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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

November 17, 1997

SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT

DCA-96-MA-070

A. ACCIDENT

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 GROUP

The following list of participants is alphabetized by organization, then by the last names of the members. Additional persons assisted the Systems Group, but were not "signing members" of the records made at the various group activities.

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

Member : Michael Huhn
Air Line Pilots Association (ALPA)
Herndon, Virginia

Member : Leigh Johnson
Air Line Pilots Association
Seattle, Washington

Member : Gene York
Air Line Pilots Association
Newport Beach, California

Member : Kevin Darcy
Boeing Commercial Airplane Group
Seattle, Washington

Member : George Fleis
Boeing Commercial Airplane Group
Renton, Washington

Member : Issa S. Ghoreishi
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Member : Vernon Gorby
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Member : Fred Jaques
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Member : Richard Lidicker
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Member : Timothy Mitchell, P.E.
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Member : David Orth
Boeing Commercial Airplane Group
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Member : Rick Parks
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Member : Tom Peacock
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Member : Dennis Rodrigues
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Member : Derek Washio
Boeing Commercial Airplane Group
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Member : Joseph Beckhans
Federal Aviation Administration (FAA)
New York, New York

Member : G. Michael Collins

Federal Aviation Administration
Seattle, Washington

Member : Gregory L. Dunn, Ph.D
Federal Aviation Administration
Renton, Washington

Member : Chris Hartonas
Federal Aviation Administration
Seattle, Washington

Member : Ed Hormel
Federal Aviation Administration
Renton, Washington

Member : Joseph Manno
Federal Aviation Administration
Washington, DC

Member : Jon Regimbal
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Renton, Washington

Member : David Zitzman
Goodyear Tire Company
Akron, Ohio

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

Member : Robert Gille, PE, A&P
Honeywell Commercial Aviation Systems,
Sensor Products Operation (CAS-SPO)
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Member : Neal Speranzo
Honeywell Commercial Aviation Systems,
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Member : Rick Jean
International Association of Machinists and Aerospace Workers (IAM)
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Member : Wadell Simon
International Association of Machinists and Aerospace Workers
Los Angeles, California

Member : Larry Turpin
International Association of Machinists and Aerospace Workers
Kansas City, Missouri

Member : Fred Liddell, for Charles Hale
International Association of Machinists and Aerospace Workers
New York, New York

Member : Todd Carlson
National Transportation Safety Board
Chicago, Illinois

Member : John DeLisi
National Transportation Safety Board
Washington, DC

Member : Dr. Gary Mucho
National Transportation Safety Board
Los Angeles, California

Member : George Peterson
National Transportation Safety Board
Los Angeles, California

Member : Michael Stockhill
National Transportation Safety Board
Seattle, Washington

Member : George Kirstetter
Tec-Star
Durham, North Carolina

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

Member : Raymond Sherley
Trans World Airlines (TWA)
Kansas City, Missouri

Member : Bobby Vanderheiden
Trans World Airlines (TWA)

Kansas City, Missouri

Member : Dr. Joseph Leonard
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Fairfax, Virginia

Member : Dale Hart
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Wright-Patterson Air Force Base, Ohio

Member : David H. Johnson
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Member : George Slenski
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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). The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title14, Code of Federal Regulations (CFR), Part 121, on a regularly scheduled flight to Charles De Gaulle International Airport (CDG), Paris, France, as Trans World Airlines (TWA) Flight 800. The airplane was destroyed by explosion, fire, and impact forces with the ocean. All 230 people aboard were killed.

Evidence of fire was found in the center wing fuel tank (CWT) and in a fuel tank located outboard of engine 4 on the right wing, known as 4 Reserve (4R). The evidence included blackened structure, melted wiring and aluminum materials, burned composite materials from the areas of the fuel tanks. Outward bulging or deformation of the CWT upper and lower surfaces was found. Systems Group members participated in the recovery of debris from the ocean and components from the interior of the CWT were in the first wreckage found along the path of flight. Material from tank 4R and the tip of the wing from beyond that fuel tank were found more than a mile down track from the initial debris.

Indications regarding the configuration of the airplane were found in the wreckage.[1] Components from the leading and trailing edge flaps were examined for extension or retraction. The majority of flap orientation damage that was identifiable was found at the retracted positions, despite finding the broken cockpit flap control between the 10 and 20 degree positions. The pitch trim jackscrew mounted forward of the horizontal stabilizer was found at three-quarters (10 threads above

[1] Summarized information in this section does not have the depth of information that is described later in this report. Refer to the individual subject documentation for details.

the carriage and 35 threads below) of the range from the bottom of the jackscrew. Evidence was found that the landing gear had been retracted and the landing gear handle in the cockpit was found in the center position, marked "OFF." [*10/26/96 Group Activity*] [2]

Although details of fire and soot documentation were performed by the Fire/Explosion Group, general observations of fire damage (or lack of) to airplane systems were made by the Systems Group. The main landing gear nearest the fire at the rear spar had heat damage, as did the tread of the tires that had been mounted nearest the rear spar where evidence of fire existed. The APU fuel line and the inside of its shroud from the wheel well were examined and found unburned to within inches of the rear spar where the general area was burned. Soot was found in vent stringers routed beyond the CWT to the right wing tip, but components in the wing tip surge tanks were not burned. The Surge Tank Protection (STP)[3] system extinguishing agent had not been discharged from the intact bottles.

Evidence was found that numerous electrically powered devices stopped at about the same time. The electrically driven altimeters of the Captain and First Officer were found to display 13,820 and 13,800 feet, respectively. Wiring schematics showed the two altimeters to be powered by separate sources on different wings. Additionally, the Captain's altimeter was found to have a two second delay for the OFF flag and the flag was not visible. The Air Traffic Control Group[4] reported that the final secondary radar return was from approximately the same time (0031.08 EDT) and altitude. The recordings of the flight data recorder (FDR) and cockpit voice recorder (CVR) were reported by those groups to have ceased within a quarter second of each other. Although the clocks had run beyond the short interval in which the previous items had stopped, the Captain's clock was found at a display of 0031.30 and the First Officer's clock was found displaying 0031.20. Each clock is set independently. The clocks are powered from the airplane battery located in the cockpit.

Cockpit panels from the flight engineer station were examined and fuel quantity indications included (left to right) tank #1R (reserve) at 3,100 pounds, #1 at 22,200 pounds, #2 at 57,500 pounds, CWT at 640 pounds[5], #3 at 60,100 pounds, #4 at 27,300 pounds, and #4R (reserve) at 3,300 pounds. The fuel used indicators showed 2680, 2710, 23570 [heavily damaged gage], and 2830 pounds. The fuel totalizer was found between 587 and 588 (X 1,000 pounds) as GROSS WEIGHT and the TOTAL FUEL shown was between the indications of 169 and 170 (X 1,000 pounds). The numbers 1, 2, and 3 crossfeed valve switches were found in the open positions and the number 4

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[2] Paragraphs followed by a dated "[*Group Activity*]" are copied (unless noted otherwise) from text that was agreed to by members of the group performing the individual examinations, although some text may be deleted to remove group member names, irrelevant information to the topic where the information was copied to, or if subsequent activities make the deletions appropriate.

[3] STP is an electrically initiated system, in which each wing tip surge tank contained an optical sensor located in each overboard vent, within inches of the outlets at the tips of the wings. TWA personnel reported that the system was designed to prevent a fire from entering through the vent system exit. System schematics showed that the optical sensors would trigger the discharge of extinguishing agent in the respective vent duct and surge tank.

[4] See ATC Group Chairman's Factual Report of Investigation for specifics.

[5] According to a Boeing telefax of April 1, 1997, in a ground attitude (parked), calculating for a CWT quantity of 350 pounds indicated that none of the fuel probes should have been in the fuel because of the low fuel level in the tank and the CWT shape. At a 3.5 degree pitch attitude in flight, only the lowest .887 inches of the aft-most (FG420A-14) probe should have been in the fuel. At 640 pounds in 3.5 degree pitch attitude, the bottom .37 inches of the FG420A-14 should have been in fuel and the bottom .20 inches of the next two forward probes (FG420A-12) should also have been in fuel.

crossfeed valve switch was found in the off position. The fuel flow indicators were all found at zero, except for the #4 indicator which was found at a display of "900."

The Safety Board and FAA asked Boeing to provide information to show possible ignition sources of a B-747 CWT from faults in the airplane. In a letter of November 12, 1996, Boeing provided information to "…demonstrate all conceivable faults and fault combinations whose occurrence could provide an ignition source…" The document provided a reference for investigating possible failure combinations that could lead to explosive conditions. Boeing wrote that no single failures were found and that "All of the conceivable failure scenarios required between two to four failures for the event to occur." The electrical and mechanical events considered by Boeing included sources in the electrical supply and distribution systems, FQIS, fuel transfer pumps, the refueling panel, lightning, wheel well system defects, static electricity, and other topics. The Boeing response contained two illustrated blocks that led to the "CONDITIONS FOR EXPLOSIVE EVENT…" and the first was that an ignition source could be introduced into the CWT.[6] Many of the Systems Group activities were spent investigating potential ignition sources. The results of those activities are contained within this factual report. The second block illustrated by Boeing described an assumption that a proper fuel/air mixture existed in the CWT to support an explosion.

Heat affects the flammability of the fuel/air mixture[7] and the B-747 CWT is located immediately over heat sources that include bleed air ducts and air conditioning packs. The manufacturer of the air conditioning system, Hamilton Standard, provided data which showed that for a hot day, the ducts delivered 353^{o}F bleed air to the packs and the hottest part shown was a short section of tubing that could reach 393^{o}F. Hamilton Standard provided the air conditioning system for Boeing to integrate into the airplane. Insulation was found on bleed air ducting from the wing leading edges, routed from the engines to the pack bay beneath the CWT. No insulation was found between the air conditioning packs or the bleed air ducts and the bottom surface of the CWT, which was in some places less than a foot above the bleed air ducts. A July 1997 Flight Test Group investigated heating of the CWT by components located beneath the tank.

Boeing listed three potential ignition sources in the letter of November 12, 1996. These were CWT internal mechanical faults that could result in ignition, introduction of an external ignition source, and "multiple electrically generated system faults." No evidence of a mechanical fault that led to ignition in the CWT of N93119 was identified by the Systems Group.[8]

Most members of the Systems Group were shown numerous examples and photographs of bomb and missile damage, although no formal training was given. The Systems Group Chairman had previously completed the post-blast investigation course taught by the Federal Bureau of Investigation (FBI) at the FBI Academy. Several group members had military experience with

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[6] Due to the proprietary nature of the Boeing information, only the general nature of the information is reported and details have been omitted, such as rates of probability, rates of occurrence, and exposure times.

[7] The American Petroleum Institute (API), National Aeronautics and Space Administration (NASA), and other sources have charted how the lower flammability limit of jet fuel vapor decreases with increasing altitude or heat. The charts are publicly available. Systems group data was shared with the Fire/Explosion Group Chairman, who contracted to have data developed for the fuel/air mixture and other aspects of this flight. Systems group members also developed a portion of the plan for the July 1996 flight tests, results of which have been documented in a separate report by Dr. Dan Bower.

[8] This does not address activities performed and documented by the Structures or Sequencing Groups.

explosives. Law enforcement agents with experience in explosive devices were always available and if any damage were found that differed from surrounding materials, the group members were told to report it, immediately. No evidence of an explosive device was found in the systems of the accident airplane.

The Systems Group inspected, removed and tested components from the accident airplane and other B-747 airplanes. Tests were conducted in electrostatic charging of fuel and vapors, fuel quantity indication system (FQIS) faults and electromagnetic interference (EMI) tolerance, wire insulation characteristics, and other subjects.

Specialized laboratory facilities were used for various functions in the investigation into the airplane systems. The facilities of the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center, located at Huntsville, Alabama, were used to examine the jettison/overide fuel pumps and to perform preliminary switch examinations. The switch and wire laboratory unit at Wright Laboratory, located at Wright-Patterson Air Force Base, has specialized experience in the examination of fuel probes, switches, and wiring taken from aircraft involved in military mishap investigations and performed detailed examinations.

A separate facility at Wright Laboratory (WL) performs research into fuels and fuel additives and conducted research into electrostatic charging of fuels. Further research into electrostatic charging of fuels was conducted by Dr. Joseph Leonard at Naval Research Laboratory. The investigation examined electrostatic charging as a potential ignition source[9] within B-747 fuel tanks. Isolated metal found in the fuel tanks of B-747 airplanes was capable of being charged by additized fuel, but a mechanism of charging to more than minimum ignition energy cited by API 2003 was only possible under laboratory conditions that utilized a fuel additive not commercially available.

The B-747 flight tests of July 1997, were used as an opportunity to perform basic EMI tests. Measurements were made of voltage and current induced on FQIS wires that led from the cockpit to the CWT. During the ground portion of the EMI testing, various personal electronic devices (PEDs) were actuated and carried along the length of the FQIS wire routing between the cockpit and the floor of the main deck (passenger cabin). The PEDs included an electric shaver, personal computer, and amateur radio (2.5 watt output) broadcasts. Aircraft electrical systems were also actuated, including lights, radios, and electric actuators. Following ground tests, voltage and current were also measured during a flight test. Dr. Dan Bower of the NTSB Research and Engineering Division documented the flight tests. Less energy was found induced into the CWT FQIS wiring by the PEDs or by airplane systems on the ground than by aircraft systems operated during the flight.
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Laboratory tests induced energy into CWT FQIS wires without a direct short circuit. Transient voltages were created by switching on and off the power in wires that had been laid parallel to the CWT bundle, simulating large power relays or motor loads. The tests induced up to .6 millijoules of energy into the CWT harness, exceeding the Boeing specification of .02 millijoules and API Practice 2003 reference for a minimum ignition energy requirement of 0.25 millijoules. The resultant voltage transient was in excess of 1,000 volts. This amount of energy was only found

[9] Criteria listed are from American Petroleum Institute (API) Recommended Practice 2003, Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents, fifth Edition, December 1991.

during a failure condition in which a spark-gap was created between the LO-Z (outer fuel probe electrode or terminal) and ground and was not found during simulations of normal conditions.

An unidentified compensator[10] fragment from a N93119 fuel tank was cut open at the NTSB laboratory and a black spot was found on a crimped wire connector. The black spot was visually similar to soot seen near a point of electrical arcing. Use of a scanning electron microscope at Wright Laboratory identified the N93119 compensator spot as a copper-sulfur[11] residue, similar to copper sulfide deposits found in previous examinations of fuel probes from military aircraft. Copper-sulfide deposits were identified on plastic around the wiring connections of fuel probes and compensators from fuel tanks of N93105[12] and similar dark deposits were seen on fuel probes from F-BPVE. No evidence of arcing was found on wires or fuel probes from the B-747 fuel probes or compensators.

Wright Laboratory documented in military and B-747 FQIS components that the copper-sulfide deposits gradually reduced insulation resistance between electrical connections. Following removal from a military trainer airplane, tests had applied more voltage than would have been available from the FQIS system and subsequent visual inspection found "discoloration and possible arcing on the bottom" of the military fuel probe. The Air Force provided the Systems Group with a copy of the laboratory report, which stated that:

> It appears the internal probe wires were damaged by a fire. Evidence of an electrical arc was evident on the nylon cap which would have provided the required energy needed to ignite residual fuel.

In addition to copper-sulfur deposits found on FQIS components from N93105 and N93119, damaged electrical insulation was found on wires that had been attached to the fuel probe terminal blocks from each airplane. Most of the conditions were concealed until the wiring was removed from probe terminal blocks and inspected under magnification. Numerous methods of routing and securing, or not securing, wires at fuel probe terminal blocks were documented where wires attached to CWT fuel probe terminal blocks in N93105.

Repaired FQIS wires from within fuel tanks were identified in N93119 and a B-747 examined by Boeing. One N93119 wing tip fuel tank FQIS wire shield had been previously broken from a ground wire and repaired with a crimp connector that was covered with adhesive tape and tied

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[10] In a letter of October 24, 1997, Honeywell noted that the Honeywell part number FG6C is a Fuel Quantity Compensator. The function is to compensate for variations in the dielectric constant of fuel. The dielectric constant varies from one type of fuel to another, and even within the same type of fuel depending on the "batch" and the age of the fuel.

[11] The actual deposits were identified by scanning electron microscope and included copper, sulfur, and silver. Sulfur is described in the referenced USAF report to be a common contaminant of jet fuel. Silver-plated copper wiring is used in the FQIS. Due to the relatively small amounts of silver, references to the residue do not mention that component.

[12] ERRATA NOTICE: Airplane N93105 (serial number 19671) was a B-747 airplane that had been retired from service by TWA on September 24, 1994, about two years before the TWA 800 accident. The TWA fleet identification for N93105 was "airplane number 17105." A mistake in the record of a Systems Group activity wrongly identified the N93105 airplane as N17105. This mistaken identification was used by subsequent activities, such as at Wright Laboratory, and is referenced in their reports. Although group records may have cited the incorrect number in the original laboratory (and other) reports from which this report has been developed, the correction from N17105 to N93105 has been made in this document.

with string. The repair did not match any standard repairs in use by Boeing or TWA. A compensator from N93119 was found to have a incorrect strain relief clamp installed that was almost three times the diameter of the wire bundle. The wiring attached to the compensator was routed through the large clamp and back through the clamp a second time before attaching to the terminal block studs. Boeing inspected a non-TWA airplane and found that the CWT FQIS wires had chafed and been repaired with fuel tank sealant.

The CWT FQIS wires were found routed with numerous power and signal wires. Boeing reported that FQIS-related wires were routed in bundles with almost 400 other wires carrying electrical power of 5 to 192 volts[13].

The general BMS13-42A (also known as Poly-X, manufactured by Raychem) wire from the fuselage of N93119 (external to fuel tanks) was found with numerous cracks in the insulation and examination found that the cracks penetrated to the core conductors. No evidence of arcing to FQIS wires was found. It was found that air carriers have instituted maintenance to conduct detailed inspections of wire bundles for cracked wire insulation and samples of cracked B-747 Poly-X wires were obtained by the Safety Board from an airline conducting a detailed inspection. The Safety Board examined older airplanes from other manufacturers and found that cracked and damaged insulation was not unique to Poly-X.

Boeing issued a service bulletin (SB 747-28-2205) on June 27, 1997 and a Notice of Status Change (NSC) for this SB on September 25, 1997. The SB contains 100 pages of instructions to describe fuel tank inspection procedures for B-747 operators. All but one of nine tasks listed for accomplishment are visual inspections and none call for removal of wiring from fuel probes or the compensator. Removal of wiring to examine the back side was necessary to find damage during the accident investigation.

On October 27, 1997, Boeing notified operators by telex (M-7220-97-1725) that a new SB is in development that will provide operators with details regarding how to inspect B-747 fuel probes and FQIS wires. Boeing also confirmed this to the Safety Board in a letter of October 30, 1997. Boeing wrote that the SB will ask for removal of wiring from terminal blocks for inspection, replacement of Series 1-3 fuel probes, reporting of damage found at Series 4 and subsequent fuel probes, replacement of certain CWT FQIS wire harnesses, inspection for proper wire routing and

[13] Attached to the FQIS wires behind the flight engineer panel were wires for the airborne integrated data system (AIDS) and refueling system; wires clamped with #4 engine fuel flow wires. The common routing passed fluorescent cabin light wires of up to 350 volts AC at frame 360, located to the right of the main cabin. Severe impact fragmentation was found to the right forward fuselage of N93119 in the area of common wire routing.

existing damage, establishment of an electrical resistance check of very low voltage, and will establish stands for permissible FQIS repairs.

D. DETAILS OF THE INVESTIGATION

TABLE OF CONTENTS

COCKPIT AND INSTRUMENTS

[*10/25/96 Group Activity, denoting that the wording was agreed to by the group that performed the examination.*]

Debris from the cockpit was received at the hangar a pile of wire and entangled broken parts that measured about five feet tall and 12-15 feet in diameter. The debris was totally separated from the exterior skin and windshield structure. When the wire was brought into the hangar, it was hung by a crane hook and photographs were taken of the individual cockpit controls and displays. Photographs were also made after removal of the individual control, indicator, and light panels that were removed from the pile and examined individually. The following set of notes were made from the component examinations and from the photographs.

The cockpit panels have combinations of navigation displays, autopilot controls, powerplant indicators, and other separable subjects. However, for ease of understanding, the instruments and other components have been grouped together by panel, from left to right and from top to bottom. Panels that contain multiple rows of instruments are generally also listed by row, from left to right, followed by the next lower row.

Although individual switch positions have been documented for the positions they were found at, few switches were of the locking type and many were found with strands of wire around the switch toggles. Many individual caution and warning lightbulb indicators were found missing or broken. Those lightbulb filaments that were examined were magnified with 10 or 15 power magnifying glasses or were taken to a variable (75X max.) binocular microscope.

The Captain's control column was found attached to the floor, but missing the yoke and top assembly. The yoke and upper portion of the column had separated at the internal bevel gear, although wiring still attached the separated assembly. The right handle of the yoke was missing and the left handle was broken from the center. The First Officer's control column was found separated at the base (floor level). The yoke was found attached to the control column and the right handle was broken.

CAPTAIN'S INSTRUMENT PANEL

(Designated by Boeing as P1)

AUTOMATIC FLIGHT ANNUNCIATOR PANEL
P/N TWA P/N 52103, S/N 11

Lightbulbs were removed from the Flight Progress Annunciator (Flight Director & Autopilot) Panel. Within each of the AUTOPILOT and AUTOTHROTTLE MASTER CAUTION assemblies were four bulbs with filaments that were visually intact, without gross distortion or distortion of the individual coils.

Within the left indicator light block were four rows of indicators that contained four bulbs each. The filaments in the bulbs were found intact, without gross distortion or distortion of the individual coils. The only exceptions were a single bulb under the GS caption with a single separation in the filament and two NAV bulbs that had green lenses which were found broken into small sections with no distortion of the coils.

Within the right indicator light block were five rows of indicators that contained four bulbs each. The filaments in the bulbs were found intact, without gross distortion or distortion of the individual coils, except for an orange-lensed ALT SEL bulb and two NAV bulbs that had green lenses. Those three bulbs had filaments that were broken into small sections with no distortion of the coils.

INSTRUMENT WARNING ANNUNCIATOR PANEL

Each instrument warning light assembly caption had a set of two light bulbs. The top INSTRUMENT WARN indicator bulbs were broken into smaller fragments with slight amounts of general distortion, but no distortion of the individual coils. The ATT bulbs had a slight distortion of the general coils, but the filaments were visually intact in this and the MON indicator. The HDG bulbs each had a single break , but were otherwise intact and not deformed. The ALT bulb filaments were intact.

The instrument panel was folded over to the right of the instrument warning annunciator panel and held no other components.

CLOCK

The only sweep hand seen was yellow and pointing toward the 12 o'clock position. The larger upper digital scale showed between 0031 and 0032. The lower elapsed time window was between 08 and 09 on the hours indicator and at one quarter distance from the 41 toward the 42 markings for the minutes indication. The selector switch was bent, but pointing toward the RUN position.

AIR SPEED INDICATOR

This instrument was found intact with facial glass and hanging about six inches from the Captain's instrument panel. On August 5, 1996, the indicator needle was seen pointing at 122 knots and the red/white "barber pole" was seen at 340 knots. The mach window was covered by a yellow flag. No external reference markers, also known as " speed-bugs" were seen.

ATTITUDE DIRECTION INDICATOR

Found with the facial glass and the airplane indicator missing. The red-orange ATT flag and two twisted red-orange indicators were visible, but the facial mask in those areas had been peeled off. The attitude ball was at a six degree roll of right wing down and the pitch indication was about three degrees nose up when a line was laid between the left and right indices. No speed, glideslope, or localizer display needles were evident.

ALTIMETER

Found intact with the facial glass in the instrument panel and not displaying any yellow, orange, or red flags. The large digital display read 13,820, the single white sweep hand was on 820, the mercury barometer window read between 1022 and 1023, the metric barometric correction window read between 3019 and 3020. A red internal pointer aligned with the "2" digit at the 2 o'clock position.

Note: See text from Maintenance Manual that has been attached to the Air Data Computer entry with respect to instrument "flagging."

RADAR ALTIMETER

Found separate from the panel but attached by the wiring harness, the glass face was intact and fogged. Through the glass, the striped OFF flag was in view and the colored portion of the altimeter needle was obscured by the needle mask.

RADIO AND DISTANCE MEASURING INDICATOR (RDMI)

Both distance measuring displays were missing from the facial cut-outs, located behind the facial glass. Two red-orange flags seen were labeled VOR 1 and VOR 2. Visible at the top of the compass rose was part of a red-orange flag that had no captioning visible. The top of the compass rose was 080 degrees, the single green arrow pointed to 144 degrees on the compass rose, and the double orange arrow was pointing toward 100 degrees on the compass rose. Both ADF/VOR selector switches were separate from the instrument and hanging by electrical wiring.

HORIZONTAL SITUATION INDICATOR (HSI)

Found and photographed with the facial glass and facial cover missing. Above the compass rose display was an indicator fixed between a black "TRUE" and red-orange "HDG." The compass rose in the photograph was oriented to about 105 degrees. The TO/FROM arrows were both in view, along with about a third of the red-orange "NAV" flag. The orange heading triangle was at the top of the display, at 103 degrees on the compass rose. The green course deviation indicator was about ¾ of the distance from the center toward the first left deviation marking. The tail of the green course arrow was bent, but was at the 7 o'clock position, with the tip at the compass rose 320 degree mark. The digital display wheels located at the upper right corner of the instrument the display were between 015 and 126. The digital display wheels located in the lower right corner of the instrument indicated 377, with mechanical damage to the center wheel. The digital display wheels located at the lower left corner of the display were also physically damaged and the "5" moved freely, but were found with a display of 35R. A vertically mounted rotating drum along the left side of the instrument was displaying the black side of the drum and concealing the striped black and red side.

ALTIMETER, STANDBY

Found intact with the facial glass and extended about one inch from the instrument panel. No orange, red, or yellow flags were in view. The digital altitude display drum mounted at the 3 o'clock position showed between 21,000 and 22,000, the sweep hand was resting at the 640 mark, the mercury barometric correction window showed 30.07, and the metric barometric window showed 1019.

GLARESHIELD PANEL

(Designated by Boeing as P10)

The Captain and First Officer's navigation control panels, marked "VHF NAV", were found with significant impact damage. The Captain's was between displays of 116.90 and 117.90, the First Officer's panel displayed 115.45.

The Automatic Flight Mode Select Panel was found as an intact unit, with the following control/display positions: The Captain's flight director lift/lock switch was found bent toward the one o'clock orientation, with corresponding damage to the blade of the locking feature. The A/T toggle switch was in the down (OFF) position, but in an area of the panel that had facial damage. Both ENGAGE toggles were found in the down (OFF) positions. The NO 1 COURSE display was 105, the Course Transfer knob was at DUAL, and the NO 2 COURSE display was at 098. The HEADING window showed 070. The NAV SELECT knob was at LAND, with physical damage to the knob, the CWS switch was in the down (OFF) position, but in an area of the panel that had facial damage. The ALT SEL window showed 15900 and the ALT HOLD/SELECT switch was in the OFF position, next to an area of physical damage. The Turbulence/Speed Mode Selector knob was between the OFF and TURB positions. Contained in the right edge of the physically damaged panel was the First Officer's FLT DIR switch in the center (OFF) position.

CENTER INSTRUMENT PANEL

The center instrument panel was found as a single intact assembly and the individual instruments are described from left to right:

The marker light assembly was found almost intact, but was missing the bulbs and lenses. Below the marker light assembly, the EPR mode panel found intact, the displays were blank. In the middle of the left panel edge, the standby attitude indicator was found intact with the facial glass internally fogged and retaining water. A red-orange flag was in view, the attitude display showed a 30 degree left roll, and the pitch display was fully brown with the ventilation holes of the indicator ball in view. At the bottom corner of the left panel edge, the flight control position indicator was missing the facial glass and had impact damage. The displays for the elevators were both at the bottoms of the scales, the rudder indicators were at the center, the right spoiler indicator was at 35 degrees, and the indicators were missing for the left spoiler display, as well as for each aileron.

The engine instrument faces were intact and glass remained in the faces of the N_2 and Fuel Flow gauges. The engine displays were of the vertical tape type and each displayed OFF flags. The EPR indicator also showed tape positions of 1.35, 1.35, 1.30, and 1.23, respectively for each of the engines. The digital EPR displays at the tops of the scales (termed “vernier counter”) were .00, .70, .00, and .71, which the TWA Flight handbook notes “indicates numerical EPR indicated by tape.” The command window at the bottom of the instrument read .33.

The display for positions of the outboard trailing edge flaps showed the left to be 28 degrees and the right to be 30 degrees. The display for positions of the inboard trailing edge flaps showed the left to be about one degree and the right to be slightly more than one degree. The facial glass for each flap indicator was intact.

The SAT and TAS displays were intact with the facial glass, but the digits were obscured by yellow flags.

The landing gear handle was in the center position, labeled as “OFF.”

Center panel annunciator lights located across the top and right edges of the panel exhibited the following indications:

The filaments in the two bulbs from the #3 REV IN TRANSIT annunciator were not deformed in general or with localized stretching of individual coils.

The filaments from the two #4 REV OPERATING bulbs were found broken into several sections, but no localized stretching of individual coils was seen.

One of the two bulbs from the #4 REV IN TRANSIT annunciator had a filament that was mildly deformed in general and with mild localized stretching of individual coils. The second bulb filament was found in small pieces that exhibited no localized stretching of the coils.

The filaments from the two red lensed GEAR bulbs were found broken into several sections, but no localized stretching of individual coils was seen.

The filaments from one of the two green lensed L E FLAPS bulbs was found intact and the other bulb's filament was found broken into several sections. No stretching of the general filament or localized coils were found in either bulb.

The filaments from the two amber lensed L E FLAPS bulbs were found intact, without stretching of the general filament or localized coils.

CAUTION/WARNING ANNUNCIATOR ASSEMBLY

The individual lights were removed from the panel and examined under magnification. The light legends are shown, preceded by the horizontal row and vertical column number of each.

1A ENG OIL PRESS 1
The filaments of the two bulbs were found without generalized or localized stretching of the coils, although one filament was in small sections.

1C ENGINE OIL PRESS 3
The filaments in the two bulbs were found as numerous small fragments.

1D ENGINE OIL PRESS 4
The filaments of the two bulbs were found intact and without distortion of the individual coils, although one exhibited mild generalized distortion of the coil.

1E OXYGEN
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

1F ESS BUS OFF
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

1G LOW N_1
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

1H RUDDER RATIO
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

2E FIRE DETECTION
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

2F GROUND PROXIMITY
One bulb had an intact filament, without gross distortion or distortion of the individual coils. The second bulb had a broken support and the filament was found in numerous small pieces.

2G INST XFR FAIL
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

2H ELEV FEEL
The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

3A HYD SYS PRESS 1

The filaments in the two bulbs were found broken into small sections, although no distortion of the individual coils was seen.

3B HYD SYS PRESS 2

One bulb had an intact filament, without gross distortion or distortion of the individual coils. The filament in the second bulb was found in numerous small pieces.

3C HYD SYS PRESS 3

The filaments in one bulb was found as numerous small fragments. The filament from the other bulb had a piece broken from the mid-section, but exhibited no gross distortion or distortion of the individual coils.

3D HYD SYS PRESS 4

The filaments in the two bulbs were found as numerous small fragments.

3E ANTISKID HYD

The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

3F AUTO STAB TRIM A

The filaments within the two bulbs exhibited mild generalized stretching.

3G AUTO STAB TRIM B

The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

3H PROBE HEAT

The filaments in the two bulbs were found as numerous small fragments.

4A AUTO BRAKE

The filaments from the two bulbs were found broken into several sections with generalized and localized stretching of individual coils.

4C YAW DAMPER UPPER

The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

4D YAW DAMP LOWER

The filaments in the two bulbs were found intact, with some mild generalized distortion, but no visible distortion of the individual coils.

4F AUTO SPOILERS

One bulb had an intact filament, without gross distortion or distortion of the individual coils. The second bulb had a break in the filament and some localized stretching of the coils near the top of a support post.

4G BRAKE OVHT

Both bulb filaments exhibited mild stretching near the support posts and one had a break between the posts.

4H GEAR NOT CENTERED

The filaments in the two bulbs were found intact, without gross distortion or distortion of the individual coils.

CENTER PEDESTAL

(Designated by Boeing as P8 and P9)

The radar control panel was found with all switches in the up position.

The #1 Automatic Direction Finder (ADF) Control Panel switch was found beyond the "OFF" position at about 7 o'clock and the displayed frequency was 262. The #2 ADF control panel was found with the switch at "ADF" and with a frequency display of 264.

The #1 High Frequency (HF) Radio Control Panel was found with the switch at "OFF" and at a frequency of 13006. The #2 HF control panel was found with the switch at "AM" and a displayed frequency of 10010.

The rudder and aileron trim knobs were broken free and had no visible alignments that corresponded to a pre-impact position.

#1 Inertial Navigation System Control Panel was found with the lower left control set at XTK/TKE and the AUTO/MANUAL switch was in the AUTO position.

#2 Inertial Navigation System Control Panel was found with the lower left corner of the panel broken away. The lower left control knob was found set at WIND, the AUTO/MANUAL switch was in the AUTO position, and most of the pushbutton lights were missing.

#3 Inertial Navigation System Control Panel was found with lower left control knob at WIND, the AUTO/MANUAL switch was in the MANUAL position.

EPR Limit Mode Select Panel was found with all buttons in the up orientation.

TCAS/ATC Control Panel from the pedestal was found broken, obscuring the mode selection position, with the altitude reporting selection switch at OFF, and with the ATC selection switch in the #2 position.

The Traffic Collision Avoidance System (TCAS) selector panel on the captain's panel (P-1) had two vertically installed toggle switches that were bent; the ELEV toggle switch toward the seven o'clock orientation and the RANGE switch was bent toward three o'clock. At the bottom of the panel, the FLT DIR CMPTR switch was at the "A" position, the DEVIATION, COMPASS, and ATTITUDE switches were found in the positions that corresponded with having the guards closed (systems 1, 2, and NORM, respectively), and the INS switch was completely missing.

The Captain's audio selection panel was found with the microphone selector buttons extended (not selected). The audio selection button frame was found broken and with the buttons in the extended positions.

The First Officer's audio selection panel was found with all features impact damaged.

#1 THROTTLE POSITION

Throttle found jammed in the idle position.
Thrust reverse lever found in stowed position.

#2 THROTTLE POSITION

Throttle found in idle position with about one inch of free play and the lever was missing.

The thrust reverser lever was missing.

#3 THROTTLE POSITION

Throttle found in the middle of the travel range with about 1.5 inches of free play.
The thrust reverser lever was found in the stowed position.

#4 THROTTLE POSITION

Throttle found jammed in the middle of the travel range. The aft lever was missing.
The thrust reverser lever was missing.

FLAP HANDLE

The knobless lever was found between the 10 and 20 degree positions, freely moving between 13 and 18 degrees.

FIRST OFFICER INSTRUMENT PANEL

(Designated by Boeing as P3)

INSTRUMENT WARNING ANNUNCIATOR PANEL

The red "Pull Up" Light Module, amber Light Module for "INS 1," "INS 2," and "INS 3" are missing. The red/amber "Instrument Warning," "Attitude," "Monitor," "Heading and Altimeter," light module is missing.

AUTOMATIC FLIGHT ANNUNICATOR PANEL

The Flight Director / Auto Pilot caption bezel is missing above the F/D-A/P annunciator panel. The light dimmer sensor in the upper left corner is partially missing. The green/amber light module for F/D-A/P are intact. The light dimmer sensor in the upper right corner is intact. The red/amber light modules for "Auto Throttle" and "Auto Pilot" are missing face plates.

CLOCK

The clock "second" hand is missing and the elapsed minute indicator is missing. The "elapsed time" (ET) selector is missing. The "GMT" and "Event" selectors are intact. The "GMT Time Indicator" displays 00:31:15. The "Elapsed Time" is between the 8 and 9 displays in the tens digit for hours, an 8 in the single hours position, and a 13 in the section for minutes.

AIRSPEED INDICATOR

The glass face plate is missing and the amber airspeed reference "bug" and selector knob are missing. The "Mach" indicator yellow flag covers the numbers .578. The white airspeed pointer is between the mark for 108 knots and the number 120 knots, at approximately 114 knots. The red/white "Barber Pole" indicator pointer is at 400 knots. The case is torn/broken on the bottom and sides.

ATTITUDE DIRECTOR INDICATOR

The glass face plate is missing and the "slow-fast" pointer is missing. The "Flight Director" indicator and white "Airplane" indicator are missing. The attitude is at approximately 15 nose

up, wings level. The yaw indicator "ball" is missing. The "200' to Ground" indicator is missing. The case has crush marks on all sides.

ALTIMETER

The inner glass face is cracked, the outer glass face is intact, and there is sand visible between the glass face plates. The amber altimeter "Bug" and selector knob is missing. The barometer setting is 1018MB and 30.06 in HG. The red altimeter flag is visible just above the altitude read-out of 13,800'. Part of the "Hundreds" pointer is visible on top of the red flag and points to 100'.

RADAR ALTIMETER

The glass face plate is missing. The amber "Bug" is at 95' and the selector knob is missing. The green pointer is at the 11 o'clock position between the number 25 and the number zero. The red/white "Barber Pole" indicator is partially visible. The light "Reset Button" is intact. The altitude "limit" light module amber lens is missing. The case front is broken/missing from 1 o'clock to 7 o'clock position.

RADIO AND DISTANCE MEASURING INDICATOR (RDMI)

The front part of the indicator (approximately 2") is missing. The green single pointer indicator VOR/ADF selector knob is hanging by two connector wires. The red "VOR-1, VOR-2" indicator is hanging by two connector wires. The entire case has heavy crush damage. The amber double pointer selector knob and black caption baezel with
"1-DME-2" and "VOR/ADF" in the lower left and lower right sections is loose and not connected to the remainder of the RDMI indicator case.

HORIZONTAL SITUATION INDICATOR

The glass face plate and caption bezel is missing. Above the compass rose display is an indicator fixed between a black background/white lettered "TRUE" and orange background/black lettered "HDG." The compass rose heading indication is at 125 (at the 12 o'clock position). The white triangles for "TO' and "FROM" are both visible. The green "COURSE" indicator bar is centered and the course selector pointer is fixed at the 161 position. The amber triangle (selected heading) indicator is fixed at the 120 position. The "DISTANCE" indicator is fixed at the 028 position. The "DRIFT" indicator is fixed at the 6 6 R position. The "GROUND SPEED" indicator is fixed at the 3 7 7 position. A partial red "NAV" flag is visible.

TCAS/VERTICAL SPEED INDICATOR

About two inches of the forward section was found broken away from the rest of the indicator case and hanging by two sets of wires. The indicator glass face is intact. The indicator is blank, it is the TCAS indicator and V/S indicator in one instrument and is a CRT display.

PRIMARY INSTRUMENT SUPPORT PANEL

The primary instrument support panel was found with heavy crush-type damage. A green "F/D on WNDSHR" light module above the altimeter is intact. The caption from the TCAS select panel below the vertical speed indicator is missing. The two TCAS selector switches for "ABOVE/BELOW" and "RANGE/DISTANCE" are visible. The selector for

"ABOVE/BELOW" is bent down toward the panel at the 7 o'clock position. The "RANGE" selector switch is in the mid position.

NORMAL BRAKE ACCUMULATOR INDICATOR

The glass face plate is missing. The pointer is missing. The indicator is not connected to the panel.

WATER INJECTION (DEACTIVATED) SELECTOR/ANNUNCIATOR PANEL

The "Water Low Press" light module is missing. The water pump selector guarded switch is bent downward to the panel face at the 7 o'clock position.

ALTERNATE INSTRUMENT SWITCH PANEL

The "Flight Director Computer" selector switch is missing.
The guarded "Deviation" selector switch is at the 6 o'clock position.
The "INS" selector switch is missing.
The guarded "Compass" selector switch guard is broken. The selector switch is in a mid position.
The guarded "Attitude" selected switch guard is broken. The selector switch is bent toward the panel face to the 12 o'clock position.

PILOT'S OVER-HEAD PANEL

(Designated by Boeing as P5)

FLIGHT CONTROLS HYDRAULIC POWER PANEL

The caption panels were extensively damaged with some shards remaining.

RUDDERS ELEVATORS

The System 1, System 2, and System 4 guarded "ON/OFF" switches were found in their normal "ON" position. The System 3 switch guard is missing and the switch is broken in a mid position. The amber "VALVE CLOSED" light modules for System 1, System 2, and System 3 are missing the bulb receptacle and caption plates. The System 4 light module is intact.

SPOILERS, AILERONS, CCA (Central Control Actuators)

The System 1 and System 2 guarded "ON/OFF" switches were found in their normal "ON" position. The System 3 and System 4 guards are missing, and the System 3 and System 4 "ON/OFF" switches were found bent over toward the panel face at the 12 o'clock and 1 o'clock positions, respectively. The System 1 amber "VALVE CLOSED" light module is intact. The light module bulb receptacle and caption plates for System 2, System 3, and System 4 are missing.

YAW DAMPER

The test switches for TURN COORDINATOR LEFT/YAW DAMPER RIGHT (TCL/YDR) UPPER (UPR) and TCL /YDR LOWER (LWR) were found in their normal mid position. The guards for the "ENGAGE/OFF" UPR and LWR selector switches are missing and the switches were found in "ENGAGE" position and bent over toward the panel face to the 9 o'clock position.

RUDDER RATIO TEST

Panel was found empty.

AUTO-BRAKE PANEL

The take-off" ARM/OFF" selector switch was found in the "OFF" position. The "LANDING" selector was found at the 12 o'clock (MIN) position.

The guards for the "ANTI-SKID" and "BODY GR STRG" (Body Gear Steering) selector switches are missing. The anti-skid "ON/OFF" selector was found in the "ON" position. The "BODY GR STRG" selector switch was found in the "DISARM" position.

FIRE PULL 1/FIRE PULL 2 PANEL

The pull handles for Engine 1 and Engine 2 are missing. The amber LBTL/RBTL discharge light modules for Engine 1 are intact. The Engine 2 LBTL light module bulb receptacle and caption plate are missing. The RBTL light module for Engine 2 is intact.

MACH A/S (Air-Speed) WARNING PANEL

The test switch was found in the 6 o'clock position.

OVER ROTATION

Deactivated.

INS (Inertial Navigation System) MODE SELECT PANEL

The INS-1 selector switch was found in the 1 o'clock "NAV" position. The green "READY NAV" and red "BAT" light lenses are missing.

ALT GEAR EXT (Alternate Gear Extension) PANEL

The guard for the "NOSE EXT-ARM-OFF" selector is intact and the switch was found in the "OFF" position. The guards for the left wing and right body-wing selectors are missing. The guard for the left body is partially remaining. The selector switch for the left wing was found in the mid ("ARM") position. The selector for left body was found in the "OFF" position. The selectors for the right body and right wing were found in the "OFF" position.

WSHD PANEL (Windshield Washer System)

The selector switches for the LEFT/RIGHT "WASHER/ON" were found at the 6 o'clock position. The REP (Rain Repellent) buttons are intact. The left/right wiper speed control switch knobs are missing.

WHEEL WELL FIRE DET (Detector) PANEL

The test button is missing. The red caption plates for "WHEEL WELL," "APU (auxiliary power unit)" and "LWR (lower) CARGO" are missing. The entire APU light module is missing. The "WHEEL WELL" and "LWR CARGO" light modules are intact. The "LWR CARGO" light module is loose at panel face and is attached to its connector wires.

CVR (Cockpit Voice Recorder) PANEL

The area microphone, green test button and the test indicator are extensively damaged. The erase button is depressed.

COMPASS PANEL

The SLAVED/SYNC (Syncronized) selector switch for Compass-l was found bent over toward the panel face to the l0 o'clock position. The SLAVED/SYNC selector switch for Compass-2 was found bent over toward the panel face to the 7 o'clock position.

INS MODE SELECT PANEL

The INS-3 selector switch was found in the 3 o'clock position (ATTITUDE). The green "READY NAV" and red "BAT" light lenses are missing.

CABIN INTER-PHONE PANEL

All selector switches are missing. The "PA IN USE" caption plate and bulb receptacle are missing. The caption face plate for "CALL" is missing.

NO SMOKING PANEL

The "NO SMOKING" AND "FASTEN SEAT BELTS" "ON" caption plates are missing. The "GRD (Ground) CREW CALL" and "FLT DK (Flight Deck) DOOR REL (Release)" bulb receptacle and caption plates are missing.

EMERGENCY LIGHTS PANEL

The guarded "ON-ARMED-OFF" selector switch was found in the "OFF" position and the guard is extensively damaged. The amber "UNARMED" caption plate is missing from the light module.

STAND-BY POWER PANEL

The "POWER ON" light module is intact. The guarded selector switch is bent over toward the panel face at the 7 o'clock position and guard is missing.

ENGINE IGNITION PANEL

The "GRD (Ground)/ON/START" selector bulb receptacle and caption plate for Engine 2 are missing. The "GAD/ON/START," "OFF," and "FLT (Flight)/START/ON" selectors are intact. The Engine 1 "VALVE OPEN" light module is missing. The Engine 2 "VALVE OPEN" light module bulb receptacle and caption plate are missing. The Engine 3 "VALVE OPEN" LIGHT MODULE IS INTACT. The Engine 4 "VALVE OPEN" light module bulb receptacle and caption plate are missing.

FIRE PULL 3-FIRE PULL 4 PANEL

The "PULL" handles for Engine 3 and Engine 4 are missing. The light modules for "LBTL/RBTL DISCHARGE" are missing bulb receptacles and caption plates; the light modules are loose behind the panel and hanging by connector wires.

STALL WARNING PANEL

The "TEST-NORMAL-HTR (Heater) OFF" selector is bent in toward the panel face at the 7 o'clock position. The black/white test indicator disc glass face is missing. The amber "POWER OFF " light module bulb receptacle and caption plate are missing.

INS MODE SELECT PANEL

The INS-2 selector switch was found in the 10 o'clock "OFF" or "STBY"position. The "READY NAV" and "BAT" lenses are missing.

EVAC (Evacuation) SIGNAL PANEL

The speaker, the red "EVAC" indicator, and the "Horn Cut-Off" button are extensively damaged. The guarded "COMMAND" selector was found in the 12 o'clock ("ON") position and the guard is missing.

WING ANTI-ICE PANEL

The "ON-OFF-GAD (Ground) TEST" selector switch is bent over toward the panel face to the 9 o'clock position. The left/right blue "VALVE" caption plates are missing. The bulb receptacle for the "RIGHT" light module is missing.

NACELLE ANTI-ICE PANEL

The "ON/OFF" selector switches were found in the "OFF" position for engines 1 and 4. The selector switches for engines 2 and 3 were found in the "ON" position. The four "NACELLE VALVE OPEN" and blank light modules are extensively damaged and were found behind the panel face.

SELCAL (Selective Call) PANEL

The "SELCAL-1" selector and amber "SELCAL" light is intact. The selector was found at the VHF-2 position. The "SELCAL-2" selector was found at the VHF-1 position and the amber "SELCAL" light is missing.

FLIGHT RECORDER PANEL

The "ON-OFF-TEST" selector is bent downward toward the panel face to the 5 o'clock position. The "OFF" light module is missing.

RADIO MASTER BUS PANEL

Extensively damaged.

ALT (Alternate Extension) FLAPS PANEL

The trailing edge INBD/OUTBD "NOSE DOWN-NOSE UP PITCH" selector switches are bent down toward the panel face to the 6-7 o'clock position. The guarded "Arm-Off" switch was found in the "Off" position and the guard is missing. The leading edge "UP-OFF-DOWN" selectors for 1 and 2 were found in the "UP" position. The selector for 3 was found in the "DOWN" position. The selector for 4 was found in the "OFF" position. The guarded "ARM-OFF" selector switch was found in the "OFF" position and the guard was missing.

PROBE HEATERS PANEL

Missing.

WINDOW HEAT PANEL

The left "2-3 ON/OFF" selector switch was found in the "ON" position. The left “1 ON/OFF" selector was found in the "ON" position. The right "1 ON/OFF" selector switch was found in the

"ON" position, and the switch assembly was partially in front of and behind the panel face. The right "2-3 ON/OFF" selector is missing.

LIGHTS CONTROL PANEL

The Storm "ON/OFF" selector was found in the "ON" position. The "MAIN PANEL BACKGROUND" rheostat was found in the 1 o'clock position. The "OVHD(Overhead)" rheostat is missing. The Landing "OUTBD L" and "OUTBD R" Selector switches were found in the "ON" position. The Landing "INBD L" selector switch was found in the "ON" position, and the "INBD R" selector switch was found in the "OFF" position.

The Runway Turn-off "ON/OFF L" selector was found in the "OFF" position. The Runway Turn-off "ON/OFF R" selector was missing from the panel face and is one of the two selector switches hanging by connector wires behind the panel face.

The "NAV,' selector switch is missing from the panel face and is one of me two selector switches hanging by connector wires behind the panel face.

The BEACON "ON-OFF-Dim" selector switch was found in me "ON" position.

The WING "ON/OF F" selector was found in me "OF F" position.

The LOGO "ON/OFF" selector switch was found in the "OFF" position, and the switch was bent over toward me panel face at the 5 o'clock position.

CAPTAIN'S AUXILIARY PANEL, LOWER

(Designated by Boeing as P44)

WEATHER RADAR DISPLAY

Marked SYS 12, the facial glass of the weather radar was in the casing with cracks, but no penetrations.

OXYGEN MASK CONTROL PANEL, CAPTAIN'S

Marked SYS 15, this panel was found with wire around the toggle switches, the EMERGENCY switch was at the ON position, the OXYGEN switch was at 100%, and the FLOW SUPPLY switch was at OFF.

FLIGHT ENGINEER'S STATION, UPPER LEFT

APU PANEL

None of the APU panel gauges had glass, but the indicator needles remained in immobilized positions against the faces of the dials. The RPM needle was at 25%, the OIL QTY needle was at 1 quart, the EGT needle was found at 250 degrees C. The BLEED AIR toggle switch was bent toward 10 o'clock, the START/STOP switch was physically damaged and found in the STOP

position, the APU FIRE DET switch was in the center BOTH position, FIRE TEST toggle switch A was bent toward 1 o'clock and toggle B was bent toward 11 o'clock, and the SQUIB TEST switch was bent toward 2 o'clock. Of the panel annunciator lights:

The SQUIB OK bulb filaments were found in numerous unstretched pieces.

The FIRE pull handle contained four bulbs, one of which was broken. Of the others [*edited*], one had the filament fused to the glass, one had general and localized filament stretching, and one had deformations in the glass and a filament with localized and general stretching on one side.

The DC PUMP ON, APU DOOR, and APU FAULT annunciator bulb filaments were found broken, with mild coil stretching in the first two.

The DISCHARGE annunciator had one bulb with a broken filament that exhibited mild stretching and one with a broken filament that exhibited no stretching.

Both BTL PUSH lights exhibited no stretching in the filaments or filament fragments, although one was broken and one was not.

AC (Electrical Power) PANEL, AUXILIARY POWER

The upper portion of the panel, located above the AC POWER caption, was extensively damaged and all of the switches were found bent to the right. The left AC AMPS gauge was missing and the needle in the glassless right AC AMPS dial (for APU #2 - not installed) was fixed against the face at the zero mark.

GENERATOR CONTROL MODULE #1

The module was separated from the F/E panel, severely impact damaged, and was identified by attached wiring. The generator gauge (KW/KVAR) indicator glass was found broken and the pointer was at the +10 position. The back of the indicator was separated from the indicator case. The constant speed drive (CSD) oil temperature indicator case was found split and was missing the glass; the pointer was at 15 degrees C. The "BUS TIE" switch was found in the center position, with the back of the switch broken away from the toggle. The "GEN" switch was found in the center position, missing the locking stops, and with the back of the switch separated from the switch case. The "FIELD" switch was found intact and in the center position. The "CSD DISCONNECT" switch guard was missing and the switch was bent upward into the one o'clock position with the back of the switch separated from the case.

GENERATOR CONTROL MODULE #2

The module was separated from the F/E panel, severely impact damaged, and was identified by attached wiring. The generator gauge (KW/KVAR) was missing the facial features and the back of the indicator was separated from the indicator case. The constant speed drive (CSD) oil temperature indicator was missing the glass and the pointer was at 19 degrees C. The "BUS TIE" switch was found in the "TRIP" position, with the switch bent toward the six o'clock position. The "GEN" switch was found in the center position. The "FIELD" switch was found in the center position, bent toward three o'clock. The "CSD DISCONNECT" switch guard was

missing and the switch was in the center position (the panel with the caption information was missing). The bus tie ”OPER” annunciator light cap was missing, as was the generator “OPER” light assembly. The “FIELD OFF” and “GEN BRG FAILURE” modules were found pushed back from the panel face. The CSD disconnect “PRESS” light module was missing the lens.

GENERATOR POWER PANEL #3

The BUS TIE, GEN, and FIELD lift/lock switches were each bent to the right, but with physical damage to the locking mechanisms at the center CLOSE positions. The guarded CONSTANT SPEED DRIVE DISCONNECT switch was also bent to the upper right CLOSED position and the CSD PUSH light filaments were found broken with no stretching visible. The generator gauge had no glass and the needle was fixed to the instrument face at -20 KW/KVAR**.** The GEN OPEN annunciator filaments had single breaks with mild stretching of the general coil structure and of the individual coils. The FIELD OFF annunciator filament was broken into many fragments with no generalized or local stretching of the coils seen. The CSD OIL TEMP gauge was missing the facial glass and the needle was fixed to the instrument face at about 103 degrees C.

GENERATOR POWER PANEL #4

The panel was found damaged with the KW/KVAR indicator glass in place and is broken with the pointer at +15. The back plate of the indicator is separated from the case. The CSD oil temp indicator has the glass missing and the back is separated from case. The pointer is at 8°C, the BUS TIE switch is in center position and slightly bent toward the 6 o’clock position. The back of the switch is broken away from the toggle. Generator toggle switch is out of center position and is resting on the bottom part of base. The back plate is missing from the switch plate. The FIELD switch is bent down to about the 5 o’clock position. The CSD DISC. switch is in normal position and guard is missing, the BUS TIE open light module is missing, the GEN. OPEN light face plate is missing, the FIELD OFF and GEN. BRG. FAIL light modules are pushed back from panel face, and the GEN. DISCONNECT “Press” light module face plate is missing.

OIL SYSTEM INDICATING PANEL

# 1 OIL QTY	Indicator glass face is missing; pointer missing.
# 2 OIL QTY	Indicator glass face is missing; pointer missing.
# 3 OIL QTY	Indicator glass face is missing, pointer missing, and an INOPERATIVE sticker is present.
# 4 OIL QTY	Indicator glass face is missing, and the QTY face plate is missing between the 2 and 6 gallon marks. The pointer is missing.
# 1 OIL TEMP	Indicator glass face is missing; the pointer is at -18°c
# 2 OIL TEMP	Indicator glass face is broken and partially missing; the pointer is at -22°c
# 3 OIL TEMP	Indicator glass face is missing; the pointer is below -40°c
# 4 OIL TEMP	Indicator glass face is in place and broken; the pointer is at -30°c
# 1 OIL PRESS	Indicator module is out of case; pointer is at 54 psi
# 2 OIL PRESS	Indicator glass face is intact; pointer is 49 psi
# 3 OIL PRESS	Indicator glass face is intact; pointer 50 psi

4 OIL PRESS Indicator glass face is broken; pointer at approx. 50 psi

1 FILTER BYPASS Light module face plate missing.
2 FILTER BYPASS Light module face plate missing.
3 FILTER BYPASS Light module in place; face plate attached.
4 FILTER BYPASS Complete light module missing.

FLIGHT ENGINEER'S RADIO AUDIO SELECTOR PANEL

Microphone selector buttons found in extended positions

#1 VHF vol/sel knob missing
#2 VHF vol/sel knob setting is at 2 o'clock pos.
#3 VHF vol/sel knob set at 2 o'clock pos.

#1 & #2 HF vol/sel knob set at 12 o' clock pos.

FLT. INT vol/sel knot missing

#1 VOR vol/sel knob set at 8 o'clock pos.
#2 VOR vol/sel knob set at 7 o'clock pos.

MKR vol/sel knob set at 7 o'clock pos.

#1 ADF vol/sel knob set at 8 o'clock pos
#2 ADF vol/sel knob is missing

INT CABIN/SERV vol/sel knob set at 11 o'clock pos

ALT/NORM selector switch is in mid pos.

SPKR vol/sel knob set at 5 o'clock pos.

#1 & #2 DME vol/sel knob is missing

RANGE vol/sel knob is missing

VOICE vol/sel knob is bent down to 5 o'clock pos.

SERV INT selector switch set at OFF

STANDBY light switch is broken and partially missing

FLIGHT ENGINEER HEADSET PLUG PANEL

The headset tip/ring body is broken off and in the headset receptacle, the PTT switch is in place, and the hand microphone receptacle is pushed back away from face of panel.

MAIN GENERATOR and APU GENERATOR CAUTION AND WARNING PANEL

Found deformed with the light modules loose and held by wiring. The “READ” selector switch is missing. The “RESET” switch is intact.

GALLEY POWER PANEL

All Galley Power switches are selected to “ON” position.
The #3 GALLEY POWER switch is bent to 2 o’clock position.
The panel is deformed. The “TRIP OFF” light modules are broken and face plates missing.
The #4 light module is pushed back away from panel.

DC BUS ISOLATION PANEL

Panel is deformed.
1 BUS switch is missing.
2 BUS switch is bent upward toward 12 o’clock position.
3 BUS switch is missing.
4 BUS switch is bent to 3 o’clock position.
1, # 2, and #4 “OPEN” light module is missing.
3 “OPEN” light module is pushed back from panel and face plate is missing.

DC METERS PANEL

DC Volt indicator glass face is broken; pointer is at 1 position.
Connect plug is broken off back of indicator.
DC AMPS indicator: glass face is intact. Pointer at 60 DC AMPS.
Battery switch is missing and toggle base is pushed back from panel face.

FLIGHT ENGINEER DC METERS PANEL

DC METERS selector panel retains the APU BATTERY and TR-1 “ON” selector buttons. The Essential, Battery, TR-2 and TR-3 “ON” buttons are missing.

ESSENTIAL AC BUS PANEL

This panel was missing.

AC METERS PANEL

The FREQUENCY HZ/CSD RPMx1000 indicator is deformed. The glass face is missing. The pointer is at 387 Hz position. The AC VOLTS/PMG Volts indicator is deformed. The glass face is missing. The pointer is at 106 AC VOLTS/30PMG Volts position.

#1 Generator “ON” Light Module is pushed out in front of panel and partially crushed
#2 Generator “ON” Light Module is missing.
#3 Generator “ON” Light Module is broken and pushed out.
#4 Generator “ON” Light Module face plate is missing.

The Generator Test “ON” Light Module is intact.
The APU Generator “ON” Light Module is intact. The lower edge of the face plate is bent upward.
APU Generator #2 “ON” Light Module is missing.

EXTERNAL POWER #1 “ON” Light Module is pushed out and twisted to the right.
EXTERNAL POWER #2 “ON” Light Module is missing.

CABIN ZONE TEMPERATURE CONTROL PANEL

The Zone 1, upper deck left, upper deck “R” selector switches are missing. The Zone 1 indicator glass face plate is broken. The compartment (COMPT) pointer is at 71°F. The duct pointer is at 45°F and the back plate is broken off the case.

Zone 2 indicator is intact. The compartment pointer is at 65°F. The duct pointer is at 68°F and the back plate is broken off the case.

The Zone 3 indicator glass face plate is broken. The compartment pointer is below 60°F. The duct pointer is at 70°F and the back plate is missing.

The Zone 4 Indicator glass face plate is missing. The compartment pointer is below 60°F. The duct pointer is bent and at 100°F. The TRIM AIR switch is open. The upper deck “L” and uupper deck “R” heat control switches are missing.

Upper deck over-heat light module face plate is missing. The Zone 1 Over-heat light module is intact. Zone 2, 3, & 4 Over-heat light module face plates are missing.

#1 Zone trim valve indicator: maximum cooling position
#2 Zone trim valve indicator: mid-cool (10 o’clock) position.
#3 Zone trim valve indicator: mid-heat (2 o’clock) position.
#4 Zone trim valve indicator: mid-cool (11 o’clock) position.

#1 Zone temperature control is selected to “Cool” (9 o’clock) position.
#2 Zone temperature control is selected to “Warm” (4 o’clock) position.
#3 Zone temperature control is selected to “Normal” (11 o’clock) position.
#4 Zone temperature control is selected to “Warm” (2 o’clock) position.

PACK CONTROL PANEL (Panel is heavily damaged and deformed)

ACM OUTLET

The indicator glass face plate is broken, the pointer is at 100°F, and the back plate is missing.

COMPRESSOR DISCHARGE

The indicator glass face plate is missing, the indicator is heavily damaged, and the back plate is missing.

LOW PRESSURE DUCT

The glass face plate is missing, the pointer is at the bottom of green band at 75PSI, and the back plate is missing. The pack selector “ON” switches (Pack 1, Pack 2, Pack 3) are missing. The pack selector switches are attached by their wire bundle only. The instrument panel is broken and bent where the Pact Select switches are supposed to be held in place at the panel face. The face plates for the three pack selector switches labeled “ON-Pack 1,” “ON-Pack 2,” and “ON-

Pack 3," are missing and their back plate connectors are detached and hanging by their respective wire bundle.

PACK CONTROL SELECTOR SWITCHES

All 3 selector switches are bent upward toward the 12 o'clock position. The #1 Switch is in the "MANUAL" position (MAN); however, switch contact position was not determined.

MANUAL TRIM-AIR VALVE

The "heat/cool" switch is bent upward toward the 12 o'clock position. Switch contact position cannot be determined without removal and tear-down inspection. The By-pass Valve indicator glass face plate is missing. The pointer is at 9 o'clock position and the back plate is hanging by an orange wire.

INLET DOOR

The trim-air valve indicator bezel is badly deformed near the face of the of indicator and the glass face plate is missing.

EXIT DOOR

The trim-air valve indicator is intact with the glass face plate cracked from 6 o'clock to 2 o'clock and with a cloudy-opaque substance on the inside of glass. The pointer is at the 10 o'clock position and the indicator is attached to a broken-off piece of the panel and is held by its connector wire bundle.

PACK VALVES, ISOLATION VALVES, AND BLEED AIR CONTROL PANEL

The GASPER "On/Off" switch is bent toward the 2 o'clock position. The back portion of switch is missing behind the panel face. The reset switch is is intact. The pack trip indicator face plates for Pack 1 and Pack 2 is missing. The Pack 3, pack-trip light module is intact.

PACK VALVES.

The pack valves selector switch for Pack 1 is in the vertical position ("ON"). The selector switch for Pack 2 is in the vertical position . The selector switch for Pack 3 is in an intermediate position oriented in the 10 o'clock-5 o'clock position.

RECIRCULATING FANS

The Zone 1 On-Off selector switch is in the "OFF" position.
The Zone 2 selector switch is in an intermediate position between "ON" and "OFF."
The Zone 3 selector switch is in the "ON" position.
The Zone 4 selector switch is in the "OFF" position.

WING ISOLATION VALVES

Left isolation valves switch is in an intermediate position and is oriented to the 10 o'clock - 4 o'clock position. The right isolation valve switch is in the horizontal position and is oriented from the 9 o'clock to 3 o'clock position ("ON").

OVER-HEAT--VALVE CLOSED-- HIGH STAGE BLEED AIR LIGHT MODULES

Each engine has an amber Over-heat and Valve Closed Bleed Air Light Module and a green High Stage Light Module. Of the total 12 Bleed Air Light Modules, only 3 remain, hanging by their connecting wires. Two (2) light modules are from the left wing and one is from the right wing. It was not determined to which engine the light modules were related.

The Duct Pressure indicator glass face plate is missing. The left pointer is at the 7 o'clock position (approximately 5 PSI). The Right Pointer is loose and is at the 6 o'clock position pointing to letter the letter "D" of Duct. The rear portion of the Duct Press indicator is badly damaged.

CABIN PRESSURE SELECTOR PANEL

Very little remains of the plastic face panel. The Mode Select switch is at 12 o'clock (AUTO) pos. The altitude select indicator face glass is missing. The flight altitude/cabin differential pressure indicator are covered and obscured by the upper aluminum bracket which is crushed down and into the altitude selection indicator face. The altitude selector knob is missing.

BARO SET

The indicator face glass is missing. The IN.HG/MB setting is 30.02 and 1016.5.

RATE

The decrease/increase knob is missing and the knob shaft back plate is destroyed; the shaft is sticking out of the panel face.

RATE LIMIT

The test switch is bent upwards toward the 12 o'clock position.

OUTFLOW VALVES

The indicators have the left pointer at the 6 o'clock position, and the glass face is broken with four small glass shards remaining. The right pointer is broken off its shaft, lying loose at bottom of indicator, and the glass face is intact. The manual control switches are in the mid position, between OPEN and CLOSE.

TOTAL AIR TEMPERATURE

The glass face of the Total Air Temperature indicator is missing, the body of the indicator is broken into two parts, and the forward part including the DRUM is hanging by connecting wires. The "MINUS" indication bar is visible, and the numbers drum index mark is on the 190 side of 201.

CLOCK

The clock module is partially crushed forward through the panel face with the glass face intact. The back plate is broken off and is hanging by connecting wires. The hour pointer is midway between 24 and the "•" dot (1 o'clock) position. The minutes pointer is midway between the 31 and 32 minute displays. The seconds hand is midway between the "24" at the top of the indicator and the first second line (i.e. ½ second).

WATER

The indicator facial glass is missing and the instrument bezel is lying across the face of the indicator between the 2 o'clock and 7 o'clock positions. The indicator face is crushed from the 4 o'clock to the 7 o'clock position, with the pointer at the 8 o'clock position. The drain valve switch cover is missing and the switch is bent up towards 12 o'clock position, against the panel face.

LIGHT MODULES

The amber light modules captioned AUTO FAIL, PRESS RELIEF, and PRESS RELIEF are missing, the light modules are pushed behind the face of the panel, and are hanging by connection wires.

CABIN PRESSURIZATION STATUS PANEL

The cabin DIFFERENTIAL PRESSURE indicator glass face and pointer are missing.

The cabin CLIMB indicator glass face is missing and the pointer is at the 4 o'clock position, at a display of approximately 1,820 feet per min. down.

The CABIN ALTITUDE indicator face is intact, with the interior and back of indicator missing. The 10,000 foot pointer is midway between the "1" and "2" on the face of the indicator face, the 1000 pointer is at the "9", and the hundreds indicator is at a display of 330 feet.

The ALT HORN CUTOUT switch button has been sheared off at the face of the panel.

LOWER CARGO FIRE PROTECTION PANEL

The red light modules that are captioned "FWD" and "AFT" are missing and the light modules are hanging by the connector wires behind the panel face. The compartment selector switch was found at the AFT position and the number one and two discharge bottle selection switches, with the associated switch protector covers, are intact. The plastic DETECTOR TEST facial panel is missing above the FWD1, FWD 2, AFT5, AFT6, SQUIB TEST, and BOTTLE 1/BOTTLE 2 is missing. The six "push to test" buttons are intact. The SQUIB green light module is missing the green logo panel and the SQUIB TEST selector switch is selected to the AFT 6 o'clock position. The BOTTLE selector switch is midway between the numbers 1 and 2 selection positions.

NACELLE TEMPERATURE INDICATION PANEL

The panel was found intact, with four vertical display instruments. Each instrument contained a left (A) and right (B) temperature scale. Below each instrument is a left/right switch to isolate discrepant temperature loops. In the first of the four indicators, the left needle was at the bottom of the scale and the right needle was at a display slightly above the "1". The switch was bent down toward the 6 o'clock position. The second indicator had the left needle between the 8 and 9, in the red band, and the right needle was slightly above the 4, in the amber colored band. The second switch was bent toward 2 o'clock. The third of the indicators had the left needle obscured at the bottom of the scale by salt or corrosion deposits in the face of the instrument, the right needle was at the "1," in the green band. The switch was in the right (B) position. The fourth indicator was obscured below the "4" on the left scale and below the "1" on the right scale; neither needle was visible. The fourth switch was in the left (A) position.

Below the nacelle indicators, the amber FAULT light was missing, the A-loop FIRE/FAULT TEST switch was missing, and the B-loop switch was in the FIRE TEST position.

CAUTION AND WARNING PANEL

Ten of the thirty-two light modules in the caution and warning panel are blanks (no assigned function). The GRD SAF RELAY ON is the only green face in the panel, all others installations are colored amber. The only amber logo light module panels found intact are: WINDOW 1 OVHT and NAC 3 TAI (thermal anti-ice) VALVE, other than one blank. There is one light module with a missing logo face and bulb housing directly below WINDOW 1 OVHT, in the NAC 2 TAI VALVE position.

The remaining amber light modules are hanging by their connection wires behind the panel face and all remaining light module logo face plates are missing.

The oxygen indicator is intact and the white pointer, captioned “C” for “crew” indicates 1200 psi. The orange pointer, captioned “P” for “passenger” indicates 400 psi. The amber “ON” face plate is missing. The ON/NORM switch is selected to the NORM position and the switch guard is missing.

DISINSECTION PANEL

[*Edited for clarity from text agreed to by the group.*] The removed disinsection system was used to fumigate the airplane on some international routes. The disinsection system had been deactivated, the panel was badly deformed, and the plastic bezel face was missing.

AFT CARGO HEAT PANEL

The plastic bezel of the face plate is missing, the amber OVERHEAT and green ON logo face plates are missing, and the remainder of the light modules are intact. The aft cargo heat selector switch is selected to the NORMAL position.

EQUIPMENT COOLING PANEL

The plastic bezel face plate is missing, the amber SMOKE logo face is missing from the otherwise intact light module, the TEST switch is bent over toward the 9 o’clock position. The VALVE CONTROL switch guard is missing, the switch is bent to the panel face at the 7 o’clock position, and the RESET button is intact. The BLOWER SELECTOR switch is selected to the mid position, captioned NORM. The amber NO AIR FLOW logo face is missing from the light module and the light module is loose, hanging by the connector wire bundle on the rear side of the panel.

SQUIB TEST PANEL

The plastic bezel face plate is missing. The green SQUIB OK light module for engine 1 is intact. The logo face plates for engine 2 and engine 3 are missing. No. 2 light module remainder is intact, No. 3 light mod. Is loose behind panel and hanging by connector wires. No. 4 light mod is missing. The left bottle/right bottle SW. is bent over toward 7 o’clock position.

HYDRAULIC SYSTEM CONTROL PANEL

UPPER SECTION

The plastic lighting and caption plate was extensively broken and missing, although shards did remain.

The “Guarded” NORMAL BRAKE SOURCE select switch is intact, the guard is closed, and the switch is in the down (PRIM SYS 4) position. The green (SEC SYS 1) and amber (LOW PRESS) light modules remain, but without the captions. The switch for ELEC PUMP HYD SYS 4 is bent downward toward the six o’clock (OFF) position.

The amber OVER HEAT light module for hydraulic system 1 and 4 were missing, for hydraulic systems 2 and 3 were found intact, other than missing the caption faces

HYDRAULIC SYSTEM 1

The HYD PRESS indicator gauge facial glass is missing, the tip of the pointer is missing, and the remaining needle part is at 4 o’clock pos. (400 PSI in Red Band Area). The [amber air driven pump low] PRESS light face was missing, although the remainder of the light module was intact. The AIR [driven] PUMP selector switch was found in the “OFF” position with the switch bent downward toward the six o’clock (CONTINUOUS) position. The blue indicator light for the [continuous pump operation] RUN caption face plate was missing, although the light module was loose behind the panel face, attached to its connector wires. The amber LOW QTY logo face was missing and the remaining light module was intact. The amber PRESS light indicator for the engine driven hydraulic pump was missing the caption plate and the light module was partially both behind and in front of the panel. The engine pump selector switch was found selected to the NORMAL position. The HYD QTY gauge glass face has a crack from the 10 o’clock position to the six o’clock position, the pointer is in the green band midway between the number eight and a line representing nine U.S. GAL. (8.5 GAL.). The back plate of the indicator is broken from its case and is hanging by its connecting wires.

HYDRAULIC SYSTEM 2

The hydraulic system pressure gauge facial glass face was missing and the pointer was in red band at the third short line (300psi) from “0” (zero). The amber [air driven pump low] PRESS light module was intact, the AIR [driven] PUMP selector switch was found in the mid (OFF) position, bent downward toward the seven o’clock position. The blue indicator light for the [continuous pump operation] RUN caption face plate was missing, although the light module was intact. The amber LOW QTY caption face and 2-bulb light module was missing, although the module casing remains. The amber PRESS indicator light for the engine driven hydraulic pump was missing the caption plate and the light module was found partially dislodged from the panel face. The ENG PUMP selector switch was found in the NORMAL position. The HYD QTY gauge glass face was missing and the pointer is midway between the numbers six and seven U.S. Gal.(6.5 Gal).

HYDRAULIC SYSTEM 3

The HYD PRESS gauge glass face was missing and the pointer was missing. The amber [air driven pump low] PRESS indicator light face was missing, although the remaining light module was intact. The AIR [driven] PUMP selector switch was in the CONTINUOUS detent, bent downward toward the panel face 6 o’clock position. The blue indicator light for

the [continuous pump operation] RUN caption face plate was found intact. The amber LOW QTY light caption plate was missing, although the light module was intact. The amber PRESS light indicator for the engine driven hydraulic pump was missing the caption plate, although the light module was intact. The engine pump selector switch was found selected to the NORMAL position. The HYD QTY gauge glass face was missing and the pointer was midway between the numbers six and seven U.S. Gal (6.5 Gal.)

HYD SYS 4 - HYD

The HYD PRESS indicator gauge facial glass and the pointer were missing. The [amber air driven pump low] PRESS assembly was missing. The AIR [driven] PUMP selector switch was found in the "OFF" position with the switch bent downward toward the six o'clock (CONTINUOUS) position. The blue indicator light for the [continuous pump operation] RUN caption face plate was missing, although the light module was intact. The amber LOW QTY logo face was found intact. The amber PRESS light indicator for the engine driven hydraulic pump was missing the caption plate and the light module was behind the panel face, attahced to the wiring. The engine pump selector switch was found selected to the NORMAL position with the switch bent toward the 10 o'clock orientation and in toward the panel face. The HYD QTY gauge glass face was missing and the pointer was in the green band, half dsitance between the 8 and 9 U.S. GAL lines.

LANDING GEAR ANNUNCIATOR PANEL

Thirteen of the 14 light modules remain and the light modules with remaining caption plates were the (amber) LWING DR OPEN, L BODY DR OPEN, L WING TILT, L BODY TILT. The remaining nine light modules were loose behind the deformed annunciator panel bracket and hanging by the connecting wires.

ANNUNCIATOR PANEL LABELED "GEAR - TILT - DOOR"

The PRIM/ALT 'ON' selector switch, the TILT-PRIM/ALT' 'ON' selector switch, and the door PRIM/ALT' 'ON' selector switch were found intact, but loose behind the panel face, hanging by the connector wires.

LEADING EDGE FLAP ANNUNCIATOR PANEL

Two light modules with amber logo 4 were found of the display. One light module was missing. The remaining (13) light modules were missing the captioned faces and six light modules were missing the light modules.

ENGINE VIBRATION MONITOR

The toggle switch was found between the LOW SPEED ROTOR position
and the deactivated high speed rotor AVM pos.

BRAKE TEMP MONITOR PANEL

The LEFT WING BODY indicator is intact and the LEFT WING pointer was midway between "0" and a line representing 1 in the green band. The LEFT BODY pointer was in the red band between the line representing seven and the displayed Number 8. The RIGHT BODY WING indicator was found opaque and unreadable. The amber OVERHEAT light module caption plate

and the module was missing. The selector switches LF,RF,LR,RR were intact and the test button was missing.

ANTI-SKID CAUTION/WARNING ANNUNCIATOR PANEL

All of the amber left wing light modules were missing all or parts of the assemblies.

BODY GEAR STEERING PANEL

The amber PRESS light module light receptacle and face were missing, the left body unlocked light module and right body unlocked light module were found intact. The PRIM/ALT selector switch was found at the PRIM position. The plastic bezel face with the ALT legend was missing, the ACARS selector box had been deformed. The ETA, DLA, and Link test selector switches were missing. The selector switch was intact.

AIR CONDITIONING & PNEUMATICS (ATA 21-00-00, 36-00-00)

Heat and pressure sensors in the B-747 provide flight deck indications for air conditioning pack operation. The valves and components of the pressurization system were generally as delivered in 1971, without product improvements that could also result in changing valve opening after a loss of power.

Boeing design illustrations showed the three heat exchangers and air cycle machines (ACMs), known as packs, with pack number one located to the left of the keel and under the wing center section, pack two located immediately aft of pack one, and pack three located to the right of pack one and the keel beam. Packs one and three were found in the first debris field and pack number two was found further along the flight path, nearer to where the center section portions of the airplane were recovered. [*10/26/96 Group Activity*]

The three systems were reassembled and examined for evidence of preimpact leaks that may have heated the center fuel tank, uncontained rotor bursts from the ACM's, inward or outward punctures of the thin material, and general condition. Disassembly of the ACM's found no evidence of rotational scoring in housing areas adjacent to the impellers. Although numerous ducts and the heat exchanger headers exhibited flattening on the upper surfaces after reassembly, no evidence of preimpact anomalies were identified. Where the pack ducting was found broken or ripped, no localized color changes were identified. Where breaks occurred in the heat zones of welds, the Safety Board metallurgist examination disclosed no evidence of fatigue-type failures at Calverton. [*10/26/96 Group Activity, edited for clarity*]

One duct flange examined with the Safety Board metallurgist was from the right side of the keel, beneath the CWT and separated from the main landing gear well by a fiberglass composite covering. The fiberglass cover was missing and the adjacent areas of the rear spar and fuel tank were

examined for evidence of duct rupture. No radial patterns [emanating from the flange] were found in the paint or sealant. [*10/26/96 Group Activity*]

All three turbine bypass valves were found about 10 degrees from the fully closed positions, the two recovered ram air inlet doors were found fully open, and the recovered numbers one and three ram exit actuators were found fully in the retracted/door open positions. A Hamilton Standard Service Manual (HSSM) showed that these positions would have corresponded to running all three packs to cool the cabin of the airplane. However, disassembly of the three air cycle machines found no evidence of rotation. [*10/26/96 Group Activity*]

The flow control valves found were in the closed position, but the Hamilton Standard Service Manual showed that without pneumatic pressure a spring would move the valve into this position. [*10/26/96 Group Activity edited for clarity*]

PRESSURIZATION OUTFLOW VALVE AND AFT ACTUATOR [*10/26/96 Group Activity*]

Green Tag No. CU03, No recovery date on part observed. The unit was found predominantly intact. The mount was broken. The motor was intact. A wire bundle into a single cannon plug ran out from the unit several feet. The cannon plug and the housing were bent in and laterally approximately 40 degrees. The auto circuit connector housing was bent. One of the two actuators arms to the valve flapper was broken off. The other actuator arm was intact and retained its mounting bolt into the valve flapper connecting point. The valve flapper mount was torn out. The valve flapper was missing.

OVERPRESSURIZATION VALVES [*10/26/96 Group Activity*]

Both overpressure valves were found in the fuselage, separated from the actuating mechanisms. The upper valve was found closed and the lower valve was found open, but loose and in a broken frame. The operating portions of both valves were found broken away from the fuselage skin mounted valves.

AIR CYCLE MACHINES (ACM) AND AIR CONDITIONING PACKS [*10/26/96 Group Activity edited for clarity*]

Fan housing P/N 727622 and fan housing P/N 730419 sustained the most severe impact damage. The pack #2 fan housing was missing.

The fan containment housing for Pack #1 received minimal impact damage. Pack #2 received moderate damage and Pack #3 received heavy impact damage.

The impact damage to the fan containment housing for Packs #2 and #3 dislocated the mounting diameters. The locating pins were broken or bent. Pack #3 containment housing was impaled on the fan blades. Pack #2 had indications of fan to fan housing impact damage, however, the fan had not penetrated through the fiber glass in the throat area.

Neither the pack #2 or the pack #3 ACMs exhibited rotational scratches in the housings or of the rotors in the direction of rotation.

There were no rotative scratches in the pack one and three ACMs. Pack #2 had been rotated prior to disassembly and some light scratches were noticed, in the scroll area.

After disassembly, all three packs rotative assemblies could be turned, although the rotation was rough. Extensive salt water and corrosion material was found covering the assemblies. Nothing was found that would have prevented operation prior to impact and no evidence was found of ACM over-heat.

Packs #1 and #2 turbine housings P/N 737101 had been repaired in the throat and scroll areas with plasma spray, a repair technique that is defined in the Hamilton-Standard Overhaul Manual, Section 21-51-03.

The ACM wicks were in good condition and absorbing oil. The sump oil was relatively clean, other than containing some water.

A Hamilton Standard Service Engineer provided the following written description for soot found on the RAM inlet face of the heat exchanger P/N 719235:

> As the flight time on the heat exchangers increases, soot does build up on the RAM faces. The amount of soot is dependent, on the usage of the aircraft and the accumulated hours. If an aircraft is used for short flights, at airports where there are long lines of planes waiting to take off, then the heat exchangers will soot up faster than an aircraft that is used for longer flights. TWA maintenance records reports the following times on the heat exchangers:
>
> Pack #1 = 2,219 Hours TSO
> Pack #2 = 2,219 Hours TSO
> Pack #3 = 6,189 Hours TSO
>
> TWA also reports that aircraft 93119 flies about 15 hours per day with an average flight of 6 hours. Based on the usage rate and flight times, the amount of soot build up is believed to be in the normal range.

The maintenance manual showed that the compressor discharge over-temperature switch should shut the pack down if the compressor discharge temperature exceeded 425°F.

VALVE POSITIONS [*10/26/96 Group description of 8/23/96 observation*]

> Turbine bypass valve - All three turbine bypass valves were positioned at approximately 10° open from the full closed position.
>
> The master trim air valve was open about 5-10° from the full closed position.
>
> Two flow control valves (FCV) were found closed, but the Hamilton-Standard representative noted that the FCV would close when pneumatic pressure was removed. The fragment found of the third flow control valve had no indication of pre-impact position.

The RAM outlet actuators for Pack #1 & 3 are both in the DOORS OPEN position. Due to the damage to the door linkage, the Pack #3 doors were found closed, although the actuator was in the "Doors Open" position. Pack #2 was received without a RAM air outlet actuator.

The RAM inlet actuators are both in the open position. The third RAM inlet actuator has not been found.

According to Hamilton Standard requirements charts, the flight would have been in a regime of flight (temperature, speed, and altitude) that had high air conditioning requirements. For high air conditioning requirements, the RAM inlet and outlet doors will be open and the turbine bypass valves closed or nearly closed.

P/N AND S/N'S FOR AIR CONDITIONING PACKS

[*10/26/96 Group Activity*]

Part Name	Find #	Pack #1	Find #	Pack #2	Find #	Pack #3
FLOW CONTROL VL	1	P/N 764476-2 S/N B1219		**	22	P/N 764476-2 S/NKB5189 KB51
Air Cycle Machine	2	P/N 719238-10 S/N ----07	11	*	23	P/N 719238-7 S/N KE 10372
Water Separator	3	* P/N 719226 Fiberglass S/N	12	P/N 7503999-Z AL S/N 880727	24	P/N 750399 - 3 S/N 910424
Turbine Bypass Valve	4	P/N 719223-3 S/N B A14694	13	P/N Can't Read S/N JL 14196	25	P/N 719223-4 S/N KD 14338
Heat Exchanger	5	*	14	P/N 719235-9 S/N 32284	26	P/N 719235 S/N A 3293
Compressor Bypass Check Valve	6	*	15	*Badly Corroded	27	P/N 717998-4 S/N J - 0461
Compressor Over Pressure Switch	7	P/N 728504-4 S/N 8402746	16	P/N 728504-4 S/N 8611918	28	P/N 728504-4 S/N 52227--
Back Discharge Temp Sensor		**	17	**		**
Duct Over Temp Switch		**	18	P/N 705895-4 S/N EG16145?		**
Fan Inlet Diffuser Housing	8	TWA P/N 289-5923 S/N #4 ***		**		**
RAM Air Exit Actuator	9	P/N 742868-5 S/N 006836		**	29	**P/N 10300 S/N AA1180
RAM Air Inlet Actuator		*** TWA P/N 10300 ** S/N JL309 **		*** TWA P/N 10300 ** S/N JL359 **		
RAM Air Inlet Check VL		P/N 9032-4 ** S/N084 **	20	P/N 38069 ** S/N 584 **		
Deoxo Cataly-ozone Converter	10	P/N D-1933-2 S/N 02089	21	N02007 CW * 9482504500	30	P/N D-19333-2 S/N 02103

***** = No HS Name Tag; TWA name Tag** ****Position Unknown**
**** = Part has not been found** *** = No name plate found**

- Duct Isolation Valve (Not HS Part) BAC 60 B00026-5 S/N ---023

- Master Trim Air Valve P/N 738341-5 S/N KA 2105 REFTW-1

- Safety Valves P/N 715995-3 S/N B2072 P/N715995-2 S/NJL 2120

- 2 Outflow Valve frames were found but no name tag

- 1 zone Valve TWA P/N 18441 S/N KE15439?

- 1 Pylon Valve P/N 738362-8 S/N 81206 No HS Name tag marked on HSG

NOTES: All three heat exchangers cores were not made by Hamilton standard. There was an AIREPAIR name tag on two of the three, but no Hamilton Standard name/data tag.

CARGO COMPARTMENT TEMPERATURE [*10/26/96 Group Activity*]

The aft cargo compartment TEMP light was reported to have been illuminated prior to the flight. According to the B-747 MM (21-44-00, pg. 1), the aft cargo compartment overheat thermostat upper actuating limit would have been 110 degrees Fahrenheit.

ELECTRICAL (ATA 24-00-00)

Debris from the cockpit and the electrical/equipment (E/E) center, located behind the nose landing gear, were received at the hangar as two piles of wire and entangled broken parts that each measured about five feet tall and 12-15 feet in diameter. Other smaller bundles of wire and electrical components were received and examined, as well. [*10/22/96 Group Activity*]

Wiring diagram and training documents show that the Boeing 747 electrical system is designed so that each engine drives a generator that is capable of providing electrical power. Electrical power may also be supplied by the auxiliary power unit (APU) driven generator located in the tail of the airplane, although evidence was found that the APU was not in operation at the time of the accident. Each engine driven generator is connected to relays located in the E/E by an independent set of generator cables that are routed along the forward side of the front spar from the engine pylon, through a set of pressure seals that are located in the fuselage skin immediately forward of the front wing spar, then above the forward cargo compartment ceiling to the E/E. In the area where the cables enter the fuselage from the wings, the cables are routed immediately in front of the center wing fuel tank. [*10/22/96 Group Activity*]

The cables enter the fuselage in front of the forward wing spar and although the location is in front of the CWT, the forward limit of the fueled portion of the N93119 CWT did not reach the forward wing spar; terminating instead at spanwise beam #3.

Boeing noted that during ground operation electrical power can be supplied from the APU generator. Further, before flight the APU generators are automatically de-excited when the engine driven generators take over supplying power to the aircraft's main AC system buses.

Other than impact-type of breakage, the sets of engine generator cables were complete between the E/E and fuselage station (FS) 980, where tension and crushing types of failures were found. No evidence of arcing at FS 980 was found. The forward ends of the generator cables had the generator relay contacts still attached and none were found welded to any other material. The remains of the bus tie relays were examined and found broken into small pieces. No visible evidence of arcing or welding in the relays were found and the preimpact positions (closed or open) were not evident. [*10/22/96 Group Activity*]

No evidence of arcing was found on the recovered generator cables that could be identified as from between the forward wing spar and the E/E compartment.

Portions of the generator cables from the wings were also recovered and examined. In the wing leading edges, both over the pylons and at the inboard end, was evidence of burning and the cables had both arcing and tension-type failures. The insulation was missing from numerous areas in the wing leading edges, but this was in areas of fire and other damage. [*10/22/96 Group Activity*]

Boeing requested on October 27, 1997, that the previous paragraph of the group's records be further defined by stating that the evidence of burning and the cables with arcing and tension-type failures had been in the right wing leading edge, not both wings. The group had not made this distinction.

Each of the ~~engine and~~ APU sets of generator cables from the fuselage were located in the wreckage and examined, although wiring diagrams showed that the cables should not have been energized. The APU generator cables were missing small sections in the forward fuselage, but also were cut at FS 980. The #1 APU generator cables were missing segments between FS 980 and the tail of the airplane. The #2 APU cables were missing between FS 980 to aft of the landing gear well and only smaller portions were found from the aft fuselage. Evidence of arcing or short circuiting was not found on any of the sections of APU generator [feeder] cable ~~that were from forward of the aft pressure bulkhead~~. In the aft fuselage, immediately forward of the APU firewall, APU battery cables were found with both arc and tension-type damage with burned insulation. Reconstruction of the area found no evidence of heat on the adjacent structure or on the APU fuel line. [*edited 10/22/96 Group Activity*]

One APU-type and four engine driven electrical generators were identified in the wreckage, although none had the generator case with the data plate. No evidence of fire or heat damage was found in general or to the varnish-type coating of the internal wiring. Two had the drives remaining and the drives were not found sheared. Only the APU generator had the armature, field, and generator leads still attached. [*10/26/96 Group Activity*]

The Systems Group review of the B-747 electrical system found that cabin lighting circuits had up to 350 volts.

ELECTRICAL LOAD DISTRIBUTION (ATA 24-50-00)

WIRE EXAMINATIONS

[Most of the wiring found in the wreckage of N93119 was marked with 42A in green and the]Green wire markings on the BMS13-42A wires identified the basic wiring, according to the specification. A common number seen on the BMS13-42A wires was W42A/8/1-18 06090 [*8/27/97 Group Activity*]

W42A denotes BMS13-42A
/8/ denotes BMS13-42A Type 8
1- denotes Class (single conductor)
18 denotes gage size
06090 denotes the manufacturer, in this case Ray-Chem

The BMS13-42A specification states that "The primary insulation of one or more layers shall be crosslinked extruded alkane-imide polymer. When more than one layer is employed a coating of modified imide polymer may be used between the layers. The alkane-imide polymer shall be an off-white color readily distinguishable from the basic brown color of the imide coating." The specification also states that "A coating of modified imide polymer shall be applied over the insulation. This coating shall be continuous and free from cracks, splits, blisters and other defects when examined without the aid of magnification." An illustration on page 17 [of the BMS13-42A specification] showed three layers over the tin-coated copper core conductor, inner and outer layers of primary insulation with a thickness of .009 inch minimum (Sizes 24 through 10), and a coating of .0015 inch minimum. [*8/27/97 Group Activity*]

About every foot was a Boeing wire number in black and those wire numbers were used to identify what circuit each wire was part of. Under magnification, the black markings could be seen hot-stamped into the outer surface of the insulation. The black markings were frequently missing or almost non-existent and only one was found to penetrate the outer insulation, but not to the core conductor. Some wire markings were found to have significant variability between the depth of different letters within the same marking. [*8/27/97 Group Activity*]

The wiring from the scavenge pump relay was found to have deeply hot stamped wire markings and a crack was propagating from a numeral "1". It was found that the crack penetrated the inner layer of insulation to the core conductor. The wire was found to be BMS13-42 (aliphatic polyimide), as used with the commercial name of "Poly-X" and has two layers. BMS13-42 is known to have a cracking phenomenon when subjected to stress, such as tight bend radii, according to Boeing representatives. [The group noted that] wiring removed for an airworthiness directive (AD) pertaining to wing fuel pumps [AD 96-26-01] had cracked insulation. [*8/21/97 Group Activity*]

A Boeing telefax of June 25, 1997, stated that:

The Poly-X wire was used as a general purpose wire on the RA164 (TWA 800) aircraft.

Wire insulation known as Poly-X had three in-service problems:

- Abrasion of the insulation in bundles installed in high vibration areas.
  (This problem was corrected by Boeing Service Bulletin No. 747-71-2105, Dated July 19, 1974)
- Random flaking of the topcoat.
- Insulation radial cracks in tight bend radii

Radial cracking phenomena of the Poly-X wire was mainly associated with mechanical stress. Bend radius is the largest contributor to mechanical stress in installed wire or cable. Presence of moisture in conjunction with mechanical stress is also a contributor.

Evidence of arcing or short circuiting was found in the fuselage of N93119, in addition to what was found in the wiring from the raceway below the left cabin floor and near the forward wing spar. The only evidence found in the fuselage, aft of the forward wing spar was associated with the APU battery cables. Forward of the forward wing spar, evidence of arcing was seen on fuselage frames, located adjacent to the routing of missing emergency cabin lighting wires. Wiring diagrams showed that the emergency lighting system operated at 28 volts, was powered by the battery in the cockpit, and should have been actuated by loss of other electrical power.

Fuselage rib and stringer structure from aft of the cockpit were found to have blackened areas near electrical ground studs and the pre-impact location of wire routing. Examination found that each of these locations corresponded to the routing of the emergency lighting bundles. Wire diagrams show that these wire bundles would have been powered from batteries located near the flight engineer station in the upper deck of the forward fuselage. [*6/27/97 Group activity*]

WIRING CONTAMINATION

Black soot-like residues were found in the P14 electrical panels of N93119 and in retired B-747 airplanes from several other operators. The P14 panel is located below the main deck and aft of the nose landing gear. The interior of the panel is enclosed and separated from the main deck of the airplane, although cooling air is drawn through the panel. A sample of wire (bundle W118, connector D19471) from the P14 of a non-TWA airplane (RA104, S/N 19670) was taken to the Boeing laboratory for identification of the material. The Analytical Engineering Report (9-5576-WP-97-394-R1) from Boeing, dated October 31, 1997, stated that:

> The deposits were identified as a complex mixture of organic and inorganic environmental debris [containing] silicates, sulphates, and phosphates. The deposits contain water-soluble elements, suggesting that the material may have been deposited with water.

Although the source of the elements was not identified, the elements were found listed on the labels of common cleaners.

EQUIPMENT/FURNISHINGS (ATA 25-00-00)

The following two cockpit seats were received with the bundle of wire from the cockpit. Each was documented as it was taken out, before sending the seats to the Interiors hangar: [*10/26/96 Group Activity*]

SEAT, CAPTAIN'S

The Captain's seat was found separated from any other structure in the bundle of cockpit wiring. The left seat track on the floor still had a portion of the base of the seat attached, with the forward edge of the seat part 4¾" from the forward seat stop. A mark on the right seat track was at an identical position as the attached seat base part found on the left track.

SEAT, FIRST OFFICER'S

The First Officer's seat was also found in the bundle of cockpit wiring. The left seat track was missing and the right had a mark that was similar to the mark on the Captain's track, but at 9¼" from the forward stop.

CARGO COMPARTMENT (ATA 25-50-00)

A report was received from a mechanic who worked at another airline, noting that damage to the cargo compartment ceilings and wiring could be incurred by tilting of LD-3 cargo containers. A loading diagram obtained from the Operations Group Chairman for flight 800 showed that the flight had carried LD-3 cargo containers toward the forward end of the forward cargo compartment. The clips that had held the CWT FQIS wires were found attached to the bottom of the floorboard supports from over the aft end of the forward cargo compartment. The forward cargo compartment equipment was examined for indications of cargo position at the time of impact.

No damage matching the LD-3 containers was seen on the water bottles that were mounted on the forward spar of the reconstructed fuselage. No brownish fiberglass from the water bottles was seen on the LD-3 containers.

Red stops for the cargo containers were found intact in the forward cargo compartment at the aft ends of the cargo compartment floor tracks. Moveable stops were found affixed to the tracks between the rear stops and the middle of the compartment. The floor tracks were missing from the front of the compartment. The track support structure was missing from below the level of the tracks and above the lower fuselage skins at about the area where the loading documents showed the containers.

FIRE PROTECTION (ATA 26-00-00)

Fire extinguisher bottles from the number one and three pylons were found with the actuating squibs and diaphragms intact. The Halon 1301 fire extinguisher bottles from the forward and aft cargo compartments were also found with the actuating squibs and diaphragms intact. [*10/26/96 Group Activity*]

All four Fuel Vent Surge Tank Protection (STP) system compressed fire extinguisher (freon) bottles from each wing were examined and found unfired, although one of the eight bottles had external damage. The electronic sensor from the right wing tip was recovered intact, other than the salt water immersion, and a light coating of dark film was seen on the sensor glass. The left sensor was attached to a crushed section of vent tube and was not removed. [*10/26/96 Group Activity*]

FLIGHT CONTROLS (ATA 27-00-00)

At least a portion of every flight control surface from the tail of the airplane was recovered and identified. Due to the high degree of fragmentation and the extent of how the wreckage was dispersed, not all of the wing control surfaces and actuators were accounted for, although a portion of each may have been recovered. Although numerous short segments of control cable were recovered, the original locations of very few were identified and control cable continuity was not established. Cables had also broken through the sides of various pulleys found in the wreckage. [*10/26/96 Group Activity, edited*]

LATERAL CONTROL SYSTEM, INCLUDING AILERONS (ATA 27-10-00)

The B-747 lateral control system consists of two ailerons on each wing, an inboard and an outboard. Although each wing carries a ground spoiler inboard of five flight spoilers, all twelve spoilers were identified consecutively from the left tip to the right tip (1 through 12). Most of the lateral control system was recovered as independent and separate parts. [*10/26/96 Group Activity, edited*]

CENTRAL CONTROL AREA

The following parts were found with the keel beam between FS 1241 and FS 1350:

AILERON TRIM ACTUATOR

Found extended 7 1/8 inches between the bolt centers. [*10/26/96 Group Activity*]

FEEL & CENTERING MECHANISM

Found sprung with no pre-impact position information. [*10/26/96 Group Activity*]

LEFT & RIGHT AILERON PROGRAMMERS,

The programmers were found below each Central Control Actuator and no pre-impact position information was found. [*10/26/96 Group Activity*]

LEFT & RIGHT AILERON CENTRAL CONTROL ACTUATORS (CCA). The lower left CCA piston extension was measured as 10 11/16 inches. The upper left CCA extension was measured as about 2 1/4 inches, but was almost concealed in a position that may have introduced some error into this measurement. The right CCA was found with 5.75 inch extension. [*10/26/96 Group Activity*]

GROUND SPOILER CONTROL VALVE

The rig pin hole in the lever was found 7/16 inches above the mating slot in the body (between centers). [*10/26/96 Group Activity*]

LEFT & RIGHT SPOILER MIXERS

No pre-impact position information was found. [*10/26/96 Group Activity*]

SPOILER SPEEDBRAKE SEQUENCE MECHANISM

No pre-impact position information was found. [*10/26/96 Group Activity*]

AILERONS (ATA 27-10-00)

LEFT OUTBOARD AILERON

About 60% of the outboard left aileron was recovered in smaller pieces, some of which were burned. The piston extension to the centerline of the attaching bolt measured 4¾ inches. The aileron lock-out mechanism and actuator were found intact and the actuator measured 9¼ inches between the bolt centerlines. The two counter balance arms and weights, as well as the reaction link were found attached. [*10/26/96 Group Activity*]

LEFT INBOARD AILERON

About 40% of the fire damaged inboard left aileron was recovered with the PCU attached and the extension to the bolt center was measured as 8½ inches. The reaction link also remained attached. [*10/26/96 Group Activity*]

RIGHT INBOARD AILERON

Only the PCU was recovered of the right inboard aileron and the extension to the bolt centerline was 5½ inches. [*10/26/96 Group Activity*]

RIGHT OUTBOARD AILERON

About ¾ of the aileron was recovered in smaller pieces. The PCU had Green Tag No. Z-2552 and recovery date marked on part as 09/09/96. The PCU was still mounted to a portion of the forward attach fittings on the rear right wing spar and had salt-water and corrosion residue. A portion of the spar was missing, outboard of both sides of the unit. The power package linkage was in place and the piston was extended 5½ inches. The measured length of the lock-out mechanism actuator was nine inches between bolt centers. [*10/26/96 Group Activity*]

RUDDER (ATA 27-20-00)

Approximately 80% of the upper rudder and 10% of the lower rudder were recovered and identified. Although neither had an identification plate, both rudder PCUs were recovered and measured for extension; the upper at eight inches and the lower as nine inches. [*10/26/96 Group Activity*]

UPPER RUDDER

The upper rudder had the control arm for the position transmitter attached, but without the position transmitter. The rudder trim actuator was recovered separate from the vertical fin. The rudder trim cables exhibited an overload type of failure at the ends and the trim drum was found with 10 wraps of cable, positioned 3 wraps from bottom at 2 5/16 inches (neutral is 1.98±.040). [*10/26/96 Group Activity*]

TRIM, CENTERING, AND FEEL MECHANISM

The trim, centering, and feel mechanism was recovered, but no pre-impact position data was identified. [*10/26/96 Group Activity*]

RUDDER RATIO ACTUATOR, LOWER RUDDER

The ratio changer (P/N 10305, S/N 30-72AC) was recovered and found at the full restricted (high speed) position. [*10/26/96 Group Activity*]

ELEVATOR (ATA 27-30-00)

Portions of the elevator control system components from the tail of the airplane were found. All four elevator power control units (PCUs) remained attached to the horizontal stabilizer and the two left PCUs also were attached to pieces of the respective left elevators. [*10/26/96 Group Activity*]

LEFT OUTBOARD ELEVATOR

The PCU was contained within the horizontal stabilizer and attached to the rear spar. The attached elevator was received in the hangar tied with rope in the full trailing edge up position and the PCU extension was not measured. About 85% of the elevator was also recovered. [*10/26/96 Group Activity*]

LEFT INBOARD ELEVATOR

The PCU was found extended 9¾ inches from the actuator housing to the center of the clevis bolt. This unit was attached to both a portion of the horizontal stabilizer and a portion of elevator. The control bellcrank on top of the actuator was found to freely rotate. About 60% of the elevator was also recovered. [*10/26/96 Group Activity*]

RIGHT INBOARD ELEVATOR

The PCU extension measurement was 8½ inches. About 10% of the elevator was also recovered. [*10/26/96 Group Activity*]

RIGHT OUTBOARD ELEVATOR

The PCU was found in the horizontal stabilizer, with the elevator spar fitting attached to the actuating shaft. The fore-aft actuating shaft was found at about the full aft extension and measured 10¼ inches. About 90% of the elevator was also recovered. [*10/26/96 Group Activity*]

AFT QUADRANT

The aft elevator quadrant was missing the left torque tube, although the right was still attached. The elevator field adjustment was found broken at the vernier. All four control cables showed signs similar to an overload type of failure. [*10/26/96 Group Activity*]

ELEVATOR FEEL COMPUTER

Recovery date on part 08/29/96. The unit was found intact and attached to a 12-inch portion of the bulkhead by four mounting bolts. No elevator position information was derived from this part. [*10/26/96 Group Activity*]

HORIZONTAL STABILIZER (ATA 27-40-00)

HORIZONTAL STABILIZER PITCH TRIM DRIVE MECHANISM

The B-747 adjustable stabilizer has a carriage mounted in the center of the forward spar for adjustments to pitch trim, pivoting on points mounted near the stabilizer aft spar. The carriage attached to the front spar is moved up and down on a jackscrew that is driven by the pitch trim drive mechanism. [*10/26/96 Group Activity*]

The pitch trim drive mechanism (labeled 65B80410-1) was found to be missing the carriage assembly and upper portion of the jackscrew. The shaft remaining with the drive mechanism was about 27.5 inches long (about 35 1/2 to 36 grooves of the shaft). The remainder of the jackscrew was found attached to the center section of the horizontal stabilizer. The jackscrew was found top have broken flush with the bottom of the carriage and about 10 threads were exposed above the jackscrew. The drive mechanism was also missing the two primary brake assemblies and two hydraulic motors. [*10/26/96 Group Activity*]

HORIZONTAL STABILIZER CONTROL MODULE

Serial Number: 450AF, Recovery date on part 08/14/96. The unit was predominately intact and showed some signs of post-impact corrosion. The unit was completely separated from its spar location. The four mounting bolts which held the unit in place were sheared off. The four bolt holes in the mounting plate were slightly elongated. Four solenoid-operated control valves were located. Two of the valves were intact. The other two valves were broken. The motorized shutoff valve was broken off and missing. Four hydraulic lines running into the unit were identified. Two of the lines were broken off flush with the tops of their respective B-nut connectors. One line had 10 inches of tubing running from the B-nut connector. it was necked and broken at the end. The last of the four lines had 5 inches of tubing running from a B-nut connector was necked and broken at the end. [*10/26/96 Group Activity*]

HORIZONTAL STABILIZER CONTROL MODULE, NUMBER 2

Recovery date on the part: 08/29/96, Serial Number: 228AG. The body of the unit was predominately intact. Three of the four solenoid valves on the unit were broken off. The hydraulic shutoff valve on the unit was broken off at the unit body. One of the control arms was in place. Four hydraulic lines going into the unit were broken off at the B-nuts. The unit was torn out of its mount. The mounting bolts were sheared. [*10/26/96 Group Activity*]

WING LEADING EDGE SLATS AND TRAILING EDGE FLAPS (ATA 27-50-00)

FLAP CONTROL LEVER

In the cockpit, the broken flap control lever was found loose and would move between the 13 and 18 degree positions. [*10/26/96 Group Activity*]

FLAP HYDRAULIC PRESSURE REGULATOR

Recovery date on the part: 08/24/96. The body of the unit was intact. The mount was intact. A small piece of broken structure remained behind the mount. Locations for two one-inch diameter hydraulic lines going into and out of the unit were identified. One was line was predominately intact with its attaching hex-nut located at the end. The other line was necked and broken at the end. [*10/26/96 Group Activity*]

FLAPS, LEADING EDGE

The B-747 has 26 leading edge flaps, numbered consecutively from the left to right wing tips. The outboard ten panels on each wing are variable camber flaps and the inboard three leading edge devices are Krueger flaps. The drive units are interchangeable and the MM (27-81-03) shows how to determine the stroke adjustment (flap position) by means of a vernier marking, located under a data plate. [*10/26/96 Group Activity*]

Six of the eight leading edge flap drive units were recovered and identified (S/N 49P-245, 101P-1935, and 99P-632, three with missing data plates). [*10/26/96 Group Activity*]

KRUEGER FLAP JACKSCREWS

Of the six recovered Krueger flap jackscrews, three were found stowed, two were found in over-extended positions, and one was missing. The stowed parts (P/N 65B80380-5) were identified as 0139-4, 3073M, and a Krueger flap attached to a panel with a ground stud that was marked STA. R 416, WLP. 17. [*10/26/96 Group Activity*]

VARIABLE CAMBER FLAP ACTUATORS

Two AIResearch drive units from the variable camber leading edge flaps were identified, S/N 99P632 and an actuator with wire W820-C257 and bundle marker W820-C362B. The data plates from each were removed and the vernier was found rusted. The actuators were found in the full retracted positions. [*10/26/96 Group Activity*]

PART RESEMBLING A LEADING EDGE POWER CONTROL UNIT

Recovery date on part 08/09/96. Green Tag No. Z3114. Part Number 14811. The unit housing was broken open exposing two internal gears and some internal components. The unit showed signs of extensive post-impact corrosion. The inlet duct was broken off. The four mounting bolts holding the inlet duct to the unit were sheared off and missing. One mounting bolt was intact and bent slightly. The mount to which the bolt ran through was broken off on both sides of the mount hole. A 4-inch long, 1/4-inch wide gash was observed in the right upper casing of the unit. Extensive corrosion was observed in the area of the gash. [*10/26/96 Group Activity*]

RIGHT WING TIP, VARIABLE CAMBER LEADING EDGE FLAPS

Variable camber panels #23, #24, #25, and #26 were attached to the right wing tip and were all found in the closed positions. [*10/26/96 Group Activity*]

FLAPS, TRAILING EDGE

The Boeing 747 is equipped with four trailing edge flaps, two on either side of the airplane, with four transmission/ballscrew assemblies and four flap tracks on each wing. All seven of the recovered ballscrews were found with marks or the flap carriages at the upstops (flaps retracted). All eight flap tracks were recovered and had damage in the areas consistent with the flaps in the retracted positions. [*10/26/96 Group Activity*]

The trailing edge flap panels were found in numerous pieces. Once pieces from each flap had been accounted for, no further effort was made to reconstruct the wing flap panels. [*10/26/96 Group Activity*]

The trailing edge flap drive units (inboard and outboard) were shown in maintenance training documents as hydraulically driven. No unique features were found to associate the drive units with pre-impact flap positions. The aft trailing edge flap cable quadrant and linkage from FS 1350 were found, along with the inboard trailing edge flap control module, and no unique features were found to associate with pre-impact flap positions. [*10/26/96 Group Activity*]

INBOARD FLAP ANTI-COAST BRAKE

The unit was intact and attached of an 8 inch piece of bent airplane structure. The coupling and the torque tube was broken at one end of the unit. The shaft was locked up and showed no rotation. One coupling was missing leaving the gear exposed. The exposed gear showed signs of corrosion. [*10/26/96 Group Activity*]

TRAILING EDGE FLAP ANGLE GEARBOX

Boeing casting number 65B81136-5 was found on the predominately intact unit. The three unit mounts were broken at mid-span. Both gears into and out of the unit showed signs of post-impact corrosion. The gear shaft showed rotation. [*10/26/96 Group Activity*]

INBOARD FLAP DRIVE UNIT

This unit, from aft left of the 1350 Bulkhead, was found in the wreckage, however no features were found to take an extension measurement from. [*10/26/96 Group Activity*]

OUTBOARD FLAP DRIVE UNIT

This unit, also from the aft left of the 1350 Bulkhead, had no features to take an extension measurement from. [*10/26/96 Group Activity*]

SPOILERS (ATA 27-60-00)

LEFT HAND OUTBOARD SPOILER POWER UNIT ACTUATOR [*10/26/96 Group Activity*]

Recovery date on the part 08/19/96. The unit was found intact and had saltwater and corrosion deposits on the surface. Two hydraulic lines were attached to B-nuts, with one B-nut broken off. The other line had 12 inches of hydraulic line extending outward from the nut. Three plugs were identified, although two of the plugs were broken off. The safety wires associated with the plugs were also broken. The piston was extended 3 and 1/2 inches from the housing to the center of the I-bolt. The actuator arm on the side of the unit was bent inward. A 1/4-inch diameter linkage extending from a nut at the end of the actuator arm was broken off. The attachment mount to the aircraft structure was broken and bent. The unit remained attached to a 16 inch piece of airplane structure. Control cables to the spoiler package were kinked and frayed at the ends. Some cable was wrapped around the bottom of the package.

LEFT WING SPOILERS [*10/26/96 Group Activity*]

The #5 spoiler was found, but position was not determined.

The #6 spoiler was found closed, approximately 25% recovered with fire damage on the surface and with the PCU attached to the aileron. The inboard hinge had been broken.

RIGHT WING SPOILERS [*10/26/96 Group Activity*]

The #7 spoiler was found closed and locked.

The #8 spoiler PCU was attached to the spar, with the spoiler closed and locked, and with the hinge bolts and fitting intact. Some fire damage was present, approximately 20% of spoiler panel was recovered and identified.

The #9, #10, #11, and #12 were all found closed with fire damage.

FUEL SYSTEM (ATA 28-00-00)

GENERAL

Each piece of recovered fuel system tubing was inspected to find CWT parts and to identify evidence of internal and/or external soot, heat damage, arcing, bursting, crushing or lengthwise

collapsing. Other than arcing, each of these features were found. Lengthwise collapsing of jettison system tubing was identified in CWT parts, both inboard main tanks, and tubes from the left outboard main fuel tank Fuel feed tubes were found in a noncontinuous pattern of collapsed tubes and tubes that were not collapsed in the inboard and outboard tanks of each wing. Tank vent tubes were found collapsed in the left inboard wing fuel tank. Evidence of heat damage was restricted to the center wing fuel tank (CWT) and tank 4R (reserve), located near the right wing tip. Two discolored tubes (65B92229-11 and -20) were found in the right wing dry bay, located outboard of the burn damage in tank 4R, in an area that had been exposed by loss of the lower wing skin. Two other discolored tubes (65B92601-13 and 65B92637-12) were found from the inboard main wing tanks, but the areas the tubes came from revealed no other evidence of heat or fire. Numerous sooted tubes were found from the center and right fuel tanks, but none from the left. Several boxes of tubes that were burned and/or exhibited lengthwise collapse remained unidentified after the examination. [*3/19/97 Group Activity, edited for clarity*]

The right wing tip jettison valve was found in the closed position. Most of the other fuel valves from N93119 were found to be interchangeable. Many valves were received separated from structure or large tubing sections that could be used to identify the original sources of the valves. Review of the TWA illustrated parts catalog showed that although there were several types of valves, the same types were used in various installations. For example, a motor-operated valve for the jettison system in tank 2 was interchangeable with the valve from tank number 3.

TANK 4 RESERVE

The right wing tip had separated at fuel tank 4R and components of that tank were reconstructed. A burned rib was found with thin sheetmetal exhibiting petalling of the edges and the petalled edges conformed tightly to the larger features in one direction that was away from the break. The inboard portions of the tank had evidence consistent with fire damage, but none was apparent on the lightly sooted wing tip portion of the tank. The internal surfaces of the wing tip portion of the tank had a very light soot. [*3/19/97 Group Activity*]

Within the 4R tank was a burst jettison fuel tube and two burst vent tubes. The vent tubes were different portions of the same line and had sooting on the external surfaces, but no soot was found on internal surfaces visible through the burst or from either end. The jettison tube had been mounted at the inboard end of the tank, on the airplane side of the valve. An extensive and uneven pattern of soot on the internal features of the jettison tube matched the pattern of soot on the outside of the tube. The burst area was found slightly flattened in the area of the burst and opening the flattened area showed that the same heavy sooting pattern was inside the flattened features. Each of the tubes were sent to the NTSB Materials Laboratory to determine whether the bursts had occurred before or after initiation of fire in the 4R fuel tank. [*3/19/97 Group Activity*] The NTSB laboratory found that the burst tubes had been heated prior to the damage.

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inboard portions of the tank had evidence consistent with fire damage, but none was apparent on the lightly sooted wing tip portion of the tank. The internal surfaces of the wing tip portion of the tank had a very light soot. [*10/26/96 Group Activity*]

TANK DESCRIPTIONS AND MAINTENANCE (28-11-00)

According to Boeing, the 640 pound fuel depth [as seen on the flight engineer CWT indicator] in the center wing fuel tank would have been three inches at the aft spar and that the fuel would have been deep enough to extend forward about 55 inches [+3.5 degree nose attitude]. This forward limit would have been near spanwise beam 1. Boeing drawing 65B92601, sheet three, shows that refill nozzles hang down at station 1182.12, which would be between stringers 4 and 5. A detail view shows that the bottom of the nozzles are located at the mid-point of the stringers. Stringers in the center wing fuel tank from TWA 800 were measured and where unreinforced, were found to be three inches tall [at locations between lower panel intercostals]. Measurement between stringers found a distance of 8.7 inches. [*3/20/97 Group Activity*]

The only openings between the floor areas that were sectioned apart [fore-aft] by the stringers was at the stringer ends, located within 7 inches of the side of body ribs. Stringer 4 had been separated from the floor at the left end and the tank floor had a 1.5 inch wide area that was not covered with tank sealant. At the right end of stringer 4, was an opening of about 2.0 inch width and .6 inch height. Flattened [rectangular] tube sections were found between the areas located fore and aft of stringer 5. The left tube was found sealed in place, but flattened and the stringer immediately above was broken. The right tube was found sealed in place, with a small amount of sealant covering the ends, so the actual opening was .75 X .37 inches. [*3/20/97 Group Activity*]

Separating the right from left areas of the tank between the rear spar and spanwise beam one was structure known as the Butt-Line Zero (BL 0) Rib, although most of the lower edge was missing [not placed in the reconstructed CWT]. In the open area between the BL0 rib and stringers 4 and 5, sealant was found approximately .12-.37 inch thick. [*3/20/97 Group Activity*]

The floor of the center wing fuel tank was examined and found to be covered with a green colored finish. Boeing's initial description of the finish is that the aluminum structure is chromic acid anodized, then coated with BMS 10-20 zinc chromate epoxy primer. Within three inches of the tank bottom that is aft of spanwise beam 1, the finish was seen to evenly coat the interior surface and the stringers. Fasteners were seen covered with sealant and/or green primer where the surface finish was not obscured by soot or damage. [*3/20/97 Group Activity*]

Boeing drawing 65B92601 shows that six refueling nozzles would have been in the center wing fuel tank. Two crushed and burned refueling nozzles were found. The only fuel tank with evidence of an internal fire, in addition to the center wing fuel tank, was tank 4R, from the right wing. The drawing showed that no nozzles would have been installed in tank 4R. The ends of the nozzles were examined under a microscope and no evidence of arcing was found. [*3/20/97 Group Activity*] Boeing reported on October 27, 1997, that an outlet from the refuel valve in tank 4R directs fuel toward the bottom of the tank.

Two pieces of wing tank fuel tubing were found and on one was a set of two teflon-cushioned clamps. A tag on the tube was marked "#4 MAIN, 65B92463-2, INSTALL PER 65B92401, Sht 3, ZN A6/5, OPP 65B92463-1." The cushioned clamps were twisted and deformed, but bolted together and one clamp was marked TA4C44D32T; the other was marked ADEL 475-16. An inventory list showed that TWA had no similar clamps in stock at New York and reported that deletion from inventory occurred after a part number was inactive for five years. [*3/20/97 Group Activity*]

STATIC INVESTIGATION (ATA 28-11-01)

Summary

Electrostatic hazards have been recognized for many years and numerous publications on the subject have been produced, such as American Petroleum Institute (API) Document 2003. [14] In summary, the conditions necessary to produce an explosion are a means of generating a charge, such as through fuel movement, the accumulation of sufficient charge to produce an incendive spark, a means of discharge (spark gap), and a combustible vapor in the gap.

The investigation examined electrostatic charging within fuel tanks through fuel movement as a potential ignition source. Metallic components in the form of Teflon insulated tube clamps, also known as Adel clamps, were found electrically isolated from the airplane (ground) in fuel tanks and capable of retaining static charges. At Wright Laboratory, an electrical path to the grounded tubing that the Adel clamps were mounted on was created by fuel that had anti-static additives when a pressurized leak wetted the entire clamp assembly. These tests were unsuccessful in reaching the calculated minimum ignition energy (MIE) for the clamp tested. In summary, although electrically isolated metal found in the fuel tanks of B-747 airplanes was capable of being charged by fuel to more than API 2003 referenced MIE values, a mechanism of charging to those levels with the conditions believed to exist in the accident airplane was not found.

Determination of maximum obtainable charge on an isolated Teflon Adel clamp by fuel was performed by Dr. Joseph Leonard under contract to the NTSB. His work found that for the fuel to impart a sufficient electrostatic charge required additives no longer manufactured or available in fuel from the Athens or JFK airports. Rather than allowing an electrical path to ground to be created by flowing fuel, as at Wright Laboratory, Dr. Leonard found that the clamp retained up to .84mj in 5800 volt sparks from an interrupted stream (fast drip) with the unavailable additives previously mentioned.

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[14] Criteria listed are from American Petroleum Institute (API) Recommended Practice 2003, Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents, fifth Edition, December 1991.

[15] API document 2003 describes the difference between a non-incendive and incendive spark in stating that "The mere fact that a spark results from high voltage does not mean that ignition of a flammable mixture will occur. For combustion to be initiated, sufficient energy must be transferred from the [incendive] spark to the surrounding flammable mixture."

The API notes that the potential for sparking can also be reduced by electrically bonding all conductive components in fuel tanks, thus, eliminating the separate mechanisms of charge generation and accumulation. Although air carrier airplanes are electrically bonded to dissipate static electricity to the atmosphere through dischargers that are located along trailing edges, FAA regulations[16] address the need to prevent the ignition of fuel vapors within a fuel system through regulations for lightning protection. Ignition by static discharge is not specifically addressed by regulations, although a non-regulatory advisory circular mentions static charges in composite fuel tanks. An accepted method of protection against both static and lightning has been to keep fuel system components within the metal structure of the airframe and bonded to airframe components.

FLEXIBLE FUEL TUBE (WIGGINS) COUPLINGS

Wiggins couplings were removed from a scrapped Continental B-747 (N78020) after tests found that some coupling bodies were electrically isolated from the fuel tubes that they connected together. The company that made the coupling had developed couplings that electrically bonded the components with two springs, preventing charge accumulation in the later design. The potential for use of the later design in previously built airplanes was examined and found to require replacement or rework of each fuel tube in the airplane.

The flexible coupling is comprised of subcomponents described in Boeing specification BACC42R and may be procured from IMO DeLaval Inc, Wiggins Connectors Division, of Los Angeles, California. Each sub-component has a call-out for MIL-A-8625 anodize, but only the ferrule specifies the type of anodize to be applied; TYPE II. The specification shows retention areas for two o-rings and states that:

> THIS COUPLING ASSEMBLY PERMITS UP TO 4^{O} MISALIGNMENT FROM TUBE CENTERLINE, UP TO .2500 INCH AXIAL MOVEMENT AND UP TO .0625 INCH OFFSET BETWEEN TUBE ENDS.

Electrical resistance measurements were made between components from the fuel system [of N93119]. The results of the measurements showed wide variability in resistance, between very low (5 tests of less than 1 ohm) and very high (4 tests between 4.5 & 9.9 megohm). [*10/22/96 Group Activity*]

Intermittent electrical continuity in new flexible fuel tube couplings had previously been documented the FAA and National Aeronautics and Space Administration (NASA).[17] The FAA stated that flexible couplings may be poor conductors and noted:

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[16] 14 CFR Part 25.954, Fuel System Lightning Protection. Advisory Circular (AC) 20-53A, Protection of Airplane Fuel Systems Against Vapor Ignition Due to Lightning.

[17] Aircraft Lightning Protection Handbook, DOT/FAA/CT-89/22, September 1989.

Lightning Protection of Aircraft, NASA Reference Publication 1008, October 1987.

> …a slight change in the relative position of the mating surfaces, or introduction of dirt or residue might drastically change the electrical capability of a [flexible] coupling. It is probable that the electrical capability [conductivity] of a typical pipe coupling changes many times during a flight as a result of relative motion caused by structural vibrations and flexing.

The FAA and NASA references are also critical of electrically bonding the fuel tubes with straps for lightning protection. The Safety Board notes that in the FAA and NASA illustrations, as well as in the Boeing 747 maintenance publications, the straps cross over the coupling bodies, but the bodies are excluded from the connection. AEA Technology, a United Kingdom-based company with a lightning laboratory, tested similar new couplings for resistance to arcing created by induced lightning energy. AEA noted that even with apparent metal to metal contact, large sparks were created. During multiple lightning tests in the presence of flammable gas, AEA found that ignition occurred.

Boeing maintenance procedures[18] call for "on-condition" replacement of rubber components in the fuel system, rather than specifying a number of flight hours or distinct time interval. Numerous 1971 date-stamps were found on fuel system components in the N93119 wreckage and o-rings were found that were hardened and deformed in cross-section. The cross-section of some o-rings had conformed to the square shape of the installation glands. O-rings removed from N93119, N93105, and N78020 were found cracked around the periphery.

NASA examined cracked and hardened o-rings from the accident airplane. In the report from the examination, NASA also reported that o-rings of the type found in the TWA 800 wreckage and 17-20 years of age have been able to maintain a seal in simulated space hardware. However, based on MIL-STD 1523A, most nitrile rubber materials have a useful life of no more than 10 years from the cure date when used as o-ring seals.

ELECTROSTATIC SUB-GROUP ACTIVITY OF JANUARY 22, 1997

The Systems Sub-Group convened at the Evergreen Air Center, located at Pinal Air Park, Marana, Arizona, on January 21-22, 1997, to examine a TWA Boeing 747 (B-747) and other B-747 materials.[19] Numerous entries were made into the center wing (CWT) and inboard right tank of airplane 17109 to visually examine for potential static charging mechanisms, bonding of fuel system components, and to obtain materials for subsequent bench tests.

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[18] Boeing 747 Maintenance Review Board Report, Boeing 747 Maintenance Program, January 1970, Page 19, Note g.

[19] Note: All the capacitance measurements made during this trip on both the Continental B-747, N78020 and TWA, N17109 aircraft fuel components were taken using a small portable capacitance meter (BK Precision, model unknown). Tests to compare measurements for capacitance of removed components were made by the Electrostatic Laboratory personnel at Wright Laboratory and are included in their report. Values were found to change with movement of the tubing with the Wiggins couplings, making comparisons questionable. Therefore, measurements made by the group during this trip are cited, but the accuracy of the field values could not be verified.

While in the aft right bay of the CWT, an electrically isolated metal clamp was found on the fuel cross-feed tube, attached to a clamp on a pump wetting tube. The maximum resistance measured in five checks between fuel tubes, clamps, and structure measured 4.1 milliohms. Boeing safety procedures regarding electrical test equipment allowable in fuel tanks were followed and the equipment could only obtain milliohm measurements.

The group measured resistance and capacitance of components in the exposed fuel tanks of a Continental B-747, N78020, that was in the process of being scrapped and which had the fuel tanks exposed. Flexible fuel couplings were found electrically isolated[20] and with varying levels of capacitance.

Examination was also made for potential points of leakage. Extensively cracked o-rings were found in the wreckage of the Continental airplane, including from a flexible fuel coupling in the #1 pylon fuel feed line. TWA personnel reported that fuel leaks were not common, but that they had found more leaks from cracked pipe welds than from flexible fuel tube couplings. The forward fuel pump in the #3 tank of 17109 had safety wire installed in such a way that the twisted portion was pulled tightly against slightly less than an eighth of circumference of the fuel inlet tube.

> Note: On October 27, 1997, Boeing noted that O-rings were picked up off the ground after exposure to the elements for an unknown time and that the parts may have come from another airplane previously scrapped in the area. In response, o-rings cited with a source were directly removed from the airplane in the process of being scrapped and were within Wiggins couplings. Wiggins couplings were also opened and cracked o-rings were found in the wreckage of N78020, N93105, and the accident airplane, N93119. The term "extensively" was used in the agreed group notes. The cracks were found through through more than half of some o-rings and the radial cracks were continuous around the circumference.

Pressurization of the cross-feed and jettison/refuel manifolds revealed leakage, appearing as a steady dribble, coming into the CWT at the forward end of the left pressure fill outlet (piccolo tube). A flexible fuel tube coupling was found externally wet between the mid-spar and spanwise beam 2 and a small puddle of fuel was on the tank floor, below that coupling. Wetness was found on the tank floor at the aft spar beneath the right fill valve, although a source was not identified and no active leaks were seen.

Airplane 17109 had arrived the previous week and the last flight legs reported were Rome to New York to Los Angeles to New York to Marana. The TWA representative to the group reported that the total time recorded for the airplane was 102,712.23 hours and that the total flight cycles were 18,697.

The fuel panel in the cockpit of 17109 was checked. The pump and valve switches were found off/closed and the fuel system circuit breakers were at the "in" position. The letter "H" was

[20] The Fluke Multimeter used for the resistance tests had a maximum scale reading of 30 megohms. Greater resistance levels were considered to be electrically isolated.

penciled into the small white triangles above both of the #1 tank pump switches and almost a nearly erased “H” was seen above the right pump switches for tanks #2 and #3. The fuel indicators had the following readings:

GROSS WEIGHT		3700
TOTAL FUEL	10.0	
#1R		0
#1		03.95
#2		00.83
CWT		99.85 (below zero)
#3		00.54
#4		06.16
#4R		00.05

After the group arrived at about 8am on Tuesday morning, mechanics working on airplane 17109 stated that the fuel tanks had been opened two days earlier and had been vented with pressurized air for the complete previous day (Monday). The mechanics mentioned that they believed fuel may be leaking into the CWT, but no active leaks were noted and the only CWT standing fuel was found under the left jettison/override system inlet. The group found fuel fog coming out of each of the fuel tank openings and inspection inside revealed denser levels of fog in the mid-bays of the CWT. The CWT aft spar access port was opened and further air lines added.

In the CWT, the scavenge pump check valve was found marked with a 1992 date, the horizontal check-valves that were installed between the jettison/override pump and the cross-feed manifold tubing were marked 1970.

A cushioned metal clamp, commonly referred to as an Adel, was installed on the fuel cross-feed tube in the right aft ~~right~~ bay of the CWT, attaching the tube to a nylon clamp on a pump wetting tube. The metal part of the clamp (TA4C44D28AF) was found electrically isolated from the cross-feed tube. After the clamps were removed and loosely slipped onto another fuel tube of the same diameter, about 390 picofarads of capacitance was measured; after clamping tightly, the capacitance measured 2.04 nanofarads. Another clamp was used and measured about 3.2 picofarads. The group examined the clamp location for potential impingement by leakage from flexible fuel tube couplings and found none within several feet, although many flexible fuel couplings were within the same compartment of the tank.

Using an Avtron Bonding Tester (milliohmeter) of the type approved by Boeing for use in fuel tanks, 4.1 milliohms was found from the cross-feed tube to the wetting line, near a bonding strap that connected the two. The resistance between two points on the cross-feed were measured as a test and .001 milliohms was found. Resistance between a bonding clamp on the jettison tube and the tube was 3.6 milliohms. Resistance between the same clamp and structure measured 1.2 milliohms.

All flexible fuel couplings were found safety wired and the tubes were connected by bonding straps or bonding straps were found between tubes and structure.

Measurements of resistance and capacitance were made after filing bare spots on tube and coupling surfaces with a file. Tubing and O-rings were retained for later laboratory examinations and to verify field capacitance measurements.

Results of the measurements made between tubing and flexible and hard (fixed) fuel tube couplings found in Continental airplane N78020 were found isolated and with up to 17 nanofarads

ELECTROSTATIC GROUP ACTIVITY OF MARCH 7, 1997

A systems investigation sub-group was convened in a specialized laboratory at WP on March 3-7, 1997, to examine potential triboelectric charging of fuel sprayed from various shaped and sized orifices onto electrically isolated targets. Changing variables of both the fuel spray and target during tests found that the variable strongly affected charging on the target. The variables identified or discussed by the group included fuel temperature, cabinet temperature, cabinet humidity, variations in dielectric (clamp cushion and o-ring) resistance, fuel conductivity, contaminants, distance between the target and orifice, orifice size, target surface area, fuel pressure, and orifice shape. [*3/7/97 Group Activity with edits from Cindy Obringer of WL/POSF*]

The group found at least four types of cushioned clamps that had been installed in Boeing 747 fuel tanks. A Teflon clamp that had been removed from the inboard main fuel tank of another airplane accumulated the most charge seen, at 658 volts. [*3/7/97 Group Activity*]

Using the measured capacitance of 0.0442 nano-farads and the API document No. 2003 relationship to solve for voltage required to produce a minimum ignition energy of 0.25 milli-Joules, resulted in a required voltage of 3363 volts (5 times the voltage found).

A second cushioned clamp that was to be installed into the fuel tank of a B-747 airplane, was found to be a silicone cushioned steel band. The specification for this type of clamp states that the cushion material is “NOT RESISTANT TO PETROLEUM BASED FLUIDS.” [*3/7/97 Group Activity*]

The test cabinet was part of an integrated fuel test stand. The cabinet was part of a closed loop system, supplied by a drum that acted as a reservoir, an electrically driven fuel pump, and approximately 70 feet of one inch diameter stainless steel tubing. The 70 feet of tubing was installed for the test to permit relaxation of static charges induced by fuel movement through the fuel pump, prior to entry into the test area. The cabinet acted as a faraday cage and was equipped for quick plumbing changes, nitrogen inerting, controlling distances between orifice and target, attachment of test and measurement equipment. An isolated .617 inch inner diameter stainless tube of 6.87 inch length in the cabinet was installed to measure streaming current. [*3/7/97 Group Activity*]

To prevent static charging of the removable Plexiglas face panel of the cabinet, the spray fixture was oriented to keep fuel from impinging on the Plexiglas. However, during the first day (3/4/97) that fuel was sprayed, the removable Plexiglas face panel of the cabinet was found to

accumulate static charges of up to seven kilovolts (KV) and a copper mesh was attached to the surface of the Plexiglas. The face panel was also sprayed with ionized air to neutralize the static charge and frequently checked for surface charge. [*3/7/97 Group Activity*]

Fuel was received in two 55 gallon drums from JFK. Conductivity of the fuel was measured for each test and recorded on the test result sheets. Testing for water content was conducted by the Carl Fisher method and found between 80 parts per million (+/- 10). [*3/7/97 Group Activity*]

Note: Wright Laboratory reports will take precedence if conflicting information exists with this text.

Within the cabinet were targets that included BACC42R flexible fuel tube couplings and cushioned metal clamps that had been found electrically isolated in B-747 fuel systems. No targets were from the accident airplane and most (including all BACC42R couplings) had been removed from a Continental B-747, N78020[21]. One cushioned clamp was from the center wing tank of a TWA B-747, identified as airplane 17109. [*3/7/97 Group Activity*]

Four types of cushioned tube clamps were identified and three were tested. None were marked BACC10DK[size], as called for by the Boeing 747 illustrated parts catalog. The first target was a teflon cushioned metal clamp that was received intact on a section of tube that had been cut from N78020[22] and that clamp was marked UMPCO MS21919DG26. The clamp was received with the cushion shifted so that the metal of the clamp was .016 inches from the metal tube. After handling, the gap was measured again and found to be .040 inches. A photograph of a similar clamp and text identifying that clamp as teflon-cushioned were found in a United Air Lines (UAL) Report No. F-1467, concerning an investigation into a May 3, 1970, fuel tank explosion at Minneapolis, Minn. [*3/7/97 Group Activity*]

An INTER-OFFICE CORRESPONDENCE, written by Mr. W.G. Dukek of Esso Oil Company to the file, dated March 16, 1971, noted that the refueling at Minneapolis was being conducted at 110% of rated flow, compared with 60% of rated flow at other locations. Mr. Dukek also wrote that due to the build-up of static charge on Teflon clamps found in B-727 fuel tanks, Boeing "was about to issue a Service Bulletin to eliminate unbonded metal clamps in 727 tanks (a deficiency noted upon investigating the May accident to UAL) when the second (December 23, 1970) accident occurred. Suspecting that more drastic revisions to the 727 fuel system might be needed, they held up this bulletin pending the results of more research." Mr. Dukek noted that Boeing's testing found that the unbonded metal clamp being tested could store up to 5 mj of energy.

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[21] N78020 was built within the year following N93119 and was in the process of being scrapped at an aircraft storage facility at Marana, Arizona in January 1997. The International Association of Machinists and Aerospace Workers noted that TWA was the only operator of the accident airplane since delivery from Boeing and that differences existed between TWA and Continental Airlines operations, maintenance programs, and maintenance standards.

[22] According to the military specification, MS21919 is the basic part number for this style of clamp, a "W" denotes a wedge style cushion, a "DG" denotes an aluminum clamp with chloroprene cushion material, and the final number denotes diameter in eigths of an inch.

In a letter of April 3, 1997, Boeing identified unbonded Teflon clamps in the B-747 that were located by design on tubing in the CWT and in the inboard main fuel tanks.

A clamp removed from TWA 17109 had a black cushion that was painted red on one side and marked TA4C44D28AF. TWA supplied replacement MS21919 DG clamps of various diameters that were similar to the clamp from 17109, without the red coloring. [*3/7/97 Group Activity*]

After removal of the clamp from 17109, an aircraft storage facility mechanic (not a TWA employee) got a replacement clamp to install in the airplane and the group asked to keep the clamp as a new specimen. The mechanic agreed and put another clamp into airplane 17109. The replacement clamp was marked UMPCO MS21919WH29. The specification for this clamp showed it to be a Wedge [cushion style], Low Carbon Steel, Silicone Cushion. The specification also stated "NOT RESISTANT TO PETROLEUM BASED FLUIDS." [*3/7/97 Group Activity*]

Baseline electrical measurements were made by personnel from the WP Materials Laboratory's electrostatic group. Sample capacitors were used to verify equipment accuracy. Baseline capacitance values were made, then capacitance values were measured after attaching test leads and installation into the test cabinet. [*3/7/97 Group Activity*]

Resistance of o-rings that had come from the Continental airplane were included in the baseline electrical measurements. To measure resistance without penetrating the surface, each o-ring was pressed onto a flat metal plate with a five pound weight. The leads of an ohmmeter were attached to the plate and the weight. Differences of more than one exponent were found in the resistance between o-rings of [visually] identical material. Materials of o-rings that were electrically tested included chloroflourocarbon and chloroprene. Chloroflourocarbon o-rings were found with resistances of up to $5X10^{13}$ ohms. [*3/7/97 Group Activity*]

Difficulty in using correct o-rings was found in assembling the one inch flexible fuel tube coupling. The low resistance chloroprene o-rings and high resistance chloroflourocarbon o-rings were of identical black material and had no markings. The only method available to differentiate between the o-rings was to perform an electrical resistance measurement. [*3/7/97 Group Activity*]

No voltage accumulation was measured on flexible fuel tube couplings that had resistance values of up to $1.1X10^{8}$ ohms, using specified chloroprene o-rings, and which had measured capacitances of as much as 10.46 nanofarads. Measurement of a 1" coupling with an assembled resistance that measured about $1X10^{11}$ ohms that was built with chloroflourocarbon o-rings, found 14-15 volts of charge. During baseline electrical measurements of a No. 28 BACC42R Coupling, it was found that resistance dropped out of the megaohm range after application of a 250 test voltage. [*3/7/97 Group Activity*]

An orifice was manufactured with an actual crack of about .58 inch length and the ends were covered with aluminum foil. At 42 psi pressure, 6 inch approximate distance, 93 ½ ^{o}F, fuel temperature, this orifice produced 544 volts over a 5 ½ minute period, when the test stand ran out of fuel. This was the largest rate of charge measured and all other measurements were made at 15 minutes or when the charge stopped increasing. [*3/7/97 Group Activity*]

Charging was found affected by certain variables and other variables were discussed by the group. These variables included the following: [*3/7/97 Group Activity*]

1. Increased fuel temperature was found to increase the rate of charge. The differences in charge are recorded in the test sheets.

2. Cabinet temperature was discussed. Atomization of fuel is affected by temperature, according to Wright-Patterson personnel.

3. Cabinet humidity was found to be a variable by Wright-Patterson in static-charging tests of foam used in fuel tanks.

4. Dielectric (clamp cushion and o-ring) resistance was measured and found substantially different, even between like parts [of same part number or type] from the same vendor.

5. Fuel conductivity had been previously found to affect charging rate by Wright-Patterson and Dr. Leonard.

6. Contaminants, such as water were discussed, due to citations by the API and others.

7. Target distance of 1.75 to eight inches were tested and found to affect charging rate.

8. Orifice size was changed as a variable and found by test to affect charging. Smaller orifices generally had higher initial charging rates and more atomization was seen, but maximum voltages found were less than with larger orifices.

9. Target surface area was discussed.

10. Fuel pressure was tested as a variable and found to affect charging.

11. Orifice shape was discussed. In engine fuel nozzles, previous Wright-Patterson tests found that orifice shape affected atomization. [*3/7/97 Group Activity*]

ELECTROSTATIC SUB-GROUP ACTIVITY OF APRIL 8-11, 1997

On April 8-11, 1997, a series of tests were performed at Wright Patterson Air Force Base Laboratories to examine the potential for developing a static charge by spraying Jet-A fuel. Numerous tests were conducted to examine the charging mechanism created by fuel that was sprayed into other fuel and of the charging of a standardized target plate. The maximum surface charge on the standing fuel that was measured was 80 volts and the maximum vapor charge found was 88 volts across a 4 inch vent. [*4/11/97 Group Activity*]

An instrumented aluminum plate was placed in the fuel spray, first to deflect fuel impingement into the fuel that was standing in the chamber tank, then as a charge collector. As a charge collector, the plate was used to develop data as spray variable were changed. The maximum

steady current observed in the remote room used by the parties was 6.9 nanoamperes in test 19, using fuel with a conductivity of 32 picoSiemens/meter. Higher values of up to 11 nanoamperes were later seen when using higher conductivity fuel, but spray nozzle difficulties created irregular results. Data was collected at varying temperatures, spray distances, impingement angles, and with other variables. [*4/11/97 Group Activity*]

A set of dry measurements of electrical characteristics was made. After the sheet was written, Viton o-rings[23] were obtained for use in the "T7/T8" Wiggins coupling that was from the Continental (N78020) B-747 airplane. Using the o-rings increased the resistance of the coupling to about 2 X 10^{11} ohms. [*4/11/97 Group Activity*]

FUEL TEMPERATURE SENSING (ATA 28-11-21)

Temperature sensors are typically used to detect the potential for fuel icing and are located near each engine and in an outboard wing fuel tank.

After a test of August 26, 1996, Boeing reported that operating the three air conditioning packs raised the center tank fuel temperature by approximately 40 degrees Fahrenheit, to about 115 degrees. The 115 degree value was within Trans World Airlines B-747 Flight Handbook maximum tank fuel temperature limit of "54.5C (130F), except JP-4 which is 43C(110F)." However, the temperature rise was significantly more than the "additional 10-20F" noted by the Handbook, which goes on to state, that "warm fuel…may cause pump cavitation and low pressure warning lights may come on steady or flashing." Additionally, the group found that the temperature indicator at the flight engineer station had selections that included the left outboard main tank and at the four engines, downstream of the fuel/oil coolers, but none for the CWT position. [*3/19/97 Group Activity*]

FUEL VENT SYSTEM (ATA 28-13-00)

MARK FOUND IN RIGHT SURGE TANKS

A Wiggins™ coupling was found in the right wing tip surge tank that had an unusual feature. A mark of about 3/16 inch diameter was found where a copper electrical bonding strap had been in intermittent contact with the corner of the aluminum coupling. The location of the mark was measured and found to be eight inches from the exit point of the center wing tank vent opening, in a line between the exit point of the stringer and the inlet of the tube leading overboard. The Wiggins™ coupling and the strap each connected two tubes of about five inch diameter. When viewed under a binocular microscope, the center of the mark was shiny and had striations that

[23] The Viton o-rings were obtained from a commercial distributor who did not have documentation regarding which manufacturer that the o-rings came from. The distributor measured the original o-ring sizes as "-328," but had none of that size. The o-rings obtained were military specification M83248/1-327 parts, and when installed were visually identical to the original o-rings.

resembled the orientation of the strands of the bonding strap wire. However, around the mark were two concentric rings, the inner-most seen as a halo of material that resembled a hardened dark brown plastic. This feature was not seen at other points where fretting was found. The outer ring had the black sooty appearance of aluminum oxide seen around other points of fretting. [*3/19/97 Group Activity*]

CENTER TANK VENTING AND FENWAL SURGE TANK PROTECTION (STP) SYSTEM

The B-747 Maintenance Manual (MM) shows the right surge tank connected to the center tank's left vent tube and the left surge tank is shown attached to the right vent tube in the center tank. The MM also shows that the surge tank installed in each wing tip is comprised of two adjacent rib bays that are located inboard and outboard of each other. Venting from the center tank comes into the outboard bay of each surge tank through a hollow upper wing stringer, moves through baffles into the inner bay, then again travels outboard through an outlet tube (actually shorter tube sections installed in series), past the Surge Tank Protection (STP) System flame detector that is located near the exit point on the lower wing skin. [*3/19/97 Group Activity*]

The accident airplane was equipped with a STP system, rather than a flame arrestor system. A representative of Fenwal Safety Systems, the manufacturer, said that the STP system is optically triggered and may be set off by a bright light source. According to the manufacturer, lightning and flame fronts will cause a discharge and mechanics have triggered the system with bright flashlights. TWA personnel confirmed that the system had been inadvertently discharged by use of flashlights. Discharge of an extinguishing agent occurs about one millisecond after detection. Both the sensor and discharge squibs require aircraft power and have no capacitors or other means of storing energy to operate. [*3/19/97 Group Activity*]

The wing tip STP bottles were recovered and all were found full, not discharged, although one had been damaged. The trigger device of the right wing tip flame arrestor was recovered from the ocean and was removed from the right wing tip. The optical window of the sensor was found to have a very light coating of soot or other film. [*3/19/97 Group Activity*]

SURGE TANK FLOAT SWITCHES

The B-747 Maintenance Manual (28-21-00) show that a float switch is located in each surge tank to: [*3/19/97 Group Activity*]

> "energize a fueling shutoff relay if fuel enters the surge tank due to volumetric shutoff control unit malfunction. Power to the relay and float switches is 28 volts dc from ground handling bus …or battery bus…"

The left and right float switches were removed and found to have been manufactured by Consolidated Controls Corporation as P/N 25GB10-99, S/N T238 and T172 (respectively), with functional test dates of 3/71. The Engineering Department Manager said that each switch has a donut shaped float, made of aerated epoxy, that slides along a green Teflon coated aluminum

tube. Within the aluminum tube is a hermetically sealed glass tube that holds a reed switch, actuated by small magnets in the float. The reed switch is rated for an electrical load of 28 VDC at 1 ampere. [*3/19/97 Group Activity*]

After speaking with the manufacturer, the float housings were cut off and the parts were examined, but the reed switches were not removed. No evidence of arcing was found on the external surfaces or within the float chamber of either switch. Each switch was found to function electrically, with continuity found between pins one and two when the float was only in the up position (.4 ohms between left switch pins one and two, .2 ohms between right switch pins one and two) and with continuity to ground in both switches (.2 ohms between pin three and the case). The resistance between the case and float housing of each measured .1 ohms. In the bottom of the float chambers was a black film on either side of a circular wear pattern that exposed the aluminum housing material and the wear was at the diameter of the float feet. On the non-contacting surfaces of the floats were small amounts of black coating that under magnification looked like peeling paint. [*3/19/97 Group Activity*]

The left switch was recovered from a wing section that had been underwater for several weeks and had a strong fuel smell. The float magnets were rusty and five of the eight were protruding from the lower float surface as far as the float feet. [*3/19/97 Group Activity*]

The right float switch was recovered from a wing section found floating on the water and the switch had no fuel smell. Under magnification, the surface of the float was coated with a significant amount of rusted particulate material. [*3/19/97 Group Activity*]

CWT SCAVENGE SYSTEM (ATA 28-15-00)

No evidence was found that the scavenge pump in the accident airplane had been powered at the time of the accident. Although the scavenge pump motor and impeller were not found, the other components of the system that supplied power to the pump were recovered and examined, with the exception of the pump winding circuit breakers. No evidence was found of a short circuit within the scavenge pump relay or that the contacts had stuck, been overheated, or welded from a high current loading.[24] Evidence was found that the scavenge pump relay (control) circuit breaker remained set through the accident and recovery. The scavenge pump low pressure bulb filaments were found broken without evidence of stretch, however, no evidence was found of AC power to any aircraft systems after the loss of the CVR and FDR recordings. Although examination was unable to tell the position of the scavenge pump control switch at the time the accident happened in the air, evidence was found that the switch had been in the OFF position at time of recovery. The switch examination concluded that "there was no evidence to support any

[24] Engineering data for the operation of the circuit breakers was obtained from Texas Instruments, the company manufacturing the Klixon 2TC series of circuit breakers found in the wreckage of N93119. The data showed time-current "trip" charts. The data showed that for the first 1/10 second, with a zero preload application of 115 VAC at sea level and 25°C, opening the circuit breaker could require an electrical load of approximately 1,000 times the circuit breaker rated current value.

forced movement to the “off” position by impact or some other means from the mishap breakup energy.”

SCAVENGE SYSTEM OF CWT, DESCRIPTION

The scavenge pump from N93119 was not found. The mounting ring for the pump remained attached to the rear wing spar. The locations of the pump mounting flanges were found clean and silhouetted by surrounding blackening of the spar area. The general area of the scavenge pump mounting had heat-type damage and sooting. [*10/26/96 Group Activity*]

A design review found that the scavenge pump motor was mounted external to the fuel tank, but contained fuel cooled windings. Fuel supplied to the windings passed through a tube of small diameter and a check valve. A design review found that the pump contained a thermal fuse that had been designed to open at less than 400^{o}F. The review found that the pump had passed hours of qualification tests in which it had been operated without cooling fuel and that the end of each test came when the thermal fuse had opened.

The review also found the scavenge pump successfully completed explosion proof testing by; (1) never causing an explosion in an explosive atmosphere, and (2) by containing multiple explosions intentionally set-off within the motor and preventing it from propagating to a surround explosive atmosphere. Since the group became aware of instances in which the cooling tubes had been broken or missing, a series of tests were conducted in October 1997, to determine whether the pump motor housing would continue to contain explosions with only the check valve. Samples of a new pump and one from service were tested. In each case, the explosions were contained in the housing and the explosive atmosphere surrounding the test pumps did not ignite.

Records were found that thermal fuses had opened in service, as in the qualification tests, but no records were found in which fuel vapors inside or outside of the motor housing had been ignited. The pump contained a low pressure switch designed to illuminate an amber light on the flight engineer panel when the pump had power but no pressure was being developed. The amber light was within inches of the switches and gages for the fuel tanks that would have been used for the post-takeoff cross-feed operation described in the TWA Operations Handbook.

Components in the electrical connector in the wheel well had been found deteriorated on the fuel pump of TWA (retired) airplane N93105. Additionally, it was found that a quantity of scavenge pump electrical connectors had been made with an incorrect material that had been found to degrade with long-term fuel exposure. During a group activity of October 28, 1997, a degraded connector was found in a scavenge pump obtained from another airline and examination of the pump serial number found that it was within the group manufactured with the incorrect material. The design review found that the scavenge pump connector pins were held apart by a plastic contact retention disk and that if a fire were ignited by a short circuit at the connector, it would have to pass through the flame arrestor tubes and the check valve to reach the fuel tank. The wheel well also had been equipped with heat detectors. Soot and fire patterns were not found to emanate from the rear wing spar at the fuel pump mounting hole.

Boeing provided a summary of the scavenge pump service history that had very few records for the most recent ten year period. When asked about this, the Boeing representative said that most airlines do not return the pumps the manufacturer for overhaul. [*10/26/96 Group Activity*]

In a subsequent meeting June 12, 1997 with all the party members, all the repair records from TWA on their 747 scavenge pumps were reviewed, and the records included data through May of 1997. Also the sales records of spare parts from Lear Romec were reviewed in the July 23, 1997 Scavenge Pump review.

N93105 SCAVENGE PUMP EXAMINATION

The scavenge pump was removed from N93105 for examination. TWA found no records that the scavenge pump from N93105 had been submitted for repair or shop records for the unit having been received/repaired by TWA. It was decided by representatives from the NTSB, FAA, Lear-Romec, TWA, ALPA, and Boeing representatives that this pump was not representative of an in service pump, as listed in following paragraphs. However, some of the anomalies were found in manufacturer reports from other scavenge pumps, such as the foreign objects and the broken/missing cooling tube. [*The rest of this section is excerpted from the record of the group activity*]

Visual examination of the unit revealed that the unit had been previously opened (scavenge pump was attached to motor with new machine screws, cover tabs were missing and there was no evidence of lockwire on the liner set screw. [Lear-Siegler noted that this was not representative of an in-service unit.]

Debris was found between the service shutoff valve [P/N RD24668-1] and the pump receiver housing [P/N RR24666]. Upon separation of the scavenge pump [from the housing], contamination was found as follows:

A piece of Dymo label tape backing was removed from the service shutoff valve and the receiver pump housing.

A piece of Non-chromate Polysulfide Fuel Tank Sealent, was found in the discharge ~~relief~~ [check] valve cavity of the pump housing.

A Crystalline Silica Mineral Particle was found on the outer circumference lip of the seat spring from the check valve in the receiver pump.

A piece of Metallic Aluminum Fragment found in the pump discharge chamber of the pump housing.

A piece of Chromated Polysulfide Fuel Tank Sealant was also found jammed in the pressure relief valve between the pump housing and the poppet valve. The valve was jammed open and would not operate to Boeing or supplier specifications, but would allow flow to the inlet.

[Note: October 28, 1997, inspection at Lear-Romec of a scavenge pump from another airline also found debris. However the debris was found obstructing the cooling/flame arrester tubes, as well.]

Examination of the relief valve assembly revealed that the edge/lip of the housing has been bent or rolled over. Visual and microscopic examination of the poppet valve and spring revealed traces of corrosion inside the poppet and on the spring

The AC motor assembly [P/N RG21860] was removed from the scavenge pump. Separation of the motor revealed that the preformed Packing between the motor and the ~~impeller~~ [pump] housing interface was missing. Also it has been noted that the motor cooling tube was missing from valve housing and that the helical compression spring has a small section of the cooling tube lodged inside it. The valve poppet also exhibits some wear.

The inlet in the valve housing where the cooling tube is pressed in or seated has been damaged. Dimensional analysis of the housing revealed that the inlet hole diameter for the cooling tube was measured [and] recorded at .114" to .122" and was not concentric, per supplier specification it should measure .115" to .116" and should be concentric in shape. The valve housing exhibited no other anomalies.

The scavenge pump pumping element was then removed, examination of the pump housing revealed slight contamination, (a white pasty sludge, maybe signs of emulsified fuel and water) in the shoulder area below the spring washer stack.

The scavenge pumping element which contains the two bearing sleeves, six blades, one rotor and one liner was found to be in good condition. The parts did exhibit slight wear. The bore of the pump liner was not concentric [by design] and not within the supplier specifications. The other parts had no indication of being over heated or distressed and were found to be within the supplier specifications.

N93119 SCAVENGE PUMP PICK-UP STRAINER TUBE ASSEMBLY

[*12/4/96 Group Activity*]

A short section of fuel tube assembly was found with a part number that was unique to the scavenge pump pick-up tube, installed in the center wing fuel tank. The assembly was photographed and sectioned. The internal features were found to contain no sooting or flow patterns.

Before the assembly was sectioned, the following features were noted:

An installation drawing showed that the numbered end (65B92406-9) of the assembly would have been installed forward and that the assembly would have been located at an opening in the

mid-spar. The assembly consisted of two tube fragments, connected in the middle by a safety-wired Wiggins coupling.

The tubing was measured to be one inch in diameter and the assembly was 10 ¾ inches long. The overall external features were slightly blackened. The forward tube was found flattened with two inward punctures. The aft tube had a single inward puncture. Both tubes were loosely held by the Wiggins coupling and moved freely.

On either side of the Wiggins coupling was an electrical bonding strap [with eyelets], attached by a nut and bolt. The electrical connectors each contained a fragment of electrical bonding strap, but were not connected together.

Following description of the external features and photography, the length of the assembly was sectioned and laid open. The internal surfaces of the tube had a slightly golden color, similar to anodize seen on other fuel tubing. No evidence of internal sooting or flow patterns were found.

SCAVENGE PUMP CIRCUIT BREAKERS

Two circuit breaker bodies (missing the plungers) from the scavenge pump and the reserve transfer valve #1 and #4 circuits were examined by Wright Laboratory. The transfer valve circuit breaker happened to have been attached to the scavenge pump circuit breaker, but was examined as a comparison item. Radiographic examination of each circuit breaker showed the contacts latched in the closed or near closed position, although possibly misaligned. The scavenge pump contacts measured (one volt) 250 megaohms and the transfer valve measured 150 megaohms, but each had a visible coating that was similar to the dried sea-water residue found on the flight engineer's panel. The internal mechanisms were found in the "set" positions. The internal electrical contacts had not been welded together. [*6/24/97 Group Activity, edited*]

A detailed report (WL/MLS 97-086) regarding the examinations of the scavenge pump relay and reserve transfer valves was received from Wright Laboratory.

The scavenge pump motor windings circuit breaker was removed from the P6 panel at the flight engineer station for laboratory examination. The collar and button were missing, but the circuit breaker had three sections, as shown leading to the three windings of the pump. Although the labeling of the panel was missing from the area, a chart depicting circuit breaker positions showed this to be the correct position for the scavenge pump motor windings circuit breaker. A wiring diagram showed that the attaching wires should be in bundle W006 and marked Q070, -071, and -072. The wires found attached to the circuit breaker were labeled:

Terminal Color (Marked as):		Terminal side 1:	Terminal side 2:
Red (A)	:	W6-Q70	W164-X767 and W164-X848
Yellow (B)	:	W6-Q71	W164-X770 and W164-X877
Blue (C)	:	W6-Q72	W164-X878 and W164-X775

A laboratory report is not yet complete for the examination of the scavenge pump motor windings circuit breaker assembly.

SCAVENGE PUMP SWITCH, CWT

The group noted that it was possible to move this type of switch from the (upward) ON to (downward) OFF position, but that the toggle had to be manually lifted against an internal spring to reach the ON position. The switch was received locked in the OFF position with a spring-loaded toggle and mechanical shoulder assembly that blocked movement toward ON. However, notes from a previous examination of the switch at Huntsville, Alabama, stated that the switch had been cycled. The ensuing examination was for any evidence of the switch position at the time of impact. [*6/24/97 Group Activity*]

It was noticed in subsequent examinations of switches in other airplanes that the switch toggle could move further toward the OFF direction than the edge of the mechanical shoulder. However, the damage seen to the mechanical shoulder in the switch from the accident airplane was with the toggle against the shoulder. A detailed report (WL/MLS 97-074) regarding the examinations of the scavenge pump and jettison/override switches was received from Wright Laboratory. No evidence was found by Wright Laboratory or the June 24, 1997, group that the switch had been in the ON position during the accident sequence.

SCAVENGE PUMP RELAY

The scavenge pump power relay (DR 296) was found attached to a fragment of the P52 power panel. The relay was removed for laboratory examination of the internal contacts. Markings on the relay identified it as a STRUTHERS-DUNN FCC-400-5, BOEING 10-60450-1, RELAY 4P.D.T 10 AMP. In blue ink on the cap was FT 9406. [*6/27/97 Group activity*]

In summary, none of the contacts were found melted, eroded, or excessively worn and nothing was found outside of normal wear for that age of relay. [*8/21/97 Group Activity*]

A detailed report (WL/MLS 97-078) regarding the examinations of the scavenge pump relay was received from Wright Laboratory. The report also documents that wire insulation had been “deeply penetrated” and damaged by a numbering method referred to as the “hot stamp marking process.”

VOLUMETRIC SHUTOFF UNIT (VSO) (28-21-06)

The VSO was found still mounted to its rack and in the debris of the E/E. The B-747 Maintenance Manual showed that the mounting would have been immediately forward of the

forward cargo compartment. The harness was found torn at the end of the shelf, but without punctures or burn marks in the area of the VSO mounting. The liner from the forward end of the forward cargo compartment was also examined and no evidence of fire (general or localized) or damage inconsistent with impact was found.

In summary, no evidence of electrical stress was found in the VSO, such as blackened components or electrical failures at the component levels. However, no damage was observed in a sample unit after laboratory tests subjected the unit to inputs from the LO-Z gauging compensator system of up to 500 VAC for more than 10 minutes. The circuit cards applicable to the CWT were the A2 card (Density Computer CARD), found isolated electrically from the CWT by the A3 card (Variable Resistor Card) and the A9 card (CWT Shut Off). The recovered A9 card showed no signs of electrical stress and operated within tolerance at room temperature after the replacement of 5 physically damaged components. Analysis by an independent lab showed that the replaced components that were removed from the A9 card showed no signs of electrical stress and that the only damage was physical trauma.

The Volumetric Shutoff (VSO) avionics unit was recovered from wreckage of N93119 and examined for evidence of an electrical event that may have affected the VSO from fuel quantity indication system (FQIS) wires, or evidence of a power input to FQIS wires from the VSO. No evidence of arcing was found in the unit. The circuit cards for the CWT shutoff (card A9) and fuel density computation (card A2) were found physically damaged. The A2 card had enough damage to prevent operational checks. The A9 card had five parts replaced and broken tracks bridged. The A9 card functioned within tolerance at room temperature. No short circuits were found in the primary or secondary circuits of the power supply card (card A4) that has transformers which supply power to the ground refueling panel (P42). The shutoff cards for the CWT and tank 3 had broken components replaced and were found to operate when placed in a serviceable unit. The discrepant parts are listed in the individual card descriptions. [*9/18/97 Group Activity*]

Testing was performed on a serviceable VSO to examine threshold levels of overvoltage that would damage internal circuitry. At 100 volts AC, no damage was found on the volumetric LO-Z circuitry for more than ten minutes. At 500 VAC for more than 10 minutes to an input from the LO-Z gaging compensator system, no damage was observed. [*9/18/97 Group Activity*]

Relay turn-off transients were applied to the gaging LO-Z inputs (1,000 volt), volumetric LO-Z outputs (1,000 volt), and volumetric HI-Z inputs (5 and 10 amperes). Ten sequences of ten pulses were applied in ten seconds. No degradation was found for the LO-Z testing, but at transients of between 5-10 amperes on the volumetric HI-Z, the performance of the circuit degraded to shut off at a 10% higher weight of fuel than serviceable cards that were tested. [*9/18/97 Group Activity*]

An avionics unit, known as the Volumetric Shutoff (VSO), was removed from the wreckage at Calverton, New York, for laboratory examination. The VSO was found crushed and had previously been recovered from the ocean. The data plate contained the following markings: [*9/18/97 Group Activity*]

SPEC NO.	:	60B92016-1
MFR PART NO.	:	RG1006AA01
SERIAL NO.	:	Z-17
[Unlabeled area]	:	SHUT-OFF ASSEMBLY VOLUMETRIC
TWA PART NO.	:	26001
SERIAL NO.	:	Z-17

The TWA group member confirmed that the VSO unit is powered during flight from the #1 main AC electrical bus. Part of the electrical fuse was found in the fuse holder and was examined under a variable power microscope. The metal fuse cap was found marked only with "250 VOLT." The fuse wire had residue accumulations that matched dried seawater material seen throughout the unit. The end of the fuse wire was necked and drawn in appearance, without molten look to the end or a ball shape. Next to the fuse holder on the unit face plate was the marking "AGC ½ AMP". [*9/18/97 Group Activity*]

The electrical bundle to the VSO was cut from the airplane and was still attached to the VSO unit. The bottom of the unit was opened to expose the internal wiring and no discoloration was found inside or along the external W066-Q-622 wire (LO-Z). Resistance through the connector was found to be .1 ohms, with no continuity to the case/chassis. No shorting was found between the compensator LO-Z wire and any other wire in the unit. The internal wire (depending upon application) was found by Honeywell specifications to be Polytetraflouroetylene (Teflon) (PTFE) insulated and was found to be: [*9/18/97 Group Activity*]

Honeywell call-out 6057 is MIL-W-16878/4C (chassis wire)
Honeywell call-out 7051G MIL-W-16878/5C (coaxial wire)

ENGINE FUEL FEED SYSTEM (28-22-00)

FUEL PUMP EXAMINATIONS

At least a portion of every fuel pump except the scavenge pump was recovered and identified. Although some wing fuel pumps were not examined, the housings and ink markings were of a uniform color when compared with pumps that were disassembled. No evidence of an overheated motor was found in the pumps or of an internal fire. Descriptions of the APU pump housing and of the jettison/override pumps are contained in those sections of this report.

#2 Tank Aft Boost Pump [*8/25/96 Group Activity*]
P/N 60B92404-1
S/N 03711628, S/N 06795309A(M/I)

A six inch piece of the inlet tube was attached and bent. The inlet check valve was bent and the o-ring was extruded. There was a hole in the volute. The discharge check valve was

attached but the flange was cracked. The electrical connector flange was bent outward and the o-ring was exposed. Continuity checks revealed about 4 ohms between pins 1, 2, 3[, showing continuity of the windings and thermal fuses].

#2 Tank Forward Boost Pump [*8/25/96 Group Activity*]
P/N 60-75502
S/N 02711555

The inlet check valve was broken and the o-ring was extruded. The volute discharge flange was broken and the pump housing was dented. The vapor discharge valve and housing were missing. The electrical connector flange was bent outward. Continuity checks revealed about 2.9 ohms between pins 1, 2, 3[, showing continuity of the windings and thermal fuses].
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#4 Main Tank Forward Boost Pump [*8/25/96 Group Activity*]
P/N 60B92404-2
S/N 03711604

The connector mounting flange was broken away and the pump housing mounting flange was bent and broken. The inlet was bent and the o-ring was extruded. The pressure sensing line was bent and damaged. The pressure sensing tube was broken off but the bonding strap remained attached. The inlet check valve was damaged and pushed in toward the pump. The impeller was also damaged and bent toward pump. The vapor discharge check valve flapper was broken and found inside the outer housing. Continuity checks revealed about 4 ohms between pins 1, 2, 3, indicating continuity of the windings and thermal fuses.

#4 Main Tank Aft Boost Pump [*8/25/96 Group Activity*]
P/N 60B92404-2
S/N 03711606

The housing flange was broken and the removal handle was missing. The vapor discharge tube was broken and the main discharge check valve was missing. The inlet check valve was damaged and pushed in toward the pump. The impeller was also damaged and bent toward pump. The vapor discharge check valve flapper was broken and found inside the outer housing. Black deposits were seen on the impeller and inlet adapter, with patterns indicating this occurred after the impeller fractured. The connector flange showed no evidence of corrosion. Continuity checks revealed about 4.3 ohms between pins 1, 2, 3[, showing continuity of the windings and thermal fuses].

FUEL PUMP CONDUIT

Fuel pump wiring in the outboard ends of the inboard main fuel tanks (#2 and #3) is encased in aluminum conduits. Airworthiness directive 79-06-02, referencing Boeing Service Bulletin 747-28-A2092, described a method to alleviate wire chafing by installing a double layer of teflon

sleeves over the wiring. Of the recovered conduit containing wiring that was identified, all but four pieces were from the wheel well areas. All four fuel tank-type pieces of conduit were heavily deformed, twisted, or with other impact-type damage. Of the four short pieces that were recovered of the type that were from the fuel tanks, all had the double teflon sleeves and none exhibited sooting or heat damage. The only teflon sleeved section that could be identified as to origin had come from the left wing. Each piece was examined for the condition of the teflon and wiring. Only minor surface chafing was found in the outer teflon layer. [*10/26/96 Group Activity*] Further fragments of the conduit were found after the preceding text in this paragraph was written and examinations resulted in similar findings.

To investigate an FAA theory and to check on the longevity of the 1979 AD action, Boeing issued SB 747-28-2204, entitled Fuel - Distribution - Engine Fuel Feed System Outboard Main Tank Boost Pump Wiring Inspection, dated December 19, 1996. The SB was made mandatory by AD 96-26-01, dated January 21, 1997. The SB and AD called for a one time inspection of the wiring and wiring conduits to certain B-747 boost pumps. As a result of the inspection, Boeing wrote a proprietary summary of inspection results for the Safety Board on June 19, 1997, listing a minority of airplanes inspected that had some damage to the wiring and some with minor chafes or damaged wire/contacts near the connector, but not in the conduit. There were no reports of chafe damage through both sleeves and on the wire insulation.

ENGINE FUEL FEED LINES, FITTINGS, AND O-RINGS (ATA 28-22-07)

O-rings were removed from Wiggins (flexible) fuel line couplings found from N93119. The smallest piece (in cross-section) removed was from the mounting plate of a fuel pump and was hardened when found. Boeing Part Standard cites MS29513 as the type of o-ring in the Wiggins couplings. The o-ring types are called out by the installation drawings, according to the expected fluid exposure (per BACC42R). All but the fuel pump mounting plate use the o-rings in a bore seal type of application, that is, with the contact point of the mating part at the inner-most point of the periphery. The Boeing BACC42R specification states that the maximum working pressure for the o-rings is 125 psi and that the maximum temperature is 200F.

The Boeing specification states that "THIS COUPLING ASSEMBLY PERMITS UP TO 4^{o} MISALIGNMENT FROM TUBE CENTERLINE, UP TO .2500 INCH AXIAL MOVEMENT AND UP TO .0625 INCH OFFSET BETWEEN TUBE ENDS." The fuel pump packing would have been a face seal.

[In the wreckage of N93119,] A Wheatstone Bridge was used to find the electrical resistance between various sections of fuel tubing and the attached Wiggins semi-flexible style couplings. About a third of the tests found fractions of an ohm, but another third found 4.5 to 9.9 megohms, even though all components, including those with high resistance, had visible saltwater and corrosion deposits between the tubes, ferrules, and the Wiggins clamps. Tests of similar corrosion-like materials found on fiberglass and on a wheel brake found extreme variability of the saltwater and corrosion deposit. As an example of the widely ranging results found, multiple

tests of one deposit found 113,900 ohms at one point, then 1.5 megohms in a second test. Coupling descriptions contained in Boeing Specification BACC42R, stated that the metal components were made of 2014-T6 or 2024-T6 (or -T851), and the finish for the clamp components was anodize, per MIL-A-8625, although the ferrules additionally specify TYPE II, Class 1 or 2. [*10/26/96 Group Activity*]

[In the reconstructed structure of the accident airplane,] Fuel tubing was installed in the CWT, as were vent tubes from near the root of each inboard main fuel tank. An attempt was made to find locations for previously unidentified but sooted fuel tube fragments within the CWT by matching corresponding damage, but no CWT matches were found. [*6/27/97 Group activity*]

[Within the retired N93105] CWT aft-most bay on the left, the cross-feed manifold "Y" tube and the jettison "T" tube were missing and the hardware was in cloth bags that hung by strings. Of the five o-rings found on the remaining tubes that would have connected to the missing pieces, one had numerous very small surface cracks when slightly stretched. The APU and scavenge pump tubing was held in place with teflon-cushioned hat-section clamps, but the metal was attached to structure by the mounting bolts. All other tubing was found connected by straps to structure, no paint overspray was seen on tubing or FQIS components, and a light coating of gray-colored residue was found beneath the crimped connectors on the fuel probe. The residue wiped off when touched. [*5/20/97 Group Activity*]

All tubing was found intact with the [retired N93105] CWT aft-most bay on the right, otherwise, no paint overspray was seen, and and all tubing was visually found grounded to structure. An ungrounded black Adel clamp was found on the cross-feed manifold, attached to the pump wetting line 1.5 inches from the but-line zero rib.

APU FUEL PUMP (28-25-01)

APU Pump (portion) [*8/25/96 Group Activity*]
P/N RG24660A
Boeing P/N 60B92403-6

Only the end cap was recovered. The inlet and outlet were broken off.

APU FUEL LINE AND SHROUD (28-25-04)

The APU fuel line and shroud from the upper center area of the aft wing spar was found, but not attached to the reconstruction due to the delicacy of "broom-straw" characteristics of the remaining mating surface. The separated line and shroud did not have similar "broom-straw" characteristics, but did have an extensive fiberglass repair. No evidence of leaking around the repair was found. The repair was a field procedure for the shroud line that had been approved by TWA Engineering. This repair was found in the B-747 Maintenance Manual (20-11-29 TWA, Page 801), released 8/24/89, revising a 12/25/87 procedure. [*10/26/96 Group Activity*]

Portions of the APU fuel line and shroud were found and placed into the reconstructed fuselage. The fitting which projected from the aft spar was found heavily damaged by fire. The section of shroud from immediately aft of the burned fitting was free of internal soot or fire damage, although the exterior was darkened by soot or wheel well grime. [*6/27/97 Group activity*]

JETTISON/OVERRIDE FUEL PUMPS (28-31-01)

Two of the three CWT fuel pumps were of the jettison/override type, both of which were found and examined. The left pump was found to have two pieces of a silicone foreign material inside. The right pump had evidence of rubbing between the impeller and the adapter in a uniform fashion. The thermal fuses and flame-arrestor tubes were found intact, the shafts were not found to have heat-type discoloration, and the internal wiring was not darkened as seen in a pump that was intentionally overheated. [*10/26/96 Group Activity*]

No evidence of arcing or of a pre-accident anomaly was found in the motor section of either fuel pump. The coatings on the motor windings was the same tan color as pumps from the wing fuel tanks. The windings contained thermal fuses that were found intact. A pump from a wing fuel tank was heated until the thermal fuse melted and the windings were found to have substantially darkened in color. Neither jettison/override pump had darkened motor windings that resembled the windings of the overheated pump. The jettison/override pump control switches were found in the off positions.

Diagrams from the fuel pump manufacturer showed that each fuel pump had a three phase alternating current motor, cooled by fuel drawn through narrow passages that had been sized to prevent flame passage. The rear of each motor was located aft of the rear wing spar, in the wheel well and that was where the electrical connectors were located. Each type of pump had passed qualification tests that ignited flammable vapors in the motor housing to show that the flammable vapors at the impeller (fuel tank) side of the pump would not ignite. The pumps contained a thermal fuse that had been designed to melt at less than 400^{o}F and the design had passed hours of qualification tests, operating without cooling fuel. The end of each test came when the thermal fuse melted.

A low pressure switch is mounted on the pump and designed to illuminate an amber light on the flight engineer panel when the pump switch was ON but low pressure is being developed. The amber lights were within inches of the switches and gages for the fuel tanks that would have been used for the post-takeoff cross-feed operation described in the TWA Operations Handbook.

Jettison pump electrical connectors had previously been found to degrade, and one resulted in a left wing landing gear wheel well fire in a Japan Airlines B-747. The result was that Boeing issued message M7240-95-1131 on August 2, 1995, and a correction in Alert Service Bulletin (S/B) 747-28A2194 that was sent to operators by telex on August 17, 1995. The S/B called for periodic inspections of the wiring and electrical connector. The service bulletin inspections were made mandatory by airworthiness directive (AD) 97-03-17 was issued by the FAA on August 14, 1996.

The Maintenance Records Group reported that AD 97-03-17 had been complied with in the accident airplane. The wheel well also had been equipped with heat detectors. Soot and fire patterns were not found to emanate from the rear wing spar at the fuel pump mounting hole.

The narrow cooling passages of the pumps from the accident airplane were examined and were not found blued or to have melted/burned material at the ends.

Operators reported leakage of fuel boost pumps through an electrical connector that was similar to the connector installed in the jettison/override pump. Crane Hydro-Air Division, manufacturers of the pumps, issued a July 22, 1996, Service Information Letter, and stated that the cause was "insulation breakdown of the pump connector wire terminal assembly occurring over a number of years of service, caused arcing between the power pins and the pump case." Between the fuel tank and the wheel well were the electrical connector, the motor cavity, and the narrow cooling tubes; none of which were reported to have been breached.

Reports were received regarding fuel pumps used on military aircraft which have had the housings breached due to electrical short circuits which led to ignition of fuel vapors and had localized areas of overheating at failed bearings. The jettison/override pumps from TWA N93119 were impact damaged, especially at the spar and wheel well ends, but exhibited no evidence of electrical shorts, breaching of the housing or discoloration of the shaft under the bearings indicating overheating.

Evidence of rubbing at the impeller edges and adjacent housing surfaces were found in the right jettison/override fuel pump. Overhaul records from the manufacturer described similar damage and attributed it to worn shaft bearings. Similar, but extensively deeper, galling damage had been found in fuel pumps from a Philippine Airlines B-737 that had a CWT explosion on May 11, 1990. The Safety Board had conducted two weeks of tests to learn whether galling between aluminum surfaces within the Philippine pumps could have ignited flammable vapors. The results of the testing found that the group could not ignite flammable vapors from rubbing of the impeller or by similar types of contact.

#2 Tank Outboard Jettison Pump [*8/25/96 Group Activity*]
P/N 60-70305
S/N 03712074

The inlet tube was missing and the check valve was up. The discharge valve was displaced and the mounting flange was broken off. There was a cut in the primer reservoir. A yellow insulation-like material was stuck to the motor end cap. The pressure switch port was broken. Continuity checks revealed about 1.4 ohms R to G [indicating continuity through the windings and thermal fuses. (Black wire missing).

Center Tank Left Override Jettison Pump [*8/25/96 Group Activity*]
P/N 60-70305
SIN 02712007

The end cap was broken off and the stator windings were exposed and crushed. The end of the rotor shaft was missing. The outer housing had two holes and the flange was missing. The inlet pipe check valve was in the up position and the inlet pipe was missing. The jettison transfer butterfly valve was partly open.

Teardown Notes

When the case was removed, two pieces of a clear, soft, rubber-like, translucent foreign material was found. They were located on the OD of the motor/impeller housing circumferential groove at the inlet side of the priming impeller. Infrared examination by NASA determined that the material was a silicone substance. No members of the team had ever seen this type of debris inside a pump.

When cut open, the general condition was clean - there was no evidence of fire damage, arcing or heat exposure. The impeller and adapter showed only a small amount of slight contact. The bearings looked normal. There was no thermal discoloring evident on the stator windings. The priming impeller discharge plate was lightly scored and the inlet plate was clean.

Center Tank Right Override Jettison Pump [*8/25/96 Group Activity*]
PIN 60-70305 (Hsg), 60-703104 (M/I)
SIN 2712017 (Hsg), 10690394

The inlet section of the housing was broken off and the housing mounting flange was broken off. The bottom of the volute was missing. The discharge check valve and tube was missing. There was a hole in the reprime cavity. There were areas of discoloring visible on the primer discharge check valve, volute discharge outlet, and a portion of the motor housing. The primer discharge check valve seal was missing and the inside of the valve was clean. (Swab samples were taken in these areas for possible further analysis.) The o-ring at the impeller outlet was extruded. The pressure switch was broken and wires were exposed. Some orange corrosion was visible on the electrical connector flange and the flange was bowed outward, exposing a portion of the o-ring and the connector was bent.

Teardown Notes

A CAT scan was performed. There was electrical continuity between all three stator phases, indicating that the thermal fuses (internal type) had not melted. Resistance readings were as follows: R/G .9lohms, G/B .9lohms, B/R .92 ohms. Insulation resistance checks at 9 volts DC showed: G to case .53 Mohms, B to case .54 Mohms, R to case .54 Mohms. When cut open, the general condition was clean - there was no evidence of fire damage, arcing or heat exposure, and there was no discoloration of the stator windings. There was evidence of rubbing between the impeller and the adapter in a uniform fashion - both pieces have been submitted to NASA for SEM microscopic examination. The connector potting was in good condition with one spot of corrosion on the connector. The flame arrestor inside the shaft was intact. The journal bearing near the impeller, which serves to align the shaft, was shiny on its OD with evidence of wear on about half the circumference.

The end cap bearing appeared normal. Aft of the rotor, the shaft journal appeared to have a blackish discoloring that would have required resurfacing. There was also evidence of darkening inside the end cap shaft cavity. The rotor had significant rust. The priming impeller appeared in good condition.

Additional electrical checks on the stator windings were: G/B 1.04 ohms, G/R 1.07 ohms, R/B .97 ohms. Megger checks at 9 volts DC were R to case .67 Mohms, B to case .67 Mohms, G to case .67 Mohms. Megger checks on the connector assembly at 500 VDC were: G to case 5 Mohms, B to case 400 Mohms, R to case 10 Mohms.

The end cap journal had circumferential scratches (scoring) all around in a uniform fashion over the bearing contact area. The impeller end journal was bright and shiny with minimal sign of contact.

The impeller end bearing bore was bright and shiny and appeared normal. The OD locating diameter was bright and shiny with a burnished area approximately 1/2 way around, which Boeing noted was not unusual. The spherical crown was flattened in this area, with very shallow circumferential indentations. The end cap bearing OD showed no wear and the anodize was intact. The bore was slightly roughened and appeared to be worn.

A microscopic examination (8X) of the feedthrough connector showed a shallow crack in potting in an axial direction from the connector rim to the top. A gap between the leadwires and the potting was visible when the wire was moved, indicating that the adhesion was not secure. Some corrosion was apparent around the rim of the connector, but no separation was visible.

#3 Main Tank Inboard Jettison Pump [*8/25/96 Group Activity*]
P/N 60B92603-51 60-70305 (Hsg), 60-703104 (M/I)
S/N 10690334 (Hsg), 02712059 (M/I)

The handle and the housing flange were broken. There were holes in the motor impeller housing and the outer housing. The lead wires were torn away.

Teardown Notes

There was heavy salt water corrosion on the bearing side of the reprime inlet. There was minimal evidence of rubbing between the impeller and the adapter. The impeller blade tips had little wear, the grey coating was intact in most areas. The thermal fuses (external type) on the stators appeared intact. the potting on the back of the electrical connector was intact and had no corrosion. The shaft looked clean and shiny. There was no evidence of discoloration on the stator windings.

There was electrical continuity between all three stator phases, indication that the thermal fuses had not melted. There was no evidence of thermal distress on the bearings, shaft, or journal. The o-ring under the electrical connector appeared larger than its seat. Megger testing

of the wire assembly only at 500 VDC revealed B to case 10 Mohms, R to case 5Mohms, G to case 10 Mohms.

A microscopic examination (8X) of the feedthrough connector revealed that the potting appeared sound, with no cracks or voids except small bubbles. There was corrosion around the rim of the connector that may have begun to penetrate, but the was no sign of separation. The potting was not well bonded to the leadwire at the top end.

A meltdown test was performed on the thermal fuses by placing the stator assembly in the oven. Two opened at 368 degrees F and the third melted at 378 degrees F. This is within the specified range. Discoloration was evident on the stator windings and retainers after this temperature exposure.

FUEL PUMP SWITCHES

A detailed report (WL/MLS 97-074) was written by Wright Laboratory to document the examination of the CWT left and right jettison/override fuel pump switches, in addition to the scavenge pump switch that has been previously discussed. The summary states that "…all three switches were received in the "off" position. The worst external damage, a bent knob, occurred on the left jettison pump switch. … No discernible witness marks were found on any of the switches to indicate switch position during the initial stages of the mishap. …" The final remark was that "There was no evidence to support any forced movement to the "off" position by impact or some other means from the mishap breakup energy.

FUEL QUANTITY INDICATION SYSTEM (FQIS), DESCRIPTION (ATA 28-41-00)

A functional description of how the FQIS system operates was provided by Honeywell and a summary of the Honeywell description, the Boeing 747 Maintenance Manual, and the TWA Wiring Diagrams follow.

The B-747 FQIS measures fuel quantity for display on cockpit gages and for ground refueling with a series of capacitance measurement fuel probes that measure the level of fuel at various locations in the tanks. Each fuel probe consists of an inner tubular element that is surrounded by an outer tube. A compensator, located near the low point of each fuel tank, also is constructed of an assembly of tubular elements. The compensator and each probe have a terminal block near the top for wiring connections. Wires from each fuel probe and the compensator are routed within the fuel tank through numerous nylon clips to a connector located at the rear wing spar for the CWT and at the forward spar for the main (wing) fuel tanks. At each electrical connection within the fuel tank, such as at the terminal block connectors, the silver-plated copper wiring is exposed to fuel and vapor. Outside of the fuel tanks, FQIS wires are routed from the wing spar electrical connectors to cockpit instruments, to the wing refueling panel, and from the cockpit to

the volumetric shut-off unit located on the E3 shelf in the E/E compartment and to the airborne data acquisition system (AIDS) unit, also located in the E/E.

FQIS WING SPAR ELECTRICAL CONNECTORS

Four wing spar FQIS connectors were removed from the wing spars of N93119 and inspected for evidence of electrical damage by NASA's Marshall Space Flight Center (MSFC) at Huntsville, Alabama. The October 15, 1996, summary of the MSFC report states:

> No internal or external indications of a high voltage/electrical event were found during examination of the four connectors. Thermal damage found on two connectors, consisting of charred wiring harness and wire insulation, was consistent with damage caused by an external heat source; it was not indicative of an electrical malfunction. No potential igntion sources were found.

All four connectors were photographed, examined radiographically, A large void was found perpendicular to the connectors in the potting material of the CWT spar block.

In the CWT connector, electrical examination found greater than 100 megohm resistance between all pins and sockets, as well as between the pins and case.

While disassembling the volumetric shutoff unit at Honeywell, the investigation later found that the wire and connectors used in the FQIS system were rated for higher voltage than available from the design of any airplane systems.

FQIS FUEL PROBE TERMINAL BLOCK DESIGN CHANGE

Honeywell Engineering Change Orders (ECO) were examined for the history of the FG420A tank units used in the B-747 series airplanes. An ECO (69 15826), dated December 9, 1969, was found to change the terminal block design from what had been used in Series 1-3 to Series 4 (and subsequent). The stated reason for ~~change~~ the change was "Revised terminal block incorporating threaded stud type terminals." The ECO also stated "Effectivity as soon as new terminal blocks are available." The Component Maintenance Manual (CMM, 28-40-12, Page 103, Figure 101, effective June 1/75) showed that both terminal blocks were still active parts for continued use. [*9/18/97 Group Activity*]

The Series 1-3 terminal blocks and the associated metal strain relief clamps remain in service. The Honeywell Overhaul Manual continues to identify the Series 1-3 terminal blocks and metal strain relief clamps as effective for use and Honeywell reportedly continues to supply replacement parts. The metal clamps are also considered to be effective as replacement parts, according to TWA maintenance documents. The Honeywell Overhaul Manual shows that the

earlier terminal blocks can be replaced with a later style identified as Series 4 (or later) that had no knurling. Both terminal block design styles were found in the wreckage of N93119.

In a letter of October 24, 1997, Honeywell reported that "If a customer orders one of the old style terminal blocks for series 1-3 probes (Honeywell P/N 10022188-101) we will recommend that they update the probe to a series 4 or above and will ship the new style terminal block (Honeywell P/N 10032447-101). If they order a replacement leadwire clamp for a series 1-3 probe (Honeywell P/N 10022188-101) we will provide the replacement clamp.

In a letter of October 27, 1997, Boeing requested that the following text be added: "Honeywell has stated that the series 3 or earlier terminal blocks were not used after mid 1970. A production change was made at Boeing that installed the Series 4 probes in line number 65 and on. N93119 was line number 153 and was delivered 10/27/71, so it is improbable that it was delivered with Series 3 terminal block probes."

N93119 FUEL PROBES AND COMPENSATOR EXAMS (28-41-01 & -02)

Boeing and Honeywell design documents for the fuel quantity indication system (FQIS) show that each fuel tank is equipped with varying numbers of fuel tank units (T.U.). The TU are better known as fuel probes, fragments of which were recovered, given item numbers to differentiate between them, and examined during different meetings.

The outer and inner electrodes of the recovered fuel probe fragments were electrically shorted and no capacitance or insulation resistance measurements were made. No evidence of arcing was seen on any probe. Large blackened areas were found on internal electrodes, typically where the protective urethane coating had lost integrity. Honeywell reported that this was a common observation which had no effect on the function of the fuel probes. Plastic shrink wrap, the plastic of crimped connectors, and wire insulation were found to have blackening, similar to that later identified at Wright Laboratory as copper-sulfide.

Components of the recovered fuel quantity indication system (FQIS), including fuel probe sections, were brought to an airport located at Calverton, New York for examination and documentation. Twenty two probe fragments had previously been examined by a Systems Sub-Group at Marshall Space Flight Center in Huntsville, Alabama [*on August 25, 1996*]; five were examined by a group at the NTSB Materials Laboratory in Washington, DC. [*10/16/96 Group Activity*]

Twenty-four fragments of fuel probes were visually examined and documented by group consensus, noting external features that included general condition, traceability identification of where in the ocean the pieces were recovered from, length, identifying features, existence of soot or other potential fire damage. The probe fragments were then cut open with a dremel tool and carbide cut-off wheel so that the internal features could be documented. A binocular microscope with fiber-optic illumination was available to examine probes found to be from the center wing tank or tank 4R for evidence of arcing or other anomalies. [*10/16/96 Group Activity*]

The description of the process that was described in the previous paragraph was typical of the process of examining the fuel probes. Identification of the fuel probes came from several methods. At the top of the outer and bottom of the inner electrodes were the manufacturer's identification numbers that were used to identify numerous fragments, such as the "-134" for item #1. Other fragments had to be examined for the diameters and lengths of internal electrode features and for colored spacers. The features and coloring of the spacers provide a unique identification for the different probes and by reference to engineering data from Honeywell, the group was able to establish identification for fragments that had no markings.

The following information has been summarized in the first lines, with the ensuing text from the group performing the examination. When the group was able to determine that fragments positively matched or came from different probes of the same part number, that information has been included from a separate section of notes that were taken during the examinations.

Item	Length (in.)	FBI ID	Mfg Identification	Tank

1 14.5 FG420-A41 #1 or #4

V shaped probe with terminal block attached to aircraft structure. Red (LO-Z) wire found with LOZ F10/F62 of 14 inch length used to further identify the probe. This is the top of a probe and is same source probe as item #13. At the top of this and numerous other fuel probe external electrodes is a marking, in this case a "-134," establishing identification.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

2 15.75 FG420-A8 #1R

Complete unit with terminal block. A small dent exists below the terminal block. Identified as a "-106.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

3 FG420-A36 #1 or #4

"L" shaped with only the terminal block studs remaining on the electrodes. Identified as a "129."
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

4 5.5 FG420-A39 #1 or #4

Identified as a "-132." Top of probe is different source probe than for item #6.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

5 FG420-A34 #1 or #4

Somewhat "S" shaped with a partial terminal block remaining. Identified as a "-127." Different probe than item #51, described below.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

6 9.5 FG420-A39 #1 or #4

Top of probe with no terminal block or wires attached. Identified as a"147." This is different source probe than for item #4.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

7 21 FG420-A38 #1 or #4

This fragment is 21 inches of outer electrode with about 6 inches of inner electrode exposed. One stud attached with 2 white and 2 black wires coming from it. Identified as a "-131" probe top section. Different source probe than for item #14, below.

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

8 35.25 FG420-A28 #2 or #3

Possible traces of soot on surface. About 32.25 inches long from the bottom of a probe, with 13 inches of inner tube exposed on one end and 7 inches of inner electrode exposed at opposite end. No terminal block or wires remaining. On inner tube was a slight trace of sooting. Exterior edges look somewhat fragmented in places. Bottom of item #17. Identified as a "145."

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

9 17 FG420-A31 #1 or #4

"L" shaped fragment with the terminal block installed. Four terminals with 5 wires attached. The overall length is 17 inches with some crush damage. Identified as a "-124."

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

10 FG420-A35 #1 or #4

"Z" shaped with no remaining terminal block or studs. The length of the electrodes appear to be complete and the probe was identified as a "-128."

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

11 31 FG420-A26 #2 or #3

Possible traces of soot on surface of center tube in more than one place. Bent in 2 places, the overall length is about 31 inches. No terminal block or end caps remain. Identified as a "-119" probe.

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

12 38 FG420-A24 #2 or #3

Possible traces of soot on surface of inner tube in 2 places. About 38 inches long without a terminal block or end caps. Identified as a"-117."

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

13 9 FG420-A41 #1 or #4

About 9 inches long with only one plastic end cap installed. This is the bottom of a probe and is same source probe as item #1.

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

14 17 FG420-A38 #1 or #4

Top section of probe that is "W" shaped and about 17 inches in overall length with both plastic end caps installed. The terminal block has light sooting. Wire W1180-G151. Different source probe than for item #7.

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

15 17 FG420-A33 #1 or #4

"J" shaped of about 17 inch total length with both plastic end caps installed. Different probe than item #42.

[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

16 26 FG420-A18 #2 or #3
Extensively sooted on inner tube and the soot is about 3 to 4 inches long. "V" shaped of 26 inch length with 3 plastic rings on terminal block missing. Identified as a "-111." Different probe than item #46.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

17 22 FG420-A28 #2 or #3
About 22 inches long with one end bent about 30 degrees. A wire designator was received in an attached bag. Wire W1178-Q148. The probe is the top of item #8.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

18 28 FG420-A24 #2 or #3
Possible traces of soot on surface. Blackening on inner tube does not appear to be soot. Outer tube interior appears to be clean. Includes on plastic end cap and the terminal block. Marked with Boeing P/N 60B92010-24. Identified as a "117." Wire W1178-Q146. Different probe than #12, above.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

19 33 FG420-A20 #2 or #3
Possible traces of soot on surface and blackening similar to item #18. "U" shaped and about 33 inches long with one stud remaining and both plastic end caps. Identified as a "-113." This is a different probe than item #33.
[Combined information from 8/25/96 and 10/16/96 Group Activity notes with minor editing for legibility.]

20 FG420-A21 #2 or #3
Possible traces of soot on surface of inner tube in a small area. Identified as a "-114."
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

21 15 FG420-A27 #2 or #3
Some slight discoloration next to terminal block. Complete length with minimal damage. Identified as a "-120."
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

22 Comp. FG6C
No identifying features or attached wires to determine original location.
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

23 Comp. FG6C Rt. Surge
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

24 Comp. FG6C
Fragment of a compensator.
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

25 FG-420-A8 #4R
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

26 19.25 FG420-A37 #1 or #4
Different source probe than item #47, described below.
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

27 FG420-A13 CWT
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

28 20 9-23-96-5 RK FG420-A22 #2 or #3
Different probe than item 40, described below. Bottom section with heavy crushing below the lower probe mount and irregular overall crushing. Two loose blue spacers removed at receipt. Above R&D spacers. No evidence of sooting on exterior. Interior tube visible with flaking urethane coating. Outer tubing cut away. Two red spacers at bottom still in place. Identification came from inner electrode scribe number [appears to be written in original notes as] "15" on bottom end. Discoloration, urethane coating 60% missing. In area of urethane a water stain appears near bottom of tube. At step down to smaller diameter (neck down between red & blue spacers) is dark stain similar to that seen under urethane coating at NTSB laboratory. Dark stain follows edge of tear in urethane. Manufacturing and Functional Test dates missing. [*Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.*]

29 24 9-19-96-1 DJ/LA FG420-A17 #2 or #3
Dash number -110 on outer electrode equates to FG420-A17 from #2 or #3 main tank. Wire FS1178-Q141 is from shield. The 24 inch long outer electrode is in relatively good condition and terminal block is in good condition. There is a 90^{o} bend in bottom 2 inches. There is no sooting on exterior. Green spacer visible in small inspection hole opposite terminal block. No arcing evidence. Manufacturing Date (MFD) AUG 1970, Functional Test Date (FT) OCT 1970.
[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]

30 14.5 9-22-96-1 DEL FG420-A27 #2 or #3
Dash number -120 outer electrode identifies this as a FG420-A27 from #2 or #3 main tank. 14.5 inch length includes one end cap and partial mounting bracket. The Teflon spacer from the terminal block is in place. No arcing evidence. MFD not seen. FT JAN 1971. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

31 18 9-23-96-5 RWK FG420-A30 #1 or #4
Dash number -123 from outer electrode identifies this as a FG420-A30. One end cap at bottom end in place. Wire identified as LO-Z F15/F67. Terminal block intact. Some crush evident in bottom 8 inches of outer electrode. No sooting evidence on exterior. MFD JULY 1970. FT JUL 1970. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

On September 29, 1997, Wright Laboratory personnel reported that while inspecting the wire remaining attached to the #31 fragment terminal block, both shield pigtail wires were found attached to the crimp-on ring connector. The ring connector was still firmly attached to the screw terminal on the terminal block. The other end of both pigtails had been separated from the HI-Z shields at the solder joints. One of the pigtails had a bare wire end impregnated with the solder from the joint with the shield braid. This has been in other fragments at the point of separation when the HI-Z wire(s) were missing. The other wire end was carefully wrapped in what appeared to be a piece of Mylar or Teflon film tied in place with cotton braid cable-tie material. After one

of the two tie wraps was cut, inside of the wrap was what appeared to be sand and salt residues. There were also black stains resembling the copper-sulfur fuel residue previously identified (see item 75), present on both the cotton braid material, and inside the Mylar.

Further examination found the wrapping to contain a repair to where the shield pigtail had separated at the solder joint with the shield braid, or that it had broken near that solder joint to the HI-Z shielding at the solder connection. A crimp-on butt connector was found on the end of the black pigtail wire and it appeared that some of the shielding braid was inserted into the other end. From the X-ray inspection and optical microscopy, it appeared that a length of shield braid was "gathered" from around the HI-Z center conductor and twisted into a structure resembling a stranded lead wire. In X-ray refraction, the wire appeared to be silver plated copper and was similar to a sample of shielding braid submitted to the same X-ray refraction apparatus. The gauge of the strands appeared to be the same as shielding braid when observed under an inspection microscope. This lead was doubled over and inserted into the butt connector. The connector was then crimped. After both ends were crimped, the joint was found to have been wrapped with a Teflon-type of tape. An adhesive was present on one surface of the tape.

Boeing does not have an approved repair procedure as described for in-tank applications. This type of repair may (or may not) have caused a variance in quantity reading in the main tank 1 or main tank 4, depending on where it was installed in the series of connections. There was no evidence of arcing found.

When asked whether the repair was recognized by TWA, two pages were found in the ALL TWA AIRCRAFT ELECTRICAL & ELECTRONIC STANDARD PRACTICES manual (ATA 20-51-04, pages 205 and 206, Rev. 22, dated May 20/81). The pages described a shield splice and were entitled:

3. Installation - Single Conductor - Alternate Method No. 2

The repair was described as "An alternate method of splicing single conductor, single braid shielded cables as shown in Figure 206." The repair was not illustrated or described as a method to repair the connection between a broken shield and a second wire, but did show a connector attaching two shields in a repair. The illustration showed a method to attach two shielded wires by connecting the core conductors end to end. The types of splices called for by the standard practice were described as uninsulated, knife, or pre-insulated splices. The shielding was shown next (parallel) to the core conductor splice and also spliced end to end. The complete repair was shown covered by two layers of heat-shrink tubing and a note stated that "Tube shrinkage is not complete until material has pressed out of filled all voids and tubing ends close in firmly and completely around the conductor outer jacket for a moisture tight joint." However, a separate section stated that:

I. On the engines or other high temp areas use high temp splices. Insulate shielded lead splice with two layers of TFE #8 thermofit. The 3/8 SCL thermofit used over the bonding must be covered with Teflon Tape (TWA 41-2399). Tape must be tied at both ends.

Green tag #Z3278. Dash number 119 (FG420-A26 from #2 or #3 main tank is 24 inches long (of 55.9 inch total original length). This piece is from top of unit. No end caps. Partial terminal block. Partial crush near terminal block area. No sooting evidence. No arcing evidence on exterior. MFD DEC 1970. FT DEC 1970. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

33 29 9-21-96-1 FG420-A20 #2 or #3
Dash number 113. One end cap cut and moved to obtain identification number of FG420-A20 from #2 or #3 main tank. Bottom end is missing and top 29 inches remain. No sooting evident. Outer electrode has sticky gray/black residue on exterior. Some mechanical crushing. No arcing evidence on exterior. MFD JUNE 70. FT JUNE 70. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

34 40 9-23-96-5 DMW FG420-A23 #2 or #3
Green tag # Z3397. Dash number -116 identifies this as a FG420-A23 from #2 or #3 main tank. 40 inches long (of 47 inches overall) with bottom 7 inches missing. No sooting evidence. No arcing evidence on exterior of electrode. Terminal block intact. LO-Z connector missing. Some mechanical crushing near terminal block. Crush and bend 27 inches from top of electrode. No wire labels. MFD OCT 1970. FT NOV 1970. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

35 16 9-20-96-33 JMV/BW FG420-A36 #1 or #4
Dash number -129 identifies this as a FG420-A36 from the #1 or #4 main tank. 16 inches long (of 22.75 inch overall) with end cap and mounting cap missing. Terminal block is intact. Wire numbers LO-Z F12/F64 and W776-211. Some mechanical crushing. No sooting or arcing evidence on exterior electrode. MFD APR 1970. FT APR 1970. Source probe same as item #50. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

36 9-23-96-5 ON/NY Compensator #1
Green Tag Z2708. Terminal block intact. No sooting or arcing on exterior evident. Some mechanical crush. Attached to 65B01064-87 structure from #1 main tank. No MFD. FT JAN 1971. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

The compensator was re-examined by Lou Taylor and Robert Swaim on November 6, 1997. The terminal block had a smooth surface in the area of the nylon strain relief clamp and the wires were held to the terminal block by threaded nuts on studs, rather than by screws. The opening of the nylon strain relief clamp was a larger diameter than seen in other nylon strain relief clamps and the diameter was about 2 ½ times the thickness of the jacketed cable harness passing through it. The cable harness passed upward (to the installed compensator orientation) through the clamp and was wrapped around to go upward through the hole a second time. The opening was large enough that the doubled harness (and the black shield pig-tail wires) was not firmly held. The red LO-Z wire was found routed directly from the top side of the strain relief clamp to reverse direction downward, chafed against the strain relief clamp stud, then was folded again into an upward direction into the LO-Z eyelet (the eyelet was mounted below the LO-Z terminal stud). The terminal studs and nuts were rusty.

37 14.8 9-23-96-5 FG420-A29 #1 or #4
Dash number -122 identified this as an FG420-A29 from #1 or #4 main tank. One end cap was cut and moved to get identification number. Some mechanical crushing at mid point. Fragment is 14.8 inches long (of 14.8 inch original length), although terminal block is missing. No external sooting or arcing were found. No MFD. FT JAN 1971. Some puncture marks. Two red spacers visible in bracket holes. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

38 35 9-21-96-1 FG420-A28 #2 or #3
External dash number missing. No end cap. Bottom end cut for access to internal electrode identification number. The inner electrode number found was 45, identifying this as a FG420-A28 from #2 or #3 main tank. The 35 inch length remains of 58 inch overall. Tan spacers at the bottom intact. Sooting evidence at tan spacers on inner electrode. Some mechanical crushing evident. Blue & gray spacers intact when outer electrode was cut open, as were red spacers (in fragment 38B). No additional sooting evident on inner electrode. No MFD or FT. Green residue visible at various spots. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

39 21 9-20-96-33 DJ/LA FG420-A19 #2 or #3
Dash number -112 identified this as a FG420-A19 from the #2 or #3 main tanks. Top 21 inches of 29.25 inch overall length. Terminal block is missing. Sooting evidence on outer electrode. Mechanical crushing entire length. End cap missing. MFD shown as AUG 1970. FT AUG 1970 *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

40 36 9-20-96-33 DJ/LA FG420-A22 #2 or #3
Outer electrode area containing the dash number was missing. The terminal block and upper area of probe were missing. Bottom 36 inches (of 44 inch overall) cut open to access identification number “15” written on internal electrode, showing that the probe was a FG420-A22. The red bottom spacers were found intact. No sooting on the exterior and no black marks under the varnish were visible. No MFD or FT found. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

41 14 9-20-96-35 DJ/LA FG420-A32 #1 or #4
Dash number area on outer electrode missing, the terminal block is broken, and 14 inches (of 18.5) inch length remain. The end cap is missing. Wire marking F14/ 66 was found and has a 3/8 inch black spot was found external on wire identification sleeve. A red wire was found at the terminal block. No adjacent punctures/penetrations in area of black spot. Top of outer electrode is found torn and missing material. MFD JUN 1970. FT JUN 1970. Outer electrode cut open to obtain access to inner electrode and found dash number “25” to show that this is a FG420-A32 probe from the #1 or #4 main fuel tank. No sooting on external electrode or inner electrode. Spacers found intact and no evidence of arcing was seen. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

42 14 9-20-96-33 JMY/DW FG420-A33 #1 or #4
Lower and top ends of the probe are missing and no dash number was found on the external electrode. The outer electrode has 14 inches remaining and the inner electrode has 6 inches. Wires F18/F70 and W776-Q118 and W776-Q117 found. Outer electrode cut open to see

identification number on inner electode, but area with number was missing. White spacer found at the bottom of the inner electrode. No external sooting and no evidence of arcing inside or out. Different probe than item 15, above. MFD MAR 1971. FT MAR 1971. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

43 43 9-22-96-1 DEL FG420-A25 #2 or #3
Green tag Z3386. Outer electrode 39 inches long and inner electrode 43 inches long. The outer electrode was cut and dash number -118 was found, identifying this as a FG420-A25. No arcing or sooting found externally or internally. Some crushing found on outer electrode. Five sets of spacers, 4 red and 1 yellow. Matches with item 52, below. MFD MAY 1970. FT MAY 1970. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

44 17.4 10-13-96-3 TLL/EP FG420-A11 #1R or#4R
Green tag Z3678. Heavily sooted with top end cap partially melted. No terminal block. Dash number -109 identified this as a FG420-A11 from the #1 Reserve or #4 Reserve tanks. Outer electrode cut open and the inner electrode was found heavily sooted from the middle to the top end. MFD APR 1977. FT APR 1971. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

45 Comp. [None] Compensator
Compensator received in plastic bag with two pieces of terminal block (different terminal blocks) and wire LO-Z F11/ 63 in same bag, but not attached. No arcing or sooting found externally or internally. No MFD or FT dates found. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

46 11.5 9-24-96-16 JM FG420-A18 #2 or #3
Bottom end found crushed and no sooting or arcing evidence found on exterior. Fragment is 11.5 inches long and outer electrode was cut open for identification. An orange spacer was found, black marks under the urethane coating, a gray spacer follows the orange spacer. MFD and FT dates missing. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

47 11 9-21-96-1 FG420-A37 #1 or #4
Missing top and bottom ends, the bolt from the missing terminal block remains attached. FG420-A37 from #1 or #4 tank. No sooting or arcing evidence. MFD JAN 1971. FT JAN 1971. Different source probe than for item #26. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

48 8.5 9-24-96-16 PMO FG420-A ?
Inner electrode is missing and bottom of outer electrode to center of vertical slot measures 6.1 inches. Measured distance found to match FG420 with any of the following dash numbers: -A13, -A16, -A10, -A17, -A21, -A24, -A28, -A31, -A32, -A33, -A34, or -A37. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

49 16 9-22-96-1 DEL FG420-A12 CWT
The 16 inch long outer electrode and 14 inch inner electrode remain. The inner and outer electrodes are missing both top and bottom ends. Two gray spacers found inside. On inner surface a black soot mark exists on top of urethane coating. The colored spacers and inner electrode diameter changes were used to identify this as a FG420-A12, from either the F-39 or F-

40 CWT locations. The piece is from mid-section from 28.78 inches from top of probe to 43.3 inches from top of probe. No MFD or FT dates found. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

50 8 9-20-96-33 DJ/LA FG420-A36 #1 or #4
This is the bottom piece of outer electrode, 8 inches long, with heavy crushing. Distance from lower mounting hole to end is 6.75 inches, the end cap is missing. The outer electrode was cut open for access to the inner electrode identification number and the inner electrode was found to be 7 inches long with a white spacer. No MFD or FT dates found. Source probe same as for item #35. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

51 7.5 9-20-96-33 JMY/DW FG420-A34 #1 or #4
Top end piece of 7.5 inch inner electrode and 2.5 inch outer electrode. Partial white spacer fragment found. From end of electrode to horizontal mounting hole is 6 1/8 inches long. Dark residue stains more than half of the inner electrode. No arcing evidence seen on outer electrode. MFD JUN 1970. FT JUN 1970. Different probe than item 5, above. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

52 7 9-22-96-1 FG420-A25 #2 or #3
Bottom end piece of probe, with the inner and outer electrodes measuring 7 inches long. Identification number shows this to be a FG420-A25 from the #2 or #3 main fuel tanks. Has dark stain residue 3 inches from the bottom with a random pattern. Matches with #42, above. No MFD or FT dates found. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

53 20 9-22-96-1 FG420-A15 CWT
Inner electrode measures 20 inches long, starting about 2 inches above the mounting hole. The outer piece measures 4 inches by 1.75 inches and is from the area beneath the terminal block. The area around the terminal block footprint is heavily sooted and torn. The inner electrode is mechanically flattened and bent into an “S” shape and is sooted over an irregular pattern from one end to the other. Dimensional data on outer diameter, transition points of inner electrode features, mounting bolt positions, and spacer mounting holes show this to be an FG420-A15 from the CWT. No MFD or FT dates found. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

54 N/A 9-22-96-1 FG420-A20 #3
A loose terminal block found on a red LO-Z wire marked as F49, which is attached to a FG420-A20 probe in the #3 main tank. One end is broken off. No MFD or FT dates found. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

55 2.5 [None]
A 2.5 inch long fragment of a .4 inch diameter inner electrode with no identification marks. The manufactured end resembles the top or bottom ends of the inner electrodes. *[Typed from 10/16/96 Group Activity hand-written notes with minor editing for legibility.]*

56 27.5 11/23/96-58 JB FG420-A23 #3

Top and bottom ends of probe missing and the fragment is not quite straight. A terminal block with wiring is attached. Wire number 1178-Q147 found and identified by TWA as F47, FG420-A23, from the inboard #3 main fuel tank. *[414/97 Group Activity with minor editing to match previous format.]*

57 13 11/17/96-11 DRR FG420-A23 # 2 or #3
This is the top portion of a probe identified by TWA as F24 that is broken and bent about nine inches from the top, with a metal stamped "-116" and ink-stamped manufacturing/functional test dates of “MAR 1970." The "-116" identifies this as a FG 420A23, as used in the #2 or #3 tank. The group noted that the previous probe (#56) was already identified as the part used in the #3 tank and both parts had the terminal block (only one is used for each part). *[414/97 Group Activity with minor editing to match previous format.]*

58 5.5 11/17196-9 GC FG420-A11 #1R
Small fragment of a 17.4 inch (design length) probe identified by TWA as F4 that includes the terminal block. The terminal block is scribed with 37414, a TWA stock number, which identified the probe as a FG420-A11 from # 1 or #4 reserve tank. The group noted that #4 reserve probe had previously been identified by a wire on another fragment that also had a terminal block. Another “-A11” was identified by the October 16, 1996 group as item 44; an almost complete unit which had been identified as from the #4 reserve tank. *[414/97 Group Activity with minor editing to match previous format.]*

59 14 2-13-97-134 W[illeg.] FG420-A12 CWT
This is the top 9 inches of a fuel probe outer electrode identified by TWA as F39 or F40, with five additional inches of inner electrode exposed below the outer electrode. The features of the inner electrode are unique to the FG420-A12 center wing tank fuel probe. No evidence of electrical arcing is visible, including under magnification. The outer electrode is abraded and corroded and does not include the metal-stamped probe numbering area seen on other top pieces. The inner electrode has blackened material resembling soot, located where the outer electrode has manufactured holes and is missing about 1/3 of the translucent urethane paint coating. A small amount of paint coating that remains on the top end of the inner electrode is a brown color and darkened with respect to the golden color of the rest of the paint coating. The terminal block remains, with the nylon wire clamp material partially melted, but no identifiable wire numbers. *[414/97 Group Activity with minor editing to match previous format.]*

60 16 11-11-96-19 SC FG420-A10 # 4R
Green tag attached and marked 11-9-96, T6170 -112N(A) DWN JB FUEL PROBE. The probe is a complete unit, including a structural mounting tab, missing only the bottom plastic cap. Metal stamped into the upper end is "-108". A wire tag on a white wire is marked "W1182-Q164-". A wire tag on a red wire is marked "LOZ F79". The -108 and wiring identify the probe as an FG420-A10 from the #4 reserve tank. The probe is also ink-stamped with manufacturing and functional test dates of "NOV 1970." The wire number corresponded to probe FG420-A10, from the #4 reserve tank, identified by TWA as F79. *[414/97 Group Activity with minor editing to match previous format.]*

61 22 11-14-96-105 LMV FG420-A35 # 1
Both ends of the probe are manufactured, rather than broken, and the probe is complete, missing only both plastic caps. Metal stamped into the top is "-128". The probe is ink-stamped

manufacturing and functional test dates of "JAN 1970." A wire tag on a white wire is marked "W776-Q1I9." A wire tag on a red wire is marked "LOZ F19/F71". The wire number corresponds to probe FG420A35, from the # 1 main tank, identified by TWA as F19. *[414/97 Group Activity with minor editing to match previous format.]*

62 6 10/27/96-1 DEL FG420-A18 #2 or #3
Ink-marked Z5121. A short top portion of a fuel probe that includes a metal stamped "- 111 ", corresponding to FG420-A18, identified by TWA as F27 or F50. The group noted that this appeared to be the top section of the #2 or #3 fuel tank probe fragment that was previously identified as #43. No terminal block fragments are with the "-111" piece. *[414/97 Group Activity with minor editing to match previous format.]*

63 8.5 12-14-96-46 K FG420-A23 #2 or #3
Appears to be bottom end of a fuel probe, due to the manufactured slot feature. No other identification is visible. The outer shell is 6 inches long and the 8.5 inch inner conductor is broken off at a reduction in diameter from .671-.736 (distorted) down to about .380-.40 inches. Inner electrode diameter and spacer features were found to correspond with the bottom of a FG420-A23 probe, used in tank 2 or 3, identified by TWA as F24 or F47. *[414/97 Group Activity with minor editing to match previous format.]*

64 9 11 - 17-96-2 GC FG420-A39 #1 or #4
Appears to be an upper fragment of a probe, broken off at the upper terminal block mounting hole and the terminal block is missing. Ink-stamped manufacturing and functional test dates are marked as "NOV 1970". A red spacer was found inside. Measurement of the removed inner electrode features were used to identify this as FG420-A39, as used in the #1 or #4 tanks, identified by TWA as F21 or F73. *[414/97 Group Activity with minor editing to match previous format.]*

65 6.7 12-14-96-65 FG420-A11 or -A29 # lR, #4R, #1, or #4
The fragment is the bottom end of an outer electrode, missing the inner electrode. No metal stamped numbering is visible, or any other identification. Dimensions from the bottom to the lower bracket mounting hole are equivalent to either a FG420-A11 or FG420-A29, identified by TWA as F4, F77, F16, or F68. (Note FG420-A11 = F4 or F77, -A29 = F16 or F68) *[414/97 Group Activity with minor editing to match previous format.]*

66 6.4 11 - 16-96- 10 GI(?) FG420-A17 #2 or #3
The fragment is the bottom end of an outer probe electrode, with 3.75 inches of inner electrode inside. No metal stamped numbering is visible, or any other identification. Inner electrode remains. Scribe number "38" was found on the inner electrode, identifying this as FG420-A17 from the #2 or #3 tank, identified by TWA as F28 or F51. The bottom inch of the inner fragment metal surface appears darkened and the covering urethane is loose. The light colored urethane has the original color and this combination of features has been seen in other probes where the urethane was loosely covering a lightly corroded inner element. *[414/97 Group Activity with minor editing to match previous format.]*

67 5 10-8-96-1,LEB-EP
Marked Z-1710. This is only a fragment of outer electrode, containing no identification from the manufacturer or operator. The fragment is a mid-section of probe with no identifying features.

The fragment has no visible arcing, soot, or heat damage. *[414/97 Group Activity with minor editing to match previous format.]*

68 38.7 11-11-96-69 GJ FG420-A14 CWT
Bottom section of the center fuel tank's aft-most probe, identified by the "03" found scribed on the inner electrode, identified by TWA as F38. Honeywell design drawing shows 50.3 inches length. The flattened 8.5 inch length of inner electrode at one end has a manufactured end to it and does not have the mounting features for the terminal block of the flattened probe's upper end. The probe is bent into a "J" shape. The probe has darkened material under the mud coating that covers all features, which looks like soot. Below five inches from the bottom of the inner electrode, most of the translucent paint is missing from the outside surface, but remaining fragments have the golden color seen on fuel probes from other tanks. Within 1.5 inches of the bottom, the paint has the original translucence. Of two paint fragments found five inches from the bottom, one was found totally blackened and the other fades from brown (toward the probe bottom) to black. After sectioning the inner and outer electrodes, no evidence of arcing was found. Inside of the inner electrode, a general darkening of the urethane began at a slight demarcation, located 3.75 inches from the probe bottom. All of the internal electrode's exterior urethane coating that was above the five inch measurement was found slightly darkened to black in color, rather than the original golden color. *[414/97 Group Activity with minor editing to match previous format.]*

69 19 11/17/96-11 DRR FG420-A23 #2 or #3
Fragment is bent into a "J" shape, with three inches of inner conductor exposed at one end. The inner conductor is broken off where the diameter changes and after sectioning, the internal features and the red and orange colored spacers were found unique to the FG420-A23 probe, identified by TWA as F24 or F27, from 9 to 27 inches from the top. No manufacturer or operator information was found. *[414/97 Group Activity with minor editing to match previous format.]*

70 N/A 11-5-96-25 SKC COMPENSATOR # 4R
Complete but crushed compensator unit that has wiring attached. Ink stamped with "FT APR 1971". A fragment of a blue plastic wire tag is marked [3?]4_182-2. Another fragment of a blue wire tag has a partial number of "64-". The number of wires attached is unique to the 1R or 4R fuel tanks. The fragments of wire numbers found are similar to wire numbers used in the 4 reserve tank installation. *[414/97 Group Activity with minor editing to match previous format.]*

71 15.5 11-16-96-137 GC FG420-A28 # 2 or # 3
Tag identifies fragment as found in orange zone. Ink stamped with "MFD FEB 1971". Appears to be broken off from below the mid-area of the terminal block, with no terminal block portions remaining. Internal feature dimensions are unique to the FG420-A28 probe. For future reference, this p/n was superseded by FG420-A64 and the “-A28” is not shown on all fuel probe reference documents. *[414/97 Group Activity with minor editing to match previous format.]*

72 27.5 11/16/96-168 SHE FG420-A16 CWT
Top of a fuel probe with only the top stud remaining of the terminal block assembly. The top-most five inches is missing the outer electrode and the metal stamped probe number. Ink-stamped manufacturing and functional test dates of "JAN 71". No other identification is visible from the manufacturer or operator and the internal spacers are missing. The inner

electrode dimensions are unique to the top of the 72 inch long FG420A16, identified by TWA as F43, from the forward-most probe installation in the tank. After sectioning the outer electrode to see the internal features, no arcing, soot, or heat-damage was found on any of the parts, inside or out. The inner electrode has areas where the metal surface is darkened and lightly corroded beneath the gold translucent urethane coating, but the same feature was found in most other probes from all tanks. *[414/97 Group Activity with minor editing to match previous format.]*

73 47 10/30/96-2 DMW FG420-A25 #2 or #3

Green tag marked Z-5108, this is almost a complete probe, missing the terminal block and the outer electrode from above the terminal block. Ink-stamped manufacturing and functional test dates are both "FEB 1971." From bottom to upper terminal block mounting hole measures 46.5 inches, matching only the Honeywell design drawing for a FG420A25 probe, identified by TWA as F33 or F56. This was verified by measuring the distance from bottom to lower mounting hole bracket hole. The “-A25” probe is only used in the #2 or #3 tanks. *[414/97 Group Activity with minor editing to match previous format.]*

74 44 *2*/3/97-220 GF FG420-A12 CWT

Green tag marked Z4055 attached. This is the lower portion of a longer fuel probe and is not long enough to include any of the terminal block mounting. No other marking found, including ink-stamped manufacturing or functional test dates. The group noted that on other probes, the MFD and FT marks have been found in the area of the terminal block. After cutting off the bottom 11.5 inches of outer electrode at an existing damage location, a scribe mark on inner electrode identified this as a center tank "-12" probe. The Honeywell design drawing for this part shows that the original length would have been 58 inches long. On the inner electrode is a scribed "01" which identifies this as a FG420-A12 from the center wing tank, identified by TWA as F39 or F40. The group noted that the length of this probe, combined with #59, are approximately equal to the correct total length from the bottom of a complete probe to the top of a complete probe, missing only the top five inches of the outer electrode. However, the fractures appear to be different between the lower end of #59 and the top of #74. The bottom-most 1.2-1.7 inches of urethane coating are missing from the inner electrode and that area is lightly corroded, however, no evidence of darkened urethane or overheating is visible. The outer electrode appears clean and not burned at the bottom end. *[414/97 Group Activity with minor editing to match previous format.]*

75 5.3 11/23/96-198[illeg.] COMPENSATOR

This is the flattened lower portion of a compensator unit and no marking is visible. The unit has no sooting or fire damage. After sectioning, no visible evidence of arcing was found internally on the sheetmetal pieces. Two wire connection studs were found, one with a white plastic spacer for the "HI Z" wire. The two studs were submitted to the laboratory for examination to determine whether blackening found at the wire eyelets was a product of heat or corrosion.

The other stud was for the "LO Z" wire and had a four inch wire fragment. The LO Z stud had two spacers and the crimped eyelet on the end of the wire was loose on the stud. However, an overhaul manual illustration showed that the center electrode material was missing from between the spacers and when the electrode was examined, damage could be seen where the stud had been pulled out. The plastic cover of the LO Z wire eyelet was an even tan-brown color, and under

magnification, looking into the eyelet, the blue wire insulation had a light coat of blackened coating.

The HI Z stud was pinched within the crushed compensator and fell free when the compensator was sectioned open. The plastic cover of the wire eyelet was found darkened at the end where the wire came in. No wire remained, other than corroded strands within the crimp. *[414/97 Group Activity with minor editing to match previous format.]*

76 19 11-17-96-15 GC FG420-A23 #2 or #3
This is the bottom portion of a probe, with no manufacturer or operator marking visible. The inner electrode has a "16" scribed on the element, which Honeywell design documents show to be a FG420-A23, identified by TWA as F24 or F47, from the #2 or #3 tanks. This was verified by matching the spacer coloring and dimensional changes of the inner element.

77 6 11-23-96-208 DP FG420-A39 #1 or #4
At the break, the diameter was found reduced, but due to distortion it was not measured. This is a crushed portion of the top of a probe and includes the inner electrode. A metal-stamped "-132" is at the manufactured end, which identifies this as a FG420-A39, from the #l or #4 main tank, identified by TWA as F21 or F73.

78 9-9-96-49 BJW FG420A-13 CWT
This probe was described in September 19, 1996, NTSB Laboratory Metallurgist's Factual Report No. 96-160 as item 5. The same [Wright Laboratory] testing was requested for this probe as for the previous item (59). [*6/24/97 Group Activity*]

TANK UNITS FROM N93105

To establish whether copper-sulfur deposits existed in operational airplanes, a full set of CWT probes were taken out of a TWA B-747 that had been removed from service, N93105. The fuel probes were removed with more than a foot of the FQIS wiring intact by cutting the wire harness from the fuel tank. The sets of fuel probes from the accident airplane and N93105 were submitted to the USAF switch and wire laboratory at Wright Laboratory. In addition to finding copper-sulfur deposits in the N93105 probe set that were similar to the fragment from N93119, the Air Force examination found damaged electrical insulation on FQIS wiring at the fuel probe terminal blocks. Most of the conditions were concealed until the wiring was removed from probe terminal blocks and inspected under magnification.

The set of seven fuel probes from the CWT of N93105 were examined and one was initially found to have a very low resistance path between the HI Z and SHIELD terminals. This probe was visually cleaner than most of the other probes from the N93105 CWT and no dark film residue was seen on the connector block or on the wiring. The FG420A-13 fuel probe (S/N A-16) resistance insulation path was found with a Curve Tracer to be 25K ohms at ¼ volt ($.25/10^{-9}$). The probe was then tested at 10 volts on a Hewlett-Packard High Resistance Meter and the

resistance measurement was below the measurable scale. To obtain a DC measurement, the probe was moved to a variable power supply and the voltage was brought up to 9.89 volts. However, measuring .024mA equated to a resistance of 412,083 ohms. After that test, the measurements could not be stabilized long enough to read and varied between low values and as much as 208 megaohms. [*6/24/97 Group Activity*]

In a correction dated June 25, 1997, Wright Laboratory reported that the "25K ohms" in the previous paragraph should be 25M(ega) ohms.

In some strain relief installations, variation was found in placement of the different wire colors (black was shield, white was HI-Z, and red was LO-Z) under the clamp. The black wires were on top on some installations and at the bottom of the bundle in others. Different terminal blocks retained varying quantities of wires. [*8/21/97 Group Activity*]

Honeywell drawing number FG420A, sheet 2, note 1, states STRAIN RELIEF CLAMP WILL ACCEPT A .375 MAX WIRE BUNDLE. The note is flagged to the face of the drawing where a metal type of (Series 1-3) clamp is shown. [*8/21/97 Group Activity*]

The black wire was found by chemical spectrum to be closest to polytetraflouoethylene (Teflon, PTFE), by FTIR analysis. Boeing calls for BMS13-16 or BMS13-10 to be used in these installations, according to 60B40037, which is the wire specification in CONNECTING COMPONENTS, FUEL QUANTITY SYSTEM - MODEL 747. The inner and outer layers of insulation on the white HI-Z and the insulation on the red wire was found by FTIR to be PTFE, as well. BMS13-10 and BMS13-16 are both extruded PTFE, 200 degrees C with silver plated copper conductor. [*8/21/97 Group Activity*]

Copper and sulfur were found with smaller amounts of silver in fuel residue deposits on fuel probe terminal block components and on exposed materials which were from the fuel tanks. On the underside of a metal strain relief clamp was a pattern which appeared similar to a heat pattern, however, no other indications of heat were found on the PTFE insulation which had been in contact with the clamp and the pattern was chemically found to be the copper-sulfur residue. [*8/21/97 Group Activity*]

Microscopic photos of terminal blocks show that the knurled area is actually a series of cone shapes cast into the surface of the terminal block, which are sharp-edged at the edge of the terminal block. The Honeywell (manufacturer) drawing 10022192 shows that a pattern refered to as "SHARP POINTED MEDIUM KNURL 90^{O} DIAMOND THIS AREA TO BE RAISED .015 ABOVE SURFACE B [the area of the knurl]. The drawing also had Note 1, which states ".03R OPTIONAL ON ALL SHARP CORNERS & FILLETS UNLESS OTHERWISE SPECIFIED." The notes for the tank unit FG420A, had notes 11 and 12, showing a series number within the part number. Series 1-3 call-out shows item 8 as the terminal block with the knurling and associated parts, such as the strain relief clamp. The metal clamp is Honeywell part 10022188, titled CLAMP, LEADWIRE, and is called out on the FG420A drawing as item 12. Series 4 and above call out item 133, which is a terminal block P/N 10032447, which does not have the knurling and does not have the metal strain relief clamp. The nylon strain relief is a "P" shaped loop type clamp (BACC10DK) and is provided with the wiring, according to FG420A drawing

note 8 on page 2, which states “CABLE CLAMP & NUT SHOWN FOR REF ONLY , TO BE FURNISHED BY CUSTOMER.” The fuel probes are installed and wired by Boeing and maintained by the customer. The drawings available at the meeting do not show the date of change in production. [*8/21/97 Group Activity*]

Parts from the N93105 airplane had the knurled surface on November 1969 and earlier manufacturing dates. On probes with later manufacturing dates, the knurling was not present, and that area was found to have a flat smooth surface. The later probes had the nylon “P” loop-type clamps, with the wiring contained in heat-shrink tubing. [*8/21/97 Group Activity*]

The group reviewed WL/MLSA examination of compensator FG6C1, A-161, shown in the top photo in the package distributed to the group showed the black shield wire not retained by a shield wire at the clamp. In other terminal blocks, the shield wire was retained under the clamp. The same compensator also had the red LO-Z wire lightly chafing on the stud for the clamp. The compensator had the metal strain relief clamping arrangement, rather than the plastic found on some N17119 [Should read “N93119”] probe remnants. The black shield wire was found to pass under and between the HI-Z wires, contacting one. Under microscopic examination, damage was found at the area of contact. Damage was also seen where wire was resting against a non-knurled smooth area of the terminal block, although in a different area, this terminal block did have a knurled area. The clamp was removed and the heat shrink was removed from the HI-Z and LO-Z wires. [*8/21/97 Group Activity*]

Compensator A-161 black shield wire on photo page 6 had damage that was adjacent to HI-Z wire shielding and had a similar embossed pattern to the shielding in this location. The black insulation was damaged and exposed the core conductor in two locations. The adjacent white wire HI-Z shield at this site was not exposed, but the shield was visible at other sites. Possible exposures for damage creation discussed were during (1) manufacture of the wire harness, (2) installation on the probe, (3) during service life, or (4) during removal. The harness had no indication of having been removed in sufficient time to accumulate fuel residue. On photo page 5, the wire had been moved slightly away from the HI-Z wire to take the photos and fuel residue is seen in the same site that goes into the damage. [*8/21/97 Group Activity*]

The next part reviewed was a fuel probe (FG420A14, A-9). A darkened fuel residue was visible on the inner HI-Z wire insulation visible shown above the pig-tails. The black wire laid over the HI-Z shield heat-shrink and appeared without defect until examined on the lower side. When the black wire was lifted from the heat-shrink, damage with ragged edges was adjacent to the heat-shrink. [*8/21/97 Group Activity*]

The next part was fuel probe (FG420A13, A-16) on photograph page 8 showed damaged red insulation on a LO-Z wire. The damaged area on the photo is shown as a darkened area, located half-way between the clamp and the white marker on the red wire. The loop is larger than on other terminal blocks and a proportionally smaller loop would bring the damaged area approximately under the metal clamp. A diagonal pattern shows on the surface of the red PTFE that is similar to the direction of the strands of the core conductor (copper) of the wire inside. Blackened residue is on the surface of the insulation, similar to that on the HI-Z previously

discussed. The red also has two lengthwise indentations, as other wires laid against the red wire, but not parallel to it. [*8/21/97 Group Activity*]

[The group examined] probe FG420A12, A-21, with shielding exposed on the white HI-Z wire. An arrow on the overall photo shows the approximate location of the damage, aligned near (not at) the lower edge of the metal strain relief clamp. On another image distributed separately, the lower side of the HI-Z wire shows alignment of the damage with the knurls of the plastic terminal block. The red LO-Z wire was not found on the bottom of the wire bundle against the plastic block, but was found damaged with blackened residues in fairly straight grooves along the insulation. [The group saw another case in which] the red wire was only partially retained by the clamp. The alignment was approximately similar to the edge of the clamp. A set of parallel grooves in a heat-shrink on the red LO-Z wire did not visually have the blackened fuel residue in the grooves. At the end of the grooves, the whitish shrink-wrap thinned where the grooves came together and it was not clear whether there was a (1) light amount of residue in the groove, (2) a surface residue that had been turned in with the material curl or (3) whether there was no residue at all. [*8/21/97 Group Activity*]

Compensator FG6C2, Y-147, had the post-Series 3 terminal block. Beneath the clamp and within the heat shrink that covered the bundle of wires, the black wire was found with damaged insulation. The heat shrink was pinched in this area. The damage to the wire insulation was a dimple or indentation that was below the surrounding insulation surface. The damage did not penetrate to the core conductor. The color of the insulation in this area was not the black of other shield wires and appeared to be slightly translucent, although the color appeared to be more blue. [*8/21/97 Group Activity*]

TANK UNITS FROM OTHER AIRPLANES

Additional fuel probes were recovered from a scrapped Air France B-747[25] and similarities in damage and copper-sulfur deposits were found. As found in the N93105 probes of later than Series 3, the metal strain relief clamp and knurling were deleted and the FQIS wires were held within the eye of a "P" shaped nylon clamp. A later change placed shrink-wrap material over the wiring where it was routed through the "P" clamp.

Honeywell drawings were examined for similarities in terminal block design between the B-747 and other models of airplanes. Most fuel probes were found to have electrical connectors that were external to the fuel tank. Some fuel probes had attached wiring that terminated in a plug-type connector. However, the following airplanes had terminal block electrical connectors: [*9/18/97 Group Activity*]

[The preceding paragraph is quoted from the notes agreed to by the Systems sub-group that concluded on September 18, 1997, and which included a Boeing representative. The term

[25] Boeing 747-100 series, formerly registered as F-BPVE, Serial Number 20355, Line number 105, Delivered to Air France on March 16, 1971, retired September 15, 1994, with 76,304 hours and 16,893 cycles.

"most" refered to fuel probes manufactured for many Honeywell customers and refered to the number of designs reviewed, not the number of fuel probes manufactured for any single design. In a letter of October 27, 1997, Boeing stated "The Boeing models that have terminal blocks are the 707/727/737/747/757/767 which encompass are large segment of the commercial airplane fleet."]

Boeing 707, 720, 707-320 (Iranian tanker configuration), AWACS, B-757, B-767
(Release date of February 1966)

Lockheed C-130E
(Release date of August 1976)

The terminal block from a B-757/767 configuration fuel probe was examined and found to have features that protected the attachment for the wire harness. The terminal block had cast grooves for the harness, a retaining metal clamp was mounted on a stand-off that prohibited intimate contact with the terminal block surface, and the edges of the terminal block all had a smooth radius, rather than the sharp squared edges found on the terminal block from the B-747 installation. [*9/18/97 Group Activity*]

The CWT compensator is mounted on the forward side of spanwise beam two, near the floor of the CWT. Next to the compensator are a vertically mounted fuel probe and a horizontally mounted tube. Maintenance personnel in the fuel tank must step over the horizontal tube to access the components located in the aft right area of the fuel tank. Damage in the area of the compensator, probe, and tube was found in two airplanes inspected during the investigation. A Systems Group examining the N93105 airplane found dents in the fuel probe and the horizontal tube. A Boeing inspection of B-747 RA106 on 10/25/96 found that the compensator had been broken from its mount during the D-check that was in progress. One other anomaly seen during a Boeing inspection of November 1, 1996, was a repaired HI-Z wire in airplane RA317. The inspection found that the wire had been repaired with tank sealant where it had chafed at the spanwise beam 2 (left) grommet.

Wright Laboratory had previously examined fuel probes from C-5 and T-37 airplanes and had shown test results to the group. One October 28, 1993 report about C-5 fuel probes found that insulation had dropped to 350K ohms. A T-37 report dated March 29, 1990, concerned copper-sulfide deposits that had ignited fuel vapors when voltage was applied during a test after removal from the airplane. (See Action Items) [*6/24/97 Group Activity*]

Boeing reported on September 4, 1996, that a Dielectric Withstanding test was conducted with a set of fuel probes in an altitude chamber. "The results also show that below 25,000' the Center Tank FQIS assembly maintains full 1500VAC Dielectric Withstanding capability. Voltage was increased until breakdown occurred and at sea level the breakdown between electrodes came at 3300VAC.

In a letter of October 27, 1997, Boeing requested that the following description be added for the Dielectric Withstanding test: "The September 4th,1996 activity used new 747 Center Wing Tank wiring, new probes and a new compensator to determine arcing breakdown values in the fuel

quantity system by introducing extremely abnormal levels of voltage. Nov 6th and 7th the same test was performed with used probes. The probes, compensator and wiring came off of a UPS 747 with 23 years of service. The new and used probes exhibited almost identical results. The fuel quantity system which normally operates on peak voltage values no greater than 32 volts, did not have an in tank breakdown until the 1800 VAC rms (2500 volts peak) at the accident altitude of 13,800 feet."

In a letter of October 24, 1997, Honeywell noted that the electrical breakdown found in the September 4, 1996, Dielectric Withstanding test was in one of three places; 1) under the terminal block between the terminal stud hardware and the outer electrode, 2) on the terminal block between the terminals or wiring; or 3) at the tank wall connector going into the altitude chamber.

INDUCTED ENERGY TESTING

On July 17, 1997, voltage and current on the CWT FQIS unshielded LO Z wiring was measured and recorded during both ground and flight tests conducted by the Safety Board from the John F. Kennedy International Airport. These measurements were taken in the Evergreen flight test airplane at John F. Kennedy Airport. Personal electronic devices (PED) were actuated and carried along the path of the CWT wiring, from the cockpit to the main deck floorboards at about fuselage station 920; aircraft electrical systems were cycled on and off. The PEDs used for this test included an analog cellular telephone which was repeatedly "dialed", a Sky-Tel personal pager, an amateur radio 2-meter transceiver of about 2.5 watt output, a lap-top computer performing a hard-disk "save" function, operating an audio CD on the lap-top computer, and a man's electric shaver. Aircraft systems that were cycled on the ground included all interior and exterior lights, window heaters, pitot heaters, stall warning shaker, #1 and #2 VHF radio transmissions, two radar altimeters, transponder IDENT function, electric trim, and fire detection self tests. Frequencies and potential interference with other airplane systems was not investigated.

Laboratory tests conducted to Boeing specification D6-16050-2,[26] used parts from a B-747 CWT FQIS system to determine that energy can be induced into unshielded FQIS wiring by electromagnetic interference (EMI) from an electrical load on a parallel wire.[27] The configuration of the test did not replicate a complete B-747 FQIS system, but was indicative of a transient induced from large power relays and motor loads by tightly securing the FQIS wires to a 75 foot wire that acted as a primary (input) winding. FQIS wires are routed with almost 400 wires of 5 to 192 volts, but current analysis has not found coupling of CWT FQIS wires with a 75 foot source wire with the tested amount of inductive energy. Transient voltages were created by switching on and off the power in the primary wire. Under non-failure conditions, no evidence of sparking or energy transfer was found.

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[26] Boeing specification D6-16050, Category 3 was used in the original specification and certification for the B-747. D6-16050-2 specifies a unique category of Inductive Transient testing - Category 3X. At this time, no other system on any Boeing model tests to this level for this test.

[27] During flight tests conducted in July 1997 at JFK, personal electronic devices, such as laptop computers and cellular telephones induced less energy induced into the CWT FQIS wiring than from the aircraft systems.

Additional tests in the laboratory were conducted with debris such as steel wool. The debris was placed to short the inner and outer electrodes of a fuel probe, to bridge the outer electrode to ground, and between the inner electrode wire shielding and ground. In an airplane, the shortest distance to create the latter two failure conditions was found to be about an inch. Under these conditions, it was possible to measure slightly more than .6 millijoules at more than 1,000 volts on wiring at a fuel probe when power was induced from the primary wire. The energy levels found induced into the CWT harness exceeded the Boeing specification of .02 millijoules and API Practice 2003 reference for a minimum ignition energy requirement of .25 millijoules. In a letter of October 27, 1997, Boeing stated that "the accuracy of the measurement technique [used at the Boeing laboratory] has not been determined, and that there are a number of other factors could have resulted in this being erroneous measurement."

Shielded wire was found to have been used for the HI-Z (probe inner electrode) FQIS wires in N93119 FQIS, but not for either of the LO-Z (probe outer electrode) circuits. In a letter of October 27, 1997, Boeing stated that:

> This is a common design for capacitive systems produced by most FQIS suppliers.
>
> The primary and most important purpose of the HI-Z shielding is for noise immunity. The low level signals being carried by this wire require additional immunity from noise. The secondary benefits of chafing protection and short circuit protection provide added benefits but were not the reason for shielding the HI-Z wire. If wire protection against abrasion and shorted is consider to be required special jackets or sleeves (e.g. nylon, teflon, kevlar) are provided over the wire bundle. The 747 FQIS wire bundles have a jacket consisting of a lacquered nylon braid in the pressurized and unpressurized areas outside of the tanks. There is no jacket over the wire inside of the tanks.

Jacketing was found on the compensator wiring in the CWT of N93105.

Boeing reported having changed the design and began installing an overall shield around the FQIS wires between the wing-body disconnects and flight engineer panel at line position 244[28] to provide immunity against noise that was affecting the accuracy of the fuel quantity indications. Boeing added that the change was not for the purpose of wire protection against abrasion or wire-wire shorts. Further shielding was added to FQIS wires behind the flight engineer panel at line position 428.

Boeing has requirements for separation of different types of wiring that exist for all airplane models for various reasons. The reasons include chafe protection, damage tolerance to separate essential systems, and minimization of electrical noise. In wiring diagrams and in other B-747 airplanes, examples of separation were seen as physical distance between wire bundles from generator cables and some antenna cables.

[28] The accident airplane, N93119, was built as line position 153, also known as S/N 20083 and RA164.

FUEL QUANTITY INDICATORS (28-41-03)

A new indicator was subjected to a range of over-voltage conditions, some of which left observable results in the color of a red band of paint and altered electrical characteristics. The results of the over-voltage tests had a relationship wherein less time required more voltage to create the damage and the resulting relationship was able to be defined as a curve that could be charted.

Visual physical damage during introduction of voltages above an approximate 85 volt threshold became evident with discoloration of the red painted color band on the resistor. Other color bands did not appear to discolor. As the resistors heated, the red band could either brown or disappear, and either remain totally gone, or partially or completely recover during the cool-down stage, depending upon the voltage/time variables introduced. [*3/20/97 Group Activity*]

Concurrent with color band evaluation, post-test electrical values (resistance in ohms or K ohms) of the resistors were recorded. With the application of voltage over time, the resistance values tended to increase. It was noted that those values tended to shift downward during the cooling phase. The values were recorded after driftdown appeared to stabilize. It was also noted that the resistance driftdown continued overnight, so it was determined that resistance values would again be recorded the following day. [*3/20/97 Group Activity*]

Charted results of the resistor tests were approximately similar for the change in color and for the change in resistance. Application of 115 volts took about 20 seconds to damage the resistors tested. The wiring diagrams show that 115 VAC power is brought within the indicator and a transformer within the indicator case converts that power source to the levels needed for the various parts of the system to function.

Tests of transient responses, in order to ascertain a threshold of observability for the instrument display, was evaluated using the test setup, with an airworthy indicator, SN 96100329. As a general observation, drum readout oscillations due to transient frequencies greater than 5.0 Hz were considered by observers to range between marginally observable and not observable. Transient frequencies greater than 10 Hz clearly showed no observable oscillations on the drum [due to transient frequencies]. Observations of needle [movement] were considered to be marginally observable or not observable. [*3/20/97 Group Activity*]

Tests were performed to determine rate of indication change when power was applied to the wires leading to the indicator. Application of 95 volts to the LO-Z wire resulted in a decreasing fuel level indication at about 500 pounds per minute. Application of 105 volts to the COMP LO-Z wire resulted in an increasing fuel level indication.

<u>#4 Main tank Fuel Quantity Indicator</u>

(P/N 34132 (TW), P/N JG603C2 (Honeywell), S/N 78)

The #4 main tank and the center tank (CWT) fuel quantity indicators were torn down for examination. The #4 main was not examined in the detail that the CWT indicator was subjected to.

There was a small tear and an indentation in the case. Several wires had been pulled out of the connector. When opened, the inside surface of the connector had a light coating of a fluid identified as sea water. There were existing wires in pins 2, 3, 4, 9, and 11. [*8/25/96 Group Activity*]

Two cuts were made to open the case. A film was present at the back at the solder ring, and a black deposit was seen on the inside of the case at the back. Board P/N 10022306-101 had some discoloration on CR2, CR4, and R2. The insulation sleeve on C5 was slightly yellowed. There was no discoloration of the PWB. The condition of the printing shows no evidence of heat exposure. [*8/25/96 Group Activity*]

Resistance checks on transformer and components adjacent to tank connections showed no anomalies. This includes current limit resistors and rebalance capacitor. A check of the rebalance pot (done before and after cutting the CW wire) revealed that the pot agreed with the drum counter quantity reading. [*8/25/96 Group Activity*]

Center Tank Fuel Quantity Indicator

(P/N 34134 (TW), P/N JG603C3 (Honeywell), S/N T-1)

The examination of the CWT indicator found no signs of electrical stress,.

The indicators have circuitry designed to limit the amount of current that may be put into the FQIS system by the indicator. The current limiting circuitry was not designed to limit current introduced from sources outside of the FQIS system, such as from a wire to wire short. The current limiting circuitry on the recovered CWT indicator was within the original specification tolerance.

Connections J1-6, -7, internal to indicator were broken. Connector was broken loose from indicator. Resistance readings of components adjacent to tank connectors showed no anomalies. This includes current limit resistors and rebalance capacitors. With the case opened, there was no evidence of discoloration or heat exposure on the circuit boards or any of the components. A check of the rebalance pot (done before and after cutting the CW wire) revealed that the pot agreed with the drum counter reading. It appeared that the transformer had been changed at some time. The gear train was intact and still engaged. [*8/25/96 Group Activity*]

Note: The largest wire in these two indicators is the ground wire at #22 gauge. Most wires inside the gauge are #28 and #30. There were no burnt wires inside or blown resistors found in either indicator [similar to what was found during the overvoltage tests]. [*8/25/96 Group Activity*]

Many wires exhibited heat-shrink over splices. It was noted that this is not a repair process used by Honeywell. Both A1 and A2 boards were inspected under a binocular microscope. No indications were noted of heat distress or other damage on the circuit boards, other than broken parts attributed to impact damage [similar to what was found during the overvoltage tests]. After

the aforementioned parts were replaced, the circuit boards were individually checked with low DC voltage and current draw appeared to be normal. [*12/13/96 Group Activity*]

The device T1 circuit boards were installed in a representative functional gauge (96100329). The gauge was then powered from a 400 Hz AC power supply. Voltage was ramped up, starting with 30 VAC. Current was monitored during application of voltage and remained normal. The indicator began to function at that time. Voltage was then increased in increments to normal operating voltage of 115 VAC. The gauge was found to operate normally, however it was out of calibration. [*12/13/96 Group Activity*]

A chart that followed the previous test showed that at for the CWT indicator to show a 2500 pound fuel indication, another indicator that was used as a calibrated reference showed 100 pounds. The gauge was found to react normally to recalibration using the calibration pots.

Other Indicator

Since the Sub-Group activity at Marshall Space Flight Center that examined the flight engineer panel, a loose fuel quantity gauge was found with a display of 63.0 on the digital units and a facial mark at the radial length of the needle at a reading of "63". [*10/26/96 Group Activity*]

FQIS WIRE HARNESS (ATA 28-41-09)

FQIS WIRE HARNESS DESIGN AND ROUTING

The CWT FQIS wires cross over the crown of the fuselage in the aft cockpit in a series of wire bundles, coming down into the flight engineer station area from over the P6 circuit breaker panel. The bundles had previously experienced chafing that resulted in an aborted take-off because of smoke in the cockpit. After the aborted take-off, the operator had found 42 wires damaged and 6 power feeder cables were burned and cut. The incident led to Boeing Service Bulletin 747-24A2186 and AD 94-05-07, which were implemented at TWA as Modification Order 71T80, dated 4-8-94.

Service Bulletin 747-24A2186 detailed an inspection and protective modification for a specific location by position in the airplane (STA 400, WL 385, RBL 25). Wiring from the accident airplane had been separated from the structure and the area no longer existed as cited. Wiring believed to be from the general area was examined and found wrapped around other debris, cut, and pinched. Cracked insulation was found, but whether the damage was pre-accident or followed the initiation of the accident was not determined. No localized marks were seen that had the blackening or copper splatter associated with arcing.

Wire chafing behind the flight engineer panel led to Service Bulletin 747-24-2118, which called for an inspection and protective sleeving. The area was found to be more than a foot above and forward of where the FQIS wires were routed.

In a fax of September 9, 1996, Boeing provided the following description of the wiring between the center wing fuel tank fuel gage and the fuel tank electrical connector mounted on the rear wing spar:

> [Wire bundle] W480 consists of one shielded and jacketed wire and two unshielded twisted and jacketed wires. The conductor and insulation of these wires are constructed per MIL-W-16878, Type EE, 200°C rated, 20 AWG, with extruded Teflon insulation. The jacket over the shielded wire is composed of TFE Teflon. The overall jacket on the twisted wires is a lacquered nylon braid.

Responding to a question about routing of CWT FQIS wires with other wires that may carry power, a Boeing reply showed that the CWT FQIS wires are routed with almost 400 wires that may carry electrical power[29] of up to 192 volts. The investigation found that the FQIS harness is routed with a power wire to a cabin fluorescent lighting ballast. This wire carries a nominal 200 VRMS and tests reported by Boeing on October 27, 1997, showed that the voltage may increase to approximately 218 VRMS during starting, lamp barber-poling, and rectifying lamp conditions. Lamp starting voltage on wires between the ballast and the lamps were not adjacent to the FQIS wiring.

As a summary of the CWT FQIS wiring and routing, examination of the routing in N93105 found that between the CWT and the flight engineer's panel in the cockpit gage, the FQIS was composed of one shielded wire and two unshielded wires enclosed in a common woven fiberglass sleeve. Examination of wiring from several airplanes and of wiring diagrams found that behind the flight engineer's panel, the sleeved set of Teflon insulated wires were connected to unprotected general airplane wiring[30] that was routed to the fuel totalizer and to the electrical/equipment (E/E) compartment, located behind the nose landing gear. The E/E is the primary electrical distribution center for the B-747 and the unshielded wiring was routed to a data system (AIDS) and the volumetric shutoff (ground refueling) unit. Additionally, unshielded Teflon wiring from the right wing fuel tanks was joined at a terminal strip located in the CWT, then routed through the left wing fuel tanks to the ground refueling panel gages that were located between the left two engines. Boeing noted in a letter of October 27, 1997, that the fuel tank structure provided adequate protection against the electrical noise and that wire shielding was not required in the fuel tanks. At the ground refueling panel, the fuel tank wiring was routed with other FQIS wiring to reach the refueling indicators. The other FQIS wiring included 115 VAC

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[29] According to both Honeywell and Boeing, power to the FQIS is supplied by the cockpit fuel gage and is limited to .02 millijoules, or less than 10% of minimum ignition energy[29] (MIE) referred to in American Petroleum Institute Recommended Practice 2003, Fifth Edition, December 1991, titled Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents.

[30] Samples of general aircraft wiring from N93119 were found at Wright Laboratory to be a two layer aliphatic polyimide insulation on copper wire, similar to the product sold by Raychem Corporation with the commercial name of "Poly-X." Wire markings identified the general N93119 aircraft wiring as (Boeing Specification) BMS13-42A, marketed by Raychem. The specification stated that the primary insulation was alkane-imide polymer.

power, 5 VAC power, and fuel quantity signals. The design included a relay at the refueling panel to remove power to the wing refueling indicators when the refueling panel door was closed, but power would have remained in the refueling panel bundle.

A signal generator was attached to the CWT FQIS wires at the flight engineer's panel in the cockpit and a hand-held probe emitted a warbling sound when placed against the CWT wiring, elsewhere in the routing. However, it was noted that the warbling was also heard when the probe was brought near FQIS wiring for other fuel tanks, although the sound was not quite as loud. [*5/20/97 Group Activity in N93105*]

The signal tracer was used to trace and identify the CWT FQIS wires where they were routed in large wiring bundles. The amount of energy coupled into wiring from other fuel tanks was not measured.

Tracing the CWT FQIS wiring (bundle W-480) began above the circuit breaker panel that was located to the right of the flight engineer. Interior panels were pulled back to follow the wiring over the crown of the airplane, then along the upper deck's left sidewall, below the upper deck windows. [Individual wire bundles were found routed immediately next to each other, but passed through separate clamps. Wires were found that sagged slightly between clamps or that were otherwise not routed straight and parallel.] Another wire bundle (W-528) that was routed within 3/4 inch of the CWT FQIS wires was found rubbing against antenna coaxial cables (W377-RN3005, W379-RN4005, and W-865-RN3234) at fuselage station 730 for about ten inches. The coaxial cables were found to be for the VOR antenna. On the right side of the airplane in the same area was the coaxial antenna cable (RV-381-RN3040) for the No.3 VHF top antenna (FS 1326, WL 359). The FQIS wires for the right wing fuel tanks were routed in the area of the VHF coax. [*5/20/97 Group Activity in N93105*]

The CWT FQIS wiring was found routed along the left side of the upper deck with the coaxial cables from the VOR antenna. On the right side of the airplane, the coaxial antenna cable for the No. 3 VHF antenna was routed parallel to the right wing fuel tank FQIS wires. Beneath the main deck passenger floor beams, the CWT FQIS wiring was routed with numerous other ship's wires. [*5/20/97 Group Activity in N93105*]

The CWT FQIS wiring was found routed above the passenger cabin along the left side of the airplane, turning downward toward the forward spar of the wing at fuselage station 900 and 920. The routing followed the station 900 and 920 frames to beneath the main deck passenger beams, then followed the floor beams inboard. The bundle turned aft to join numerous other wire bundles, then passed over the top of the CWT. The wiring turned downward and passed out of the fuselage pressure vessel into the roof of the left main landing gear wheel well, then was routed to a block on the rear spar. Inside of the CWT, red teflon-insulated wiring routed to each of the fuel probes. [*5/20/97 Group Activity in N93105*]

The FQIS probe connectors located between the mid-spar and spanwise beam #2 were similar to those found in the aft-most right bay. The center probe was found dented and .6 inches from the tank bottom. The compensator electrical connections had darker residue, especially on the "HI Z" eyelet. [*5/20/97 Group Activity in N93105*]

The three fuel probes mounted between spanwise beams 2 and 3 had the cleanest electrical connections. The left and right probes mounted .5 inches from the tank bottom and the center probe was 1.5 inches from the tank bottom. [*5/20/97 Group Activity in N93105*]

The bottom of the two probes were measured to be 3/8 inch from the tank floor and residue similar to what was found in the left bay was found on the fuel probe electrical connections. The translucent plastic crimped insulators on the "LO Z" wire ends also contained a brown residue. [*5/20/97 Group Activity in N93105*]

FQIS WIRE HARNESS ROUTINGS SHARED WITH FUEL FLOW WIRING

The Cockpit Voice Recorder Group Chairman reported that a comment was made regarding an abnormal number four engine fuel flow indication. Wiring diagrams for the accident airplane were examined and common routings for wire bundles were found. The W350/W1360 bundles are routed through a common series of wire clamps from the flight engineer station to the electrical equipment compartment located between the nose landing gear and the forward cargo compartment.

The forward fuselage of N93119 sustained severe fragmentation where it impacted the water on the right forward surfaces. Installation drawings show that the W350/W1360 wire bundles are routed through the fragmented area.

Commonly routed Fuel Flow Bundles:	FQIS Bundles:	Location:
W006	W006	Power source wires within the circuit breaker panel (P6)
W066	W066	Main equipment Center Right Shelf (E3-1). The Volumetric Shut-off unit and Fuel Flow Computer are on this shelf. According to Boeing, this bundle contains 46 power wires of up to 115 VAC. The shelf from N93119 had a short section of harness attached and no arcing of evidence was seen.
W186	W186	Bundle located in flight engineer (P4) panel. According to Boeing, this bundle contains 106 power wires of up to 192 VAC. The area had severe impact damage, but no evidence of arcing was seen.
	W350	Compensator LO-Z signal to electrical equipment center located behind nose landing gear. Routed

	through clamps with the W1360 fuel flow bundle along the station 360 frame on the right side of the fuselage. According to Boeing, this bundle contains 34 power wires of up to 115 VAC.
W1360	Fuel flow #4 signal wires. Routed partially with bundle W350 on the right side of the forward fuselage. Close proximity of fuel flow wires to 350 volts AC power (wire W1306-L1892-22) of the cabin flourescent lighting transformer T63 at station 360.

CWT WIRE HARNESS INSPECTION, N93119

The FQIS wiring was 100% examined from the flight engineer panel to the center fuel tank, although approximately ten feet of wiring was found missing from FS 920 to FS 1000. FQIS wiring from the other wing fuel tanks was also examined. No evidence of arcing or short circuits were found in any FQIS wiring. About six feet of wire from the wheel well, with a piece of the spar connector remaining and continuous to above the pressure seal, was found and had tension-type failures at both ends. The insulation of the individual wires was intact, but the bundle sheathing was found heavily abraded and had large portions missing. Within the center wing fuel tank, about three feet of wiring remained attached to the spar connector in an area that had moderate sooting. The remaining wire insulation was found slightly darkened. [*10/22/96 Group Activity*]

The Amphenol fuel quantity indication system (FQIS) spar blocks from the center wing tank aft spar, each front spar near the wing root, and from the right wing at station 716 were removed with the attached FQIS wiring. Three of the blocks had the attachment bolts secured with safety wire, but the station 716 (right) block had none. The spar blocks were examined by the National Aeronautics and Space Administration (NASA) George C. Marshall Space Flight Center. The Summary of the examination stated that [*10/26/96 Group Activity*]:

> No internal or external indications of a high voltage/electrical current event were found during examination of the four connectors. Thermal damage found on two connectors, consisting of charred wiring harness and insulation, was consistent with damage caused by an external heat source; it was not indicative of an electrical malfunction. No potential ignition sources were found.

On June 23-27, 1997, work was conducted with the wreckage at Calverton to recover parts and perform documentation. The complete wiring installation from the CWT fuel quantity indication system (FQIS) was found and temporarily installed in the reconstructed fuselage, excepting less than feet from fuselage station 900 in the upper fuselage to a location near the forward wing spar. A large vertical breach in the fuselage was along the same station as the vertical portion of the wire run. The wiring from above the CWT was found extensively burned. The CWT FQIS

wiring was tagged and photographed to identify corresponding fuselage station orientations and was removed for laboratory tests. [*6/27/97 Group activity*]

A visual examination found no evidence of arcing, however, the wire bundle was not disassembled for this task. A 29 inch section of wire W856-C438 was found with two localized burns. Under 10X magnification, the burns appeared to be external to the wire, but with small sparkles. A portion of the wire bundle identified by the W856 was found on wiring diagrams as routed with the CWT FQIS. However, the group could not tell if the -C438 section of wire was in the commonly routed portion of the bundles. [*6/27/97 Group activity*]

Prior to examination by this group, fuel quantity indication system (FQIS) wiring from the wreckage had been laid into the reconstructed fuselage and approximate station orientations were marked on the wires by attaching string-tags. Four sections of wire bundle W480 (containing the CWT FQIS wire) were found to lay from [*8/27/97 Group Activity*]:

1) the flight engineer's station to station 570,

2) station 570 to immediately aft of station 900,

3) a burned area located generally over the CWT, forward of station 980 to about station 1299,

4) a 9½ foot length from an unknown location.

A section of bundle W480 was not identified for the routing between station 900, in the upper fuselage, to station 980 in the lower fuselage and of the 125 feet of the original CWT FQIS wire, about 17-18 feet were not found or identified in the hangar. The area for the missing length was examined in another airplane (N93105) and the W480 bundle was found routed down the left side of the fuselage between the station 900 and 920 frames, then inboard to join a large routing of numerous other wires. In N93119, this area was found to be at a major breach in the fuselage. [*8/27/97 Group Activity*]

Recovered generator cables placed into the reconstructed area of the raceway area (M) located beneath the floorboards were found in N93105 to be more than a foot from the CWT FQIS wires. The generator cables from N93119 were not found burned in the routing which was near the CWT FQIS wiring. The bottoms of the floorboards from the area had also previously been examined and no burns had been found. [*8/27/97 Group Activity*]

Mixed evidence was found regarding the original location of the 9½ foot length of the fourth section of wire bundle. However, attached wiring was marked with bundle numbers that were in the missing 17-18 feet of wire, with no numbers from other bundles. [*8/27/97 Group Activity*]

LABORATORY EXAM OF N93119 WIRE BUNDLE, COCKPIT TO WHEEL WELL

[*8/27/97 Group Activity*]

The FQIS wire was recovered with other aircraft wiring attached to it. The complete assemblies of wire bundles were sent to the laboratory of the National Aeronautics and Space Administration (NASA) at Marshall Space Flight Center, Huntsville, Alabama for detailed examination. [*8/27/97 Group Activity*]

Examination in the NASA laboratory found no evidence of arcing in any CWT FQIS wires. Two non-FQIS broken wires had a few strands with ball-shaped ends and most of the strands in those wires were necked or cone-shaped. Two locations were found where impact-type damage was found which had penetrated the insulation of the FQIS wiring, one to the core of a single conductor wire and one to the shield of a shielded wire. Cracked insulation was found along the length of other wiring identified by markings as BMS13-42A. [*8/27/97 Group Activity*]

The FQIS wires were generally found bundled in a woven nylon sleeve, although little remained of the sleeve in the burned station 980-1299 section. Within the sleeve were a shielded white wire and unshielded red and blue wires. A TWA wiring diagram showed that the red wire was used for fuel probe LO-Z circuitry, the blue wire was used for the compensator LO-Z circuit, and the white wire was the HI-Z circuit. Wire markings found on the FQIS were attached by external sleeves on the sections from forward of station 900. The wire bundle from aft of station 980 was found burned and most of the FQIS nylon covering was missing. The PTFE insulation material[31] of the FQIS wiring from within the covering was visibly different, compared with the burned appearance of the rest of the attached bundle. The FQIS wire was visibly more intact. [*8/27/97 Group Activity*]

The woven sleeve from forward of station 900 was cut from a number of areas to examine the encased FQIS wiring. Areas were selected for examination if they were not smooth and uniform with the rest of the bundle, if local damage was seen, and in some areas to examine for possible loss of concentricity of the core copper conductor to the insulation cold-flow. Sites examined for cold-flow were at the edges of mounting clamps or at bundle ties of string-tie or ty-wraps. It was noted that the clamps were not exerting pressure on the wiring. In general, at the bundle ties, no flattening or deformation of the LO-Z FQIS wires were found. [*8/27/97 Group Activity*]

At the edge of one P-clamp from near station 810, the LO-Z insulation was slightly deformed, but cutting back the insulation found the core conductor to be approximately centered. Portions of the shielded HI-Z wire were found to have lengthwise deformations which matched the LO-Z wires. Sectioning and microscopic examination of one area found that the outer layer of insulation was slightly thinner on one side of the wire and that some movement was possible between the shielding and the inner layer of insulation. [*8/27/97 Group Activity*]

Some wires found in the section of W480 from forward of station 570 and identified as BMS13-42A had numerous cracks in the insulation. Most of the cracks in this bundle were found to expose the core conductor when examined by microscope. Only within five feet of the aft end of the W480 bundle from station 570-900 were insulation cracks found. The insulation of the BMS13-42A wiring in the station 980-1299 bundle had extensive heat damage and the group did

[31] The material is described in the Wright Laboratory meeting notes of August 21, 1997.

not determine which anomalies existed before the fire. The material specification qualified the wire for continuous 150 C (302 F) use. Qualification test requirements called for no adhesion after heating to 200 C and called for no cracking of insulation or smoking when heated to 250 C. [*8/27/97 Group Activity*]

The wire bundles were visually examined using plain white light, with occasional use of a hand magnifying glasses of 2.5 to 10 power and a variable power microscope of up to 90 power. General descriptions of each section of the bundle follow and a listing of numerous damage sites is attached. [*8/27/97 Group Activity*]

BUNDLE FROM FIGHT ENGINEER STATION TO STATION 570

[*8/27/97 Group Activity*]

The bundle from the flight engineer station to fuselage station 570 exhibited no burn damage and no evidence of arcing in, or adjacent to, the bundle. The forward end of the FQIS wires included a pin on the HI-Z wire from the connector at the flight engineer panel disconnect. A wire diagram showed that FQIS wires W480-Q324, -Q325, and -Q326 were respectively the HI-Z, Tank Unit LO-Z, and Compensator LO-Z. The bundle included numerous non-FQIS wires. The forward end of the bundle had three tags, stating:

First tag (yellow):	Second tag:	Third tag (yellow):
W480-Q324-20D W480-Q325-20R W480-Q326-20B	A green Tie-wrap with RA164 (“R” damaged)	D1663J

The wires at the aft end of the forward bundle, near station 570, were cut or had the copper strands splayed apart. Locations were also found where the nylon braid was mechanically[32] damaged and damage was visible to the FQIS wires. At each point of FQIS wire damage, mechanical damage was also found in the surrounding wires.

Multiple areas were found where the external insulation of wires marked as W42A/8/1-[varied] were found cracked, mostly as individual single sites. Along one wire were 6 cracks within a one foot section at about station 320[33]. In some cases, the next layer of insulation was visible. In some shielded wires, the shielding was visible.

Along the routing of the bundle were areas where a green color, similar to corroded copper, were found on the braided nylon sleeve material. Two locations of green marks were investigated after x-rays found material beside the core conductor within the woven or braided sleeve. These two areas were evaluated using a microscope with a video monitor and photo capability. The

[32] The term mechanical damage is used to denote observations of physical damage, such as pinching, shearing, flattening, deformation. The term excludes damage associated with fire, heat, or electrical events.

[33] Stations forward of 400 are very indefinite, since these would have been forward of the reconstructed fuselage and leading into an area which crosses over the cockpit ceiling, then routed around the circuit breaker panel to the flight engineer station. In the case of the forward-most bundle, use the station markings as simply a distance to examine position relative to the known location of the break at station 570.

microscope was a Leica 420 with a Sony 3CCD videocam, video monitor, and Sony UP5600MD printer.

The first area was at about station 388. The nylon sleeve showed a blue-green discoloration and a slight bulge was noted. The nylon sleeve was removed for about 1" on either side of the bulge. Two breaks were visible in the outer insulation of the white HI-Z wire, one circumferential and one longitudinal intersecting each other, resembling an impact-type of fracture; the circumferential break contained a larger amount of corrosion material. A side view showed a bulge in the outer insulation at the location of these breaks. The outer insulation was peeled back to expose the braided shield. The braided shield was corroded in an area of about 1/2 the wire diameter beneath the breaks. Corrosion had progressed in both directions along the shield for at least 1/4". The corrosion material was gently removed and the insulator of the primary conductor was observed to be undamaged.

The second area was about 20 inches from connector D1663J (one pin from the connector was still attached to the end of the bundle). The nylon sleeve had a blue-green discoloration and a slight bulge was noted. The nylon sleeve was removed in this area and crystal deposits resembling salt were found on the blue LO-Z wire. The deposits were washed away with alcohol and an impact-type fracture was found. Deformation of the red and white wires in the same location were also noted and those wires appeared to be crushed in this area.

Following are other observations pertaining to the bundle:

Station	Wire	Defect Observed	Comments
300	general	several broken wires, other end of wires (forward) are missing	
	W528-1W522 W528-2W522		Two wires in a green sleeve coming from station 570 and ending about 15 feet forward of station 570, although the green sleeve is missing in the forward portion. The wire diagram showed that these two wires were fire extinguisher bottle low pressure warning light circuits. 1W522 was for #1 engine and 2W522 was for #2 engine. The green Varglass sleeve was found tied to the bundle from about station 400, forward, with occasional breaks but the wires inside are missing.

BUNDLE FROM STATION 570 TO STATION 900

[8/27/97 Group Activity]

The wire bundle was found unburned and approximately half of the W480 bundle was tied to another bundle. The individual wires were found tied into bundles at less than one foot intervals. The FQIS wiring was contained in a sleeve and not visible where the sleeve had not been breached. All but three wires at the forward end of the bundle were cut within a three inch length and the individual wires were found sheared to one side under 10X magnification. The aft end of the bundle (from the forward edge of the fuselage breach) was found broken over about five feet of length. No rounded balls of copper were found on the ends of the individual wire strands. A sticky white compound was found in a nylon clamp that had attached the cable to structure and could be seen where other clamps had been stripped away. A scanning electron microscope

listed the elements of the compound and at 250 volts and over a .5 inch distance, the material was found to have an electrical resistance of about 100 megaohms.

Following are the observations.

Station	Wire	Defect Observed	Comments
			Bundles W294, W528, and W934, only; no FQIS wiring.
810	general	several cut wires, cracked insulation, damaged sleeving	General area about 6" long in bundle with damage. Damage also on W942 and W480, held near this bundle with a clamp. No sign of overheating or arcing in this area.
850	general	a few cut wires, cracked insulation, some damaged sleeving	Appears as mechanical damage with no sign of overheating or arcing in this area.
860	W528-1W27	3" to 4" of shielded and jacketed wire with jacket, shield and insulation of primary conductor missing.	Fire warning wire. Wire bundle tie goes around the middle of the area of missing insulation.
860	W492-1Q28	4" to 5" of wire with insulation missing	
860	general	other wires with cracked insulation in this area	
880	general	broken wires and missing insulation	from this point on (approx 2 - 3 feet) is extensive mechanical damage to the wire bundles.

BUNDLE FROM STATION 980 TO STATION 1299

[8/27/97 Group Activity]

The FQIS wires were found to be missing most of the sleeve material and were tangled with other wiring. The FQIS wires had no signs of damage from an electrical arc. The non-FQIS wiring had heat damage to the exterior wire surfaces, however, in no area was the insulation found carbonized or locally burned away. Following are the observations made during examination of the bundle:

Station	Wire	Defect Observed	Comments
990	white	Outer insulation cut and corrosion found on shield	Mechanical damage, longitudinal cut
1008	all	Mechanical defect, cracked insulation, broken strands on red & blue	Red wire has longitudinal crack in insulation. No sign of arcing or overheating on FQIS wires
1080			Outer nylon sleeve visible
1115			Outer nylon sleeve terminates
1126	all		All three wires end are cut cleanly, as if by a tool, with each cut end matching the opposing wire of the same color.
1168	White	Pin-hole	Underlying area swollen & greenish
1230	Blue	Not through insulation	
1233	White	Nick in white is not through insulation.	
1235	Red & White	Flattening of red matches indentation in white.	A4
1245			4-1B
1258	White	Insulation cut or cracked.	A3
1260	White	Outer insulation missing	
1273-1277	White	Exposed shield.	

1274	White	Insulation split of .3 inch.	MSFC siteA2
1277-1282	White	Outer ins. Intact but scuffed.	
1279	Red	Longitudinal insulation has .3 inch split	A1
1284	Blue	End of wire	
1284	Red	End of wire.	
1281-1299	White	Wire braid cut from 1267 & exposed to end of bundle.	

Selected wire ends from the station 980 to 1299 wire bundle were examined with a microscope that had a video monitor and photo capability. The microscope was a Leica 420 with a Sony 3CCD videocam, video monitor, and Sony UP5600MD printer. Samples of seven wire examinations follow:

1) The FQIS wires (White HI-Z, Red Tank Unit LO-Z and Blue Compensator LO-Z) were examined in this area. The white HI-Z wire was labeled A-2 and was at about station 1274. The braided shield was present and the strand ends of the shield were drawn in appearance and tapered. The inner insulator appeared drawn and was tapered; the inner conductor was separated inside of the insulator (masked by insulation).

   The red Tank Unit LO-Z wire was labeled A-1 and was at about station 1245. There was a longitudinal break in the insulation and silver plating was visible on the conductor strands. The strand ends appeared drawn and were tapered.

   The blue Compensator LO-Z wire was also labeled A-1 and was at about station 1245. The strand ends were drawn and tapered.

   The remainder of the wires observed were not FQIS wires, but were BMS13-42A wires that were observed at various places throughout the wire bundle.

2) A wire labeled Sample 4-10 was found near station 1000. The insulator was found molten and the insulation material had a translucent appearance, similar to material seen near strand ends of other samples. The strand ends were drawn and tapered.

3) A wire labeled Sample B at station 1020 had drawn and tapered strand ends. A second site had a strand end with two tips held together by some material.

4) A wire labeled Sample A found at about station 1050 had a few of the copper strands with beaded ends, but the majority were drawn in appearance or cone-shaped. This and sample B were both part of a three wire BMS13-42A 18 Gage conductor set, but the sleeve and wire ID's were missing. The wire colors were red, yellow, and blue.

5) A wire labeled Sample C was found at about station 1080 and had drawn and tapered strand ends. There was also an elongated globule of melted insulation at the wire end.

6) A wire labeled Sample 4-1L was found between station 1080 and 1165 and ended in melted translucent insulation material. Through gaps where the core conductor was visible, tin plating was found on the wire strands.

7) A wire labeled Sample D was at about station 1165. The strand ends appeared drawn and tapered. One group of approximately 6 strands was held together by what appeared to be melted insulation.

BUNDLE FROM UNKNOWN LOCATION

[8/27/97 Group Activity]

The bundle was received with five nylon P-clamps on mounting stand-offs and a loose piece of wire that was hot-stamped W480-Q244. The twisted and jacketed three wire bundle was unmarked, but of the same configuration used for FQIS common to all fuel tanks. Wire markings of other wires attached to the three wire bundle were checked against bundle routing diagrams and found to match the W480 routing with none from another bundle. No other fuel tank wiring was found in this routing.

Plastic clamps were found to have white paint overspray on standoffs, similar to that seen in the lower fuselage, beneath the floorboards. The section had double clamps and standoffs that were similar to clamps seen in photographs of N93105, where the routing ran vertically along the left wall of the fuselage at station 900, then ran inboard beneath the floorboards to the raceway. The ends of the wires in the unknown bundle did not match ends of the bundle from 570-900 and 980-1299.

The ends of the wires had no evidence of heat or balled copper strands and the ends of the bundle had extensive mechanical damage. The wires had extensive physical trauma, including numerous cuts, scrapes, and crushing. The five P-clamps were displaced so that they had come together toward the middle of the bundle length.

Following are the observations made during examination of the section. There is no station reference, the reference used here is from the end of the wire furthest from the clamps.

Station	Wire	Defect Observed	Comments
27	red & blue	Red wire insulation cracked and conductor coming out	Blue wire damaged in same vicinity and the conductor is visible. About 2” of sleeve is missing in this location
33	sleeve		Brownish mark on sleeve appears as a pen mark
70	blue	Abrasion on blue wire	Conductor is exposed through a .4 inch opening in sleeve
113			End of wire

There were two items found, which were labeled A and B by the group:

Station	Wire	Defect Observed	Comments
A-11	other	Abrasion about 11” from end	W480-Q244 wire attached to bundle by ID tag wire, wire type is marked as 42A/8/1/20
B-8		Pinched, insulation is damaged	Wire W1362-2K179
B-12		Damage to top coat, cracked	Wire W1362-2K179

			Circumferential cracks found at various locations along the wiring. General mechanical damage and scrapes were found. These damages were not associated with any noted defects in the FQIS wiring, and there is no sign of overheating or arcing.

HYDRAULIC SYSTEM (ATA 29-00-00)

The B-747 is equipped with four engine driven hydraulic pumps (EDP), four air turbine driven hydraulic pumps (ADP), and one electrically driven pump. [*10/26/96 Group Activity*]

All four EDPs[34] were found and identified, as well as four other pumps[35]. Three of four air turbine drive units were found with varying degrees of impact-type damage. None of the ADP turbines exhibited evidence of high energy damage in the plane around the turbine wheels and none had data plates. The electrically driven pump was not found. [*10/26/96 Group Activity*]

PRESSURE REGULATOR BYPASS VALVE [*10/26/96 Group Activity*]
No Tag, Serial Number 792, Recovery date on part 09/09/96. The unit was located intact and separated from its mount. The valve showed signed of some post-impact corrosion. Three lines into the unit were sheared off at the tops of their respective B-nut connectors.

MAIN HYDRAULIC RETURN FILTER (ONE OF FOUR) [*10/26/96 Group Activity*]
Green Tag No. C-186. Recovery date on part 08/08/96. The unit was intact with salt water and corrosion deposits. Two differential pressure button locations were located. One of the differential pressure buttons was in the stowed position and safety wired. The other differential pressure button was missing and the safety wire was broken. The ground power attachment fitting was attached and the dust cover was in place. The filter module unit was still attached to a part of the bulkhead. The bulkhead box was bent down and broken off 8 inches aft of the unit.

MAIN HYDRAULIC RETURN FILTER (TWO OF FOUR) [*10/26/96 Group Activity*]
Green Tag No. C-2022, Recovery date on part 08/18/96. Unit was completely broken from its mount. Both differential pressure buttons were flush with the unit and their safety wires were intact. The ground power attachment was broken off at the 90-degree elbow and was missing. The hydraulic output line was broken at the B-nut. The nut showed some impact damage. The hydraulic input line was sheared off at the B-nut. The nut remained intact and showed no damage. The housing for the poppet was broken in half exposing the threads. The poppet, spring , plug and O-ring housed in the unit were missing.

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34 #1 EDP S/N MX255144, #2 EDP MX205070A, two EDPs with no data plate.

35 P/N 15201, S/N 237; S/N MX425096; S/N 121005 with motor S/N 15244; S/N MX 245550 with part of ADP housing attached

HYDRAULIC SYSTEM PRESSURE FILTER MODULE [*10/26/96 Group Activity*]
Green Tag No. C672, Recovery date on the part: 08/22/96. The body of the unit was intact. Some minor post-impact corrosion was observed on the unit body surface. The ground service disconnect fitting was bent down and broken. The delta-P button on the unit was missing. The safety wire to the button was broken. The temperature switch was broken off. The pressure switch was still in place. A one-inch diameter line running out of the unit was bent and broken in several locations. Three inches of the air driven pump control sensing line extended out from its B-nut connection. The metal mesh surrounding the line was frayed. The internal line was broken.

INDICATING / RECORDING SYSTEMS (ATA 31-00-00)

TWA avionics engineering personnel were asked what avionics equipment in the airplane had recording capabilities, other than the cockpit voice recorder (CVR) and the flight data recorder (FDR). Specifically checked was whether the Aircraft Integrated Data System (AIDS) or Air Carrier Automated Reporting System (ACARS) units were of an older type that utilized a magnetic tape medium. It was found that the CVR and FDR were the only recording devices aboard the airplane. [*10/26/96 Group Activity*]

Wiring diagrams and other engineering/maintenance documents show that 115 VAC power wiring from both the cockpit voice recorder (CVR) and the flight data recorder (FDR) are routed above the right side of the passenger cabin from near the flight engineer panel (P4) along a raceway depicted by an "H." Each of the recorders are mounted in the aft fuselage, above and behind the fifth door on the left side of the airplane. Wiring diagrams and discussion with the responsible avionics engineer at TWA revealed that the CVR and FDR would both cease to function after loss of 115 VAC ESSENTIAL bus generator power from the engine driven generators. [*10/22/96 Group Activity*]

Approximately 79 of the 215 foot long FDR power wiring was identified and examined, the majority of which was in the forward fuselage. About 86 of 188 feet of the CVR power wiring was identified and examined and again, the majority of this wiring was in the forward fuselage. The recovered wiring was 100% visually inspected; no evidence of arcing or short circuits were found and all wires had tension-type failures or cut ends. [*10/22/96 Group Activity*]

Short segments of CVR and FDR data wiring from the upper raceways were found in the forward fuselage and in the aft fuselage. However, little of the wiring was found from the center of the fuselage. [*10/22/96 Group Activity*]

LANDING GEAR (ATA 32-00-00)

WING LANDING GEAR (ATA 32-12-00)

[*10/26/96 Group Activity*]

LEFT WING LANDING GEAR
Was found almost structurally complete, but twisted and missing many electrical and hydraulic accessories. The retraction actuator was found in a mid position, about 2 ¾ inches from full gear down. The #1F tire and brake assembly remained, as well as the 2F brake stator.

RIGHT WING LANDING GEAR
The landing gear was almost complete, with the retraction actuator attached. The retraction actuator was found in the gear up position. Has the 7F wheel/brake (no tire) and 7R tire/wheel/brake assemblies mounted.

WING LANDING GEAR DOORS (ATA 32-12-00)

[*10/26/96 Group Activity*]

LEFT WING GEAR DOOR SAFETY VALVE AND CABLE QUADRANT
Green Tag No. Z3026. Recovery date on part: 09/08/96. The unit was intact and connected to a piece of keel beam structure by two of its four mounting bolts. Two of the bolts were missing. The mount was bent and broken. Several feet of control cable was identified with the unit and wrapped around the mount structure. The linkage between two arms on the unit was intact. The feedback lever out of the unit extended 14 inches and was necked and broken at the end. One hydraulic line into the unit was broken 2 and 1/4 inches outward from the B-nut. Approximately 17 and 1/2 inches of hydraulic line ran from the unit and was bent and broken at the end.

BODY LANDING GEAR (ATA 32-13-00)

[*10/26/96 Group Activity*]

LEFT BODY LANDING GEAR
The lower portion of the left body gear was found twisted with a portion of a structural beam attached. A mark from the mating area of the uplock hook was found on the retract pin. The landing gear has the 3R wheel& brake assembly found (without tire) and 3F brake remaining. The steering actuators were found evenly extended.

RIGHT BODY LANDING GEAR
The right body gear was found with more than six feet of struture. The steering actuators were found with similar extensions. No tires remained, but all four wheel/brake assemblies were found on the axles. Only position 6F had a tire mounted on the wheel/brake assembly.

BODY GEAR TRUCK POSITION ACTUATOR PRESSURE REDUCING VALVE

Recovery date on the unit 09/09/96. The unit was found intact with the mounting bolts bent and broken off. Three hydraulic line fittings were broken off at the tops of the fittings.

NOSE LANDING GEAR (ATA 32-21-00)

[10/26/96 Group Activity]

The actuator was found loose at the end opposite the landing gear and in the extended position with grease splatters on the shaft, but the shaft was not visibly bent. A similar actuator extension was seen in a photo with the landing gear in the retracted position. The retraction mechanism was found loose and moveable. The hydraulic lock actuator housing was found burst lengthwise with the shaft in the extended position.

MAIN LANDING GEAR EXTENSION & RETRACTION (ATA 32-30-00)

[*10/26/96 Group Activity*]

Diagonal scratches on the main landing gear rollers in the contact areas of the landing gear uplock hooks and extended actuators were found. Three of the four main landing gear uplocks were found in the retracted positions; a piece of a fourth uplock was found in the extended position, but the springs were stretched and the little remained of the mechanism. The actuator extensions were not seen for either body landing gear; for the left wing was at an intermediate position of 2¾ inches from gear down, and was in the full gear up position for the right wing landing gear. The landing gear handle in the cockpit was found in the center position, marked "OFF".

LEFT HAND MAIN LANDING GEAR SELECTOR VALVE
Unit was intact and showed signs of post-impact corrosion. Input shaft into the unit was frozen in position. Two hydraulic line location fittings into the unit were broken. Both B-nuts and hydraulic lines were missing. One hydraulic line was broken off at the hex-nut flange. Approximately 18 inches of tubing from one hydraulic line ran from the fourth hex-nut fitting. The tube was necked and broken laterally at the end.

NOSE LANDING GEAR EXTEND & RETRACT (ATA 32-34-00)

[*9/11/97 Group Activity*]

The nose landing gear (NLG) doors were found without damage that matched crushing damage seen in adjacent structure. The structure of the doors and surrounding fuselage was examined and documented by the Sequencing Group and is described separately. Systems documentation and wreckage was examined for indications of pre-impact position and is described in this document, in preparation for removal and laboratory examinations.

The right side wall of the NLG compartment had a heavy black rubber deposit, although the tire did not have apparent matching damage. The NLG sequence valve shaft remained attached to the bracketry and the valve body was missing.

In summary, the pre-impact positions of the doors could not be determined from the systems components. The NLG door sequence valve was found hanging by a hydraulic line in the nearly retracted position and measured 1.2 inches from the bolt centerline to the valve face. The NLG door safety valve was found in the (upward) ON position and not toward the OFF labeling to either side of the shaft. The NLG actuator extension measured 27.5 inches between the bolt centerlines and was in the extended position. The input shaft on the NLG actuator was almost vertical (up) and measured 26^{o} above the longitudinal axis of the actuator. The positions of two main landing gear selector valves in the (aft) wing landing gear wells were found in the DOWN position on the right and UP position on the left. Four electric actuators were examined, one of which was visibly cleaner and different than the other two. The diver sheet for material which the part was recovered in, contained a location in the red zone, to the south of the yellow zone.

Boeing documents showed that the forward NLG doors are moved by a hydraulic actuator and the actuator is positioned hydraulically by a sequence valve. The aft NLG doors are moved by a crank slaved to the NLG. Within the NLG door hydraulic actuator is a mechanical locking feature. The three methods of releasing the NLG and four methods of commanding the sequence valve to release the doors found were:

1. Normal hydraulic sequencing of the landing gear.

   According to the Boeing 747 Operations Manual (page 18.50.01), normal power for NLG extension and retraction is supplied by hydraulic system No. 1. The Boeing 747 Operations Manual (page 18.50.01) also states that "Should either hydraulic source fail the ALT HYD GEAR EXT switch allows for extension of all gears from the remaining source", shown elsewhere on the page as system No. 4 for NLG. "The alternate gear extension system provides electrical unlocking of the doors and landing gear after which the gear weight, air loading and CO_2 bottles ensure extension to the locked position."

   An illustration (257U1000, sheet 3) shows that a cable is routed from the cockpit control handle to the (aft) right wing landing gear selector valve. The left wing landing gear selector valve is then actuated by another cable set from the right valve. A set of hydraulic lines are routed from the left valve to the NLG compartment.

   The right selector valve was found in the installed position in the (aft) wing landing gear well, although the entire assembly was loose from the sidewall. The cable quadrant was broken and freely moved. The input shaft missing spline was oriented[36] to 34.5 degrees counterclockwise from the neutral position. Boeing drawing 60B00216 shows the full gear down position to be 34 degrees counterclockwise.

[36] Angular dimensions may have a small amount of error due to distortion of levers and shafts.

The left selector valve was found free of any other wreckage, including the cable quadrant. The valve was marked with "FT NOV 19 1970." The input shaft missing spline was oriented to 25 degrees clockwise from the neutral position. Boeing drawing 60B00216 shows the full gear up position to be 25 degrees clockwise.

A set of hydraulic tubes are routed between the left selector valve and two sequence valves, for the NLG and NLG doors. The tubes were only examined in a cursory manner. The NLG sequence valve piston remained, but the body was missing.

The NLG door sequence valve was found hanging by a hydraulic line in the nearly retracted position and measured 1.2 inches from the bolt centerline to the valve face.

The NLG door safety valve was found in the (upward) ON position and not toward the OFF labeling to either side of the shaft.

The NLG actuator extension measured 27.5 inches between the bolt centerlines and was in the extended position. The linkages to the input shaft of the NLG actuator were missing at the idler, to the right of the actuator installation. The linkage on the actuator housing was almost vertical (up) and measured 26^{o} above (clockwise from) the longitudinal axis of the actuator. Drawing 60B00230 showed the unlocked position to be on the opposite side (counterclockwise) of the centerline and the 26^{o} clockwise position to be past the locked position. *Group Activity*]

Boeing design requirements (60B00230) state that the NLG door actuator is internally locked at the retracted end of travel and a pressure surge cannot inadvertently unlock the lock. However, the document also states that [within a 3000 psi hydraulic system], units marked with no letter "or letters "A" or "B" following the serial number, the unlock pressure shall be within 500 to 1000 psi at room temperature" or 500-1500 psi at -65 to 160^{o}F. For units marked with a "C", the unlock pressure should be within 700 to 1500 psi at room temperature" or 700-1500 psi at -65 to 160^{o}F. The part was found marked with a tag "RAM-LOC by RHUCOR" and had a serial number of 123BC.

2. Electrical ALT GEAR EXTEND from the cockpit.

The design provides for an electrical actuator and transmission assembly to be located at the left NLG well bulkhead. Similar electric actuators are used for each main landing gear and one was found attached to a main landing gear. Only in the NLG installation is the actuator not mounted in a landing gear well, as the NLG installation is mounted in the left side of the electrical and equipment center.

Four electric actuators were found, one of which was significantly cleaner than the other three. The FBI number of the clean actuator was found to correspond to a lot of parts recovered from south of the yellow zone, in the red area. However, no indexing marks were found to correlate to the rotational position of the actuator.

3. Manual release from the electrical equipment center. The airplane design incorporates provision for a port in the left NLG compartment bulkhead for a nose landing gear extension crank. The crank provides an alternative to the electrical actuator for the transmission.

   The crank was found, but the transmission was the same as for the electrical actuator and was not seen.

4. Mechanical release from the NLG compartment. The airplane design incorporates provision for a toggle that can be pulled from within the aft of the NLG compartment to release the NLG forward doors. Cable routed from the toggle was found in a tangle.

NOSE LANDING GEAR DOOR ACTUATOR TEAR-DOWN

On October 8, 1997, the nose landing gear door actuator (P/N 1U1198-3, S/N 0123) from N93119 was tested, disassembled, and examined by a Safety Board group at the manufacturer, Dowty Aerospace, in Los Angeles, California.

The actuator was cycled by hand and functionally tested according to the Dowty Acceptance Test Plan at 500 psi in low rate cycling and full stroke cycling with unlocking pressure of 800 psi. The unit passed the ATP tests. After disassembly, no indication of abnormal wear or damage was found.

BRAKES (ATA 32-40-00)

[*10/26/96 Group Activity*]

RIGHT MAIN LANDING GEAR BRAKE NORMAL & RESERVE METERING VALVES
Green Tag No. C-192, Recovery date on part 08/08/96. The unit was intact and showed signs of minor post-impact corrosion. Mounting bracket to the bulkhead was broken at two of the four locations. At the other two mounting locations, the mounting bolts were sheared off. Bolt holes showed slight elongation. Both metering valves were in place. The linkage arm connecting the two metering valves was intact. Three of four hydraulic lines were necked and broken at the hex-nut attachments into the unit. A fourth line was intact, but bent at the hex-nut connection. Approximately 10 inches of tubing remained. The tubing was necked, bent laterally and broken off at the end.

HYDRAULIC BRAKE SHUTTLE VALVE
Green Tag No. C730, No recovery date found on the part. The body of the unit was intact. There were signs of some minor post-impact corrosion on the surface of the unit. Three of the four hydraulic lines into the unit were bent and broken off at differing lengths. One line measured 5 inches. The second measured 7 inches. The third measured 4 and 3/4 inches. A

fourth line was bent back on itself and broken. It measured 6 inches in length. Two hydraulic lines out of the unit were identified. One line was broken off at the B-nut. The other line extended 4 inches out from the B-nut and was necked and broken. The two mounting bolts to the unit were intact. A two inch piece of structure remained between the mount and the hex-nuts.

NORMAL ANTI-SKID MANIFOLD
Green Tag No. C-747, Recovery date on the part 08/26/96. The unit was broken in two predominant places. The four control valves were identified. The two inboard control valve housings were broken off. The control valve mechanism was bent. The two outboard control valve housings showed minor damage. Approximately 28 inches of tubing was bent slightly upward and ran out of the unit from the B-nut. Four lines exiting the top of the unit were sheared at the B-nuts. The 5/8th tubing from the hydraulic brake release line ran from the hex-nut approximately 72 inches before coming to in inward bent 4 and 1/2 inches from a B-nut at the end of the line.

RESERVE ANTI-SKID MANIFOLD
Green Tag No. Z-2502, Recovery date on the part 09/08/96. The unit was intact and separated at the mounts. Four hydraulic lines running out of the unit were sheared off at the B-nut connections. The input line into the unit was broken off at the hex-nut. The brake release line was broken off at the hex-nut. One of the two valve housings was broken off and missing.

TIRE EXAMINATIONS (ATA 32-45-00)

[10/18/96 Group Activity]

Seventeen of the eighteen landing gear tires were brought to the Grumman Naval Weapons Center, located at an airport in Calverton, New York, for examination and documentation. Only tire 7F was missing[37]. [*Note: Recovered after the 10/18/96 group activity report was agreed to and which is copied here in the entirety.*] All Fifteen of the main landing gear tires were found burst with evidence of external forces. No signs of internally generated failures associated with heat or other operational factors were found. All exhibited secondary superficial cuts and gouges that were consistent with the general wreckage of the wheel wells. Tire 7R had a tread cut that penetrated almost to the inner surface and this cut was at the center of the burst.

Each of the four tires mounted on the left wing main landing gear had marks on the surface that were not seen on any other tire. The marks were located in the centers of the burst damage and appeared similar to light burning of the rubber material, surrounded by periodic shallow ripples. The ripples were not similar to the chevron type of marks seen in landing scuffs, in that the ripples were centered around the burn appearances. A swab sample was taken of each by the Federal Bureau of Investigation chemist. Immediately forward of these tires in the stowed positions would have been the broken aft wall of the center wing fuel tank.

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[37] The numbering convention for the main landing gear tires are shown in an attached illustration. Tire 7F would be the inboard forward tire on the right wing main landing gear.

Examination found that most of the tires had been retreaded. All Goodrich tires were found to have been retreaded by Goodyear, although the retread name may have been identified as "Air Treads." Both nose tires and the tire mounted in the 1R position had not been retreaded.

The nose landing gear was reported to have been found floating with the tires attached, although one had been loose and was not on the landing gear when examined. Neither of the nose landing gear tires were found burst. Each tire was found with a note that the tires had been deflated after recovery. One of the nose tires had shallow burn damage to the rubber.

NAVIGATION (& AVIONICS) (ATA 34-00-00)

An inventory of the recovered avionics was not required or conducted. Included in the piled wire and other debris from the cockpit and E/E were numerous avionic components. When searching for various avionic components, none were missing.

TRANSPONDER, AIR TRAFFIC CONTROL [*10/26/96 Group Activity*]

Review of wiring diagrams, discussions with the TWA Engineer responsible for the system, and a functional test on another airplane showed that transponders would not function after loss of AC electrical power from the engines, regardless of flight engineer panel switch positions.

CENTRAL AIR DATA COMPUTER (CADC) [*10/26/96 Group Activity*]
TWA P/N 31074, Boeing P/N 60B00058, S/N 7001113

The B-747 Maintenance Manual identified the part number as that of an analog, rather than digital, CADC. The written description notes that each CADC:

> provide shaft rotations for 21 electromechanical output devices…shaft information is transferred to aircraft instruments and systems requiring air data by standard three-wire synchro outputs, two-wire ac voltage analogs, and dc voltage ratios.
>
> Abnormal computing servo performance or power failure triggers a self-monitoring failure warning system within each computer. The failure warning system then activates indicators on the computer's failure warning panel display and warns each affected instrument and system using that particular computer output.

OXYGEN (ATA 35-00-00)

Oxygen panels from the cockpit were submitted to the NTSB Materials Laboratory and are the result of a separate report.

Passenger oxygen bottles and walk-around oxygen bottles were received, many of which had been damaged. The larger oxygen bottles were found without fire damage and no localized fire damage was identified around components identified as having been part of the oxygen system, other than what was found in the mid and aft cabin areas, aft of the wing leading edge, that exhibited wide-spread fire damage near the center wing fuel tank. Compressed gas bottles are listed in an inventory of the hazardous materials bunker. [*10/26/96 Group Activity*]

LAVATORY, INCLUDING WATER/WASTE (ATA 38-00-00)

TOILET TANK, UPPER DECK [*10/26/96 Group Activity*]

The top surface of two toilet tanks were cut from the wiring of the aft cockpit area. The exterior surfaces had a slight blue-green stain. On localized areas of the inner surfaces was a black tar-like material, but this blackening was restricted to only those localized areas.

AIRBORNE AUXILIARY POWER (ATA 49-00-00)

All compressor and inlet guide vanes visible were found intact, as were the turbine blades seen in the exhaust duct. The APU generator was not attached to the engine. [*10/26/96 Group Activity*]

At station 2600, two of the three right APU generator cable phase fuses were found and those were intact. [*10/26/96 Group Activity*]

DOORS (ATA 52-00-00)

The aircraft doors were found broken and have been described by the Structures Group in their report. Also found in the recovered wreckage were pressure bottles from the door assemblies, some of which had gauges showing that the bottles were empty. The other three door bottles had no pressure gauges remaining. Compressed gas bottles are listed in an inventory of the hazardous materials bunker. [*10/26/96 Group Activity*]

FUEL FLOW INDICATOR (ATA 73-30-00)

The following system description is a synopsis of information from the B-747 Maintenance Manual, the TWA Wiring Diagram Manual, and the General Electric Type 8DJ164 Fuel Flow Indicator Overhaul Manual:

The fuel flow indicating system measures the instantaneous fuel flow rate and the fuel consumed by each engine and provides continuous visual indication of both values on indicators located on the flight deck. The system consists of a servo fuel flow rate indicator, a synchronous motor type fuel used indicator, a fuel flow transmitter for each engine, an electronic module and a fuel used indicator reset switch. Power for the system is 115 VAC and power for the fuel used indicator reset operation is 28 VDC.

The fuel flow transmitter measures the fuel flow rate to each engine. Fuel to each engine is passed through a fuel flow transmitter that converts the fuel flow rate to electrical pulse signals. These pulse signals are processed in the electronic module and transmitted to the indicators.

An interruption or change to these signals caused by component failure, EMI, or wire faults including but not limited to open shields, intermittent open or shorted wires, loose connectors or solder joint deterioration could cause an erratic indication. Other possible causes in the indicator or transmitter include excessive contamination lack of lubrication, or misalignment of internal components. Other possible causes in the fuel flow electronic module include faulty parts or connections.

On July 1, 1997, a Safety Board group convened to examine fuel flow indicators from the N93119 airplane #1 engine position (S/N FF0387B), the #4 engine position (S/N DE0053), and an the fuel flow electronics module (S/N 241). The #4 indicator and the fuel flow module each contained evidence of having been internally repaired. Excerpts from the written record from that group stated that:

> BACKGROUND:
> The cockpit voice recording from TWA 800 reportedly indicated that there had been an anomaly with the fuel flow indicator from engine number four.
>
> SUMMARY:
> There was no direct physical evidence of an internal electrical failure relative to erratic or erroneous fuel flow indications. Tests performed were intended to verify the integrity of internal connections, remaining after the damage from impact, being submerged for a period of time in salt water and retrieval, relative to the functionality of the system. Internal examinations of the various components boards and discretes was limited to detecting failures which manifest themselves with direct physical evidence, such as; burning, arcing, or excessive heat.

Robert L. Swaim
Systems Group Chairman,