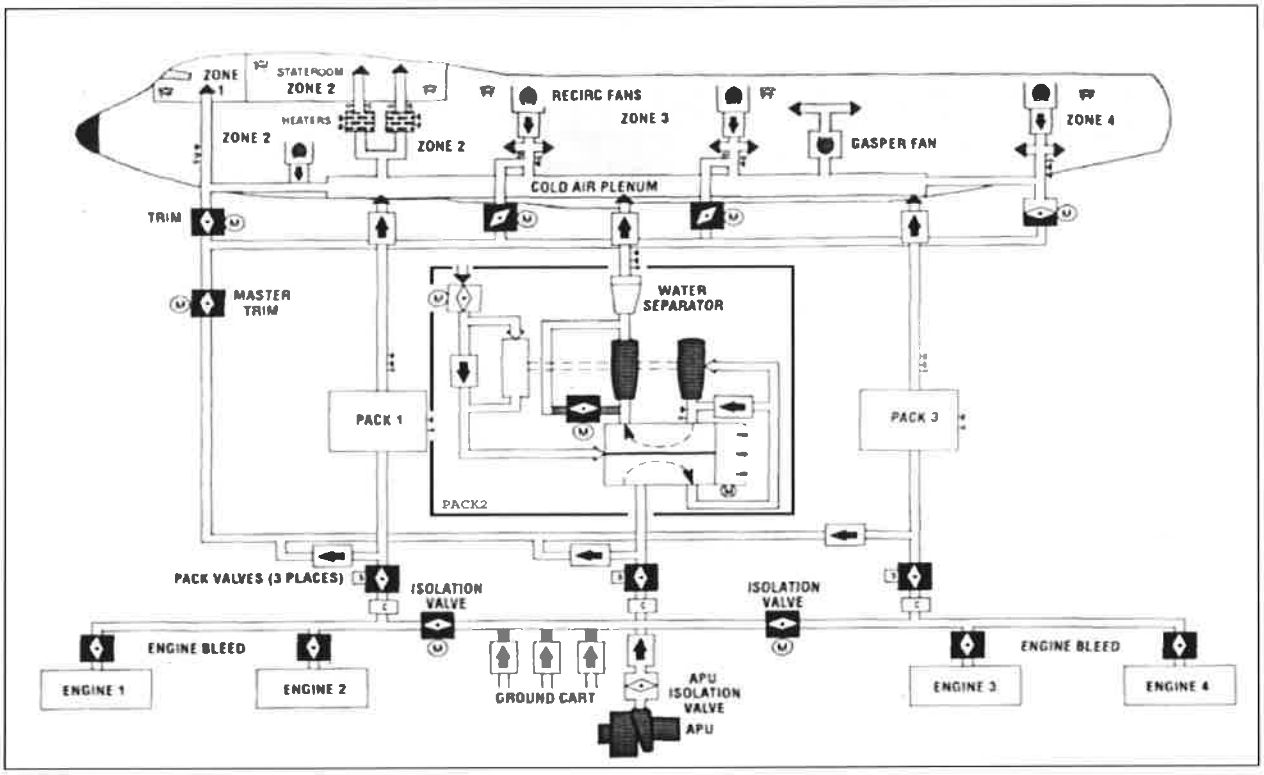
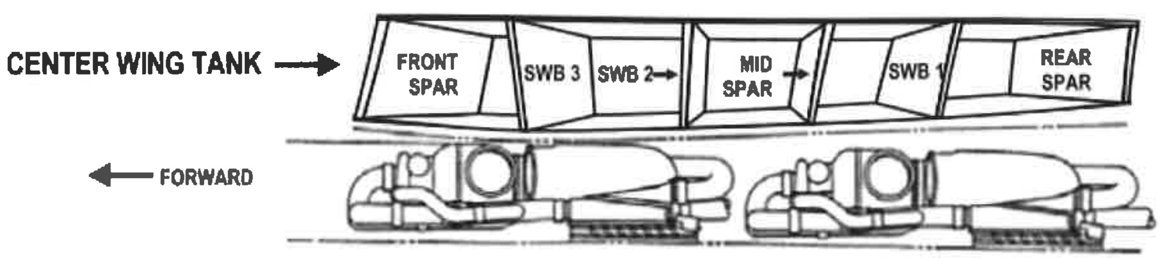
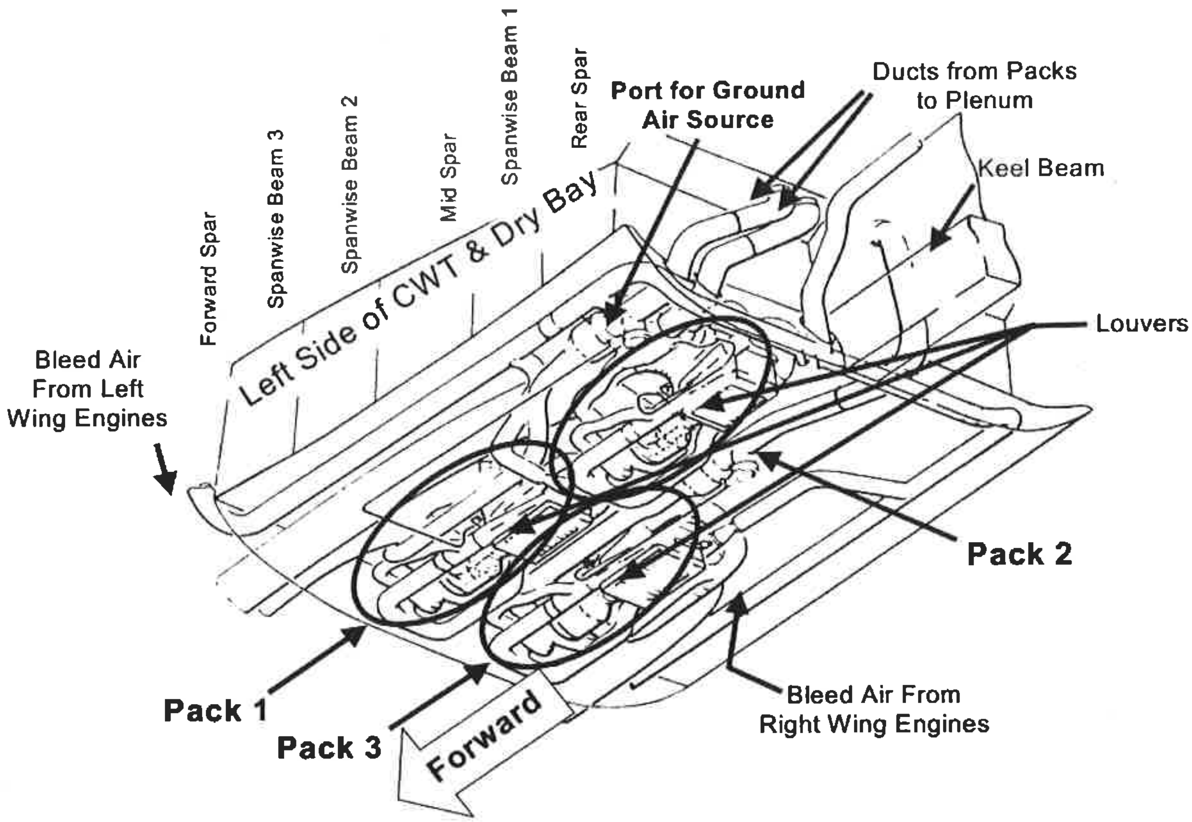


Figure 6. A schematic diagram of the 747-100's air conditioning system.





Forward Spar
Spanwise Beam 3
Spanwise Beam 2
Mid Spar
Spanwise Beam 1
Rear Spar
Port for Ground Air Source
Ducts from Packs to Plenum
Keel Beam
Left Side of CWT & Dry Bay
Bleed Air From Left Wing Engines
Louvers
Pack 2
Pack 1
Pack 3
Forward
Bleed Air From Right Wing Engines

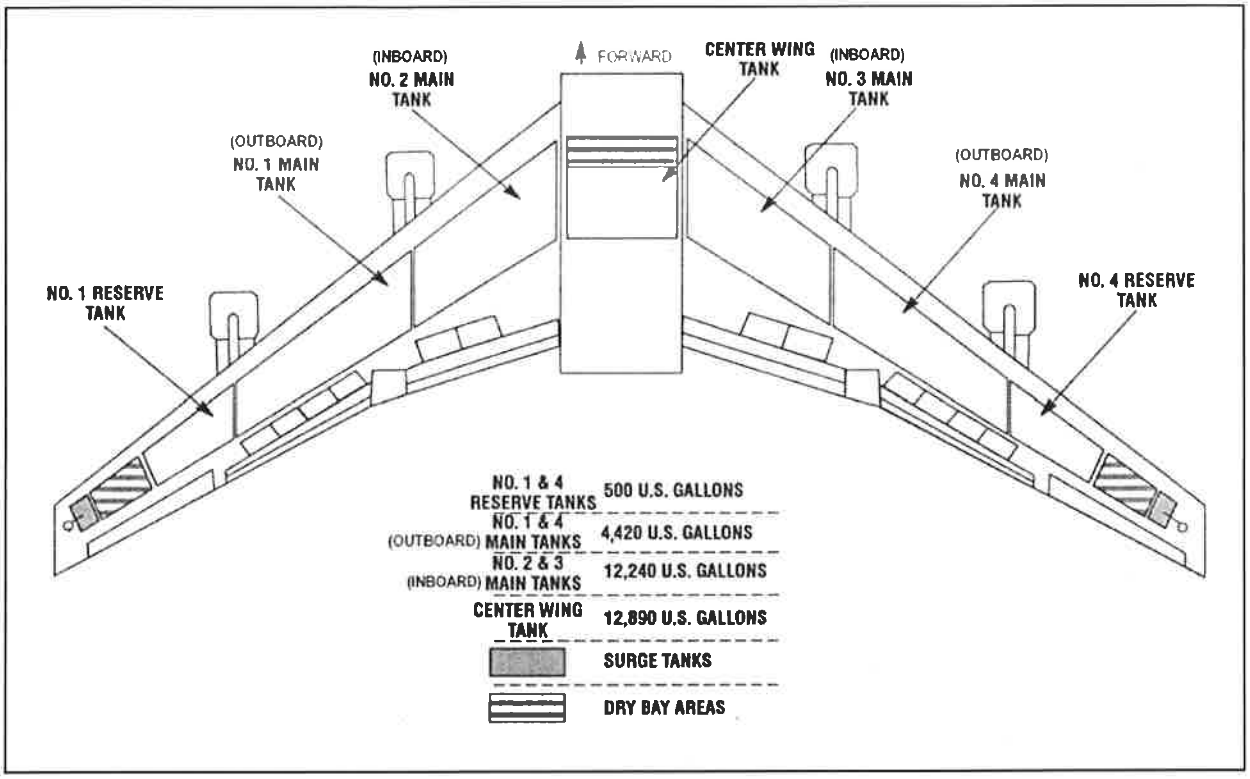


Figure 11. A schematic diagram of the 747-100 fuel tank arrangement.

To protect against the propagation of a flame from the surge tank to any of the other fuel tanks through the vent system,[61] the 747-100 surge tank overboard vents are equipped with a surge tank protection (STP) system. The STP system consists of an optical photocell located in each overboard vent designed to trigger the discharge of Halon (a fire extinguishing agent) into the surge tank when a flame or bright light source[62] is sensed in that overboard vent. Discharge of the extinguishing agent is designed to occur about 1 millisecond after the photocell senses a flame.

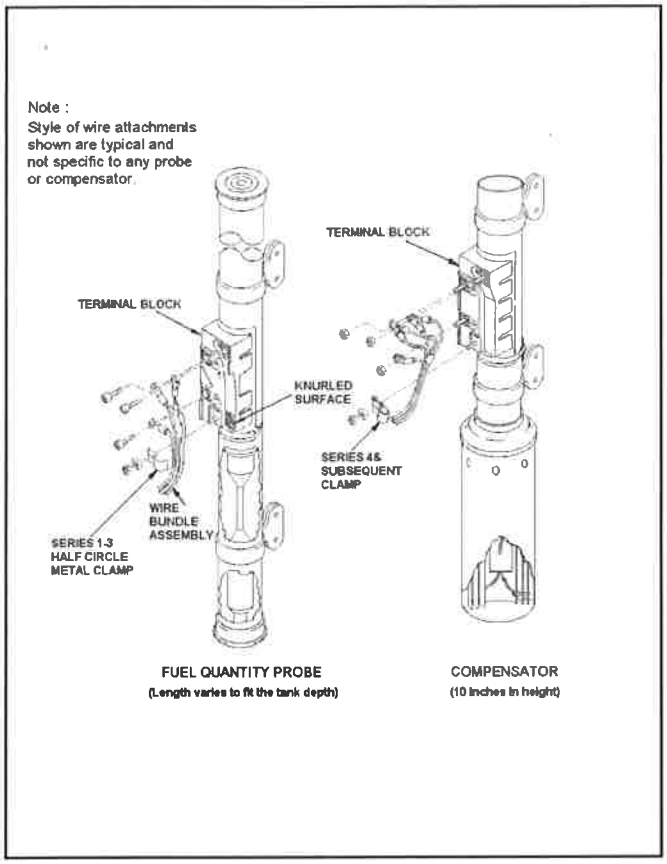


Figure 15. Diagrams of a fuel quntity probe and a compensator.

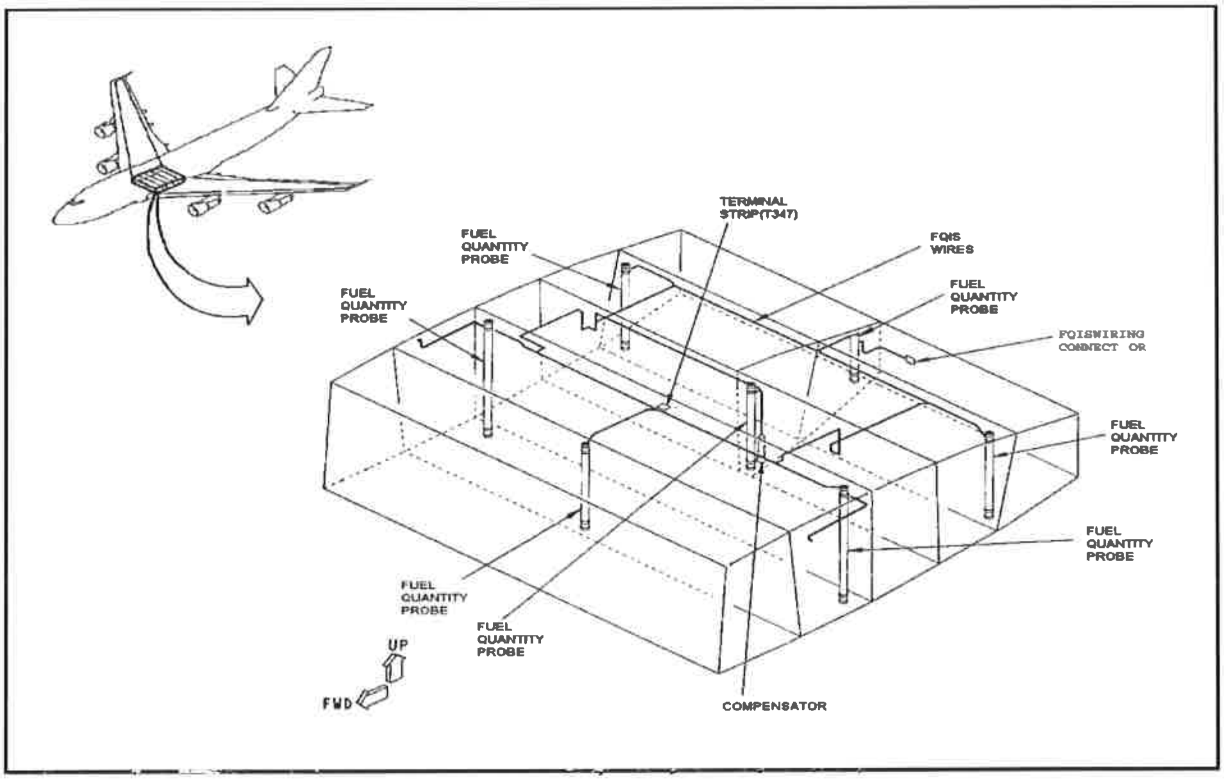


Figure 16. The fuel quantity probe and compensator locations in the 747's center wing fuel tank.

Table 2. TWA's fueling records, indicating TWA flight 800's fuel loading when it prepared to depart JFK.

Fuel Tank	Indicated Fuel Load Before Fueling (pounds)	Indicated Fuel Load After Fueling (pounds)
No. 1 Reserve	0	3,400
No. 1 Main	5,400	24,600
No. 2 Main	5,300	62,900
CWT	300	300[a]
No. 3 Main	6,900	62,700
No. 4 Main	6,300	24,600
No. 4 Reserve	0	3,300
Total	24,200	181,800

[a] The cockpit indicator has an analog scale and a digital (rotating drum) scale. When the digital display indicates 300 pounds, the analog needle would indicate near "0."

The Safety Board also measured the ambient air and component surface temperatures within the air conditioning pack bay. At the time that the flight test airplane was pushed back from the gate (after operating on the ground for 2 3/4 hours with the Nos. 1 and 3[240] air conditioning packs operating), air conditioning pack component surface temperatures ranged from 250° to 350° F, and ambient air temperatures within the pack bay ranged from 148° to 228° F.[241]

Review of the data obtained from the emulation flight test revealed that the CWT vapor samples had fuel/air mass ratios[247] of 0.034, 0.046, and 0.054 on the ground during taxi and as the airplane climbed through about 10,000 and 14,000 feet msl (see table 7). According to scientific literature[248] and tests conducted by experts at the California Institute of Technology (CIT), the lower flammability limit (LFL) of Jet A fuel is at a fuel/air mass ratio of 0.032 to 0.038.[249]

Table 7. Fuel/air mass ratios and ullage temperatures measured at the bay 2 sampling port during the TWA flight emulation flight test.

Sample	Temperature of Ullage at Sample Location in ° F	Fuel/air Mass Ratio
Emulation flight test, taxi	123	0.034
Emulation flight test, about 10,000 feet msl	115	0.046
Emulation flight test, about 14,000 feet msl	117	0.054

The accident airplane's electrical system consists of four engine-driven generators (one per engine) and one APU-driven generator,[37] all of which are capable of providing 115/200-volt,[38] three-phase, 400-Hz alternating current (a.c.). These generators are driven by a constant-speed drive located on the engine/APU gearbox, as applicable. Two 36-ampere (amp)[39]-hour nickel cadmium batteries provide 24-volt backup direct current (d.c.) power and APU start power and electrical bus[40] and switching logic for power

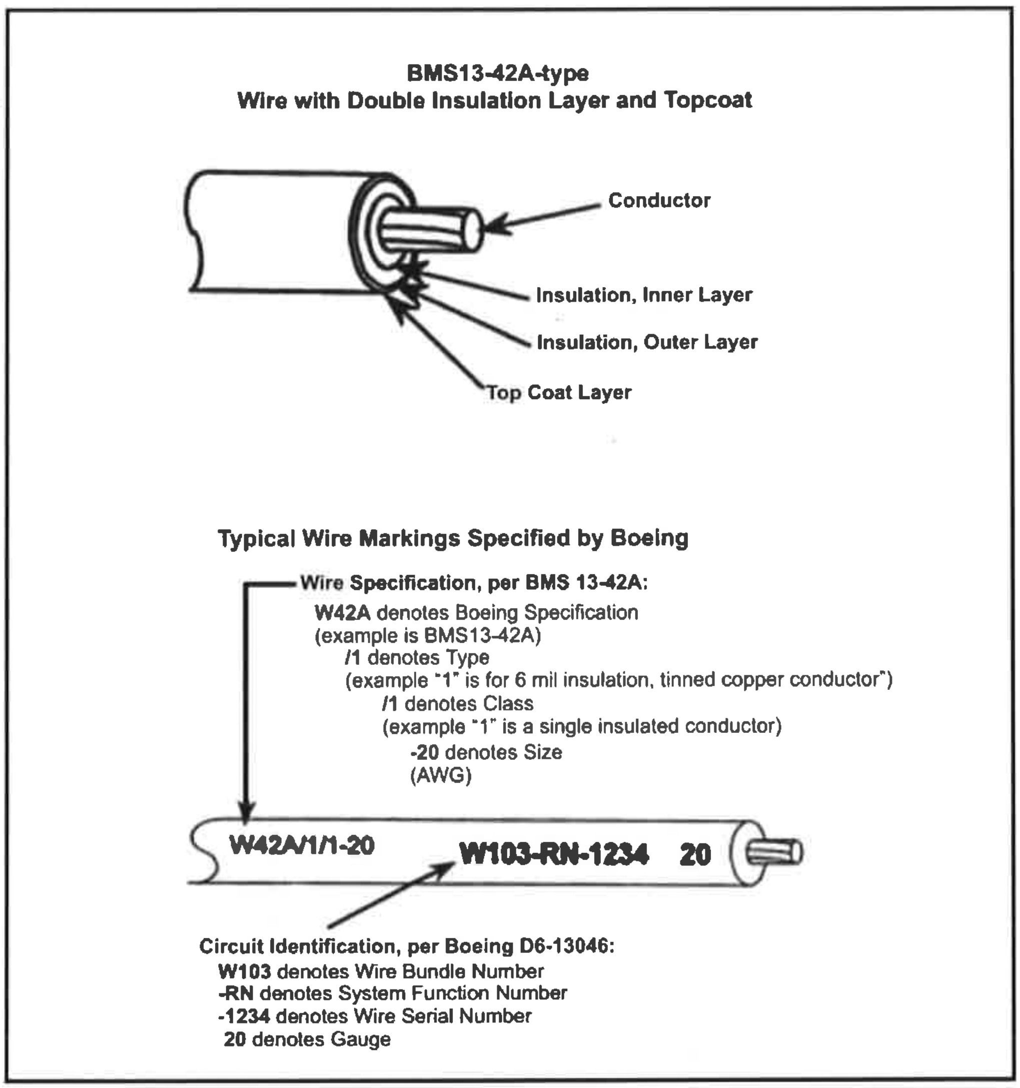


Figure 10. Diagram of a BMS13-42A Poly-X wire.

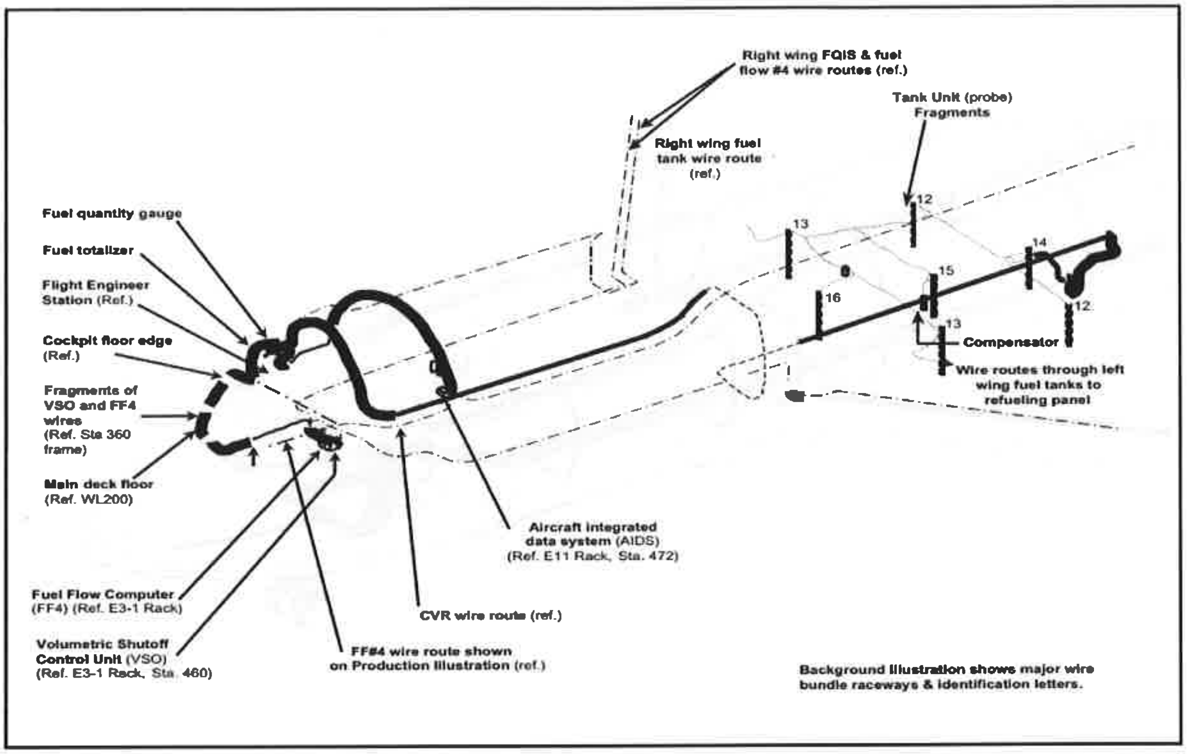


Figure 17. A schematic diagram of the 747-100's fuel quantity indication system wiring, fuel flow wiring, cockpit voice recorder wiring, and other wiring information.

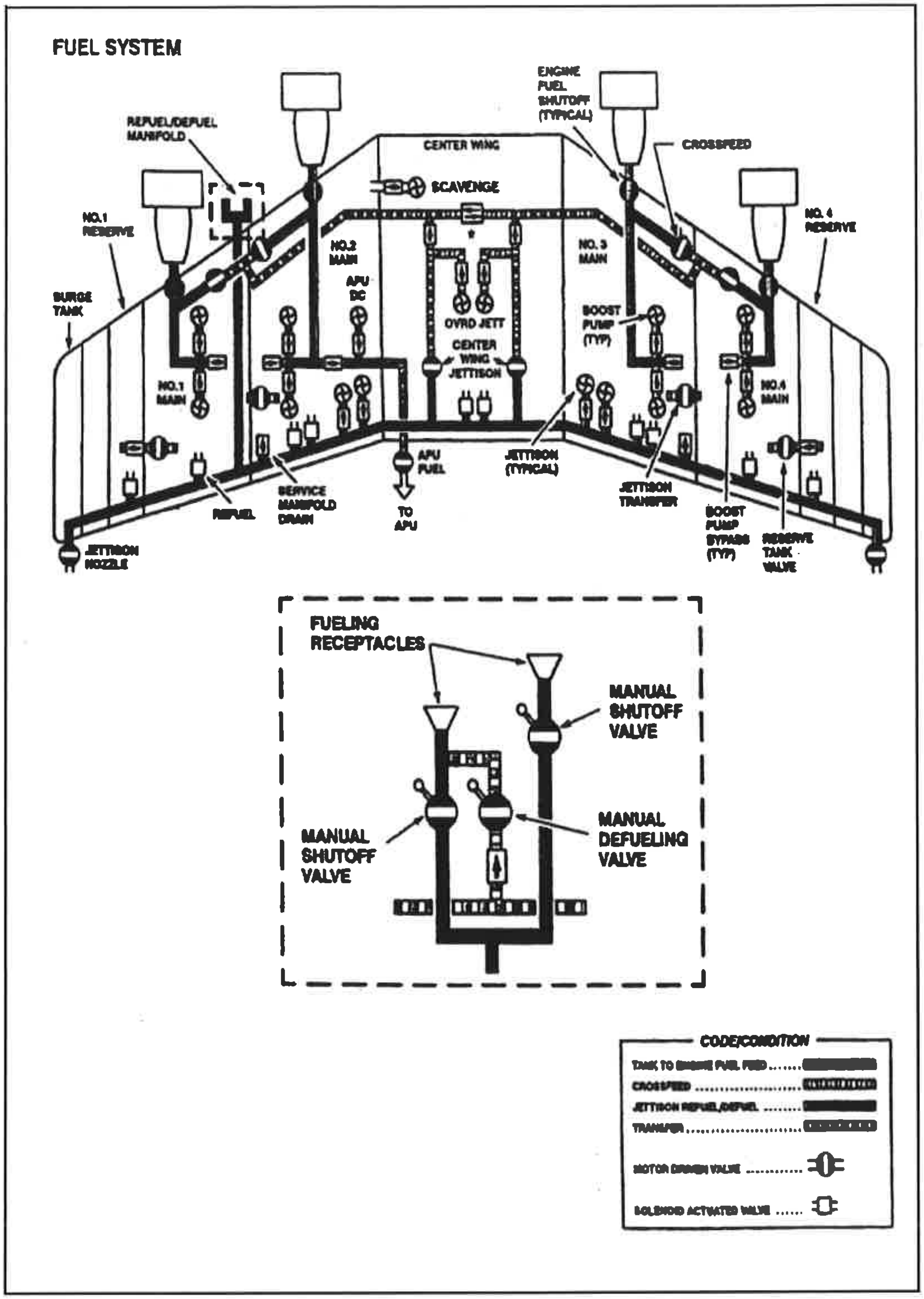
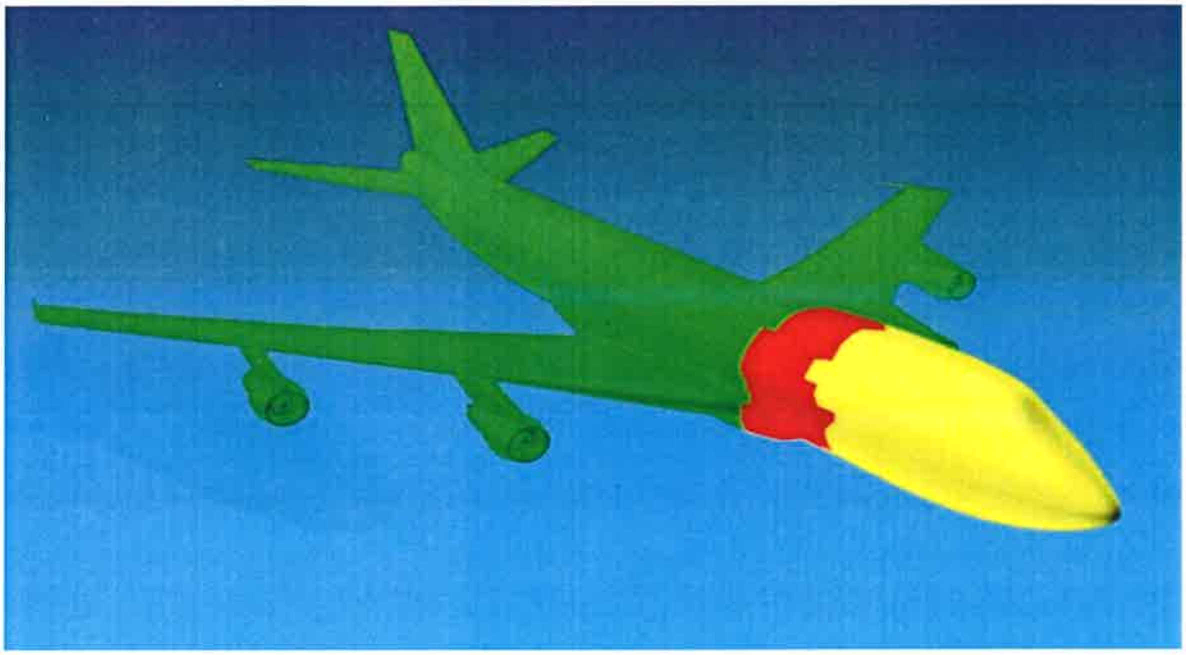


Figure 19. A schematic diagram of the fuel pump locations in the 747.

Basic Element	Failure Rate (events/hour)	Exposure Time (hours)	Basic Element Probability
Fuel/air mixture in CWT will support explosion	N/A	N/A	1×10^{-00}
Metallic object capable of creating spark in CWT	1×10^{-06}	8.0	8×10^{-06}
Tank sealant decays, resulting in exposed metal surface	1×10^{-07}	8.0	8×10^{-07}
Electrical faults in surge tank	1×10^{-07}	8.0	8×10^{-07}
Fire propagates from surge tank to CWT	1×10^{-06}	8.0	8×10^{-06}
Conductive material bridging terminals	3.55×10^{-07}	8.0	2.64×10^{-06}
Unique wire-to-wire faults route to FQIS leads in right wing	2.44×10^{-07}	8.0	1.95×10^{-06}
Fuel probe contacts CWT structure	3.55×10^{-07}	8.0	2.84×10^{-06}
Unique wire-to-wire faults route to FQIS leads in left wing	2.44×10^{-07}	8.0	1.95×10^{-06}
Fire propagates from WCS dry bay to CWT	1×10^{-05}	8.0	8×10^{-05}
Combustible fuel/air mixture in air conditioning pack bay	N/A	N/A	1×10^{-00}
Explosion-proofed equipment does not operate as designed	1×10^{-08}	60000	6×10^{-04}
Fire propagates from air conditioning pack bay to WCS dry bay	1×10^{-05}	8.0	8×10^{-05}
Fuel leak to air conditioning pack bay	1×10^{-05}	8.0	8×10^{-05}
VSO unit internal fault results in power to FQIS lead	1.4×10^{-07}	8.0	1.12×10^{-06}
FQIS wiring fault produces ignition source in main tank	1×10^{-6}	8.0	8×10^{-06}

During its evaluation of the FMEA/fault tree process for this investigation, the Safety Board noted several other accidents/incidents in which failures occurred that either had not been anticipated or had not been perceived as catastrophic and, therefore, had not been appropriately addressed in the manufacturer's fault tree analysis. For example, after a series of accidents and incidents in the 1990s involving uncommanded rudder movements on 737s, the Board recommended that the FAA convene an engineering test and review board to evaluate the 737 rudder system.[341] The resultant engineering test and review board, which convened in 1999, identified catastrophic failure modes that had not been identified through the FMEA and fault tree analyses submitted by Boeing in 1997 in connection with certification of the 737-NG airplanes. The recent in-flight failure of a horizontal stabilizer actuator on an Alaska Airlines MD-80 may be another example of a failure that was not anticipated through the FMEA/fault tree analysis process.[342]



Clock Time(s)	Event
2031:12	Initial event
2031:15.2, 2031:17.2, 2031:19.2	Forward fuselage separation
2031:46	Wing tip failure
2031:50	WCS failure adjacent to left wing

Figure 29. A photograph of the right side of the large three-dimensional reconstruction, with the support scaffolding visible.