

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

August 23, 2013

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT

NTSB ID No.: DCA12IA114

A: INCIDENT

Location: Charleston International Airport, Charleston, South Carolina
Date: July 28, 2012
Time: About 1600 eastern daylight time
Aircraft: Boeing 787-8, radio call sign Boeing 238

B: POWERPLANTS GROUP

Group Chairman: Gordon J. Hookey
National Transportation Safety Board
Washington, D.C.

Member: James Gray
Federal Aviation Administration
Burlington, Massachusetts

Member: Al Clifton
Federal Aviation Administration
Vandalia, Ohio

Member: Richard Anderson
Boeing
Seattle, Washington

Member: Carlos Oncina
Boeing
Seattle, Washington

Member: Dave Zigan
General Electric
Cincinnati, Ohio

Member: Jay Gwinn
GE Aviation
Cincinnati, Ohio

C: SUMMARY

On July 28, 2012, about 1600 eastern daylight time, a Boeing 787-8 airplane, radio call sign Boeing 238,¹ experienced a loss of thrust in the right engine, a General Electric (GE) GEnx-1B67, during a taxi test at the Charleston International Airport, Charleston, South Carolina. In preparation for the airplane's first flight, the airplane was undergoing a series of taxi tests on the runway. The airplane was to reach a speed of about 60 knots. As the airplane was accelerating through 40 knots, the right engine's N1 speed² indication rolled back. The pilots retarded the throttles to abort the test. The airplane taxied back to the ramp where the engines were shutdown. A visual examination of the right engine revealed there was damage to the low pressure turbine (LPT). Further examination of the engine revealed the forward end of the fan mid shaft (FMS) was separated from the remainder of the shaft at the rear of the forward threads.

D: DETAILS OF INVESTIGATION

1.0 *Engine information*

1.1 **Engine description**

The GE GEnx-1B engine is a dual-spool, high-bypass, axial-flow turbofan that features a 1-stage fan, 4-stage booster, 10-stage high-pressure compressor (HPC), 2-stage high pressure turbine that drives the HPC, and a 7-stage LPT that drives the fan and booster. According to the engine's data plate, the engine has a takeoff thrust rating of 69,400 pounds and the maximum continuous thrust rating of 61,500 pounds. According to the Federal Aviation Administration's Type Certificate Data Sheet, the GE GEnx-1B67 takeoff thrust rating is flat-rated to 86°F (30°C) and the maximum continuous thrust rating is flat-rated to 77°F (25°C).³ According to the Type Certificate Data Sheet, the GEnx1B engine's low-pressure rotor rotates counter-clockwise and

¹ The airplane was partially painted in the colors of Air India and had an Indian registration, VT-ANJ.

² N1 is the low pressure rotor speed.

³ 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.

the high-pressure rotor rotates clockwise, as viewed from the aft looking forward (ALF).⁴ Refer to Figure 1.

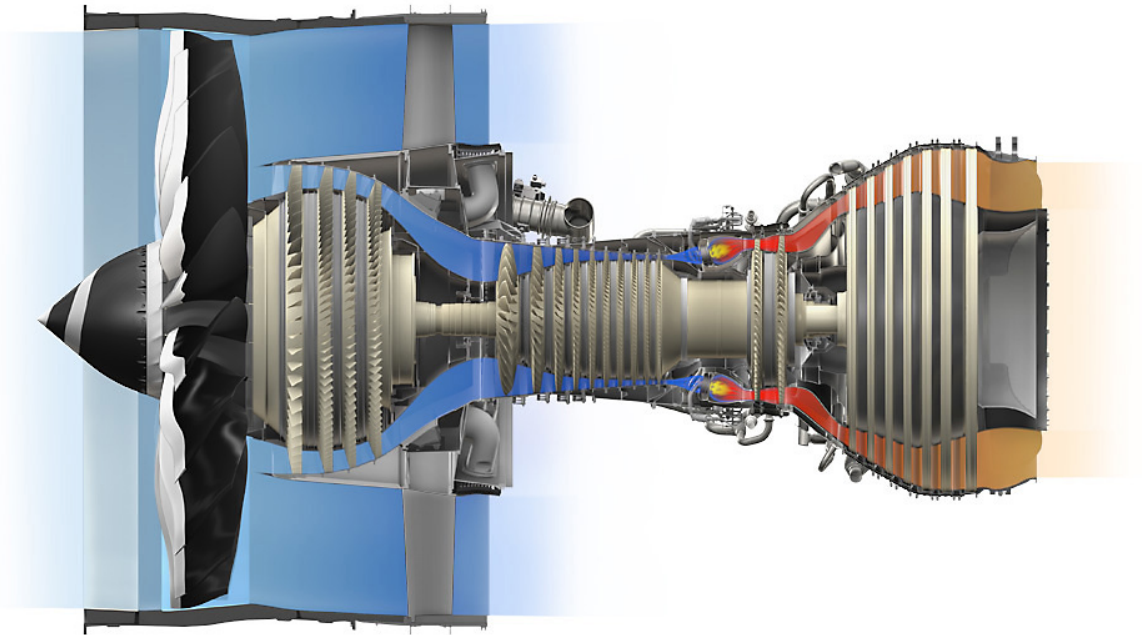


Figure 1: Cross section of GE GENx-1B engine

Source: GE

1.2 Engine history

The right engine was a GE GENx-1B, serial number (SN) 956121. According to the engine's data plate, the engine was a model number 67 G03 and production certificate PC-108. At the time of the incident, the engine had only been operated on the ground and had not yet flown. The engine's only operation was post-production testing at GE and post-installation testing at Boeing. According to GE and Boeing, at the time of the incident, the engine had been operated a total of 18:16 hours; 9:21 hours in the test cell and 8:55 hours after it had been installed on the airplane.

2.0 Fan mid shaft

2.1 Fan mid shaft description

The FMS is a tubular-shaped shaft made of a high-strength alloy that transmits the rotational energy of the LPT to the fan and booster. The forward end of the FMS has threads for the FMS retaining nut to secure the shoulder on the FMS to the shoulder on the forward fan

⁴ All locations on the engine, or directions, as referenced to the clock, will be as viewed from the aft looking forward (ALF), unless otherwise specified.

shaft. On the FMS, directly aft of the shoulder, are splines that engage with the splines on the forward fan shaft. At the aft end of the FMS, is a flange with bolt holes, through which tie bolts are inserted to secure the FMS to the LPT rotor. (Refer to Figure 2 and Photo No. 1.)

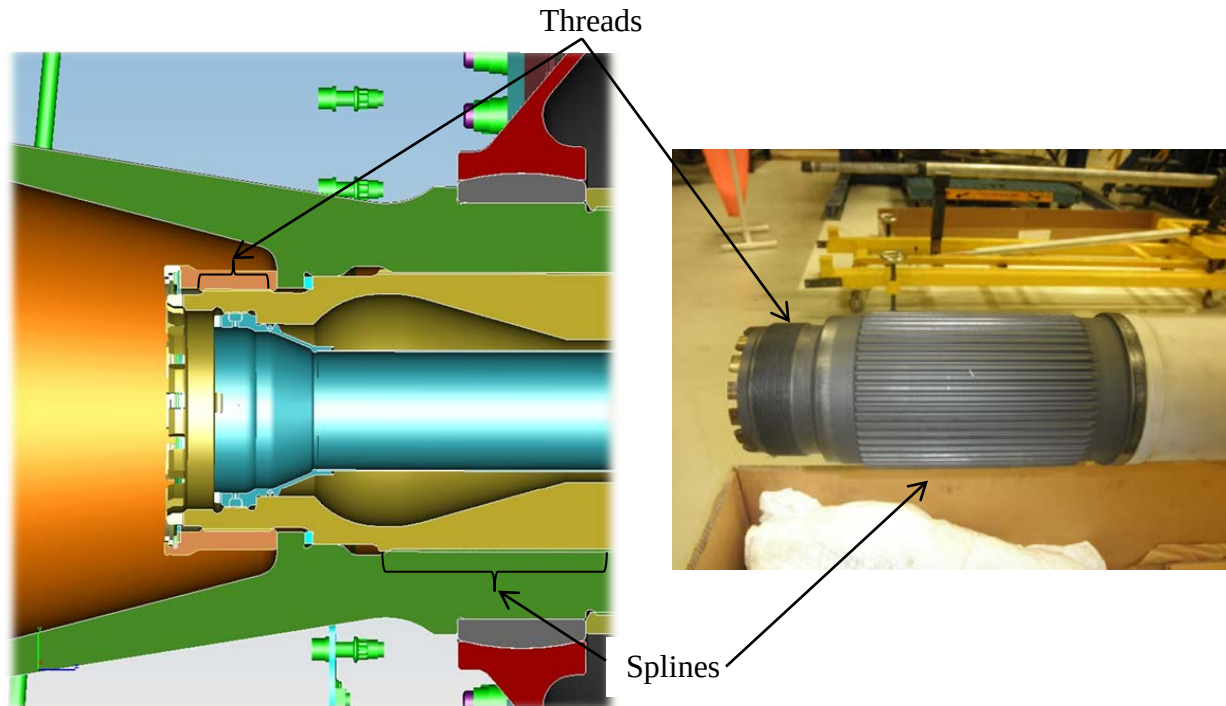


Figure 2: Cross section of fan mid shaft and front fan shaft connection. Source: GE

Photo No. 1: Front of fan mid shaft.

2.2 On-scene examination at Boeing, Charleston, South Carolina

When the A-sump⁵ bulkhead was removed from the front of the sump, it exposed the front of the FMS and the FMS retaining nut. It was noted that the FMS retaining nut was in place on the threads of the FMS. It was also noted that the front of the FMS was separated from the rest of the FMS at the rear of the threads. The front of the FMS and the FMS retaining nut along with the center vent tube (CVT) were removed through the A-sump. (Photo No. 2)

⁵ On the GE GENx series engines, the bearing sumps are identified from front to rear with consecutive letters A, B, and C beginning with A.



Photo No. 2: View of fractured forward end of fan mid shaft in retaining nut with center vent tube after removal from engine. (GE)

After the front portion of the FMS with the attached FMS retaining nut and CVT were removed from the engine, the pieces were sent to GE Cincinnati for metallurgical examination. For further details on the metallurgical examination of the FMS and FMS retaining nut, refer to the NTSB Materials Laboratory factual report. The engine was then removed from the airplane and shipped to GE, Cincinnati, Ohio for further disassembly. Refer to Sections 2.3 and 3.2 for further details.

2.3 Engine disassembly at GE, Cincinnati, Ohio

The identification marks on the FMS indicated it was part number (PN) 2331M20G02,⁶ SN JHVAY014.

In comparison to an exemplar FMS, the incident FMS was fractured circumferentially about 5-inches aft of the forward face of the wrenching lugs. The remainder of the FMS did not have any rub marks or discolorations. (Photos Nos. 3 and 4) The fracture face at the forward end of the FMS was smooth and flat with a ratchet mark.⁷ The fracture surface had two distinct colorations; a light, gray-colored area that appeared to radiate radially outward from the bore and a darker, gray-colored area that appeared to radiate inward from the outer diameter (OD). (Photo No. 5)

⁶ According to GE, the PN for the FMS and CVT assembly is PN 2305M64G02. The PN for the just the detail FMS is PN 2331M20G02.

⁷ Ratchet marks are the step-like junctions between adjacent, but out-of-plane progressive cracks that propagate and link up.



Photo No. 3: Exemplar fan mid shaft.



Photo No. 4: Fractured fan mid shaft.



Photo No. 5: Close up of fractured forward end of fan mid shaft showing two areas with different gray colorations. (GE)

The examination of the LPT spacer shim after it was removed from the engine showed that it was marked S4334-2331M29P06 JGG99 5.00 mm. The engine's build records stated the LPT spacer shim installed was a P06 shim.

The FMS-to-LPT cone shaft retaining bolts breakaway torque was measured in the loosening direction with a 0 – 600 foot-pound torque wrench, SN EV10641, that was due for calibration by September 10, 2012. The installation procedure for the FMS-to-LPT cone shaft retaining bolts is to torque the bolts to 60 foot-pounds and then turn the bolts an additional 42 to 46° angle of turn,⁸ which, according to GE, should give a final seating torque of 94 – 250 foot-pounds. The FMS-to-LPT cone shaft retaining bolts breakaway torques in foot-pounds are listed in Table 1.

⁸ GE GENx assembly procedures.

Table 1: FMS-to-LPT cone shaft retaining bolt breakaway torque in foot-pounds.

Bolt No.	Torque	Bolt No.	Torque	Bolt No.	Torque	Bolt No.	Torque
1	195	11	180	21	185	31	190
2	170	12	160	22	185	32	200
3	185	13	145	23	185	33	180
4	170	14	175	24	180	34	180
5	160	15	175	25	200	35	195
6	180	16	200	26	200	36	190
7	165	17	180	27	185	37	190
8	190	18	180	28	180	38	185
9	190	19	185	29	180		
10	175	20	200	30	200		

2.4 Fractured fan mid shaft history

The history of the FMS and the LPT module from its initial forging at ATI-Allvac⁹ and machining at IHI¹⁰ to assembly into the LPT module at GE was obtained from GE. The description of how the FMS and LPT were packaged and shipped were either obtained from GE or examination of other like components that were available.

ATI-Allvac, Monroe, North Carolina

9/29/06 Forging production date.
6/15/07 Shipped forging to IHI.

IHI, Japan

8/22/07 Forging arrives at IHI.
10/4/07 Confirm forging material.
10/23/07 Rough turn outer side.
11/16/07 Rough turning forward inner area.
12/17/07 Finish turning front area. Cut thread.
5/19/08 Splining.
5/23/08 Dimensional inspection.
5/23/08 Magnetic particle inspection.¹¹

⁹ ATI is Allegheny Technologies Incorporated, based in Pittsburgh, Pennsylvania. ATI-Allvac is a division of ATI with several facilities in Monroe, North Carolina.

¹⁰ IHI Corporation, formerly known as Ishikawajima-Harima Heavy Industries Co. Ltd., is a Japanese manufacturing company, based in Tokyo, Japan. The GENx FMS were produced at the IHI facility in Kure, Japan.

¹¹ Magnetic particle inspection is a non-destructive inspection method of detecting cracks and other defects in ferromagnetic materials such as iron or steel. The inspection consists of magnetizing the part with high amperage direct current electricity thus creating magnetic lines of flux, then applying or immersing the part in a liquid containing ferromagnetic particles in suspension. The ferromagnetic particles align themselves with the magnetic lines of flux on the surface of the part forming a pattern. If a discontinuity is present in the material on or near the surface, opposing magnetic poles form on either side of the discontinuity and the pattern is disrupted, forming an

6/20/08	SerMetel [®] paint ¹² applied.
6/23/08	Balance.
6/23/08	Applied dry film lubricant to threads.
6/26/08	Final inspection.
11/14/08	FMS shipped from IHI to GE. When an FMS is shipped from IHI to GE, it is shipped in a wood and cardboard box. The FMS is wrapped in bearing paper ¹³ and vacuum sealed in a bag. There are four bags of dessicant in the vacuum bag. There is sprayed-in expanding foam in the box at each end of the shaft.

General Electric, Erlanger, Kentucky

11/18/08	FMS arrived at GE Erlanger.
10/15/10	FMS shipped from Erlanger to GE Durham.

General Electric, Durham, North Carolina

10/16/10	FMS arrived at GE Durham.
10/27/10	FMS removed from box.
10/28/10	FMS installed in LPT module. The LPT module was also made by IHI in Japan. When the LPT modules are delivered from IHI to GE, they are shipped in an aluminum shipping container. The LPT module is minus the FMS. According to GE, LPT modules were typically airfreighted from Japan to the U.S. via either New York, New York or Chicago, Illinois, then after clearing U.S. Customs, were shipped by truck to GE Durham. During the shipment in the shipping container, the LPT module was covered with plastic and there were four to six desiccant bags in the box. The LPT module sat on a spring base in the shipping container.
11/31/10	LPT module installed on engine. GE's records show that there was a delay of several days waiting for the shim.
12/4/10	Propulsor ¹⁴ shipped to GE Peebles, Ohio. ¹⁵

"indication." The indications assumes the approximate size and shape of the surface projection of the discontinuity; however, indications are more visible when the defects are approximately perpendicular to the magnetic lines of flux.

¹² SerMetel paint is an aluminum-based corrosion protection paint.

¹³ Bearing paper is a brown-colored, wax-coated, oil-resistant paper.

¹⁴ The propulsor is the core of the GE GENx engine from the front of the booster to the turbine rear frame. It does not include the fan case, fan frame, or fan blades.

¹⁵ GE Peebles is a facility in Ohio where GE tests engines.

3.0 *Examination of rest of engine*

3.1 On-scene

3.1.1 Exterior

The engine's inlet lip and inlet duct did not have any damage or marks. (Photo No. 6)
The exterior of the engine's cowls did not have any impact marks, dents, or thermal distress.
(Photos No. 7 and 8) The examination of the interior surfaces of the engine's cowls did not
reveal any impact marks or thermal distress. (Photos Nos. 9 and 10) The blowout doors were in
the normal closed position.



Photo No. 6: View of engine's inlet lip and duct showing no damage.
Also shown are the fan blades with no damage or marks.



Photo No. 7: Left side of engine cowl showing no damage or heat distress.



Photo No. 8: Right side of engine cowl showing no damage or heat distress.



Photo No. 9: Left side of engine with cowls open showing no damage to the inner surfaces of the cowls and no soot or fire damage to the engine. (GE)



Photo No. 10: Right side of engine with cowls open showing no damage to the inner surfaces of the cowls and no soot or fire damage to the engine. The red pieces of tape mark the impact marks on the tailcone. (GE)

The thrust reverser blocker doors and blocker door struts were in the stowed position. There was no debris in the fan ducts.

The engine did not have any indication of an undercowl fire or a case rupture. (Refer to Photos Nos. 9 and 10.)

The exterior of the tailcone was heat discolored¹⁶ and had numerous impact marks.

¹⁶ The left engine's tailcone was not discolored.

3.1.2 Fan

All of the fan blades were in place in the fan hub. There was no apparent damage to the fan blades' leading edges or airfoils. There were no marks on the fan blades. (Refer to Photo No. 5) The fan rubstrip did not have any circumferential rubmarks.

The spinner cap was intact.

The fan rotor could not be rotated by hand, even when force was applied.

3.1.3 High pressure turbine

The turbine center frame (TCF) was intact. The TCF had two heat discolored areas¹⁷ at about 7:30 and 8 o'clock.

3.1.4 Low pressure turbine

The LPT case was intact. The LPT case had numerous outward bulges around the entire circumference of the case in the plane of the stage 6 rotor. There were two small splits in the LPT case at about 6 and 9 o'clock in the plane of the stage 6 rotor.

The LPT was inspected with a borescope through ports p, q, and r.¹⁸ Because the LPT rotor could not be rotated, only a small portion of the rotor could be observed through each port. The LPT stage 1 blades that were visible did not have any apparent damage. The LPT stage 2 blades that were visible had portions of the trailing edge tip shroud corner and the outer span of the airfoil trailing edge missing and impact damage to the leading edges. The LPT stage 3, 4, 5, 6, and 7 blades that were visible were broken at various lengths above the blade root platform. The LPT stage 2 nozzles that were visible were intact. The LPT stage 3 nozzles that were visible were had nicks and dents on the airfoil surfaces. Where the LPT stage 4 and 5 nozzles should have been visible, the nozzles were missing. The LPT stage 6 and 7 nozzles that were visible were in place, but the airfoils were heavily battered. On each LPT stage inspected, there was a large gap between the rear of the nozzle platform and the angel wing on the front of the blade. There was no gap between the blades' trailing edges and the front of the next nozzle segment and the edges between the two were heat discolored. There were broken airfoil and shroud segments laying in the bottom of the LPT case directly in front of the LPT stage 7 nozzles. (Photo No. 11)

¹⁷ The left engine's TCF had discolorations at the same locations, although not as discolored as seen on the right engine's TCF.

¹⁸ Borescope ports on an engine's cases provide access to insert a rigid or flexible borescope to inspect internal sections of an engine. On the GE GENx series engines, borescope ports are identified consecutively beginning with A from the front of the engine to the rear. Borescope ports P, Q, and R are between LPT stages 1 and 2, 3 and 4, and 5 and 6, respectively. Refer to Attachment 1.



Photo No. 11: View of LPT stage 7 nozzles showing broken airfoil pieces in front of the nozzle airfoils and broken LPT stage 7 blades.

The turbine rear frame (TRF) had small dents around the circumference just aft of the forward flange.

3.1.5 Magnetic chip detectors

The magnetic chip detectors for A, B, and C sumps¹⁹ and for the auxiliary and transfer gear boxes were checked and all were found to be clean and free of debris.

3.2 Incident engine disassembly at GE Cincinnati

3.2.1 Exterior

The engine was complete from the fan case front flange to the TRF rear flange. The FMS with the CVT had been removed from the engine and sent to GE for metallurgical examination prior to the shipment of the remainder of the engine. The engine did not have any indications of any uncontainments, case ruptures, or undercowl fires. (Photos Nos. 12 and 13)

¹⁹ On the GEnx-1B engine, the A sump contains the Nos. 1R, 2B, 3B and 3R bearings. The No. 1 bearing is a roller bearing, the Nos. 2 and 3B bearings are ball bearings, and the No. 3R bearing is a roller bearing. The B sump contains the No. 4R bearing, which is a roller bearing. And the C sump contains the No. 5R bearing, which is a roller bearing.



Photo No. 12: Left side of engine showing no uncontainments, case ruptures, or fire damage.

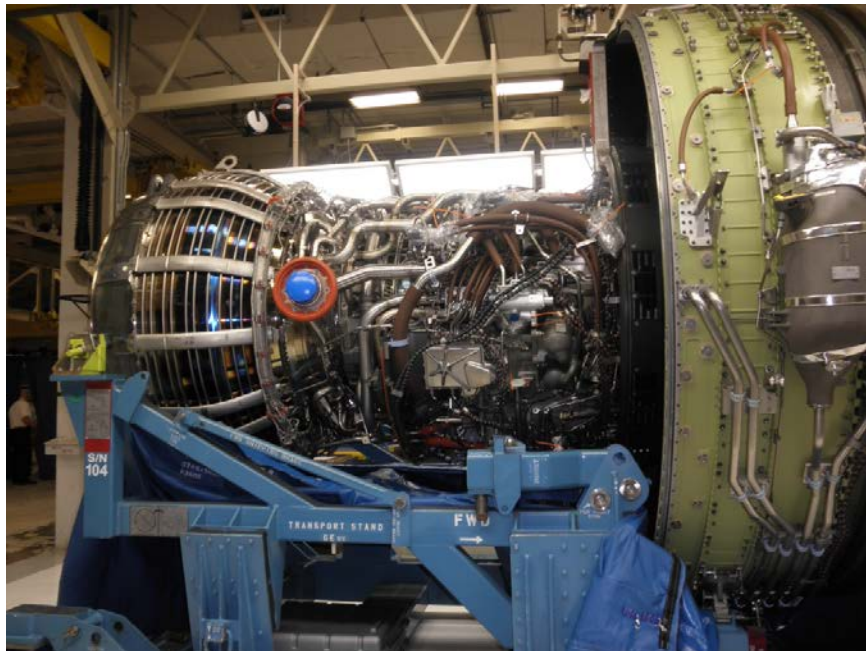


Photo No. 13: Right side of engine showing no uncontainments, case ruptures, or fire damage.

3.2.2 Fan/booster

The fan disk was intact. All of the fan blades and fan blade platforms were in place. The fan blades did not have any marks or impact damage on the leading edges, trailing edges, or airfoils. (Photo No. 14) The fan blade platforms did not have any apparent damage. The fan case abrasion rub strip did not have any circumferential rub marks. (Refer to Photo No. 14)



Photo No. 14: View of fan blades showing all are present and undamaged. Also shown is the fan blade rub strip showing no circumferential rub marks.

The fan outlet guide vanes were all in place and did not have any apparent damage. The seals between the fan outlet guide vanes were all in place.

The forward fan shaft was intact.

The booster stator and shroud case was intact. The booster spool was intact. The booster inlet guide vanes were all in place and did not have any apparent damage or impact marks. All of the booster stage 1 blades were in place and did not have any apparent damage or impact marks. The booster stage 1 abradable rub strip was in place and did not have any rub marks. The booster stage 2 vanes were all in place and did not have any apparent damage or impact marks. The booster stage 4 blades and vanes were all in place and did not have any apparent damage. The booster stage 4 abradable rub strip had two 360° parallel circumferential scoring marks that had no discernible depth that were 1.25-inches apart. The booster was not disassembled. Through gaps in the airfoils, portions of the booster stage 2 and 3 blades, vanes and abradable rub strips were visible and what was visible did not have any apparent damage or impact marks.

3.2.3 Fan hub frame

The No. 1 bearing support was intact and in place.

3.2.4 High pressure compressor

The HPC was not disassembled or examined.

3.2.5 Combustor

The exterior of the combustor case did not have any indications of a case rupture or thermal distress. The fuel nozzles and associated plumbing did not have any indications of leakage. The combustor module was not disassembled or examined.

3.2.6 High pressure turbine

The exterior of the HPT case did not have any thermal distress. The HPT was not disassembled or examined.

3.2.7 Turbine center frame

The TCF was intact. The TCF did not have any thermal distress on the exterior of the case other than the two discolored areas at about 7:30 and 8 o'clock that were noted at Charleston.

The LPT stage 1 nozzles were all in place in the TCF and did not have any apparent damage to the airfoils.

The LPT cavity brush seal was undamaged.

3.2.8 Low pressure turbine

The LPT case was intact. (Photo No. 15) The exterior of the LPT case had numerous outward dents around its circumference in the plane of the LPT stage 6 rotor between about 4.5- and 6-inches forward of the rear flange. The LPT case had an approximately 0.94-inch wide circumferential by an approximately 0.88-inch long axial hole with a tab of metal bent up on the counterclockwise side of the hole at about 12 o'clock, 5-inches forward of the rear flange. (Photo No. 16) The OD of an LPT stage 6 shroud was visible through the hole. There was an approximately 0.25-inch long split at about 2 o'clock, about 4.63-inches forward of the rear flange and an approximately 0.5-inch split at about 6 o'clock, about 5.63-inches forward of the rear flange. (Photos Nos. 17 and 18, respectively)

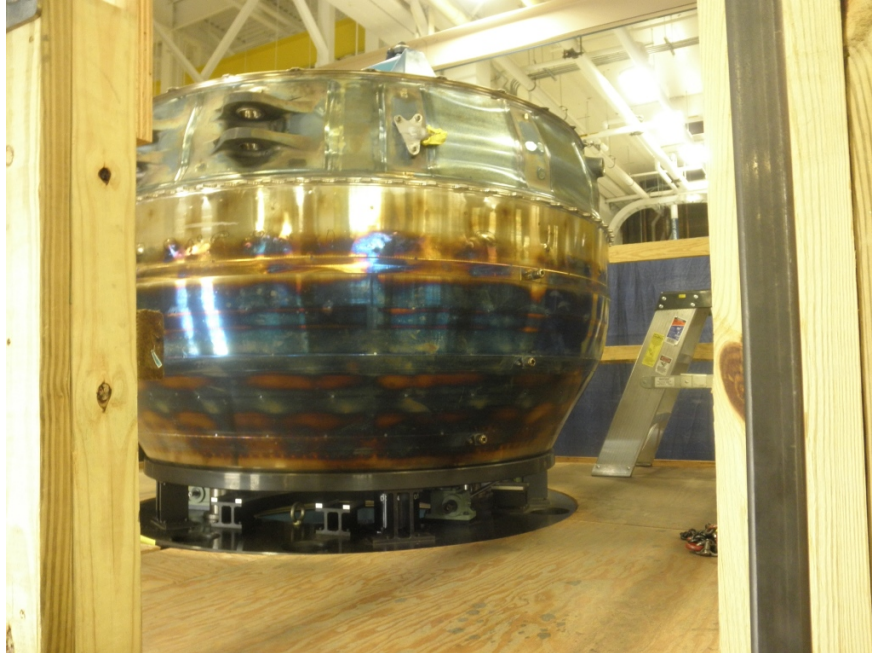


Photo No. 15: View of exterior of the LPT case showing it is intact.



Photo No. 16: Close up of hole in LPT case.



Photo No. 17: Close up of approximately 0.25-inch long split in LPT case at about 2 o'clock.



Photo No. 18: Close up of approximately 0.5-inch long split in LPT case at about 6 o'clock.

Dimension 'R', which is a measured dimension from the rear face of the No. 5 bearing support rear flange to the rear face of the LPT cone shaft castellation and recorded at assembly, was measured in four places, 1.278, 1.276, 1.276, and 1.277 inches.²⁰ According to build records, the recorded R dimension when the engine was built by GE Durham was 1.8409 inches.

²⁰ 'R' dimension was measured using a depth micrometer that was due for calibration on September 5, 2012.

The LPT stage 1 disk was intact. The LPT stage 1 blades were all in place and there was no apparent damage to the airfoils. (Photo No. 19) The aft edge of the LPT stage 1 blades' angel wings were against the front of the LPT stage 2 nozzle support front face. The LPT stage 1 blades' angel wings had heat discoloration along the aft edge that corresponded to the circumferential rub mark on the front face of the LPT stage 2 nozzle support. The rear face on all of the LPT stage 1 blades had a circumferential rub mark with heat discoloration that corresponded to the circumferential rub marks on the forward flow guide on the LPT stage 2 nozzles. (Photo No. 20)



Photo No. 19: View of LPT stage 1 disk and blades showing no damage. (GE)



Photo No. 20: Close up view of rear of LPT stage 1 blade roots showing circumferential rub marks on rear face of blade root and on edge of rear angel wing. (GE)

All of the LPT stage 1 shroud segments were in place. The shroud segment honeycomb did not have any apparent damage.

All of the LPT stage 2 nozzles were in place in the LPT case. (Photo No. 21) All of the LPT stage 2 nozzle airfoils had minor nicks and dents on the suction side of the airfoil from the midspan area outboard. (Photo No. 22)

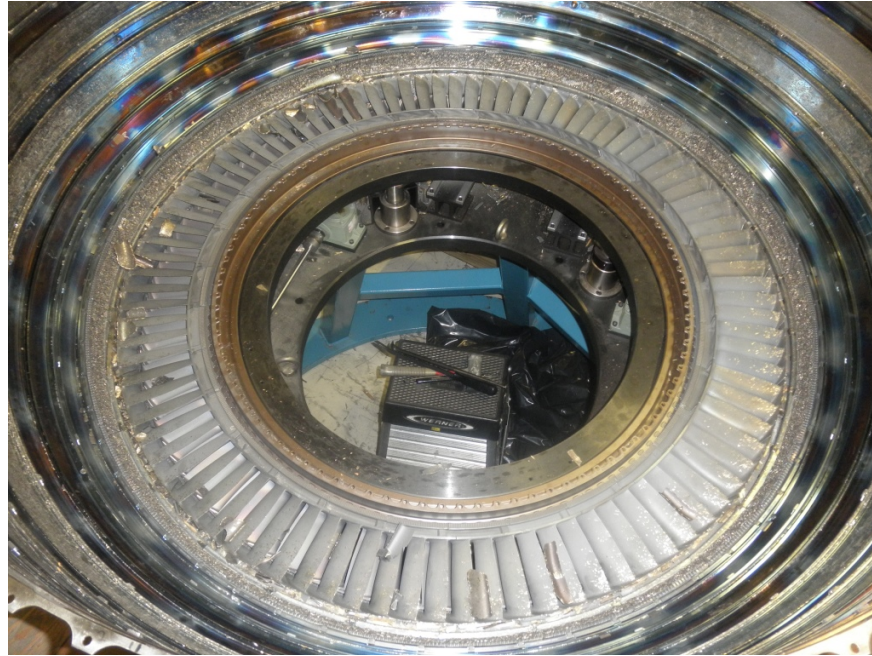


Photo No. 21: View of LPT stage 2 nozzles showing all of the nozzles are in place.

The LPT stage 2 disk was intact. The LPT stage 2 blades were all in place. (Photo No. 22) There were two LPT stage 2 blades that were fractured across the airfoil about 5 inches above the blade root platform and were missing the tip shroud. All of the LPT stage 2 blades had the blade tip trailing edge corners missing. All of the LPT stage 2 blades had minor nicks and dents on the suction side²¹ of the blade. All of the LPT stage 2 blades had a circumferential groove in the rear face of the blade root and in the airfoil at the trailing edge fillet radius that corresponded to the circumferential rub marks on the front face of the LPT stage 3 nozzle honeycomb support and the front face of the nozzle inner platform, respectively. All of the LPT stage 2 blades aft angel wings had circumferential rub marks that corresponded to the circumferential rub marks on the front face of the LPT stage 3 nozzle honeycomb support. (Photo No. 23)

²¹ The convex and concave side of a compressor or turbine airfoil are also referred to as the suction and pressure sides, respectively.



Photo No. 22: View of LPT stage 2 disk and blades after they were removed from the engine showing the disk is intact and all of the blades are in place in the disk.



Photo No. 23: Close up view of LPT stage 2 blades and stage 3 nozzles showing contact points that corresponded with circumferential rub marks on each piece.

All of the LPT stage 2 shroud segments were in place. The honeycomb material was still in place, but had numerous impact marks.

All of the LPT stage 3 nozzles were in place in the LPT case. (Refer to Photo No. 25)
All of the LPT stage 3 nozzle airfoils had nicks and dents on the convex side. (Photo No. 24)
There were several randomly located LPT stage 3 nozzles that had sections up to about 2.25-inches long radial by about 1.25-inches wide axial missing from the trailing edge.

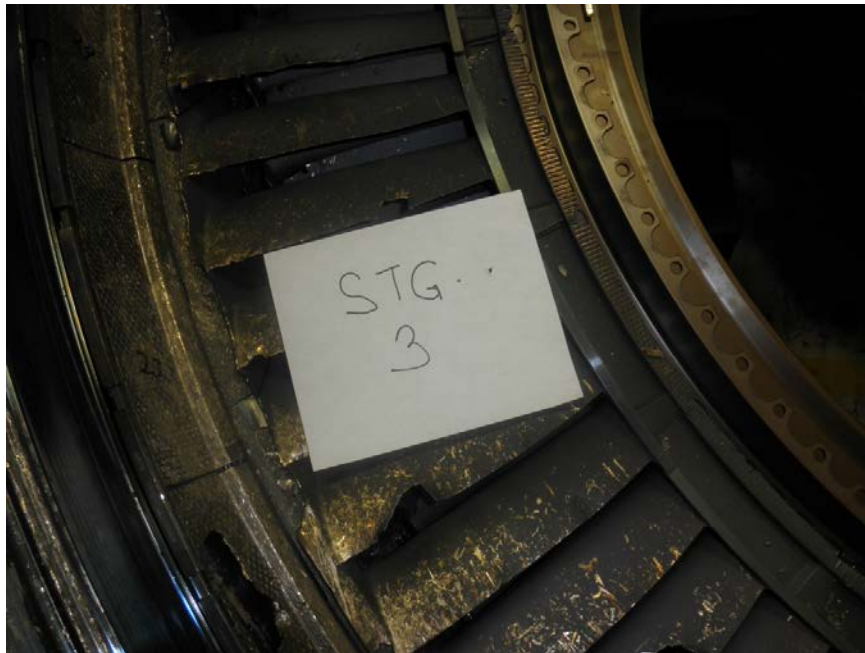


Photo No. 24: Close up view of LPT stage 3 nozzles showing impact on suction side of airfoils.

The LPT stage 3 disk was intact and did not have any apparent damage. All of the LPT stage 3 blade roots were in place in the disk. All of the LPT stage 3 blades except one were fractured transversely across the airfoil adjacent to the blade root platform. (Photo No. 25) There was one LPT stage 3 blade that was fractured across the airfoil about 1.5-inches above the blade root platform. The suction side of that airfoil had nicks and dents. The rear face of all of the LPT stage 3 turbine blade roots had an approximately 0.13-inch wide circumferential groove on the rear face that cut through the skirt. There was also a groove on the trailing edge that corresponded to the circumferential rubmarks on the LPT stage 4 nozzle honeycomb support. (Photo No. 26)

All of the LPT stage 3 shroud segments were in place. The honeycomb on the LPT stage 3 shroud segments was rubbed down to the base metal. There were four holes in the LPT stage 3 shroud segment backplates: an approximately 2.75-inch by 1.25-inch hole at about 2 o'clock, an approximately 1.75-inch by 1.25-inch hole at about 8:30 o'clock, an approximately 1-inch by 1-inch hole at about 9 o'clock, and an approximately 2.75-inch by 1.25-inch hole at about 10 o'clock. (Photo No. 27)



Photo No. 25: View of LPT stage 3 disk showing it is intact and all of the LPT stage 3 blade roots are in place. Also shown are all of the LPT stage 3 nozzles and LPT stage 3 shroud segments are in place in the LPT case.



Photo No. 26: Close up view of LPT stage 3 blade and stage 4 nozzle showing contact points that corresponded to rub marks on each component.

All of the LPT stage 4 nozzles were in place in the LPT case. (Photo No. 28) All of the LPT stage 4 nozzle airfoils had nicks and dents, primarily on the convex side. The stage 4 nozzle inner support web had an approximately 0.06-inch circumferential groove in the front

face that corresponded to the circumferential rub marks on the LPT stage 3 blades aft angle wing.



Photo No. 27: Close up view of LPT stage 3 shroud segments showing holes through several segments.



Photo No. 28: View of LPT stage 4 nozzles showing all are in place. Also shown are the LPT stage 4 shroud segments showing all are missing except one and the LPT stage 5 nozzles showing that all are missing except one platform hook.

The LPT stage 4 disk was intact and did not have any apparent damage. All of the LPT stage 4 blade roots were in place in the disk. All of the LPT stage 4 blades were fractured across the airfoil between approximately 0.25- and 6.25-inches above the blade root platform. (Photo

No. 29) All of the longer blades had nicks and dents on the convex airfoil surface. Many of the longer blades were bent opposite the direction of rotation. The aft angel wings on all of the LPT stage 4 blades had circumferential rub marks, heat discoloration, and material displacement.



Photo No. 29: View of LPT stage 4 disk showing it is intact. (All of the LPT stage 4 blades had fallen out of the disk while the rotor was being disassembled.) Also shown is all of the LPT stage 4 LPT shroud segments missing except one and all of the LPT stage 5 nozzles missing except one. Also shown is all of the LPT stage 5 shroud segments missing.

All of the LPT stage 4 shroud segments except one at about 9 o'clock were missing. The shroud segment that remained had the honeycomb material rubbed down to the backplate. (Refer to Photos Nos. 28 and 29)

All of the LPT stage 5 nozzles except one were missing from the LPT case. There was one platform hook of an LPT stage 5 nozzle segment with the airfoils fractured at the fillet radius at about 10 o'clock. (Refer to Photos Nos. 28 and 29)

The LPT stage 5 disk was intact. The OD surface of LPT stage 5 disk had numerous nicks. The knife edge seals were still in place, but there were chips in the coating. (Photo No. 30) All of the LPT stage 5 blade roots were in place in the disk. All of the LPT stage 5 blades were fractured across the airfoil at varying heights from just above the blade root platform to about 2.5-inches above the blade root platform. The LPT stage 5 turbine blade airfoils that remained had numerous nicks and dents primarily on the convex side of the airfoil.



Photo No. 30: Close up of LPT stage 5 disk showing impact marks on outer diameter and chips on coating on knife edge seals.

All of the LPT stage 5 shroud segments were missing and there were impact and scuff marks 360° around the inside of the LPT case where the stage 5 shroud segments would have been. (Refer to Photo No. 29)

All of the LPT stage 6 nozzles were in place. All of the LPT stage 6 nozzles were battered with nicks and dents on the leading and trailing edges and on both sides of the airfoils. (Photo No. 31)

The LPT stage 6 disk was intact. The front face and arm and the rear face of the LPT stage 6 disk did not have any impact marks, but the OD of the aft conical arm had several randomly located impact marks. All of the LPT stage 6 blade roots remained in the LPT stage 6 disk. All of the LPT stage 6 turbine blades were fractured across the airfoil at varying heights from just above the blade root platform to about 1.25-inches above the blade root platform. (Photo No. 32)

There were three LPT stage 6 shroud segments in the LPT case at about 12, 5 and 7 o'clock. (Refer to Photo No. 32) The shroud segment at about 12 o'clock was over the hole in the LPT case, but the counterclockwise side of the shroud segment had a section missing that matched the shape of the hole in the case. (Refer to Photo No. 16) The honeycomb material was rubbed down to the backing plates.



Photo No. 31: View of LPT stage 6 LPT nozzles showing battered airfoils.

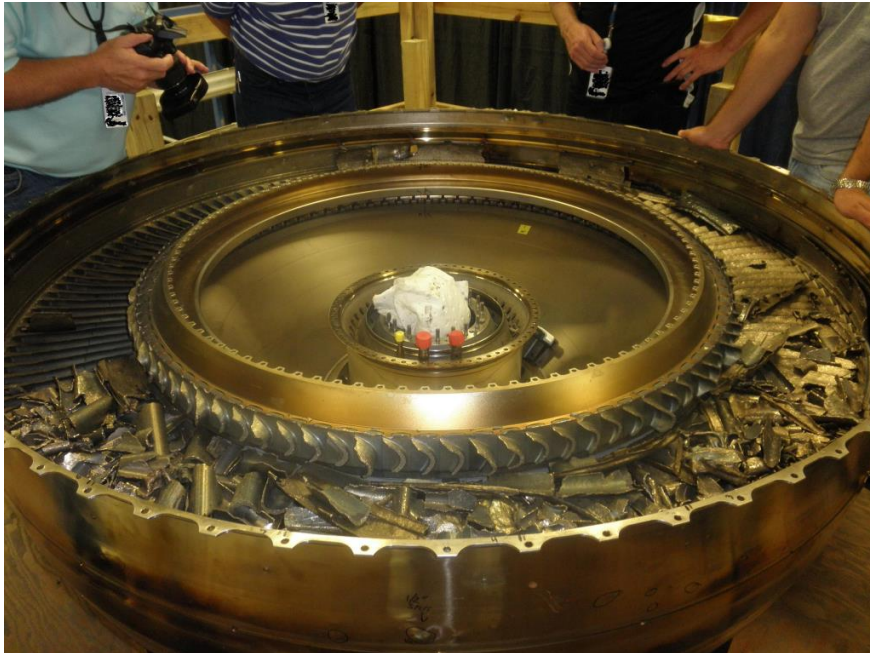


Photo No. 32: View of LPT stage 6 showing the disk is intact and all of the blade roots are in place in the disk and the blades fractured at various lengths above the blade root platform. Also shown are some of the LPT stage 6 shrouds that remained in the LPT case.

All of the LPT stage 7 nozzles were in place. All of the LPT stage 7 nozzles were battered with nicks and dents on the leading and trailing edges and on both sides of the airfoils. (Photo No. 33)



Photo No. 33: View of LPT stage 7 nozzles showing battered airfoils. Also shown are the LPT stage 7 shrouds in place in the case with the honeycomb rubbed down to the backing plate.

The LPT stage 7 disk was intact. The rear face of the LPT stage 7 disk did not have any rub marks or impact marks. All of the LPT stage 7 blades were in place, but all of the LPT stage 7 blades were fractured across the airfoils at varying heights from adjacent to the blade root platform to up to about 4 inches above the blade root platform. (Photo No. 34)



Photo No. 34: View of LPT stage 7 disk showing it is intact and that all of the blades are in place, but fractured at various lengths above the blade root platform.

The LPT stage 7 shrouds were in place between about 3 and 4 o'clock and about 5 and 11 o'clock. The honeycomb material was rubbed down to the backing plates. (Refer to Photo No. 33)

3.2.9 Turbine rear frame

The TRF was intact. (Photo No. 35) The inner diameter of the outer case had numerous nicks and dents. All of TRF struts were in place and there were no visible cracks on the inner or outer ends of the struts where they join with the inner duct or outer case, respectively. All of the struts had numerous nicks and dents, primarily on the convex side. There was one strut, strut No. 5²² at about 3:30 o'clock, that had an approximately 0.25-inch wide radial by 0.88-inch long axial hole about 0.63-inches aft of the leading edge adjacent to the outboard fillet radius. (Photo No. 36)



Photo No. 35: View of turbine rear frame showing that it is intact.

²² Gas turbine engine industry convention is to number parts in a clockwise pattern, ALF, with the No. 1 part located at the 12:00 o'clock position.



Photo No. 36: Close up view of hole in turbine rear frame strut.

3.2.10 Bearings

The No. 1R bearing, a roller bearing, and the No. 2B bearing, a ball bearing, were intact, wet with oil, and did not have any discoloration or rotational distress.

The No. 1 bearing carbon seal support was intact and the O-ring at the forward end of the support was not damaged. The No. 1 bearing carbon seal was intact.

The rear half of the No. 5 bearing sump cover was separated from the front half at the flange. The front face of the No. 5 bearing sump cover flange had circumferential scoring and heat discoloration. The circumferential rub marks on the sump cover corresponded to the circumferential rub marks and heat discoloration on the No. 5 bearing seal runner rear face. There was a strand of metal hanging from the end of the No. 5 bearing seal runner rear face outer corner.

The No. 5 bearing outer retaining nut wrenching lugs had impact marks and rub marks that corresponded to the groove in the front side of the No. 5 bearing oil jet tube.

The No. 5 bearing outer retaining nut breakaway torque was measured in the loosening direction at 105 foot-pounds using an 11:1 torque multiplier for 1155 foot-pounds.²³ The No. 5 bearing outer retaining nut installation torque is 880 to 1050 foot-pounds.²⁴

²³ The 0 – 100 foot-pounds torque wrench, SN EV16146, was due for calibration on September 14, 2012, and the 11:1 torque multiplier used was due for calibration on December 3, 2012.

²⁴ GE GENx assembly procedures.

The No. 5 bearing inner retaining nut breakaway torque was measured in the loosening direction at 40 foot-pounds using an 8:1 torque multiplier for 320 foot-pounds.²⁵ The No. 5 bearing inner retaining nut installation torque is 600 to 720 foot-pounds.²⁶

The No. 5 bearing carbon seal runner was intact. The rear face of the No. 5 bearing carbon seal runner had circumferential scoring, material transfer, and heat discoloration that corresponded to the circumferential scoring on the No. 5 bearing sump cover flange front face.

The No. 5R bearing cage was intact and the silver plating was still in place on the cage. All of the rollers were in place in the cage. Some of the rollers could be rotated. All of the rollers had an approximately 0.31-inch wide flat spot with circumferential scoring at the rear half of the roller. The outer race was intact, but there was an intermittent circumferential groove on the front face. The inner race had an approximately 0.31-inch wide circumferential groove with heat discoloration and material displacement at the front half of the race. The inner race had imprints of the rollers within the grooved area.

The LPT CVT extension duct was intact.

3.2.11 Oil system

The oil tank was full. The oil in the tank did not have an acrid smell.

The No. 5 bearing oil jet tube had a 0.13-inch wide groove on the forward side that corresponded to the impact marks on the corner of the No. 5 bearing retaining nut wrenching lugs. (Photos Nos. 37 and 38, respectively) The No. 5 bearing oil jet tube was bent rearward. The No. 5 bearing oil jet tube was cracked at the base.

²⁵ The 0 – 175 foot-pounds torque wrench, SN EV15326, was due for calibration on September 14, 2012, and the 8:1 torque multiplier used was due for calibration on April 19, 2013.

²⁶ GE GENx assembly procedures.



Photo No. 37: Close up of groove in side of No. 5 bearing oil jet that corresponded to the No. 5 bearing retaining nut wrenching lugs.



Photo No. 38: Close up of impact mark on No. 5 bearing retaining nut wrenching lug.

The No. 5 bearing carbon seal housing was intact and did not have any apparent damage. The No. 5 bearing carbon seal was in place and intact.

4.0 *Airplane examination Charleston*

4.1 Airplane information

The airplane was operating under the call sign Boeing 238. However, the airplane was partially painted in the colors of Air India and the registration number that was painted on the airplane was VT-ANJ.²⁷

4.2 Fuselage

The right side of the fuselage from just aft of the aft cargo door to just aft of the aft cabin door below the cabin floor level had numerous impact marks. There was one impact mark on the aft cabin door slightly above and in front of the window. (Photo No. 39)



Photo No. 39: View of right side of aft fuselage with red tape showing impact marks.

4.3 Right wing

The right wing had numerous impact marks on the underside of the wing to the left and right of the engine just aft of the engine. The inboard flap had impact marks on the inboard and outboard side of the flap jackscrew fairing. There was a crescent-shaped axial cut in the inboard flap outboard of the fairing. The inboard flap jackscrew fairing had two cuts: one axial and one

²⁷ VT is the prefix for the registration numbers for airplanes registered in India.

longitudinal; towards that aft end. The inboard aileron and outboard flap had several impact marks. (Photo No. 40)



Photo No. 40: View of underside of right wing aft of engine showing impact marks marked with red tape. Also shown is outboard side of right engine's pylon showing impact marks marked with red tape. (GE)

4.4 Right horizontal stabilizer

The right horizontal stabilizer had numerous impact marks on the leading edges and on the underside of the stabilizer from about the one-third span to the tip.

4.5 Pylon

The strut had several impact marks on the inboard side and numerous impact marks on the outboard side aft of the engine exhaust. (Refer to Photo No. 40)

ATTACHMENT

1. View of GE GENx-1B engine's borescope ports