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

March 13, 2013

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: ENG11IA016

A: INCIDENT

Location: Minneapolis-St. Paul International Airport, Minneapolis, Minnesota

Date: February 9, 2011

Time: 0630 central standard time

Aircraft: Boeing 757-2Q8, N704X, Delta Air Lines flight 9931

B: POWERPLANTS GROUP

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Member:	Christopher Demers Pratt & Whitney East Hartford, Connecticut
Member:	Michael A. Gotaski Hamilton Sundstrand Windsor Locks, Connecticut
Member:	Jeff Wait Air Line Pilots Association Herndon, Virginia

C: SUMMARY

On February 9, 2011, about 0630 central standard time,[1] a Boeing 757-2Q8, N704X, operated by Delta Air Lines as Flight 9931, experienced a tailpipe fire in the No. 2 (right) engine, a Pratt & Whitney (P&W) PW2037, during engine start at the Minneapolis-St. Paul International Airport (MSP), Minneapolis, Minnesota. The flight was the first since the No. 2 engine had been installed on the airplane. The airplane was pushed back from the gate and the No. 1 (left) engine was started without incident. The pilots stated that they cleared the ground crew to disconnect the tow bar and started the No. 2 engine. The pilots reported that the No. 2 engine lit off almost immediately. The pilots also reported that concurrently with the engine lighting off, they observed an orange glow on the exterior of the right side of the airplane and heard a low frequency rumble as well as hearing people talking on the ground control frequency about a fire. The pilots further stated that they observed the No. 2 engine's fuel flow was 8,300 pounds per hour (pph) and immediately shutdown the engine. The pilots stated that after they shutdown the No. 2 engine, they continued to motor it on the starter for 30 seconds. Airport fire department equipment and personnel responded to the airplane, however, the fire was out by the time they arrived. The fire department personnel stated that there was a large amount of fluid puddled in the No. 2 engine's tailpipe. The examination of the airplane revealed the underside of the right wing aft of the No. 2 engine was charred and blistered. The airplane was operating on an instrument flight rules flight plan under the provisions of 14 Code of Federal Regulations Part 121 as a repositioning flight from MSP to John F. Kennedy International Airport (JFK), Jamaica, New York. The two pilots were the only occupants on board the airplane and were not injured.

[1] All times are central standard time based on the 24-hour clock, unless stated otherwise.

D: DETAILS OF INVESTIGATION

1.0 Engine information

1.1 Engine description

The PW2307 engine 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 high-pressure turbine (HPT) that drives the HPC, a 5-stage low-pressure turbine (LPT) that drives the fan and LPC, an accessory gearbox, and an engine electronic control (EEC). The engine has a takeoff thrust rating of 37,530 pounds, flat-rated to 87°F.[2]

1.2 Engine history

The No. 2 engine was a PW2037, serial number (SN) 728843. According to Delta Air Lines' maintenance records, the engine had accumulated 24,778.0 hours time since new (TSN) and 7,758 cycles since new (CSN). The engine had just been overhauled at Delta Air Lines' Technical Operations Center (TOC), Atlanta, Georgia prior to installation on the airplane and had 0 hours time since overhaul (TSO) and 0 cycles since overhaul (CSO) and installation on the airplane. The engine was installed on the airplane at MSP on February 6, 2011. The engine had been removed from service on August 14, 2010, because of a hung start and a high exhaust gas temperature (EGT) of 615 to 621 degrees C for 3 seconds.

2.0 Airplane information

2.1 Airplane history

The airplane was a Boeing 757-2Q8, SN 28163. According to Delta Air Lines' aircraft maintenance records, the airplane had accumulated 47,209.1 hours TSN and 14,839 CSN at the time of the incident.

[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.

2.2 Airplane maintenance history

The airplane's maintenance records show that on February 5, 2011, the right engine underwent a borescope inspection and failed because of a 3rd stage turbine blade with a crack. The airplane was authorized for a two-cycle flyback before the engine had to be replaced. The maintenance records show on February 6, 2011, the right engine, SN 728783, was removed and engine SN 728843 was installed. The maintenance records show for February 7 and 9, 2011, there were two deferred maintenance items for a cockpit light and for a broken cannon plug on the nose landing gear (Refer to Section 4.1 for further details), respectively. And then on February 9, 2011, the maintenance records state, "Observed large bright flash near right side of A/C during right engine start. EGT rise was quick but within limits, however crew heard rumbling sound and shortly thereafter noticed rt eng fuel flow of 8300 lbs per hour. Crew immediately shut down right engine. At no time did any other indications on EICAS appear abnormal. Just FF was high." The maintenance records do not show any entries for the preflight engine run that was reportedly accomplished on February 7, 2011. (Refer to Section 4.2 for further details). For further details about the airplane maintenance records, refer to Attachment 1.)

3.0 On-scene airplane and engine examination

3.1 Airplane examination

The fuselage, left wing, and empennage were not damaged. The right wing's lower wing skin did not have any heat discoloration or damage. A conductivity test[3] of the right wing's lower wing skin revealed it was not damaged.

The lower surface of the main and aft inboard flaps inboard of the inboard flap track fairing were blistered, charred, and delaminated. The lower surface of the main and aft inboard flaps outboard of the inboard flap track fairing were blistered. The lower fixed trailing edge panels on either side of the inboard flap track fairing were blistered, charred, and delaminated. (Photo No. 1) There was no indication of internal damage to the inboard flaps or the fixed trailing edge panels. Grease on the inside of the panels was not melted.

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[3] A conductivity test measures the electrical resistance in metal. If the material had been heated such that the material's properties were reduced, it would be signified by a reduction of the electrical resistance.

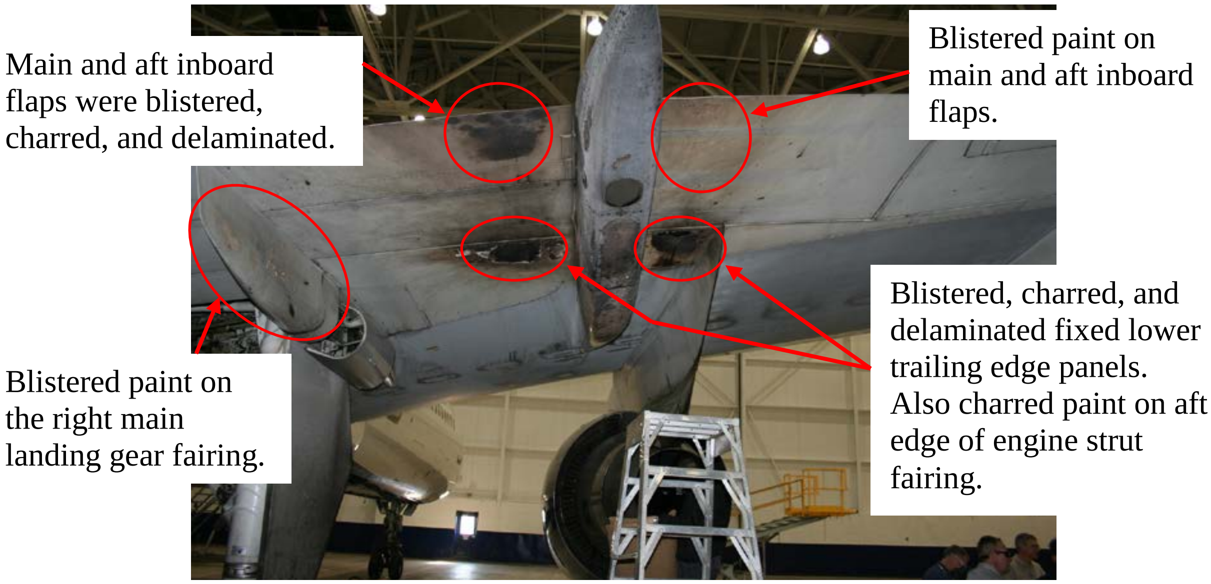

Photo No. 1: View of the underside of the right wing from the rear showing areas that were blistered, charred, and delaminated. (P&W photo)

The exterior of the aft two-thirds of the inboard flap track fairing was charred, blistered, and delaminated. (Photos Nos. 2 and 3) There was no indication of internal damage to the fairing. Grease located on the inside of the fairing was not melted.

The right main landing gear fairing had a small area of blistered paint on the exterior surface. (Refer to Photo No. 1.)

The No. 2 engine strut aft fairing had small area of charred paint on the inboard side adjacent to the wing at the aft end. (Refer to Photo No. 1.)

Photo No. 2: Left (inboard) side of the inboard flap track fairing showing damage on rear two-thirds of the rear fairing.

Photo No. 3: Right (outboard) side of the inboard flap track fairing showing damage on rear two-thirds of the rear fairing.

3.2 Cockpit examination

In the cockpit, the Engine Indication and Crew Alerting System (EICAS) was interrogated. The following information was displayed on the EICAS performance/APU [Auxiliary Power Unit] page.

	Left	Right
EPR[4] command	1.068	1.387
Actual EPR	1.067	1.388
N1	49.0	82.5
EGT	364	433
N2	76.4	88.0
Fuel flow	3.440	11.609
Burner pressure	138	364
Duct pressure	43	42
Differential oil pressure	162	118
Scavenge oil pressure	7	139
Oil temperature	109	115
Oil quantity	15	11
Vibration N1	0.0	0.1
Vibration N2	0.1	0.1
Vibration BB	0.1	0.2
APU		
EGT	315	
RPM	101	
TAT	+27	
ALT	640	

The following fault codes were displayed on the EICAS EPCS [Electronic Propulsion Control System] page.

EICAS	EPCS
	FCU/EEC
	S FCU/EEC
	P FCU/EEC
	S 351-23
	P 351-23

[4] Refer to the Glossary at the end of this report for a definition of all undefined acronyms.

According to the Boeing 757 Fault Isolation Manual, the fault codes that were displayed on the EICAS EPCS page refer to the following:

FCU/EEC	FMV position feedback data crosscheck by the EEC shows disagreement between primary and secondary valve position input data due to either a faulty fuel metering unit or interfacing circuitry.
351-23 P(S)[5]	FCU FMV failed to carry out EEC commanded position due to valve failure or failed command signal circuitry between EEC and FCU.

The following engine information was displayed on the EICAS EPCS page.

[Left]		[Item]	[Right]	
PRI	SEC		PRI	SEC
46.4	46.4	TLR	75.9	75.9
1.93	1.93	SVA	2.29	2.28
99	98	BVA	1	1
92.3	92.3	N2C	96.6	98.0
-15	-14	T2	-13	-13
14.4	14.3	P2/Ps	14.3	14.4
-0.7	-0.5	RVA	0.5	0.4

There were no exceedances displayed on the EICAS performance/APU page.

3.3 No. 2 engine examination

The No. 2 engine was in place on the strut. The exterior as well as the interior surfaces of the engine's nacelles did not have any indications of fire damage or sooting. (Photos Nos. 4 and 5)

The fan blades were all in place and did not have any damage. (Photo No. 6) The fan could be rotated with light hand pressure and the 7th stage turbine blades rotated concurrently. All of the 7th stage turbine blades were in place and did not have any damage. (Photo No. 7) There were no abnormal noises heard when the fan was rotated.

[5] The primary and secondary modes of the EEC recorded this signal error.

Photo No. 4: View of the left side of the engine with the nacelles in place showing no damage or sooting.

Photo No. 5: View of the right side of the engine with the nacelles in place showing no damage or sooting.

Photo No. 6: View of the front of the engine showing all of the fan blades were in place and undamaged.

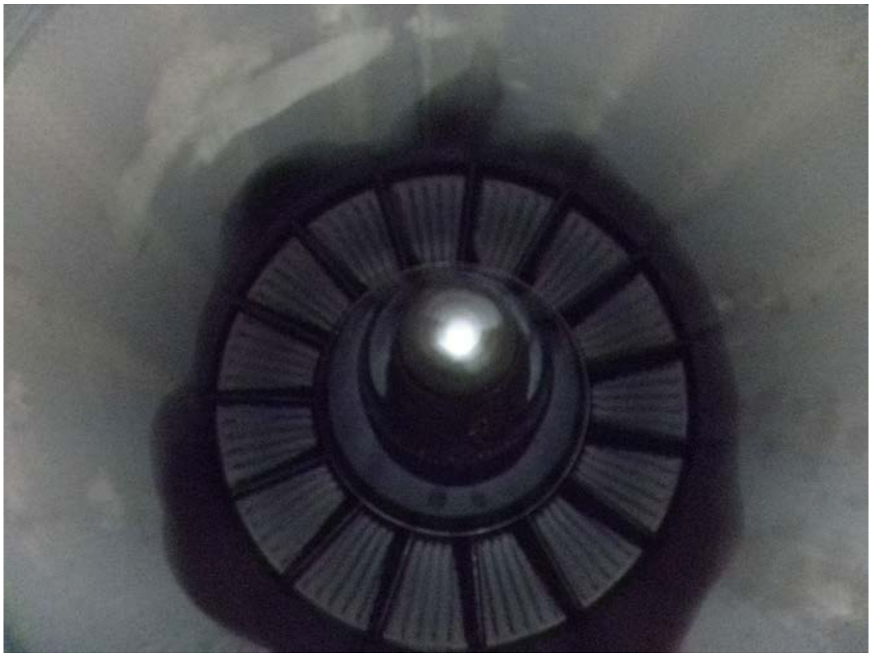

Photo No. 7: View of the rear of the engine showing all of the 7th stage turbine blades were in place and undamaged.

4.0 Interviews

4.1 Pilots

The pilots on board the airplane when the tailpipe fire occurred were interviewed by members of the Powerplants Group. Both of the pilots interviewed were represented during their individual interviews.

4.1.1 Captain

The Captain stated that he had been employed by Northwest and Delta[6] for 25 1/2 years. He stated that he had about 10,500 hours of airline flying time. The Captain stated that he was qualified on the 757 and 767 airplanes. He stated that he has flown the 757 and 767 about 17 years, 10 as captain and 7 as first officer (FO). The Captain also stated that he flew the 727 as a flight engineer, FO, and instructor; the A320 as captain, and the DC10 as FO and instructor.

The Captain stated that he thought he had between 4,000 and 6,000 hours in the 757/767 airplane. He said that he has flown about 200 hours in the last 90 days and about 600 hours in the last 12 months. He further said that his last check ride was in the simulator in September 2010, and his last line check was in February 2010.

The Captain stated that when they got to the airplane, the gate agent was waiting for them with the paperwork. The Captain stated that they had arrived at the airplane about 35 minutes before the scheduled push at 0600. The Captain stated that he did the cabin preflight while the FO did the exterior preflight. The Captain stated that he reviewed the airplane's logbook. He stated that he tries to go back through the paperwork for the previous 10 days. He stated that he noticed the right engine had been changed for failing a borescope inspection. The Captain stated that he is more careful with airplanes from the hangar. The Captain stated that he could not recall if there had been an engine run up, it was not in the logbook. He said that they went through the checklists, but shortly before the scheduled push, there was a delay because they could not establish communications with the tug driver after the jetway had been pulled back. The Captain stated that the jetway was repositioned and the mechanic came aboard and said that the cannon plug jack was broken. The Captain stated the mechanic said that they could use a walkie talkie to talk on [1]29.8. The Captain said that it took about 20 minutes to complete the paperwork to defer the broken cannon plug jack. He said the pushback was normal with the appropriate amount of wing walkers.

The Captain said that they started the left engine first. The Captain explained that he has no specific reason to start the left engine first. He said if they have passengers on board and they are going to single-engine taxi, he will start the left engine first because if they have just the right engine running, they must also have the power transfer unit running that makes a lot of noise for

[6] In 2008, Northwest Airlines merged into Delta Air Lines.

the passengers. The Captain stated that they started both engines at the gate because he thought the taxi to runway was going to be expeditious and he wanted to have two good warmed up engines. The Captain stated that if it had been a revenue trip with a long taxi, he would have single-engine taxied.

The Captain said that at Delta, the FO starts the engines. The Captain said the left engine took about 20 seconds to light off. The Captain said 20 seconds was the limit for how long the engine should take to light off. He said that he figured it took that long to light off because the engine had been cold soaked. The Captain stated that the left engine was just coming up to idle as the ground crew was leaving the airplane. The Captain said that he recalled the FO saying that the right engine lit off immediately after he turned the START-RUN switch to RUN. The Captain said that he was looking out the front window and after about 5 seconds, he noticed an orange glow out the right side windows. He said that he thought it was an airport vehicle that was approaching the airplane. The Captain said that he thought the vehicle was getting close until he heard a rumble and he looked at the gages. He stated that he saw the right engine's fuel flow was 8,300 [pph] and the normal was 1,200 [pph]. The Captain stated that they had been distracted by the orange glow, but when he saw the 8,300, he yelled to shut it down. The Captain explained that he could not say exactly how long the fuel flow was at 8,300; 10 or 15 seconds, maybe longer. The Captain stated that they saw the orange glow for about 5 seconds before they shutdown the engine and that the glow continued for another 5 to 7 seconds after they shutdown the engine. The Captain stated that they went to the QRH [quick reference handbook] that said to continue to motor the engine for 30 seconds before they secured the starter. The Captain further stated that the FO found the information relatively quickly and used the aborted engine start checklist.

The Captain explained that he had not previously heard the rumble that they heard during the engine start. He said it was a low pitch sound and he was not sure what it was.

The Captain stated that they did not call for the rescue trucks. He stated the control tower called for the rescue trucks. The Captain stated that after the glow had gone out, he called dispatch on his cell phone to advise of the bad airplane, the fuel flow, and the glow. The Captain thought he talked to dispatch about 5 to 10 minutes and at about the end of the call, he saw the fire trucks arrive. The Captain stated the he asked the FO to contact the control tower to get a frequency so they could talk to the rescue trucks. He said they got the frequency and he asked Rescue 1 to look at the right engine and also told them that the left engine was still running. The Captain stated that Rescue 1 responded that there was no damage, but that there was fuel puddled in the tailpipe. The Captain said that Rescue 1 did not say anything about the scorched skin. The Captain said that although he did not declare an emergency, he cancelled the emergency. He stated that Rescue 1 said that they would leave one truck until they returned to the gate. The Captain stated that they taxied back to the gate under their own power. He said that they then went into the manuals to find the maintenance codes for high fuel flow and then sent an ACARS [aircraft communications and reporting system[7]] message. The Captain stated that they then disarmed the doors because the maintenance personnel were trying to get into the airplane. He said the mechanics told them about the underside of the wing. He further said that the FO went

[7] Aircraft Communications Addressing and Reporting System (ACARS) is a digital datalink system for the transmission of short, simple messages between aircraft and the ground stations via radio or satellite.

out there and then he went out there to look at the wing and he noticed that the canoe was burned. The Captain said that he looked in the tailpipe, but he didn't see any fuel or fire damage. He said that he did see splatter on the main mounts. The Captain stated that they then filed ASAP [Aviation Safety Action Program[8]] reports and then he had a conference call with the [Delta Air Lines] Director of Flying, Flight Safety Office, and duty pilot.

The Captain stated the APU was running and that they started both of the engines off of the APU. He stated that he did not see any drop off in the duct pressure. He further said that the EGT was in the 200s and the N1 and N2 were normal.

The Captain said that it was dark at 0630 in the morning. He also said that the wind was from the right front side of the airplane.

The Captain stated that he did not think of discharging the fire bottles knowing where the fire bottles discharge. He added that if the fire bell had gone off or if there had been a fire warning, he would have.

The Captain said that there was about 21,000 pounds of fuel on board the airplane.

4.1.2 First officer

The FO stated he had started with Northwest in February 1992, as an instructor on the Boeing 747-400 airplane. He stated that he had previously been employed at Pan Am.[9] The FO stated that when he was at Pan Am, he was a 747 flight engineer instructor, but that he also flew the line. The FO stated that beginning in 1994, he was an instructor on the 757 for a year. He said that he was then a training manager until 1997 and manager of the training division until 1999. The FO said that in 1999, he became a flight engineer on the DC10 for a year. The FO further said that from 2000 to 2002, he was an FO on the 727. He said that he also flew as FO on the DC9 and 757. He said that beginning in March 2004, he was furloughed for about 9 months. The FO said that he has been flying the 757 for about 4 years and has about 2,400 hours in the airplane. The FO stated that he flew a lot in December and January and estimated that he flew about 200 hours in the last 90 days. He estimated that he had flown about 600 hours in the last year. The FO said that his last checkride was in October 2010.

The FO stated that the incident flight was a ferry flight and it was just he and the captain on board. He stated that he had flown with the captain previously. The FO said that when they went to the airplane, the captain did the interior preflight and he did the exterior. He said that before he started the exterior inspection, he had started the IRS [inertial reference system] alignment process. The FO stated that it was very cold outside, around -7 or -8 degrees [F]. He said he did the walk around inspection with a flashlight. The FO stated that he did not see any

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[8] Aviation Safety Action Program (ASAP) is a program to encourage air carriers and repair stations to voluntarily report safety information that may be critical to identifying safety hazards that could lead to accidents. According to Advisory Circular 120-66B, under ASAP, any safety issues identified are resolved through corrective action rather than through punishment or discipline.

[9] Pan American World Airways (Pan Am) ceased operations in 1991.

contamination on the wings. He did say that when they were walking down the jetway, they saw a little hoarfrost on the left engine's nacelle and when he ducked under the airplane, he could see that the right engine's nacelle also had the hoarfrost. The FO stated that he did look into the tailpipe, but because of his height, he cannot see the bottom part of the tailpipe. He said that he could see the top of the turbine. He said that he did not see any puddles or leaks around the airplane. He said that they knew the airplane had just come from the hangar and that the engine had just been replaced. He said the ramp was dry with patches of frozen ice. The FO stated that they thought the fire might be related to the new engine. The FO said that the captain had asked him if he had any recent landings and when he said yes, the captain said that he would fly that leg. The FO said that after they got to JFK, they were going to non-rev back to MSP. The FO said that they did the preflight checklist for the first flight of the day. The FO stated that the trip was routine and normal except that it was a ferry flight. He added that they do not do a lot of ferry flights, so they made sure what they were doing. The FO stated that the back doors were not armed, the forward doors, L1 and L2 were armed.

The FO stated that when they were getting ready to push, there was a problem with a communications jack. He said that the mechanic wanted to use a hand held walkie talkie and talk on 127.8. He said he had to contact metering[10] to cancel the push, which had previously been approved, because of the broken communications jack. The FO stated that they contacted dispatch to get the broken jack deferred. The FO stated that the metering controller approved the second push. He said that when they were pushed off of the gate, the captain was talking to the tug driver.

The FO stated that the captain called for the engine start. The FO stated that at Delta, the FO starts the engines whereas at Northwest, the captain starts the engines. The FO stated that he has only been starting the engines for about a year. He said that he has not started the engines as much as the captain had. The FO explained that when he starts the engines, he turns off the [air conditioning] packs and verifies that there is sufficient duct pressure. The FO stated that he remembered the duct pressure was about 30 [psi]. He stated that when he turns the packs off, he waits a little if the pressure is a little slow coming back up. But he reiterated that he thought the duct pressure was at 30 or close to 30 as it was coming up. He then turns the start switch as he calls out start and the engine position and he starts the clock so he can time how long it takes for the engine to light off. He said that he looks for and calls out rotation when he sees an N2 indication. He said that he puts his hand on the fuel switch and looks for an oil pressure indication and 25 percent N2 when he calls fuel and turns the fuel on. He said that it takes about 20 seconds for the engine to light off. The FO explained that he looks at the EGT to determine when the engine lights off. The FO stated that the engine must light off within 20 seconds. He stated that the engine usually lights off right away. He said that he knew it was cold and he had done lots of cold weather starts, but the left engine's slow start got his attention and he pointed it out to the captain. The FO stated that the captain said to give it a second and he said that the engine started within the 20 second requirement although he still thought the engine took a long time to start. The FO stated that when he was starting the right engine, he turned the start switch, started the clock, and saw rotation. He said that he moved his hand to the fuel lever, called oil pressure and when the [N2] rpm got to 25 percent, he turned on the fuel lever. The FO said that

[10] At MSP, metering is a Federal Aviation Administration ramp control function that all aircraft must contact for authorization to push back from the gate. (Attachment 2)

the right engine lit off right away. The FO stated that he thought the right engine's start was more normal than the left engine's start. The FO stated that he saw that the EGT was 100 to 200 degrees and he did not think that it was not going to go hot. He said that he had seen hot starts in training, but he had never seen a real hot start. (Refer to Section 5.0)

The FO stated that when they started the engines, it was about 0630 and it was dark outside. He stated that he saw a pulsating glow on the right side of the airplane and he pointed it out to the captain. He said that they both thought it was an emergency vehicle. The FO thought the glow had distracted both of them. The FO said that they heard a rumble and when they looked at the gages, the captain said high fuel flow and to shutdown the right engine. The FO stated that he thought that there would have been a bang associated with a hot start. The FO said that he could see white smoke out of the captain's window. The FO stated that he thought the glow lasted for about 10 seconds after he had shutdown the engine. The FO stated that the captain called for the aborted start checklist and they motored the engine for 30 seconds. The FO said that he thought that they had a tailpipe fire and that they would need to go back to the gate because they were not going to JFK. The FO stated that they then saw the emergency vehicles. The FO said that captain asked him to contact ground control to ask if the trucks were for them which he did and the ground controller confirmed that the trucks were for them. The FO stated that he thought the ground controller did a good job, but no one told them that there was a fire on the right side of the airplane and no one said the trucks were for them because they had a fire. The FO stated that they did not know the severity of the fire. The FO said that the captain asked him to get the frequency so that he [the captain] could talk to the fire rescue trucks. The FO said that the fire rescue people reported back that they had looked at the wing and fairing and that it looked bad.

The FO stated that when they were ready to go back to the gate, the captain decided to taxi in rather than be towed in. The FO stated that ground control asked him if they wanted to cancel the emergency and that got his attention because he had not declared an emergency. The FO stated that they canceled the emergency and that they then taxied back into the gate and shutdown the [left] engine. The FO said that they talked to maintenance who asked if they had overtemped[11] the engine. The FO said that he had initially said yes, but the captain had corrected him saying that they did not have any exceedances.

The FO stated that when they pushed off of the gate, they contacted metering on [1]33.57.[12] He said the controller was working both metering and ground control. He stated that they started talking to the controller on [1]33.57 and then she had them go to 121.9.[13]

[11] Overtemped, which is a contracted form of overtemperatured, meaning exceeded the engine's red line EGT limit.
[12] At MSP, 133.57 is the frequency for the metering controller. (Attachment 3)
[13] At MSP, 121.9 is the frequency for the south area ground controller. (Refer to Attachment 3.)

4.2 Maintenance personnel

The engine was installed on the airplane on February 6, 2011. On February 7, Delta aviation maintenance technicians (AMT) accomplished a ground run of the newly installed right engine. The AMTs that occupied the cockpit's left and right seats for that ground run were interviewed by the members of the Powerplants Group. Both of the AMTs were represented during their individual interviews.

4.2.1 Maintenance technician – left seat

The AMT who occupied the left seat for the ground run stated that as of April 6, 2011, he had been with Delta for 30 years. He stated that he has an A&P [airframe and powerplants] mechanics certificate. He stated that he is preflight engine run-qualified on the 767-300 and -400, MD-88, 777, and 757 airplanes. The AMT further stated that he has been preflight engine run-qualified on the 757 and 767-300 and -400 airplanes about 8 to 10 years, the MD-88 airplane for about 5 to 8 years, and the 777 airplane for about 3 to 4 years. The AMT stated that he has done about 50 757 engine runs. He stated that the majority of his work is in Atlanta, Georgia, but he further stated that he has done a few engine runs on the road.

The AMT stated that on February 7th at about 1358, the airplane was pushed out of the hangar to do an engine change preflight engine run. (Attachment 4) He said that he did a fire detector check. He said that the preflight checklist is used prior to engine start. The AMT stated that he started the engines and the right engine started right away with the N1 and N2 [rpms] coming up in the allotted time. The AMT that was seated in the left seat stated that there was another AMT who was in the cockpit jump seat who was timing the engine start. The AMT who was in the left seat stated that after the engine was started, it was allowed to warm up. The AMT stated that he monitored the EGT during the engine start. He stated that the EGT, rpms, and pressures were all normal, although he could not remember any specific numbers. The AMT stated that he then proceeded to start the left engine. He said that everything went smoothly. The AMT stated that the paperwork states to let the engine warm up for at least 5 minutes. The AMT stated that after the 5 minute warm up period, they positioned all of the switches per the preflight checklist. He stated that before they taxied to the run up pad, they did a leak check and disconnected the generator on the right engine. The AMT stated that they contacted ground control to get clearance to taxi to the run up pad. The AMT stated that they taxied to the run up pad and positioned the airplane so that the engines' inlets were pointed into the wind. The AMT stated that they did the test per the paperwork. The AMT said that everything worked per the paperwork; the temperatures were correct, the minimum and approach idles were correct. He stated that they did the power assurance check. The AMT stated that the highest power level that they attained was during the bleed shift check. He said that they needed to get to 1.7 EPR before they could do the snap acceleration (accel) checks. The AMT stated that the bleed shift and snap accels were per the paperwork. The AMT stated that they did another fire warning test and they did a generator test. The AMT also stated that he cycled the left engine into and out of reverse. The AMT said that when they returned to the hangar and shutdown, he did not know if the AMTs on the ground checked the engine for any leaks.

The AMT stated that after they had returned to the hangar and shutdown the engines, he did not look into the engines' tailpipes. The AMT stated that he had all of the minimum idle data written down. He stated that he gave all of the trim sheets to a MSP-based Delta inspector and told him to keep the paperwork.

The AMT stated that when he does a preflight engine run, he does not pull the FDR circuit breaker. He did not remember pulling the FDR circuit breaker. He thought the FDR circuit breaker was depressed.

4.2.2 Maintenance technician – right seat

The AMT that occupied the right seat stated that he had worked for Republic Airlines, Northwest Airlines, and now Delta since 1980.[14] The AMT stated that he has an A&P mechanics certificate. The AMT stated that he is right seat qualified on all Delta airplanes. The AMT stated he works the day shift, four-10 hour days, from Sunday to Wednesday. He stated that his job title is inspector.

The AMT who occupied the right seat stated that the AMT who occupied the left seat had come up from Atlanta specifically to run the airplane. This engine run was also to be a training mission to learn what was involved. He stated that the AMT who occupied the left seat was in charge of the engine run and started the engines. He stated that he did not start the engines.

The AMT stated that they started out by pulling the checklist, airport chart, and procedures. They did the final checks on the airplane that was then pushed out of the hangar. The AMT stated that he was in the right seat and the AMT who had come up from Atlanta occupied the left seat. The AMT stated that there was another MSP-based AMT in the cockpit and that individual occupied the right jumpseat.

The AMT who occupied the right seat stated that there were maintenance personnel outside the airplane to do the leak check of the engine when the cowls were open. The AMT stated that he did not know how many personnel were outside the airplane and he could not see them, but he stated that he thought that there were at least two. The AMT stated that they went through the checklist and started the right engine and it stabilized at idle. He stated that the leak check was successful and they did the constant speed drive disconnect and the generator dropped off line. The AMT stated that they shutdown the right engine to reset the generator and then close up the engine's cowls.

The AMT stated that they started the engines and contacted ground control to taxi to the run up pad. He stated that all of the engine parameters were normal. The AMT stated that he could not recall how long it took to start the engines, but he thought it was normal in comparison to other engine starts. He stated that when they got to the run up pad, they turned the airplane so the nose was into the wind. The AMT stated that the AMT who occupied the left seat did the run

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[14] In 1986, Republic Airlines merged into Northwest Airlines, and in 2008, Northwest Airlines merged into Delta Air Lines.

up checks and explained the checks. The AMT who occupied the right seat stated that the engine run up took about 20 minutes and there was nothing unusual. He stated that they did the power assurance check and snap accels. He stated that they did an event record at about 95 percent [N1] power. He said that there is an event record button that will record engine data when the button is pushed. The AMT stated that after the engine run up was completed, they taxied back to the hangar and shutdown normally. He stated that the airplane was then pushed back on the ramp. The AMT stated that he then took the AMT who occupied the left seat into the hangar because he had to catch a flight back to Atlanta and he completed the paper work for the leak check.

The AMT who occupied the right seat stated that he could not recall with certainty the order of the power assurance and snap accel checks. He stated that there were other checks before the bleed valve check and bleed shift check. He stated that the throttles were advanced for the pressure check. He stated that although he recalled looking at the engine data, he could not remember exact numbers for the fuel flow and EGT. He stated that he thought the EGT was in the 300s.

The AMT who occupied the right seat stated that he has participated in hundreds of engine runs. He stated that he has participated in 757 engine runs about a half-dozen times in the last year. He stated that this was the first time he has occupied the right seat versus sitting in the jump seat. He stated that on the previous engine runs, he had been an observer while maintenance did the engine run. The AMT stated that the person in the right seat reads the checklist and handles the radio communications. He stated that if he saw anything wrong, he would point it out. He stated that they had talked before they started the engines about what they were going to do if anyone saw anything. He stated none of the other AMTs in the cockpit expressed any concern about anything abnormal.

The AMT stated that he was not sure if looking into the engine's tailpipe was part of the leak check. He said that when he does a leak check, he tries to look into the engine's tailpipe.

The AMT stated the weather was good, it was dry, and there was a slight breeze. He stated that it was cold outside. He could not remember the temperature, but it was below zero. He said that the engine run was accomplished during daylight and the light was good.

5.0 Delta Air Lines pilot training and guidance

According to a Delta Air Lines 757 training captain, Delta has three engine starting problem scenarios in the simulators: no ignition, rapid rise of EGT, and starter valve malfunction. The training captain stated that tailpipe fires are not taught in the simulators, but they are discussed in the classroom near the end of the training session. Delta's 757 full motion simulators are not programmed to simulate a high fuel flow on start scenario. However, at least one of the Delta's 767 fixed-base training simulators was programmed to simulate a high fuel flow on start scenario.[15]

[15] Delta Air Lines 757 pilots are also type rated on the 767-200 and -300 airplanes.

The training captain demonstrated several engine starts in a 757 full motion simulator. On each of the start attempts, engine light off was consistently indicated by a rapid rise in EGT that occurred about 10 seconds after the fuel cutoff switch was moved to the run position. The fuel flow indication is located on the lower EICAS display. The actual fuel flow is displayed digitally, although there is a needle that moves on a gage-like icon that has no numerical markings or graduations. When there is zero fuel flow, the needle is pointing to 3:00 o'clock. During the engine starts as soon as the fuel cutoff switch was moved to the RUN position, the fuel flow would increase to 400 pph, which is the minimum flow condition, and then continue to increase to about 1,100 to 1,200 pph as the engine accelerated to and stabilized at idle power. As the fuel flow increased, the needle moved in a clockwise direction. When the power levers were advanced to attain a fuel flow indication of 8,300 pph, the needle moved in a clockwise direction until it was pointing to about 5 o'clock. When the power lever was advanced, there was an approximate 1 second lag before the indicated EGT would respond.

The Delta 757/767 Operations Manual states in part to do the ABORTED ENGINE START checklist when one or more of the following conditions occur:

- Fuel flow is abnormally high or fluctuating;
- EGT fails to rise within 20 seconds of selecting RUN or if EGT rising rapidly or approaching limit;
- EGT quickly nears or exceeds the start limit.

The Boeing 757 Maintenance Manual has a caution that states, "If an instantaneous light up occurs (light up occurs in 1 to 2 seconds after you put the fuel control switch to the run position), immediately put the fuel control switch into the cutoff position. If you do not obey these instructions, you can cause damage to the engine.

6.0 Component testing

6.1 Fuel control

6.1.1 Fuel control history

The FCU was a Hamilton Sundstrand JFC104-2 fuel control, part number (PN) 827104-1, SN F56696. According to Delta Air Lines' maintenance records, the FCU had accumulated 25,017 hours TSN and 7,940 CSN, and 5,453 hours TSO, and 1,670 CSO. (Attachment 5) According to Delta Air Lines, the FCU was removed from the engine while the engine was undergoing repair for the hung start and 3-second high EGT. However, there was no record that the FCU was tested while the engine was under repair at the TOC.

6.1.2 Fuel control testing at Delta

When the AMTs were disconnecting the harnesses from the FCU in preparation for removal, they noted that the D4848 W1 harness was loose and the connector was only hand tight. The AMT reported that he still had to make a number of turns on the connector to disconnect the connector from the FCU. The AMT stated that the red indicator band was covered. The AMT also reported that the W2 harness and connector were both tight.

The FCU was transferred to the Delta TOC controls shop for further examination and testing.

The visual examination of the exterior of the FCU did not reveal any distress. All of the electrical connector pins were straight and did not have any evidence of arcing or foreign material. The visual examination of the minimum pressure shutoff valve (MPSOV) spool through the discharge port showed axial scoring and discoloration that was reported to be typical for service run parts. The technician stated that the sleeve appeared to ride higher than normal in the housing discharge port.

The electrical cavity cover was removed from the FCU. All of the wires appeared to be in good condition with no apparent indication of chafing, nicks, cuts, or insulation breaks. There was some fuel wetting present within the cavity with some discoloration noted adjacent to a potting injection hole on the top of the start/run solenoid. The feedback cavity cover was also removed. The inside of the feedback cavity had some residual dry film lubricant that was reported to be typical according to the Hamilton Sundstrand group member and the Delta technicians. All of the linkage and feedback mechanisms appeared to be properly assembled and aligned.

The input drive quill could be easily rotated in both directions by hand. The torque required to rotate the input drive quill in each direction was 8 – 10 inch-ounces as measured with a torque wrench.[16] The rotational operation of the drive quill and the attached overspeed governor valve did not have any indications of a malfunction.

The main and fine filters were removed. Both of the filters had a discoloration that was reported by the Hamilton Sundstrand group member and the Delta technicians to be typical for service run parts. There was no corrosion or contamination on either of the filter elements. Fuel samples were obtained from two separate areas of the FCU. The first was obtained from the inlet filter bore area after removal of the filters. This fuel sample appeared to be clear and bright.[17] The second sample was obtained from the spring loaded side of the overspeed governor. This fuel sample appeared to be visually dirty. (According to Hamilton Sundstrand and Delta, fuel samples collected from this area are typically dirty.)

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[16] The Hamilton Sundstrand group member who assisted with the disassembly of the FCU later stated the CMM does not have a specific instruction or requirement to do the torque check. He stated that checking the torque with a torque wrench gives him a quantitative assessment of the freedom of movement of the input drive quill.

[17] According to ASTM International Standard D1655 Aviation Grade Turbine Fuel, the visual appearance of jet fuel should be clear and bright.

The pressure regulating valve (PRV) and FMV were examined with a borescope while they were still in the FCU housing. Although the viewing access was limited, what could be viewed of each valve showed that there was no corrosion on the sleeves on each valve.

The FCU was mounted on a test rig. The FCU was hooked up to an electrical test box. Before the hydraulic pressure was turned on, the channel A and B resolver angles were measured. The channel A resolver angle was 87.30 degrees and the channel B resolver angle was 92.45 degrees. The specification limits are 84.7 ±0.2 degrees. Channel A was 2.4 degrees over the high limit and channel B was 7.55 degrees over the high limit. Resistance checks of the FCU FMV resolver, shutoff switch, and start and shutoff solenoids were accomplished in accordance with Component Maintenance Manual (CMM) 73-21-06 Section 7 initially at room temperature and then again about the FCU had been cold soaked overnight to -10 degrees F. At room temperature, the FCU passed all of the electrical checks. Refer to Attachment 6. After the FCU had been cold soaked and the electrical checks were redone, the FCU channel A and B resolver rotor resistance was low, 42.6 and 42.9 ohms, respectively, in comparison to the required 44 – 61 ohms. Additionally, the FMV channel A and B torque motor resistance was low, 82.8 and 83.9 ohms, respectively, in comparison to the required 87 – 102 ohms. Refer to Attachment 7.

When the test stand was started, the FCU FMV showed a smooth translation from the fully open position to the minimum flow position.[18] The channel A FMV resolver angle was measured at 7.42 degrees and the Channel B FMV resolver angle was measured at 12.38 degrees. Specification limits at the minimum flow position are 5.0 +/-0.4 degrees. Channel A was measured at 2.02 degrees over the high limit and Channel B was measured at 6.98 degrees over the high limit. Testing of the FCU FMV channel A flow schedule per CMM 73-21-06 Table 107 revealed that the intermediate flow points above minimum flow but below the maximum flow point were below the required amount. Refer to Attachment 8.

A complete as-is test was accomplished in accordance with CMM 73-21-06 Section 7. Other than the resolver position shift already observed, only one other out-of-limit condition was observed. That condition was the trip flow that was measured at 625 pph versus a 1,000 pph minimum requirement. The complete flow test was repeated on 24 February and showed similar results to the previous test. Refer to Attachment 9.

[18] According to the Hamilton Sundstrand group member, when the engine is not operating, the FMV is in the fully open position. During engine start, the FMV translates to the minimum flow position.

6.1.3 Fuel control testing at Hamilton Sundstrand

The FCU was sent to Hamilton Sundstrand, Windsor Locks, Connecticut for further testing.

The FCU was disassembled. The feedback linkage and electrical cavity covers were removed.

The feedback linkage cavity did not have any discrepancies. The wires did not have any indications of breaks or chafing.

The PRV did not have damage or corrosion.

The start/run and shutoff solenoids were in place and did not have any apparent damage. The electronic hydraulic servo valves (EHSV) for the air-oil cooler and stator vane actuators were in place and did not have any apparent damage. The O-rings on both of the EHSVs were slightly flattened. There was no evidence of leakage past the O-rings.

The FMV sleeve had brown substance around the base on the chamfered. (Photo No. 8) The inner diameter (ID) of the FMV sleeve also had the brown substance that had axial scratches. (Photo No. 9) The ID of the sleeve also had a witness mark, a circumferential dark mark, which corresponded to the O-ring on the FMV spool.

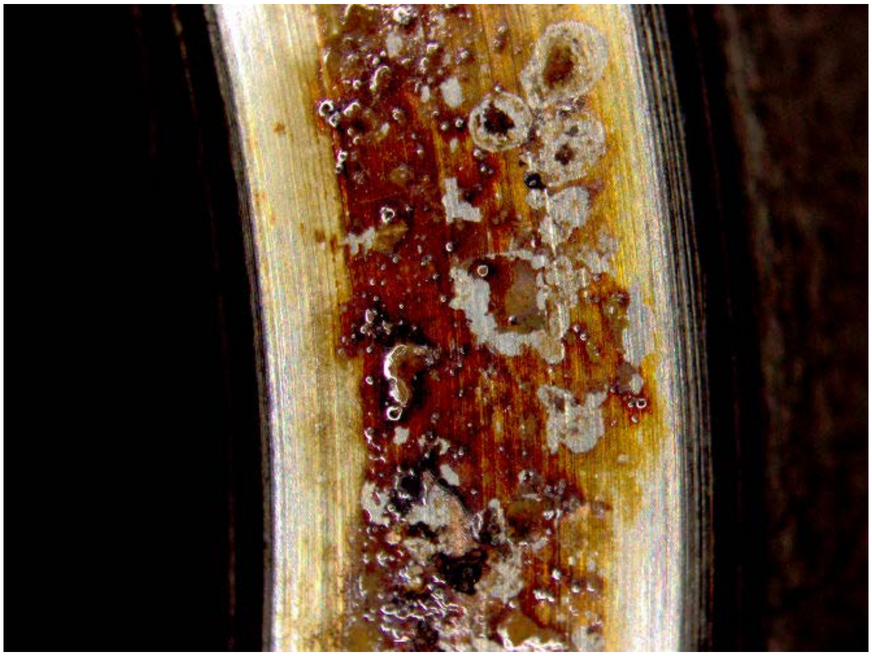

Photo No. 8: Close up view of FMV sleeve showing brown substance on chamfer. (Hamilton Sundstrand)

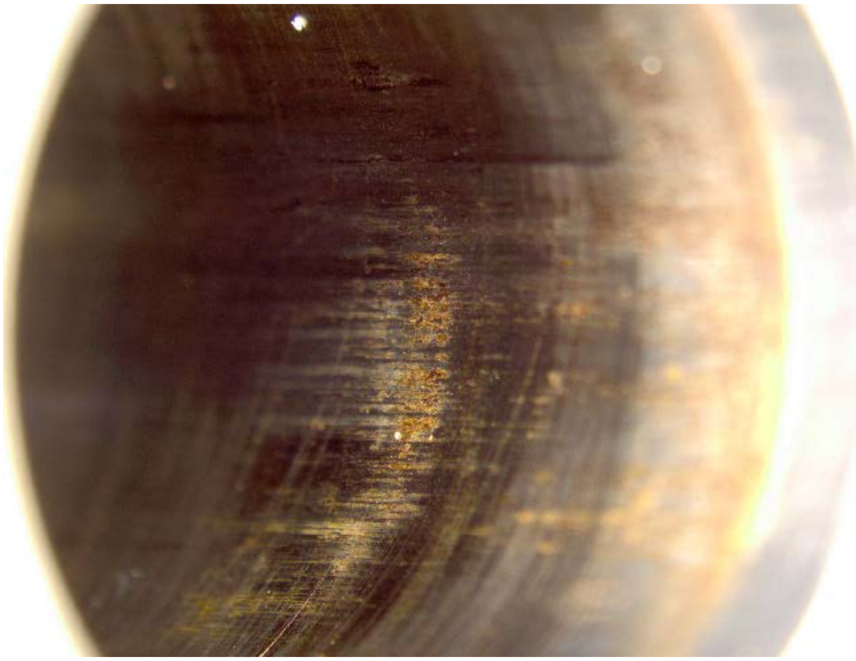

Photo No. 9: Close up view of FMV sleeve showing brown substance with axial scratches. (Hamilton Sundstrand)

The 'A' and 'B' channel FMV resolvers were removed from the FCU. The resolvers had the following markings:

7030-827110-1 REV A
3030-SOCN827109-1 REV A
Item Ident 050088-CU41093023.

The channel 'A' resolver was SN U0230 0479 and the channel 'B' resolver was SN U0237 0518. The FMV resolvers were sent to Kearfott Motion Systems, for disassembly and examination. Refer to Section 6.3.

The fine flow filter was partially obstructed. An exemplar filter when held up to a light would show light through the filter element whereas the fine flow filter removed from the FCU would not.

6.2 Electronic engine control

The EEC was PN 824998-4-003, SN 2037-2054, EEC 104-60, Mods L3/5/6.

The PW2037 engine's EEC has two redundant channels, channel A and channel B, that monitor and control the engine. At all times, one channel is active monitoring and controlling the engine while the other channel remains in a hot standby mode to assume control should the first channel fail. According to Hamilton Sundstrand, on this model of EEC, channel A is always in control unless there is a failure of some kind at which time channel B becomes active.

Prior to the arrival of the Powerplants Group, but with the authorization of the Group Chairman, Hamilton Sundstrand accomplished an acceptance test procedure, thermal cycle test, and vibration test on the EEC. The EEC passed all three of the tests.

The EEC was disassembled. The separator shield was intact. The boards on the channel A and B sides of the EEC were in place, intact, and did not have any apparent damage.

The burner pressure[19] sensor port screen was clear. The wall on the counterbore hole inside the EEC cover had a white powder on one side.

6.3 Resolvers

The FCU FMV channel A and B resolvers were shipped to the manufacturer, Kearfott Motion Systems, Asheville, North Carolina for disassembly, examination, and testing in the presence of members of the Powerplants Group.

6.3.1 Channel A resolver

The channel A resolver was Hamilton Sundstrand PN 73030-827110 Rev A, Kearfott PN 05088-CU41093023, SN 0479

External examination

The examination of the exterior of the resolver revealed a film wetting the leads at the exit side of the sleeving. There was a lubricant on the gear teeth and shaft. There was some fluid visible on the potting and lead end on the exit side. There was a broken piece of potting on the inside screw on the back of the resolver. The screws were wet. There was contamination on the channel A resolver that was similar to the contamination that was observed on the channel B resolver. The potting compound surrounding the wire leads at the exit area of the resolver was not bonded to the wire sleeving or the housing and the potting would move when the wire leads were manipulated.

There was evidence of a lubricant coating the screw heads and threads on the gear end. On the opposite end, the wire side, the screws had some corrosion.

The channel A resolver's solid black wire, which is the cosine return wire, had one dent at the same location as the channel B resolver's solid black wire. There was no bare wire exposed. All of the crimping appeared to be in good condition. The pin hole and the location of the wires were okay.

[19] On the PW2037 engine, burner pressure is the pressure within the diffuser case annulus.

Disassembly

The disassembly of the channel A resolver did not reveal any evidence of corrosion or contamination. The inside of the rear cover appeared to be in good condition. The inside of the channel A resolver appeared to be dry.

The rotor was separated from the stator housing and appeared to be in good condition. There was no evidence of corrosion or contamination on either the stator housing or the rotor. The stator housing and rotor appeared to be clean.

Electrical tests

The channel A resolver underwent several electrical checks. The checks and results are listed in Table 1.

Table 1: Channel A resolver electrical checks

Characteristic	Criteria	Results
Primary DCR	44.2 – 89.8 ohms	49.58 ohms (Passed)
Sine DCR	61 – 82 ohms	71.36 ohms (Passed)
Cosine DCR	61 – 82 ohms	71.14 ohms (Passed)
Insulation Resistance	500 VDC 100 Mohms min	Red/White wire to case - 42.12Gohms (Passed) Red wire to case - 7.036 Gohms (Passed) Red/White to red wire - 10.35 Gohms (Passed)
Input current	7.1 mA max	5.24 mA (Passed)
Transformation ratio	0.485 – 0.515	0.499 (Passed)

6.3.2 Channel B resolver

The channel B resolver was Hamilton Sundstrand PN 73030-827110 Rev A, Kearfott PN 05088-CU41093023, SN 0518

External examination

The exterior of the channel B resolver had contamination and there was moisture where the wires entered the bottom of the resolver case. There was moisture on the potting compound between the sleeve and stator housing. There was moisture between the exposed rubber and the rubber sleeve. The potting compound around the wire leads where they entered the case were not bonded to the wire sleeves or the case and the potting would move when the wires were manipulated. The top side of the resolver with the gear had oil on the flange. The exterior of the sleeve was dry, but the inside of the sleeve where the wires were located was wet.

The channel B resolver's solid black wire, which was the cosine return wire, had a dent at the same location as was noted on the channel A resolver's solid black wire. There was no bare wire exposed. The crimps appeared to be in good condition. The leads on the yellow and black wires had cracks in the plastic covering, but there was no evidence of damage to the wires. The solid red wire was crimped incorrectly, the red wire's insulation extended into the barrel and was crimped into the pin. After the initial electrical check, the red wire lead was removed and the check was repeated and there was no change in the test result.

Disassembly

When the channel B resolver was disassembled, there was heavy corrosion and contamination on the rotor and internal cavity of the stator housing. (Photos Nos. 10 and 11) The rotor assembly was difficult to remove. There was moisture throughout the internal cavity of the resolver. The Kearfott personnel who disassembled the resolver stated that they had never seen that type of corrosion before.

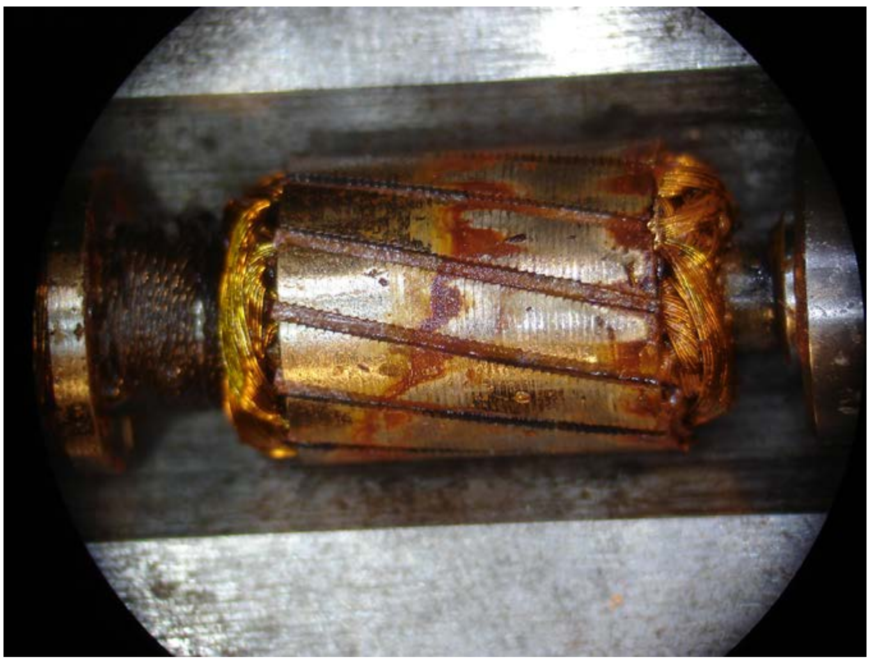

Photo No. 10: Close up of FCU FMV channel B resolver showing corrosion on the rotor assembly.

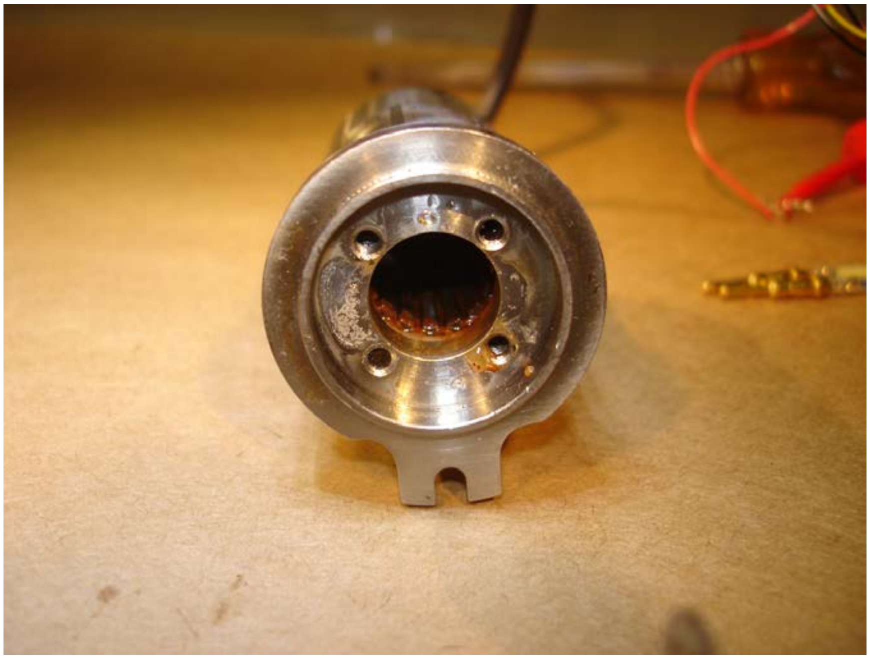

Photo No. 11: Close up of end of FCU FMV channel B resolver stator body showing corrosion on the inside of the housing.

Electrical tests

The channel B resolver underwent several electrical checks. The checks and results are listed in Table 2.

Table 2: Channel B resolver electrical checks

Characteristic	Criteria	Results
Primary DCR	44.2 – 89.8 ohms	49.03 ohms (Passed)
Sine DCR	61 – 82 ohms	69.69 ohms (Passed)
Cosine DCR	61 – 82 ohms	Open (Failed)
Insulation Resistance	500 VDC 100 Mohms min	Red/White wire to case - 15.6Mohms (Failed) Red wire to case - 1.1 Mohms (Failed) Red/White to red wire - 10.7 Mohms (Failed) Yellow wire to case - 1.3 Mohms (Failed)
Input current	7.1 mA max	5.46 mA (Passed)
Transformation ratio	0.485 – 0.515	0.499 (Passed)

The insulation resistance check was repeated after the unit was disassembled and the rotor was removed from the stator housing. The red wire insulation was cut back and recrimped before repeating the test. The measurement taken the second time is shown in Table 3.

Table 3: Channel B resolver insulation resistance retest results

Insulation Resistance	500 VDC 100 Mohms min	Red/White wire to case - 59.1 Mohms (Failed) Red wire to case - 3.2 Mohms (Failed) Red/White to red wire - 406.8 Mohms (Failed) Yellow wire to case - 1.3 Mohms (Failed)

6.4 Fuel pump

The fuel pump was a Hamilton Sundstrand pump, PN 5010224A, SN 288. The fuel pump was tested at the take off and starting flow rates on a test bench at Delta's TOC. The bench, an RB211, CFM56, and PW2037 main fuel pump test stand, PN BEI 3856, SN 7832, had a calibration sticker indicating it was due for calibration on November 29, 2011. The results of the fuel pump tests are listed in Table 4.

Table 4: Fuel pump test results

Takeoff	Actual	Limits
Total flow	21,947 pph	21,698 pph minimum
Boost rise	119 psi	105 psi minimum
Servo delta P	0 psi	8 psi maximum
Starting		
Total flow	2,506 pph	2,502 pph minimum
Servo delta P	0.2 psi	8 psi maximum

7.0 Engine disassembly

The engine was removed from the airplane and shipped to Delta's TOC for disassembly in the presence of members of the Powerplants Group.

7.1 External

The engine was complete from the fan case front flange to the turbine exhaust case rear flange. The fan spinner and spinner cap and the turbine exhaust cone and tailplug were also in place on the engine. The engine did not have any indications of an uncontainment, case rupture, burn thru, or an undercowl fire. (Photos Nos. 12 and 13) The engine's primary exhaust nozzle had been removed from the engine and was stored vertically in the disassembly shop area.[20]

[20] The Powerplants Group Chairman had authorized Delta to remove some components including the exhaust nozzle in preparation for the engine disassembly.

The engine's HPT and LPT modules and the turbine exhaust case had a slight odor that was similar to the smell of the exhaust from a diesel engine.

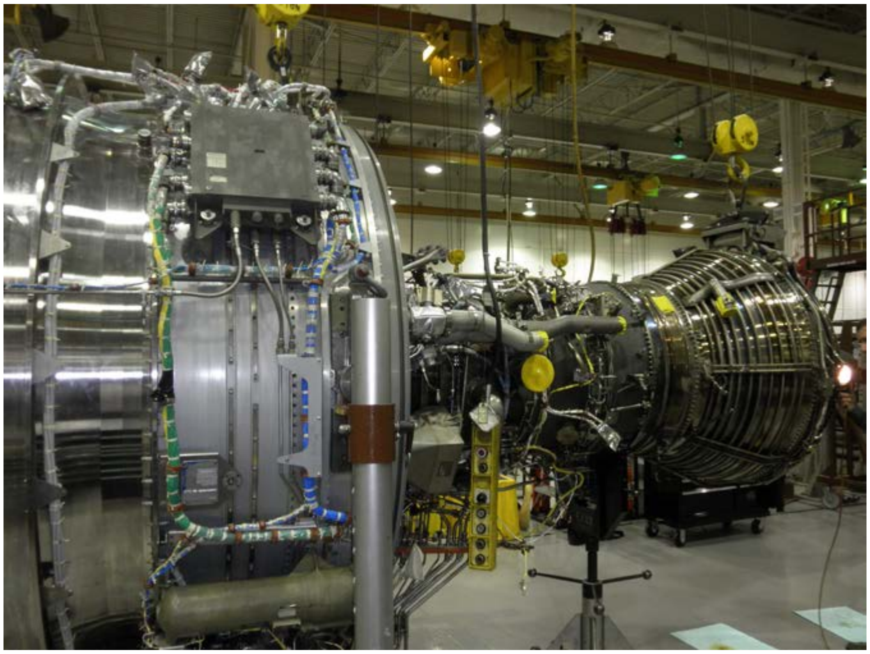

Photo No. 12: View of the left side of the engine showing no fire damage or sooting.

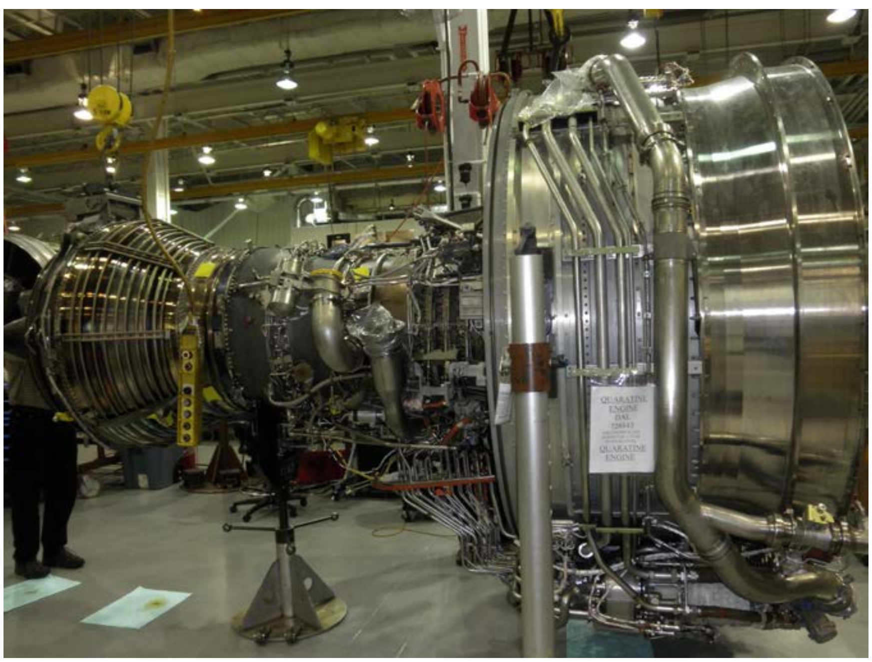

Photo No. 13: View of the right side of the engine showing no fire damage or sooting.

7.2 Fan

The fan blades were all in place and the airfoils did not have any damage. The fan was rotated 360 degrees and there was no resistance or abnormal noises when it was rotated.

The fan exit vanes were all in place and did not have any damage.

7.3 Low pressure compressor

A visual check of the visible forward two stages of the LPC did not reveal any damage. The engine was not disassembled to examine the remainder of the LPC.

7.4 High pressure compressor

The engine was not disassembled to examine the HPC.

7.5 Combustor

The exterior of the diffuser case did not have any areas of thermal distress or discoloration.

The combustor inner and outer liners and bulkhead were intact. The interior surfaces of the combustor inner and outer liners and bulkhead were a bright off-white color. (Photo No. 14) The interior surfaces of the combustor inner and outer liners had random areas of soot on the surface. The combustor inner liner had numerous trailing edge cracks on each of the louvers. The combustor was not disassembled to expose the exterior of the combustor liners.

The fuel nozzle heatshields were all in place and were a dark, almost black color. Several randomly located fuel nozzle heatshields were damp.

The combustor chamber clamp was intact, but had an arc of heat discoloration in front of almost every 1st stage turbine vane.

Photo No. 14: View of the combustor outer liner showing random sooting.

7.6 High pressure turbine

The HPT case had a dark purple discoloration between the front flange and the front rail, which was about 3-inches aft of the front flange. The HPT case, between the front rail and the middle rail that was about 5-inches aft of the front flange, had a purple discoloration that was slightly less dark than the discoloration noted between the front rail and the middle rail.

The HPT module was removed from the engine, but was not disassembled.

The 1st and 2nd stage turbine blades were all in place in their respective disks and did not have any apparent damage to the airfoils. The 1st and 2nd stage turbine blade airfoils and blade root platforms had a dark, almost black discoloration. (Photo No. 15)

Photo No. 15: Close-up view of the 1st stage turbine blades showing the dark discoloration on the airfoil surface.

The 1st and 2nd stage turbine ceramic outer air seal segments were all in place. The segments had a dark gray color in the blade path and a dark beige color elsewhere.

The 1st stage turbine vanes were all in place. All of the 1st stage turbine vane airfoils were a dark, almost black color, but they also had a beige colored band adjacent to the outer platform. (Photos Nos. 16 and 17) There were four adjacent 1st stage vanes at about 7 o'clock[21] that had light beige colored streaks adjacent to the inner platform. Many of the 1st stage turbine vanes had dark glossy black colored streaks extending aft from the cooling air holes. There were six non-consecutive randomly located vanes that had the coating delaminating from the leading edge and one vane each at about 7 and 10 o'clock that had a small piece of the coating chipped away from the convex surface just aft of the leading edge. A piece of the delaminated coating was broken off and analyzed with energy dispersive spectroscopy[22] (EDS). The EDS analysis indicated the material was the ceramic coating.

[21] All references to position or directions, as referenced to the clock, will be as viewed from the rear, looking forward, unless otherwise specified.
[22] In energy dispersive spectroscopy, the object to be analyzed is bombarded with charged particles such as electrons that cause an excitation of the individual atoms and the associated electron shells that produces an X-ray spectra that can provide a qualitative assessment of the chemical makeup of the object.

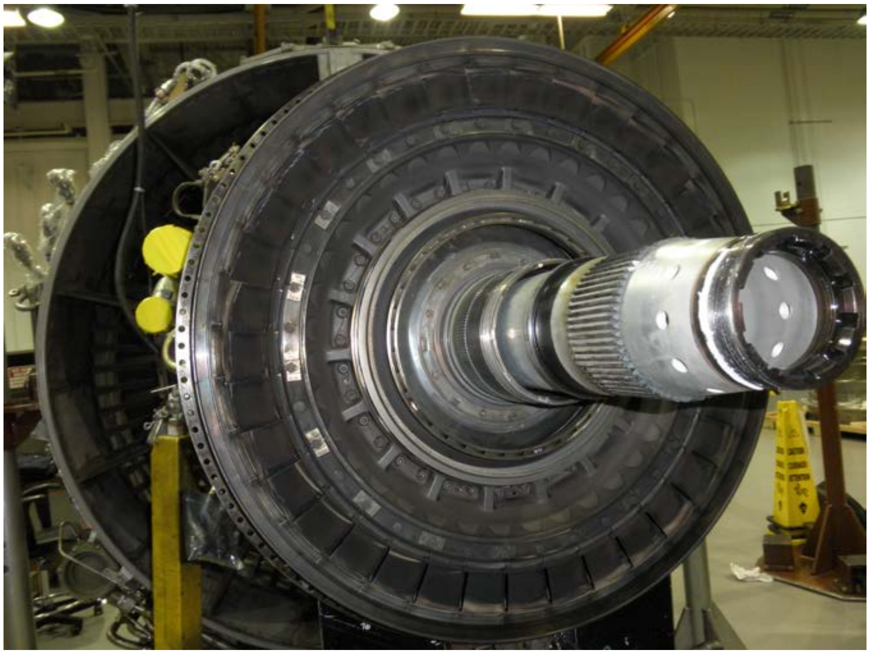

Photo No. 16: View of the 1st stage turbine vanes showing they were all in place and had a dark discoloration.

Photo No. 17: Close up view of the 1st stage turbine vanes showing dark discoloration on airfoils and light-colored areas on outer platforms.

7.7 Low pressure turbine

The LPT case had purple discolorations around the circumference of the case that were approximately in line with the 3rd, 4th and 5th stage rotors.

The LPT module was removed from the engine, but was not disassembled.

All of the LPT transition duct segments were in place in the LPT case and had a dark, almost black discoloration.

The 3rd stage turbine vanes were all in place in the LPT case and were intact. There was no apparent damage to the 3rd stage turbine vanes. All of the 3rd stage turbine vanes had a dark, almost black discoloration.

The 7th stage turbine vanes have a black stain adjacent to the outer foot on the convex side of the airfoil.

The 7th stage turbine blades were all in place in the disk and did not have any apparent damage. The 7th stage turbine blades had a dark, almost black discoloration. (Photo No. 18)

Photo No. 18: View of the 7th stage turbine blades showing dark discoloration.

7.8 Turbine exhaust case

The turbine exhaust case and all of the struts were intact and in place. The ID of the turbine exhaust case and outer diameter of the turbine exhaust case inner duct and all of the struts had a dark, almost black discoloration. Many of the turbine exhaust case struts had elliptical-shaped areas on the convex side extending aft from the leading edge that although still a dark color, were more of a gray color rather than black. (Photo No. 19)

Photo No. 19: Close-up view of the turbine exhaust case inner and outer ducts and struts showing dark discoloration all around and the elliptical-shaped areas on the struts.

The turbine exhaust case inner support had small bits of a gray powdery substance that were similar in appearance to the anti-seize compound that is used on the flange bolts and nuts.

The turbine exhaust case No. 5 bearing inner support had a black stain on the rear inner surface from the No. 5 bearing housing rear cover aft that was about 5 inches long and 1 inch wide.

The turbine exhaust cone and plug were in place on the turbine exhaust case inner support.

There was a gray powdery substance on the bottom of the turbine exhaust cone just aft of the forward flange and near the rear flange that was similar in appearance to the anti-seize compound that is used on the flange bolts and nuts.

The EGT harness and probes were checked using a Fluke 87 V True RMS Multimeter, SN S647047. The multimeter was tagged indicating the calibration is valid until September 16, 2012.

The six EGT probes were tested. There were no shorts to ground on any of the probes. The measured resistance on the probes are listed on Table 5.

Table 5: Measured resistance of engines' EGT probes.

Probe	Primary	Secondary
1	1.2 ohms	2.5 ohms
2	1.3	2.5
3	1.3	2.4
4	1.3	2.5
5	1.3	2.5
6	1.2	2.5

According to the PW2000 CMM, Section 77-21-03, the limits for the EGT probe resistance are 1.03 to 1.34 ohms for the primary and 2.05 to 2.78 ohms for the secondary.

The EGT harness on the turbine exhaust case and between the turbine exhaust case and the EEC were checked. Neither of the EGT harnesses had any short circuits to ground.

7.9 Oil system

The master (oil tank) and No. 5 bearing magnetic chip detectors (MCD) did not have any debris on the ends. The main gear box, Nos. 1, 2, and 3 bearings, and accessory gearbox MCDs each had one very small chip on the ends. The No. 4 bearing MCD had two very small chips on the end.

The oil from the oil tank was drained through a screen and there was no debris found on the screen. About 6 1/2 quarts of oil were drained from the gearbox.[23] The oil drained from the engine did not have an acrid smell.

The No. 5 bearing compartment did not have any oil collected in the bottom of the compartment.

7.10 Bearings

The No. 5 bearing compartment rear cover was clean and the O-ring was intact. The No. 5 bearing was intact, wet with oil, and did not have any rotational damage. The No. 5 bearing components were not discolored. The No. 5 bearing oil jet was removed and was found to be clean and clear. The No. 5 bearing scavenge screen was also clean.

The engine was not disassembled to expose the other mainshaft bearings.

[23] According to the Boeing 757 Aircraft Maintenance Manual Section 79-11-00, the PW2037 oil capacity is 30 quarts.

7.11 Fuel system

The fuel was drained and collected from the fuel pump filter bowl. The fuel was clear and bright and did not have any debris or apparent water. The bottom of the filter bowl did not have any debris or visible water. The filter element was clean.

The fuel distribution valve filter had several small bits of debris in the filter element.

7.12 Engine wiring harnesses

The W1 (channel A) and W2 (channel B) engine wiring harnesses from the EEC to the FCU were tested as installed on the engine. Continuity, insulation resistance, and manual shake test (resistance) were performed on each pin and socket. All of the measurements were found to be within limits.

8.0 Recorders

8.1 Cockpit voice recorder

The cockpit voice recorder (CVR) was removed from the airplane and sent to NTSB Headquarters for playback in the Recorder Laboratory. According to the Cockpit Voice Recorder Specialist's Factual Report, the audio sounds on the CVR were consistent with the incident engine start having been overwritten. For further details, refer to the Cockpit Voice Recorder Specialist's Factual Report.

8.2 Flight data recorder

The flight data recorder (FDR) captured the incident start. However, the preflight test ground run was not recorded on the FDR. The last operation of the engines just prior to the incident engine start that was recorded on the FDR involved an actual flight.

For the incident engine start, the FDR data shows that the left engine was started first followed by the right engine about 1 minute 40 seconds later. The FDR data shows that when the left engine was started, the N2 rpm increased from zero to about 26 percent over a 34 second period, stabilized momentarily, and then after the indication for the fuel switch showed it changing from OFF to ON, the N2 began to further increase slowly as the N1 rpm began to increase. After about one minute, the left engine's N2 and N1 rpm indications stabilized at about 57 percent and 20 percent, respectively. The left engine's fuel flow indication indicated about 1,000 pph[24] and the EGT indication was about 300 degrees C. When the right engine was started, the N2 indication began to increase and about 20 seconds later when the N2 rpm

[24] The FDR recorded the fuel flow data once every 72 seconds.

indication was about 25 percent, the fuel switch indication changed from OFF to ON. The right engine's N2 indication continued to increase until it stabilized at about 40 percent without any intermediate stabilization or even slowing down. The right engine's N1 indication increased very slowly getting up to a maximum of about 10 percent before decreasing slowly. The right engine's fuel flow indication, which was recorded about a minute after the N2 indication began to increase from zero, was about 8,000 pph. The FDR data shows that after the high fuel flow was recorded for the right engine, the right engine's fuel switch was moved from ON to OFF and the N2 indication decreased to about 30 percent where it remained for about a minute before further decreasing to zero. For further details, refer to the Flight Data Recorder Specialist's Factual Report.

GLOSSARY

A	amperes
ACARS	aircraft communications addressing and reporting system
ACT	actual
ALT	altitude
AMT	aviation maintenance technician
APU	auxiliary power unit
A&P	airframe and Powerplants
BB	broad band
BVA	intercompressor bleed valve resolver angle
C	Celsius
CMD	commanded
CMM	component maintenance manual
COS	cosine
CSN	cycles since new
CSO	cycles since overhaul
CVR	cockpit voice recorder
DCR	direct current resistance
delta-P	differential pressure
Duct Pr	duct pressure
EEC	engine electronic control
EGT	exhaust gas temperature
EHSV	electronic hydraulic servo valve
EICAS	engine indicating and crew alerting system
EPCS	electronic propulsion control system
EPR	engine pressure ratio
F	Fahrenheit
FCU	fuel control unit
FDR	flight data recorder
FMV	fuel metering valve
FO	first officer
G	giga
HPC	high pressure compressor
HPT	high pressure turbine
ID	inner diameter
IRS	inertial reference system
JFK	John F. Kennedy International Airport
LPC	low pressure compressor
LPT	low pressure turbine
L1	left side most forward cabin door
L2	left side mid-cabin door just in front of wing
M	mega
mA	milliamperes
MCD	magnetic chip detector
MPSOV	minimum pressure shutoff valve

MSP	Minneapolis-St. Paul International Airport
NTSB	National Transportation Safety Board
N1	low pressure rotor speed
N2	high pressure rotor speed
N2C	high pressure rotor speed, corrected to standard day conditions
P	primary
PN	part number
pph	pounds per hour
PRI	primary
PRV	pressure regulating valve
psi	pounds per square inch
P&W	Pratt & Whitney
P2/Ps	ratio of inlet pressure to static pressure
QRH	quick reference handbook
REV	revision
rpm	revolutions per minute
RVA	thrust reverser actuator resolver angle
S	secondary
SEC	secondary
SN	serial number
SVA	stator vane resolver angle
TAT	total air temperature
TLR	throttle lever resolver angle
TOC	Technical Operations Center
TSN	time since new
TSO	time since overhaul
T2	inlet temperature
VDC	volts, direct current
Vib N1	Low-pressure rotor vibration
Vib N2	High-pressure rotor vibration
Vib BB	Broad band vibration
W1	wire harness, channel A
W2	wire harness, channel B

ATTACHMENTS

1. Airplane maintenance records
2. Minneapolis-St. Paul International Airport ramp control chart 10-9B
3. Minneapolis-St. Paul International Airport airport diagram
4. Engine preflight run checklist
5. Fuel control unit history
6. Fuel control unit electrical test at room temperature
7. Fuel control unit electrical test after being cold soaked
8. Fuel control unit fuel metering valve channel A flow schedule test
9. Fuel control unit as-received functional test