

NATIONAL TRANSPORTATION SAFETY BOARD

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



July 2, 2019

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-030

A. ACCIDENT INFORMATION

Place : Honolulu, Hawaii
Date : August 8, 2018
Vehicle : MD Helicopters 369D, N369MH
NTSB No. : WPR18LA221
Investigator : Mike Huhn (AS-WPR) / Van McKenny (AS-40)

B. COMPONENTS EXAMINED

Tail boom and tail rotor transmission assembly, pitch control assembly, fork assembly, and hub assemblies.

C. DETAILS OF THE EXAMINATION

Overall views of the submitted components are shown in figure 1. The tail rotor transmission assembly had fractured from the aft end of the tail boom, and the outboard teetering bolt had fractured. Teeter bearings for the outboard tail rotor blades were fractured from the fork assembly, and one of the outboard teeter bearings was missing. One of the teeter stops for the outboard blades was also missing.

The tail boom was a Federal Aviation Administration Parts Manufacturing Authority (FAA-PMA) component manufactured by Aerometals (El Dorado Hills, California). The data plate on the tail boom indicated it was part number 369X23500-505, serial number 0798. On the FAA-PMA tail boom, the tail rotor transmission assembly is attached with four MS21250-04026 bolts¹ that are threaded into MS21075L4 locking nut plates.² The nut plates are riveted to brackets that are in turn riveted to the interior surface of the tail boom. In the original equipment manufacturer (OEM) tail boom, the tail rotor transmission assembly is attached using studs extending from the aft end of the tail boom and fastened with lock nuts.

1. Tail Rotor Transmission Assembly Attachment

The aft end of the tail boom is shown in figure 2. The operator had reportedly cleaned the mounting lugs on the aft end of the tail boom after the accident. The two tail rotor transmission assembly attachment bolts at the left side of the tail boom were fractured, and closer views of the tail boom lugs with the fractured attachment bolts are

¹ Cadmium-plated steel tension bolt.

² Cadmium-plated steel self-locking nut plate with dry film lubricant.

shown in the upper and lower images in figure 2. On the right side of the tail rotor transmission housing, the lugs on the attachment flange were fractured as shown in figure 3. The assembly attachment bolts from the right side were intact and were received disassembled from the tail boom as shown in figure 1.

The tail rotor transmission housing was painted black and had a yellow-green layer under the black paint consistent with primer. Primer and paint were observed on the contact areas where the tail rotor transmission housing lugs mated to the tail boom lugs. Dashed lines in figure 3 indicate the areas on the left side of the tail rotor transmission housing flange that mated to the tail boom lugs. A piece of the paint and primer was flaked from the surface of the transmission housing flange with a scalpel, and the thickness measured 0.0058 inch. In figure 2, unlabeled arrows indicate black and yellow-green deposits that were observed on the mating surfaces of the tail boom lugs consistent with paint and primer transfer from the transmission housing to the mating tail boom lug surfaces. According to the OEM component overhaul manual, instructions for preparing the tail rotor transmission assembly for painting include a requirement to “mask all exposed gearshafts, input and output seals, mounting surfaces, holes, and pads.” The OEM maintenance manual notes in the tail rotor transmission installation instructions, “Ensure all paint and sealant is removed from mating surfaces.”

a. Attachment Bolts

In order to facilitate a detailed examination of the fractured tail rotor transmission assembly attachment bolts, rivets attaching the upper left nut plate bracket were drilled out to release the bracket from the tail boom. Once the rivets were removed, the nut plate bracket separated from the tail boom, but the attachment bolt piece remained within the upper left tail boom lug. The fractured attachment bolt had also separated from the nut plate. The upper left attachment bolt was then easily pushed out of the tail boom lug. The lower left attachment bolt was also found to be disengaged from the nut plate and was easily pushed out the aft end of the tail boom lug without removing the lower left nut plate bracket.

An overall view of the four assembly attachment bolts and the removed upper left nut plate bracket is shown in figure 4. The threads and portions of the grip areas of the attachment bolts appeared to be covered with black greasy deposits. A yellow-green coating consistent with primer was also noted on the threads. Slivers of fractured threads were observed intermixed with deposits on the threads of the lower left attachment bolt. According to the FAA-PMA tail boom maintenance practices in the Instructions for Continued Airworthiness, primer is applied to the assembly attachment bolts, and the assembly is installed while the primer is still wet.

The FAA-PMA specifies the assembly attachment bolts as MS21250-04026 bolts. Markings on the head of the two intact attachment bolts were consistent with the specified bolt type, and the length of the shanks measured 2.037 inches, also consistent with the standard for the specified bolt.

The greasy deposits on the threaded ends of the fractured assembly attachment bolts were wiped from the threaded portions of the fractured attachment bolt pieces, and the attachment bolts were then cleaned using an ultrasonic cleaner while submerged in acetone. A view of the fractured assembly attachment bolts after cleaning is shown in figure 5. Both attachment bolts were fractured in the grip portion of the shank. The lengths of the fractured attachment bolt pieces measured 1.220 inches and 0.898 inch for the upper left and lower left attachment bolt pieces, respectively.

Brackets in figure 5 indicate areas of thread damage where thread peaks were sheared on each fractured attachment bolt. The outer diameter of the threads was measured in the damaged area and where the threads were intact for each fractured attachment bolt. On both fractured attachment bolts, the outer diameters of damaged threads measured 0.233 inch. Intact threads adjacent to the grip on both fractured attachment bolts had an outer diameter of 0.243 inch measured thread peak-to-peak. The specified major diameter of the threads of a MS21250-04026 bolt is 0.2475 inch to 0.2495 inch.

Approximately 9 threads showed evidence of engagement with mating threads on the contact flanks and 8 threads were sheared on each fractured attachment bolt. The MS MS21075L4 locking nut plates into which the bolts were installed had 5 threads along their axial length. According to Aerometals Service Bulletin SB-001, the forward ends of the attachment bolts should extend beyond the nut plate to an extent that 1 to 4 threads should be visible after installation.

Optical images of the fracture surfaces for the fractured attachment bolts are shown in figure 6, and scanning electron microscope (SEM) images of the fracture surfaces are shown in figure 7. Portions of the fracture surfaces on each fractured attachment bolt had relatively flat fracture features with curving boundaries oriented in a plane perpendicular to the bolt axis, features consistent with fatigue. Dashed lines in figure 6 indicate these fatigue regions. The fatigue cracks initiated from multiple origins at the surface located around the circumference on each fractured attachment bolt and covered a relatively small portion of the total cross-sectional area, features consistent with low-cycle fatigue with relatively high stress levels. Dimple features consistent with ductile overstress fracture were observed in the central portion of each fractured attachment bolt during the SEM examination.

b. Nut Plates

The upper left nut plate shown in figure 4 was cleaned using acetone and cotton swabs, and a view of the cleaned threads is shown in figure 8. Sheared thread peaks were observed on the interior of the nut plate. The inside diameter was measured perpendicular and parallel to the line defined by the nut plate attachment rivets, and the inside diameter measurements were 0.232 inch and 0.230 inch, respectively. According to the thread specification for a MS21075L4 locking nut plate, the minor diameter for the threads is specified as 0.2152 inch to 0.2229 inch before deformation is applied for the locking function.

New MS21250-04026 bolts were purchased to facilitate measurement of running (drag) torque for the two right side nut plates on the tail boom. The drag torque was measured using a PCB Load and Torque³ Model 962 Recorder with a rotary torque angle transducer having a capacity of up to 20 pound inches. Primer was sprayed on the threads of the bolts consistent with the FAA-PMA installation instructions before each measurement, and the nut plates were wiped of debris using a cotton swab. Before measurement started, the bolts were threaded into the nut plates by hand until an increase in resistance was felt. Then the torque measurement device was applied to measure and record the drag torque as the bolt was threaded into the nut plate until approximately 2 threads were visible extending from the forward end of each nut plate, a total of approximately 4 turns. Measurements were conducted first using a new bolt in each nut plate (arbitrarily selected and labeled A and B), then the new bolt that had been used for the lower right nut plate (bolt B) was then reused for another test of the lower right nut plate followed by another test of the upper right nut plate.

Drag torque measurement results are listed in table 1. The minimum peak load measured was for the second test of the lower right nut plate, where the peak drag torque was 3.8 pound inches. The highest peak load was measured during the first test of the upper right nut plate, where the peak load measured 11.6 pound inches. According to the Torque Maintenance Practice section of the OEM maintenance manual, the drag torque should be within a range of 3.5 pound inches to 30 pound inches for the specified attachment bolt thread size. The Torque Maintenance Practice section also states that the drag torque should be added to the specified torque value provided in the maintenance instructions.

Table 1. Drag Torque Measurements

Test Number	Bolt Reference	Nut Plate Position	Peak Drag Torque (pound inches)
1	A	Upper right	11.6
2	B	Lower right	4.5
3	B	Lower right	3.8
4	B	Upper right	7.1

The Torque Maintenance Practice section of the OEM maintenance manual also states torque values listed apply to cadmium-plated bolts and cadmium-plated nuts coated with molybdenum disulfide dry lubricant. The manual further states manufacturer-applied lubricant should not be removed, and no additional lubricant should be added. Tail rotor transmission installation instructions in the Aerometals Service Bulletin SB-001 state primer should be added to the attachment bolts before installation but does not specify where the primer should be applied. For installation of a tail rotor transmission assembly on an OEM tail boom, the OEM maintenance manual states primer should be applied to holes and to the grip section of the attachment studs.

³ PCB Piezotronics, Inc., Depew, New York.

After the torque tests were completed, the lower right nut plate bracket was removed from the tail boom by drilling out the rivets attaching the bracket to the tail boom. The threads of the nut plate were then cleaned with a cotton swab and acetone. A view of the intact cleaned threads for the lower right nut plate is shown in figure 9. The inside diameter of the nut plate threads measured 0.217 inch and 0.220 inch for measurements obtained perpendicular and parallel to the nut plate attachment rivets, respectively.

2. Fork Assembly with Teeter Bearings

The arms of the tail rotor fork assembly were intact as shown in figure 1. The fork assembly rotated smoothly and freely, and continuity through the tail rotor transmission was noted with corresponding rotation of the tail rotor transmission input shaft. The inboard teeter bearings remained installed in the fork assembly, and the outer teeter bearings had separated from the assembly. Only one of the two outboard teeter bearings was recovered as shown in figure 1.

Close views of the recovered outboard teeter bearing are shown in figures 10 and 11. The teeter bearing consisted of concentric metal rings separated by layers of elastomer as shown in the view in figure 11. Cracks were noted in the elastomer, and small chunks of elastomer had accumulated on the radially outward surface in grooves between the concentric metal rings.

As installed, the teeter bearings are bonded to the fork assembly. Remnants of gray adhesive were observed in isolated areas of the mating surfaces of the recovered outboard teeter bearing and on the bearing seats in the fork arms. In some areas the apparent adhesive material appeared to be discolored yellow, brown, and black. Fretting damage was noted on the surface of the recovered outboard teeter bearing around approximately $\frac{1}{4}$ the circumference as noted in figure 10, and corresponding fretting damage was noted on the fork assembly on one of the outboard bearing seats. The fretting damage on the fork arm was located on the inboard trailing quadrant on the bearing seat surface. An arc-shaped inward deformation was observed on the side of the recovered outboard teeter bearing as indicated in figure 10, consistent with off-axis contact with the edge of the bearing seat. The fretting damage appeared continuous across the deformation, consistent with the deformation occurring after the fretting damage.

The bearing seat in the fork arm that held the missing outboard teeter bearing is shown in figure 12. Isolated areas of gray adhesive were noted on the surface on the radially outward face of the fork arm. On the bearing seat surface, isolated areas appearing consistent with discolored adhesive in shades of yellow, brown, and black were observed as indicated in figure 12. No evidence of fretting damage was observed on the bearing seat surface for the missing outboard teeter bearing.

Adhesion of the inboard teeter bearings to the fork assembly was tested by placing the fork assembly in a vice and fastening a bolt to the center of one of the inboard teeter bearings. The bolt was then rotated with a wrench, and movement of the concentric metal rings was observed. The process was repeated on the opposite inboard teeter bearing.

In both cases, the concentric rings rotated consistent with adhesion between the inboard teeter bearings and the fork arms and between individual bearing elements.

After the adhesion tests were completed, one of the inboard teeter bearings was selected for disassembly from the fork arm. To complete the disassembly, the fork arm was heated with a heat gun while applying pressure to press the bearing out of the bearing seat, resulting in a cohesive fracture in the adhesive. Views of the separated inboard teeter bearing and the mating bearing seat in the fork assembly are shown in figures 13 and 14, respectively. Gray adhesive material remained attached to both the bearing surfaces and the mating seat surfaces with uniform coverage. Isolated areas of the adhesive appeared discolored to a yellow and brown color. The recovered outboard teeter bearing is shown for comparison at the left in figure 13.

The radially outward face of the removed inboard teeter bearing is shown in figure 15. Cracks were noted in the elastomer, and small chunks of elastomer had accumulated on the radially outward surface in grooves between the concentric metal rings.

According to the OEM component overhaul manual, when replacing the teeter bearings in the fork assembly, primer is applied to the mating surfaces of the bearing and the bearing seat in the fork assembly before installation. After the primer is dry, adhesive is applied to the mating surfaces of the bearing and the fork assembly, and a glass-fiber scrim cloth is applied to the bearing where it mates to the bearing seat.⁴ Each teeter bearing is then inserted and aligned in the bearing seat, and a specified spring force is applied to press the bearings into the seats as the adhesive cures. A similar teeter bearing installation procedure is noted in the OEM engineering drawing for a new tail rotor fork assembly, including application of primer on the mating surfaces of the teeter bearings and fork arms and application of a glass-fiber scrim cloth with the adhesive applied to the mating surfaces.

No evidence of primer was observed on the exposed surfaces of the recovered outboard teeter bearing or in the exposed outboard bearing seats of the fork assembly. Additionally, no evidence of a glass-fiber scrim cloth was noted in the adhesive remnants of the outboard bearing seats, recovered outboard teeter bearing, or in the fractured adhesive from the removed inboard teeter bearing. According to a representative for the OEM participating as an investigative party member, the scrim cloth is used in the joint to ensure proper spacing is maintained in the adhesive joint during the bonding process.

3. Tail Rotor Hubs and Teeter Bolts

Close views of the inboard faces of the tail rotor hubs are shown in figures 16 and 17. Marks corresponding to contact with teeter stops were observed on both hubs as noted in figures 16 and 17. The inboard teeter bolt was intact and is shown disassembled from the inboard tail rotor hub in figure 1. The outboard teeter bolt was fractured in its

⁴ A scrim cloth is applied to the mating surfaces to facilitate consistent bond strength and to prevent excessive adhesive squeeze-out from the force applied during the adhesive curing procedure.

shank and remained within the outboard tail rotor hub as shown in figures 17 and 18. According to the OEM engineering drawing for the teeter bolt, the bolt material is specified as nickel alloy 718.

The fractured outboard teeter bolt was removed from the outboard tail rotor hub and was cleaned using an ultrasonic cleaner while submerged in a solution of Alconox detergent and water. A close view of the cleaned fracture surface is shown in figure 19. Curving crack arrest lines consistent with fatigue were observed extending across approximately 75 percent of the fracture surface to the curving boundary indicated by a dashed line in figure 19. The fatigue features emanated from an origin at the location indicated in figure 19. Relatively rough faceted features were observed on a plane perpendicular to the bolt axis near the origin up to a depth of 0.061 inch. Then the fracture transitioned to relatively smoother features on a plane at a slight angle relative to the bolt axis to the fatigue boundary. Beyond the fatigue boundary, fracture occurred at approximately 45 degrees to the axis consistent with ductile overstress fracture of the remaining ligament.

An oblique view of the outboard teeter bolt is shown in figure 20. A relatively smooth rubbed area consistent with contact damage associated with movement between the bolt and the mating surface was observed adjacent to the fracture surface as indicated in figure 20. The fatigue origin was located at the surface near the edge of the rubbed area.

The fractured outboard teeter bolt was subsequently examined using an SEM. The fracture surface was surveyed and imaged, but much of the fracture surface near the origin was covered with nonconductive oxides and imaging was difficult due to the height of the sample. Therefore, the bolt was removed from the SEM and cut through the shank to reduce the length of the piece with the fracture surface. Then the piece with the fracture surface was submerged in Evapo-Rust⁵ for approximately 15 minutes followed by gentle cleaning with a soft-bristle brush. Further examination in the SEM revealed the cleaning process had removed oxides that had obscured fracture features near the origin.

An overall view of the fatigue region as imaged using the SEM is shown in the upper image in figure 21, and a closer view of the relatively rough faceted region extending to a crack depth of 0.061 inch is shown in the lower image in figure 21. In the lower image in figure 21, the relatively rough faceted region appears darker due to the difference in angle relative to the electron detector.

Figures 22 through 24 show typical features progressing from the origin to the fatigue boundary and into the overstress region of the remaining ligament as viewed in the SEM. Unlabeled arrows in each figure point in the direction of local crack growth. Figure 22 shows typical fatigue features in the faceted region near the origin. The upper image in figure 22 shows an overall view near the origin area where remaining oxides on the surface appear brighter. Fatigue crack growth along faceted planes was observed

⁵ Evapo-Rust is a chelating agent-based rust remover manufactured by Harris International Laboratories, Springdale, Arkansas.

consistent with fatigue in nickel alloy 718. The lower image in figure 22 shows typical fatigue features in one of the facets, and crack arrest lines have a jagged appearance consistent with microstructural interaction with the advancing crack front.

Figure 23 shows fatigue features farther from the origin near the edge of the faceted region (upper image) and in the smoother region at a location approximately 75 percent of the total fatigue crack depth (lower image). The upper image in figure 24 shows fatigue features near the fatigue boundary. Unlabeled arrows in figure 24 point to a striation associated with crack growth. Linear crystallographic features appearing as parallel light-gray and dark-gray lines oriented at approximately ± 45 degrees to the crack growth direction were also observed on this facet.

Dimple features consistent with ductile overstress were observed on the remaining 25 percent of the fracture surface beyond the fatigue boundary. The lower image in figure 24 is a representative sample of the observed overstress features beyond the fatigue boundary.

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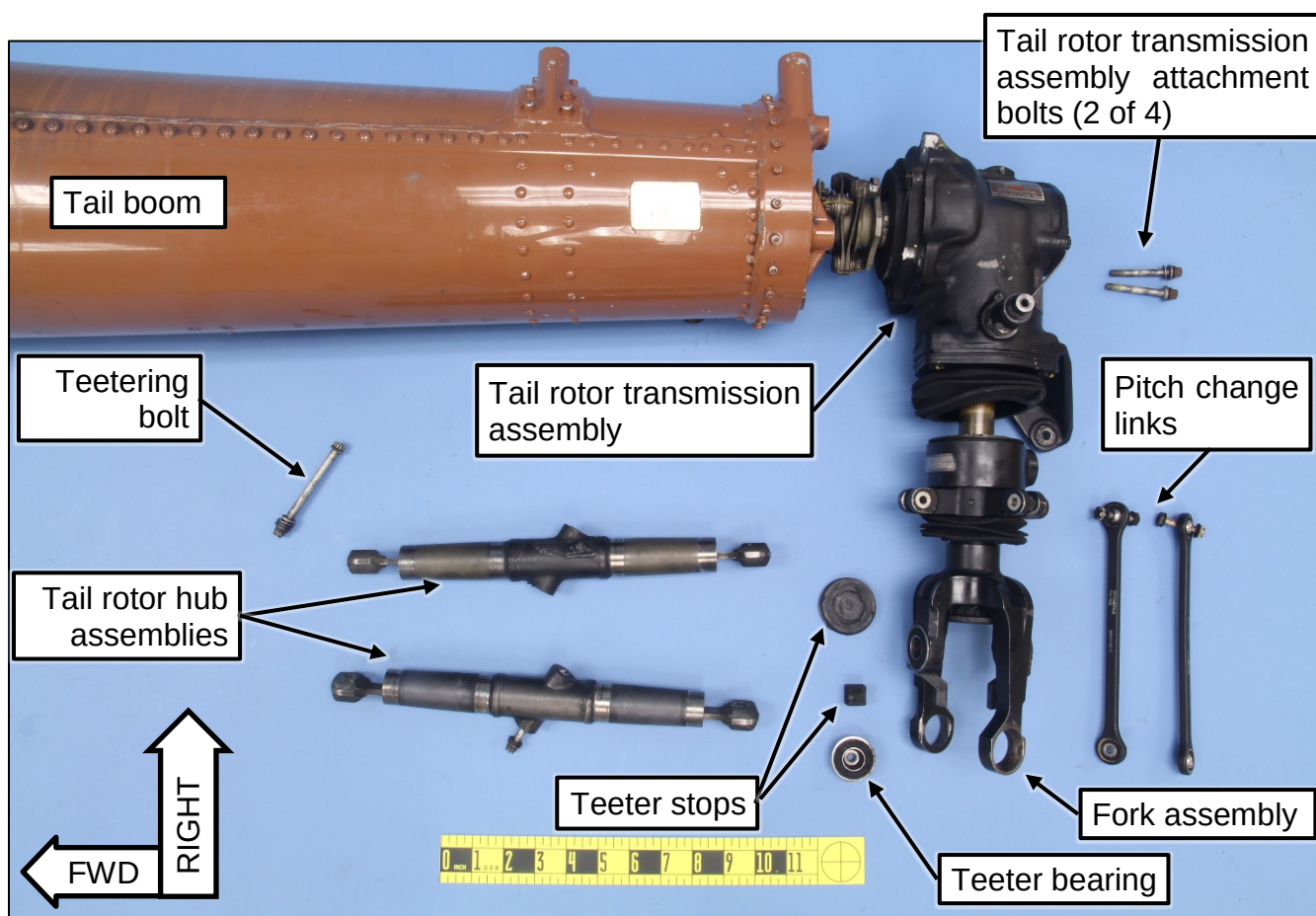
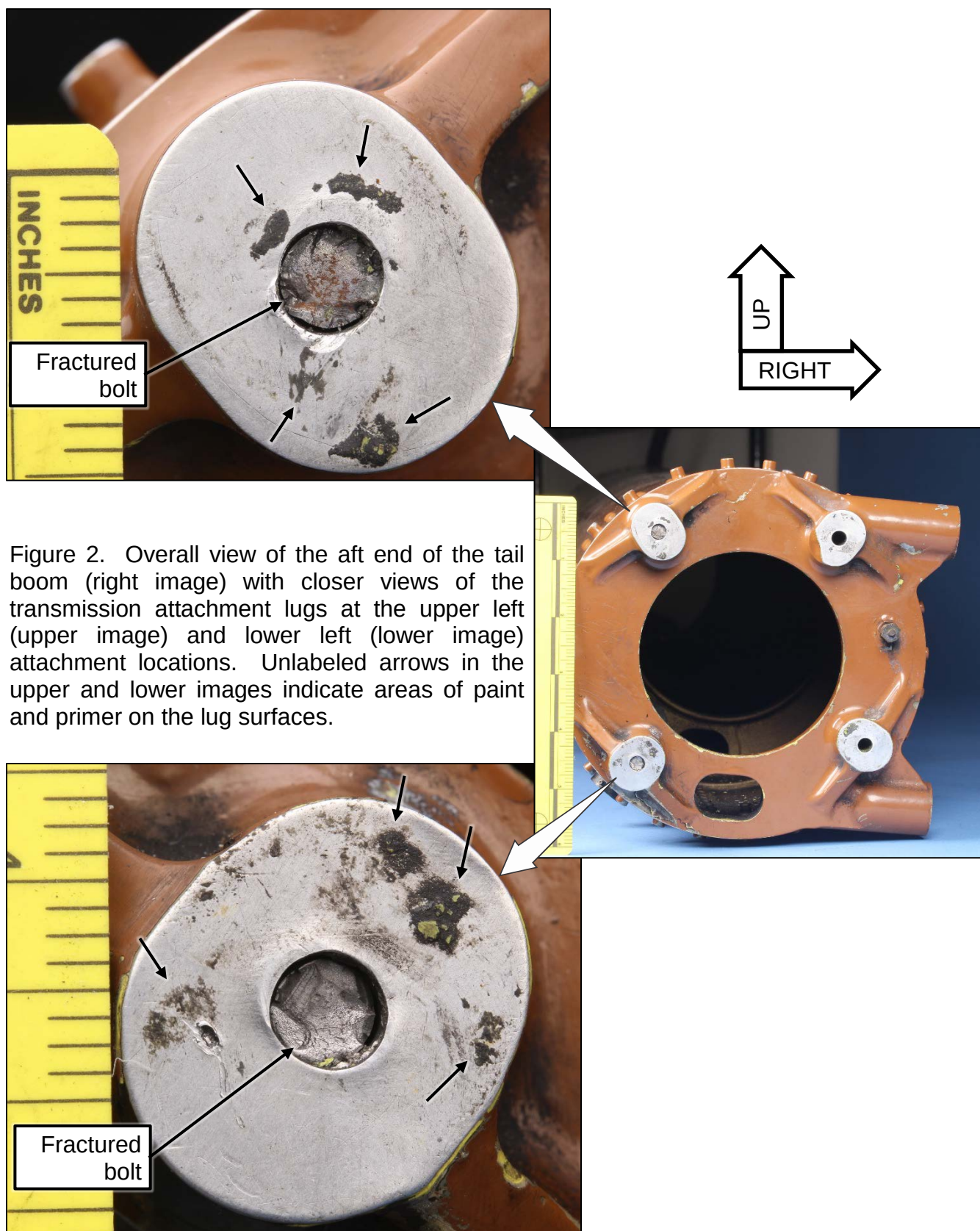
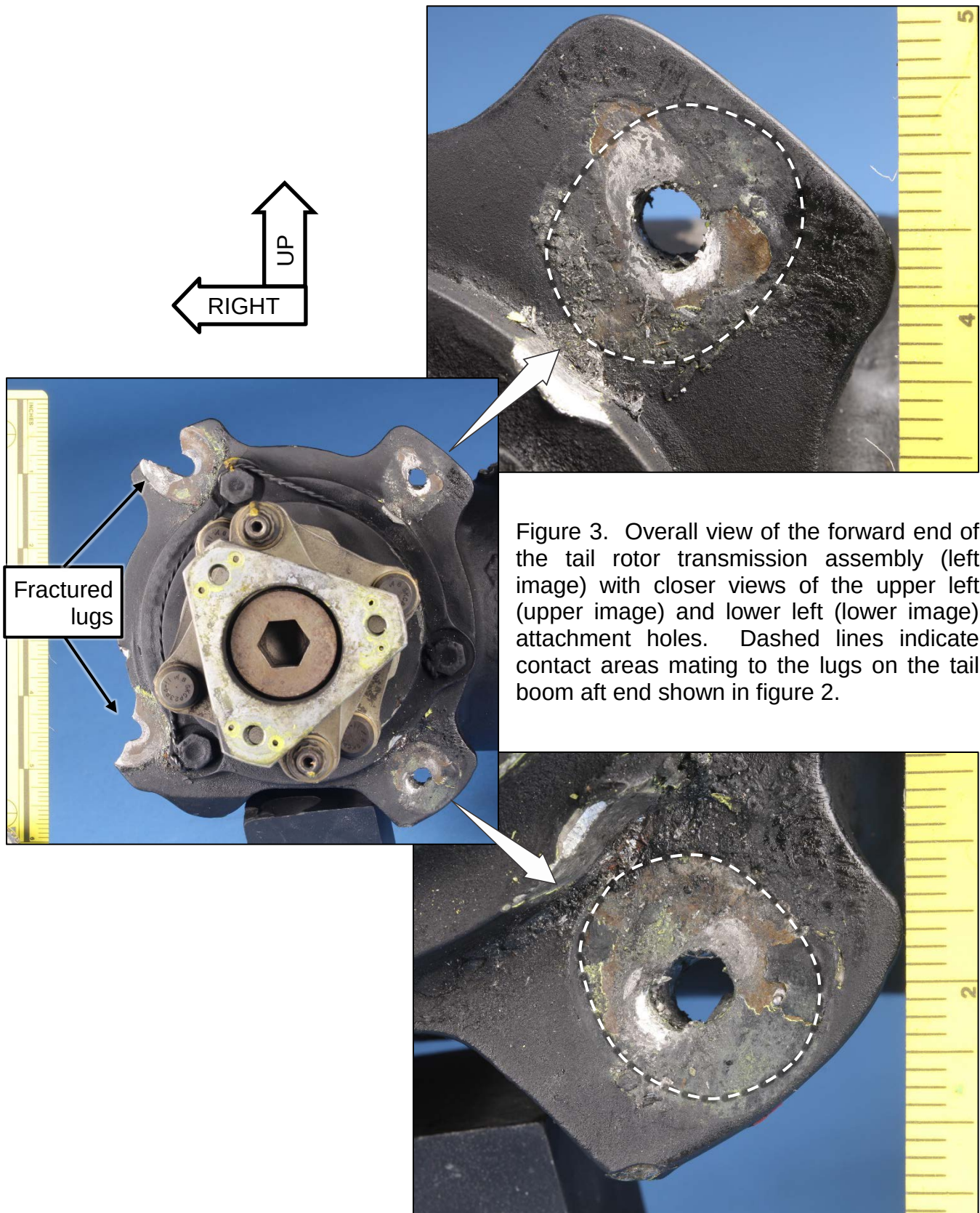


Figure 1. Overall view of the submitted components (upper image) with a closer view of the tail rotor assembly at the aft end of the tail boom (lower image).





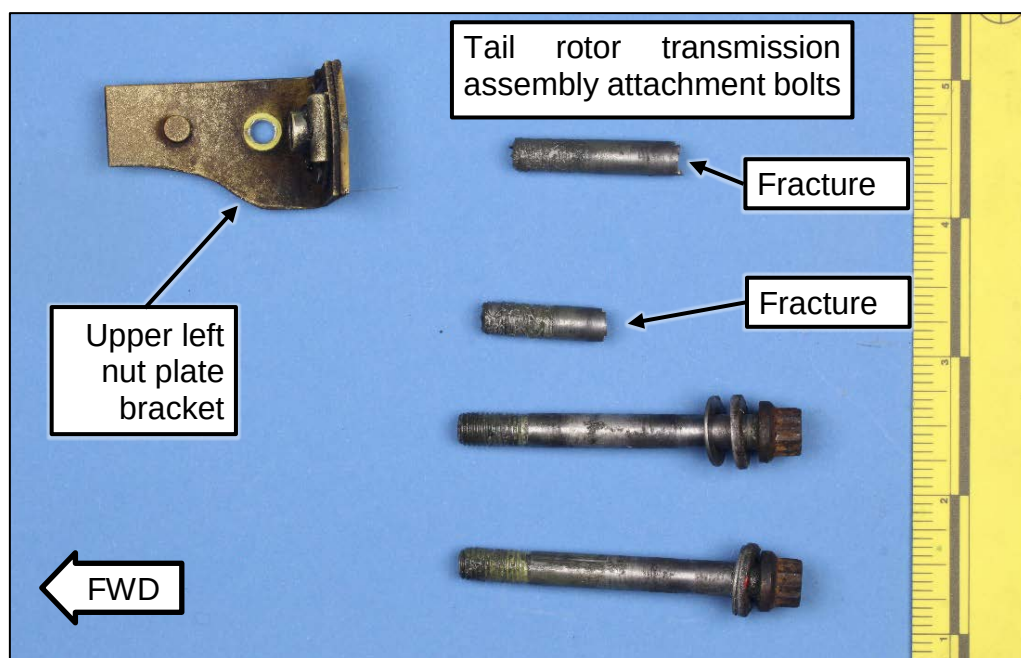


Figure 4. Tail rotor transmission assembly attachment bolts and tail boom upper left nut plate bracket after disassembly from the tail boom.

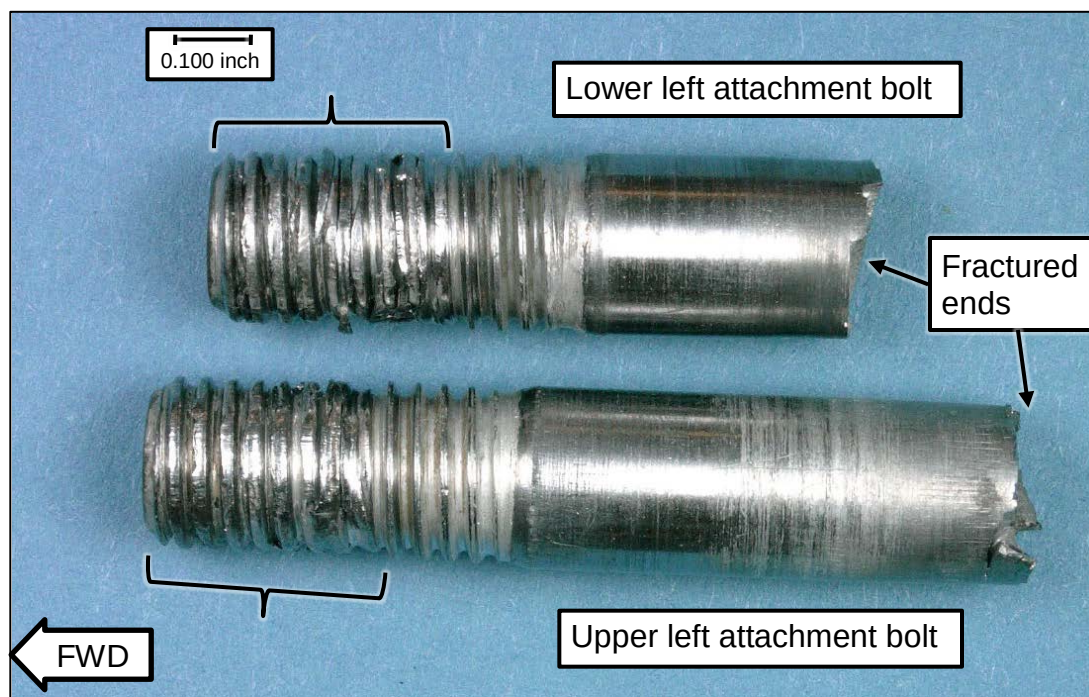


Figure 5. Close view of the fractured tail rotor transmission assembly attachment bolts after cleaning. Brackets indicate threads with sheared thread peaks.

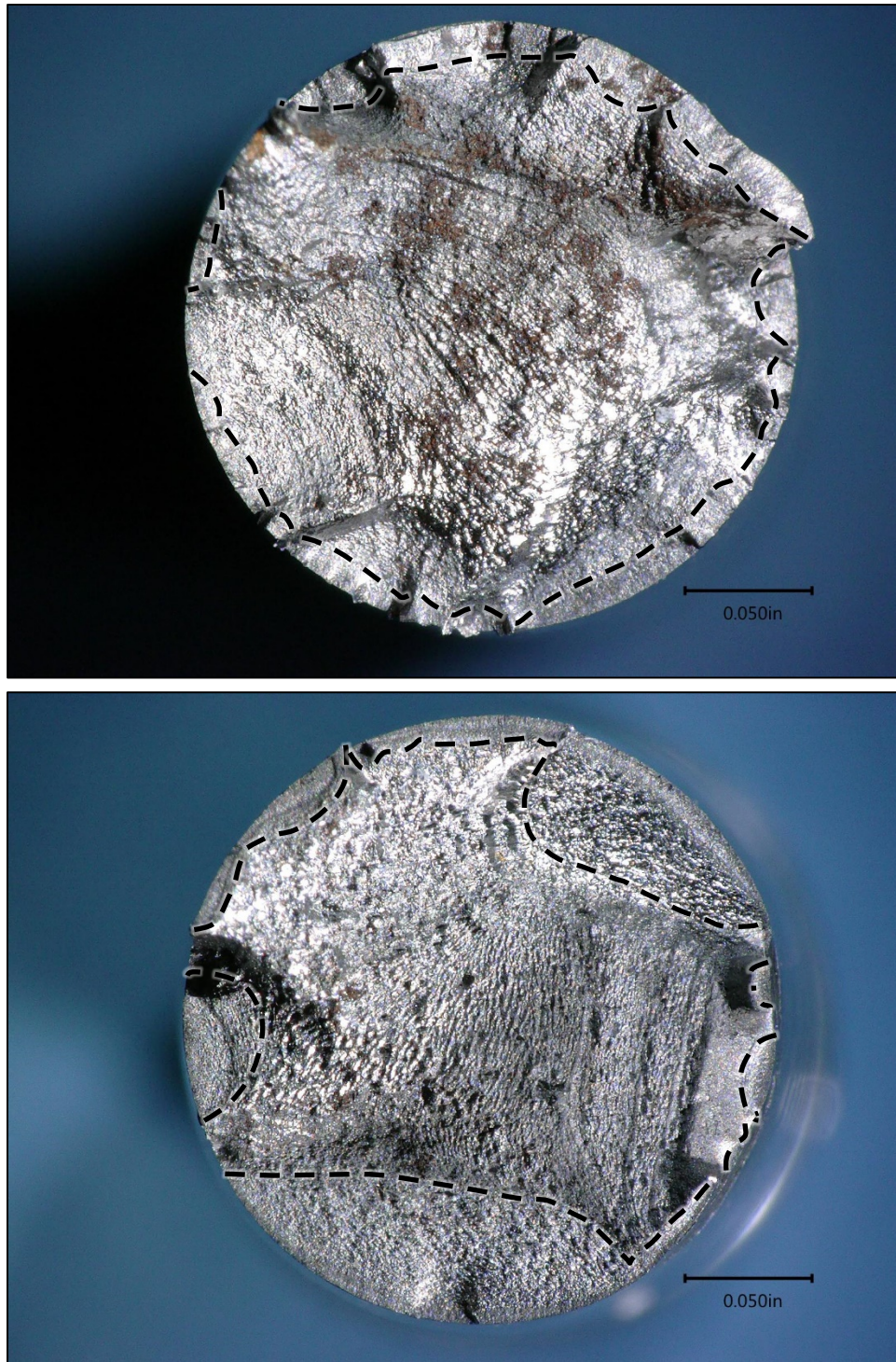


Figure 6. Optical images of the fracture surfaces on the tail rotor transmission assembly attachment bolt pieces from the upper left (upper image) and lower left (lower image) positions. Dashed lines indicate boundaries of relatively flat fatigue regions.

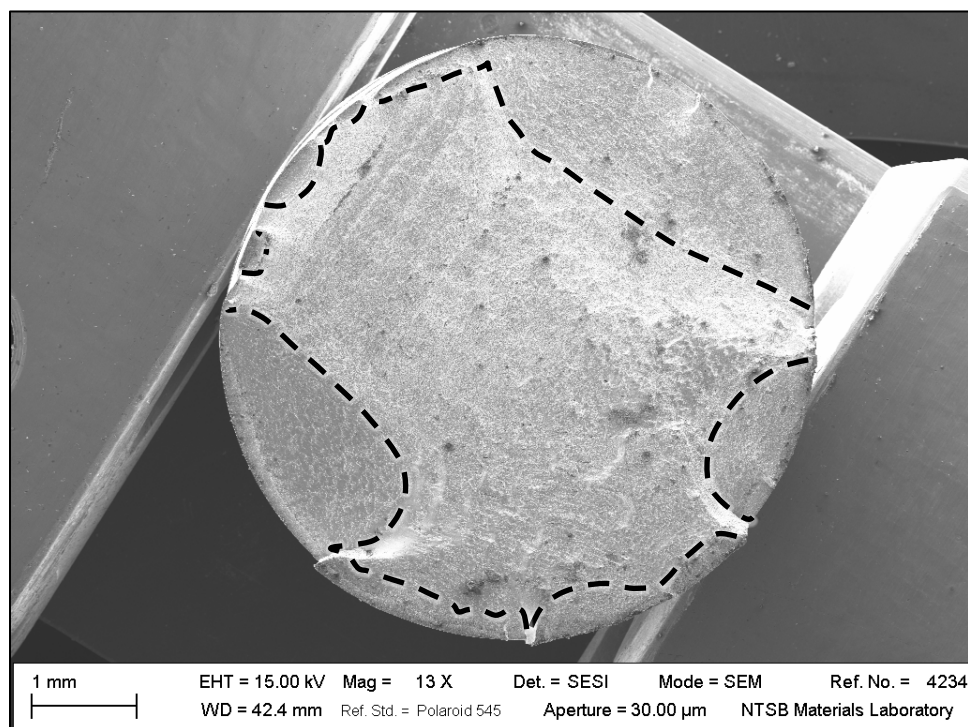
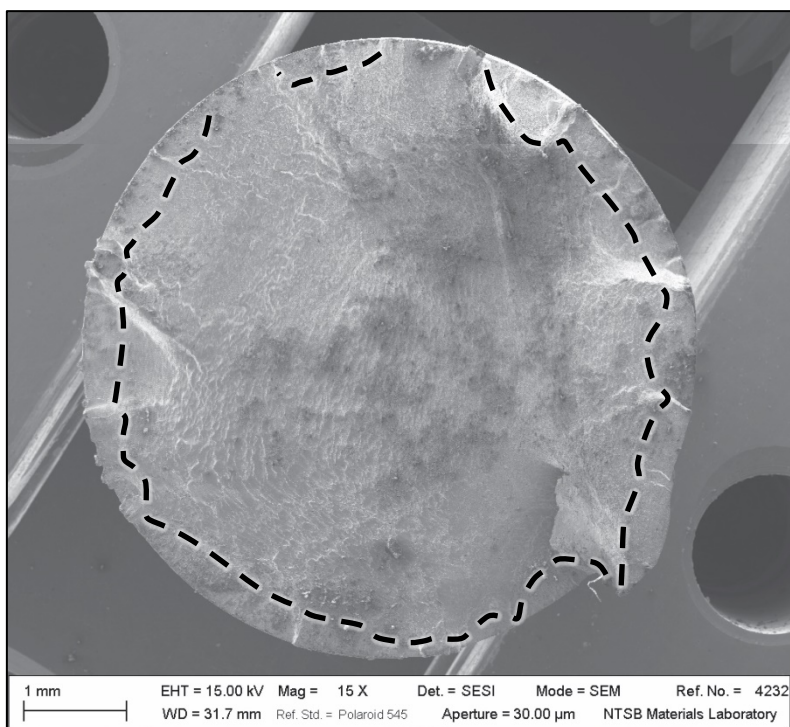


Figure 7. SEM images of the fracture surfaces on the tail rotor transmission assembly attachment bolt pieces from the upper left (upper image) and lower left (lower image) positions. Dashed lines indicate boundaries of relatively flat fatigue regions.

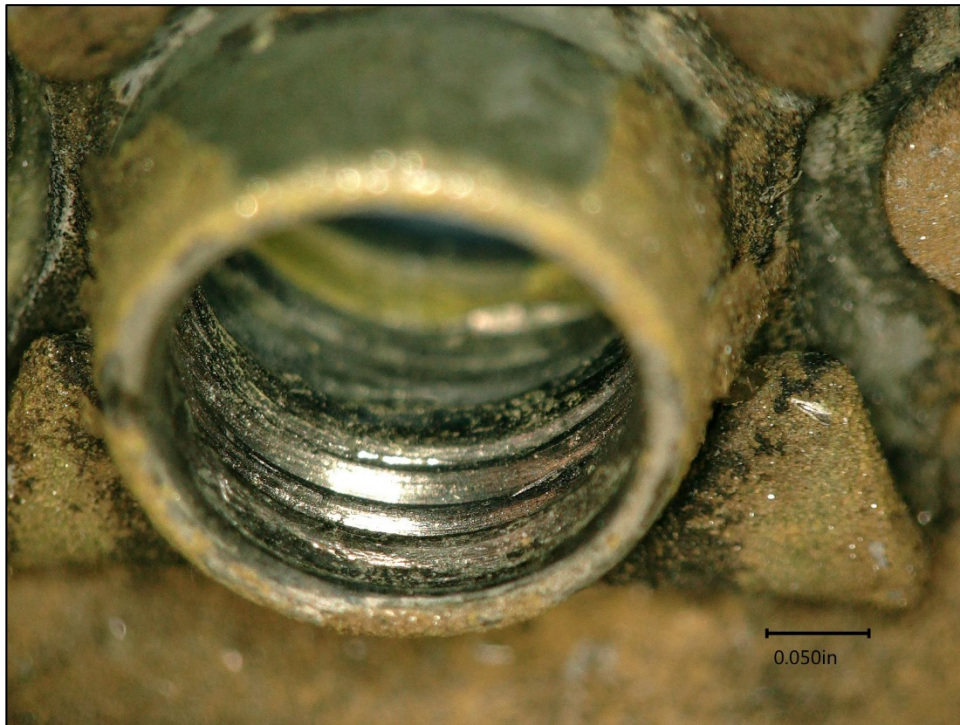


Figure 8. Optical image of the upper left nut plate after disassembly from the tail boom and after cleaning showing damaged screw threads.



Figure 9. Optical image of the lower right nut plate after disassembly from the tail boom and after cleaning showing intact screw threads.

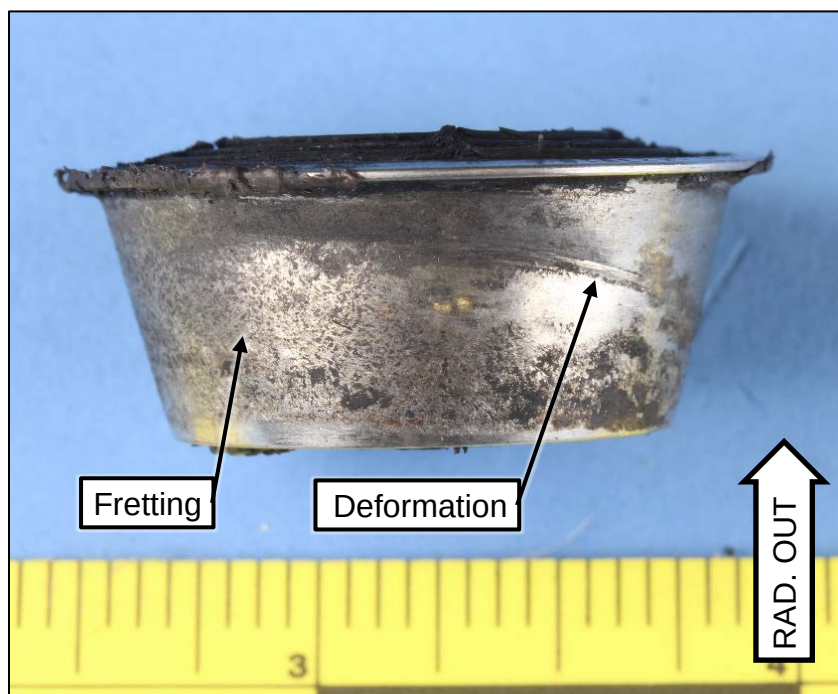


Figure 10. Side view of the recovered outboard teeter bearing. Locations of fretting damage and off-axis contact deformation are indicated. The radially outward direction is also indicated for reference.



Figure 11. Close view of the radially outward side of the recovered outboard teeter bearing.



Figure 12. Fork assembly showing the seat for the missing outboard teeter bearing. Remnants of adhesive on the mating surfaces are indicated.

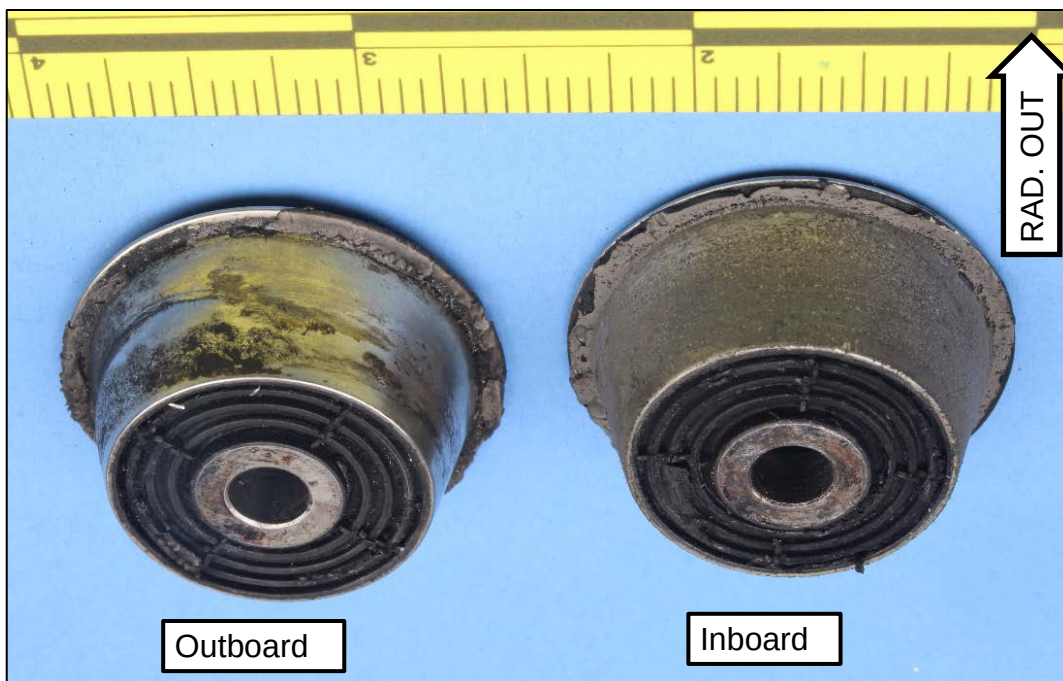


Figure 13. Views of the recovered outboard teeter bearing and one of the inboard teeter bearings after the inboard teeter bearing was pressed out of its seat in the fork assembly.



Figure 14. Inboard teeter bearing seat after the teeter bearing was removed. Gray adhesive covered the seat surface.



Figure 15. Close view of the radially outward side of the removed inboard teeter bearing.



Figure 16. Inboard face of the inboard tail rotor hub showing contact marks corresponding to contact with the teeter stop.

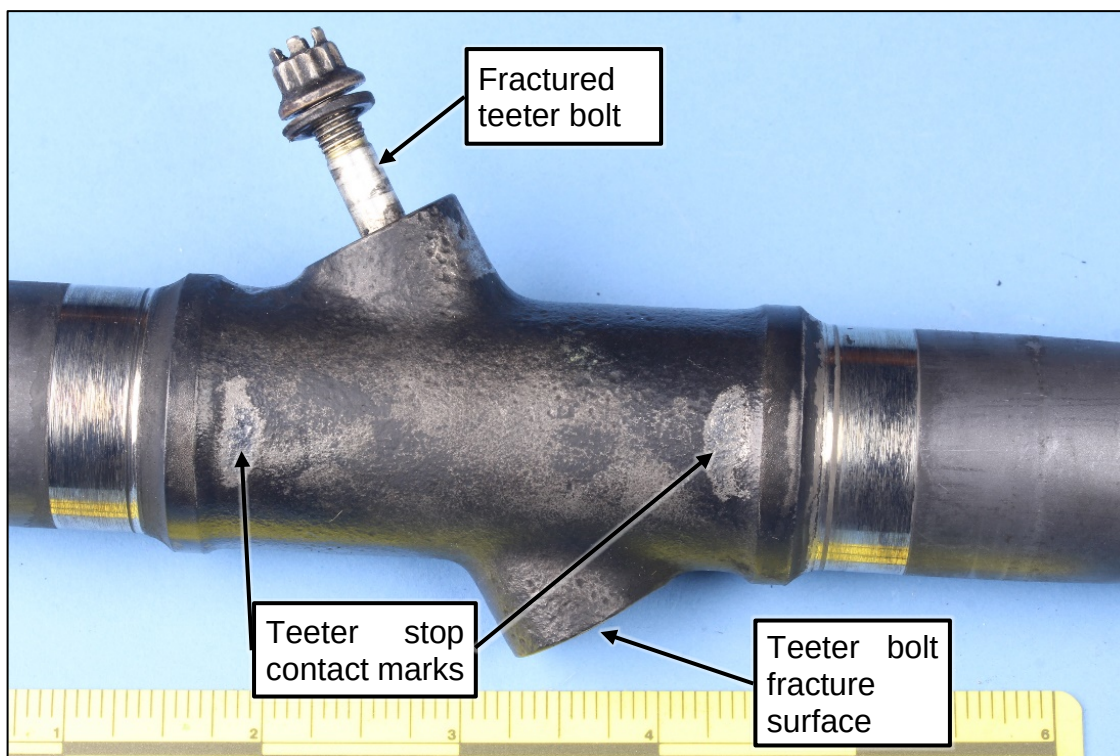
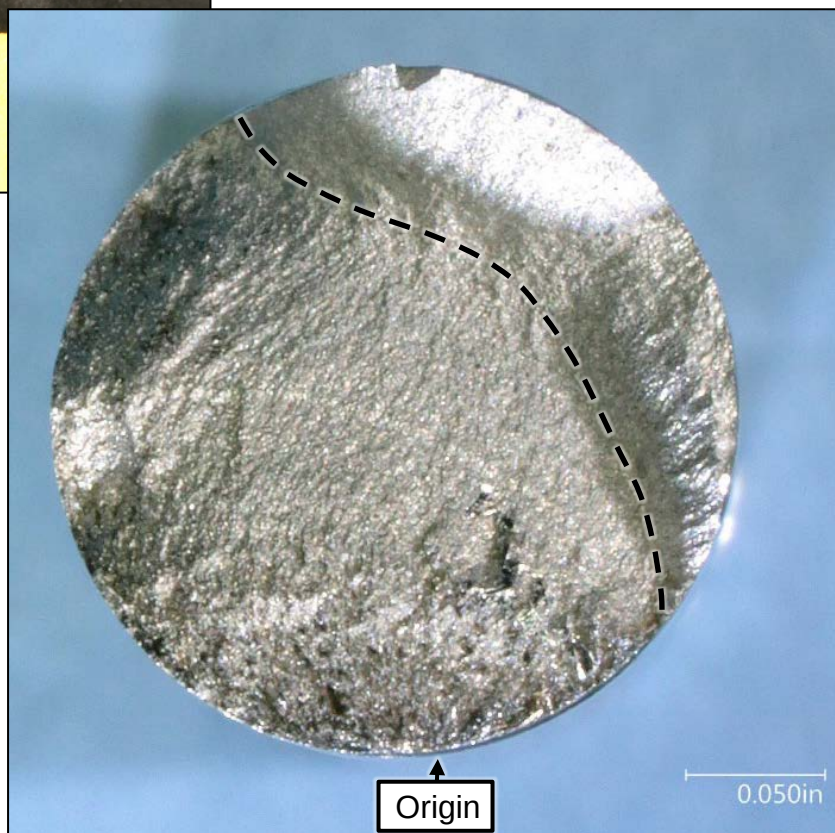


Figure 17. Inboard face of the outboard tail rotor hub showing contact marks corresponding to contact with the teeter stop.



Figure 18. Outboard teeter bolt fracture surface before removal from the hub.

Figure 19. Outboard teeter bolt fracture surface after removal from the hub and cleaning with a brush using Alconox detergent and water. The fatigue origin is indicated, and a dashed line indicates the fatigue boundary.



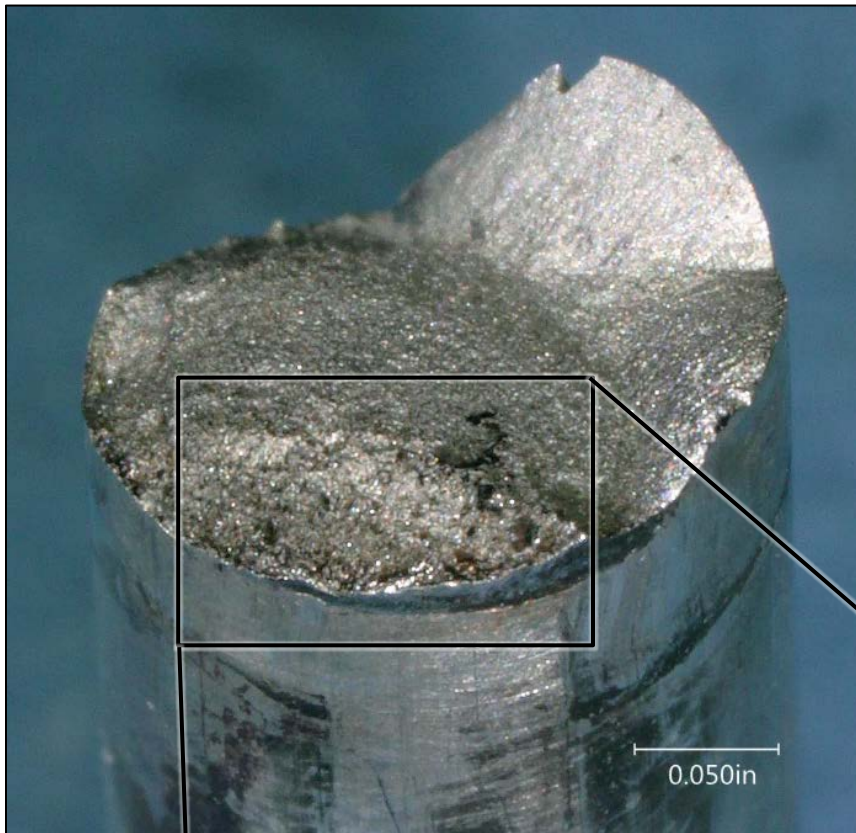
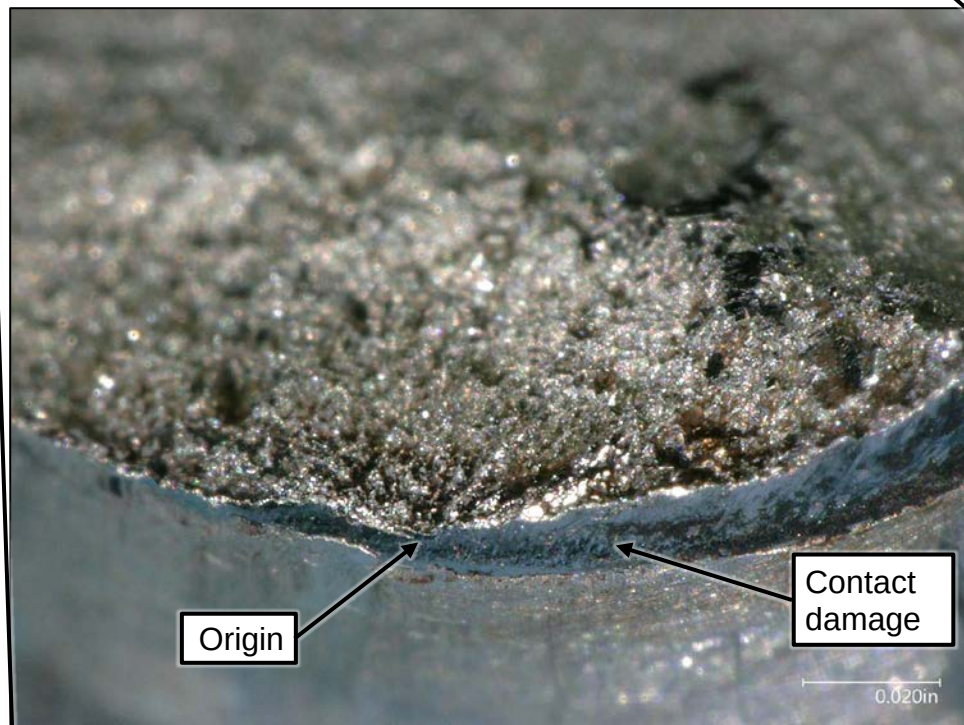


Figure 20. Oblique view of the outboard teeter bolt fracture surface shown in the previous figure. The origin was located at an area of contact damage on the outer surface.



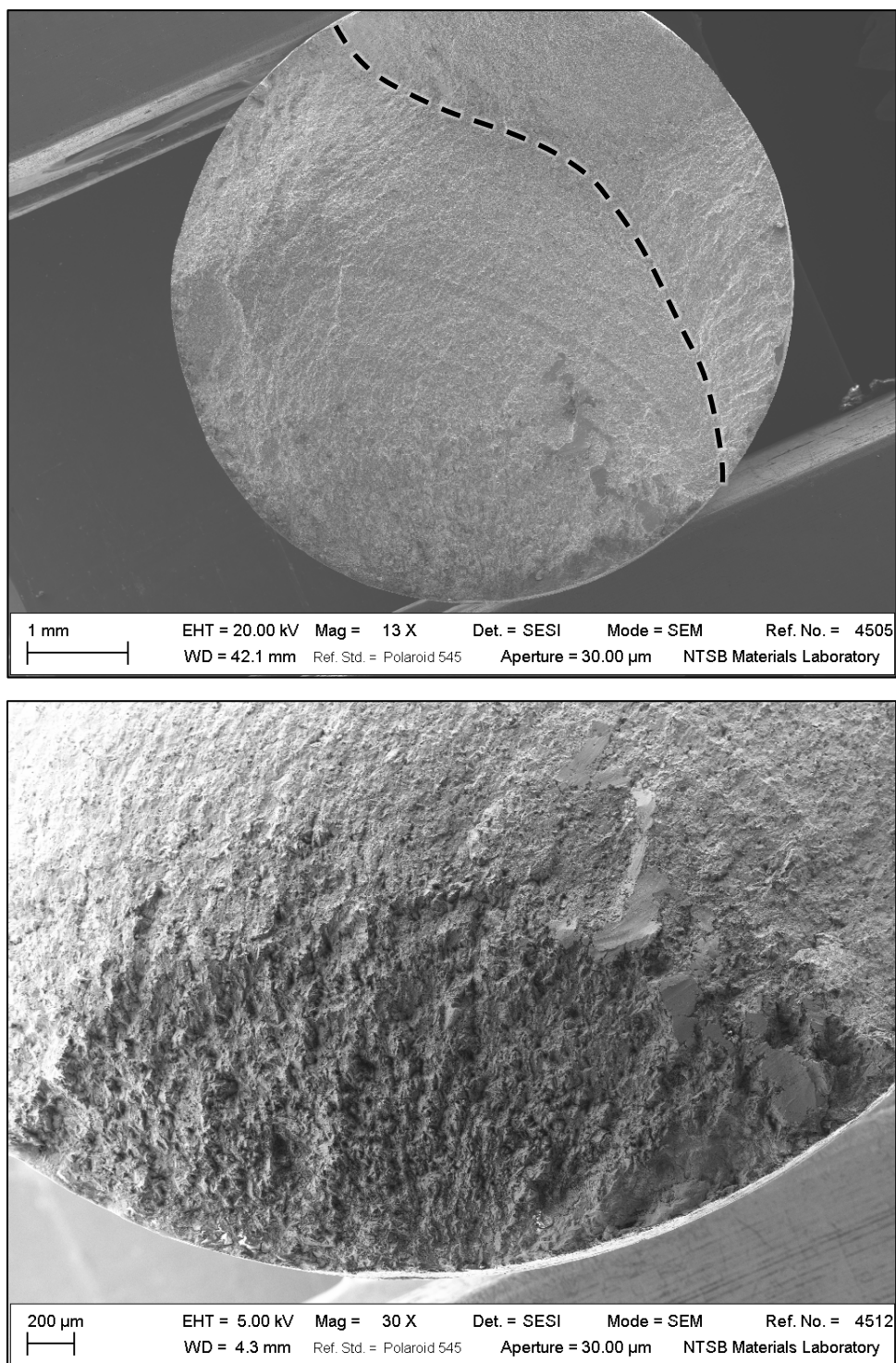


Figure 21. SEM images of the outboard teeter bolt fracture surface after cleaning with Evapo-Rust and a soft-bristle brush showing the entire fatigue region (upper image) with a closer view of the relatively rough region near the origin (lower image). A dashed line in the upper image indicates the fatigue boundary.

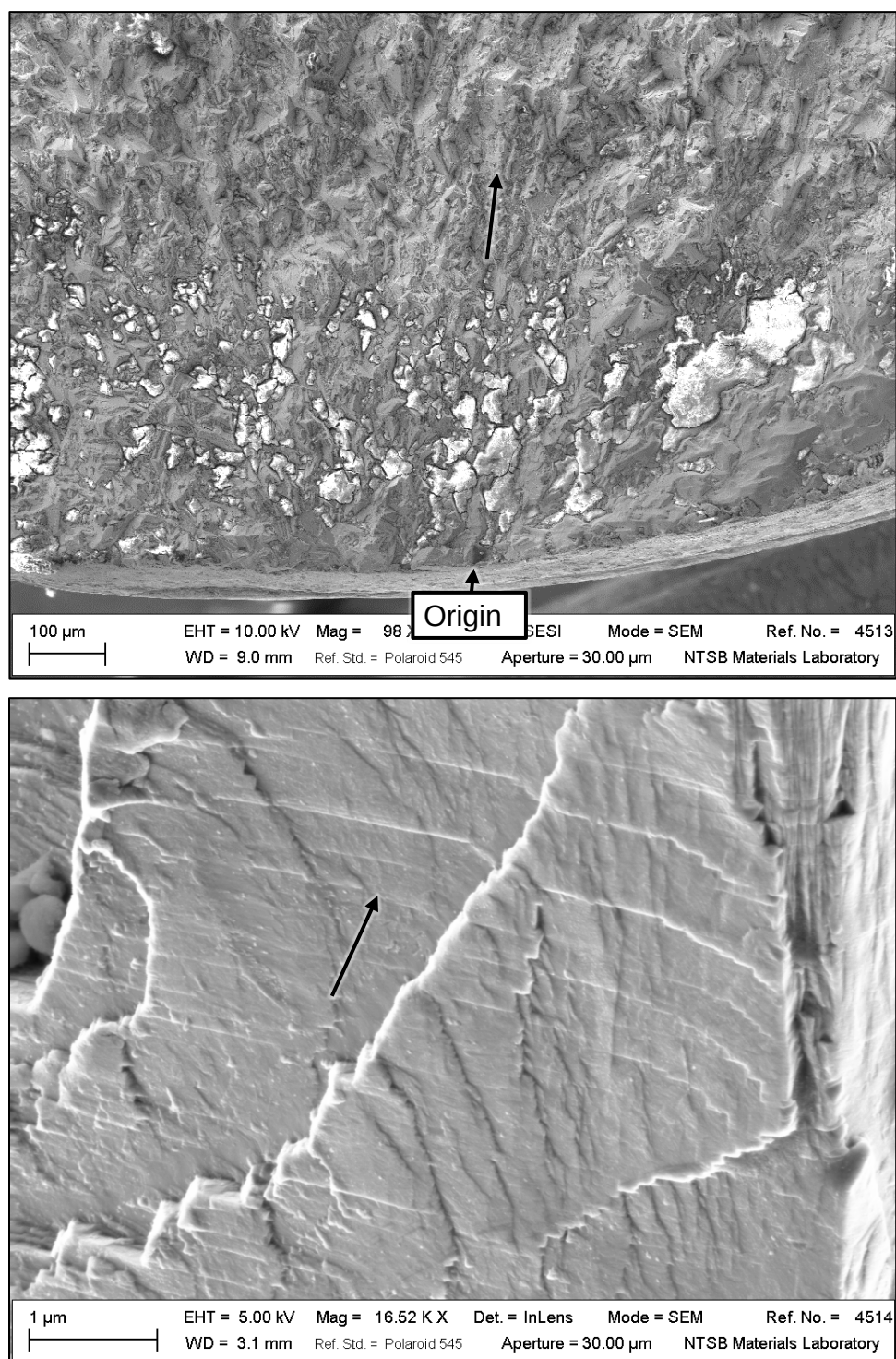


Figure 22. SEM images of the fracture surface shown in figure 21 showing the origin area (upper image) with a closer view of typical fatigue features near the origin (lower image). The brighter areas in the upper image are nonconductive oxides that appear brighter due to charging. Unlabeled arrows indicate crack propagation directions.

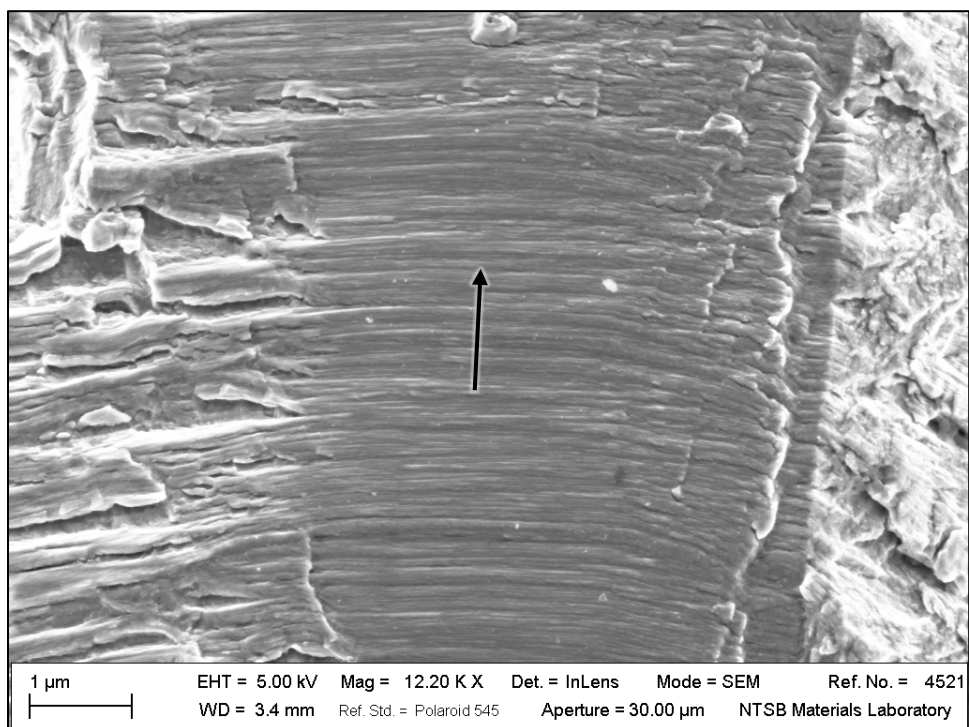
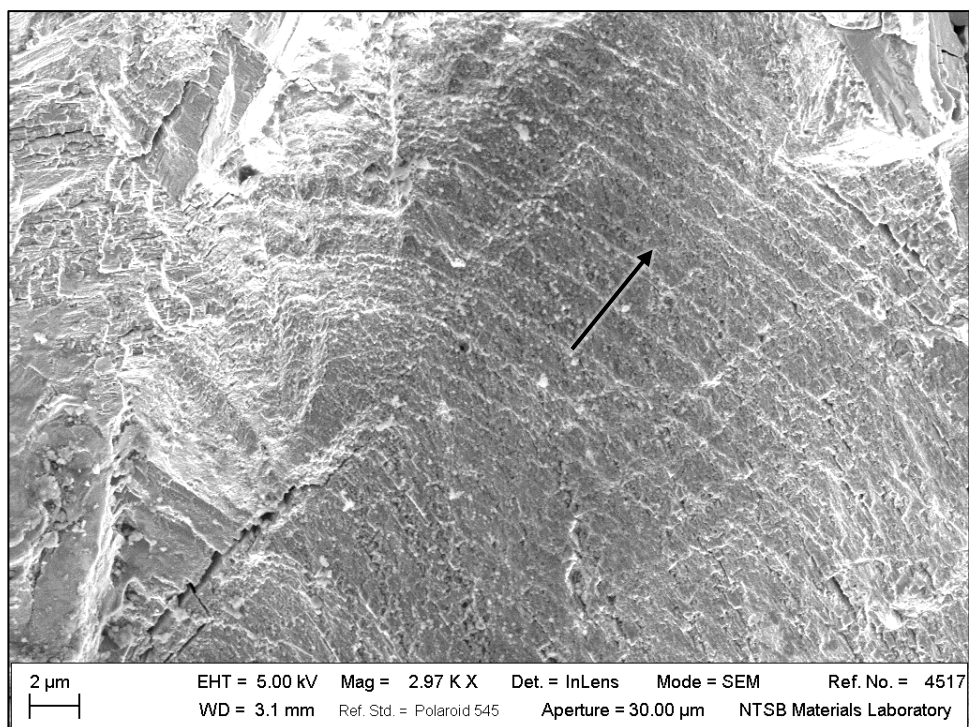


Figure 23. SEM images of the fracture surface shown in figure 21 showing fatigue features near the boundary of the rougher region (upper image) and at a location approximately 75 percent of the total crack depth (lower image). Unlabeled arrows indicate crack propagation directions.

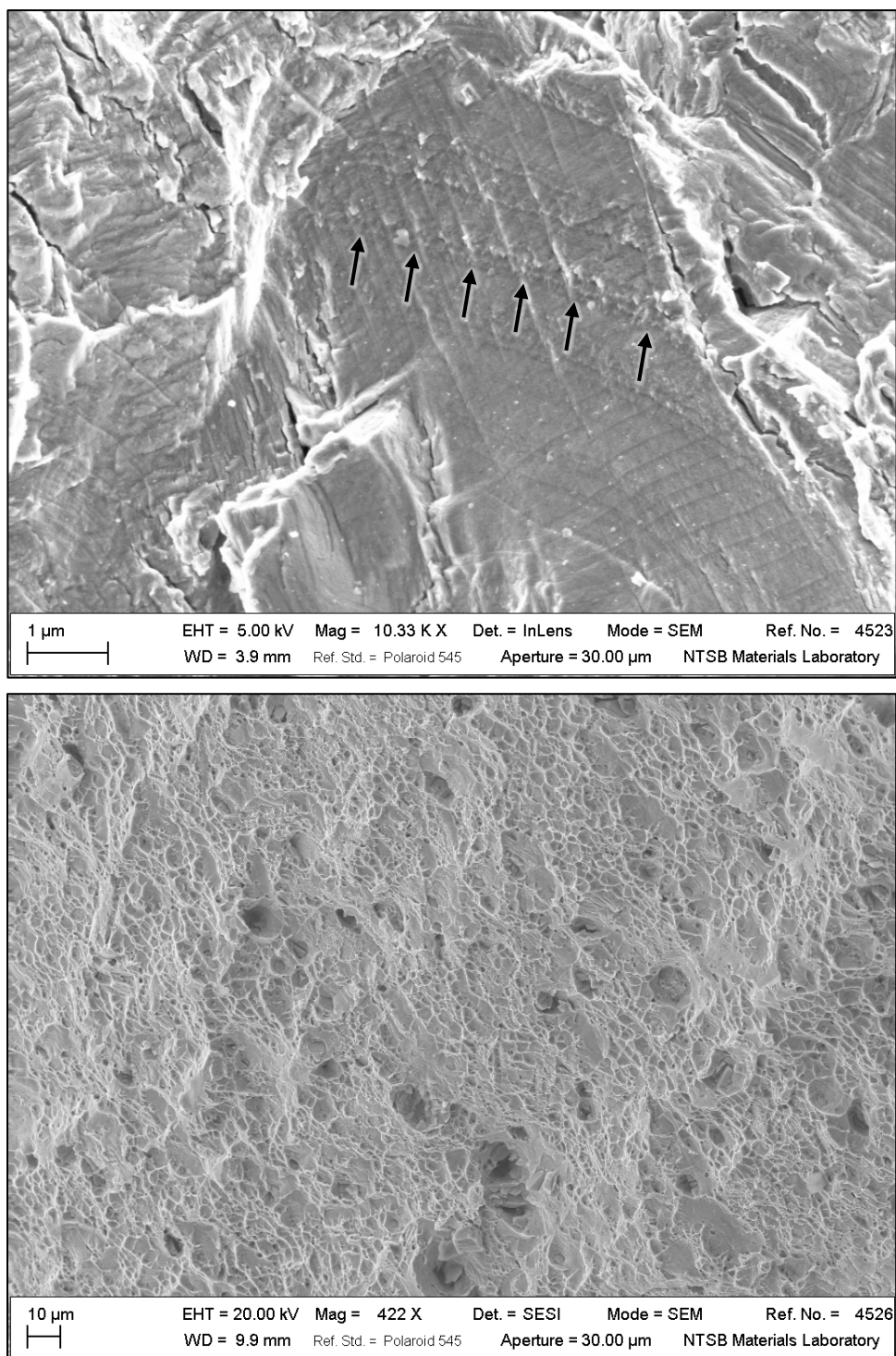


Figure 24. SEM images of the fracture surface shown in figure 21 showing fatigue features near the fatigue boundary (upper image) and ductile dimple features in the overstress region (lower image). Unlabeled arrows in the upper image indicate the crack propagation direction and point to a fatigue striation.