

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

July 7, 2017

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: ENG16IA001

A: INCIDENT

Location: Russian airspace on Airway B241 near GITRU fix
Date: October 2, 2015
Time: About 0500 UTC
Aircraft: Boeing 747-451, N662US, Delta Air Lines flight 158

B: POWERPLANTS GROUP

Investigator-in-Charge:	Gordon J. Hookey National Transportation Safety Board Washington, D.C.
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C: SUMMARY

On October 2, 2015, at about 0500 coordinated universal time, Delta Air Lines flight 158, a Boeing 747-451 airplane, N662US, sustained low-pressure turbine (LPT) damage and a loss of power in the No. 3 engine, a Pratt & Whitney (P&W) PW4056, while in cruise flight in Russian airspace on the B241 airway near the GITRU fix. The pilots reported that about 3:40 hours after takeoff, they heard a loud band that was followed by the No. 3 engine's N1¹ rpm decreasing, while the exhaust gas temperature (EGT) increased. The pilots stated that they shut down the engine, declared an emergency with Russian air traffic control, and diverted to Tokyo-Narita International Airport (NRT), Tokyo, Japan where the airplane landed without further incident. The airplane was operating on an instrument flight rules flight plan under the provisions of 14 Code of Federal Regulations Part 121 as an international passenger flight from Seoul, Korea to Detroit, Michigan. There were no injuries to the 4 pilots, 14 flight attendants, and 316 passengers on board.

The engine was disassembled and examined at Delta's Technical Operations Center on October 20 to 23, 2015, in the presence of members of the Powerplants Group. The examination of the engine revealed one 3rd stage vane cluster was completely missing except for a small portion of the bolt hole tab that remained attached to the inner transition duct support. A portion of a vane cluster's inner shroud that included the ends of three airfoils was found in the 3rd stage turbine plane of rotation near the location of the missing vane cluster.

The metallurgical examination of pieces from the engine's LPT was accomplished at Pratt & Whitney's Materials Laboratory in East Hartford, Connecticut. The examination of the 3rd stage vane cluster bolt hole tab that remained attached to the inner transition duct revealed evidence of fretting. The examination of the other 3rd stage vane clusters that remained in place also showed evidence of fretting on the bolt hole tab. The examination of the piece of the 3rd stage vane cluster inner shroud revealed evidence of fatigue that had originated on the aft side of forward flange and progressed forward. The examination of the inner shroud fragment also revealed a wear pattern that suggested the vane cluster had shifted out of position. The

¹ N1 is the low-pressure rotor speed.

examination of the LPT case revealed wear in the 3rd stage turbine vane hooks at the location of the missing vane cluster as well as two nearby locations.

D: DETAILS OF INVESTIGATION

1.0 Engine information

1.1 Engine description

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 a 4-stage 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).² When the PW4056 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).³

1.2 History

1.2.1 Engine history

The engine's serial number (SN) is 717530. According to Delta Air Lines' records, the engine had accumulated 94,778 hours time since new and 11,814 cycles since new, 35,545 hours and 4,362 cycles since the last heavy maintenance, and 29,194 hours and 3,532 cycles since the last shop visit. The last heavy maintenance was accomplished on the engine in October 2005 at P&W's Cheshire Engine Center, Cheshire, Connecticut.⁴ (Attachment 1)

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

³ When the PW4056 engine is installed on a Boeing 767 airplane, the maximum continuous thrust rating is 49,530 pounds, flat-rated to 77°F (25°C).

⁴ P&W's Cheshire Engine Center was a Federal Aviation Administration-certificated Part 145 repair station, No. PQBR676X. The Cheshire Engine Center ceased operations in 2011.

1.2.2 Low pressure turbine module history

The LPT module installed in the engine was SN D17579. Delta Air Lines' maintenance records show LPT module SN D17579 had accumulated 95,180 hours time since new, 11,623 cycles since new, 52,987 hours since the last heavy maintenance and 6,546 cycles since the last heavy maintenance. The engine had been received by the Cheshire Engine Center with LPT module SN D17531 installed. The records show that Cheshire swapped out LPT module SN D17531 for LPT module SN D17579 from Northwest Airlines⁵ PW4056 engine 717684 to expedite the engine build. (Attachment 2) The records further show that at the time LPT module D17579 was installed in the engine at the Cheshire Engine Center in October 2005, it had already accumulated 59,635 hours since new, 7,261 cycles since new, 17,441 hours since the last heavy maintenance, and 2,184 cycles since the last heavy maintenance. (Refer to Attachment 1) For the 3rd stage inner and outer duct segments, the records were annotated ND NR, which stands for not disassembled, not required. (Attachment 3) For the LPT case modification for the 3rd stage through the 6th stage anti-rotation slots, the records were annotated PCW, which stands for previously complied with. (Attachment 4) For the 3rd stage turbine vane clusters' modification to remove material from the gussets, the records were marked PCW. (Attachment 5)

2.0 3rd stage turbine vane clusters

2.1 3rd stage turbine vane cluster No. 29

2.1.1 Disassembly

The No. 29⁶ 3rd stage turbine vane cluster was missing from the turbine case at about 8:30 o'clock.⁷ (Photo No. 1) The bolt hole tab from the missing cluster remained attached to the inner transition duct support. The fractured end of the bolt hole tab and the adjacent side of the nut were burnished. (Photo No. 2)

⁵ Northwest Airlines merged with Delta Air Lines in 2008.

⁶ Gas turbine engine industry convention is to number parts in a clockwise pattern, as viewed from the rear looking forward, with the No. 1 part at the 12:00 o'clock, or top dead center, position.

⁷ All references to position or direction, as referenced to the clock, will be as viewed from the rear looking forward, unless otherwise specified.



Photo No. 1: View from the front of the location of the missing 3rd stage turbine vane cluster. (Delta)



Photo No. 2: Close-up view of bolt hole tab and retaining nut that remained attached to the inner transition duct. (P&W)

A piece of a 3rd stage turbine vane cluster inner shroud was recovered from the debris in the LPT case's 3rd stage turbine rotor's plane of rotation at about 8 o'clock, near the location of

the missing cluster. (Photo No. 3) The piece was about 1.5-inches wide from the front face or the inner shroud and included the leading edges of three airfoils that were about 0.62-inches long. The piece had three distinct circumferential grooves that were worn into the inner shroud. There was a circumferential groove across the underside of the shroud just forward of the honeycomb and the normal operating position of the shroud that corresponded to the 3rd stage rotating air seal knife edge. (Photo No. 4) There was a circumferential groove worn into the rear of the inner shroud and airfoils that corresponded to the leading edge of the rim of the 3rd stage rotating air seal. (Photo No. 5) And there was a groove on the flow path side of the inner shroud that cut across three airfoils on the forward side of the fragment that corresponded to the rim of the 3rd stage rotating air seal. (Photo No. 6) There was no heat discoloration or any cracking around any of the grooves cut in the piece of the 3rd stage turbine vane inner shroud.



Photo No. 3: View from the rear of the location of the missing 3rd stage vane cluster with an arrow pointing to the piece of 3rd stage vane cluster inner shroud. (P&W)



Photo No. 4: Side view of piece of 3rd stage turbine vane cluster inner shroud showing relation of circumferential rub mark on underside of shroud to 3rd stage rotating air seal knife edge.
(P&W)



Photo No. 5: Side view of 3rd stage vane cluster inner shroud showing the circumferential rub mark on the rear of shroud in relation to the edge of the rim of the 3rd stage rotating air seal.
(P&W)



Photo No. 6: View of 3rd stage turbine vane cluster inner shroud showing relation between rub mark across the airfoils in relation to the 3rd stage rotating air seal. (P&W)

2.1.2 Metallurgical examination

The examination of the No. 29 3rd stage turbine vane cluster bolt hole tab that remained attached to the inner transition duct revealed wear that was consistent with fretting, a high frequency low amplitude relative motion. The fretting wear that was observed on the fractured tab was similar to that observed on the other 3rd stage turbine vane cluster bolt hole tabs. The fracture surface on the tab was smeared and there were no resolvable features.

The examination of the fragment of the inner shroud that was recovered revealed remnants of fatigue on the counterclockwise (CCW) side of the forward flange. The fatigue had progressed forward from multiple origins along the aft surface of the flange. The fatigue had progressed to a maximum depth of 0.026 inches. However, the fracture surface beyond the fatigue was smeared and it could not be determined if the fatigue had progressed further. The examination of the inner shroud fragment also revealed two wear patterns on the CCW mating face consistent with contact with the No. 28 3rd stage turbine vane cluster. There was one wear pattern that was indicative of the normal installed position of the vane cluster and there was a second wear pattern that was indicative of the vane cluster having moved out of position. There were no wear patterns on the clockwise (CW) side of the inner shroud fragment.

2.2 Remaining 3rd stage turbine vane clusters

All of the remaining 3rd stage turbine vane clusters remained in place secured to the LPT case and the inner transition duct assembly. The inner transition duct tabs on the 3rd stage turbine vane clusters were the rounded configuration. The No. 26 3rd stage turbine vane cluster had heavy tapered wear on the aft foot that engages with the LPT case rail. The 3rd stage turbine vane clusters that remained in the LPT case did not have any circumferential rub marks on the aft face or the undersides of the inner shrouds. The 3rd stage turbine vane clusters' airfoils had nicks and dents along the leading and trailing edges and there was material missing from the trailing edges up to about 2.27-inches long radially and about 0.5-inches axially. (Photos No. 7) The circumferential face of the outer shroud of 3rd stage turbine vane cluster No. 30 was heavily battered.



Photo No. 7: Other 3rd stage turbine vane clusters, trailing edge on the top and leading edge on the bottom.

From the front of the module, the radial step between the adjacent inner and outer shroud segments did not exceed 0.030-inches. The circumferential gap between adjacent inner and outer 3rd stage cluster shrouds was greater than 0.010-inches except between the outer diameter of vane clusters Nos. 31 and 32 where the 0.010-inch feeler stock could not be inserted between the clusters. The measurements were accomplished in accordance with Engine Manual Task 72-00-53 inspection Check 10.

The LPT case with the 3rd stage turbine vane clusters still installed was shipped to P&W, East Hartford, Connecticut for further examination. On April 4, 2016, members of the Powerplants Group convened at P&W to remove the inner transition duct assembly, 3rd stage turbine vane clusters, and outer transition duct segments. The breakaway torque of the nuts

securing the inner transition duct segments to the 3rd stage turbine vane clusters was measured in the tightening direction using a Snap-On 0-1200 inch-pounds (in-lbs) digital torque wrench. The torque wrench had a sticker indicating the calibration was valid through July 19, 2016. The assembly torque for the nuts securing the inner transition ducts to the 3rd stage turbine vane clusters is 180 – 200 in-lbs (Reference PW4000 94 inch EM 72-53-00-400-001 Assembly). All of the measurements were in inch-pounds (in-lbs). The measurements were started at the nut at vane cluster No. 30, which was adjacent to the location of liberated vane cluster, No. 29, and then continued in a clockwise direction, as viewed from the rear. The breakaway torque measurements for the nuts securing the inner transition ducts to the 3rd stage turbine vane clusters are listed in Table 1.

Table 1: Inner transition duct securing nut breakaway torque
(All measurements are in-lbs.)

No.	Torque	No.	Torque	No.	Torque
30	663	4	645	17	641
31	638	5	678	18	740
32	640	6	700	19	611
33	735	7	674	20	706
34	629	8	668	21	638
35	680	9	671	22	661
36	766	10	568	23	733
37	702	11	716	24	700
38	689	12	692	25	618
39	517	13	617	26	638
1	605	14	556	27	686
2	571	15	651	28	646
3	740	16	645	29	706

2.3 Corrective actions

On November 7, 2012, the FAA issued Airworthiness Directive (AD) 2012-14-09 for PW4000-94 inch and PW4000-100 inch engines because of reports of 3rd and 4th stage turbine vane fractures. Specific to the 3rd stage of the LPT, the AD requires a dimensional inspection of the turbine vane clusters and the LPT case. Specific to the 4th stage, the AD requires an inspection of the 4th stage turbine vane clusters and removal of those turbine vane clusters that have a non-conforming airfoil fillet radii and vane clusters that have had more than one strip and recoating repair accomplished. The AD also requires the disassembly and reassembly of the HPT 2nd stage turbine rotor and the LPT 3rd stage turbine rotor. The AD stated that it was issued to prevent 3rd and 4th stage turbine vane fractures in the LPT that could lead to damage to the engine, uncontained engine failure, and damage to the airplane.

3.0 *Remainder of low pressure turbine*

3.1 Low pressure turbine case

3.1.1 Examination

The LPT case was PN 50N348-003, SN VZ7299. The LPT case was intact, but had two small holes on the left side and one on the right side of the case. There was an approximately 0.5-inch long circumferential by 0.38-inch axial hole at about 9:15 o'clock (Photo No. 8) and an approximately 0.62-inch long circumferential by 0.56-inch wide axial hole at about 10:30 o'clock (Photo No. 9) in the plane of the 3rd stage turbine rotor. There was an approximately 0.69-inch long axial by 0.44-inch wide circumferential hole at about 2:45 o'clock in the plane of the 5th stage turbine rotor. (Photo No. 10) There were lifted tabs of metal adjacent to all three holes on the clockwise side of each hole. There were several bulges, some with splits in the metal, around the circumference of the LPT case in the planes of the 3rd, 4th, and 5th stage rotors. The exterior of the LPT case had seven rows of light-colored marks that were coincident with the impingement holes in the cooling air tubes.

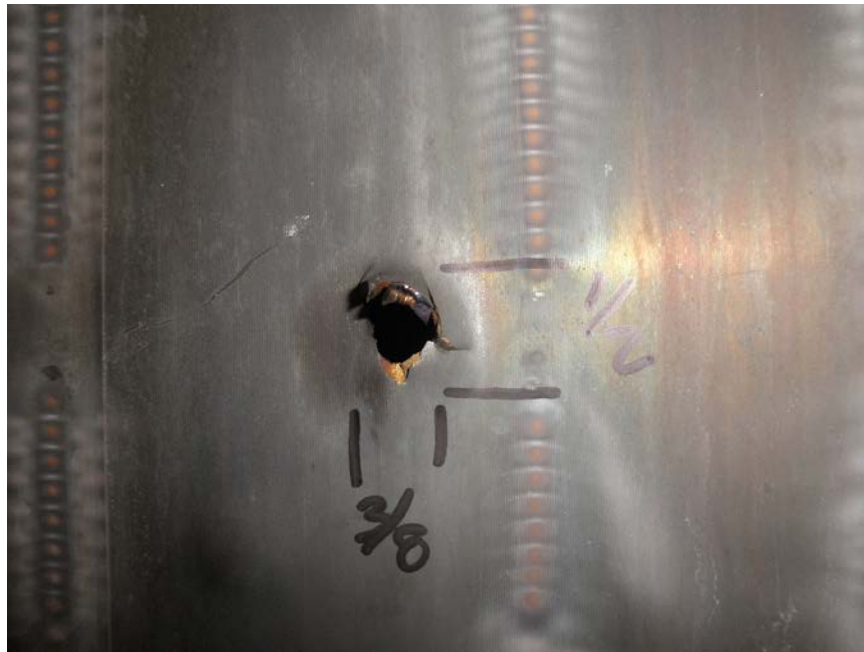


Photo No. 8: Hole in LPT case in place of 3rd stage turbine rotor at 9:15 o'clock.



Photo No. 9: Hole in LPT case in plane of 3rd stage turbine rotor at 10:30 o'clock. (P&W)

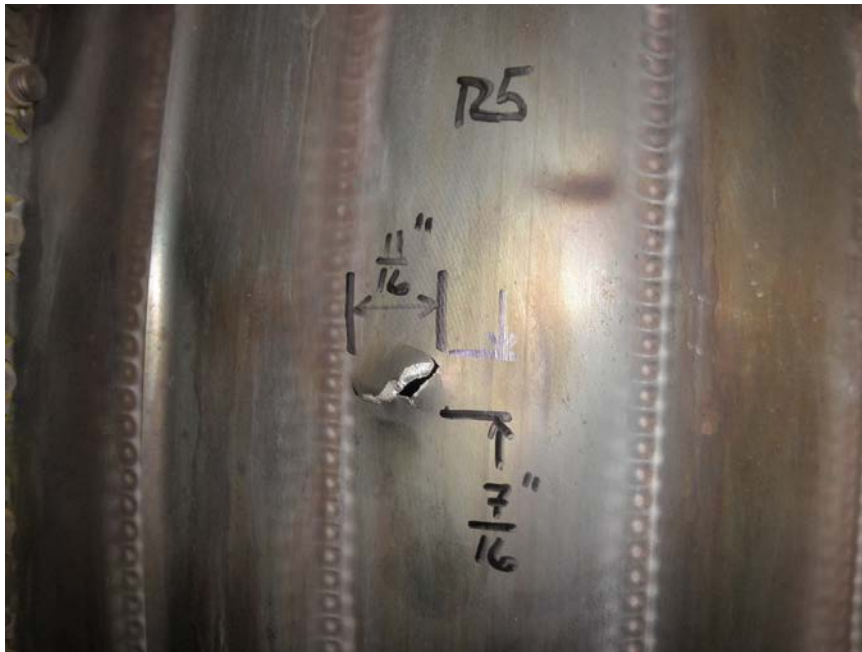


Photo No. 10: Hole in LPT case in plane of 5th stage turbine rotor at 2:45 o'clock.

The LPT case 3rd stage vane hooks had wear 360° around that was typical for a service run case. The wear was most pronounced at the location of vane cluster No. 29. The hooks at vane clusters Nos. 26 and 27 had wear that was more than typically observed. There were randomly located cracks in the hooks around the circumference of the LPT case, but the hook at the location of vane cluster No. 29 had three visible cracks.

The LPT case vane hooks and rails in the 4th, 5th, and 6th stages did not have any notable distress. In the area of the missing 3rd stage turbine vane cluster, the case hook had three axial cracks and appeared to have tapered wear on the inside of the hook. The LPT case's 3rd stage turbine vane cluster aft rail in the area of the missing cluster was heavily battered as was the heatshield underlying that vane cluster. There was tapered wear noted to the case rail in the area of 3rd stage turbine vane cluster No. 26.

The inner diameter of the LPT case under the outer transition ducts had black stains extending from the impingement holes consistent with cooling air flow.

3.1.2 Metallurgical examination

The examination of the LPT case was focused on the hooks and rails associated with the outer transition ducts and 3rd stage turbine vane clusters.

The examination of the outer transition ducts' forward hooks revealed wear on the outer diameter. The wear on the ducts' hooks outer diameters was heavier on the CCW side of the duct in comparison to the wear on the CW side of the duct. The most significant wear was observed on the hooks for outer transition duct No. 6, which is a borescope location. The examination of the LPT case's outer transition duct aft rail-3rd stage turbine vane cluster front hook rail inner diameter revealed wear from the outer transition ducts' aft tabs. The wear was heaviest at the locations of outer transition ducts Nos. 1, 4, 5, 7, and 8.

The examination of the LPT case's 3rd stage turbine vane cluster forward hooks revealed wear at the hooks for vane clusters Nos. 26, 27, and 29. The wear was a chamfering of the aft outer diameter corner of the hook. The wear was most pronounced on the CW side at the No. 29 turbine vane cluster. The LPT case's outer transition duct aft rail-3rd stage turbine vane cluster front hook had several axially oriented cracks. The LPT case's 3rd stage turbine vane cluster aft rail had impact and battering secondary damage at the location of vane cluster No. 29. Because of the secondary damage, it was not possible to assess the condition of the rail at that location. The rail had significant wear at the location of vane clusters Nos. 26 and 27 that had a chamfered appearance consistent with motion between the LPT case and the 3rd stage turbine vane clusters. The remainder of the circumference of the 3rd stage turbine vane clusters had similar witness marks without the wear.

3.1.3 Dimensional inspection

P&W accomplished a dimensional inspection of the LPT case that showed the case was oval-shaped oriented on an approximately 1:30-to-7:30 o'clock axis with the case being out-of-round upwards of about 0.080 inches.

3.2 Transition ducts

3.2.1 Examination

The outer and inner transition duct segments were all in place and did not have any apparent damage. The feather seals were in place between the 1 and 2, 3 and 4, 6 and 7, 9 and 10, 10 and 11, 11 and 12, and 12 and 13 outer transition duct segments. There were portions of the feather seals between the 2 and 3 and 8 and 9 outer segments. The feather seals were missing from between the 4 and 5, 7 and 8, and 13 and 1 outer segments. There were two seals from the front side of the outer transition duct aft rail in front of the outer transition liner at about 6 o'clock. There was a seal from the front side of the outer transition liner aft rail wrapped around the leading edge of a 3rd stage turbine vane cluster airfoil. On the aft end of the outer transition duct at the location of the missing 3rd stage turbine vane cluster about 8:30 o'clock, the cover plate over the slot was missing. The outer transition duct segment in front of the location of the missing 3rd stage turbine vane cluster was gouged on the aft edge.

The outer transition duct segment seal plates were all in place except for parts of segments Nos. 5 and 10. On segment No. 5, the CCW seal plate was twisted and fragmented and not all of the pieces could be located. On segment No. 10, almost all of the CW seal plate was missing. The No. 10 CW seal plate was the location of the missing 3rd stage turbine vane cluster. The results of the examination of the outer transition duct segment seal plates are listed in Table 2.

Table 2: Outer transition duct segment seal plate inspection

Seal Plate No.	Counterclockwise segment	Clockwise segment
1	The CCW seal plate was in place, but was loose. Both of the rivets were in place.	The CW seal plate was in place, but was loose. The rivets were in place, but the CW rivet was partially pulled through the hole.
2	The CCW seal plate was in place and was loose. Both of the rivet holes were open.	The CW seal plate was in place and was loose. Both of the rivet holes were open.
3	The CCW seal plate was in place and was loose. Both of the rivet holes were open. The CW rivet hole was elongated in the CW direction and was angled slightly inward.	The CW seal plate was in place and was loose. Both of the rivet holes were open.

4	The CCW seal plate was in place and was loose. Both of the rivet holes were open.	The CW seal plate was in place and was loose. Both of the rivet holes were open.
5	The CCW seal plate was fragmented and twisted. Not all of the pieces of the CCW seal plate could be accounted for.	The CW seal plate was in place and intact. The CCW rivet was in place, but the CW rivet hole was open.
6	The CCW seal plate was in place and intact. Both of the rivet holes were open.	The CW seal plate was in place and intact. The CCW rivet was partially pulled through the hole and the CW rivet hole was open.
7	The CCW seal plate was in place and intact. Both of the rivet holes were open.	The CW seal plate was in place and intact. The CCW rivet was in place and the rivet head flush with the surface of the plate. The CW rivet hole was open.
8	The CCW seal plate was in place and intact. Both of the rivet holes were open.	The CW seal plate was in place and intact. Both of the rivet holes were open.
9	The CCW seal plate was in place and intact. Both of the rivets were in place and the rivet heads were flush with the surface of the plate.	The CW seal plate was in place and intact. Both of the rivets were in place and the rivet heads were flush with the surface of the plate.
10	The CCW seal plate was in place and intact. The rivets were in place and the rivet heads were flush with the surface of the plate.	The CW seal plate was missing except for the CW-most end that was about 0.85-inch long. (This was the location of the missing 3rd stage turbine vane cluster.)
11	The CCW seal plate was in place and intact. Both of the rivet holes were open.	The CW seal plate was in place and intact. Both of the rivets were in place and the rivet heads were flush with the surface of the plate.
12	The CCW seal plate was in place and intact. Both of the rivet holes were open.	The CW seal plate was in place and intact. Both of the rivet holes were open.
13	The CCW seal plate was in place. There was an approximately 0.15-inch long (circumferential) step worn into the CCW side of the outer diameter	The CW seal plate was in place. The seal plate was displaced approximately half of the transition duct segment pitch. The outer approximately 0.08-inch of

	ears that corresponded to the tabs on the otter transition duct. Both of the rivet holes were open.	the ears were worn away. Both of the rivet holes were open.
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3.2.2 Metallurgical examination

The visual examination of outer transition duct No. 10, which was the location of 3rd stage turbine vane cluster No. 29, showed it did not have any significant wear to the inner diameter surface of the aft tabs. The examination of the duct's aft tab inner diameters for the adjacent vane clusters, Nos. 28 and 30, showed that those tabs had heavier wear. The examination of the other outer transition ducts showed that all had some level of wear on the inner diameter of the tabs. The examination showed that the wear varied from duct segment to duct segment and even between tabs on the same duct segment.

The examination of the inner transition duct segments revealed wear between the aft side of the inner duct segments and the 3rd stage turbine vane clusters as well as wear between individual adjacent segments. The wear between the inner transition duct segments and the 3rd stage vane was heaviest on the CCW side of each vane location. When the inner transition ducts were removed from the LPT case, the wear between the individual duct segments and the aft seal portion of the inner transition duct segment was heaviest on the CW side. This wear on the inner transition duct segments was heaviest on the segment that corresponded to 3rd stage turbine vane cluster No. 29, with less extensive wear patterns observed at locations Nos. 10, 11, 16, 17, and 18. The examination of inner transition duct segment No. 29 revealed extensive wear patterns on the mating surfaces on the CCW and CW sides that indicated the segment had been displaced radially inward as well as aft of the adjacent segment. The wear patterns were oxidized suggesting that the segment had been displaced for some period of time.

3.2.3 Transition duct heatshields

The four transition duct OD heatshield segments were all in place and the shiplap tabs were in place with their rivets all in place.

The trailing edge spring seal exhibited typical service wear 360 degrees around except at three locations. From the center of vane cluster No. 39 to the center of vane cluster No. 3, the aft approximately 0.650 inch of the seal was broken away. There was about a 1.2-inch long crack from the CCW end of the missing spring seal progressing forward. From the center of vane cluster No. 9 to the CW end of vane cluster No. 13, the wear extended into the underlying heatshield. At the location of vane cluster No. 9, there was about a 2-inch long circumferential hole and at the location of vane cluster No. 12, there was about a 2.75-inch long circumferential hole. There was about a 1.1-inch long crack progressing forward from the center of the 2.75-inch hole at the location of vane cluster No. 12. And at vane cluster No. 21, there was about a 0.300-inch hole.

3.3 3rd stage turbine

The 3rd stage turbine vane heatshield was in place 360° around. In the area of the missing 3rd stage turbine vane cluster, the heatshield was battered and dented. There were dark-colored impingement marks on the forward inner diameter surface that were uniformly located around the circumference of the heatshield.

The 3rd stage rotating air seal was intact. The 3rd stage rotating air seal had an approximately 3.25-inch long section of the knife edge tip that was fractured down almost to the pedestal. The remainder of the 3rd stage rotating air seal had circumferential rub marks on the knife edge. The 3rd stage rotating air seal front face and integral arm outer diameter had circumferential rub marks with material transfer and heat discoloration.

The 3rd stage turbine disk was intact. The 3rd stage turbine disk rim rear face had circumferential scuff marks.

All of the 3rd stage turbine blade roots were in place in the disk. All of the 3rd stage turbine blades were fractured. Most of the 3rd stage turbine blades were fractured transversely across the airfoil adjacent to the blade root platform. (Photo No. 11) There were 16 3rd stage turbine blades that were fractured across the airfoil between about 0.5 and 1.5 inches above the blade root platform. The fracture surfaces on all of the 3rd stage turbine blades were coarse and grainy. (Photo No. 12) All of the 3rd stage turbine blades that had a partial airfoil were rubbed along the leading edges that remained. The 3rd stage turbine blade roots' rear face had circumferential scuff marks. There were four 3rd stage turbine blades, two adjacent, blades Nos. 8 and 9,⁸ and two randomly located, blades Nos. 102 and 123, that had portions of the inner or outer aft blade root flow guides broken off.

⁸ Blade No. 1 was identified as the blade in line with the disk balancing mark, a triangle and then the blades were numbered in the clockwise direction as viewed from the rear.

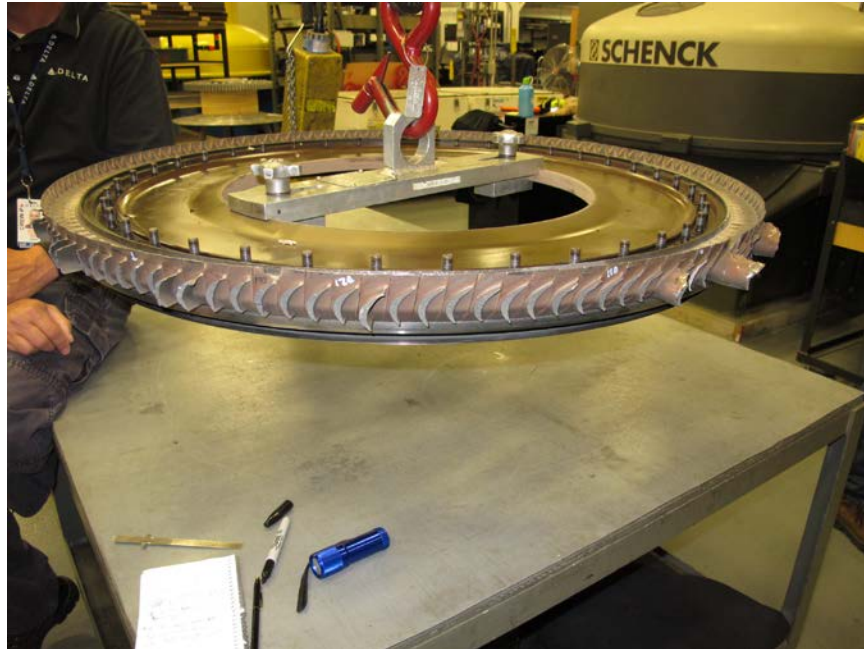


Photo No. 11: View of 3rd stage turbine disk showing it is intact and all of the blades were in the disk, but the airfoils are fractured. (P&W)

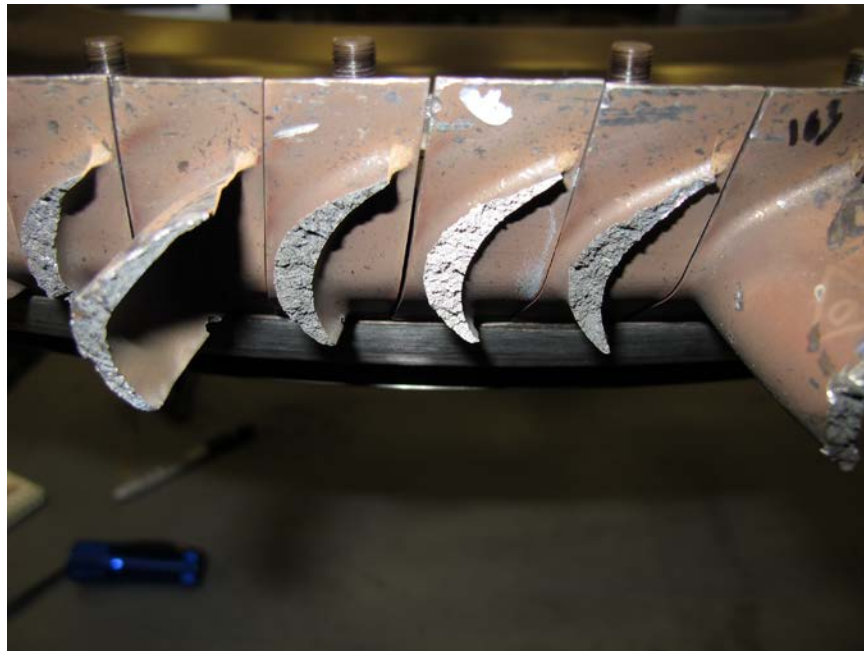


Photo No. 12: Close up view of fractured 3rd stage turbine blades showing coarse fracture surface. (P&W)

All of the 3rd stage blade outer air seals (BOAS) were heavily fragmented and broken up into pieces.

3.4 4th stage turbine

The 4th stage turbine vane clusters were all in place in the LPT case. (Photo No. 13)
The 4th stage turbine vane clusters did not have any fractured airfoils. The 4th stage vane cluster's inner shrouds were all aligned with the adjacent shrouds. The gussets and hooks did not have any cracking. There was no apparent clashing between the inner shrouds. The 4th stage turbine vane inner shrouds did not have any apparent wear in the pin pocket areas. There was no wear on the honeycomb. There were nicks and dents on the rear face of the clusters' rear foot. There were several vane clusters that had wear on the inner shroud contact surfaces. There was one cluster that had light wear on the pin pocket and a vane cluster had wear on the pin itself. There were a pair of adjacent clusters that had wear on the ends of the honeycomb. There were a pair of adjacent clusters that had galling on the inner shroud contact surfaces. The 4th stage turbine vane cluster airfoils had nicks and dents on the leading edges and were missing material from the leading edge up to about 2.75-inches long radial and 0.5-inches wide axial. (Photo No. 14)



Photo No. 13: View of 4th stage turbine vane clusters showing all are in place in the LPT case. (P&W)



Photo No. 14: Close up view of 4th stage turbine vane clusters showing damage to the leading and trailing edges of airfoils.

The 4th stage turbine disk and the integral spacers were intact. The 4th stage turbine disk had some circumferential scuff marks on the rear face of the rim. All of the 4th stage turbine blade roots were in place in the disk. All of the 4th stage turbine blades were fractured transversely across the airfoil adjacent to the blade root platform. (Photo No. 15) The fracture surfaces on all of the 4th stage turbine blades were coarse and grainy. (Photo No. 16) There were no circumferential rub marks on what remained of the blades' leading edges.

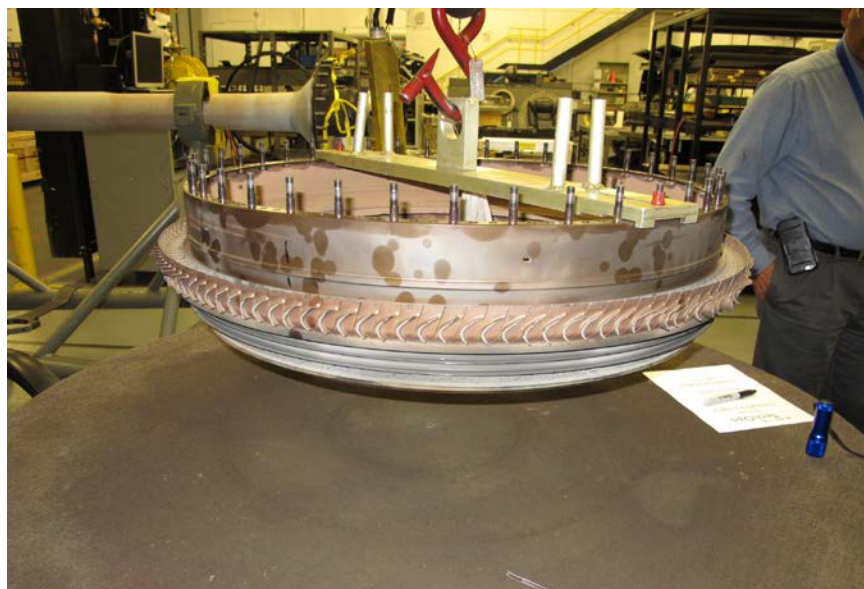


Photo No. 15: View of 4th stage turbine disk showing it is intact and all of the blades are in the disk, but are fractured across the airfoils. (P&W)



Photo No. 16: Close up view of fractured 4th stage turbine blades showing coarse fracture surface. (P&W)

The 4th stage rotating air seal was intact. The 4th stage rotating air seal front and rear knife edges had some light rub marks and small dents.

The 4th stage BOAS Nos. 1 through 4 between 12 and 2 o'clock were in place, but were heavily battered and the honeycomb was rubbed down to the base metal. The remaining 4th stage BOAS, Nos. 5 through 22, were accounted for, but the segments were heavily fragmented and broken up into pieces. The LPT case inner diameter, where the 4th stage BOAS segments and underlying insulation blankets were broken and missing, had circumferential scuffing and heat discoloration.

3.5 5th stage turbine

The 5th stage turbine vane clusters were all in place. (Photo No. 17) The Nos. 1, 2, 4 through 14, 17, 18, and 20 through 29 5th stage turbine vane clusters were full length with the inner and outer shrouds in place and engaged. The No. 3 cluster at about 12:30 o'clock and No. 19 cluster at about 7 o'clock had all three airfoils in the cluster broken at the outer end adjacent to the shroud and canted forward while the inner shroud remained engaged. The Nos. 3 and 17 5th stage turbine vane clusters were rubbed on the inner shroud aft face. The No. 17 5th stage turbine vane cluster had approximately 0.37- by 0.25-inch notches rubbed into the airfoils adjacent to the inner shroud. The Nos. 15, 16, and 30 through 36 5th stage turbine vane clusters consisted of only the outer shroud with the airfoils and inner shrouds missing. The 5th stage turbine vane cluster airfoil leading edges had nicks and dents and were missing sections up to about 2.5-inches long radial by 1-inch deep axial adjacent to the outer shroud. (Photo No. 18)

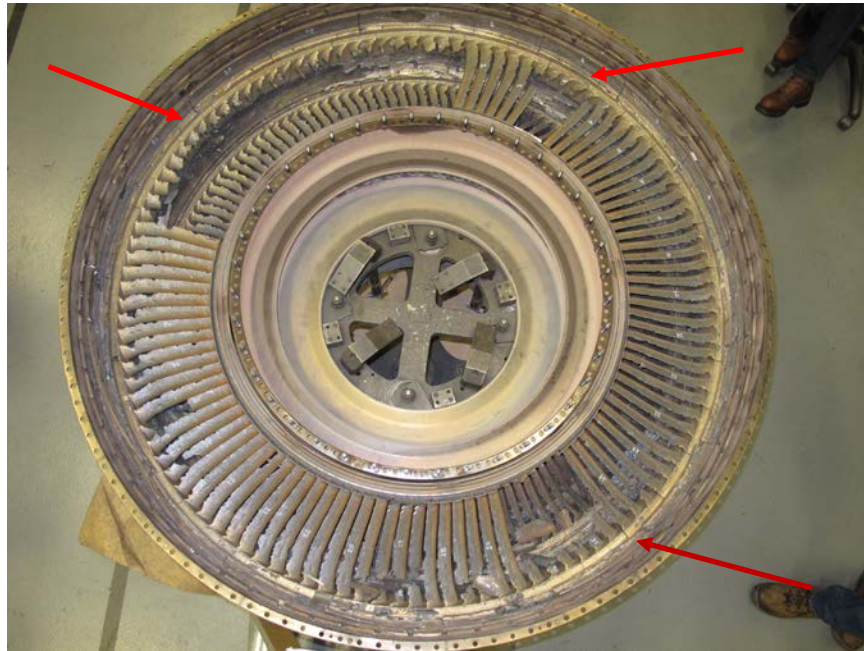


Photo No. 17: View of 5th stage turbine vane clusters showing all of the clusters or the clusters' outer shrouds remained in place. Arrows point to where only the outer shroud remained. (P&W)



Photo No. 18: Close up view of damage to leading edges of 5th stage turbine vane clusters. (P&W)

The 5th stage turbine disk and the drive cone were intact. (Photo No. 19) There were circumferential scuff marks on the rear face of the disk rim. All of the 5th stage turbine blade roots were in place in the disk. All of the 5th stage turbine blades were fractured transversely

across the airfoil adjacent to the blade root platform. On those 5th stage turbine blades that had part of the airfoil trailing edge remaining, all of them had an impact mark on the convex side of the airfoil. The fracture surfaces on all of the 5th stage turbine blades were coarse and grainy. (Photo No. 20) There were no circumferential rub marks on what remained of the blades' leading edges.



Photo No. 19: View of 5th stage turbine disk showing that it was intact. (P&W)



Photo No. 20: Close up view of 5th stage turbine blades showing coarse and grainy fracture surfaces. (P&W)

The 5th stage rotating air seal was intact. The 5th stage rotating air seal's forward knife edge seal was rubbed with heat discoloration and material transfer. The forward knife edge seal was fractured down to the pedestal for an arc of about 90 degrees. The aft 5th stage rotating air seal aft knife edge did not have any apparent damage. The thrust balance seal was intact and did not have any apparent damage.

The 5th stage BOAS were all in place. The 5th stage BOAS had heavy rubbing and gouging down to the base metal around the entire circumference. The No. 5 5th stage BOAS had an approximately 1.37-inch hole at the clockwise end that was coincident with the hole in the right side of the LPT case. The No. 7 5th stage BOAS had an approximately 1-inch hole in the center of the segment. The No. 8 5th stage BOAS had an approximately 3.25-inch long piece missing from the clockwise end. The No. 9 5th stage BOAS had an approximately 4-inch long piece missing from the counter-clockwise end of the segment and there were pieces of broken airfoil under the segment. The No. 10 5th stage BOAS had approximately 1.75 and 4-inch long sections of the segment missing. The No. 14 5th stage BOAS had an approximately 3-inch long section missing from the counter-clockwise end. The No. 15 5th stage BOAS had an approximately 1.5-inch long section missing from the clockwise end. The No. 19 5th stage BOAS had an approximately 3.5-inch long section missing from the center of the segment. At the locations where sections of the 5th stage BOAS were missing, the underlying insulation blanket was missing exposing the LPT case interior wall that had scuffing.

3.6 6th stage turbine

The 6th stage turbine vane clusters or the outer shroud of the cluster were all in place except for one cluster at about 8:30 o'clock that was missing. (Photo No. 21) The 6th stage vane clusters that were still intact were Nos. 5 through 15 between about 1 and 4 o'clock, No. 18 at about 5 o'clock, and No. 25 and 26 at about 8 o'clock. The complete vanes were heavily battered on the leading edges and convex surface of the airfoil at the trailing edge. The 6th stage turbine vane clusters had nicks and dents on the leading edges and large sections up to about 3.5-inches radial by 1-inch deep axial of the leading edge adjacent to the outer shrouds missing. The trailing edges and adjacent convex surfaces of the remaining airfoils had nicks, dents, and sections missing along their full length. (Photo No. 22) The remaining 6th stage turbine vane clusters were missing the airfoils and the inner shroud with only the outer foot remaining in the case. The sheet metal insulation blanket under where the missing vane cluster was located did not have any impact damage.



Photo No. 21: View of 6th stage turbine vane clusters with an arrow showing the location of the missing cluster. (P&W)



Photo No. 22: Close up view showing damage to 6th stage turbine vane cluster airfoil leading edges.

The 6th stage turbine disk and integral spacer were intact. (Photo No. 23) The 6th stage turbine disk's integral spacer knife edges were in place. The tips of the knife edges had a very light uniform fresh rub around their entire circumference. The hard face coating on both of the knife edges was chipped on the edge around the entire circumference. The rear face of the 6th

stage turbine disk and the outer diameter of the integral spacer had some random scuff marks. All of the 6th stage turbine blade roots were in the slots except for 12 randomly located blade roots that were missing. There were 10 6th stage blade roots recovered from the debris at the bottom of the LPT case. All of the 6th stage turbine blades, including those found at the bottom of the LPT case, were fractured transversely across the airfoil adjacent to the blade root platforms. All of the 6th stage turbine blades had the leading edge flow guides broken off except for an approximately 30 degree sector where the flow guides were intact. The fracture surfaces on all of the 6th stage turbine blades were coarse and grainy. (Photo No. 24) There were no circumferential rub marks on what remained of the blades' leading edges.



Photo No. 23: View of 6th stage turbine disk showing that it was intact. (Delta)



Photo No. 24: Close-up view of 5th stage turbine blades showing coarse and grainy fracture surfaces.

The 6th stage BOAS were all in place. The 6th stage BOAS had heavy rubbing and gouging down to the base metal around the entire circumference.

3.7 Low pressure turbine shaft

The LPT shaft did not have any circumferential rub marks. The LPT shaft between the forward end just aft of the splines and the bell appeared to have had the corrosion coating reapplied with a brush. The coating was flaking and peeling away from the forward end. The paint under the brushed-on coating had flaked and peeled away and on the bell had a smooth burnished appearance.

3.8 Cooling air manifolds

The upper and lower turbine cooling air manifolds and tubes were in place. The upper No. 2 turbine cooling air tube⁹ had an impact mark on the clamp at end of the tube at 9:15 o'clock (Photo No. 25) and there was an approximately 0.62-inch diameter dent with an approximately 0.18-inch long puncture at the bottom of the dent at about 10:30 o'clock. (Photo No. 26) The dent and the impact mark were both coincident with the holes in the LPT case in

⁹ The turbine cooling air tubes are numbered 1 through 7 from front to rear.

the plane of the 3rd stage turbine rotor. The cushions between the clamps and the cooling air tubes were in place and appeared to be in good condition. The turbine cooling air plenum had an impact mark adjacent to the hole in the LPT case in the plane of the 5th stage rotor.



Photo No. 25: Close-up view of dent on turbine cooling air manifold clamp. (P&W)



Photo No. 26: Close-up view of dent on inner surface of turbine cooling air manifold. (P&W)

4.0 *Remainder of engine*

4.1 Exterior examination

The engine was complete from the fan case front flange to the rear of the exhaust sleeve. The engine did not have any indications of an uncontainment, case rupture, or under cowl fire. The interior of the exhaust sleeve and the exterior of the exhaust plug had random small impact nicks, dents, and scratches.

There was no apparent damage to the front and rear engine mounts.

The fan rotated freely and the LPT rotated concurrently with the fan.

It was reported that there was no damage to the interior surfaces of the engine cowling and that they were returned to service when the engine was removed and replaced at NRT. It was also reported that there was no debris recovered from inside the engine cowling.

4.2 Fan

The fan case did not have any apparent damage. The fan blade rub strip did not have any rub marks. All of the fan exit guide vanes were in place and did not have any apparent damage.

The fan disk was intact. All of the fan blades were in place and did not have any apparent damage. None of the fan blades' mid span shrouds were shingled.¹⁰

4.3 Low pressure compressor

The LPC was not disassembled as part of the investigation.

4.4 Intermediate case

The engine was not disassembled sufficiently to examine the intermediate case.

¹⁰ Shingled is the condition where the mid span shroud of one fan blade overlaps the shroud of an adjacent blade in lieu of abutting at the contact surfaces.

4.5 High pressure compressor

The HPC was not disassembled as part of the investigation. However, a borescope inspection of the several stages of the HPC showed that the condition was consistent with a service run engine.

4.6 Diffuser combustor

The exterior of the diffuser case did not have any thermal distress. The engine was not disassembled sufficiently to examine the combustor. However, a borescope inspection of the combustor showed that there was some distress to the combustor louvers that included cracking and burning and erosion of the fuel nozzle splash plates. The distress that was noted was consistent with a service run engine.

4.7 High pressure turbine

The HPT case did not have any thermal distress. The HPT rotor turned smoothly.

The 1st and 2nd stage turbine disks were intact. The 1st and 2nd stage turbine blades were all in place in their respective disks. The 1st stage turbine blades did not have any damage. There were randomly located 2nd stage turbine blades that had nicks and dents on the airfoil and pieces up to approximately 0.25 by 0.25-inch missing from the trailing edges. (Photo No. 27) The 1st and 2nd stage turbine blade radial tip clearance with their respective BOAS was about 0.12 and 0.18-inches, respectively.



Photo No. 27: Close up view of 2nd stage turbine blades showing damage to trailing edges and the erosion to the blade outer air seals. (P&W)

The 1st and 2nd stage turbine vanes were all in place. The 1st stage turbine vanes did not have any apparent damage. There were several 2nd stage turbine vanes that exhibited leading edge mid span burning that exposed the internal air cavity. There were several other 2nd stage turbine vanes that had the thermal barrier coating burned away down to the base metal in the mid chord, mid span area of the airfoil.

The 1st and 2nd stage BOAS segments were all in place. The 1st stage BOAS had several segments that had the thermal barrier coating on the ends, either one or both, partially eroded and missing that exposed the base metal. There were two 2nd stage BOAS at about 3 and 7 o'clock that had the thermal barrier coating on the counter-clockwise edge of the BOAS segment partially eroded and missing that exposed the base metal. (Refer to Photo No. 27)

The HPT 2nd stage seal (dog bone) seal was intact. The dog bone seal was the 104 hole configuration and all of the holes were open.

The condition of the HPT module was consistent with a service run engine.

4.8 Turbine exhaust case

The exterior of the turbine exhaust case did not have any apparent damage. The flow path surface of the turbine exhaust case had numerous nicks and dents. The flow path surface of the turbine exhaust case between the case's front flange and the leading edge of the turbine exhaust case struts had heavy circumferential scoring and gouging. The turbine exhaust case wall between the front flange and the struts was slightly bulged outward. The turbine exhaust case front flange was canted forward between 7 and 12° in the unconstrained state.¹¹

The turbine exhaust case struts were all in place. All of the struts had nicks, dents, and gouges on the convex surface and several of the struts had a few nicks on the concave surface. The turbine exhaust case struts inner standup welds were all intact and the outer standup welds on struts Nos. 6 through 8 and 10 through 13 were also intact. Strut No. 1 had an approximately 2-inch axial by 1.5-inch radial section of the strut torn back from the leading edge along the outer stand up weld and displaced in the direction of rotor rotation about 0.5-inches. Strut No. 2 had an approximately 2.5-inch axial by 1.75-inch section of the strut torn back from the leading edge along the outer stand up weld and displaced in the direction of the rotor rotation about 1-inch. Strut No. 3 had an approximately 3-inch axial by 5-inch radial section of the strut torn back from the leading edge along the outer stand up weld and displaced in the direction of rotor rotation about 5-inches. Strut No. 4 had an approximately 5.5-inch by 6-inch radial section of the strut torn back from the leading edge along the outer stand up weld and displaced in the direction of rotor rotation about 4-inches. Strut No. 5 had an approximately 2.25-inch axial by 1-inch radial hole about 1.75-inches aft of the leading edge adjacent to the outer stand up weld. There were

¹¹ The angle was measured using a 360° protractor.

pieces of airfoil in the hole. Strut No. 9 had an approximately 1-inch axial by 0.5-inch radial hole about 1-inch aft of the leading edge adjacent to the outer stand up weld. There was a piece of airfoil in the hole.

The turbine exhaust case inner duct had a few nicks and dents on the outer surface.

4.9 Bearings

The No. 4 bearing rollers were all in place, free to rotate, wet with oil, and did not have any rotational distress. The No. 4 bearing inner race did not have any damage. The No. 4 bearing carbon seal was intact. The oil from the No. 4 bearing compartment was clear and did not have an acrid odor.

The engine was not disassembled sufficiently as part of the investigation to expose the other main shaft bearings.

5.0 Pilot reports

5.1 Captain

The captain stated that he was the pilot monitoring. The captain stated while in cruise flight at FL330,¹² they heard a “pop” that was followed by the No. 3 engine’s N1 rpm decreasing and the EGT increasing. The captain stated that QRH [Quick Reference Handbook] 7.6 memory items were accomplished and when they had verified that they had identified the correct engine, the start lever was placed to off. The captain stated that they then accomplished QRH 7.13 to verify that the engine was secured. The captain stated that the engine’s EGT, N1, N2¹³ all returned to normal and that the oil quantity was 17 quarts and the oil pressure was about 50 psi [pounds per square inch] that was consistent for a wind milling engine. The captain said that they made a visual inspection of the engine and could see no damage. The captain stated that they declared an emergency with Russian air traffic control and requested a descent to FL290. The captain stated that they contacted Atlanta to advise them of the situation and to discuss a diversion airport. The captain stated that they initially discussed diverting to Seattle where the weather was forecast to be 800 foot overcast and 2 miles visibility for their expected arrival time. Because the weather forecast for NRT was expected to be scattered clouds and visibility 40 km, they opted to divert to NRT. The Captain stated that at NRT, they requested the fire department to stand by and accomplished a 3-engine landing without incident. The captain stated that they taxied to the gate where they deplaned normally.

¹² Flight level 330 is 33,000 feet mean sea level based on an altimeter setting of 29.92 inches of mercury.

¹³ N2 is the high-pressure rotor speed.

5.2 First officer

The first officer (FO) stated that he was the pilot flying. The FO stated that about 4 hours after takeoff while cruising at FL330 in Russian airspace on the B241 airway near the GITRU fix, they heard a sudden pop or bang that was followed by the No. 3 engine rolling back while the EGT increased. The FO stated that the QRH procedures for Engine Limit or Surge or Stall and Engine Failure QRH procedures were accomplished. The FO stated that once the engine was secured, they declared an emergency with Russian air traffic control and requested a descent to FL290. The FO stated that they decided to divert to NRT where an engine inoperative approach and landing was accomplished without incident.

6.0 Flight data recorder

The digital flight data recorder (DFDR) was removed from the airplane and forwarded to the NTSB's Recorder laboratory for readout. The DFDR recorded the incident flight that consisted of data from engine start at ICN to engine shutdown at NRT. In addition, data from five previous flights were recorded on the DFDR.

On the incident flight, around subframe reference number¹⁴ (SRN) 156979, the No. 3 engine's N2 rotor began to rotate. Around SRN 156981, the No. 4 engine's N2 rotor began to rotate. Around SRN 157079, the No. 4 engine stabilized at 66 percent N2 rpm, engine pressure ratio (EPR)¹⁵ 1.016, exhaust gas temperature (EGT) 346°C, and fuel flow (Wf) 1,824 pounds per hour (pph). Around SRN 157079, the No. 3 engine stabilized at 66 percent N2 rpm, EPR 1.016, EGT 368°C, and Wf 1,952 pph. Around SRN 157080 and 157090, the Nos. 2 and 1 engines' N2 rotors, respectively, began rotating. Around SRN 157184, the No. 1 engine stabilized at 66 percent N2 rpm, EPR 1.014, EGT 350°C, and Wf 1,696 pph. Around SRN 157195, the No. 2 engine stabilized at 66 percent N2 rpm, EPR 1.023, EGT 343°C, and Wf 1,664 pph.

Between around SRN 157184 and 157672, the Nos. 1 and 4 engines' N2 rpm intermittently increased from 65 percent up to a maximum of 75 percent as the airplane's heading changed consistent with the airplane taxiing.

At around SRN 157672, the Nos. 1, 2, 3, and 4 engines' EPR were 1.102, 1.102, 1.096, and 1.102; N2 were 65, 65, 66, and 65 percent; EGT were 382, 371, 402, and 370°C, and Wf were 1600, 1504, 1824, and 1632 pph, respectively. At around 157673, the engines' EPR, N2, EGT, and Wf indications began to increase. The N2 indications for engines Nos. 1, 2, and 4 increased evenly and the N2 indication for the No. 3 engine lagged the other three by about 2 percent. At around SRN 157682, the airspeed began to indicate. At around SRN 157683, the

¹⁴ A subframe is equal to 1 second of time.

¹⁵ 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.

Nos. 1, 2, and 4 engines stabilized at about 97 percent N2 and the No. 3 engine stabilized at about 96 percent N2. The Nos. 1, 2, and 4 engines' other performance indications were EPR 1.451, 1.51, 1.508; EGT 460, 463, 485°C; and Wf 13,792, 14,432, 16,704 pph, respectively. The No. 3 engine's performance indications were EPR 1.508, EGT 508°C, and Wf 16,416 pph. At around SRN 157726, the airplane lifted off at a speed of 184 knots and the engines' performance were: No. 1: EPR 1.498, N2 98 percent, EGT 562°C, Wf 21,856 pph; No. 2: EPR 1.498, N2 97 percent, EGT 556°C, Wf 21,248 pph; No. 3: EPR 1.5, N2 97 percent, EGT 595°C, Wf 22,048 pph; and No. 4: EPR 1.5, N2 98 percent, EGT 564°C, Wf 21,280 pph.

At around SRN 158451, the airplane was climbing through FL 180 with all four engines at an EPR of 1.408. The engines' other performance indications were: No. 1 – N2 96 percent, EGT 506°C, Wf 13,344 pph; No. 2 – N2 95 percent, EGT 492°C, Wf 12,832 pph; No. 3 – N2 95 percent, EGT 542°C, Wf 13,888 pph, and No. 4 – N2 95 percent, EGT 505°C, Wf 13,280 pph. Around SRN 159399, the airplane leveled off at FL 330. Around SRN 159699, 5 minutes after the airplane leveled off at FL 330, all four engines were at an EPR of 1.363. The engines' other performance indications were: No. 1 – N2 94 percent, EGT 459°C, Wf 7,488 pph; No. 2 – N2 93 percent, EGT 449°C, Wf 7,200 pph; No. 3 – N2 92 percent, EGT 491°C, Wf 7,964 pph, and No. 4 – N2 93 percent, EGT 461°C, Wf 7,552 pph.

Prior to the event between around SRN 169800 and 170166, the engines' EPRs varied between 1.273 and 1.359 and the N2s varied between 91 and 93 percent. During this period of time, the variation between the individual engines' EPRs were usually the same value and when they did differ, the level was never greater than 0.002.

At around SRN 170166, the No. 3 engine's performance indications were EPR 1.281, N2 91 percent, EGT 458°C, and Wf 7,072 pph. At around SRN 170167, with the EPR remaining at 1.281 and N2 at 91 percent, the EGT began to increase and the fuel flow began to decrease. The EGT continued to increase until around SRN 170183 when it peaked at 659°C before it began to decrease. Concurrently, the EPR decreased from 1.297 to 0.92 in 2 seconds, the N2 began to decrease from 92 percent, and the Wf continued to decrease. At around SRN 170193, while the EPR was at 0.631 and the N2 and EGT continued to decrease through 67 percent and 607°C, respectively, the Wf began to increase from 3,520 pph to 18,144 pph in 4 seconds before decreasing down to zero in the next 6 seconds. There was no increase in the N2 RPM or EGT associated with the increase in Wf.

The FDR contained data from five previous flights. The data for the cruise portions of those flights were examined for differences between the Nos. 1, 2, and 4 engines and the No. 3 engine.

For the previous flight at around SRN 133200 when the airplane was at FL340 with all four engines at 1.244 EPR. The No. 1, 2, and 4 N2 were 89, 88, and 88 percent, respectively; EGT were 372°C, 363°C, and 370°C, respectively, and Wf were 5,824, 5,568, and 5,824 pph. For the No. 3 engine, the N2 was 88 percent, EGT was 393°C, and Wf was 6,080 pph.

For the second previous flight at around SRN 93300 when the airplane was at FL330 with all four engines at 1.215 EPR. The No. 1, 2, and 4 N2 were 90, 89, and 89 percent,

respectively; EGT were 384°C, 374°C, and 383°C, respectively, and Wf were 5,856, 5,600, and 5,888 pph. For the No. 3 engine, the N2 was 88 percent, EGT was 405°C, and Wf was 6,080 pph.

For the third previous flight at around SRN 64700 when the airplane was at FL370 with all four engines at 1.246 EPR. The No. 1, 2, and 4 N2 were 88, 87, and 88 percent, respectively; EGT were 360°C, 351°C, and 360°C, respectively, and Wf were 4,992, 4,768, and 5,024 pph. For the No. 3 engine, the N2 was 87 percent, EGT was 379°C, and Wf was 5,184 pph.

For the fourth previous flight at around SRN 35700 when the airplane was at FL340 with all four engines at 1.229 EPR. The No. 1, 2, and 4 N2 were 90, 89, and 89 percent, respectively; EGT were 387°C, 378°C, and 387°C, respectively, and Wf were 5,792, 5,536, and 5,792 pph. For the No. 3 engine, the N2 was 89 percent, EGT was 409°C, and Wf was 6,016 pph.

For the fifth previous flight at around SRN 10700 when the airplane was at FL370 with all four engines at 1.268 EPR. The No. 1, 2, and 4 N2 were 90, 89, and 89 percent, respectively; EGT were 384°C, 375°C, and 384°C, respectively, and Wf were 5,248, 5,024, and 5,312 pph. For the No. 3 engine, the N2 was 88 percent, EGT was 403°C, and Wf was 5,504 pph.

For further information, refer to the Recorder Specialist's Factual Report in the public docket for this incident.

ATTACHMENTS

1. FAA Form 337 Major Repair and Alteration for heavy maintenance accomplished on PW4056 engine SN P717530 by P&W Cheshire Engine Center, Cheshire, Connecticut on October 7, 2005.
2. Cheshire Engine Center Swap sheet documenting transfer of LPT module D17579 from PW4056 engine 717684 to engine 717530.
3. Excerpt from build records for LPT module D17579 showing inner and out duct segments were not removed from the LPT case.
4. Excerpt from build records for LPT module D17579 showing the LPT case modification of the 3rd through 6th stage anti-rotation slots had been previously complied with.
5. Excerpt from build records for LPT module D17579 showing the modification of the 3rd stage vane clusters to remove material from the gussets had been previously complied with.