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

December 21, 2010

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: ENG08IA038

A: INCIDENT

Location:	McCarran International Airport, Las Vegas, Nevada
Date:	August 6, 2008
Time:	15:40 Pacific daylight time
Aircraft:	Boeing 757-232, N666DN, Delta Air Lines, Flight 624

B: POWERPLANTS GROUP

Group Chairman:	Gordon J. Hookey National Transportation Safety Board Washington, D.C.
Member:	Harry Reichel National Transportation Safety Board Washington, D.C.
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Member:	Paul Terjak Boeing Seattle, Washington
Member:	Douglas Zabawa Pratt & Whitney East Hartford, Connecticut
Member:	James Peretto Pratt & Whitney East Hartford, Connecticut
Member:	Peter S. Frey Air Line Pilots Association Danbury, Connecticut

C: SUMMARY

On August 6, 2008, at about 15:40 Pacific daylight time, Delta Air Lines flight 624, a Boeing 757-232 airplane, N666DN, equipped with Pratt & Whitney (P&W) PW2037 engines, experienced an uncontained release of high pressure turbine (HPT) material from the right (No. 2) engine as the power was increased at the start of the takeoff roll at the McCarran International Airport (LAS), Las Vegas, Nevada. The captain stated that at the start of the takeoff roll, they heard a loud bang and they observed that the right engine had lost power and that the right engine fire warning had illuminated. The captain further stated that they stopped the airplane on the runway and shut down the right engine. The captain stated that the fire warning light went out when they shut down the engine, so they did not discharge a fire bottle into the engine's nacelle. The captain also stated that they declared an emergency and requested the airport fire department personnel inspect the engine. The airport fire department personnel stated that they observed a hole in the bottom of the right engine's nacelle and that there was a glow inside the nacelle. The airport fire department personnel further stated that they discharged a hand-held fire bottle into the nacelle through the open pressure relief doors. After the airport fire department personnel determined that there was no fire, the airplane was allowed to taxi to the gate and the passengers and crew deplaned normally. 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 flight from LAS to John F. Kennedy International Airport, Jamaica, New York. The 2 pilots, 4 flight attendants, and 166 passengers on board were not injured.

The examination of the airplane revealed a hole in the bottom of the right engine's core cowl, but there was no other damage noted to the airplane. The examination of the engine revealed a hole in the HPT and low pressure turbine (LPT) cases at the adjoining case flanges.

The engine was removed from the airplane and shipped to Delta Air Lines' Technical Operations Center (TOC), Atlanta, Georgia for disassembly and examination. On August 25 to 28, 2008, the engine was disassembled and examined in the presence of the Powerplants Group. The examination of the engine's 2nd stage turbine hub revealed that there were portions of five adjacent blade retaining lugs that were fractured and missing from the hub. There were three 2nd stage turbine blades associated with the fractured blade retaining lugs that were fractured transversely through their respective blade root fir tree attachments and a fourth adjacent 2nd stage turbine blade was missing completely. The metallurgical examination of the fractured lugs revealed fatigue fractures that had started from the base of the fir trees' middle serration. The metallurgical examination also revealed the material conformed to the material requirements.

The visual examination of the 2nd stage turbine hub's blade slots revealed varying contact patterns. A subsequent dimensional inspection revealed that incident hub's diametrical features conformed to the engineering drawing, but that the full length of the blade slots were missing some material. P&W conducted tests that demonstrated aggressive grit blasting using the 500 grit media that is used to clean hubs prior to inspection could cause excessive material removal.

D: DETAILS OF INVESTIGATION

1.0 Engine information

1.1 Engine description

The PW2037 is a dual-spool, axial-flow, high-bypass turbofan engine that features a 1-stage fan, 4-stage low pressure compressor (LPC), 12-stage high pressure compressor (HPC), annular combustor, 2-stage HPT, and a 5-stage LPT. The engine has a takeoff thrust rating of 37,530 pounds, flat-rated to 87°F [Fahrenheit].[1]

1.2 Engine operating history

The right engine on Delta Air Lines' Boeing 757-232 airplane N666DN was a P&W PW2037, serial number (SN) 728705. According to Delta Air Lines' maintenance records, the engine had accumulated 21,378.5 hours time since new (TSN) and 9,091 cycles since new (CSN) and 10,880.7 hours and 4,392 cycles since the last heavy maintenance.

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

2.0 On scene examination

2.1 Airplane

Members of the Powerplants Group examined the airplane on the day after the incident. The examination of the airplane did not reveal any damage to the fuselage, landing gear, or opposite engine.

2.2 Right engine

The right engine was in place on the strut. There was no apparent damage to the forward engine mount including the two thrust links, intermediate case clevises, and mount beam. There was also no apparent damage to the rear mount including the turbine exhaust case mount rails, mount links, and mount beam.

The engine nacelle, which included the inlet cowl, thrust reverser, core cowl, and exhaust nozzle, was still in place. According to Delta maintenance personnel, who responded to the airplane while it was still on the runway after the fire department had determined that there was no fire, the core cowl doors were still closed and latched. The core cowl door latch hooks were intact. The Delta maintenance personnel reported that when they initially arrived at the airplane, the two over-pressurization doors on the core cowl were open. The right engine's left hand core cowl had a hole on the lower left side.[2] Refer to Section 10.9 for specific details on the size of the hole and other damage that was noted to the core cowl. There was a white powdery residue on the inside surface of the lower half of both thrust reverser doors.[3]

Refer to Sections 3.0 and 4.0 for the examination of the 2nd stage turbine hub and blades, respectively. Refer to Sections 6.0 and 10.0 for the examination of the remainder of the HPT and engine, respectively.

2.3 Airport property

The airplane was departing from LAS Runway 25 Right (R) when the incident occurred. (Refer to Attachment 1.) A LAS operations agent, who was on duty and on the airfield at the time of the incident, witnessed the event. He stated that he observed a flash of fire just as the airplane was passing taxiway Alpha 2. The operations agent further stated that the airplane stopped on the runway shortly after he observed the flash. The debris that was found on the runway was collected and provided to the investigation team. The identifiable pieces of debris collected from the runway included a piece of the LPT active clearance control[4] (ACC) tubing, HPT blade outer air seal fragments, HPT blade airfoil fragments, nuts and bolt heads, four pieces

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[2] All references to location on the engine or to position or directions as referenced to the clock will be as viewed from the rear, looking forward, unless otherwise specified.

[3] Airport fire department personnel stated that they discharged a hand-held fire bottle into the nacelle through one of the open pressure relief doors after they noted a "glow" inside the engine.

[4] The active clearance control system provides air to externally cool the turbine cases to minimize the thermal growth of the cases that reduces the gaspath leakage between the turbine blade tips and turbine case air seals to improve an engine's fuel efficiency.

of intact second stage turbine blade outer air seal supports (one of which was identifiable by part number (PN)), one piece of HPT blade root that included a partial airfoil and outer two serrations of the fir tree that included a part number, and four disk lug fragments. The four disk lug fragments consisted of the outer two serrations of the fir tree attachment and did not have any identifying markings.

The east end of the area bounded by Runway 25R and taxiways Alpha, Alpha 2, and Alpha 3; and the area southeast of the intersection of Runway 25R and taxiway Alpha 2 to the airport perimeter fence was searched several days after the incident occurred for engine debris with negative results.

3.0 High pressure turbine 2nd stage hub

3.1 Disassembly examination

The 2nd stage turbine hub was intact except for five adjacent disk lugs, Nos. 2 through 5, that were fractured transversely through the fir trees.[5] (Photo 1) Disk lug No. 1 had the forward blade retaining plate retention hook fractured. The fracture surface on disk lug No. 1 had a dark-colored, elliptical-shaped flat surface radiating from the inner diameter of the retaining plate snap fillet outward. (Photo 2) The fracture surfaces on disk lugs Nos. 2 through 5 had dark-colored, elliptical-shaped flat features radiating from the front acute corner. (Photo 3) The visual inspection of the 2nd stage turbine hub revealed 11 other lugs, Nos. 6, 9, 13, 14, 18, 28, 29, 40, 47, 58, and 59 were cracked. (Photo 4) The front and rear faces of the hub as well as the hub bore did not have any rub marks. The following markings were noted on the 2nd stage turbine hub: PN 1B6602J, SN DKLBA86546, heat code PHNLS 2007, 33459 S/N, 408.

[5] In accordance with gas turbine engine convention, parts are numbered consecutively in a clockwise direction as viewed from the rear looking forward. Blade No. 1 was arbitrarily identified as such because it was the first blade in the cluster of four fractured blades. Disk lugs Nos. 1 and 2 retain blade No. 1.

Photo 1: Close up of 2nd stage turbine hub showing fractured lugs Nos. 2 through 5 (P&W)

Photo 2: Close up of lug No. 1 with arrow pointing to the dark-colored, elliptical-shaped fracture surface feature (P&W)

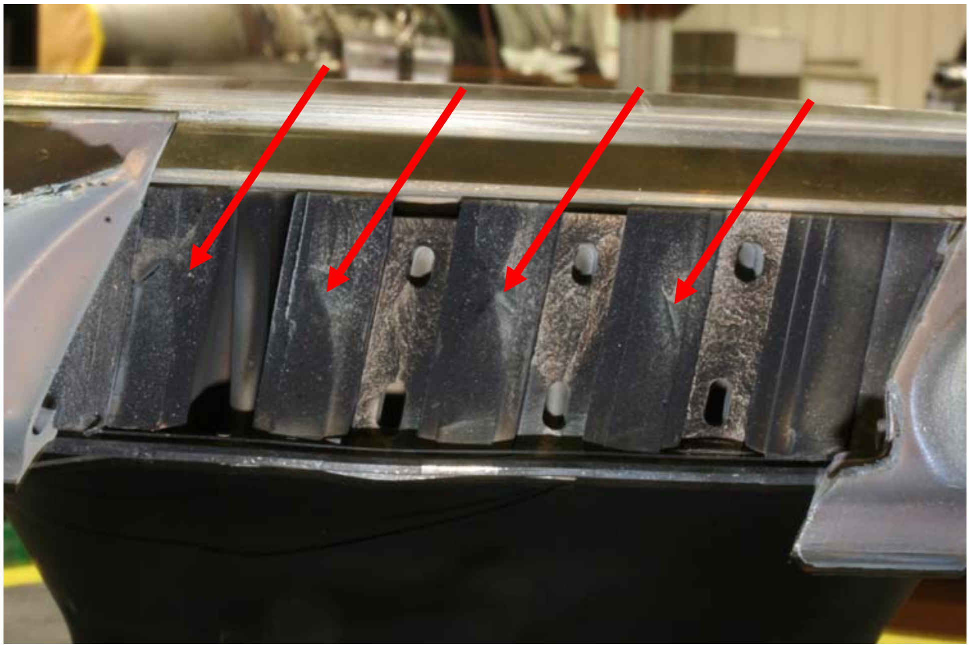

Photo 3: Close up of facture lugs Nos. 2 through 5 with arrows pointing to the elliptical-shaped fracture surface features (P&W)

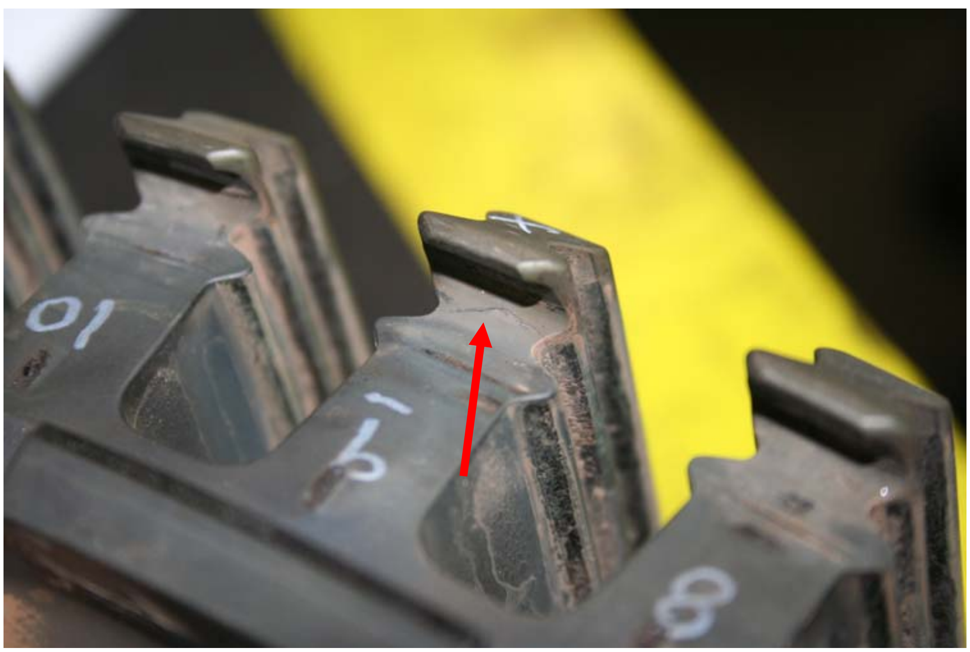

Photo 4: Close up of lug No. 9 with arrow showing crack (P&W)

3.2 Metallurgical examination

Following the disassembly of the engine, the fractured hub was shipped to P&W's East Hartford, Connecticut facility for further examination. At P&W, the hub was visually examined, cleaned with soapy water, and fluorescent penetrant inspected (FPI).[6] The visual examination revealed non-uniform contact patterns on the blade root serrations. Additionally, the visual examination revealed cracks in 22 of the blade root serrations. Subsequently, the FPI revealed 59 crack indications on 35 of the blade slot lugs. In addition, the hub was dimensionally inspected. (Refer to Section 3.3.)

In accordance with a cut plan that was agreed upon by the Powerplants Group, several of the blade retaining lugs were cut from the hub. The lugs cut from the hub included the fractured lugs, Nos. 2 through 5 as well as Nos. 11 through 14, and 24 through 29. The lugs were then shipped to the Safety Board's Materials Laboratory for further metallurgical examination.

According to the Safety Board's Materials Laboratory report, the examination of lugs Nos. 2 through 5 revealed fracture surfaces that were smooth and flat, consistent with fatigue. The areas of fatigue on lugs Nos. 2 through 5 originated from multiple origins along the root radius between the middle and inner serration on the pressure side of the lug. The examination of the fracture surfaces on lugs Nos. 2 through 5 with the scanning electron microscope revealed the fractures were consistent with fatigue at elevated temperatures. Lug No. 5 had the largest area of fatigue. On both sides of the blade retaining lugs, but primarily on the pressure side, the inner tooth non-contacting area had a wavy surface pattern that was most prominent at the tip and extended back about 0.3 to 0.6 inches from the front face of the hub.

One of the lugs had a rectangular region with a discernible step consistent with material removal from outside the region. There was a part marking on the middle area of the region. The height of the step varied from 0.001 inches on the suction side to 0.002 inches high on the pressure side of the lug.

The examination of the other lugs that had FPI crack indications that were cut from the hub were found to have fatigue cracks similar to those observed on lugs Nos. 2 through 5, although the cracks were smaller.

The metallurgical examination also revealed the hub's material conformed within statistical sampling to the material specifications for the specified alloy. The examination not did reveal any material anomalies or metallurgical defects.

For further details, refer to NTSB Materials Laboratory Factual Report No. 09-076.

[6] FPI is a nondestructive inspection method of detecting cracks and other surface anomalies. The inspection consists of applying or immersing the part in a low-viscosity penetrating fluid containing fluorescent dyes and allowing the fluid to penetrate into any surface defects. Excess penetrant is removed and a "developer" is applied that acts as a blotter to draw the penetrant out from any surface defects that will luminesce when viewed under an ultraviolet light.

3.3 Dimensional inspection

The 2nd stage turbine hub was dimensionally inspected at P&W using a coordinate measuring machine (CMM) and optical comparator.[7] The dimensional inspections showed that hub's various diameters, concentricity, and perpendicularity conformed to the requirements of the engineering drawing. The hub's blade slots were measured with a CMM in the center section of the slots and with an optical comparator at the forward and aft edges. The dimensional inspection of the hub's blade slots revealed that 48 of the remaining 61 slots deviated from the engineering drawing's profile tolerance of ± 0.0005 inches and some were up to 0.0035 inches over the profile tolerance. In addition, the dimensional inspections showed that the hub's blade slot profiles diverged from the aft edge to the forward edge by up to 0.0092 inches.

3.4 Operating history

According to Delta Air Lines' maintenance records, the 2nd stage turbine hub was PN 1B6602J, SN DKLBA86546. The maintenance records show that the hub had accumulated 29,097.5 hours TSN and 12,540 CSN and 10,880.7 hours and 4,392 cycles since the last heavy maintenance. According to the PW2000 series engine manual, the PW2037 2nd stage hub PN 1B6602 has a life limit of 15,000 cycles.[8] The maintenance records show that the hub had originally been installed with zero time and cycles in PW2037 engine SN 728704 when the engine was new, also with zero time and cycles. The records further show that the hub was removed from engine SN 728704 on November 30, 2004, when the engine and hub had accumulated 18,216.8 hours TSN and 8,148 CSN. The records show that the hub was then installed in PW2037 engine SN 728705, the incident engine, on March 18, 2005, when the engine had 10,497.8 hours TSN and 4,699 CSN. (Attachment 2)

3.5 Maintenance history

The maintenance records for the 2nd stage turbine hub, PN 1B6602J, SN DKLBA86546, show that it was overhauled between December 10 and 22, 2004. The overhaul records show that the hub underwent a four-step chemical descaling process (For further details, refer to Section 7.1.), then grit blasted with 500 grit aluminum oxide at 30 psi (For further details, refer to Section 7.2.), steam cleaned, oven dried, underwent an FPI, steam cleaned again, and then underwent a dimensional inspection. (Attachment 3)

4.0 Second stage turbine blades

Of the 64 2nd stage turbine blades, 1 was missing completely, three were fractured transversely through the inner most blade root serrations, and the remaining blades were in the blade slots. The blades in slots Nos. 1, 2, and 3 were fractured transversely through the inner most blade root serrations. There was one 2nd stage turbine blade recovered that had an airfoil

[7] An optical comparator, also referred to as a shadowgraph, is an inspection device that projects an enlarged silhouette of an object onto a large projection screen. The silhouette is compared against an enlarged template of the object's feature being inspected.
[8] PW2000 series Engine Manual, Section 05-10-00, Table 804

and partial root recovered with a fracture surface that corresponded to the fracture surface on the root section in blade slot No. 1. The blade in slot No. 4 was missing completely. Blade No. 5 had a crack in the inner most serration on the pressure side. The airfoils of blades Nos. 5 through 62 varied in length from 2 3/4 inches to 3 1/4 inches above the blade root platform. The airfoils of blades Nos. 63 and 64 were 3/4 and 1/2 inches long, respectively, above the blade root platform. (Photo 5) All of the near full length blades had rub marks with heat discoloration on the tips and nicks, dents, and break outs on the leading edges, trailing edges, and the airfoil surfaces. All of the blades roots had the cover plate over the aft cooling air hole. The fracture surface on blade root No. 2 had two-elliptical shaped, relatively flat dark colored areas radiating from just aft of the front corners of the blade root. The fracture surface on blade root No. 3 had a single elliptical-shaped, relatively flat dark colored area radiating from just aft of the front obtuse corner. (Photo 6) The fracture surfaces on blade root No. 1 and the remainder of the fracture surfaces on blade roots Nos. 2 and 3 were coarse and grainy.

Photo 5: 2nd stage hub with 2nd stage turbine blades showing missing blades, blades fractured near platform, and remaining blades damaged (P&W)

Photo 6: Close up of fractured 2nd stage turbine blade root ends (P&W)

The contact patterns of the 2nd stage turbine blade root serrations were qualitatively evaluated. With the exception of blades Nos. 1 and 5, all exhibited six-tooth contact, but the degree/heaviness of the contact on the pressure side serrations varied from blade to blade. (Photo 7) Refer to Table 1.

Photo 7: 2nd stage turbine blades Nos. 1 and 6 showing different wear patterns on root fir trees (P&W)

Table 1. 2nd stage turbine blade visual inspection results

Blade No.	Part Number	Serial Number	Fir Tree Cracking (Y/N)	Six tooth contact (Y/N)	Repair marking (Y/N)
1	P1B7522H	4C5119704-45	Broken	N	Y
2	Unknown	Unknown	Broken		
3	Unknown	Unknown	Broken		
4	Unknown	Unknown	Broken		
5	P1B7522H	4C5119704-28	Y	N	Y
6	P1B7522H	4C5119704-16	N	Y	Y
7	P1B7522H	4C5119704-53	N	Y	Y
8	P1B7522H	4C5119704-09	N	Y	Y
9	P1B7522H	4C5119704-50	N	Y	Y
10	P1B7522H	4C5119704-02	N	Y	Y
11	P1B7522H	4C5119704-42	N	Y	Y
12	P1B7522H	4C5119704-12	N	Y	Y
13	P1B7522H	4C5119704-57	N	Y	Y
14	P1B7522H	4C5119704-20	N	Y	Y
15	P1B7522H	4C5119704-36	N	Y	Y
16	P1B7522H	4C5119704-34	N	Y	Y
17	P1B7522H	4C5119704-58	N	Y	Y
18	P1B7522H	4C5119704-59	N	Y	Y
19	P1B7522H	4C5119704-15	N	Y	Y
20	P1B7522H	4C5119704-26	N	Y	Y
21	P1B7522H	4C5119704-63	N	Y	Y
22	P1B7522H	4C5119704-13	N	Y	Y
23	P1B7522H	4C5119704-22	N	Y	Y
24	P1B7522H	4C5119704-46	N	Y	Y
25	P1B7522H	4C5119704-30	N	Y	Y
26	P1B7522H	4C5119704-52	N	Y	Y
27	P1B7522H	4C5119704-14	N	Y	Y
28	P1B7522H	4C5119704-23	N	Y	Y
29	P1B7522H	4C5119704-32	N	Y	Y
30	P1B7522H	4C5119704-40	N	Y	Y
31	P1B7522H	4C5119704-29	N	Y	Y
32	P1B7522H	4C5119704-64	N	Y	Y
33	P1B7522H	4C5119704-60	N	Y	Y
34	P1B7522H	4C5119704-18	N	Y	Y
35	P1B7522H	4C5119704-01	N	Y	Y
36	P1B7522F	PW022439-47	N	Y	Y
37	P1B7522H	4C5119704-43	N	Y	Y
38	P1B7522H	4C5119704-56	N	Y	Y
39	P1B7522H	4C5119704-61	N	Y	Y

40	P1B7522H	4C5119704-11	N	Y	Y
41	P1B7522H	4C5119704-35	N	Y	Y
42	P1B7522H	4C5119704-06	N	Y	Y
43	P1B7522H	4C5119704-08	N	Y	Y
44	P1B7522H	4C5119704-47	N	Y	Y
45	P1B7522H	4C5119704-19	N	Y	Y
46	P1B7522H	4C5119704-54	N	Y	Y
47	P1B7522H	4C5119704-04	N	Y	Y
48	P1B7522H	4C5119704-41	N	Y	Y
49	P1B7522H	4C5119704-17	N	Y	Y
50	P1B7522H	4C5119704-33	N	Y	Y
51	P1B7522H	4C5119704-03	N	Y	Y
52	P1B7522H	4C5119704-48	N	Y	Y
53	P1B7522H	4C5119704-05	N	Y	Y
54	P1B7522H	4C5119704-10	N	Y	Y
55	P1B7522H	4C5119704-44	N	Y	Y
56	P1B7522H	4C5119704-21	N	Y	Y
57	P1B7522H	4C5119704-24	N	Y	Y
58	P1B7522H	4C5119704-31	N	Y	Y
59	P1B7522H	4C5119704-07	N	Y	Y
60	P1B7522H	4C5119704-38	N	Y	Y
61	P1B7522H	4C5119704-62	N	Y	Y
62	P1B7522H	4C5119704-51	N	Y	Y
63	P1B7522H	4C5119704-39	N	Y	Y
64	P1B7522H	4C5119704-37	N	Y	Y

During the deblading of the 2nd stage turbine rotor, 59 intact dampers and 59 intact seals were removed from between the blades.

All of the 2nd stage turbine blade front retaining plates and the rear retaining plate were intact and in place on the 2nd stage turbine hub. The underlying wire seals were in place and intact. However, the front retaining plate segment adjacent to the broken turbine blades was bulged radially outward in the center and buckled out from the hub front face slightly. (Photo 8) The 2nd stage turbine blade front retaining plate segments were marked as being PN 1B0815E. All of the 2nd stage turbine blade front retaining plate segments had circumferential scuff marks on the front face. All of the 2nd stage turbine blade front retaining plates were returned to P&W, East Hartford, Connecticut for dimensional inspection on a CMM. The retaining plate that was adjacent to the broken blades could not be measured because of the aforementioned damage. However, the dimensional inspection of the remaining seven 2nd stage turbine blade front retaining plates showed that all of them conformed to the engineering drawing's dimensional requirements. All of the 2nd stage turbine blade front retaining plates, including the damaged one, were weighed and all were within one gram of the expected weight. (For further details, refer to Attachment 4.)

Photo 8: Front 2nd stage turbine blade retaining plate that was buckled (P&W)

The rim of the 2nd stage turbine blade rear retaining plate in the area of the missing 2nd stage turbine blades was heat discolored. The 2nd stage turbine blade rear retaining plate had numerous circumferential scuff marks on the rear face. All of the 2nd stage turbine blade retaining plate rivets and the plugs in the rear retaining plates were tight.

5.0 Other PW2037 high pressure turbine 2nd stage hubs

Delta reported finding two other PW2037 2nd stage hubs that had FPI crack indications in the blade slots.

5.1 American Airlines 2nd turbine hub SN DKLBA84592

In June 2007, Delta reported finding a PW2037 2nd stage turbine hub, which had been operated by American Airlines[9] and was undergoing a routine overhaul at the Delta TOC, that had FPI crack indications at 26 locations on the disk lugs, two of which were confirmed visually to be cracks in adjacent lugs. According to the maintenance records, the 2nd stage turbine hub, PN 1B6232,[10] SN DKLBA84592, had accumulated 30,630 hours TSN and 10,888 CSN.[11] The hub had accumulated 14,426 hours and 5,855 cycles since the previous overhaul. (Attachment 5)

The overhaul records for 2nd stage turbine hub SN DKLBA84592 show that it had to be recycled several times for additional cleaning before the FPI could be accomplished. There were

[9] Most of American Airlines' Boeing 757 airplanes are powered by Rolls-Royce RB211-535 turbofan engines. However, AMR Corporation, the parent company for American Airlines, acquired a number of P&W PW2037-powered 757s with its acquisition of Trans World Airlines in 2001.
[10] PN 1B6232 is for the assembly. The hub, disassembled down to the piece part level, is PN 1B6602.
[11] According to the PW2000 series engine manual, Section 05-10-00, Table 804, PN 1B6602 2nd stage turbine hubs have a life limit of 15,000 cycles.

several comments in the record indicating the hub had background florescence that prevented accomplishing the FPI. The shop traveler,[12] Shop Order: G05043, for the 2nd stage turbine hub SN DKLBA84592 was originated on January 18, 2002. On January 24, 2002, the hub's blade slots underwent a plastic media blast.[13] The shop traveler noted on January 29, 2002, that the "part retains too much background to inspect properly. Route for more aggressive cleaning." On January 31, 2002, the hub underwent another plastic media blast of the blade slots. The shop traveler noted on February 1, 2002, that the "hub still has excessive background on pressure faces and on front face of blade slots. More aggressive cleaning is needed. SPOP 10 is allowed. Dry abrasive blast 500 grit. Evaluate and route." On February 7, 2002, the hub underwent a third plastic media blast. The shop traveler noted on February 12, 2002, "still unable to F.P.I. due to carbon type laminate on blade pressure faces [and] retaining slot when viewed with white light [and] 15X magnification. It is clearly on part surface [and] not galling. Route for SPOP 10…" On February 13, 2002, the hub was grit blasted per [Delta Process Standard] PS900-1-1 No. 13, using 500 grit at 30 psi to remove deposits on fir tree [forward] face and pressure faces. After the hub was grit blasted, the shop traveler the next task was an FPI. But the signature block for that FPI task was marked deleted. On February 14, 2002, the hub underwent another grit blast operation per PS 900-1-1 No. 13 using 500 grit at 30 psi because the "part still has heat scale on some fir tree pressure faces." The shop traveler showed that the hub was steam cleaned per PS900-1, oven dried, and then on February 19, 2002, was FPIed. for further details, refer to Attachment 6.

The metallurgical examination of hub SN DKLBA84592 by P&W confirmed that the FPI indications on two adjacent lugs were cracks up to 0.9 inches long. The cracks were located in the bottom of the radius of the outboard serrations and had progressed from multiple origins due to elevated temperature low cycle fatigue (LCF). One lug also exhibited a crack in its middle serration front acute corner that had progressed in LCF. The visual examination of the lugs found that the front edge profile was significantly rounded and the serrations exhibited a wavy appearance along the peaks of their teeth that was most prominent on the middle tooth and extended up to 0.5 inches in the blade fir tree slots. There were no indications of material or processing anomalies.

P&W accomplished a dimensional inspection of hub SN DKLBA84592 with a CMM and an optical comparator. The CMM inspection revealed a divergence from the trailing edge to the leading edge of the fir tree slots of up to 0.0038 inches. The optical comparator inspection revealed the fir tree slot pressure faces were out of the profile requirements by up to 0.0024 inches in comparison to the tolerance of +/- 0.0005 inches.

[12] A shop traveler breaks down the overhaul and inspection process of a component into individual tasks, which include excerpts or references to the appropriate manual, service bulletin, or job instruction card and include a signature block for the technician or inspector performing the task.

[13] Plastic media blast is a cleaning method where small plastic balls are propelled by air through a nozzle at a part to remove dirt.

5.2 Delta Air Lines 2nd turbine hub SN DKLBCT5130

In February 2009, Delta reported finding a second PW2037 2nd stage turbine hub that had been undergoing a routine overhaul that had an FPI crack indication in the serration of a blade slot. According to the maintenance records, the hub, PN 1B8002, SN DKLBCT5130, had accumulated 20,384 hours TSN and 7,207 CSN.[14] The hub had accumulated 13,196 hours and 4,248 cycles since the previous overhaul. (Attachment 7)

The overhaul records for 2nd stage turbine hub SN DKLBCT5130 show that it underwent only one grit blast cycle prior to being FPIed. The shop traveler, Shop Order R83057, showed that on April 29, 2005, the hub's blade slots had been grit blasted in accordance with PS900-1-1 No. 13 using 500 grit at 30 psi. (Attachment 8)

The metallurgical examination of hub SN DKLBCT5130 by P&W revealed a 0.3-inch long by 0.06-inch deep crack in the outermost serration of the blade slot. Numerous lugs on the hub including the cracked lug had a wavy surface appearance. This wavy appearance was most prominent on the forward side of the hub and the on the peaks of the teeth and extended approximately half way along the length of the slots before gradually fading away. On the lug with the part identification, there was a shiny rectangular region surrounded by two distinct lines consistent with masking. There was a step of up to 0.003 inches with the area outside the lines lower than the area where the part identification markings were located. The area between the inboard and outboard lines was 0.0005 inches lower that the area where the part identification markings were located.

P&W accomplished an optical comparator dimensional inspection on hub SN DKLBCT5130. The inspection revealed the fir tree serration pressure faces were out-of-profile by up to 0.0035 inches in comparison to the specified tolerance of +/- 0.0005 inches.

6.0 Remainder of high pressure turbine

The HPT case had a 4 1/4-inch long axial crack at 6 o'clock between the rear flange and the rail that turned clockwise and progressed approximately 11 inches to the turbine cooling air (TCA) temperature probe boss at 8 o'clock. The flap of the fractured HPT case was displaced radially outward about 3 inches. (Photo 9) The fracture surface on the flap of the HPT case matched the fracture surface on the body of the HPT case. The HPT case, in the plane of the 2nd stage turbine vanes, had a purple discoloration 360 degrees around the case.

[14] According to the PW2000 series engine manual, Section 05-10-00, Table 804, PN 1B8002 2nd stage turbine hubs have a life limit of 15,000 cycles.

Photo 9: View of tab of displace material on ruptured HPT case (P&W)

The upper HPT ACC air duct had the locating bushing broken off. The bracket on the lower HPT ACC air duct was pulled out and remained attached to the upper duct. The lower HPT ACC air supply duct was buckled and crushed at 6 o'clock. There was a 1 1/2-inch long circumferential by 1-inch wide axial hole at the right end of the tube about 2 inches from the end. The locating bushing was separated from the duct and was lying inside the duct. The HPT ACC pipes on the bottom of the engine were deflected forward.

Both TCA valves were in the open position. The push-pull cable that controls the left hand valve was fractured at the right hand valve connection. The three TCA pipes were intact and clear of obstruction. There were no visual indications of leakage past the end flanges of the pipes.

The HPT shaft was intact. The forward end of the HPT shaft heat shield on the inner diameter had an approximately 2-inch wide axial 180 degree rub mark that corresponded to the 2-inch wide rub mark on the outer diameter of the LPT shaft. (Photo 10) The center of the rub mark on the HPT shaft heat shield was located 180 degrees from the missing 2nd stage turbine blades.

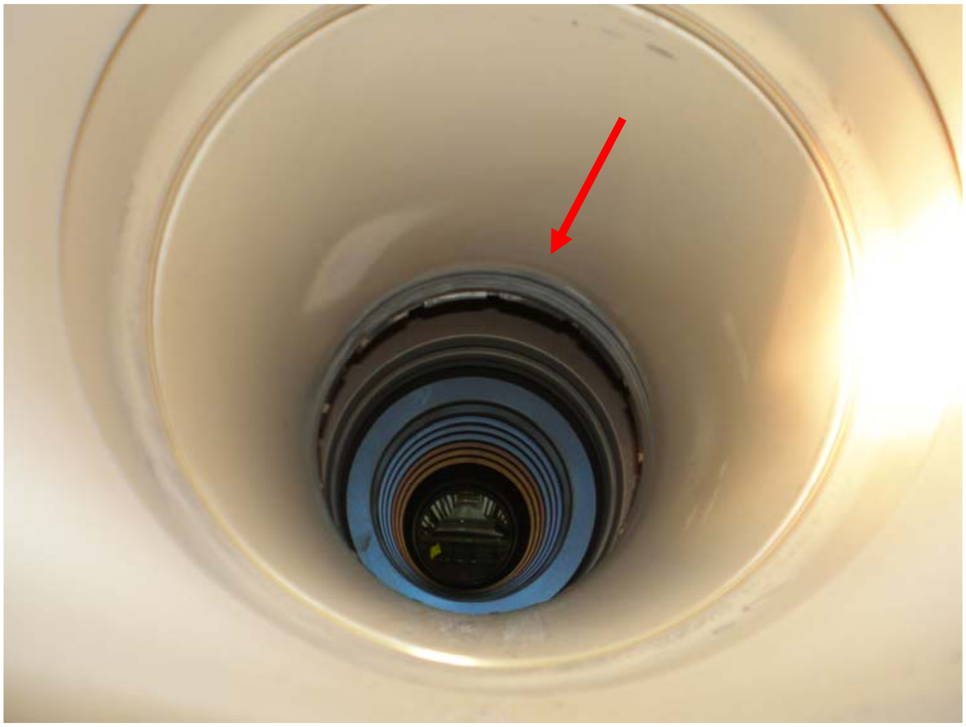

Photo 10: Inside of HPT shaft with arrow showing rub mark

The HPT tie rods were all in place and intact. All of the HPT tie rod nuts were tight.

The 1st stage turbine disk was intact except for the tangential onboard injector air seal land that was fractured along a 90 degree arc between 12 and 3 o'clock.[15] All of the 1st stage turbine blades were in place in the disk and all of the blades had rub marks on the tips. There was a continuous sector of 14 1st stage turbine blades approximately centered on the location of the missing 2nd stage turbine blades where the tips were rubbed through into the internal cavity. (Photo 11) All of the 1st stage turbine blades had chips in the thermal barrier coating on the convex surfaces of the airfoils.

[15] For the examination of the rotating parts such as the 1st stage turbine disk, 12:00 o'clock was in reference to the location of the broken 2nd stage turbine blades.

Photo 11: Close up of 1st stage turbine blade tips showing rub into internal cavity

The 1st stage turbine blade front retaining plate was in place on the disk. The 1st stage turbine blade front retaining plate had numerous circumferential scuff marks across the front face of the plate. Both of the knife edges on the 1st stage turbine blade front retaining plate were worn elliptically. The plugs in the 1st stage turbine blade front retaining plate were tight, but were battered. The 1st stage turbine blade rear retaining plates were all in place, but had numerous nicks and scuff marks on the surface. The knife edge seals on the rear retaining plates over the blades that had the heavy tip rub into the internal cavity were missing with circumferential scoring on the outer diameter of the knife edge seal arm. The knife edge seals on the rear retaining plates opposite the 1st stage blades with the heavy tip rub into the internal cavity were also missing, but had circumferential scoring on the inner diameter.

The lenticular seal was in place between the 1st and 2nd stage turbine disks and was intact. The lenticular seal knife edges were all in place, but the knife edges in line with the missing 2nd stage turbine blades were rubbed down to the pedestals.

The 1st stage turbine vanes were all in place. (Photo 12) The 1st stage turbine vanes did not have any apparent damage, but the concave surfaces of the airfoils between the leading and trailing edges had a black-colored coating. The convex surfaces of the airfoils did not have any of the black-colored material. The thermal barrier coating on the convex surfaces of the airfoils appeared to be intact. The 1st stage turbine vanes did not have any indications of burning or hot gas erosion.

Photo 12: 1st stage turbine vanes all in place (P&W)

The 2nd stage turbine vanes were all in place in the HPT case. (Photo 13) There were several randomly located 2nd stage turbine vanes that had the rear flow guides missing. All of the other 2nd stage turbine vanes had circumferential scoring marks on the inner diameter of the rear flow guides. All of the 2nd stage turbine vanes had nicks and dents on the trailing edges and convex surfaces of the airfoil and the thermal barrier coating was chipped. The 2nd stage turbine vanes did not have any indications of burning or hot gas erosion.

Photo 13: 2nd stage turbine vanes all in place in the HPT case (P&W)

The 2nd stage turbine inner air seal was in place on the 2nd stage turbine vanes inner diameter. The 2nd stage turbine vane inner air seal had five 3/16-inch wide grooves in the honeycomb that corresponded to the spacing of the knife edges on the lenticular seal.

The 1st stage turbine blade outer air seal segments were all in place in the HPT case and intact. The 1st stage turbine blade outer air seal segments had circumferential rub marks around most of the circumference.

The 2nd stage turbine blade outer air seal segments were all in place except for a continuous sector of segments between 4 and 7 o'clock that were missing. There were four adjacent segments between 7 and 8 o'clock that had holes in the center of the segment.

7.0 Delta cleaning shop review

Members of the Powerplants Group reconvened at Delta's TOC on November 5 and 6, 2008, to review Delta's cleaning and inspection procedures for the PW2000 2nd stage turbine hub. According to Delta Air Lines, the overhaul process for a PW2037 engine consists of the following steps:

1) Receive engine;
2) Disassemble engine into smaller components or subassemblies;
3) Distribute small components or subassemblies to the appropriate specialty shop; within the Delta facility;
4) Further disassemble the small components and subassemblies down to piece part level, as required;
5) Within the component or subassembly specialty shops, inspect and plan any necessary repairs;
6) Parts such as the 2nd stage turbine hub are sent for cleaning, non-destructive testing, inspection, and repair (Refer to Sections 7.1 through 7.6.);
7) Final visual and dimensional inspection and approval for return to service; and
8) Final reassembly of engine.

7.1 Chemical cleaning process

The chemical cleaning is a four-step chemical descaling process that is defined by Delta's PS900-1-3-2 No. 10, which conformed to the P&W Standard Practice Manual (SPM) Service Process Operation Procedure (SPOP) 213 Four-Step Alkaline Rust Remover and Acidic Descaling (Without Inhibited Phosphoric Acid) current at the time the Delta Air Lines and American Airlines 2nd stage turbine hubs were cleaned as well as at the time of the review.[16] SPOP 213 required the part be:

Degreased;
Soaked in alkaline rust remover solution at 180° - 200°F for 15 – 30 minutes;

[16] P&W stated that it had revised SPOP 213 since the cleaning process was reviewed at Delta Air Lines.

Pressure spray rinse with cold water over the alkaline rust remover tank. Dip in cold water; then, pressure spray rinse;
Soak in acidic scale conditioner solution[17] for 15 – 30 minutes;
Pressure spray rinse with cold water over acidic scale conditioner solution tank. Dip in cold water tank; then, pressure rinse;
Soak in alkaline permanganate solution tank at 180° - 200°F for 15 – 30 minutes;
Pressure spray rinse with cold water over alkaline permanganate solution tank. Dip in cold water tank; then pressure spray rinse;
Soak in alkaline rust remover solution at 180° - 200°F for 5 – 10 minutes;
Pressure spray rinse with cold water over alkaline rust remover tank. Dip in cold water; then, pressure spray rinse;
Put part fully in hot water at 150° - 200°F until the temperature of the part is the water temperature to flash dry;
Apply corrosion inhibitor, as necessary.

The Delta four-step chemical descaling process uses a semi-automated system that puts the basket containing the parts to be cleaned into the solution tank and then raises the basket out of the tank at the end of the cleaning step. The agitation of the cleaning solution and rinse tanks is accomplished by the up and down movement of the baskets. The temperatures and solution and rinse water levels in the tanks are continuously monitored by the system. If a temperature and/or fluid level goes out of range, the system automatically raises the basket out of the tank to stop the process. In addition, if an out-of-range temperature or fluid level is sensed, the system will activate a red light that is easily visible to the operators to alert them to the condition. The concentration levels of the cleaning solutions are sampled once a week and the results are reported to the appropriate operators and managers within 24 hours.

7.2 Dry grit blasting

The dry grit blasting process that was used on the incident disk was defined by Delta's PS900-1-1 No. 13 that conformed to P&W's SPM SPOP 10 Dry Abrasive Grit Blast (500 Grit Aluminum Oxide).[18] The dry grit blast using 500 grit aluminum oxide media was accomplished after the chemical cleaning process. SPOP 10 required:

Degrease the part, if necessary;
Mask the part, as necessary to prevent material entrapment;
Blast the part with aluminum oxide grit to remove oxides, nozzle-to-part distance: 3 – 4 inches, angle to work surface: 45 to 60 degrees, for pressure type machines: 25 – 30 psi [pounds per square inch], for suction type machines: 50 – 60 psi;
Blow clean with air at 30 psi maximum to remove any remaining media;
Remove the masking;

[17] SPOP 213 lists five different acidic scale conditioner solutions that have different operating temperatures.
[18] Because of the problems associated with the use of SPOP 10 Dry Abrasive Grit Blast, in February 2010, P&W deleted SPOP 10 from the PW2000 Engine Manual and was replaced with SPOP 15 Wet Abrasive Grit Blast (500 Grit Aluminum Oxide) to clean the PW2000 2nd stage turbine hubs.

> Visually check that the part has been evenly cleaned and that there are no remaining blasting media or masking tape;
> Apply corrosion inhibitor.
>
> SPOP 10 has a caution that states, "DO NOT STAY IN ONE AREA FOR MORE THAN TWO SECONDS; USE CONTINUOUS MOTION."[19]

Dry grit blasting was not a mandatory operation in the overhaul of the PW2037 2nd stage turbine hubs. However, it was permitted in accordance with the PW2037 engine manual, section 72-52-00 – Cleaning 01, after the four-step chemical cleaning. Delta stated that they dry grit blasted all of their PW2037 2nd stage turbine hubs. SPOP 10 Dry Abrasive Grit Blast (500 Grit Aluminum Oxide) is no longer permitted on the PW2017 2nd stage turbine hub.

In 2002, Delta's common practice for the PW2037 2nd stage turbine hubs was to use plastic media blasting, SPOP 19, to remove any scale from the fir tree slots.[20] P&W reported that the plastic media blasting was an option to clean the hub until it was deleted from the engine manual in the April 2008 revision. P&W stated that it was deleted because it was no longer effective in removing the scale from the turbine hubs.

Delta reported that by 2004, grit blasting was routinely used to clean the fir tree areas on the PW2037 2nd stage turbine hub. Delta stated that it was necessary to grit blast the hubs because they were routinely being returned by the FPI inspectors for additional cleaning. The inspectors were noting that the plastic media blasting was not completely removing the heat scale from the hubs that was resulting in excessive background fluorescence and that a more aggressive cleaning process was required on a regular basis.

According to Delta Air Lines, between 2002 and 2004, there were only four people that routinely operated the grit blasting machines. Delta stated that at the time of the review, the grit blasting duties were spread among the entire staff of 75 operators. It was noted that the Delta incident hub and the American Airlines hub were both grit blasted during the 2002 to 2004 time period. It was further noted that the same person had signed off the grit blasting operation for Delta incident hub and the first of the two grit blasting operations accomplished on the Delta Air Lines' cracked 2nd stage turbine hub SN DKLBA84592.

Delta reported that new grit blasting machines were installed in the shop in November 2007. The Delta incident hub and the American Airlines hub were both blasted using the old equipment that was no longer in the shop and could not be examined. Delta reported that the new grit blasting machines were installed for various improvements. The older grit blasting

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[19] As a result of this investigation, P&W stated that it had revised SPOP 10 to add an additional warning that the process could result in material removal. In addition, P&W stated that SPOP 10 was no longer a permissible cleaning process for the PW2037 2nd stage turbine hub.

[20] SPOP 19, Dry Plastic Blast, requires the part to be degreased to prevent contamination of the media, masked as necessary to prevent the media from becoming entrapped, the machine air pressure should be set at 30 – 40 psi for pressure-type machines and 60 – 80 psi for suction type machines, blast with the plastic media as necessary with the gun 3 – 4 inches from the part at a 45 – 60 degree angle to the work surface, and blow clean with 30 psi air to remove all remaining media.

machines developed significant dust clouds within the enclosure reducing the operator's visibility and view of the part. The new grit blasting machines feature improved visibility. With the new grit blasting machines, the flow rate and filtering of the media were improved. In addition, there were ergonomic improvements for the operators.

The grit blasting machines in which the PW2037 2nd stage turbine hubs are grit blasted are dedicated to 500 grit media size. The operator cannot change the media size. The media flow is locked out and cannot be adjusted by the operator. However, the pressure regulating controls are not locked out to permit the operator to adjust the operating pressures depending upon the process being used and the part being grit blasted. There are other grit blasting machines in the area that are dedicated to other processes that require a different media size. The machine that is used to grit blast the PW2037 2nd stage turbine hub has a mounting fixture to permit the operator to mount the hub at about a 45 degree angle. The fixture allows the operator to rotate the hub about its centerline. During the grit blasting operation, the hub is flipped over to permit grit blasting of the other side. The blade slots are blasted from both directions. It was noted that the blade slot pressure faces and the front face of a hub that was being cleaned during the review required extra grit blasting.

While observing the grit blasting operation of a PW2037 2nd stage turbine hub, it was noted that the operator used a fast, quick cyclic pattern that was concurrent with a slow sweeping flowing pattern to blast the part. There was no fixture to control the distance or angle of the nozzle to the part being blasted.[21] The position of the blasting nozzle was controlled by the operator. The operator would stop blasting the part and check the cleanliness and then resume blasting the same area if it was not suitably clean. The determination of whether a part was clean enough was up to the discretion of the individual operator. The operator controls the dwell time of blasting in any one area of the part. Dwell time is not specifically defined by P&W's SPM or by Delta's process standard. P&W's Standard Practice Manual states that a dwell time of not more than 2 seconds is permissible per the SPOP. Delta's process standard states that no dwell is permissible.

7.3 Steam cleaning

Following the grit blasting operation, the PW2037 2nd stage turbine hub is steam cleaned to remove any dust and residue from the blasting operation. The steam cleaning operation was not reviewed.

7.4 Oven dry

After the 2nd stage turbine hub is steam cleaned, it is dried in an oven. The oven dry process was not reviewed.

[21] SPOP 10 did not require a distance or angle fixture.

7.5 Fluorescent penetrant inspection

In accordance with the PW2037 engine manual, the PW2037 2nd stage turbine hub undergoes an ultra-high sensitivity FPI per SPOP 84 and the equivalent Delta PS 900-6-3 No. 2, Class 2. Delta applies the emulsifier with the spray option followed by rinsing, drying, and application of a dry developer. After an initial inspection of the part, Delta applies a non-aqueous developer to critical areas of rotating parts and then performs an additional inspection.

A PW2037 2nd stage turbine hub that was cleaned with the four-step chemical cleaning process, but not grit blasted, underwent an FPI in the presence of members of the Powerplants Group. It was noted that the chemical cleaning process was not effective enough to clean all of the scale off of the part. Using a white light, the scale was observed on the fir tree slots and front retaining plate lug areas. When using an ultraviolet light for the FPI, the scale that remained on the fir tree slots and front retaining plate lugs areas, as well as other areas of the hub, fluoresced.

7.6 Inspection

The Delta inspection shop measures and records six diametric features on the PW2037 2nd stage turbine hubs, but did not measure any of the blade slot features.[22] Although the blade slots are not measured, a Delta inspection shop inspector stated that they had scrapped hubs due to erosion in the blade slots. The inspector stated that he had seen a wavy pattern on the blade slots of hubs that were excessively grit blasted.

8.0 Grit blasting tests

In support of the investigation, P&W conducted grit blasting tests using the SPOP 10-specified 500 grit aluminum oxide media on samples of IN-100, the nickel alloy for the PW2037 2nd stage turbine hub. In addition, several samples that were made of Inconel 718 and Waspaloy nickel alloys were also grit blasted for comparison to the results of the tests on the IN-100 samples.

In the development of the test and test procedures, P&W identified the critical parameters to grit blasting as:

Distance between the nozzle and the part;
Cycles (how many times the part was blasted);
Movement (Dwell on one spot or continuous movement);
Angle between nozzle and the part;
Pressure.

P&W reported that the results of the tests showed that time, distance, and angle all had a highly significant effect when grit blasting the samples. Movement of the nozzle was also highly significant for depth of material removal, but not so for the amount of material that was removed. P&W stated that the most aggressive material removal was when the nozzle was at a

[22] The dimensional inspection of the blade slots was not required prior to the Delta incident at LAS.

45 degree angle to the sample. P&W stated that varying the pressure did not have a significant impact on the removing material from the samples. Additionally, P&W stated that the number of times a part was blasted did not have a significant effect on removing material. P&W also stated that using SPOP 10 grit blasting procedures on Inconel 718 and Waspaloy, which are not grit blasted per SPOP 10 in the field, had a similar effect to that noted on the IN-100 material. P&W stated that continuous motion of the nozzle significantly minimized the depth of material removed while grit blasting. P&W also stated that all of the test points that were run in accordance with the SPOP 10 requirements resulted in material loss that was less than 0.000125 inches

9.0 Corrective actions

On October 16, 2008, the Safety Board issued two recommendations to the Federal Aviation Administration (FAA), one of which was urgent. The two recommendations were:

> Require that Pratt & Whitney PW2037 engines be removed from service for inspection of the 2nd stage turbine hubs when they have accumulated significantly fewer hours and/or cycles than the incident engine (10,880 hours and/or 4,392 cycles). (A-08-85) Urgent

> Require that Pratt & Whitney PW2037 2nd stage turbine hubs undergo recurring inspection when they have accumulated significantly fewer hours and/or cycles than the incident engine (10,880 hours and/or 4,392 cycles) until the cause for the previous instances of cracking is identified and corrective action to prevent future cracking is implemented. (A-08-86)

On November 3, 2008, P&W issued Alert Service Bulletin (ASB) PW2000 A72-734, "Engine – Hub, 2nd Stage Turbine – Inspection for Nonconforming Blade Slots," in response to the uncontained failure of the 2nd stage turbine hub that occurred on the Delta 757 at LAS on August 6, 2008. The bulletin stated that laboratory analysis of the 2nd stage turbine hub found that the measured variation in the lug geometry resulted in a reduction of the fatigue life of the lug resulting in fracture of the lug. The bulletin further stated that the root cause of the variation remained under investigation. The bulletin stated that the solution was to send the parts to an approved source for a special dimensional inspection of the 2nd stage turbine hub blade slots. The bulletin was a category 6 bulletin meaning that it should be accomplished when the subassembly (i.e. modules, accessories, components, build groups) is disassembled sufficiently to give access to the changed part and to all changed spare parts. The bulletin listed Pratt & Whitney Global Services Partners as the approved vendor to accomplish the inspection. The actual inspection consisted of placing a 2nd stage turbine hub on an optical comparator and comparing the profile of the blade slot to a master profile template. The inspection was demonstrated to members of the Powerplants Group and it was noted that the inspection only checked every fourth slot on the hub in accordance with the ASB.

The FAA issued Airworthiness Directives: Pratt & Whitney Models PW2037, PW2037(M), and PW20340 Turbofan Engines, AD 2009-10-08, effective June 17, 2009, to require the inspection of the 2nd stage turbine hub in accordance with P&W ASB PW2000 A72-734.

On October 30, 2009, P&W issued ASB PW2000 A72-734 Revision 1 that included an option for an eddy current probe as an alternate means of compliance to the using the optical comparator to measure the PW2037 2nd stage turbine hub fir tree slot profiles.

10.0 Remainder of engine

10.1 External examination

The engine was complete from the fan case front flange to the exhaust duct rear flange. Except for the hole through the HPT and LPT case flanges, the engine did not have any other indications of an uncontainment or case rupture. The engine did not have any indications of an under cowl fire; however, there appeared to be dry chemical residue on the bifurcation panel.[23] (Photo 14)

10.2 Fan

The fan blades were all in place in the fan disk. (Photo 15) The fan blades did not have any apparent, unrepaired damage. There were a number of blades that had previous blends to the leading edges, including several that had soot trails extending back from the blend. The fan could be rotated freely for a range of about 2 inches before it would stop. When the fan rotor was moved, the 7th stage turbine blades moved concurrently. The fan blade rub strip did not have any circumferential gouging.

The intermediate case had ground up black material at the bottom of the case.

10.3 Low pressure compressor

The LPC rotor drum was intact. The 2nd and 5th stage compressor blades were all in place, full length, and did not have any apparent damage. The inlet guide vanes (IGV) were all in place and did not have any apparent damage. The 2nd stage shroud rub strip had erosion lines in line with IGVs. The 5th stage rub strip had a circumferential groove that was in line with the 5th stage compressor blade tips and the width of the groove corresponded to the chord length of the blade tip. (Photo 16) The exterior of LPC case was coated with ground up black material. The LPC module was not disassembled.

[23] According to Las Vegas Airport Fire Department personnel, a hand-held fire extinguisher was discharged into the engine nacelle through the open pressure relief doors after they had arrived at the airplane where it was stopped on the runway and they observed a glow within the nacelle.

Photo 14: Close up of bifurcation panel showing dry chemical fire extinguishing agent

Photo 15: Fan blades all in place and undamaged (Delta)

Photo 16: 5th stage compressor blades with groove worn in rub strip

10.4 High pressure compressor

The 10th stage bleed air duct, at the tubular-to-conical section welded joint at 4 o'clock, was buckled and had two approximately 1/4-inch by 1/8-inch holes.

The variable stator vane (VSV) actuators and rigging were all in place. The unison rings and the vane arms were all intact. When the VSV bellcrank was rotated, the actuator, unison ring, and vane levers all moved concurrently. When the VSV bellcrank was moved between the open and closed position, there was a slight amount of resistance that was reported by the Delta mechanics to be slightly more than normal. With the bellcrank rotated to the full open position, the actuator to bellcrank rigging was out of alignment by 7/64-inch in the open direction. With the VSV bellcrank rotated to the fully closed position, the unison ring rigging was found to be correctly aligned.

The VSV actuator rod jam nut safety wire was broken. The jam nut locking tabs were bent and the two jam nuts were 5/32-inch apart.

The HPC cases were intact and did not have any breaches, burn-throughs, or thermal distress.

The HPC rotor was intact and all of the HPC blades were in place in the rotor. (Photo 17)

Photo 17: HPC rotor showing all of the blades were in place

The tips of all of the 6th, 7th, 8th, and 9th stage compressor blades had circumferential rub marks. The 6th, 7th, 8th, and 9th stage compressor blades oriented towards the side of the rotor that had the missing 2nd stage turbine blades had the heaviest tip rubs with material displaced in both the direction of and away from rotation. (Photo 18) The 8th stage compressor blades were burned on the trailing edge tip corner between 7 and 1 o'clock. The 9th stage compressor blades were burned on the trailing edge tip corner between 8 and 2 o'clock. All of the 10th stage compressor blades were burned on the trailing edge tips corners. All of the 11th through 17th stage compressor blades were burned on the tips and leading and trailing edges that were progressively more severe towards the rear of the HPC. (Photo 19) There were several randomly located 6th and 7th stage compressor blades that had the leading edge tip corners bent back opposite the direction of rotation.

Photo 18: 8th stage compressor blades showing displaced material on the tips (P&W)

Photo 19: Burned compressor blade tips at rear of compressor

All of the HPC stator vanes were in place. Many of the HPC stator vane airfoils had nicks and dents and those airfoils towards the rear of the compressor were burned.

The HPC rear hub had a 180 degree groove worn into the outer diameter at the base of the cone near the shaft. The groove was centered on the missing 2nd stage turbine blades.

10.5 Diffuser/combustor

The diffuser case did not have any thermal distress.

The combustor liner was in place in the diffuser case and the fuel nozzles were in place on the combustor liner. The combustor liner was intact except for the mount lugs at 3, 5, 7, and 11 o'clock that were broken off, although only three of the broken lugs were recovered from within the diffuser case. (Photo 20) The lugs at 1 and 9 o'clock were cracked. The combustor liner had an axial crack in the 4th louver at 2 and 5:30 o'clock and axial cracks in the 3rd, 4th, and 5th louvers at 8:30 o'clock.[24] The aft edge of the 5th louver was buckled slightly inward at 8:30 o'clock. There were four fuel nozzle guides adjacent to the igniter plug ports that had erosion around the edges. The interior and exterior of the combustor liner had numerous small pieces of black-colored, irregular-shaped material located randomly around the liner. There was a non-uniform deposit of black soot on the exterior of the combustor dome. The thermal barrier coating was intact and there were no indications of a burn through or hot gas erosion.

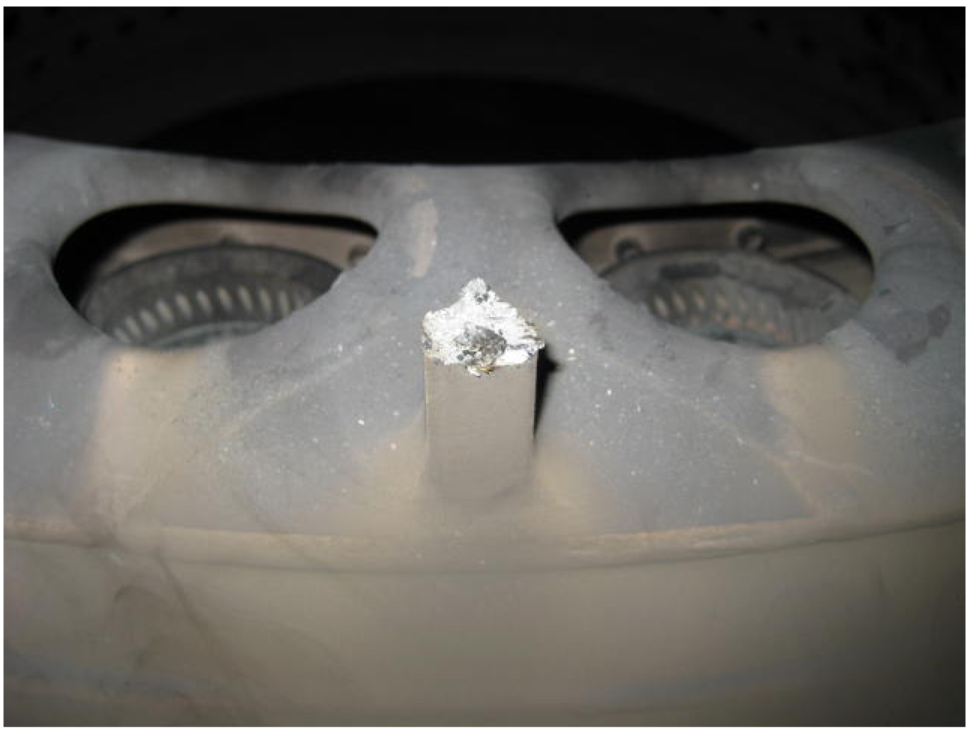

Photo 20: Broken lug on combustor dome (Delta)

10.6 Low pressure turbine

The LPT case was intact except for a 4-inch long axial crack from the front flange at 6 o'clock that progressed clockwise about 20 inches. (Photo 21) The flap of the fractured LPT

[24] The combustor louvers are numbered from front to rear from the dome, then Nos. 2, 3, 4, and 5.

case was displaced radially outward about 3 inches. The fractured surfaces of the LPT case matched. The three most forward LPT ACC tubes were bent aft at the bottom of the engine. The most forward LPT ACC tube was fractured.

Photo 21: View of LPT case showing displacement of fractured front flange (P&W)

The LPT shaft was intact. The LPT shaft had four 360 degree circumferential rub marks. There was a 1/8-inch wide rub mark at 14 13/16 inches from the rear face, a 2-inch wide rub mark at 33 5/16 inches from the rear face, a 5/16-inch wide rub mark at 35 3/16 inches from the rear face, and a 1/8-inch wide rub mark at 84 1/2 inches from the rear face. (Photo 22) The 2-inch wide rub mark on the LPT shaft corresponded to the rub mark on the HPT shaft heat shield inner diameter.

The 3rd, 4th, 5th, 6th, and 7th stage turbine disks were intact. All of the LPT tie rods were in place and the respective tie rod nuts were tight. All of the LPT rotating airseals were intact and had no apparent damage to the knife edge seals.

All of the 3rd, 4th, 5th, 6th, and 7th stage turbine blades were in place in their respective disks. All of the 3rd, 4th, 5th, 6th, and 7th stage turbine blades except for five 3rd stage turbine blades were full length. (Photos 23, 24, and 25) All of the 3rd, 4th, and 5th stage turbine blades had nicks and dents on the airfoil surfaces and the leading and trailing edges. The 6th and 7th stage turbine blades had light nicks, dents, and scuff marks on the airfoil surfaces. The 3rd, 4th, and 5th stage turbine blades had numerous circumferential scuff marks on the front and rear surfaces of the tip shrouds.

Photo 22: LPT shaft showing various circumferential rub marks

There were five randomly located 3rd stage turbine blades that were fractured between 1 7/8- and 3 1/4-inches above the blade root platform. (Refer to Photo 23.) The ends of four of the five fractured blades were found adjacent to the blade. There was one blade end that was not recovered. The fracture surfaces on all of the fractured blades were coarse and grainy. There were several 3rd stage turbine blades that had tears in the trailing edge with the material displaced opposite the direction of rotation. A piece of a 2nd stage turbine blade outer air seal segment was found in the 3rd stage turbine blade rotor.

There was one 4th stage turbine blade that had the tip shroud shingled.[25] There were three groups of three 4th stage turbine blades that had the tip shroud rear seal broken off about 1/8-inch below the adjacent seals.

There were two 5th stage turbine blades, which were separated by 10 blades, that had the tip shroud rear seal bent rearward.

[25] Shingled is the condition of the shroud of one blade overlapping the shroud of an adjacent blade in lieu of abutting at the contact surfaces.

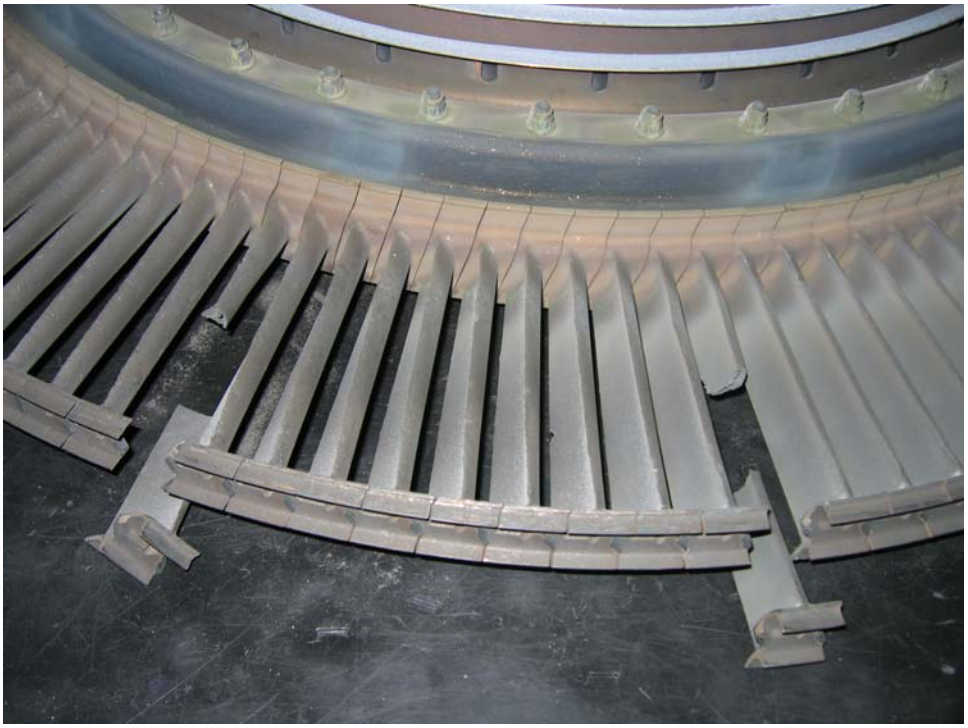

Photo 23: 3rd stage turbine blades showing random broken blades (Boeing)

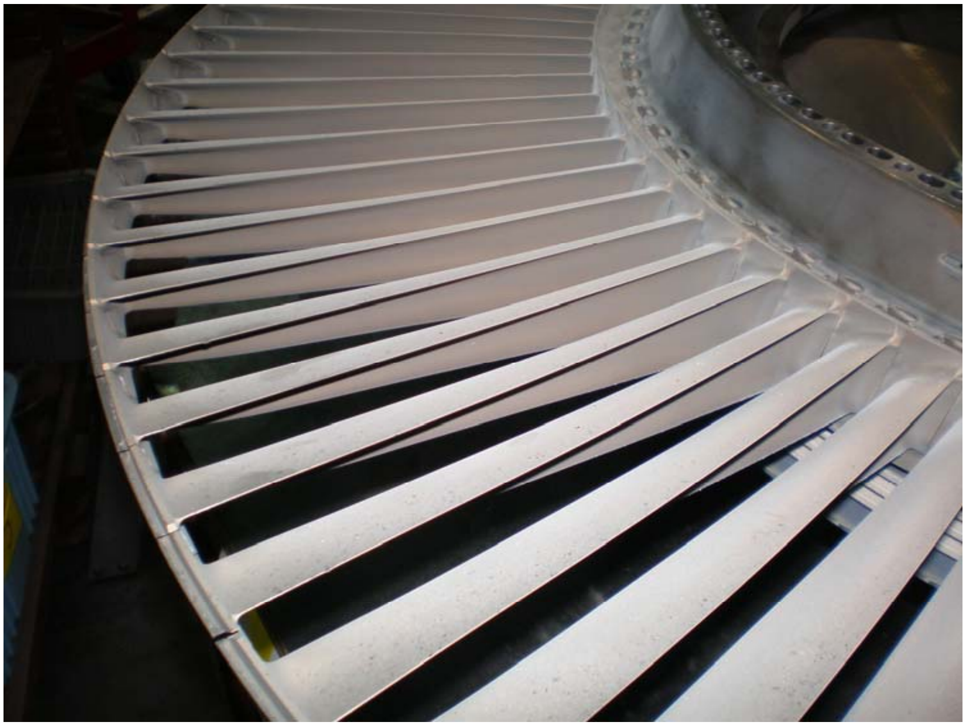

Photo 24: 4th stage turbine blades showing impact marks on airfoils

Photo 25: 5th stage turbine blades

There were three 3rd stage turbine vane clusters, two that were adjacent, that had 1/4- to 1/2-inch deep gouges on the vanes' leading edges adjacent to the outer platform. Most of the LPT vanes had nicks and dents on the airfoil surfaces. The damage to the LPT vane airfoils was progressively lighter from the front to the rear of the module.

10.7 Exhaust

The turbine exhaust case was in place between the LPT case and the turbine exhaust duct. The turbine exhaust case struts did not have any apparent damage.

The exhaust duct was in place on the rear flange of the turbine exhaust case. The interior of the exhaust duct did not have any apparent damage.

10.8 Oil system and bearings

The oil in the oil tank was up to the bottom of the scupper. The oil was dark in color, but did not have an acrid odor. When the oil was drained from the tank through a screen, there were several small metallic shards collected in the screen. (Photo 26) When the oil was drained from the accessory gearbox, there was no debris collected in the screen. The oil filter had a few very small pieces of shiny metal and black-colored material in the filter element and there were several small pieces of shiny metal in the bottom of the filter bowl. (Photo 27)

Photo 26: Metal debris in screen from oil drained from engine oil tank

Photo 27: Debris in oil filter screen

The magnetic chip detectors (MCD) were pulled. The MCD for the No. 4 bearing compartment had metallic fuzz around the perimeter of the plug. (Photo 28) The master MCD from the oil tank had a few small metallic shards on the tip. (Photo 29) The remaining MCDs did not have any debris on the plugs.

Photo 28: Metallic material on No. 4 bearing MCD (P&W)

Photo 29: Metallic material on master MCD (P&W)

With the radial drive shaft still installed, it was not possible to rotate the main gearbox with a wrench and adapter. With the radial drive shaft and the starter removed, the main gear box could be rotated through the starter drive spline, but it rotated roughly and there was a grinding noise that could be heard.

The main gear box housing was intact and did not have any indications of distress. The oil scavenge pump idler gear mount bolt studs were sheared off. The sheared off studs with the nuts still in place were found on the bottom of the gearbox housing. All of the gearbox gears and bearings were wet with oil, rotated freely, and did not have any rotational damage. Delta Air Lines reported that the sheared off idler gear bolt studs was a recurring maintenance issue on the PW2037 engine. The oil scavenge pump was disassembled and revealed the pump walls had circumferential scoring.

The No. 1 and 2 bearings were intact, wet with oil, free to rotate, and did not have any rotational damage.

The engine was not disassembled sufficiently to expose the No. 3 bearing. But with the compressor rotor in the vertical build stand, the rotor rotated freely and smoothly on the No. 3 bearing.

The No. 4 bearing housing cover was in place and intact. The interior surface of the No. 4 bearing housing cover had a black coating. The interior of the bearing housing also had an acrid smell. The No. 4 bearing support was broken through the race track slots 360 degrees around and the aft end was rotated and telescoped through the forward end. The No. 4 bearing was intact and wet with oil, but the ends of the rollers had rotational scoring. (Photo 30)

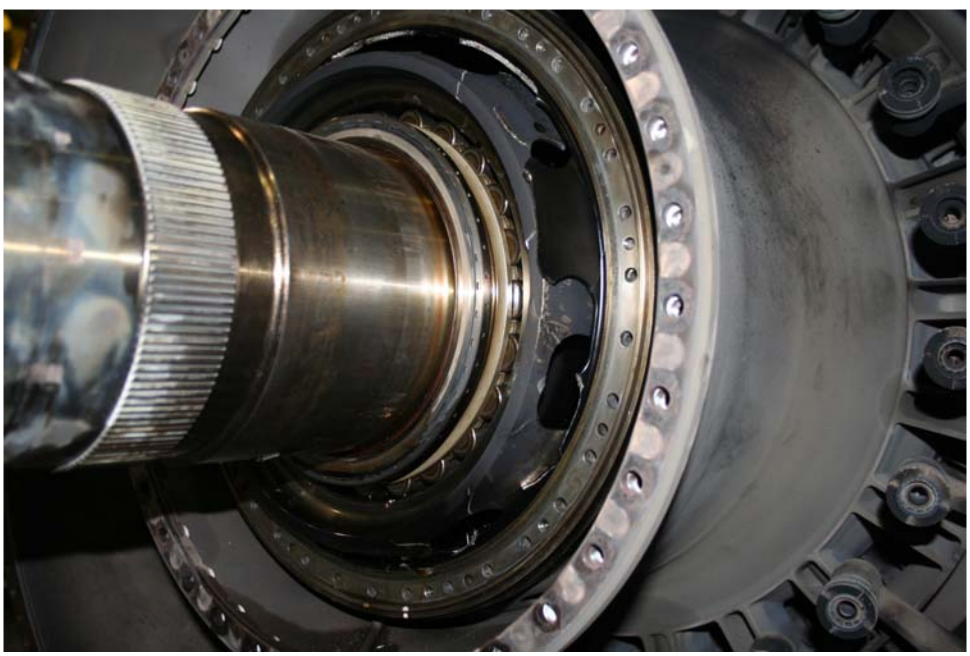

Photo 30: No. 4 bearing showing roller ends and broken housing (P&W)

The No. 5 bearing compartment did not have any coke.[26] The No. 5 bearing was intact, did not have any rotational damage, and was wet with oil.

[26] Coke is the hard, crystalline residue of turbine engine oil.

The rear of the No. 5 bearing cover was clean and did not have any soot or coke buildup.

There was a slight amount of coke built up on the inside of the turbine exhaust case boss for the No. 5 bearing scavenge tube.

10.9 Core cowl

The left side core cowl had a 12 3/4-inch long circumferential by 5-inch wide axial hole at about 8 o'clock, 19-inches forward of the rear flange, centered between the ribs. (Photo 31) There was a 5-inch long circumferential crack at 8:30 o'clock in line with the hole. The core cowl was buckled on either side of the crack and hole. The total length of the damaged area was about 22-inches long. There were no indications of an under cowl fire. The latches and hinges were intact.

Photo 31: Hole in left core cowl

There were several pieces of metallic debris found inside the core cowl. Some of the debris was confirmed by part number and visual comparison to be 2nd stage turbine outer air seal segments.

11.0 Crew statements

11.1 Pilots

The two pilots submitted individual statements of the incident. The pilots stated that shortly after the application of takeoff thrust just after the EPR [engine pressure ratio[27]] switch had been pushed, they heard a loud bang, what one of the pilots referred to as a compressor stall.[28] The pilots stated that the takeoff was discontinued below 80 knots and they notified the control tower. The pilots also stated that they made an announcement to the passengers to remain seated and await further instructions. The pilots also stated that shortly after they made their initial announcement to the passengers, there was a right engine fire warning. The pilots stated that they then declared an emergency and requested the emergency equipment. The pilots stated that they accomplished the QRH [quick reference handbook] "ENGINE FIRE OR SEVERE DAMAGE OR SEPARATION" checklist up through pulling the fire switch. The pilots stated that by the time they pulled the fire switch, the fire warnings had ceased. The pilots stated that after the airport fire department personnel had determined there was no fire and Delta maintenance personnel had determined the airplane was safe to taxi, the airplane was taxied under its own power without further incident back to the terminal where the passengers deplaned normally.

11.2 Flight attendants

The four flight attendants provided individual statements of the incident. The flight attendants stated that shortly after the beginning of the takeoff roll, one estimated about 5 seconds, they heard a very loud bang and the airplane came to a stop immediately thereafter. All four of the flight attendants stated that the captain made an announcement to advise what had happened and requested the passengers to remain seated. All four of the flight attendants also stated that they looked out the windows adjacent to their assigned seats. The flight attendants in the forward and rear portions of the cabin stated that they did not see any fire; however, the flight attendant in the mid-cabin area stated that when she looked out the 2R [right] door[29] window that she momentarily saw flames from the right engine's tailpipe. The two flight attendants that were seated in the forward jump seats reported hearing the fire bell in the cockpit. The flight attendants stated that the captain made several more announcements to state that there had been a fire in the right engine and that even though the fire had been extinguished with the built in fire extinguishers, the fire department was still going to go out to the airplane to make sure the fire was out. The flight attendants reported that the passengers remained calm and in their seats throughout the incident.

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[27] Engine pressure ratio, EPR, is a measurement of engine power as a ratio of the total pressure of the gases in the exhaust pipe divided by the total pressure of the air entering the engine inlet.

[28] A compressor stall, which is also referred to as a compressor surge, is a disruption of airflow through a jet engine and are typified by loud bangs and flames from the engine's inlet and/or tailpipe.

[29] The Boeing 757-200 airplane is equipped with three main cabin doors on each side of the airplane that are numbered 1, 2, and 3 from nose to tail and furthered identified with an L or R to signify the left or right, respectively, side of the airplane. Door 2R would be the mid cabin door just forward of the wing and engine on the right side of the airplane.

<u>ATTACHMENTS</u>

1. Las Vegas International Airport airport diagram

2. Delta Air Lines' Life Limited Part History record for HPT stage 2 hub PN 1B6602, SN DKLBA86546

3. Delta Air Lines' shop overhaul record for HPT stage 2 hub PN 1B6602, SN DKLBA86546

4. 2nd stage turbine blade front retaining plate PN 1B0815 inspection results

5. P&W 14 CFR 21.3 report to FAA for HPT stage 2 hub PN 1B6232 SN DKLBA84592 operated by American Airlines

6. Delta Air Lines Shop Order G05043 for American Airlines HPT 2nd stage turbine hub, PN 1B6232 SN DKLBA84592

7. Delta Air Lines' Life Limited Part History record for HPT stage 2 hub PN 1B8002, SN DKLBCT5130

8. Delta Air Lines Shop Order R83057 for Delta Air Lines HPT 2nd stage turbine hub, PN 1B8002, SN DKLBCT5130