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

February 5, 2000

ADDENDUM TO SYSTEMS GROUP CHAIRMAN FACTUAL REPORT, FUEL QUANTITY INDICATORS

A. ACCIDENT : DCA96MA070

Location : East Moriches, New York

Date : July 17, 1996

Time : 2031 Eastern Daylight Time

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

B. SYSTEMS SUB-GROUP

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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). All 230 people aboard were killed. The airplane was being operated as a Code of Federal Regulations (CFR) Part 121 flight to Charles De Gaulle International Airport (CDG) at Paris. France, as Trans World Airlines (TWA) Flight 800.

A Systems Group met on August 19, 1998, to examine fuel quantity indicators (indicators) from the reserve fuel tanks of the accident airplane (tanks 1R and 4R). The group again met on January 11, 1999, to examine the gross weight/total fuel weight indicator (totalizer) from the TWA flight 800 wreckage.[1] The electrical connector from the CWT indicator was also examined during the meeting of January 11.

The Safety Board worked with the Boeing Engineering Quality Analysis Laboratory to examine two B-747 fuel quantity indicators on October 28, 1998. The inoperative indicators were not from the accident airplane and had been provided by an airline after maintenance personnel noted that the parts had an acrid burned smell.

The Systems Group obtained documents pertaining to the FQIS and indicator failure history and failure modes and the records included the number of spare part (transformer) shipments made by Honeywell and a transformer manufacturer. The search for documents about fuel quantity indication system (FQIS) problems also found Boeing Document (D3-11796-1), dated July 31, 1980, and titled KC-135 FUEL QUANTITY INDICATING SYSTEM FAILURE ANALYSIS. The report stated that a KC-135 aircraft experienced a ground fire in the aft body [fuel] tank, that a possible ignition source was

[1] The flight engineer station instrument is described in the Trans World Airlines 747 OPERATIONS MANUAL as the GROSS WEIGHT/TOTAL FUEL WEIGHT INDICATOR. An illustration in the manual shows the indicator with GROSS WT as an upper digital display and TOTAL FUEL WINDOW as the lower display. The group referred to the instrument by the reference "totalizer indicator" that Honeywell provided in the FUEL QUANTITY INDICATING SYSTEM MAINTENANCE DATA document (or as "totalizer").

believed to be associated with the fuel quantity probe, and that the manufacturer of the KC-135 FQIS had been Honeywell. An Air Force engineering assignment tasked Boeing Military Airplane Company (BMAC) to perform the failure analysis.

D. DETAILS OF THE INVESTIGATION

COMPONENT EXAMINATIONS

RESERVE INDICATORS

The group examined two reserve fuel quantity indicators at the Honeywell laboratory in Minneapolis, Minnesota. The data plates on the indicators had the following markings:

#1 Left Reserve Fuel Quantity Indicator

SPEC NO.	60B92010-1
MFR PART NO.	JG603C4RG1006AA01
SERIAL NO.	Q-150
TWA PART NO.	34127
SERIAL NO.	Q-150

#4 Right Reserve Fuel Quantity Indicator

SPEC NO.	60B92010-1
MFR PART NO.	JG603C4
SERIAL NO.	A-19
TWA PART NO.	Not Readable
SERIAL NO.	A-19

Both Reserve Fuel quantity indicators exhibited signs of corrosion and the indicator faces were missing. The electrical connector from indicator A-19 was pulled out of the case and the interior was

exposed. The case of indicator Q-150 was split at the mechanical section. The indicator cases were cut off and the circuit boards inside were found bent and cracked. Both indicator circuit boards were removed and cleaned.

The circuit boards in indicator A-19 were put into an operable indicator and the indicator worked properly, during the bench test, except the indicator could not be calibrated. Capacitors C6 and C7 were noted to be missing from the bridge card during the bench check and a review of the photographs showed that C6 and C7 were missing when the indicator was disassembled. Evidence of impact damage was found in the area. The missing components were in the control circuit and the group agreed that the calibration problem was due to the missing components.

The schematic (C13386AA02) provided by Honeywell for the examination shows that connector pin 11 provides an airframe ground through capacitors C6 and C7. The Honeywell representative noted that without this ground the capacitance circuit would create a low indication and that operation would be affected. The bench test indicated a zero value of 188 picofarads (pf[2]) and full value of 362 pf, with a calibration error of 30 pf. The group agreed that indicator A-19 appeared to have been able to function prior to the accident. The circuit boards were then removed from the sample indicator.

The amplifier circuit board from Indicator Q-150 had impact damage to the C5 capacitor and Q4 transistor and both damaged components were found in the case. Both components were replaced and the circuit boards were soldered into the sample indicator used to test the components from indicator A-19. The unit could not be calibrated during bench tests: with the zero fuel indication at 185 pf and full indication at 413 pf. The calibration errors were 32 pf at zero and 51 pf at full. The group agreed that indicator Q-150 appeared to have been able to function prior to the accident and then removed the circuit boards from the sample indicator.

TEAR-DOWN OF GROSS WEIGHT/TOTAL FUEL WEIGHT INDICATOR (totalizer)

The totalizer was received without extensive distortion of the case. the glass missing from the case, and a puncture in the top surface. At the face of the indicator. the GROSS WT display on the face of the indicator was between 587.0 and 588.0. The TOTAL FUEL display digits were between 169.0 and 170.0. When touched with a finger. the digits would slightly rattle, but did not change values. The set knob was bent downward and away from case center. The front bezel was loose and hanging from the knob.

The group found hand-written black ink spelling “TWA#34134” and orange ink-stamps spelling “MFD (illegible)9.” and “MAY 196(illegible).” The accident instrument had an outline of adhesive in the same area and shape as the data plate found on a sample instrument. Markings were found imprinted into the case and were in the same orientation as those on the sample. but the markings on the sample were not imprinted into the case metal. The markings were:

[2] A measurement of electrical capacitance.

For the sample instrument fields:

STOCK NO. SPEC NO.
MFR PART NO. SERIES SERIAL NO.
[NOMENCLATURE]

For the accident instrument markings:

60B92010-5
JG613C1 5 A-8
INDICATOR, FUEL QUANTITY AND GROSS WEIGHT

The upper two case screws located above the totalizer connector were found with space beneath the screw-heads and with visible thread. The forward (as installed) screw has a safety wire tab and gap of .06 inches. The aft screw has a .04 inch gap and is slightly tilted. Three of the case screws, including the two with visible thread, were loose.

The electrical connector of the indicator was received mated with the airplane side of the connector and slightly less than a foot of airplane wiring. The airplane wires were found to have the following pin orientation:

CONNECTOR PIN #	WIRE NUMBER	DIAM (in.) w/ INSULATION	COPPER DIAM. w/ NO INSULATION
1	W186-Q608	.053	
2	W186-Q638	.052	
3	W186-Q623	.052	
4	(Plugged)		
5	W186-L914	.052	
6	W186-L913	.053	
7	W186-Q753	.042	.030
8	W186-4743	.052	
9	W186-Q613	.050	.038
10	W186-Q618	.052	.038
11	W186-Q628	.052	
12	W186-Q633	.052	

The aircraft wire insulation measured about .007 inches thick and after stripping the wire ends, the wires were taped to a paper next to the associated pin numbers. All external wires were marked W42A/1/1/20. except for W186-Q753, which was marked W42A/1/1/22. The resistance between pairs of wires was checked with a Fluke 77 Multimeter (measurements attached).

The connector was opened without difficulty and two pins from the indicator remained with the red rubber grommet of the connector. The pins were from location numbers 9 and 12. that the electrical schematic provided by Honeywell shows for tanks one and four, respectively. Small bits of material fell from the opened connector area and under 10X magnification the material contained both gray, black,

and red particles. The red particles were approximately the same shade as a o-ring found inside of the connector.

A break-out connector was attached to the instrument and the continuity across most of the instrument pins were checked with the Fluke 77. Those values that were beyond the capability of the Fluke 77 multimeter were measured with a Multimeter of (maximum) 2.8 giga-ohm capability (Hewlett-Packard Model 3457A, found with the Fluke 77 to have an output of 1.45 volts at 11 megohms). In each of the electrical measurements, the lowest resistance found to CWT pin 3 was .85 mega-ohms. in separate measurements to both the transformer and to pin 4. The CMM circuit diagram shows resistors between pin 3 and the case ground of (maximum) 739,000 ohms, although the Honeywell Overhaul Manual (October 1, 1982) indicates that the resistance between pin 3 and ground should be approximately 439,000 ohms maximum.

The case was cut open and the gear from the rebalance potentiometer (pot A1 R1) fell out of the case. The servo motor was loose, rusty, hanging by the wires, and the shaft would not rotate under light finger pressure. The case contained dried adhesive around the calibration resistor screw port. The rebalance pot (A1 R1) was found loose and hanging by the wires with the aft portion of the case separated and skewed. The transformer was found loose, with the mounting bracket broken at the forward edge of the core. The gray and brown wires were separated from the transformer body. A white/black wire was found loose behind the transformer, but a mating attachment point was not visible.

Although found electrically open (not in contact), the soldered internal side of connector pins 3 (CWT) and 11 (from tank 3) appeared to be touching and paper could not be slipped between the contacts. Slowly increasing voltage from a controllable source resulted in current flow (limited to .5 milliamperes) at a reading that was between the 250 and 300 volt graduations. The test was repeated three times. Post-test inspection found that the crack between the solder connections had opened slightly, but the crack was still less than half the width of a wire of .011 inch diameter.

The Honeywell Component Maintenance Manual (CMM) shows that the printed circuit card nearest to the external electrical connector was card A-2 and that it contains eight adjustable (variable) trim resistors. The circuit card was found slightly warped around the hole for the wire bundle, but generally intact. The A-2 card has 4 colors of trim resistors with 1968 and 1986 date codes. (Component manufacturer BOURNES provided the date codes.) The following observations were made for components on the card:

The R1 trim resistor was brown.

The R5 trim resistor was green, marked:

10025148-144 [IRC Company part number (p/n)]
6837 [date code]

The R9 BOURNES trim resistor was blue and marked with the following markings:

RJ22CW104
MADE IN MEXICO

8626M [date code]

The R12 trim resistor was black and marked:
10025148-147

The R14 trim resistor was black and marked:
M175PCT204A
200K
CTS 2968.

The R16 resistor was black and marked:
M175PCT204A
200K
CTS 2968.

The R18 trim resistor was black and marked:
M175PCT504A
500K
CTS6838.

The CMM indicated that the R20 and R21 resistors were installed in series in with connector pin 3, attached by airplane wiring to the center wing fuel tank compensator LO-Z. The R20 resistor was green and marked “6837.”

The A-3 printed circuit card was found tilted with the (as installed in the aircraft) forward side displaced about 1/2 inch toward the connector. The circuit card was more extensively damaged than the A-2 card. The following was found on this card:

The CR4 was found lifted at one end and separated from the card at the C1 end.

The C1 capacitor was found marked:
CK06CW 103K
200V
E8133 [date code]

The C2, C3, and C7 capacitors were not flush with the circuit card. The C2 and C7 capacitors were in a warped area of the circuit card and the area of the C3 capacitor was flat.

The C4 capacitor visually appeared cracked at the inboard lead.

The R2 resistor was found broken.

The R5 resistor was found cracked.

The R10 (RN55C1402F) resistor was loose at one end (area of damaged circuit card) and separated from the card.

The Q4 transistor was found rusty and rust was on the surrounding components.

EXAMINATION OF CWT INDICATOR CONNECTOR

After examination of the totalizer found the near-contact of solder at pins 3 and 11 (previous section), the connector from the CWT indicator was examined. The solder connections for the internal wires were found to have been had been previously removed by melting the solder for disassembly.

On the green encapsulated surface of the connector, an iridescent sheen was found between the center pin and pins 2, 3, and 4. The Maintenance Data Operations and Flight Data Manual (page 7, fig 2) shows the center connection to be from the shielded HI-Z. The figure shows pin 2 attach to the tank unit LO-Z wire (then to the refuel door switch and the aircraft press-to-test switch). pin 3 connect to the COMP LO-Z, and pin 4 connect to the 5V ground and aircraft frame. When electrically tested with a high resistance multimeter (HP Model 3457A), between all pin combinations. the readings were all greater than the measuring range of the meter (min. 2.8 giga-ohms). (Note: The Multimeter was checked with a Fluke 77 of 11.1 mega-ohm resistance and found to have an output of 1.13 volts.)

The CWT indicator wire harness (<12 inches of W186 wire bundle) was received with the airplane side of the connector. The assembly was electrically tested for continuity between all pin combinations with the high resistance multimeter (HP Model 3457A) and all measurements were greater than the measuring range (min. 2.8 giga-ohms).

TRANSFORMER FAILURES

The Safety Board worked with the Boeing Engineering Quality Analysis Laboratory (ref. EQA Report 1858T) to examine two B-747 fuel quantity indicators on October 28, 1998. The indicators had been provided by an airline after maintenance personnel noted an acrid burned smell. The examination found that the connector on each indicator had been improperly inserted into the worn connector of a ground test set during maintenance. Reference to an electrical schematic (C13386AA02) provided by the Honeywell representative revealed that the improper assembly had applied 115 volt (AC) power to circuits designed for less than 28 volts. The examination found that one indicator had a short circuit between the 115 volt (AC) primary transformer winding and the winding leading to the pin that connected to a fuel tank wire. Portions of the yellow tape on the windings of the transformer were dark

brown to black in color. The Honeywell schematic shows a limiting resistor between the transformer and connector pin.

Following tear-down of the indicators, the indicator tear-down records for transformers from the accident airplane were re-examined. For the indicators that were recovered and examined, the records did not reveal short circuits and none had the darkened areas on the yellow tape that had been found in the Boeing EQA examinations of the two failed transformers.

DOCUMENT SEARCH RESULTS

TRANSFORMERS

Manufacturer and operator documents pertaining to the FQIS and the indicators were obtained for an examination of FQIS failure history and failure modes. A November 19, 1998, letter from Schott Corporation, one manufacturer of transformers, stated that "short circuits between windings are a known failure mode for transformers of any origin. Typically, drawing excessive current from one or more secondary windings causes field failures of this nature."

The records from Honeywell and Schott show that 237 new transformers had been sent to airlines during the 1992 to 1998 period. Honeywell Service Bulletin JG603-28-01 provides instructions for the modification of a JG603C4 indicator into a JG603C80 indicator and that the modification requires replacement of the transformer. Honeywell wrote that "the quantity of 69 dash 106 transformers in 1992 is most likely associated with performing this modification."

CIRCUIT PROTECTION

The schematic provided by Honeywell shows a limiting resistor between the transformer and connector pin. Boeing and Honeywell did not have design records that specified the values (ohms) to be used for resistors that prevent introduction of energy into fuel tanks through the FQIS. The TWA wire diagram 31-35-33 (SGT 2, PAGE 1) shows that between the airborne integrated data system (AIDS) and splice SM65, which attaches wires that lead to the CWT, also is a limiting resistor (R468). Boeing described the sizing of the resistor value for an AIDS resistor in a letter of January 29, 1999.

Boeing Specification 60B92010 contains the following numbered paragraphs:

3.1.11.2 The energy supplied to the tank and compensator units shall not exceed .02 millijoules.

3.1.11.3 The current in the tank and compensator unit leads shall not exceed .010 amperes under any one of the following conditions:

a) Normal operation with any desired bridge circuit adjustment.

b) Failure of any component in the current limiting circuit.

c) Shorting of any or any combination of tank and compensator units and any capacitor in the bridge circuit.

3.1.11.4 The current in the tank and compensator unit leads shall not exceed .150 amperes under any combination of (b) and (c) above.

KC-135 FUEL QUANTITY INDICATING SYSTEM FAILURE ANALYSIS

A search for documents about fuel quantity indication system (FQIS) problems revealed Boeing Document (D3-11796-1), dated July 31, 1980, and titled KC-135 FUEL QUANTITY INDICATING SYSTEM FAILURE ANALYSIS. The report stated that a KC-135 aircraft experienced a ground fire in the aft body [fuel] tank, that a possible ignition source was believed to be associated with the fuel quantity probe, and that the manufacturer of the KC-135 FQIS had been Honeywell. The KC-135 report includes a complete circuit diagram and a diagram that shows the portion that Boeing studied. The studied portion includes (in order) a transformer, variable resistor, limiting resistor. (connector pin not shown), connected outside of the indicator to a fuel probe with a ground fault.[3] An Air Force engineering assignment tasked Boeing Military Airplane Company (BMAC) to perform the KC-135 failure analysis and the Boeing report is attached.

Robert L. Swaim
TWA800 Systems Group Chairman
2/7/00

[3] The Component Maintenance Manual (CMM) for Boeing 747 fuel gages shows the same items in the same order (without the ground fault).