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

April 2, 2015

POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT

NTSB No: ENG14IA019

A. INCIDENT

Location: LOS ANGELES, CALIFORNIA

Date: July 11, 2014

Time: 13:28 pacific daylight time

Aircraft: Delta Air Lines, Boeing 767-332, registration number N139DL, Flight 101

B. POWERPLANT GROUP

Safety Board Group Chairman:	Jean-Pierre Scarfo Powerplant Lead Engineer Washington D.C.
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	Anna Sharpsten Propulsion Safety Seattle, Washington
Air Line Pilots Association Member:	Norm Lindsey ALPA Air Safety Representative Atlanta, Georgia
Federal Aviation Administration Member:	Kas Sharifi Engineer - CF6 Focal Point Burlington, Massachusetts

C. SUMMARY

On July 11, 2014, 13:28 pacific daylight time, a Boeing B-767-332, registration number N139DL, operated by Delta Air Lines (DAL) as flight 101, and powered by two General Electric (GE) CF6-80A2 turbofan engines, experienced a left engine (No. 1) fire during climb at about flight level (FL) 190 (19,000 feet) from Los Angeles International Airport (LAX), Los Angles, California. The flightcrew reported observing a left engine fire indication during climb and declared an emergency, performed the Quick Reference Handbook (QRH) engine fire procedures which included shutting down the affected engine, and an air turnback to LAX was initiated. Upon shutting down the affected engine, the fire warning extinguished and no fire suppression bottles were discharged. The airplane made a successful and uneventful overweight single-engine landing at LAX and Aircraft Rescue and Fire Fighting (ARFF) personnel met the aircraft and observed no damage. The airplane taxied to the gate without incident. Delta Maintenance personnel opened the left engine cowling and observed heat damage, scorching, and sooting. Of the 200 passengers, 8 crewmembers and one cockpit jump-seater on board the flight, no injuries were reported. The incident flight was a 14 *Code of Federal Regulations* (*CFR)* Part 121 domestic passenger flight from LAX to Hartsfield–Jackson Atlanta International Airport (ATL) Atlanta, Georgia. Day visual meteorological conditions prevailed at the time, and an instrument flight rules flight plan was filed.

The Powerplant Group, comprised of members from GE, Boeing, DAL, Air Line Pilots Association (ALPA), Federal Aviation Administration (FAA), and the National Transportation Safety Board (NTSB), reconvened at the DAL Technical Operations (TechOps) facility in Atlanta Georgia on July 21, 2014 to perform a detailed examination of the incident engine and completed its work on July 24, 2014. Examination of the engine revealed that the fire damage was concentrated under the engine heatshield from about the 6:00 o'clock position to the 8:30 o'clock position (aft looking forward) and forward of the accessory gearbox. The fire and thermal distress included melted and consumed electric wire insulation, melted and consumed accessory gearbox fire loop isolators, melted and consumed tubing P-clamps, exposed electric wire conductors, and soot deposits.

Wet motoring[1] of the engine revealed a fuel leak from the integrated drive generator (IDG) fuel/oil heat exchanger main housing just aft of the forward weld (fuel inlet port) at about the 12:00 o'clock position (as installed on the engine). The unit, which is located below the engine heatshield, was removed and additional leak tests and a fluorescent penetrant inspection confirmed a circumferential through-wall crack in-line with where the inner core is brazed into the main housing, a second crack indication adjacent to the through-wall crack, and no internal leak between the fuel and oil sides of the inner core. Removal of the IDG power feeder cables revealed evidence of chaffing and arc burn; this damage was not related to the fire damage that was observed overall as a result of the actual fire. The IDG power feeder cables were reinstalled and examination of the engine hardware along the path of the IDG power feeder cables from their IDG terminal block to the pass-through hole in the engine heatshield (this portion of the IDG power feeder cables are located below the engine heatshield in the fire zone) revealed that the accessory drive lube and scavenge pump pressure (supply) line support bracket, which is located on the front side of the accessory gearbox just below the hydraulic pump pad, exhibited evidence of melted material consistent with an arc burn. The location of the arc burn on the bracket was in-line with the arc burn observed in the IDG power feeder cables.

[1] Wet motoring is the process by which the engine core is rotated through the starter and fuel is allowed to flow through the fuel system with no ignition. This procedure is used in troubleshooting the engine for leaks.

Examination of post event engine photos (prior to the removal of any parts) and matching the arc damage on the IDG power feeder cables with the accessory drive lube and scavenge pump pressure line support bracket revealed that the IDG power feeder cables (below the engine heatshield) were not tight and straight along its support bracket but exhibited slack and dangling below the support bracket. A review of the installation drawing from the various aircraft and engine maintenance manuals, along with other exemplar DAL 767 CF6-80A powered airplanes, discovered there should be no slack in the IDG cables; instead the cables should run straight and tight along its support bracket and gently bend upward towards the cutout hole in the engine heatshield. The DAL work specific cards for the installation and routing of the IDG power feeder cables at the time of the event included sketches that showed the proper routing along the support bracket with no slack. Based on this event, DAL: 1) updated those work cards to provide additional information and guidance on the proper routing of the IDG cable both above and below the engine heatshield in order to clarify any potential confusion and to prevent future arcing events, 2) conducted a once-through-the-fleet inspection for misrouted IDG power feeder cables, and 3) promptly corrected any non-conforming routing of the cables.

Metallurgical examination of the IDG fuel/oil heat exchanger at the NTSB Materials Laboratory in Washington DC found that the fracture surfaces of the circumferential through-wall crack showed features consistent with multiple fatigue crack initiation sites emanating from the inner diameter surface of the main housing and propagated radially outwards until it reached the outer diameter. A second fatigue crack location was also identified in the vicinity of the through-wall crack. This second crack location however was not a through-wall and exhibited cracks emanating from both the inner and outer diameter surfaces but did not link up to create a through-wall crack. No anomalies were detected in the area of either of the cracks or at their fatigue crack origins. The microstructure of the base material of the housing was consistent with what was specified by the manufacturer.

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AC	Alternating Circuit	IPC	Illustrated Parts Catalog
ALF	Aft Looking Forward	KVA	Kilovolt-amps
ALPA	Air Line Pilots Association	LAX	Los Angeles International Airport
AMM	Aircraft Maintenance Manual	LPC	Low Pressure Compressor
ARFF	Aircraft Rescue and Fire Fighting	LPT	Low Pressure Turbine
ATL	Atlanta's Hartsfield International Airport Atlanta, Georgia	N1	Low Pressure Rotor Rotation Speed in %
CFR	Code of Federal Regulations	N2	Low Pressure Rotor Rotation Speed in %
CMM	Component Maintenance Manual	NTSB	National Transportation Safety Board
CSLI	Cycles Since Last Inspection	OD	Outer Diameter
CSLSV	Cycles Since Last Shop Visit	PBM	Powerplant Buildup Manual
CSN	Cycles Since New	PN	Part Number
DAL	Delta Air Lines	PSI	Pounds per Square Inch
EM	Engine Manual	QRH	Quick Reference Handbook
ENG	Engine	SEM	Scanning Electron Microscope
ESN	Engine Serial Number	SN	Serial Number
EXT	Extinguish	TEC	Turbine Exhaust Case
FAA	Federal Aviation Administration	TechOps	Technical Operations
FDR	Flight Data Recorder	TLA	Throttle Lever Angle
FL	Flight Level	TR	Thrust Reverser
FPI	Florescent Penetrant Inspection	TSLI	Time Since Last Shop Inspection
GE	General Electric	TSLSV	Time Since Last Shop Visit
H	Hertz	TSN	Time Since New
HPC	High Pressure Compressor	UAP	United Aircraft Products
HPT	High Pressure Turbine	V	Volt
ID	Inner Diameter	WOW	Weight on Wheels
IDG	Integrated Drive Generator	XRF	X-ray Fluorescence

D. DETAILS OF THE INVESTIGATION

1.0 ENGINE AND AIRPLANE INFORMATION

1.1 ENGINE HISTORY

The No. 1 engine installed on the incident airplane was a GE CF6-80A2 turbofan engine, engine serial number (ESN) 580-397 (PHOTO 1). At the time of the fire event, ESN 580-397 had accumulated 52,550 hours time since new (TSN), 22,708 cycles since new (CSN), 7,892 hours time since last shop visit (TSLSV), 2,350 cycles since last shop visit (CSLSV), 6,184 hour time since last inspection (TSLI), and 1,743 cycles since last inspection (CSLI).

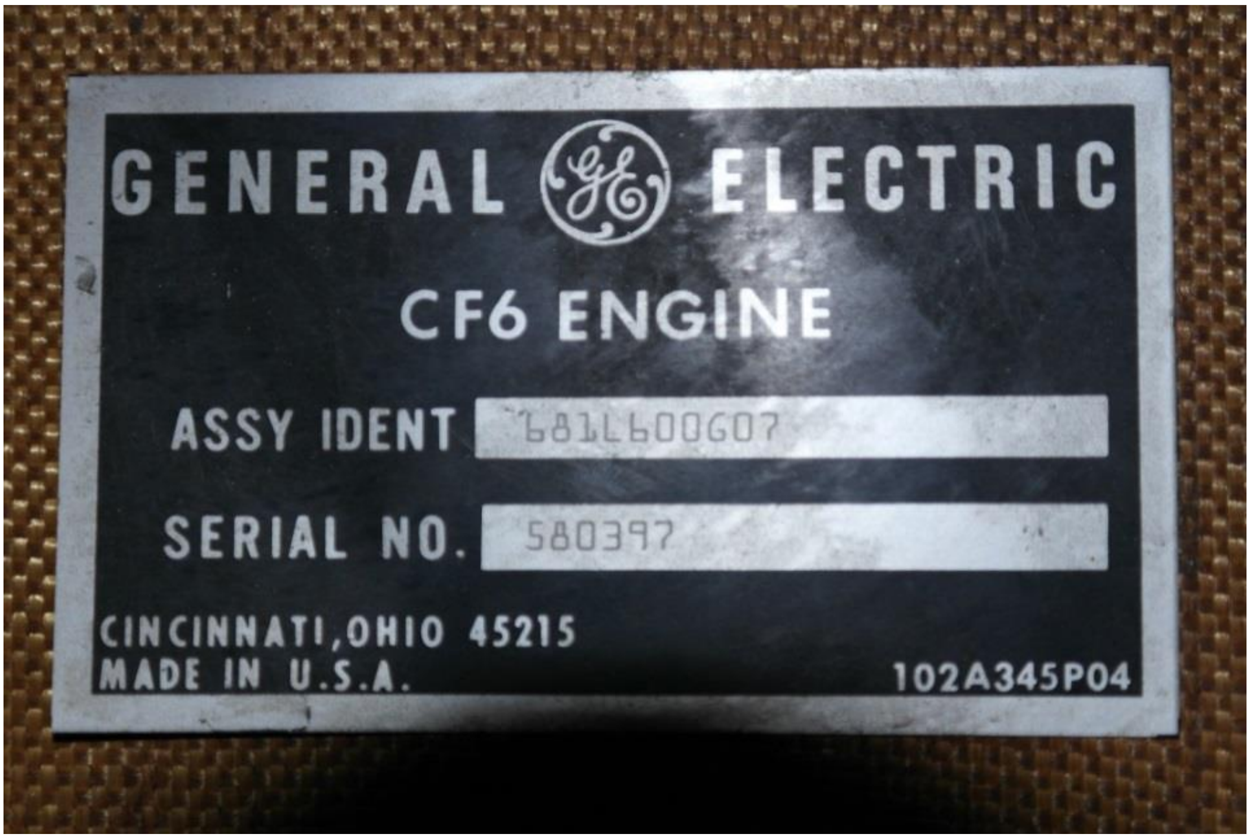

PHOTO 1: ENGINE DATA PLATE

Photo Courtesy of GE

ESN 580-397 had been previously installed on airplane N125DL and was removed on December 23, 2007 for maintenance. The engine had accumulated 44,658 hours TSN and 20,358 CSN when removed from N125DL. After maintenance was completed, ESN 580-397 was installed on airplane N132DN in March 2008 and remained installed until August 16, 2010 when it was removed as a ready spare at the operator's convenience. The engine had accumulated 46,366 hours TSN, 20,965 CSN, 1,708 hours TSLSV, and 607 CSLSV at that time. Before the engine was installed on another airplane, DAL performed an 'Engine Zero Letter Check' on June 18, 2012. An 'Engine Zero Letter Check' is a series of inspections and maintenance actions, such as checking the engine magnetic plugs for debris and replacing filters, performed by DAL in preparation for the engine to be reinstalled on another airplane. The event engine was installed on the incident airplane on July 7, 2012 where it remained until the event.

The hydraulic pump was manufactured by Vickers, Troy, Michigan. According to the data plate, the model number was PV3-240 2 G, part number (PN) was 350880-7, and serial number (SN) was MX257142. It was installed new on the incident engine during the last shop visit in 2008. So at the time of the event, the hydraulic pump had accumulated 7,892 hours TSLSV and 2,350 CSLSV.

The integrated drive generator (IDG) fuel/oil heat exchanger was manufactured by United Aircraft Products (UAP) Inc., Dayton, Ohio. According to the data plate, the UAP PN was UA538297-6 Rev B, UAP SN was 0088, Boeing PN was S332T200, and the unit was manufactured October 1982. At the time of the event, the IDG fuel/oil heat exchanger had accumulated 19,960 hours TSN and 7,630 CSN. The last overhaul of the unit was performed by AMETEK® in March 2006. At the last overhaul, the unit had accumulated 8,298 hours TSN and 3,950 CSN. The unit was installed on the event engine in June 2006 where it remained until the event. During the 2008 engine shop visit the unit was visually examined while it remained installed on the engine. No anomalies were reported.

1.2 Engine Description

The incident airplane was powered by two GE CF6-80A2 turbofan engines (**Figures 1** and **2**). The CF6-80A2 is a dual-spool rotor, axial flow, high bypass turbofan that features an integrated front fan and low pressure compressor (LPC) driven by a 4-stage low pressure turbine (LPT), an annular combustor, and a 14-stage high pressure compressor (HPC) driven by a 2-stage high pressure turbine (HPT). Engine stations are identified in numeric sequence from front to rear (**Figure 3**). According to the engine's FAA Type Certificate Data Sheet E13NE, Revision 25, dated June 10, 2013, the engine has a maximum takeoff thrust rating of 48,670 pounds, flat-rated[2] to 92°F (33.3°C) and a maximum continuous thrust rating of 45,720 pounds flat-rated to 77°F (25°C).

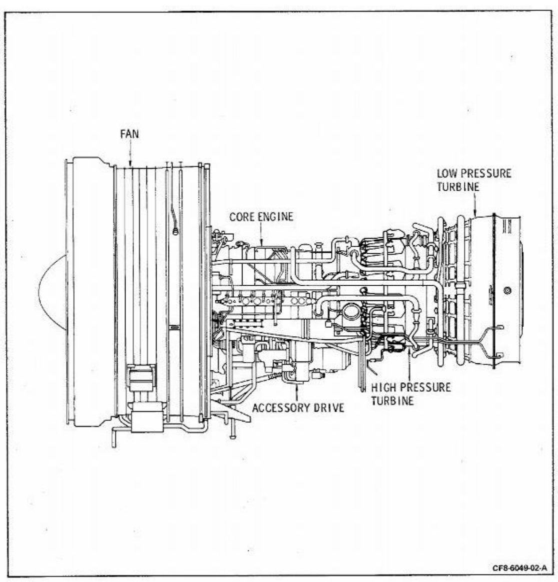

Figure 1: Left Side of Engine

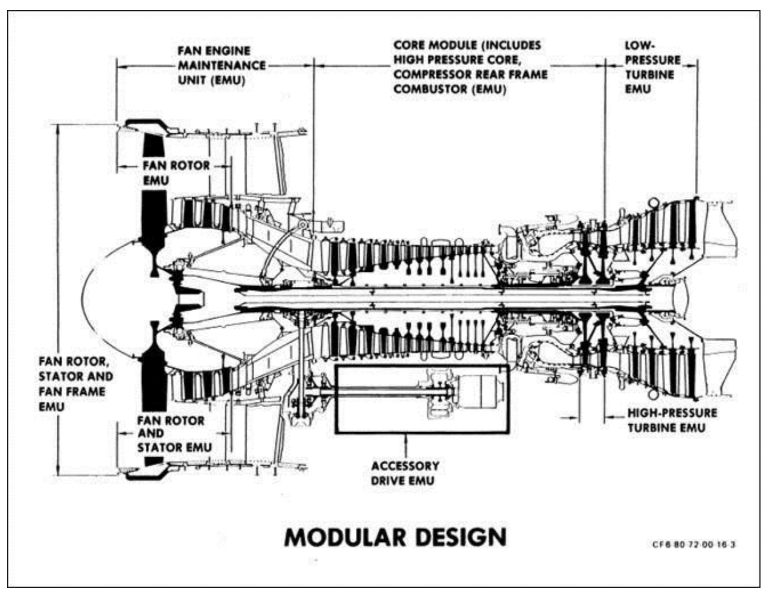

Figure 2: Cross-Section of Engine

2 Flat-rated to a specific temperature indicates that the engine will be capable of attaining the rated thrust level up to the specified inlet temperature.

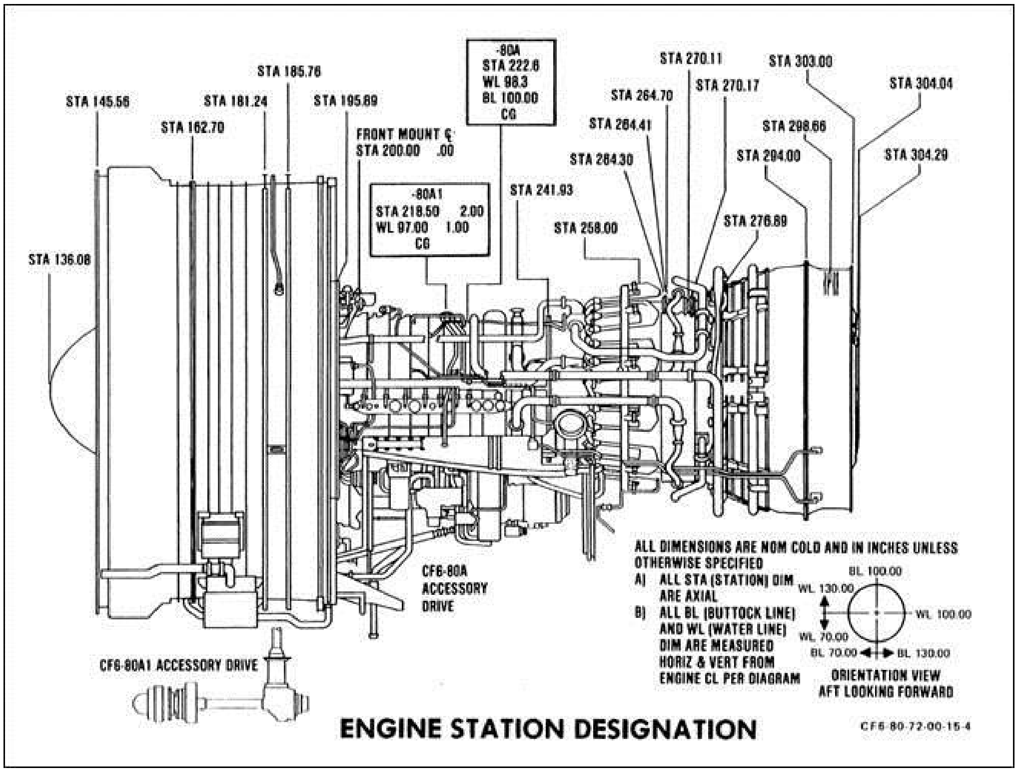

FIGURE 3: ENGINE STATION IDENTIFICATION

All directional references to front and rear; right and left; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position, and progressing sequentially clockwise ALF. The direction of rotation of the engine is clockwise ALF.

1.3 DESCRIPTION OF ENGINE NACELLE

The engine inlet cowl (also known as the inlet duct), fan cowl, reverser-fan duct cowl (consisting of the thrust reverser (TR) and fan duct cowl), core cowl, and exhaust nozzle, comprise the boundaries of the engine nacelle and consist of fixed and hinged components. The fixed components include the inlet cowl, and exhaust nozzle; while the hinged components include the fan cowl, fan reverser, and core cowl (**FIGURE 4**). The left TR outer barrel incorporates a ventilation air outlet panel at the 6:00 o'clock position used for vent flow of the nacelle and is also used in the event of an over-pressurization event. The left TR inner barrel incorporates the IDG access panel and is not intended to be used for an over-pressurization event. The inlet duct is bolted to the engine fan case and the exhaust nozzle to the turbine rear frame (TRF). The fan cowl, reverser-fan duct cowl (subsequently referred to simply as the TR), and core cowl are each in two halves, hinged at either side of the strut, and joined by latch hooks on the bottom centerline. The TR inner barrel inner skin is coated with MA25S red/orange-colored thermal coating[3] for fire protection. All of the nacelle hardware, including the TR, is provided by Boeing and the engine is supplied by GE.

[3] MA25S is a Polyoxymethylene (POM) thermoplastic that has high heat resistance and is produced under the trade name Duracon®. The 'S' in MA25S stands for standard grade.

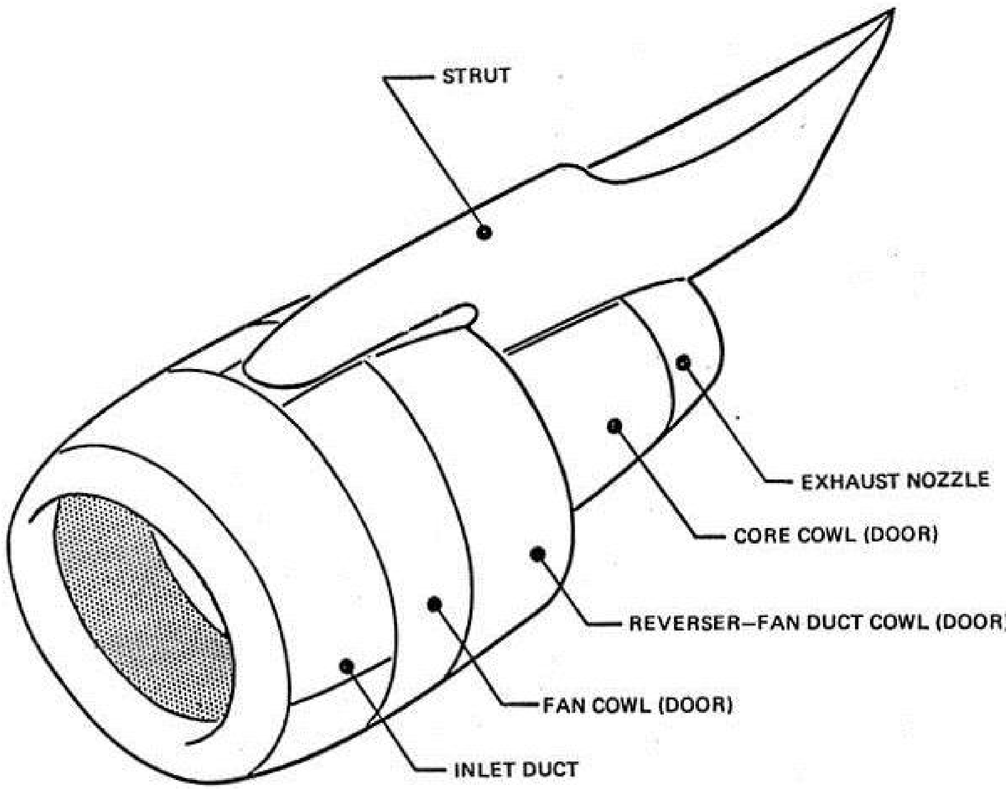

FIGURE 4: BOEING 767 NACELLE NOMENCLATURE AND LOCATION

2.0 INITIAL ON-SITE EVALUATION OF THE NO. 1 ENGINE AT LAX

The following information was provided by DAL since the Powerplant Group did not travel to LAX for an on-site examination and evaluation of the event airplane and engine. The inlet cowl, the fan cowl, and the core cowl were undamaged (**Photo 2**); they remained on the airplane and were not sent with the engine for further evaluation by the Powerplant Group. The left TR exhibited the most thermal distress and fire damage while the right TR exhibited minor thermal distress. DAL mechanics at LAX found damage to the IDG power feeder cables (subsequently referred to as simply the power feeder cables) and repaired them in accordance with the Standard Wiring Practice Manual (D6-54446) Chapter 30-30-13 and, 20-30-11; the power feeder cables were cut at the engine heatshield and were sent with the engine and TR halves for evaluation.

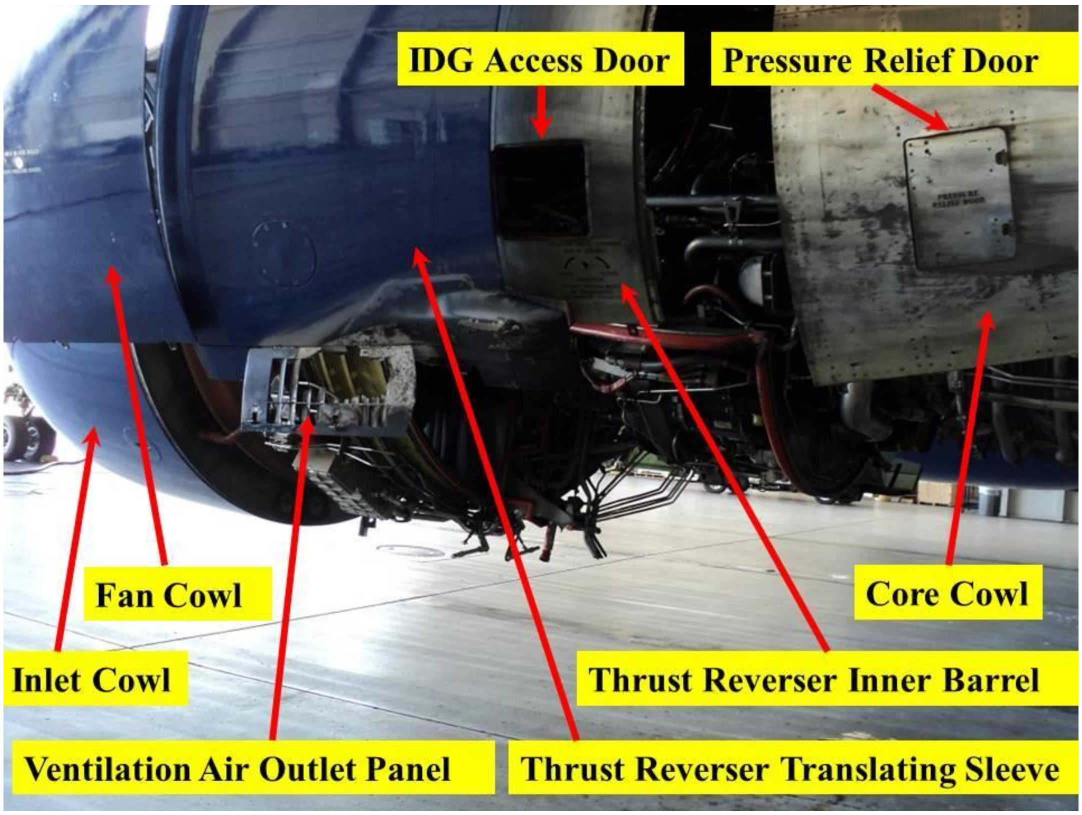

Photo 2: No. 1 Engine Nacelle Hardware Condition – Left Side

Photo Courtesy of Delta

DAL mechanics confirmed the No. 1 engine experienced an undercowl fire and the damage was located primarily on the left side of the engine under the engine heatshield forward of the accessory gearbox (**Photo 3**).

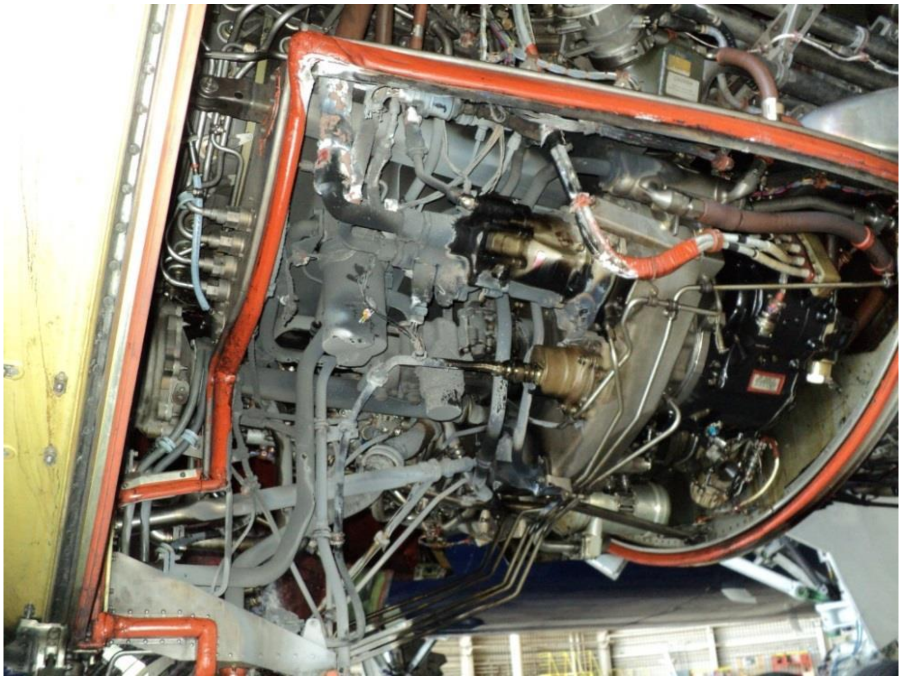

PHOTO 3: THERMAL AND FIRE DAMAGE ON LEFT SIDE OF NO. 1 ENGINE UNDER ENGINE HEATSHEILD

Photo Courtesy of Delta

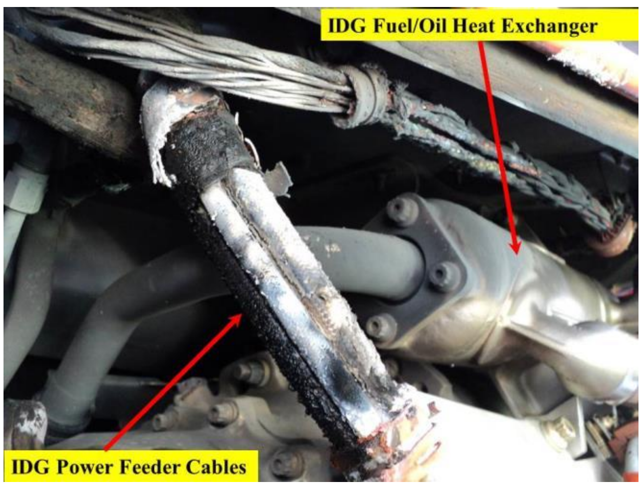

PHOTO 4: THERMAL DAMAGE TO IDG POWER FEEDER CABLES AND IDG FUEL/OIL HEAT EXCHANGER LOCATION

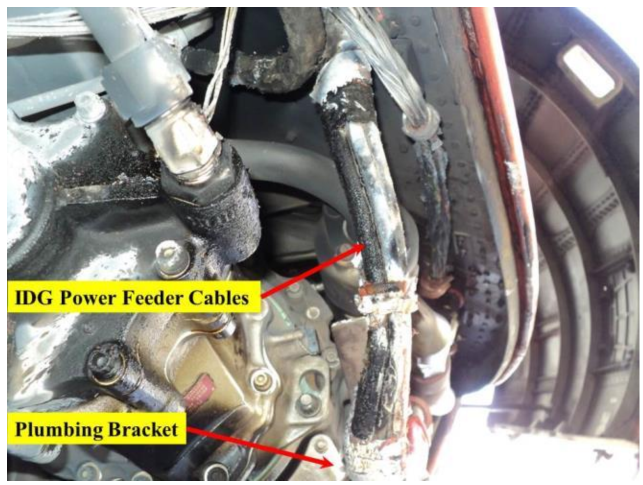

PHOTO 5: THERMAL DAMAGE TO IDG POWER FEEDER CABLES & LUBE AND SCAVENGE PUMP PRESSURE LINE SUPPORT BRACKET LOCATION

Photos Courtesy of Delta

3.0 DETAILED EXAMINATION OF THE NO. 1 THRUST REVERSER AND ENGINE

The No. 1 engine and both thrust reverser halves were removed from the airplane at LAX and shipped to the DAL TechOps in ATL where they were quarantined until the Powerplant Group arrived. The Powerplant Group, comprised of members from GE, Boeing, DAL, ALPA, FAA, and the NTSB, convened at the DAL TechOps (subsequently referred to as simply TechOps) in Atlanta Geogia from July 21 - 24, 2014 to perform a detailed examination of the incident engine.

3.1 No. 1 Engine Thrust Reverser (TR)

The right TR was in generally good condition with the only thermal damage noted on the lower bifurcation panel (vertical wall) of the inner barrel inner skin. Areas of the lower bifurcation panel exhibited some of the top coat of the MA25S coating peeled away, was brittle, and had a white/gray discoloration but was intact beneath (**Photo 6**). All 5 TR latch hooks (3 located on the outer barrel, 1 on the torque box forward wall, and 1 located on the inner barrel) were in good condition, intact, and functioned properly. The guide pin hole located near the front of the TR was undamaged. The bypass air flow path exhibited no damage and the TR hardware such as the blocker doors and blocker door drag link. The translating sleeve was in good condition. All the thermal and fire damage was located in a designated fire zone.

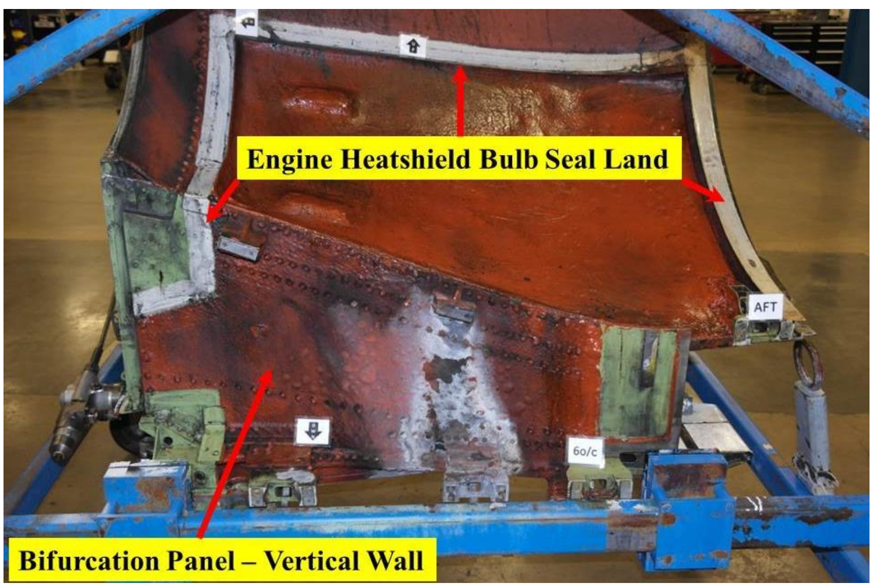

Photo 6: Right TR Inner Barrel Inner Skin Thermal Damage

Photo Courtesy of GE

The left TR exhibited more thermal and fire damage than the right TR. All the thermal damage was located within the area surrounded by engine heatshield bulb seal land (**Photo 7**). The thermal damage to both the curved portion of the TR inner barrel skin and the lower bifurcation panel was concentrated on the forward part of the TR. The majority of the thermal damage to the curved portion of the inner barrel skin extended from the bulb seal land to about 19-inches aft of the leading edge. The top coat of the MA25S coating in this area turned white/gray in color with the coating beneath appearing to be intact except for a 3 x 5-inch triangular-shaped portion near the longitudinal bulb seal land where the MA25S coating was consumed. The aluminum inner barrel skin beneath the consumed MA25S coating was visible but no burn-through or apparent thermal damage was noted. An oil-like residue was also noted on top of the MA25S coating aft of the white/gray discolored area with the MA25S coating beneath appearing to be intact. The lower bifurcation panel exhibited similar thermal damage to the top coat consisting of the MA25S coating turning white/gray in color. This area of top coat damage extended from the bulb seal land to about 27-inches aft of the leading edge; the coating beneath appeared to be intact. The IDG access door was found in the CLOSED and latched position, and the latches and the return springs were in good condition and functioned properly. Initial photos provided by DAL of the airplane at LAX shows the IDG access door was in the OPEN position. DAL mechanics at LAX who worked on the airplane after the event indicated that when they first arrived at the airplane that everything was normal, saw some oil dripping from the core cowl, and decided to the open up the TR and core cowls to gain access to the engine. The mechanics made no mention of the IDG access door in the OPEN position, so it is assumed that it was initially CLOSED but was opened as the mechanics gained access to the engine as shown in **PHOTO 2** and was not opened as a result of a nacelle over pressurization event. All five latch hook keepers and the TR guide pin were in good condition and intact. Similar to the right TR, the bypass air flow path exhibited no damage, and the TR hardware such as the blocker doors and blocker door drag links and the translating sleeve were in good condition. All the thermal and fire damage was located in a designated fire zone.

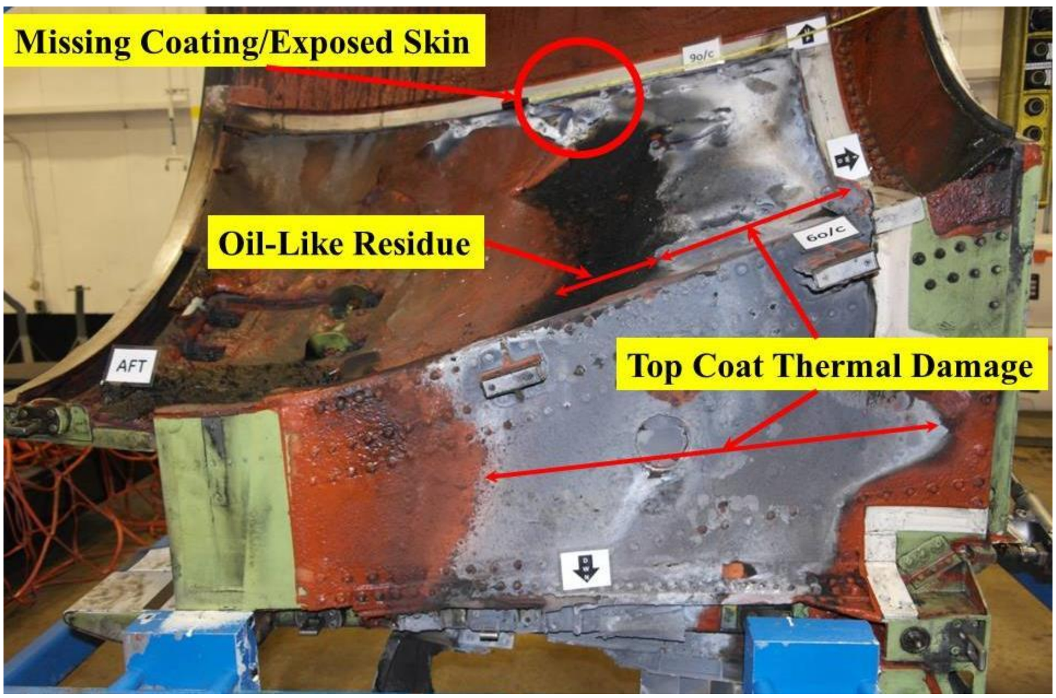

PHOTO 7: LEFT TR INNER BARREL INNER SKIN THERMAL DAMAGE

Photo Courtesy of GE

3.2 NO. 1 ENGINE AS-RECEIVED CONDITION

Thermal damage consisting of melted and consumed wire insulation and P-clamp insulation, exposed wiring, accessory gearbox fire loop isolators melted or consumed, and sooting was observed underneath the accessory gearbox heatshield from the 6:00 o'clock position to approximately the 8:30 o'clock position forward of the accessory gearbox (**PHOTO 8**). No thermal damage was noted on the right side of the engine underneath the heatshield (**PHOTO 9**), or aft or above the heatshield; only oil-like deposits and drips were noted on the right side of the engine both underneath and aft of the heatshield. The rubber clamping block for the drain lines located at the 6:00 o'clock position exhibited thermal damage (rubber was brittle and crumbly) and on the left side was partially consumed exposing one of the attachment bolts. On the right side of the clamping box, thermal damage was observed but the rubber remained pliable. The section of the accessory gearbox fire loops that ran along the drain lines at the 6:00 o'clock position and its electrical junction box were intact and sooted; the four isolators from the electric junction box rearward were either present with thermal damage or totally consumed.

PHOTO 8: FIRE DAMAGE ON LEFT SIDE OF ENGINE UNDERNEATH HEATSHIELD

PHOTO 9: NO FIRE DAMAGE ON RIGHT SIDE OF ENGINE UNDERNEATH ENGINE HEATSHIELD

Photos Courtesy of GE

In the vicinity of the hydraulic pump located on the forward left-hand side of the accessory gearbox at about the 8:00 – 8:30 o'clock position, several components and tubes were relatively clean and wetted, unlike the surrounding components and tubes that were heavily sooted. The red/orange-colored fire sleeve on the pressure and drain lines to the hydraulic pump were present and essentially intact but exhibited partial melting and some consumption (**PHOTO 10**). The pressure and return line fittings to the hydraulic pump were found loose and could be turned by hand; the hydraulic pump case drain line fitting was not fully threaded onto the outlet elbow – about 6 threads were exposed. Examination of an exemplar CF6-80A engine in the TechOps shop showed that only 1 or 2 threads should be visible. Examination of the initial photos of the engine after the event revealed that the drain line fitting had been fully seated after the event; thus indicating that the hydraulic lines had been disconnected at some point after the event and before the engine arrived at TechOps.

Examination of the oil tank sight-glass revealed that the quantity indicator ball was resting at the bottom of the sight-glass. According to GE component descriptions, the ball at the bottom of the sight-glass indicated that the tank is at least 3 quarts below full (when the engine oil temperature is cold). The tank capacity for the CF6-80A engine is 6.75 gallons (27 quarts). The oil was drained and collected to ascertain the amount of oil that remained in the oil tank. 18.2 liters (4.81 gallons/19.2 quarts) was collected. The tank was replenished with fresh oil in order to perform the wet motoring of the engine (See Section 4.0 'NO. 1 ENGINE WET MOTORING RESULTS' for details and results of the test).

The fire proof bulb seal runs along the perimeter of the engine heatshield and mates with the TR. The entire heatshield bulb seal was in good condition, pliable, and the typical red/orange-color except at two locations. The bulb seal on the front left corner of the heatshield (transition corner from the vertical to the longitudinal part of the seal) exhibited thermal distress, discoloration (white-ash color), and consumption of part of the seal (PHOTO 10). The vertical bulb seal on the left side of the bifurcation exhibited thermal distress to the glossy top coat but remained intact and pliable (PHOTO 11). All the other bulb seals were undamaged.

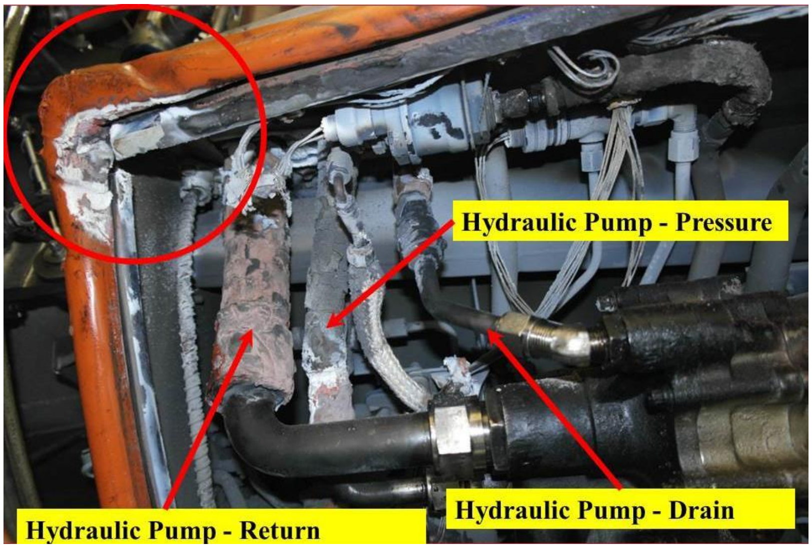

PHOTO 10: LEFT SIDE CORNER BULB SEAL DAMAGE

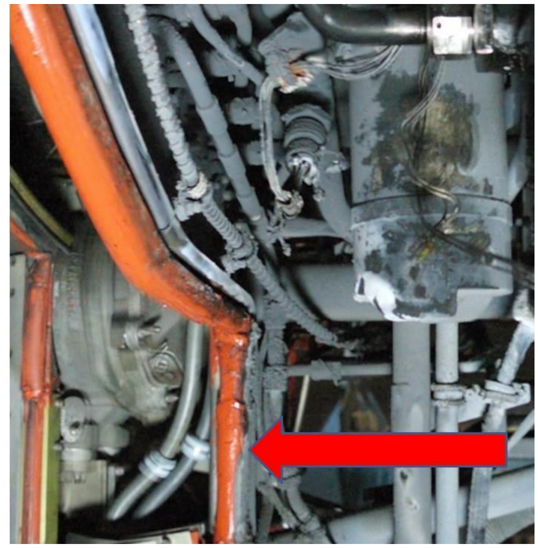

PHOTO 11: LEFT SIDE VERTICAL BIFURCATION DAMAGE

Photos Courtesy of GE

4.0 NO. 1 ENGINE WET MOTORING RESULTS

Before the engine was wet[4] motored, all the hydraulic pump fittings were tightened to their required torque and the hydraulic pump and its associated lines were pressure checked using shop air to determine if any leaks were present. Wet motoring involves rotating the engine and introducing fuel to the fuel system (fuel shutoff in the OPEN position) with no ignition (FIGURE 5).

[4] Wet motoring is the process by which the engine core is rotated through the starter and fuel is allowed to flow through the fuel system with no ignition. This procedure is used in troubleshooting the engine for leaks.

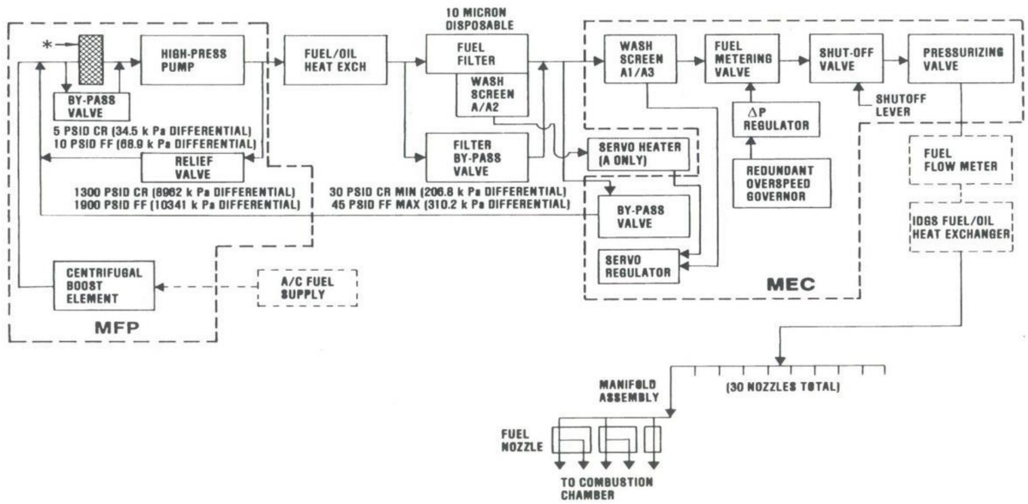

FIGURE 5: FUEL SYSTEM SCHEMATIC

With the pressure and return lines capped where those lines connect to the airplane pylon, 100 pounds per square inch (psi) of air pressure was introduced into the case drain line and held. A decrease in air pressure would indicate a leak; the air pressure held at 100 psi. This test was repeated with the pressure and case drain lines capped and air introduced into the return line with similar results; no loss of air pressure. When the return and case drain lines were capped and air introduced into the pressure line, the air pressure slowly decreased but stabilized at about 52 psi. Initial observation indicated that fluid leaked from the forward flange area between the valve block and control subassembly (subsequently referred to as the valve block) and adapter and case relief valve subassembly (subsequently referred to as the adapter valve) (**PHOTO 12 – SEE BLUE BOX TO DROPLETS**). The hydraulic pump was removed (very little hydraulic fluid was present confirming the fact that the hydraulic fitting has been disconnected prior to the engine's arrival at TechOps) and was disassembled to ascertain the condition of the flange seals (See Section 5.1 'HYDRAULIC PUMP DISASSEMBLY' for results).

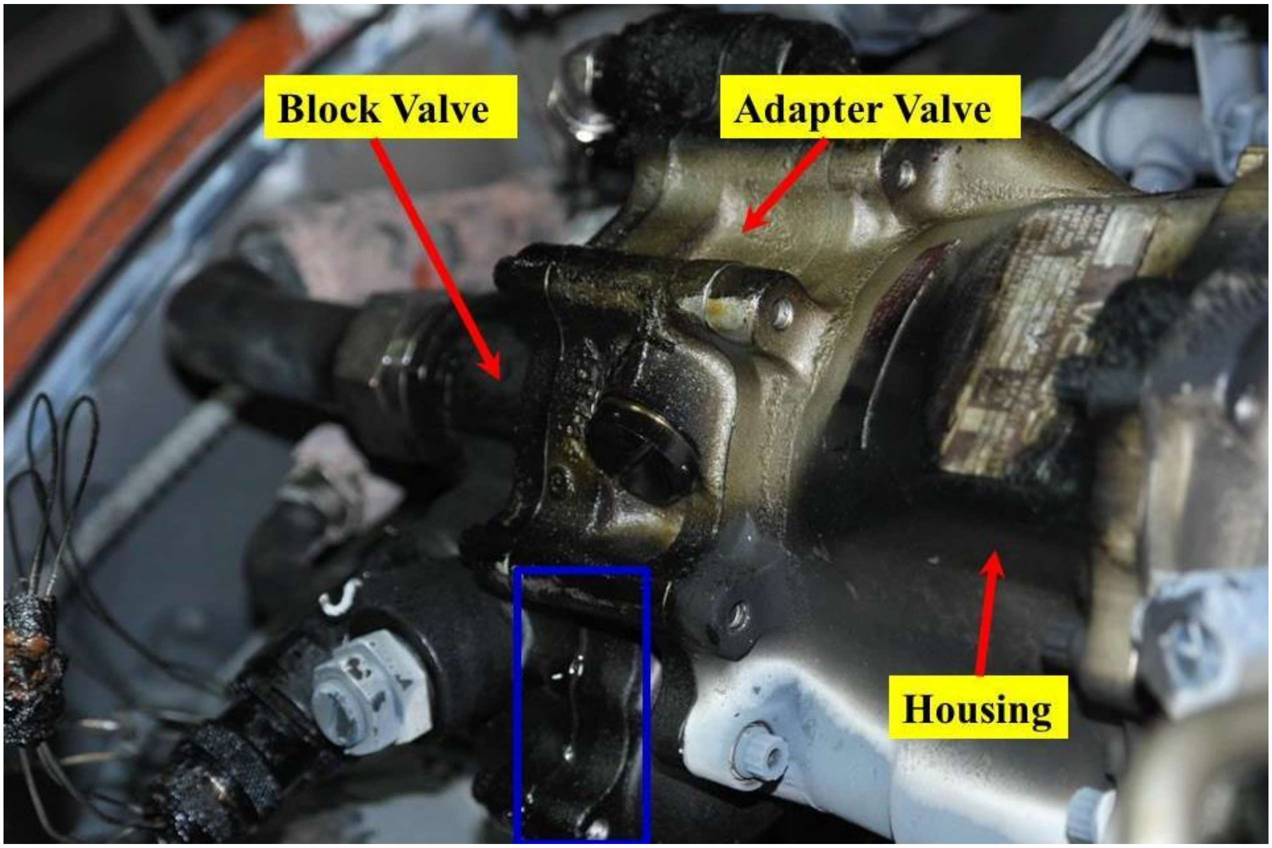

PHOTO 12: HYDRAULIC PUMP LEAK

Photo Courtesy of GE

With the hydraulic pump removed, wet motoring of the engine was accomplished by installing a blanking plate where the hydraulic pump had been installed, a fuel line was connected to the inlet port of the main fuel pump, an electrical connection to the fuel shutoff solenoid to shuttle the valve OPEN or CLOSE and an air supply line to the air starter to rotate the core. Wet motoring involves rotating the engine and introducing fuel to the fuel system (fuel shutoff in the OPEN position) with no ignition (**FIGURE 5**). Wet motoring of the engine revealed a fuel leak from the IDG fuel/oil heat exchanger main housing just aft of the forward weld (fuel inlet port) at about the 12:00 o'clock position as installed in the engine (**PHOTO 13**). The forward weld attaches the inlet port cap to the main housing body. There is a similar aft weld used to attach the outlet port cap to the main housing body. Removal of the unit revealed a surface circumferential imperfection that measured about 4¾-inches (about a 90° arc) and was located approximately 0.80-inches aft of the inlet port circumferential weld in main housing body (**PHOTO 14**). Fluid was found weeping from the surface imperfection indicating a through-wall crack (**PHOTO 14**). The cracked measured about 0.25-inches circumferentially. The IDG fuel/oil heat exchanger was sent to the TechOps fuel shop for pressure testing (See Section 5.2 'IDG FUEL/OIL HEAT EXCHANGER TESTING' for results).

PHOTO 13: FLUID LEAK FROM TOP OF IDG FUEL/OIL HEAT EXCHANGER AFTER WET MOTOR

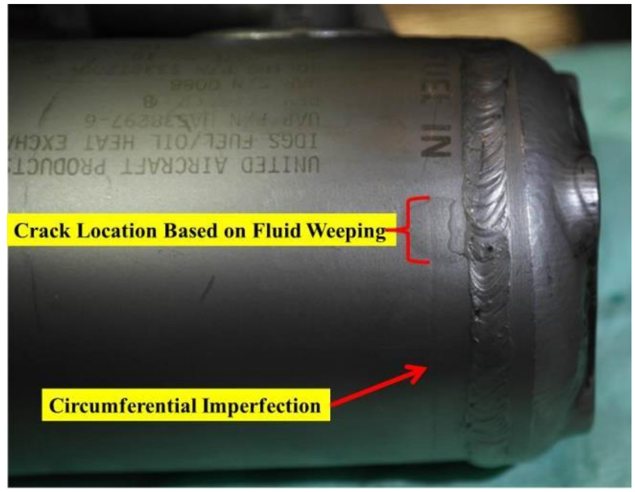

PHOTO 14: IDG FUEL/OIL HEAT EXCHANGER CRACK & CIRCUMFERENTIAL IMPERFECTION

Photos Courtesy of GE

5.0 DETAILED ENGINE EXAM AND COMPONENT TESTING AND DISASSEMBLY

5.1 HYDRAULIC PUMP DISASSEMBLY

The valve block was separated from adapter valve exposing the impeller. The impeller was intact and black debris was found slung out on the diffuser (**PHOTO 15**). The debris was not brittle but somewhat pliable. The valve block packing used to seal between the valve block and adapter valve was intact, pliable, and exhibited no compression set but was not tightly seated within its recess groove on the valve block as intended but was loose. Comparing a new exemplar valve block packing with the event valve block packing revealed that the event packing diameter was larger, consistent with it expanding or swelling (**PHOTOS 16** and **17**). The two other packings on the adapter valve appeared intact and in good condition.

PHOTO 15: BLACK DEBRIS IN HYDRAULIC PUMP

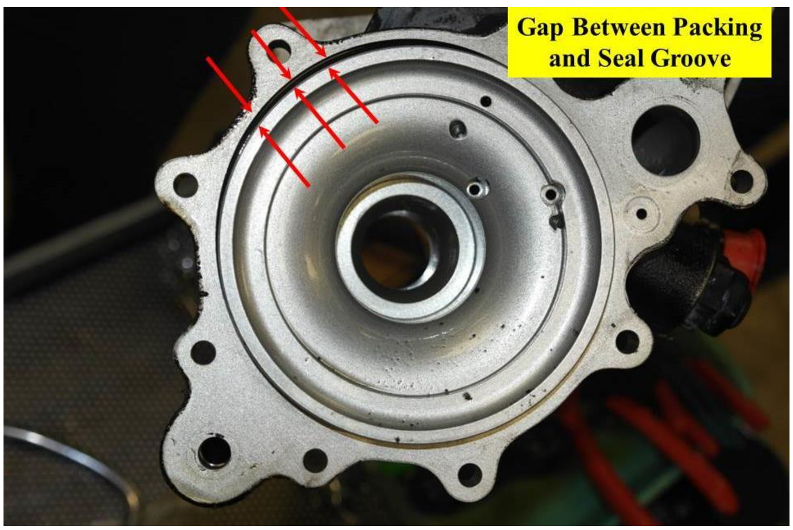

PHOTO 16: EVENT VALVE BLOCK PACKING LOOSE WITHIN RECESS GROOVE OF THE VALVE BLOCK

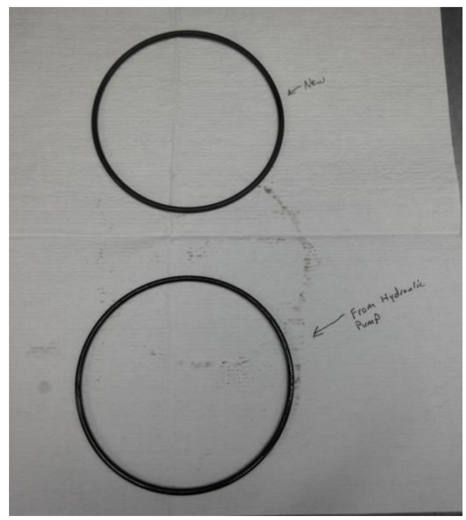

PHOTO 17: COMPARISON OF EXEMPLAR AND EVENT PACKING

Photos Courtesy of GE

5.2 IDG FUEL/OIL HEAT EXCHANGER TESTING AND EXAMINATION

The test was performed on Fuel Flow Test stand #22 (46271), with a calibration sticker indicating re-calibration due date of May 9, 2015. With the oil inlet and outlet ports capped, fluid was flowed at various pressures through the core and fluid was observed spraying from the crack previously identified. At 10 pounds psi fluid pressure a light spray was observed (**PHOTO 18**). According to the IDG Fuel/Oil Heat Exchanger Component Maintenance Manual (CMM) the fuel side of the unit is pressure checked by capping off the fuel outlet port and applying 1800±20 psi fuel pressure to the inlet port for 2 minutes. No external or internal leakage is permissible. Due to concerns with the structural integrity of the unit because of the main housing body crack, the Powerplant Group decide not to bring the pressure up to the CMM test pressure of 1800±20 psi but instead agreed to bring the pressure up to only 400 psi. At 60 psi fluid pressure, the spray pattern was more pronounced. At 100 psi fluid pressure, the spray pattern was visible essentially the same as at 60 psi test point (**PHOTO 19**). At 250 psig fluid pressure, the spray pattern was visible essentially the same as at 60 psi and 100 psi test points but appeared a little more dense (**Photo 20**). At the last test point of 400 psi fluid pressure, the spray pattern fanned out more and the spray appeared more atomized (**Photos 21** and **22**).

Photo 18: Leak at 10 psi Fluid Pressure

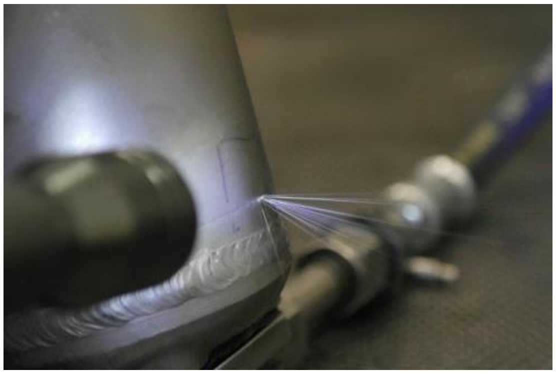

Photo 19: Leak at 60 psi Fluid Pressure

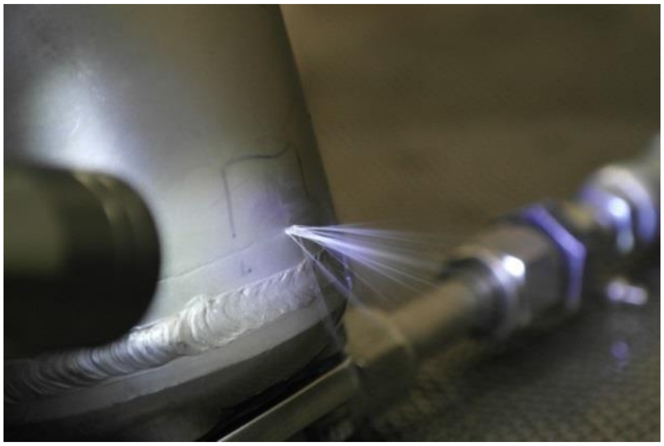

Photo 20: Leak at 250 psi Fluid Pressure

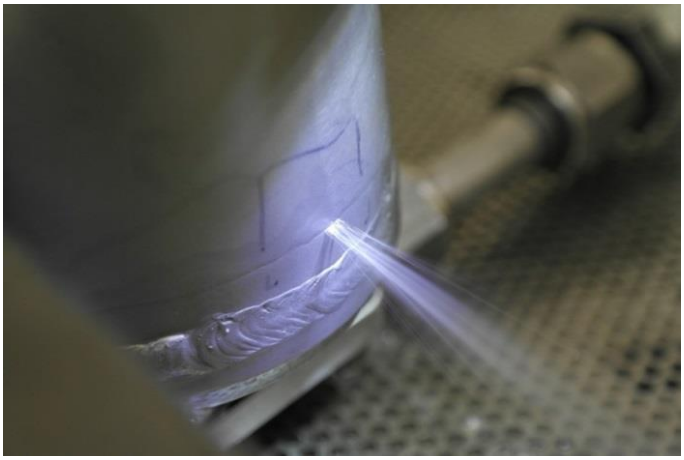

Photo 21: Leak at 400 psi Fluid Pressure

Photo 22: Leak at 400 psi Fluid Pressure

Photos Courtesy of GE

After the pressure test, a florescent penetrant inspection (FPI) was performed on the main body housing. The through-wall crack location ❶ held the penetrant as did a second surface indication ❷ (**Photo 23**), also aligned with the circumferential surface imperfection previously documented in **Photo 14**. This second indication measured about 0.25-inches in length. Looking into the inlet fuel port, penetrant was observed at the core-to-main body housing junction. An attempt was made to x-ray the housing to quantify the crack; the location of the crack coupled with the density of the housing and the inner core prevented the crack from being observed.

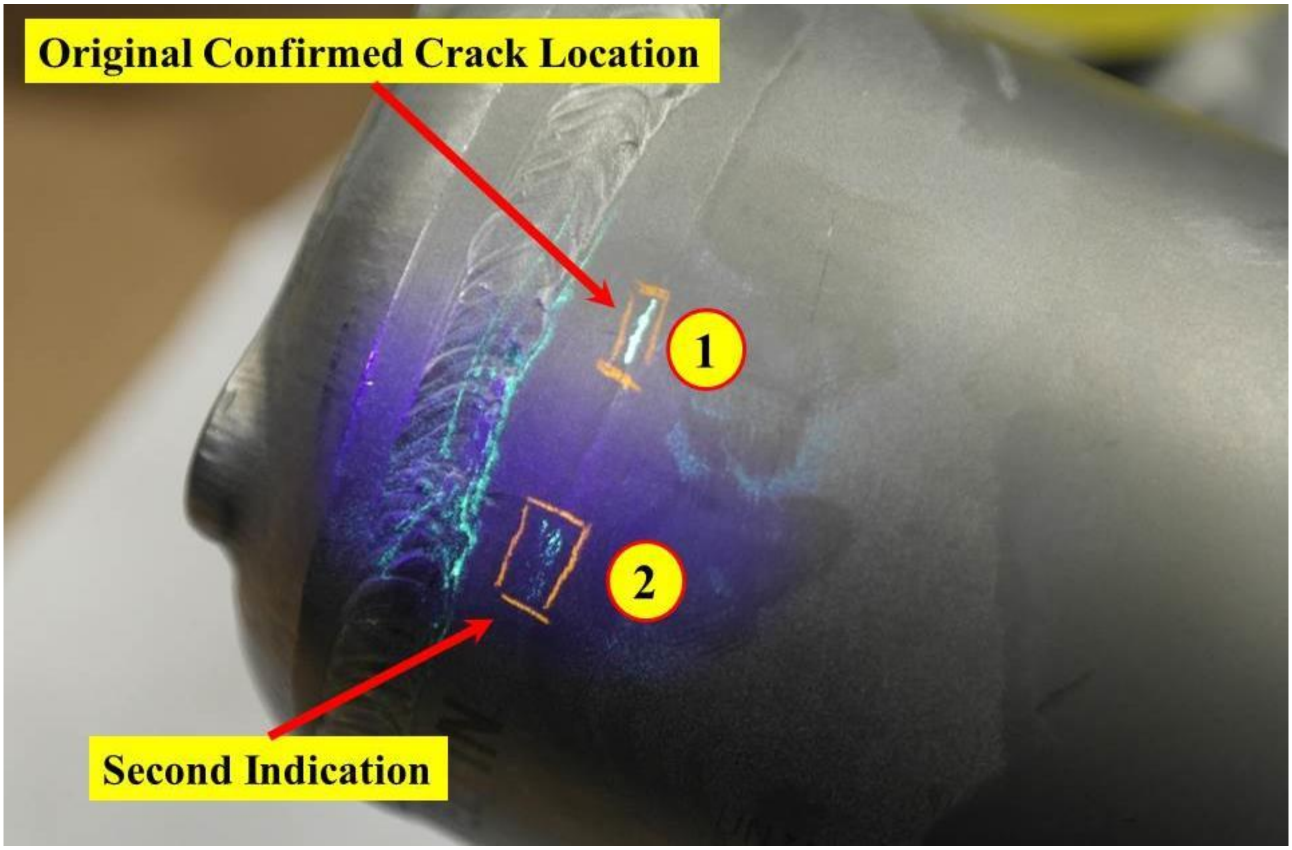

Photo 23: IDG Fuel/Oil Heat Exchanger Main Housing FPI Indications

Photo Courtesy of GE

In order to determine if the oil side of the heat exchanger leaked, an air hose was attached to the oil inlet port and the oil outlet port was capped; the fuel inlet and output ports were uncapped. The heat exchanger was then submerged in water and air pressure at about 90 psi for 20 minutes then again at about 200 psi for another 20 minutes was applied. No bubbles were observed at either of the two test pressures.

5.3 IDG Power Feeder Cable Examination and Installation

Examination of the IDG power feeder cables revealed thermal distress that included melted and missing outer protective sheathing, exposed inner cloth insulation, and exposed electrical cable (**Photo 24**). The IDG is mounted to the aft left hand side of the accessory gearbox and converts the varying input speed of the engine into 115/200 voltage (V), 3-phase (hence the 3 power cables and 1 neutral cable), 90 kilovolt-amps (KVA) at 400±4 hertz (H) frequency. The electrical power feeder cables provide the transmission of the alternating current (AC) power to the airplane's electrical power distribution system. Closer examination of the power feeder cables revealed evidence of chafing on the outer sheath of cables Nos. 2 and 4 and evidence of an arc burn on cable No. 3 (**Photo 25**).

Photo 24: Thermal Distress to IDG Power Feeder Cables

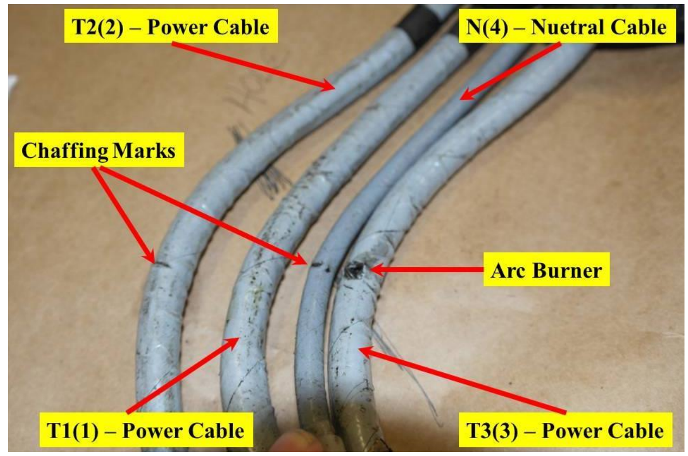

Photo 25: Chafe Marks and Arc Burn on IDG Power Feeder Cables

Photos Courtesy of GE

Examination of the engine hardware along the path of the IDG power feeder cables from their IDG terminal block to the pass-through hole in the engine heatshield revealed that the accessory drive lube and scavenge pump pressure (supply) line support bracket (PN 9254M14P001A), which is located on the front side of the accessory gearbox just below the hydraulic pump pad, exhibited signs of an arc burn (**Photos 26** and **27**). For simplicity the accessory drive lube and scavenge pump pressure line support bracket will be subsequently referred to as the 'oil line bracket'.

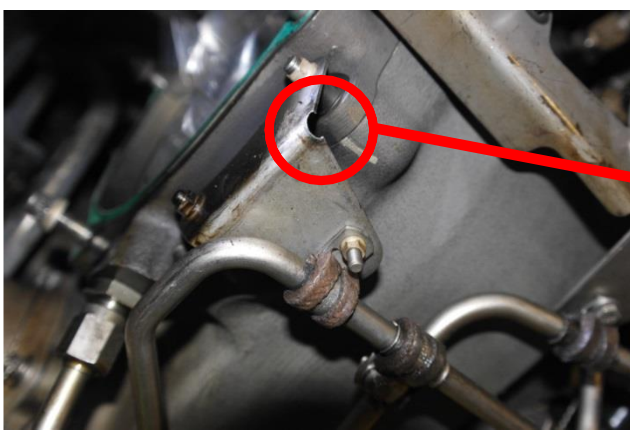

Photo 26: Oil Line Bracket Corner Consumed

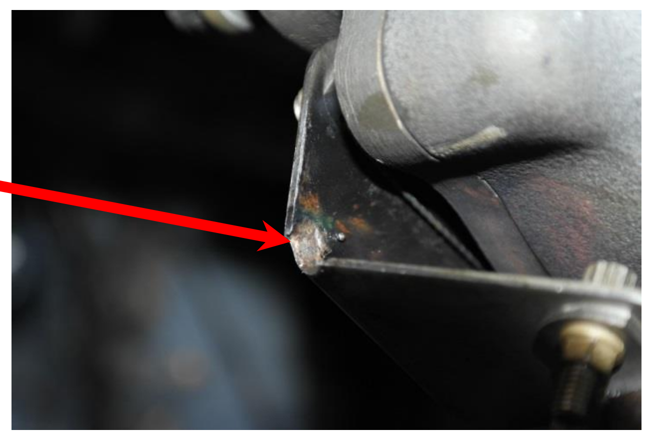

Photo 27: Molten Metal on Aft Side of Oil Line Bracket

Photos Courtesy of GE

Power feeder cable No. 3 that had the arc burn was reinstalled on the engine to access the relative position of the arc burn observed on the cable to the oil line bracket that also had an arc burn. The No. 3 feeder cable was reinstalled as close to the event orientation as possible (**Photo 28** – See **Photos 3** and **30** for at event installation position). The arc burn on the No. 3 cable aligned closely with the arc burn on the corner of the oil line bracket (**Photo 29**).

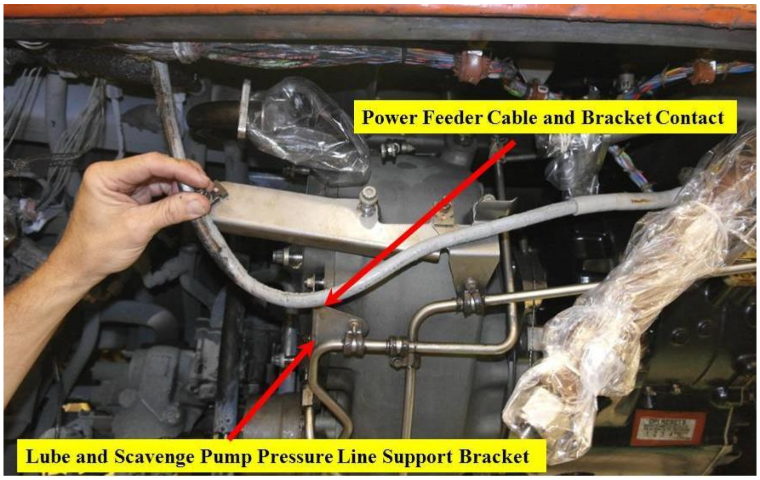

PHOTO 28: POWER FEEDER CABLE NO. 3 REINSTALLED SIMILAR TO EVENT INSTALLATION ORIENTATION

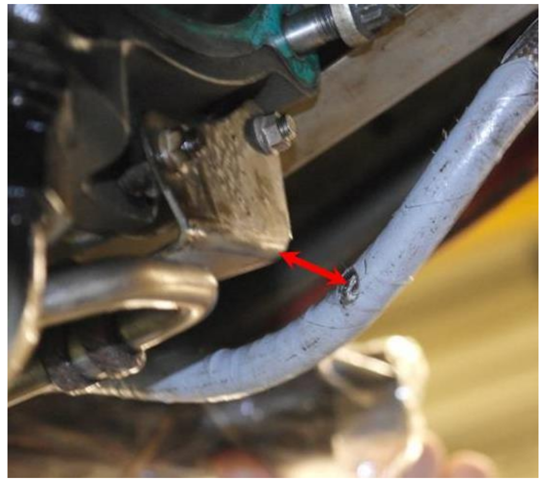

PHOTO 29: MATCHING ARC BURN DAMAGE ON POWER FEEDER CABLE AND OIL LINE BRACKET

Photos Courtesy of GE

The slack observed on the IDG power feeder cables for the event engine was compared to an exemplar DAL 767 CF6-80A powered airplane. On the exemplar engine, the power feeder cables ran along the power feeder cable support bracket (PN 332T1111-142)[5] and had no slack before it passed-through the engine heatshield (**PHOTO 31**), which was not the case in the event installation. For simplicity the power feeder cable support bracket will be subsequently referred to as the 'cable bracket'. Also noted was the difference in orientation of the forward P-clamp; on the event engine the clamp was oriented down (attachment bolt is above the clamp) and on the exemplar engine the clamp was oriented up (attachment bolt is below the clamp). The correct orientation of the forward P-clamp is up (See Section 6.0 for more details). Also noted was the amount of tape to bundle the event power feeder cables was much more extensive than what was observed on the exemplar engine.

PHOTO 30: EVENT ENGINE IDG POWER FEEDER CABLE ORIENTATION WITH FORWARD P-CLAMP DOWN

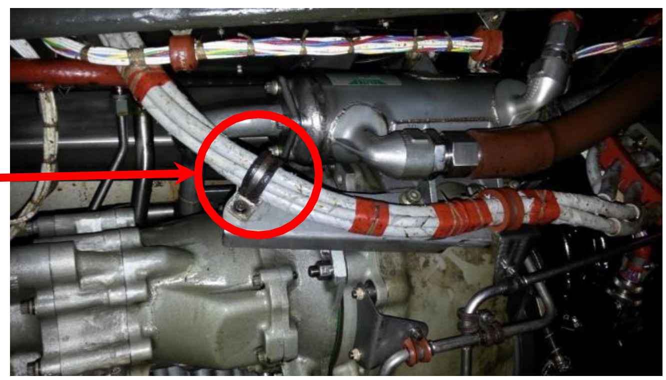

PHOTO 31: EXEMPLAR ENGINE IDG POWER FEEDER CABLE ORIENTATION WITH FORWARD P-CLAMP UP

Photos Courtesy of DAL

With **all** the power feeder cables installed, the forward P-clamp was then installed in the correct orientation to access its impact on the observed slack. The orientation of the forward P-clamp did not seem to affect the amount of slack that could be introduced to the power feeder cables.

[5] No part number was stamped on the bracket to provide a positive identification. However, Boeing was able to confirm the part number by comparing photographs of the event bracket with drawings from the various bracket PN options.

6.0 METALLUGICAL EXAMINATION OF THE IDG FUEL/OIL HEAT EXCHANGER

The IDG fuel/oil heat exchanger was submitted to the NTSB Materials Laboratory in Washington DC for a metallurgical examination. The OD of the main housing was examined in more detail using a 5X to 50X magnification stereo-zoom microscope. The through-wall crack (❶ in **Photo 23**) was a distinct linear crack exhibiting a brown-colored stain around it (**Photo 32**). The second indication area (❷ in **Photo 23**) was confirmed to be very short linear cracks that appeared to be linked together by nonlinear bridging cracks and consisted of a cluster of small lines and dots (**Photos 33** and **34**). This second crack was not a through-wall crack and was co-located within what appears to be a weld/braze bead (**Photos 33** – yellow dotted line).

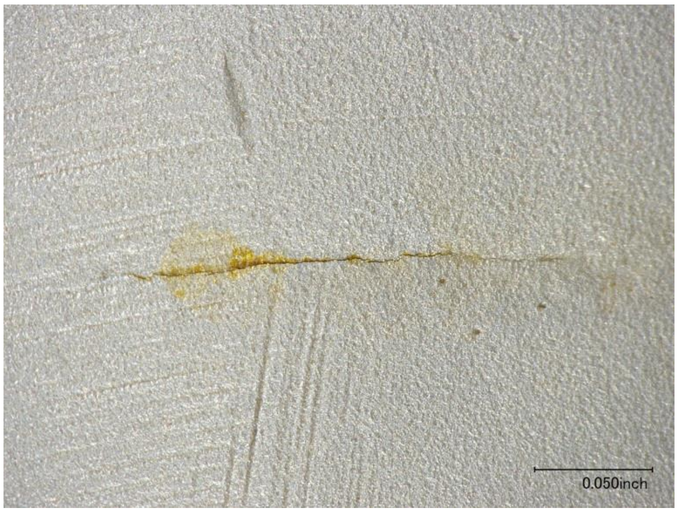

Photo 32: High Magnification of Through-Wall Crack (❶)

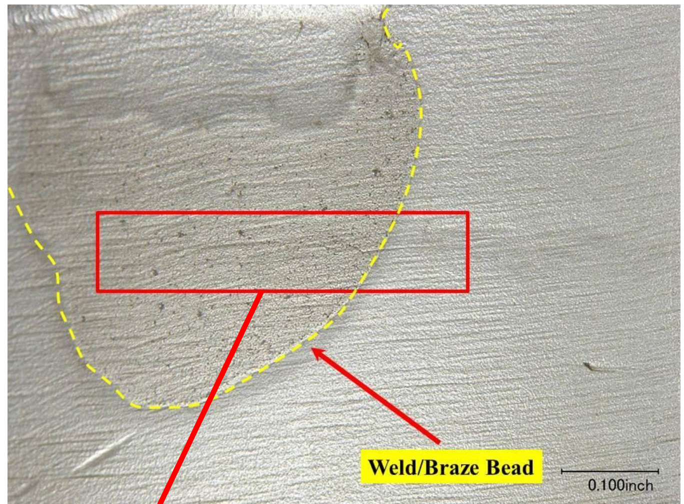

Photo 33: High Magnification of Non Through-Wall Crack (❷)

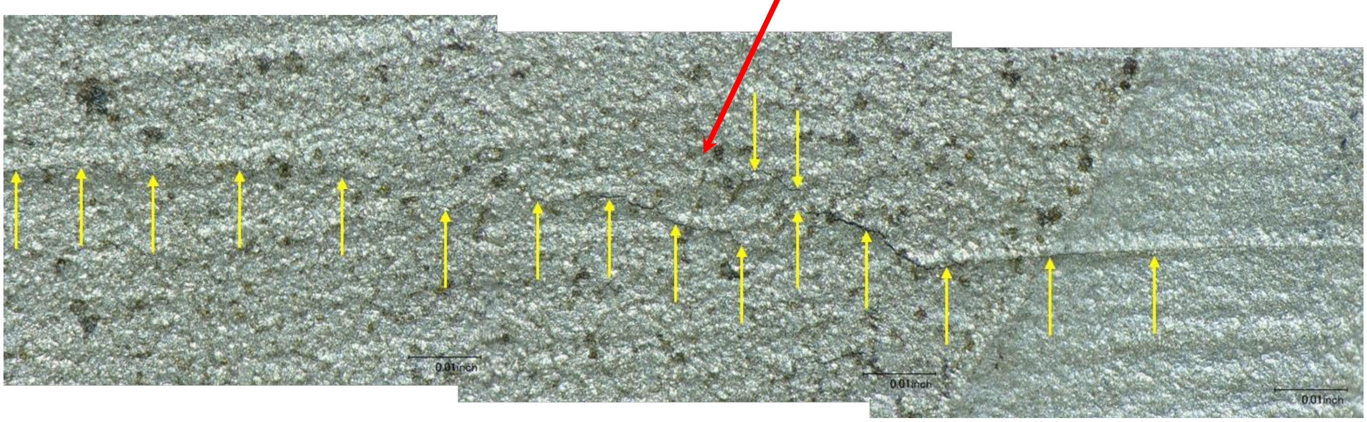

Photo 34: Higher Magnification of Non Through-Wall Crack (❷)

The main housing was sectioned in the area near the through-wall (❶) and the non-through wall cracks (❷), the cracks were mechanically exposed, and the fracture surfaces were analyzed in a field emission scanning electron microscope (SEM). The through-wall crack fracture surfaces showed features consistent with multiple fatigue crack initiation sites that included thumbnail-shaped patterns and ratchet marks (**Photos 35** and **36**). A distinct step was observed on the fracture surfaces approximately two-thirds of the way through the housing wall thickness from the ID of the housing (See **Photo 36** – yellow dotted line). The multiple fatigue cracks emanated from the ID surface of the housing and propagated radially towards the OD and the crack orientation - circumferential instead of longitudinal - was more consistent with high longitudinal stresses than with hoop (radial) stresses (**Figure 6**). The fracture surfaces of the non though-wall crack also consisted of features consistent with fatigue cracking. However different from the through-wall crack, the non through-wall crack had multiple small OD surface cracks with a larger ID crack; the ID and OD cracks did not link up to produce a through-wall crack (**Photo 37**). The OD cracks appeared to be confined to the weld/braze bead.

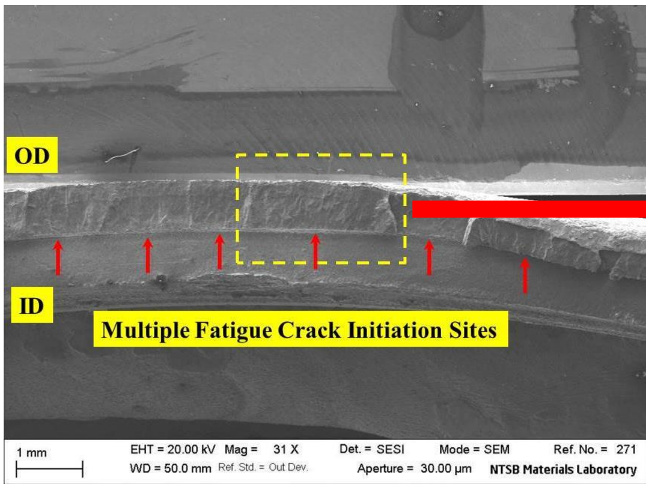

Photo 35: Multiple Through-Wall Crack Initiation Sites

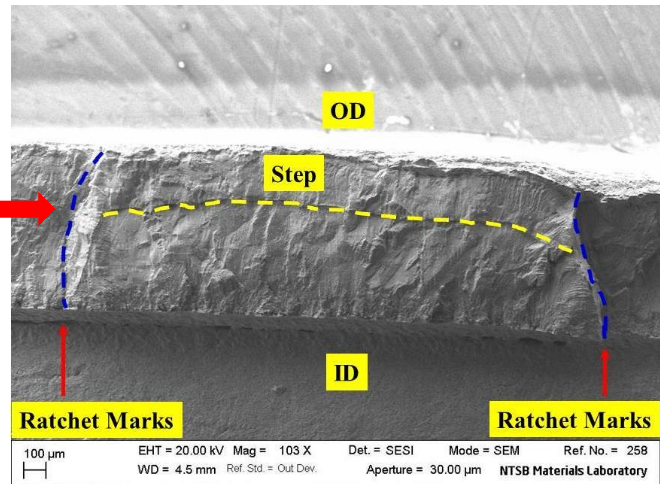

Photo 36: Through-Wall Crack Fracture Features

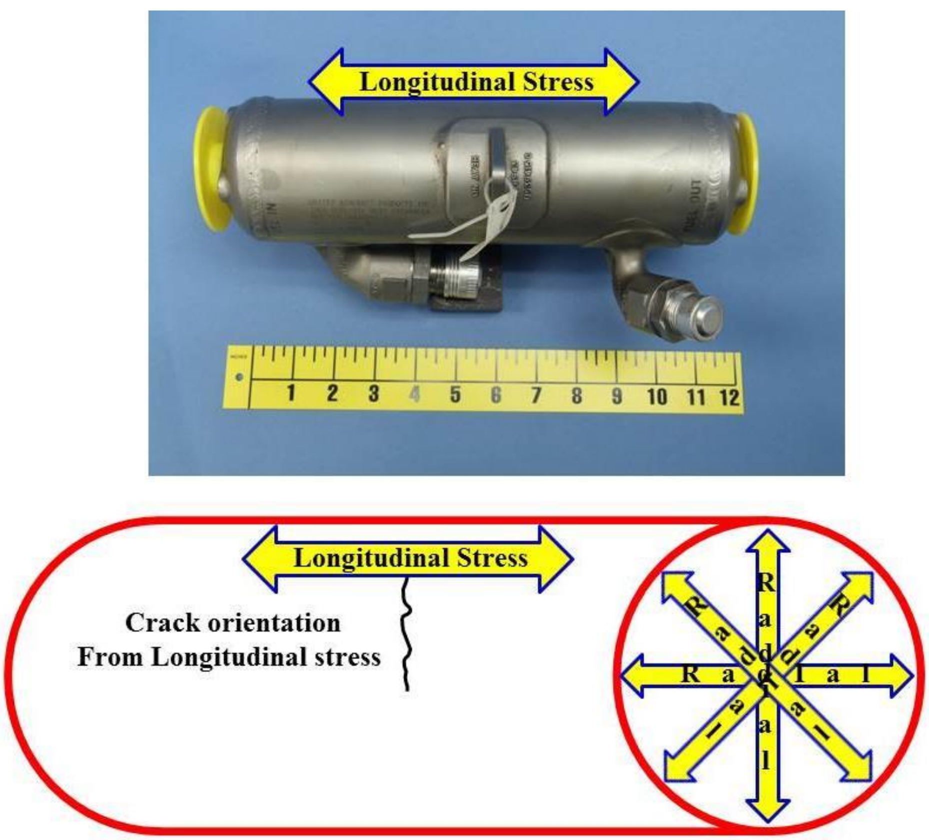

Figure 6: Stress Orientation

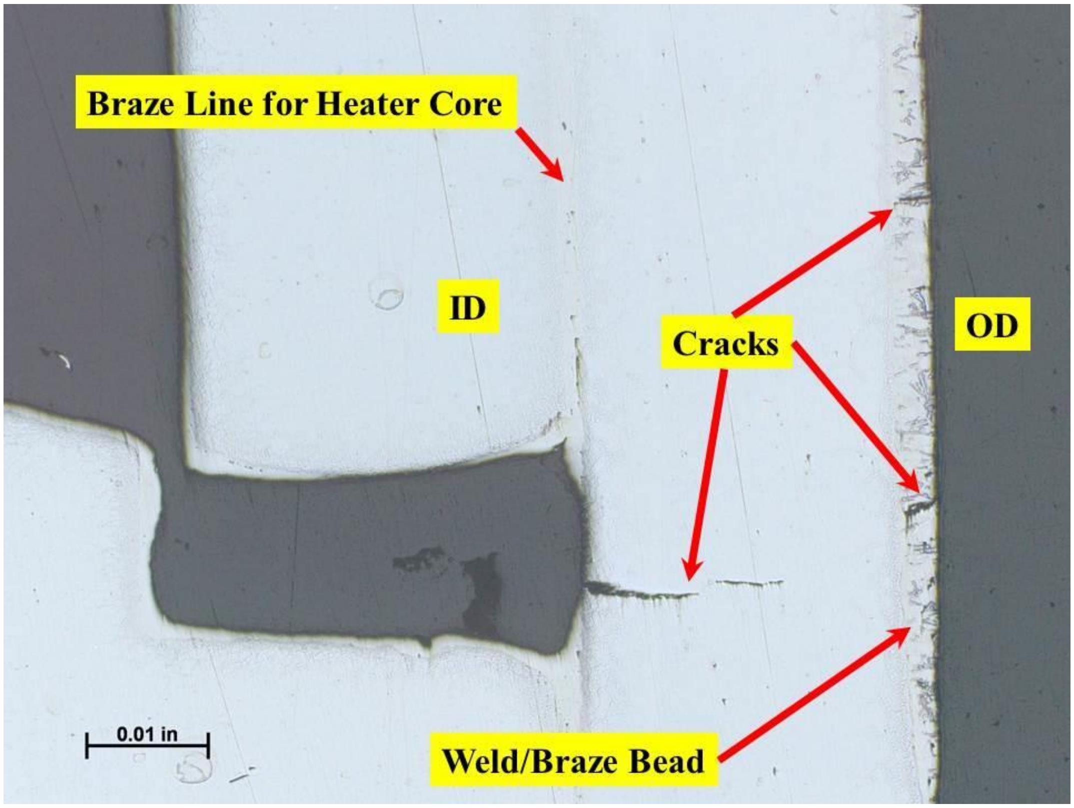

PHOTO 37: NON THROUGH-WALL CRACK (❷) LOCATION SHOWS ID AND OD CRACKING (UNETCHED)

Cross-sections were prepared through both the through-wall and the non through-wall cracks. In both locations, the cracks were relatively flat and transgranular, and were consistent with fatigue cracking. No anomalies were detected in the area of the cracks or at the fatigue crack origins. The microstructure of the base material of the housing was consistent with austenitic stainless steel. The housing material was analyzed using a Thermo Scientific Niton XL3T-980 x-ray fluorescence (XRF) alloy analyzer. The housing material was consistent with Type 321 stainless steel as specified by the manufacturer.

7.0 IDG POWER FEEDER CABLE INSTALLATION

Since the IDG power feeder cables are part of the airplane and remained attached to the pylon when an engine change occurs; the Boeing airplane manuals provide the instructions and illustrations for installing and routing the power feeder cables and it is these manuals that are used when an engine is installed. Review of the various Boeing manuals that address the IDG power feeder cable installation and routing; such as the 767 Aircraft Maintenance Manual (AMM) (CF6-80A Series Engine) Chapter/Subchapter/Section 71-00-02; 767 Powerplant Buildup Manual (PBM) (CF6-80A Series Engine) 71-00-02; and 767 Operator dedicated Task Cards, found they all used essentially the same illustration that depicted: 1) the IDG power feeder cable routed from the pylon to the engine heatshield had a smooth large radius bend and that the cables are routed underneath the LPT air cooling supply tube and manifold (FIGURE 7) and 2) the IDG power feeder cable routed beneath the heatshield runs along the cable support bracket with no apparent slack with the forward P-clamp installed up and the aft

P-clamp installed down (**Figure 8**. The Boeing 767 Aircraft Maintenance Manual (CF6-80A Series Engine) Standard Practices Engine Maintenance Procedure Chapter/Subchapter/Section 70-00-00 provides general instructions for installing electrical cables and connectors. The instructions state that:

> During the electric cable installation, adjust the cable through the clamps to get the smoothest and largest radius… and prevent a sharp bend, a turn or a kink.

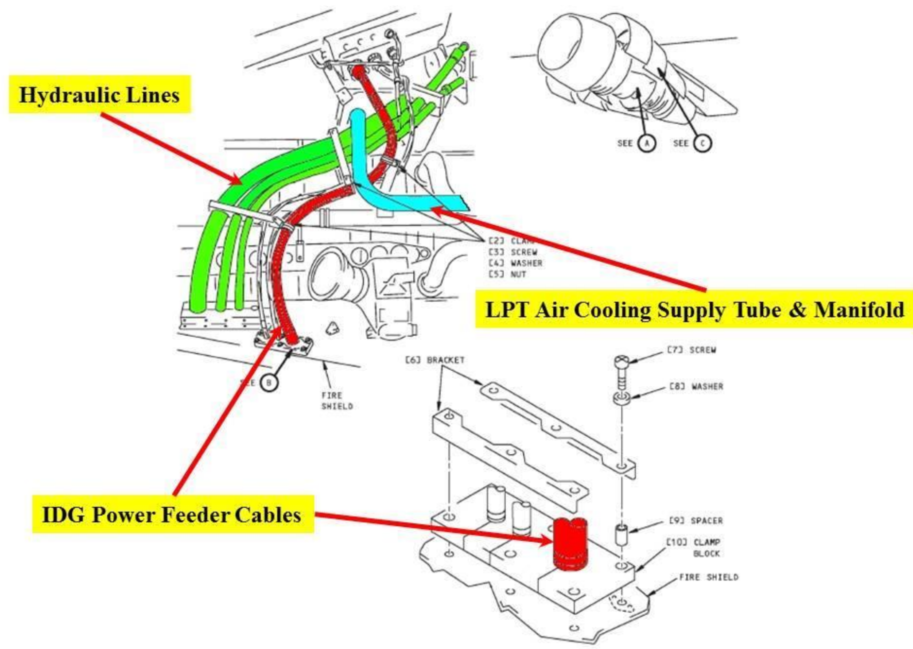

Figure 7: Typical Illustration of IDG Power Feeder Cable Routing Above Engine Heatshield in the Boeing 767 Manuals

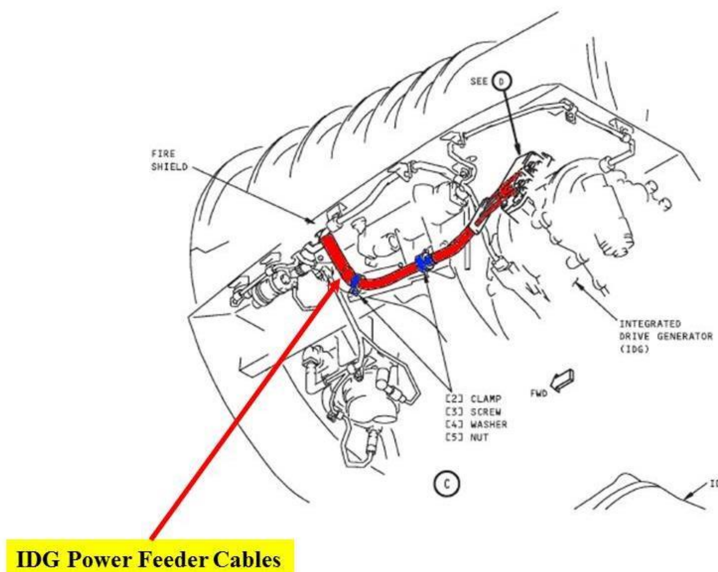

Figure 8: Typical Illustration of IDG Power Feeder Cable Routing Below Engine Heatshield in the Boeing 767 Manuals

Review of the GE CF6-80A Boeing Illustrated Parts Catalog (IPC) and the Engine Manual (EM) found multiple illustrations that depict the installation of the IDG power feeder cables beneath the heatshield. As mentioned before, when installing and routing the IDG power feeder cables, the Boeing manuals are to be used; therefore, the illustrations found in the GE manuals are for reference only. In all the illustrations in the IPC and EM, the IDG power feeder cables run along the cable support bracket with no apparent slack just as depicted in the Boeing manuals. In all the IPC illustrations, the forward P-clamp installation was up and the rear P-clamp was down, again consistent with the Boeing manuals. In the EM illustrations, the rear P-clamp in all the illustrations were down, which is the correct orientation and in agreement with the Boeing manuals, however, a mixture of up and down forward P-clamp orientation was dependent on the illustration.

DAL developed their own specific job instruction work card, No. 7100-4450 titled "CF6-80A ENG CHG/Drop ELECTRICAL CONNECTIONS – 300" that provides instructions for connecting the IDG power feeder cables. The job card is a standalone document that provides all the instructions and diagrams needed to perform that task without the need for additional reference material. The job card that was current when the event engine was installed on the incident airplane back in July 2012 provided instructions for the orientation of the P-clamps on the cable bracket (**FIGURE 9**) but did not provide detailed instructions on the amount of slack allowed beneath the engine heatshield nor any guidance on the routing of the power feeder cables from the heatshield to the pylon. Subsequently, based on this event DAL has modified work card No. 7100-4450 to provide additional information on the proper routing of the IDG cable (See Section 9.2 for more details).

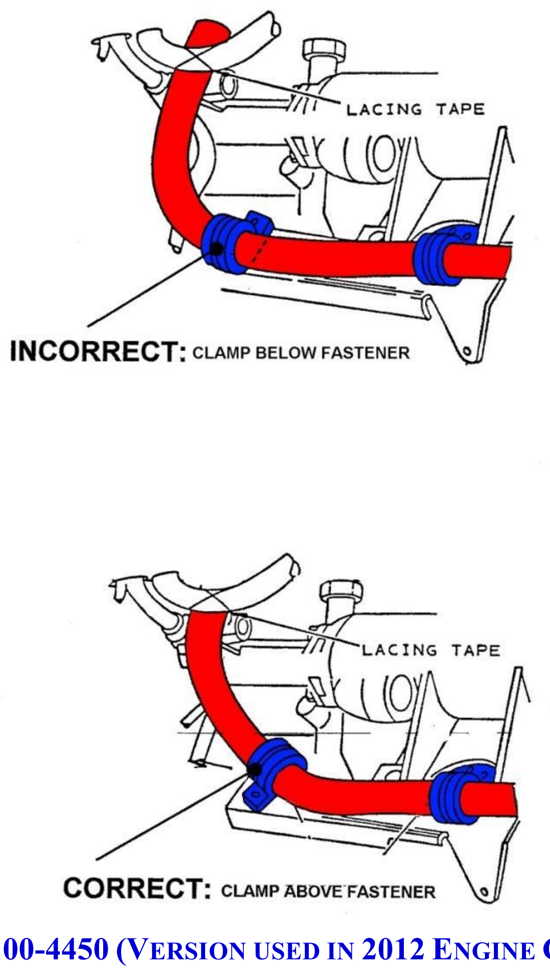

FIGURE 9: WORK CARD NO. 7100-4450 (VERSION USED IN 2012 ENGINE CHANGE) P-CLAMP ORIENTATION

8.0 RECORDED DATA

The flight data recorder (FDR) was sent to the NTSB's Headquarters in Washington DC and was readout by the Vehicle Recorder Group. A sequence of events timeline was created based on data from the FDR for the incident flight. It should be noted that parameters are sampled at different rates based on the need for the fidelity of data and are recorded at different times. For example, the fire warning, engine fan speed (N1) and throttle lever angle (TLA) are all sampled every second; the engine fuel cutoff, engine fuel valve shutoff, and core speed (N2) are sampled every 4 seconds, and the fuel flow (FF) is sampled every 64 seconds and recorded. None of these parameters are recorded at the same time but are staggered time-wise from one another. Since the FF sample rate was so low, it was not used in the sequence of events because it did not provide an appropriate and timely reflection of the engine operation during the fire sequence. It should also be noted that parameters with the same sample rate are often recorded on the FDR at different increments within the same second; for this particular FDR, a second is divided into 12 increments. Although the fire warning, N1 and TLA are all sampled every second, their values were recorded at different times with the 12 increments that make up that second. Due to various in sample rates and recording times, it was not possible to align all the parameters on a common time, instead the information is provided in chronological order as it is recorded. Times are rounded to the nearest whole second for simplicity. See **TABLE 1** for the timeline and also see the FDR Group Chairman's Report for additional data.

Table 1: Incident Time Line	
FDR data (minutes/ seconds)	
T = -714s (-11min 54s)	Airplane Takeoff – Weight on Wheels (WOW) – AIR
T = -20s	From T = -20s to the time of the fire event (T = 0s) Airspeed constant at about 328 knots Airplane climbing at about 1,500 feet/minute through 18,936 feet ENG1 N1 constant at about 101% ENG1 N2 constant at about 103% ENG1 TLA constant at about 106.9°
T = 0s	**ENG1 Fire** Airspeed constant at about 328 knots Airplane climbing at about 19,435 feet ENG1 N1 constant at about 101% ENG1 N2 constant at about 103% ENG1 TLA constant at about 106.9° **Master Warning** – **ON** Fire warning and Master Warning recorded within the same second – Fire warning recorded first
T = +13s	**Master Warning** – **OFF** No change in ENG1 TLA, N1 or N2
T = +62s (+1min 2s)	ENG1 TLA starts to move back
T = +65s (+1min 5s)	ENG1 N1 starts to roll back – N1 at about 98%
T = +67s (+1min 7s)	ENG N2 starts to roll back N2 at about 99.3% – **NOTE**: N2 is sampled every 4 seconds ENG N1 at about 94%
T = +81s (+1min 21s)	ENG1 TLA stabilizes at about 76.6° ENG1 N1 stable at about 71%
T = +83s (+1min 32s)	ENG1 N2 stable at about 90%
T = +152s (+2min 32s)	ENG1 Fuel Cutoff – CUTOFF ENG1 Fuel Valve – NOT OPEN Fuel Cutoff and Fuel Valve recorded within the same second – Fuel Cutoff recorded first
T = +159s (+2min 39s)	ENG1 Fire – NORMAL
T = +850s (+14min 10s)	Airplane Landing – WOW – GRND
	ENG1 Fire EXT Switch – fire handle never pulled throughout the flight ENG1 vibrations remained under 1 aircraft unit throughout the flight

9.0 CORRECTIVE ACTIONS

9.1 DAL Inspection of its' Boeing 767 Fleet for IDG Power Feeder Cable Issues

Based on the initial investigative finding of chaffed IDG power feeder cables on the event engine, DAL conducted a once-through-the-fleet inspection of all their Boeing 767 airplanes powered by GE CF6-80A2 engines for IDG power feeder cable damage. The DAL fleet is comprised of 12 airplanes for a total of 24 engines. The power feeder cables stay with the airplane and are removed for an engine change; therefore the once-through-the-fleet inspection is an airplane inspection and not an engine inspection and only pertain to installed engines. For engine changes, one end of the IDG power feeder cables are disconnected from the IDG terminal block, which is installed on the engine, while the other end remains attached within the airplane pylon.

DAL reported that of the 24 installed engines inspected, none exhibited damaged IDG power feeder cables. Along with the chaffing damage, the investigation identified routing issues – above and below the engine heatshield - that contributed to the observed excessive slack in the IDG power feeder cables below the engine heatshield. **Photo 38** provides an exemplar of the misrouting of the IDG power feeder cables found during the fleet inspection; the dashed greens lines indicate the correct routing. **Photo 39** shows the entire routing of the IDG power feeder cables on the event engine. The once-through-the-fleet inspection found that 3 airplanes totaling 3 engines had the excessive slack. Of note, both engines on the event airplane, N139DL, were found to have excessive slack; this included the IDG power feeder cables that had been repaired to return the airplane to service. Subsequently the IDG power feeder cables on all 5 engines were rerouted to remove the slack.

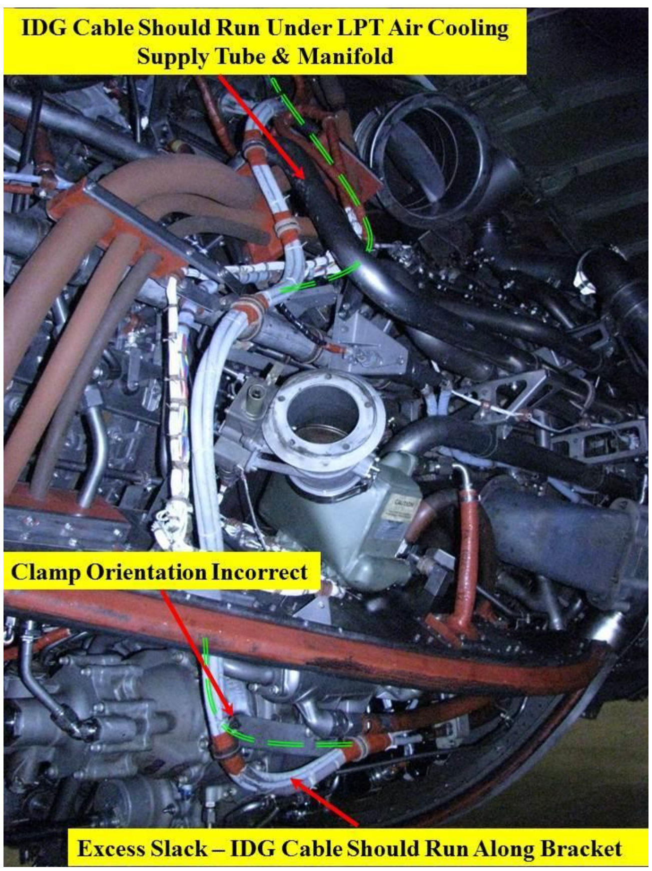

Photo 38: Misrouted IDG Power Feeder Cable Found During the Fleet Inspection

Photos Courtesy of DAL

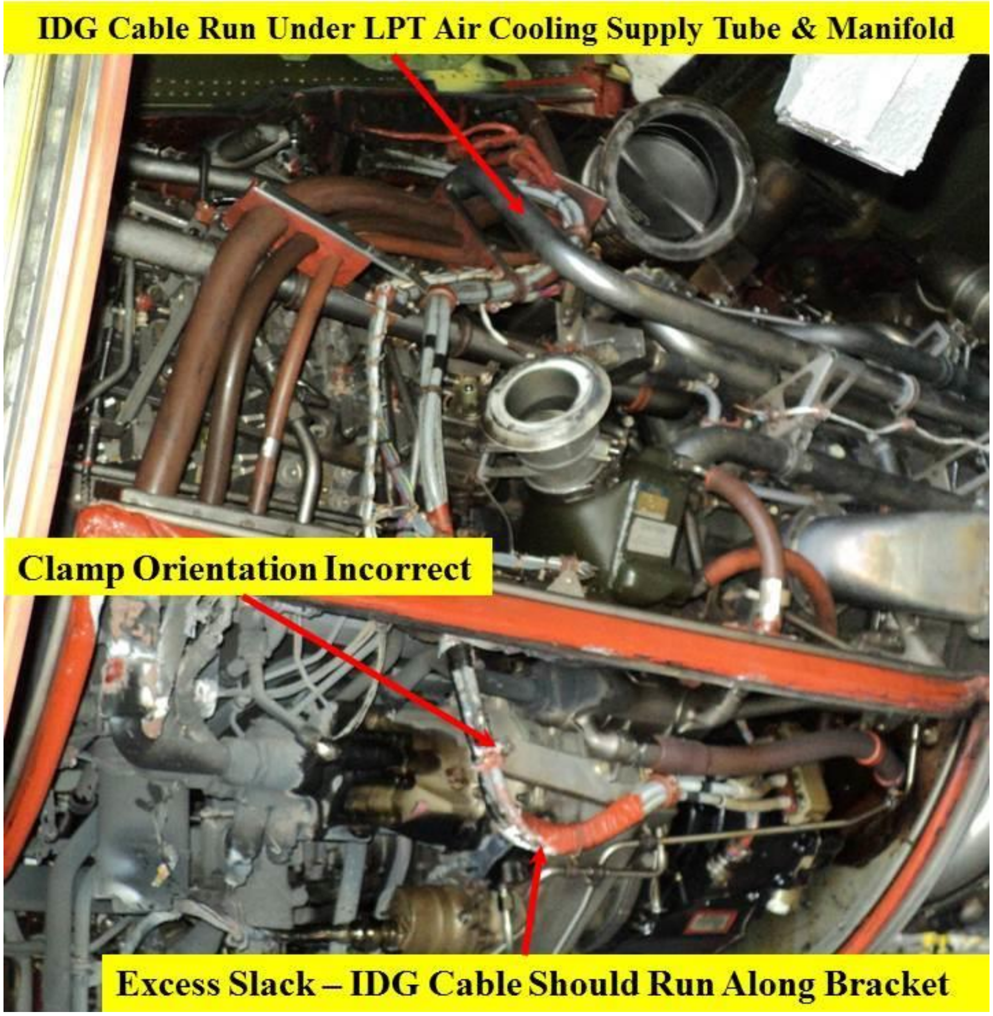

PHOTO 39: MISROUTED IDG POWER FEEDER CABLE ON EVENT ENGINE

Photo Courtesy of DAL

9.2 DAL INSTRUCTIONS FOR ROUTING THE IDG POWER FEEDER CABLES

While DAL performed the once-through-the-fleet inspection for chafed and misrouted IDG power feeder cables, they determined that their job instruction work card, No. 7100-4450, could and should provide more specific installation instructions; so on July 25, 2014, DAL issued a revision to No. 7100-4450 that included a CAUTION (see below) and a detailed figure for the proper routing of the power feeder cables both above and below the engine heatshield (**FIGURE 10**). The added CAUTION reads as follows:

> **Caution**: proper generator feeder cable routing and feeder cable clamp orientation is critical to prevent interference with engine components which could cause arcing. Ensure that generator cables do not rub against T/R cowling when closed to prevent chafing of cables.

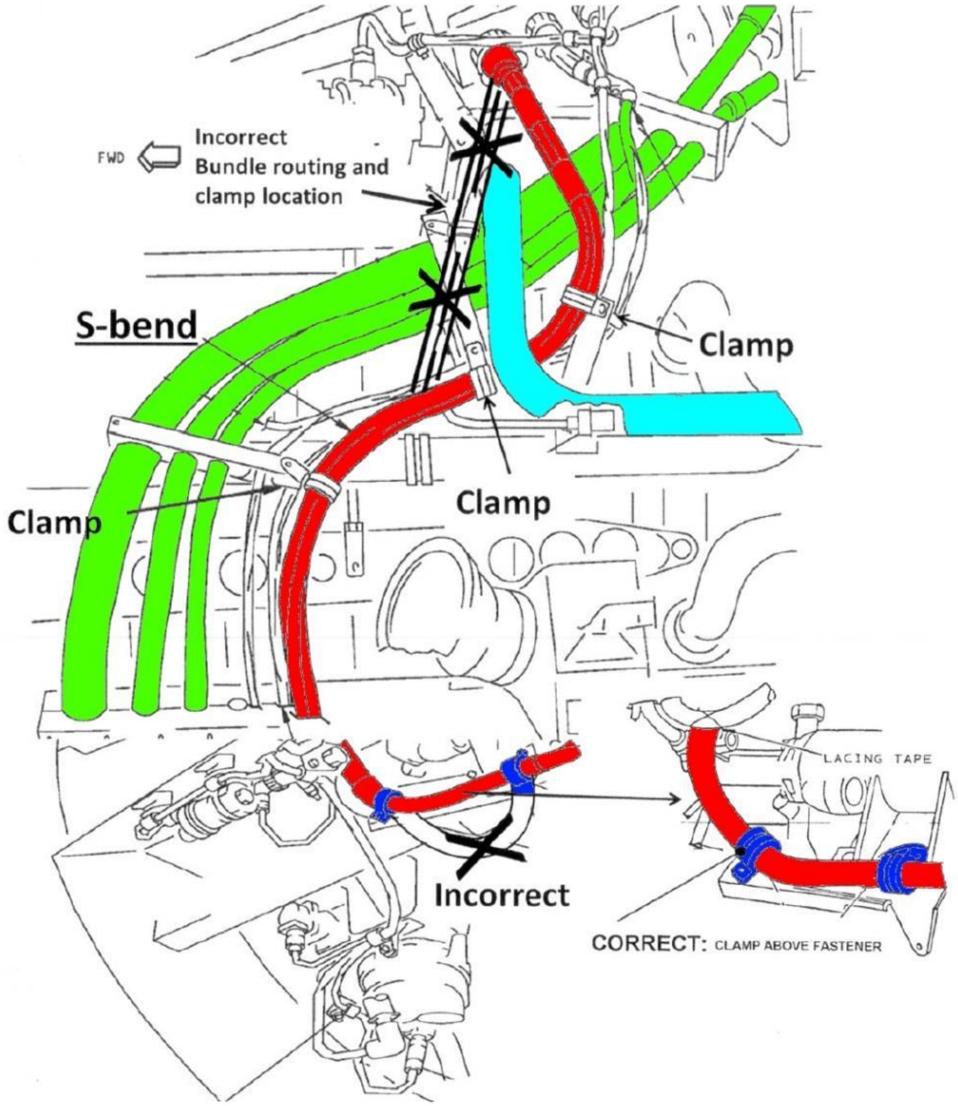

FIGURE 10: REVISED WORK CARD NO. 7100-4450 FOR P-CLAMP ORIENTATION AND CABLE ROUTING

9.3 CHANGES TO THE GE MANUALS FOR IDG POWER FEEDER CABLE ISSUES

GE has indicated to the Safety Board that they are in the process of correcting the effected illustration in the CF6-80A EM to depict the correct forward P-clamp orientation. Since the Boeing manuals are used for the installation of the power feeder cables and the GE manuals are for reference only, the corrections will be made using the normal EM revision process and no immediate revision released was warranted.

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