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National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 13, 1996

In reply to refer to: A-96-174 through -177

Honorable Linda Hall Daschle
Acting Administrator
Federal Aviation Administration
Washington, D.C. 20591

On July 17, 1996, about 2031 eastern daylight time, a Boeing 747-131, N93119, operated as Trans World Airlines Flight 800 (TWA800), crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport (JFK), Jamaica, New York. All 230 people aboard the airplane were killed. The airplane, which was operated under Title 14 Code of Federal Regulations (CFR) Part 121, was bound for Charles De Gaulle International Airport (CDG), Paris, France. The flight data recorder (FDR) and cockpit voice recorder (CVR) ended simultaneously, about 13 minutes after takeoff. Evidence indicates that as the airplane was climbing near 13,800 feet mean sea level (msl), an in-flight explosion occurred in the center wing fuel tank (CWT);[1] the CWT was nearly empty.

A substantial portion of the airplane wreckage has been recovered from the ocean floor. Among the debris found along the first part of the wreckage path were CWT parts from spanwise beam Nos. 2 and 3, the forward spar, and debris from beneath and forward of the center wing section (see Figure 1). The cockpit of the airplane and pieces of the forward fuselage were found in a second debris field that was more than 1 mile from the beginning of the wreckage path. Fragmented wing and aft fuselage parts were recovered from a third debris field farther along the wreckage path.

Portions of the airplane have been reconstructed, including the CWT, the passenger cabin above the CWT, and the air conditioning packs and associated ducting beneath the CWT. The reconstruction thus far shows outward deformation of the CWT walls and deformation of the internal components of the tank that are consistent with an explosion originating within the tank. Airplane parts[2] from in and around the CWT recovered and identified to date contain no evidence

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[1] The flight engineer from the previous flight remembered having left about 300 pounds, or about 50 gallons, of fuel in the approximately 13,000 gallon capacity tank. The recovered fuel gauge indicated slightly more than 600 pounds (about 100 gallons) of fuel remaining in the CWT.

[2] Includes portions of the fuselage structure from above, air conditioning packs and ducting from below, wing structure from both sides, all tires from behind, and numerous components that included the large fiberglass water and cargo fire extinguisher containers from forward of the CWT.

of bomb or missile damage. The investigation into what might have provided the source of ignition of the fuel-air mixture (including a bomb or missile) in the CWT is continuing.

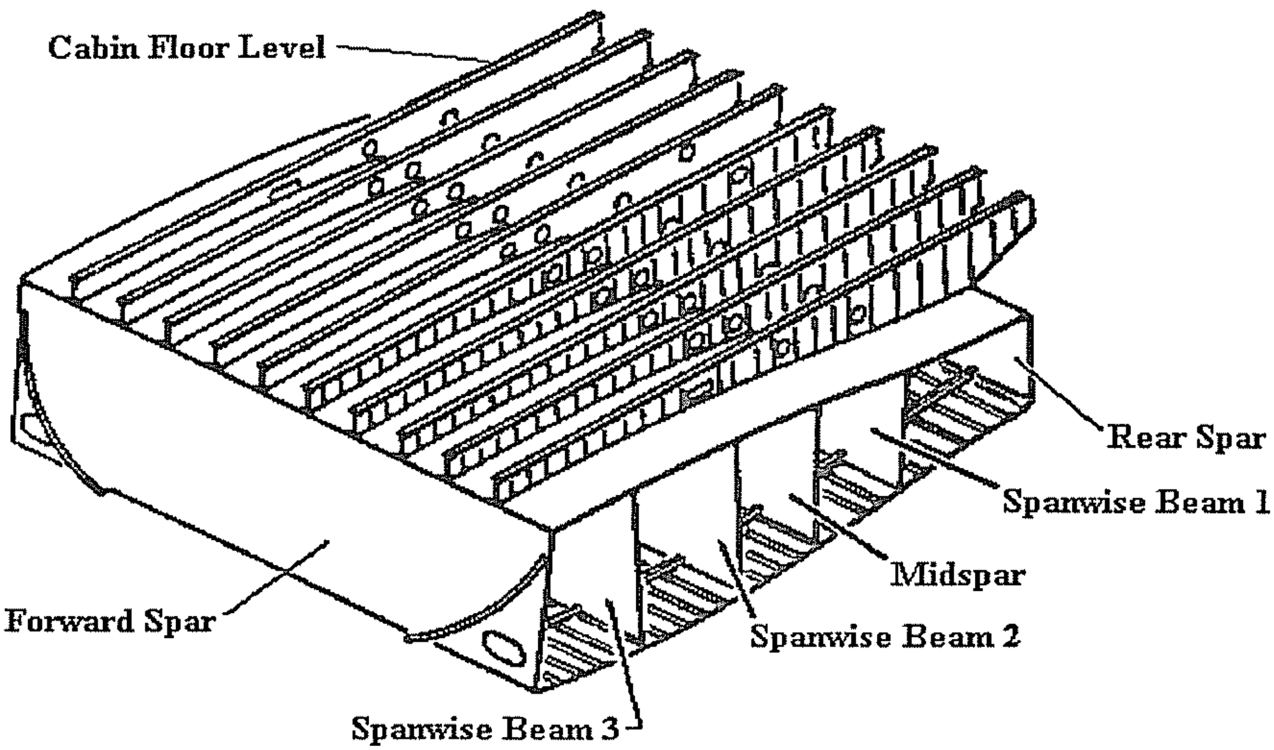

Figure 1. Center Wing Fuel Tank

Since 1985, the Safety Board has investigated or assisted in the investigation of two other fuel tank explosions involving commercial transport-category airplanes. The most recent accident involved a Philippine Airlines B-737-300 at Ninoy Aquino International Airport, Manila, Philippines, on May 11, 1990. In that accident, the CWT ullage[3] fuel-air vapors exploded as the airplane was being pushed back from a terminal gate, resulting in 8 fatalities and 30 injuries. The ambient temperature at the time of the accident was about 95°F, and the airplane had been parked in the sun. Although damage to wiring and a defective fuel quantity sensor were identified as possible sources of ignition, a definitive ignition source was never confirmed.

The Safety Board also assisted in the investigation of the crash of Avianca flight 203, a B-727, on November 27, 1989. The airplane had departed Bogota, Colombia, about 5 minutes before the crash. Examination of the wreckage revealed that a small bomb placed under a passenger seat, above the CWT, had exploded. The bomb explosion did not compromise the structural integrity of the airplane; however, the explosion punctured the CWT and ignited the fuel-air vapors in the ullage, resulting in destruction of the airplane.

Earlier, the Safety Board conducted a special investigation of the May 9, 1976, explosion and in-flight separation of the left wing of an Iranian Air Force B-747-131, as it approached Madrid, Spain, following a flight from Iran. Witnesses reported seeing a lightning strike to the

[3] In a fuel tank, the ullage is the vapor-laden space above the level of the fuel in the tank.

left wing, followed by fire, explosion, and separation of the wing. The wreckage revealed evidence of an explosion that originated near a fuel valve installation in the left outboard main fuel tank. The Safety Board's report[4] noted that almost all of the electrical current of a lightning strike would have been conducted through the aluminum structure around the ullage. While the report did not identify a specific point of ignition, it noted that static discharges could produce sufficient electrical energy to ignite the fuel-air mixture, but that energy levels required to produce a spark will not necessarily damage metal or leave marks at the point of ignition.

Fuel tank explosions require an energy source sufficient for ignition and temperatures between the lower explosive (flammability) limit (LEL)[5] and upper explosive limit (UEL), which will result in a combustible mixture of fuel and air. Current Federal Aviation Administration (FAA) regulations require protection against the ignition of fuel vapor by lightning, components hot enough to create an autoignition, and parts or systems failures that could become sources of ignition. Specifically:

> **Fuel system lightning protection.** The fuel system must be designed and arranged to prevent the ignition of fuel vapor within the system by (a) direct lightning strikes to areas having a high probability of stroke attachment; (b) swept lightning strikes to areas where swept strokes are highly probable; and (c) corona and streamering at fuel vent outlets. (Part 25.954)
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> **Fuel Tank Temperature.** (a) The highest temperature allowing a safe margin below the lowest expected auto ignition temperature of the fuel in the fuel tanks must be determined. (b) No temperature at any place inside any fuel tank where fuel ignition is possible may exceed the temperature determined under paragraph (a) of this section. This must be shown under all probable operating, failure, and malfunction conditions of any component whose operation, failure, or malfunction could increase the temperature inside the tank. (Part 25.981)

However, a 1990, Society of Automotive Engineers technical paper comments, "... if the ignition source is sufficiently strong (such as in combat threats), it can raise the fluid temperature locally and thus ignite a fuel that is below its flash point temperature. This is particularly true with a fuel mist where small droplets require little energy to heat up."[6] Elevated, possibly extremely high local temperatures would have been associated with the lightning strike of the Iranian B-747 in 1976.

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[4] NTSB-AAR-78-12. The Safety Board did not determine the probable cause of this foreign accident because it had no statutory authority to do so. Several hypotheses addressing the sequence of events and possible causes of the accident were presented in the Board's report.

[5] Marks' Standard Handbook for Mechanical Engineers, Eighth Edition, states, "The lower and upper limits of flammability indicate the percentage of combustible gas in air below which and above which flame will not propagate. When a flame is initiated in mixtures having compositions within these limits, it will propagate and therefore the mixtures are flammable." Marks' states further, "The autoignition temperature of an air-fuel mixture is the lowest temperature at which chemical reaction proceeds at a rate sufficient to result eventually (long time lag) in inflammation." (In the TWA800 CWT, the LEL was about 115°F, and the autoignition temperature was about 440°F.)

[6] Society of Automotive Engineers (SAE) Technical Paper Series 901949, Flammability of Aircraft Fuels, by N. Albert Moussa, BlazeTech Corp., Winchester, Massachusetts, as presented at the Aerospace Technology Conference and Exposition, Long Beach California, on October 1-4, 1990.

Despite the current aircraft certification regulations, airlines, at times, operate transport-category turbojet airplanes under environmental conditions and operational circumstances that allow the temperature in a fuel tank ullage to exceed the LEL, thereby creating a potentially explosive fuel-air mixture. For example, on August 26, 1996, Boeing conducted flight tests with an instrumented B-747 airplane that carried about the same small amount of fuel in the center wing tank as that carried aboard TWA800. All three air conditioning packs were operated on the ground for about 2 hours to generate heat beneath the CWT. The airplane was then climbed to an altitude of 18,000 feet msl. The temperature of the fuel in the center tank of the test airplane was measured at one location, and the air temperature within the tank was measured at four locations. In this test, the fuel-air mixture in the CWT ullage was stabilized at a temperature below the LEL on the ground. However, as the airplane climbed, the atmospheric pressure decreased (the LEL decreases with decreasing atmospheric pressure) reducing the LEL temperature and allowing an explosive fuel-air mixture to exist in the tank ullage.

Fuel tank temperatures may also become elevated, allowing explosive fuel-air mixtures to exist in the ullage, when airplanes are on the ground between flights at many airports worldwide during warm weather months. When the temperature of a combustible fuel-air mixture exceeds the LEL, a single ignition source exposed to the ullage could cause an explosion and loss of the airplane. This situation is inconsistent with the basic tenet of transport aircraft design--that no single-point failure should prevent continued safe flight.[7]

Without oxygen in the fuel-air mixture, the fuel tank ullage could not ignite, regardless of temperature or ignition considerations. The military has prevented fuel tank ignition in some aircraft through the creation of a nitrogen-enriched atmosphere (nitrogen-inerting) in fuel tank ullage, thereby creating an oxygen-deficient fuel-air mixture that will not ignite. Although this technology could be applied to civil aircraft, there are no transport-category airplanes of which the Safety Board is aware that currently incorporate nitrogen-inerting systems to reduce the potential for fuel tank fires and explosions.

Nitrogen-inerting has been accomplished several ways: by adding nitrogen to fuel tank(s) from a ground source before flight; by discharging onboard supplies of compressed or liquified nitrogen in flight; or by the use of on-board inert gas generation systems that separate air into nitrogen and oxygen. Such systems in current-generation military aircraft incorporate lightweight, permeable plastic membrane systems that produce high nitrogen flow rates and require only "on-condition" maintenance. Nitrogen-inerting using a ground source of nitrogen might prevent explosions such as those that occurred to the TWA800 and Avianca airplanes, but may not prevent an explosion after the fuel tanks have been emptied during flight through fuel consumption, or when ullage is exposed to warmer air as an airplane descends--situations that existed in the Iranian Air Force B-747 accident. Nitrogen-inerting fuel tank ullage has been used for more than 25 years in military airplanes and could be used to protect commercial air transportation. However, the Safety Board recognizes that development and installation of such

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[7] FAA Advisory Circular (AC) 25.1309-1A, System Design and Analysis, paragraph 5.a.1 states, "In any system or subsystem, the failure of any single element, component, or connection during any one flight (brake release through ground deceleration to stop) should be assumed, regardless of its improbability. Such single failures should not prevent continued safe flight and landing, or significantly reduce the capability of the airplane or the ability of the crew to cope with the resulting failure conditions."

systems are expensive and may be impractical because of system weight and maintenance requirements in some airplanes.

Therefore, the Safety Board has considered other modifications of the airplane that would reduce the potential for aircraft fuel tank explosions. A reduction in the potential for fuel tank explosions could be attained by reducing the heat transfer to fuel tanks from sources such as hot air ducts and air conditioning packs[8] that are now located under or near fuel tanks in some transport-category airplanes. This may be achieved by installing additional insulation between such heat sources and fuel tanks that must be collocated with heat-generating equipment such as hot air ducting and air conditioning packs.

Because the Safety Board believes that the FAA should require the development and implementation of design or operational changes that will preclude the operation of transport-category airplanes with explosive fuel-air mixtures in the fuel tanks, significant consideration should be given to the development of airplane design modifications, such as nitrogen-inerting systems and the addition of insulation between heat-generating equipment and the fuel tanks. Appropriate modifications should apply to newly certificated airplanes, and where feasible, to existing airplanes.

The Board recognizes that such design modifications take time to implement and believes that in the interim, operational changes are needed to reduce the likelihood of the development of explosive mixtures in fuel tanks. Two ways to reduce the potential of an explosive fuel-air mixture could be by refueling the CWT to a minimum level from cooler ground fuel tanks or by carrying additional fuel. Therefore, by monitoring fuel quantities and temperatures (when so-equipped), by controlling the use of air conditioning packs and other heat-generating devices or systems on the ground, and by managing fuel distribution among various tanks to keep all fuel tank temperatures in safe operating ranges and a to-be-determined minimum fuel quantity in the CWT, flightcrews could reduce the potential for fuel tank explosions in the B-747. The Safety Board believes that pending implementation of design modifications, the FAA should require modifications in operational procedures to reduce the potential for explosive fuel-air mixtures in the fuel tanks of transport-category aircraft. In the B-747, consideration should be given to refueling the CWT before flight whenever possible from cooler ground fuel tanks, proper monitoring and management of the CWT temperature, and maintaining an appropriate minimum fuel quantity in the CWT.

The Safety Board has also found that the Trans World Airlines B-747 Flight Handbook used by crewmembers understates the extent to which the air conditioning packs can elevate the temperature of the B-747 CWT. The Handbook notes that pack operation may elevate the temperature of the CWT by an additional 10 to 20°F. However, in the August 26, 1996, B-747 flight tests with three air conditioning packs in operation, the temperature of the center tank fuel increased by approximately 40°F. A 40°F temperature increase in the CWT of TWA800 would have raised the temperature of the ullage above the LEL of its fuel-air mixture. The Handbook also states, "warm fuel...may cause pump cavitation and low pressure warning lights may come

[8] Airplanes other than the B-747 also have heat-producing equipment in the vicinity of fuel tanks. For example, the A-320 and other Airbus Industrie commercial transport airplanes are similar to those from Boeing in that the air conditioning packs and ducts are beneath the CWT.

on steady or flashing." The Board is concerned that the flight handbooks of other operators of the B-747 may have similar deficiencies. Therefore, the Safety Board believes that the FAA should require that the B-747 Flight Handbooks of TWA and other operators of B-747s and other aircraft in which fuel tank temperature cannot be determined by flightcrews be immediately revised to reflect the increases in CWT temperatures found by flight tests, including operational procedures to reduce the potential for exceeding CWT temperature limitations.

Although the TWA B-747 Flight Handbook (and the Boeing Airplane Flight Manual) instruct flightcrews not to exceed fuel temperatures of "54.5C (130F), except JP-4 which is 43C (110F)," the only fuel tank temperature indication displayed for flightcrews is that of the outboard main tank in the left wing. The designs of the B-747 and some other airplanes currently provide no means to measure the temperature of the fuel or ullage of fuel tanks that are located near heat sources. The Safety Board believes that flightcrews need to monitor the temperature of fuel tanks that are located near heat sources, including the CWT in B-747s. Therefore, the Safety Board believes that the FAA should require modification of the CWT of B-747 airplanes and the fuel tanks of other airplanes that are located near heat sources to incorporate temperature probes and cockpit fuel tank temperature displays to permit determination of the fuel tank temperatures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require the development of and implementation of design or operational changes that will preclude the operation of transport-category airplanes with explosive fuel-air mixtures in the fuel tanks:
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> > **(a)** Significant consideration should be given to the development of airplane design modifications, such as nitrogen-inerting systems and the addition of insulation between heat-generating equipment and fuel tanks. Appropriate modifications should apply to newly certificated airplanes and, where feasible, to existing airplanes. (A-96-174)
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> > **(b)** Pending implementation of design modifications, require modifications in operational procedures to reduce the potential for explosive fuel-air mixtures in the fuel tanks of transport-category aircraft. In the B-747, consideration should be given to refueling the center wing fuel tank (CWT) before flight whenever possible from cooler ground fuel tanks, proper monitoring and management of the CWT fuel temperature, and maintaining an appropriate minimum fuel quantity in the CWT. (Urgent) (A-96-175)
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> Require that the B-747 Flight Handbooks of TWA and other operators of B-747s and other aircraft in which fuel tank temperature cannot be determined by flightcrews be immediately revised to reflect the increases in CWT fuel temperatures found by flight tests, including operational procedures to reduce the potential for exceeding CWT temperature limitations. (A-96-176)

Require modification of the CWT of B-747 airplanes and the fuel tanks of other airplanes that are located near heat sources to incorporate temperature probes and cockpit fuel tank temperature displays to permit determination of the fuel tank temperatures. (A-96-177)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman