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METALLURGIST'S FACTUAL REPORTS
9 PAGES

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NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

August 6, 1996

METALLURGIST'S FACTUAL REPORT Report No. 96-131

A. ACCIDENT

Place	: Pensacola, Florida
Date	: July 6, 1996
Vehicle	: MD-88, N927DA
NTSB No.	: DCA96-M-A068
Investigator	: Thomas Conroy, AS-IO

B. COMPONENTS EXAMINED

Separated front hub-front compressor PIN 5000501-01, SIN R32971 and associated components from a Pratt and Whitney JT8D-219 engine.

C. DETAILS OF THE EXAMINATION

Initial examination of the components was performed in the field by Michael L. Marx, Chief, Materials Laboratory Division on July 8th and 9th, 1996. The recovered pieces of the front hub-front compressor (fan hub) were then submitted to the NTSB materials laboratory for detailed examination.

An overall view of the fan hub is shown in figure 1, as received in the laboratory. The fan hub separated into three major pieces. The largest piece, labeled "1" in this figure, comprised approximately 2/3 of the bore and conical section and contained 20 complete blade slots. The second piece, labeled "2 , was comprised of approximately 1/3 of the bore and contained 12 complete blade slots. The third piece, labeled "3", consisted of 1/3 of the conical section.

Examination of the separated fan hub pieces was performed at the NTSB materials laboratory between July 10 and 15. The following party representatives participated at various stages of the examination:

1. Stephen E. Pearlman, Materials and Mechanical Engineering, PWA;
2. Louis E. Hess, Manager, Materials Engineering, PWA;
3. Aubrey E. Carter, Supervisor, Aircraft Structural Technology, Delta Airlines;
4. Robert E. Guyotte, Manager, Engine Certification Branch, FAA;
5. R.J. Zelezniocar, Principal Engineer, Metallurgy, Douglas Aircraft Company

1. GENERAL INFORMATION

Information provided by PWA indicated that the fan hub was manufactured in 1989 by Volvo Flygmotor in Trolhatten, Sweden. The total time on the fan hub at the time of the accident was 13,835 flight cycles of which 1,142 cycles had been accumulated since the last fluorescent penetrant inspection (FPI).

PWA further reported that a blue etch anodize (BEA) inspection performed by Volvo on the as-manufactured part revealed an indication in a tierod hole located 180° from an in-process identification mark on the hub. The hub at manufacturing was subsequently visually examined for surface condition. Reportedly the area with the BEA indication passed the surface inspection requirements, and the hub was determined to be acceptable by the inspection standards in place at that time.

2. VISUAL EXAMINATION OF FAN HUB PIECES

The fan hub on the JT8D-200 series engines is attached to the air seal on the forward side and to the 1.5 stage disk on the aft side with 24 tierods. The holes for tierods are located around the circumference of the hub bore and alternate with 24 smaller diameter stress redistribution holes that are also used for weight balancing. The blade slots on the fan hub were arbitrary numbered "1", "2, "3" ... , clockwise on the forward face during the on-site examination. Upon receiving the hub pieces in the material laboratory, the tierod holes were marked "IT, "2T", "3T"..., so that the tierod position "IT" was adjacent to the blade slot position No. 1. Examination revealed that the conical hub surface contained an electroetched marking "R3297_" (the last digit was not legible). This marking was approximately aligned with tierod holes "18T" and "19T" and was about 180 degrees away from the tierod hole "6T". No other markings were found on the surface of the hub.

Four of the blade attachment tangs on hub piece 2 had separated typical of overstress at the locations denoted by arrows "a" in figure 1. Two of separated tangs were recovered and submitted with the parts (shown just below hub sections in figure 1). As received, 10 blade root attachments and airfoil stubs were still present in the hub rim slots numbered 20, 22, 23, 24, 25, 26, 27, 28, 31, and 32. However, many of the blades were reportedly removed in the field to facilitate shipment of the parts. Those separated blade sections and pieces of fan blades recovered in the field were examined by Michael L. Marx and were found to be typical of overstress separations. There were also seven separated tierod pieces still in the hub tierod holes at positions 2T, 4T, 9T, 12T, 16T, 18T, and 19T. Twelve approximately $8^1/_2$-inch-long portions of tierods containing nuts at the threaded ends and ten approximately 1 inch long head portions were received at the NTSB Materials Laboratory at different times later into the examination. The fracture faces on all tierod sections were typical *of* overstress separations resulted from bending and/or direct shear forces.

The No. 1 bearing journal on the fan hub was fractured off and not submitted. The front air seal was partially missing and was separated just forward of the balance weight flange. All fractures in these areas were typical of overstress separations.

One of the radial separations of the hub was through tierod hole 6T, at the position shown by arrows "f" in figure 1. Visual examination revealed that a portion of this fracture on the inboard side of the tierod hole contained features indicative of preexisting cracking. The fracture surface of the smaller piece (piece 2) contained considerable post fracture damage and most of the fine fracture features were obscured by this damage. The larger piece (piece "1") in the most part was relatively undamaged and displayed clear evidence of fatigue cracking. However, the fatigue area at the aft inboard corner of the tierod hole in this piece contained post-fracture damage which distorted this portion of the fracture.

Another bore to rim radial separation occurred through tierod hole 21T. This fracture contained features typical of an overstress separation with no evidence of fatigue cracking. Overstress progression was both radially inboard and outboard from the tierod hole. All other breaks in the hub and associated components were typical of overstress separations indicating the primary break in the fan hub was at the 6T tierod hole. Positioning of the hub fragments with the fractures at hole 21T placed relative to each other as if intact showed that the hub had deformed circumferentially producing a gap of approximately 6 inches at hole 6T, the primary fracture location.

3. EXAMINATION OF THE FRACTURE THROUGH TIEROD HOLE 6T.

The mating fracture faces through tierod hole 6T were cut from the bulk of the fan hub for ease of manipulation during the examination. Figure 2 shows a view of the lesser damaged fracture face removed from the segment of the hub labeled "1" in figure 1. Fatigue fracture features emanated from two major origin areas located on the tierod hole wall surface in the positions denoted by arrows "o1" and "o2" in figure 2. Origins "o1" and "o2" were at distances of 0.307 inch and 0.553 inch, respectively, from the aft edge of the tierod hole[1]. From origins "o1" and "o2", the fatigue cracking propagated approximately 1.5 inches radially inboard in the directions shown by the unlabeled arrows up to the approximate position denoted by the dashed line in figure 2. Beyond the dashed line position the fracture features were typical of an overstress separation. A portion of the fatigue fracture between the origin areas and the dotted line in figure 2 appeared somewhat discolored (darker) then the remainder of the fatigue region. This discolored region extended from the aft inboard corner of the tierod hole inboard along the aft face about 0.46 inch as well as forward along the hole wall about 0.9 inch.

Two photographs in figure 3 depict close up angled views of the aft portion of the primary fracture in segments "1" and "2". The two major fatigue origins on the mating fracture faces are denoted by brackets "o1" and "02" in this figure. Examination with the aid of a binocular microscope revealed two circumferential "scuff marks" on the hole surface of piece "1" associated with the two fatigue origin locations, see arrows "s1" and "s2" in the bottom photograph. The hole surface adjacent to the fracture surface on segment 2 was damaged by scoring. However, a faint scuff mark associated with origin "o2" was also observed in this

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[1] Due to extensive damage to the portion of the hub adjacent to the aft face of the hole on piece "1", the locations of origins were measured on piece "2".

piece, see arrow "s2" in the top photograph of figure 3. Small, shallow surface "chips" were noted in the scuffed areas. Examination of the hole surface also revealed three gouge marks extending through both pieces (see arrows "g" in both photographs of figure 3) and an isolated gouge mark on piece 2 (see arrow "ig" in the top photograph).

During manufacturing of the fan hub, the tierod holes are reportedly drilled, then bored and honed. The surface of the "scuff marks" exhibited evidence of circumferential machining marks, probably from the boring operation. The remainder of the hole surface away from the scuff marks exhibited a cross hatched pattern, typical of a honing operation. With the exception of the gauge marks, the hole surface finish appeared to conform to the drawing specification requirement of 20 AA.

4. SCANNING ELECTRON MICROSCOPE EXAMINATION, ENERGY DISPERSIVE X-RAY ANALYSIS

To facilitate scanning electron microscope (SEM) examination, the inboard portions of the fractures on pieces "1" and "2' containing the mating fatigue origin areas were cut off from the outboard fracture portions along the length of the tierod hole. A section containing the fatigue origin areas on piece "1" was then ultrasonically cleaned in acetone to remove loose deposits and dirt. The mating fracture face on piece 2 was not cleaned and was preserved in its "as-received" condition. The appearance of the fracture surface in the sectioned off portion of piece 1 after the cleaning is shown in figure 4 with arrows "o1" and "o2" showing the fatigue origins and the dashed line outlining the fatigue fracture region.

Figure 5 is an SEM view of the fracture origin area denoted by arrow "o1" in figure **4.** The fatigue fracture features emanated from a 0.085 inch (2.15 mm) wide by 0.009 inch (0.222 mm) deep thumbnail mark, outlined by the dashed line in figure 5. Examination at higher magnifications disclosed that the shallow thumbnail area consisted of two zones, indicated by arrows "zl" and "z2" in this figure. Figure 6 shows a higher magnification view of the interface between the two zones. Zone *1,* measuring 0.059 inch (1.50 mm) wide by 0.004 inch (0.096 mm) deep, was immediately adjacent to the hole wall surface and had fracture features indicative of an overstress separation. Zone 2 was immediately adjacent to Zone 1 and contained evidence of fatigue progression in the form of microfissures, as displayed in figure 7.

Clear evidence of classical fatigue striations was observed at a distance of about 0.01 inch (0.3 mm) from the hole surface. From this point and up to an approximate distance of 0.70 inch (17.9 mm), the fatigue striations were typical of low cycle fatigue, as shown in figure 8. Between the distances of 0.70 inch (17.8 mm) and 1.4 inch (35.6 mm), fatigue striations were not easily discernable as shown in figure 9. Beyond the overall fatigue region at 1.4 inch, the fracture features were typical of an overstress separation.

Using the base of the origin "o1" thumbnail zone as a beginning reference point, average striation spacings were measured at various incremental points radially inboard in the fatigue region. The number of striations between each successive incremental point (n) was then calculated by dividing the distance between points by the average striation spacing found at the furthest incremental point. At each increment point the accumulated striations from the original reference point were also compiled (N). The results of these measurements and calculations are shown in Table 1.

Figure 10 is an SEM view of the fracture origin area "02". The SEM examination disclosed that this origin also consisted of two zones, an overstress zone adjacent to the surface of the hole (zone 1), followed by a zone containing fatigue propagation in the form of microfissuring (zone 2). The two zones are indicated by arrows "zl" and "z2" in figure 10 . The entire thumbnail area at origin "o2" measured 0.077 inch (1.95 mm) wide by 0.006 inch (0.144 mm) deep and is outlined by the dashed line in this figure. Zone **1** in origin "o2" measured 0.037 inch (0.936 mm) wide by 0.002 inch (0.063 mm) deep.

Figure 11 is a low magnification SEM photograph of scuff marks on the surface of the tierod hole at and near the origin area "02". The SEM examination revealed that the scuff mark at the origin contained numerous parallel cracks (ladder cracks) shown by arrowheads in this figure. These ladder cracks were parallel to the thumbnail area at the origin. Also noted were small shallow chip outs (see arrows "c", figure 11), which appeared to be associated with the ladder cracking.

X-ray energy dispersive analysis of the hub material, performed at the fracture surface, generated a spectrum typical for the specified PWA 1215 titanium alloy containing 6% aluminum and **4%** vanadium.

5. METALLOGRAPHIC EXAMINATION, MICROHARDNESS PROFILE TEST, EDDY CURRENT INSPECTION

A transverse section through the middle of the scuff mark at origin "02" (see sectional arrows "X-X in figure 11) was prepared for metallographic examination. The section was cut using an electrical discharge machine (EDM) to preserve the adjacent fatigue fracture origin area "o1". Figure 12 is a low magnification composite micrograph showing the microstructure at the surface of the hole adjacent to the fracture face. The microstructure along the hole wall adjacent to the fracture location was severely deformed and contained numerous secondary cracks (previously mentioned ladder cracks), most of which are shown by arrowheads in figure 12.

Three photographs in figure 13 are higher magnification micrographs at the locations denoted by brackets "a", "b", and "c" in figure 12. The metallographic examination disclosed that the layer of distorted microstructure adjacent to the fracture face consisted of two zones, indicated by brackets "zl" and "z2" in the upper left photograph of figure 13. The thicknesses of zones "z1" and "z2" were 0.002 inch (0.06 mm) and 0.0035 inch (0.09 mm), respectively, and were consistent with the thicknesses of zones "zl" and "z2" observed during the SEM examination of origin "o2".

The microstructure in zone "zl" appeared unclear and heavily layered. The microstructure in zone "z2" consisted from heavily deformed alpha and beta grains (alpha light etching and beta darker etching). The depth of the distorted microstructure diminished circumferentially away from the fracture plane to the approximate circumferential length of about 0.34 inch from the fracture surface. At the location denoted by bracket "b" in figure 12 (see upper right photograph in figure 13), no evidence of layered microstructure observed in zone 1 was found. At the location denoted by bracket "c" in figure 12 (see bottom photograph in figure 13), no evidence of deformed microstructural constituents observed in zone 2 was found. The microstructure of the base material consisted of equiaxed alpha grains in a transformed beta matrix, typical for a titanium base alloy processed below the beta transus temperature (required processing).

A knoop (HK) microhardness traverse perpendicular to the hole wall and near the fracture plane was performed on section **X-X.** The results, shown in table 2, indicate that the hardness values ranged between 52 HRC (581 HK) at a distance *of* 0.001 inch from the surface of the tierod hole and 41 HRC (416 HK) up to a distance of 0.014 inch. Hardness of the base material away from the hole surface measured between 34 HRC (347 HK) and 36 HRC (359 HK), conforming to the material specification requirement of 39 HRC, maximum.

The overstress fracture on the outboard side of the primary fracture at hole No. 6T had a rough irregular appearance. Examination of a radial metallographic section through this region revealed a uniform microstructure typical of a properly processed PWA 1215 titanium alloy. **No** microstructural anomalies were found. The microstructure at the surface of the tierod hole was undistorted as would be expected of a normally machined surface.

An attempt to perform an Eddy Current (EC) inspection of the tierod holes in the two separated pieces of the hub was made by a representative of Delta Airlines using a recently designed EC probe and a standard containing a 0.020 inch long by 0.015 inch deep EDM machined notch. The results of inspection were inconclusive due to distortion and damage to the holes.

[redacted]

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Office of Research and Engineering
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METALLURGIST'S FACTUAL REPORT — Report No. 97-25

A. ACCIDENT

Place : Pensacola, Florida
Date : July 6, 1996
Vehicle : MD-88, N927DA
NTSB NO. : DCA96-M-A066
Investigator : Thomas Conroy, AS-IO

B. COMPONENTS EXAMINED

Section of the front hub-front compressor PIN 5000501-01, SIN R32971.

C. DETAILS OF THE EXAMINATION

A section of the fracture face containing fracture origins was cut out from a piece of the hub labeled "2" in Materials Laboratory Metallurgist's Factual Report No. 96-131, dated August 6,1996. During metallurgical examination of the hub, piece 2 had not been cleaned in order to preserve the fracture face in its "as received" condition.

The excised section **of** the hub was taken to Evans East laboratory for testing of dye penetrant residue on the surface **of** the part. Delta Air Lines provided two reference samples of fluorescent penetrant inspection (FPI) fluids. One sample was of Delta Class **1** "high sensitivity" FPI fluid that was used during December, 1995 inspection of the hub. The second sample was Delta Class 2 "ultra high sensitivity" fluid that, reportedly, has been used by Delta exclusively since May 1996. The Class 2 dye penetrant has never been used to inspect the accident hub.

According to Delta Air Lines, Class **1** fluid contains the following components:

- Heavy aromatic solvent naphtha (petroleum),
- Solvent refined acid-treated heavy naphthenic DI,
- Dipropylene glycol dibenzoate,
- Octyl epoxy tallate,
- Epoxidized soybean oil,

and Class 2 fluid contains the following components:

- Heavy aromatic solvent naphtha (petroleum),
- Isodecyl diphenyl phosphate,

- Solvent refined acid-treated heavy naphthenic DI,
- Polysiloxane-copolymer,
- Fluorol Yellow 088.

The analyzed hub section is shown in figure 1 with arrows "o1" and "o2" denoting the fracture origin areas. Evans East performed a Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS) analysis at three general locations of the fracture surface --the fracture origin area "o1" (see arrows "a", "b", and "c" in figure 1), the far aft end of the fracture (see arrow "d") and the overstress separation zone (see arrow "e") Similar analysis was also performed on the submitted samples of the dye. The hub section was analyzed before the analysis of the control dyes, thus preventing any possibility of cross contamination. The results of the analyses are summarized in the Evans East report[1], which is presented in Appendix 1. No unique chemical identification related to the dye penetrant was found on the fracture surface of the hub.

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[1] Time -of Flight Secondary Ion Mass Spectrometry Analytical Report, David A Cole, October 10, 1996.

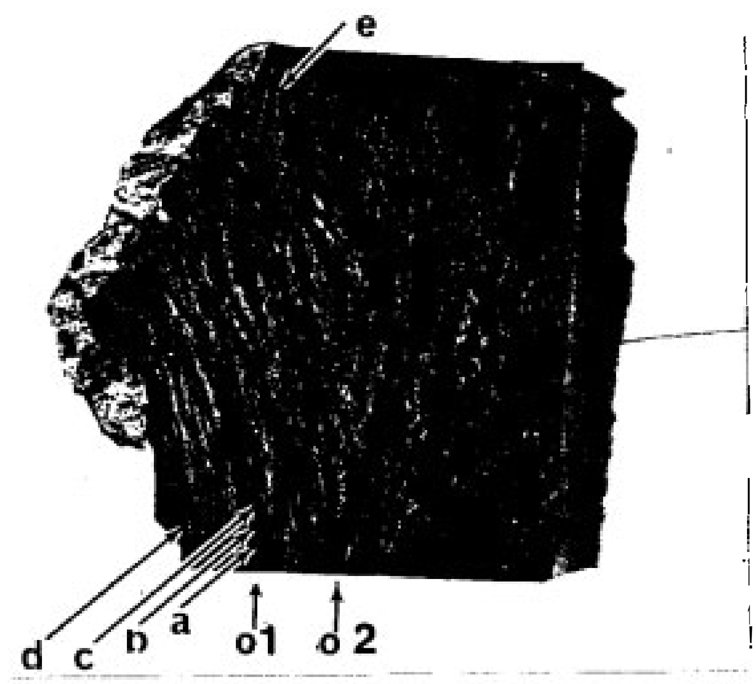

Figure 1. Section of the hub used for TOF-SIMS analysis. Arrows "a", "b", "c", "d", and "e" denote the locations of the acquired spectra. Magnification 1.7X.