NATIONAL TRANSPORTATION SAFETY BOARD

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

September 29, 1995

METALLURGIST'S FACTUAL REPORT Report No. 95-146

A. ACCIDENT

Place	: Carrollton, Georgia
Date	: August 21, 1995
Airplane	: Embraer EMB 120, N256AS
NTSB No.	: DCA 95-M-A054
Investigator	: Jerome Frechette, AS-40

B. COMPONENTS EXAMINED

Separated Hamilton Standard 14RF-9 aircraft propeller blade, P/N RFC11M1-6A, S/N 861398, from the No. 1 engine.

C. DETAILS OF THE EXAMINATION

1. GENERAL

The inboard piece of the blade was recovered from the accident scene shortly after the accident and was immediately transported to the Safety Board's Material Laboratory for examination. The outboard piece of the blade was recovered September 15, 1995, and was received in the laboratory on September 18. Information gathered from the outboard portion of the blade was added to the body of the report where needed for completeness.

The blade is a composite structure consisting of a solid forged aluminum alloy spar (made from 7075-T73 aluminum alloy per AMS 4141), and a glass fiber-filled epoxy airfoil (or shell). The shell is adhesively bonded to the face (flat) and camber sides of the spar, and the cavities at the leading and trailing edges of the blade are filled with foam. The spar has a conical hole (taper bore) that progresses from the spar's inboard end to blade station 21 inch.[1] The outboard end of the taper bore contains compacted lead wool for blade balance. When the separated blade was manufactured, a cork was inserted in the taper bore to retain the lead wool in the taper bore's outboard tip. Sealant was applied to the cork to keep moisture out.

Markings on the inboard piece of the blade shell included the following: "PS960A ASB66", "DWG. NO. RFC11M1-6", "MFG. NO. 861398". The presence of "PS960A" on the

[1] Blade stations are measured from a reference point 3.427 inches inboard of the blade pin platform on the inboard end of the blade.

shell indicates that a Hamilton Standard repair procedure (Propeller System 960A) was used to blend damage from the taper bore surface. The presence of "ASB66" indicates that the blade passed the ultrasonic inspection referenced in Alert Service Bulletin (ASB) 14F-9-61-A66. Stamped characters on the inboard end of the spar included the following: "792231-1 F" (part number of the spar), "S/N 0093" (spar serial number).

The airfoil surface was generally in very good condition. On the outboard piece of the blade, minor airfoil surface damage was noted in two locations: (1) The camber face contained a scuff mark progressing from the separation outboard to the trailing edge. (2) The trailing edge near the tip contained a small nick.

2. FRACTOGRAPHY AND TAPER BORE CONDITION

An overall view of the inboard piece of the blade is shown in figure 1. The blade spar was separated at blade station 16.6 (about 13.2 inches outboard of the blade pin platform). Figures 2 and 3 show overall views of the mating faces of the fracture surface on the spar. Minor damage was noted on the inboard face of the fracture while the outboard face was undamaged. Initial visual examination revealed that a portion of the spar fracture was on a flat transverse plane and contained crack arrest positions, typical of fatigue cracking. The crack arrest positions emanated from an origin area on the taper bore at the location indicated by arrow "O" in figures 2 and 3. A ratchet mark[2] (arrow "R" in figure 2) extended from the origin area about half of the way to the face side of the spar (side of the blade closer to the top of figures 2 and 3). On the inboard blade piece, the fracture surface on the top of the ratchet mark and adjacent to the taper bore surface on the counterclockwise[3] side of the ratchet mark contained smearing damage. These areas appear darker in figure 2. The remainder of the surface was generally free of significant damage.

From the origin area, the fatigue cracking propagated toward the face side of the blade and circumferentially around both sides of the taper bore. The unlabeled arrows on the fracture surface in figure 2 indicate fatigue crack propagation directions away from the origin area. Also, the dashed line position in this figure indicates the extent of the fatigue cracking, which progressed through about 75% of the spar cross section. The fracture surface in areas beyond the terminus of the fatigue region contained rougher features with a matte appearance, typical of an overstress region stemming from the fatigue crack.

The taper bore surface, including the area adjacent to the fatigue initiation area, contained a series of nearly circumferential sanding marks. The marks extended over about 180 degrees of the circumference of the taper bore and to a maximum distance of about 1.5 inches inboard of the fracture surface, as shown in figure 4. Outboard of the fracture, the sanding marks extended about 2 inches from the fracture surface. Remnants of flexible

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[2]A ratchet mark is a vertical step in the fracture plane and will usually be created between fatigue origin areas on slightly offset planes.

[3]For the purposes of this report, clockwise and counterclockwise directions are oriented as if the fracture is viewed looking inboard.

sealant (arrow "S" in figure 4) was found at a location about 1 inch inboard of the fatigue origin area. The taper bore surface also contained several dark-appearing streaks of deposited material. Later analysis indicated that these deposits were composed of lead.

Surface profilometer measurements, using a Mitutoyo Surftest Analyzer, were conducted on the taper bore sanding marks, yielding a value of Ra 180 microinches[4]. Service bulletin requirements specify that a reworked surface maintain a surface finish of RMS 63 microinches[5]. Visual comparison with reference surface finishes indicated that the sanding marks had a surface finish of approximately Ra 125 microinches. Surface profilometer measurements of the originally manufactured surface (away from the sanding marks) yielded a value of Ra 40 microinches, which meets the surface finish requirement of Ra 63 or better specified on the engineering drawing for the original manufacture of the taper bore surface.

Figure 5 shows an oblique view of the origin area on the inboard face of the fracture. Visible in this figure are taper bore lead deposits (arrows "L"), sanding marks, the ratchet mark (arrows "R") on the fracture, and fracture surface damage (arrows "D"). A fatigue origin area was noted on the clockwise side of the ratchet mark (toward the trailing edge of the blade), about 0.06 inch from the mark, at the position indicated by arrow "O1" in figure 4. Examinations of the outboard face of the fracture at high magnification (shown later in figure 14) revealed that an origin area was also located on the counterclockwise side of the ratchet mark (toward the leading edge), approximately at the position indicated by arrow "O2" in figure 5.

Figure 6 shows a higher magnification view of the inboard fracture surface in the vicinity of the origin area on the clockwise side of the ratchet mark (arrow "O1" in figure 5). The fatigue initiation appeared to be from a small area (as opposed to a specific point) adjacent to the taper bore surface, as indicated by arrow "O1" in figure 6. Arrowheads on the fracture surface in this figure indicate crack propagation directions away from this origin area. Figure 7 shows a detailed view of the taper bore surface adjacent to origin area "O1" on the inboard face of the fracture. A portion of the origin area followed a sanding mark. However, small pits were also noted within the origin area.

3. MEASUREMENT OF THE TAPER BORE

The diameter of the taper bore hole was measured in the chordwise (leading edge to trailing edge) direction, and found to be 1.019 inches. That size is consistent with the interpolated specification requirement of 1.019 - l.026 inches at the 16.6 inch station. Diameter measurements in the width direction (face side to camber side) could not be made because of deformation to the overstress portion of the fracture (opposite from the origin area). The minimum thickness of the spar between the taper bore hole and the spar's face side was

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[4]Surface finishes are measured in microinches. Larger numbers correspond to a rougher surface. "Ra" is the internationally accepted symbol for arithmetic average roughness.

[5]Roughness measurement instruments calibrated to the RMS (root mean square) scale read approximately 25 percent higher on a given surface than those instruments calibrated for Ra.

measured at 0.403 inches. A representative of Hamilton Standard indicated that the calculated design requirement for this dimension was 0.3623 inch to 0.4223 inch.

The outboard face of the fracture was removed from the remainder of the blade by means of a chordwise cut located less than 0.5 inch outboard of the fracture. The cut surface was then ground flat and lightly polished to give a uniform edge between the taper bore hole and the cut surface. A Smart Scope Video Measuring System was used to estimate the amount of material removed from the taper bore surface when the sanding marks were created. Portions of the taper bore surface that were within the fatigue area and were free of sanding marks were used to generate a reference circle representing a best-fit diameter. The center of the generated circle was defined as the zero point for radial measurements. Then, the distance from points within the area containing sanding marks to the reference circle was measured. These measurements indicate that a maximum of about 0.002 inch of material was removed from the taper bore surface during the sanding process.

4. INITIAL SEM EXAMINATION

The origin area on both the inboard and outboard faces of the fracture was examined with a scanning electron microscope (SEM) before the faces were cleaned in any manner. The fracture surface in the vicinity of the origin area on both faces of the fracture contained a layer of heavy oxide deposits that had a mud-cracked appearance. Figure 8 shows a backscatter electron image of the origin area on the inboard face (origin area indicated by bracket "O1" in figure 6). The extent of the layer of heavy oxide deposits on this face of the fracture is indicated by the dashed line position. These deposits extended to a maximum depth of 0.049 inch from the taper bore surface. Their maximum circumferential width was 0.130 inch, based on the examination of the undamaged outboard fracture face. In many areas, the oxide deposits had a mud-cracked appearance, as shown in figure 9. X-ray energy dispersive spectroscopy (EDS) of the deposits generated spectra with major peaks for aluminum and oxygen, a substantial peak for chlorine, and a minor peak for zinc[6]. Figure 10 shows the EDS spectrum generated from one area of oxide deposits.

5. FRACTURE CLEANING

Following the initial SEM examination, the inboard face of the fracture was cleaned by repeated plastic tape replication, by immersion in ultrasonically agitated acetone, and by scrubbing with a soft bristle brush while immersed in an Alconox (soap) solution. The fracture was then rinsed in water and acetone.

The cleaning process removed the lead deposits from the taper bore surface. Also, visual examination of the taper bore surface revealed the presence of isolated areas of corrosion pitting, including an area near the ratchet mark (at the location indicated by arrow "P" in figure 5).

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[6]Zinc is an alloying element in the 7075 aluminum alloy specified for the spar.

Visual reexamination of the fracture surface after cleaning revealed a distinct fatigue banding pattern in the portion of the fracture between the point at which the crack broke through to the face side of the spar and the overstress region. A maximum of 15 bands of striations were counted on each side of the taper bore hole.

6. ADDITIONAL SEM EXAMINATION

Figure 11 shows an overall SEM photograph of origin area "O1" after the cleaning process had removed a substantial portion of the corrosion deposits from the fracture surface. Examination of the fracture surface in the vicinity of the origin area revealed a line of corrosion pits located between arrows "C" in figure 11. The overall width of this corrosion pitted area was about 0.070 inch. In this figure, oxides remaining in the pits appear as brighter areas near the corner between the fracture and the taper bore surface.

The fatigue cracking emanating from origin area "O1" appeared to initiate from a portion of the corrosion pitted area (see bracket "O1" in figure 11). Figure 12 shows a higher magnification SEM view of this area. The maximum depth of the corrosion pitting below the taper bore surface was measured as slightly less than 0.006 inch at the location indicated by arrow "X" in figure 12. Smaller unlabeled arrows on the fracture surface in figures 11 and 12 indicate fatigue propagation directions away from the origin, based on fatigue striation patterns.

In the origin area bracketed "O1" in figure 11, the taper bore surface contained intermittent, thin areas adjacent to the bore that appeared to be corrosion-free. EDS of these thin areas showed only very small peaks for oxygen, confirming that these areas were essentially uncorroded. EDS of the areas within the corrosion pitting region (just below the corrosion free areas) generated substantial peaks for oxygen.

The taper bore surface contained an additional area of corrosion damage near the fatigue origin location. This corrosion area is denoted by arrow "P" in the lower right corner of the photograph in figure 11. One end of a streak of lead deposits partially obscured this area before the fracture was cleaned. Arrow "P" in figure 5 indicates the overall location of this corrosion pitting area.

Higher magnification examination of the fracture surface in the origin area revealed what appeared to be a corroded fatigue striation pattern still partially obscured by the mud-cracked oxide deposits, as shown in figure 13. The SEM examination of the inboard face of the fracture also confirmed that the fatigue features on the counterclockwise side of the ratchet mark were largely obliterated by smearing damage. For this reason, the outboard face of the fracture was examined in the area corresponding to the smeared zone on the inboard face. This examination revealed that the fatigue features on the other side of the ratchet mark initiated from the position corresponding to the location indicated by arrow "O2" in figures 5 and 6. A line of corrosion pitting similar to that found at the "O1" location was also found at origin "O2". The deepest penetration of the pitting at the "O2" location was approximately 0.003 inch. Origin area "O2" on the outboard face of the fracture surface is shown in figure 14. The white area adjacent to the taper bore surface (at the bottom of the photograph) is an oxide-filled corrosion pit. Fatigue crack propagation directions away from the pit are indicated by unlabeled arrows on the fracture surface.

7. METALLOGRAPHY

A section through the origin area was cut from the blade and prepared for a metallographic examination. The initial plane of the cut was approximately 0.020 inch on the clockwise side of the deepest point of corrosion penetration at origin "O1" (see larger arrow, figure 12). The section was mounted, then polished in steps to the position indicated by section lines "A-A" in figure 12. At each step of the polishing, uncorroded metal was noted at the taper bore surface, but areas of corrosion pitting were found below the surface. Figure 15 shows a portion of the section at the location indicated by the section lines in figure 12. At this location the fracture surface in the vicinity of the origin area contained three corrosion areas (indicated by the unlabeled arrows in figure 15), that were separated by what appeared to be metal largely unaffected by corrosion. The maximum extent of the corrosion pitting from the taper bore surface was 0.006 inch, corresponding to the maximum depth of the corrosion pitting found during the SEM examination (see arrow "X", figure 12).

Step-polishing the section a slightly greater amount showed the presence of an elongated corrosion pit on the taper bore surface, as well as additional pitting slightly below the surface. The elongated direction of these pits followed the forging flow lines in the spar. Etching of the section revealed a microstructure typical of the specified alloy and condition.

8. TENSILE STRENGTH, HARDNESS, CONDUCTIVITY, AND COMPOSITION

At the request of the Safety Board, two specimens from the spar material were provided to Hamilton Standard for machining specimens and tensile testing. Tensile testing of these specimens generated values of 74.4 ksi and 75.5 ksi for the ultimate tensile strength of the material. These values are above the specified minimum strength requirement for the spar material.

Hardness measurements on a piece cut from the spar near the plane of the fracture averaged 81.3 HRB. Conductivity measurement of the blade spar material indicated a conductivity of 38.9% IACS, which is in the acceptable range based on the measured tensile properties of the material.

X-ray energy dispersive spectroscopy of the spar material generated spectra consistent with the specified composition for 7075 aluminum alloy, with zinc, magnesium, and copper as alloying elements.

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