



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

October 1, 2021

Powerplants Group Chairman's Factual Report
NTSB No: DCA18LA163

A. ACCIDENT

Location: Hartsfield-Jackson Atlanta International Airport (ATL) – Atlanta, Georgia

Date: April 18, 2018

Time: 1809 eastern daylight time (EDT)

Aircraft: Airbus A330-323, N806NW, Delta Air Lines Flight 30

B. POWERPLANTS GROUP

Group Chairman: Robert Hunsberger
National Transportation Safety Board
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Member: Michael Millat
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East Hartford, Connecticut

Member:	Taylor Smith Delta Air Lines Atlanta, Georgia
Member:	Jeremy Katt Parker Aerospace Irvine, California
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C. SUMMARY

On April 18, 2018, about 1809 eastern daylight time, a Delta Air Lines (DAL) Airbus A330-323, N806NW, equipped with two Pratt & Whitney (P&W) PW4168A-1D turbofan engines, experienced a No. 2 (right) engine fire during initial climb from Hartsfield-Jackson International Airport (ATL), Atlanta, Georgia. The flight crew reported receiving a No. 2 engine fire electronic centralized aircraft monitor (ECAM) indication at about 700 feet above ground level (AGL). The flight crew declared an emergency, shutdown the No. 2 engine, discharged both fire extinguishing bottles, and initiated an air turn back to ATL where they made an uneventful overweight single-engine landing. Airport rescue and firefighting (ARFF) crews met the airplane on the runway and observed smoke and flames emanating from the No. 2 engine. ARFF sprayed the engine with fire retardant foam and extinguished the fire. The airplane was towed to the gate and the passengers were deplaned. There were no reported injuries to the passengers or crew. The flight was being operated in accordance with 14 *Code of Federal Regulations* Part 121 and was a regularly scheduled flight from ATL to London Heathrow International Airport (LHR), London, England, United Kingdom.

D. DETAILS OF THE INVESTIGATION

1.0 ENGINE INFORMATION

1.1 Engine History/Maintenance

According to DAL records the No. 2 engine had accumulated the following hours and cycles:

Engine Position	Serial Number	Time Since New (hours)	Cycles Since New	Time Since Overhaul (hours)	Cycles Since Overhaul
Right/No. 2	733603	49,722.5	6,515	25,008.5	3,170

The last engine shop visit/overhaul was completed in November 2012 at Eagle Services Asia (ESA)¹, Singapore. The engine was installed in the No. 2 position on N806NW, Manufacturer's

¹Eagle Services Asia is a joint venture between SIA Engineering Company and Pratt & Whitney, a division of United Technologies Corp.

Serial Number 0578, on December 21, 2012. DAL reviewed all maintenance records dating back to the airplane delivery to Northwest Airlines² on March 19, 2004, and there were no maintenance actions identified that would have involved removal of the rigid fuel pipe upper or lower flange attaching hardware.

DAL aviation maintenance technicians (AMT) at Amsterdam Airport Schiphol (AMS), Schiphol, Netherlands provided written statements to summarize the recent maintenance performed on the airplane. On April 15, 2018, three days before the accident flight, DAL AMTs at AMS noticed fuel puddling on the ground under the No. 2 engine drain mast during pre-departure checks. The cowls were opened, and fuel was observed dripping from the Main Fuel Supply (FM-13) Hose to Pylon Interface Panel³ connection (**Photo 1**). The FM-13 hose upper flange Gask-O-Seal^{®4} was replaced and a No. 2A engine motor leak test⁵ (wet method) was performed. No fuel leaks were observed during the leak test or during subsequent post maintenance/pre-departure checks, and the airplane was returned to service. Two flights later (AMS to Minneapolis-Saint Paul International Airport (MSP), Minneapolis, Minnesota to AMS), on April 17, 2018, maintenance crews at AMS again observed fuel puddling under the No. 2 engine drain mast during pre-departure checks. DAL AMTs performed a visual inspection of the engine and reported a leak that appeared to originate from a tear on the FM-13 hose fire sleeve and the sleeve was wet and shiny along the length of the exterior silicone surface (**Photo 2**). A wet method leak check was performed, and AMTs reported that fuel appeared to leak from the cut in the main fuel supply line fire sleeve. The FM-13 hose and upper and lower Gask-O-Seals[®] were removed and replaced with new parts. No leaks were observed during post maintenance/pre-departure checks and the airplane was returned to service. The accident engine fire occurred three flights later (AMS to MSP, MSP to ATL, accident flight-ATL to LHR).

2 Northwest Airlines was absorbed into Delta Air Lines by a merger in October 2008.

3 Pylon Hydraulic Interface Panel and Pylon Interface Panel are used interchangeably throughout this report.

4 Gask-O-Seal[®] is a trademark of Parker Hannifin. An elastomeric element is molded into the grooves of a metal plate and when fastened between two flat surfaces, the elastomer deforms, creating a seal.

5 A wet motor leak check is performed with the cowl doors closed. The engine is accelerated to idle to pressurize the fuel system and while the engine is running, AMTs visually inspect for fluid leaks from the drain mast. After the engine is shutdown, the cowl doors are opened, and the engine is inspected for leak indications.

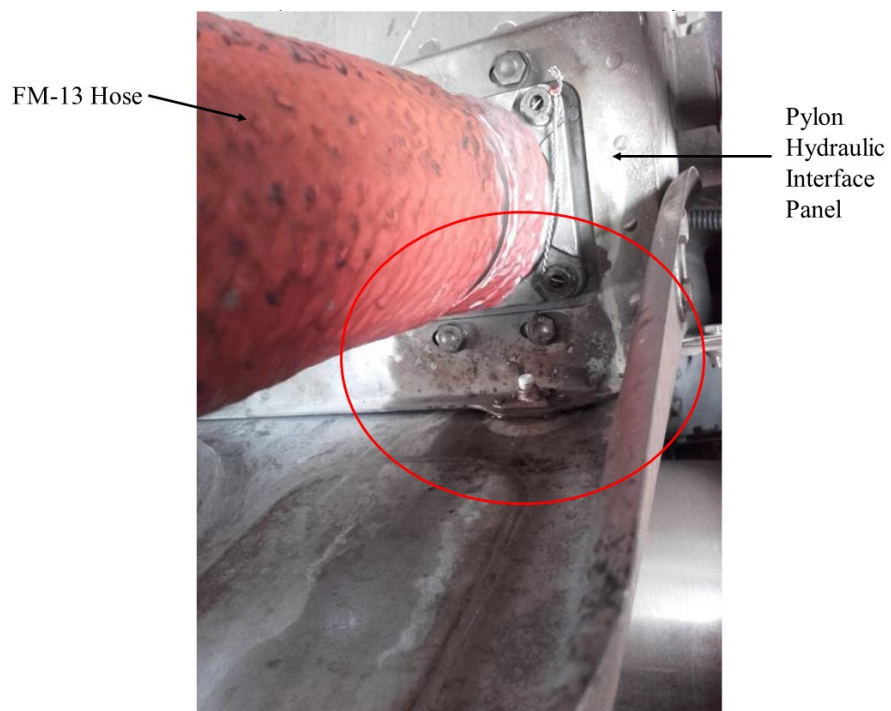


Photo 1- Fuel Leak Finding at AMS, April 15, 2018 (Photo Courtesy of DAL AMS Maintenance)

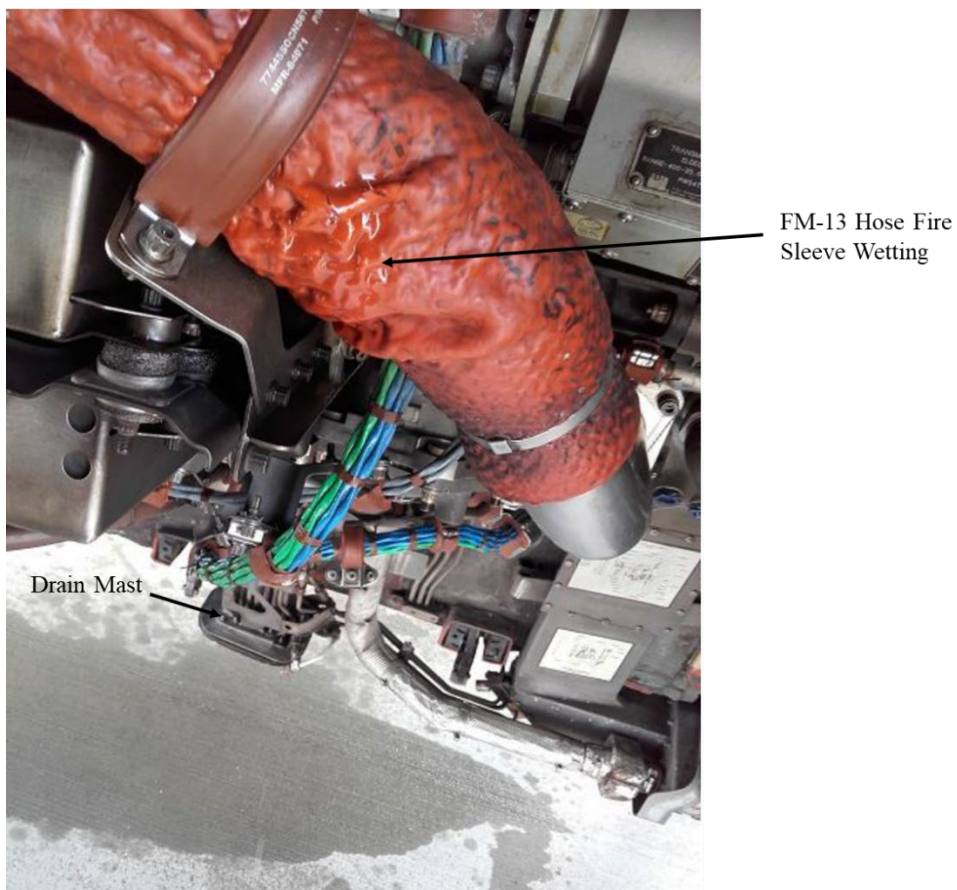


Photo 2- FM-13 Hose Wetted and Puddling Under Engine Drain Mast at AMS, April 17, 2018 (Photo Courtesy of DAL AMS Maintenance)

1.2 Engine Information

The P&W PW4168A-1D is a model of the PW4000-100 inch fan engine and part of the PW4000 family of engines. The PW4168A-1D is a derated version of the PW4170 (Advantage70[®]) engine.

The PW4000-100 inch fan engine is a high bypass ratio axial flow turbofan engine. The basic engine includes a 100-inch diameter fan with 34 shrouded fan blades coupled to a five-stage Low Pressure Compressor (LPC); both are driven by a five-stage Low Pressure Turbine (LPT) (collectively the fan, LPC, and LPT are called the low, or N1, rotor). The core of the engine includes an 11-stage High Pressure Compressor (HPC) driven by a two-stage High Pressure Turbine (HPT) (collectively, the HPC and HPT are called the high, or N2, rotor).

The engine is controlled by a Full Authority Digital Engine Control (FADEC) that includes an Electronic Engine Control (EEC). A Fuel Metering Unit (FMU), mounted to the main fuel pump (MFP), meters fuel to the Fuel Injectors (nozzles) based on inputs from the EEC.

According to the type certificate data sheet No. E36NE Revision 7, the PW4168A-1D has a rated Take-Off thrust of 68,600 pounds and a Maximum Continuous Thrust of 59,357 pounds. The PW4168A-1D was certified by the Federal Aviation Administration (FAA) on 25 November 2008.

All directional references to front and rear, right and left, top and bottom, and clockwise and counterclockwise are made aft looking forward (ALF). A cross section and flange identification diagram of the engine is shown below in **Figures 1 and 2**.

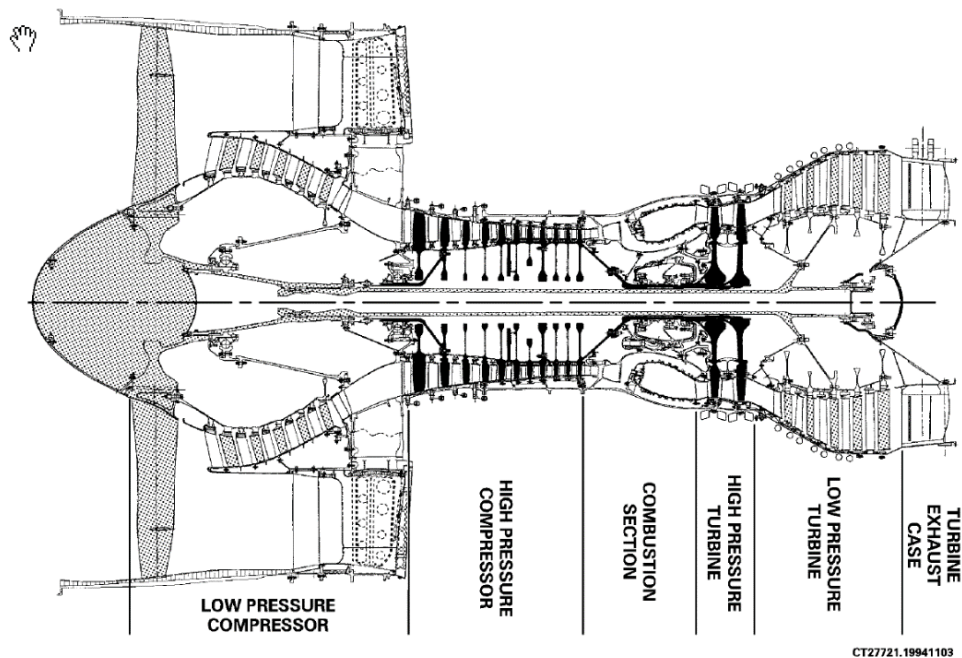


Figure 1-PW4168A-1D Engine Cross Section

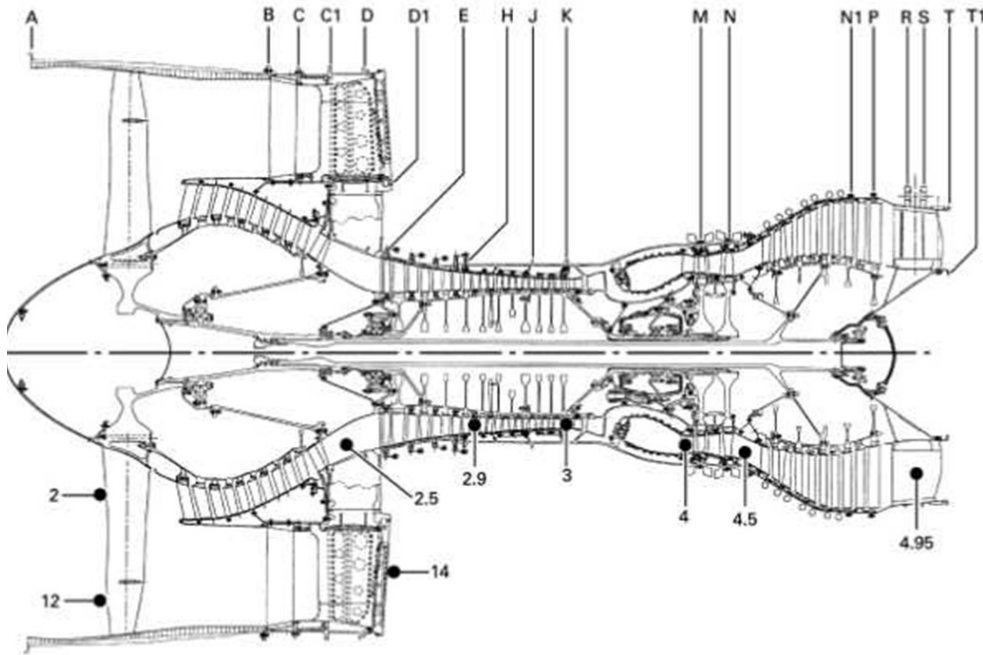


Figure 2- PW4168 Engine Flange Identification Diagram

1.2 Main Fuel Supply (FM-13) Hose

The FM-13 hose carries fuel from the rigid fuel pipe connection at the pylon hydraulic interface panel to the engine fuel pump and is secured to the engine by three clamps (**Figure 3**)⁶. The FM-13 hose is comprised of a polytetrafluoroethylene (PTFE) line wrapped in a corrosion resistant steel metal braid and a silicone covered fiberglass fire sleeve. The fire sleeve has crimped metal bands on each end that hold the sleeve in place to prevent bunching. As part of the manufacturing quality assurance process, every hose is pressure proof tested to 500 pounds per square inch (psi)⁷ prior to shipment. The FM-13 hose is disconnected at the pylon hydraulic interface panel connection and remains with the engine during an engine change.

According to the part drawing, the FM-13 hose conforms to the Society of Automotive Engineers (SAE) AS1055 Type 11a Class B standards⁸. This standard certifies that the part is fireproof rated up to 15 minutes. Fire resistant/fireproof certification is discussed in more detail later in this report.

⁶ The FM-13 hose is manufactured by Parker Stratoflex and is a Pratt & Whitney component. The pylon hydraulic interface panel is an Airbus component.

⁷ According to the FM-13 hose specification, the hose operating pressure is rated at 250 psi.

⁸ According to the SAE International website: This SAE Aerospace Standard (AS) establishes uniform requirements and procedures for the fire testing of flexible hose assemblies and rigid tube assemblies (including coiled tubes) to be used in aircraft or aerospace vehicle fluid systems.

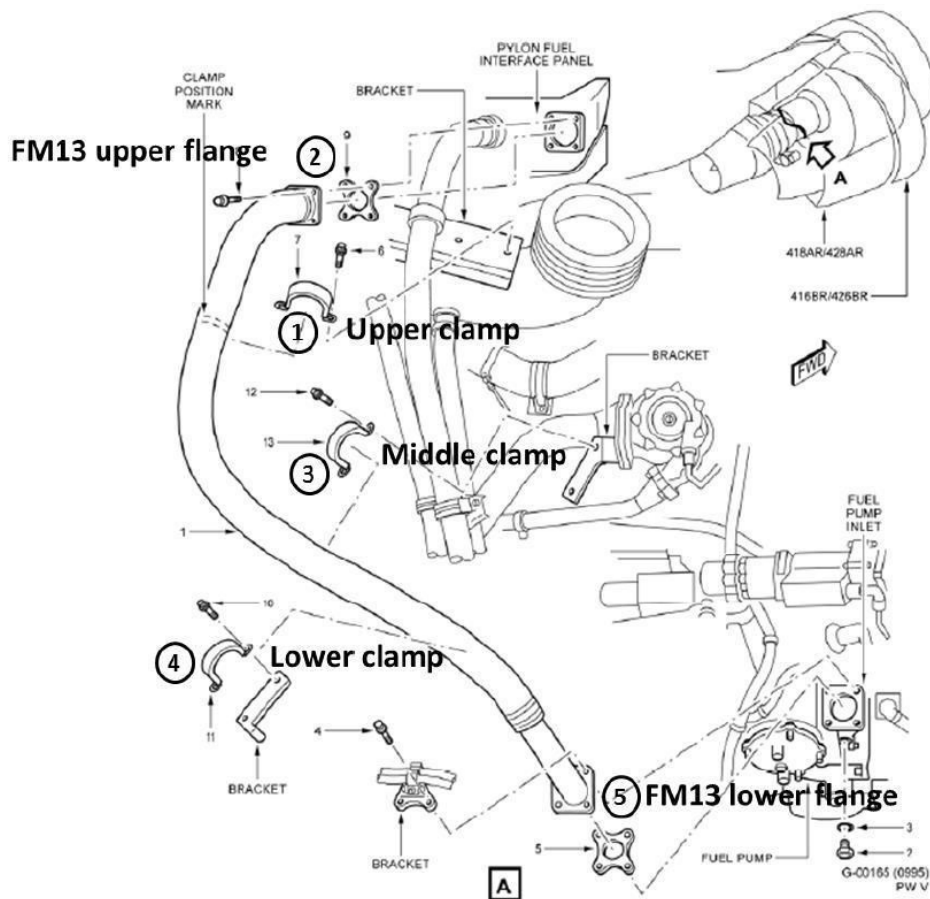


Figure 3- FM-13 Hose Installation

1.3 Thrust Reversers

The thrust reverser (TR) is an Airbus component. The TR door assemblies are a structural/loading sharing component of the nacelle system that form part of the fan discharge duct. The TR doors are made up of a torque box, a translating cowl and internal fixed structure (IFS) (**Figure 4**). Each TR door is attached to the pylon structure by three hinges that allow the doors to open and close. The TR doors are secured closed by seven latches at the 6 o'clock position. When reverse thrust is commanded to slow the aircraft during landing, hydraulic actuators move the translating sleeve aft and extend blocker doors into the fan discharge duct to force airflow through a series of fixed cascades that redirect the airflow in the forward direction.

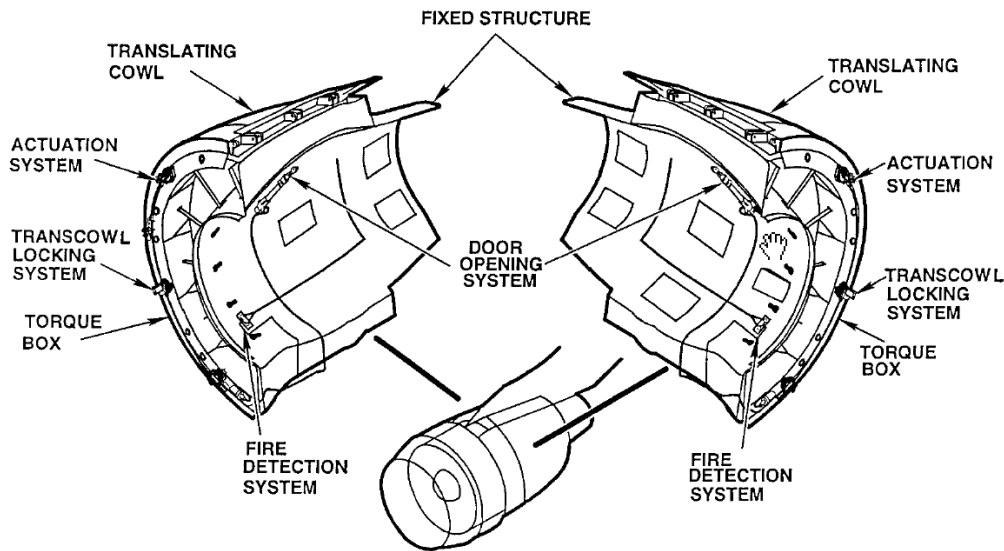


Figure 4- Airbus A330-300/PW4168 Thrust Reverser

The IFS has two pressure relief doors (PRD) on each side. The PRDs are designed to prevent over pressurization of the core compartment. Each door has two hinges located on the forward side and two load sensitive latches on the aft side. The doors are designed to unlatch at a maximum door load of 146 pounds (lbs.), which corresponds to differential pressure of 3.3 psi between the core compartment and outside ambient pressure. A ratchet secures the PRD to the cowl structure, limits the door open angle, and prevents the door from closing until manually closed by ground crews. The right (outboard) IFS has a hydraulic filter service access door, and the left (inboard) IFS has an oil tank access door and an integrated drive generator (IDG) starter access door. There is a lower access door located at the 6 o'clock position on the TR cowl latch structure (**Figure 5**).

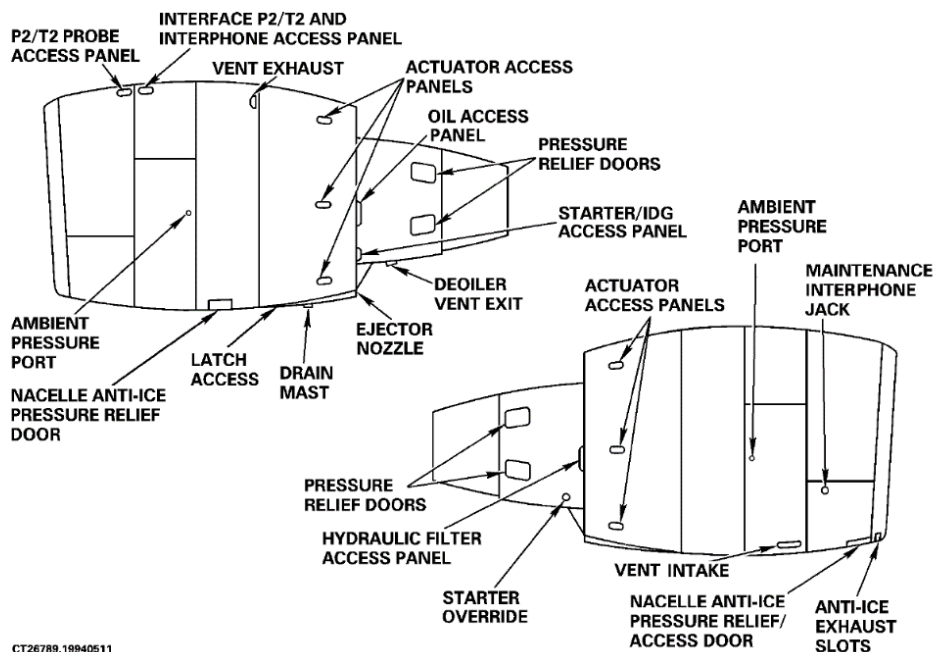
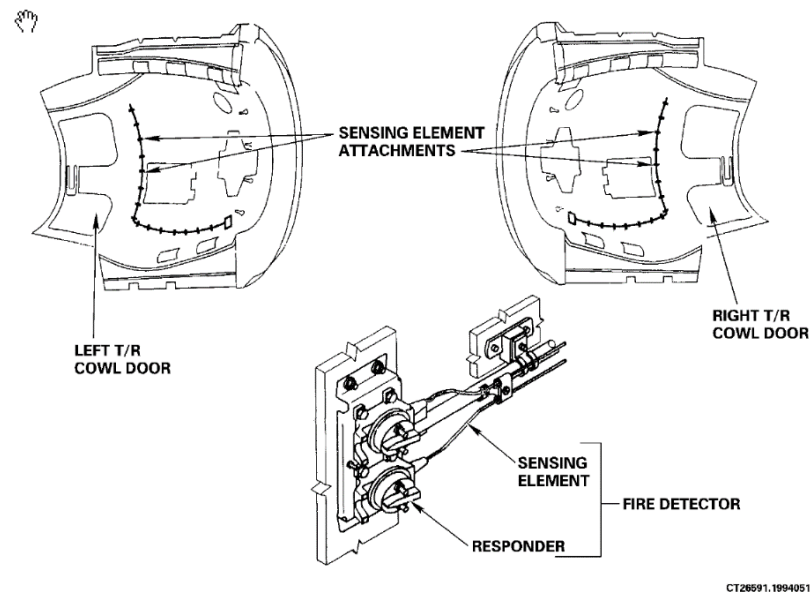


Figure 5- A330-300/PW4168 Nacelle Exterior

The fire detection system features two dual redundant channels (“A” and “B”), each channel has three fire loops, one loop on each TR door, and a smaller loop below the pylon structure in the engine core compartment (**Figures 6 and 7**). The fire loop sensor tubes contain helium gas and a hydrogen charged core material. When exposed to an increase in temperature, the internal gas pressure increases until a preset threshold is exceeded, causing a pressure diaphragm assembly located in the responder assembly to close an electrical contact. The fire detection unit (FDU) will then trigger an engine fire warning in the cockpit.



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Figure 6- A330-300/PW4168 Fire Detection Loop Routing and Fire Detector

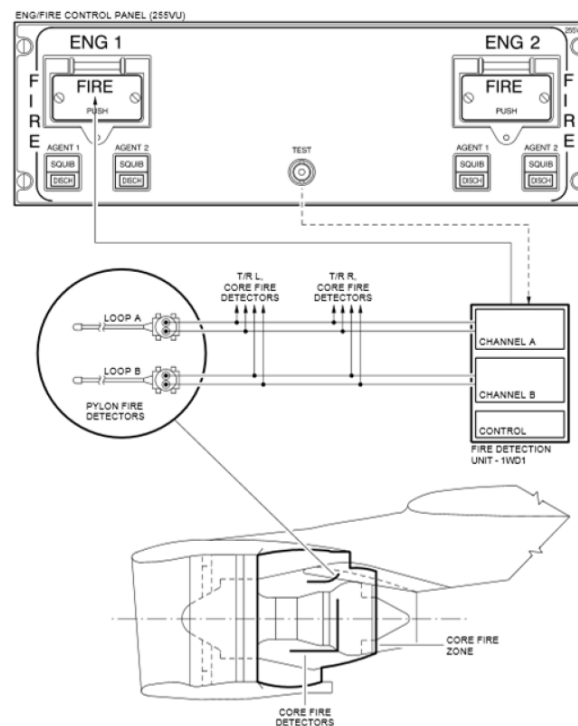


Figure 7- A330-300/PW4168 Fire Detection System and Cockpit Engine/Fire Control Panel

The engine fire extinguishing system for each engine is comprised of two halon fire extinguishing bottles, rigid plumbing, and five outlet nozzles (**Figure 8**). When the fire push button is pressed in accordance with the A330-300 engine fire quick reference handbook (QRH) procedures, fuel flow and hydraulic fluid are shut off from the engine by the low-pressure fuel shut-off valve (LPSOV⁹) and hydraulic shut-off valve respectively. Both the fuel and hydraulic shut-off valves are in the pylon, outside of the designated engine fire zone. The flight crew is then instructed to press the fire agent button, which detonates an explosive squib that punctures the bottle diaphragm and releases pressurized agent into the core fire zone through the nozzles. The halon gas chemically interrupts the combustion process to extinguish the fire.

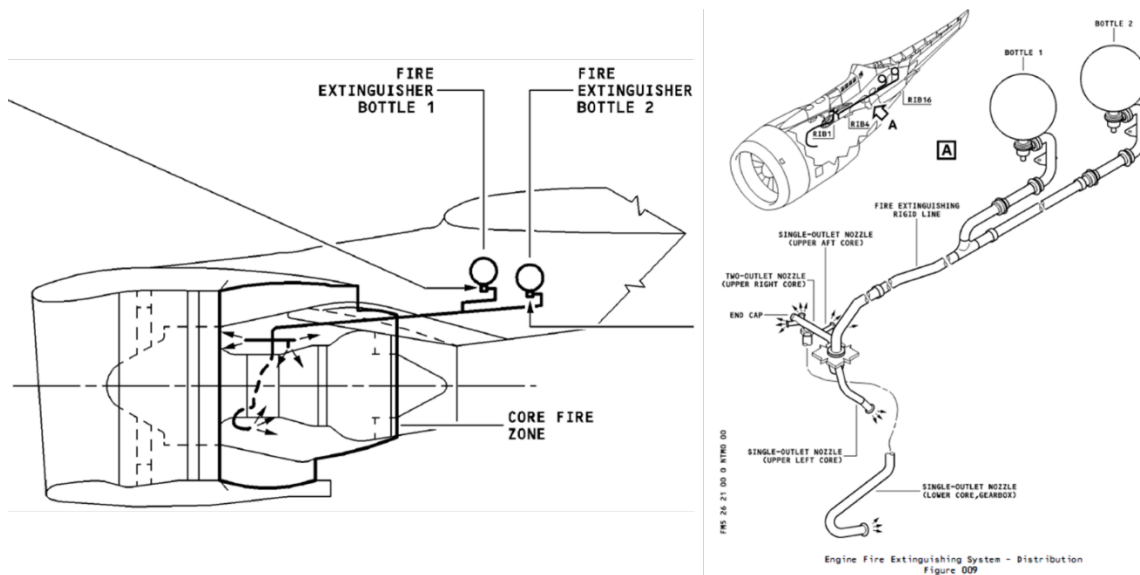


Figure 8- A330-300/PW4168 Fire Extinguishing System

1.4 Hydraulic System

The Airbus A330-323 features three closed loop hydraulic systems, identified as yellow, blue, and green. The blue hydraulic system is plumbed to the No. 1 engine, the yellow system is plumbed to the No. 2 engine, and hydraulic system redundancy is provided by the green system which is plumbed to both engines (**Figure 9**). Engine driven pumps (EDP) cycle hydraulic fluid through the system and maintain system pressure. If engine power is lost, electric pumps are activated as a backup to the EDPs. The hydraulic operating system pressure is regulated to 3,000 psi and the reservoir tanks are pressurized to 70 psi with bleed air from the No. 1 engine. Skydrol[™] and HyJet[™] hydraulic fluids¹⁰ are approved for use and AMTs are permitted to service or top up the systems with either fluid. According to the product technical data sheet, Skydrol[™] has a flash point¹¹ temperature of 350°F (177°C) and an autoignition temperature of 752°F (400°C) and HyJet[™] has a flash point temperature of 366°F (186°C) autoignition temperature of 800°F (427°C).

⁹ The low-pressure fuel shut-off valve (LPSOV) also known as the LP valve, are also commonly referred to as the spar valve on other airplane models.

¹⁰ Skydrol[™] is a trademark of Eastman Aviation Solutions and HyJet[™] is a Mobil trademark. Both are Type V fire-resistant phosphate ester hydraulic fluids.

¹¹ Fire point is the temperature at which lubrication combustion can be sustained. Autoignition temperature is the temperature at which a material is combust without an external ignition source.

The hydraulic suction (supply) lines transfer hydraulic fluid to the EDPs, and each have an in-line fire shut-off valve (FSOV) that is installed outside of the designated engine fire zone. The hydraulic pressure (return) lines transfer hydraulic fluid from the EDPs away from the engine to circulate back into the applicable hydraulic system. The yellow and green EDP case drain lines remove internal EDP leakage and send the fluid back to the applicable system reservoir. Both the pressure (return) and case drain lines have in-line one way check valves installed outside of the designated engine fire zone that prevent hydraulic fluid from flowing back down to the engine. In the event of a fire, the FSOV is closed when the crew presses the fire button in the cockpit and hydraulic fluid supply the engine is stopped. The No. 2 engine green system EDP, also referred to as the aft hydraulic pump, is located on the left side of the engine and the yellow EDP, also referred to as the front hydraulic pump is located on the right side of the engine (**Figure 10 and Photo 3**).

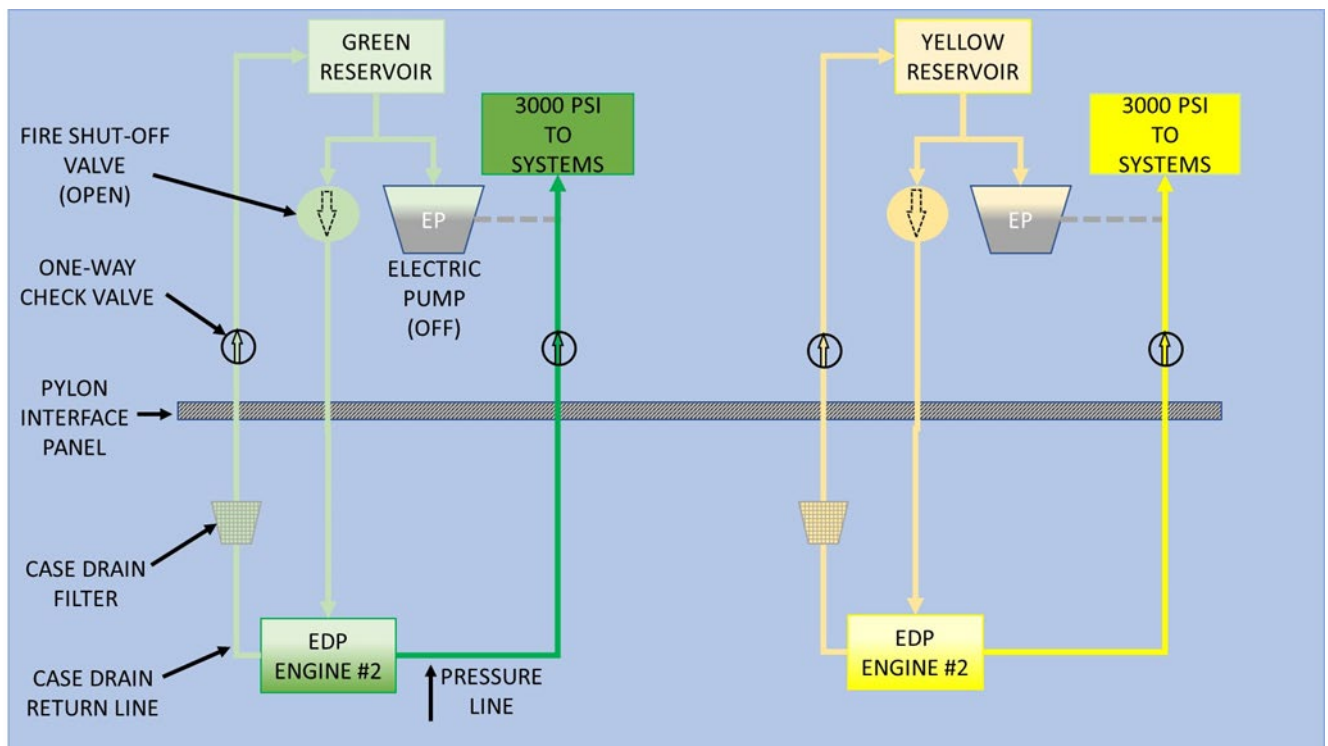


Figure 9- Simplified Green and Yellow Hydraulic System Layout

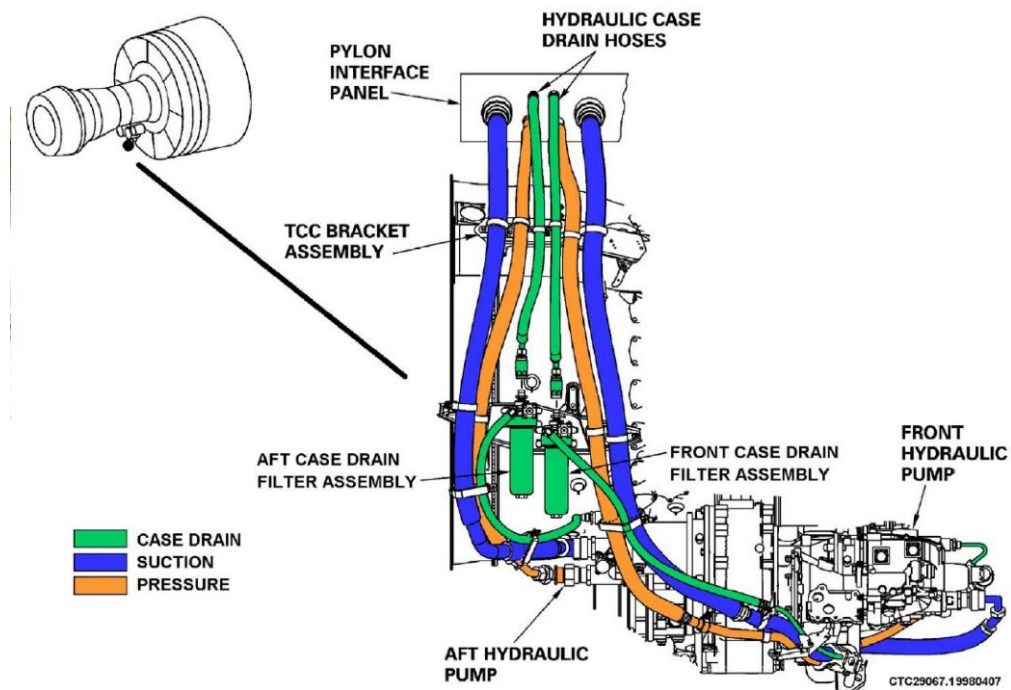


Figure 10- Hydraulic System Routing

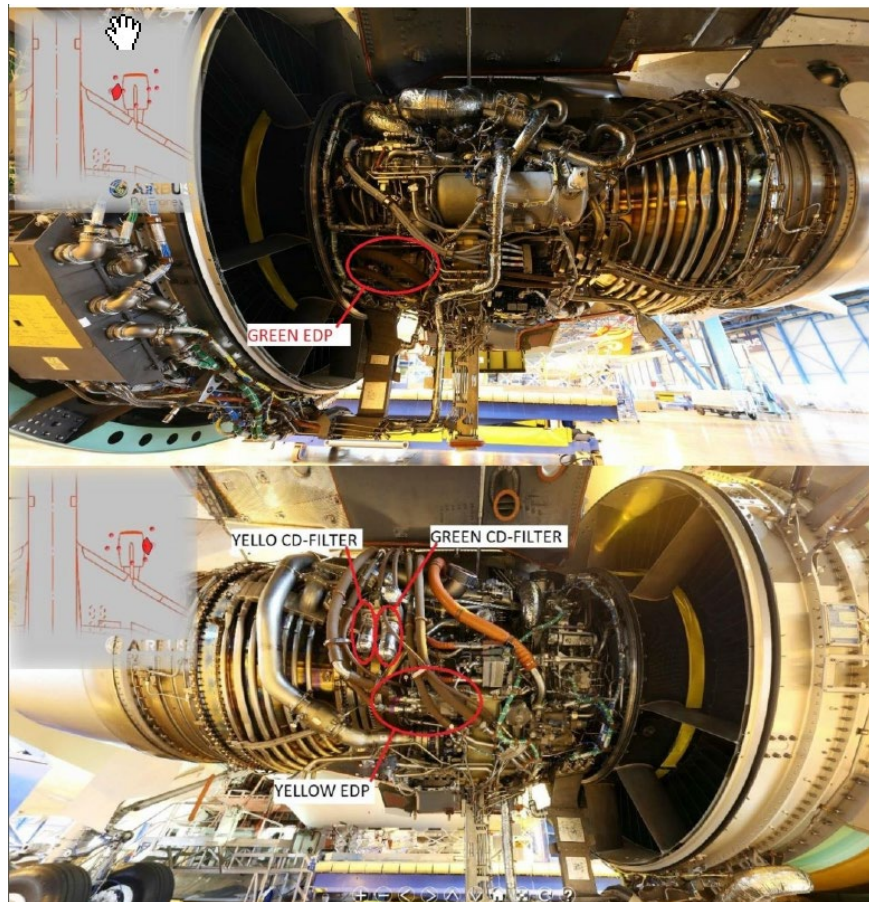


Photo 3- Hydraulic System Engine Drive Pumps and Case Drain Filters on Exemplar Engine (Photos Courtesy of Airbus)

2.0 SUMMARY OF DAL ACTIONS AFTER INITIAL NOTIFICATION

The airplane was moved to the DAL TechOps maintenance hangar after the accident flight. The inlet, aft, and forward fan cowls were intact, but had discoloration along the cowl door interface seams (**Photo 4**). The thrust reverser cowls had sooting and discoloration on the exterior surfaces. Both PRDs and both service access panels on the inboard thrust reverser door were found open. The outboard (right) reverser door upper PRD was separated and missing, the bottom PRD was open, and the service access panel was separated and found resting loose in the cowl. The outboard thrust reverser door PRD was later recovered near Lawrenceville, Georgia and returned to DAL.



Photo 4- No. 2 Engine, Outboard Side

Before the investigation team arrived in ATL, the NTSB gave DAL permission to perform a FM-13 hose fuel pressurization check. The No. 2 engine fire handle was reset in the cockpit to open the LPSOV and gravity feed fuel into the FM-13 hose. Minor fuel wetting was observed along the length of the FM-13 hose after the LPSOV was opened, but no clear leak origin was visible. The fuel boost pump was cycled on, and a large quantity of fuel sprayed through the FM-13 hose outer wall (**Photo 5**). Fuel was also observed dripping at the main fuel supply line to pylon hydraulic interface panel connection. Charred debris was collected in the pylon hydraulic interface panel drip tray prior to the pressurization check. The No. 2 engine was removed and transferred to the DAL TechOps engine test cell shop for examination. The FM-13 hose lower flange was separated from the engine fuel pump as part of the engine removal process. The FM-13 hose lower flange to engine fuel pump attaching bolt run-on torque values were measured by setting a torque wrench to 180 inch-pounds (in.-lbs.), the minimum bolt torque called out in the Aircraft Maintenance Manual (AMM) and recording the number of turns in the clockwise

(tightening) direction until the indicated torque¹² was reached (Table 1). The lower Gask-O-Seal[®] was present between the FM-13 hose flange and the engine pump.

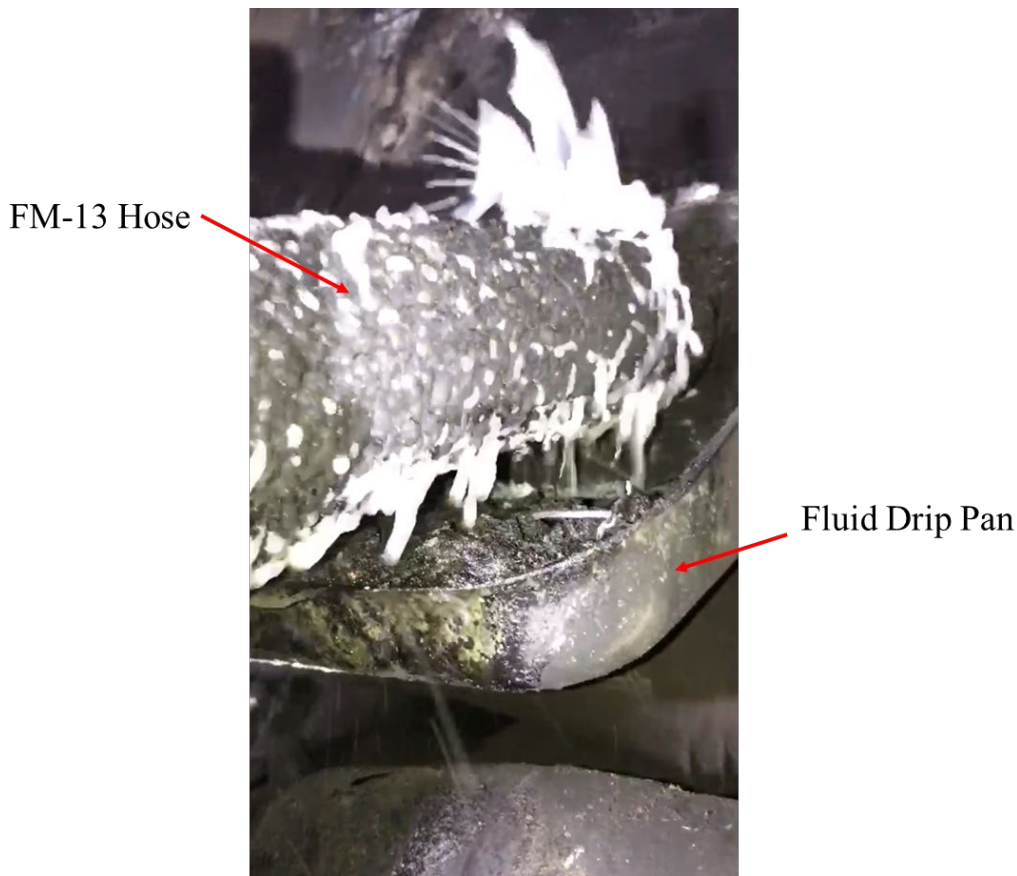


Photo 5- Upper Section of FM-13 Hose Immediately After the Boost Pump was Turned On

Bolt Position	Turns to Reach 180-in.-lbs..
Top Left	$\frac{1}{8}$ to $\frac{1}{4}$ turn
Top Right	$\frac{1}{8}$ turn
Bottom Left	$\frac{1}{8}$ turn
Bottom Right	$\frac{1}{8}$ turn

Table 1- FM-13 Hose to Engine Fuel Pump Attaching Bolt Run-On Torque

With NTSB approval, the airplane was parked outside from the morning of Sunday, April 22 through the morning of Monday, April 23. The pylon was wrapped in plastic to protect the components from weather. Party members from DAL, Airbus, Pratt & Whitney, The Airline Pilots Association (ALPA), and the National Transportation Safety Board met at DAL TechOps in Atlanta, Georgia to examine the airplane and engine from April 23-27, 2018.

¹² According to the AMM, the FM-13 hose to engine fuel pump attaching bolt torque is 180-200 in-lbs.

3.0 PYLON EXAM

After engine removal, the FM-13 hose, yellow hydraulic pressure line, green hydraulic pressure line, and the yellow hydraulic case drain line were left connected to the pylon hydraulic interface panel. The pylon was intact, but all surfaces were heavily sooted and thermally damaged (**Photo 6**). The green and yellow hydraulic suction lines and the green hydraulic case drain line were separated on the pylon (outboard) side of the pylon hydraulic interface panel during the accident flight and what remained of each line was thermally damaged (**Photo 7**). A fractured section of the yellow hydraulic system EDP remained attached to the lower end of the yellow hydraulic pressure line. All separated hydraulic lines were recovered from the nacelle and retained for analysis.

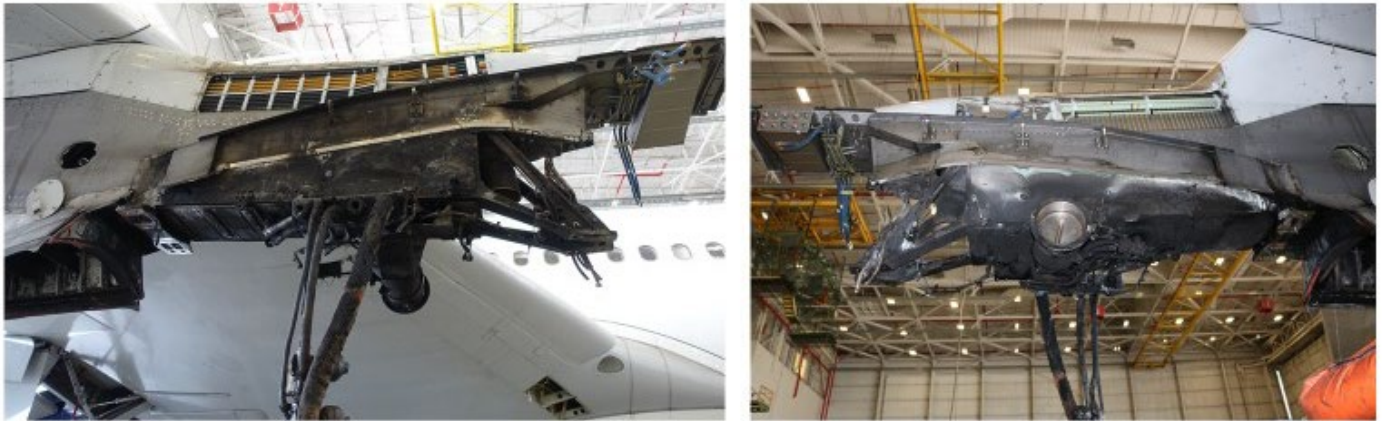


Photo 6- (L) No. 2 Engine Pylon, Outboard Side (R) Inboard Side

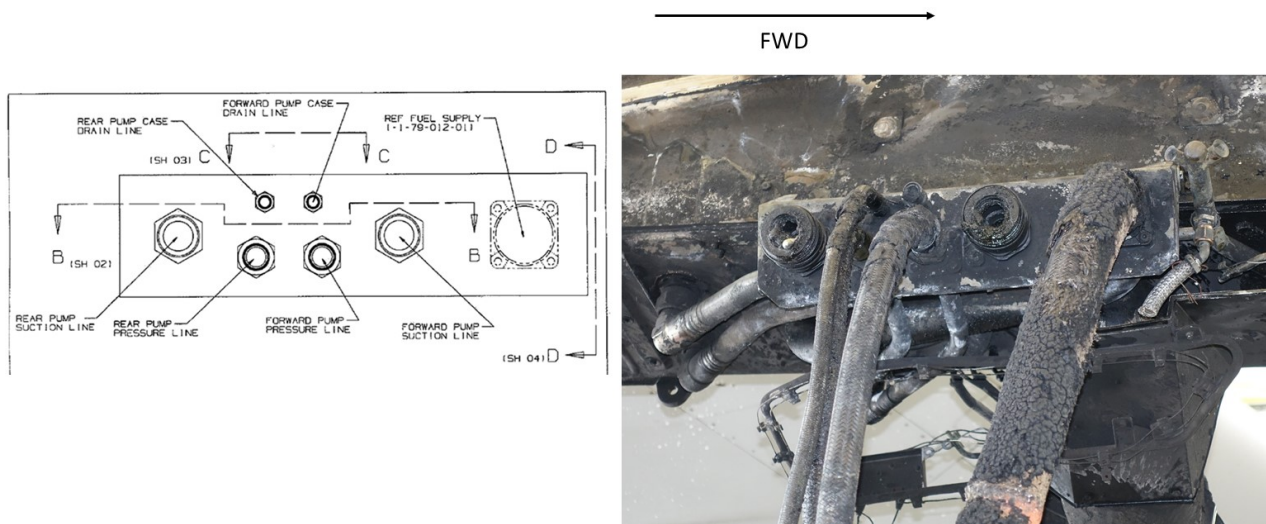


Photo 7- Pylon Hydraulic Interface Panel, (L) Drawing of Panel Connections, (R) Accident Panel

The rigid hydraulic pipes and rigid fuel pipe between the pylon hydraulic interface panel and the underside of the pylon box were coated in dark residue and soot (**Photo 8**). The fluid drip pan¹³ installed

¹³ The pylon drip pan is positioned under the pylon hydraulic interface panel to collect fuel and hydraulic leaks. The bottom of the drip pan is plumbed to the drain mast located at the bottom of the engine to transport flammable fluids outside of the core fire zone and overboard.

under the pylon hydraulic interface panel was thermally damaged on all surfaces and had charred debris and residue accumulation in the pan catch surface (**Photo 9**).

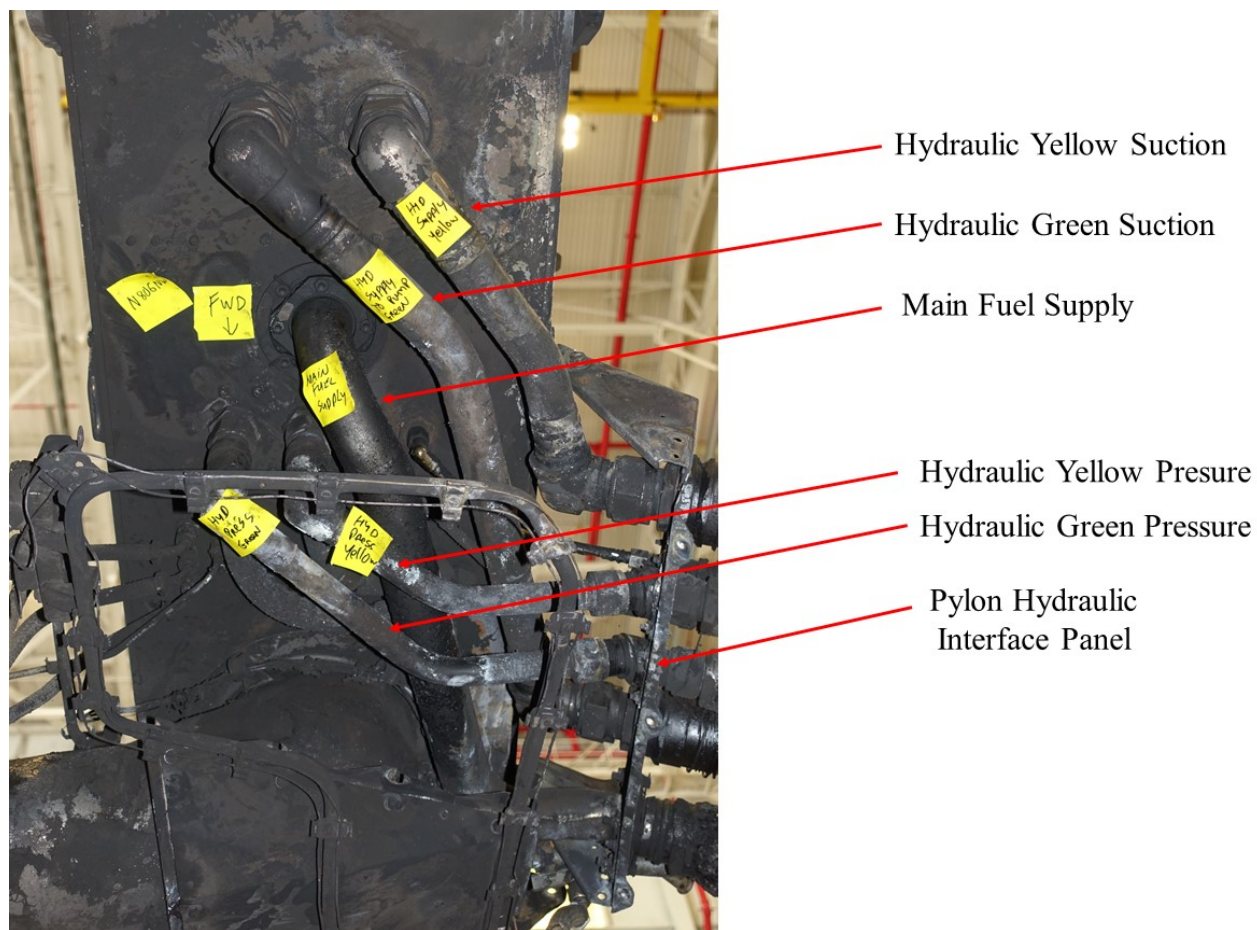


Photo 8- Rigid Pipes Between Bottom of Pylon Box Structure and Pylon Hydraulic Interface Panel



Photo 9- Fluid Drip Pan Located Under Pylon Hydraulic Interface Panel

A borescope inspection of the inside of the pylon box was performed to check for indications of thermal damage or fluid accumulation. There were no anomalies noted other than what appeared to be a light residue on the pylon box adjacent to the main fuel supply line (Photo 10).

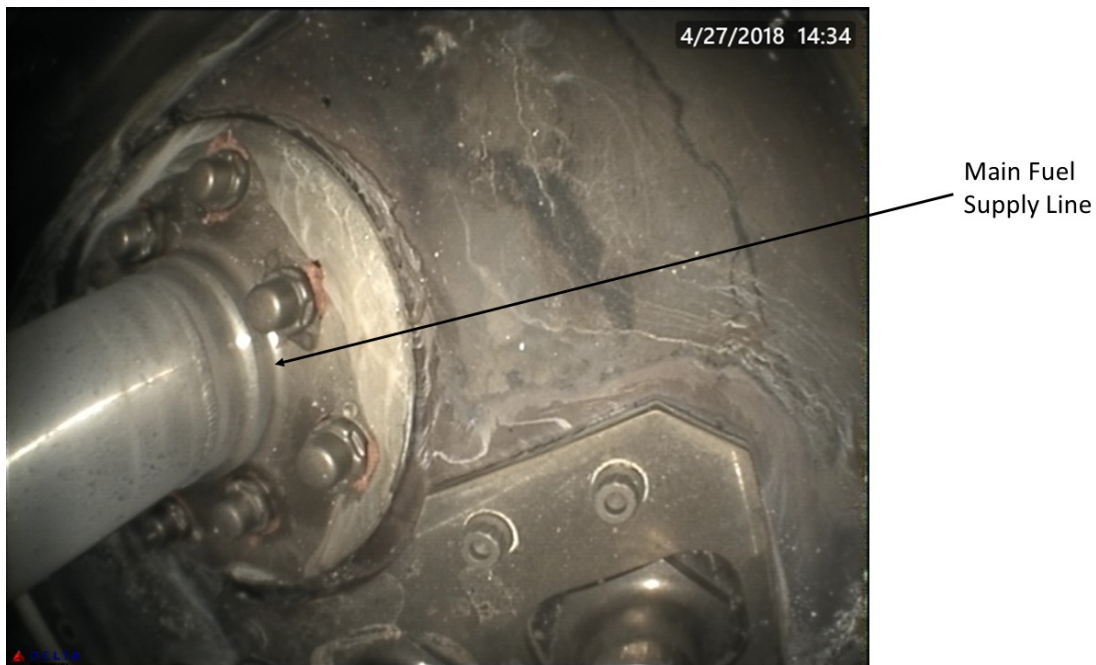


Photo 10- Borescope Photo of Rigid Main Fuel Supply Pipe Flange Inside Pylon

The rigid hydraulic pipes were disconnected from the bottom of the pylon box and breakaway torque values were recorded (**Table 2**). The yellow hydraulic suction line b-nut initially broke loose at the torque listed, but two mechanics and a pipe wrench were required to completely unthread the nut.

Line	Torque (ft.-lbs.)
Hydraulic Green Suction	95
Hydraulic Yellow Suction	85
Hydraulic Green Pressure	95
Hydraulic Yellow Pressure	80

Table 2- Hydraulic Pipe Pylon Connection Torque Values

A borescope probe was inserted into each of the open hydraulic bosses on the underside of the pylon box to inspect the inner walls of the rigid hydraulic pipes that extended into the pylon. All the hydraulic lines had varying amounts of coking/discoloration. The borescope inspector provided an estimate of how far the coking/discoloration extended in each line by measuring the length of borescope probe inserted until coking/discoloration was no longer visible (**Table 3**).

Hydraulic Pipe	Residue/Coking Visible (inches)
Green Suction	10
Yellow Suction	36
Green Pressure	18
Yellow Pressure	1
Green Case Drain*	18
Yellow Case Drain	1

Table 3- Hydraulic Pipe Coking

*The green case drain pipe was completely obstructed. The borescope probe was pushed through a few inches of residue to record the measurement.

DAL AMTs performed hardness checks on the pylon as part of the airplane return to service inspections. Several hardness measurements were out of limit and there was visible warping on the pylon right side panel. The No. 2 engine pylon assembly was removed and replaced.

The rigid fuel pipe lower flange was installed on the pylon (right) side¹⁴ of the pylon hydraulic interface panel on the No. 1 engine and on the engine (left) side of the hydraulic interface panel on the No. 2 engine (**Photo 11 and Figure 11**). Airbus compared these findings with the installation drawings and then visually inspected several A330-300 airplanes hangared in Toulouse, France and confirmed the lower rigid fuel pipe flange was installed incorrectly on the No. 2 engine at the time of the event.

¹⁴ The pylon interface panel is located on the right side of both engines. In this report, the right side of the panel is referred to as the “pylon side” and the left side of the panel is referred to as the “engine side.”

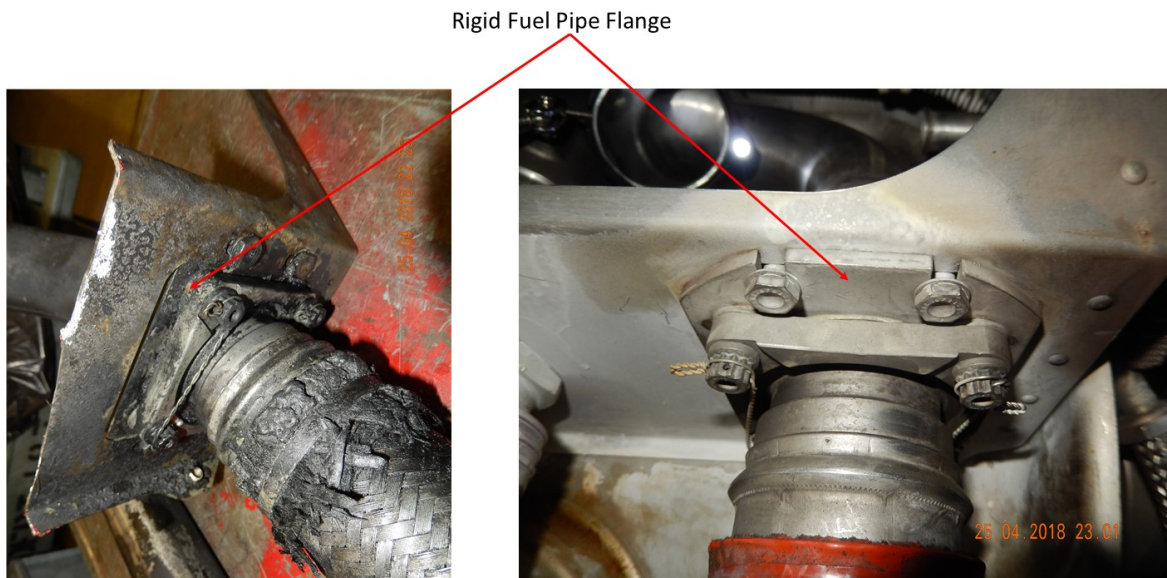


Photo 11- Pylon Hydraulic Interface Panel Rigid Fuel Pipe Flange Position, (L) No. 2 (Right) Engine, (R) No. 1 (Left) Engine, Installed in Accordance with Airbus Drawings.

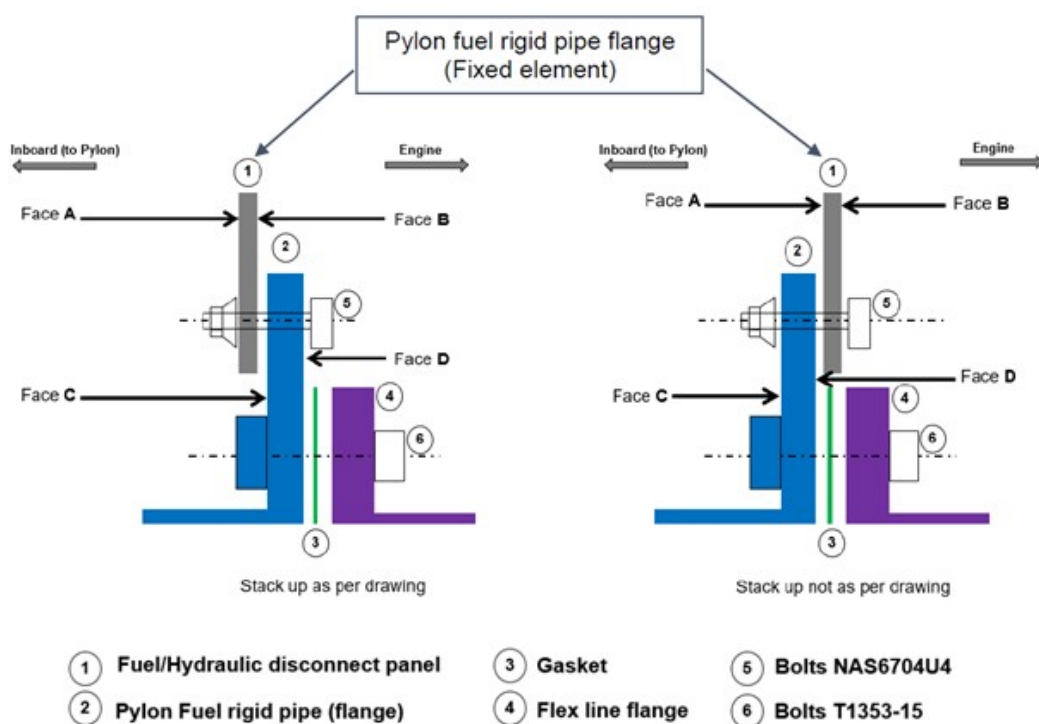


Figure 11- FM-13 Hose to Rigid Fuel Pipe Stack-Up, (L) Per Drawing, (R) Accident No. 2 Engine (Figure Courtesy of Airbus)

4.0 NO. 2 ENGINE, SERIAL NUMBER 733603 EXAMINATION AND DISASSEMBLY

The engine was installed in work pedestals when the investigation team arrived (**Photos 12, 13, and 14**). An initial visual examination of the engine was completed to document the as-received condition. The engine oil tank had oil visible to the top of the yellow line on the sight glass and contained

7.5 gallons (28.4 liters) of oil when drained. There was no oil visible in the integrated drive generator (IDG) sight glass, and about 1 gallon (3.8 liters) was drained. The No. 3 bearing compartment magnetic chip detector (MCD) on the main oil pump (MOP) was not present. The No. 1-1.5-2 bearing compartment, No. 4 bearing compartment, and angle gearbox MCD bayonets were separated and only the MCD bayonet housings remained threaded in the MCD ports located on the main gearbox (MGBX). The check valves located within the MCD housing on the MOP were depressed and had spring tension. The condition of the o-rings in the check valve assemblies could not be confirmed. The No. 3 bearing compartment MCD was thermally damaged but complete and did not have any debris accumulation. The starter and oil tank MCDs also had no metal debris accumulation (**Photo 15**).

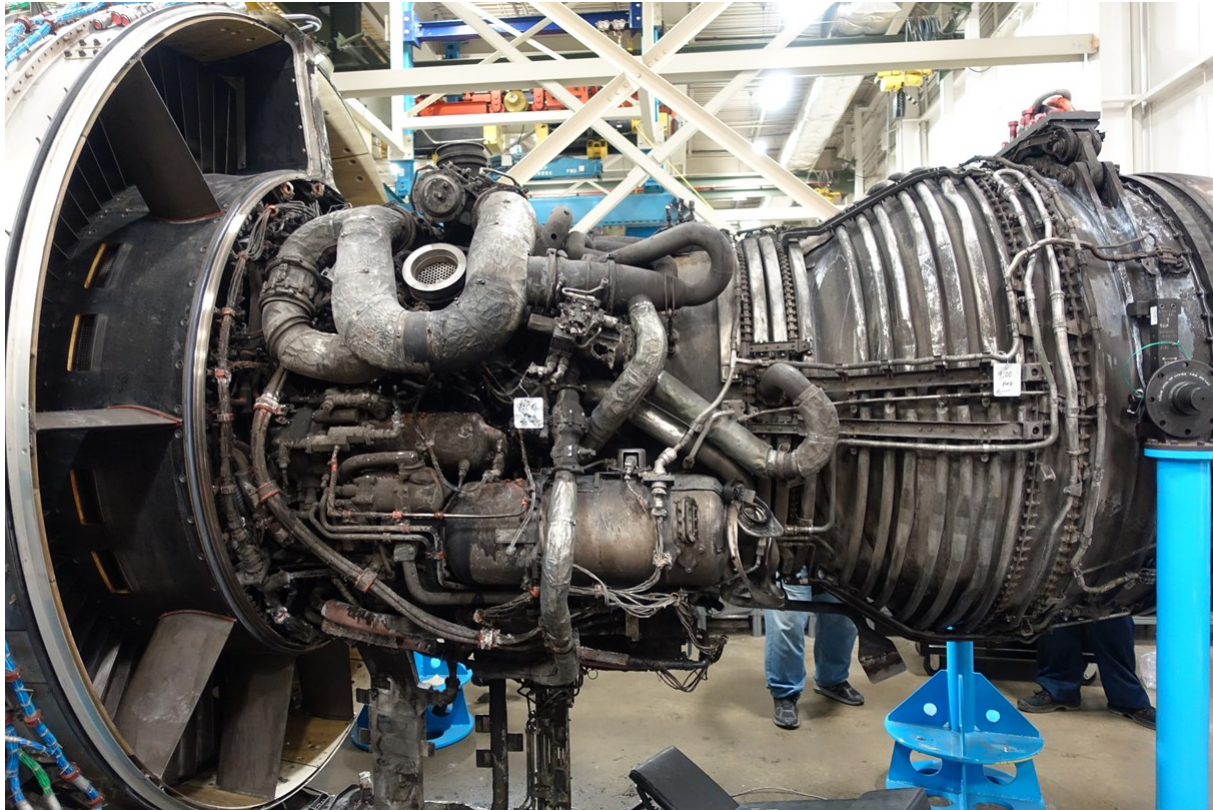


Photo 12- Left Side of Engine, As Received

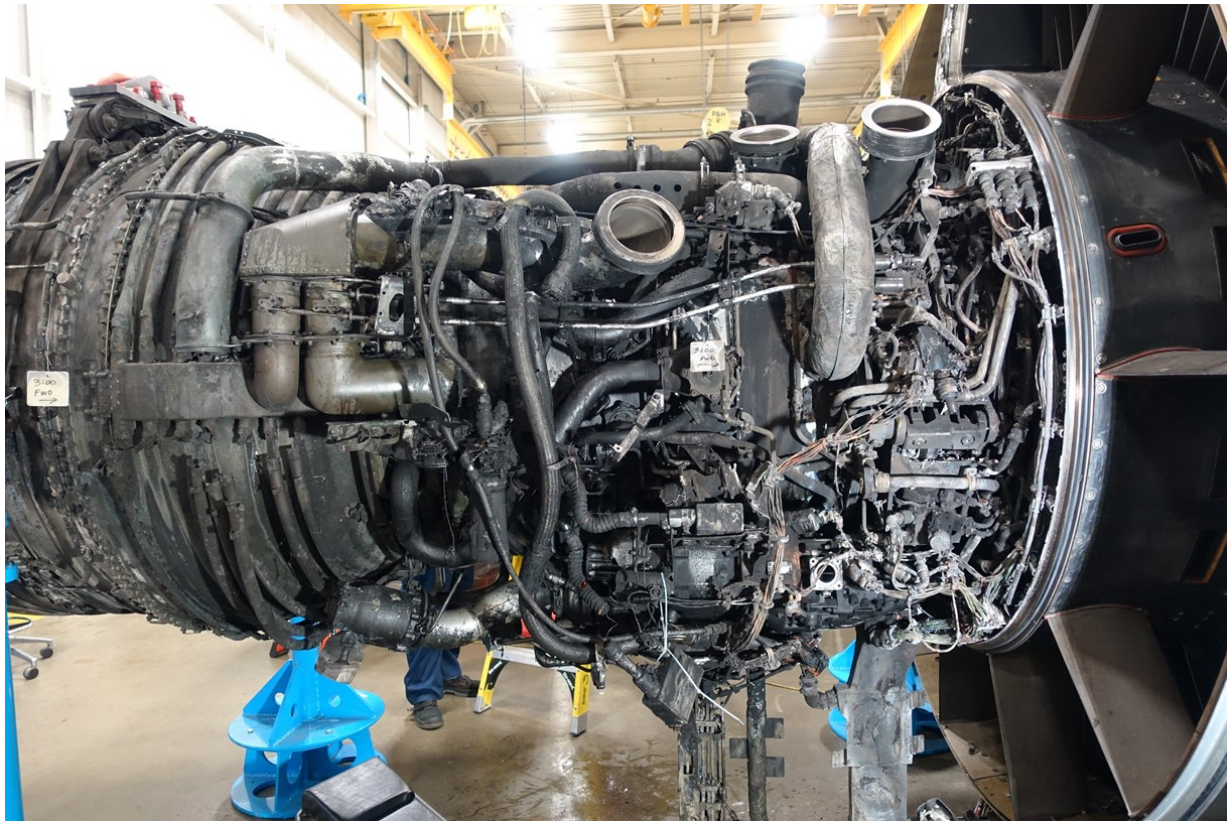


Photo 13- Right Side of Engine, As Received



Photo 14- Engine Data Plate



Photo 15- Magnetic Chip Detectors

All the fan blades were intact and in good condition. There were no indications of leading-edge damage or fan case rub along the fan blade tip path. The fan was seized and could not be rotated by hand. Loose debris was collected at the 6 o'clock position at the bottom of the fan case, forward of the fan blades. The fan case external surfaces were intact and in good condition with no signs of thermal damage or discoloration. All wire sheathing and clamps on the fan case exterior were undamaged.

The exterior engine surfaces aft of the D1 flange exhibited thermal damage, discoloration, and heavy sooting. The thermal damage and discoloration were most concentrated circumferentially from the 12 to 6 o'clock positions, axially between the D1 flange and the P flange (LPT to turbine exhaust case). All wire sheathing and clamps in the area were discolored and brittle. The turbine case cooling (TCC) valve air actuator located at the 2 o'clock position, about six inches aft of the D1 flange, was thermally consumed. The stator vane actuator (SVA) was heavily sooted and had melted metal slag on the top of the actuator housing. The fuel flow transmitter (FFT) was separated at the inlet and outlet ports and was resting loose on an air duct¹⁵. About half of the loose FFT housing was fractured. The forward section of the fuel flow divider valve (FDV) was separated up to the support bracket between the fuel manifold supply lines and the divider valve. The eight fuel manifold supply lines were intact. Both igniter leads were separated from the igniters and the bottom ignition exciter box was loosely hanging from the engine but had been secured to an engine bracket with a zip tie during engine removal. Both igniters and the igniter leads were discolored and thermally damaged. The yellow (forward) hydraulic EDP housing was partially fragmented, and as previously noted, the aft section of the housing was separated and remained attached to the yellow hydraulic pressure line on the pylon interface panel (**Photo 16**). The yellow EDP shaft was sheared. The yellow hydraulic filter housing was separated and missing. The starter was intact but heavily sooted and the starter air valve duct was separated and missing from the 1 to 3 o'clock positions. The TCC lines were thermally damaged and separated between the 2 and 3 o'clock positions on

¹⁵ Photographs provided by DAL confirmed that the FFT was separated and caught in other engine externals immediately below where it is normally installed when the thrust reverser doors were opened following the accident flight. The FFT was later moved to an air duct to prevent it from falling during engine removal and transport.

the LPT case. The exhaust gas temperature (EGT) thermocouple harness on the TEC was damaged from the 3 to 4 o'clock positions.

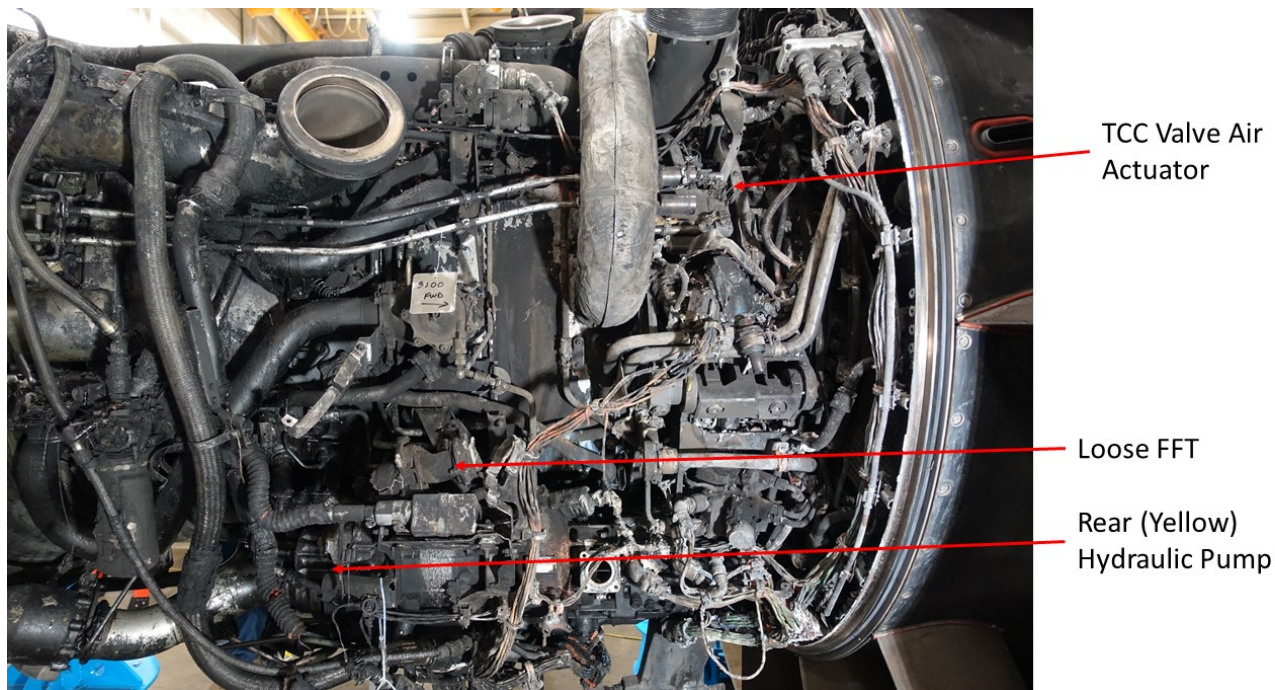


Photo 16- Damaged Components on the Right Side of the Engine

The LPT 7th stage blades visible through the exhaust were intact and in good condition. The exhaust struts were unremarkable. There was fluid pooling in the exhaust nozzle at the 6 o'clock position.

The left side of the engine exhibited thermal damage and sooting/discoloration axially from the D1 flange to the P flange, and circumferentially from the 6 to 12 o'clock positions. All wiring harnesses and clamps were discolored and brittle. The IDG wire harness was separated for visual examination. The harness was sooted and exhibited thermal damage including melted material but there were no indications of electrical arcing. The high pressure bleed valve (HPV) at the 10 o'clock position had burn through on the actuator section of the valve¹⁶. The green (aft) hydraulic EDP was intact but sooted. All components on the bottom of the engine including the IDG and MGBX were blackened and covered in an oily residue. The top of the engine was discolored/sooted and loose debris was resting on case surfaces.

4.1 Fuel Nozzle and Manifold Leak Check

External ducting, lines and accessories around the diffuser case were removed to gain access to the fuel manifold supply lines and fuel nozzles. The forward section of the FDV was separated from the bracket and AN¹⁷ fittings were used to port regulated ~85 psi shop air to the eight fuel supply lines that feed the fuel manifold triplets in accordance with the engine maintenance manual. Each fuel nozzle pad was cleaned with isopropyl alcohol and a brush and then sprayed with leak detection fluid

¹⁶ According to Airbus, the HPV valve is commanded closed when the fire push button is pressed in the cockpit. Undercowl air leakage during the accident event would have been minimal.

¹⁷ AN thread is a fitting used to connect flexible hoses and rigid metal tubing. AN is an acronym for Army and Navy. It was a joint standard agreed to by both United States military branches in the 1940's.

(soapy water). No leak indications were observed from the fuel manifold supply lines, or the fuel nozzle braze joints.

4.2 Eagle Services Engine Teardown

Eagle Service Asia (ESA)- Singapore is the contracted maintenance, repair, and overhaul (MRO) shop for DAL PW4000 100-inch fan engines. Following the on-scene investigation, the engine was released from the investigation and shipped to ESA as part of the normal engine evaluation process. Airbus requested and were granted observer status during the engine teardown.

The teardown did not reveal evidence of internal engine component failure or fire. As engine externals were removed, additional documentation of fire affected zones was completed by Airbus. The TCC manifolds pipes located above and below the TCC collector box located at the 3 o'clock position were thermally damage (melted) and/or partially consumed (**Photo 17**). The starter air duct was thermally damaged along the length of the full duct, but thermal deformation was most concentrated at the 3 o'clock position, outboard of the TCC collector box (**Photo 18**). After removal of the TCC ducting, a piece of resolidified metal was found adhered to the LPT case at the 3 o'clock position. The case damage and adhered slag material were located behind/inboard of the TCC collector box (**Photos 19 and 20**). The LPT case and resolidified metal piece were shipped to the P&W Materials Laboratory in East Hartford, Connecticut for metallurgical analysis and material identification.

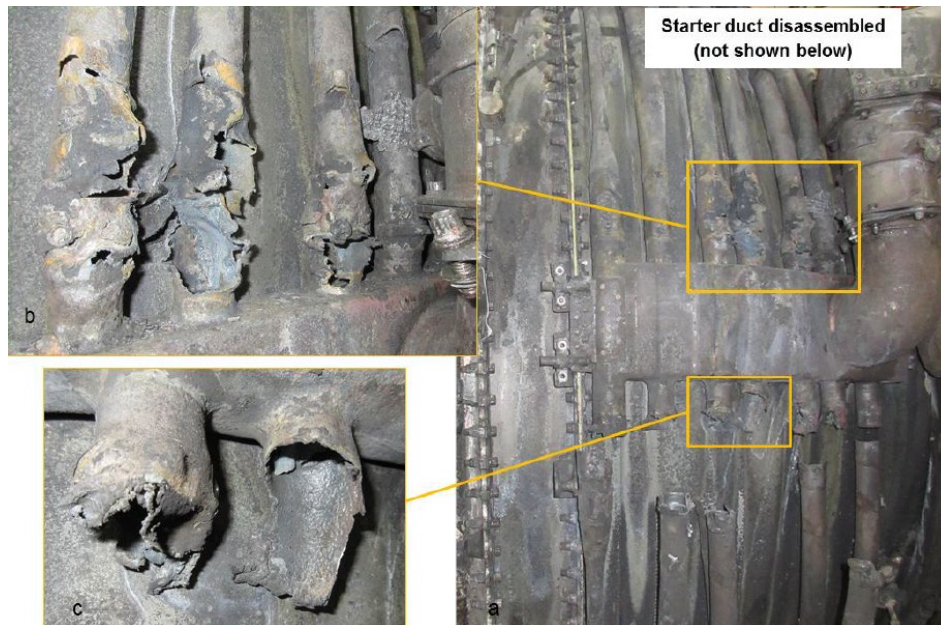


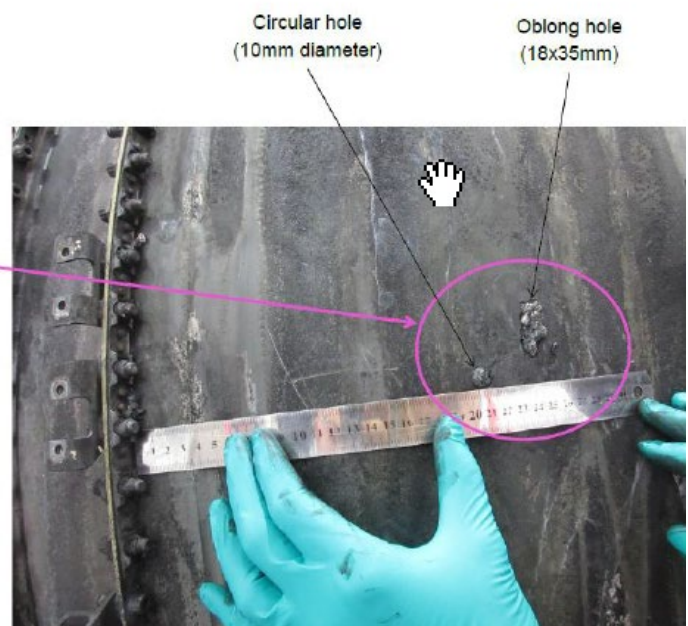
Photo 17- No. 2 Engine Turbine Case Cooling Manifold, Right Side of Engine, ~3 o'clock Position (Photos Courtesy of Airbus)



Photo 18- No. 2 Engine Starter Duct Damage, (L) Accident Engine, (R) Exemplar Engine (Photos Courtesy of Airbus)



LPT2 rotor axial
position (TBC)



Circular hole
(10mm diameter)

Oblong hole
(18x35mm)

Photo 19- No. 2 Engine LPT Case Damage, Right Side of Engine (Photos Courtesy of Airbus)



Photo 20- Photograph of Resolidified Metal Adhered to LPT Case (Photo Courtesy of Airbus)

5.0 THRUST REVERSER EXAMINATION

The thrust reverser doors were quarantined with the No. 2 engine at DAL TechOps, and initial documentation was completed during the on-scene portion of the investigation. A follow up examination was completed with investigation party members from DAL, Airbus, Pratt & Whitney, the BEA, and the NTSB from March 19-20, 2019.

5.1 Right (Outboard) Thrust Reverser Door

The outboard TR door torque box was in good condition. The outboard translating sleeve was complete, and the only visible damage noted was thermal damage at an access panel located at the 6 o'clock position. The access panel thermal damage was concentrated near the latch assembly where paint discoloration, burn-through holes, and torn/distorted material. The PRD was separated and dropped along the flight path and later recovered near Stone Mountain, Georgia. The lower PRD was in the fully open position. The hydraulic filter access door was separated. The IFS inner barrel fire blanket exhibited fire damage, sooting, dark discoloration, and streaking (**Photo 21**). The IFS composite structure was thermally damaged and was burned through/collapsed at the 2 o'clock position, forward of the upper PRD (**Photo 22**). The IFS outer skin that was in contact with the fan bypass airflow had dark sludge and streaking most concentrated between the 1 and 5 o'clock positions along the length of the IFS. The streaking on the IFS skin continued into PRD and access door openings. The fire detection loops sustained severe thermal damage and were severed at multiple locations. A majority of the fire detector loop isolator grommets were thermally consumed, and a section of the loop was detached from the IFS. The fire detector responder unit was thermally damaged, charred, and missing material (**Photo 23**).



Photo 21- No. 2 Engine Right (Outboard) Thrust Reverser Door IFS

Upper PRD
Separated



Photo 22- No. 2 Engine Right (Outboard) Thrust Reverser Door, Upper PRD Separated



Photo 23- No. 2 Engine Right (Outboard) Thrust Reverser Door, Fire Detection System Damage

5.2 Left (Inboard) Thrust Reverser Door

The left thrust reverser door torque box was in good condition. The translating sleeves were intact but thermal damage was observed at the 6 o'clock position. The IFS outer skin was sooted, discolored, and blistered (**Photo 24**). The inner surface fire blanket of the IFS exhibited discoloration, sooting, and thermal damage on all surfaces (**Photo 25**). The fire blanket was partially detached from the IFS structure between the 6 and 8 o'clock positions. The upper and lower PRDs and both the IDG and oil tank access door were in the fully open position. The PRD and access door hinges were discolored and sooted but did not appear deformed. The fire detection loop was complete and secure, but all wire sheathing exhibited thermal damage and most of the isolator grommets were thermally consumed. The IFS outer skin had traces of soot and discoloration aft of the PRD and access door openings, consistent with fire/smoke and hot gases exiting the PRDs during flight.



Photo 24- No. 2 Engine Left Thrust Reverser Door, Upper and Lower PRDs Open



Photo 25- No. 2 Engine Left (Inboard) Thrust Reverser Door IFS Fire Blanket

5.3 Thrust Reverser Chemical Layer Analysis

Investigation party members from DAL, Pratt & Whitney, Airbus, the BEA, and the NTSB met at DAL TechOps from March 19-20, 2019, to complete additional documentation of the No. 2 engine thrust reverser doors. Sections of the thrust reverser IFS were removed in areas that were adjacent to pressurized engine fuel and hydraulic components where the most significant thermal damage was observed on the engine and thrust reverser IFS fire blankets. The thrust reverser samples and the right thrust reverser door upper PRD were shipped to the Airbus Bremen, Germany Materials Laboratory for materials laboratory analysis. A micro layer analysis of the thrust reverser fire blanket/IFS inner barrel

was performed to identify flammable fluid combustion byproducts using energy-dispersive X-ray spectroscopy (EDS). According to Airbus, identification of the byproducts present at each layer could theoretically be a tool to determine the order which fluids/combustion byproducts contacted the IFS fire blanket surface during the accident flight. The Airbus report, “A330 MSN 578 DAL Fire Event- Analysis of Surface Residue” is available in the investigation docket as Powerplants- Attachment 1- Airbus Analysis of Thrust Reverser Surface Residue.

The NTSB Office of Research and Engineering fire specialists reviewed the preliminary chemical layer analysis findings provided by Airbus and consulted with the FAA William J. Hughes Technical Center in Egg Harbor Township, NJ. A literature search for published research articles on the method was also completed. It was determined that findings from the chemical layer analysis cannot be considered valid until additional research and testing is conducted to prove the test results are accurate and repeatable in conditions like the accident undercowl engine fire event.

6.0 HYDRAULIC SYSTEMS

The hydraulic page on the system display in the cockpit indicated yellow hydraulic quantity was at the bottom of the scale, green hydraulic quantity was slightly above the minimum, and blue hydraulic quantity was at the top of the scale (**Photo 26**). The hydraulic service panel under the airplane indicated yellow hydraulic quantity at -5, green hydraulic quantity at -5, and blue hydraulic quantity at +5¹⁸ (**Photo 27**). Hydraulic fluid was not visible in either the yellow or green hydraulic reservoir sight glasses and was at the top of the sight glass on the blue hydraulic reservoir (**Photo 28**). The green and yellow hydraulic fluid reservoirs were drained and contained 4.5 gallons (17.0 liters) and 1.5 gallons (5.7 liters) respectively. According to Airbus engineering, the nominal reservoir fill volumes as marked on each reservoir sight glass were, green reservoir - 26 liters (6.9 gallons) and yellow reservoir - 14 liters (3.7 gallons). The blue hydraulic reservoir was not drained because the blue hydraulic system is not connected to the No. 2 engine and there was no evidence of fluid loss on the cockpit display, reservoir indicator or sight glass.

The green and yellow hydraulic FSOVs were functionally tested while installed in the aircraft in accordance with Airbus instruction. The dial indicator on the outside of each valve cycled open and closed properly and the FSOVs were then removed for additional testing (**Photo 29**). The FSOVs dial indicator position was not recorded prior to the main fuel supply line pressurization check.

¹⁸ Hydraulic quantities were visual observation and are not exact values.

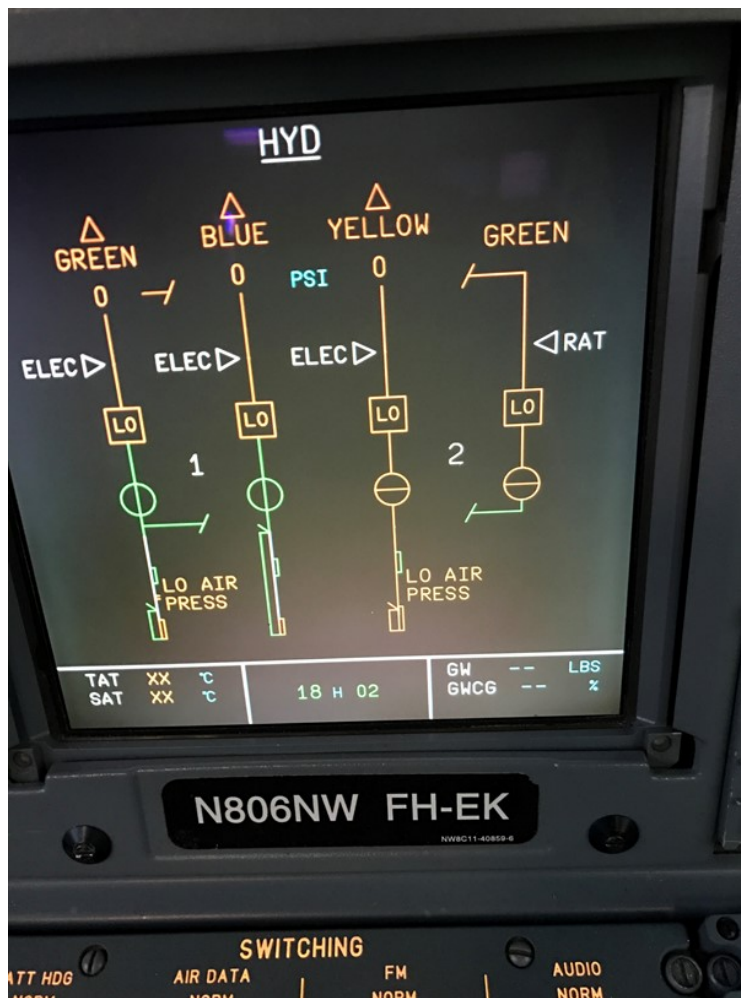


Photo 26- Cockpit Hydraulic System Display



Photo 27- Hydraulic Service Panel (L) Yellow, (C) Green, (R) Blue

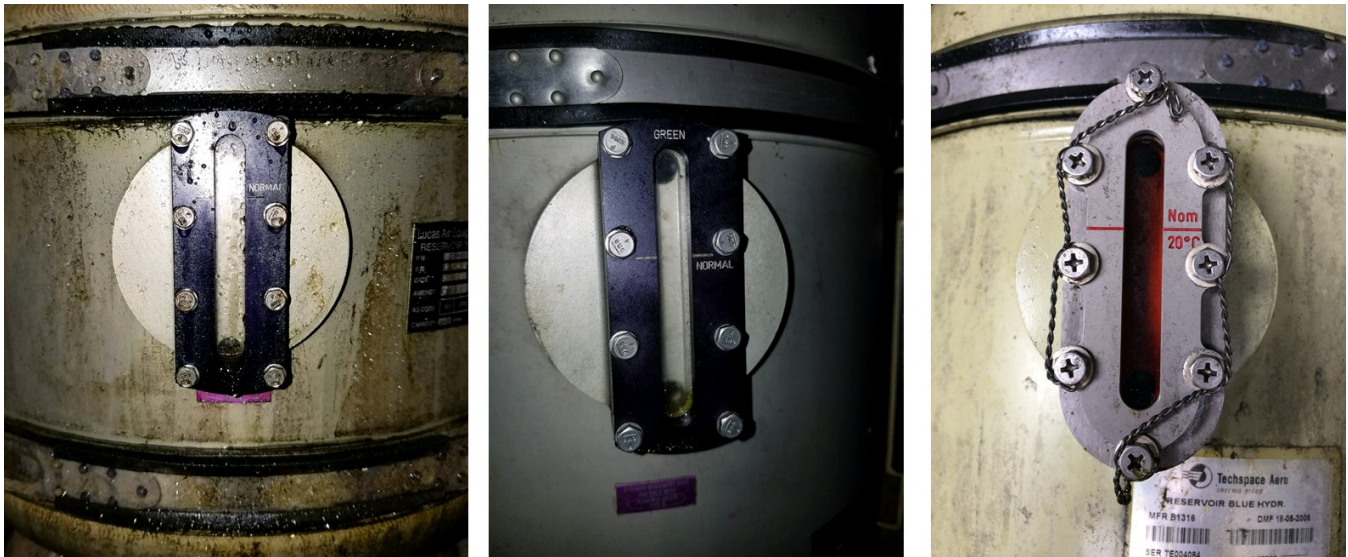


Photo 28- Hydraulic Reservoir Quantity, (L) Yellow, (C) Green, (R) Blue

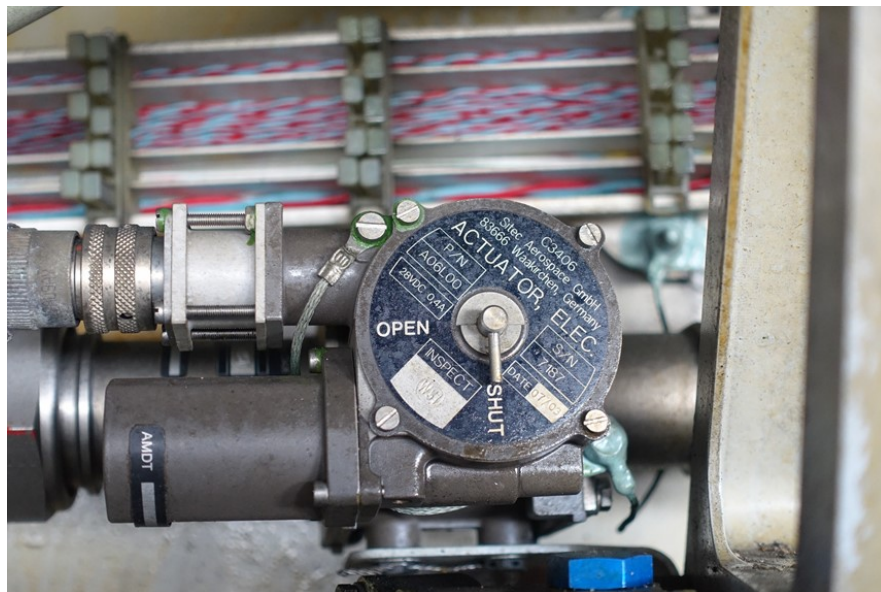


Photo 29- No. 2 Engine Hydraulic Fire Shut-Off Valve, Installed in Right Wing

6.1 Hydraulic Check Valve Testing

The yellow and green hydraulic check valves (pressure/return and case drain) were functionally tested in the DAL TechOps hydraulic shop. The yellow and green hydraulic case drain check valves were pressurized to 50 psi and then 65 psi opposite the direction of flow and no leaks were observed.

The yellow and green hydraulic pressure check valves were pressurized to 1000, 2000, and 3000 psi with no leaks. The green pressure check valve was held at 65 psi for three minutes to check low pressure function with no leaks. The yellow hydraulic pressure check valve was pressurized to 61 psi for

about three minutes to perform a low-pressure leak check and a leak rate of 4 drops per minute was recorded¹⁹.

The check valves were shipped to Airbus for detailed testing and examination. The testing corroborated the findings from DAL TechOps, and no anomalies were noted during a visual examination. The Airbus report, “Hydraulic Test_A330 MSN 578 ATA29 Check Valves” is available in the investigation docket as Powerplants- Attachment 2- Airbus Hydraulic Check Valves Test Report.

6.2 No. 2 Engine Hydraulic Fire Shut-Off Valve Testing

The green and yellow hydraulic system FSOVs were shipped to the original equipment manufacturer (OEM), Sitec Aerospace GmbH in Tölz, Germany for examination an acceptance test procedure (ATP) on August 9, 2019. Both FSOVs arrived in good condition. The leak rate was measured by installing each valve on a test bench, closing the valve, and measuring leak rate past the valve at different pressures. The electric actuator of each valve was cycled twice, and the travel time and performance were measured. The valves were then installed on the test bench a second time to check leak rate. Finally, a torque measurement was recorded to move the valve ball into the shut-off position. The FSOVs met specification for each test performed.

Both FSOVs were disassembled to examine the internal components and the electronic card, wiring, and reduction gear system were all in good condition with no visible damage. The Sitec Aerospace report, “Engineering Investigation Report for Valve, Fire Shut-Off” is available in the investigation docket as Powerplants- Attachment 3- Sitec Aerospace Hydraulic Fire Shut-Off Valves Test Report.

In addition to the testing at SITEC Aerospace, the yellow hydraulic system FSOV circuit board was x-rayed at the BEA materials laboratory to examine for defects such as soldering micro-cracks, without any findings.

6.3 Yellow Hydraulic System Engine Driven Pump

As noted in the engine examination section, the yellow engine driven hydraulic pump was found separated into two pieces. Both pieces were shipped to Airbus-Bremen and then onto the OEM, Eaton Aerospace Systems in Bedhampton, Hampshire, United Kingdom (**Photo 30**). A group exam was completed with party members from the United Kingdom Air Accident Investigation Brach (AAIB), the BEA, Airbus, DAL, and Eaton from April 10-11, 2019.

¹⁹ According to the component maintenance manual (CMM), 29-11-06, the maximum leak rate at 21.76 psi (1.5 bar) is 5 drops per hour or less.



Photo 30- Yellow Hydraulic Engine Driven Pump, as Received at Eaton (Photo Courtesy of Eaton)

Computerized tomography (CT) scans of the two EDP pieces were taken at Southampton University on April 10, 2019, to help establish the examination workscope. The CT scans confirmed the rotating group assembly was intact with no component damage or visible abnormalities evident.

The bottom EDP piece contained the rotating group, and the top piece contained the valve block, compensator, adaptor block, and wafer plate (**Photo 31**). An inspection of the dynamic surfaces did not reveal any evidence of excessive or accelerated wear or mechanical failure. The aluminum impeller was thermally damaged and fractured into three pieces (**Photo 32**). There was no evidence of EDP malfunction prior to the engine fire event.

A metallurgical examination of the EDP components was completed at Eaton. The metallurgy findings concluded that the microstructure of the EDP housing and adaptor block, impeller had been exposed to temperatures high enough to change the material microstructure and weakened the grain boundaries, resulting in lower tensile and shear strength. The internal EDP forces were then great enough to fracture the housing and pull the mounting lugs apart. The analysis concluded that the EDP was exposed to temperature in excess of 1112°F (600°C). The Eaton metallurgy report, “Level 1 Investigation Report L1/Bdh/19/011” is available in the docket as Powerplants- Attachment 4- Eaton Hydraulic Engine Driven Pumps Investigation Report.



Photo 31- Yellow Hydraulic Engine Driven Pump, Bottom Section (Photos Courtesy of Eaton)

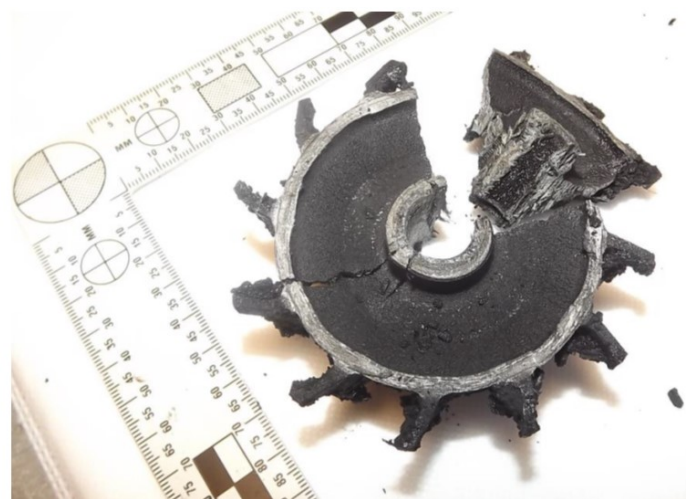


Photo 32- Yellow Hydraulic Engine Driven Pump Impeller (Photos Courtesy of Eaton)

The green EDP did not arrive at Eaton in time for the group exam, but a visual exam was performed on June 6, 2019. The pump was intact, and it was noted that there was black sludge contamination in the hydraulic ports. Due to a lack of evidence that the green EDP was involved in the accident sequence, Eaton was notified that disassembly of the part was not required.

7.0 MAIN FUEL SUPPLY (FM-13) HOSE

The FM-13 hose removed at AMS on April 17, 2018, was shipped to DAL TechOps (See Section 1.1. for details). The DAL fuel lab fabricated a test set up to pressurize the fuel line to 30 psi and no leaks were observed.

The FM-13 hose to pylon hydraulic interface connection removed from the accident aircraft were left intact. Both the FM-13 hose and the rigid fuel pipe were cut with a cutting wheel to fit the hydraulic interface panel connection in the DAL TechOps x-ray machine (**Photo 33**). The x-rays did not conclusively show the condition of the interface.

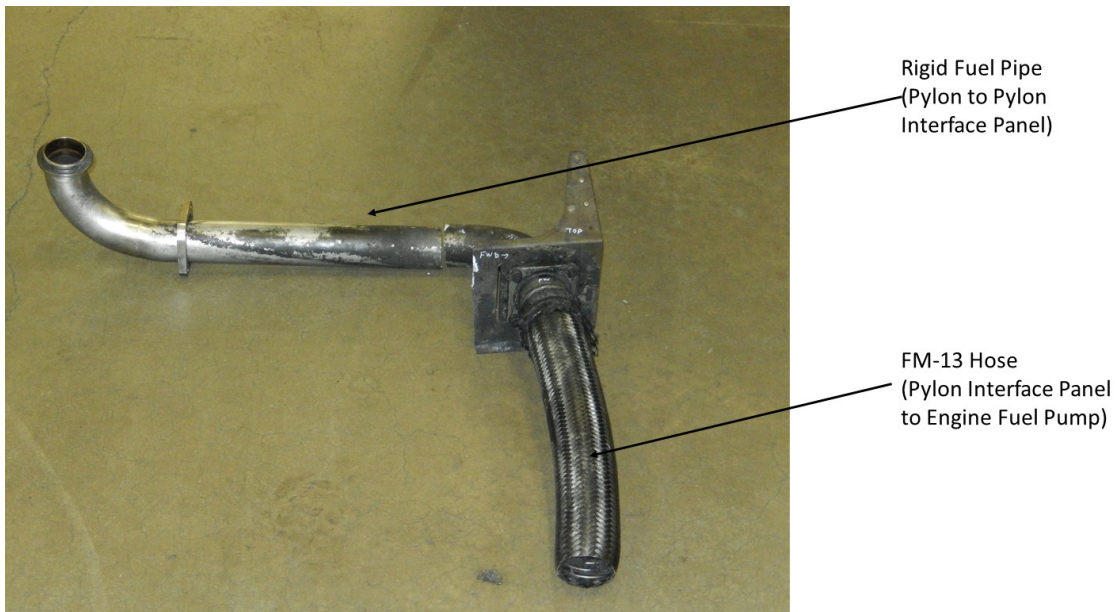


Photo 33- Rigid fuel pipe to FM-13 hose Connection at Pylon Hydraulic Interface Panel

Both sides of the main fuel supply line were cleaned with mineral spirit solvent to remove soot and coking. The lower section of the cut rigid fuel pipe was taken to the DAL TechOps non-destructive testing (NDT) shop for cleaning and fluorescent penetrant inspection (FPI). The rigid fuel pipe was cleaned in an ultrasonic bath and dye penetrant was applied to all welds on the pipe. A crack indication at the rigid line flange radius was observed, but the crack could not be verified by eddy current inspection and was later confirmed to be a false indication during follow up testing at the Airbus materials laboratory. A summary of metallurgy findings is discussed later in this report.

7.1 FM-13 Hose Group Examination and Testing

The FM-13 hose from the accident flight and the FM-13 hose removed in AMS, one day prior to the accident flight, were shipped to the OEM, Parker Stratoflex in Fort Worth, Texas. A group examination was held with investigation party members from DAL, Airbus, Pratt & Whitney, Parker Aerospace, the BEA, and the NTSB from August 1-2, 2018. The lines were quarantined at Parker Stratoflex and both boxes were sealed when the investigation group arrived.

7.2 FM-13 Hose Removed in AMS Pressure Test

The AMS FM-13 hose fire sleeve had multiple tears and exhibited degradation of the silicone layer (**Photo 34**). The hose was installed in the Parker Stratoflex pressure test bench with production tooling (**Photo 35**). The test bench used water as the pressure fluid. The hose was leak tested at the pressures and time durations shown below in **Table 4**. No leaks were observed.



Photo 34- AMS FM-13 Hose, As Received



Photo 35- AMS FM-13 Hose in Pressure Test Bench

Pressure (psi)	Time (minutes)	Leak
30	10	No
50	10	No
72	2 minutes x 3 cycles*	No

Table 4- AMS FM-13 hose Pressure Leak Check

*The pressure was cycled from 50 psi to 72 psi for the first cycle and then from 0 psi to 72 psi for the second and third cycles.

The AMS FM-13 hose fire sleeve was cut lengthwise and removed after testing to examine the metallic braid. The metallic braid was intact and in good condition with no visible nicks or deformation (**Photo 36**).



Photo 36- AMS FM-13 Hose Fire Sleeve Removal

7.1.2 Accident FM-13 Hose Upper Flange Pressure Test

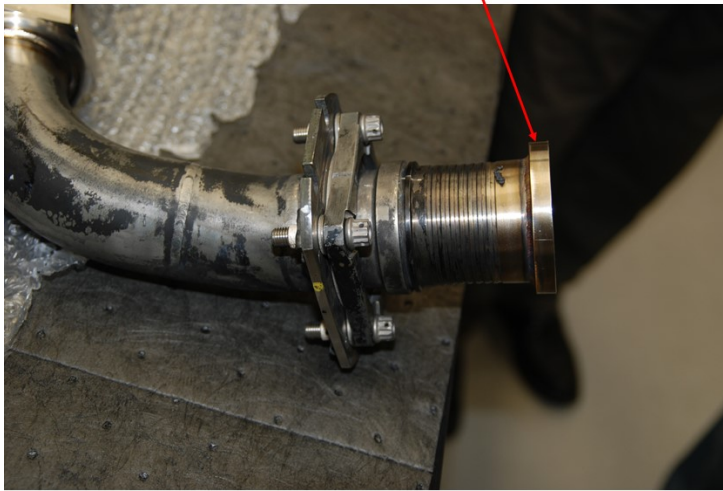
The accident FM-13 hose was disassembled to separate the upper flange for pressure testing. A cutting wheel was used to separate the fire sleeve retaining band and the crimped socket was cut to separate the metal braid from the hose nipple (**Photo 37**). Parker Stratoflex stated that the nipple and socket appeared to be OEM hardware. A steel blank plate was welded onto the accident FM-13 hose nipple to create a seal. A brazed tube end (BTE) fitting was welded onto the cut end of the accident rigid fuel pipe. (**Photo 38**). A new Gask-O-Seal and new bolts were installed between the FM-13 hose and rigid pipe flanges and the assembly was plumbed into the pressure test bench (**Photo 39**). The test pressures, time duration, and bolt torque values²⁰ are listed in **Table 5**. There were no leaks observed during the tests.



Photo 37- Accident FM-13 Hose Upper Flange Disassembly

²⁰ The AMM FM-13 hose installation procedures call for a bolt torque of 180-200 in-lb.

FM-13 Hose Welded Plate



Brazed Tube End Fitting

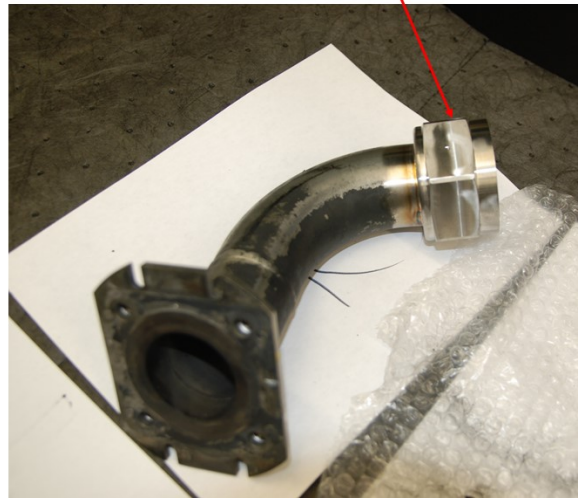


Photo 38- (L) FM-13 hose with Welded Plate, (R) Rigid Fuel Pipe Welded Brazed Tube End Fitting



Photo 39- Accident Hardware Installed in Pressure Test Bench

Pressure(psi)	Time (minutes)	Bolt Torque (in-lbs.)	Leak
30	10	100 (50%), 200 (100%)	No
50	10	100 (50%), 200 (100%)	No
72	2 x 3 cycles*	100 (50%), 200 (100%)	No

Table 5- Accident Hardware Pressure Leak Check

*The pressure was cycled from 50 psi to 72 psi for the first cycle and then from 0 psi to 72 psi for the second and third cycles.

The Airbus A330-300 AMM procedure calls for the attaching bolts between the two flanges to be torqued diametrically. The bolts were intentionally torqued in the wrong sequence, by torquing the two bolts on one side and then the two bolts on the other side to 200 in-lbs. and no leaks were observed when the assembly was pressurized.

The accident hardware was removed from the pressure test bench and the flanges were separated. To simulate Gask-O-Seal damage, a razor was used to cut through the elastomer in the radial direction at one location. The Gask-O-Seal was then installed between the rigid pipe flange and the FM-13 hose flange hardware was torqued to 200 in.-lbs. torque in accordance with the AMM procedure. The assembly was pressurized to 72 psi and no leaks were observed. In the next test, approximately 45 degrees of elastomer material from a new Gask-O-Seal® was removed and then installed between the flanges and torqued in accordance with the AMM. The assembly began leaking heavily when pressure reached about 30 psi.

7.1.3 AMS and Accident FM-13 Hose Rigid Pipe Pressure Test

The AMS FM-13 hose to rigid pipe flange was secured to the top of a ladder with zip ties and the hose was allowed to hang to the ground to roughly simulate the orientation of the hose when installed (**Photo 40**). A new Gask-O-Seal® was installed between the FM-13 flange fitting and the accident rigid pipe flange and the bolts were torqued to 200 in-lbs. The pressure test bench water line was plumbed into the brazed tube end fitting welded onto the rigid pipe. The test pressures and time durations are listed in **Table 6**. No leaks were observed during the test.



Photo 40- AMS FM-13 hose to Accident Rigid fuel pipe Flange Test Setup

Pressure (psi)	Time (minutes)	Leak
30	10	No
50	10	No
72	2 minutes x 3 cycles*	No

Table 6- AMS FM-13 hose and Accident Rigid fuel pipe Flange Pressure Leak Check

*The pressure was cycled from 50 psi to 72 psi for the first cycle and then from 0 psi to 72 psi for the second and third cycles.

7.1.4 Accident FM-13 Hose Flange Misalignment Test

A test was setup to check if misalignment during FM-13 installation could result in a false torque indication on the attaching bolts. A new FM-13 upper junction flange was provided by Parker Stratoflex and the interface sealing surface of the FM-13 hose was intentionally misaligned when mated to the rigid fuel pipe/pylon hydraulic interface panel. Approximately 200 in-lbs. of torque was applied to each bolt per the AMM procedure. The FM-13 hose seated while torque was applied to the fourth flange bolt. When the FM-13 hose flange seated, all attaching bolts lost run-on torque. The parts were disassembled, and deformation was visible when the flange was placed against a straight edge ruler.

7.1.5 AMS FM-13 hose Fire Sleeve Chemical Analysis

The FM-13 hose fire sleeve that was removed in AMS was shipped to Parker Aerospace in Irvine, California in January 2020 to identify the chemical residue on the silicone surface (**Photo 41**). A new piece fire sleeve was also submitted for testing as a control. Samples were collected from multiple areas on the fire sleeve exterior and interior surfaces and were analyzed by Fourier-transform infrared spectroscopy (FTIR) and EDS. The samples identified markers consistent with jet fuel, but no phosphate ester type hydraulic fluid markers were detected on any of the samples. The Parker Aerospace laboratory report, “LR 253984 Analysis of the Fire Sleeve from FM-13 (A330, PW4000 Engine) Fuel Line” is available in the docket as Powerplants- Attachment 5- Parker Aerospace AMS FM-13 Fuel Line Fire Sleeve Chemical Analysis Report.



Photo 41- AMS FM-13 Hose Fire Sleeve, As Received at Parker Aerospace (Photos Courtesy of Parker)

8.0 FIRE EXTINGUISHING BOTTLES

The No. 2 engine fire extinguishing bottles were removed from the pylon for inspection and weight measurements. The bottles were in good condition with no visible damage and weighed 12.13 and 12.12 lbs. respectively, consistent with the empty weight listed on the bottle label.

The serial numbers for all four halon bottles installed on N806NW at the time of the accident flight were provided to the OEM, Meggitt Safety Systems in Simi Valley, California, who confirmed that the bottles were manufactured and filled as part of the same production lot. The halon bottles from the No. 1 (left) engine were shipped to Meggitt for halon quality testing in May 2020. The halon water concentration in the two bottles were 8 and 10 ppm above limit and all other test parameters met specification. According to Meggitt, the high water content would not have affected fire bottle performance. A copy of the halon quality test results, “Delta Bottle Analysis” is available in the investigation docket as Powerplants- Attachment 6- Meggitt Safety Systems No. 1 Engine Fire Extinguishing Bottle Analysis Report.

9.0 RECORDERS

The digital flight data recorder (DFDR) and cockpit voice recorder (CVR) were quarantined immediately after the accident flight and prepared for shipment to the NTSB Recorders Laboratory in Washington, DC for download. Multiple other non-volatile memory sources from the accident airplane and ground support were evaluated as part of the investigation process and are summarized below.

9.1 Digital Flight Data Recorder

The No. 2 engine parameters were plotted, and all engine related parameters appeared nominal leading up to the time of the engine fire (**Figures 13 and 14**). According to P&W engineering the repeated data spikes (appear to be color blocks on Figure 14) beginning at approximately timestamp 18:14:00 are consistent with data drop out due to thermal damage and the NTSB agrees with this assessment.

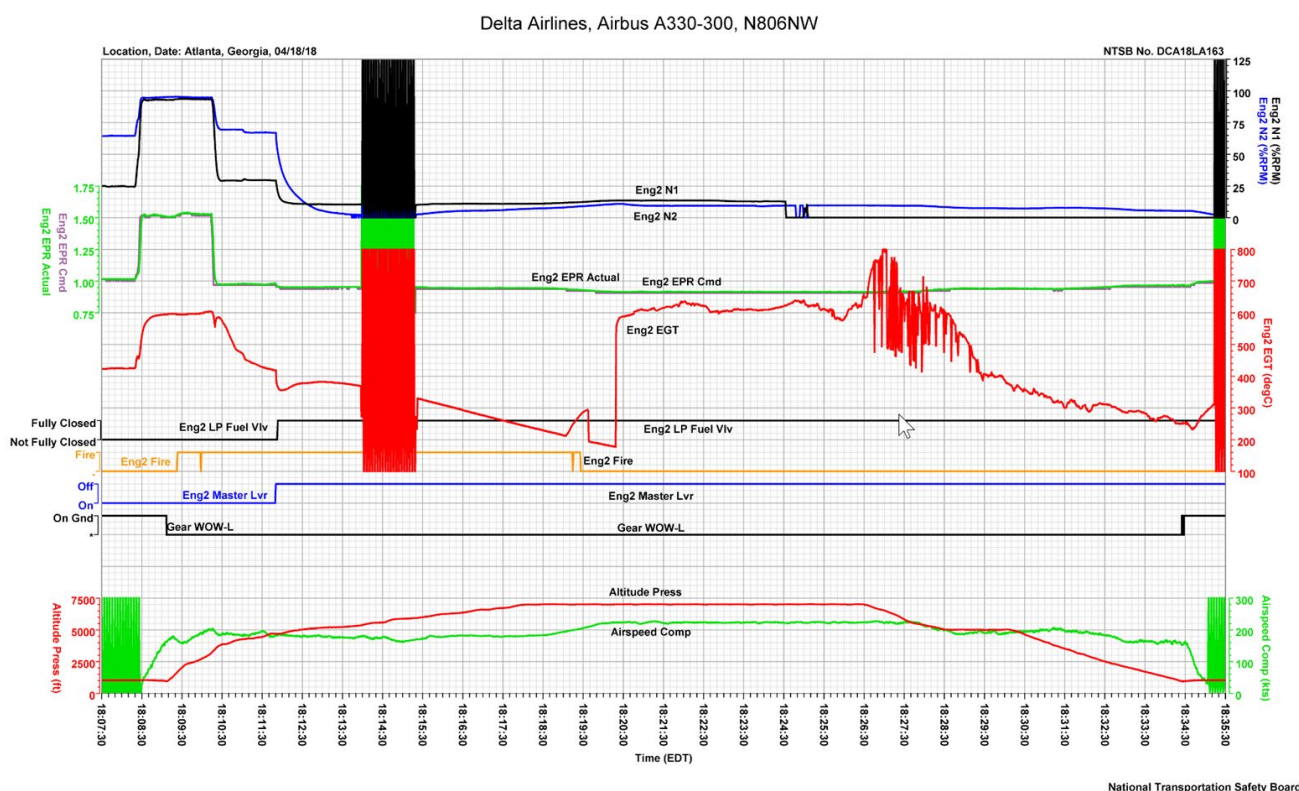


Figure 12- Select DFDR Parameters, Full Accident Flight

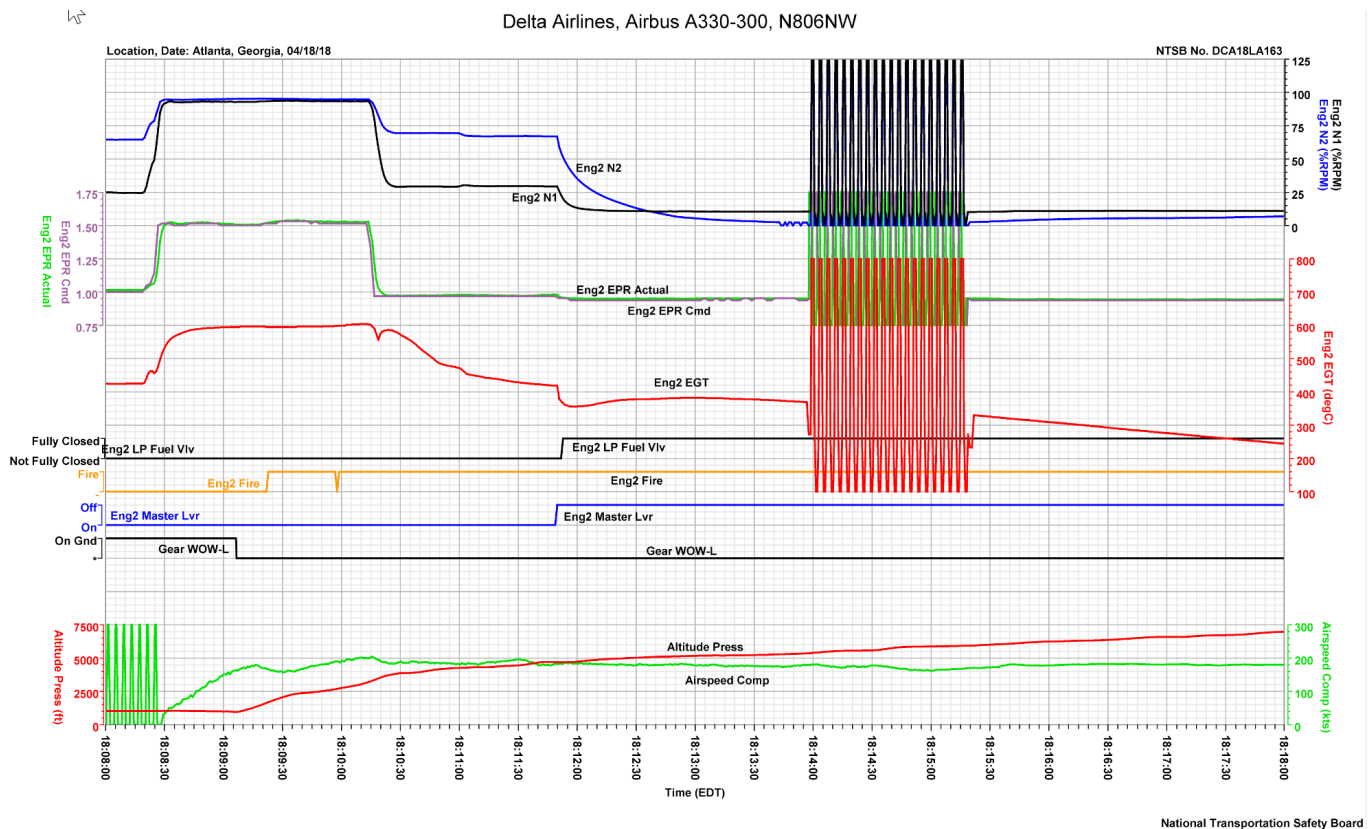


Figure 13- DFDR No. 2 Engine Parameters, Focus on Takeoff

9.2 Cockpit Voice Recorder

The cockpit voice recorder (CVR) was secured and shipped to the NTSB Recorders Laboratory in Washington, DC for download and audition. Radio communications from the ATL ground tower were audible but the accident flight was not captured. It was determined that the CVR was not properly secured by maintenance personnel at the gate and the CVR continued to record until the accident flight was overwritten. According to DAL Flight Safety, the procedures for securing a CVR after an incident/accident flight have been updated to avoid the same error in the future.

9.3 AIRMAN Report

AIRMAN or **AIR**craft **M**aintenance **A**alysis is an Airbus proprietary aircraft health monitoring tool that constantly monitors aircraft systems status and transmits faults and warning messages to ground control. Selected parameters are recorded in a one minute window.

9.4 Pratt & Whitney PW4168 Electronic Engine Control

The electronic engine control (EEC) unit was downloaded under NTSB supervision at DAL TechOps during the initial on-scene phase of the investigation. A copy of the file was transferred to P&W in East Hartford, Connecticut for conversion and a summary of fault/warnings. P&W engineering also completed a DFDR to EEC correlation to assist with event timeline development. The P&W EEC correlation analysis "Delta Airlines (DAL) A330-200 Aircraft Registration N806NW PW4168A-1D

Engine #2 P733603 Cracked Fuel Supply Line & Engine Fire During Takeoff’ is available in the investigation docket as Powerplants- Attachment 7- Pratt & Whitney EEC Correlation Analysis Report.

9.5 Fire Detection Unit

The FDU was sent to the OEM, L’Hotellier²¹ in Antony, France for download of the non-volatile memory (NVM). According to L’Hotellier, the FDU did not log any faults that would indicate the system was not functioning properly prior to sustaining fire damage and a message was recorded in the NVM that confirmed discharge of the first fire extinguishing bottle (agent 1)²².

9.6 Airport Video

The ATL ARFF station was contacted to request the video files of the firefighting response on the runway. According to the ATL ARFF department, the FLIR Systems camera system installed on the responding fire trucks were not set to record, so no video was captured.

ATL airport operations provided video files from the FAA Air Traffic Control Tower. DAL Flight 30 enters the video frame shortly after landing at 18:34:34 according to the video timestamp. A faint smoke trail is visible from the No. 2 engine as it enters the video frame, and the smoke continues to intensify as the airplane decelerates (**Photo 42**). ARFF crews arrive at 18:35:56 and begin spraying fire retardant into the No. 2 engine.



Photo 42- FAA Tower Video

10.0 ACCIDENT TIMELINE

The DFDR, AIRMAN report, Post Flight Report (PFR) and EEC data were compiled to produce an accident timeline (**Table 7**).

²¹ L’Hotellier is part of the aerospace and defense sector of KIDDE INTERNATIONAL, a Collins Aerospace company.

²² The FDU was designed to record messages in chronological order without a timestamp.

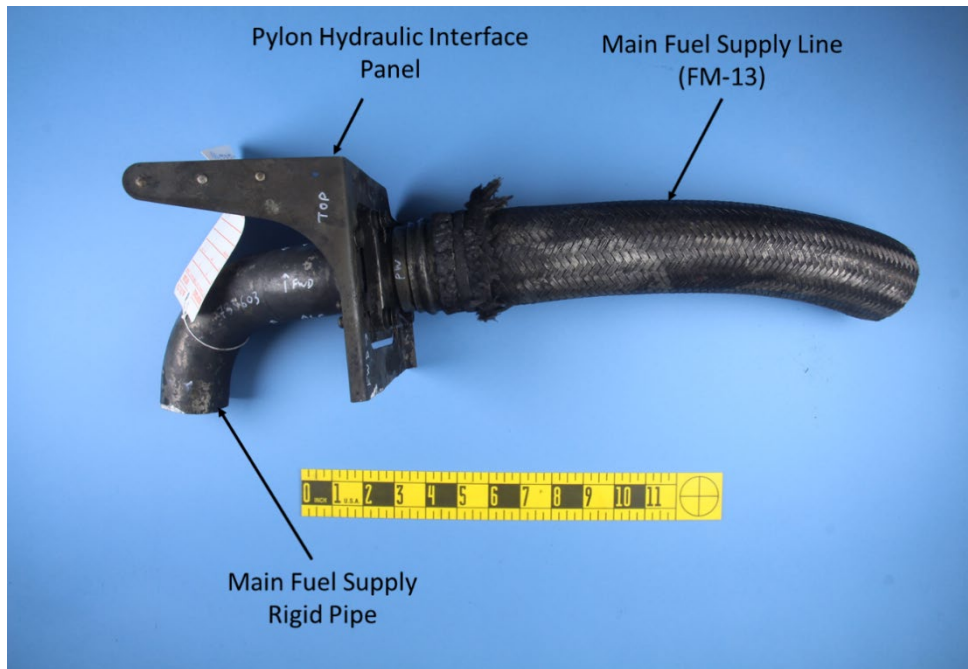
TIME (UTC)			EVENT DESCRIPTION	ECAM	COMMENTS
22:08		22:08:00	N806NW WAS STOPPED, WITH ITS PARKING BRAKE ON, AND ALIGNED WITH RUNWAY 26 L		Digital flight data recorder (DFDR) indicated that both thrust levers were at their idle position and each of the following airplanes hydraulic systems (Blue, Yellow, & Green) were indicating 3,000 psi. The engine parameters were nominal.
		22:08:16	TAKEOFF ROLL BEGAN		Four seconds after the parking brake was released, takeoff thrust started to be gradually applied until reaching maximum continuous thrust (MCT) notch 11 seconds later.
		22:08:58	V1 SPEED of 144 KNOTS REACHED		The V1 speed used for departure from ATL runway 26 was 144 knots
22:09		22:09:05	LIFT OFF		The engine gas temperatures (EGT) stabilized on both engines around 600°C. The landing gear lever was selected up and the Auto Brake disarmed after gear retraction.
		22:09:22	“ENG 2 FIRE” WARNING	ENG 2 FIRE WARNING	At approximately 700 ft radio altitude (RA) and an airspeed of about 165 knots, the ECAM displayed an (“ENG 2 FIRE”) warning; this warning was displayed for 34 seconds (22:09:22 to 22:09:56). The DFDR showed that there was no noticeable impact on the engine N1/N2 speed, EGT or EPR. The Captain’s Master Warning also illuminated for 4 seconds (22:09:23. to 22:09:27).
		22:09:39	THE FIRST OFFICER BECAME THE PILOT FLYING		
		22:09:57	“ENG 2 FIRE” WARNING TURNS OFF FOR ONE SECOND		No. 1 (left) engine generator becomes primary (35s after the fire warnings).
		22:09:58	“ENG 2 FIRE” WARNING ILLUMINATED WITH ITS ASSOCIATED MASTER WARNING	ENG 2 FIRE WARNING	
22:10		22:10:13	THRUST LEVER (T/L) NUMBER 2 WAS RETARDED TO IDLE		The T/L was retarded to idle 51 seconds after the fire warning occurred at approximately 2400 feet RA. At this time, T/L1 (No. 1 engine) was pushed to TOGA position.
		22:10:15	ELEC GEN 2 FAULT		
22:11		22:11:49	ENGINE #2 SHUTDOWN PERFORMED BY THE FLIGHT CREW BY POSITIONING THE MASTER LEVER TO OFF.		Two minutes and 27 seconds after the fire alarm occurred, the Number 2 engine’s master lever was switched OFF. DFDR data indicates that the LP SOV and HP SOV closed; accordingly, HP SOV at 22:11:50 and LP SOV at 22:11:52.
		22:11:53	ELECTRIC HYDRAULIC PUMPS START FOR THE YELLOW HYDRAULIC SYSTEM.		The yellow Electric Pump will start automatically as soon as the engine "running" condition turns false (i.e., "engine off" based on N2<50%).

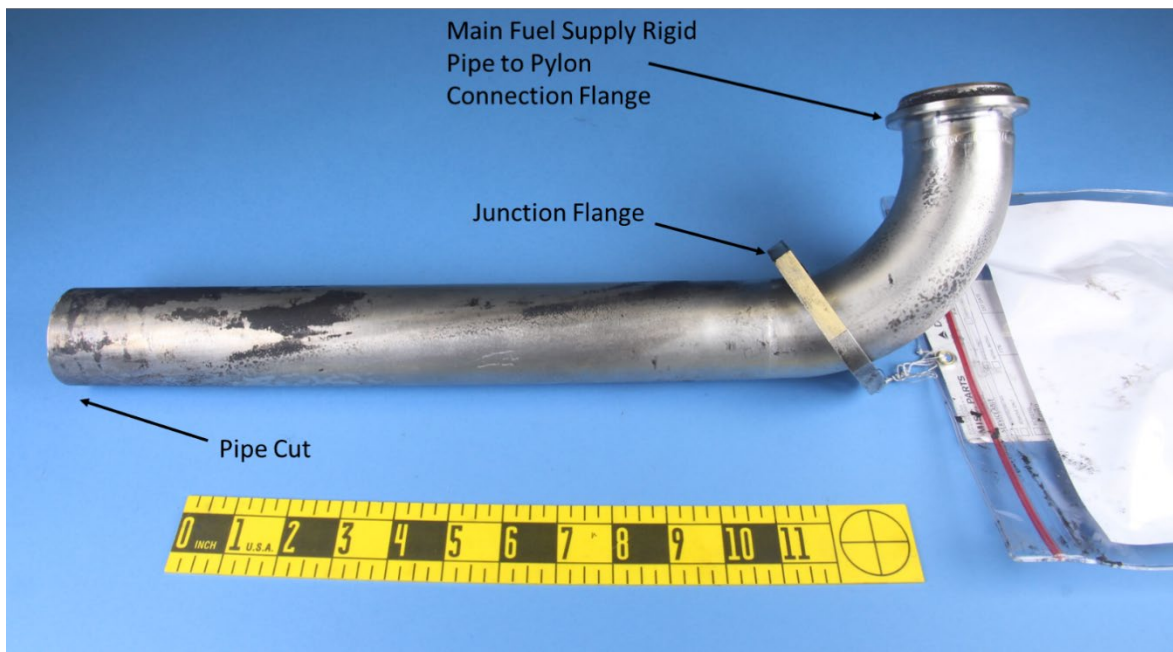
22:12:00 to 22:12:59	NUMBER 2 ENGINE FIRE BOTTLE		FIRE EXTINGUISHING BOTTLE 1 (AGENT 1) AND BOTTLE 2 (AGENT 2) DISCHARGE		During the time between 22:12:00 and 22:12:59, the PFR recorded the Number 2 engine's Fire extinguishing bottle N°1 parameter as transitioning from pressurized to not pressurized. This likely indicates that the crew activated the Agent 1 discharge switch.
		22:12:05	LIKELY TIME THE YELLOW AND GREEN FIRE SHUT-OFF VALVES WERE CLOSED.		The QAR does not record the position of the yellow and green fire shut-off valves (FSOV); therefore, their position is based on the position of PRV2 and HPV2. According to the DFDR, these two valves transitioned to close at 22:12:05. According to Airbus, this is an indication of the time for when the Number 2 engine fire push button was pressed and released.
22:13		22:13:56	EGT DATA BECOMES UNRELIABLE		
22:15		22:15:53	BUS TIE CONTACTOR NUMBER 1 OPENED AND MASER WARNING WAS DISPLAYED FOR 5 SECONDS.		DFDR indicated that BTC Number 1 opened and AGC closed indicating that side 2 power supply is now coming from the APU generator; this will be the case till the end of the flight.
22:19	ENG FIRE DET FAULT ENG FIRE LOOP B FAULT ENG FIRE LOOP A FAULT				
		22:19:12	ENG 2 FIRE WARNING EXTINGUISHED FOR LESS THAN ONE SECOND		
		22:19:13	ENGINE 2 FIRE WARNING ILLUMINATED WITH ITS ASSOCIATED MASTER WARNING	ENG 2 FIRE WARNING	When the "ENG 2 FIRE" warning illuminated again, the master warning triggered again for two seconds.
		22:19:25	ENG 2 FIRE WARNING EXTINGUISHED FOR THE REMAINDER OF THE FLIGHT		
22:23	YELLOW HYDRAULIC RESERVOIR LOW LEVEL WARNING				The AIRMAN report included a hydraulic service monitoring unit notification at 22:23. The same corresponding alert was at 22:24. Both systems send one sample per minute.
22:24	HYD Y SYS LO PR FAULT MESSAGE	22:24:50	CREW COMMANDED SHUTDOWN OF THE ELECTRIC MOTOR PUMP RESULTING IN THE YELLOW HYDRAULIC PRESSURE DROPPING TO 0.0 PSI		Yellow hydraulic warning triggered accordingly. Spoilers 4 and 6 were not available anymore. This is the consequence of Flight Crew having switched the yellow Electric Pump off manually, in accordance with the ECAM procedure for "HYD Y RSVR LO LVL" triggered at 22:23 UTC.
22:31 TO 22:35	"RSVR AIR PRESS LO" WARNING	22:34:24	N806NW TOUCHED DOWN ON RUNWAY 26 R		The yellow circuit emitted a RSVR AIR PRESS LO warning during deceleration phase (landing) of the incident flight (sometime between 22:31 and 22:35 (alert is inhibited during landing phase)).

Table 7- Accident Flight Timeline

11.0 MATERIALS ANALYSIS

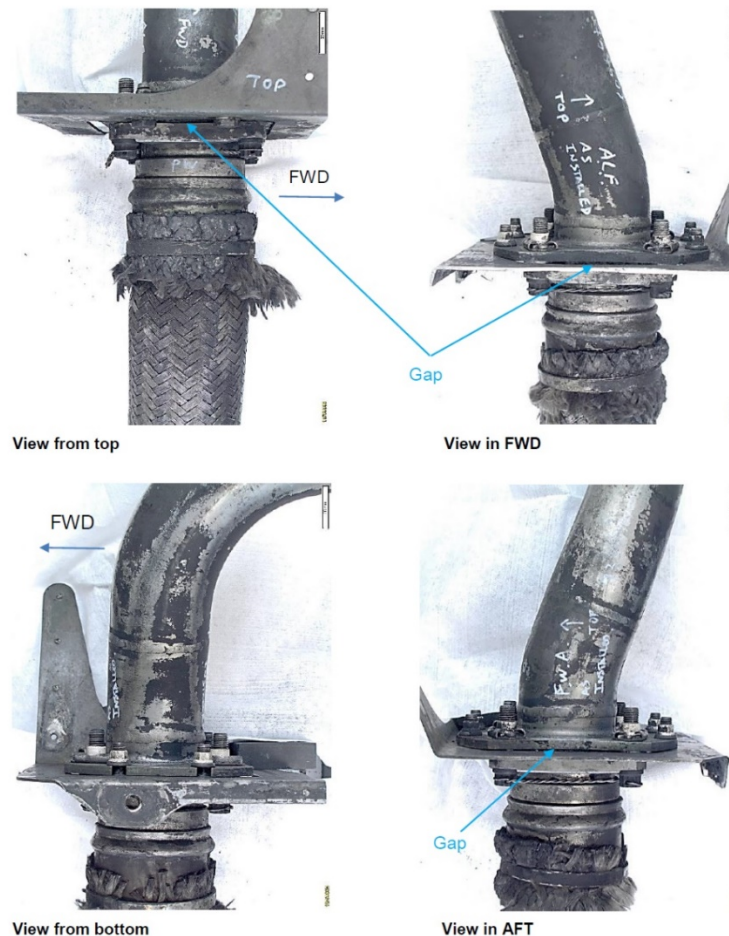
The assembled main fuel supply line (FM-13), pylon hydraulic interface panel section, and sectioned rigid fuel pipe (both sides) were shipped to the NTSB Materials Laboratory in Washington, DC for preliminary examination. The parts were photographed, and a preliminary visual and binocular inspection was completed (**Photos 43, 44, and 45**). The NTSB materials engineers recommended that the part be shipped to the Airbus Materials Laboratory in Bremen, Germany for analysis.



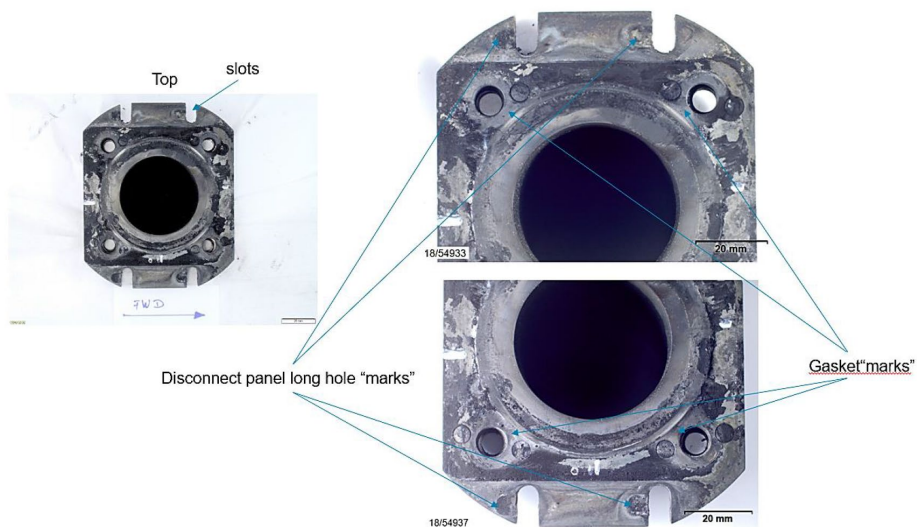
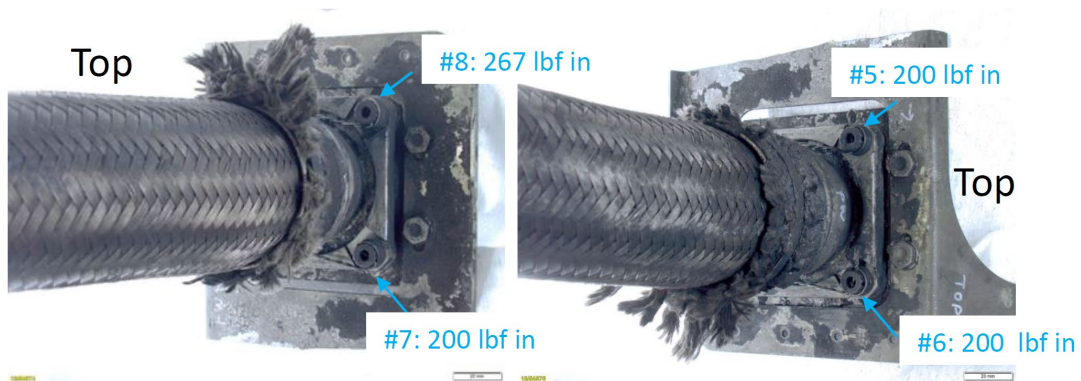
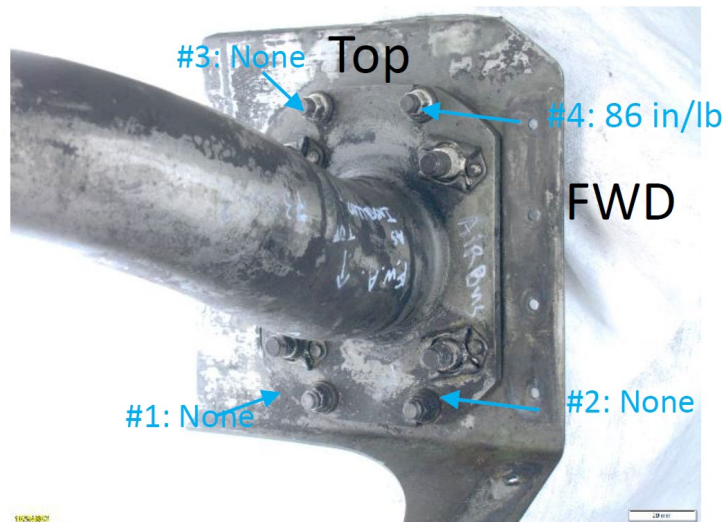


11.1 Airbus Bremen Materials Group Examination

Prior to the group examination, Airbus Bremen was given permission to open the box containing the accident parts and CT and blue light three-dimensional (3D) laser scan the assembly. In the as received photos of the assembly, a gap was visible between the main fuel supply rigid pipe flange and the FM-13 flange (**Photo 46**).



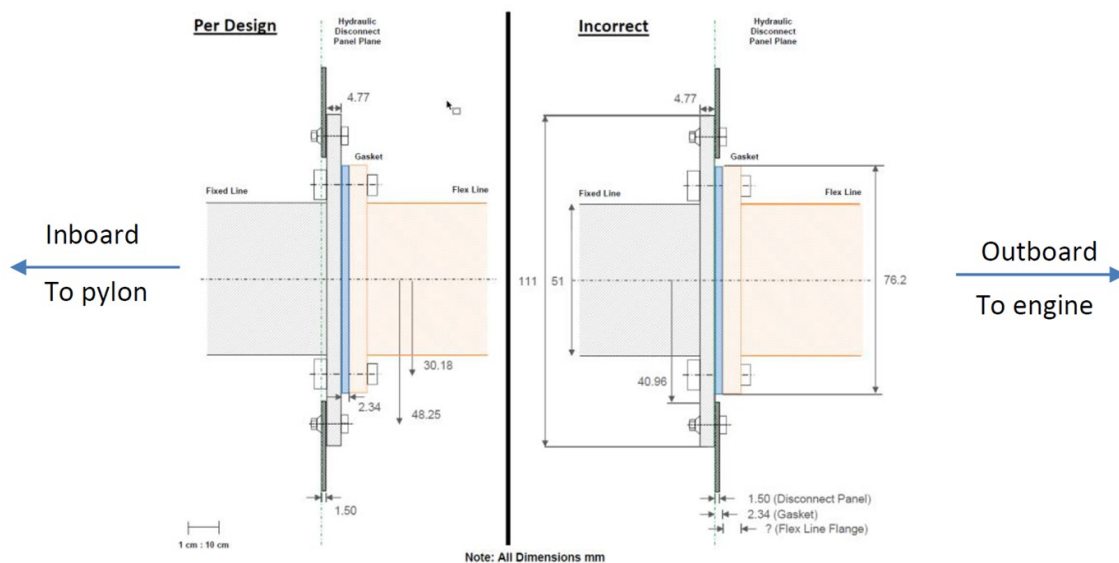
Breakaway torques were measured on the four bolts connecting the rigid pipe to the pylon hydraulic interface panel and the four bolts connecting the FM-13 flange and the rigid pipe flange. The torque value of each of the four bolts connecting the rigid fuel pipe and FM-13 hose were 200 in-lbs. or greater. Three of the four bolts connecting the rigid pipe flange to the pylon hydraulic interface panel had no breakaway torque and the fourth bolt torque was 86 in-lbs. The torque values for each of the eight connections are identified in **Photos 47 and 48**. When the flange faces were separated, gasket residue was visible on both the FM-13 hose flange and rigid pipe flange sealing surfaces, consistent with proper Gask-O-Seal installation and elastomer contact (**Photo 49**).



The parts were cleaned in a soapy water bath, scrubbed with isopropyl alcohol, and then brushed with soapy water to remove as much residue from the engine fire as possible. A flatness check of the sealing surfaces on the rigid fuel pipe and FM-13 hose was performed using a De Meet 400, geometrical metrology machine. The rigid fuel pipe had a maximum deviation from the mating surface of 0.1312 mm and a flatness (distance of lowest to highest theoretical plane) of 0.2337 mm. The FM-13 hose upper flange surface had a maximum deviation at the mating surface of 0.0182 mm and a flatness of 0.0340 mm.

A 3D laser scanner was used to measure the flatness of the flange mating surfaces as received at Airbus- Bremen. P&W requested that the FM-13 hose flange and/or components outboard of the hydraulic interface panel plane not be scanned and part drawings were not provided for the evaluation because of proprietary design. The rigid fuel pipe computer-aided design (CAD) model deviated from the actual part, so an overlay of the CAD and 3D scan was performed, and the sealing plane (point of Gask-O-Seal® elastomer contact) was chosen as the reference plane. The circular mating surface of the rigid fuel pipe had a flatness deviation of 0.201 mm and the maximum deformation on the outer surface (outside of the sealing surface) was 0.501mm.

A dimensional stack-up was created using measurements from the accident parts to calculate the displacement caused by the incorrect installation of the rigid fuel pipe on the inboard side of the pylon hydraulic interface panel. The sum of the rigid fuel pipe flange thickness, 4.77 mm, and the thickness of the hydraulic interface panel, 1.50 mm, resulted in a 6.22 mm total offset. According to the Parker Stratoflex drawing, the FM-13 hose has a manufacturing tolerance of +/-17mm in the inboard/outboard direction (**Figure 15**).



A visual inspection of the lower rigid fuel pipe flange was performed to check for evidence of imprints created by the attaching nuts in the flange nut slots. Two imprints were identified on the engine side (inboard) flange face consistent with installation in the as received installation. One imprint was identified on the pylon (outboard) flange face consistent with installation in accordance with Airbus drawings at an unknown point in the airplane service history (**Photo 50**).

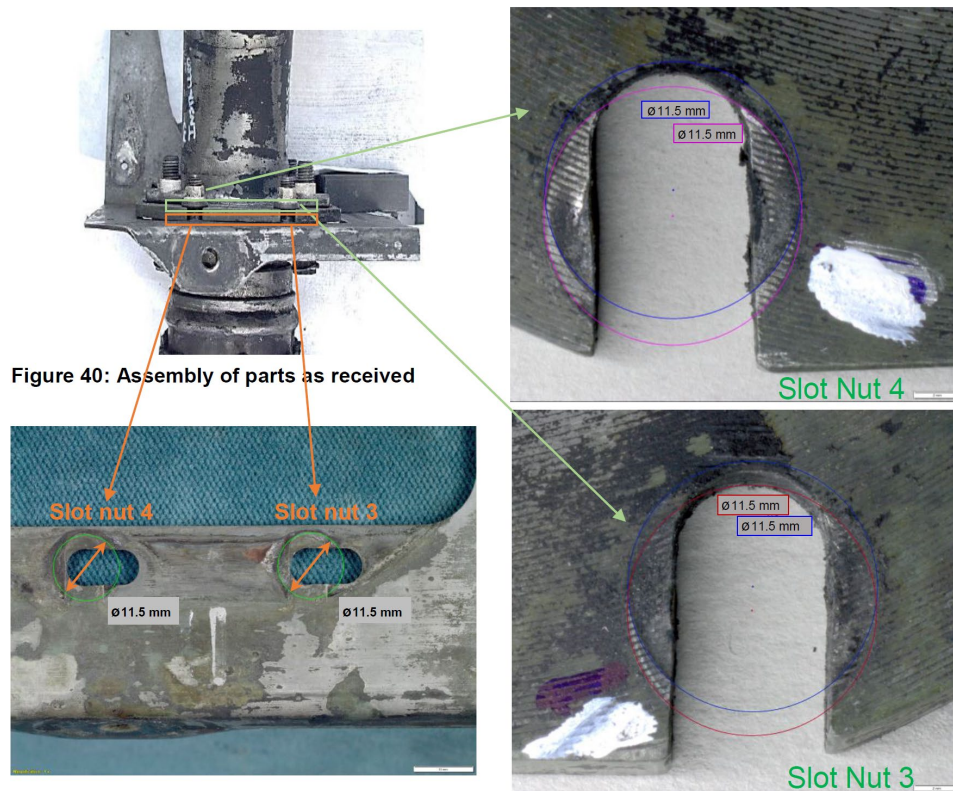
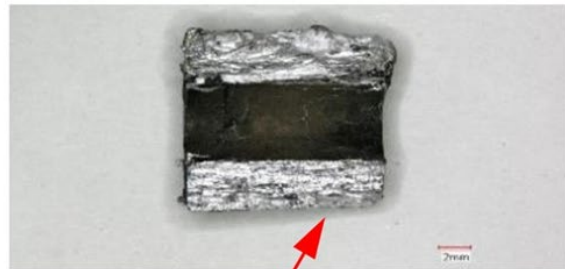
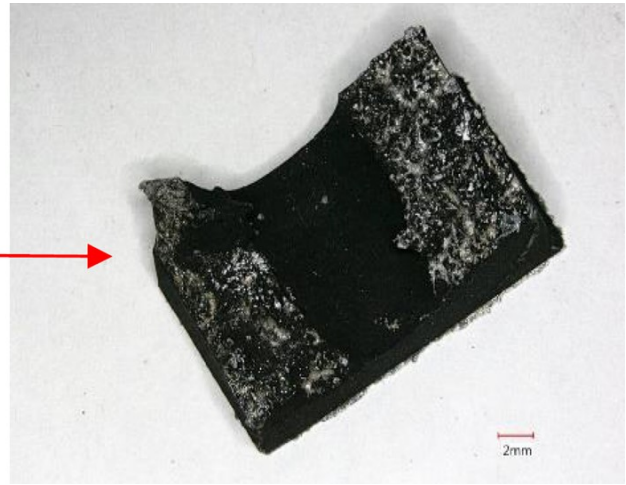
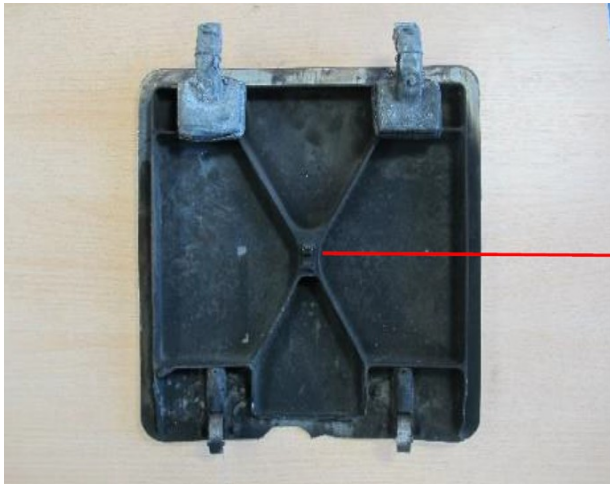


Figure 40: Assembly of parts as received

A fluorescent penetrant inspection of the rigid fuel pipe flange where crack indications were observed at DAL TechOps was performed in accordance with AITM6-1001, an Airbus non-destructive testing specification, and no cracks were detected. A high frequency eddy current inspection of the same area was performed in accordance with Non-Destructive Testing Manual (NTM) AITM6-6003 and again no cracks were detected. The Airbus Materials Laboratory report, “A330 MSN 578 DAL Fire Event- RH Engine/Pylon Fuel Connection Technical Report” is available in the investigation docket as Powerplants- Attachment 8- Airbus No. 2 Engine/Pylon Fuel Connection Materials Laboratory Analysis Report.

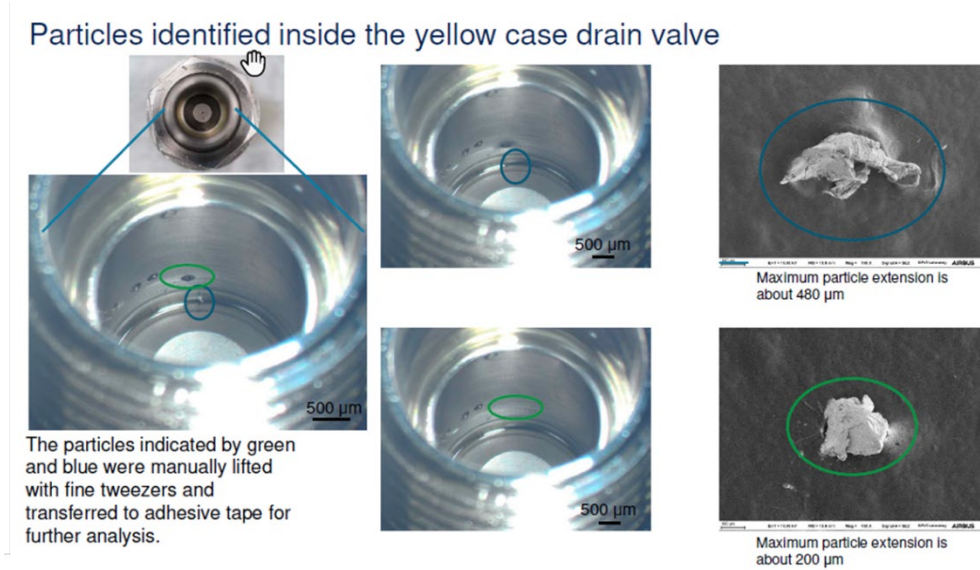
11.2 Right (Outboard) Thrust Reverser Cowl Upper Pressure Relief Door

The separated right thrust reverser upper PRD that was dropped from the airplane during the accident flight was sent to Airbus Bremen Materials Laboratory for examination of the ratchet lug and hinge fracture surfaces (**Photos 51 and 52**). The ratchet lug surface was covered in residue and exhibited significant thermal distress. The fracture surface was intensely cleaned, but laboratory staff were unable to remove all residue and consequently, a detailed fracture surface morphology was not possible. The fracture surface had visible indications of free solidified material. The fracture surfaces on the hinges appeared shiny typical of melting and free solidification.



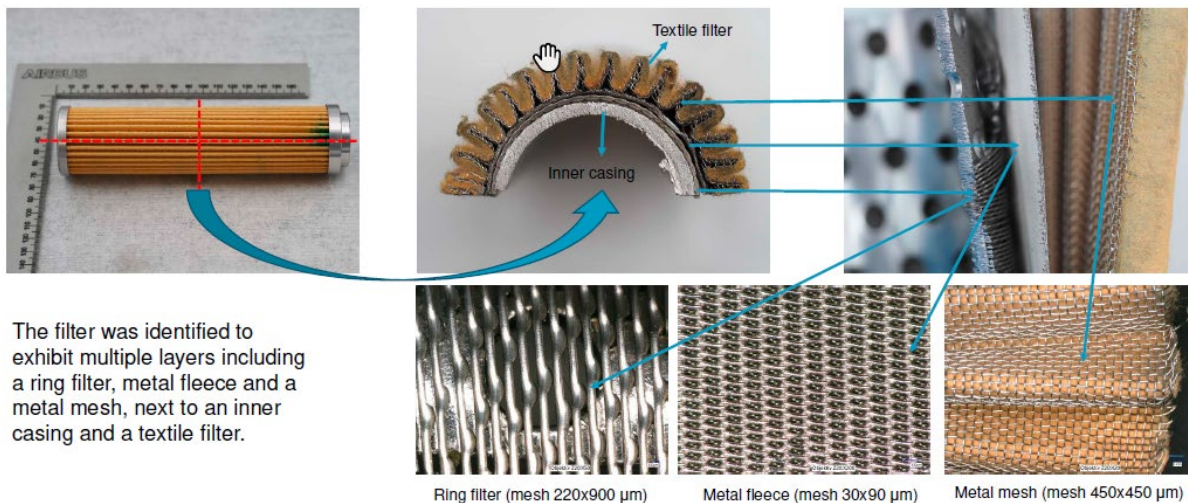
11.3 Yellow Hydraulic System Case Drain Check Valve

The yellow hydraulic system case drain check valve was examined at the Airbus Materials Laboratory in Bremen, Germany to look for debris/residue inside the valve²³. A binocular examination was performed, and multiple small particles were found adhered to the valve wall (**Photo 53**). Two of the particles were removed with a fine tweezers and were analyzed to determine the material composition. EDS and chemical analysis revealed that the particles contained Iron (Fe), Chromium (Cr), and Nickel (Ni), this combination is consistent with stainless steel. Aluminum (Al) was also identified during the analysis.



P&W supplied a new hydraulic case drain filter assembly that Airbus Materials Engineers dissected and analyzed to identify what material each part of the filter was made from (**Photo 54**). EDS analysis showed that the ring filter, metal fleece, and metal mesh portions of the filter were stainless steel. The full materials laboratory report titled “A330 MSN 578 DAL Fire Event- Hydraulic Check Valve Technical Report” is available in the docket as Powerplants- Attachment 9- Hydraulic Check Valve and Hydraulic Case Drain Filter Materials Analysis Report.

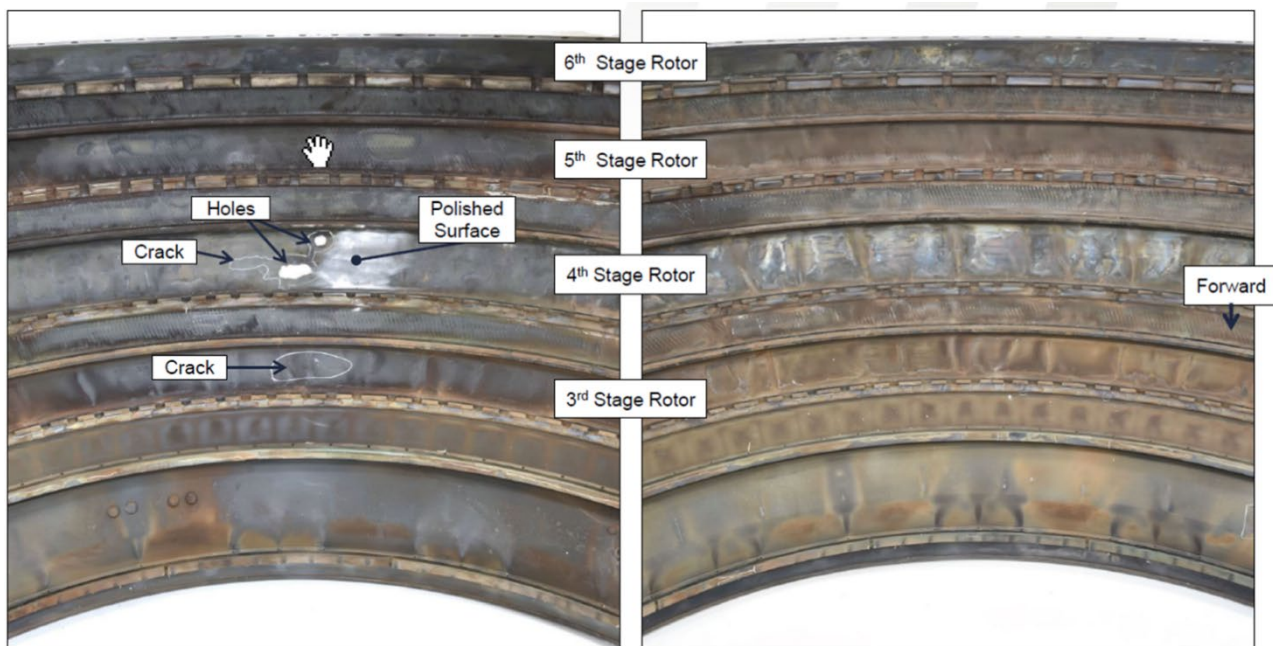
²³ The yellow hydraulic system case drain check valve had previously been pressure leak checked on two separate occasions at the DAL TechOps Hydraulics Shop and the Airbus Hydraulic Lab. Fresh fluid was used for each of the pressure leak checks.



11.4 No. 2 Engine Low Pressure Turbine Case

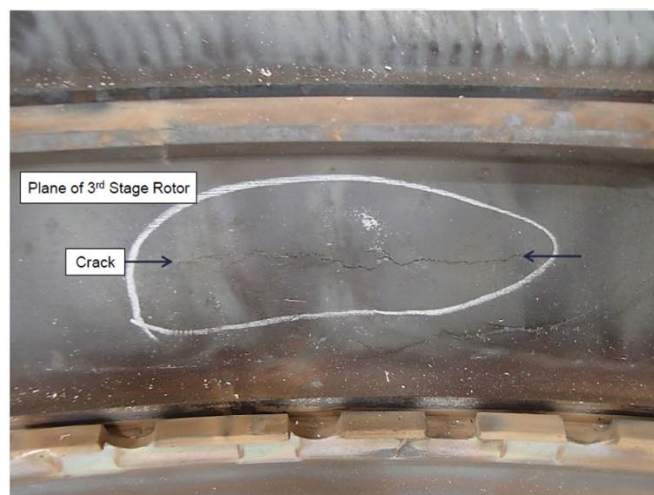
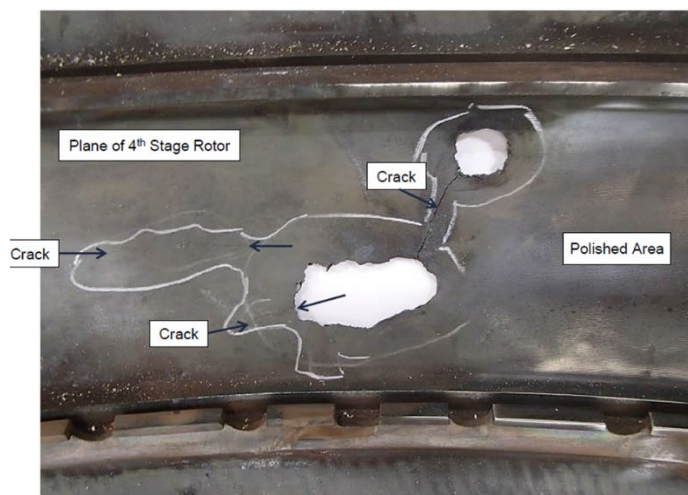
The No. 2 engine LPT case was shipped from ESA Singapore to the Pratt & Whitney Materials Laboratory in East Hartford, Connecticut for examination and hardness testing. The area of focus was the two molten deposits that were discovered beneath the TCC manifold at the 3 o'clock position. Destructive metallography of a case section taken near the deposits identified melting of the grain microstructure, consistent with exposure to temperatures in excess of 2400°F (1316°C) on the outer case diameter. The deposits removed from the case had a composition with high amounts of Al, Ni, and Cr. The material composition did not match any known materials used on the PW4168 engine and may be a mixture of multiple materials.

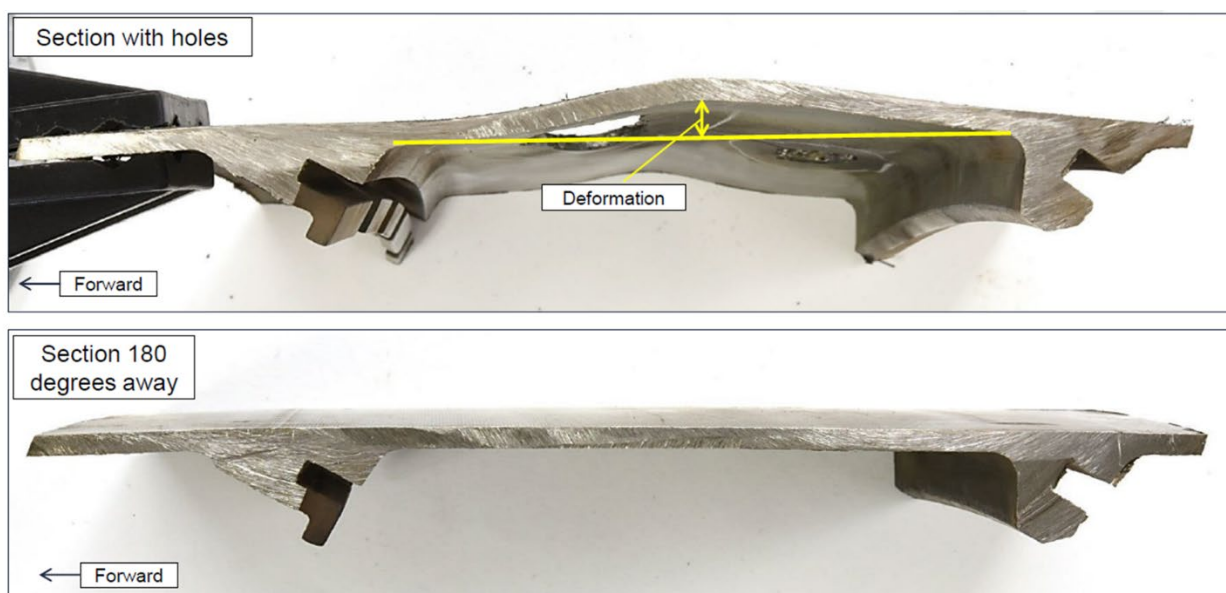
The two molten deposits were located in-line with the LPT 4th stage rotor place of rotation (**Photo 55**). The LPT case was deformed near the deposits and exhibited a dark, mottled appearance and texture from sooting and metal splatter according to the P&W lab. Cracks were observed extending from the larger hole to the smaller hole (**Photos 56 and 57**). The P&W materials lab report "PW4168 ESN 733603 Undercowl Fire LPT Case Examination" is available in the docket as Powerplants- Attachment 10- Pratt & Whitney PW4168A-1D LPT Case Materials Analysis Report.



Approximately 3 o'clock position
Internal surface exhibited a dark discolored appearance

Approximately 9 o'clock position
Internal surface appeared typical





12.0 ADDITIONAL INFORMATION

12.1 Flammable Fluid Volume Estimate After Fire Shut-Off Valve Closure

As noted in the system descriptions section of this report, when the engine fire button is pushed in the cockpit, the LPSOV and the hydraulic FSOVs in the pylon close to isolate the engine and cut fuel and hydraulic fluid supply. A list of oil, fuel, and hydraulic components/lines below the LPSOV, hydraulic FSOV, and hydraulic check valves was compiled to estimate the volume of flammable fluids that may have provided a fuel source to the fire after engine isolation (**Table 8**). The volume estimates assume the lines and components were filled at the time of the event.

Fluid	Quantity (liters/gallons)	Comments
Oil		
• Engine Tank	30.2 / 8.0	No evidence of loss.
• IDG	4.2 / 1.1	No evidence of loss.
• Starter	~1.0 / ~0.3	Lost
Fuel		
• Rigid fuel pipe (LPSOV to Pylon Interface Panel)	6.9 / 1.8	Lost
• FM-13 hose	4 / 1.1	Lost
• Fuel Pump (internal cavity and servo)	1.4 / 0.4	Lost

• High Pressure Externals (fuel triplets/manifolds, FM-01-FM-08 fuel metering lines, FDV to FFT tube, and FM09 line)	1.2 / 0.3	Partially lost
• Low Pressure Externals (FM10, FM11, and FM 13)	5.8 / 1.5	Lost
• Fuel Control	2.4 / 0.6	Unknown
Hydraulic Fluid		
Yellow System		
• FSOV to EDP (suction)	13.3 / 3.5	Lost
• EDP to Pylon Check Valve (pressure)	2.1 / 0.6	Lost
• EDP To Pylon Check Valve (case drain)	0.9 / 0.2	Lost
• EDP	1.5 / 0.4	Lost
Hydraulic Green System		
• FSOV to EDP (suction)	17.2 / 4.5	Lost
• EDP To Pylon Check Valve (pressure)	5.9 / 1.6	Lost
• EDP	1.5 / 0.4	Unknown

Table 8- Flammable Fluid Volume Estimates in Engine Following Engine Isolation

12.2 Yellow Hydraulic System Case Drain Check Valve High Temperature Testing

Testing was performed at the Airbus Bremen Hydraulics Laboratory with a yellow hydraulic system case drain check valve (CAR101) to determine if 302°F/150°C HyJet V® hydraulic fluid could cause the check valve to stick under various test conditions. Test were completed in conditions where the check valves were heat soaked to test at steady temperatures and thermally shocked to see if rapid temperature spikes would affect check valve operation. No anomalies were noted during testing and the check valves tested performed as designed. High temperature hydraulic fluid testing more exemplary of fire conditions could not be conducted due to hazardous fumes and fire risk. The Airbus test report titled, “LR DAL Engine Fire Investigation, Check Valve High Temperature Test” is available in the investigation docket as Powerplants- Attachment 11- Airbus Hydraulic Check Valve High Temperature Test Report.

12.3 A330 Fire Extinguishing Systems Certification and Evaluation

The A330 engine fire extinguishing certification was completed in accordance with FAA Part 25 airworthiness standards. To meet certification requirements the extinguishing system must be capable of maintaining a 6% concentration of Halon 1301 in the engine core compartment (fire zone) for a minimum of 0.5 second at conditions representative of maximum compartment airflow, in-flight engine windmilling. Multi-channel gas analyzers were placed at 12 locations in the engine core compartment. Tests are conducted with both the IDG and engine air-oil coolers in the open position at an undercowl airflow rate of 1.94 kg/s (kilograms/second) and with the engine air-oil cooler valve locked closed and the IDG air-cooler valve open at an undercowl airflow rate of 1.26 kg/s. The fire extinguishing system

maintained at least 6% halon concentration for 1.44 seconds at 1.26 kg/s airflow and 1.81 seconds at 1.26 kg/s airflow. On the accident flight, both the engine and IDG air-oil cooler valves were closed. The assumed undercowl airflow rate with both valves closed was 0.59 kg/s.

12.4 Pratt & Whitney 4168 / Airbus A330 Fire Certification

P&W provided the NTSB with a copy of the PW4168/A330 Propulsion System Fire Safety Certification Report, Revision B, dated December 18, 1998. Engine fire protection certification is governed by 14 Code of Federal Regulation Part 33.17. Paragraph b. of 14 CFR 33.17 states: "Except as provided in paragraph (c) of this section, each external line, fitting, and other component, which contains or conveys flammable fluid during normal engine operation, must be fire resistant or fireproof, as determined by the Administrator. Components must be shielded or located to safeguard against the ignition of leaking flammable fluid."

The terms fireproof and fire resistant are defined in FAA Advisory Circular 33.17-1A, dated August 3, 2009:

"c. Fireproof: The capability of a part or component to withstand, as well as or better than steel, a 2000°F average flame temperature ($\pm 150^\circ\text{F}$ individual thermocouple tolerance) for a minimum of 15 minutes, while still performing those functions intended to be performed when exposed to a fire.

d. Fire Resistant: The capability of a part or component to perform those functions intended to be performed while exposed to the heat and other conditions that are likely to occur at the particular location, and to withstand a 2000°F average flame temperature ($\pm 150^\circ\text{F}$ individual thermocouple tolerance) for a minimum of 5 minutes."

12.5 Additional A330-300/PW4168 Fuel Leak Finding

The NTSB was notified of a second Airbus A330-300/P&W PW4168A-1D fuel leak finding that occurred in March 2018 with a different operator. The fuel leak did not cause an engine fire and the leak was traced to the FM-13 hose to rigid fuel pipe interface at the pylon hydraulic interface panel. The aircraft had recently undergone maintenance where the FM-13 hose was separated at the hydraulic interface panel and a new Gask-O-Seal® was installed. Eight flights after the maintenance, ground crews observed fuel puddling under the engine drain mast after aircraft pushback and engine start. Maintenance crews reported that the four FM-13 hose to pylon hydraulic interface flange attaching bolts were lock wired, but the lower two bolts were found loose. The FM-13 hose was removed, and the flange and Gask-O-Seal® were inspected and determined to be in serviceable condition. The FM-13 hose was reinstalled, the attaching bolts were retorqued and the aircraft was released back to service. There have been no additional fuel leak findings since the maintenance was performed. Low resolution photographs of the FM-13 hose to pylon hydraulic interface panel interface were sent to Airbus for review where it was observed that the rigid fuel pipe lower flange was installed on the wrong side of the pylon hydraulic interface panel.

In response to the fuel leak event, Airbus performed an airworthiness risk assessment. The root cause of the fuel leak was determined to be either inadequate torquing of the FM-13 hose upper flange bolts either due to too low a torque or not using a cross pattern during the torquing process. Airbus also concluded that installation of the rigid fuel pipe on the wrong side of the pylon interface panel was not suspected to be a contributing factor. The risk assessment was reviewed and approved by EASA.

13.0 CORRECTIVE ACTIONS

13.1 Delta Air Lines

After the on-scene pylon and engine examination, DAL reviewed their A330 AMM and Aircraft Illustrated Parts Catalog (AIPC)²⁴ and determined that the rigid fuel pipe installation position on the Pylon Hydraulic Interface Panel was depicted incorrectly in several figures (**Figure 16**). The Rigid fuel pipe lower flange was shown installed on the engine side of the Hydraulic Interface Panel as was documented on the No. 2 engine, rather than the pylon side in accordance with Airbus drawings. The applicable figures were revised to show the correct installation in accordance with the Airbus drawings (**Figure 17**). DAL then voluntarily performed a fleetwide inspection of all their Pratt & Whitney PW4168 powered Airbus A330-300 airplanes to check for rigid fuel pipe installation errors. There were no additional rigid fuel pipe installation error findings in the DAL fleet, but the inspection did identify one mis-seated FM-13 upper flange (**Photo 58**). There was no evidence that the mis-seated FM-13 hose flange had resulted in a fuel leak. DAL then initiated a second fleetwide inspection campaign to verify that all FM-13 hoses were properly seated, with no additional findings.

DAL revised their AMM and applicable FM-13 hose installation work card (“Engine Main Fuel Supply Line, A330 (PW4168); ETOPS; Replace; Section 02”) to add warning and caution statements regarding improper installation of the FM-13 hose. Additional verbiage was also incorporated to clarify proper FM-13 flange seating and a require inspection item (RII) sign off requirement was added at both the installation and inspection steps.

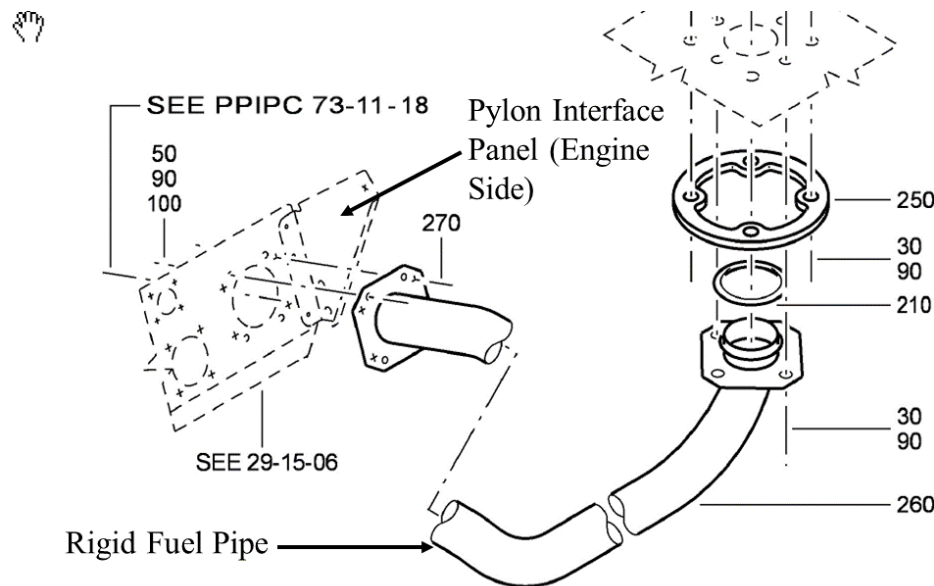


Figure 15- Original DAL A330-300/PW4168 IPC Figure

²⁴ The DAL A330-300/PW4168A AMM and IPC manuals are provided by Airbus and maintained by DAL.

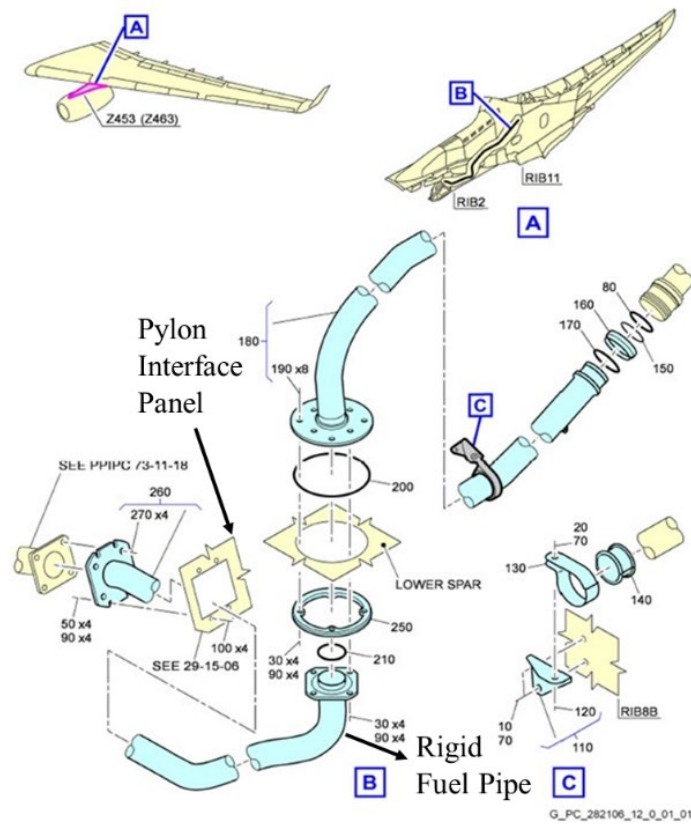


Figure 16- Revised DAL A330-300/PW4168 IPC Figure

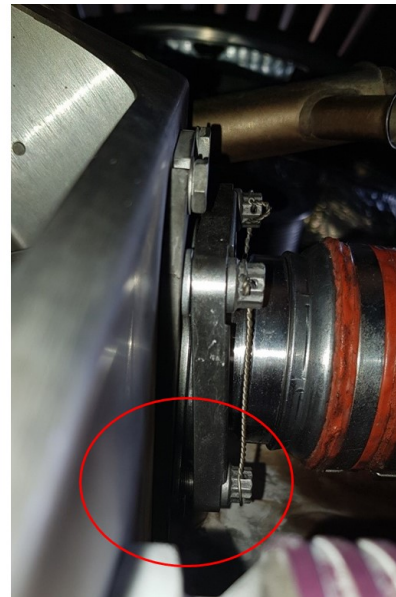


Photo 58- FM-13 Hose Upper Flange Installation Error Finding During DAL Fleet Inspection

13.2 Airbus Corrective Actions

Airbus reviewed the Airbus A330-300/PW4168 AMM and AIPC manuals and also identified that the rigid fuel pipe installation position on the pylon hydraulic interface panel was depicted incorrectly in several figures (**Figure 18**). The applicable figures were revised to show the correct installation in accordance with the Airbus drawings (**Figure 19**).

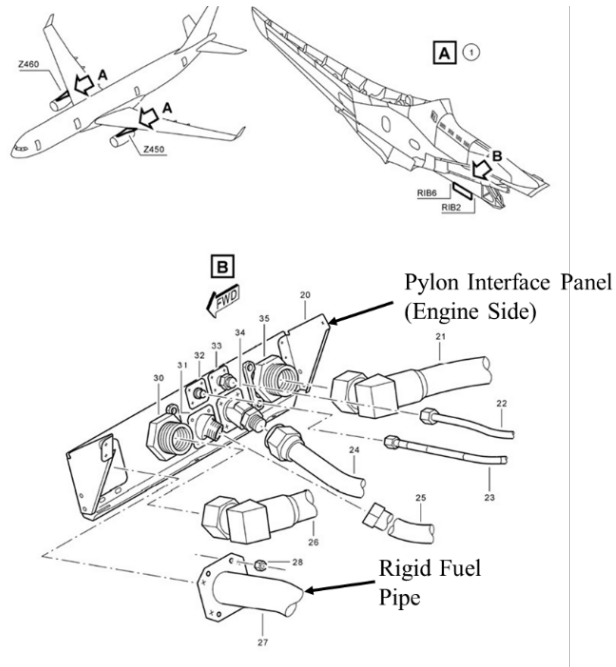


Figure 17- Original Airbus A330-300/PW4168 AMM Figure

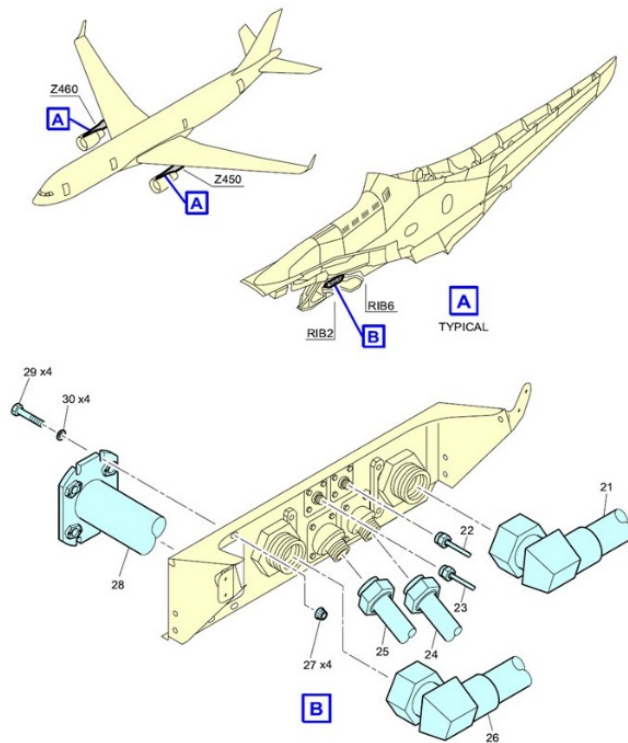


Figure 18- Revised Airbus A330-300/PW4168 AMM Figure

Robert Hunsberger
NTSB
Aerospace Engineer- Powerplants