

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN24LA162

MATERIALS LABORATORY

Factual Report 24-070

October 28, 2024

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A. ACCIDENT INFORMATION

Location: Longview, Texas
Date: April 12, 2024
Vehicle: American Champion 7ECA, N793L
Investigator: Zane Brown, AS-CEN

B. COMPONENTS EXAMINED

Rudder and lower hinge attachment hardware.

C. EXAMINATION PARTICIPANTS

Specialist Matthew R. Fox, Ph.D.
NTSB
Washington, DC

Engineering Technician Edward Komarnicki
NTSB
Washington, DC

D. DETAILS OF THE EXAMINATION

An overall view of the submitted rudder and lower hinge attachment hardware is shown in figure 1. The middle knuckle was fractured from the rudder post at the lower hinge location as shown in the lower image in figure 1. The lower hinge attachment bolt was intact, and the nut was received with the attachment bolt. Two bushings from the upper and lower knuckles (vertical stabilizer side) of the lower hinge were also received as shown.

The middle knuckle surfaces and adjacent areas on the rudder post at both the upper and lower hinge locations were covered with blue paint. A layer of white paint or primer was observed under the blue coating, and a black paint or primer layer was observed under the white layer.

At the lower hinge location, the rudder post fractured at the toes of the welds attaching the middle knuckle to the post along the left and right sides of the knuckle and along the lower side as shown in close views of the fracture in figure 2. At the upper end of the fracture, the fracture path on each side extended upward beyond the welds before turning to intersect approximately 0.25 inch above the upper ends of the welds. At the upper end of the fracture, the rudder post wall piece that remained attached to the knuckle piece was deformed forward relative to the lower welded portion of the wall.

The middle knuckle piece from the lower hinge was submerged in a beaker of acetone and cleaned using an ultrasonic cleaner for 15 minutes followed by a soak for approximately 30 minutes. When removed from the beaker, the coatings on the piece were substantially softened with the blue and white layers loosely adhered. The blue and white coating was removed mostly in one piece, and remaining pieces were gently cleaned from the surface using a cotton swab. The black coating remained partially intact, but many areas began to peel with the solvent exposure. The piece was rinsed in water then ethanol and was dried with compressed air.

Views of the cleaned rudder post fracture surfaces on the knuckle side of the fracture are shown in figure 3. Relatively flat fracture features were observed around the lower side of the fracture and along the left side of the knuckle following the profile of the weld toes. Unlabeled arrows in figure 4 point to crack arrest lines near the upper end of the knuckle consistent with fatigue fracture initiating at the weld toe on the outside diameter surface of the post. However, flat features with curving boundaries and ratchet marks were observed on the opposite side of the fracture consistent with fatigue initiating at the interior surface of the weld post. Dashed lines in figure 4 indicate the extent of the fatigue regions initiating at the interior surface. The precise origin areas and extent of fatigue fracture were uncertain due to rubbing damage on the surfaces. However, the overall pattern was consistent with reverse bending fatigue with larger fatigue regions having originated at the toe of the weld on the outer surface of the post.

The post fracture surfaces on the knuckle side of the fracture were further examined using a scanning electron microscope (SEM). Fine fracture features were mostly obscured or obliterated by oxidation and fracture surface recontact damage. However, flat fracture features with ratchet marks¹ were observed such as the area shown in figure 5, features consistent with reverse bending fatigue. The origin area at the forward side of the fracture in this location was smeared by recontact damage, but a ratchet mark is noted consistent with multiple origins at the outside surface. At the lower end of the fracture, the intersection between the fatigue regions was associated with an abrupt change in fracture plane. Dimples consistent with ductile overstress fracture were observed at the upper right side of the fracture consistent with an area of final fracture.

The upper and lower faces of the middle knuckle for the lower hinge are shown in figure 6. The lower face around the bearing was worn as indicated in the right image in figure 6, and the outer edge of the face had a deformation lip that extended radially outward around the outer circumference. The upper surface, shown at the left in figure 6, was free of deformation and wear. When initially

¹ A ratchet mark is a small step in the fracture surface formed when two adjacent fatigue cracks originate on slightly offset planes.

received, the worn area on the lower side of the middle knuckle, partially visible in the lower image in figure 2, was mostly covered with grease and blue paint.

The bushings from the upper and lower knuckles on the vertical stabilizer side of the lower hinge are shown in figure 1. One of the bushings had a worn end consistent with being positioned in the lower knuckle, and closer views of the worn bushing are shown in figure 7. The lower bushing had a groove worn into one side consistent with contacting the lower end of the bearing on the fractured middle knuckle piece. At the inside diameter of the worn groove, material was deformed and lipped up over the original machined surface. Blue paint with a glossy surface finish was observed within the wear groove around approximately 1/3 of the circumference. Additionally, blue paint with a rubbed surface was observed lodged under the paint with the glossy surface near the 3 o'clock position in the view shown at the right in figure 7. The opposite end of the lower bushing and both ends of the upper bushing had flat machined surfaces that appeared free of wear or deformation.

Lengths and outside diameters were measured on the two bushings. The upper bushing measured 0.690 inch long and 0.310 inch to 0.313 inch in diameter. The lower bushing measured 0.680 inch long at the outside diameter and 0.695 inch long near the inside diameter at the deformation lip. The outside diameter of the lower bushing measured 0.310 inch to 0.312 inch.

After an initial examination of the rudder post shown in figure 1, the rudder skin was peeled away from the rudder post around the lower hinge location. Transverse cuts were then made above and below the fractured area. The sectioned rudder post piece was then submerged in acetone and cleaned using an ultrasonic cleaner for approximately 10 minutes. Additional cleaning was completed with soft-bristle brushes dipped in acetone and plastic scrapers to remove coatings from the surfaces around the fracture.

A view of the rudder post section after cleaning and a closer view of the fractured area around the lower hinge middle knuckle are shown in figure 8. Small scattered beads of molten metal were observed solidified on the surfaces around the weld consistent with weld spatter. Grinding marks were observed on the post and on a weld bead to the right of the fracture. At the upper right side of the fracture, the post wall was deformed inward adjacent to the fracture surface. At the lower side of the fracture, the right half of the post wall was bent outward adjacent to the fracture, and a vertical crack extended downward at the left edge of the deformed piece.

Secondary cracks located in the heat-affected zone were observed on the external surface on the left side of the fracture as shown in figure 9. Rub damage was also observed at the edge of the fracture surface along the left side of the fracture and on the adjacent external surface.

Compositional analysis and dimensional measurements were made on the sectioned and cleaned piece of the rudder post. Dimensions were measured in areas where the coatings had been removed, and a portion of the exterior surface was ground to remove surface oxidation and remaining coatings for analysis using an Olympus Vanta x-ray fluorescence (XRF) alloy analyzer. The alloy analyzer identified the material as steel alloy 4130, and dimensional measurements revealed the outside diameter and wall thickness were 0.996 inch and 0.0355 inch, respectively. According to an engineering drawing for the rudder provided by the airplane manufacturer, the rudder post for the American Champion Aircraft model 7ECA is constructed of 4130 steel tube with a nominal diameter and wall thickness of 1 inch and 0.035 inch, respectively. Compositional analysis and dimensional measurements showed results consistent with engineering drawing specifications for the rudder post.

A metallographic sample of the rudder post was prepared for examination in the plane approximately indicated by a dashed line in the left image in figure 8. The metallographic sample was encased in a metallurgical mount and polished, and the polished sample was then etched using a solution of 2 percent concentrated nitric acid added to methanol (2% nital). Arrows at the ends of the dashed line in figure 8 indicate the viewing orientation for the resulting metallographic brightfield images shown in figures 10 through 14.

Overall views of the etched microstructure at the left and right fracture surfaces are shown in figures 10 and 11, respectively. Deformation associated with rub damage noted in figure 9 is indicated at the outside edge of the left fracture surface in figure 10. The outside surface of the rudder post generally etched lighter than the bulk of the thickness consistent with decarburization, and the heat affected zones showed a different microstructure relative to the rest of the circumference. The heat-affected zones had a lath microstructure consistent with tempered martensite as shown in the representative micrograph in figure 12. In contrast, the remainder of the circumference showed dispersed round particles (carbides) in a white background (ferrite) as shown in the representative image in figure 13, a microstructure consistent with spheroidization.

The cross-section adjacent to the left side fracture shown in figure 10 had a curvature that was consistent with the overall diameter of the post cross-section. The wall adjacent to the right side of the fracture shown in figure 11 had a local reverse bend in the polished cross-section. Traversing toward the fracture from the right side of the post, the wall first bent locally inward (outside the field of view in figure 11), then closer to the fracture, the wall bent locally outward. At the fracture surface, the inside edge of the fracture was bent inward.

A series of secondary microcracks were observed in the polished cross-section in the heat-affected zone adjacent to the right fracture surface. Micrographs showing one of the microcracks in the as-polished and the etched conditions are shown in

figure 14. A dominant microcrack with limited crack branching was observed extending from a cluster of smaller branched crack-like features near the surface. Similar microcracks appeared to extend from small pits on the external surface.

No secondary cracks were observed in the polished cross-section near the left side of the fracture. Although secondary cracks were observed during the fractographic examination on the outside surface near the left fracture surface, the polished cross-section for the metallurgical examination was located above the secondary cracks indicated in figure 9.

Vickers microhardness measurements were conducted on the polished cross-section using a Leco LM248AT microindentation hardness testing machine with a 500-gram load. At a distance of approximately 0.12 inch from the fracture surface, the average hardness was 26 HRC (271 HV), which corresponds to a tensile strength of 125 ksi. The rudder post material was specified to conform to Military Specification MIL-T-6736. According to Military specification MIL-T-6736B dated May 3, 1965, round tube in the HT-125 condition should have a minimum tensile strength of 125 ksi.

Next, a series of Vickers microhardness indents were made near the center of the post wall thickness at varying distance from the weld toe on the left side of the middle knuckle. Results from this series of microindents are shown plotted in figure 15. An inset image in figure 15 illustrates how distance from the weld toe was measured. Hardness values ranged from a maximum of 35 HRC (342 HV) at a location 0.002 inch from the weld toe to a minimum of 93 HRB (200 HV) at a location 0.029 inch from the weld toe.

Views of the intact middle knuckle at the rudder's upper hinge location are shown in figure 16. As received, the surfaces of the middle knuckle were covered with blue paint, including upper and lower surfaces around the bearing as shown in the upper right image in figure 16. After an initial examination, the rudder skin was peeled away from the rudder post around the upper hinge location. Transverse cuts were then made through the rudder post above and below the upper hinge location, and a vertical cut was made through frame members attached to the aft side of the post, which separated a section of the post with the upper hinge middle knuckle from the remainder of the rudder. After an isolated scraping with a scalpel on the outside of the knuckle, the sectioned rudder post from the upper hinge location was then submerged in acetone and cleaned using an ultrasonic cleaner for approximately 10 minutes. Additional cleaning was completed with soft-bristle brushes dipped in acetone and a plastic scraper to remove coatings from the upper hinge middle knuckle and surrounding area on the post.

Views of the middle knuckle from the rudder's upper hinge location after cleaning are shown in the upper right, lower right, and lower left images in figure 16. The blue and white coating layers were mostly gone, and the black coating remained

partially intact. A worn contact surface (indicated in the lower right image in figure 16) was observed on the lower side of the middle knuckle around the bearing in areas that had previously been covered with blue paint. The upper surface (upper right image in figure 16) was free of deformation and wear. Weld spatter was observed on the surfaces around the weld, and a wire consistent with a welding filler rod was observed attached at the upper end of the middle knuckle as shown in figure 16. No visual crack indications were observed around the weld toes at the upper hinge middle knuckle when examined at optical magnifications of up to 300x.

The sectioned rudder post from the upper hinge location was scanned using a Keyence VL-500 series 3-dimensional (3D) coordinate measurement machine (CMM). Three separate scans were stitched together to obtain a 3D representation of the piece shown in figure 17. Cylinders were fit to the post, the middle knuckle, and a tubular frame element cut from the aft side of the post. The rudder centerline was defined by the direction between the frame tube axis and the rudder post axis in the horizontal plane, where the horizontal plane normal was defined parallel to the rudder post axis. In figure 17, the Z axis points upward parallel to the rudder post axis, the X axis is the forward direction parallel to the rudder centerline in the horizontal plane, and the Y axis points to the left.

The upper hinge middle knuckle axis was rotated slightly relative to the rudder post axis and was located to the right of the rudder centerline as shown in the measurements in figure 17. In the view looking aft (upper image in figure 17), the hinge middle knuckle was rotated slightly clockwise relative to the rudder post axis. The resulting angle between the middle knuckle axis and the horizontal left direction was 89.1-degrees as measured in the Y-Z plane. Looking downward (lower image in figure 17), the centerline of the middle knuckle was observed to be to the right of the rudder centerline. At the upper and lower ends of the middle knuckle, the middle knuckle axis was located 0.029 inch and 0.039 inch, respectively, to the right of the centerline. The angular measurement of 2.1 degrees in the lower image in figure 17 represents the angle between the rudder centerline and the middle knuckle axis location at the upper end of the middle knuckle measured in the X-Y plane with the angle's vertex positioned at the rudder post centerline.

Submitted by:

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Chief Technical Advisor, Materials Laboratory

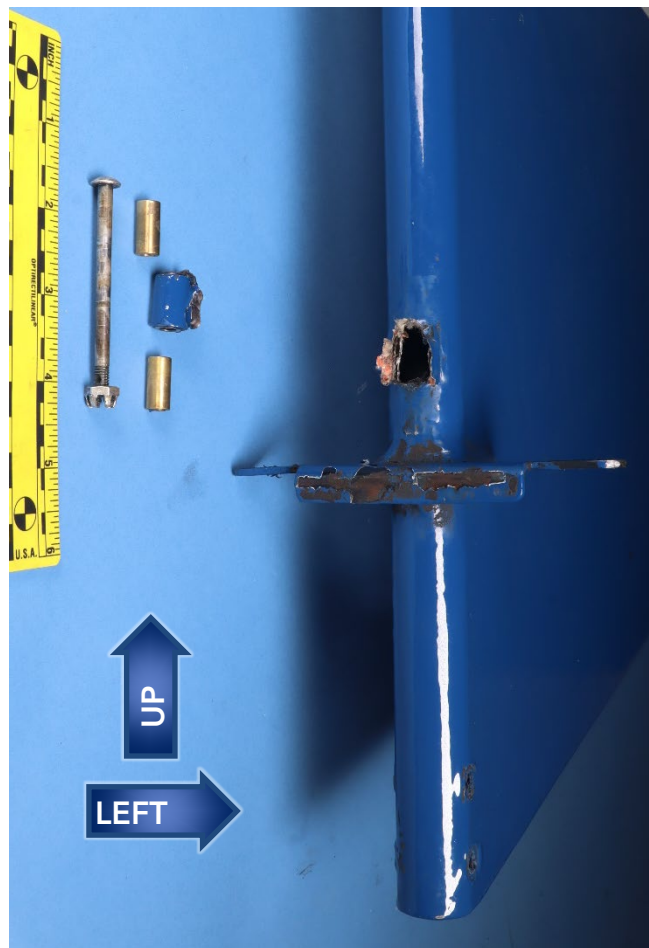
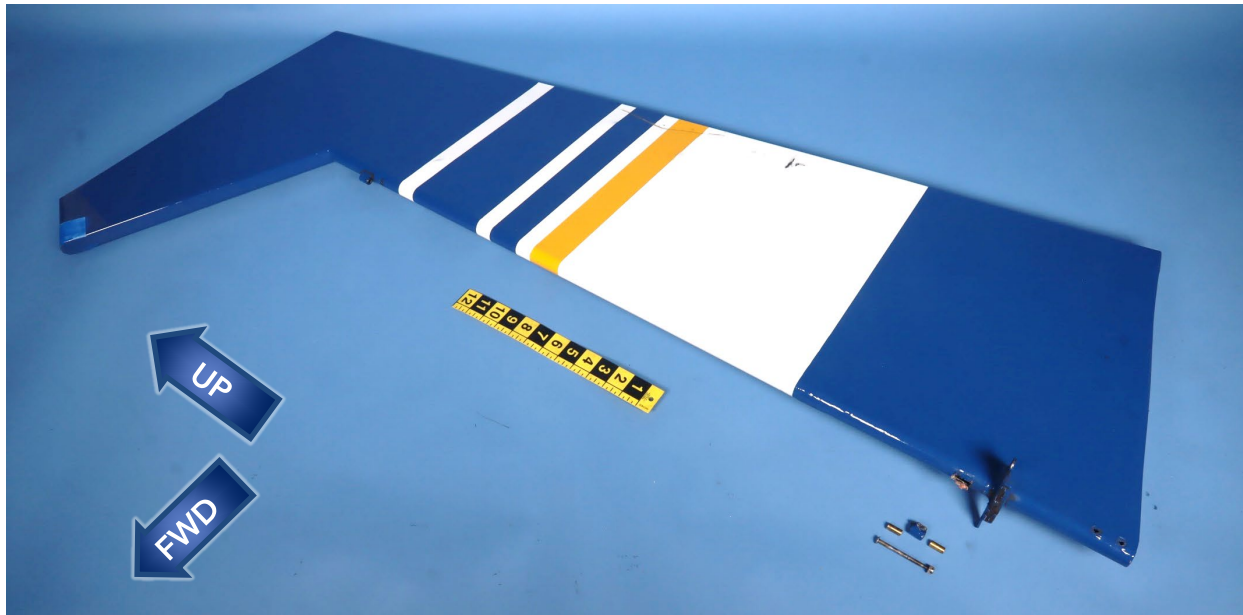


Figure 1. Overall view of the submitted rudder (upper image) with a closer view of the fractured lower hinge area and submitted hardware (lower image).



Figure 2. Knuckle side of the rudder post fracture surfaces as received showing the left, right, and lower sides (upper left, upper right, and lower images, respectively).

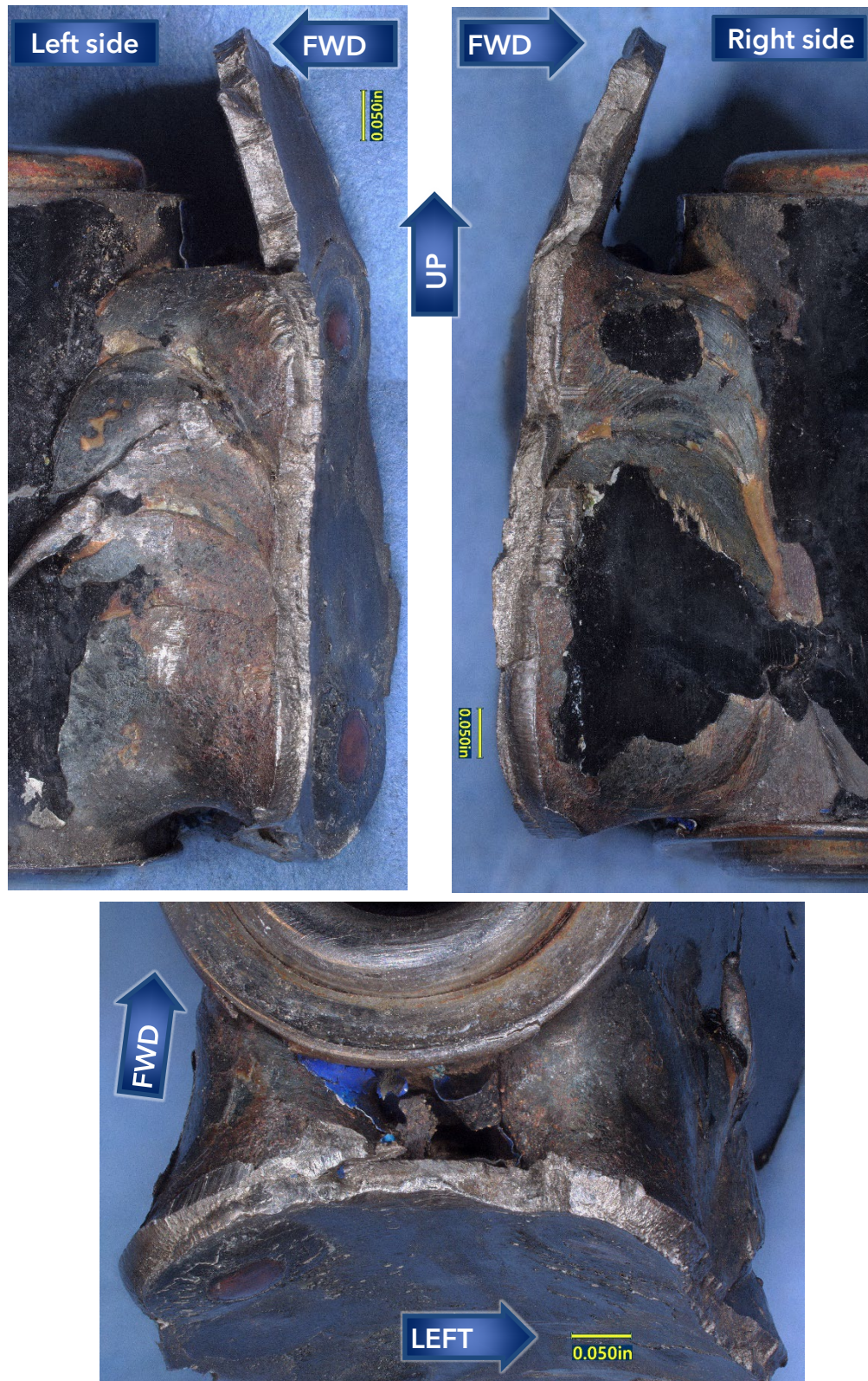


Figure 3. Knuckle side of the rudder post fracture surfaces after cleaning with acetone showing the left, right, and lower sides (upper left, upper right, and lower images, respectively).



Figure 4. Lower portion of the middle knuckle showing fracture features on the left side. Dashed lines indicate fatigue regions originating at the interior surface, and unlabeled arrows indicate curving crack arrest lines for a fatigue region extending from the weld toe. An SEM image of the area within the rectangle is shown in figure 5.

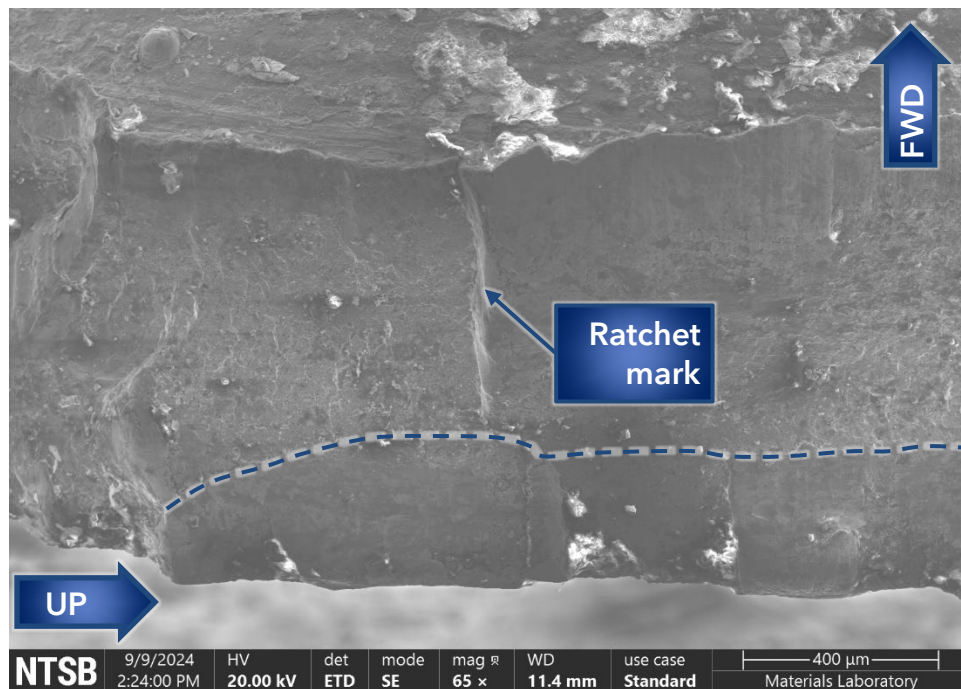


Figure 5. SEM image of the fracture surface on the left side of the middle knuckle piece in the area indicated in figure 4. A dashed line indicates the boundary of the fatigue region extending forward from multiple origins at the inner surface of the rudder post.

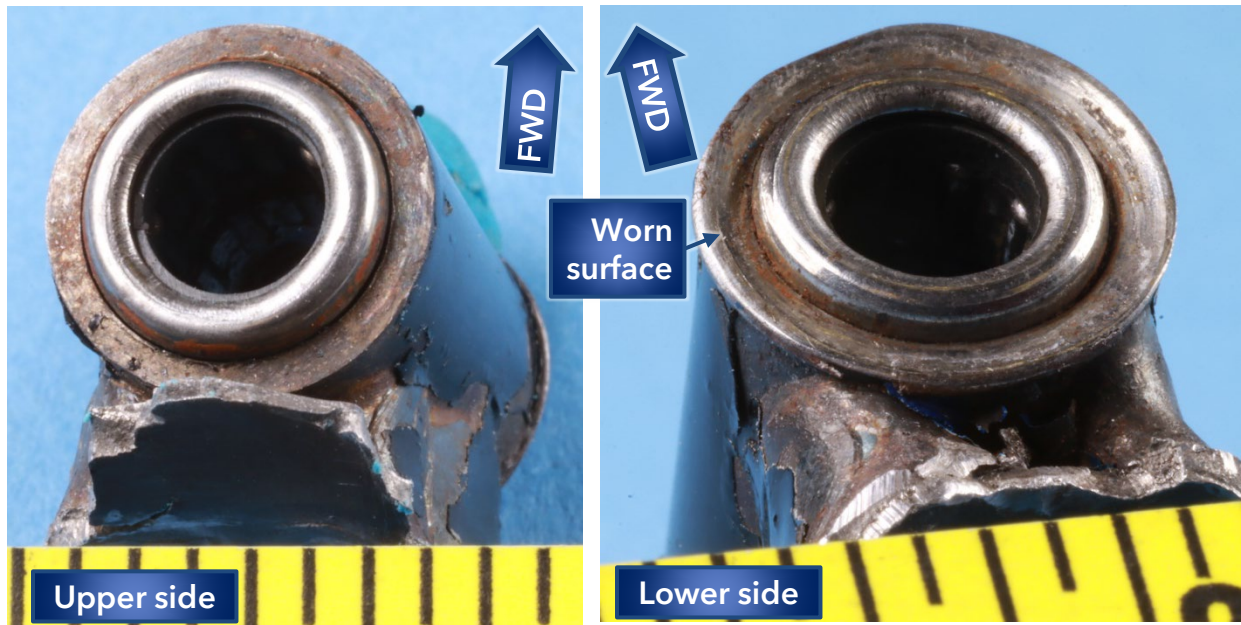


Figure 6. Upper (left image) and lower (right image) sides of the middle knuckle for the lower hinge. The lower face of the middle knuckle around the bearing was worn and deformed radially outward.



Figure 7. Bushing from the lower hinge with a wear pattern consistent with positioning in the lower knuckle attached to the vertical stabilizer. The lower image shows a closer view of deformation, wear, and paint deposits at one end of the bushing.

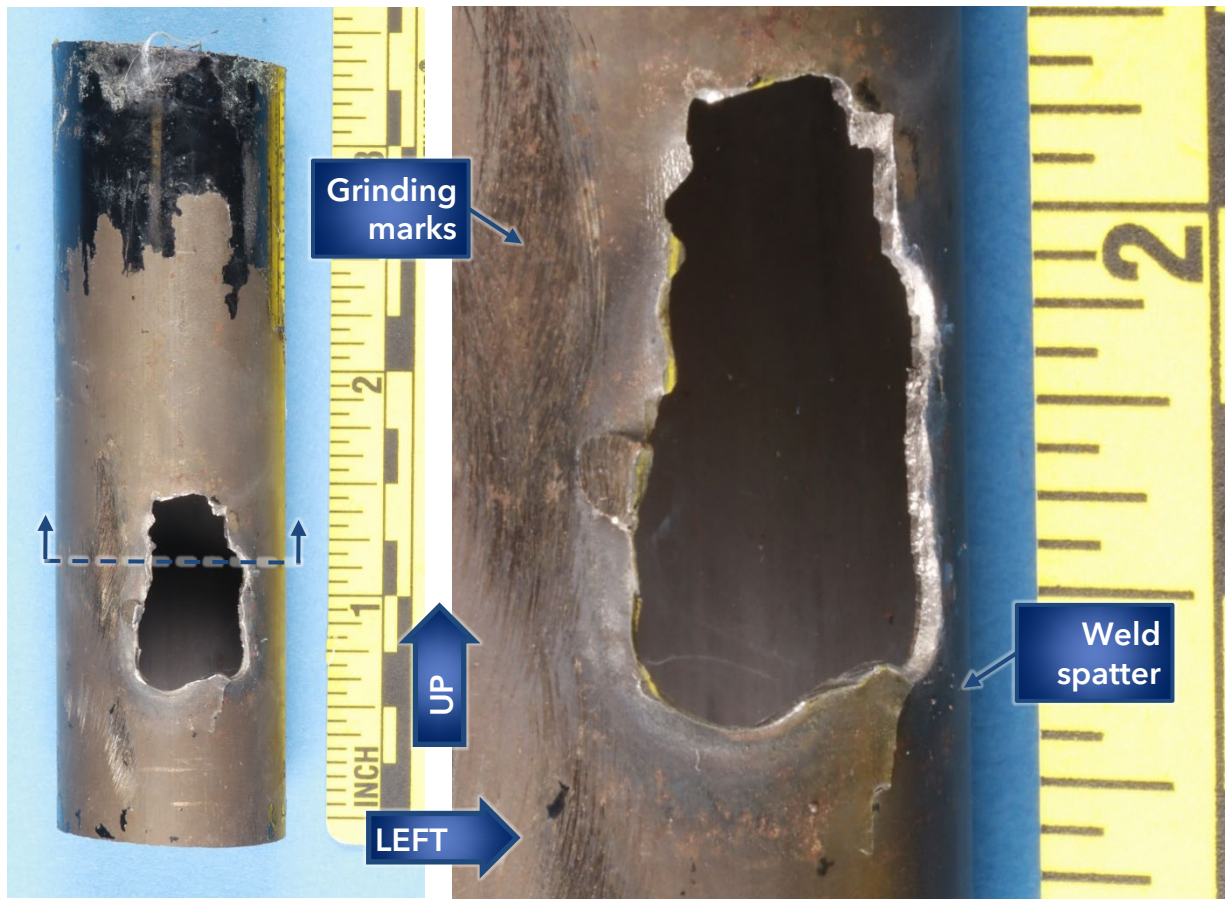


Figure 8. Sectioned piece of the rudder post at the lower hinge location after skin and paint removal and cleaning with acetone. A dashed line with arrows indicates the location of a cut to prepare a cross-section for metallography.

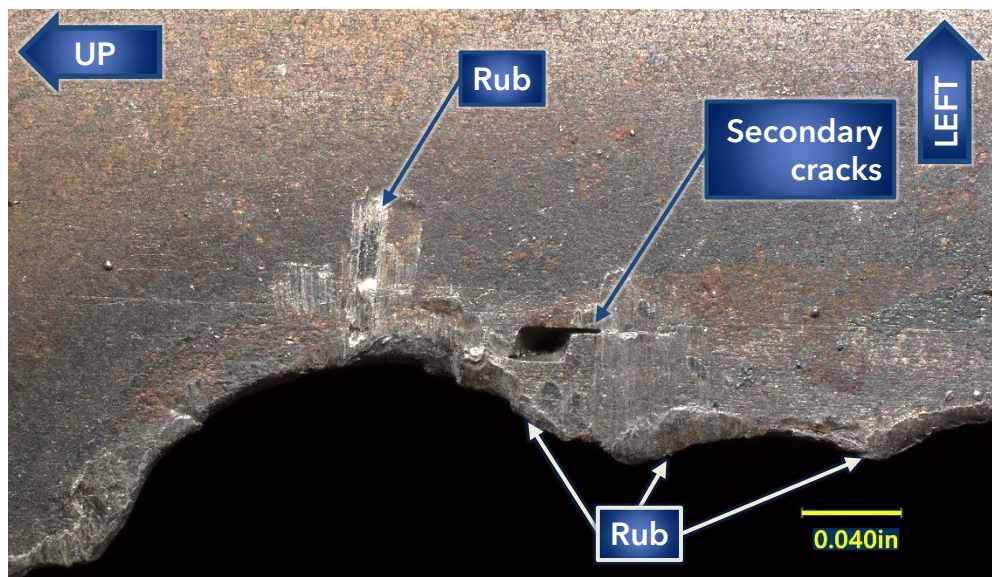


Figure 9. External surface adjacent to the left side of the fracture at the upper end of the middle knuckle weld.

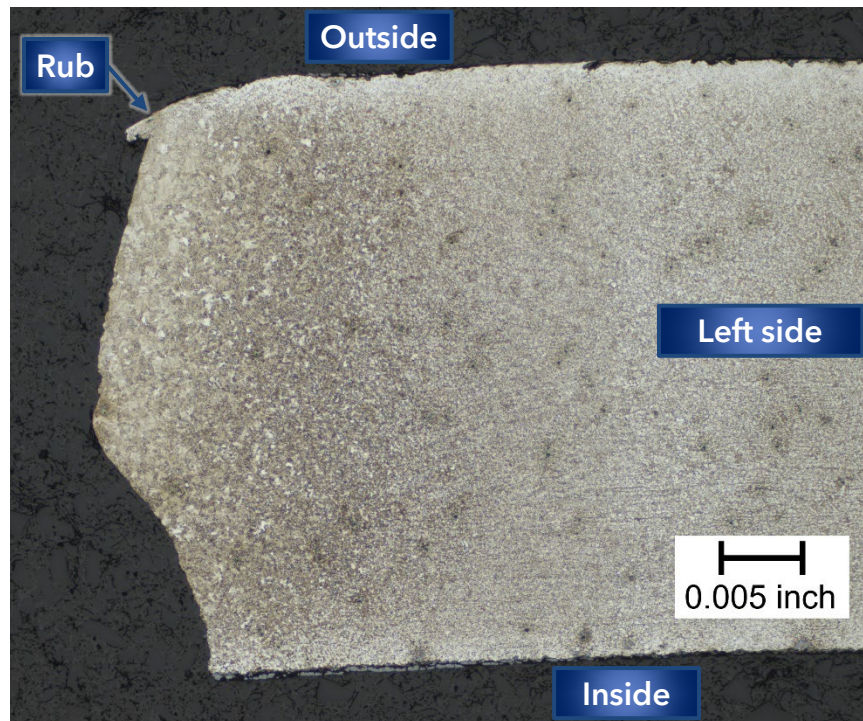


Figure 10. Polished and etched cross-section of the rudder post intersecting the fracture at the left side of the hinge middle knuckle. (2% nital etch)

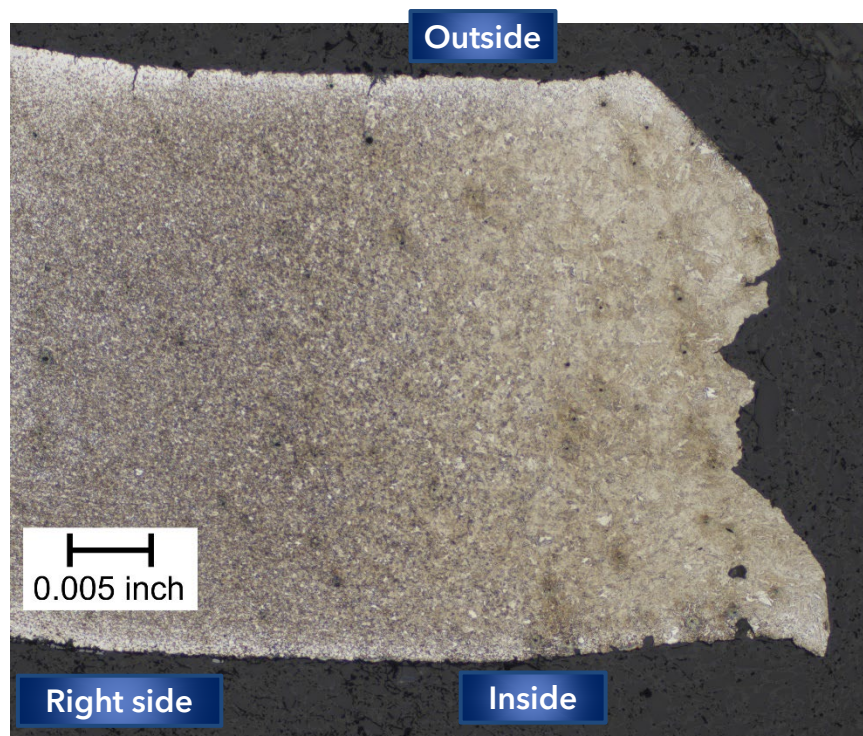


Figure 11. Polished and etched cross-section of the rudder post intersecting the fracture at the right side of the hinge middle knuckle. (2% nital etch)

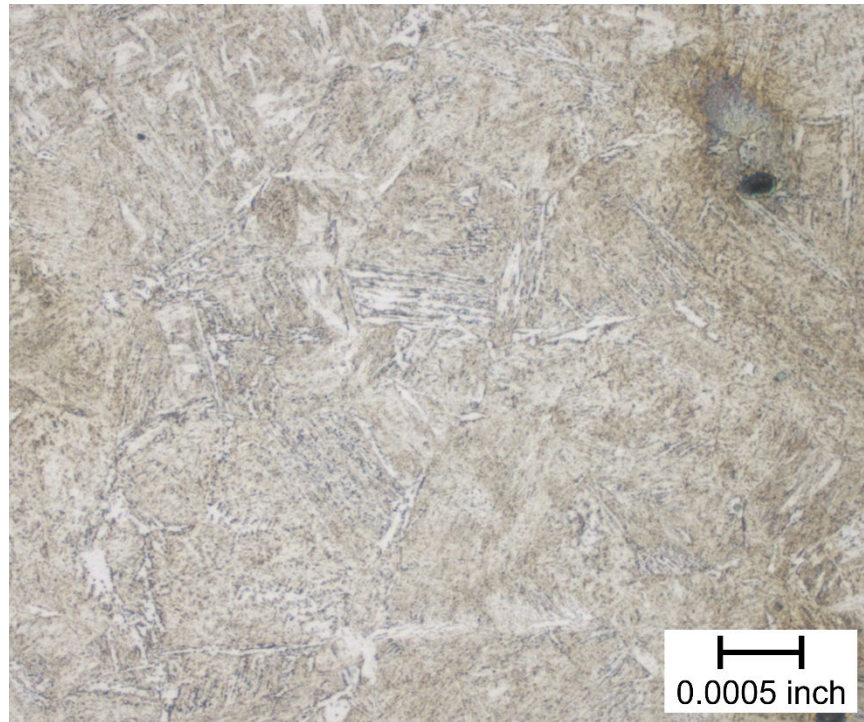


Figure 12. Polished and etched section of the rudder post showing the microstructure in the heat-affected zone near the fracture surface. (2% nital etch)

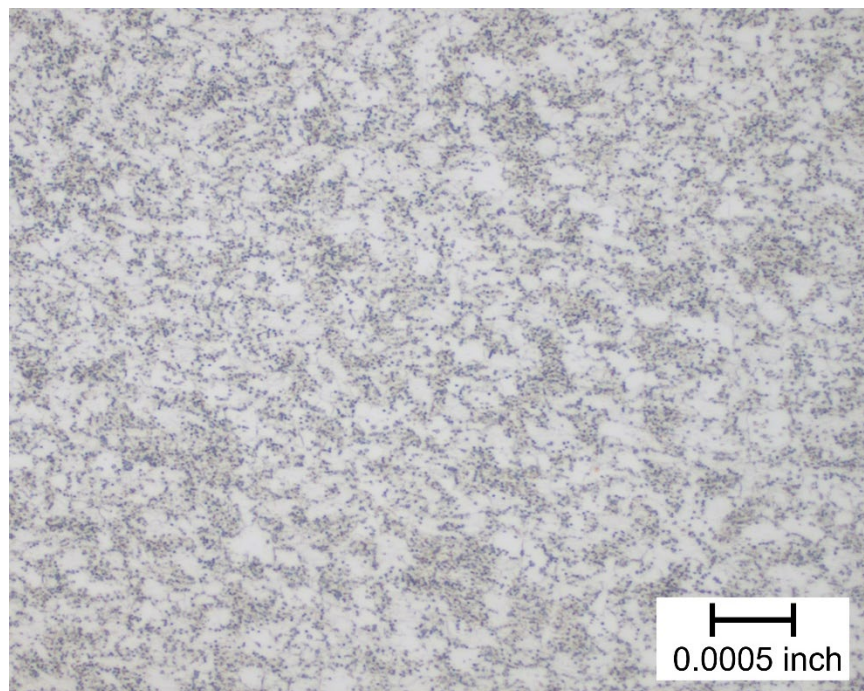


Figure 13. Polished and etched section of the rudder post showing the microstructure near the middle of the thickness away from the heat-affected zone. (2% nital etch)

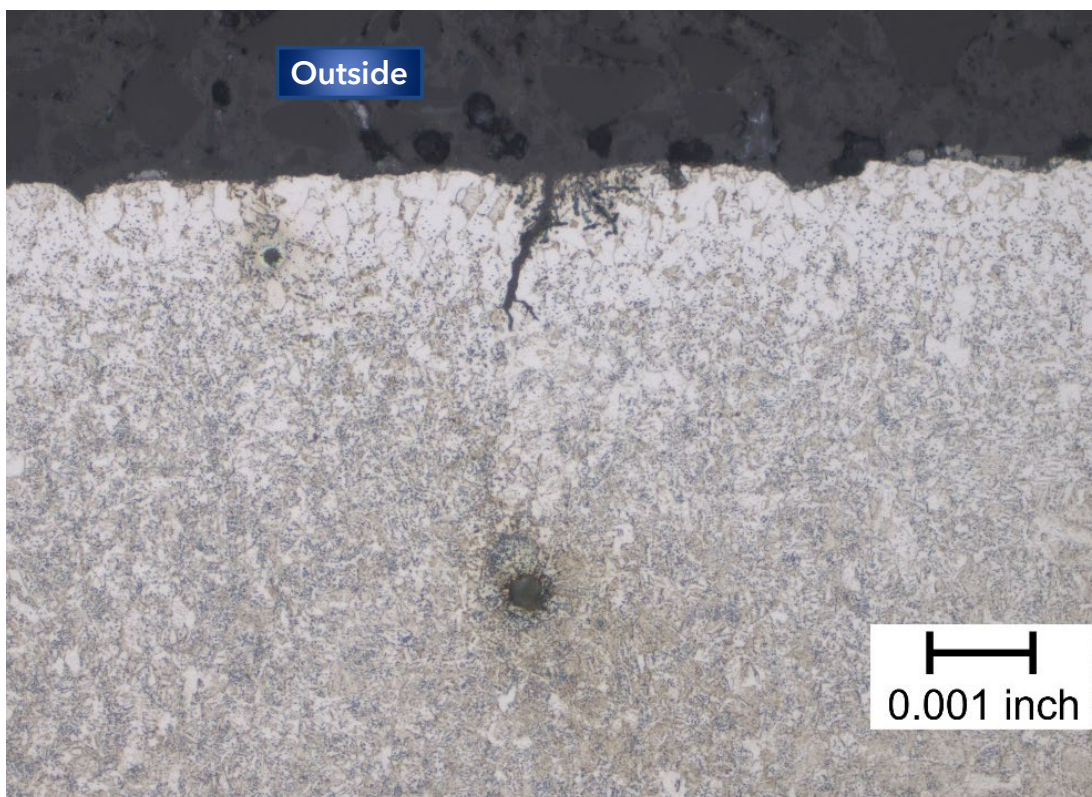
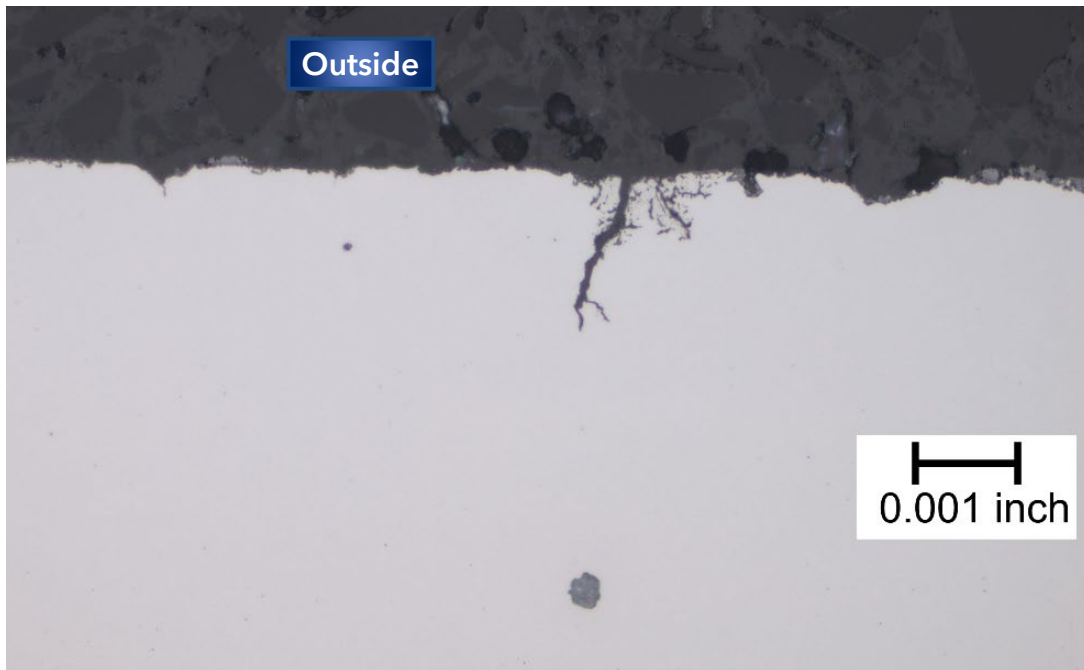


Figure 14. Secondary crack at the external surface in the rudder post cross-section near the right fracture location shown in the as-polished condition (upper image) and after etching with 2% nital (lower image).

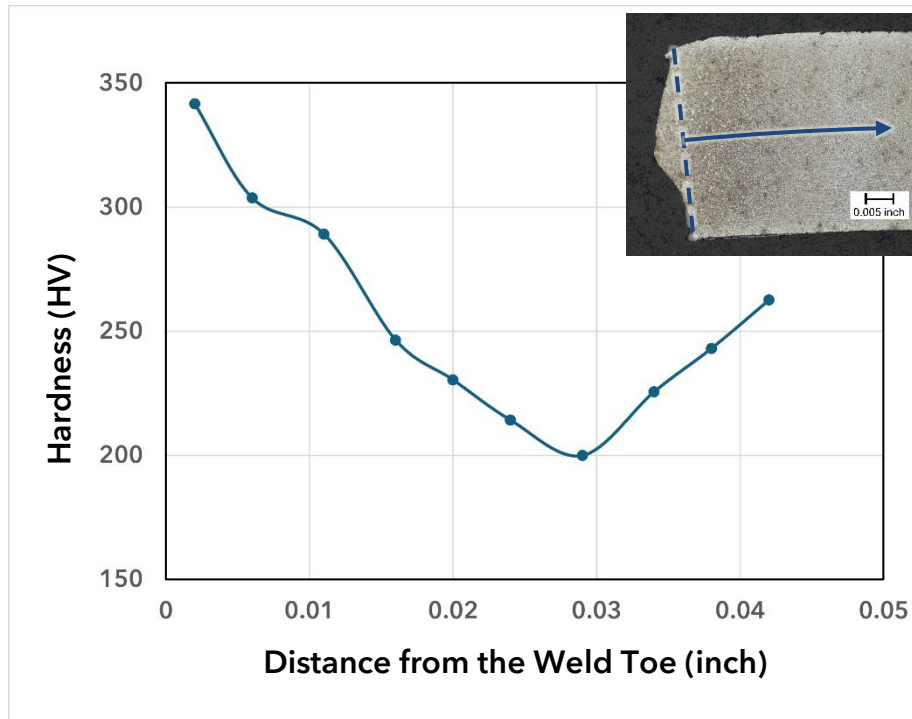


Figure 15. Plot of Vickers microhardness as a function of circumferential distance from the weld toe to the left of the middle knuckle (see inset image for illustration of the distance measurement).

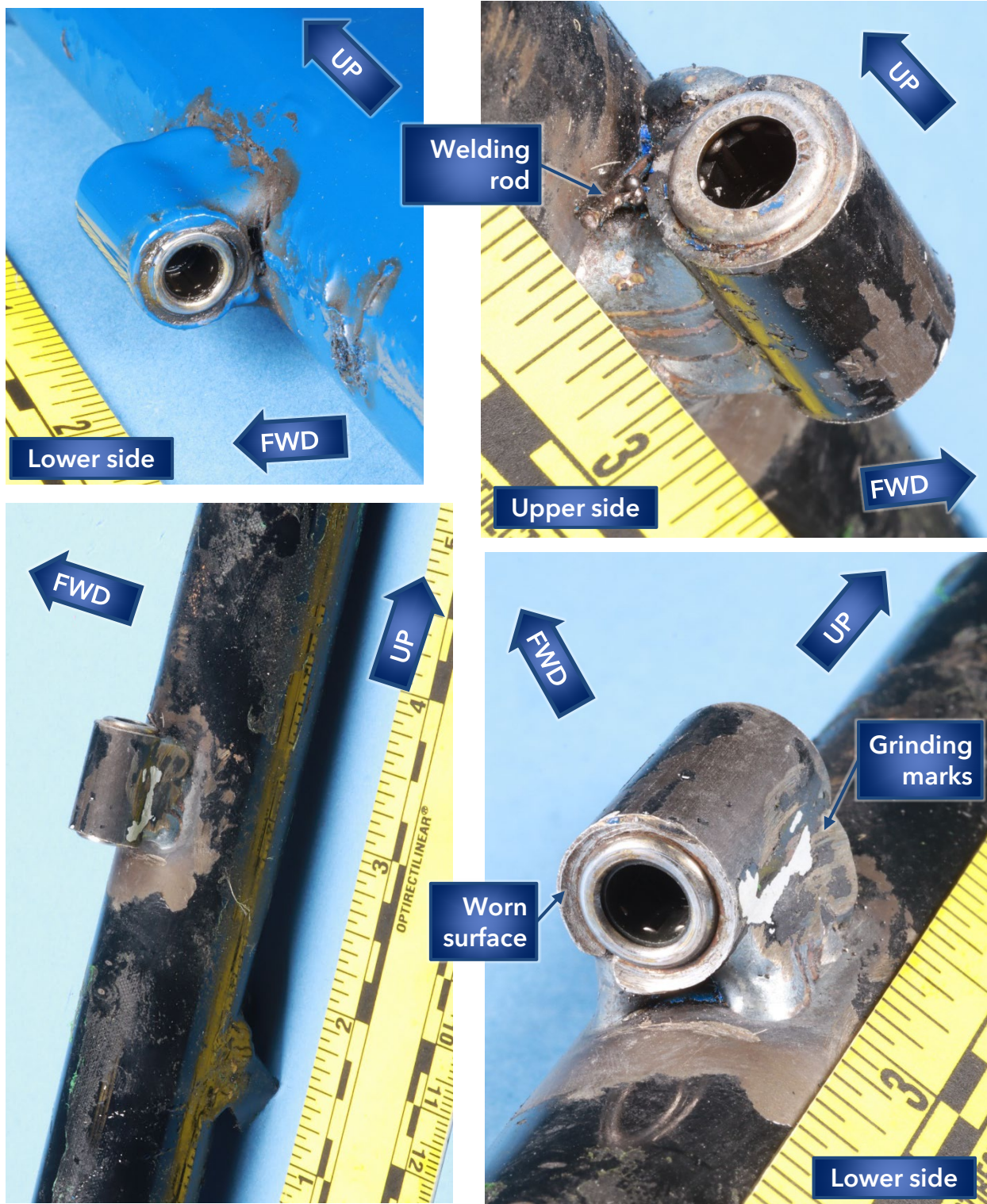


Figure 16. Views of the middle knuckle for the rudder's upper hinge as received (upper left) and after skin removal, sectioning, and cleaning with acetone (remaining 3 images).

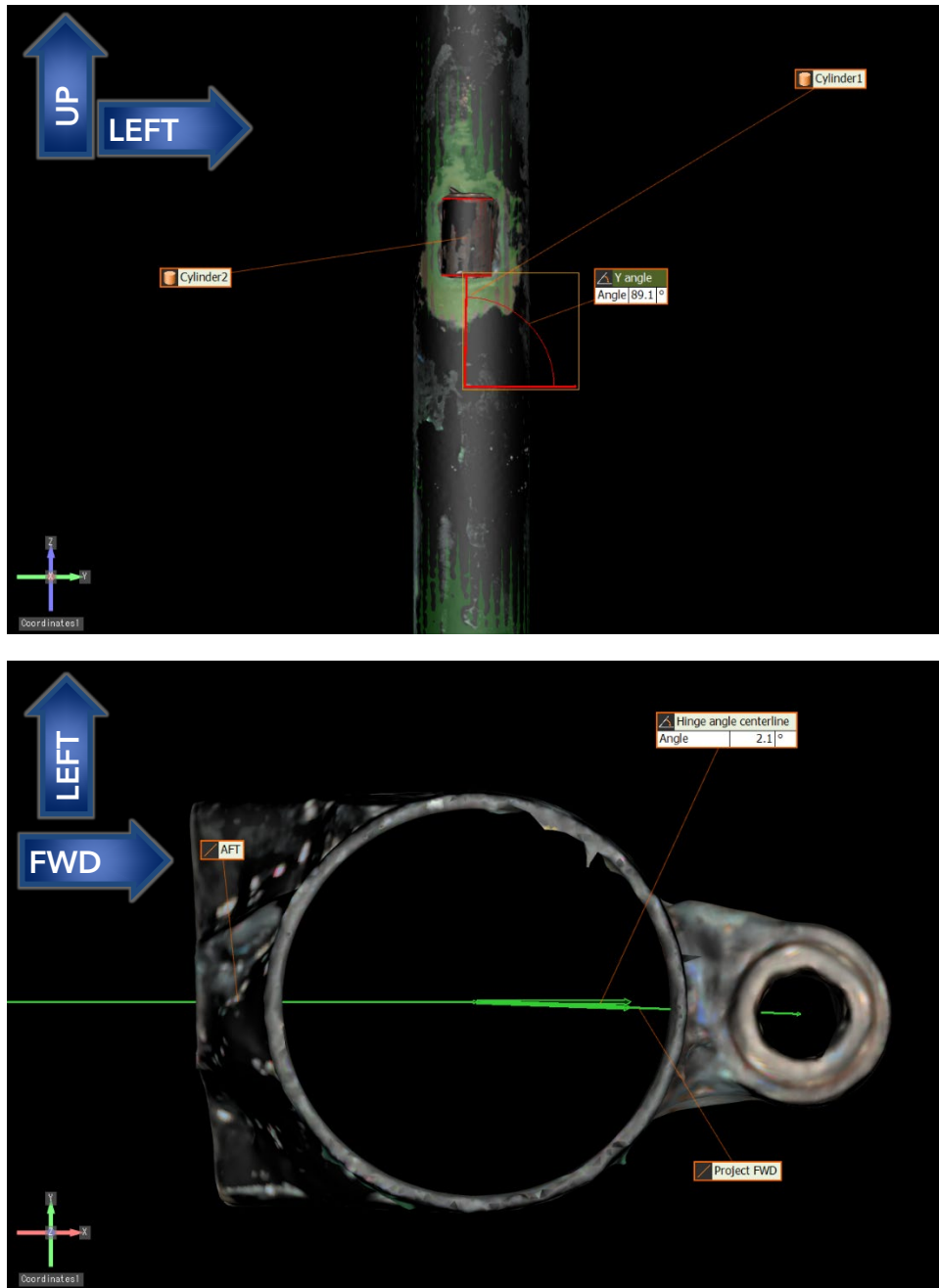


Figure 17. Three-dimensional representations of the sectioned and cleaned rudder post at the upper hinge location after scanning with a Keyence VL-500 series CMM. The upper image shows the angle between the post and middle knuckle axes as measured in the Y-Z plane, and the lower image shows the angular displacement of the hinge middle knuckle axis relative to the rudder centerline measured in the X-Y plane.