Aviation Investigation Final Report

Location:	Seattle, Washington	**Incident Number:**	ENG17IA003
Date & Time:	October 26, 2016, 15:50 Local	**Registration:**	N855NW
Aircraft:	Airbus A330 223	**Aircraft Damage:**	None
Defining Event:	Powerplant sys/comp malf/fail	**Injuries:**	120 None
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

The No. 1 engine fire was caused by a fuel leak that originated from a high cycle fatigue crack on the fuel nozzle No. 1 fuel manifold supply line. Fuel nozzle No. 1 is located at the 12 o'clock position on the engine, so the fuel that leaked from the crack ran down the diffuser case and ignited on the engine case surface. The diffuser case reaches high enough temperatures during engine operation to auto-ignite Jet A fuel. The greatest concentration of soot/discoloration was observed from the 6 to 9 o'clock positions between the forward flange of the HPT case to the aft flange of the diffuser case, consistent with fuel collecting at the bottom of the engine and in the lower half of the thrust reverser cowls and creating a rich fuel to air mixture.

Engine vibration testing was performed on multiple PW4000-94 and -100 inch series fan engines featuring a TALON II combustor. The testing identified a combustor tone that excites a natural (resonant) frequency in the fuel manifold assemblies. The amplitude of the combustor tone varied significantly between the four engines tested and the reason for this variation has not yet been determined.

Pratt & Whitney released service bulletins for both the PW4000-94 inch and -100 inch fan engines recommending the installation of brackets and clamps on the fuel manifold assemblies. Engine vibration testing was performed on the same engine before and after installation of the brackets and clamps and the testing confirmed that the design was effective in dampening the elevated vibration levels driven by the combustor tone.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be: A No. 1 engine fire caused by a fuel manifold supply line high cycle fatigue crack which led to a

fuel leak that subsequently ignited on hot engine case surfaces. The fatigue crack originated and progressed due to elevated fuel manifold assembly vibration levels. Engine vibration testing identified a combustor tone that excites a natural (resonant) frequency of the fuel manifolds at specific engine speeds on Pratt & Whitney PW4000-94 and -100 inch fan series engines that feature a TALON II combustor.

Findings

Aircraft	Fuel distribution - Failure

Factual Information

History of Flight

Initial climb	Powerplant sys/comp malf/fail (Defining event)
Initial climb	Fire/smoke (non-impact)

HISTORY OF FLIGHT

On October 26, 2016, at about 1550 Pacific daylight time, a Delta Air Lines (DAL) Airbus A330-223, N855NW, equipped with two Pratt & Whitney (P&W) PW4168A-1D turbofan engines experienced a No. 1 (left) engine fire during initial climb from Seattle-Tacoma International Airport (SEA), Seattle, Washington. The flight crew declared an emergency, discharged both fire bottles, and returned to SEA for an uneventful overweight single engine landing. The electronic centralized aircraft monitor (ECAM) system fire indication warning remained illuminated on the cockpit display after both fire bottles were discharged. Airport rescue and firefighting (ARFF) crews met the airplane on the runway and did not observe fire or smoke coming from the engine. Water was sprayed on the airplane landing gear as a precautionary measure, but no water or fire retardants were sprayed on/into the No. 1 engine. There were no passenger or crew member injuries reported. The flight was a regularly scheduled flight from SEA to Hong Kong International Airport (HKG), Chep Lap Kok, Hong Kong and was conducted under the provisions of Title 14 *Code of Federal Regulations* Part 121.

DAMAGE TO THE AIRPLANE

There was no damage to the airplane structure. The left engine thrust reverser exhibited thermal damage and discoloration on all interior surfaces, most concentrated near the 6 o'clock position. The thrust reverser fire loops were thermally damaged and multiple fire loop rubber grommets were deformed or missing.

TEST AND RESEARCH

Engine Examination and Disassembly

The No. 1 engine was removed from the airplane by maintenance crews at SEA and prepared for shipment to Delta TechOps in Atlanta, Georgia for examination and partial disassembly. The engine was sooted/discolored from the 5 o'clock to 12:30 positions, between the fan case and exhaust case. The soot/discoloration was most concentrated from the 6 to 9 o'clock positions between the forward flange of the high pressure turbine (HPT) case and the aft flange of the diffuser case. Clamps, wiring harness cables, and the electrical power cables (feeder cables) exhibited thermal damage. Localized soot/discoloration was observed at the 12 o'clock position on the diffuser case, adjacent to fuel nozzle No. 1. Immediately above the area of localized sooting, the middle of three pressure regulating valve pneumatic lines exhibited burn through.

Fuel System Pneumatic Leak Check

Each fuel nozzle was individually numbered and photographed. All engine case openings that were exposed during removal of external engine components were covered with tape. The fuel flow transmitter was removed and pressurized shop air (~120 pounds per square inch (psi)) was ported into the supply side of the fuel distribution valve in accordance with the engine maintenance manual. An air leak was detected coming from the fuel manifold supply line that feeds fuel nozzle No. 1, located at the 12 o'clock position. Fuel nozzle No. 1 and the attached fuel manifold supply line were cleaned, and a fine crack was observed on the manifold supply line near the nozzle braze joint. A second pressure check was completed after each fuel manifold and nozzle assembly was cleaned with isopropyl alcohol with no additional findings.

Recorded Data

The digital flight data recorder (DFDR) and electronic engine control (EEC) files were downloaded and reviewed. The only anomaly observed during the incident flight was an increase in the exhaust gas temperature (EGT) reading shortly after the No. 1 engine fire warning indication. According to P&W Flight Safety, there are several historical cases where EGT readings have increased due to an undercowl fire (external to the engine) in proximity to the EGT probes.

Materials Laboratory Analysis

The fuel manifold supply line that supplies fuel nozzle No. 1 was cut several inches away from the supply line-to-nozzle elbow braze joint to facilitate removal of the nozzle from the engine case. The nozzle and manifold supply line were shipped to the P&W materials laboratory in East Hartford, Connecticut as an assembly with the fuel nozzle b-nut torqued in the same condition as when it was removed from the engine. The remaining section of the fuel manifold triplet assembly was also shipped with fuel nozzles No. 2 and No. 3 removed.

A visual and binocular examination identified a crack that originated from the run out of the braze fillet around the toe of a ball tack weld (**Figure 1**). Scanning electron microscopy was used to examine the crack surface features and they were consistent with high cycle fatigue (HCF). There were no defects or material damage on the manifold supply line near the crack origin. A test of the manifold supply line material confirmed the material met drawing specification. The braze joint where the manifold supply line joins the elbow fitting had sufficient coverage and no voids in the braze material were observed. A complete copy of the materials laboratory report is available in the docket under the title "Pratt & Whitney Materials & Processes Engineering Metallurgical Investigation of Fuel Triplet and Fuel Nozzle from PW4168 Engine P733619**."**

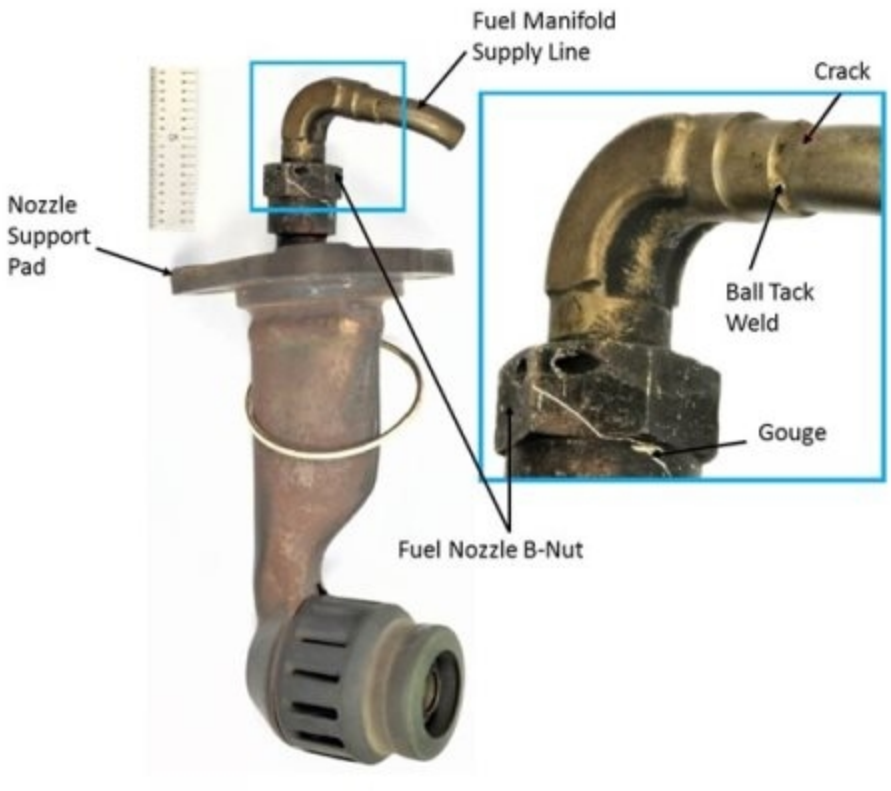

Figure 1- Fuel Nozzle No. 1 and Fuel Manifold Supply Line Section

Engine Vibration Testing

Between July 2017 and November 2017, P&W performed vibration testing on two PW4000-100 inch fan engines and two PW4000-94 inch fan engines with TALON (**T**echnology for **A**dvanced **Lo**w **N**Ox) II combustors at P&W's Eagle Services Asia (ESA) facility in Singapore. One of the PW4000-94 inch fan engines had experienced three prior fuel leak events due to fuel manifold cracks. The other three engines tested had no history of fuel leaks. The testing identified an acoustic tone created by the combustor during engine operation that excites a dynamic (resonant) response in the fuel manifold assembly. The amplitude of the vibratory response at the fuel manifolds varied between engines but was present at the same frequency on all engines tested. One engine was tested to correlate the combustor tone/resonant frequency to an engine speed range. The combustor tone peaked near the end of a 5 second snap acceleration (rapid increase in throttle position from idle to a designated high power setting) and then decreased when the engine was allowed to dwell at the higher speed. According to the tests, the tone that excites the resonant response in the fuel manifold assemblies occurs between 9,000 revolution per minute (RPM) (86% low pressure rotor speed (N2)) and 10,000 RPM (95.6% N2).

ADDITIONAL INFORMATION

Eagle Services Asia Engine Teardown

The incident engine was shipped to ESA Singapore after it was released from the investigation for disassembly and parts evaluation as part of the normal repair process. The NTSB requested a copy of the

engine teardown findings report. ESA did not identify any engine anomalies that may have contributed to the engine fire and the condition of all internal components, including the combustor and diffuser assemblies were consistent with similar service run engines.

Engine Build Audit

At the request of the NTSB, an announced build audit of a PW4000-100 inch fan engine diffuser and combustor assembly build was conducted at ESA in March 2018. During the assembly process, there were no deviations from the engine assembly manual procedures observed and both the part numbers and condition of all parts used met manual specifications.

Corrective Action

On November 8, 2017, P&W released SB PW4ENG-73-224 recommending the installation of fuel manifold brackets and clamps on PW4000-94 inch fan engines with TALON II combustors. The FAA issued AD 2019-06-02 on March 26, 2019 to mandate the SB. The AD has the same compliance requirements as those recommended in the SB and the AD effective date was April 30, 2019. Additional information about SB and AD scope and compliance is included in the NTSB powerplants group chairman's factual report in the docket.

On March 14, 2018, P&W released service bulletin (SB) PW4G-A73-48 recommending the installation of brackets and clamps on the fuel manifold assemblies to dampen the resonant vibratory response to a combustor tone on PW4000-100 inch fan engines with TALON II combustors. The FAA mandated the installation of the fuel manifold brackets and clamps with airworthiness directive (AD)-2019-06-07 on March 28, 2019.

Information

Certificate:	**Age:**
Airplane Rating(s):	**Seat Occupied:**
Other Aircraft Rating(s):	**Restraint Used:**
Instrument Rating(s):	**Second Pilot Present:**
Instructor Rating(s):	**Toxicology Performed:**
Medical Certification:	**Last FAA Medical Exam:**
Occupational Pilot:	**Last Flight Review or Equivalent:**
Flight Time:	

Aircraft and Owner/Operator Information

Aircraft Make:	Airbus	**Registration:**	N855NW
Model/Series:	A330 223 223	**Aircraft Category:**	Airplane
Year of Manufacture:	2004	**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	0621
Landing Gear Type:	Retractable - Tricycle	**Seats:**	
Date/Type of Last Inspection:	Unknown	**Certified Max Gross Wt.:**	513676 lbs
Time Since Last Inspection:		**Engines:**	2 Turbo fan
Airframe Total Time:		**Engine Manufacturer:**	Pratt & Whitney
ELT:	Installed	**Engine Model/Series:**	PW4168A-1D
Registered Owner:	DELTA AIR LINES INC	**Rated Power:**	59357
Operator:	DELTA AIR LINES INC	**Operating Certificate(s) Held:**	Flag carrier (121)

Meteorological Information and Flight Plan

Conditions at Accident Site:	Unknown	**Condition of Light:**	Day
Observation Facility, Elevation:	SEA,433 ft msl	**Distance from Accident Site:**	0 Nautical Miles
Observation Time:	22:53 Local	**Direction from Accident Site:**	
Lowest Cloud Condition:	Few / 2700 ft AGL	**Visibility**	10 miles
Lowest Ceiling:	Broken / 3200 ft AGL	**Visibility (RVR):**	
Wind Speed/Gusts:	3 knots /	**Turbulence Type Forecast/Actual:**	/
Wind Direction:	190°	**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	29.79 inches Hg	**Temperature/Dew Point:**	14°C / 12°C
Precipitation and Obscuration:			
Departure Point:	Seattle, WA (SEA)	**Type of Flight Plan Filed:**	
Destination:	(HKG)	**Type of Clearance:**	Unknown
Departure Time:	15:50 Local	**Type of Airspace:**	Unknown

Airport Information

Airport:	Seattle-Tacoma Intl SEA	**Runway Surface Type:**	
Airport Elevation:	432 ft msl	**Runway Surface Condition:**	Unknown
Runway Used:		**IFR Approach:**	Unknown
Runway Length/Width:		**VFR Approach/Landing:**	Unknown

Wreckage and Impact Information

Crew Injuries:	12 None	**Aircraft Damage:**	None
Passenger Injuries:	108 None	**Aircraft Fire:**	In-flight
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	120 None	**Latitude, Longitude:**	47.447223,-122.314163(est)

Administrative Information

Investigator In Charge (IIC):	Hunsberger, Robert
Additional Participating Persons:	Shannon Masters; Delta Air Lines; Atlanta, GA Ryan Kennedy; Delta Air Lines; Atlanta, GA John S Koza; Pratt & Whitney; East Hartford, CT
Original Publish Date:	September 30, 2019
Last Revision Date:	
Investigation Class:	Class
Note:	The NTSB did not travel to the scene of this incident.
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=94306