PRATT & WHITNEY

SUBMISSION

AIRCRAFT ACCIDENT

DELTA AIR LINES, INC. FLIGHT 1288

MD-88, N927DA

PENSACOLA REGIONAL AIRPORT
PENSACOLA, FLORIDA

JULY 6, 1996

Pratt & Whitney (P&W) is a designated party to the National Transportation Safety Board (NTSB) investigation of the aircraft accident involving Delta Airlines Flight 1288 at Pensacola Regional Airport, Pensacola, Florida. Pursuant to 49 C.F.R. 831.14, P&W provides its submission to the NTSB.

1. Factual Information

1.1 History of Flight

On July 6, 1996, at 1424 central standard time, a McDonnell Douglas MD-88, operating as Delta Flight 1288, experienced a number one engine position uncontained failure. The aircraft was in the beginning of its takeoff roll on runway 17 at Pensacola Regional Airport in Pensacola, Florida when the event occurred. Two passengers were fatally injured. One passenger sustained serious injuries and two passengers received minor injuries.

1.2 Damage to Aircraft

The aircraft, Reg. N927DA, received substantial damage as the result of the number 1 position engine uncontainment. Numerous entry and exit punctures / holes were found at the fuselage upper hemisphere in the area of seat row 37.

1.3 Damage to Powerplants

P&W JT8D-219 engine, S/N 726984, was installed at the number 1 position. The engine experienced a Front Compressor Front Fan Hub (Fan Hub) rupture and uncontainment. The number 2 engine did not experience any abnormality and was not investigated.

The Fan Hub, part number 5000501-01 and serial number R32971, ruptured into two segments; one approximately 1/3 and the other 2/3 of the hub circumference. In addition to the liberated hub segments, portions of the fan containment case were also liberated and impacted the aircraft fuselage. The larger rotor disk segment exited the engine at the approximately 12 o'clock position (viewed from rear) and was found about 2400 feet to the right side of the aircraft. The smaller segment exited at approximately 7 o'clock position and was found about 900 feet to the left side of the aircraft. The liberated hub segments did not impact the fuselage. The fuselage was penetrated by fan blade debris.

The primary area of damage to the left fuselage skin consisted of several large holes/tears between fuselage stations (FS) 1250 to FS 1282 and from the top window belt to longeron (L) -2. The upper section of the window belt was severed between FS 1250 and 1271. The fuselage frame at FS 1250 was buckled at L-7 and between L-8 and L-9 and was cracked at L-11. The frame at FS 1271 was severed from the top of the window belt to L-4. Damage to the right fuselage skin consisted of seven exit holes/punctures/tears between FS1228 to 1271, longeron to longeron 11. See Attachment 1.

1.4 Manufacturing History of the Front Compressor Front Hub.

The fan hub, part number 5000501-01 and serial number R32971, was manufactured in June of 1989 by Volvo Flygmotor in Trollhattan, Sweden under a partnership agreement with P&W. The hub had accumulated 16, 542 hours and 13,835 cycles in service.

1.5 Post Manufacturing History of the Front Compressor Front Hub

The hub was installed new in engine S/N 725528 at P&W in November 1989 . The engine was installed at the number two position on MD-88 Aircraft Registration N956DA and was delivered to Delta in April 1990. The engine continued into service until January 1992 at which time the engine (and hub) was removed for FOD after it had accumulated 4,456 cycles. The hub underwent a shop visit inspection at that time.

The hub was reinstalled in engine S/N 725627 in March 1992 . The engine continued in service until September 1995 when it was removed for turbine work. The hub had accumulated 12,693 cycles when it underwent another shop visit inspection.

The hub was reinstalled in engine S/N 726984 in December 1995 and the engine continued in service until the time of the event in July 1996.

2. Analysis

2.1 Manufacturing

The fractured fan hub underwent metallurgical examination at the NTSB materials laboratory. Low cycle fatigue had initiated in a tie-bolt hole and propagated radially inward towards the bore of the hub. The fatigue progressed until it reached critical crack length and then went into tensile shear overload. It is estimated that the fatigue had propagated for approximately 13,000 cycles and broke the surface of the rear face of the hub before reaching critical crack length. The estimated cycles of fatigue propagation is close to the total service cycles of the hub indicating the fatigue initiated during the first few cycles of engine operation.

The fatigue's initiation point was located approximately 1/2 inch inboard from the aft face of the tie-rod hole. The original machined surface at the origin had a layer of about 17 mils in depth that displayed altered microstructure or work hardened material. The hardness of the surface was above the blueprint requirements.

Review of the manufacturing process at Volvo found that the tie-rod holes and counterweight holes for this P/N had been fabricated using coolant channel drills as well as conventional drills.

The coolant channel drill is designed with two holes, or channels, drilled through the shank. Cooling liquid is flowed through these channels to the cutting surface during the drilling process. The coolant and drilling chips are intended to continuously flow up through the drill flutes and exit at the top of the part. This continuous flow of coolant and chips allows the hole to be drilled with one continuous procedure. By comparison, when drilling with a conventional drill, 1/4 inch of material in depth is drilled, then the drill is removed, and the hole is flushed of drilling chips. The conventional drill is re-inserted and another 1/4 inch of material is drilled and the drill is again removed for flushing of the hole. The process continues until the hole is drilled completely through the part.

The use of the coolant channel drill was discontinued because of a high incidence of drill burning, drill breakage or dimensional deviations.

It was concluded, after reviewing the process and finding evidence of titanium transfer on the shanks of several coolant channel drills, that the continuous flow of coolant fluid and drilled chips was periodically interrupted, possibly due to congestion of material in the drill flutes. This jammed material could cause local overheating which could lead to a work hardened material on the surface of the drilled hole.

The manufacturing process for this P/N also includes a subsequent boring process to the tie-rod and counterweight holes. This boring process is designed to remove greater than 10 mils in additional material, to ensure that the hole surface is free from any damage or unevenness produced by the drilling process.

A review of the manufacturing quality inspection records of the fractured hub did not reveal any discrepancies that would cause rejection of the hub. During the etch inspection process by Blue Etch Anodize (BEA), a visual observation was noted by the inspector and documented at the particular hole that had the fracture origin. The visual response was not rejectable to the existing etch standards that were in place for BEA process inspections. The visual observation was reviewed by Volvo at the time of manufacture under requirements of the P&W quality procedures and was considered acceptable.

2.2 Post Manufacturing

The P&W JT8D engine manual calls for the inspector to pay particular attention to all holes during Fluorescent Penetrant Inspection (FPI) of the fan hub. During testimony in the NTSB public hearing, it was learned that most inspectors had never seen a crack in a disk or hub, although they had seen cracks in other engine parts such as stators or aluminum parts. There was also testimony that crack detection could be hampered by water or other contamination remaining on the part after cleaning.

Based on the technical reviews conducted by the FAA special team to review non-destructive inspection methods for critical engines parts, there was no data of findings of cracks in disks or hubs by airline inspectors. It could not be determined what probability of detection (POD) could be expected for the fluorescent penetrant process (FPI) employed by the airlines.

2.3 Damage to Aircraft

The fuselage uncontained debris penetration pattern showed numerous holes and tears forward of the plane of rotation of the fan. These holes were caused by both the broken fan blade fragments as well as the engine casing material surrounding the fan rotor. Evidently, the bursting fan rotor had initially contacted the engine casing in a tangential manner as the individually released segments continued to rotate about their mass center. This action resulted in the breakup in the fan blades around circumference of the rotor and when the engine casing subsequently burst in an uncontainment, these blade and case fragments were expelled outwards as multiple fragment uncontained debris.

Since the initial bursting action of the rotor disk fragments still contained significant energy in rotation, the initially crushed and broken fan blade tip fragments were mostly deflected from the engine blade containment casing, and began to travel forward of their initial plane of rotation while the still fractured rotor disk was continuing to rotate. When the rotor disk pieces shortly thereafter breached the engine casings, these forward traveling blade particles were then free to reach the nearby fuselage while retaining considerable energy.

The FAA provided guidance [AC20-128 to FAR 25.903(d)(1)] for "design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure.." issued 3/9/88, specifically mentions the potential ejection of high energy fan blade debris at angles forward of the plane of rotation by as much as 15 degrees. However, this advisory material notes that this experience is confined primarily to high bypass ratio engines without inlet guide vanes.

3.0 Corrective Actions

3.1 Post Manufacturing

Initial review of manufacturing records found that 9 (including the fractured hub) hubs had similar comments documented during BEA or FPI inspection. Two of those hubs had been scrapped at Volvo and six were in service. P&W notified the operators of those six hubs and all were removed from service by July 11. Subsequent nondestructive and destructive inspection of the hubs by P&W found no rejectable anomalies.

P&W issued Alert Service Bulletin A6272, "Eddy Current Inspection For Cracks - Hub, Front Compressor (LPC) (Fan Hub)" in September 1996. The bulletin requires the eddy current and florescent penetrant inspections of tie-rod and counterweight holes. This initial bulletin identified a suspect population of 719 hubs by part serial numbers that had been manufactured by coolant channel drills. At the time of this submission, approximately 45% of the 719 hubs have been inspected with no reported cracks.

Further analysis by P&W and Volvo determined that the suspect population should include any disk (fabricated by a conventional or coolant channel drill) that had a manufacturing quality review notification in its records to any tie-rod bolt or counterweight hole. A population of 253 hubs were identified by part serial number (113 of these hubs were fabricated by coolant channel drills and already addressed by initial bulletin). A revision is planned to the initial bulletin in June 1997.

3.2 Manufacturing Process

The use of coolant channeled drills to fabricate tie-rod or counterweight holes in 8D-200 fan hubs has been suspended.

The BEA inspections standards have been expanded to include detection and rejection of work hardened material.

3.3 Lessons Learned

The investigation of the manufacturing process revealed two significant lessons learned:

a) Volvo has done extensive testing to re-create work hardened material. It was found that that it is extremely difficult to produce this abnormality. Volvo has drilled over 300 test pieces and has only been able to re-create 5 samples of work harden material. The samples could only be duplicated when the parameters used in the drilling process (such as speed, feed, coolant flow, drill dimensions) were altered outside of standard practice.

b) Blue etch anodize (BEA) inspection was developed by P&W to detect specific microstructure abnormalities in titanium surface that may be associated with alloy segregation, excessive grain growth or forging laps. This investigation has revealed that work hardened material will also produce a visual response during BEA inspection. A BEA visual standard to identify and reject work hardened material has been added to the appropriate P&W quality manuals.

4.0 Conclusions and Recommendations

4.1 Conclusions

Since the investigation is typically considered on-going and active in the period following the public hearing and prior to the release of the draft final report, we would like to take this opportunity to set forth a list of potential causal factors in this accident. It is recognized that the NTSB typically issues "probable cause" following an accident, however, in the interest of a full consideration of causes, lessons learned and the attendant possibility of the board issuing future safety recommendations, the following listing is proposed for the Safety Board's consideration:

a) The manufacturing process control at the time of manufacture permitted an abusively machined layer of work hardened material to exist after the final hole boring operation (over 17 mils deep).

b) The post machining inspection, which included BEA at the time of manufacture, did not have a criteria for detecting and rejecting abusively machined holes.

c) The engine manufacturer recommendations in its engine manuals did not have a focused in-service inspection to detect crack initiation within high length versus diameter rotor holes.

d) There is no standard administered by the FAA for POD (probability-of-detection) for cracks in rotor disks.

e) The release of multiple high-energy fragments from the uncontained fan blade debris appeared to be beyond that specified in guidance material for FAR 25.903(d)(1).

4.2 Recommendations:

a) There is a need to recognize the factors which can contribute to abusive machining of rotor disks and to apply process controls that minimize the extent (depth) to which this damage may occur.

b) There is a need to develop and implement inspection criteria to detect abusive machining prior to release of the manufactured article to service.

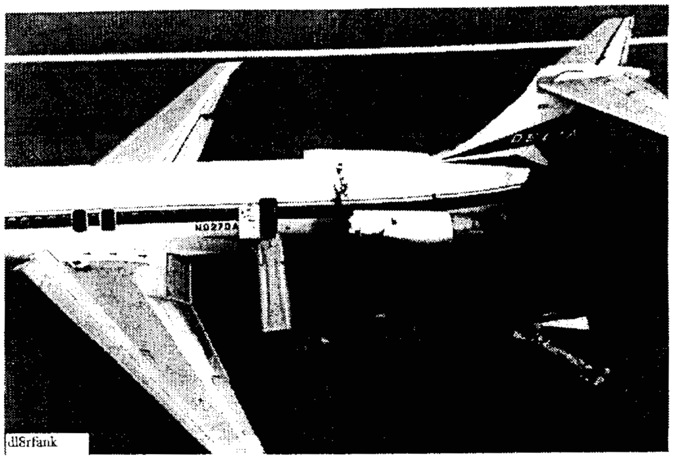
c) The FAA should emphasize the manufacturer to define in his continued airworthiness instructions concerning critical features of his life limited parts, which must be thoroughly inspected (focused vs global) during in-service inspections.

d) The FAA should require a calibration of critical in-service inspections against POD rather then just relying on process.

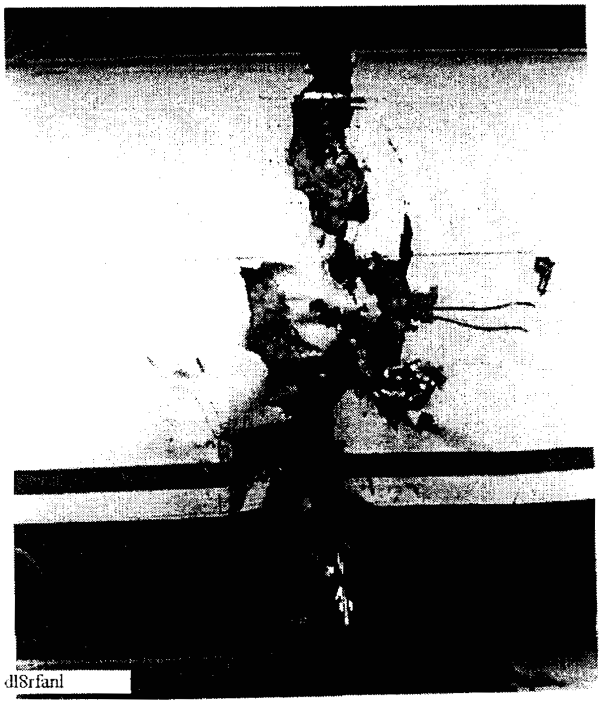
e) The FAA should update the advisory material to FAR 25.903(d)(1) to better reflect the quantities, sizes, energies and trajectories of all particles that may be released in an uncontained rotor burst.

Attachment 1

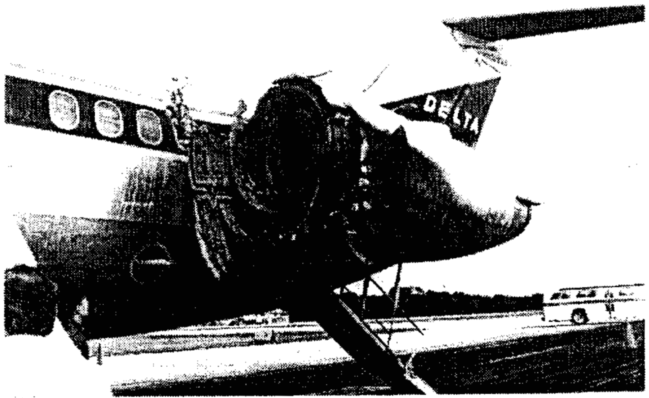
Photos of Aircraft Damage



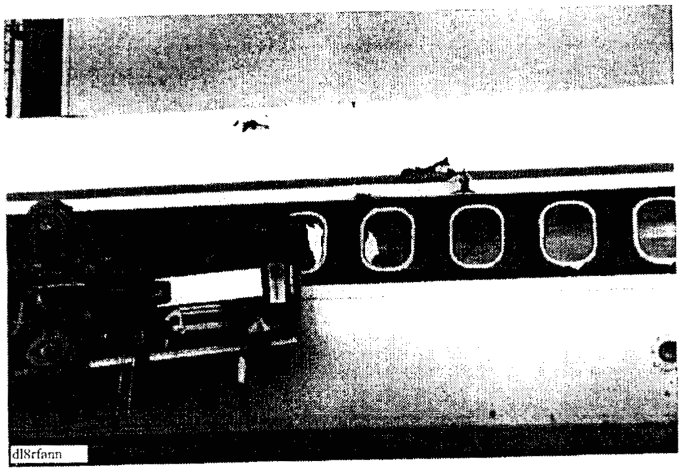
Aerial view showing damage to left fuselage and left engine.



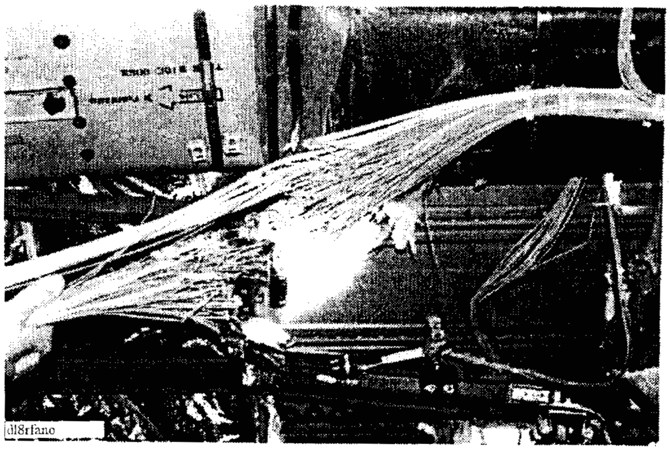
Left fuselage penetration damage.



Left fuselage and engine damage, including fire damage to nacelle.



Right fuselage exit damage.



Wire bundle located along right longeron 4; 146 of I the 154 wires in the wire bundle had been severed.

Interior view of left fuselage penetration damage adjacent to row 37