DOCKET NO. **SA- 516**

EXHIBIT NO. **9D**

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON,

ACCIDENTS, INCIDENTS, AND SAFETY RECOMMENDATIONS REFERRED TO DURING THE INVESTIGATION

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

[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.

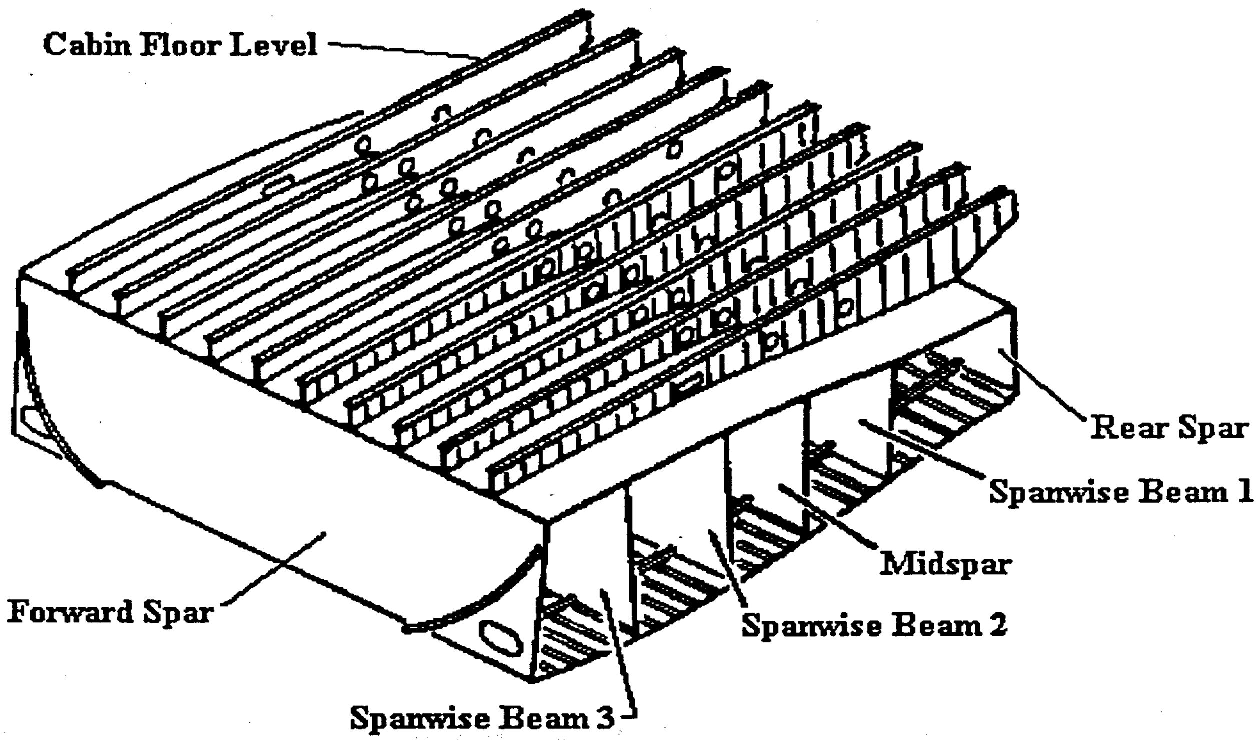

Figure 1. Center Wing Fuel Tank

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)
>
> **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:

(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)

(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)

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

U.S. DEPARTMENT OF STATE
OFFICE OF LANGUAGE SERVICES
Translating Division

LS No. 108019
BL
German

TECHNICAL INVESTIGATION

LUFTHANSA TECHNIK

Report No. 9.97/TO5B
Date: September 22, 1997

Type of Event: Special Event
Place of Event: New York
Date of Event: July 19, 1997
Time of Event: 6:45 p.m.

Type of Aircraft: B747-200 SF
ATA Chapter: 27
Device: wiring harness
Aircraft Registration: D-ABZC
System: Flaps
Operator: LCAG
Manufacturer: Boeing

Subject: Burned Cable Harness in the Front Cargo Hold of the D-ABZC

Contents

Issued by: FRA TQ 9 Henze, Telephone 2218
Auditors: Mr. Wächter, Mr. Kurtenbach, Telephones 3397, 6454

Distribution: [see original German text]

OPTIONAL FORM 99 (7-90) 10/10/97 English Translation requested
FAX TRANSMITTAL # of pages ▶ 6

To Robert Swaim	From JOAN GRAVATT
Dept./Agency NTSB/AS40	Phone # 647-9341
Fax # 314-6349	Fax # 647-4311

000008

1. Event

During the landing approach of LH flight 8174 to the New York airport on April 19, 1997, various circuit breakers in the flight control system of the D-ABZC opened.

This investigation was conducted to ascertain why this malfunction occurred, and whether there are any connections with similar cases in the B747-SF fleet.

The investigation was conducted in July and August 1997 by FRA TQ 9

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2. Summary

During the approach to New York's JFK Airport, diverse circuit breakers (C/B) of the flight control system opened.

The cause turned out to be a burned cable harness in the front cargo hold. The cable harness contains 42 cables, about 20 cm of which were burned and scorched.

The damage was repaired under the supervision of LHT personnel by employees of United Airlines (UA).

The damaged parts were not secured before or during the repair work. For that reason, an examination of the entire cable harness for possible causes of the short circuit, and clear findings on why the cables caught fire was not possible.

There have been similar cases in B747 SF aircraft which were remodeled into cargo-only aircraft by the Bedek Company. In those cases, shavings from drilling left in the cable harnesses were suspected as the likeliest causes of the malfunctions.

Because of this latest event, an action order (A/O) was issued, and the area in question and the cable harness on these aircraft was especially checked for foreign bodies. In all these aircraft, drill shavings and other dirt were found in the cable harnesses or their immediate surroundings. On the basis of this fact, it can be assumed that drill shavings in the cable harness of the D-ABZC also caused the short circuit, and therefore the malfunction, in this case.

Since further events of this kind cannot be excluded, FRA WF 2, together with FRA WB 42=PE, is working out precautions to be taken.

3. Results

3.1 Results of the Investigation

The following C/Bs opened during the approach of the LHC D-ABZC to JFK:

- ALT LE DRIVE NO. 2, NO. 3, NO. 4
- ALT INBD TE FLAP
- ALT OUTB TE DRIVE NO. 2
- TE FLAP ASYM AND FAIL
- INB FLAP CONTROL
- BEACON LT.

These C/Bs, with the exception of BEACON LT., could not be reset.

United Airlines mechanics found that in the front cargo hold, next to cargo door STA 775, a length of about 20 cm of a cable harness was burned out and scorched. The cable harness, consisting of the three cable harnesses W 818, W 824, and W 834, includes a total of 42 cables. The skin of the fuselage in this area was discolored dark brown by the heat.

After consultation with JFK SW, two FZE and one materials expert were called in from the Lufthansa Technical Service (LHT) in Frankfurt.

Foucault current checks and conductivity measurements in the damaged area did not show any changes in the structure of the material.

The burned and scorched cables were identified, cut out, and replaced by UA employees. The required checking of the functioning of the parts in question was carried out by LHT personnel.

At the same time, the following defects were detected and repaired:

a) C/B TE flap asym. & fail popped	- diode M2255 replaced
b) C/B control pos flap inbd. popped	- indb. flap asym. det. unit replaced
c) C/B alt. LE flap drive # 3 popped	- handled in accordance with MEL ZB. LE drive unit # 3 replaced in Frankfurt.

Concerning a): short circuit in the diode. The diode is no longer available.
Concerning b): the flap asym. det. unit was shipped to the U.S. by Allied Signal in Raunhelm on August 5, 1997. Evaluation report and damaged parts were requested.
Concerning c): LE flap drive unit was repaired at WG 535. The scorched electromotor was replaced and scrapped.

After replacement of these parts, the operational checks were normal, and all systems functioned normally during the subsequent operation of the aircraft.

According to Boeing WDM Wire List 91-11, no aromatic polyamide (Kapton) wires were used in the assembly (wire type codes -WTC).

WTC	Wire Part Number/Specification	Pieces
PA	BMS 13-48 Type 10 Class 1	34
PK	BMS 13-48 Type 11 Class 1	2
UA	BMS 13-48 Type 8 Class 1	6

The cable harness that was removed was not preserved in its entirety. Subsequently, only one single cable could be obtained. Therefore an examination of the entire cable harness for possible causes of the short circuit, and thus a clear determination of what caused the burning of the cable, is not possible. The one cable obtained was sent to TQ 23 for lab tests.

At first, a cable clamp was suspected of being the cause for the fire.

It is improbable that the cables in this area could have rubbed against each other, since the cable harness was mounted with plastic clamps and installed behind a panel which it did not touch. Therefore, it is assumed that a foreign body had gotten into the cable harness and caused the short circuit and burning of the cable.

The laboratory report indicates that one single cable is insufficient for making a determination whether the presence of foreign bodies, such as drill shavings, was responsible for the short circuit that led to the fire. The presence of melted copper droplets on the cable indicates that the temperature at that spot must have been more than 1,083 degrees Centigrade.

(1) Complaint

The preservation of evidence in accordance with QS-R 13.1.1 in cases of special irregularities did not take place. Replaced parts were not specially tagged.

Action

(a) All employees must be informed accordingly.

(b) In order to ensure a uniform approach in cases of special irregularities, TQ 9 will initiate an investigation of the matter.

Research has shown that similar malfunctions occurred in the B 747 SF aircraft with a side cargo door which had been converted to cargo planes by the Bedek Company. The suspected causes were drill shavings in the cable harnesses. In the checks for foreign bodies ordered at the time, drill shavings were found in all cases.

From 1990 to 1993, Bedek converted the ABYT, ABYW, ABYY, ABYZ, ABZC, and ABZA. The ABZC was converted in April 1993.

WB 42-PE issued an action order (A/O) for a special investigation of the above-mentioned aircraft on the basis of this incident. It involved checking the area in question and the cable harness for foreign bodies. Drill shavings and other dirt were found in the cable harnesses or their immediate surroundings in all these aircraft

The drill shavings were passed on to HAM TQ 23 for lab tests.

The investigation showed that it was impossible to determine the age of the drill shavings. The shavings analysed consist of the aluminum alloys 7075 and 2024, which are used for the frame and skin of the fuselages.

The action order also covered the former B747-200 combination aircraft ABYR, ABYM, ABYX, and ABZE, which were converted into the full pax version.

In these, no shavings or other dirt were found. Based on this fact, it can be assumed that such incidents can be limited to the aircraft converted by the Bedek Company.

The aircraft converted by the Bedek Company have meanwhile all been subjected to a D check by WD in HAM or by Iberia in MAD. ABZA is at present undergoing a D check by AMECO in PEK.

According to Iberia Maintenance Quality Assurance, no shavings were removed in this area during the D check of the ABZC in MAD in August 1996.

This also results from the documentation available to us. The entire area above the floor of the cargo hold was not opened, the insulation sheets were not removed, and thus no visual inspection of this area took place. It can therefore be assumed with almost total certainty that the drill shavings, if they were responsible for the burning of the cable, originated in the conversion by the Bedek Company.

3.2. Further Procedure

In spite of the action order carried out on the B 747-SF aircraft in question, further incidents of this kind cannot be completely excluded.

In a conversation between FRA TQ 9, FRA WF 2, and FRA WB 42-PE, the following approach was agreed upon:

FRA WF 2 will devise a program for determining the degree of pollution. In order to prevent similar malfunctions in the future, appropriate preventive measures must be introduced as soon as possible.

4. Documentation

No.	Date	Designation	Prepared by
1	07/19/97	alert notice 40557 - Wire Bundle W834 STA 775 R/H side below cargo floor burned	JFKLHSW
2	07/19/97	TLB/ROD Ref.: TU88149, TU88152, TU88155, TU88157, TU88159	LHT
3	07/19/97	various telexes	JFKSWLH
4	07/19/97	maintenance report No. 381/97	FRA WB 42
5	07/21/97	reporting of a malfunction subject to reporting under Art. 5 of the Rules of the Air	FRA TF
6	07/21/97	deviation from QS-H pursuant to QS-R - United Airlines personnel	FRA TQ 9
7	07/21/97	deviation from QS-H pursuant to QS-R 1.3.2 - - second check -	FRA TQ 9
8	07/28/97	technical report	JFKSW
9	08/05/97	life time record - leading edge flap drive unit SN : 6300 : PN : 126748-5-400	HAM WG 5
10	08/08/97	fax: D-ABZC incident	Iberia QA-Mgr.
11		WDM wire list 91-21-11	Boeing
12		Standard Wiring Practices Manual Chapter 23-00-13	Boeing
13		Technical Standards Manual Chapter 20-82-08	LHT
14	01/24/96	technical evaluation report 9.96/T))# "D-ABZC - Electrical Fire in the Upper Deck Behind Toilet U 5"	FRA TQ 9
15	01/06/96	OS-R 13.1.1 evaluation of special irregularities within the maintenance framework	HAM TQ
16	08/22/97	lab tests of the drill shavings of the D-ABZC	HAM TQ 23
17	08/26/97	lab tests of the drill shavings of the D-ABYT, D-ABYY, D-ABYZ	HAM TQ 23
18	08/27/97	lab test of a cable of the D-ABZC	HAM TQ 23

******* PSDS GENERATED *******

1 SCOPE

a. This specification covers insulated wire and cable with tin-coated copper, nickel-coated and silver-coated high strength copper alloy conductors and a primary insulation of cross-linked Ethylenetetrafluoroethylene (ETFE).

b. The wire and cable specified herein is intended for "General Purpose" use in both pressurized and unpressurized areas of aircraft. Its application will include exposure to temperatures from -65 C to +150 C and to various corrosive fluids. The operating potential of circuits where this wire and cable is utilized will be limited to 600 Vrms. Stabilized conductor temperature during continuous operation will be limited to 150 C. This specification requires qualified products.

1.1 CONTENTS

Swaim Bob

From: Swaim Bob
Sent: Wednesday, October 01, 1997 8:30 AM
To: 'Richard J Lidicker (BOEING)'
Cc: 'Rodrigues, Dennis (BOEING)'; Dickinson Al
Subject: Wire specifications

Dick -

I found that the Lufthansa B-747 had BMS13-48 as the general purpose ship's wire. Isn't that Kapton? Could you please send me a copy of the wire spec for BMS13-48?

Thanks,
Bob

Recommendation Report

Friday, September 05, 1997

ACCIDENT DATE:3/17/91 MODE:AVIATION

Log Number 2303

Issue Date 8/14/91 GOOSE BAY CAN 17-Mar-91

ON MARCH 17, 1991, AT 1618 ATLANTIC STANDARD TIME, DELTA AIR LINES FLIGHT 15, LOCKHEED L-1011-385-3, N753DA, WAS EN ROUTE FROM FRANKFURT, GERMANY TO ATLANTA, GEORGIA AT FLIGHT LEVEL (FL) 330 WHEN IT EXPERIENCED A FIRE BELOW THE AFT CABIN FLOOR AND IN THE CABIN. THE FLIGHT WAS CONDUCTED UNDER THE OPERATING RULES OF PART 121 OF TITLE 14 CODE OF FEDERAL REGULATIONS (CFR) AND CARRIED 218 PASSENGERS, 10 FLIGHT ATTENDANTS, 2 PILOTS, AND 1 FLIGHT ENGINEEE. FLIGHT 15 HAD EN ROUTE FOR ABOUT 7.5 HOURS, WHEN ABOUT 180 MILES EAST OF GOOSE, BAY, LABRADOR, CANADA, A FLIGHT ATTENDANT NOTICED FLAMES RISING FROM THE BASE OF THE LEFT CABIN SIDEWALL PANEL TO THE HEIGHT OF THE SEATBACK TRAY AT THE NEXT TO LAST ROW PASSENGER SEATS (SEAT 41A). THE FLIGHT ATTENDANT PROMPTLY DISCHARGED A HALON FIRE EXTINGUSIHER INTO AN OPENING IN THE BASE OF THE SIDEWALL FROM WHICH THE FLAMES APPEARED TO ORIGINATE. THE FIRE WAS EXTINGUISHED AND A PRECAUTIONARY LANDING WAS MADE AT GOOSE BAY.

Recommendation # A-91-070

Overall Status CAA **CLOSED - ACCEPTABLE**

Priority CLASS II

THE NTSB RECOMMENDS THAT THE FEDERAL AVIATION ADMINISTRATION: REQUIRE SPECIFIC QUALITY CONTROL & INSPECTION PROCEDURES FOR WIRE BUNDLE INSTALLATIONS ON TRANSPORT CATEGORY AIRCRAFT TO VERIFY PROPER BEND RADII, CHAFE PROTECTION, AND ROUTING PRACTICES BY AIRCRAFT MANUFACTURERS DURING FABRICATION AND BY AIRLINES DURING MAINTENANCE OPERATIONS THAT EXPOSE WIRE BUNDLES.

FAA **CLOSED - ACCEPTABLE** **10/5/93**

10/30/91	Addressee	THE FAA REVIEWED BOEING'S AND MCDONNELL DOUGLAS' APPROVED QUALITY CONTROL AND TYPE DESIGN DATA FOR WIRE BUNDLE INSTALLATION AS THEY APPLY TO PROPER BEND RADII, CHAFE PROTECTION, AND ROUTING PRACTICES AND DETERMINED THAT THE APPROVED INSPECTION CRITERIA FOR THE WIRE BUNDLE INSTALLATIONS ARE ADEQUATE. THE FAA'S REVIEW ALSO INDICATED THAT THE INSPECTION ACCEPTANCE RECORDS ARE ADEQUATELY MAINTAINED AND DOCUMENTED. THE FAA IS REQUESTING THAT EACH CERTIFICATION DIRECTORATE EVALUATE ITS TRANSPORT CATEGORY MANUFACTURERS' WIRE BUNDLE INSPECTION REQUIREMENTS AND PLACE SPECIAL EMPHASIS ON THESE SYSTEMS DURING THE NEXT AUDIT OR EVALUATION.
4/29/92	NTSB	Letter on File
10/5/93	Addressee	THE FAA REVIEWED BOEING'S AND MCDONNELL DOUGLAS' APPROVED QUALITY CONTROL AND TYPE DESIGN DATA FOR WIRE BUNDLE INSTALLATION AS THEY APPLY TO PROPER BEND RADII, CHAFE PROTECTION, AND ROUTING PRACTICES AND DETERMINED THAT THE APPROVED INSPECTION CRITERIA FOR THE WIRE BUNDLE INSTALLATION WERE ADEQUATE. EACH CERTIFICATION DIRECTORATE HAS ALSO BEEN ASKED TO EVALUATE ITS TRANSPORT CATEGORY MANUFACTUERERS' WIRE BUNDLE INSPECTION REQUIREMENTS AND PLACE SPECIAL EMPHASIS ON THESE SYSTEMS DURING THE NEXT AUDIT OR EVALUATION. TO ENSURE THAT EFFECTIVE QUALITY CONTROL PROCEDURES ARE CARRIED OUT AT THE FACILITIES OF INDIVIDUAL OPERATORS, THE FAA ISSUED HANDBOOK BULLETIN 91-15, ORIGI AN PROPAGATION OF INACESSIBLE AIRCRAFT FIRE UNDER IN-FLIGHT AIRFLOW CONDITIONS. THE BULLELTIN REQUESTS THAT PRINCIPAL MAINTENANCE INSPECTORS REVIEW THEIR OPERATORS MAINTENANCE PROGRAMS TO ENSURE THAT THEY INCLUDE INSPECTION OF AIRCRAFT WIRING, ESPECIALLY IN INACCESSIBLE AREAS. THE BULLETIN SPECIFICALLY REFERENCE ADVISORY CIRCULAR 43.13-1A, ACCEPTABLE METHODS, TECHNIQUES, AND PRACTICES--AIRACRAFT INSPECTION AND REPAIR, PAGE 203 CHAPTER 11, SECTION 7, PARAGRAPH 515, CONCERNING WIRE BEND RADII, THIS BULLETIN HAS BEEN INCORPORATED INTO FAA ORDER 8300.10, AIRWORTHINESS INSPECTORS HANDBOOK.
2/10/94	NTSB	THE BOARD HAS REVIEWED HANDBOOK BULLETIN 91-15, "ORIGIN AND PROPAGATION OF INACCESSIBLE AIRCRAFT FIRE UNDER IN-FLIGHT AIRFLOW CONDITIONS," WHICH REQUESTS

FLIGHT STANDARDS PRINCIPAL MAINTENANCE INSPECTORS TO REVIEW THEIR OPERATORS' MAINTENANCE PROGRAMS TO ENSURE THAT THE PROGRAMS INCLUDE INSPECTION OF AIRCRAFT WIRING, AND TO ENSURE THAT EFFECTIVE QUALITY CONTROL PROCEDURES ARE I PLACE THAT WOULD DISCOVER INSULATION BREAKDOWNS. THE BOARD NOTES THAT THE FOREGOING MATERIAL HAS BEEN INCORPORATED INTO FAA ORDER 8300.10 "AIRWORTHINESS INSPECTORS HANDBOOK." BASED ON THIS INFORMATION, RECOMMENDATION A-91-70 IS CLASSIFIED "CLOSED--ACCEPTABLE ACTION."

Recommendation Report

Friday, September 05, 1997

ACCIDENT DATE:3/17/91 MODE:AVIATION

Log Number 2303

Issue Date 8/14/91

GOOSE BAY CAN **17-Mar-91**

ON MARCH 17, 1991, AT 1618 ATLANTIC STANDARD TIME, DELTA AIR LINES FLIGHT 15, LOCKHEED L-1011-385-3, N753DA, WAS EN ROUTE FROM FRANKFURT, GERMANY TO ATLANTA, GEORGIA AT FLIGHT LEVEL (FL) 330 WHEN IT EXPERIENCED A FIRE BELOW THE AFT CABIN FLOOR AND IN THE CABIN. THE FLIGHT WAS CONDUCTED UNDER THE OPERATING RULES OF PART 121 OF TITLE 14 CODE OF FEDERAL REGULATIONS (CFR) AND CARRIED 218 PASSENGERS, 10 FLIGHT ATTENDANTS, 2 PILOTS, AND 1 FLIGHT ENGINEEE. FLIGHT 15 HAD EN ROUTE FOR ABOUT 7.5 HOURS, WHEN ABOUT 180 MILES EAST OF GOOSE, BAY, LABRADOR, CANADA, A FLIGHT ATTENDANT NOTICED FLAMES RISING FROM THE BASE OF THE LEFT CABIN SIDEWALL PANEL TO THE HEIGHT OF THE SEATBACK TRAY AT THE NEXT TO LAST ROW PASSENGER SEATS (SEAT 41A). THE FLIGHT ATTENDANT PROMPTLY DISCHARGED A HALON FIRE EXTINGUSIHER INTO AN OPENING IN THE BASE OF THE SIDEWALL FROM WHICH THE FLAMES APPEARED TO ORIGINATE. THE FIRE WAS EXTINGUISHED AND A PRECAUTIONARY LANDING WAS MADE AT GOOSE BAY.

Recommendation # A-91-071

Overall Status CAA **CLOSED - ACCEPTABLE**

Priority **CLASS II**

THE NTSB RECOMMENDS THAT THE FEDERAL AVIATION ADMINISTRATION: NOTIFY PRINCIPAL MAINTENANCE INSPECTORS & OPERATORS OF TRANSPORT CATEGORY AIRCRAFT OF THE FIRE HAZARD POSED BY ACCUMULATIONS OF LINT AND OTHER DEBRIS ON WIRE BUNDLES.

FAA	**CLOSED - ACCEPTABLE**	**8/13/92**

10/30/91	Addressee	THE FAA HAS DRAFTED AN AIRWORTHINESS INSPECTOR'S HANDBOOK BULLETIN ENTITLED ORIGIN AND PROPAGATION OF INACCESSIBLE AIRCRAFT FIRE UNDER INFLIGHT AIRFLOW CONDITIONS. THIS BULLETIN PROVIDES INFORMATION ON THE POTENTIAL SAFETY HAZARD APPLICABLE TO ALL TRANSPORT CATEGORY AIRCRAFT FROM THE ACCUMULATION OF LINT AND OTHER DEBRIS ON WIRE BUNDLES. THIS BULLETIN REQUESTS THAT PRINCIPAL MAINTENANCE INSPECTORS DISSEMINATE THIS INFORMATION TO ALL OPERATORS OF TRANSPORT CATEGORY AIRCRAFT. THE BULLETIN ALSO REQUESTS THAT PRINCIPAL MAINTENANCE INSPECTORS REVIEW THEIR OPERATORS' MAINTENANCE PROGRAMS TO ENSURE THAT THEY INCLUDE INSPECTION OF AIRCRAFT WIRING AND REMOVAL OF CONTAMINANTS, ESPECIALLY IN ACCESSIBLE AREAS.
4/29/92	NTSB	Letter on File
8/13/92	Addressee	THE FAA AGREES WITH THIS SAFETY RECOMMENDATION. ON DECEMBER 9, 1991, THE FAA ISSUED HANDBOOK BULLETIN 91-15, ORIGIN AND PROPAGATION OF INACESSIBLE AIRCRAFT FIRE UNDER IN-FLIGHT AIRFLOW CONDITIONS. THIS BULLETIN PROVIDES INFORMATION ON THE POTENTIAL SAFETY HAZARD APPLICABLE TO ALL TRANSPORT CATEGORY AIRCRAFT FROM THE ACCUMULATION OF LINT AND OTHER DEBRIS ON WIRE BUNDLES. THIS BULLETIN REQUESTS THAT PRINCIPAL MAINTENANCE INSPECTORS OF TRANSPORT CATEGORY AIRCRAFT OPERATORS ENSURE THAT PROGRAMS ARE IN PLACE TO ADDRESS THE INSPECTION OF AIRCRAFT WIRING AND THE REMOVAL OF CONTAMINANTS, ESPECIALLY IN INACCESSIBLE AREAS. THIS BULLETIN HAS BEEN COORDINATED WITH THE AIRCRAFT CERTIFICATION SERVICE AND WILL BE DISTRIBUTED TO ALL CERTIFICATION OFFICES FOR THEIR INFORMATION AND COORDINATION WITH MANUFACTURERS FOR INCLUSION IN FUTUR DESIGN CONSIDERATIONS.
10/20/92	NTSB	THE BOARD NOTES THAT THE FAA AGREES WITH THIS RECOMMENDATION & ON 12/9/91, ISSUED HANDBOOK BULLETIN 91-15, ORIGIN & PROPAGATION OF INACCESSIBLE AIRCRAFT FIRE UNDER IN-FLIGHT AIRFLOW CONDITIONS. THIS BULLETIN PROVIDES INFORMATION ON THE POTENTIAL SAFETY HAZARD (APPLICABLE TO ALL TRANSPORT CATEGORY AIRCRAFT) FROM THE ACCUMULATION OF LINT & OTHER DEBRIS ON WIRE BUNDLES. ALSO, THIS BULLETIN HAS BEEN COORDINATED WITH THE AIRCRAFT CERTIFICATION SERVICE & WILL BE DISTRIBUTED TO ALL CERTIFICATION OFFICES FOR THEIR INFORMATION & COORDINATION

WITH MANUFACTURERS FOR INCLUSION IN FUTURE DESIGN CONSIDERATIONS. BASED ON THIS INFORMATION, RECOMMENDATION A-91-71 IS CLASSIFIED AS "CLOSED--ACCEPTABLE ACTION."

Log Number 2303

Issue Date 8/14/91 | GOOSE BAY CAN | 17-Mar-91

ON MARCH 17, 1991, AT 1618 ATLANTIC STANDARD TIME, DELTA AIR LINES FLIGHT 15, LOCKHEED L-1011-385-3, N753DA, WAS EN ROUTE FROM FRANKFURT, GERMANY TO ATLANTA, GEORGIA AT FLIGHT LEVEL (FL) 330 WHEN IT EXPERIENCED A FIRE BELOW THE AFT CABIN FLOOR AND IN THE CABIN. THE FLIGHT WAS CONDUCTED UNDER THE OPERATING RULES OF PART 121 OF TITLE 14 CODE OF FEDERAL REGULATIONS (CFR) AND CARRIED 218 PASSENGERS, 10 FLIGHT ATTENDANTS, 2 PILOTS, AND 1 FLIGHT ENGINEEE. FLIGHT 15 HAD EN ROUTE FOR ABOUT 7.5 HOURS, WHEN ABOUT 180 MILES EAST OF GOOSE, BAY, LABRADOR, CANADA, A FLIGHT ATTENDANT NOTICED FLAMES RISING FROM THE BASE OF THE LEFT CABIN SIDEWALL PANEL TO THE HEIGHT OF THE SEATBACK TRAY AT THE NEXT TO LAST ROW PASSENGER SEATS (SEAT 41A). THE FLIGHT ATTENDANT PROMPTLY DISCHARGED A HALON FIRE EXTINGUSIHER INTO AN OPENING IN THE BASE OF THE SIDEWALL FROM WHICH THE FLAMES APPEARED TO ORIGINATE. THE FIRE WAS EXTINGUISHED AND A PRECAUTIONARY LANDING WAS MADE AT GOOSE BAY.

Recommendation # A-91-072

Overall Status CAAA — **CLOSED - ACCEPTABLE ALTERNATE ACTION**

Priority CLASS II

THE NTSB RECOMMENDS THAT THE FEDERAL AVIATION ADMINISTRATION: REQUIRE THAT TRANSPORT CATEGORY AIRCRAFT MANUFAC TURERS AND AIRLINES AMEND MAINTENANCE MANUALS AS NECESSARY TO ENSURE THOROUGH INSPECTION & CLEANING OF AREAS WHERE LINT AND OTHER DEBRIS MAY ACCUMULATE AND POSE A POTENTIAL FIRE HAZARD.

FAA		CLOSED - ACCEPTABLE ALTERNATE ACTION	8/13/92
10/30/91	Addressee	THE FAA HAS DRAFTED AN AIRWORTHINESS INSPECTOR'S HANDBOOK BULLETIN ENTITLED ORIGIN AND PROPAGATION OF INACCESSIBLE AIRCRAFT FIRE UNDER INFLIGHT AIRFLOW CONDITIONS. THIS BULLETIN PROVIDES INFORMATION ON THE POTENTIAL SAFETY HAZARD APPLICABLE TO ALL TRANSPORT CATEGORY AIRCRAFT FROM THE ACCUMULATION OF LINT AND OTHER DEBRIS ON WIRE BUNDLES. THIS BULLETIN REQUESTS THAT PRINCIPAL MAINTENANCE INSPECTORS DISSEMINATE THIS INFORMATION TO ALL OPERATORS OF TRANSPORT CATEGORY AIRCRAFT. THE BULLETIN ALSO REQUESTS THAT PRINCIPAL MAINTENANCE INSPECTORS REVIEW THEIR OPERATORS' MAINTENANCE PROGRAMS TO ENSURE THAT THEY INCLUDE INSPECTION OF AIRCRAFT WIRING AND REMOVAL OF CONTAMINANTS, ESPECIALLY IN ACCESSIBLE AREAS.	
4/29/92	NTSB	Letter on File	
8/13/92	Addressee	THE FAA DOES NOT AGREE WITH THIS SAFETY RECOMMENDATION. IN RESPONSE TO SAFET RECOMMENDATION A-91-71, THE FAA ISSUED HANDBOOK BULLETIN 91-15 WHICH ADDRESSES THE INSPECTION OF AIRCRAFT WIRING AND THE REMOVAL OF CONTAMINANTS, ESPECIALLY IN INACESSIBLE AREAS. I BELIEVE THAT THIS ALTERNATE ACTION ADDRESSES THIS SAFETY ISSUE.	
10/20/92	NTSB	THE BOARD NOTES THAT FAA HANDBOOK BULLETIN 91-15 ADDRESSES THE INSPECTION OF AIRCRAFT WIRING & THE REMOVAL OF CONTAMINANTS, ESPECIALLY IN INACCESSIBLE AREAS, & RECOMMENDS THAT INSPECTORS REVIEW OPERATOR'S MAINTENANCE PROGRAMS TO "ENSURE. . . EFFECTIVE QUALITY CONTROL . . ." BASED ON THIS INFORMATION, THE BOARD CLASSIFIES RECOMMENDATION A-91-72 AS "CLOSED--ACCEPTABLE ALTERNATE ACTION."	

To:	**Dean Klempel**	A Dickinson **96-1989**
Office Phone:	**227-2186**	
FAX:	**227-1181**	516-989-8236
Telephone Contact		
Date:	**October 17, 1996**	
Reported by:	**Rodney Horning**	**Phone No.: 266-8101**
FAA Contact:	**Dean Klempel**	

This FAX completes the reporting requirements of FAR 21.3 and Boeing Operations Procedure B-7000-090. Dated: 12/1/93

The following is submitted in accordance with reference procedure.

Title: Wire Bundle Arcing and Fire in Forward Lower Lobe Cargo Hold - On Ground

Airplane Identity			
Model Series	Serial No.	Date Occurred	Location
747-200 F	24177	October 12, 1996	Singapore

Product or Part Causing Event/Part No: unknown

Part Name and Function as applicable: ________

For TSO approved articles only: S/N: ________ Model: ________

If associated with engines: Model: ________ S/N: ________

Nature of failure, malfunction or defect:

The operator reported an arcing wire bundle and resultant fire at the aft bulkhead of the forward lower lobe cargo hold (BS 1000) during post C-check functional testing on the ground. The damage was to the wire bundle, insulation blankets on the bulkhead, the bulkhead itself and possibly the center tank sealant.

See attached telex for additional information.

Additional Information (i.e. fleet experience)

Everett 21.3 Focal: Dennis Capovilla (266-8221) **Renton 21.3 Focal: Meghan Gordon (237-5715)**

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PREPARED FOR: SapkosK

DATE: 14-Oct-96 11:11am PAGE: 1

View Message

Message Number:	Action File Name:	Status:
SIA-SIN-96-2545TE	SIA-SIN-96-2545TE	Closed

Model: 747-200 ATA: 2400-60

Subject: WIRE BUNDLE ARCING AND FIRE IN FOREWARD LOWER LOBE CARGO HOLD - ON GROUND

DIR 747S

/ATTN (747S) BILL STAUFENBERG - ASE MGR

SIA-SIN-96-2545TE 12 OCT 96
ATA 2400-60 MODEL 747-200
WIRE BUNDLE ARCING AND FIRE IN FOREWARD LOWER LOBE CARGO HOLD - ON GROUND
REF /A/ WDG 27-81-81 SHEET 1 PAGE 9 (AIRPLANE 301) DRAWING 61B74733, DCN BE
AIRPLANE HOURS/CYCLES
9V-SKQ
RR566
LN710

// RESEND, TO ADD INFORMATION ABOUT APPARENT LACK OF FIRE WARNING //

WE ARE SENDING THIS TELEX TO BILL STAUFENBERG.

SIA HAD AN ARCING WIRE BUNDLE AND RESULTANT FIRE AT THE AFT BULKHEAD OF THE FOREWARD LOWER LOBE CARGO HOLD (STATION 1000 BULKHEAD) ON THEIR 747-200 FREIGHTER 9V-SKQ. THIS OCCURRED WITH THE AIRPLANE ON THE GROUND, DURING POST C-CHECK FUNCTIONAL TESTING.

THE RESULTANT DAMAGE WAS TO THE WIRE BUNDLE, THE INSULATION BLANKETS ON THE BULKHEAD, AND TO THE BULKHEAD ITSELF (AND POSSIBLY TO THE CENTER TANK SEALANT, WHICH IS STILL TO BE EXAMINED). THE AIRPLANE IS CURRENTLY IN THE HANGAR UNDERGOING REPAIR.

THIS TELEX DESCRIBES THE ARCING AND FIRE. THERE IS CURRENTLY NO REQUESTED ACTION FOR YOU.

WE ARE SENDING A SEPARATE TELEX, ATA 5711-00, DESCRIBING IN DETAIL THE STRUCTURAL DAMAGE AND REQUESTING REPAIR INFORMATION FROM YOU AS SOON AS POSSIBLE.

THE SEQUENCE OF EVENTS:

- THE AIRPLANE WAS AT A PARKING BAY JUST OUTSIDE OF THE SIA HANGAR UNDERGOING POST C-CHECK FUNCTIONAL TESTING. THE APU WAS RUNNING. NO ENGINES. ALL CARGO DOORS WERE CLOSED.
- THE 'LE FLAP CONT A' CIRCUIT BREAKER HAD POPPED SOME TIME BEFORE (MINUTES, NOT HOURS).

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- THE "NUMBER 2 CCMA" CIRCUIT BREAKER POPPED.

- THE MECHANICS IN THE FLIGHT DECK SMELLED SMOKE, AND ONE WENT TO THE MAIN DECK TO INVESTIGATE.

  AT THE SAME TIME, A MECHANIC IN THE MAIN DECK SMELLED SMOKE IN THE VICINITY OF THE CARGO HANDLING POWER DRIVE UNIT 10L (ABOUT AT STATION 1000). HE PUT HIS HAND ONTO THE MAIN DECK AND FELT THAT IT WAS WARM.

- 2 MECHANICS GRABBED THE SMALLER FIRE EXTINGUISHER ON THE MAIN DECK LEFT FOREWARD SIDEWALL AND WENT DOWN TO THE FOREWARD LOWER LOBE CARGO HOLD THROUGH THE ELECTRONICS BAY. THEY FOUND IT FILLING WITH BLACK SMOKE.

- UPON REACHING HALF WAY TO THE AFT BULKHEAD, THEY NOTICED A GLOW COMING FROM BEHIND THE AFT BULKHEAD CANVAS COVER. THE GLOW WAS FROM THE BILGE AREA ON THE RIGHT SIDE OF THE AIRPLANE.

- THEY TORE DOWN THE CANVAS COVER (PARTIALLY), OBSERVED SOME FLAME, AND DISCHARGED THE FIRE EXTINGUISHER. THIS PUT OUT THE FIRE.

  ONE COMMENTED THAT THIS SEQUENCE TOOK SOME 5 MINUTES. HE WAS COUGHING A BIT AND EXPLAINED THAT HIS THROAT HURT A LITTLE.

- THE MECHANICS COMMENTED THAT THEY HAD NOT SEE ANY SMOKE DETECTION INDICATION PRIOR TO OR DURING THE EVENT.

  SIA AND WE SPECULATED THAT THEY HAD NOT SEEN ANY INDICATION BECAUSE OF ONE OR MOREOF THE FOLLOWING CONSIDERATIONS:

  - THE PERSONNEL IN THE FLIGHT DECK WERE BUSY TRYING TO IDENTIFY THE SOURCE OF THE SMOKE THEY HAD SMELLED.

  - THEY HAD MANY CIRCUIT BREAKERS PULLED DURING THEIR FUNCTIONAL TESTING AND MAY HAVE HAD THE SMOKE DETECTION POWER PULLED.

  - THE SMOKE APPARENTLY WAS CONCENTRATED BEHIND THE CANVAS COVER AT THE AFT END OF THE CARGO COMPARTMENT AND MAY NOT HAVE BEEN IN SUFFICIENT CONCENTRATION IN THE COMPARTMENT ITSELF TO TRIP THE SMOKE DETECTION SYSTEM.

DAMAGE DESCRIPTION:

- INITIALLY, PRIOR TO ANY CLEANUP, THE ENTIRE AFT BULKHEAD WAS BLACKENED WITH SMOKE. THE ASSOCIATED INSULATION BLANKETS WERE HEAVILY DAMAGED, SOME CONSIDERABLE BLANKET DEBRIS WAS IN THE BILGE, THE WIRE BUNDLE JUST INBOARD OF THE P131 PANEL WAS BLACKENED AND SEVERAL WIRES WERE SEPARATED (MANY WITH VISIBLE COPPER), AND THERE WAS VISUAL EVIDENCE OF POSSIBLE PAINT BLISTERING ON THE BULKHEAD JUST AFT OF THE WIRE BUNDLE.

- FOLLOWING CLEANUP:

  - THE WIRE BUNDLE HAD 19 SEPARATED WIRES (OF APPROXIMATELY 100). THE BUNDLE RUNS VERTICAL AT THIS LOCATION, AND IT'S ABOUT 2 INCHES IN FRONT OF THE STA 1000 BULKHEAD,

ABOUT A FOOT INBOARD OF THE P131 PANEL. THE LOCATION OF THE ARCING WAS ABOUT EVEN WITH THE P131 PANEL.

SEE BELOW FOR MORE DETAIL ON THE WIRE BUNDLE DAMAGE.

- THE CARGO LINER (AFT BULKHEAD CANVAS) WAS NOT DAMAGED, EXCEPT FOR A FEW SMUDGES. IT DID CONTAIN A NUMBER OF CUTS (1/2 TO 3 INCHES LONG), BUT NONE ALIGNED MUCH WITH THE WIRE BUNDLE DAMAGE. THIS COVER IS SOME 22-23 INCHES FOREWARD OF THE WIRE BUNDLE.

- THE STATION 1000 BULKHEAD DID EXHIBIT EVIDENCE OF HEAT DAMAGE, IN 4 LOCATIONS:

  - A 4 X 10 INCH WEB AREA RIGHT BEHIND THE ARCING LOCATION - THIS LOCATION HAD A SIMILAR SIZED PAINT BLISTER ABOUT 1/4 INCH AWAY FROM THE BULKHEAD. ADDITIONALLY, THE BULKHEAD WAS BULGED OUT ABOUT 0.1 INCH.

  - A SIMILAR SIZED AREA JUST BELOW THIS ONE, WITH PARTIALLY BLISTERED PAINT.

  - 2 OTHER AREAS SOME DISTANCE FROM THE WIRE BUNDLE, WITH LITTLE VISUAL BLISTERED PAINT.

NOTE - SEE THE ASSOCIATED TELEX, ATA 5711-00, FOR MORE DETAILS.

REPAIR PLANS:

- SIA IS ASKING FOR BOEING ASSISTANCE IN THE STRUCTURAL REPAIR OF THE STATION 1000 BULKHEAD.

- SIA IS ASKING FOR BOEING ASSISTANCE IN WHAT TO LOOK FOR INSIDE THE CENTER TANK, IN THE WAY OF POSSIBLE DAMAGE TO THE CENTER TANK SEALANT.

- SIA IS IN THE PROCESS OF REPLACING ALL THE WIRES IN THE BUNDLE IN THE VICINITY OF THE ARCING.

- SIA IS ALSO REPAIRING ALL OF THE WIRING DAMAGED BY THE HEAT FROM THE RESULTANT FIRE (SMALLER WIRE BUNDLES MOSTLY IN THE BILGE AREA NEAR THE STATION 1000 BULKHEAD).

WIRING DAMAGE:

- THE SEPARATED WIRES WERE:

W834-G920
-G942
-G943
-(UNREADABLE)

W846-G927

W1524-C1757
-C1758
-C1759
-C1760
-C1771
-C2136

4/5

PREPARED FOR: Sap

DATE: 14-Oct-96 11:11am PAGE:

-C2137

W370-C2136
-C2137
-(5 MORE UNREADABLE)

- THE P131 PANEL CONTENTS APPEAR TO BE HEAT DAMAGED.
- A SO FAR UNIDENTIFIED WIRE BUNDLE ON THE RIGHT SIDEWALL NEAR THE STATION 1000 BULKHEAD IS DAMAGED (WITH VISIBLE COPPER).

OUR INVESTIGATION:

SIA AND WE HAVE REVIEWED THE WIRING DIAGRAM WIRE LIST AND THE REF /A/ DIAGRAM, AND WE HAVE DISCOVERED THE FOLLOWING:

- ALL OF THE ABOVE IDENTIFIED WIRES ARE ATAS 27-81 AND 32-35.

  NONE ARE ASSOCIATED WITH THE ENGINE-2 CCMA. HOWEVER, WE MAY NOT YET HAVE FOUND ALL THE DAMAGED WIRES, OR THE CCMA BREAKER POPPING MAY HAVE BEEN FROM THE HEAT DAMAGE TO THE P131 PANEL.

- THE REF /A/ DIAGRAM INDICATES THAT A NUMBER OF THE ABOVE IDENTIFIED WIRES WERE FED 115 V AC FROM CB C26 "PRIMARY LEADING EDGE FLAP CONTROL A", THROUGH WIRES W370-C2117-18 AND W370-C2118-18 (DRAWN JUST ABOVE THEP131 PANEL IN THE DIAGRAM).

WE HAVE TAKEN A 36-PHOTO ROLL OF 35 MM FILM OF THE AIRPLANE. WE PLAN TO HAVE IT DEVELOPED BY MONDAY, AND WE WILL SEND THE PHOTOS TO YOU APPROXIMATELY BY TUES.

SIA PLANS TO PROVIDE TO US THE REMOVED WIRES FROM THE ARCING WIRE BUNDLE, AND WE WILL SEND THEM TO YOU FOR YOUR EXAMINATION.

R NOVA BOEING CUSTOMER SERVICES SINGAPORE

BOESEA-X2RI01-00204-10/12/96-1355Z
@BFSDEN@TEL MAIL M7420 MAIL
/

BOESEA-X2RI01-00204-10/12/96-1355Z

FSE-BOECOM SAT 10/12/96 23:07:12
BOESEA-X2SO01-00002-10/12/96-1507Z

CIVIL AVIATION AUTHORITY OF SINGAPORE
AIRWORTHINESS & FLIGHT OPERATIONS DIVISION
ROOM NO.046-025, 4TH STOREY TERMINAL 2
SINGAPORE CHANGI AIRPORT
SINGAPORE 819643
REPUBLIC OF SINGAPORE

CAAS

FACSIMILE MESSAGE (URGENT/IMMEDIATE/NORMAL)
(if you received this telefax in error, please contact the undersigned)

To : MR THOMAS E HAUETER ACTING CHIEF, MAJOR INVESTIGATIONS DIVISION NTSB, USA		Fax: (202) -314-6319
From: HO SEE HAI INSPECTOR OF ACCIDENTS		Tel: (65) 541-2476 Fax: (65) 545 6519
Page 1 of 8	Ref: AW/AAI/AIB.US	Date: 21 OCTOBER 1996

Dear Mr Haueter

B747-200 CARGO HOLD FIRE

Please refer to your fax letter of 17 Oct 96.

2 On 12 Oct 96, the subject aircraft had undergone scheduled maintenance and was being wrapped up. Maintenance work in the forward cargo hold area had been completed and the cargo hold door was closed.

3 While performing the last tests in the flight deck, the maintenance crew smelt smoke. They shutdown immediately the APU which was supply electrical power and airconditioning air and investigated the cause of the smell. Other maintenance personnel on the main deck could feel the floor board was warm.

4 The maintenance crew made their way from the main equipment centre to the cargo hold and spotted glows at the front spar of the centre wing tank. They put out the fires quickly.

5 Please refer to Sketch 1. Imagine you are in the lower forward cargo hold looking aft. The front spar of the centre wing tank is the rectangle in the sketch. Fire had broken out at a bundle of wires (darkened) at location 1, next to junction box P131. The fire could have spreaded down causing the glows seen by the maintenance personnel who fought the fire.

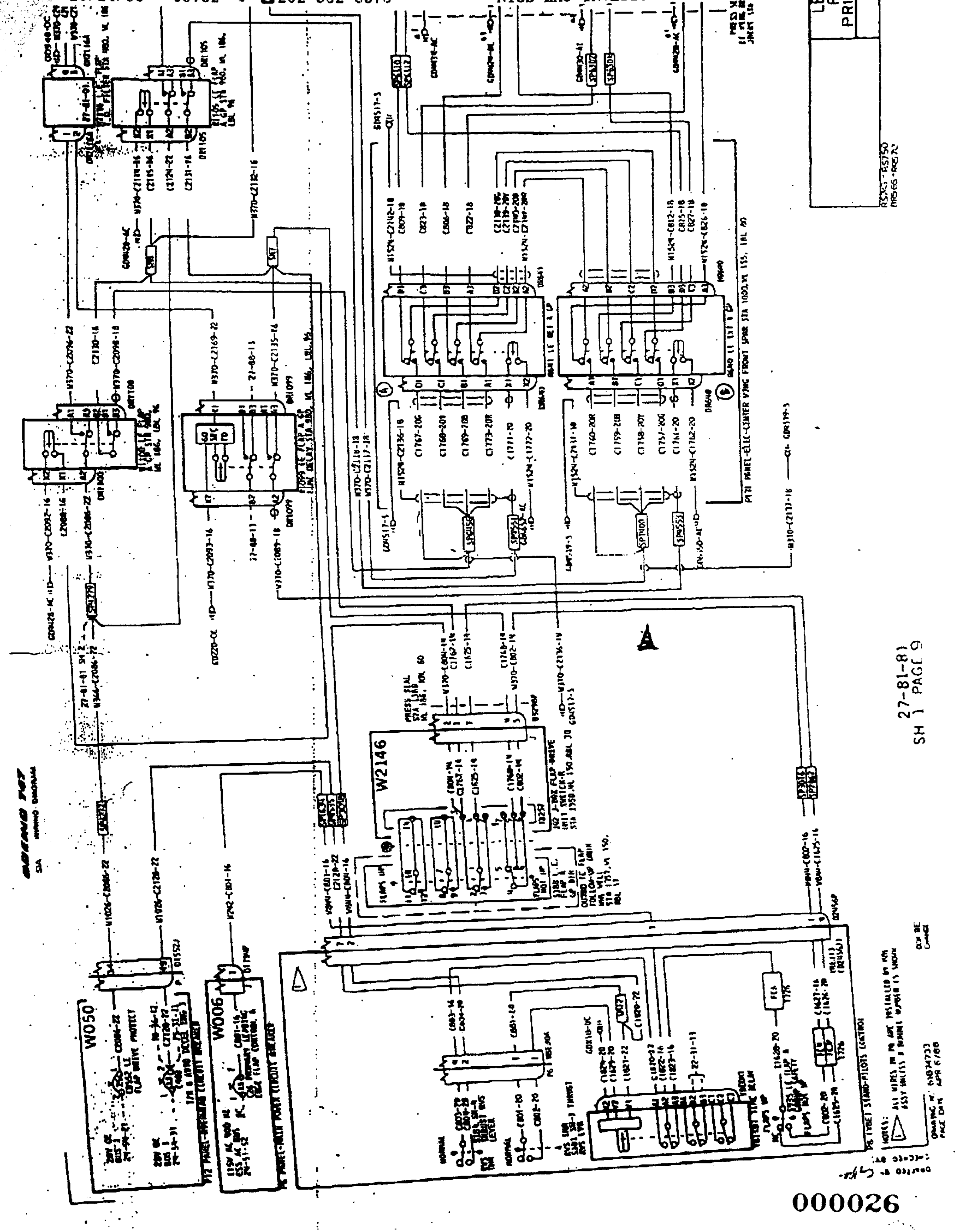
6 The locations shown as A,B,C and D were found to be affected by heat and a conductivity test was carried out in those areas. These areas were found to have been affected beyond the Boeing Structural Repair Manual limits.

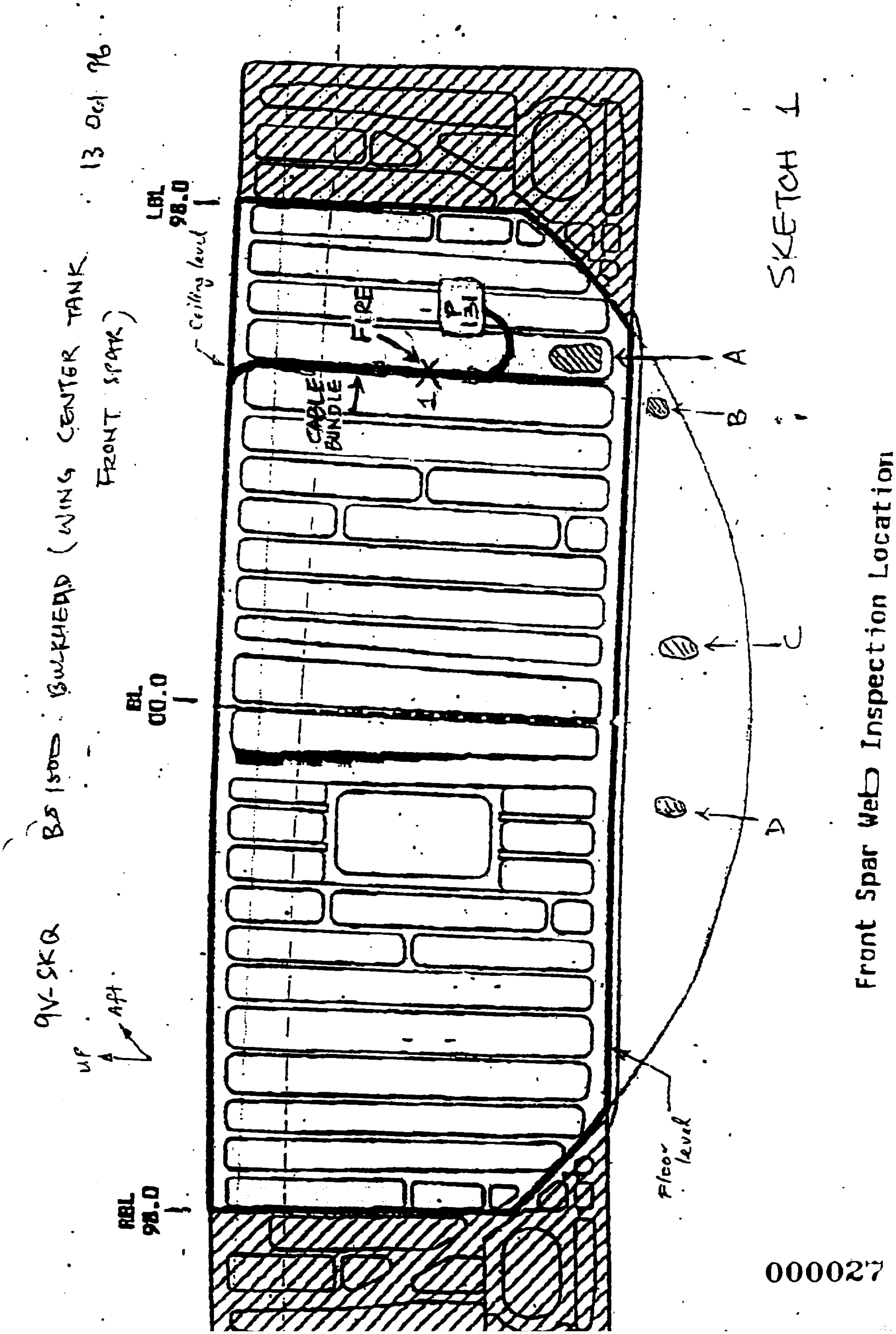
7 The fire was thought to have started at splice SP7400 indicated with a dark triangle on Sh1 page 9 of Boeing Wiring Diagram 27-81-81 (attached). The suspect splice was couriered to Boeing and we are expecting a response from Boeing on 21 Oct 96.

8 There was no evidence that the wire bundle had suffered prior damage by cargo. The intact cargo liner is a good 20 odd inches from the insulation blanket and the cables.

9 Sketches 2, 3 and 4 show the details of the affected areas A, B and C. Sketch 5 (a mirror image of sketch 4) shows affected area D. We will provide more information as soon as Boeing gets back to us. In the meantime if there is anything else you need please do not hesitate to contact me.

HO SEE HAI
for DIRECTOR-GENERAL OF CIVIL AVIATION


W050
W006
W2146
27-81-81
SH 1 PAGE 9


9V-SKQ
BS 1500 BULKHEAD (WING CENTER TANK FRONT SPAR)
13 Oct 96
SKETCH 1
UP
AFT
LBL 98.0
BL 00.0
RBL 98.0
Ceiling level
Floor level
FIRE
CABLE BUNDLE
1
A
B
C
D
Front Spar Web Inspection Location

)ENT

aft Type and Registration:	Boeing 747-136, G-AWNO	
& Type of Engines:	4 Pratt & Whitney JT9D-7A turbofan engines	
ar of Manufacture:	1973	
te & Time (UTC):	8 February 1996	
cation:	O'Hare Airport, Chicago	
pe of Flight:	Public Transport	
ersons on Board:	Crew - 18	Passengers - Not known
njuries:	Crew - Nil	Passengers - N/A
Nature of Damage:	Damage confined to Flight Attendant's control panel at door 4R	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	54 years	
Commander's Flying Experience:	15,000 hours (of which 8,000 were on type) Last 90 days - 194 hours Last 28 days - 37 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot and additional investigations by AAIB	

On arrival at Chicago, the cabin crew reported that, during the landing, sparks and audible arcing had been coming from the cabin attendant's control panel at door 4R and that a localised fire had been extinguished. The control panel was removed and the connector and electrical wiring to the panel were temporarily insulated for the return flight to London. The damage had been confined to this panel, on which the wiring and Passenger Services System/Passenger Entertainment System (PSS/PES) switches were burned and melted.

Investigation of the damaged panel, by the operator, showed that the PSS ON/OFF switch, which carries the 115 Vac and 28V DC supplies on the panel, had experienced severe electrical and heat damage. This had been attributed initially to moisture ingress allowing the 115 Vac supply to arc across the contacts, however, the panel had been repaired and the switch disposed of before the AAIB became involved, so it was not possible to examine any of these damaged parts further. The operator was aware of several similar previous occurrences, and the UK CAA's database identified eight occurrences which were possibly related.

During the course of this investigation, a similar panel, from another of the operator's 747 fleet, was returned for overhaul with a similar defect. This had not been the subject of an air safety report and had not created any significant problems in the cabin. The AAIB's examination of this second damaged panel showed that a similar switch, with the same type of internal mechanism and performing the same function, had burned, causing considerable sooting of adjacent switches, the wiring loom and the panel itself. The stainless steel switch casing had been burned through and the internal plastic parts were destroyed. Resistance checks showed that several of the switch pin terminals had low resistance paths to earth. Further investigation of the door 4R area on several aircraft suggested that this panel was reasonably well protected from moisture ingress and that this was unlikely to have contributed to the cause of the switch failure.

The Boeing Commercial Airplane Group advised AAIB that several similar switch failures had been investigated by the manufacturer and moisture was not considered to be a factor. The problem had been identified as a mechanical failure of the switch internal mechanism creating a short circuit between 115 Vac and ground. Boeing advised that there was sufficient energy in such a short circuit to cause a limited fire and burn through the switch. Boeing also advised that, as a result of their investigations, an Alert Service Bulletin (ASB) 747-33-2252 was being prepared which would provide modification instructions to operators. This Service Bulletin will recommend that a new type of switch be installed, with an improved mechanism to prevent a short circuit from power to ground in the event of a mechanical failure. Following an evaluation of the first switches, in July, it was anticipated that the ASB and parts will be available to operators in October.

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16. Abstract

On May 9, 1976, an Imperial Iranian Air Force Boeing 747-131 crashed as it approached Madrid, Spain. Witnesses observed lightning strike the aircraft followed by fire, explosion, and separation of the left wing. The report includes fire pattern studies, structural failure descriptions, trajectory analysis, fuel flammability calculations, gust loading analysis, and an analytical treatment of several hypotheses.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D. C. 20594

SPECIAL INVESTIGATION REPORT

ed: October 6, 1978

WING FAILURE OF BOEING 747-131
NEAR MADRID, SPAIN
MAY 9, 1976

INTRODUCTION

On May 9, 1976, an Imperial Iranian Air Force (IIAF) B-747-131, t ULF48, crashed near Madrid, Spain. The aircraft was a military tics flight en route to McGuire Air Force Base, U.S.A., from Teheran, with an intermediate stop at Madrid, Spain. The plane crashed g daylight at approximately 1430 G.m.t. while the aircraft was aching Madrid. It was reported that the left wing had separated the aircraft during flight. Since this was a military aircraft, er the Convention on International Civil Aviation nor any of its es applied to the investigation. Nevertheless, in a manner similar at described in the ICAO Convention, the Spanish Government delegated nvestigation to the Iranian Government.

Since the aircraft involved was a Boeing 747, a type used extensively ommercial operations worldwide, and, in view of the nature of the ident, the United States National Transportation Safety Board requested an was granted permission to assist in the investigation.

As the field phase of the investigation progressed, investigators realized that the determination of the cause of the wing failure would require extensive studies and examinations. An agreement was reached with the Governments involved to transport the left wing and engines to the United States where closer proximity of pertinent industry and necessary facilities would expedite the investigation. The wing was cut into manageable pieces and transported to the United States by the Iranian Air Force and commercial aircraft. The parts were fumigated at the port-of-entry and trucked to Atlantic City, New Jersey. The wing was reassembled in a mockup at the Federal Aviation Administration's National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

The National Transportation Safety Board requested that the American aviation industry assist in the examination of the left wing. In a period of over a year the aviation industry provided 48 specialists with various engineering expertise, material and logistic support, extensive data, and special studies. The IIAF continued to supply support via flight test aircraft and participation in the wing and wing parts examinations.

The Federal Aviation Administration, the National Aeronautics and Space Administration, the U.S. Air Force, and the U.S. Army provided experts, special studies, materials, and logistic assistance. Various specialists, studies of CVR tapes, and operational information were provided by American Airlines, United Airlines, Pan American World Airways, Trans World Airlines, and the Air Line Pilots Association. The Fenwall Corporation, Pratt & Whitney Corporation, and the Minneapolis Honeywell Corporation assisted in special examinations and research. Consultants were provided by the General Electric Company and the Batelle Institute. Specialists in aerodynamics, structures, and metals were provided by the Boeing Company, the Douglas Aircraft Corporation, Lockheed Georgia, and Lockheed California. These Government and industry personnel produced over 100 investigative reports.

Several hypotheses of possible causes of the wing failure are presented in this report. One hypothesis is that an explosion in a fuel tank destroyed the left wing and that lightning-strike currents ignited the tank explosion. Another credible hypothesis is that severe turbulence was encountered which caused the wing to fail as a result of structural overloads.

BACKGROUND INFORMATION

History of the Flight

On May 9, 1976, Imperial Iranian Air Force Flight 228, a Boeing 747-131, serial No. 5-283, was being operated as a military logistic flight from Teheran, Iran, to McGuire Air Force Base, New Jersey, with en route stop at Madrid, Spain.

The aircraft departed Merhabad Airport as Flight ULF48 at 0820 1/ for Barajas Airport, Madrid, Spain, with 10 crewmembers and 7 passengers aboard. The estimated time of arrival was 1450. The planned flight altitude was flight level (FL) 330. At 1415, about 26 minutes before the accident, ULF48 gave an estimated time of arrival of 1440. At 1419, Madrid control issued a clearance to CPL VOR via Castejon and advised the flight that radar contact had been acquired.

At 1422 ULF48 was given the Madrid weather. At 1425 Madrid control cleared ULF48 down to FL 100. ULF48 acknowledged and reported that he was leaving FL 270. At 1430 he advised Madrid that he was diverting to the left because of thunderstorm activity, and at 1432 Madrid cleared ULF48 to 5,000 ft and directed him to contact Madrid approach control.

At 1433 the flightcrew of ULF48 contacted Madrid approach control and advised them that there was too much weather activity ahead and requested to be vectored around it. Madrid advised ULF48 of radar

1/ All times herein are Greenwich mean time, unless otherwise indicated.

contact and asked confirmation of this request for vectors. The flightcrew confirmed their request and advised they were left of course and were going to CPL. Madrid advised ULF48 to proceed on a heading of 260°. The crew acknowledged the heading and informed Madrid that they were descending to 5,000 ft. This was the last radio contact with ULF48 although Madrid made several attempts for further contact. The aircraft crashed on farmland at an elevation of 3,000 ft m.s.l.

Aircraft Information

The aircraft was purchased from Trans World Airlines and delivered to the Imperial Iranian Air Force on March 1, 1976. Before delivery all Airworthiness Directives (AD) were complied with and a large cargo door was installed on the left side of the fuselage by the Boeing Company at Wichita, Kansas.

The aircraft was last inspected by the Imperial Iranian Air Force on May 4, 1976; the aircraft had accumulated 14 hours since that inspection. Maintenance records for the aircraft were not available for specialists to review in the United States.

When ULF48 departed Teheran, its gross weight was 610,299 lbs, which included 254,600 lbs of fuel, a mixture of JP-4 and jet-A types. The center of gravity was within allowable limits.

Witness Observations and Weather

At the time of the accident the weather was cloudy with rain and lightning; visibility was good. Severe thunderstorms were in the area, and in fact, the day is remembered by local witnesses as "the day of the storm."

All witnesses were located south of Valdemoro and along the probable aircraft flightpath. At least two witnesses reported seeing lightning strike the aircraft. Some stated that they saw an in-flight fire confined to the No. 1 engine; others stated that they only saw the aircraft flying in and out of clouds. Those witnesses who reported seeing the in-flight explosion and fire followed by in-flight separation of parts, agreed that the time of occurrence was 1630 local, that the aircraft's altitude was about 6,000 ft above the ground, and that the aircraft's magnetic heading was about 220°.

There were no pilot weather reports, radar weather observations, or satellite weather observations available pertinent to the time and place of the accident. Surface and upper air charts for 1200, prepared by the Meteorological Analysis Center at Madrid, showed a closed low-pressure system that was centered over Spain.

A theory was developed that considered the engine fan rub, the engine mount damages, and the damage pattern of the wing outboard of the No. 1 engine position. It was proposed that, if the upper skin plank above and inboard of the No. 1 engine position had come loose for some reason, the aeroelastic properties of the wing and in particular the outboard section of wing, would be drastically changed. In addition, the loss of box structure integrity could lead to some loss of engine support which in turn resulted in fan rubbing and engine oscillations. According to this theory, the damages to the wingtip can be attributed to such oscillations. The overall conclusion would then be that the wing had not failed because of gusts or turbulence, but failed because of the original event in the wing box structure, which was caused by the loosening of the plank.

CONCLUSIONS

After analyzing all of the available evidence, it is concluded that the most probable sequence of events which culminated with multiple structural failures and separation of the wing began with an ignition of the fuel vapors in the No. 1 fuel tank. The damage to the structure in the area of the tank provided positive indications of an explosion.

The possibility that the explosion was a secondary result of structural failure caused by excessive aerodynamic forces developed during high velocity gusts and turbulence cannot be completely dismissed; however, the evidence and the probabilities of an aircraft's encountering these unique environmental conditions make this hypothesis less supportable.

Ignition of Fuel Vapor in No. 1 Fuel Tank

By accepting the hypothesis that the explosion in the No. 1 tank was the first destructive event, the various wing failures can be explained as follows: The explosion failed the fasteners that held the stringers to the ribs and the skin to the spars; the integrity of the aft wing box was lost as a result, which greatly reduced the torsional strength of the wing; and support of the No. 1 engine in the pitch plane also was lost. The fact that explosive forces could be developed in the tank verified that the wing skin forming the top of the tank was whole before the explosion. The probable sequence of wing destruction follows:

(1) Overpressure was generated in the No. 1 fuel tank as a result of ignited fuel vapors. The location of this overpressure was the aft outboard corner of the tank adjacent to the closure rib or the nacelle rib.

(2) Because of the overpressure, the upper skin panel, including stiffeners, pulled loose from ribs inboard of the nacelle rib and aft of the midspar. The stringer to rib fasteners separated by combined tension and shear, which resulted from the overpressure and subsequent inboard displacement of ribs at WS 1140 and WS 1168.

(3) The inboard displacement of the ribs ruptured the rib attachments to the lower surface and spars, and the ribs became detached.

(4) The upper skin panel billowed upward because of the explosion until bending fractures occurred at the mid and rear spars and the fasteners were sheared. The failure began at WS 1140 and progressed inboard and outboard from that position.

(5) The upper skin shear tie attachments at the nacelle support rib and the flap track support rib fractured in bending because of the continued upward movement of the upper surface. The upper surface stiffener ties to the nacelle rib separated because of the outboard movement of the nacelle rib; the outboard movement was caused by the overpressure on the inboard side.

(6) When the upper wing skin panel which was attached to the mid and rear spars separated, the aeroelastic properties of the wing, and especially the outboard section of wing were altered drastically.

(7) The stiffness of the No. 1 engine mount was greatly reduced in the pitch axis by the loosening of the skin and the resultant loss of wing box integrity.

(8) The loss of structural integrity of the wing box permitted increased torsional deflection of the wing.

(9) The outer wing began to oscillate, and lateral loads were generated by the vibrating engine.

(10) The oscillations developed inertial loads on the high-frequency antenna and outer tip and caused them to separat

(11) The changing aerodynamic load on the outer wing and the lateral forces generated by the oscillating engine caused compression failures in the upper skin above the deflecting rear spar. This compression fracture progressed over the whole span of upper wing skin.

(12) The front box maintained the structural integrity of the forward wing until oscillations of the outer wing (torsional bending) and engine-induced lateral loads caused its destruction.

Lightning As An Ignition Source

Based on the hypothesis that an explosion occurred in the No. 1 fuel tank, the lightning strike became a plausible source of ignition. During its descent into Madrid and shortly after descending through 10,000 ft, the aircraft was apparently struck by lightning. The following observations and events support this hypothesis:

(1) The cockpit statement of too much "activity" in front and the request for a vector around 130 seconds before the end of the CVR recording;

(2) the cockpit discussion about an active "CB" in front 86 seconds before the end of the CVR;

(3) the cockpit remark about being "in the soup;"

(4) the audible sound and electrical transients on the CVR recording 52 seconds before the end of the recording;

(5) eyewitness reports: One who said lightning struck the aircraft "midway between the (No. 1) engine and the wingtip," and another who reported seeing the aircraft get struck with lightning that "wouldn't go away" and the aircraft "flying off in flames;"

(6) surface weather reports of cumulus clouds or thunderstorm activity in the area; and

(7) the physical evidence of lightning attach points on the wreckage.

This evidence indicated the following plausible sequence of events: The lightning first entered a forward part of the aircraft, perhaps on top of the cockpit, and exited from a static discharger on the left wingtip. As the aircraft continued forward, the flash hung on to the initial attachment point until the vertical fin reached the location where the forward part had originally been. The flash then reattached to the vertical fin and continued to exit from the left wingtip.

The lightning current's conductive path to the static discharger at the tip was through a bond strap along the trailing edge. Concentration of current at the riveted joint between this bond strap and a wing rib caused melting and release of molten metal and gasses; these were sufficiently conductive to cause the flash to reattach to this rivet and to leave the discharger.

Before the apparent lightning strike, there were no unusual noises, or sounds of turbulence on the CVR recording. Immediately after an explosion was heard, there were sounds of objects bouncing around, some crashing sounds, and a discussion about loss of control.

The fact that the explosion occurred right after the theorized lightning strike and in the wing which conducted the current suggests that a strike is plausible and was the cause. The strike current would have had to ignite the JP-4 fuel which was in the flammable range. Several possible places for the fuel to ignite were examined.

The vent outlet--Fuel did not ignite at the fuel vent outlet. The lightning did not strike the outlet nor anywhere near it. Furthermore, the aircraft was descending, and air would have been flowing into the outlet and not out of it. Evidence indicated that the surge tank's protective system was operable but was not activated by a flame in the vent.

Holes melted through tank skins--Neither lightning attachment points nor holes were found on any of the fuel tank skins. Thus, it was concluded that fuel did not ignite as a direct result of lightning attaching to the skin.

Electrical sparks at structural joints in fuel tank walls and skins--The possibility of ignition by this cause was remote since the structure was so massive.

Access doors and filler caps--The access doors and filler caps are not located in probable lightning-strike zones on the aircraft; no strike evidence was found on them; and they were coated with conductive material to guard against the very remote possibility that they could be struck.

Sparking at fuel quantity measurement devices as a result of induced voltages--Fuel did not ignite at the overfill compensator probe located in the wingtip. Tests showed that it took more voltage to spark the probe than would conceivably be induced in its wiring; microscopic examination found no evidence of sparking; and the other fuel-quantity probes were similar to the compensator probe, so the possibility of a spark in them was equally as remote.

Couplings in plumbing--An electrical spark at one of the fuel line couplings was a possibility because these couplings present points of intermittent electrical contact where sparks may occur. Electrical tests of two couplings removed from the IIAF B-747 showed both the ability and inability to carry currents of probable magnitudes associated with a lightning strike. The variation was apparently caused by the wear of the insulating coating within the coupling. The fuel lines were electrically connected to tank structure which provides a circuit for flowing currents. If this circuit is interrupted or intermittent, sparking may occur.

Twenty-nine fuel line couplings were inspected, but no marks to indicate electrical sparking were found.

<u>Motor-operated fuel valves</u>--Several motor-operated valves were present in the fuel tanks, and the electric motors which operate these valves were mounted on the outside surfaces of the front or rear spar. The motors were connected to the valves by mechanical couplings or drive shafts which penetrate the spars. The motor for the valve in the No. 1 fuel tank at WS 1168 was never recovered. The drive shaft was found and was determined to be electrically insulated from the valve housing. If the shaft were for some reason electrically insulated at the spar penetration, the mechanical-coupling/drive-shaft arrangement may have provided a path for an electric current to enter the tank and cause a spark. The level of residual magnetic field strength in this area of the wing was indicative of high currents. Lightning certification tests indicated that this area about the rear spar was a lightning attachment zone.

A domestic carrier experienced electrical failures in several motors of the fuel valves after the aircraft was struck by lightning. Lightning currents penetrated the motor circuits and short-circuited electrical filters which disabled the motors.

The evidence (1) that the explosion in the No. 1 tank occurred in the immediate area of a motor-driven fuel valve, (2) that the motor was never recovered, (3) that a high level of residual magnetic field still existed in the ferrous material at this area, (4) that certification tests showed this area to be a likely lightning-attachment point, (5) that the lightning strike is known to have disabled the motors on other aircraft, and (6) that no other possible ignition source could be determined provides a foundation for an hypothesis that the tank explosion could have been ignited by a spark at this motor-driven valve.

<u>Similar systems on other aircraft</u>--Assuming that a lightning strike can generate a source of ignition to fuel vapors, aircraft fuel explosions could occur more frequently. However, events must combine simultaneously to create the explosion, and this combination would occur rarely. In this case, the events were:

(1) An intermittently conductive path which closed and opened an electrical loop, (2) a lightning-induced current of sufficient intensity flowed in this path and formed a spark, and (3) a flammable vapor surrounded this spark.

Possibly this combination of events has occurred a number of times before, in the following accidents:

* Milan, Italy (Constellation)
* Elkton, Maryland (B-707)
* Madrid, Spain (USAF KC-135)
* KSC, Florida (USAF F-4)
* Pacallpa, Peru (L-188)

Evidence of a lightning strike to a wing followed by an explosion in the same wing exists in each of these cases, yet no specific lightning-related cause, such as ignition at a vent outlet, was found.

Structural Overload due to Gust Penetration or Turbulence

The most likely alternative to destruction of the wing by lightning and explosion is its destruction by turbulence. This alternative gains credibility if much of the evidence is interpreted accordingly.

The CVR tape shows that violent weather conditions existed along the flightpath. The aircraft was vectored around one thunderstorm but another lay ahead. The captain's remark that the weather ahead "will tear us apart" if entered, and another crewmember's remark that "we're in the soup" after the captain's statement could indicate that the aircraft had entered the thunderstorm.

The fracture of the upper skin plank at WS 1300, which was concluded to be the initiating skin-plank failure point, was caused by compression when the wing bent from an upward gust. The crack propagation from this initial fracture was compatible in type and direction to that which would be created by severe compression.

The NASA studies proved that, when horizontal gust components are considered, loads could be developed at below-stall angles of attack which would cause the wing to fail structurally. However, evidence against the gust-turbulence hypothesis must also be considered.

Although conversations on the CVR tape allude to possible turbulence, the voices are calm and unshaken, and exhaustive examinations of the tape did not reveal evidence of turbulence before the lightning strike and explosion.

The absence of turbulence might also be interpreted from the soot tracings within the fuel tank along the front spar. These show that the surface of the fuel was relatively calm when the vapors were ignited. This would not have been the case if the fuel were sloshing because of turbulence.

The wing parts first found on the ground were neatly and orderly arranged in a pattern. Heavy, dense objects were deposited to the right of the aircraft's course, and light objects of low-density were to the left of the course. This pattern would not likely have occurred if turbulence was involved. Gusting winds would have deposited the material in an intermixed and random order on the ground.

Wing loads cannot be carried through the flexibly mounted No. 1 tank access doors. These doors, however, did fail from pressure loads resulting from an explosion. It is questionable whether pressure of sufficient magnitude to fail these doors could have developed in the tank space if the wing tank were open and not enclosed by skin planking.

Finally, structural experts have offered the opinion that gusts of sufficient magnitude to cause wing failure would also have caused the engine mounts to fail. These mounts are fused to fail at lesser loads than the wing, as a safety measure. The fuses held. In addition, the experts also believe that severe gust loads would cause the front spar to fail first, and that subsequently large sections of the wing would fall off the aircraft. Such gust loads would not be likely to tear off the high-frequency antenna and tip structure as separate pieces from the wingtip.

Nonetheless, the NASA analysis did show that the most significant conclusion of this study is that turbulence alone can impose loads which exceed the ultimate design loads of the airplane structure. No "new" or generic problem surfaced during this analysis; however, the accident does serve as a reminder that turbulence associated with thunderstorms can impose loads sufficient to cause failure of the primary structural elements of modern transport aircraft.

FINDINGS AND PLAUSIBLE HYPOTHESES

(1) The aircraft was fueled with a mixture of JP-4 and Jet A fuels.

(2) Lightning struck the aircraft an instant before an explosion.

(3) The first wreckage on the ground contained a considerable number of parts of the left wing outboard of No. 1 engine.

(4) Damage to the wing in the area of the No. 1 fuel tank was the result of a low-order explosion.

(5) The ullage of the No. 1 fuel tank contained a flammable mixture of fuel.

(6) Pressures provided by the ignited fuel were sufficient to cause the damages.

(7) Three fires occurred--in No. 2 tank, in No. 1 tank, and in the wingtip surge tank.

(8) The crushing or collapsing of the fuel tube in No. 1 tank required an application of pressure only available from an explosion.

(9) The pressure required to detach the stringers and skin from the wing were in the range of pressures developed by the explosion.

(10) The first deposit of wreckage formed a pattern of light objects downwind and heavy objects upwind. This pattern is not compatible with gusting or turbulent wind conditions, but is compatible with an explosion in calm or steady wind conditions.

(11) The high-frequency antenna and wingtip edge were snapped off the wing by inertial loads developed by an oscillating outer wing.

(12) The loosening of the stringer/plank unit from the wing destroyed the aft wing box of the wing.

(13) Extreme engine oscillations developed as a result of wing box damage.

(14) The loss of the rear box structure allowed the wing to twist torsionally and to deflect up and down about the rear spar.

(15) The first objects along the flightpath were units from inside the No. 1 fuel tank.

(16) The three areas of fire within the left wing contained electrical devices.

(17) The highest level of residual magnetic field was along the rear spar aft of the No. 1 tank. A motor normally mounted in this position was never found.

(18) Damages to the fuel tank access doors could only result from inside pressure. No structure loads were applied to these doors.

(19) The 28-Hz oscillations superimposed on the powerline were in the area of the third harmonic of the wing oscillations (9 Hz) which were attributed to engine fan rub in the early service history of the B-747.

(20) The inertial damage to the extreme wingtip (high-frequency antenna and coupler) could result only if the inboard section of the wingtip was still attached to the inner wing.

(21) Throttle lever vibration in synchronization with the wing oscillations was observed during previous incidents.

(22) The damages to the wingtip cannot be caused by gust loads or aerodynamic loads. They were due to wing oscillations.

(23) The wing oscillations were the result of rear box failure.

(24) The deformation to rib WS 1168 was caused by pressure loads before it separated from the wing along with the jettison fuel line.

(25) The flight control difficulty mentioned on the CVR was probably related to the outer wing damages.

(26) The crossover vent duct for the forward outboard end of the No. 1 tank was severely burned; the aft end was never recovered.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ FRANCES H. McADAMS
Member

/s/ PHILIP A. HOGUE
Member

October 6, 1978

Mr. Horff

2/13/79

AFS-140

NTSB Special Investigation Report No. NTSB-AAR-78-12, Wing Failure of Boeing 747-131, near Madrid, Spain, May 9, 1976

Acting Director, Flight Standards Service, AFS-1

ANW-1

The subject NTSB report indicates that a low-order explosion resulting from lightning-induced ignition of the fuel vapors in the No. 1 fuel tank was the most probable cause of wing failure and loss of control. Since the NTSB did not have statutory authority to make any recommendations for corrective action, the following comments on the report are provided for your consideration in developing whatever measures may be appropriate to prevent a recurrence of this accident. These comments focus on the following findings in the report pertaining to probable ignition sources and are numbered accordingly:

1. Fuel did not ignite at the overfill compensator probe located in the wingtip (pg. 24).

2. The evidence gathered from examination of the vent ducts and upper wing skin established that flames did not travel between the surge tank and the No. 1 and the No. 2 main tanks (pg. 14).

3. The evidence . . . provides a foundation for a hypothesis that the tank explosion could have been ignited by a spark at this motor-driven valve (pg. 25).

Comments:

1. The NTSB concludes that the overfill compensator in the left wingtip surge tank was not an ignition source since microscopic examination found no evidence of sparking (sparkover marks). This conclusion is qualified, however, by the notations on pg. 12 that "energy levels required to produce a spark will not necessarily damage metal or leave marks" and on pg. 15 that "a 4-millijoule spark would have provided sufficient energy to ignite the fuel. This level of spark energy will not necessarily leave physical evidence."

The enclosed photographs show the localized burned and melted portions of the plastic sleeves of the compensator wiring harness where the black unshielded leadwire joins the HI Z leadwire. This is the same area where flashover to the HI Z terminal was observed at 6.9 kilovolts during voltage breakdown tests on new compensators as shown in the enclosed Figure A-6 from the test report. Evidence of arcing was difficult to detect following these tests. It may be noted in the photographs that the bottom edge of the leadwire plastic support is also burned and that a side of the plastic sleeve around the WI Z and black leadwires is not burned. In view of the fact that flammable fuel vapors can be ignited by a very low electrical energy which is less than that required to produce any physical evidence and in consideration of the internal condition of the compensator, we suggest that a careful review should be given of the compensator as a possible ignition source.

2. We concur with the NTSB conclusion that flames did not travel between the surge tank and the No. 1 and No. 2 main tanks, however, the report does not refer to the soot and temperature patterns in the No. 1 main tank vent in the surge tank which could indicate ignition of fuel vapor at the trough of the No. 1 main tank vent above the compensator and flame propagation in-board within the vent. This flame front apparently trailed into the airstream after leaving the surge tank when the top skin over the vent in the dry bay between the surge tank and the No. 1 main tank separated prior to wing tip separation. The matter of interest here is the likelihood that the possible ignition source in the compensator might have initiated a flame front which would have propagated through the vent from the surge tank into the No. 1 main tank if there had not already been an explosion created by another ignition source in the No. 1 main tank.

3. The subject NTSB report concludes that the probable ignition source in the No. 1 main tank could have been a spark at the main tank transfer valve and refers to electrical failures experienced by a domestic carrier in several motors of the fuel valves after the aircraft was struck by lightning. The intent of the NTSB is apparent in pointing out that the main tank transfer valve was affected by lightning strikes to at least two B747 aircraft.

It is considered that the subject NTSB report, in conjunction with our supplementary discussion, warrants your review of the B747 fuel system, including the compensator and main tank transfer valve, from a lightning protection viewpoint. We would appreciate being advised of the corrective action you propose to recommend.

/s/ J. A. Ferrarese

J. A. FERRARESE

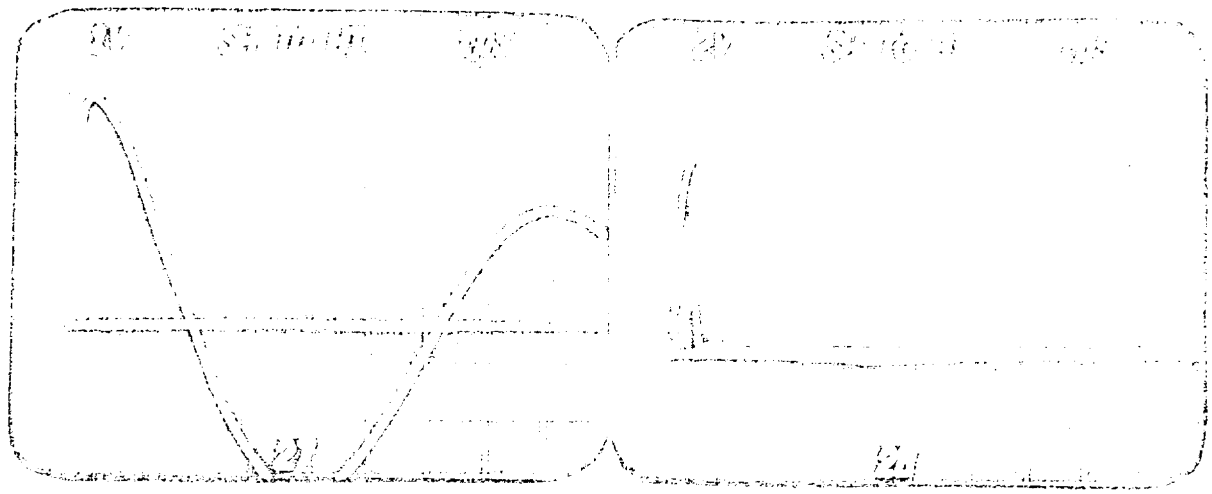
2 Enclosures

cc: AFS-1/100/140/TGH/ASF-1/AVS-1
AFS-140:TGHoreff:dmm:1/22/79
REWritten per AFS-100:drm:2/6/79

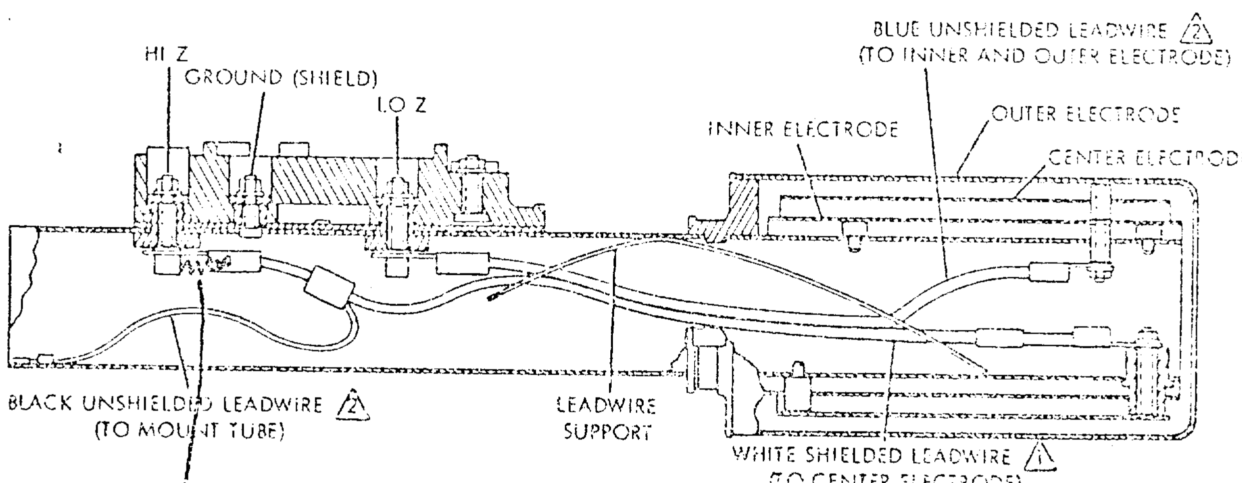
8020

Clean

Shield to HI Z



1 Scope Volt = 1.04 kV

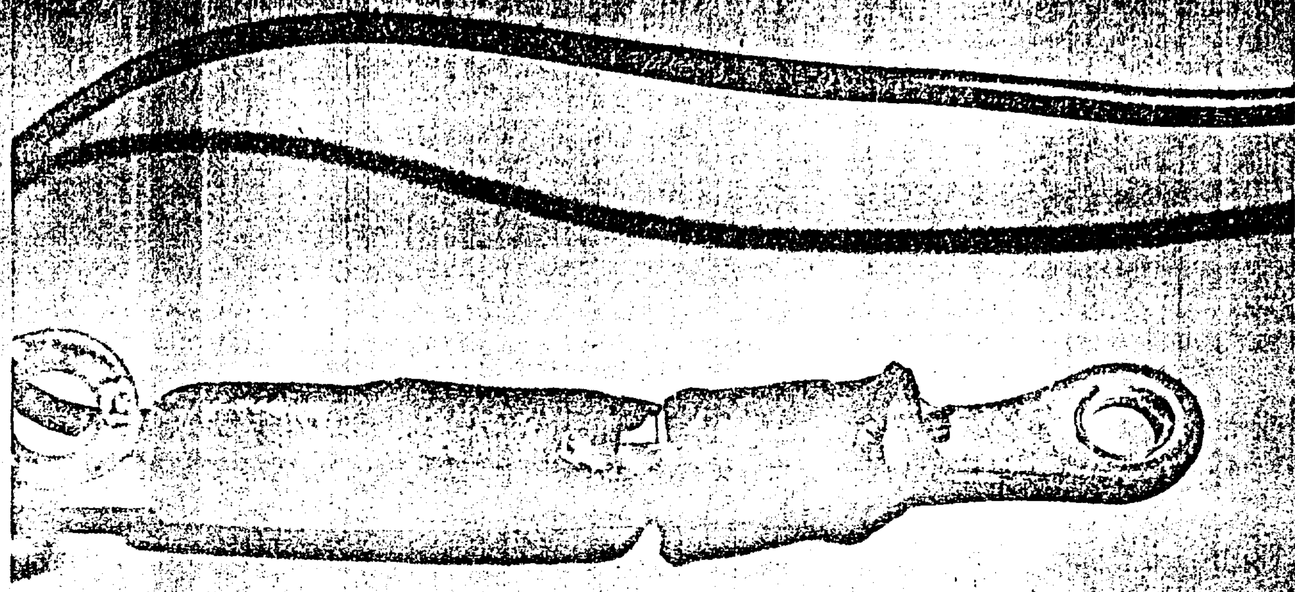


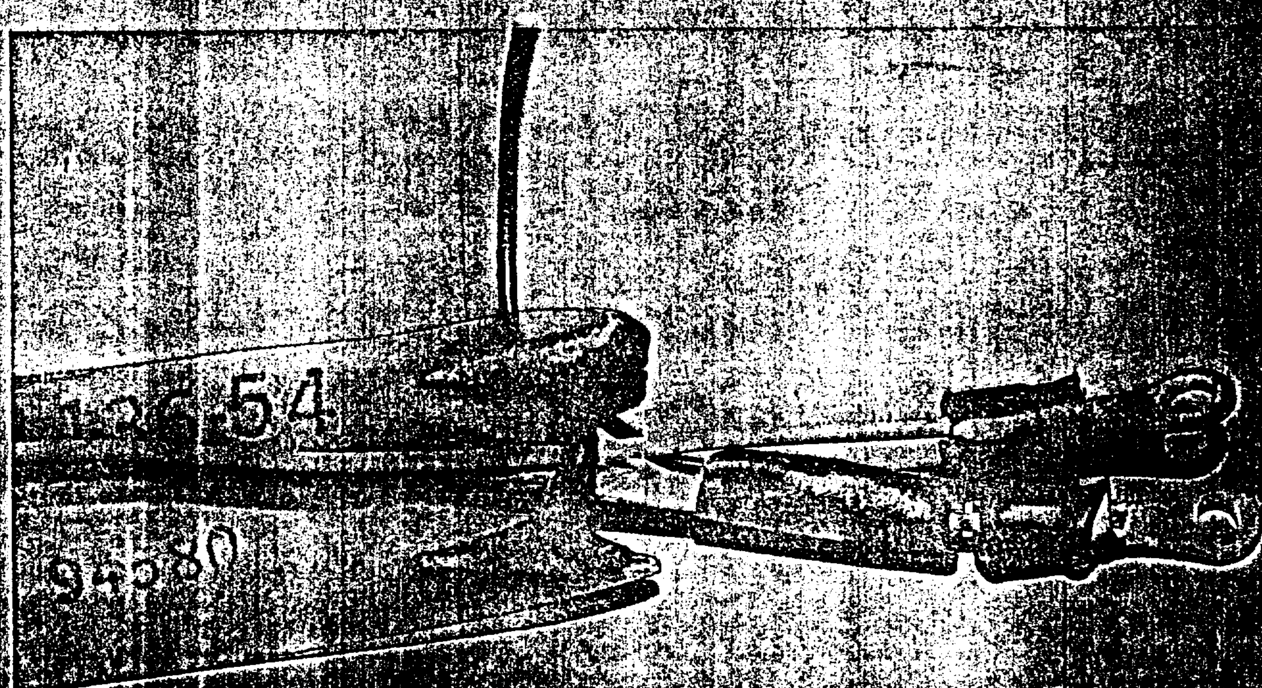
NOTES:

1. USE MIL-W-16878/5, NO. 22 AWG SHIELDED INSULATED LEADWIRE.
2. USE MIL-W-16878/5, NO. 22 AWG UNSHIELDED LEADWIRE.
3. FG6C1 CONFIGURATION SHOWN.

FG6C SH1

Figure A-6





Mr. Horeff

May 18, 1979

AFS-140

National Transportation Safety Board (NTSB) Special Investigation Report NTSB-AAR-78-12 Wing Failure of Boeing 747-131 ANM-1 ltr of 4/27/79 to AFS-1

Chief, Engineering and Manufacturing Division, AFS-100

ANM-200

In addition to advising that you expect to publish a proposed Airworthiness Directive (NPRM) requiring several B-747 fuel system lightning protection design improvements, the subject letter also suggested that Advisory Circular 20-53 be updated to include information covering additional design criteria and evaluation of fuel electrification as a result of a lightning strike. In order to consider your suggestions, however, some clarification will be necessary.

We concur that AC 20-53 should be updated and are currently preparing revisions to the simulated lightning test waveform and acceptable skin thickness criteria. In regard to your suggestion to include testing to determine if the fuel can serve as a conductor or an ignition source due to a lightning strike, we are not familiar with any theory concerning generation of electrical charges in the fuel as a result of a lightning strike and would be interested in learning of the basis of your suggestion. If Boeing is conducting a study in this area, we would also appreciate receiving any information which might be available on such tests. Your comments would also be of assistance on other examples of deficiencies in AC 20-53 which were not cited in the subject letter.

Enclosed is a draft copy of an advisory circular which was prepared by AFS-500 to provide guidelines on the safe use of electrically powered components in fuel tanks. Your review and comments on these guidelines would be appreciated.

/s/ James O. Robinson

JAMES O. ROBINSON

Enclosure

cc AFS-100/140/TGH

AFS-140 TGHoreff dmm 5/15/79

FILE 8020

000047

mr. Horeff

AFS-140/79-2

Prepared by: T. G. Horeff
Date: 1/25/79

BRIEFING MEMORANDUM
Engineering and Manufacturing Division

Subject: Transport Aircraft Lightning/Fuel Tank Explosion Experêence and Standards

Transport aircraft are struck by lightning on the average of one strike to each airplane in service per year. In-flight fuel tank explosions attributed to lightning strikes have occurred in the following civil and military transport-type fatal accidents:

1. L-1649A, Milan, Italy, June 26, 1959 - avgas - 68 fatalities
2. B-707, Elkton, MD, Dec. 8, 1963 - Jet A/B mixture - 81 fatalitées
3. B-747, Huete, Spain, May 9, 1976 - Jet A/B mixture - 17 fatalities
4. C-130E, Cottageville, SC, Nove. 29, 1978 - Jet B (no foam) - 6 fatalities
5. KC-135Q, Madrid, Spain - Jet B - 3 fatalities

All fatal turbine aircraft accidents resulting from lightning-caused fuel tank explosions have involved aircraft using Jet B or Jet A/Jet B blended fuels. No explosions have occurred to date following lightning strikes to aircraft using Jet A fuel, e.g., a strike on March 22, 1978, to a B-747 using Jet A affected the same main tank transfer valvewithh out causing an explosion that was concluded by the NTSB to have been the probable cause of the explosion in the B-747 accident in Spain on May 9, 1976.

C-130 aircraft have also experienced a non-fatal external pylon tank explosion in-flight and a suppressed explosion in a foam-filled tank while parked on the ramp as a result of lightning strikes. The USAF removed the foam from the C-130 fuel tanks in 1974,hhowever, one of the recommendations of the Nov. 29, 1978, C-130E accident investigation board is to reinstall the foam. A survey of lightning strikes to British RAF aircraft reported 46 strikes which involved external and ventral fuel tanks of which 12 resulted in fires or explosions, although no aircraft were lost. One USAF F-4 was lost in Florida as a result of a lightning-caused fuel tank explosion.

Standards

Advisory Circular 25-3, "Protection of Aircraft Fuel Systems Against Lightning," was issued on 7/22/65 following the B-707 Elkton accident. ADs 64-03-01, 64-05-01, and 67-23-02 were issued to modify B-707 fuel tank access panels, increase protection of the wing skin over the fuel vent surge tanks against penetration by lightning strikes, and protect against lightning-induced ignition at the fuel tank vent outlet. AC 25-3 was superseded by AC 20-53 on 10/6/67 to provide guidance for showing compliance with the fuel system lightning protection requirements of FAR 25.954 which were adopted in Amendment 25-14 on 8/11/67. These requirements specified that the fuel system must be designed to prevent ignition by direct and swept lightning strikes and corona and streamering at fuel vent outlets.

New FAR 25.976 was proposed in NPRM 74-16 on 3/27/74 to require a fuel tank explosion prevention system for transport aircraft. NPRM 74-16 was withdrawn on 8/15/78 because existing systems would produce significant cost, weight, logistics, and servicing penalties, and would not provide protection of damaged tanks in the post-crash situation. Industry claimed that NPRM 74-16 was unnecessary relative to the lightning strike hazard since compliance with FAR 25.954 had resulted in satisfactory service experience.

Efforts are underway in AFS-140 to revise Advisory Circular 20-53 to incorporate the lightning test waveforms and techniques described in the report by SAE Committee AE-4L, dated May 5, 1976, and to issue a new Advisory Circular which provides guidelines on the safe use of electrically powered components in fuel tanks. These efforts are being expedited and will suppèement the design guidelines contained in NASA Reference Publication 1008, "Lightning Protection of Aircraft," which was prepared by Messrs. F. A. Fisher and J. A. Plumer of the General Electric Company in October 1977.

cc: AFS-100/140/TGH/AFS-142/105
AFS-140:TGHoreff:dmm:1/24/79
REWritten per AFS-100:dmm:1/25/79

Mr Horeff

DEC 4 1979

AWS-140

Boeing 747 improved fuel system lightning protection, AD 79-20-11

Chief, Aircraft Engineering Division, AWS-100

ANW-200
Attn: ANW-210

The subject airworthiness directive requires modification of B-747 fuel systems in accordance with Boeing Service Bulletins 747-28-2068, 2069, 2084, and 747-57-2035 to improve the lightning protection design. As indicated in several of these service bulletins, the B-747 fuel system modifications are based on new data from recent industry studies and we wish to explore whether these new data can be obtained to upgrade the lightning protection state-of-the-art for application to other airplanes.

The service bulletins advise that Boeing conducted simulated lightning tests on a forty-foot production section of a B-747 outboard wing to study the lightning strike environment effects on the wing beyond those used for initial certification and to develop test criteria and techniques which would permit improved state-of-the-art evaluation of airplane fuel systems when subjected to a lightning environment. We note that the tests resulted in the following modifications which are required by the subject AD:

1. Improved metal-to-metal contact between fuel vent and jettison tubing and structure based on simulated lightning strikes at the jettison tube exit.

2. Wiring shrouds and a relay circuit for the fuel quantity system to reestablish the desired safety margin using the new data.

3. Replacement of plastic fuel cell access doors with aluminum doors to eliminate a possibility of electrical discharge from surge tank drain lines based on extrapolation of test data using improved techniques.

We believe that the results from the Boeing test program should be used to develop generalized criteria to enhance fuel system lightning protection. These criteria would be included in Advisory Circular 20-53 currently being updated and in another advisory circular currently being developed to provide guidelines on the safe use of electrically powered components in fuel tanks. Your assistance in obtaining the cooperation of Boeing to provide us with information on their new test criteria and techniques for this purpose would be appreciated.

Original signed by:
T. G. Horeff

JERRY CHAVKIN

cc: AVS-1/AWS-1/100/140/TGH
AWS-140:TGHoreff:dmm:12/4/79
FILE:

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20591

DATE:

IN REPLY REFER TO: AFS-140

SUBJECT: NTSB Special Investigation Report No. NTSB-AAR-78-12, Wing Failure of Boeing 747-131, near Madrid, Spain, May 9, 1976

FROM: Acting Director, Flight Standards Service, AFS-1

TO: ANW-1

The subject NTSB report indicates that a low-order explosion resulting from lightning-induced ignition of the fuel vapors in the No. 1 fuel tank was the most probable cause of wing failure and loss of control. Since the NTSB did not have statutory authority to make any recommendations for corrective action, the following comments on the report are provided for your consideration in developing whatever measures may be appropriate to prevent a recurrence of this accident. These comments focus on the following findings in the report pertaining to probable ignition sources and are numbered accordingly:

1. Fuel did not ignite at the overfill compensator probe located in the wingtip (pg. 24).

2. The evidence gathered from examination of the vent ducts and upper wing skin established that flames did not travel between the surge tank and the No. 1 and the No. 2 main tanks (pg. 14).

3. The evidence . . . provides a foundation for a hypothesis that the tank explosion could have been ignited by a spark at this motor-driven valve (pg. 25).

Comments:

1. The NTSB concludes that the overfill compensator in the left wingtip surge tank was not an ignition source since microscopic examination found no evidence of sparking (sparkover marks). If this is correct, then the ignition source for the isolated fire on the outboard side of the center rib in the surge tank remains unidentified. The NTSB conclusion is qualified, however, by the notations on pg. 12 that "energy levels required to produce a spark will not necessarily damage metal or leave marks" and on pg. 15 that "a 4-millijoule spark would have provided sufficient energy to ignite the fuel. This level of spark energy will not necessarily leave physical evidence." In view of the fact that flammable fuel vapors can be ignited by a very low electrical energy which is less than that required to produce any physical evidence and in consideration of the internal condition of the compensator which is the only component in the area, we suggest that a careful review of the compensator should be given as a possible ignition source for the isolated fire in the surge tank.

The enclosed photographs show the localized burned and melted portions of the plastic sleeves of the compensator wiring harness where the black unshielded leadwire joins the HI Z leadwire. This is the same area where flashover to the HI Z terminal was observed at 6.9 kilovolts during voltage breakdown tests on new compensators as shown in the enclosed Figure A-6 from the test report. Evidence of arcing was difficult to detect following these tests. It may be noted in the photographs that the bottom edge of the leadwire plastic support is also burned and that a side of the plastic sleeve around the HI Z and black leadwires is not burned. This type of localized damage tends to indicate that a brief flame stream could have been initiated at the lug end of the HI Z leadwire which was directed upward through the compensator as the unit is mounted in the surge tank.

The burn damage of the compensator wiring harness was described to Mr. E. VonWolffersdorff of Boeing during a visit by Office of Aviation Safety personnel. At that time, he expressed an interest in studying the enclosed photographs.

2. We concur with the NTSB conclusion that flames did not travel between the surge tank and the No. 1 and No. 2 main tanks, however, the report does not refer to the soot and temperature patterns in the No. 1 main tank vent in the surge tank which indicate ignition of fuel vapor at the trough of the No. 1 main tank vent above the compensator and flame propagation in-board within the vent. This flame front apparently trailed into the airstream after leaving the surge tank when the top skin over the vent in the dry bay between the surge tank and the No. 1 main tank separated prior to wing tip separation. The matter of interest here is the likelihood that the possible ignition source in the compensator initiated a flame front which would have propagated through the vent from the surge tank into the No. 1 main tank and would have been the primary cause of an explosion if there had not already been an explosion created by another ignition source in the No. 1 main tank.

3. The subject NTSB report concludes that the probable ignition source in the No. 1 main tank could have been a spark at the main tank transfer valve and refers to electrical failures experienced by a domestic carrier in several motors of the fuel valves after the aircraft was struck by lightning. This experience may include the lightning strike incident of May 22, 1978, to a NWA B747 after which the crew was unable to reset the No. 1 main tank transfer valve

circuit breaker which had popped after the lightning strike. Maintenance then replaced the No. 1 main tank transfer valve actuator due to an overheated switch. The intent of the NTSB is apparent in pointing out that the main tank transfer valve was affected by lightning strikes to at least two B747 aircraft.

ANW-254 letter of June 14, 1978, advises that Boeing has issued Service Bulletin Summary 747-28-2068, dated May 5, 1978, which recommends rework of the fuel vent and jettison tube fittings and structure to improve metal-to-metal contact and also that the main tank transfer valve housing parting surfaces be reworked in accordance with ITT Service Bulletin 125423-28-02.

It is considered that the subject NTSB report, in conjunction with our supplementary discussion and Boeing Service Bulletin, warrants your review of the B747 fuel system including the compensator and main tank transfer valve, from a lightning protection viewpoint. We would appreciate being advised of the corrective action you propose to recommend.

J. A. FERRARESE

2 Enclosures

44-65-58-515 KC135Q MAJOR ACCIDENT

DAMG CLAS - DESTROYED INJ CLAS - FATAL

TYPE - FIRE/EXPLOSION IN THE AIR

COND -

PHASEOPR - LANDING APPROACH

BASIC - MALFUNCTIONED OR FAILED

DESCRIPTION KC-135Q. THE FLIGHT OF TWO COMPLETED A NORMAL AIR REFUELING MISSION AND RETURNED TO THE INITIAL APPROACH FIX. LEAD WAS CLEARED FOR DESCENT TO FL 200 AND THE WINGMAN TO FL 210 IN THE HOLDING PATTERN. LEAD WAS CLEARED FOR A TACAN/ILS APPROACH TO THE RUNWAY AND DEPARTED THE INITIAL APPROACH FIX (IAF) AT 0920L. A RADAR WEATHER SCAN WAS PERFORMED THROUGHOUT PENETRATION. NO BRIGHT CELLS WERE OBSERVED AT ANY RANGE UNDER 50 NM AT ANY TILT OR RECEIVER GAIN SETTINGS. LIGHT TO MODERATE RAIN SHOWERS AND VERY LIGHT TURBULENCE WAS EXPERIENCED DURING THE PENETRATION. THE WINGMAN WAS CLEARED FOR A TACAN/ILS APPROACH COMMENCING PENETRATION FROM FL 210. THE PILOT CALLED DEPARTING IAF AT FL 210 TO APPROACH CONTROL. HE WAS THEN CLEARED TO TOWER FREQUENCY. AT 0923;10L THE PILOT REPORTED TO THE TOWER THAT HE WAS PASSING FL 170. AT 0923;25L HE ACKNOWLEDGED THE ALTIMETER SETTING GIVEN BY THE TOWER. THIS WAS THE LAST TRANSMISSION RECEIVED. THE AIRCRAFT IMPACTED THE GROUND 21 NM FROM THE TACAN. THE FIVE CREW MEMBERS RECEIVED FATAL INJURIES.

CAUSE FACTOR KC-135Q. PRIMARY CAUSE. MATERIEL FACTOR IN THAT AN EXPLOSION IN THE CENTER WING AND NUMBER ONE FUEL CELLS INITIATED THROUGH A MALFUNCTION OF THE FUEL PROBE OR ASSOCIATED WIRING WHICH PROVIDED THE MECHANICAL MEANS FOR AN ELECTRIC ARC IN AN EXPLOSIVE ATMOSPHERE. POSSIBLE CONTRIBUTING CAUSES. (1) WEATHER PHENOMENA IN THAT THE ELECTRICAL PULSE WHICH PRODUCED IGNITION ORIGINATED FROM A LIGHTNING STRIKE OR STATIC DISCHARGE. (2) MAINTENANCE FACTOR IN THAT PERSONNEL PERFORMING FUEL CELL MAINTENANCE INADVERTENTLY CREATED A BONDING FAULT WHICH WAS NOT DETECTED IN SUBSEQUENT INSPECTIONS. THIS DEFECT COULD HAVE PROVIDED THE MECHANICAL MEANS FOR ELECTRICAL IGNITION OF EXPLOSIVE VAPORS.

THIS INFORMATION IS TO BE USED SOLELY FOR ACCIDENT PREVENTION AND SAFE
PURPOSES WITHIN YOUR ORGANIZATION - NO FUTHER RELEASE IS AUTHORIZED

NTSB/AAR-95/04 PB95-910404

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

CRASH DURING EMERGENCY LANDING
PHOENIX AIR, LEARJET 35A, N521PA
FRESNO, CALIFORNIA
DECEMBER 14, 1994

Adopted: August 1, 1995
Notation 6588

Abstract: This report explains the accident involving the Phoenix Air Learjet 35A that crashed while attempting an emergency landing at Fresno Air Terminal, Fresno, California, on December 14, 1994. Safety issues in the report focused on maintenance, inspection and quality assurance. Safety recommendations concerning these issues were made to the Federal Aviation Administration, Phoenix Air, and the Department of Defense.

EXECUTIVE SUMMARY

On December 14, 1994, about 1146:23 pacific standard time, a Phoenix Air Group, Inc. (Phoenix Air) Learjet 35A, registration N521PA, crashed in Fresno, California. Operating under the call sign Dart 21, the flightcrew had declared an emergency inbound to Fresno Air Terminal due to engine fire indications. They flew the airplane toward a right base for their requested runway, but the airplane continued past the airport. The flightcrew was heard on Fresno tower frequency attempting to diagnose the emergency conditions and control the airplane until it crashed, with landing gear down, on an avenue in Fresno. Both pilots were fatally injured. Twenty-one persons on the ground were injured, and 12 apartment units in 2 buildings were destroyed or substantially damaged by impact and fire.

The National Transportation Safety Board determines that the probable causes of this accident were: 1) improperly installed electrical wiring for special mission operations that led to an in-flight fire that caused airplane systems and structural damage and subsequent airplane control difficulties; 2) improper maintenance and inspection procedures followed by the operator; and, 3) inadequate oversight and approval of the maintenance and inspection practice by the operator in the installation of the special mission systems.

Safety issues in this report focused on maintenance, inspection and quality assurance. Safety recommendations concerning these issues were made to the Federal Aviation Administration, Phoenix Air, and the Department of Defense.

3. CONCLUSIONS

3.1 Findings

1. Weather was not a factor in the accident.

2. Air traffic services were proper and did not contribute to the causes of the accident.

3. The pilots were properly trained and qualified for the flight.

4. The flightcrew experienced an in-flight fire leading to a request for an emergency landing.

5. The special mission wiring was not installed properly, leading to a lack of overload current protection.

6. The FAA Form 337s provided instructions for the correct installation, and the mission power modifications made by another operator on 3 of the 18 special mission Learjets were correct.

7. Neither the mechanic(s) who installed the wiring nor the mechanic(s) holding the inspection authorization, who approved the installation, noted the nonconformity with the FAA Form 337 in the installation on N521PA and 14 other Learjets modified by the operator.

8. The in-flight fire most likely originated with a short of the special mission power supply wires in an area unprotected by current limiters.

9. The fire resulted in false engine fire warning indications to the pilots that led them to a shutdown of the left engine.

10. The intense fire, which burned through the aft engine support beam in flight, can be explained by a compromised fuel line resulting from a battery explosion.

11. The in-flight fire caused substantial damage to the airplane structure and systems in the aft fuselage and may have precluded a successful emergency landing.

12. At the time of impact, the left engine was not producing power; and the right engine was producing at least flight-idle power.

13. The City of Fresno police, fire fighting, and rescue responses, which were assisted by units from Fresno Air Terminal, were timely and effective.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable causes of this accident were: 1) improperly installed electrical wiring for special mission operations that led to an in-flight fire that caused airplane systems and structural damage and subsequent airplane control difficulties; 2) improper maintenance and inspection procedures followed by the operator; and, 3) inadequate oversight and approval of the maintenance and inspection practice by the operator in the installation of the special mission systems.

To : **Mr. Al Dickinson**
National Transportation Safety Board
490 L'Enfant Plaza S.W.
Washington, DC 20594
Tel. (202) 314-6310

From : **John E. Mariani,**
Northrop-Grumman
2000 W. NASA Blvd.
Melbourne, FL 32902
Tel. (407) 951-6120

Date: **August 4, 1997**

Subject: **Failure Report for Fuel Pump (Parker-Hannifin 3B7-4) in the GTCP331-350[J] Auxiliary Power Unit Installation of the Joint Stars E-8C (modified Boeing 707-338C) Aircraft**

Dear Mr. Dickinson:

I am a Technical Specialist for Northrop Grumman and also a Designated Engineering Representative for the FAA (DER No. SO-521, for the disciplines of Powerplant and Structures).
It is my understanding that you are the Chief Investigator for TWA Flight 800 and that the scavenge fuel pump of the center tank is receiving special attention in the investigation (ref. AW&ST, June 16, 1997). Although I am not familiar with the type or installation details of this scavenge pump, I felt I should submit to you, for your information, the subject Failure Report for a fuel pump installed in our E-8C Joint Stars, which is a modified Boeing 707.
The subject Failure Report concluded that, if the fuel pump was allowed to run in dead-headed conditions, the increased temperature of the fuel inside the pump motor housing caused the failure of one of the pump terminal posts (constructed of DELRIN, a Dupont acetal resin) at a fuel temperature below the setting (363°F) of the thermal shutoff fuse inside the pump motor housing. The failure of any of the two terminal posts would then allow hot fuel to leak out of the pump motor housing and therefore the pump could no longer be considered explosion-proof. If the pump continued to operate while leaking fuel, there could be a possibility of ignition of the fuel or fuel vapors.

If, in your judgment, you see no similarity or parallel between the B-747 center tank scavenge pump and our fuel pump failure, please disregard the enclosed Failure Report.

If, however, you have any additional questions, please do not hesitate to call me at (407) 951-6120.

Sincerely,

John E. Mariani

Enclosure

No Occ Phs Subj Mod Pers
-- --- --- ----- ---- ----
1 171 520 Fire Takeoff
C 14400 1224 Exhaust system <> Fractured
C 12013 1121 Electrical system,electric wiring <>
Deteriorated

****
****

NTSB ID No. City, State:
Type
Reg. No. / Airport Proximity Aircraft
Make/ of Operator/ Injuries
Status Date Docket No. Airport Name (Ident.)
Model/Damage Operation D. B. A. F S M N
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---------- ----------- --------------- --- --- --- ---

Public 08/13/94 LAX94FA323 PEARBLOSSOM ,CA: LOCKHEED
C-130A 137 Public JAMES A. 3 0 0 0
ACC N135FF/

Destroyed use VENABLE / HEMET
2073
VALLEY FLYING

SERVICE

WITNESSES SAW THE AIRCRAFT IN LEVEL FLIGHT AND OBSERVED A BRIGHT ORANGE FLASH NEAR THE WING ROOT. THE FIRST FLASH WAS FOLLOWED ABOUT 1 SECOND LATER BY A MUCH LARGER DARK ORANGE FIREBALL AND BLACK SMOKE. THE RIGHT MAIN WING THEN SEPARATED FROM THE AIRCRAFT. THE WRECKAGE WAS DISTRIBUTED OVER 1 MILE IN MOUNTAINOUS TERRAIN. UNBURNED CENTER WING BOX SKIN, FOAM INSULATION PIECES, AND AUX TANK FRAGMENTS (ALL FROM THE AREA WHERE THE FIRST FLASH WAS OBSERVED BY THE WITNESSES) WERE THE FIRST DEBRIS FOUND IN THE WRECKAGE DISTRIBUTION PATH. THE DRY BAY AREA OF THE RIGHT WING CONTAINS HIGH PRESSURE FUEL LINES, UNSHIELDED AND EXPOSED ELECTRICAL WIRING, AND IS IN CLOSE PROXIMITY TO THE NO. 3 ENGINE. THE MAIN FUEL TANK IS LOCATED OUTBOARD OF THE DRY BAY. NO LIGHTNING ACTIVITY WAS REPORTED IN THE VICINITY OF THE AIRCRAFT. C-130 AIRCRAFT HAVE A HISTORY OF FUEL LEAKS IN THE DRY BAY. THE SOURCE OF THE LEAKS, FLATTENED OR PINCHED O-RINGS, ARE ON-CONDITION REPLACEMENT ITEMS. THE AIRCRAFT WAS IN LONG TERM STORAGE IN THE DESERT FOR 2 YEARS PRIOR TO ACQUISITION BY THE OPERATOR FOR FIRE TANKER DUTIES. U.S. AIR FORCE EMERGENCY PROCEDURES WARN OF FUEL LEAKS IN THIS AREA AND REQUIRE INSPECTIONS PRIOR TO EACH FLIGHT.

No Occ Phs Subj Mod Pers
-- --- --- ----- ---- ----
1 170 540 Fire/explosion Cruise
C 15100 1154 Fuel system <> Leak
C 12013 1101 Electrical system,electric wiring <> Arcing
C 16902 1169 Powerplant <> Other
C 17001 1132 Fluid,fuel <> Exploded
2 130 540 Airframe/component/system failure/malfunction Cruise

To: T.H.
FRM: G.M.

4 Aug, 97

To Whom It May Concern:

I am an active duty Flight Engineer assigned to the 418th Flight Test Squadron at Edwards AFB, Ca. Due to
the protracted time involved in your ongoing investigation of Flight 800, I feel I must ask this question to insure this has been considered.

Several years ago I witnessed a C-141 blowup at Travis AFB, Ca. The cause was in the scroll housing for the fuel boost pumps. Over the years, corrosion had allowed fuel into the wiring of the fuel pump. This alone did not cause the explosion. The combination of the explosive level of the atmosphere in the fuel tank, the explosive level of the fuel itself, in addition to the temperature of the fuel, in combination with the ignition source mentioned above all worked to cause the explosion. Since I know that the aircraft involved was 30 odd years old I feel this is a possibility. When the entire C-141 fleet (250 odd aircraft at that time) was inspected as a result of this mishap, they found several other aircraft with this same problem.

You have probably considered this months ago, but I figured I would mention it, just in case.

TSgt Fred Harp
418th FLTS, Edwards

11 910051 NRN

REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF TRANSPORTATION AND COMMUNICATIONS
AIR TRANSPORTATION OFFICE
PASAY CITY, METRO MANILA 1300

December 26, 1990

Honorable James L. Kolstad
Chairman
National Transportation Safety Board
Washington D. C., 20594

S i r :

At 1500H, 11 May 1990, a Boeing 737-300 aircraft with Registration No. EI-BZG exploded and burned at the Domestic Terminal of the Ninoy Aquino International Airport (formerly Manila International Airport). The accident occurred when passenger embarkation was already accomplished and the aircraft was being pushed back from the terminal in preparation for take-off. There were eight fatalities and 30 suffered physical injuries out of the 114 passengers on board.

In the investigation of this accident, we were fortunate to have received assistance from several agencies, including the National Transportation Safety Board. May I, therefore, take this opportunity to extend to you my deepest appreciation for the assistance your Office has given to the Philippine Government.

For your information, we are forwarding to you a copy of the Preliminary Report of the Philippine Aircraft Accident Investigation Board, together with the actions that this Office has required of Philippine Airlines.

Pending the final report of this accident, it is our hope that United States authorities may consider issuing pertinent precautionary measures on the suspected components.

Thank you and best regards.

Very truly yours,

OSCAR M. ALEJANDRO
Officer-In-Charge

REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF TRANSPORTATION AND COMMUNICATIONS
AIR TRANSPORTATION OFFICE
PASAY CITY, METRO MANILA 1300

INVESTIGATION REPORT

B737-300 / PR143
11 MAY 1990
MANILA, PHILIPPINES

Republic of the Philippines
Department of Transportation and Communications
AIR TRANSPORTATION OFFICE
Pasay City, Metro Manila

PRELIMINARY FINDINGS IN THE INVESTIGATION OF PAL B737-300 EXPLOSION/FIRE AT MANILA/11 MAY 1990

Abstract

While being pushed back from the gate at the Manila Domest Terminal, a Philippine Airlines Boeing 737-300, EI-BZG, explod and burned. Of the 114 passengers and six crew members, eig were fatally injured and 30 sustained injuries. At the time the explosion, the engines were not yet running and the aircra electrical power and air conditioning were supplied by t operating Auxiliary Power Unit (APU).

The investigation was focused on the center fuel tank, which w determined to be the source of the explosion, and the possibili of an explosive or incendiary device, an external source ignition or a mechanical and/or electrical failure as a source ignition.

The source of ignition has not been determined at this tim However, as a precautionary measure to ensure that the rest the Boeing 737-300 in the Philippines were free from defec found in this aircraft (EI-BZG), recommendations to inspect t suspected components were issued and had been complied with.

Explosive or Incendiary Devices

Considering the conditions present during the accident, initi concentration of the investigation was on the possibility explosive or incendiary device as a source of the ignition. Bo and fire propagation experts from various government departments of the Philippines, the United States and the Unit Kingdom as well as from Boeing Corporation assisted t Aircraft Accident Investigation Board of the Philippine A Transportation Office in the detection and assessment of explosive or incendiary device as the source of ignition.

No trace of an explosive or incendiary device was found. A available X-rays of fatalities and injured passengers we examined for foreign fragment penetration with negative result Seat cushions were also x-rayed and examined with the sa results.

Further, the findings of the National Transportation Safety Board of the United States in their spectrographic analysis of the explosion recorded in the Cockpit Voice Recorder showed a fuel/air explosion rather than an explosive device.

Boeing Company, however, decided not to close this possibility. It is believed that further metallurgical tests are being conducted.

External Source of Ignition

The possibility of fire propagation from an external source to the center tank through the vent system was also investigated. Per witnesses, external source of ignition at the time of the accident was not observed.

Electrostatic

This possibility was deliberated on by the investigation group and with the atmospheric conditions at the time of the accident, the humidity was high and possibility of static discharge was very remote, if not impossible. This was eliminated.

Float Switch

The examination of the float switch at the Equipment Quality Assurance (EQA) Laboratory of the Boeing Company at Seattle revealed an unusual physical appearance. It was apparent that some metal portion was missing in the internal cavity of the switch body. This was initially suspected as results of an internal arcing, but further inquiry with the manufacturer revealed that until three years ago, rework was performed whenever a switch failed quality control. The process required the drilling out of the defective reed switch and the reinstallation of a new one. Per Boeing, evidence of machining and bits of aluminum were found in the switch body and the potting compound respectively.

If an electrical short circuit occured inside the cavity of the switch, it would be impossible to ignite the fuel/air mixture in the tank due to the presence of a shielding conduit. Neither would it be possible for the switch to reach a high temperature to cause auto ignition of the explosive atmosphere because the high conductivity of the metal body which is mounted to a large metal plate would act as a heat sink.

Another possiblity was presented, and although remote, it was not impossible. It was noted that the construction of the body of the float switch was actually made of two separated pieces and joined together with epoxy adhesive. These are a hollow aluminum stem that houses the reed switch and an aluminum body which serves as mounting to the aircraft structure. With this construction, the metal stem could in fact be insulated from the switch body. If, by chance a non-design power is allowed to contact the stem of the switch with it insulated from the body, an arcing is possible between the stem and the magnetic float housing. This possibility would put the arcing outside of the switch and within the explosive atmosphere. A cold solder in the reed switch of the bits of aluminum in the potting compound could possibly bridge the non-design power to the stem.

Per NTSB report [1], the energy required to produce an ignition is only 0.25 millijoules and within this amount, traces of arcing between the stem and the float housing might not be visible.

Inasmuch as the float switch is only powered during the time the refueling panel is in the open position and at the time of the accident the panel was closed, it was imperative to examine the float switch wiring for any non-design power source to support the above possibilities.

Float Switch Wires

The whole length of the float wires and the wire bundles were examined at the investigation site and the EQA Laboratories of Boeing. The examination revealed a damaged insulation resulting to exposed wires in the float switch wires of approximately 9.525 mm (3/8 inch.) In the vicinity of the damaged insulation of the float switch, two other wires had damaged insulation. These were the 15 volt proximity sensor wire of the number 6 slat and the input wire to the right wing anti-ice valve supplying 115 VAC. It is believed that these wires were damaged during the manufacturing of the aircraft as other wire bundles were also found to be damaged, or the damage could have occurred during the installation of the logo lights.

No evidence was found to indicate whether arcing bewteen the wires had occurred but the possibility of a direct contact exists. It was initially believed that the presence of a 115 VAC would damage the transient suppression diode across the center fuel valve, but further analysis of the circuit also showed that if there was a direct short in the float switch, there existed a possibility that the diode might not detect the alternating current. Furthermore, the time required to have an igniting spark in the float switch could be so short to affect the diode or circuit breakers.

Fuel Quantity Indication System

Since this unit is inside the center fuel tank, it was one of the suspected sources of ignition. All the tank units and associated components were removed and later examined at the EQA laboratory of Boeing. The dielectic tests and functional test were all satisfactory. Furthermore, the power supply current to these tank units were found to be incapable of producing the necessary spark to cause an ignition. The unit was eliminated as an ignition source.

Fuel Booster Pumps

The two center wing tank booster pumps were examined at Seattle Boeing Plant and at the manufacturer's plant in the United Kingdom, GEC Aerospace Limited.

Dielectric tests of the unit were found to be below the limits due to the presence of water in the motor section of the pumps. The water ingress is believed to be contamination of fire fighting materials used during the accident. After thorough cleaning and drying, the dielectric tests were found to be within limits.

It was also noted that the left pump showed evidence of wear in the carbon bearing that caused the inducer to rub against the pump housing.

Although it is understood that the pumps should be turned off whenever the low pressure lights are illuminated, it was noted that this was not emphasized. This does not even appear even on the B737-300 flight manual.

The flight deck crew reported that they turned on the center booster pumps during the cockpit preparation checks and verified that the low pressure warning light were extinguished. Although no fuel was loaded in the center tank, fuel from the surge tank in the wings would drain to the center tank. It is therefore presumed some fuel must have drained to the center tank for the pumps to create positive pressure and extinguish the low pressure warning lights. Shortly or during the pushback, the master warning light illuminated indicating that both center booster pumps sensed low fuel pressure in their outputs. The crew cancelled the master warning light but did not turn off the booster pumps.

Both center fuel booster pumps were tested in explosive atmosphere at the manufacturer's facility in the United Kingdom. A series of tests ranging from 15 to 45 minutes were done without successfully igniting the explosive atmosphere.

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Although the tests were done to approximate the conditions that existed during the accident, the probability rate of ignition is not known. It is also a known fact that ignition is possible with the rubbing of these two metals (i.e. stainless steel and aluminum alloy) according to the researches of Powell and Belinge (1985)[2] and Takaoka et al (1966)[3]. We believe that the rubbing test conducted by Plessey in the certification of the pumps or these tests that were conducted on the center booster pumps are not enough to conclude and negate the results of the researches that were done by Powell and Takaoka.

We believe that further tests should be conducted on the compatibility of metals used in the fuel pumps to ensure that frictional spark or thermite reaction is impossible.

Conclusions

The source of ignition in this accident is not known at this time. The chances of pinpointing the exact source of ignition might be remote. It is therefore necessary to probe deeper into the suspected components before concluding this investigation.

In the investigation that was undertaken there is still some doubt on the elimination of the float switch and the booster pumps as ignition sources. We believe that the necessity of ensuring that the same conditions do not exist in the rest of the Boeing B737 aircraft utilized by air carriers in the Philippines is imperative if we were to preclude a similar incident. In the absence of an Airworthiness Directive issued by the FAA, the Aircraft Accident Investigation Board of the Air Transportation Office found it prudent to recommend the following action on the suspected components as precautionary measures pending the completion of the investigation:

1. A one time check of the aircraft fuel system. - Complied 26 May 1990,[4]

2. A visual and physical check of the logo light wiring from the center tank to the wing tips as well as the associated wire bundles. - Complied 29 June 1990,[5]

3. A visual check of the float switch wiring for chaffed and damaged insulation from the float switches to the refuelling panel. - Complied 10 August 1990,[6]

4. A one time check of all center tank booster pumps. Complied 17 September 1990,[7] and

5. Amend the fuel booster pumps operating procedure to emphasize and disallow the dry running of the pumps. Complied 15 September 1990.[8]

By the Aircraft Accident Investigation Board: 20 November 1990.

GALILEO L. BANAQUED
Chairman

RICARDO B. EXCONDE
Vice Chairman

DEO B. DEOCAMPO
Secretary/Member

SATURNINO S. DELA CRUZ
Member

ELFREN P. CALDOZA
Member

REUBEN B. STERNBERG
Accredited Representative

APPENDIX:

1. National Transportation Safety Board Report dated 0 August 1990
2. Powell, F., Ignition of fuel-air mixtures by ho surfaces and sparks produced between stainless stee and aluminum alloy.
3. Takaoka, S., et al, Safety In Mines Researcl Establishment, Ministry of Power, May 1968
4. Air Transportation Office (ATO) Directive dated 25 Ma 1990
5. Air Transportation Office (ATO) Directive dated 28 June 1990
6. Air Transportation Office (ATO) Directive dated 03 August 1990
7. Air Transportation Office (ATO) Directive dated 14 September 1990
8. Air Transportation Office (ATO) Directive dated 14 September 1990

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National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 1, 1990
In reply refer to: A-90-100 thru -103

Honorable James B. Busey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On May 11, 1990, a Boeing 737-300, Ireland registration EI-BZG, leased to and operated by Philippine Air Lines, exploded and burned at Manila, Republic of the Philippines, shortly after pushback from the ramp. At the time of the accident, the airplane was operating on power from the auxiliary power unit. Of the 119 persons on board, 8 persons were fatally injured and 30 received serious injuries. The airplane was destroyed by fire.

Although the Philippine Government is currently investigating the accident, the National Transportation Safety Board has been involved in the investigation through its U.S. accredited representative in accordance with the provisions of Annex 13 to the International Civil Aviation Organization (ICAO) treaty.

The investigation has found no evidence of a bomb, an incendiary device, or sabotage. Preliminary evidence indicates that ignition of the fuel-air mixture in the center fuel tank was the cause of the explosion and subsequent fire. The investigation has yet to reveal the exact ignition source. Examination of the cockpit voice recorder (CVR) data disclosed that a one-cycle transient spike occurred approximately .2 second before the explosion. The source and nature of the spike -- whether it was electrically induced on the CVR signal wire or electromagnetically picked up by the area microphone or pilot boom microphones -- has not been determined. The investigation has found potential defects involving the center tank float switch and the wiring for the float switch, both of which could have been the source of the ignition. Additionally, interference rub marks were found on the fuel booster pump impeller and pump body.

At the time of the accident, all the fuel boost pumps were in the "ON" position. The center fuel tank had not been filled since March 9, 1990. During the pushback of the airplane the center fuel tank low pressure light illuminated, indicating that the center fuel tank had been emptied of all usable fuel. Laboratory examination of fuel samples from the airplane and fuel storage tanks indicates that the fuel vapor in the center tank would have had a flash point of between 112° and 117° F. At flash point, a heat source of between 400° to 500° F or an electrical arc of .25 milli-joule would have been sufficient to initiate an explosion of the fuel-air mixture. Ambient temperature at the time of the accident was 95° F.

Laboratory examination of the float switch (Revere Aerospace part number F8300-146) for the center fuel tank refueling valve has found portions of the switch housing and its reed switch tube missing and metal fragments in the remains of the switch epoxy potting material. The examination of the components and discussions with the manufacturer indicate that it is possible that the switch did not pass inspection when originally assembled. Prior procedures at Revere were to drill out the epoxy potting material and reed switch from the housing then install a new reed switch. This procedure would explain the damage to the switch housing and the metal fragments that were found in the epoxy potting material. Revere modified its procedures approximately 3 years ago to prohibit this practice. All of the float switches that Boeing has in stock, approximately 850, were manufactured prior to this change in procedure. These float switches were subject to dielectric tests at the Boeing Company's facilities. All of the switches passed these tests. However, investigators and laboratory technicians are uncertain as to the efficacy of current acceptance tests and lot sampling procedures. Therefore, the development of additional testing techniques may be necessary. The same model float switch is used on all three fuel tanks in the Boeing 737 series airplanes, in the auxiliary fuel tanks of 100 Boeing 727s, and possibly on other manufacturer's airplanes.

Normally, the fuel tank float switches are only electrically powered when the refueling panel access door is open. The door would have been closed during the pushback of the airplane when the explosion occurred. However, examination of the 28-volt direct-current power wires for the float switch, which lead from the center tank to the refueling panel on the right wing, disclosed an area approximately 3/8 inch long in which the wire insulation had been compromised and the conductor was exposed. The exposed wires were crushed, but no evidence of electrical arcing was found. The exposed section of wire was inside the inboard vapor seal at the right engine pylon. Examination of the wire bundle in the vapor seal revealed several other wires that had damaged insulation and exposed conducting material, including a wire powered by 115-volt alternating current. Further examination of the wire bundles for both the left and right wings found numerous areas in which wire insulation had been damaged.

It is possible that the combination of a faulty float switch and damaged wires providing a continuous power supply to the float switch may have caused an electrical arc or overheating of the switch leading to the ignition of the center fuel tank vapor.

The investigation determined that after delivery of the airplane, Philippine Air Lines had installed logo lights on the wingtip trailing edges. This installation would have required mechanics to insert additional wires through the vapor seals, the fuselage pressure seal, and inside numerous clamps. Thus, the installation of the wires for the logo lights could have been the source of the damage to wires in the wire bundles. However, the damage may have resulted from the installation of the wire bundle at the factory because other damaged wires were found that were not related to the installation of the wires for the logo lights. For example, intercom wires in the left fuselage wire bundle were found with damaged insulation and exposed conductor. Additionally, many airplanes are often modified after delivery, requiring the installation of additional wires in the wire bundles of the wings. Boeing has informed the Safety Board that there were minor changes to the wing wire bundles in the 737-300, -400, -500 series airplanes as compared to the 737-100 and -200 series. However, the wire bundle routing and the wire bundle vapor seals are considerably different.

The Safety Board believes that the finding of damaged float switch wiring and a potentially defective float switch, as well as the potential for a fuel tank explosion requires the immediate inspection or testing of float switch wiring of the three fuel tanks on Boeing 737-300, -400, and -500 series airplanes. The Safety Board believes that immediate inspection of the float switch wiring should be accomplished to verify that electrical power is not being supplied to float switches by damaged wiring. Inspection or testing of the float switches should be accomplished after Revere, Boeing, and the Federal Aviation Administration (FAA) are confident that satisfactory testing techniques have been developed.

The Safety Board notes that the FAA has sent a letter to Philippine Air Lines requesting that the other two airplanes modified by the airline be inspected for damaged wiring. The Safety Board does not believe that this action is adequate because it does not address the problem of faulty float switches. Additionally, the FAA action does not decrease the potential of another accident because many airplanes have the same float switch installed and the possibility of damaged wiring exists whether or not the airplane was modified after original manufacture.

The Safety Board believes that it would be prudent, at the next maintenance inspection, for all 14 CFR Part 121 airplanes that have had additional wires added to their wing wire bundles since delivery to be inspected for damage to the wires under the clamps and inside pressure seals and vapor seals.

Lastly, laboratory examination of the left booster pump for the center fuel tank on the accident airplane found evidence of an interference rub between the pump impeller and pump body, and a slight wearing of the bearings. The manufacturer has stated that such material wear is common when pumps have been run in a dry condition. The manufacturer also stated that some operators will let the booster pumps run with a tank empty for extended periods and that no problems have been noted. However the service life of the pump bearings is less than expected. Investigators have been unable to find adequate test data on the dry running of the booster pumps in jet fuel vapor at flash point temperatures to eliminate the rubbing of the pump impeller as a possible ignition source. The Safety Board believes that appropriate tests should be accomplished to determine if the pumps are airworthy for all operating conditions. Such tests would include continuously running the pumps in fuel vapor at flash point with the impeller rubbing the pump body.

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

> Issue an airworthiness directive to require immediate inspection or testing of float switch wiring from the float switches to the refueling panel for chaffed or damaged insulation material on Boeing 737-300, -400, and -500 series airplanes. The directive should state that special emphasis be placed on inspecting the wire bundle where it passes through the wing pylon vapor seals and under the wire bundle clamps. (Class I, Urgent Action) (A-90-100)

> Develop testing techniques to ensure that float switches manufactured by Revere Aerospace are free from defect that could cause an explosion or fire. After testing techniques are developed, issue an airworthiness directive to require testing of Revere Aerospace float switches and replacement if they are defective. (Class II, Priority Action) (A-90-101)

> Issue an airworthiness directive applicable to all 14 CFR Part 121 airplanes to require, at the next scheduled major maintenance inspection, an inspection of the wires in wire bundles in the wings where additional wiring has been added since the airplane was manufactured. The inspection should be directed to the determination of insulation damage where the wire bundle is under clamps and inside vapor seals and pressure seals. (Class II, Priority Action) (A-90-102)

> Conduct a detailed engineering design review and testing of the fuel pumps used in the Boeing 737-300 series airplanes (P/N 10-62049-3) to verify that overheating and interference between the rotating components of the pump and its case will not cause a fire hazard. Testing should be conducted in jet-fuel vapor at flash point. (Class II, Priority Action) (A-90-103)

KOLSTAD, Chairman, COUGHLIN, Vice Chairman, and LAUBER, Member, concurred in these recommendations. BURNETT, Member, filed the statement below.

By: James L. Kolstad
Chairman

BURNETT, Member, concurring in part and dissenting in part:

I would have preferred that the first and second recommendations contained in this letter have been worded as originally adopted by the Board as follows:

Issue an airworthiness directive to require immediate inspection or testing of float switch wiring from the float switches to the refueling panel for chaffed or damaged insulation material on all airplanes equipped with float switches manufactured by Revere Aerospace, P/N 8300-146. The directive should state that special emphasis be placed on inspecting the wires where it passes through the wing pylon vapor seals and under the wire bundle clamps. (Class I, Urgent Action)

Issue an airworthiness directive to require testing of Revere Aerospace float switches, P/N F8300-146, and replacement if they are defective. (Class I, Urgent Action)

OUTGOING FAX COVER SHEET

Commander, Naval Safety Center
375 A Street
Norfolk, Virginia 23511-4399

Aviation Safety Directorate
John Cataldo
Executive Assistant
Code 101

Date: 19 AUG	Time:	# of pages (including cover sheet): 19

TO:

Name: BOB SWAIM		Activity: NTSB		Code:
Autovon prefix:	Commercial area code and prefix: 202 314	FAX #: 6349	Desk ext:	

FROM:

John Cataldo	DSN: 564-3520 ext 7226 COM: 757-444-3520 ext 7226 FAX: 564-7049/757444-7049

E MAIL: JCATALDO@SAFCEN.NAVY.

SUBJECT:

C-130 FIRE

REMARKS:

BOB, I SUMMARIZED PART OF REPORT AND CLEANED UP OTHER PARTS — YOU CAN RELEASE THE 18 PAGES HERE - OR RETYPE AND CONSOLIDATE IF YOU CHOSE.

John C.

OPERATOR:	RECEIVED BY:	CODE:	DATE:	TIME:

A search of Naval Safety Center records revealed a similar mishap that occurred over 25 years ago. The information contained here was obtained from that record. Some of the information in the report was gained by giving promises that the information would only be used for Naval aviation safety and never released. Those promises will be kept and that information where another source could not be discovered was omitted from this summary.

Narrative. A Navy C-130 had an explosion and fire shortly after takeoff. The crew crash landed the burning aircraft and escaped uninjured. While climbing through 7500 feet an explosion was felt and a fire discovered in the outboard portion of the left wing. The number one engine was secured and its fire extinguishing agent discharged on the chance the engine was contributing to the fire. attempts to reduce or control the fire were unsuccessful. As the fire continued, and the pilot's ability to maintain control of the aircraft deteriorated, a decision was made to land the aircraft in open terrain.

Field Investigation. The engines were inspected and eliminated as cause factors in the accident. Weather was also ruled out as a factor. The outer 10 feet of the port wing, exclusive of the leading edge, was consumed by fire. The leading edge had collapsed inward to form a flat vertical surface due to fire weakening the internal strength members. there was evidence that an explosion had occurred in the vicinity of the fuel quantity transmitter probe located between outer wing station 491.6 and the wingtip. The anti-icing shut-off valve that directs engine hot bleed air to the outer wing leading edge skin was found in the off position. The wing-tip lights were off.

The aircraft had flown for over three months with a maintenance discrepancy on the number one fuel tank quantity indicator. The efforts to correct the discrepancy centered around repair of solder connections in the amphenol cannon plug at the back of the fuel quantity indicator. Another attempt was made to repair the solder connections in the cannon plug four flights before the mishap flight. Maintenance personnel were unable to satisfactorily complete the repair in the time available before that days flight. They hurriedly reassembled the cannon plug and verbally warned the oncoming flight engineer to leave the number one fuel tank quantity indicator system circuit breaker out to prevent the indicator motor from running and ruining the internal clutch. The aircraft then flew four flights prior to the accident. The verbal warning was passed between flight engineers, except on the fourth flight. While conducting preflight procedures the fourth flight engineer noticed the circuit breaker to be out and reset it. The circuit breaker popped within seconds and was then left out for the flight back to home field. The circuit breaker was reset by an unknown person between the time the aircraft landed and the preflight the next day by the mishap crew. The mishap flight engineer stated that all circuit breakers were in at takeoff, however, the number one indicator system circuit breaker was found popped after the aircraft made the crash landing.

e. Safety Engineering Investigation. The cannon plug which had been attached to the fuel quantity indicator and the fuel probe positioned farthest outboard on the port wing were transported to the Naval Air Rework Facility, Norfolk, Virginia, for x-ray, disassembly and inspection.

(1) The x-ray of the cannon plug showed the wires to be twisted internally. The metal sleeve that normally slips over the center pin was properly soldered to the coaxial cable shield but was resting on the shoulder of the center pin and jammed over to one side. The 115 volt electrical lead was in contact with the coaxial cable shield.

(2) Disassembly of the plug disclosed arcing between wires with some pins melted.

(3) Inspection of the fuel probe and associated wiring found two places on the coaxial cable shield where arcing had occurred. The coaxial cable shield had chafed against the internal wing tank structure. The chafing presented the opportunity for an arc to occur between the coaxial cable and the tank structure. An arc occurring under the surface of fuel will only activate the circuit breaker. If the arc occurs above the surface in a proper fuel-air mixture an explosion in the tank will result before the circuit breaker can activate. Aircraft attitude and the quantity of fuel in the tank will determine the position of the coaxial cable relative to the surface of the fuel.

[redacted]

III. FUEL QUANTITY INDICATING SYSTEM

a. DESCRIPTION OF FUEL QUANTITY INDICATING SYSTEM

1) With the elimination of the above possible ignition sources, the fuel quantity indicating system came under close examination for two reasons: one, the #1 fuel quantity circuit breaker was found open on the post-crash investigation of the cockpit (enclosure L8), and two; the fuel quantity system wiring is the only internal #1 fuel tank wiring.

A capacitance type fuel quantity indicating system is used in the [redacted]C-130. Ten probes and one probe compensator are located in the #1 tank (enclosure K8). Probes consist of two concentric tubes which form an inner and outer electrode to form a capacitor. The inner electrode is a tube made of insulating material. Two metallic patterns, insulated from each other, are applied to the surface of the inner electrode. Wires lead from the probe to an electrical connector P/N 165-61-1014 connected to the fuel quantity indicator. One pattern is connected to the amplifier input in the indicator via wire 1E108 to pin H on the indicator's electrical connector. (See enclosure (L9) and enclosure (K15).) The other pattern is connected to ground via coax wire 1E109 to the center ground post of the indicator's electrical connector. The outer shield of this wire is connected to a shield connector cap which is in turn connected to the shield ground connection on the indicator's electrical connector.

The outer electrode is an aluminum tube externally coated with an insulating material. The fuel quantity indicator is located in the engineer's overhead panel and contains an amplifier, a bridge circuit, and a two-phase induction motor and power supply. Single-phase 400 Hz 115 volt AC current powers the indicator itself, but this voltage is not passed out to the fuel tank probes. All leads enter the indicator through an electrical connector (enclosure L15). The 115 volt AC enters the indicator through the "B pin" on the electrical connector (see wiring diagram (enclosure K4) and enclosure (L10)).

Preliminary tests of this system were conducted at the crash site. In order to preserve as much evidence as possible,

[redacted]

[redacted]

[redacted]

the following technical procedures were followed:

b. INITIAL FIELD INVESTIGATION

1) The entire fuel quantity wiring system was evaluated with emphasis on areas in which a high or abnormal voltage could have entered the fuel tank to provide an ignition source. It was initially decided that the indicator cannon plug should not be removed from the indicator until the indicator could be forwarded for engineering analysis. Also, it was decided that enough wiring for the #1 system should be removed from the aircraft so that all tank wires could be examined which parallel the 115 VAC power lead. This required that approximately 5 to 6 feet of wire in the wire bundle aft of the connector be removed. The indicator and attached wiring was then transported [redacted] for initial analysis, [redacted] The remaining fuel quantity wiring still in the aircraft was checked for any electrical short with a type PSM-2A megometer. The results were negative.

2) With the assistance of the TECHNICAL [redacted] representatives and the Board members, [redacted] THEY elected to perform a continuity check of the wires harness while attached to the indicator, with the following results (enclosure Q4):

The 115 volt AC power supply wire 1E100A18V was shorted to wire 1E109 shield either through the electrical connector or through the indicator itself. Additionally, the shield wire, 1E109, was itself not at ground potential which indicated an available path of 115 VAC into the fuel tank through this 1E109 shield wire. The indicator was then removed from the electrical connector and cable harness and the continuity test was again performed with the same results (enclosure Q3). This indicated that the 115 volt AC power wire, 1E100A18V, was shorted to the shield wire, 1E109, within the connector and that 1E109 was not ground as it should have been.

3) The connector, wire harness and indicator were forwarded [redacted] for engineering analysis [redacted]. The final report of that analysis has not been received by the Board at this time, but will be forwarded upon receipt.

[redacted] [redacted]

[redacted]

The results of the investigation were transmitted via phone conversation to the Board and photographs (enclosures L10,11,12&13) were forwarded. Engineering investigation revealed severe arcing inside the electrical connector (enclosures L11,12&13) and confirmed that the 115 volt AC power lead wire, 1E100A18V (pin B), was well shorted to the shield connector as well as to wire 1E107 (pin D), which connects to the fuel probe compensator.

4) The results of these tests indicate that an internal short in the electrical connector between the 115 volt AC power lead and the coax shield passed 115 volts AC through this wire to the #1 fuel tank.

THEY

[redacted] also performed engineering investigation on the recovered portion of the #10 fuel quantity probe and a piece of coax wire that lead from the probe back into the wing. These items were recovered from the wing portion which separated from the aircraft 350 feet forward of the touchdown point and were therefore fortunately undamaged by ground fire. These items are both located in the exploded area. Investigation of the fuel quantity probe indicated evidence of arcing on the probe connector. This data was THEY inconclusive, since [redacted] could not determine when this arcing had occurred. The coax wire was also examined and indications were that the wire had arced in two places but this information was also inconclusive as far as proving that this was the location of the ignition spark.

c. DESCRIPTION OF DOCUMENTED MAINTENANCE ACTION PERFORMED ON THE ELECTRICAL CONNECTOR

[redacted]

1) This investigation found that fuel quantity discrepancies, both in the tank and at the indicator, were very common in the squadron. Many of these discrepancies involved the indicator's electrical connector. [redacted] AE's who commonly worked on this type of discrepancy, [redacted], indicated that they considered the repair of the connector to be quite difficult

[redacted]

[redacted]

[redacted]

and irksome. The stated reason for this difficulty was the inaccessibility of the indicator connection itself, which is located in the engineer's overhead panel in the cockpit, and the short length of wire bundle leads behind the panel which necessitates an extra man being assigned to the job just to pull and hold this wire bundle through the indicator opening in the panel. The AE's further revealed that soldering in this position is extremely difficult. Most of the difficulty was generally experienced in soldering the coax shield wire #1E109 connection to the indicator's electrical connector itself (see enclosure L14). This connection, once soldered, often broke again when the rubber grommet (enclosure L14) was forced down the wire bundle into position. This sometimes required the wire leads to be cut and resoldered, further shortening the leads and making the job still more difficult.

2) A fuel quantity inoperative discrepancy is not considered a "downing" discrepancy as long as only one indicator is inoperative for each wing. Such non-downing discrepancies do not receive a high priority for completion and are worked off when the aircraft is available. [redacted] all AE's, including all work center supervisors, considered the repair of the electrical plug connector to be essentially routine maintenance on a "harmless" system. [redacted]

[redacted]

[redacted]

2) Engineering investigation indicated the 115 VAC wire 1E100A18V and the shield wire to be shorted. X-ray photographs (enclosure L10) indicated that the rubber grommet twisted when the plug was retightened and the shield connector did not properly seat itself on the indicator

cannon plug connector. The wires were brought into contact in this manner and the potential existed for 115 VAC to be passed into the tank. This was prevented at the time by the open circuit breaker.

e. EXAMINATION OF FACTORS

[redacted] the circuit breaker remained in because the unknown area that finally produced the ignition arc was at this time under the fuel itself (as it was when the circuit breaker was reset [redacted] the day before). [redacted] a combination of factors lead to the explosion:

1) First of all, with the circuit breaker in, and the cannon plug shorted 115 VAC power was available to the #1 fuel tank. As long as the two suspected areas of ignition, the #10 fuel quantity probe, and the coax ground wire, remained under the fuel no spark could be generated. However, [redacted] hirty minutes of engine operation and

[redacted]

the approximately 7° nose up attitude of the aircraft in its climbout combined to place the suspected components in an ideal air-fuel mixture. The aircraft had departed with full main tanks. It is estimated that 3 to 5% of the volumetric capacity of the tank would be an airspace at the instant of the explosion. [redacted] the result was an arcing which resulted in an explosion in the #1 main fuel tank in the forward center area beneath the outboard access plate in the vicinity of the #10 fuel quantity probe. [redacted] the explosion tore open the upper forward surface of the wing with the explosive force concentrated upward and forward. The remaining fuel cushioned the bottom and aft areas of the #1 main fuel tank.

The surface of the fuel instantly ignited into a continuous fire. The aircraft initiated an emergency descent with a series of left turns until its crash landing. The resultant fire burning on the surface of the fuel combined with the emergency descent forced the fire in a blow torch manner into the tank and aft. During the remainder of the flight it is estimated that the center and after portions of the access plate were burned off and literally vaporized. Thus weakened by the explosion, increased airspeed and burnt out area, the frame of the access plate and a position of the upper wing structure in the immediate area of the explosion separated during landing and came to rest 350 feet from the initial impact point.

The short period of flight and emergency descent (270 KIAS) confined the fire to the area immediately aft of the explosion. After the aircraft came to rest in the cornfield the wing burned for 36 minutes, thus causing the majority of the fire damage as the remaining fuel in the tank continued to burn. The fire continued burning aft and inboard (enclosure L16) before it was extinguished by a local volunteer fire department.

K. CONCLUSION

I. The aircraft suffered an inflight explosion in the left wing 5 minutes after takeoff. The explosion occured in the #1 main fuel tank in the forward center area beneath the outboard access plate in the immediate vicinity of the #10 fuel quantity probe. The explosion tore open the upper forward surface of the wing from OWS 369 to OWS 576 (enclosure L18). The surface of the fuel instantly ignited into a continuous fire forcing the flight crew to complete an emergency landing in an open field 5 minutes after the explosion. The aircraft's left wing continued to burn on the ground for an additional 36 minutes. Fifteen feet of the outer left wing was consumed by the fire.

The explosion was caused by the introduction of 115 volt single phase 400 Hz power into the fuel quantity indicating system for the #1 main fuel tank. An arc occured in the fuel tank airspace from either one of two sources:

a. From the #10 fuel quantity probe to an unknown ground.

b. From the coax cable in the immediate vicinity of the #10 fuel quantity probe to an unknown ground.

While considering all of the possible sources which could have caused the wing explosion, the fuel quantity indicating system came under close observation for two primary reasons:

1. The quantity circuit breaker was open.

2. The quantity system wiring is the only internal tank wiring.

In order to preserve as much evidence as possible, the following technical procedures were followed:

1. The entire wiring system was evaluated with primary emphasis on areas where high or abnormal voltages could have entered the fuel tank to provide an ingintion source. As a result of this analysis the decision was made as follows:

a. The indicator cannon plug should not be removed from the indicator.

b. Enough wiring for the #1 system should be removed from the aircraft so that all tank wires could be visually examined which parallel the system power leads.

The following wires were of primary concern:

1E108	wiring to the tank probes
1E109	wiring to the tank probes
1E109 shield	wiring to the tank probes
1E107	wiring to the tank probes
1E100A18V	115V single phase 400 Hz power source

The following wires were of secondary concern:

1E112	press to test
1E110N	ground
1E117	to totalizer circuit

2. Actual removal of the wiring and indicator was as follows:

All overhead control panels were lowered to provide access to the appropriate wire bundles. It was decided that the wiring to the tank probe should not be cut until they separated in the wire bundles from the 115V power wire. This point was approximately 5 to 6 feet aft of fuel panel in the overhead. Wire 1E110N, ground, was disconnected from the ground stud provided in the overhead panel.

[redacted]

[redacted]

The two remaining wires, 1E112 and 1E117, were cut at appropriate lengths to facilitate further study and identification. The indicator and wiring was then removed from the aircraft and transported [redacted] for further examination.

3. The aircraft wiring was checked with a megohmmeter, type PSM-2A, to determine if any short circuits were present. The results were negative.

4. A complete continuity check of wire harness while attachded to the indicator was performed with a triplett model 310 ohmeter. The test results were as follows:

Wire 1E100A18V was shorted to wire 1E109 shield
Wire 1E100A18V was not shorted to 1E109
Wire 1E100A18V to 1E107 - 2500 ohms
Wire 1E100A18V to 1E108 - 2500 ohms
Wire 1E100N to case - shorted
Wire 1E100N to 1E109 shield - 150 ohms
Wire 1E100A18V to case ground - 150 ohms

The conclusion of this test is that the 115 volt AC power wire is shorted to wire 1E109 shield either through the indicator or through the connector. The shield should have been at case ground potential. It was not. This indicates the available path of 115 VAC into the fuel tank through 1E109 shield.

5. An identical test as in item 4 was conducted on the cable harness with the indicator removed. The test results were as follows:

Wire 1E100A18V was shorted to wire 1E109 shield
Wire 1E100A18V was not shorted to wire 1E109
Wire 1E100A18V to 1E107 - open
Wire 1E100A18V to 1E108 - open
Wire 1E110N to case ground - short
Wire 1E110N to 1E109 shield - open
Wire 1E100A18V to case ground - open

The conclusion of this test is that the 115 VAC power wire is shorted to wire 1E109 shield within the connector. 1E109 was not grounded as it should have been. This test further confirms the electrical path available to the fuel tank.

6. Additional testing of the wire harness at the Naval Safety Center confirmed the above findings.

[redacted]

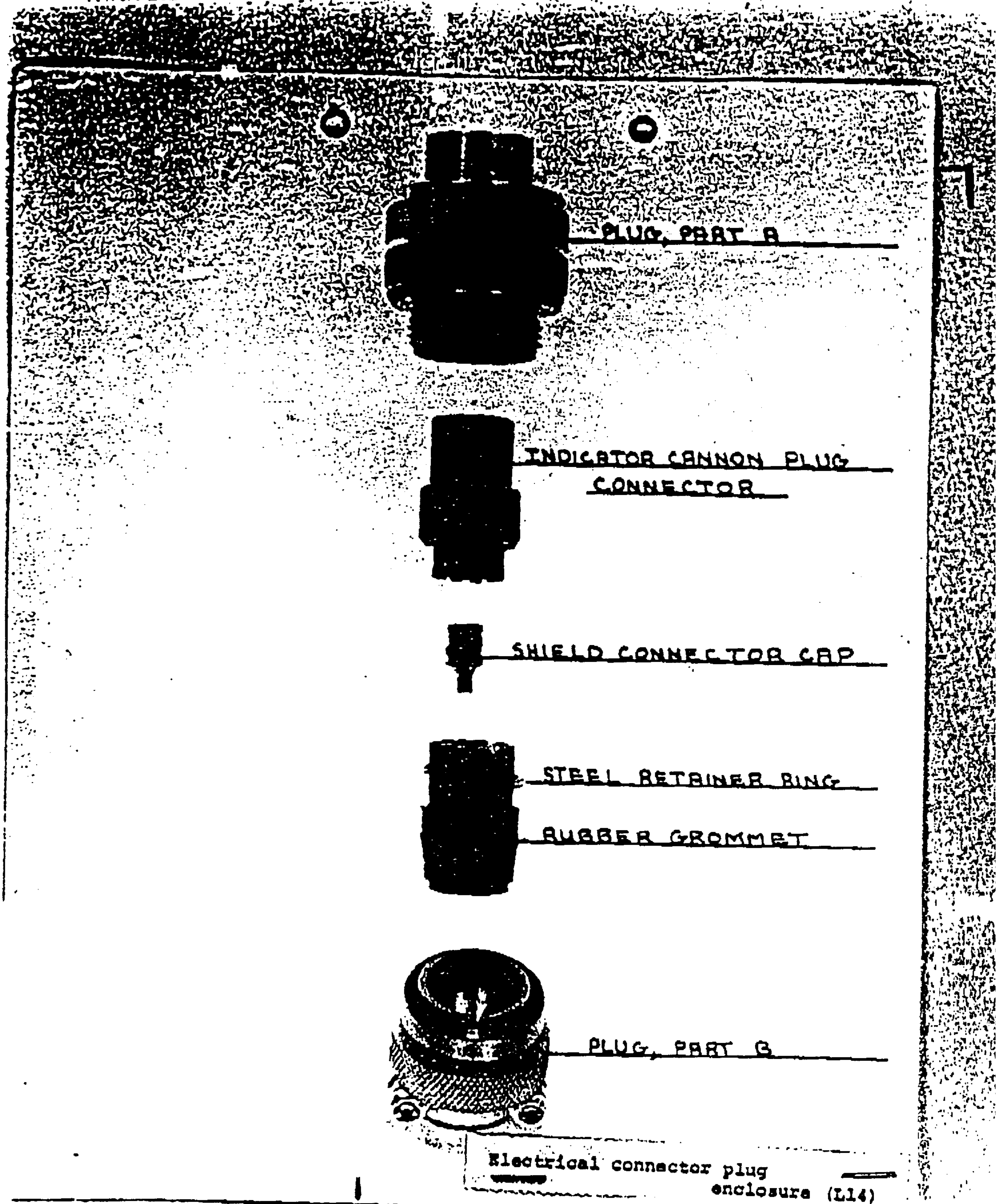
[redacted]

7. The indicator was field tested with a TF 20 tester and found to be discrepant. Laboratory teardown of the indicator showed an internal mechanical malfunction not associated with the electrical findings.

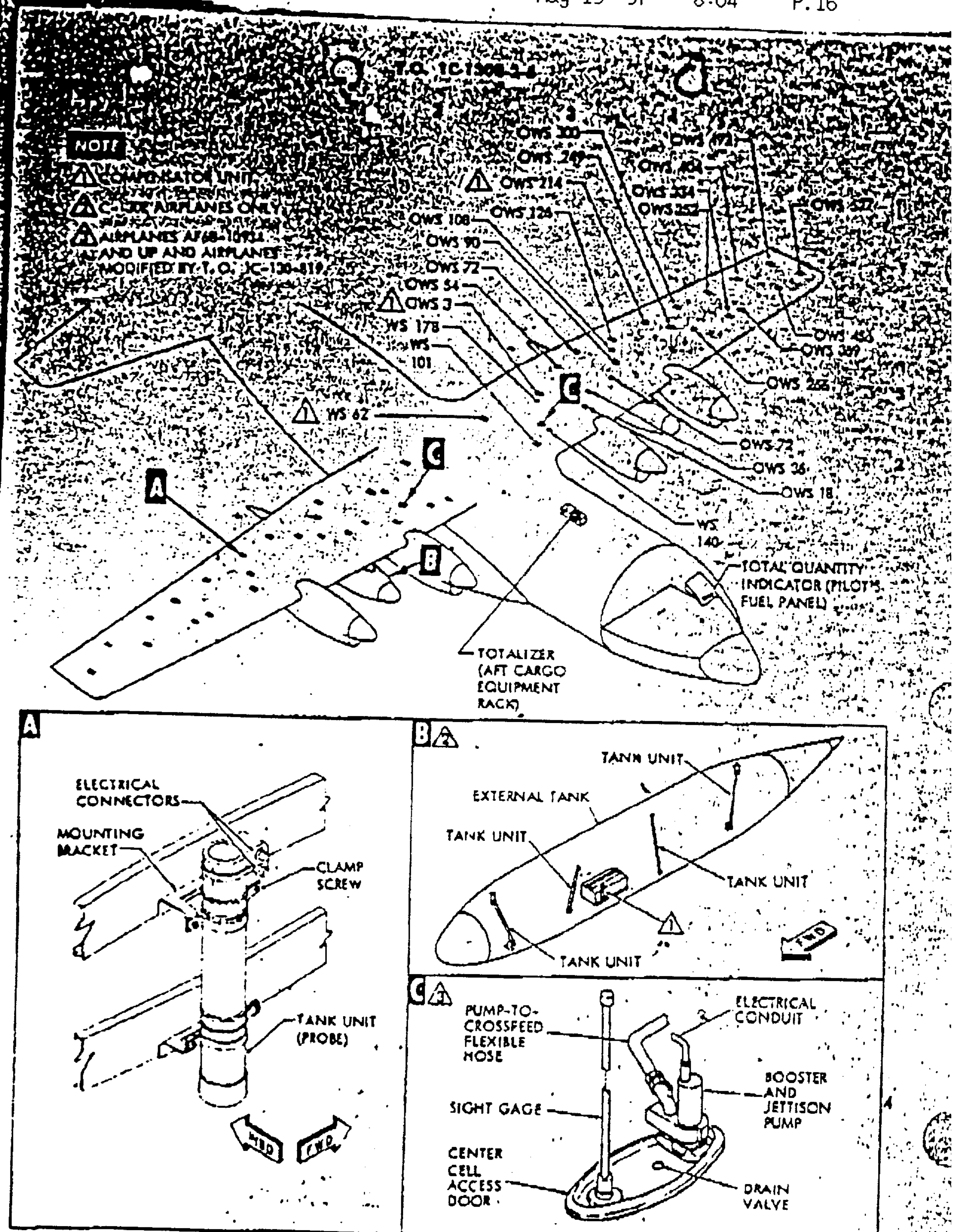
8. Examination of a section of coaxial wire 1E129 (tank extension of wire 1E109) at the approximate location of the explosion disclosed two segments which appeared to have been burned by arcing.

[redacted]

[redacted]

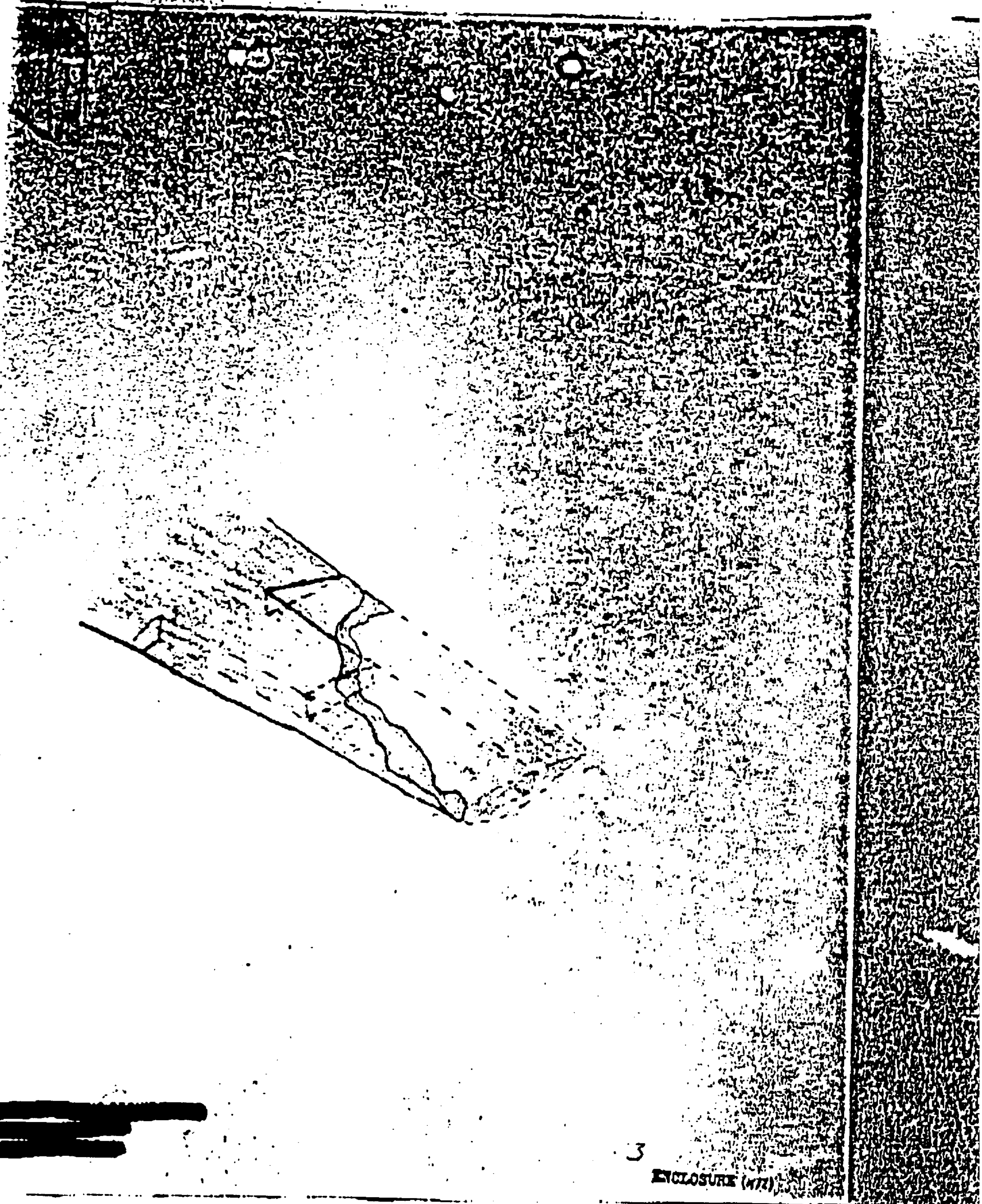


Electrical connector plug
enclosure (L14)



[redacted] *Fuel Quantity Indicating System Components Locations*

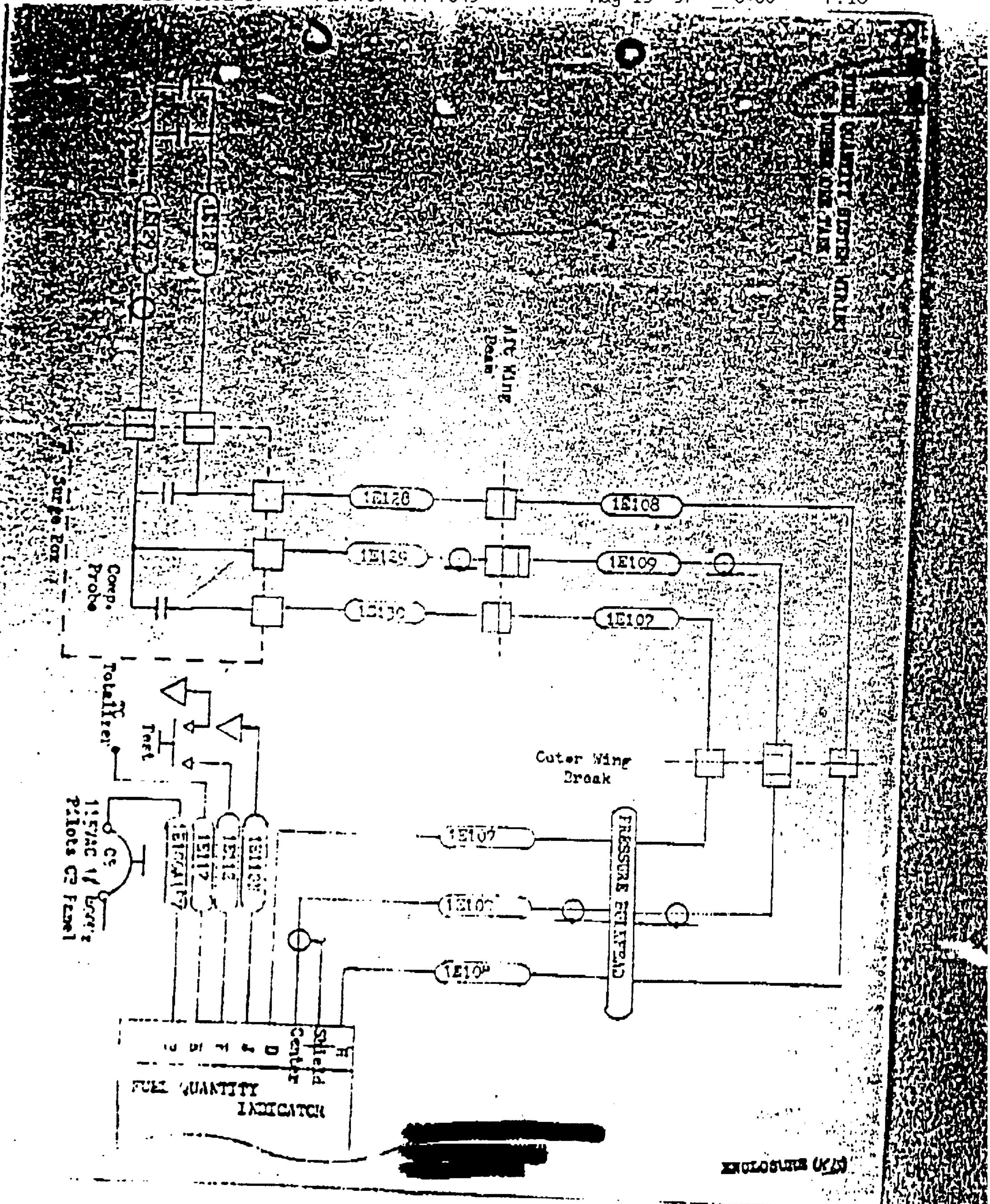
ENCLOSURE (#3)



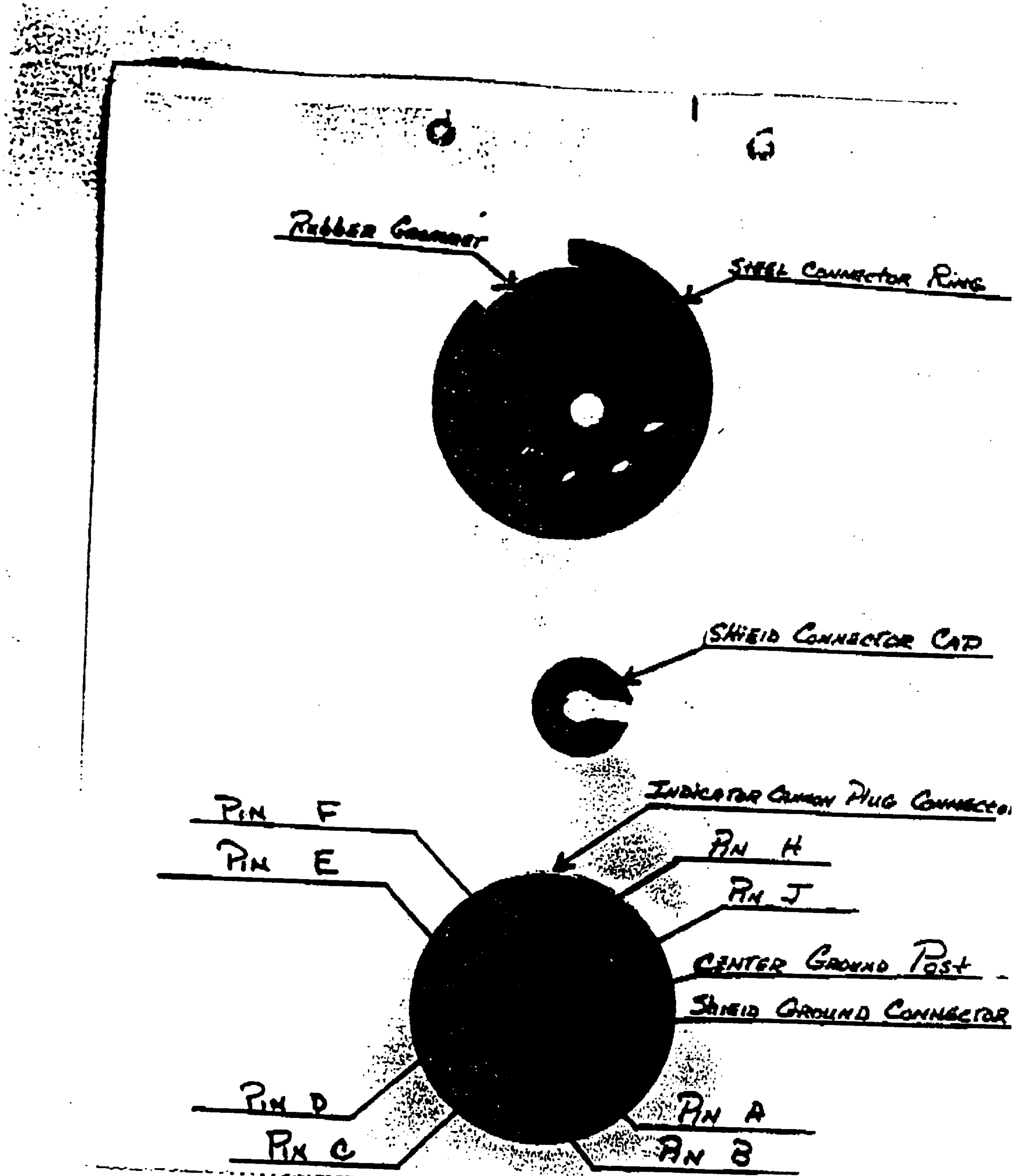
[redacted]

3

ENCLOSURE ([illegible])


1E128
1E108
1E109
1E107
Outer Wing
Break
FUEL QUANTITY
INDICATOR

[redacted]



Normal electrical connector plug enclosure (L9)

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Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

ENGINEERING REPORT RAPPORT TECHNIQUE	LP 28/89

EXPLOSION & FIRE ANALYSIS

Messerschmitt Boelkow Blohm BK 117 A-3D, (
Toronto/Buttonville Airport, Ontario
28 January 1989

ENGINEERING BRANCH REPORT

RAPPORT DE LA DIRECTION DE L'INGÉNIERIE

Canada

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3.4 CASB Engineering has reservations concerning the aforementioned scenario occurring for Jet A (Jet A1) fuel, unless an influential factor such as significant heating of fuel and/or fuel vapor took place as part of the event (ie. as per paragraph 2.33, MBB Alert Service Bulletin ASB-MBB-BK 117-60-107 applies). Review of the flammability properties of Jet A fuel indicated that the explosion and fire hazard associated with this fuel are relatively small, if the pressure and temperature of the fuel are equal to the values reported at the time of the occurrence. If the fuel involved is Jet B, preliminary calculations indicate that it is within flammability limits for these referenced conditions. It should be noted that if Jet A fuel is mixed with Jet B fuel, only a small quantity of Jet B fuel is required to transform Jet A fuel flammability characteristics into Jet B fuel characteristics (refer to Appendix "P"). Both Jet A and Jet B fuels are approved for use in this helicopter.

3.5 CASB Engineering considers heating of fuel and/or fuel vapor in order to create a flammable, explosive vapor mixture (initially addressed in paragraph 2.33, refer to MBB Alert Service Bulletin ASB-MBB-BK 117-60-107) to be of particular importance and applicability to this investigation. Similarly, bonding throughout the airframe (specifically with respect to the fuel tank and fuel vent systems), is considered to be of equal importance. The report of only two MBB BK 117 explosion/fire occurrences for a large fleet of helicopters in service worldwide, might be explained by the fact that the hazardous situation referred to in paragraph 2.33 may only exist for a short period of time following helicopter shutdown. An explosion may only take place during this time frame if a suitable ignition source is provided in the right manner, at the right moment. Further investigative work is required to collect reliable reference data and corroborate assumptions the hypothesis is based on.

4.0 CONCLUSIONS

4.1 The momentary fuel transfer pump caution light indication reported during the landing flare prior to the occurrence, was assessed as most likely being a false indication generated by a pitch attitude change with a low fuel state in the forward main fuel tank.

4.2 Assessment of limited biological and structural evidence indicates that the "bang" reported at the time of the occurrence is consistent with a fuel/air vapour deflagration explosion occurring in the forward main fuel tank.

4.3 Analysis of the hypothesis that the explosion was caused by electrostatic charging of the fuel and associated arcing within the forward main fuel tank indicates that this scenario is unlikely. This deduction is based on the timing of the occurrence, the probable fuel charge dissipation rates (relaxation times) involved, and the probable minimum ignition quenching distances for the forward main fuel tank.

4.4 Based on the limited information available, analysis indicates that the most probable explosion/fire scenario for this occurrence is as follows:

i) generation of heated (flammable) fuel air vapor in the fuel vent system, the top of the supply tank and in the forward main fuel tank, due to the draining of heated fuel from the engine fuel return lines following shutdown of the helicopter;

ii) ignition of flammable fuel air vapor at an exterior fuel line vent, due to electrostatic arcing between the fuselage and the vent as a result of charge accumulation from precipitation static;

iii) flash back of the flame front into the fuel vent line, into the supply fuel tank, and across into the forward main fuel tank through the tank overflow tubes;

iv) deflagration explosion of the flammable fuel air vapor concentrated in the near empty forward main fuel tank;

v) overpressure rupture of the forward main fuel tank through the bottom of the fuselage as well as through the fuselage floor, venting combustion gases around the edge of the air ambulance floor, blowing the passenger/medical and emergency exit doors off the fuselage, ejecting the blue medical resuscitator box;

vi) spillage of liquid fuel underneath the helicopter due to rupture of the fuel tank(s);

vii) ignition of liquid fuel as a consequence of the fuel air vapor deflagration explosion, engulfing the helicopter in flames; and

viii) destruction of significant portions of helicopter structure as a result of a large, fuel fed post-blast fire.

1 INTRODUCTION

During pressure refuelling of British Eagle International Airlines Ltd. (B.E.I.A.) Britannia G-ARKA at London Airport at 00.15 hours on 30th August 1966, an explosion occurred within the starboard wing causing tank rupture and limited structural damage in the region of No. 4 bag and to the engine nacelle skinning beneath it.

Heavy rain was reported to be falling at the time of the incident. The aircraft had been on the ground nine hours since its return from Italy and although some engines had been tested in this interval the one nearest to the explosion had not. The crew were on board at the time doing pre-flight checks, which involved activating the fuel gauging system, though the tank pumps were not switched on.

There were few obvious ignition sources in the region of the tank which exploded and hence an electrostatic discharge within the tank itself was suspected as the cause of the accident. Since this would be the first known incident in a civil aircraft, (a number of Canadian military aircraft have suffered tank explosions during refuelling which were attributed to this cause) an exhaustive examination of all possible ignition sources had to be made.

2 EXAMINATION OF EVIDENCE

2.1 Bonding

Two pressure refuellers were bonded to the aircraft via leads attached to the undercarriage damper strut (starboard refueller) and an undercarriage door panel (port refueller). The refuellers were earthed to the hard standing via a copper plate; the hoses were not bonded throughout their length and the refuelling connector bonding wire may or may not have been used.

Subsequent enquiries revealed that the existing single 'Appleton' bonding connection on the starboard side of the nose wheel bay was not used due to its inaccessibility and matching difficulties with the refueller bonding wire terminations. It was reported that fuelling crews are apt to use undercarriage components, flaps etc, including aluminium painted rubber hydraulic pipes, which must all be regarded as unsuitable bonding points. Hoses were non-conducting and unbonded on the particular vehicles operated by the fuel supplier concerned; difficulty had also been expressed by the service engineers in making bonding connections across the Avery Hardoll pressure refuelling units.

However the bag tank specification (F.P.T. Hycatrol H.G. 334) issued at the date of manufacture states:- 'small isolated internal metal items such as lift-the-dot fasteners, need not be bonded. The drawing shall specify which metal fittings are not required to be bonded'.

Presumably this relaxation of bonding requirements was permitted in the case of the fasteners because of their very small capacitance value (estimated 10-30 pFs) which would require voltages of 6-4 kV to produce sparks having the minimum energies needed to ignite fuel vapour/air mixtures. In view of the relative distances from the stud at the time of the explosion of the liquid surface (tank half full) and the earthed stringers, it is most unlikely that such potentials would have been attained. When further considered against the background of evidence pointing to an internal tank explosion, these metallic studs are discounted as the probable source of ignition.

(b) <u>Within No. 4 bag</u>

If we again assume the existence of free charge, concentrated either on the liquid surface or suspended in the vapour space above, a variety of possible discharge paths between these 'centres' and the earthed components in the tank must be considered. Of these earthed components, perhaps the most significant are the sharp projections associated with the inlet valve, including locking wire, the metallic float support, and possibly the outer casing of the fuel contents gauges. Allowing for the half-filled state of the tank, the most likely discharge paths are considered to have been either between mist-born concentrations and the inlet nozzle, or between the float support and the liquid surface. No visual evidence of such a discharge was detected. However the occurrence of an explosion is perhaps the only evidence to be expected in the absence of any recording instrumentation.

4 CONCLUSIONS

It is concluded that an internal fuel tank explosion occurred within No. 4 bag and that the mist or foam generated by refuelling must have been ignited by an electrostatic discharge in the tank ullage. There is no positive evidence to support this choice of ignition source and, in fact, conditions seemed unsuitable for dangerous charge accumulation at the time of this incident. However all other ignition sources are discounted.

5 RECOMMENDATIONS TO PREVENT A RECURRENCE OF THIS INCIDENT

(i) Measures should be taken to prevent the build up of charge within fuel entering the aircraft tanks. The employment of anti-static additive or charge relaxation techniques should give a substantial reduction in the risk of explosion due to electrostatic charging of the fuel. No. 1

(ii) Alternatively the extension of the filling pipe to the bottom of the tank would give a marked improvement in safety and make the fuelling arrangements comparable to those of the majority of present day aircraft. 2

(iii) Standard refuelling bonding points more convenient than those now provided should be specified and used, and bonding standards generally should be maintained. 3

(iv) Sharp projections within fuel tanks i.e. locking wire and split pins should be avoided if possible; and especial attention should be devoted to the bonding of all components in or adjacent to the fuel system, including 4 tank support buttons. (Implementation of this recommendation is desirable, but does not warrant retrospective modifications if these prove difficult.) 5

(v) Bag embrittlement (due to overheating by the jet pipe) should be prevented by improved insulation techniques.

Acknowledgements

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The assistance and co-operation of the aircraft manufacturer, the operator the fuel and accessory suppliers is acknowledged, together with that provided by Shell International Petroleum Co. Ltd.

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