

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN24LA038

MATERIALS LABORATORY

Factual Report 24-063

September 12, 2024

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A. ACCIDENT INFORMATION

Location: Lowell, Indiana
Date: November 14, 2023
Vehicle: Bede Corp BD-4C, N931AS
Investigator: Laura Abraham, AS-CEN

B. COMPONENTS EXAMINED

AXSport Aviation AX3-70 propeller hub and fractured blades

C. EXAMINATION PARTICIPANTS

Specialist Michael Meadows
National Transportation Safety Board
Washington, District of Columbia

D. DETAILS OF THE EXAMINATION

On November 14, 2023, a Bede Corp BD-4 C, N931AS, was substantially damaged when it was involved in an accident near Lowell, Indiana. The pilot sustained minor injuries. The airplane was operated as a Title 14 Code of Federal Regulations Part 91 personal flight.

According to the preliminary report, the pilot reported that the engine began to run roughly and shake violently while enroute. He performed an off-airport landing and flipped over upon touchdown. After exiting the airplane, the pilot noticed that one of the propeller blades was missing.

The NTSB materials lab received portions of the propeller hub and two propeller blades which had been removed from the hub as shown in figures 1 and 2. A portion of the third blade root was fractured and was retained in the hub as shown in the right image of figure 1. The outboard portion of the blade was not recovered. The two recovered blades were measured to be consistent with a 70-inch diameter propeller. The following identification information was engraved on the forward face of the hub:

AXSPORT
S/N 0109

The AXSport Aviation propeller system, designed and manufactured out of Cape Town, South Africa, is advertised as an experimental three-blade electric constant speed/variable pitch propeller designed for non-type certified aircraft. The

blades are carbon fiber reinforced epoxy composite structures integrated with an aluminum alloy root section which are assembled into an aluminum alloy hub.¹

The pitch change motor had partially separated from the forward face of the hub and the pitch change hard stops were bent. The lower pitch change hard stop, as oriented in figure 1, was fractured through the reduced section in a manner consistent with overstress separation. A combination of on-scene photographs and identification markings on the pitch change block were used to establish the blade positions which will be referred to as 1, 2, and 3 throughout this report. No identification markings attributable to blade position were observed on the blade roots. Blade 2 was fractured through the metallic root section which was retained in the hub as indicated in the right image of figure 1.

Blade 1 appeared mostly intact, however Blade 3 exhibited partial chordwise cracks and spanwise separation as shown in figure 2. The inboard portion of the leading edge abrasion strip had partially separated from the blade and exhibited bending and buckling deformation. Partial spanwise separation of the composite blade was observed along the leading and trailing edges and through the aft side of the foam core. Soil deposits were impacted within the leading edge split. An ultraviolet light inspection was performed over the surfaces of blades 1 and 3 for evidence of organic deposits, and no relevant fluorescing indications were observed. The damage signatures observed on Blade 3 were consistent with ground impact forces.

The hub was partially disassembled to remove the fractured blade root which is shown with the other propeller blades in figure 3. Each blade root was fitted with three cartridge style bearings separated by spacer rings with a needle roller thrust bearing with washers located between the last cartridge bearing and the cam follower disk which was secured to the base of the blade root by five button head cap screws and one socket head cap screw which received the blade cam follower.

The fracture surface of Blade 2 was oriented transversely through the hollow cylindrical blade root between 2.6 - 3.1 inches from the base of the cam follower disk and intersected three evenly spaced radial holes. The cam follower disk, bearings, and spacers were removed from the fractured blade root which was then cleaned ultrasonically using soap and water followed by ethanol. The left image in figure 4 shows a digital microscope image of the cleaned fracture surface, viewed inboard along the blade axis, with the radial holes labeled as I, II, and III for the purposes of this report. The same image is shown on the right, annotated to show fracture initiation and progression as detailed below.

¹ Source: <https://www.axsportaviation.com/>

At hole I, darker gray and brownish thumbnail shaped regions were observed extending from each corner of the hole at the inner surface of the blade root as indicated by white arrows. Curvilinear progression marks continued through the wall of the blade root and around toward holes II and III, as indicated by black dashed arrows, consistent with progressive crack growth. Spacing between curved bands of crack progression marks between holes I and II increased as the crack front grew towards hole II and areas rougher in appearance were observed between curved bands, consistent with increased stress amplitude and an increased rate of crack growth. Yellow boundary lines corresponded to intersections with additional progressive cracks which originated at hole corners and thread roots as indicated by white arrows and bracketed regions, with growth directions indicated by black dashed arrows. Closer views of these areas are shown in the following figures. Areas highlighted in red exhibited a rougher matte gray appearance, consistent with tensile and/or bending overstress during final separation.

A scanning electron microscope (SEM) was used to examine the fracture surface. Typical SEM images are shown in figure 5 from the progressive fracture region located between holes I and II where macroscopic curved progression marks were observed. The lower magnification image on the left shows feathery regions of finer curved progression marks, oriented horizontally, interspersed with regions of dimpled features. The direction of crack growth is downward in these images. The fracture surface appearance was consistent with mixed-mode fracture dominated by fatigue under a relatively high stress amplitude as evidenced by ductile dimpled features which were consistent with overstress. The higher magnification image on the right shows finer curved striations within more prominent curved progression marks, consistent with a fatigue fracture mechanism with variable stress amplitudes.

Figure 6 shows a closer tilted view of the primary fracture origin areas observed at the inner edges of hole I, indicated by white arrows. The fracture origins were located at thread roots which intersected the radial hole. Curved brown and dark gray progression marks oriented perpendicular to radial fracture features emanated away from the origins through the wall and around the blade root. The fracture surface near the origin on the right side of the hole as pictured exhibited a darker battered appearance, consistent with rubbing contact. The threads exhibited chatter marks along the flank surfaces.²

Figure 7 shows a closer view of a portion of the fracture surface adjacent to the primary fracture origin between holes I and III where multiple fatigue cracks were observed originating at the inner surface of the blade root along a thread root. Yellow arrows indicate visible ratchet mark features, consistent with multiple fracture initiation sites.³ Curvilinear progression marks were observed extending through the

² Chatter marks refer to wavy surface imperfections on the work being machined, usually caused by vibrations transferred from the tool-work interface during machining.

³ Ratchet marks are slight vertical steps in the fracture that link slightly offset planes of fatigue cracking

wall of the blade root towards the outer surface. Smaller ratchet mark features were observed extending from the thread root at the inner surface in the area indicated by a yellow bracket as shown more clearly in the inset image. The location of these ratchet mark features correlated well with the presence of chatter marks from the thread machining process.

Figure 8 shows closer views of the fracture surface near hole III where two smaller thumbnail shaped progressive cracks were observed at the intersection of thread roots with the inner corners of the hole indicated by white arrows. The inset image shows a closer view of the thumbnail shaped crack observed on the upper side of the hole as oriented in this figure. The right image in figure 8 shows a radial view of the inner surface of the blade root at hole III. A visible crack was observed along the bottom thread root which extended along a portion of the hole surface as indicated between the two red arrows.

Figure 9 shows closer views of the fracture surface near hole II. Progressive cracks with curved arrest marks were observed extending from a thread root at the inner hole edges as indicated by white arrows. Ratchet marks were observed on the fracture surface extending from the thread root along the crack observed below the hole as oriented in this image. The right image shows a view of the outer surface of the blade root at hole II, where this crack had grown through the entire wall thickness of the blade root as highlighted by a yellow dashed line. The remaining ligament of material above this crack, when viewed from above, exhibited thumbnail shaped progressive cracks which initiated near the outer surface at the hole edge, indicated by a red arrow, and grew inward, consistent with a reversal in the load path.

Figure 10 shows a view of the disassembled hub with the aft section removed, looking inward along the bore of blade position 2. The plastic pitch change block was fractured into two pieces between blade positions 2 and 3. Black greasy witness marks and gouged plastic were observed along the ledges of the cam follower slot, as indicated by black brackets, consistent with contact between the pitch change block and the cam follower from blade 2. The fracture originated at the corner radius of the L-shaped cam follower slot as indicated by red arrows on the larger and smaller mating fragments shown in the left and right images, respectively. Radial fracture ridges were observed extending away from the fracture origin area toward the free surfaces of the part as indicated by white arrows in the right image. The fracture was consistent with overstress separation.

Figure 11 shows the root ends of blades 1 and 3 as viewed from the trailing edge side. The bearing elements have been removed from the blade roots in the upper image. Retention pins were observed in the radial holes through which blade 2

at a fatigue origin area. Ratchet marks generally are aligned in the direction of cracking and taper off as distance from the origin is increased and a unified crack front is produced.

had fractured. Visual inspection of the outer surface of the metallic blade roots did not reveal any visible cracks. Spanwise cracks and chipped polymeric material were observed at the trailing edge side of the blade roots through a resin-rich fillet at the base of the composite blade where it interfaced with the metallic root section, as indicated by red arrows. Separation between the resin-rich fillet and the metallic root section was observed around the circumference of the interface, evidenced as a small gap, indicated by yellow arrows.

The interior of the metallic root sections of blades 1 and 3 were examined with a borescope. Visual inspection of the internal threads and radial holes were obscured by an inner metallic sleeve, foamlike filler material, and other adhesive type materials. The inner ends of the retention pins were observed to be engaged in the inner sleeve as shown in figure 12.

Blade 3 was sectioned for closer examination. The composite blade was cut chordwise approximately 0.5 inch above the metallic blade root. Additional spanwise section cuts were made through the root section at each of the retention pin holes. Figure 13 shows a photograph of the interior of the sectioned blade root, with a closer view of the typical cross section on the right. A metallic threaded collar which engaged the threads on the metallic blade root was observed around the outer surface of the composite blade root. A metallic inner sleeve was observed on the inner surface of the composite blade root.

Figure 14 shows closer views of the typical blade root cross section at the tip end of the metallic blade root (left) and at the retention hole (right). The gap observed between resin fillet and metallic root section as documented in figure 11 was measured to be approximately 0.02 inch, indicated by yellow arrows in the left image. The composite blade root was disbonded from the metallic blade root and threaded collar as evidenced by separation of the adhesive layer and a near surface delamination of the composite blade root along the path indicated by blue arrows. An adhesive bond between the metallic blade root and the threaded collar appeared to remain intact. Voids were observed within the composite portion of the blade root. The section of the retention pin hole within the composite blade root, indicated by red dashed lines in the right image, was shifted relative to the hole through the metallic blade root, indicated by dashed black lines. This observed offset was consistent with pin bending loads relative to the composite and metallic blade roots.

The cross sectioned holes in the metallic blade root were examined more closely. Several relatively flat crack profiles were observed extending toward the outer surface from thread roots as circled in digital microscope images presented in figure 15. These visible crack profiles ranged in size from 0.008 inch to 0.097 inch and were consistent with progressive fatigue cracks.

Chemical analysis was performed on the fractured metallic blade root using X-ray fluorescence (XRF) spectroscopy. The alloy was consistent with a 6XXX series aluminum alloy with predominant additions of silicon, magnesium, and manganese. Hardness and electrical conductivity measurements were performed in accordance with Aerospace Material Specification (AMS) 2658 Hardness and Conductivity Inspection of Wrought Aluminum Alloy Parts. The average hardness was calculated as 48.5 HRB.⁴ Electrical conductivity was measured to be 46.4 %IACS.⁵ These results were consistent with a heat treated condition.

Submitted by:

Michael Meadows
Materials Engineer

⁴ HRB refers to the Rockwell "B" hardness scale. 10/100 kg minor/major load, 1/16-inch diameter carbide ball indenter

⁵ %IACS refers to the International Annealed Copper Standard where the conductivity of annealed copper, $5.8001 \times 10^7 \text{ S/m}$, is defined to be 100% IACS at 20°C.

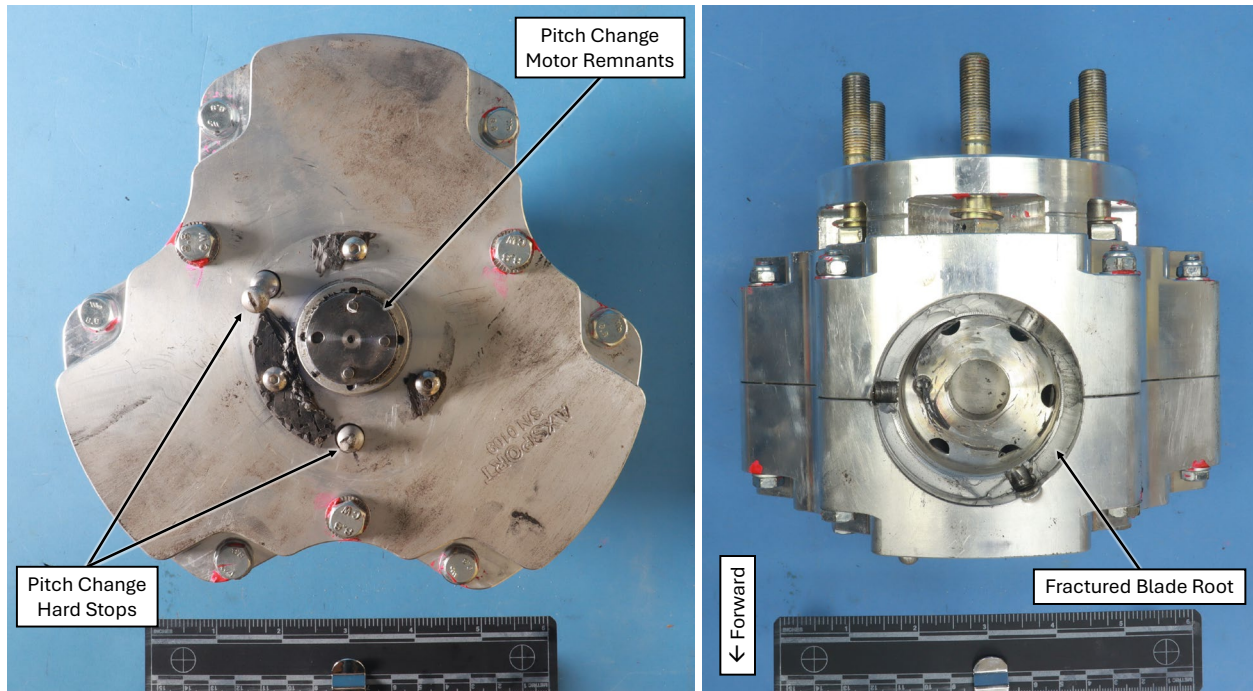


Figure 1. Photographs of the propeller hub as received looking aft (left) and looking axially inboard along the bore of blade position 2 (right). A portion of the fractured blade 2 root was retained in the hub as indicated in the right image.

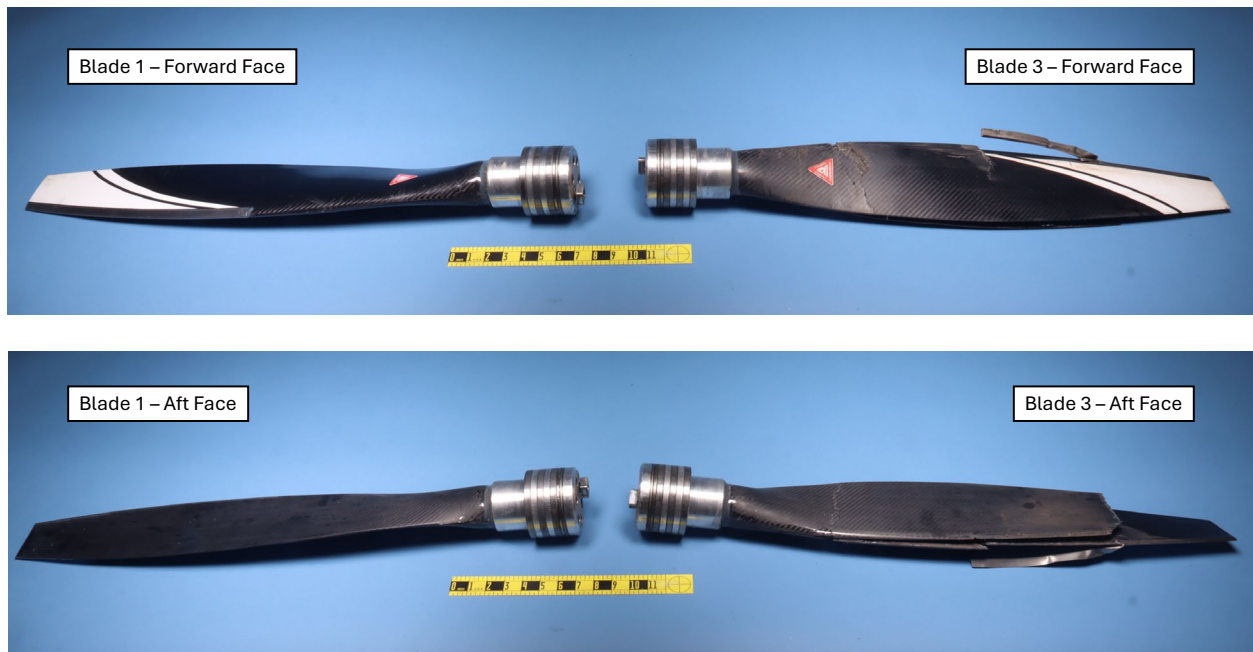


Figure 2. Photographs of the other two propeller blades as received. Blade 1 (left) was relatively undamaged whereas Blade 3 exhibited damage from ground impact.

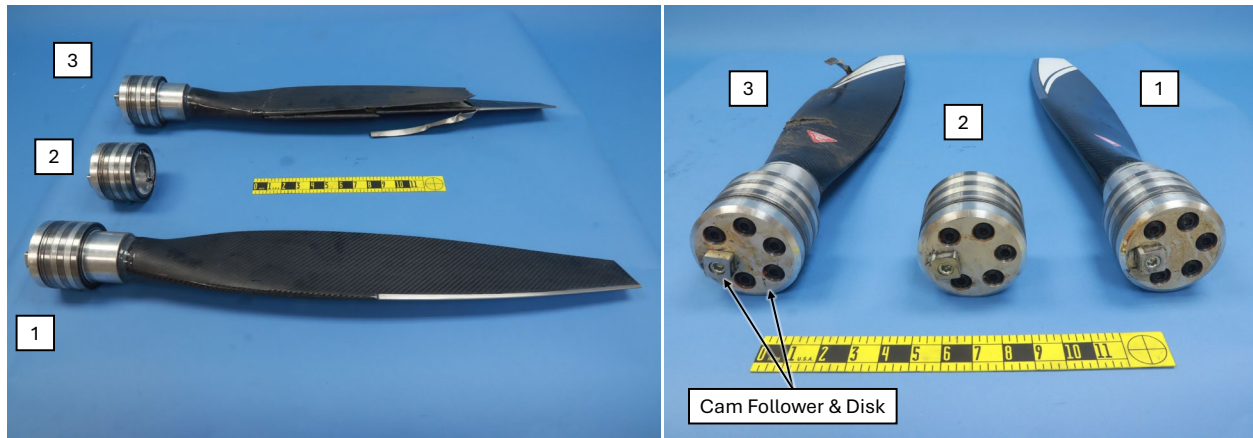


Figure 3. Photographs of the three propeller blades after removal of the fractured blade 2 root from the hub.

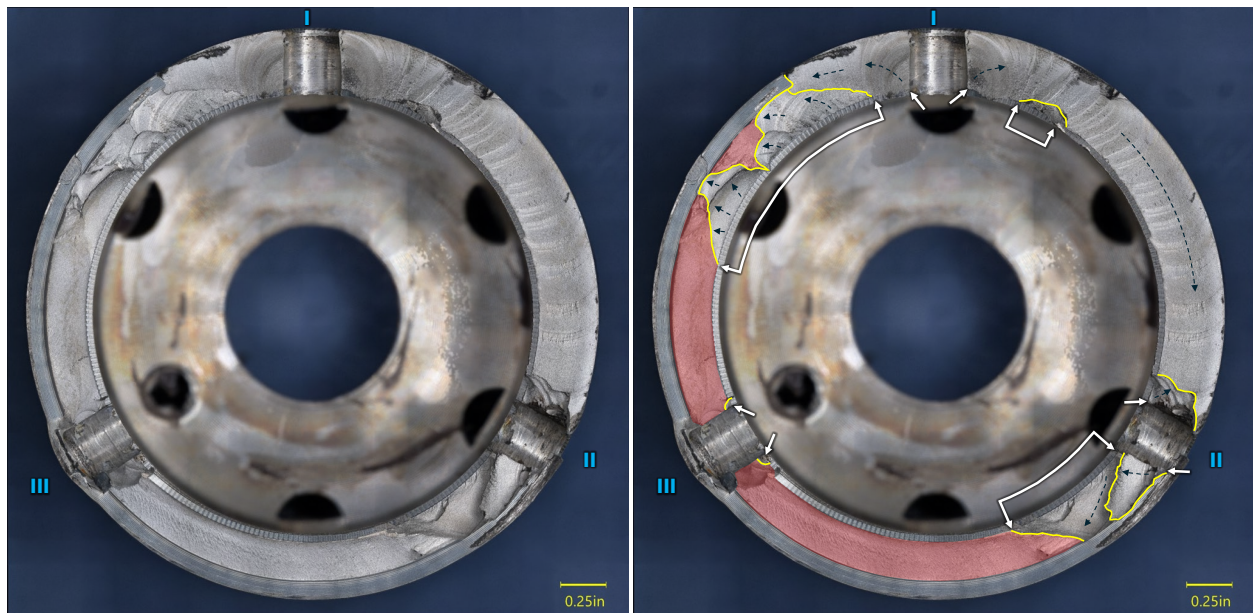


Figure 4. Digital microscope image of the fracture surface of the root of blade 2 with radial holes labeled as I, II, and III. Right is an annotated view of the left image showing fracture origin areas (white arrows), progressive crack growth directions (black arrows), intersections of progressive crack regions (yellow lines), and overstress regions (red).

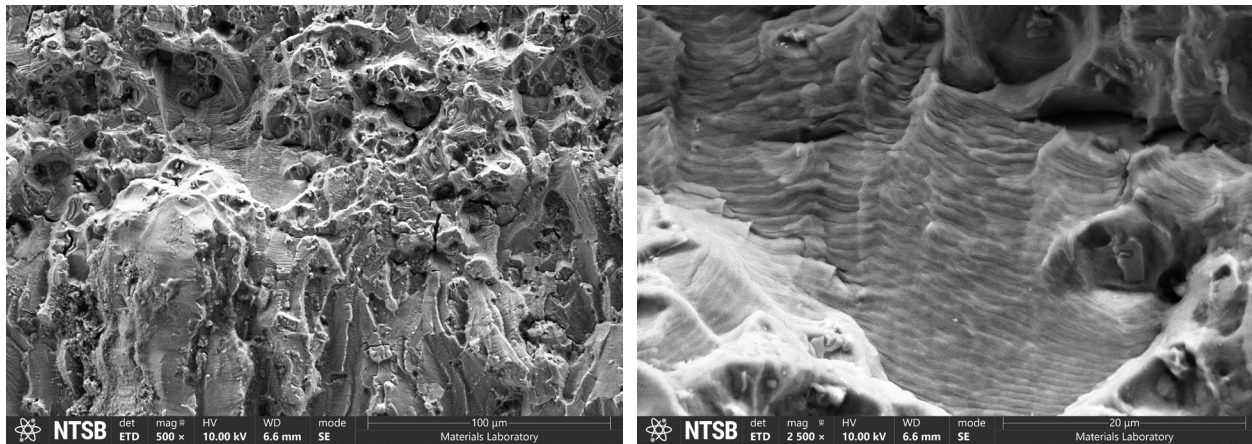


Figure 5. Scanning electron microscope images (secondary electron detector) of the progressive fracture region of the blade root between holes I and II. The left image shows a lower magnification view of feathery regions with curved progression/arrest marks (oriented horizontally) which are interspersed with circular dimpled features. The right image shows a higher magnification view where finer fatigue striations are observed between more prominent curved progression marks. Crack growth direction is from top to bottom in these images.

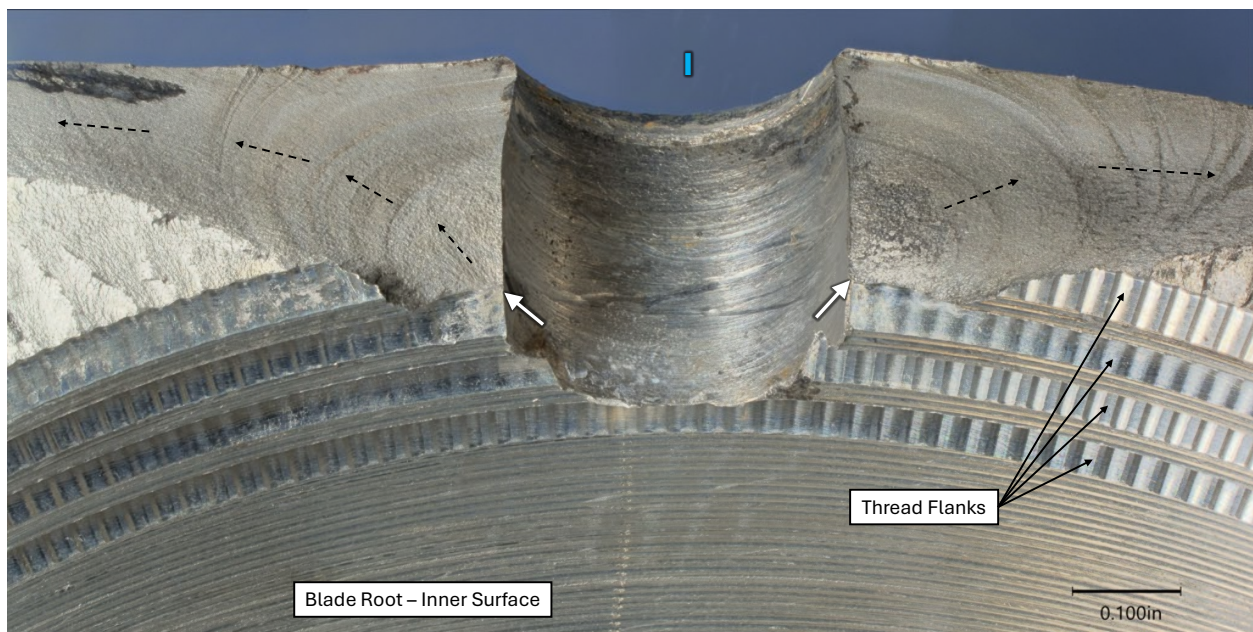


Figure 6. A digital microscope image (tilted view) of the inner surface of the fractured blade root showing the primary fatigue fracture origins (white arrows) where thread roots intersected the edges of radial hole I. Crack growth directions are indicated by black arrows, perpendicular to visible curved progression marks. Chatter marks were observed on the thread flanks and exhibited a wavy surface appearance.

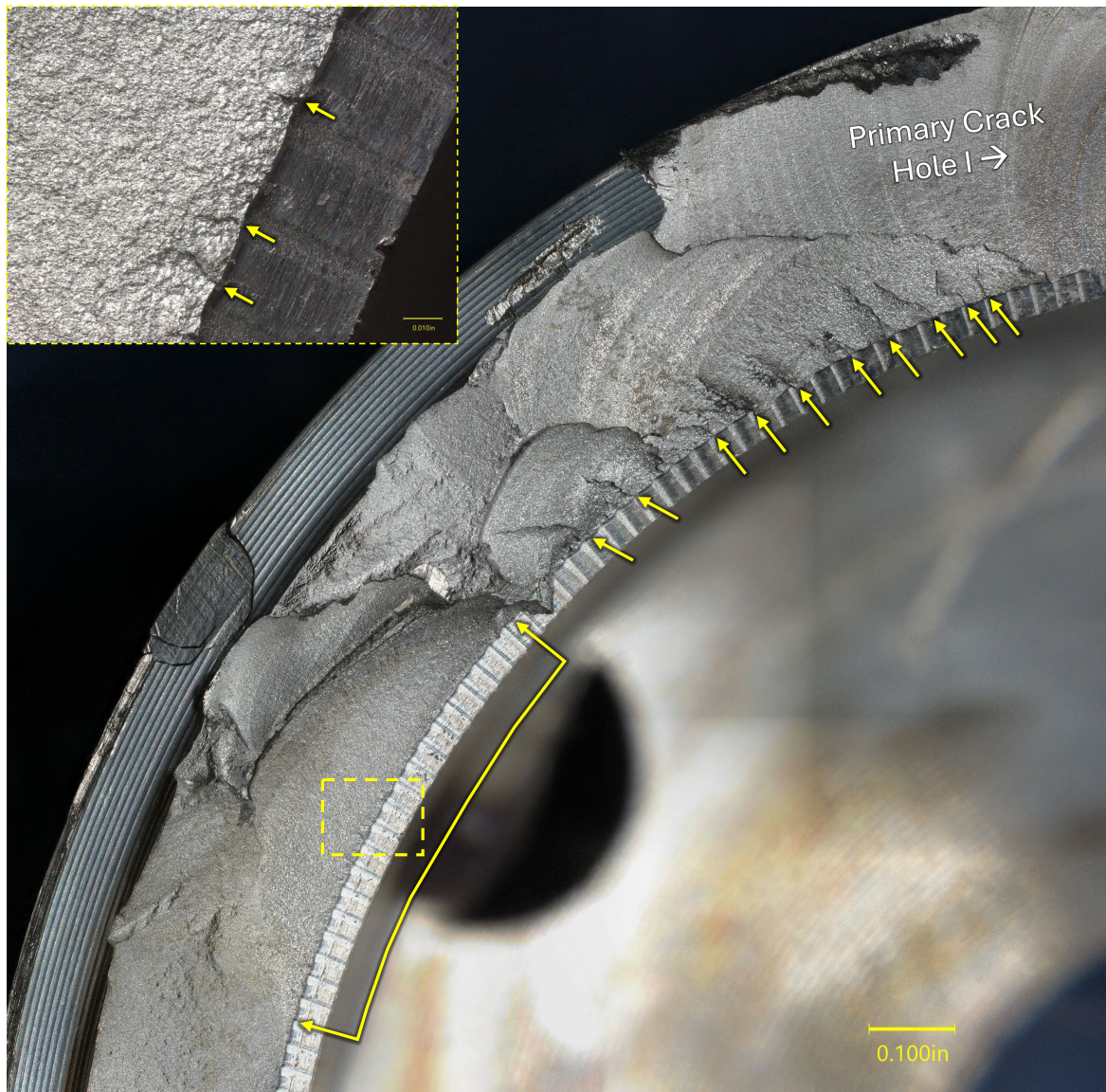


Figure 7. Digital microscope image of the fracture surface adjacent to the primary fracture origin between holes I and III where multiple fatigue cracks were observed originating at the inner surface of the blade root along a thread root. Yellow arrows indicate visible ratchet mark features. The inset image shows a closer view of the boxed area.

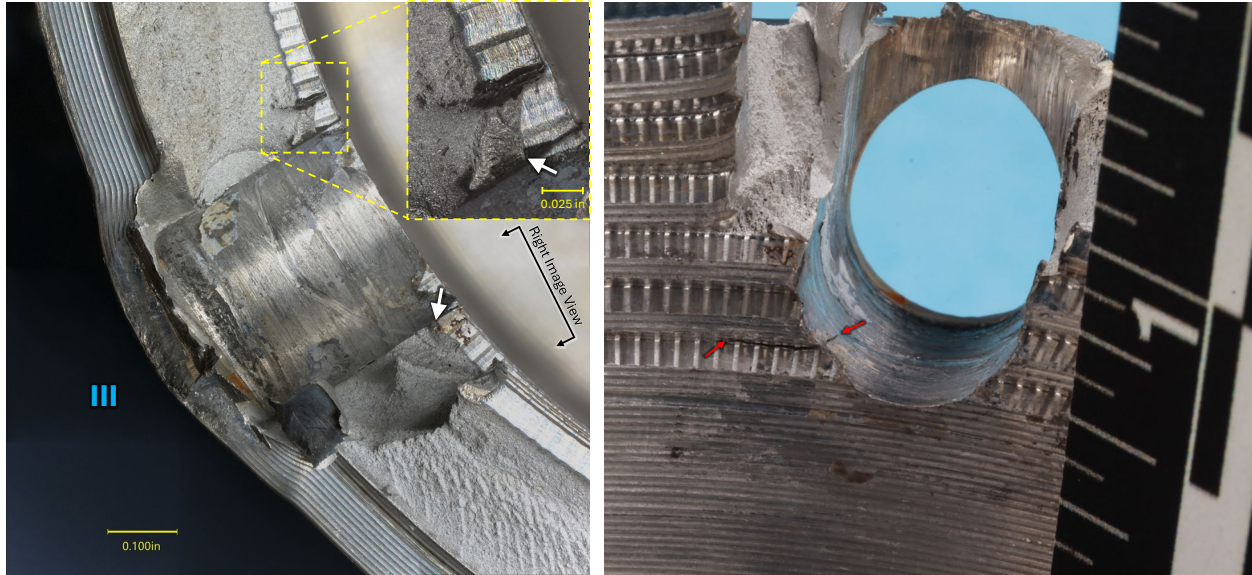


Figure 8. Digital microscope image (left) of the blade root fracture surface at hole III. Thumbnail shaped progressive cracks were observed to originate where thread roots intersected the hole edges at the inner surface as indicated by white arrows. A partial crack was observed in the bottom thread root as shown between red arrows in the right photo of the inner surface of the blade root at hole III.

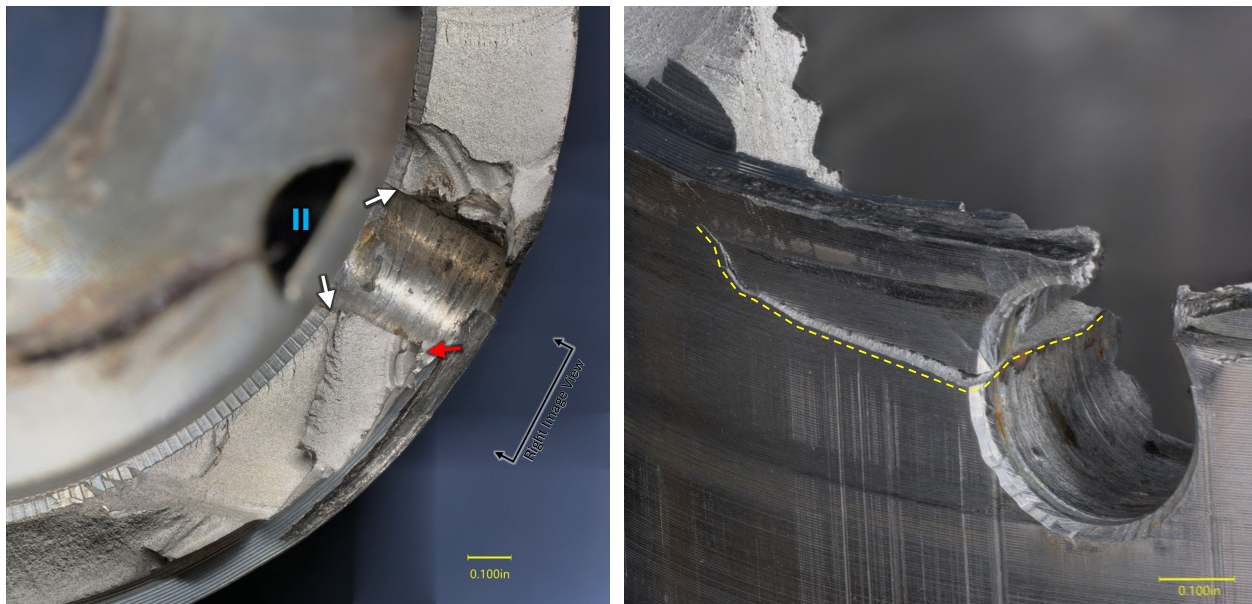


Figure 9. Digital microscope image of the blade root fracture surface at hole II (left). Progressive cracks were observed to originate where thread roots intersected the hole edges at the inner surface as indicated by white arrows. The left image shows a view of this hole from the outer surface where the crack had grown through the blade root wall as indicated by a yellow dashed line. The ligament of material above this crack exhibited a secondary fatigue crack which initiated at the hole edge near the outer surface and grew inwards as indicated by the red arrow.

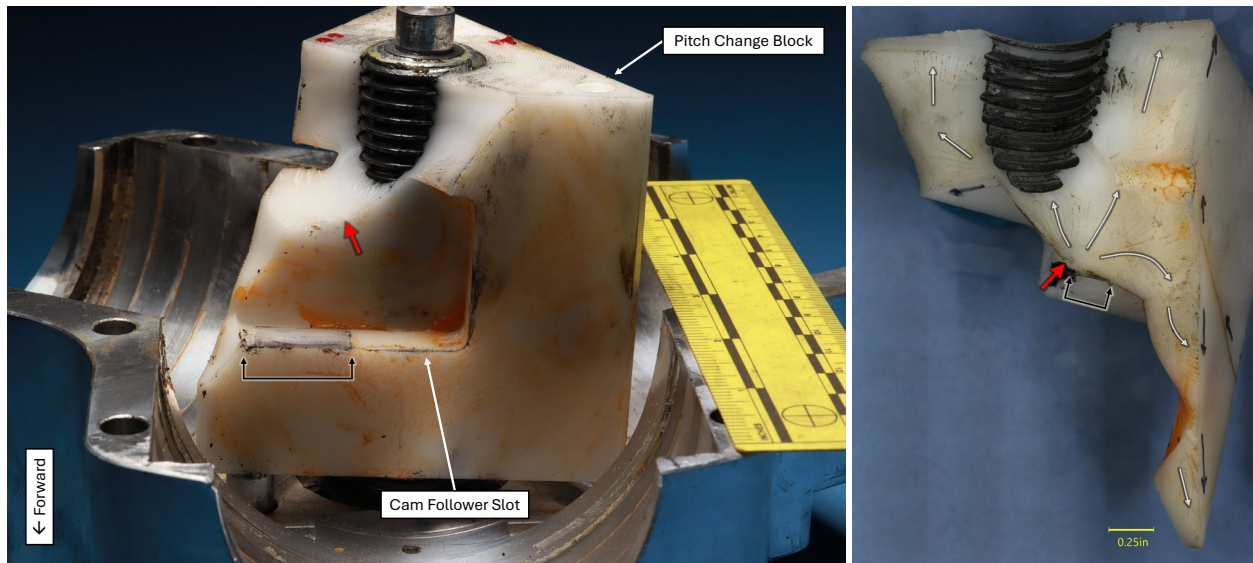


Figure 10. Photographs of the mating pieces of the fractured pitch change block in the partially disassembled hub as viewed along the bore of blade position 2. The fracture initiated at a radius in the cam follower slot (red arrows) near contact marks (black brackets) and continued towards the free edges of the part as indicated by white arrows. Radial fracture features were consistent with overstress.

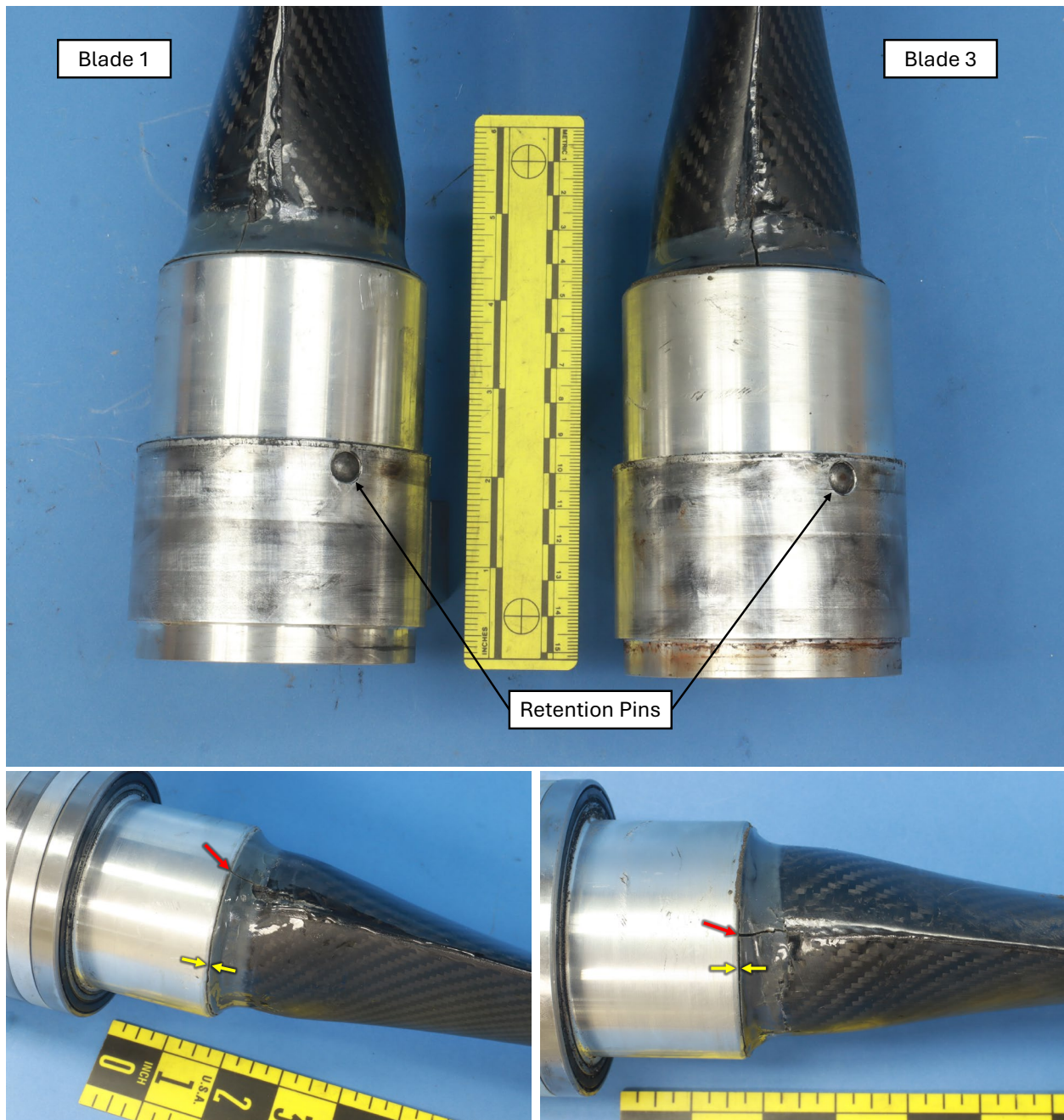


Figure 11. Photographs of the blade roots from blades 1 (left) and 3 (right) showing retention pins secured in the radial holes which were exposed when bearings and spacers were removed. Cracks and chipped resin at the trailing edge of the base of the composite section were observed (red arrows). A gap was observed at the base of a resin rich fillet where the composite section interfaced with the metallic root as indicated by yellow arrows.

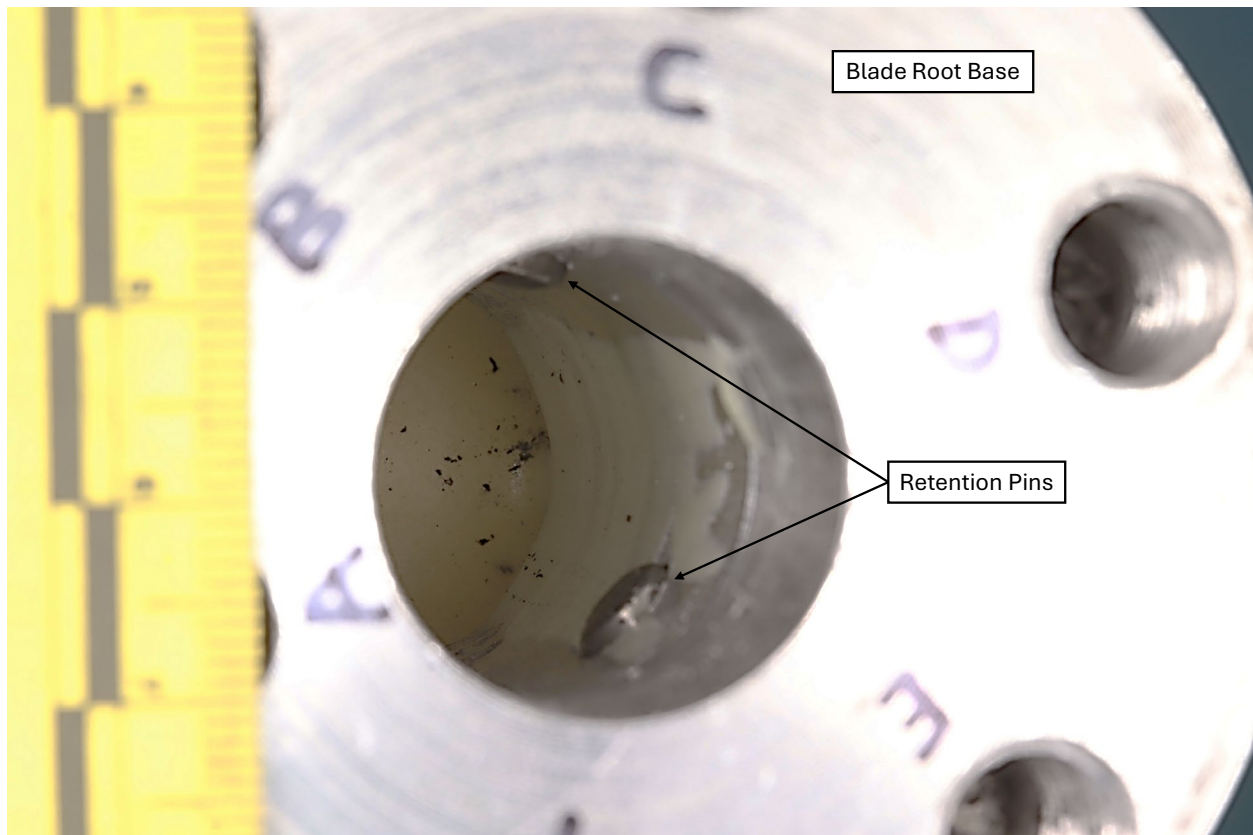


Figure 12. A typical view of the inner surface of one of the intact blade roots, after removal of the cam follower disk, showing retention pins engaged with an internal metallic sleeve.

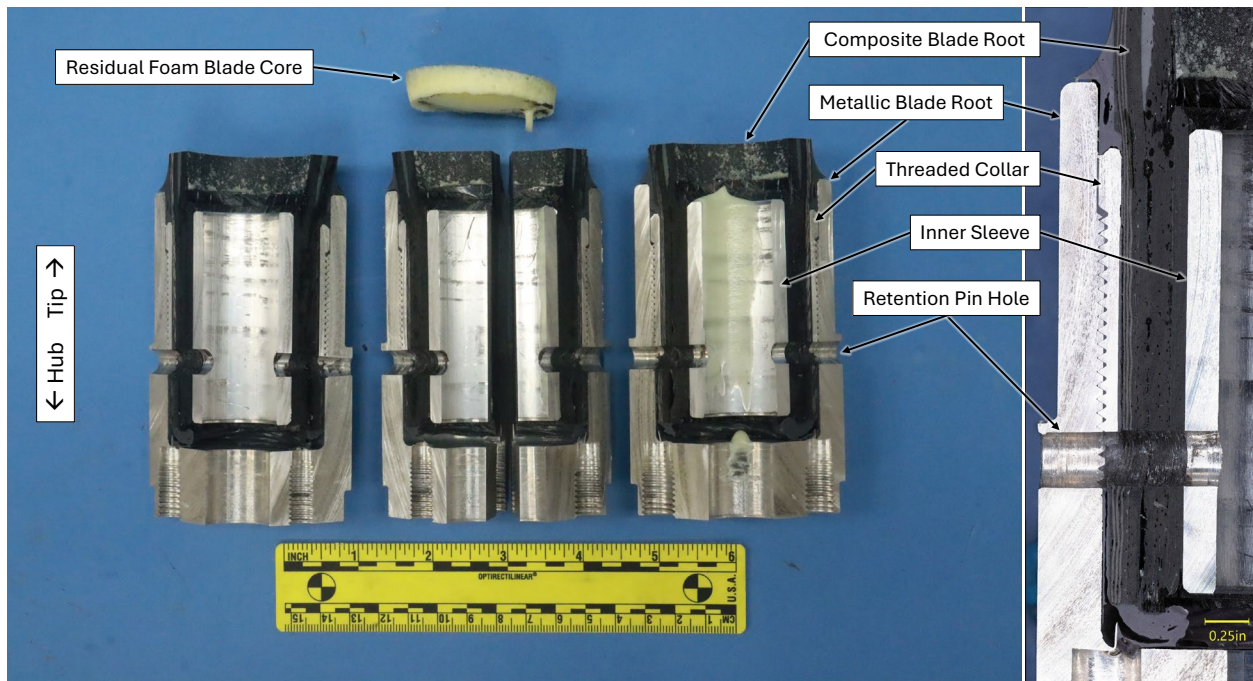


Figure 13. Photograph showing an internal view of the blade root as sectioned through the retaining pin holes. A closer view of the typical cross section is shown on the right.

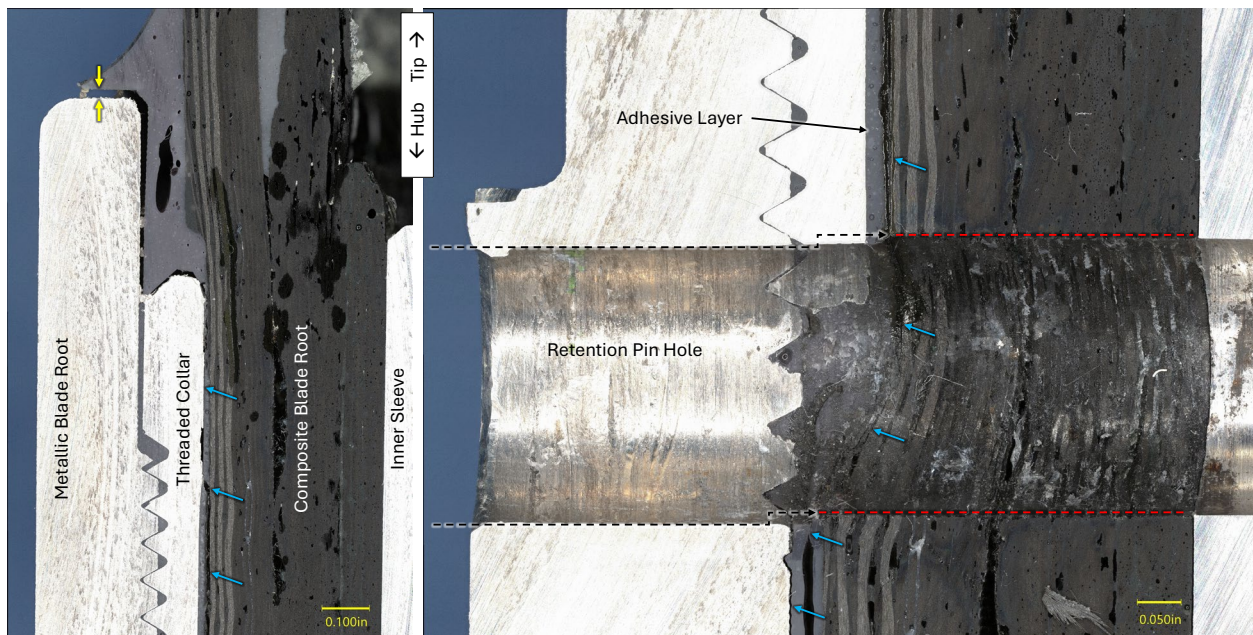


Figure 14. Digital microscope images of the typical blade root cross section showing a gap between the composite and metallic sections (yellow arrows). The composite root section was disbonded from the threaded collar and metallic blade root and delaminated near this adhesive joint along the path indicated by blue arrows. The composite section of the hole (red dashed lines) was shifted relative to the metallic section (black dashed lines).

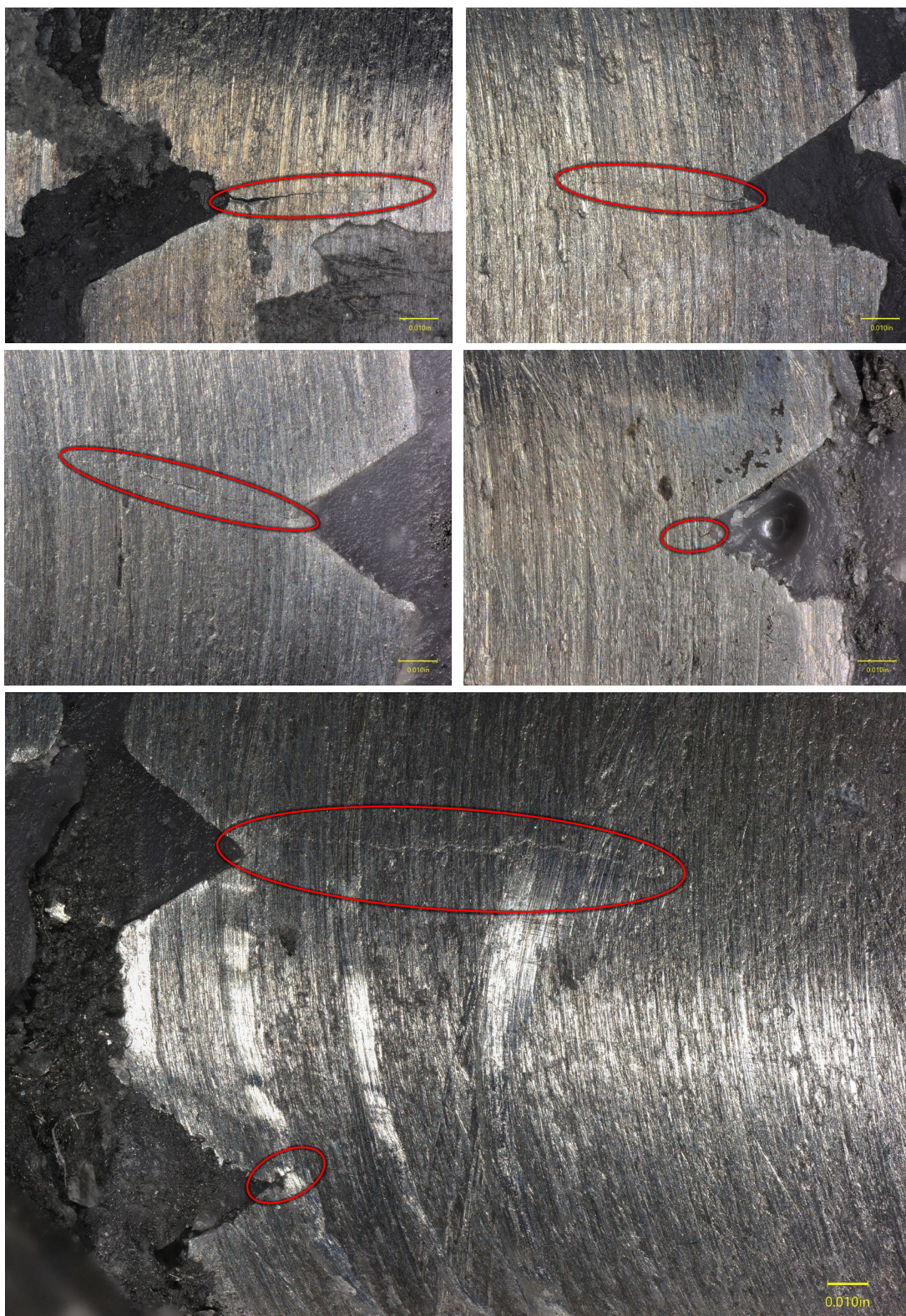


Figure 15. Digital microscope images of the retention pin hole through the metallic blade root showing flat crack profiles extending from the thread roots toward the outer surface as circled in red.