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POWERPLANTS GROUP CHAIRMAN'S FACTUAL
REPORT, REV. 1
MARCH 7, 1997

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NATIONAL TRANSPORTATION **SAFETY** BOARD
Office of Aviation Safety
Washington, D.C. 20594

March 7,1997

POWERPLANTS GROUP CHAIRMAN'S FACTUAL REPORT, **REV. 1**

DCA96MA068

A. <u>ACCIDENT</u>

Location: Pensacola Regional Airport, Pensacola, Florida

Date: July 6, 1996

Time: 1424 central daylight time (CDT)

Aircraft: McDonnell Douglas MD-88, N927DA, Delta Air Lines, Flight 1288

B. <u>POWERPLANTS GROUP</u>

George W. Anderson Group Chairman	National Transportation Safety Board Washington, District of Columbia
Phillip Powell	National Transportation Safety Board Atlanta, Georgia
Raymond Vakili	Federal Aviation Administration Long Beach, California
Gregory Saylor	Air Line Pilots Association College Park, Georgia
Steven R. Wesley	Pratt & Whitney Atlanta, Georgia
Bruce Samborski	Pratt & Whitney East Hartford, Connecticut
James Sunamoto	Pratt & Whitney East Hartford, Connecticut
Wade Reynolds	McDonnell Douglas

	Atlanta, Georgia
Alexander Holin	McDonnell Douglas Oslo, Norway
Christopher Seals	Delta Air Lines Atlanta, Georgia

C. SUMMARY

On July 6, 1996, at about 1424 central daylight time, (CDT), a McDonnell Douglas MD-88 airplane, N927DA, operated by Delta Air Lines as flight 1288, sustained an uncontained fan hub failure of the number 1 engine fourteen seconds after initial power application during the takeoff roll at Pensacola Regional Airport, Pensacola, Florida. The airplane was equipped with Pratt & Whitney (P&W) model JT8D-219 turbofan engines. The flight crew heard a loud noise and rejected the takeoff stopping the airplane on the runway approximately 1,350 feet from the threshold. The airplane was being operated under Title 14 Code of Federal Regulations (CFR) Part 121 on an instrument flight rule (IFR) flight plan as a regularly scheduled flight to Atlanta, Georgia. Fragments from the failed engine entered the passenger cabin killing two passengers and injuring three others.

The Powerplants Group commenced the on-site examination of the airplane and engine on July 7, 1996. The fan hub had ruptured with a large section of rim being found to the left of the runway and a smaller rim section found to the right of the runway and off the airport property. The fan containment ring was ruptured and the inlet cowl assembly had separated. The upper left side of the fuselage was penetrated adjacent to the number 1 engine fan. Several fan blades and a small segment of the fan hub conical section were later recovered from inside the aircraft cabin. There was scorching on the nacelle surface extending from the rupture in front to the tailpipe in the rear. (Photo 2) Examination of the hub by an NTSB metallurgist revealed evidence of fatigue in a bolt hole. The hub and all the recovered fan blades were shipped to the Safety Board materials laboratory for further examination. The Powerplants Group completed the on-site portion of its investigation on July 10, 1996.

The Powerplants Group reconvened at the Delta Air Lines Technical Operations Center at Hartsfield International Airport, Atlanta, Georgia on July 15, 1996, to disassemble, inspect, and document the condition of the engine and its attached components. The low pressure turbine (LPT) shaft was rubbed at several locations and the LPT disk measurements showed no growth from overspeed. The group completed its duties on July 18, 1996.

The NTSB Metallurgist's Factual Report No. 96-131, dated August 6, 1996 identified two fatigue origins in a tie bolt hole on the fractured fan hub. From these two locations fatigue striations extended approximately 1.5 inches into the material. The hole areas near the crack origins had numerous surface cracks running parallel to the hole axis. The microstructure in these areas was found to be deformed and hardness tests indicated values as high as **52** on the Rockwell C hardness scale (HRC) as compared to the material specification of **39** HRC maximum.

The Powerplants Group, in cooperation with the Swedish Accident Board, visited the manufacturer, Volvo Aero Corporation, Trollhattan, Sweden, on August **28-29, 1996.** The drilling, boring, and honing processes used in manufacture of the fan hub were examined along with the work and inspection instructions. Volvo briefed the Powerplants Group on its process quality system and provided detailed documentation of inspection results and part disposition.

D. DETAILS OF THE INVESTIGATION

1.0 ENGINE INFORMATION

The number **1** engine was a P&W **JT8D-219** turbofan engine, serial number (SN) **726984.** The JT8D-200 **series** engine is an axial-flow front turbofan engine having a fourteen stage split compressor, a nine can combustion chamber, and a split four stage reaction impulse turbine. The engine had a total operating time of **7,371.7** hours and **5,905** operating cycles at the time of the accident. The engine had been installed on January 1, **1996.** Since then it had accrued **1,528** hours and **1,142** cycles. Documentation of the engine buildup records and maintenance history are presented in the Maintenance Group Chairman's factual report.

The number **2** engine showed no external signs of failure and was not investigated further.

2.0 ON-SITE INVESTIGATION

2.1 ENGINE COWLING

The entire nose cowl was found on the runway **563** feet from the runway threshold. It was lying nose down and fractured predominately at the "B" flange with some portions of the front fan case (that section between " B and " C flange) still attached. There was a large dent in the inlet lip measuring **29** by **9** inches, centered at 12:30 o'clock af? looking forward (ALF)[1]. Six inlet guide vanes (IGV) had trailing edge (TE) secondary damage near their outside diameters (OD). They were located in a group between the 3:00 and 9:00 o'clock position. What appeared to be combustion soot and a light oil film was observed to be present on the OD of the nose cowl. Rivets securing the cowl **skin** to the aft bulkhead were tom or pulled out in a line extending from 12:00 to 3:00 o'clock. Both the IGV anti-icing tubes were fractured at the tube elbow to the IGV

[1] **Circumferential positions** will normally be **described using clock references** as **would** be **seen** by an **observer viewing the engine** or **the component from the** aft **looking** forward (ALF).

outer box shroud. Also, the nose cowl anti-icing tube fractured at the 12:00 o'clock position.

The nose cowl inlet lip had oil stains extending from the 3.00 to 6:00 o'clock position. Buckling of the nose cowl structure in the longitudinal direction existed through 360 degrees of the inlet ID just forward of the IGV's. The forward fan case (from " B to " C flange) is fractured from 6:00 to 2:00 o'clock. Fragments of the forward fan case were found that had multiple fractures and score marks oriented at a 45 degree angle relative to the engine center line. The acoustic liner material on the cowl inlet ID showed several gouges and tears extending into the honeycomb in the 3:00 to 4:00 o'clock area.

2.2 NOSE BULLET

The nose bullet was found on the runway approximately twenty feet to the left of the inlet cowl. The front accessory support cover was still attached and no obvious installation or handling damage was noted. The P_{T2} air tube (provides part of the engine pressure ratio signal) appeared to be intact and functional. The aft inboard rivet of the moisture trap support bracket was popped loose and protruding approximately 1/16 inch from the bullet outer surface. The external surfaces were coated with an oil film on the **OD** from 9:00 to 1:00 o'clock. Soot was present similar to that observed on the upper and lower cowl sections. The soot deposits were not uniform and appeared most prominent towards the rear of the assembly where the part joined the IGV assembly. **A** prominent dent on the forward OD at the 3:30 position showed abrasion marks that contained stains resembling asphalt.

2.3 FAN

The fan hub and blade assembly were separated from the engine. The surrounding engine outer case and cowl was ruptured with torn and missing sections. Also missing was the forward portion (integral spacer) of the stage 1.5 compressor disk. The integral spacer fastens to the rear of the fan hub using 24 tie bolts. It was separated at a 360 degree circumferential fracture located just forward of the stage 1.5 disk bore. The integral spacer had further fractured into at least five pieces that were found in the debris field around the aircraft. (Photo 3)

The fan hub broke into three major pieces with a smaller fourth piece remaining in the number 1 bearing assembly. (Photo 4) The largest piece, consisting of approximately 2/3 of the hub rim and the adjoining conical section, was located 714 feet to the left of the runway centerline. (Photo 5) **A** prominent scar on the tarmac of the runway pointed to four tandem divots in the field which pointed to the final resting place of the hub segment. (Photo 6) The smaller portion of the hub rim was found 2400 feet to The right of The runway centerline in a sports field. (Photo 7) The third **major piece,** a triangular shaped part of the conical section, measuring approximately 11 by 10 inches on edge, was found imbedded in the right side fuselage interior just above the window at seat row 37.

The fan hub was fractured through a tie bolt hole and blade slot at both rim locations. There were two fan blade roots still in place on the small rim segment and 13 on the large one. Three **of** the 13 blades were full length and bent counterclockwise ALF. *An* additional smaller fracture surface was located at the forward section of the integral conical hub. This fracture was oriented at right angles to the hub axis and extended 360 degrees around the part circumference. The fracture also passed through the number 1 bearing oil supply holes. (Figure 6) The aft portion of this fracture surface was free of oil, coke, and soot.

The fracture surfaces of the hub rim were examined on-scene by a Safety Board metallurgist and one surface was found to have evidence of fatigue cracking. (Photo **8)** The hub and fan blades were shipped to the Safety Board's materials laboratory for further study.

The outer engine case separated primarily at the "C" flange. Forward of this, the case remained attached to the cowl. Between " C and " D flange, the case was tom and fragmented in two areas centered approximately at the 1:00 and 7:00 o'clock positions. The 1:00 o'clock position was missing a segment from 12:30 to 2:00. From 2:00 to 3:00 the case was intact but torn loose from " D flange. A 12 to 14 inch circumferential segment of the fan rear case was found on the runway 61 feet right of centerline and 441 feet from the runway threshold. Abradable material was largely missing from the ID of the fan rear case and there were multiple gouges distributed around the entire circumference oriented generally in a 45 degree angle with respect to the engine centerline.

Other observations were made of the forward case and fan area. Acoustic honeycomb in the fan case area was ripped, torn, and missing in many places. The fan exit guide vanes (EGV) were damaged from 9:00 to 11:30. The damage consisted primarily of tearing and deformation on the LE portions of the vanes. Light LE damage was also noted on six vanes in the 2:00 to 4:00 o'clock position. The splitter fairing was missing from 1:00 to 7:00. A tom piece of the splitter remained attached at the 5:00 o'clock position. Twelve first stage stator vanes were present on the remaining splitter fairing. The inner diameter ends of the vanes were separated from the inner shroud and bent in the direction of rotation.

Three hub tangs (the retaining walls of the blade dove-tail slots on the hub rim) were sheared off of the smaller rim segment One tang was adjacent to one of the hub fracture sites Only two tangs were recovered Thirty-one of the 34 fan blade roots were recovered There were witness marks in the front side of several dovetail slots on the hub **rim.** The fan **blades** that were on the larger fan hub section showed minor **LE** object damage The front inner air seal support structure was fractured at two locations and was still attached to both hub segments The rotating knife edge seal was separated from the support because all of the rivets fractured. The blade retention lock ring was recovered inside the left side of the aircraft fuselage. Twelve fan hub tie bolts were recovered, The recovered tie bolts appeared uniformally sheared near the bolt heads.

2.4 ACCESSORY DRIVE GEAR

Impact damage was observed on the rear outer diameter of the gear. The accessory drive gear's snap ring was missing.

2.5 NUMBER 1 BEARING AREA (Figure 6)

The carbon seal metal face appears normal. The carbon part of the seal is completely missing. The bearing inner race appears normal with some impact damage observed on the forward OD. The inner bearing race was cocked on the fractured hub journal. A light blue 3/8 inch wide roller track was noted on the inner race and appears consistent with normal bearing service experience.* Material resembling asphalt was found in the race-hub journal interface.

The fracture surface of the forward portion of the hub that remained mated to the Number 1 bearing inner race had a dark, oil/coke-like color. The fracture surface propagated through the oil supply passage holes and exhibited sharp edges and some local foreign object damage. One smear was present on the carbon seal metal face adjacent to the hub fracture surface. Impact damage was noted on the aft face of the front accessory spur gear. Number 1 bearing inner race retaining nut had thread damage through 360 degrees. The threads appeared to be flattened and the *nut* was distorted so that it would not lie face down on a flat surface without showing visible gaps of up to 3/8 inch.[3]

The number 1 bearing roller cage shows secondary damage due to impact and some indications of normal wear elsewhere. Seventeen out of 24 complete roller bearings and 4 fragments were recovered. No other abnormal conditions were noted. (Photo 9)

The bearing outer race was fractured into many pieces. A 180 degree segment was lodged in the number 1 bearing support assembly. No other abnormal conditions were noted. The carbon seal support was recovered. All carbon seal material was missing. There was oil and coke-like stains on all internal seal support surfaces that would normally be oil-wetted in service. The seal support is distorted out

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[2] See Overhaul limits, Table 1, Pratt & Whitney Overhaul Standard Practices Manual, ATA Chapter 70-35, Page 7.

[3] This distortion is related to the geometric tolerancing feature of flatness that is formally defined in American National Standards (ANSI) Specification Y14.5M. Flatness is defined as limiting a surface to remain within two parallel planes positioned a specified distance apart. flatness is usually measured by laying the part on a flat surface and measuring the separation of points that are not in contact. When the face of a large nut is distorted beyond a serviceable flatness limit it will be tenned out of flat. It is used here primarily to describe the type of distortion.

flat and out of round.[4] An "O" ring from the rear of the No. 1 bearing support housing was found separated into three or more pieces. Both stationary and rotating number 1 bearing airseals were recovered. The outer stationary seal exhibited normal wear and was distorted out of round from secondary damage. Oil and soot were present on the seal ID. The knife edges of the rotating inner air seal had impact damage. Undamaged surface segments showed only light wear. The overall seal assembly had fractured axially, was out of round, and out of flat.

2.6 FRONT ACCESSORY SUPPORT COVER

The N1 drive spur gear bearing housing was split at the 12:00 position. The scavenge pump gear shaft was warped. The shaft was binding but could be turned by hand. The attachment lugs were fractured. The reddish-brown colored "O" ring sealing the support cover-to-bearing housing interface was severed in one place. No other damage was noted.

3.0 ENGINE DISASSEMBLY

The disassembly of the engine was accomplished at Delta Air Lines, Inc. Technical Operations Center, Hartsfield International Airport, Atlanta, Georgia, on July 15-18, 1996.

3.1 ENGINE AND COWL DOORS

The cowl doors were not burned through in any location. All fire damage was located from the 6:00 to the 9:00 o'clock position on the exterior of the cowling. There was no fire damage or evidence of fire on the inside of the upper or lower cowl doors. The lower forward cowl door exhibited the most severe fire damage. This was based on the amount of soot and blistering present. In other areas the paint had burned off, was blistered, discolored, or grainy from heat.

3.2 FAN AND FRONT COMPRESSOR SECTION

The fan rear case was torn axially and circumferentially between 12:30-2:00 o'clock and the C and D flanges. A piece of the rear case was missing from this area. The fan rear case had a circumferential tear forward of the D flange that extended from approximately 2:OO-4:00 o'clock. The fan rear case between 12:30 and 4:00 o'clock was deformed radially outward. The fan rear case had an axial tear extending from the C flange to the D flange at 6:00 o'clock. This tear connected to a circumferential tear in the fan rear case forward of the D flange that extended from 6:00 to 9:00 o'clock.

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[4] Out of round describes the departure from the geometric feature of circularity that is fonually defined in American National Standards (ANSI) Specification Y14.5M. It is used here to describe *the* type of distortion not the exact value.

Portions of the first stage stator outer shroud remained between 3:00 and 4:00 o'clock. The stator outer shroud in the plane of the 1.5 stage rotor was missing from 2:30 to 3:30. The rubber outer blade tip seal was missing from the 1.5, 2nd, 3rd, and 6th stages. The aluminum 1.5, 2nd, 3rd, and 6th stage backing for the rubber blade tip seal was rubbed 360 degrees around. The 4th and 5th stages were not viewed. Fan EGVs were buckled from approximately 8:00 to 10:00 o'clock. One fan EGV was broken at the base at the 9:00 o'clock position. This vane was found in the exhaust area. One first stage stator vane was found at the 6:00 o'clock position immediately aft of the fan EGV in the fan flow path. Another first stage stator vane was found approximately three feet aft of the fan EGV in the fan duct. Fine metal debris was found inside the remaining low pressure compressor rotor section. This debris was mostly 1/4 inch or smaller but included one piece of acoustic liner material about 1.5 inches long.

Circumferential rub marks were found on the 1.5 stage stator inner shroud front lip. Two blades in the stage 1.5 rotor were displaced but were still in their slots. Stage 1.5 blades had TE damage. Stage 1.5 blade had less TE damage but showed some cuts and dents. Two adjacent stage 1.5 blades were missing from the blade slot at 10:30 o'clock. Some dovetails were curled out at the trailing edge. One of the stage 1.5 blades was found lying just forward of the fan EGVs at the 6:00 o'clock position.

Recovered fan blade fragments were visually examined in the Safety Board materials laboratory. There was no evidence of fatigue or other pre-accident discrepancies.

3.3 FRONT COMPRESSOR OUTER FAN DUCT

The front compressor fan duct was fractured circumferentially 360 degrees at a position approximately 2.75 inches forward of the F flange. (Photo 10) The fracture surfaces were still in alignment. There were matching areas of deformation on both sides of the duct fracture at the 6:00 o'clock position. The acoustical liner was buckled near 6:00 o'clock adjacent to the circumferential fracture.

3.4 MAIN GEARBOX

The tower shaft turned freely by hand. Mechanical continuity of the gearbox extended from the tower shaft through the gearbox to the generator and hydraulic pump output splines.

3.5 EXTERNALS AND ACCESSORIES

The forward elbow connecting the fuel-oil cooler and fuel flow transmitter was broken off This elbow was recovered from the runway. Front and rear brackets to the fuel-oil cooler were broken. The fuel line running aft from the fuel oil cooler had a dent forward of the first clamp. The same line was buckled at the rear of the fuel-oil cooler. The oil pressure line to the #1 bearing was broken at the fitting on top of the fuel-oil cooler.

The 8th stage bleed air line was broken at 10:00-11:00 o'clock, just downstream of the anti-ice (A/I) valve and aft of the E flange. The electrical actuator on the 8th stage bleed air A/I valve at the 10:00-11:00 o'clock position was broken off from the valve body. The 8th stage bleed air duct was broken at 2:00 o'clock at the D flange. The 8th stage bleed air line was dented and punctured at the 2:00 o'clock position just downstream of the IGV, A/I valve. The valve appeared undamaged. The 8th stage bleed air line to the IGVs was slightly dented where it passed over the 13th stage bleed air line at 12:00 o'clock. The cowl A/I bleed air line was deformed at the 12:00 o'clock position. The electrical actuator on the cowl A/I valve was partially separated from the valve body.

The upper forward section of the oil tank was dented downward and inward. The upper aft end of the oil tank was separated from the gearbox about 1/2 inch and the upper attach bolt was broken and the rubber bushing was missing. The lower aft section of the oil tank adjacent to the mounting surface was folded. The oil tank support strap was broken at the rivets on the outboard side. (8:00 o'clock) Approximately 1.5 pints of oil remained in the oil tank and there was no evidence of leaking. An El flange segment was broken out at 6:00 o'clock and was still attached to the main gearbox forward mounting bracket.

The fuel pump was disconnected from main gear box. Mounting splines on the pump housing and main gearbox were damaged. Metal shavings were present in both the drive end of the pump and on the mating surface of the drive. The shavings found were approximately 2-3 inches long. No damage was noted to the drive splines on the pump shaft. This "disconnect" was in-plane with the front compressor fan outer case fracture just forward of the F flange.

The shorter of the two fuel control support brackets was broken in the upper eye. The eye was elongated and the bolt and bushing were undamaged. Both fire loops were intact. All the accessory clamps and brackets were undamaged. There was no evidence of fire in the external accessory area. Soot was present at the 7:00-9:30 position on the fan case between the C and D flanges.

The starter oil supply did not leak out. The bottom end of the tower shaft, its housing, and the associated mating surface on the main gearbox appeared normal with no scratches, broken parts, or debris. The wire bundle mounted just forward of the D flange was cut at the 2:00 o'clock position. 9 wires were cut, one was damaged, and 16 appeared normal. Wires along the C flange at 7:00-10:30 were cut, pulled apart, and/or broken. These wires were blackened and sooted. Some wire insulation was burned. No damage was noted to the ten electrical plugs at the pylon disconnect. There was no corrosion on any of the pins or sockets on the pylon electrical plugs.

3.6 INTERMEDIATE CASE AREA

Five 6th stage stator vanes had nicks in the trailing edge. The tower shaft interface to bull gear area had a typical in-service appearance. The N2 assembly could be rotated by turning the tower shaft. The 8th stage bleed valves had a heavy metal buildup on the ID.

3.7 COMBUSTOR

The combustor section contained some metal debris and a fine, light metallic discoloration distributed on the burner cans. The combustion section otherwise had a typical in-service appearance.

3.8 BEARING 4.5 AND LOW PRESSURE TURBINE SHAFT

Bearing number 4.5 had a typical in-service appearance. Four circumferential rub marks were located on the LPT shaft OD. The position of these marks was established by measuring their distance from the shaft's LPT gauge spacer reference.

Location from reference	Circumferential Location	Mark Appearance
8.5-9.5"	11:30 to 1:30	superficial, no depth
22 -25"	1:30 to 6:30	superficial, no depth
58-59"	10:30 to 11:30	superficial, no depth
58-59"	4:30 to 7:30	superficial, no depth

In addition to the rub marks a brown discoloration was present on the LPT shaft 6 to 8 inches aft of the LPT gauge spacer reference.

3.9 HIGH AND LOW PRESSURE TURBINE

There was no apparent wear of the honeycomb on the 4th stage turbine outer air seals. Fine dust-like metal powder was found at the blade tips of the 4th stage turbine rotor. Light metallic discoloration was present on the blades at the inlet and outlet of the high pressure turbine (HPT) and the LPT. The 2nd stage turbine inner knife edge air seal had uniformly rubbed the circumference of the rear air seal flange on the first stage turbine hub. A deposit on several 2nd stage turbine nozzle guide vanes on the convex leading edge was flaking off The snap measurements and bore measurements for the 2nd, 3rd, and 4th disks were compared to the inspection limits and part drawings as a check on possible growth due to overspeed. All dimensions were determined to be within limits.

3.9.1 Number 6 Bearing

The carbon seals had a typical in-service appearance. The rest of the assembly appeared normal.

3.9.2 Turbine Exhaust Case

One fan EGV, a 3 inch section of the first stage outer shroud, and other small debris were present at the 6:00 o'clock position. Metal shavings were present in the gas path and on the mixer.

3.10 THRUST REVERSER ASSEMBLY

Physical inspection of the thrust reverser revealed no apparent physical damage. The thrust reverser assembly was not disassembled.

4.0 METALLURGICAL INVESTIGATION OF FAN HUB

4.1 FAN HUB DESCRIF'TION

The fan hub, P&W part number **5000501-01,** Serial Number R32971, was manufactured by Volvo Aero Corporation, Trollhattan, Sweden in January of **1989.** At the time ofthe accident it had completed **13,835** total flight cycles and **1,142** cycles since the last visual and fluorescent penetrant inspection (FPI). The service life of this hub is presently limited to **20,000** cycles. Details of the hub maintenance and operations history as well as the manufacturing inspection and quality control records are presented in the Maintenance Records Group Chairman's Report.

The major portion of the hub consists of a disk forging that holds **34** fan blades in dovetail slots. Integral to this disc is a cone shaped nose piece whose small end engages the inner race of the number 1 bearing. The aft end of the hub attaches to the stage **1.5** disk with **24** tie bolts that pass through holes drilled in the hub rim just inside of the dovetail slots. The fan hub is forged from a titanium based alloy containing 6% aluminum and **4%** vanadium. The material specification is P&W **1215,** which is based on the Aerospace Material Specification 4928.[5]

4.2 METALLURGICAL EXAMINATION

The accident hub fractured in two places on the rim circumference as well as longitudinally in the cone area (Photo **4).** The forward end also fractured 360 degrees where it engages the No. 1 bearing inner race. According to the Metallurgist's Factual Report (Attachment 1), one of the radial fractures contained fatigue striations that originated at two points on **a** tie bolt hole interior surface. The origins were located at distances of 0.307 and **0.553** inches from the aft edge ofthe hole and were on the inboard side of the hole with reference to the hub centerline. Enlarged photographs of the fracture face on the largest rim segment showed fatigue striations and the interior surface of the bolt hole. (See Figure 2, Attachment 1) *The* striations propagated radially outward from

[5] **Aerospace Material Specification published by the Society of Automotive Engineers (SAE)**

the origins for a distance of approximately 1.5 inches. Outside of this region, the fracture surface showed features that are typical of an overstress separation.

Closer views of the hole inner surface in the vicinity of the crack origins showed two areas that were described as scuff marks. These scuff marks are visible in Figure 3 of Attachment 1. A closer look at the larger mark in Figure 11 of the same report showed numerous secondary ladder cracks running parallel to the hole center line. Microhardness measurements at the surface of the hole in the scuffed area were found to exceed the maximum specification hardness of 39 HRC. The maximum actual hardness measured was 52 HRC measured at a distance of .001 inch from the fracture plane. A transverse section was cut through the middle of one of the scuff marks so that the microstructure could be viewed. The microstructure extending from the hole wall to a depth of approximately .002 inch appeared unclear and heavily layered. Below this was a layer (zone) approximately .0035 inch that consisted of heavily deformed alpha and beta grains.

5.0 FAN HUB MANUFACTURING

5.1 OVERVIEW

The Powerplants Group traveled to Volvo Aero Corporation, Trollhattan, Sweden and spent two days, August 28 and 29, 1996, reviewing the processes and procedures used in creating the tiebolt holes in the fan hub Volvo Aero provided the Powerplants Group with a copy of the drilling, boring, and honing processes with an addendum that reflects changes from 1984 to the present The group also interviewed the manager of hub quality, Mr Bertil Andersson on items that were not addressed in the process documents The Group members observed each step of the current process and asked questions of the operators and inspectors

The manufacturing records indicated that a coolant channel drill in a Burkhardt Weber computer controlled machining center was used to drill both the tie bolt and stress redistribution holes in the accident hub rim The Group inspected the drill and determined that it is a conventional pattern twist drill with carbide cutting edge inserts It also has an internal drilling or passage for coolant to flow down the core of the drill and enter the hole just behind the two carbide cutting edges The Group noted that the machine also has multiple nozzles that direct coolant streams to the surface of the hole and against the drill flutes

Following the drilling, two steps of boring are executed using a single point tool mounted in the same type machine The holes are finished on a different machine that uses a boron nitride hone with Castrol 971 lubricant or honing oil

The inspection process according to the Volvo shop process sheet includes dimensional, visual, fluorescent penetrant (FPI), and blue etch anodize (BEA) procedures The dimensional inspection checks the location, concentricity, diameter and, perpendicularity of the hole (Fig **3).** The visual inspection checks surface finish and absence of residual machine marks. The FPI detects physical defects such as cracks, voids, and metal porosity.

The **BEA** inspection process is unique to titanium. It consists of a visual inspection of an applied anodized surface for anomalies that are identified with microstructure changes in the parent metal. The inspector is provided color pictures of defects to use as the inspection standards. These anomalies are: alpha and beta phase segregation, excessive grain **growth,** and forging laps. The BEA procedure in effect at the time the accident hub was manufactured does not have any failure criteria that would have identified the microstructural changes present in the tie rod hole of the accident hub.

5.2 DRILLING PROCESS

The process in place at the time the accident hub was produced is described per the Volvo Machining Drawing **0-169282,** sheet 4 (Figure 4) and addendum 1, Drill History (Figure *5).* **A 12.2** mm drill bit turning at 700 revolutions per minute and advancing in the material at a rate of .1 mm per revolution produces the rough tie bolt hole. According to Mr. Bertil Andersson there was no interruption or cycling of the drill out of the hole during this operation. Again according to **Mr.** Andersson the coolant used was CIMCOOL MB602 distributed by Cincinnati Milacron. Coolant fluid was delivered both through a drilling in the drill shank to the cutting face and also through multiple nozzles that were directed toward the drill and the hole entrance. The coolant served also as a lubricant and flushing agent to remove the drill chips from the hole. According to Mr. Andersson this was significant as titanium drill chips tend to be short and are easily compacted in areas of hole-drill interface.

The Powerplants Group observed that the machine operator managed the drill from a control position about **six** feet away from the drill chuck. There was no control of drill torque or automatic shutdown if the coolant was interrupted. **Mr.** Andersson stated that at the time the accident disc was drilled the operator was responsible for identifying when a drill became dull. The current procedure is to change the drill after **24** holes are produced. The Group observed that the hub was mounted on a machining table and remained indexed to this table throughout the drilling and boring steps. The machine, a Burkhardt Weber machining center, used a computer controlled program to position the table for each operation. The following table summarizes and compares the drilling variables between the process used on the accident hub and the current one. [6]

[6] Source: **Volvo** Critical **Drawing** No. O-169282, current **date September** 1, **1993** ***with addendums*** **dating back to** 1984.

Coolant Channel (Accident)	700	.1 Hole drilled in one pass	Yes	Yes
High Speed Steel (Present)	300	.1 Drill is withdrawn every **5mm** to clear chips	Yes	No

5.3 BORINGPROCESS

Volvo controlled the boring process using Volvo Drawing O-169282. The boring process proceeded in two steps. The first step opened the hole to 12.9mm (.508 in) using the same type of spindle that held the drill. **A** single point, one piece boring tool was used. The holes were presented to the tool by indexing the table which had maintained the same setup since the drilling operation. The second step opened the hole to 13.095mm (.516 in). Boring speed and feed for both steps were: 800 RPM and .05 mm/rev, respectively. Mr. Andersson explained that the same boring tool was used in both steps but that the offset in the tool holder was changed. The offset adjustment was performed by the operator using hand tools.

5.4 HONINGPROCESS

Honing is the process of abrasively removing material from a cylindrically shaped surface such as the interior of a hole. The tool is a rotating abrasive medium that maintains a close dimensional tolerance of the hole with respect to roundness and straightness.' It also generates surface finishes that range in the 1 to ***63*** micro-inches range.[8] At Volvo the Powerplants Group noted that honing was done in a machine that rotates the tool around the hole centerline while moving up and down in a reciprocating motion, The tool had three spring loaded surfaces that contact the hole wall. They are coated with boron nitride abrasive grain which performs the material removal. The machine rotates at 230 RPM and removes a final .050mm (.002in) of material. According to the Volvo machine operators the honing oil which flushes the hole during operation serves primarily to carry away waste and prevent clogging of the abrasive grains. According to the Volvo Drawing the oil used is CASTROL 971. The Volvo shop process records showed that after honing the holes were visually inspected for surface finish and other features according to the standards of P&W VIS Standard 454.

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[7] Machinery's Handbook, 22nd Edition, Oberg, Jones, and Horton, Industrial Press, Inc., New York, **NY.1984.** Page **2047**

[8] Pratt & Whitney Standard Practices Manual, (ATA) chapter **70-31** page **64,** Table 6, October 1, 1987

5.5 VISUAL INSPECTION OF HOLES

P&W VIS Standard 454 is discussed in the Maintenance Group Chairman's Factual Report. A remark not classified in VIS Standard 454 as an inspection discrepancy was recorded in the accident hub manufacturing record (also called a shop traveler). It was made by the BEA inspector in the visual inspection line of the form. Translated from the Swedish language it reads: "R32971 has manufacturing marks in hole 13.145 mm, 180 degrees relative to the S/N Marking." This remark refers to the same hole described in the Safety Board's Materials Laboratory report. There is no further information in the manufacturing records to describe the type of manufacturing marks and specifically where in the hole they were found.

5.6 BLUE ETCH ANODIZE INSPECTION

The BEA process is performed after all machine work is completed on the hub. The process was observed by members of the Powerplants Group at both the Volvo and Pratt & Whitney facilities. The inventor of the process, Mr. Donald J. Baron, P&W, explained the major features of the process. According to Mr. Baron the intent of BEA is to detect specific microstructural anomalies in the titanium alloy surfaces that may be associated with: alloy segregation[9], excessive grain growth[10], or forging laps[11]. These conditions have been shown to develop unique patterns or visual signatures. There is no detailed description of a BEA indication in the Volvo manufacturing records of the accident hub. The BEA inspector wrote that the hole, which became the subject of the investigation, had manufacturing marks present inside. After the accident, Volvo and P&W identified 8 fan hubs that had similar remarks on the shop traveler during manufacture. The remarks noted unusual conditions that were brought to the attention of the visual inspector who made the final disposition. The seven hubs that entered service were properly certified as meeting the BEA and visual inspection criteria. The anomalies noted in these hubs were:

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[9] Alloy segregation as used here refers to the separation of alpha and beta crystals into separate groups instead of being mixed homogeneously throughout the alloy.

[10] Grain size is a metallurgical variable that affects material properties and is controlled during manufacture.

[11] Forging laps are defects that form whenever metal folds over itself during die forging.

S/N	Discreuancv	Insoection Tvoe
P66756	Machining damage in hole (by balance mark)	BEA
T50827	Inspection of surface texture requirements in six holes (minor alpha case)	BEA
R32926	Poor surface in one hole 12.117 mm	BEA
R32960	"hole" in radii on 2 holes	FPI
T50823	Burrs in one ofthe holes 12.167 nun	BEA
T50693	1 hole 12,85 mm damaged during machining	BEA
S25443	Boremark in 1 hole. Dia: 12.167-12.217mm is .18 mm above maximum only locally by the mark SCRAPPED	BEA
T50574	Hole diameter 12.167 - 12.217is .02 mm above maximum on 1 hole. - SCRAPPED	BEA
R32971	Has manufacturing marks in hole 13.145 180 degrees relative to S/N marking. - ACCIDENT HUB	BEA

The FAA acting on the above information issued Airworthiness Directive (AD) 96-15-06, dated July 16, 1996. This AD required the immediate removal from service and return to P&W of the first six hubs listed above. A complete reinspection and metallurgical analysis of these six hubs was conducted by P&W. There were no metallurgical anomalies found in any of the hubs.

[redacted]

George W. Anderson
Powerplants Group Chairman

3/7/97