NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

February 1, 2000

SYSTEMS GROUP CHAIRMAN FACTUAL REPORT ADDENDUM FOR DEPOSITS ON FUEL TANK ELECTRICAL COMPONENTS

A. ACCIDENT: DCA96MA070

Location : East Moriches, New York

Date : July 17, 1996

Time : 2031 Eastern Daylight Time

Airplane : Boeing 747-131, N93119
Operated as Trans World Airlines (TWA) Flight 800

B. SYSTEMS SUB-GROUP

Chairman : Robert L. Swaim
National Transportation Safety Board (NTSB)
Washington, D.C.

Member : Chris Hartonas
Federal Aviation Administration (FAA)
Seattle, Washington

Member : Jon Regimbal
FAA
Seattle, Washington

Member : Richard Lidicker
Boeing Commercial Airplane Co.
Seattle, Washington

Member : Lou Taylor
Honeywell Commercial Aviation Systems,
Sensor Products Operation (CAS-SPO)
Minneapolis, Minnesota

Member : William Savage
Honeywell Commercial Aviation Systems,

Sensor & Guidance Products
Minneapolis, Minnesota

Member : Ken Craycraft
Trans World Airlines (TWA)
Kansas City, Missouri

Additional participants:

Dr. Merritt M. Birky
NTSB
Washington, D.C.

Dr. Joseph Kolly
NTSB
Washington, D.C.

Michael Collins
FAA
Seattle, Washington

William Emmerling
FAA
Atlantic City, New Jersey

Ivor Thomas
FAA
Seattle, Washington

Bill Wall
FAA
Atlantic City, New Jersey

George Slenski
United States Air Force Research Laboratory (AFRL)
Dayton, Ohio

David Johnson
AFRL
Dayton, Ohio

Cindy Obringer
AFRL
Dayton, Ohio

Dr. John Grant
University of Dayton Research Institute (UDRI) at AFRL
Dayton, Ohio

Mr. Robert Kauffman
UDRI at AFRL
Dayton, Ohio

Dale Hart
UDRI at AFRL
Dayton, Ohio

Betty Rodrigues
United States Air Force
Dayton, Ohio

Dr. Robert Peck
Arizona State University
Phoenix, Arizona

Robert Zeliff
BFGoodrich Aerospace
Vergennes, Vermont

David Adkins
Boeing Commercial Airplane Co. (Boeing)
Seattle, Washington

Dr. Catherine Barron
Boeing
Seattle, Washington

Jerry Hulm
Boeing
Seattle, Washington

Dr. Bruce Skoropinski
Boeing
Seattle, Washington

Stanley Blum
Crane Company, Hydro-Aire
Burbank, California

Paul Russ

Crane Company, Lear-Romec
Cleveland, Ohio

Dr. Michael McKubre
Stanford Research Institute International
Menlo Park, California

C. SUMMARY

On July 17, 1996, at 2031 EDT, a Boeing 747-131, N93119, crashed into the Atlantic Ocean, about 8 miles south of East Moriches, New York, after taking off from John F. Kennedy International Airport (JFK). All 230 people aboard were killed. The airplane was being operated as a 14 Code of Federal Regulations (CFR) Part 121 flight to Charles De Gaulle International Airport (CDG) at Paris, France, as Trans World Airlines (TWA) flight 800. Wreckage from the airplane was recovered from more than nine square miles of ocean. Reconstruction of portions of the wreckage found evidence of an explosion in the center wing fuel tank (CWT).

On April 4, 1997, the Systems Group found blackened deposits on fuel quantity indication system (FQIS) electrical connectors that came from fuel tanks of the accident airplane and other airplanes. An investigation into the deposits included laboratory research; a search for documents; and meetings with others who researched the subject for the FAA, the Air Force, manufacturers (of airplanes, FQIS, and pumps), and universities.

D. DETAILS OF THE INVESTIGATION

TABLE OF CONTENTS

TOWER AIR TERMINAL STRIP

A May 28, 1998, letter to FAA Inspector Charles Fowler from Mr. Paul Marks of Tower Air stated that on April 9, 1998, Tower Air personnel found deposit on a CWT (T347) terminal strip while performing maintenance on a Boeing 747. Maintenance personnel had been troubleshooting FQIS problems related to refueling included premature and delayed refueling shutoff, as well as problems with system wiring. The terminal strip was removed and given to FAA personnel on the scene, who provided it to the Safety Board.

The Safety Board tested portions of the terminal strip at different laboratories and the resulting reports are attached. Safety Board personnel first brought the terminal strip to the United States Air Force Research Laboratory (AFRL) Electronic Failure Analysis Laboratory[1] to test the electrical resistance and to document the deposits. The part was then carried the part to the Evans-East Laboratories in Plainsboro, New Jersey, on April 20, 1998, for testing of the chemical properties of the deposits in further depth. The part was carried back to AFRL, where Dr. John Grant of the University of Dayton Research Institute (UDRI) was provided with a section of the T347 terminal strip. The AFRL subsequently tested areas of the terminal strip to document how the deposits would react to electrical loads. A final portion of the terminal strip was used to attempt a breakdown test in the presence of flammable jet fuel vapors at the AFRL Electronic Failure Analysis Laboratory and the Fuels Branch Laboratory.

EVANS-EAST LABORATORY REPORTS

The attached laboratory reports that resulted from testing at Evans East were:

- Dated April 22, 1998, for examinations conducted with positive and negative time-of-flight secondary ion mass spectrometry (TOF-SIMS).

- Dated April 242, 1998, for examinations conducted with X-Ray Photoelectron Spectroscopy (XPS).

AIR FORCE RESEARCH LABORATORY REPORTS

The Safety Board sent numerous FQIS parts from the accident airplane and other airplanes to the AFRL Electronic Failure Analysis Laboratory. The parts included fuel quantity probes (tank units), CWT terminal strips (including the T347 part from Tower Air), and FQIS wiring. The laboratory submitted three[2] reports that were identified as:

- Report No. AFRL/MLSA 99-2, dated January 26, 1999.

[1] Materials Integrity Branch of the Systems Support Division

[2] A previous AFRL report (WL/MLS 97-102) documented residues on FQIS components. A copy of the report was included in the Systems Group Chairman's Factual Report of November 17, 1997.

Report No. AFRL/MLSA 99-2 documented examination of FQIS parts removed from a retired 747, N134TW, that had entered service in 1970. Electrical resistance was measured between all combinations of the Hi-Z, Lo-Z, and Shield (ground) wire terminal posts. Appendix B to the report contained the results of XPS examinations performed at AFRL by Dr. John Grant of UDRI.

- Report No. AFRL/MLS 99-33, dated June 21, 1999,

  Report No. AFRL/MLS 99-33 further documented FQIS components from N134TW (a retired TWA airplane) and included the examination of parts from other airplanes. Deposits were typically found on terminal block surfaces at locations where silver-plated copper wire was exposed to jet fuel and on wire insulation near exposed core conductors or shield braid. Electrical tests found resistance between terminals and direct probing of the deposits on the surface of various parts was conducted at closer distances to replicate the spacing between adjacent wires. Report No. AFRL/MLS 99-33 also described the T347 terminal strip that had been provided by Tower Air from a 747 CWT.

- Report No. AFRL/MLS 99-68, dated October 18, 1999.

  Report No. AFRL/MLS 99-68 described how the thin-film sulfidation deposits break down under electrical loads and described development of a substitute deposit (vapor-deposited carbon on glass slides) used for repeatability of laboratory tests. Electrical break-down of the vapor-deposited carbon substitute deposits was used to repeatably ignite flammable (lighter fluid) vapors in an enclosed dish.

The Electronics Laboratory was not equipped to conduct testing with fuel vapors. Personnel from the Electronics Laboratory supplied seven vapor-deposited carbon samples to the Fuels Branch Laboratory for testing in fuel vapors. The Fuels Branch tests used a different test apparatus than had been used in the Electrical Laboratory and submitted a report dated January 6, 2000, that discussed the attempted ignition of fuel vapors.

INFORMATION FROM BOEING

The Safety Board requested that Boeing provide any documents pertaining to silver or copper sulfides on December 19, 1997. The Safety Board again asked for information about sulfidation on March 6, 1998, requesting information about fuel pump electrical motors that may have contained evidence of sulfidation and arcing damage. These requests resulted in a Boeing letter of April 23, 1998. The following documents were attached to the Boeing letter (and are attached to this report):

1. Boeing Materials Technology (BMT) Engineering Report MS21053, dated June 17, 1988, which described the examinations of 18 Hydro-Aire electrical fuel pump stators.

2. Boeing Analytical Engineering Report 2-5323-WP-91-97, dated March 20, 1991, described the "Analysis of Wing Tank Indicator Silvered Braid" from a B-757.

3. A Parker Bertea Aerospace Memorandum, dated August 18, 1992, documented the conditions of FQIS components removed from DC-10 airplanes.

4. Boeing Laboratory Report 9-5576-P+CA-025P, dated March 30, 1993, described examinations of electrical hardware from the fuel tanks of 747, 737, and DC-10 airplanes.

5. Boeing Laboratory Report 9-5576-P+CA-025P1, dated April 29, 1993, was the second report for an examination of electrical hardware from the fuel tanks of 747, 737, and DC-10 airplanes.

   Boeing conducted a literature search as part of Report 9-5576-P+CA-025P1 and attached were the following two reports:

   A. A report dated April 22, 1973, titled "Copper and Silver Corrosion by Aviation Turbine Fuels," written at the Indian Institute of Petroleum.

   B. The Journal of the Institute of Petroleum published a report dated September 1970, titled "Silver Corrosion by Aviation Turbine Fuel,"

6. Boeing Analytical Engineering Report 9-5576-WP-97-272, dated August 5, 1997, (and discussions documented in the meeting of April 29, 1998) described electrical tests of FQIS parts that had sulfidation.[3]

Boeing submitted Equipment Quality Analysis Report (EQA) 7564R, dated April 28, 1999, to the Safety Board. The report includes numerous sections pertaining to Boeing inspections of two complete sets of Honeywell B-747-200 FQIS components and testing of selected components. Analytical Engineering Reports attached to EQA 7564R describe testing the FQIS parts electrically with a Vitrek Model 944I Dielectric Analyzer and Andeen Hagerling Model 2500A Ultra-Precision Capacitance Bridge.[4] Attached to Report 7564R are other Analytical Engineering Reports that describe component examinations:

[3] This report was also received attached to Equipment Quality Analysis Report 7564R, dated April 28, 1999.

[4] Examples are Analytical Engineering Reports 9-5576-WP-97-329, dated September 17, 1997, and 9-5576-WP-98-136, dated May 20, 1998.

Analytical Engineering Report 9-5576-WP-97-318, dated September 2, 1997, describing examination of a compensator.

Analytical Engineering Report 9-5576-WP-98-135, dated May 15, 1998, described testing of five parts "to visually determine the effectiveness of mechanically cleaning the surfaces and to quantify effects on electrical properties."

Analytical Engineering Report 9-5576-WP-98-136, dated May 20, 1998, noted that the Safety Board had requested input regarding further testing that could be performed.

On August 31, 1999, Boeing submitted EQA Report 7895R, dated June 7, 1999, containing the records of examining B-737 FQIS components.

MEETINGS

MEETING AT NTSB ON APRIL 29, 1998

The Systems Group met at Safety Board headquarters in Washington, DC, on April 29, 1998, to discuss progress in examinations of deposits found on fuel quantity indication system (FQIS) components. The group agreed that:

1. The deposit is a complex mixture with majority components of copper-sulfide and silver sulfide. The deposit was referred to as "sulfides" (or later as "sulfidation") in the plural tense, denoting that the term is a summary and not a precise definition.

2. The chemical characteristics were not sufficiently understood in the topics of deposit development, cleansing, or removal.

3. The accumulation of the deposit appeared to be time-dependent, rather than dependent upon flight time or another factor.

4. The deposit is extremely brittle and can be disturbed by removal of samples from fuel tanks.

5. Terminal strips found in fuel tanks have deposits that are generically similar to fuel probe and compensator terminal blocks, but allow increased samples for testing.

6. Electrical testing of the Tower Air T347 terminal strip at the Air Force Research Laboratory (AFRL) had found that the electrical resistance of the deposit varies with the test voltage applied. As a result, the group agreed that further testing

would require strict record keeping that includes applied voltage, test equipment type, and any other parameters.

7. Electrical testing of the same terminal strip found that thicker deposits had increased resistance. Resistance was between 10E4 to greater than 10E7 ohms in the laboratory tests that did not control operational altitude, humidity, and other atmospheric variables.

8. Boeing reported testing two shipsets of B-747 fuel probes and compensators that had been received. The Safety Board subsequently received further detail in Boeing report 7564R, dated April 28, 1999 (description attached).

9. During 1987-1988, eighteen Hydro-Aire fuel pump stators with arc-type damage had been submitted to the Boeing Equipment Quality Analysis (EQA) Laboratory. It was reported that the primary cause of the arcing was the cracking of the wire insulation which provided locations for arcing to adjacent metal components. In one pump, testing found that silver-sulfide deposits had been involved. (The complete report was discussed in a previous section as Report BMT MS21053.)

APRIL 20, 1999, MEETING AT AFRL

The Systems Group met at the AFRL with an FAA group that was organized to research sulfidation on April 20, 1999. The FAA Program Manager, Mr. William Emmerling, described the FAA research plan that had been funded as part of the Aircraft Catastrophic Failure Prevention Program. Mr. Emmerling introduced Dr. Michael McKubre as the FAA researcher into the subject of sulfidation. Mr. George Slenski presented the results of AFRL research conducted for the Safety Board investigation, which was subsequently described in AFRL reports (attached).

Mr. Robert Kauffman of UDRI described the prior research that he and others had conducted into sulfidation, oxidation, sulfide deposits, and other topics. Mr. Kauffman also showed the group numerous samples of sulfidation that he had created in his laboratory. Mr. Kauffman explained that some fuels have less sulfur content than others and that low-sulfur fuels created more deposits than fuels containing higher relative sulfur amounts. He presented a list of EXPECTED RESULTS FROM LOW SULFUR FUEL USAGE (attached).

Mr. Kauffman informed the group about the existence of National Aeronautics and Space Administration (NASA) Report TN-D-4327, dated November 20, 1967, and titled CHEMICALLY INDUCED IGNITION IN AIRCRAFT AND SPACECRAFT ELECTRICAL CIRCUITRY BY GLYCOL/WATER SOLUTIONS. (The report is attached.)

NOVEMBER 9, 1999, MEETING AT ARIZONA STATE UNIVERSITY

Mr. Kauffman had conducted testing since the meeting of April 20, 1999, and reported his results to a joint meeting of FAA/NTSB/industry personnel that was held at Arizona State University on November 9, 1999. Mr. Kauffman reported that substitution of jet fuel for the glycol[5] that was discussed in NASA Report TN-D-4327 resulted in black deposits on silver-plated wires and that flashes of light developed that were similar to what NASA had reported.

Dr. Robert Peck had an associate demonstrate a variation of this reaction with direct current to the meeting which subsequently ignited fuel vapors.

Dr. Michael McKubre reported that the formation of sulfur-containing conductive deposits from jet fuel on silver wire was possible with both AC and DC current. Dr. McKubre also provided a presentation on the electrochemical processes that had been identified or theorized for the FAA investigation.

MINIMIZING SULFIDATION

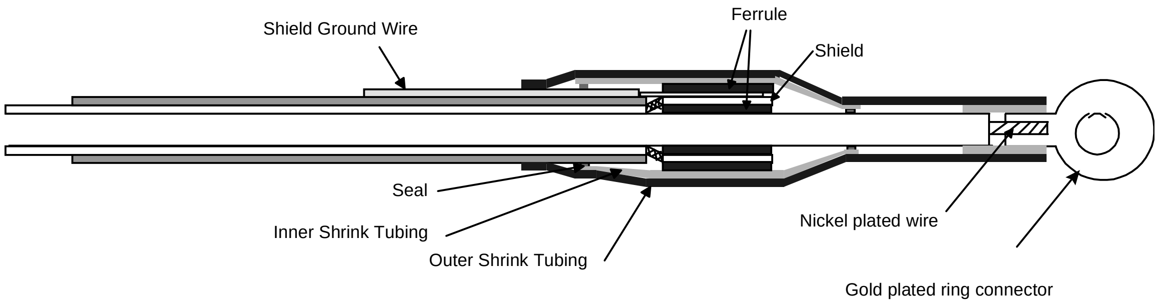
BFGOODRICH FQIS CHANGES TO MINIMIZE SULFIDE CREATION

The BFGoodrich representative to the meeting of November 9, 1999, related that the company improved the accuracy and reliability of military FQIS through a design changes that began in about 1993. The following were the changes to fuel tank wire termination methods:

1. Use of nickel-plated wire,
2. Use of fold-plated ring connector,
3. Sealant used in shrink tubes,
4. Separate inner and outer layers of shrink tube.

BFGoodrich also provided the Safety Board with sample assemblies and the following graphic (aircraft model identification deleted):

[5] Defined as ethylene glycol by the Webster's New World Dictionary, Third College Edition.



BFGoodrich Illustration of FQIS Ring Connector Attachment to Wire

The BFGoodrich representative stated that the improvement resulted in a large reduction in FQIS accuracy problems and that the inaccuracies had been based on leakage currents through the deposits. The BFGoodrich representative noted that approximately six years had elapsed since the change and that the time was nearly equal to the period that preceded the AFRL report.

REPLACEMENT OF WIRING IN FUEL TANKS

Boeing was asked about feasibility of replacing FQIS wiring in fuel tanks with nickel-plated wiring as is used on the Model 777 airplane. In a letter of December 7, 1999, Boeing wrote that "overall, the wholesale replacement of FQIS bundles in the tank is not recommended." The Boeing letter is attached.

On January 20, 2000, Boeing wrote that in addition to BFGoodrich, at least two other companies provide wire harness that have terminations that are resistant to sulfidation and the companies are Smiths Industries Aerospace - Civil Systems - UK, and Cinch Connector, Inc.; both of which supply fuel tank wire harnesses to Boeing.

[Original Signed By]
Robert L. Swaim
TWA 800 Systems Group Chairman