

**NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594**

December 15, 2017

**POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT
NTSB ID: ENG16IA027**

A. INCIDENT

Location: Jamaica, New York
Date: July 7, 2016
Time: 1307 UTC
Aircraft: Boeing 757-200, N706TW, MSN 6804

B. POWERPLANTS GROUP

Group Chairman: Carol M. Horgan
National Transportation Safety Board
Washington, DC

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Federal Aviation Administration
Burlington, MA

Member: Becca Friesen
Delta Air Lines
Atlanta, Georgia

Member: Michael McDonald
Delta Air Lines
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Member: Paul Buron
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Member: Douglas J. Zabawa
Pratt & Whitney
East Hartford, CT

Member: Jerome T. Chaklos
AMETEK Aerospace & Defense
Wilmington, MA

C. INCIDENT

On July 07, 2016, about 1307 UTC, a Delta Air Lines (DAL) Boeing B752, N706TW, experienced a right¹ engine under cowl fire shortly after takeoff from John F. Kennedy International Airport at Jamaica, NY (JFK). The flight declared an emergency after receiving a right engine fire warning at approximately 400 feet agl. The flight crew reported that they shut down the right engine and that the fire warning extinguished following shutdown. Neither fire bottle was discharged. The flight returned to JFK and landed without incident. An airport rescue and firefighting unit met the airplane and determined that there was no active fire. The airplane damage was minor, and no injuries were reported. The airplane was being operated as a 14 CFR Part 121 scheduled flight from JFK to San Diego International Airport Lindbergh Field, San Diego, California (SAN). A post-incident airplane inspection found a hole in the right nacelle inboard core cowl consistent with a burn through. See Figure 1.



Figure 1. Right nacelle, showing cowling burn-through

DAL reported that maintenance performed the morning of the flight included replacement of the right engine fuel flow transmitter (FFT).

¹ Directional references are as viewed from aft of the aircraft looking forward unless otherwise noted.

An NTSB examination of the airplane at JFK found that the fire damage was limited to the right nacelle and the external components of the right engine. A rubbery, blue-colored substance was noted where the fuel OUT tube attaches to the FFT (FFT-to-fuel OUT tube joint).

It was determined that the flammable fluid source was a fuel leak at the FFT-to-fuel OUT tube joint. The FFT, fuel IN line and fuel OUT line were removed as an assembly. The assembly was pressure tested and a leak was observed at the suspect joint. The fuel OUT tube was removed, and the tube's O-ring was missing a 90° arc of material. The separated O-ring ends were shallowly angled. The O-ring was replaced with a new packing. The assembly was again pressurized, and pressure held with no leakage.

Several errors were found in the B757 Airplane Maintenance Manual (AMM) FFT removal and installation instructions during this work. The Boeing B757 FFT installation instructions were revised as a result of the findings.

D. DETAILS OF THE INVESTIGATION

1.1 Engine information

The incident airplane was powered by two Pratt & Whitney PW2037 turbofan engines.

1.2 Engine description

The PW2037 is a dual rotor, axial flow, high bypass turbofan that is takeoff rated at 37,530 pounds thrust. It features a single-stage fan and four-stage low pressure compressor driven by a five-stage low pressure turbine, a twelve-stage high pressure compressor (HPC) driven by a two-stage high pressure turbine (HPT), and an annular combustor.

1.3 Engine data

model	serial number	time since new (hours)	cycles since new	time since last shop visit (hours)	cycles since last shop visit	time since repair (hours)	cycles since repair
PW2037	728732	51,142	18,855	3,871	965	< 1	1

Table 1. Engine data, PW2037 engine S/N 728732

1.4 Engine service history

DAL airplane service records showed recent maintenance entries to correct an anomalous right engine fuel flow indication. The mechanic's notes describing this maintenance state that the fuel flow signal fluctuated during the post-maintenance engine run following a July 6, 2016 FFT replacement. The corrective maintenance was deferred in accordance with the airplane's minimum equipment list procedure. Another FFT was installed on July 7, 2016.² A 10-15-minute post-maintenance engine check run showed normal fuel flow indications, and no leaks were observed. The airplane was released to service. The under-cowl fire incident occurred during the next flight, shortly after takeoff.

² The FFT data plate was partially consumed by fire. DAL service records show that FFT part number 8TJ124GGN3, S/N B1382DL, was installed on the engine at the time of the incident. According to the FFT manufacturer, Ametek, B1382DL is not a valid S/N. A DAL records search on S/N B1382DL found a cross-reference to S/N 01382, which is a valid 8TJ124GGN3 S/N.

2.0 Flight data recorder (FDR)

Data downloaded from the airplane's FDR showed that a right engine fire warning occurred about three seconds before lift-off. The fire warning was active for about 45 seconds. The data also showed that the fire extinguisher switch was not activated and that engine parameter indications began dropping off about 55 seconds after the fire warning. All engine parameter data were lost approximately 24 seconds later. The loss of the engine signal data is consistent with wire thermal damage/separations noted during the engine examination.

3.0 Airplane damage assessment

An NTSB Powerplants Group was formed. DAL and Pratt & Whitney documented the airplane condition at a Port Authority hangar at JFK.

3.1 Pylon

The pylon was inspected through the access panel and door on the inboard side of the strut. No indications of soot, heat distress, or fire were found.

3.2 Nacelle

No thermal damage was noted to the inlet cowl or the fan cowls. The paint was blistered on the aft 11 inches of the thrust reverser cowl inner fan duct flowpath. The ablative coating on the inner surfaces of the thrust reverser cowl was intact between 12 and 3 o'clock³ and charred and fractured with some exposure of the underlying honeycomb structure between 3 and 12 o'clock. See Figures 2 and 3.



Figure 2. Thrust reverser cowl inner surface, 12 to 4 o'clock



Figure 3. Thrust reverser cowl inner 7 to 11 o'clock



Figure 4. Outboard core cowl

The skin at the aft end of the outboard core cowl was buckled between 4 and 6 o'clock. See Figure 4.

³ Clock positions refer to approximate circumferential locations in a clockwise direction viewed from the rear of the engine looking forward unless otherwise noted.

A cannon plug/lead wire assembly fell from the nacelle when the thrust reverser cowls were opened. These parts were identified as remnants of the partly-consumed FFT assembly shell and identification plate assembly.

The inboard core cowl was deformed and was missing a 25-inch long (axial) section at 7 o'clock. The missing section measured 3.5 inches wide at the forward end and 14.5 inches wide at the aft end and included the aft edge of the pressure relief door (PRD) cut-out. The edges of the hole were thinned and irregular. A pattern of discoloration and soot surrounded the PRD cut-out and missing cowl section and extended aft. See Figure 5. There were rough, matte-gray deposits adhering to the aft end of the exhaust nozzle outer surface between 4 and 10 o'clock. See Figure 6.



Figure 5. Right engine inboard core cowl burn-through



Figure 6. Exhaust nozzle deposits

The inside surfaces of the core cowls were coated with soot.

4.0 Engine damage assessment

Engine inlet and exhaust inspections found no evidence of mechanical failure. The N1 rotor turned freely at the fan with rotor continuity confirmed at the LPT. No abnormal fluid leaks were noted.⁴ There were no indications of uncontainment.

The engine fan section was in good condition, with no evidence of thermal damage. On the core compartment side of the bifurcation panel, tubes and components were sooted and the wiring, insulation and attachment hardware were thermally damaged. On the outboard side of the bifurcation panel, the tubes and wiring showed no evidence of thermal distress. See Figure 7. The panel bulb seal was in good condition. See Figure 7.

⁴ The EICAS right engine oil quantity indicated 22 quarts, which is considered full. An unpressurized hydraulic oil quantity indicated 1.20, which Delta Air Lines considers typical.

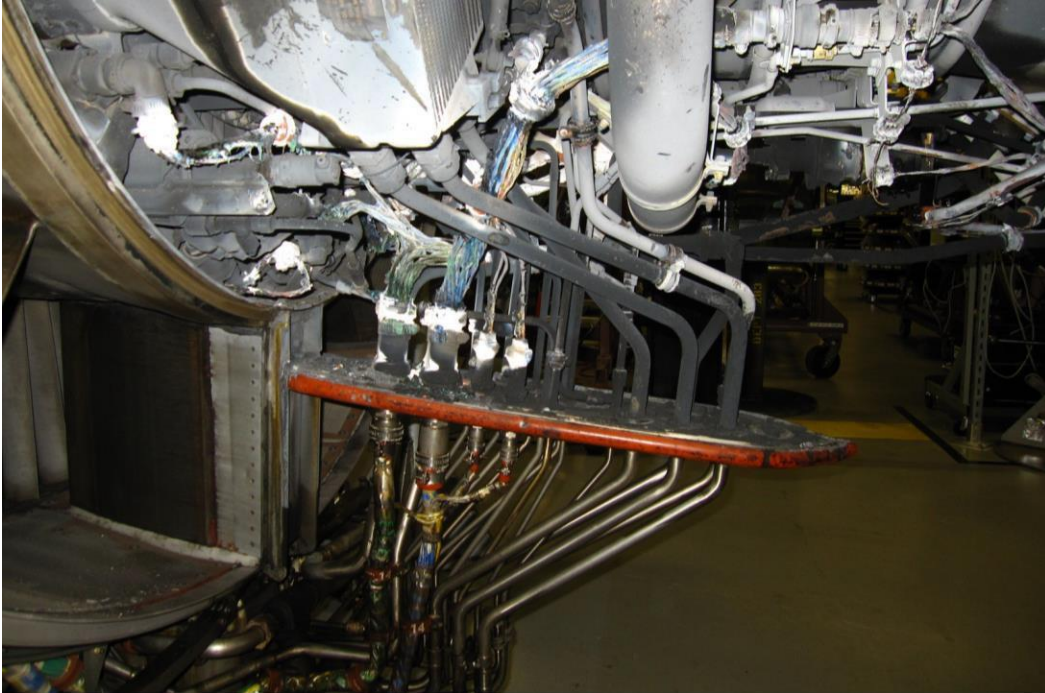


Figure 7. Bifurcation panel, showing isolation of the fire damage to the core compartment

The engine thermal distress was limited to the core compartment fire zone. Soot was deposited over the entire core. The HPC between 1 and 4 o'clock showed the least thermal damage. See Figure 8.

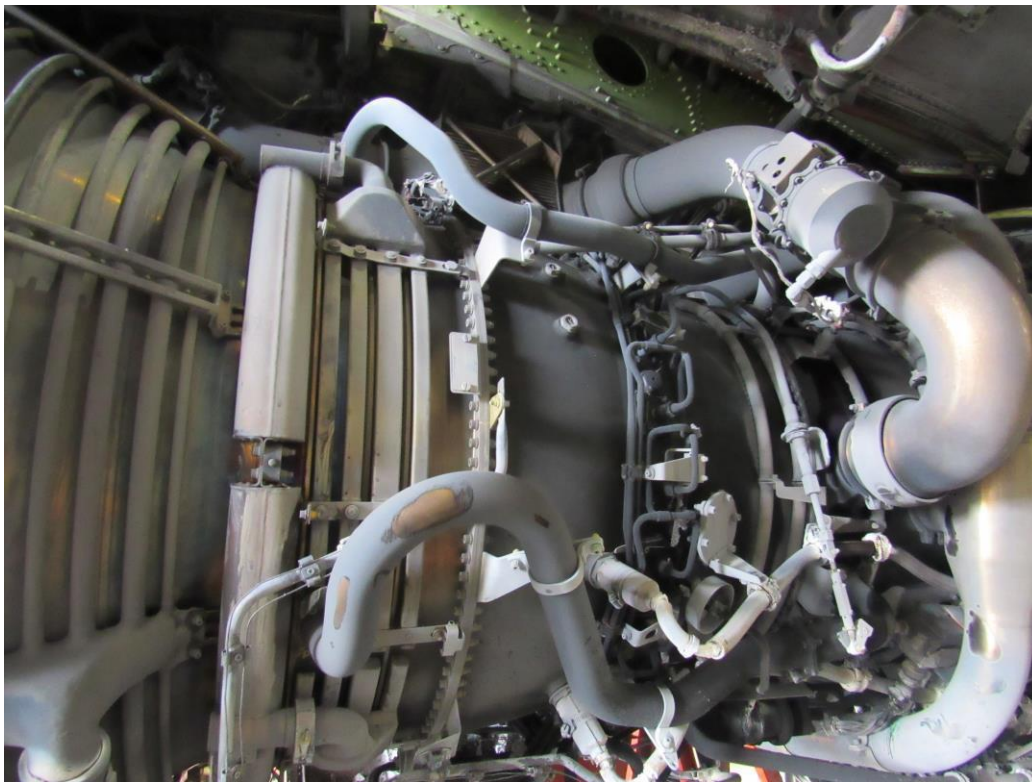


Figure 8. Upper right side of engine

Most of the engine electrical harnesses, insulation material and attachment hardware between 4 and 1 o'clock were thermally distressed. The damage included melted wiring harness insulation, eroded P-clamp cushions, whitened and flaking flexible fuel line fire sleeves and melted or missing fire loop grommets. The turbine case cooling line (TCC line) was ruptured 21.5 inches aft of the V-groove at 9 o'clock. The rupture was approximately 2 inches across and the fractured edges were petalled outward. The fan air valve actuator housing was heat deformed and was partially consumed. See Figures 9 – 11.



Figure 9. General thermal distress, engine externals on left side of the engine



Figure 10. Ruptured TCC line



Figure 11. Partially-consumed fan air valve

The most pronounced thermal damage was to the diffuser/HPT area between 6 and 9 o'clock where bare and separated wires were noted, including burner temperature, turbine cooling air and EGT signal wires, and both aft lower fire loops. The sooting had the darkest appearance between 6 and 7 o'clock where the FFT assembly shell and identification plate assembly was partially consumed by fire. See Figure 12. A rubbery blue-colored substance consistent with fuel-resistant O-ring material⁵ protruded from the top and left sides of the FFT-to-fuel OUT tube joint. See Figure 13.



Figure 12. Right side of the FFT showing heavy sooting

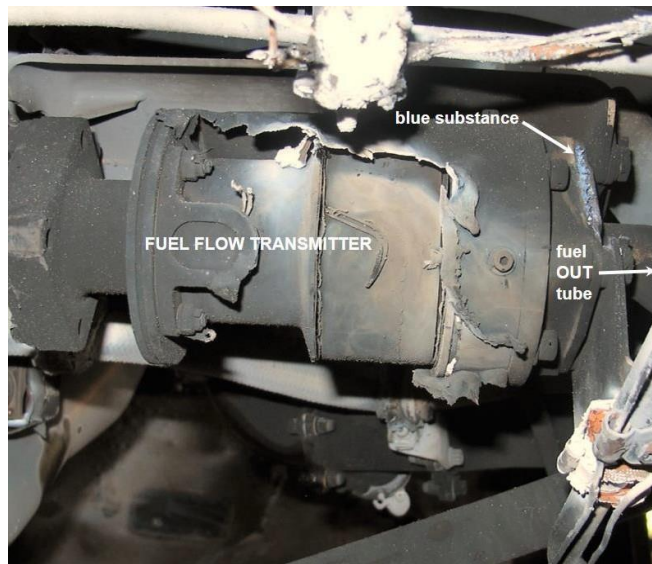


Figure 13. FFT thermal damage and blue substance at the FFT-to-fuel OUT joint

Pressurizing the fuel system on wing was determined not feasible and the engine was removed and shipped to Delta Tech Ops (DTO), Atlanta, Georgia.

5.0 Evaluation at DTO

An inspection at DTO determined that the flammable fluid source was a fuel leak at the FFT-to-fuel OUT tube joint. The FFT, fuel IN line and fuel OUT line were removed as an assembly and pressurized on a DTO fuel flow bench. A leak was observed at the suspect joint with 25 psig fluid pressure applied. Increasing fuel pressures resulted in increasing leak volumes at the joint.⁶ It was decided to further examine the assembly at the FFT manufacturer and the FFT, fuel IN tube and fuel OUT tube assembly along with the cannon plug and lead wires recovered from the thrust reverser cowling were shipped to the FFT manufacturer, Ametek Aerospace & Defense.

6.0 FFT assembly assessment

The FFT assembly was evaluated on August 9, 2016 at Ametek Aerospace & Defense, Wilmington, Massachusetts.

⁵ A P/N M25988/3-217 O-ring is used at this joint. The AMS-R-25988/3 specification describes P/N M25988/3-217 as a Type 1 Class 1 Grade 60 rubber fluorosilicone/elastomer oil- and fuel-resistant [blue-colored] packing.

⁶ According to the field notes describing the evaluation, the test was stopped after application of 185 psig resulted in fluid streaming from the bottom of the joint.

6.1 FFT description

The FFT is an electro-mechanical measuring device installed in the metered fuel flow line between the main fuel control fuel outlet port and the engine fuel distribution valve to provide a cockpit indication of the fuel volume delivered to the engine combustor. It is located in the HPT diffuser case area at 6 o'clock. See Figure 14.

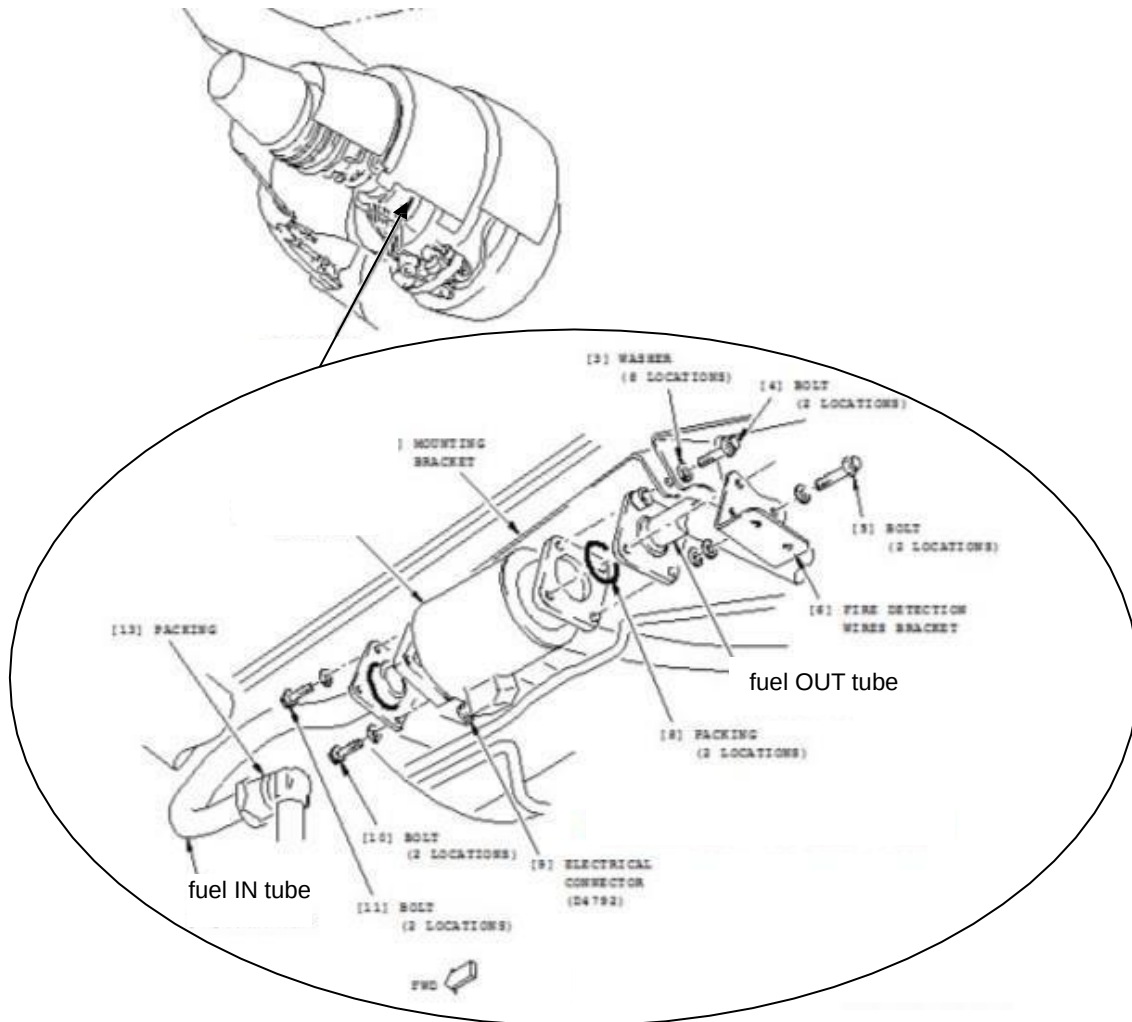


Figure 14. FFT installation

6.2 Receiving inspection

The FFT was heavily sooted and fire damaged. The damage was concentrated at the fuel inlet end. Approximately 65% of the FFT assembly shell and identification plate assembly, including the electrical connector housing and lead wires, was missing/thermally destroyed.⁷ See Figure 15. The edges of the remaining assembly shell at the fuel OUT end were deformed and drooping at 6 o'clock. The coil electromagnetic interference shield had separated at its braze points, exposing the start signal coil/stator

⁷ The FFT assembly shell and identification plate assembly is a thin aluminum cover that attaches to the main housing and encloses the electrical components. It includes an electrical connector housing and the unit data plate.

assembly. The exposed area of coil and silicone shrink sleeve was thermally consumed. Silicone shrink sleeve remnants observed under the shell appeared dry and brittle. The ground strap was partially consumed. There was no obvious thermal damage to the main and end housings. Material consistent with oil- and fuel-resistant fluorosilicone protruded from the FFT-to-fuel OUT tube joint and was adhered to attachment bolt threads.

6.3 As-received leakage test

The fuel OUT tube end was capped, and the assembly was filled with Stoddard solvent MIL-C-7024E (Royco 950 Type 2 calibration fluid). Fluid immediately leaked at the FFT-to-fuel OUT tube interface. A hand-operated hydraulic pump and pressure gauge was attached at the end of the fuel IN tube. See Figure 16.



Figure 15. FFT receiving inspection

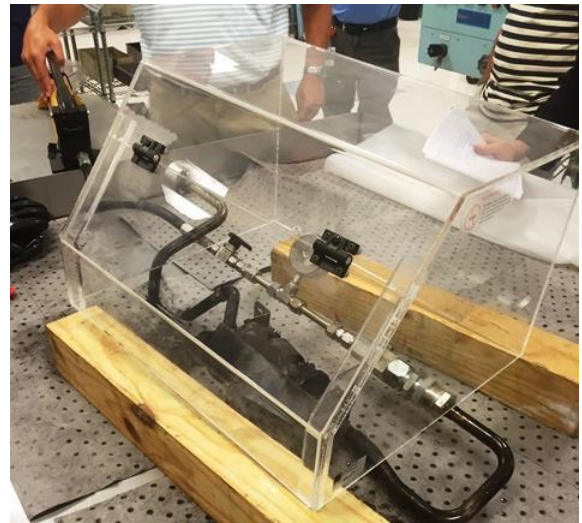


Figure 16. Test setup

Fluid was pumped into the rig. The drip became a steady spray with 8 psig applied at the inlet. See Table 2.

<i>applied pressure</i>	<i>finding</i>
0 psig	Steady drip past protruding O-ring material at FFT end cap-to-fuel OUT joint
8 psig	Spray, same location

Table 2. As-received leakage test results

6.4 FFT-to-fuel OUT joint inspection

The four fuel OUT tube to FFT attachment bolts were undamaged and washers were installed under the bolt heads. The bolt heads were correctly safetied. It was acknowledged that exposure to fire can alter torque values; however the bolt breakaway torques were measured. See Table 3.

bolt position ⁸	bolt P/N	breakaway torque
1	NAS6704-6	85
2	NAS6704-5	85
3	NAS6704-5	100
4	NAS6704-6	finger tight

Table 3. Fuel OUT tube bolt breakaway torques (fire-exposed)

There was a small dent inboard of the outlet chamfer at 3 o'clock; a probe of the dent indicated some depth. A small ferrous sliver was recovered from the inside flow path wall.

The fuel OUT tube O-ring was seated in the gland but was missing a 90° arc of material. The separated O-ring ends were shallowly angled. See Figure 17.



Figure 17. Fuel OUT tube showing damaged O-ring in tube gland and O-ring material deposited on flange surface

The surface of the O-ring was rough and eroded. Deteriorated O-ring material was found between 9 and 12 o'clock, on the tube flange along the rim of the flow path outlet between 8 and 1 o'clock, and at the No. 4 attachment bolt hole and the dowel pin. There was an approximately 0.25-inch longitudinal cut at 8 o'clock adjacent to bolt hole 3. There was a longitudinal tear at 5 o'clock. There were parallel longitudinal abrasion marks and axial gouges. See Figure 18.

The O-rings were retained for further evaluation.

⁸ The attachment bolts were numbered 1-4 in the clockwise direction, as viewed facing the end of the FFT and with the dowel (alignment pin) at 12 o'clock.



Figure 18. FFT fuel OUT tube O-ring showing (a) missing arc of material and (b) O-ring surface damage

6.5 AMM FFT reassembly

A new O-ring was lubricated and installed in the fuel OUT tube gland. The tube was reassembled to the FFT and the retaining bolts were torqued to the minimum required torque per the engine manual (65 lb in).

Boeing B757 AMM FFT installation procedures were referred to and several discrepancies were noted. See Section 7.0.

6.6 Re-test

The initial test procedure set-up was duplicated. The assembly was pressurized and held at 200 psig for five minutes with no leaks observed. See Table 4. The FFT was not disassembled.

applied pressure	finding
200 psig	No leakage
5 minutes at 200 psig	No leakage

Table 4. Post O-ring replacement leakage test results

6.7 Additional FFT observations

6.7.1 Fuel IN tube assembly

The fuel IN O-ring was found entire and seated in its gland. It was heavily eroded with a rough appearance like the fuel OUT O-ring. There was a 360° deposit of the O-ring material at the base of the tube adjacent to the flange interface. There was a small gouge in the O-ring at 12 o'clock. A piece of O-ring material dimensionally consistent with the gouge was found just downstream of the gouge. O-ring material was also

deposited 360° around the fuel IN end cap mechanism spring assembly, with a small buildup found slightly downstream between 10 and 12 o'clock. There were score marks at the edges of the flow inlet entry.

6.8 Further O-ring examinations

6.8.1 O-ring materials analysis

The fuel IN and fuel OUT O-rings were submitted to the NTSB Materials Lab for evaluation. A Fourier transform infrared spectrometry analysis found spectra consistent with Type 1 Class 1 Grade 60 rubber fluorosilicone/ elastomer, which conformed to the drawing specification. The surface texture of both O-rings was gummy and easily deformed and the outer surface of the fuel OUT tube O-ring also exhibited flaking and delamination. These conditions are consistent with polymer reversion.⁹

6.8.2 O-ring failure mode

Parker Aerospace, a globally recognized manufacturer of seals and O-rings, was asked to assess the fuel OUT O-ring damage. Parker reported that the similar angle/plane cuts on both O-ring ends is commonly observed and is a typical result of installation error.

7.0 Maintenance instruction review

7.1 Boeing B757 AMM

Review of the B757 AMM FFT maintenance procedure noted the following:

- Boeing B757 AMM Task 73-31-01-404-018-P00, *Install the Fuel Flow Transmitter*, did not include an instruction to lubricate O-rings prior to installation¹⁰ or specify a torque value for the tube attachment bolts. It incorrectly directed that the fuel tube O-rings be installed on the FFT rather than into the fuel tube O-ring glands.
- Boeing B757 AMM Task 73-31-01-004-010-P00, *Remove the Fuel Flow Transmitter*, referred to the fuel IN and fuel OUT tube O-rings as installed on the FFT rather than in the fuel tube glands.

7.2 DAL task card

Review of the DAL FFT installation instructions used by the DAL technician to install the FFT directly aligned with the Boeing AMM and included the omissions/errors noted above.

Boeing has revised these instructions.

⁹ Polymer reversion is the breakdown of the cross-linking bonds that give the polymer its strength and elasticity. Reversion can occur due to exposure to high heat or non-compatible chemicals/materials.

¹⁰ Parker Hannifin Publication ORD5700, *Parker O-Ring Handbook* pg. 10-5 states that use of a suitable grease or oil during assembly helps protect the O-ring from damage by abrasion, pinching, or cutting.