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

September 9, 2019

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: DCA19MA086

A: ACCIDENT

Location:	Anahuac, Texas
Date:	February 23, 2019
Time:	1239 central standard time
Aircraft:	Boeing 767-375BCF, N1271A, Atlas Air flight 3591

B: POWERPLANTS GROUP

Group Chairman:	Gordon J. Hookey National Transportation Safety Board Washington, D.C.
Member:	Dan Kemme GE Aviation Cincinnati, Ohio

C: SUMMARY

On February 23, 2019, at 1239 central standard time, Atlas Air flight 3591, a Boeing 767-375BCF airplane, N1271A, entered a rapid descent from 6,000 feet and impacted a marshy bay area about 40 miles southeast of George Bush Intercontinental Airport (KIAH), Houston, Texas. The airplane was destroyed and highly fragmented. The two pilots and one nonrevenue jump seat pilot were fatally injured. The domestic cargo flight was operating on an instrument flight rules flight plan under the provisions of *14 Code of Federal Regulations Part 121* from the Miami International Airport (KMIA), Miami, Florida to KIAH.

The engines installed on the airplane were General Electric (GE) CF6-80C2B6F turbofans. Although both engines were also highly fragmented, pieces of all of the major component modules from both engines were recovered and identified. The engines did not have any indications of an inflight fire, case rupture, or uncontainment. The damage noted on both engines was consistent with both engines operating at the time of impact.

D: DETAILS OF INVESTIGATION

1.0 Engine information

1.1 Engine description

The engines installed on the airplane were GE CF6-80C2B6F turbofans. The CF6-80C2B6F engine is a dual-spool, axial-flow, high-bypass turbofan engine that features a 1-stage fan, 4-stage booster, 14-stage high-pressure compressor (HPC), annular combustor with 30 fuel nozzles, 2-stage high-pressure turbine (HPT) that drives the HPC, and a 5-stage low-pressure turbine that drives the fan and booster. The CF6-80C2 engine's low pressure and high pressure rotors rotate in the clockwise direction as viewed from the aft looking forward (ALF). The 'F' in the engine model designation indicates the engine was equipped with a full authority digital engine control (FADEC). According to the Federal Aviation Administration's (FAA) Type Certificate Data Sheet (TCDS), the CF6-80C2B6F engine has a normal takeoff thrust rating of 60,030 pounds, flat-rated to 86°F (30°C).[1] The CF6-80C2B6F engine has a maximum continuous thrust rating of 56,170 pounds, flat-rated to 77°F (25°C). Refer to Figures 1 and 2 for a cross-section view and a side view of the engine's exterior, respectively.

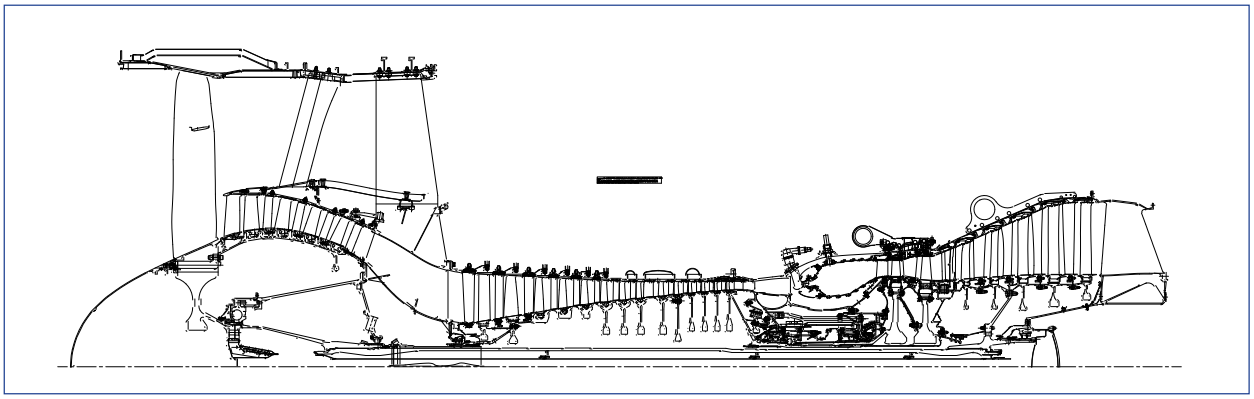

Figure 1: CF6-80C2 engine cross-section. (GE)

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

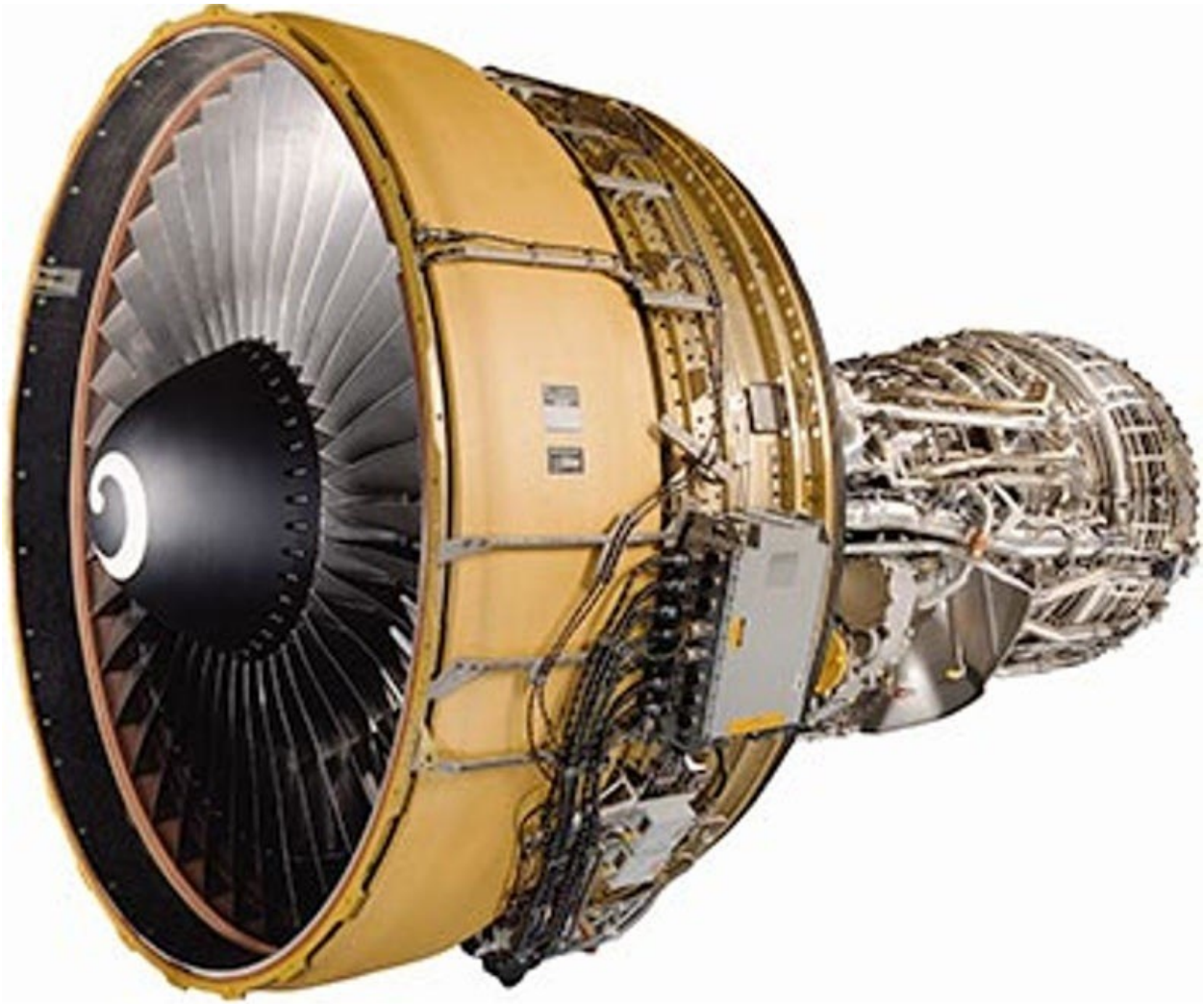

Figure 2: CF6-80C2 engine side view. (GE)

1.2 Engine history

The engines installed on the airplane and their respective operating histories are listed in Table 1.

Table 1: Engine operating history

Position	1	2
Serial number (SN)	702680	702250
Time since new (hours)	109,590	107,540
Cycles since new	14,345	17,312
Time since install (hours)	4,024	4,024
Cycles since install	1,354	1,354

Install date	3/22/17	3/22/17
Last shop visit date	3/3/17	2/20/17

The last shop visit for both engines was accomplished at Evergreen Aviation Technologies (EGAT), Taoyuan, Taiwan. EGAT is an FAA-approved Part 145 repair station, No. E8VY0800.

2.0 Engine identification

The engines were highly fragmented and the engines' data plates were separated from the engine wreckage. It was necessary to identify the engines by the part numbers (PN) and serial numbers (SN) found on individual pieces and cross-referencing those numbers to Atlas Air's engine maintenance records. Other pieces of recovered engine hardware were, when possible, associated with one engine or the other by matching fracture surfaces or by the process of elimination. The engine wreckage was recovered from the water at the crash site or around the two marsh islands or from on the marsh islands.

There were two large pieces of engine wreckage recovered. There was a large piece of engine wreckage that extended from the HPC stage 14 disk to the rear flange of the turbine rear frame (TRF). (Photo No. 1) The other large piece of engine wreckage extended from the stub shaft and the front of the HPC, which was complete, to the LPT stage 3 disk. (Photo No. 2) The two large pieces of engine wreckage were both recovered from the water. Also recovered was an individual HPC stage 2 disk, part number (PN) 9390M27P03, SN SNG05682, which was found on a marsh island, that was identified from engine maintenance records as having been installed in the No. 1 engine. (Photo No. 3) The engine wreckage shown in Photo No. 2 had a complete HPC that included the HPC stage 2 disk. Since the recovered HPC stage 2 disk that according to maintenance records had been installed in the No. 1 engine, that would make the engine wreckage shown in Photo No. 1, which was missing the front of the HPC including the HPC stage 2 disk, the No. 1 engine. Since the wreckage shown in Photo No. 1, is the No. 1 engine, that would make the engine wreckage shown in Photo No. 2 the No. 2 engine.

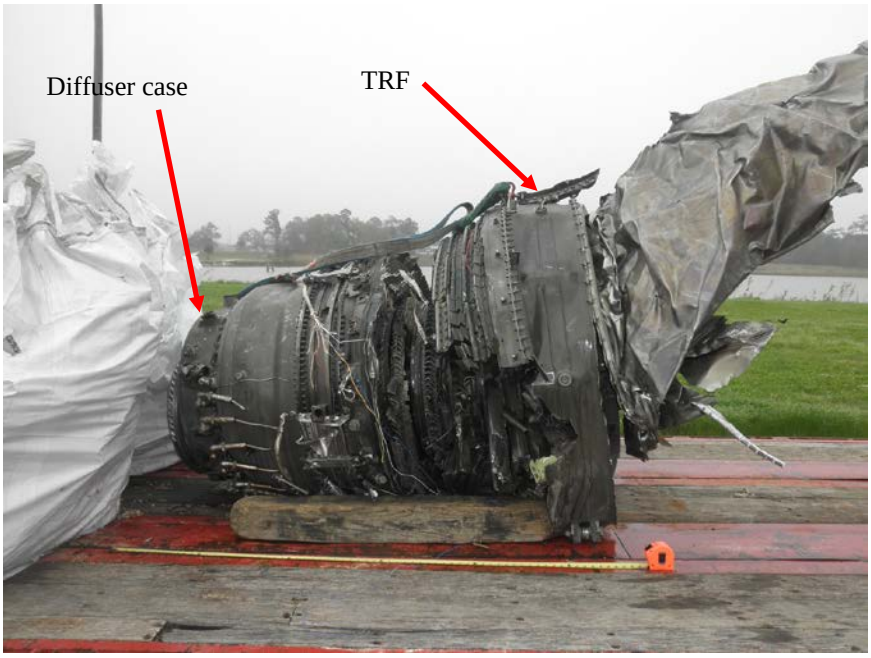

Photo No. 1: Largest piece of No. 1 (left) engine recovered that extended from front of diffuser on left to turbine rear frame on the right.
To the right of the turbine rear frame is the crushed exhaust duct.

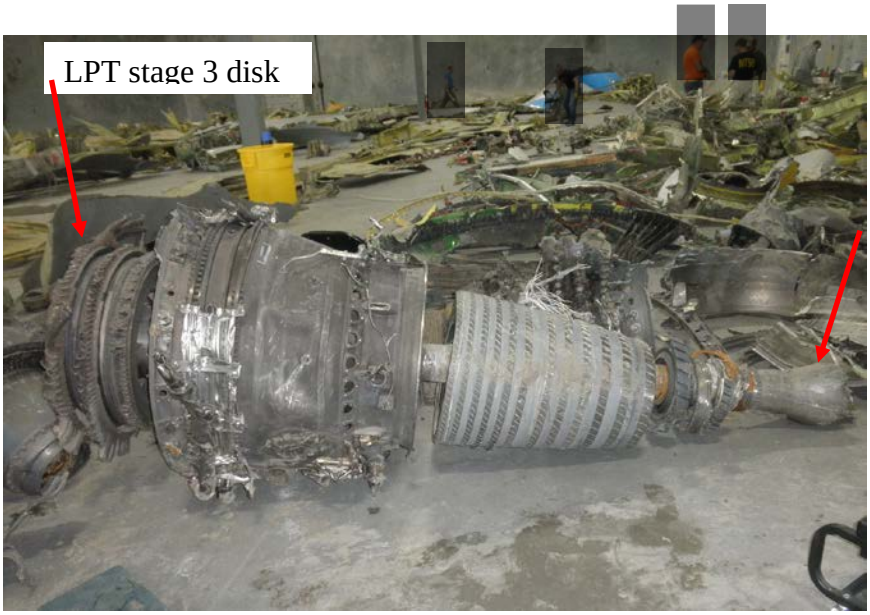

Photo No. 2: Largest piece of No. 2 (right) engine recovered that extended from stub shaft on the right to LPT stage 3 disk on the left.

Photo No. 3: HPC stage 2 disk, PN 9380M27P03 SN SNG05682, laying on the ground, front side up, at the crash site identified from records as having been installed in the No. 1 (right) engine. (GE)

A bracket was recovered that had the engine's data plate indicating the engine was a CF6-80C2B6F SN 702680, that corresponded to the records for the No. 1 engine. (Photo No. 4)

Photo No. 4: A data plate from one of the engines confirming the engine SN as 702680. (GE)

3.0 Engine No. 1

3.1 Fan

The fan disk was intact. (Photo No. 5) The No. 1 engine's fan disk was found on one of the marsh islands down range from the point of impact. The forward end of the stub shaft remained attached to the fan disk. The forward end of the stub shaft was fractured at various

lengths from the front flange that ranged from adjacent to the flange to about 2.75-inches aft of the flange.

Photo No. 5: Left engine's fan disk, front face down, with 28 of 38 fan blades in place in the blade slots, laying on marshy ground at the crash site. The forward end of the stub shaft is still bolted in place to the rear of the fan disk.

There were 28 of 38 fan blades that remained in the blade slots. Of the fan blades that remained in the slots, 10 fan blades were still fully in the slot and 18 were displaced rearward out of the slots for various lengths. All of the fan blades were fractured transversely across the airfoil adjacent to the blade root platform except for an arc of five blades that were fractured across the airfoil between about 5.5- and 8-inches above the blade root platform. The fracture surfaces on all of the fan blades had shear lips and chevrons[2] that pointed towards the leading edge.

The aft end of the stub shaft was attached to the front of the LPT shaft, but was broken about 16.5-inches forward of the bevel drive gear. (Refer to Photo No. 16)

3.2 Booster

There was a piece of the upper and lower half of the booster case, PN 9385M68G06 SN AB2J899, that corresponded to the No. 1 engine, that was about 9-inches long circumferential by about 6-inches axial. There were five 3rd stage booster vanes on the inner surface of the case that were all fractured across the airfoil adjacent to the case wall.

[2] Chevron marks are V-shaped fracture features, the peaks of which point back to the origin of a fracture.

There was a piece of the booster spool that measured about 34-inches circumferential by about 13-inches axial and included stages 1, 2, and 3. There were booster blades in each stage: 11 stage 1 blades, 15 stage 2 blades, and 10 stage 3 blades; most of which were fractured transversely across the airfoil adjacent to the platform. (Photo No. 6) There were several blades that had a bit of airfoil up to about an inch that were bent opposite the direction of rotation. There was complete stage 4 booster rim that was twisted, but the bore was missing. (Photo No. 7) All of the booster stage 4 blades were in the disk slots with the blades being various lengths from fractured directly adjacent to the platform to being full length. All of the longer blades were bent opposite the direction of rotation.

Photo No. 6: Piece of No. 1 engine's booster spool, stages 1 through 3.

Photo No. 7: The No. 1 engine's booster stage 4 disk rim.

3.3 Fan frame

There was a piece of fan frame that was about 21-inches wide and included one full length strut. Also attached to this piece were a left side engine yoke with an engine mount clevis with an approximately 5-inch long piece of thrust link still attached, an approximately 17.5-inch long axial by 18.5-inch wide circumferential piece of the upper left side of the front HPC case that included the first four stages of variable stator vanes (VSV), and a VSV actuator, PN 1211342-005 SN RT848 that corresponded to the No. 1 engine, and a variable bleed valve actuator. There was a piece of fan frame that was about 16-inches long and included an approximately 22-inch long piece of the engine yoke with a right hand engine mount clevis and an approximately 6-inch long piece of the thrust link, and two full length struts. The strut to the clockwise side[3] had an approximately 24-inch long piece of the outer fan case attached. The mount yoke was identified as PN 9383M43G14 SN WACV1301 that corresponded to the No. 1 engine.

3.4 High pressure compressor

The HPC stage 2 disk, PN 9380M27P03, SN SNG05582, that corresponded to the No. 1 engine, was intact. (Photos Nos. 8 and 9) There was an arc of eight blade lugs that had the front tangs partially or completely broken off. And then separated by nine blade posts in the clockwise direction, there were arcs of three and five blade posts, which were separated by three blade posts, that had the rear tangs broken off. There were circumferential rub marks and gouges

[3] All locations on the engine, or directions, as referenced to the clock, will be as viewed ALF, unless otherwise specified.

on the outer diameter of the blade posts. All of the HPC stage 2 blades were missing from the blade slots.

Photo No. 8:The No. 1 engine's HPC stage 2 disk laying on the ground at the crash site. (GE)

Photo No. 9: Serial number of No. 1 engine's HPC stage 2 disk.

The HPC stage 3-to-9 spool was complete and intact. There was an axial line of holes punched into the spool between stages 6 and 9. All of the blades were in place except for two stage 7 blades and one stage 9 blade that were missing. The HPC stage 3 through stage 6 and stage 9 blades were all fractured transversely across the airfoil adjacent to the blade platform. Most of the HPC stage 7 and 8 blades were also fractured transversely across the airfoil adjacent to the platform. Those HPC stage 7 and 8 blades that still had the airfoils were bent opposite the direction of rotation and slightly forward flat against the outer diameter of the spool. (Photo No. 10)

Photo No. 10: The No. 1 engines HPC stage 3-to-9 spool with blades broken off adjacent to platform or bent over opposite the direction of rotation.

There was an unknown stage HPC disk that had the bore and inner part of the web intact. (Photo No. 11) This disk had an approximately 7-inch long circumferential by 2.25 inch wide radial piece of the outer web about 3.5-inches outboard of the bore missing. This disk had an approximately 150° arc of the blade rim still attached with arcs of 3 and 14 blade roots still in the blade slots. The front and rear faces of the disk had circumferential scoring marks and scratches. The rim of this disk was bent aft slightly. All of the blades except one were fractured across the airfoil directly adjacent to the platform. The one longer blade was fractured about 0.75-inches above the platform and the end of the airfoil was bent opposite direction of rotation.

Photo No. 11: An unknown stage HPC disk from the No. 1 engine.

The HPC 14th stage disk, which is part of the stage 11-to-14 spool, was loose laying on the LPT shaft in front of the diffuser case. (Photo No. 12) The disk's web and bore were intact although there was circumferential scoring and scratches on the front and rear faces. The drive cone was broken away from the rear of the disk at the transition radius between the rear face of the disk and the drive cone. The aft inner end of the cone was visible in the bore of the diffuser case, but the cone portion was all broken up. There was about a 260° continuous sector of HPC 14th stage blades, 55 of 76 blade platforms, still in the disk. The rim of the disk was bent aft slightly. All of the blades' airfoils were fractured transversely across the airfoil directly adjacent to the platform. Within the approximately 90° arc of missing blades, there was an approximately 60° arc that was also missing the disk's rim section.

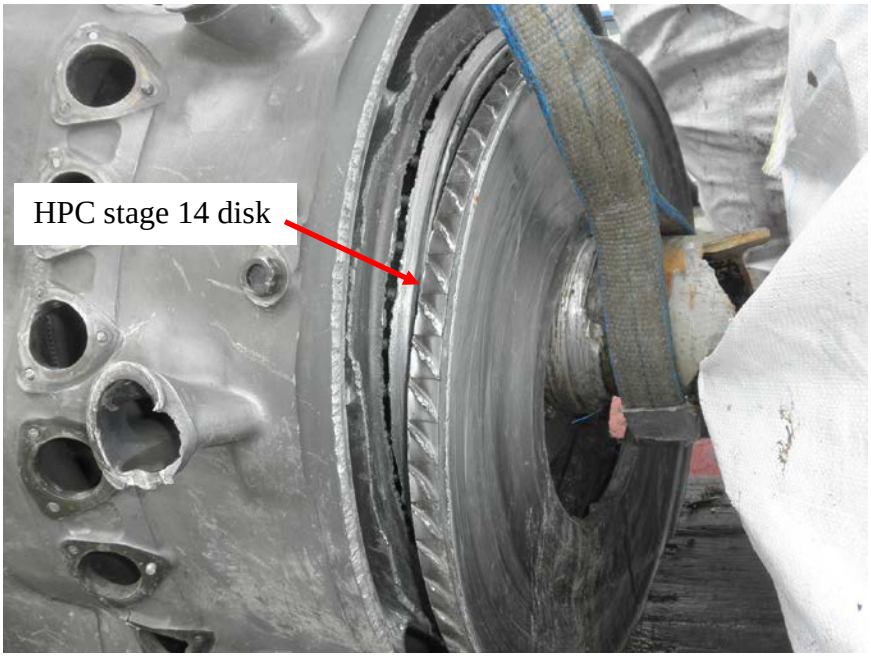

Photo No. 12: The No. 1 engine's HPC stage 14 disk laying on the LPT shaft.

3.5 Diffuser/combustor

The diffuser case was in place on the front of the HPT case. The forward flange of the diffuser case was missing. (Photo No. 13) The diffuser case measured about 22 inches from the rear flange to the forward edge. The diffuser case did not have any indications of thermal distress. The diffuser case was buckled inward and had multiple dents between about 10 and 7 o'clock. There were seven fuel nozzles that were still in place in the diffuser case with five of the seven fuel nozzles partially out of the case and bent rearward. The diffuser case between about 5 and 7 o'clock had circumferential cracks between the fuel nozzle mount pads. The fuel manifolds attached to the fuel nozzles were bent rearward. The dome of the combustor liner was visible from the front of the diffuser. The combustor dome did not have any thermal distress or metal spray material. (Photo No. 14) The igniter plug at 3:30 o'clock was completely missing and the igniter plug at 5 o'clock was broken off flush with the exterior of the diffuser case.

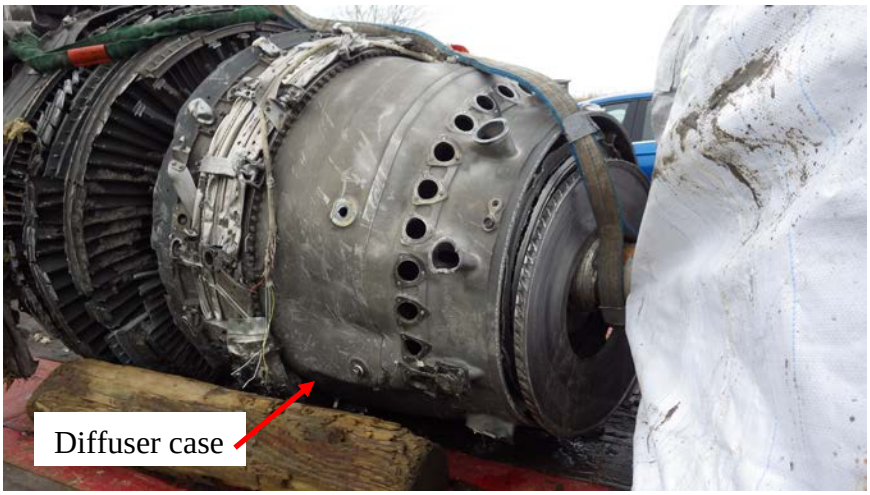

Photo No. 13: The No. 1 engine's diffuser case. (GE)

Photo No. 14: The No. 1 engine's combustor dome showing no metal spray.

3.6 High pressure turbine

The HPT case was in place between the diffuser case and LPT case. The case appeared to be intact except for two HPT stage 2 nozzle cooling air bosses at about 8 and 11 o'clock that were broken away flush to the case. (Photo No. 15) The HPT case did not have any visible dents or holes. Only parts of the HPT active clearance control (ACC)[4] tubes and manifolds

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

remained in place on the HPT case and what remained of the HPT ACC hardware was crushed in against the HPT case.

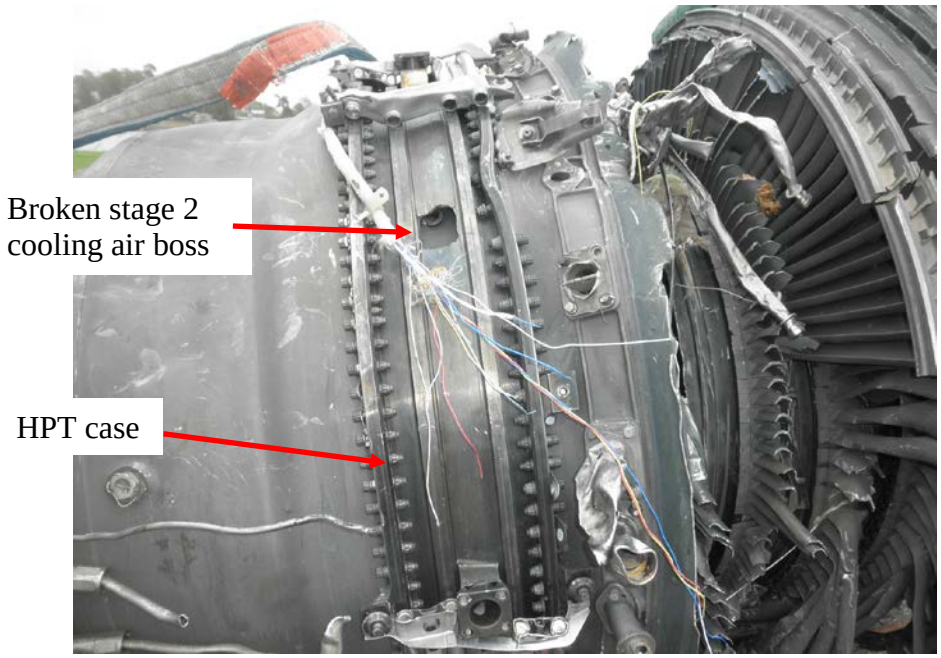

Photo No. 15: The No. 1 engine's HPT case showing one of the stage 2 cooling air bosses broken away.

3.7 Low pressure turbine

The LPT shaft was broken into several pieces not all of which were recovered. There was an approximately 61-inch long piece of the LPT and stub shaft. (Photo No. 16) The stub shaft and LPT shaft were still joined and the stub shaft extended about 16.5 inches forward of the bevel drive gear and the LPT shaft extended about 45 inches aft of the bevel drive gear. The outer diameter of the LPT shaft just aft of the bevel drive gear had circumferential rub marks. The bevel drive gear's teeth were intact. There was a piece of the LPT shaft that was in the piece of engine consisting of the diffuser to TRF that was sticking out in front of the diffuser case. There was a triangular-shaped notch on the fractured forward end of the LPT shaft sticking out the front of the diffuser. (Photo No. 17) The fractured ends of the 61-inch long piece and the piece in the diffuser case did not match.

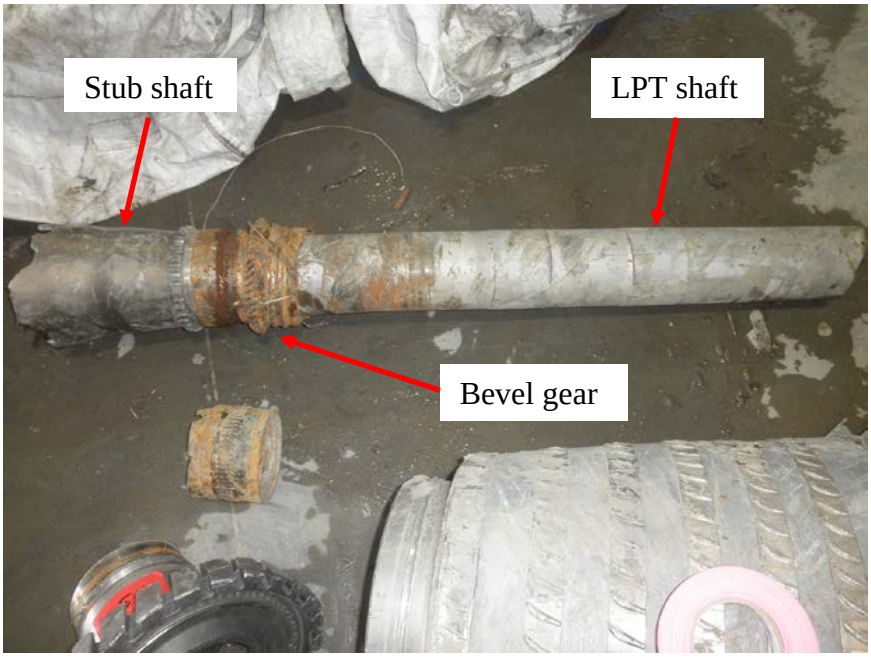

Photo No. 16: The No. 1 engine's stub shaft and LPT shaft.

Photo No. 17: The broken aft end of the No. 1 engine's LPT shaft.

The inlet gearbox horizontal drive bevel gear shaft was broken off at about 4.75-inches from the aft end. The spline teeth were in place and intact.

The LPT case and turbine rear frame were clocked about 180° from the diffuser case. The LPT case forward flange and about 5.5-inches of the forward part of the case and the LPT case rear flange and about 2.5-inches of the rear part of the case remained attached to the HPT case and TRF, respectively. The center portion of the LPT case was split open exposing the LPT

nozzles and blades. (Photos Nos. 18 and 19) The fractured ends of the LPT case did not match. There was one LPT stage 3 and two LPT stage 4 outer air seal segments that remained in the LPT case. The inside of the LPT case and the outer air seal honeycomb did not have any circumferential marks. The LPT stage 1 nozzles were in place, although most of the nozzles had damage to the trailing edges. All of the LPT stage 2 nozzles are missing. Most of the LPT stage 3, 4, and 5 nozzles were in place, although all had damage to the airfoils and many are bent rearward. All of the LPT rotor stage 1, 2, 3, 4, and 5 blades were present. All of the LPT blades had varying degrees of damage to the airfoils from being fractured transversely across the airfoil adjacent to the blade root platform to full length airfoils that were bent at the tips. There was an approximately 90° arc of the LPT stage 3, 4, and 5 blades that were bent opposite the direction of rotation. (Photo No. 20) There was an approximately 45° arc where the blades were bent and twisted rearward. The LPT nozzle and blade airfoils did not have any metal spray material or visual signs of thermal distress. The LPT ACC hardware was missing, although there was a circumferential pattern of small black marks on the LPT case consistent with the LPT ACC hardware having been in place.

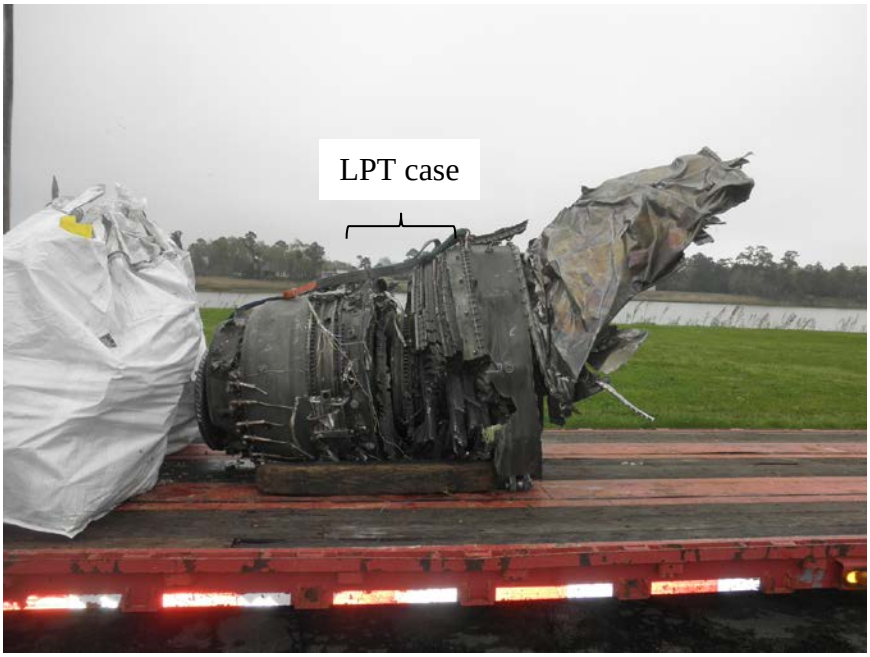

Photo No. 18: The left side of No.1 engine showing the LPT case between the diffuser case and turbine rear frame on a truck bed.

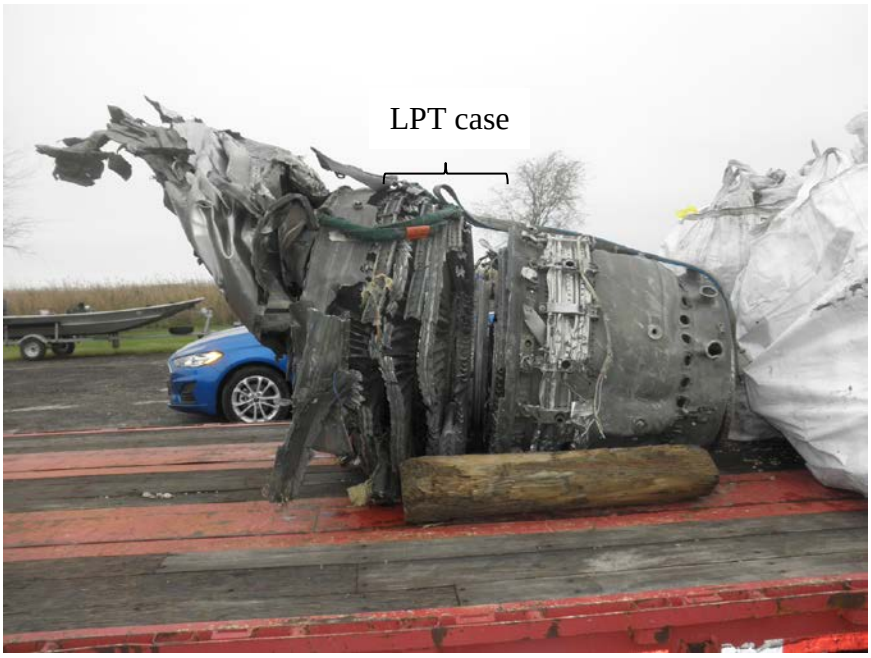

Photo No. 19: The right side of No.1 engine showing the LPT case between the diffuser case and turbine rear frame on a truck bed.

Photo No. 20: Close up view of the No. 1 engine's LPT blades that are bent and broken.

3.8 Turbine rear frame

The TRF was in place. The TRF outer ring was missing from about 11 to 2 o'clock including the right hand engine mount. The remaining parts of the TRF were buckled around its circumference.

The TRF inner hub rear face had a part of the drag link embedded in it at about 12 o'clock. (Photo No. 21)

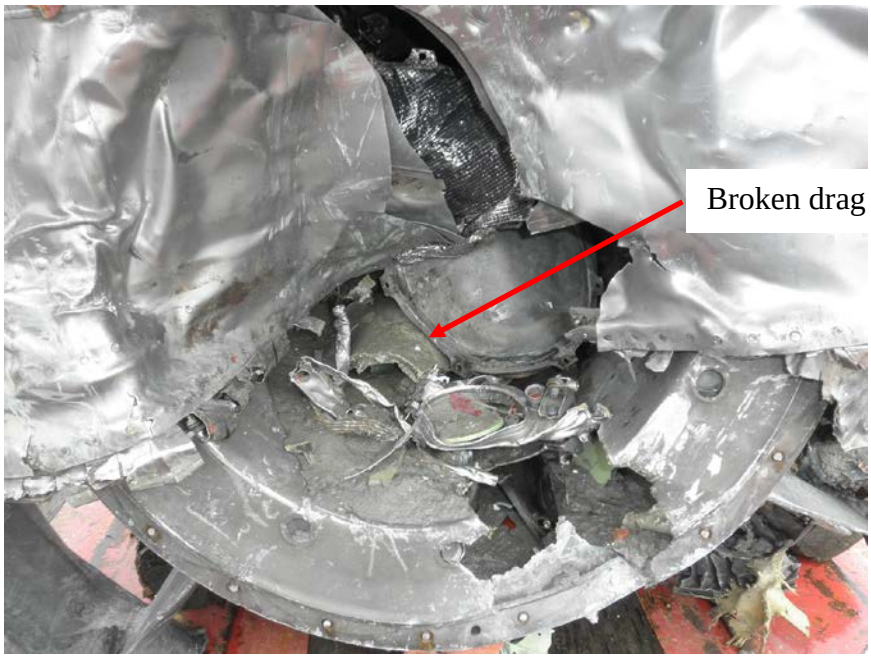

Photo No. 21: The rear of the No. 1 engine's TRF inner hub with embedded pieces of the broken drag link.

The exhaust nozzle was in place on the rear of the TRF. The exhaust nozzle was crushed downward and forward against the back of the TRF. The exhaust center body remained attached to the TRF inner hub and was crushed with the exhaust nozzle. (Refer to Photo No. 18)

3.9 Bearing

The A-sump bearing housing, PN 1472M33G02 SN VAEU0839 that corresponded to the No. 1 engine, was intact. There were no parts of the No. 1 bearing attached to the bearing housing. Part of the A-sump remained attached to the bearing housing at the A-sump's forward flange. The A-sump forward flange was complete, although it was cracked radially. There was an approximately 150° arc of A-sump that was completely missing aft of the forward flange. The remainder of the A-sump was bent up and was broken between about 8 and 15 inches aft of the forward flange.

4.0 No. 2 (right) engine

4.1 Fan

There was an approximately 186-inch long circumferential piece of the upper part of the rear fan case with portions of the fan containment case still attached. The 12:00 o'clock location was located at about 94-inches from the right hand end. The right hand end of the rear fan case was split circumferentially adjacent to the front flange from about 2 o'clock to the fractured end at about 3 o'clock. The rear fan case was also split circumferentially in about the center of the case from the fractured end at about 9 o'clock to about 2 o'clock. The fan blade rub strip was rubbed circumferentially, but generally not down to the base metal. The fan case under the fan blade rub strip was split circumferentially between about 10 and 11 o'clock and the rub strip was also missing at that area. The Kevlar wrap was pulled off of most of the fan case, although it remained attached in the upper right side of the case. The outer feet of the outlet guide vanes were in place in the rear fan case, although all but a sector of five were broken off adjacent to the outer foot. The five outlet guide vanes that remained were fractured in the midspan area.

The fan disk was intact. (Photo No. 22) The fan disk was found on a marshy island with the front side facing up. The forward end of the stub shaft remained attached to the fan disk. The stub shaft was fractured at various lengths from the front flange that ranged from adjacent to the flange to about 3.5-inches aft of the flange.

Photo No. 22: The No. 2 engine's fan disk laying face up on marshy ground at the crash site.

There were 34 of 38 fan blades that remained in the blade slots. Of the fan blades that remained in the blade slots, 7 were still fully in the slot and 27 blades were displaced rearward for various lengths. There was an arc of eight blades that were fractured between about 6.5- and

11-inches above the blade root platform. All of the other remaining fan blades were fractured transversely across the airfoil adjacent to the blade root platform. The fracture surfaces on all of the fan blades had chevrons that pointed towards the leading edge and shear lips. (Photo No. 23)

Photo No. 23: Close up of the No. 2 engine's fan blade fracture surfaces showing the chevrons pointing forward.

The stub shaft was broken about 18-inches forward of the bevel drive gear.

4.2 Booster

There was a piece of booster case that encompassed one complete case half and parts of the other case half all of which measured about 114-inches circumferentially. The booster case half individually measured about 84-inches circumferentially. There were four rows of booster vanes in these pieces of the booster case. Almost all of the booster vanes that were in the case halves were full length, but most were bent in various directions.

The booster spool, PN 1856M77P01 SN VOL86364, that corresponded to the No. 2 engine, was broken up with six identifiable pieces recovered. (Photo No. 24) The pieces were arbitrarily identified A through F and are listed in Table 2.

Table 2: Booster spool pieces

Piece	Description
A	Piece A was about 24-inches in circumference and included all four stages of booster. There were axial fractures at either end of the piece. The clockwise side fracture corresponded to the fracture on the counterclockwise side of piece B. The stage 4 bore was

	missing There were 5 each stage 1, 2, and 4 booster blades and 10 stage 3 booster blades in the blade slots. All of the booster blades were broken off adjacent to the platform with the exception of one stage 3 blade that was full length and was bent opposite the direction of rotation.
B	Piece B was about 54-inches in circumference and included all four stages of booster. There were axial fractures at both ends and there was an axial crack that went almost all the way from the front to rear with only about 3-inches of material remaining. The counterclockwise side fracture on piece B corresponded to the clockwise side fracture on piece A. The stage 4 bore was missing. There were 23 stage 1 blades, 19 stage 2 blades, 15 stage 3 blades, and 29 stage 4 blades in the piece B's blade slots. All of the blades were fractured adjacent to the blade root platform except for two stage 2 blades that were full length and bent opposite the direction of rotation and five stage 4 blades that were full length but were bent and twisted.
C	Piece C was an approximately 45-inch long circumferential section of the stage 1 part of the booster spool. The fracture surfaces on the ends of piece C corresponded to the fracture surfaces on the sides of pieces A and B. There were 17 stage 1 blades in piece C and all but 2 were fractured at or near the blade root platform. The two other blades were full length and were bent opposite the direction of rotation.
D	Piece D was an approximately 50-inch long circumferential section of the stage 2 blade slot that also had an approximately 18-inch long section of the stage 3 blade slot attached at the clockwise end. The counterclockwise end of the stage 2 blade slot was twisted rearward. The fracture surfaces on the ends of the piece corresponded to the fracture surfaces on the sides of pieces A and B. There were 16 stage 2 blades in the slot with all broken adjacent to the blade root platform except for a cluster of 5 where 4 of the 5 were full length and were bent opposite the direction of rotation and the other blade was fractured across the airfoil at various lengths above the blade root platform. There were seven stage 3 blades in the slot and all were fractured adjacent to the blade root platform.
E	Piece E was an approximately 23-inch long circumferential section of the stage 4 blade slot. The fracture surface on the counterclockwise end of piece E

	corresponded to the fracture surface on the side of piece B. There were six stage 4 blades in piece E. There were two blades that were fractured adjacent to the blade root platform and four blades that were full length with one bent opposite the direction of rotation.
F	Piece F was an approximately 20-inch long circumferential section of the stage 4 blade slot. There were two blades in the circumferential slot and both were fractured adjacent to the blade platform.

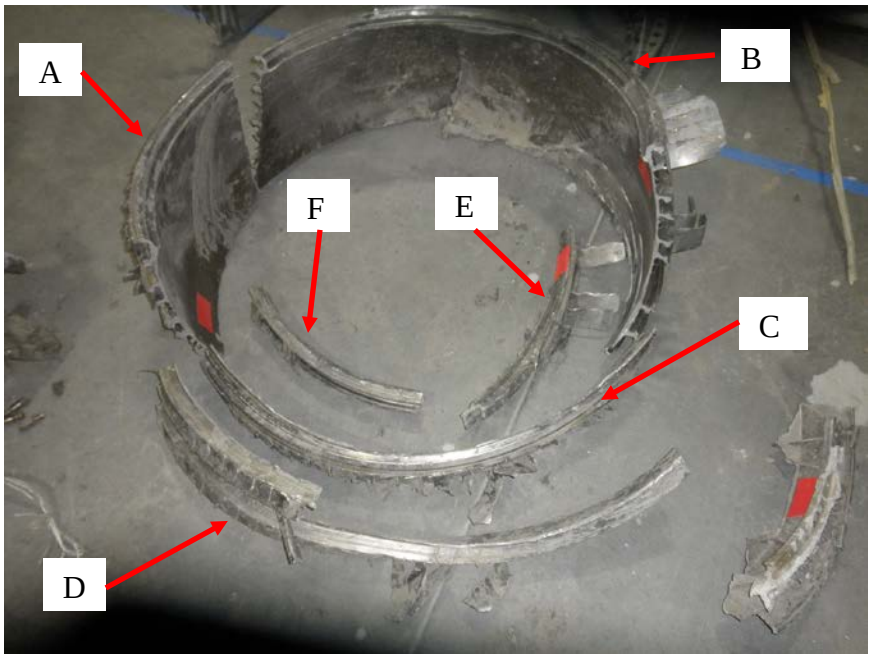

Photo No. 24: The pieces of the No. 2 engine's booster spool.

4.3 Fan frame

There was a piece of fan frame that was about 28-inches wide and included one strut that was broken off at the outer end and the left side engine yoke that was about 15-inches long and the left side clevis that had the bolt holes broken out.

4.4 High pressure compressor

The upper front compressor case half, PN 9367M90G12 SN CDPJ8672, that corresponded to the No. 2 engine, was torn open circumferentially in line with the HPC stage 4 VSV bosses from left to right. The left side of the rear half of the case was bent radially outward and back. Most of the VSVs were missing from the case. The VSV airfoils that remained had nicks and dents on the leading and trailing edges and were bent up in various directions. The

fixed stators in the rear of the case were bent in various directions. The three air plenums on the exterior of the case were partially ripped off and were crushed.

The HPC stage 1 disk was PN 1644M21P04 SN DC338937-F that corresponded to the No. 2 engine. The HPC stage 1 disk was in place around the LPT shaft, but was separated from the HPC stage 2 disk. The HPC stage 1 disk bore was intact, but the disk was missing an approximately 170° arc of blade posts and the adjacent web. (Photo No. 25) The disk was separated from the integral spacer arm adjacent to the rear face of the disk. The integral spacer arm remained intact and was in place between the HPC stage 2 disk and the bearing journal. The integral spacer arm was separated from the HPC stage 2 disk. All of the bolt holes in the integral spacer arm were intact and did not appear to be elongated. There were no HPC stage 1 blades in the disk's blade slots.

Photo No. 25: Close up of the No. 2 engine's HPC stage 1 disk.

The HPC stage 2 disk's hub and bore were intact, but the disk was missing an approximately 180° arc of blade posts. The HPC stage 2 disk was in place around the LPT shaft, but was separated from the HPC stage 1 disk and HPC stage 3 to 9 spool. (Photo No. 26) There were no blades in the blade slots. There was about a 60° arc of the HPC stage 2 disk rim that was bent forward.

Photo No. 26: Close up of the No. 2 engine's HPC stage 2 disk.

The remainder of the HPC from the from the stage 3 to 9 spool to the stage 14 disk was intact although the drive cone on the stage 14 disk was broken away directly aft of the disk. (Photo No. 27) All of the HPC blades between stage 3 and 14 were in place in their respective slots. There were random blades in stages 6, 7, 9, 10, and 11 that still had part of the airfoil all of which were bent over opposite the direction of rotation. All of the other HPC stage 3 to 14 blades were fractured transversely across the airfoil directly adjacent to the blade platforms.

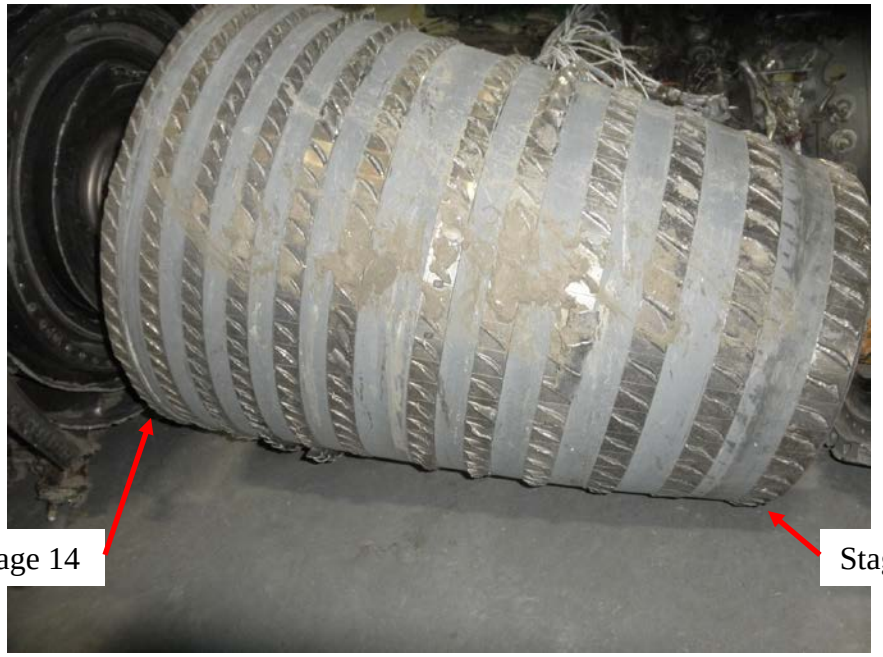

Photo No. 27: The No. 2 engine's HPC between stages 3 and 14.

4.5 Diffuser/combustor

The diffuser case was in place on the front of the HPT case. (Photo No. 28) The diffuser case's forward flange from about 12 to 6 o'clock was missing. The remainder of the flange was in place and all of the bolt holes were in place, but the flange was bent rearward in several locations. The diffuser case was crushed inward between 6 and 8 o'clock and cracked circumferentially along the fuel nozzle bosses. The diffuser case was buckled in several places around the center of the case just aft of the pressure bosses and igniter plug bosses. The diffuser case did not have any indications of thermal distress. Both of the igniter plugs were missing. All of the fuel nozzles were missing except for seven between about 12 and 2 o'clock and one each at about 5 and 9 o'clock. All nine fuel nozzles that remained in the diffuser case were fully in the diffuser case. The dome of the combustor did not have any metal spray material.

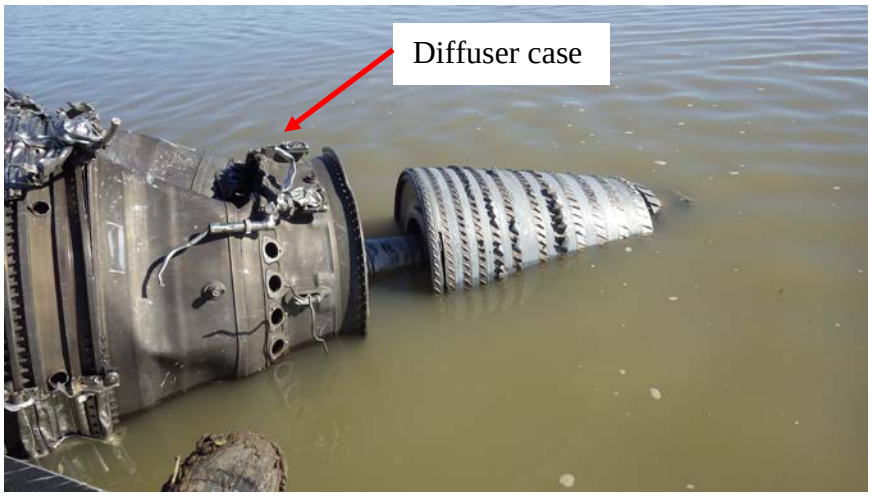

Photo No. 28: The No. 2 engine's diffuser case when it was still in the water at the crash site. (GE)

4.6 High pressure turbine

The HPT case was in place between the diffuser case and LPT case. The HPT case was intact, but the HPT nozzle cooling air bosses were broken off. The front flange of the HPT case around the bottom of the case was bent rearward. There were parts of the HPT ACC manifolds pressed into the outside of the HPT case.

The HPT stage 1 disk was not visible and not all of the HPT stage 1 blades were visible. The HPT stage 1 blades that were visible were full length, intact, and did not have any indications of impact damage or thermal distress. The visible convex aft side of the airfoils had some minor nicks and dents.

The HPT stage 2 disk was intact and all of the HPT stage 2 blades were in place in the disk. The HPT stage 2 blades varied in length from about 0.75-inches to about 2.5-inches above the blade root platform. The HPT stage 2 blades were rubbed on the trailing edge about an inch into the airfoil and the rubbed edges were bent forward. (Photo No. 29)

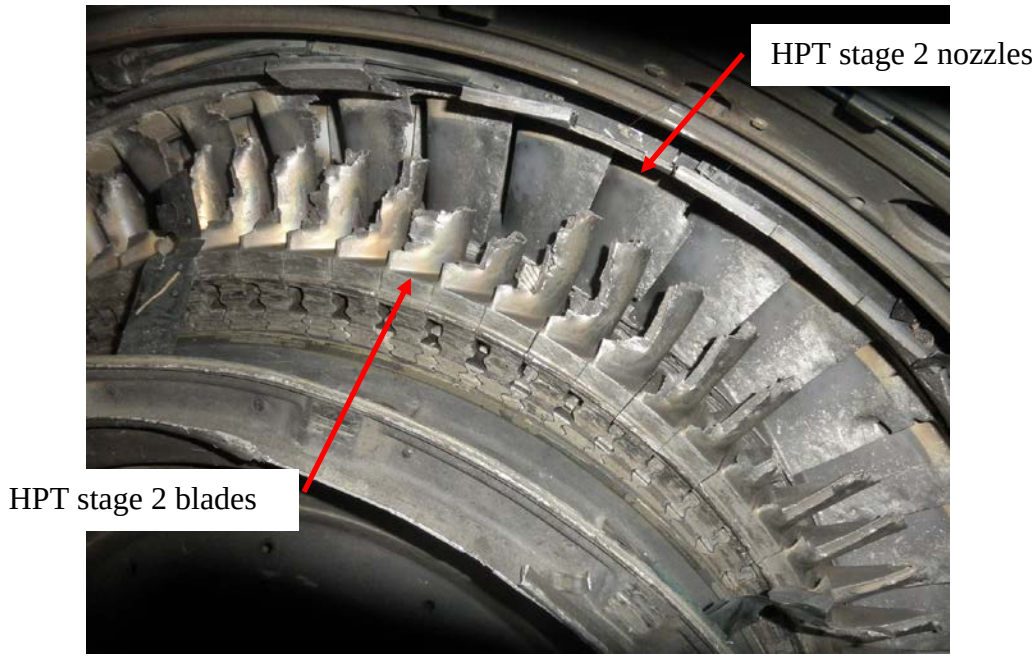

Photo No. 29: Close up of No. 2 engine's HPT stage 2 blades and nozzles.

The HPT stage 2 nozzles were all in place. The HPT stage 2 nozzles had impact damage with nicks, dents, and pieces missing from the trailing edges. (Refer to Photo No. 29)

None of the visible HPT airfoils had any metal spray or thermal distress.

4.7 Low pressure turbine

The forward end of the LPT shaft was visible between the HPC stage 2 disk and the front of the HPC stage 3 to 9 spool. (Photo No. 30) The aft end of the LPT shaft was visible between the rear of the HPT rotor and front of the LPT rotor. When the LPT rotor was turned, the stub shaft would turn concurrently and independently of the HPC and HPT.

Photo No. 30: The No. 2 engine's stub shaft.

There was an approximately 4-inch long axial piece of the forward part of the LPT case between the front flange and the skirt that remained attached to the HPT case.

The LPT stage 1, 2, and 3 disks were in place, intact, and attached to each other as well as to the LPT shaft. (Photo No. 31) There were 42 of 118 LPT stage 1 blades that were missing from the blade slots. Of the remaining 76 blades, a few were broken below the platform and the others were fractured across the airfoil up to about 2-inches above the blade root platform. Of the 124 LPT stage 2 blades, there was sector of 14 blades that were fractured transversely across the airfoil adjacent to the blade root platform and the remaining 110 blades varied in length from about 0.5-inches to about 3.5-inches above the blade root platform. Of the 88 LPT stage 3 blades, there were 55 that were fractured transversely across the airfoil adjacent to the platform. There was one LPT stage 3 blade that was completely missing. And the remaining 32 blades varied in length from about 1- to 9-inches above the blade root platform and there was only 1 blade that still had the tip shroud.

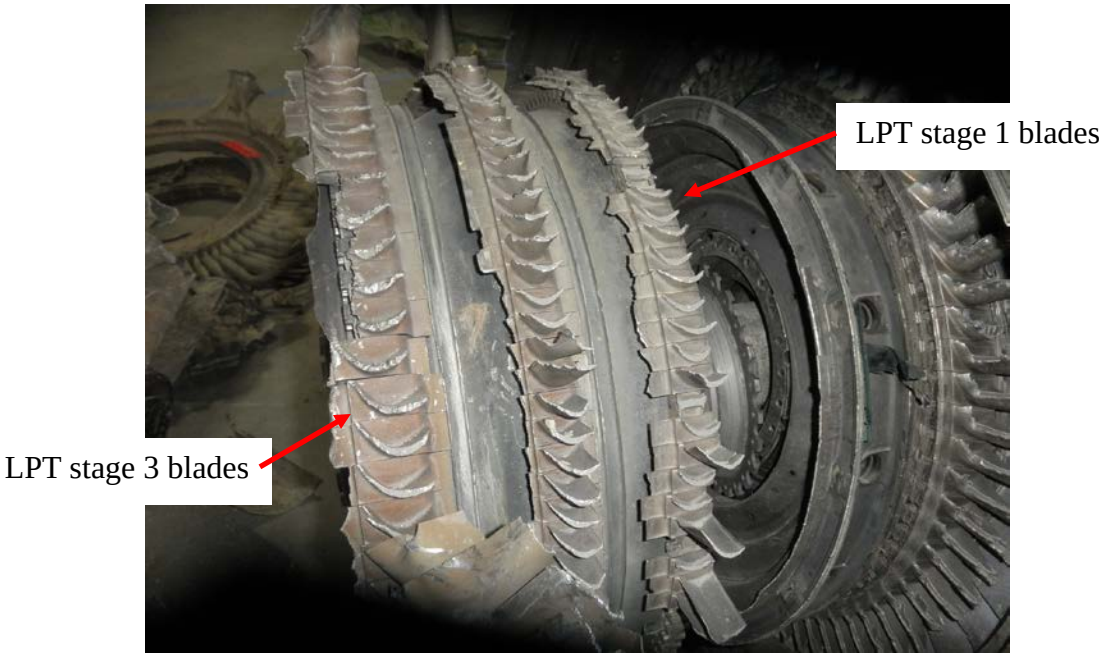

Photo No. 31: Close up of No.2 engine's LPT stage 1 through 3 broken blades.

The LPT stage 4 and 5 disks were attached to each other, but the two disks were separated from the remainder of the LPT rotor. The LPT stage 4 and 5 disks are intact. (Photo No. 32) The stage 4 disk forward flange had about 140° of the bolt circle remaining. The bolt holes were intact and did not appear to be elongated. The remainder of the flange was missing along the middle of the forward spacer arm. All of the LPT stage 4 blades were in the blade slots in the disk. There was a continuous sector of 25 LPT stage 4 blades that had at least part of an airfoil from about 0.75-inches above the blade root platform to full length. Most of the airfoils were bent opposite the direction of rotation although the longer full length airfoils were bent and twisted randomly at the tip. There were five LPT stage 4 blades that had the tip shrouds still in place. The remaining LPT stage 4 blades were fractured transversely across the airfoil adjacent to the blade root platform. All 98 of the LPT stage 5 blades were in the slots. There were 67 LPT stage 5 blades that still had a portion of the airfoil ranging in length from about 0.75-inches above the blade root platform to full length. There were 16 blades that still had the tip shroud in place. The blades that had parts of the airfoils remaining were clustered in an arc of 7 blades, then 5 blades with no airfoil, then an arc of 57 blades, then 14 blades with no airfoil, ,and then a cluster of 3 blades with airfoils. Almost all of the blades were bent opposite the direction of rotation. The tips on the longer blades were bent and twisted in random directions. The LPT stage 4 and 5 blade airfoils did not have any metal spray material on the airfoils or visual signs of thermal distress.

Photo No. 32: The No. 2 engine's LPT stage 4 and 5.

All of the LPT nozzles, stages 1 through 5 were missing. The LPT stage 1 nozzle inner support was in place albeit loose between the HPT and LPT rotors.

4.8 Turbine rear frame

The TRF inner hub was intact, although the rear face of the hub had an approximately 8-inch wide section at about 12 o'clock that was torn and pushed forward about 8.5-inches. The inner barrel of the hub did not have any oil staining or coking. There were four full struts from about 2 to 4 o'clock that had the outer casing of the TRF still in place. The strut at about 12 o'clock was completely missing and parts of the other struts ranging in length from about an inch above the hub to about 10 inches long.

The exhaust nozzle was recovered and it was all bent up, twisted, and crushed. The exhaust center body was separated from the TRF hub. The exhaust center body was crushed and bent up.

4.9 Bearing

The No. 1B bearing cage, SN MDA231DU, that corresponded to the No. 2 engine, was intact, but was bent slightly. The cage pockets did not have any rotational distress. The silver plate was still in place on the cage. All of the bearing balls were missing. (Photo No. 33)

Photo No. 33: Close of the No. 2 engine's No. 1 bearing cage.

The oil tank remained attached to the fan case by the oil line at the top of the tank. The engine's oil tank is comprised of two cylinders. The aft cylinder of the oil tank was broken away and the lower half of the forward cylinder was broken away.

5.0 Miscellaneous parts

The following parts could not be associated to a specific engine.

5.1 Inlet

There was an approximately 180-inch long piece of the inlet duct bulkhead recovered. The bulkhead had a radial fracture and the fractured ends of the bulkhead did not match. The inlet lip was broken open with only parts of the lip remaining attached to the bulkhead. Also still attached to the bulkhead was the anti-ice bleed air connector. There was another piece of inlet duct that was about 72-inches long and consisted of just the inlet lip. There was an approximately 185-inch long piece of inlet duct bulkhead and inlet lip that was twisted and buckled. The fractured ends did not match. This piece of the inlet duct bulkhead also had an anti-ice bleed air connector.

5.2 Fan

There was a 154-inch long piece of the rear fan case with a continuous sector of six outlet guide vanes recovered.

There were four broken pieces of spinner recovered including two domes. (Photos Nos 34, 35, and 36)

Photo No. 34: Broken piece of spinner cap.

Photo No. 35: Broken piece of spinner cap.

Photo No. 36: Two broken pieces of spinner cap.

There were 35 pieces of fan blades ranging in size from about 7-inches long to about 28-inches long that were fractured at various locations from in the shank just under the root platform to outboard of the midspan shrouds. There was one fan blade that still had the dove tail root attached. Most of the airfoils were bent opposite the direction of rotation. Many of the airfoils had pieces of the leading and trailing edges missing. (Photos Nos. 37 and 38) The pieces of fan blade that had the mid span shrouds did not have any indications of shingling.[5]

Photo No. 37: Broken pieces of fan blade.

[5] Shingling is the condition of the mid span shroud overlapping the shroud of an adjacent blade in lieu of abutting at the contact surfaces.

Photo No. 38: Broken pieces of fan blade.

There was an approximately 21-inch by 7.5-inch piece of stub shaft that was twisted back onto itself. (Photo No. 39)

Photo No. 39: Close up view of a piece of stub shaft that is twisted back onto itself.

5.3 Booster

There were several pieces of spool case recovered. Some of the booster case pieces still had the splitter attached. There was a piece of booster case that was about 108-inches long circumferential and included all four stages of booster from the splitter to the rear flange as well as the left and right side horizontal split lines. (Photo No. 40) The airfoils that remained in place were mostly full length, but some were bent in the direction of rotation, some were bent in the direction opposition of rotation and some were straight. There was an approximately 15-inch long circumferential by 8-inch wide axial piece of booster case that included a left side horizontal split line and six booster inlet guide vanes and four partial stage 1 booster vanes. There was an approximately 17-inch long circumferential by 10-inch wide axial piece of booster case that included two stages of booster. The forward row of booster vanes consisted of 8 vanes that were all broken across the airfoil adjacent to the outer foot and the aft row consisted of 11 vanes that were full length, but were bent in various directions.

Photo No. 40: Large piece of spool case.

There was a an approximately 76.5-inch long piece of spool disk bore that was separated from the spool and fractured radially. The fractured ends did not match.

5.4 Fan frame

There was a piece of fan frame that was about 37-inches long and could not be attributed to either engine. There were several other pieces of the fan frame and the fan frame struts that could not be attributed to either engine.

5.5 High pressure compressor

There were many pieces of the HPC case recovered that could not be attributed to a particular engine. The pieces were all broken up and twisted. Some of the pieces were twisted almost to the point of being inside out. The forward parts of the compressor case still had some VSVs in place, although they were bent and twisted in various directions as well has having nicks and dents on the leading and trailing edges. In the rear portion of the compressor cases, the fixed vanes were either broken adjacent to the case wall or the airfoils were bent in the direction of rotation. (Photo No. 41)

Photo No. 41: View of several broken pieces of HPC case.

5.6 Low pressure turbine

There were eight pieces of LPT case recovered that could not be attributed to a particular engine. (Photos Nos. 42 and 43) Of the eight pieces, five were essentially one or two stages wide and varied in length from about 8- to 51-inches long. There was a piece of LPT case that was approximately 21-inches long circumferential by 9-inches wide axial and spanned about three stages of LPT. There was a piece that was about 32-inches long circumferential by 21-inches long axial and spanned about four stages of LPT between about the stage 2 to stage 5. This piece included the rear flange of the LPT case. This piece was split circumferentially in the middle from the counterclockwise side There was a piece that was about 52-inches long circumferential by 11-inches wide axial and spanned about two stages of LPT. This piece also included the rear flange and was split circumferentially in the middle from the counterclockwise side.

Photo No. 42: Broken pieces of LPT case.

Photo No. 43: Broken pieces of LPT case.

Also recovered were several LPT blades and blade airfoils that were missing the blade root.

There were 27 LPT vane segments or pieces of a vane segment from stage 2, 3, 4, and 5 that were recovered that could not be associated with a particular engine. (Photo No. 44) Most of the segments were full length and straight. Some of the segments had dents on the leading

edge and/or were bent up. None of the LPT stator vane airfoils had any metal spray material on the leading edges or the convex surfaces or visual signs of thermal distress.

Photo No. 44: LPT vane segments.

5.7 Accessories

Also recovered were two hydromechanical units (fuel controls) (Photos No. 45 and 46), ignition exciter (Photo No. 47), starter (Photo No. 48), oil filter (Refer to Photo No. 48), and drain mast manifold (Photo No. 49).

Photo No. 45: Hydromechanical unit (fuel control).

Photo No. 46: Hydromechanical unit (fuel control).

Photo No. 47: Ignition exciter box.

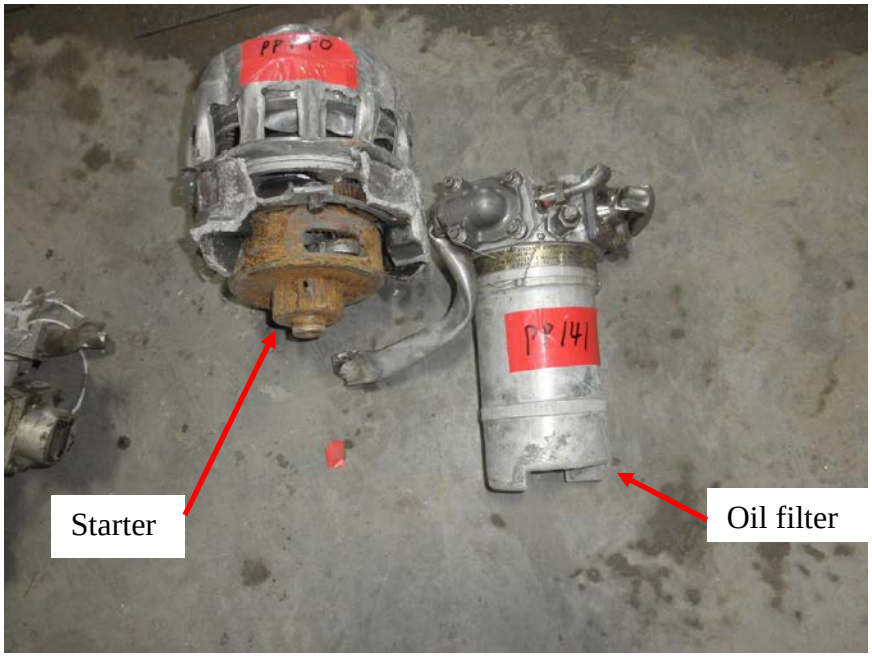

Photo No. 48: Starter on the left and fuel filter on the right.

Photo No. 49: Drain mast manifold. (GE)

6.0 Auxiliary power unit

The auxiliary power unit (APU) and the APU exhaust duct were recovered. The APU was broken into three pieces. The APU exhaust duct was crushed.