Aviation Investigation Final Report

Location:	Tokyo,	**Incident Number:**	ENG17IA026
Date & Time:	June 7, 2017, 09:50 UTC	**Registration:**	N668US
Aircraft:	Boeing 747 451	**Aircraft Damage:**	None
Defining Event:	Loss of engine power (total)	**Injuries:**	326 None
Flight Conducted Under:	Part 121: Air carrier - Scheduled		

Analysis

The disassembly and examination of the engine revealed a 5th stage compressor blade was fractured transversely across the airfoil directly above the blade root platform. Unfortunately, that fractured blade was lost during the shipment of the engine parts from Delta Air Lines to P&W's Material and Processes Engineering Laboratory. However, the similarity of the elliptical-shaped fracture surface on that 5th stage compressor blade to the elliptical-shaped fracture surfaces on 6th, 7th, 8th, and 9th compressor blades that were confirmed as fatigue fractures would indicate the 5th stage compressor blade also fractured due to a fatigue crack. The PN 5th stage blade that fractured in this engine and the compressor blade that it had superseded had a combined total of 38 airfoil fractures that would suggest some subtle interrelationship that would cause a resonance leading to a fracture. A detailed examination of the HPC did not identify anything that could have triggered an airflow disturbance. The fractured blade 5th stage compressor blade was subsequently superseded with a new blade in 2011 that has not experienced any fractures suggesting that whatever was causing the fractures was designed out.

The engine's turbine sections sustained extensive thermal and mechanical damage. When the 5th stage compressor blade fractured, the cascade of damage through the HPC disabled the compressor's ability to pump air. The FDR showed that following the loss of power after the 5th stage compressor blade fractured, the fuel flow dropped to zero but then recovered to a sub idle level probably from the electronic control's auto relight feature activating the igniter plugs. Although the fuel flow was less than what was seen when the airplane taxied out for departure, with little to no airflow through the engine, the combustion flame would stagnate around the turbine vanes and blades burning off the early stages and the liberated pieces causing the mechanical damage to the trailing stages.

This incident was initially reported as an uncontained event because of the 360° circumferential split in the LPT case. The examination of the split showed that the edges were not pursed outward indicating there was not a ballistic challenge of liberated blade to the case. The examination of the LPT case showed that the case's walls were not bulged radially outward indicating that there was not a ball up of material whirling around the case. The examination did show that the edges of the cut in the case matched the edges of the circumferential breaks in the 6th stage blade outer airseal segments that both matched the geometry of the 6th stage blade tip shroud indicating that a tip shroud was dragged around by one of the near full length blades as the engine wind milled during the return to NRT. So although the LPT case was cut in half, this was not an uncontained event.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be:

The PW4056 engine lost power due to the fatigue fracture of a 5th stage compressor blade. The cause of the fatigue fracture could not be determined.

Findings

Aircraft	Compressor section - Fatigue/wear/corrosion

Factual Information

History of Flight

Enroute-cruise	Loss of engine power (total) (Defining event)

HISTORY OF FLIGHT

On June 7, 2017, about 0950 universal coordinated time, Delta Air Lines flight 276, a Boeing 747-451 airplane, N668US, experienced a loss of power from the No. 1 engine, a Pratt & Whitney (P&W) PW4056, while in cruise flight over the Pacific Ocean northeast of Japan. The pilots reported that the airplane was level at FL 320 on the G344 airway between the CUTEE and CARTO waypoints when there was a sudden thump and the airplane yawed to the left. The pilots further reported that following the thump; the No. 1 engine's EPR [engine pressure ratio] and N1 were decreasing, the EGT [exhaust gas temperature] was increasing, and the oil quantity indicated about 9 quarts. The airplane was stabilized with the rudder and as the engine's EGT limit was reached, the engine's thrust lever was retarded to idle. The Engine Failure Checklist was accomplished and the VNAV drift down procedure was initiated while turning 45° off track to the right. The pilots declared an emergency and the airplane descended to FL 280. After consulting with Delta Air Lines' dispatch and maintenance at Atlanta, Georgia, it was determined that the airplane would divert back to Tokyo Narita International Airport (NRT), Tokyo, Japan. The pilots reported that about 30 minutes prior to landing, they jettisoned fuel to reduce the airplane's weight to below the maximum landing weight. The airplane landed at NRT without further incident. The airplane was operating on an instrument flight rules flight plan under the provisions of 14 *Code of Federal Regulations (CFR)* Part 121 as a regularly scheduled international flight from NRT to Detroit Metropolitan Wayne County International Airport, Detroit Michigan.

INJURIES (OR SURVIVAL ASPECTS OR MEDICAL AND PATHOLOGICAL INFORMATION)

There were no injuries to the 4 pilots, 13 flight attendants and 309 passengers on board.

PERSONNEL INFORMATION

The captain, age 61, held an Air Transport Pilot certificate with airplane single-engine land, airplane single-engine sea, airplane multi-engine land, and airplane instrument ratings. The captain was type rated in the Boeing 747-400 airplane as well as the Boeing 737 and 747 airplanes. The captain held an FAA first class medical certificate that was dated March 21, 2017, with no reported limitations. The captain's most recent proficiency check was dated December 14, 2016, and was accomplished in a Boeing 747-400 airplane. The captain's reported flight time was 11,528 hours with 6,082 hours in the Boeing 747-400 airplane and 227 hours in the previous 90 days. The captain occupied the left seat and was the pilot flying.

The first officer (FO), age 59, held an Air Transport Pilot certificate with airplane single-engine land, multi-engine land, and airplane instrument ratings. The FO was type rated in the Boeing 747-400 airplane as well as the Boeing 737 and McDonnell Douglas DC-9 airplanes. The FO held an FAA first

class medical certificate that was dated February 11, 2017, with no reported limitations. The FO's most recent proficiency check was dated November 10, 2016, and was accomplished in a Boeing 747-400 airplane. The FO's reported flight time was 19,591 hours with 507 hours being in the Boeing 747-400 airplane and 209 hours in the previous 90 days. The FO occupied the right seat and was the pilot monitoring.

AIRCRAFT INFORMATION

The airplane was a Boeing 747-451, serial number (SN) 24223, registered as N668US, and operated by Delta Air Lines. The Boeing 747-451 airplane is a four-engine transport category airplane. The airplane has a maximum takeoff gross weight of 870,000 pound. The airplane was loaded with 48,808 gallons of Jet A-1 fuel. The airplane was manufactured in 1990 and was originally delivered to Northwest Airlines. Delta Air Lines acquired the airplane in the merger with Northwest Airlines. According to Delta Air Lines records, at the time of the incident, the airplane had accumulated 113,100 hours of flying time.

The No. 1 engine was a P&W PW4056, SN P717513. The PW4056 is a dual-spool, axial-flow, high-bypass turbofan engine that features a 1-stage 94-inch diameter fan, a 4-stage low-pressure compressor (LPC), an 11-stage high-pressure compressor (HPC), annular combustor, a 2-stage high-pressure turbine (HPT) that drives the HPC, and 4-stage low-pressure turbine (LPT) that drives the fan and LPC. The PW4056 engine has a takeoff thrust rating of 56,750 pounds, flat-rated to 92°F (33°C). When the PW4046 engine is installed on a Boeing 747 airplane, it has a maximum continuous thrust rating of 47,970 pounds, flat-rated to 86°F (30°C). The PW4056 engine can also be installed on a Boeing 767 airplane where it has a maximum continuous thrust rating of 49,350 pounds, flat-rated to 77°F (25°C). According to Delta Air Lines' maintenance records, engine P717513 had accumulated 82,303 hours and 10,645 cycles since new and 5,446 hours and 600 cycles since the last overhaul. The engine's last overhaul was accomplished in May 2014 at Delta's TechOps facility. Delta's records show that the engine had been installed on the airplane on November 30, 2016. Delta's records also show that the engine had been previously installed on and removed from two other airplanes that had been retired from service.

FLIGHT RECORDERS

The airplane was equipped with a cockpit voice recorder (CVR) and a digital flight data recorder (DFDR). The DFDR was returned to the NTSB's Recorder Laboratory for readout. The CVR was not removed from the airplane for readout because of the elapsed time from when the event occurred to when the airplane landed at NRT would have resulted in the event being overwritten.

From the time the airplane departed NRT up until just prior to the incident, the four engines' N2 rpm, EPR, EGT, and Wf [fuel flow] were evenly matched. The vibration levels on the No. 1 engine were slightly lower than the other three engines.

At subframe reference number (SRN) 180253, the No. 1 engine's EPR, N2, EGT, and Wf were 1.29, 91 percent, 410°C, and 6,944 pounds per hour (pph), respectively. The No. 1 engine's throttle resolver angle (TRA) was 58.89°. Concurrently, the EPR, N2, EGT, and Wf for the Nos. 2, 3, and 4 engines were as follows: No. 2: EPR – 1.29, N2 – 92 percent, EGT - 431°C, Wf – 7,136 pph; No. 3: EPR – 1.29, N2 – 92 percent, EGT - 415°, Wf – 6,944 pph; and No. 4: EPR – 1.29, N2 – 91 percent, EGT - 447°C, and Wf – 7,008 pph. The EPR commanded was 1.29.

At SRN 180254, the No. 1 engine's EPR had decreased to 0.76, N2 had decreased to 86 percent, the EGT had increased to 418°C, Wf had decreased to 6,400 pph, and the TRA remained at 58.89°. Between SRN 180254 and SRN 180263, the EPR decreased from 0.76 to 0.66, N2 decreased from 86 to 66 percent, the EGT increased from 418 to 591°C, Wf had decreased from 6,400 pph to zero, and the TRA increased from 58.89 to 60.29°.

Between SRN 180269 and 180281, the Wf indication alternated between zero and 576 pph. During this time period, the EGT increased from 591 to 609°C.

Between SRN 180282 and 180371, the Wf varied from 576 pph down to a low of 512 pph to a high of 608 pph and back down to 544 pph. During the same time period, the EGT initially decreased from 605 to 566°C and then increased to 751°C, the EPR was steady at 0.65, and the N2 varied between 43 and 47 percent. Also within this same time period, from SRN 180282 to 180312, the TRA increased from 67.15 to 71.63° and the commanded EPR increased from 1.37 to 1.54.

Between SRN 180325 and 180337, the TRA changed from 71.63 to 33.4° where it essentially remained for the duration of the recording.

At SRN 180370, the No. 1 engine's fuel cutoff parameter changed from Run to Cutoff. The Wf decreased to zero and remained at zero for the duration of the recording. The EGT had reached a maximum of 751°C and then decreased for the duration of the recording.

DAMAGE TO AIRPLANE (WRECKAGE AND IMPACT INFORMATION)

There was no damage to the airplane. The No. 1 engine's outboard (left) and inboard (right) core cowls had minor impact damage to the interior surfaces. The inboard core cowl had two small splits in the skin that were coincident to impact damage on the interior surface although it did not appear that any debris passed through the split.

FIRE

There was no fire.

TESTS AND RESEARCH

The engine was removed from the airplane at NRT and sent to Delta Air Lines' TechOps engine maintenance facility in Atlanta for disassembly and examination by the Powerplants Group. The disassembly of the engine revealed extensive damage through the HPC, HPT, and LPT. In addition, the LPT case had a 360° split in line with the 6th stage turbine rotor.

The initial examination of the HPC revealed that all of the HPC airfoils, from the 5th to the 15th stage, were damaged with nicks, dents, and tears to the leading and trailing edges and/or were broken off at various lengths above the blade root platforms. There was one 5th stage compressor blade that was fractured transversely across the airfoil adjacent to the blade root platform and had an elliptical-shaped pattern on the fracture surface that radiated from the convex side of the airfoil. There were many 6th, 7th, 8th, and 9th stage compressor blades that were fractured transversely across the airfoils adjacent to the blade root platforms and many of those blades had elliptical-shaped patterns on the fracture surfaces that radiated mostly from the convex side of the airfoil. The disassembly of the HPC also revealed two

variable inlet guide vanes (IGV) that were missing and the airfoils were fractured adjacent to the outer button. The 5th through 9th stage compressor blades and the two variable IGVs were removed from the engine and sent to P&W's Material and Processes Engineering Laboratory for metallurgical examination. The 5th stage compressor with the elliptical-shaped pattern on the fracture surface was lost during the shipment between Delta and P&W. The examination of the remaining 5th stage compressor blades revealed fracture surfaces that were consistent with overload or were too smeared and damaged to be able make an assessment of the fracture surface. However, the examination of the 6th through 9th stage compressor blades with the elliptical-shaped pattern showed that those patterns were fatigue fractures. The examination of the two variable IGVs revealed fracture surfaces that were consistent with overload. Because of the large number of HPC blades with fatigue cracks, the Powerplants Group made a more extensive examination of the LPC and HPC to look for something that may have caused the fatigue cracking but nothing was found.

The HPT and LPT also had extensive damage. The HPT, both stage 1 and 2, had the tips of all of the airfoils missing. The stage 1 blade tips appeared to have been burned off and the stage 2 blade tips appeared to have been broken off. The 3rd stage turbine vanes, the first stage in the LPT, had an arc between about 5 and 7 o'clock, where the airfoils were burned out and the remaining airfoils were thermally damaged. The 4th stage turbine vanes had an arc between about 4 and 8 o'clock where the airfoils were missing and appeared to have been broken out. All of the LPT blades, stages 4 through 6, were in place, but all were damaged with nicks, dents, and being broken at various lengths above the blade root platform. There were some 6th stage turbine blade that were almost full length.

The examination of the engine revealed the LPT case had a 360° split in line with the 6th stage turbine rotor. The LPT case did not have areas were the edges of the split were pursed radially outward nor was the case bulged outward. In addition to the LPT case being split, the 6th stage blade outer airseal segments (BOAS) were broken up circumferentially as well as axially. The edges of the split in the LPT case matched the edges of the circumferential breaks in the 6th stage BOAS that matched the shape of the 6th stage turbine blade tip shroud.

HPC 5TH STAGE COMPRESSOR BLADE HISTORY

The PW4000 94-inch fan engine has had a long history of 5th stage compressor blade fractures. The fractured 5th stage compressor blade was part number (PN) 58H305. According to P&W, the PN 58H305 blade has had 16 airfoil fractures. The PN 58H305 blade superseded another part numbered blade that had 22 airfoil fractures. The PN 58H305 was itself superseded by the PN 50S805 blade in 2011 that according to P&W has not yet had a reported blade fracture.

The PN 58H305 blade as well as the superseded blade has also had a number of blade root fractures. Although the PW4000 94-inch engine has had a number of 5th stage compressor blade fractures in the airfoil and root, only one was reportable to the NTSB in accordance with 49 *CFR* 830.5 and subsequently investigated. That incident involved a Delta Air Lines Boeing 747-451 airplane that had a 5th compressor blade, which was a PN 58H305 blade, fracture through the root shank during take off from Atlanta. (Reference: ENG14IA027) The resultant vibration following the blade fracture loosened the B-nut on a hydraulic line causing a leak and leaking the hydraulic fluid ignited off of the hot engine cases. The blade fractured from a fatigue crack that was caused by the improper grit blasting of the blade's root shank during the overhaul of the blade by a repair vendor.

ADDITIONAL INFORMATION

On the PW4000 engine as with many other engine models, the LPT case is removed as a package with the turbine exhaust case. With the LPT case split 360° around in line with the 6th stage turbine rotor that is just forward of the LPT case rear flange, it would not possible to remove the LPT module. In order to remove the LPT module, it was necessary to weld eight straps between the front and rear portions of the LPT case to hold them together when the turbine exhaust case and LPT case were removed from the engine.

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:	Boeing	**Registration:**	N668US
Model/Series:	747 451 451	**Aircraft Category:**	Airplane
Year of Manufacture:	1990	**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	24223
Landing Gear Type:	Tricycle	**Seats:**	403
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	870000 lbs
Time Since Last Inspection:		**Engines:**	4 Turbo fan
Airframe Total Time:		**Engine Manufacturer:**	P&W
ELT:	Installed	**Engine Model/Series:**	PW4000 SER
Registered Owner:		**Rated Power:**	24900 Horsepower
Operator:		**Operating Certificate(s) Held:**	Flag carrier (121)

Meteorological Information and Flight Plan

Conditions at Accident Site:	Unknown	**Condition of Light:**	Not reported
Observation Facility, Elevation:		**Distance from Accident Site:**	
Observation Time:		**Direction from Accident Site:**	
Lowest Cloud Condition:		**Visibility**	
Lowest Ceiling:		**Visibility (RVR):**	
Wind Speed/Gusts:	/	**Turbulence Type Forecast/Actual:**	/
Wind Direction:		**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:		**Temperature/Dew Point:**	
Precipitation and Obscuration:			
Departure Point:	Tokyo	**Type of Flight Plan Filed:**	IFR
Destination:	Detroit, MI (KDTW)	**Type of Clearance:**	IFR
Departure Time:		**Type of Airspace:**	Unknown

Wreckage and Impact Information

Crew Injuries:	17 None	**Aircraft Damage:**	None
Passenger Injuries:	309 None	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	326 None	**Latitude, Longitude:**	35.771945,140.392776(est)

Administrative Information

Investigator In Charge (IIC):	Hookey, Gordon
Additional Participating Persons:	David Gerlach; Federal Aviation Administration; Washington,, DC Jo-Ann Theriault; Federal Aviation Administration; Burlington, MA Joshua Migdal; Delta Air Lines; Atlanta, GA David Shinsky; Delta Air Lines; Atlanta, GA Van Winters; Boeing; Seattle, WA Douglas Zabawa; Pratt & Whitney; East Hartford, CT Stephen Yee; Pratt & Whitney; East Hartford, CT Jeffrey Strasbaugh; Pratt & Whitney; East Hartford, CT Jeffrey Wait; Air Line Pilots Association; Herndon, VA
Original Publish Date:	September 15, 2020
Note:	The NTSB did not travel to the scene of this incident.
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=95320