

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



ERA23FA340

MATERIALS LABORATORY

Factual Report 23-099

January 3, 2024

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A. ACCIDENT INFORMATION

Location: Fort Pierce, Florida
Date: August 17, 2023
Vehicle: Piper PA-28-161, N9855S
Investigator: Adam Gerhardt, AS-ERA

B. COMPONENTS EXAMINED

Center wing box and inboard pieces of the left and right wing main spars.

C. EXAMINATION PARTICIPANTS

Specialist	Matthew R. Fox, Ph.D. NTSB Washington, DC
Group Chair / IIC	Adam Gerhardt NTSB Washington, DC
Group Chair / IIC	Clint Crookshanks NTSB Denver, Colorado
Group Member	Leani Benitez Cordona NTSB Washington, DC
Group Member	Gideon Jose Federal Aviation Administration College Park, Georgia
Group Member	Fred Caplan Federal Aviation Administration College Park, Georgia
Group Member	Mike Gordon Piper Aircraft Vero Beach, Florida
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Group Member Joseph Banks
 Piper Aircraft
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D. DETAILS OF THE EXAMINATION

The submitted center wing box and the left and right wing main spar pieces are shown in figure 1 as received. The main spars for the left and right wings were fractured at or near the inboard wing attachment locations. The outboard ends of the center wing box were deformed upward relative to center, and the upper spar was crippled consistent with high upward wing loads on both the left and right wings before fracture.

An investigative group was convened on November 14 and 15, 2023 to examine the submitted components. The group members listed above consisted of the NTSB investigator in charge, the NTSB structures group chairman, another NTSB structures group member, and investigative party representatives from the Federal Aviation Administration (FAA) and Piper Aircraft.

Closer views of the right wing spar fracture location are shown in figure 2. The right main spar lower cap was fractured at the outboard attachment holes for attaching the wing spar to the center wing box as shown in the image of the lower cap fracture surface in figure 2. The upper and lower caps showed upward deformation adjacent to the fracture and rough, matte-gray fracture features consistent with ductile overstress fracture. No evidence of any preexisting cracks or defects were observed associated with the fracture surfaces as determined by optical microscopy and subsequent scanning electron microscopy (SEM) examinations of the fracture surfaces on the lower cap.

A closer view of the left wing main spar lower cap fracture location is shown in figure 3. The lower cap was fractured outboard of the main spar attachment bolt holes for attaching the wing to the fuselage, and the fracture intersected the inboard two rivet holes attaching the wing lower skin and spar doublers to the lower cap. The upper cap was also fractured at a similar location spanwise just outboard of the attachment location. The lower cap was bent downward adjacent to the fracture, and the inboard end of the wing's lower skin and spar web doublers were also deformed downward. The upper cap had rough matte gray features consistent with ductile overstress fracture. The fracture surface of the lower cap had mostly rough matte gray features, but the lower edge of the fracture had a smoother shiny appearance, features consistent with ductile overstress fracture with smearing at the compression side of a fracture with local bending. The overall deformation pattern on the left wing was consistent with a downward bending load associated with the left wing fracture following the upward load associated with the center wing box deformation.

1.0 Disassembly and Examination of Attachment Hardware

Each wing main spar lower cap was attached to the center wing box with 10 bolts; half located in a spanwise row forward of the spar web, and the other half located in a spanwise row aft of the spar web. For reference, the bolts were labeled by position using the number and letter convention provided in Piper maintenance and service publications with an added letter to denote the left or right wing. The first letter in the bolt labels was L or R, indicating the left or right wing, respectively. The second letter in the label was a C for the row of bolts located forward of the spar web or a D for the row located aft of the spar web.¹ The final digit was a number from 1 to 5 indicating the relative position in each row starting with the outboard attachment bolt.

Intact torque paint was observed on each nut before disassembly. The torque paint was green at the outboard holes LC1, LD1, RC1, and RD1, and the remaining hardware had red torque paint. The bolt heads at the outboard holes were also marked differently than the rest with a dimple in the middle of the head and NAS 6606 13 marked around the edge, consistent with installation of new bolts following bolt hole inspections associated with FAA Airworthiness Directive (AD) 2020-26-16 and Piper Service Bulletin (SB) 1345. The remaining bolts had a flat head and were marked with an x inside a triangle consistent with Air Force - Navy (AN) standard bolts specified for the wing spar attachment hardware that remains in place during inspections associated with AD 2020-26-16 when no crack indications are detected.

To facilitate further examination of the fracture surfaces, the attachment bolts for the main spar lower caps were disassembled from the lower caps. The torque required to loosen the nut (breaking torque) was measured at each location, including locations RC1 and RD1 that intersected the right wing lower cap fracture, and results are shown in table 1. For reference, the specified installation torque for the attachment bolts is 30 to 32.5 pound feet.

During disassembly, most of the bolts required gentle tapping with a hammer and punch to push the bolts out of the respective holes. As bolts were removed, care was taken to note the washer profiles and positions, and relative positions were maintained on the removed bolts as nuts were reattached to the bolt as shown in figure 4. Each of the bolts had been installed with one washer between the head and the upper side of the doubler and with two washers between the nut and the lower skin. However, none of the assemblies had washers that had been installed in accordance with specification.

As described in Piper SB 1366, fastener assemblies in rows C and D should have a washer with a rounded edge profile installed under the bolt head, and the

¹ Letters A and B are used for labeling attachment bolts associated with the upper cap.

side with the rounded profile should face toward the spar doubler to provide a positive clearance with the fillet radius in the adjacent doubler. Assemblies at the inboard ends (number 5 positions) should only have two washers installed; one under the head and one under the nut, and both washers should have a rounded edge that faces toward the attached structure.

Table 1. Breaking Torque Values

Bolt	Breaking Torque (pound feet)	Bolt	Breaking Torque (pound feet)
LC1	8.3	RC1	7.0
LC2	20.5	RC2	26.6
LC3	27.6	RC3	30.9
LC4	28.2	RC4	37.4
LC5	13.2	RC5	30.1
LD1	7.6	RD1	9.0
LD2	27.9	RD2	29.3
LD3	28.6	RD3	32.2
LD4	20.7	RD4	34.2
LD5	12.9	RD5	26.5

Most of the lower cap attachment hardware had washers with square edges on both sides of all three washers such as the RC1 assembly shown in figure 4. Assemblies LC2, LC3, LD2, and LD4 were the only assemblies that had a round-edged washer installed within the assembly, and each had the round-edged washer installed between the nut and lower skin. In assembly LC2, the face with the rounded edge was against the lower skin, and in the other three assemblies, the face with the rounded edge was against the nut. Close views of assemblies LC2 and LD2 after disassembly are shown in figure 4 where rounded edges on the washers are indicated.

Contact damage was observed on the spar doubler at locations corresponding to the square edges of washers that were installed under the bolt heads such as areas

near holes RD1 and RD5 as shown in figure 5. Many of the washers installed under the bolt head had a deformed or worn edge in one portion of the circumference on the side of the washer facing the doubler consistent with contact with the fillet radius. A similar wear pattern was also observed on washers installed under the nut with square edges facing the lower skin corresponding to contact with the fillet radius on the stringer. The washers installed under the bolt heads at the LC1, LD1, RC1, and RD1 positions were deformed upward at the edge on one side of the washer consistent with contact with the fillet radius to the web. The deformed edge for the washer installed under the bolt head at position LC1 is indicated in figure 4. The deformation to the washers under the bolt head at the four number 1 positions was substantially greater than the wear and deformation observed at the remaining positions.

2.0 Examination of the Right Wing Main Spar Lower Cap

An overall view of the lower surface of the inboard end of the right wing main spar lower cap is shown in figure 6 after disassembly from the center wing box. The labels associated with each attachment hole are also shown for reference. The right spar cap was covered with a greenish yellow primer, and the attachment holes were also covered with primer on both spar caps. No primer was observed on the shanks of the attachment bolts that had been removed from the holes. According to Piper representatives, during the manufacturing process, the spars are coated with primer before the attachment holes are drilled, and the holes remain uncoated in the original assembly.

Close views of the lower surface on the outboard piece of the right wing main spar lower cap adjacent to the fracture at holes RC1 and RD1 are shown in figure 7. Primer in the area around the attachment holes was missing, and the underlying exposed surfaces mostly had a circular scratch pattern consistent with orbital sanding methods used during manufacture. The area on the outboard side of holes RC1 and RD1 was disturbed, and the circular scratch pattern was eliminated by rubbed and smeared surfaces consistent with fretting contact damage as indicated with unlabeled arrows in figure 7.

Closer views of the fretted areas outboard of attachment holes RC1 and RD1 are shown in figures 8 and 9. Small crack indications as indicated with unlabeled arrows in figures 8 and 9 were observed on the lower surface outboard of the holes near the edges of the fretted regions. The crack indications were oriented in the transverse direction outboard of the holes both forward and aft of the centerline for each hole.

A transverse cut was made through the lower cap within a couple inches outboard of the fracture, and the sectioned piece was submerged in acetone and cleaned using an ultrasonic cleaner. The sectioned piece was then examined using an SEM. Small crack indications that were observed visually were also observed by

SEM. An SEM image of surface cracks near hole RC1 forward of the hole centerline is shown in figure 10. The four largest crack features in figure 10 corresponded to the visual crack indications shown in the upper image in figure 8.

Next, an attempt was made to open the crack indications near hole RC1. Using a selection of handheld saws, a spanwise cut was made between hole RC1 and the vertical flange followed by a transverse cut to isolate hole RC1. Then transverse cuts were made toward crack tips on either side of the hole centerline, followed by a vertical cut from the upper side of the cap toward the lower surface. An initial attempt to open the cracks was unsuccessful, and a piece aft of the hole broke away without intersecting the crack indications. Additional cutting including making a notch at the upper surface of the cap piece was completed, and the notched side was pinched in a vice to produce a lab fracture of the cracks forward of the RC1 hole centerline, which were the crack indications shown in the upper image in figure 8 and in the SEM image in figure 10.

The outboard side of the lab fracture that exposed cracks outboard of hole RC1 was cleaned using an ultrasonic cleaner while submerged in acetone. A portion of the fracture appeared relatively dark consistent with preexisting cracks. The preexisting cracks had relatively flat fracture features with curving crack arrest lines, features consistent with fatigue. Close views of fatigue cracks exposed by the lab fracture are shown in figure 11, where dashed lines indicate the extent of the fatigue region, and brackets indicate fatigue origin areas. The cracks had multiple fatigue origins with broad origin areas relative to the crack depth. The largest of the fatigue regions shown in the detail image in figure 11 was 0.040 inch long where it intersected the lower surface and extended up to 0.006 inch deep.

The lab fracture near hole RC1 was further examined using an SEM, and SEM images of the fatigue regions are shown in figure 12. The SEM images showed flat features with curving crack arrest lines consistent with fatigue extending to the boundaries shown. The cap lower surface adjacent to the crack was disturbed from fretting damage, but no other anomalies were observed associated with the fatigue origins.

A secondary crack was observed on the lower surface outboard of the lab fracture that had opened slightly during the lab fracture. The secondary crack had flat features with radial marks, ratchet marks, and curving crack arrest lines consistent with fatigue emanating from multiple origins indicated with unlabeled arrows in figure 13. The lower surface of the cap around the secondary crack was also disturbed consistent with fretting damage.

3.0 Examination of the Left Wing Main Spar Lower Cap

An overall view of the lower surface of the inboard end of the left wing main spar lower cap is shown in figure 6 after disassembly from the center wing box. The

labels associated with each attachment hole are also shown for reference. The left spar cap was covered with a green primer. Similar to observations on the right wing main spar lower cap, the attachment holes were also covered with primer on both spar caps, and no primer was observed on the shanks of the attachment bolts that had been removed from the holes.

Close views of the lower surface at holes LC1 and LD1 in the left wing main spar lower cap are shown in figure 14. Compared to the right wing lower cap surface, more primer was present in the area around the attachment holes, but areas on the outboard side of holes LC1 and LD1 were disturbed, and the circular scratch pattern was replaced with rubbed and smeared surfaces consistent with fretting contact damage as indicated with unlabeled arrows in figure 14. The diameter of holes LC1 and LD1 were measured in the spanwise and transverse directions, and results showed elongation in the spanwise direction as shown in table 2.

Table 2. Hole Diameter Measurements

Hole	Diameter in the Spanwise Direction (inch)	Diameter in the Transverse Direction (inch)
LC1	0.414	0.379
LD1	0.412	0.381

Closer views of the fretted areas outboard of attachment holes LC1 and LD1 are shown in figure 15. In the upper image in figure 15, a crack indication in the fretted area outboard of hole LC1 is circled, and arrows point to additional cracks emanating from the forward and aft sides of the hole. The circled crack indication and the crack at the forward side of hole LC1 were oriented in the transverse direction while the crack at the aft side of the hole angled aft and outboard.

Several relatively prominent grooves were observed on the outboard side of the hole near the lower surface as indicated with a bracket in the upper image in figure 15. A series of circumferential machining grooves were observed in the interior surface of hole LD1 as shown in the lower image in figure 15.

A transverse cut was made through the center of holes LC2 and LD2 to facilitate further examination of the lower cap piece, and the sectioned piece was submerged in acetone and cleaned using an ultrasonic cleaner. The bores for holes LC2 and LD2 were then examined directly. Nearly circumferential grooves were observed in hole LC2 as shown in figure 16. A relative depth profile was obtained for the hole surface along a line parallel to the hole axis using a Keyence VHX-7000 microscope with a 100x objective, and the resulting profile is shown in figure 16. The

scanned grooves had relative depths of 0.0018 to 0.0020 inch (46.6 to 50.3 microns) deep, and the spacing between the two grooves was 0.0203 inch (514.5 microns).

The lower surface of the left cap piece was examined using an SEM around holes LC1 and LD1. An SEM image of the crack feature at the outboard side of hole LC 1 is shown in figure 17. The lower surface had a smooth rubbed appearance adjacent to the crack in this area. Further scanning of the lower surface revealed isolated areas with angular impressions and embedded faceted nonconductive particles such as the area shown circled in figure 18. Energy dispersive x-ray spectroscopy (EDS) was used to analyze the composition of the embedded particles, and two examples of typical EDS spectra obtained with a 20 kV accelerating voltage are presented in figure 19. The spectra generally consisted of a high peak of silicon and smaller peaks of oxygen and carbon as shown in both spectra in figure 19. Some spectra also contained a peak of aluminum as shown in the lower spectrum in figure 19.

Next, an attempt was made to open the transverse crack indication near hole LC1. Using a selection of handheld saws, a spanwise cut was made aft of the hole centers for holes LC1 and LC2 followed by a transverse cut from the forward edge aft to the crack tip. This was followed by vertical and angled cuts from the top side through most of the thickness to form a notch on the upper side of the cap. The notched side was then pinched in a vice to produce a lab fracture of the crack shown circled in figure 15.

The inboard side of the lab fracture that exposed the crack outboard of hole LC1 was cleaned using an ultrasonic cleaner while submerged in acetone. A portion of the fracture appeared relatively dark consistent with a preexisting crack. The preexisting crack had relatively flat fracture features with curving crack arrest lines, features consistent with fatigue. A close view of the fatigue crack exposed by the lab fracture is shown in figure 20, where dashed lines indicate the extent of the fatigue region, and arrows point to two fatigue origin areas. The exposed fatigue region was 0.146 inch long where it intersected the lower surface and extended up to 0.064 inch deep.

The lab fracture near hole LC1 was further examined using an SEM, and SEM images of the fatigue region are shown in figures 21 and 22. The upper image in figure 21 is a montage of SEM images stitched together to provide an overall view of the fatigue region, and the lower image in figure 21 shows a closer view of the fatigue origins. In figure 22, unlabeled arrows indicate local fatigue crack propagation directions consistent with cracks emanating from the origin areas indicated in figure 21. The SEM images showed flat features with curving crack arrest lines consistent with fatigue. The cap lower surface adjacent to the crack as shown in figure 23 was smeared from rubbing damage that deformed the edge of the crack and obscured any potential features associated with the fatigue origins.

Submitted by:

Matthew R. Fox, Ph.D.
Chief Technical Advisor - Materials



Figure 1. Overall image of the submitted components.



Figure 2. Right wing fracture location as viewed from the aft (lower image) and looking outboard at the outboard side of the right wing spar lower cap fracture (upper right image).

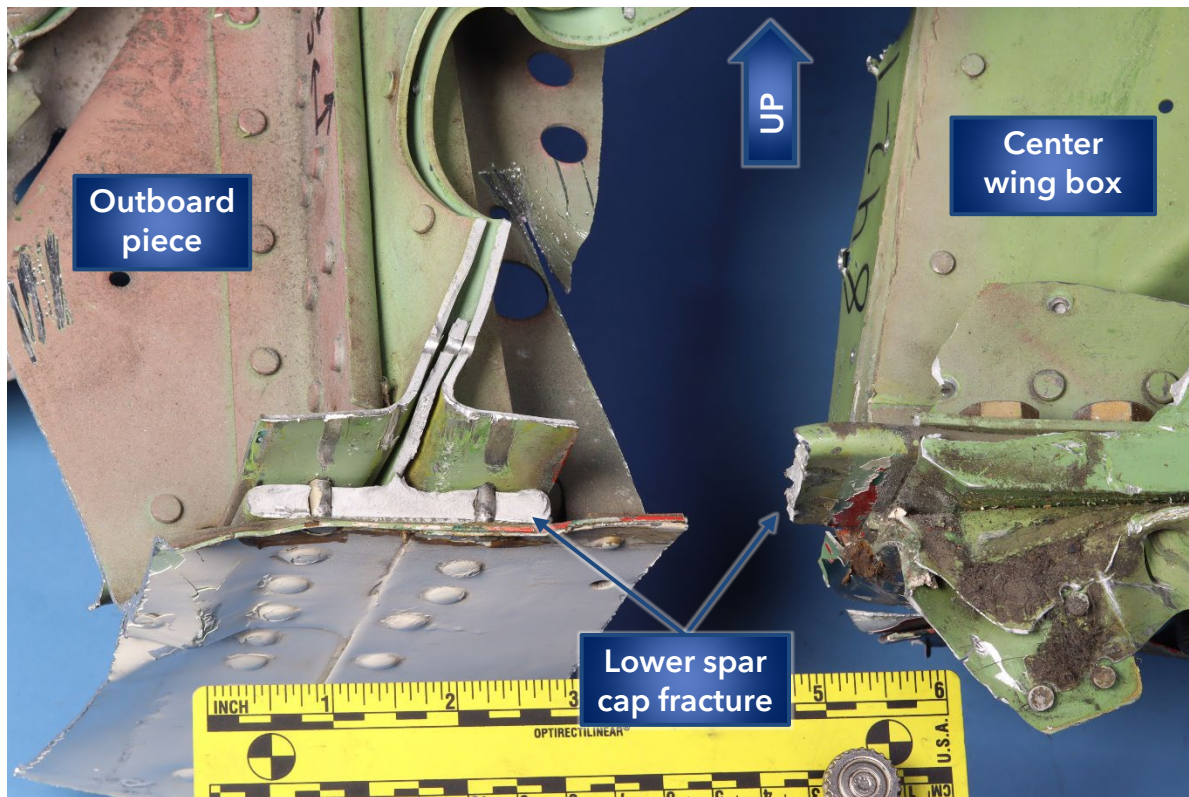


Figure 3. Overall view of the lower cap fracture features at the left wing fracture location. The outboard piece is rotated forward relative to the center wing box to show the fracture surface on the outboard side of the fracture.

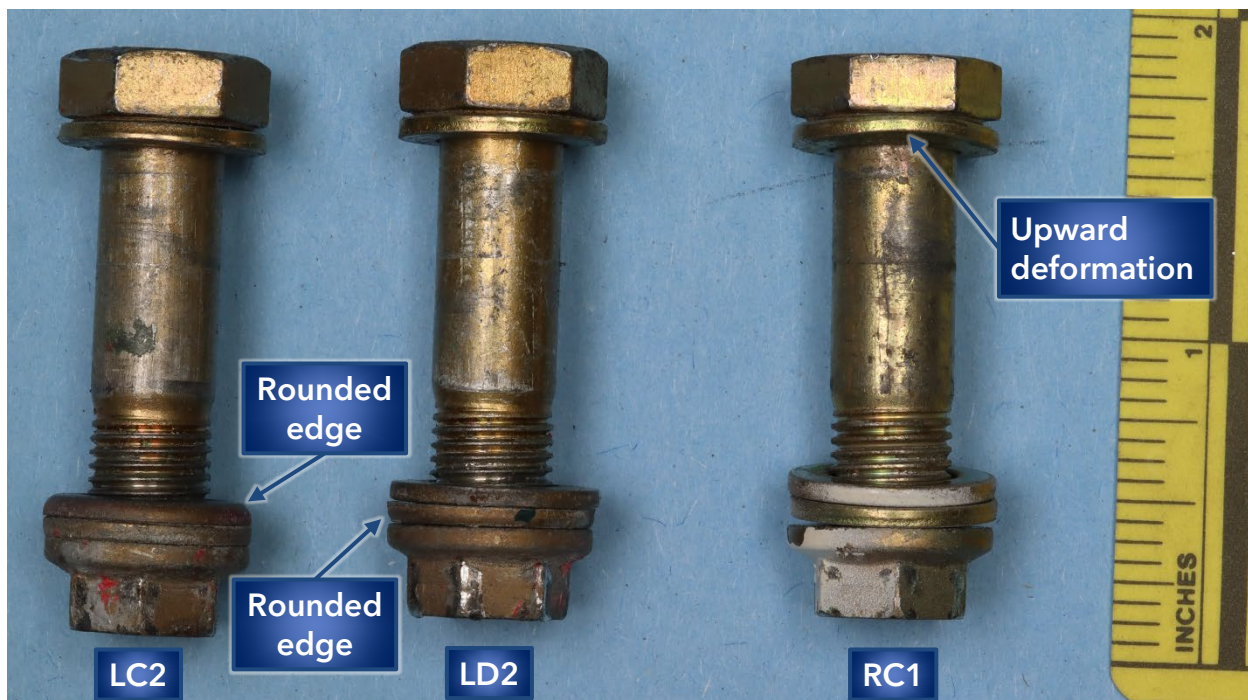


Figure 4. Selected hardware showing washer configurations and deformation.

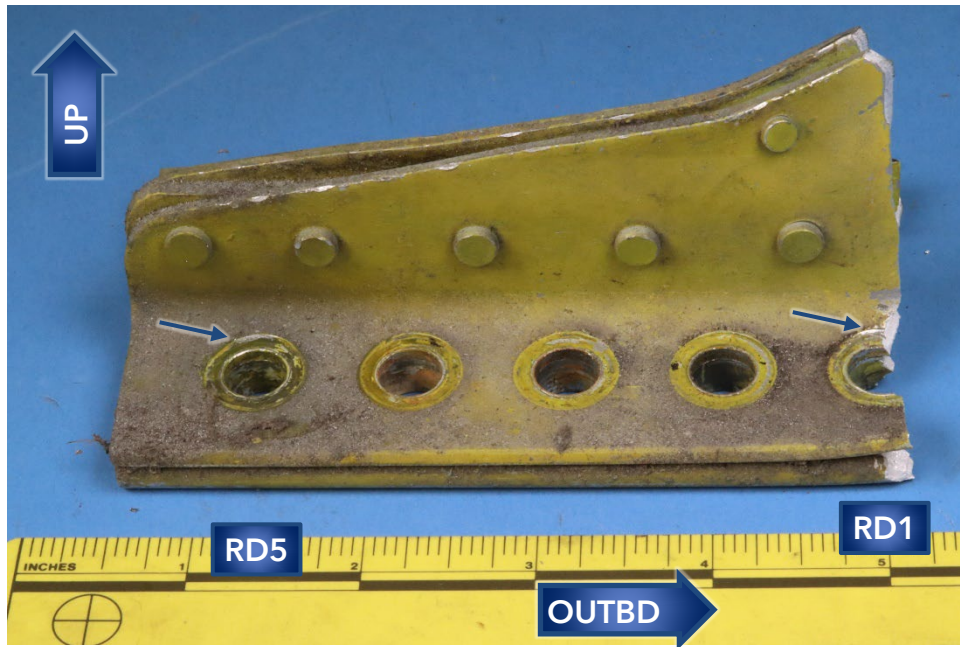


Figure 5. Inboard end of the right wing spar lower cap after disassembly from the center wing box. Unlabeled arrows indicate washer contact damage forward of attachment holes RD1 and RD5.

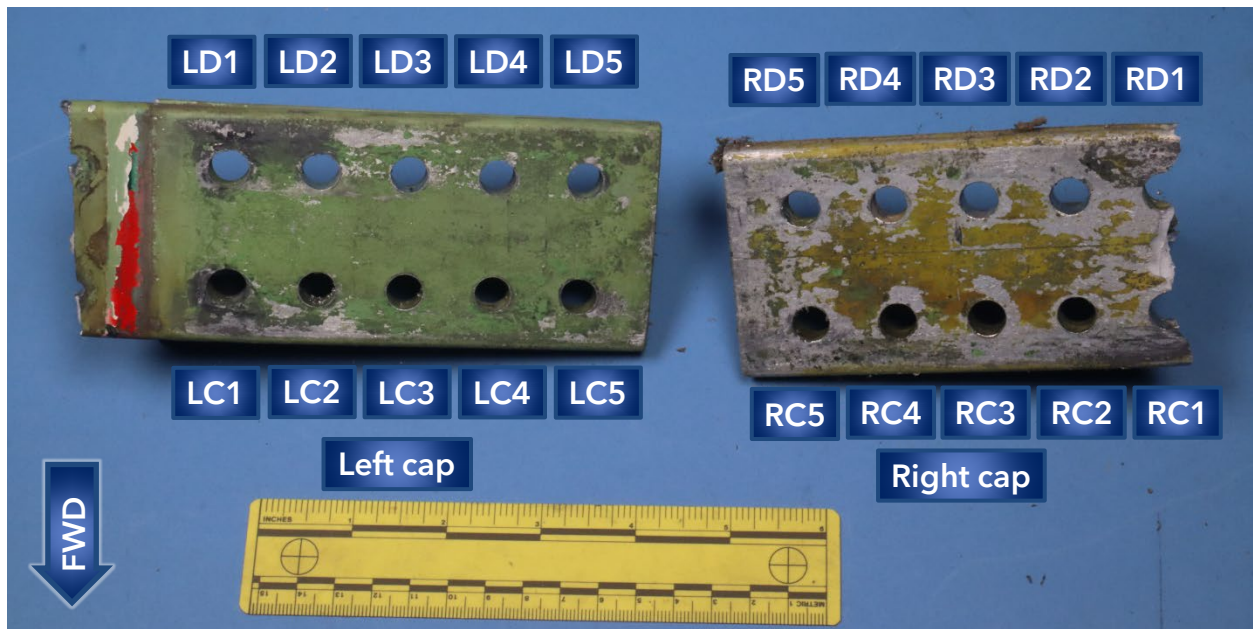


Figure 6. Lower surfaces of the inboard ends of the main spar lower caps from the left and right wings after disassembly from the center wing box. Hole numbers were labeled as shown.

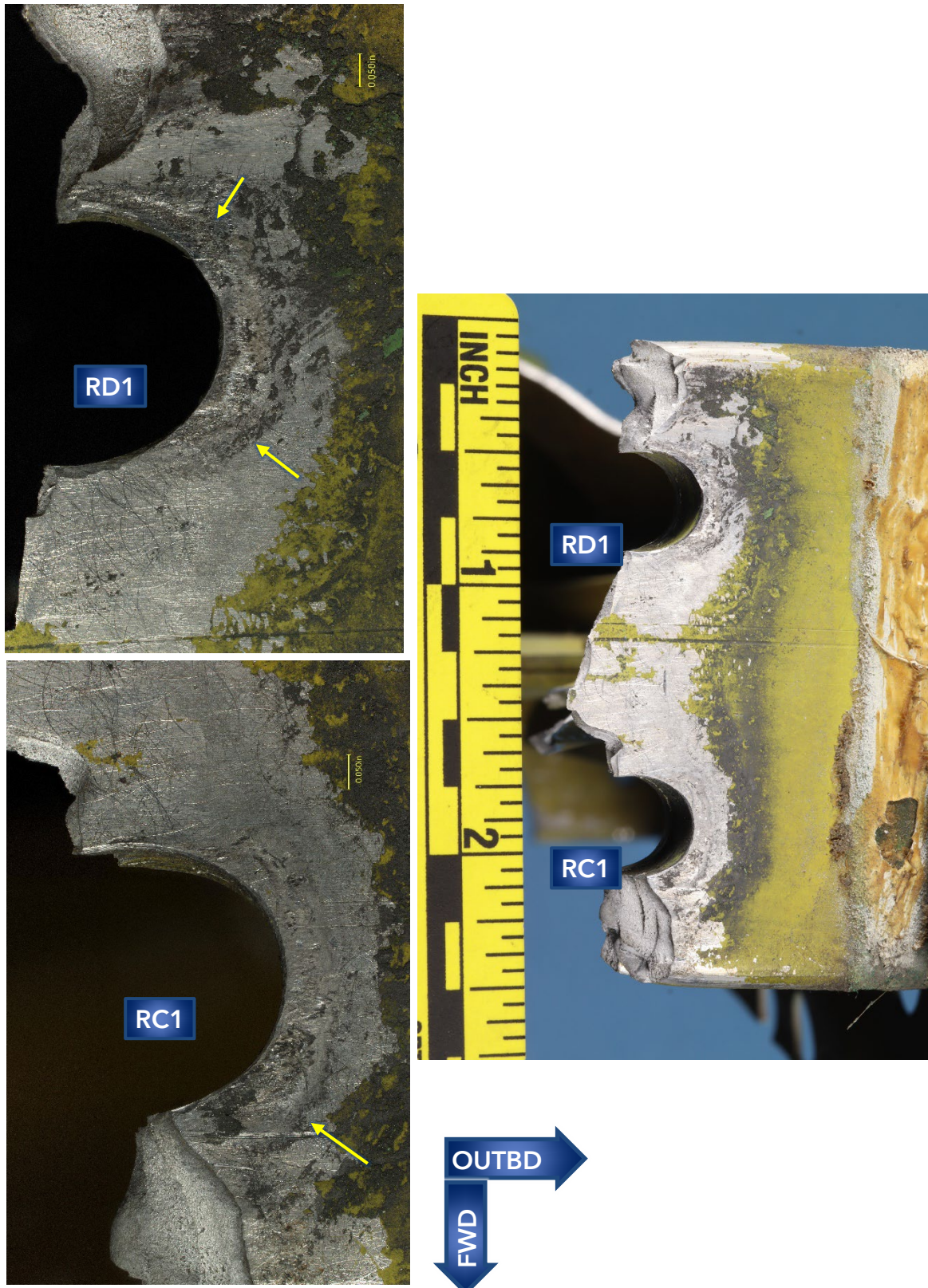


Figure 7. Right wing main spar lower cap showing the lower surface outboard of the fracture through attachment holes RC1 and RD1. Arrows in the left images indicate areas of fretting damage adjacent to the holes.

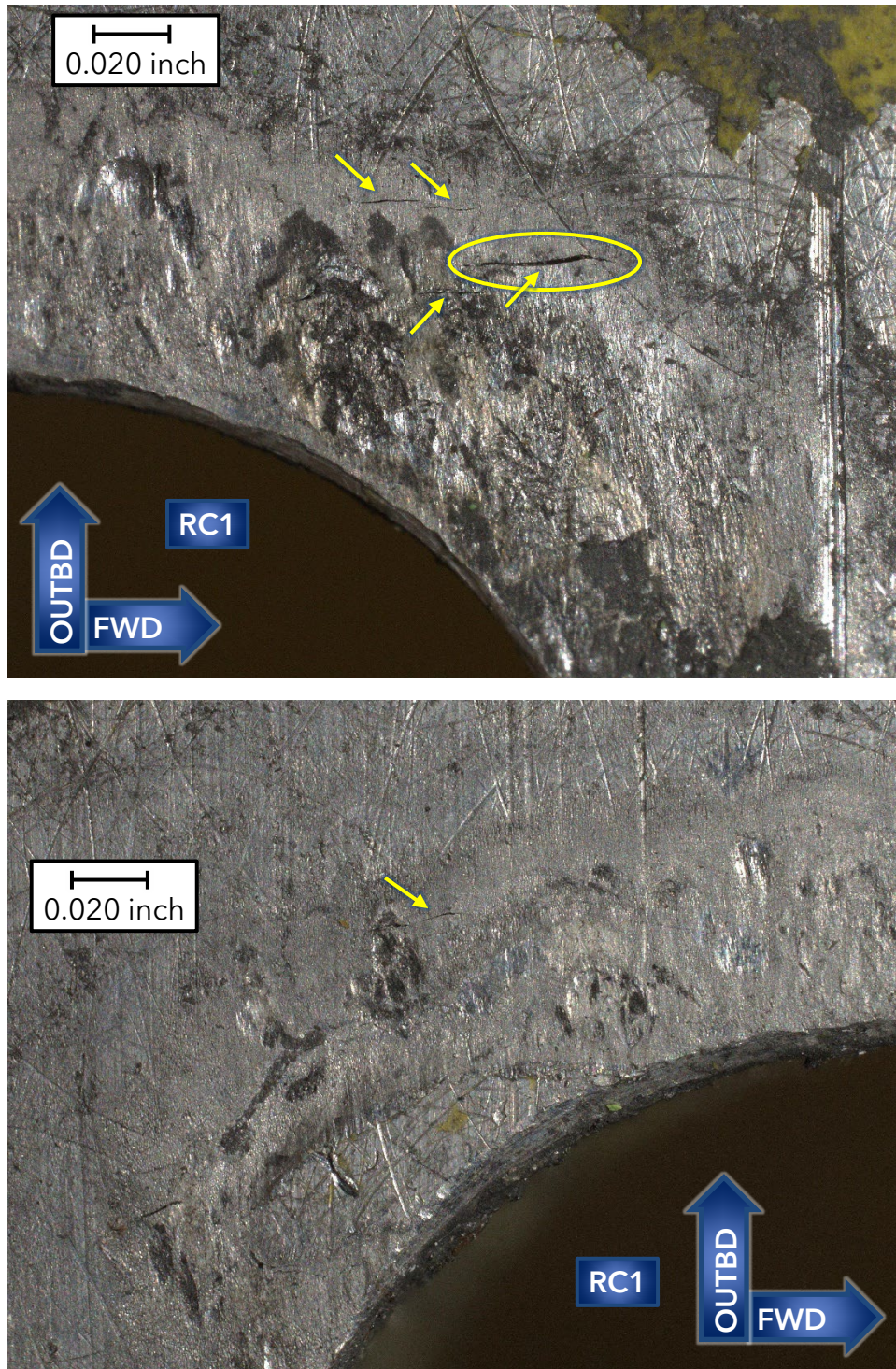


Figure 8. Closer views of the lower cap lower surface outboard of hole RC1. Unlabeled arrows indicate locations of small visual crack indications, and the circle indicates a crack that was opened by laboratory fracture.

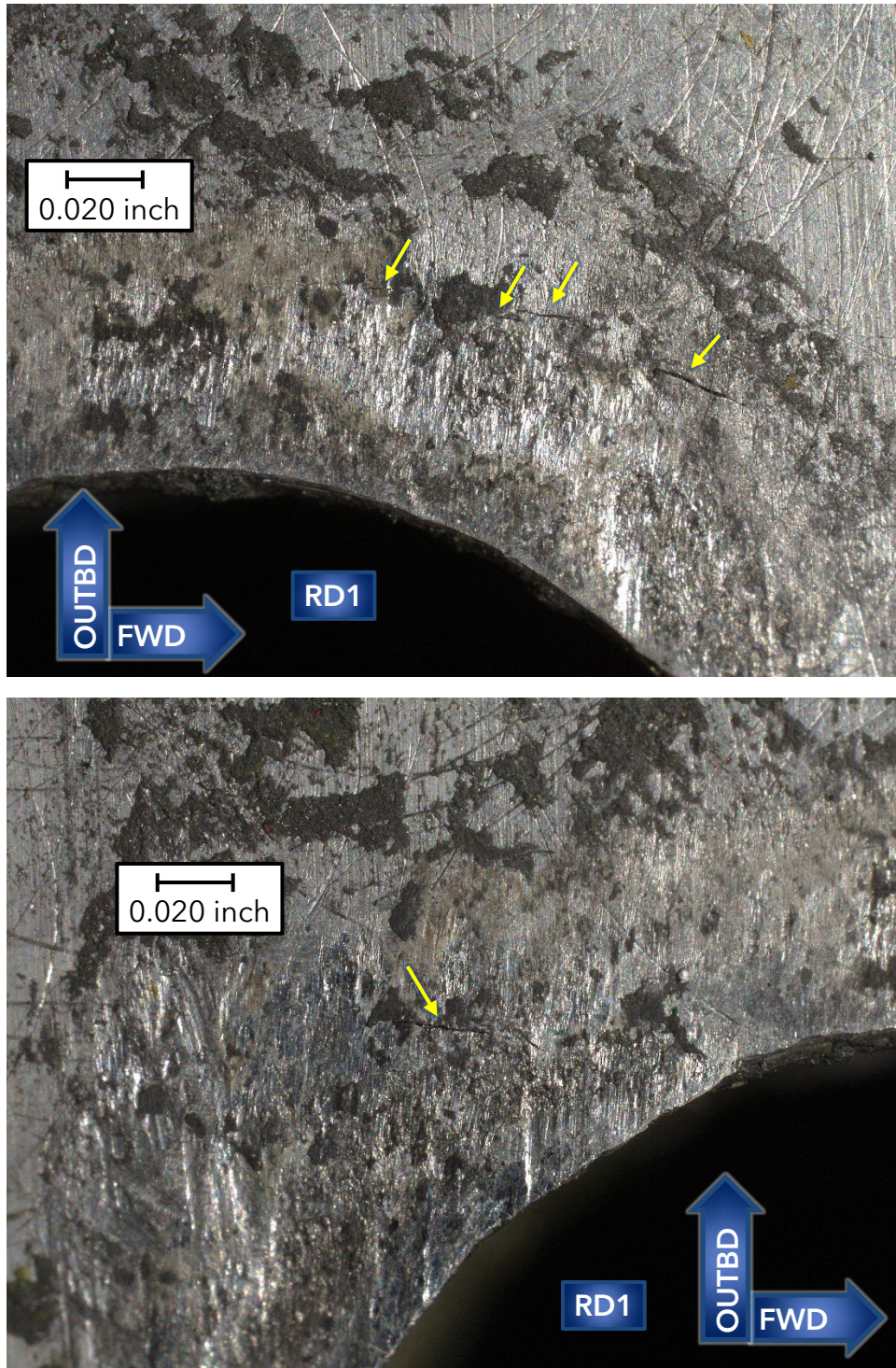


Figure 9. Closer views of the lower cap lower surface outboard of hole RD1. Unlabeled arrows indicate locations of small visual crack indications.

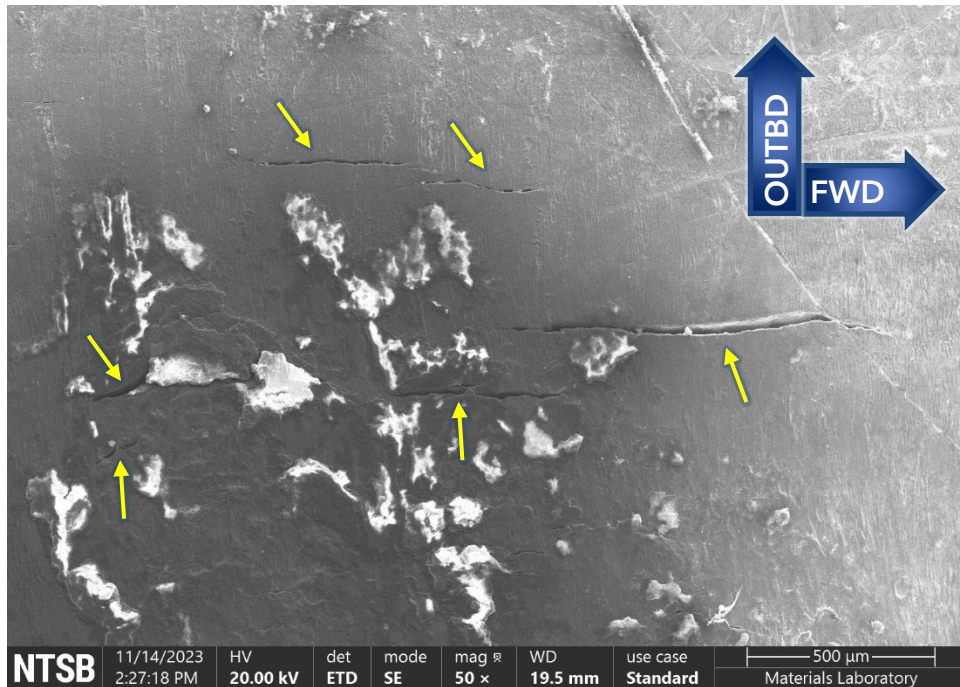


Figure 10. SEM image of crack features shown in the upper image in figure 8. Arrows indicate crack indications observed using an SEM.

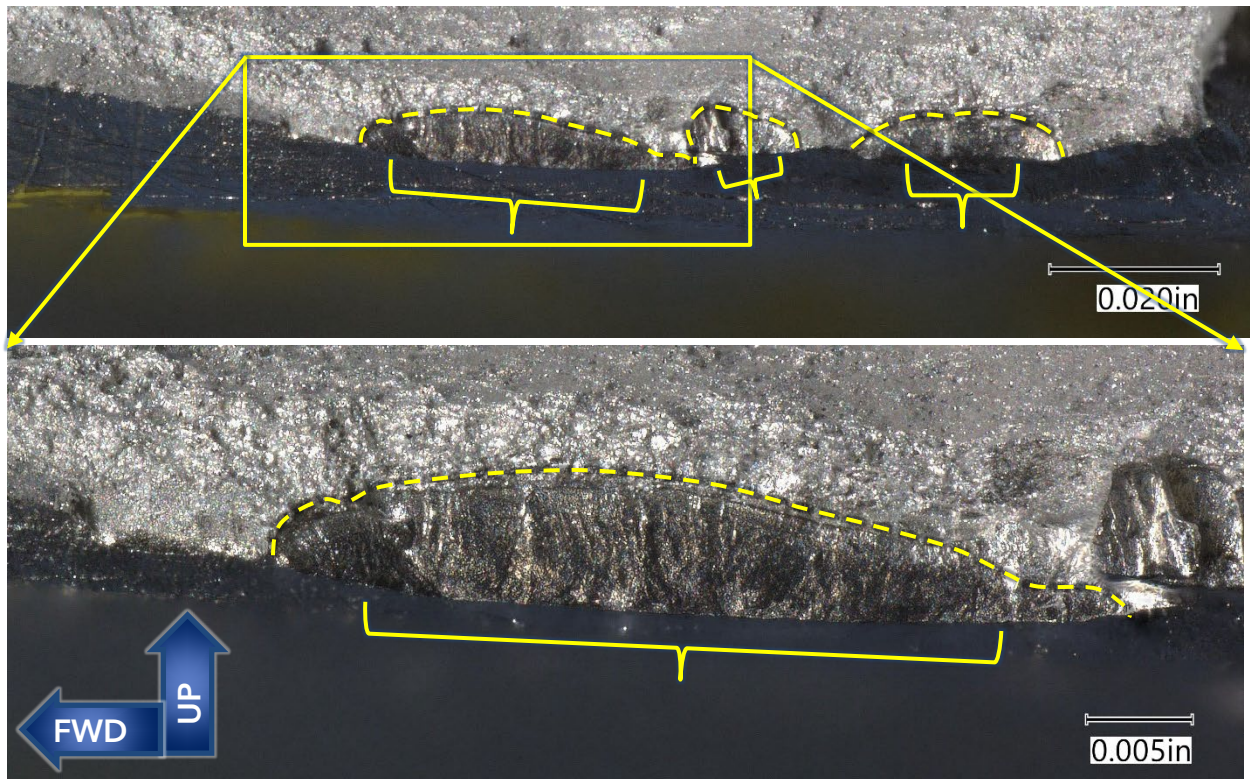


Figure 11. Outboard side of laboratory fracture outboard of hole RC1 after opening the crack shown circled in figure 8. Dashed lines indicate the fatigue boundaries, and brackets indicate the fatigue origin areas.

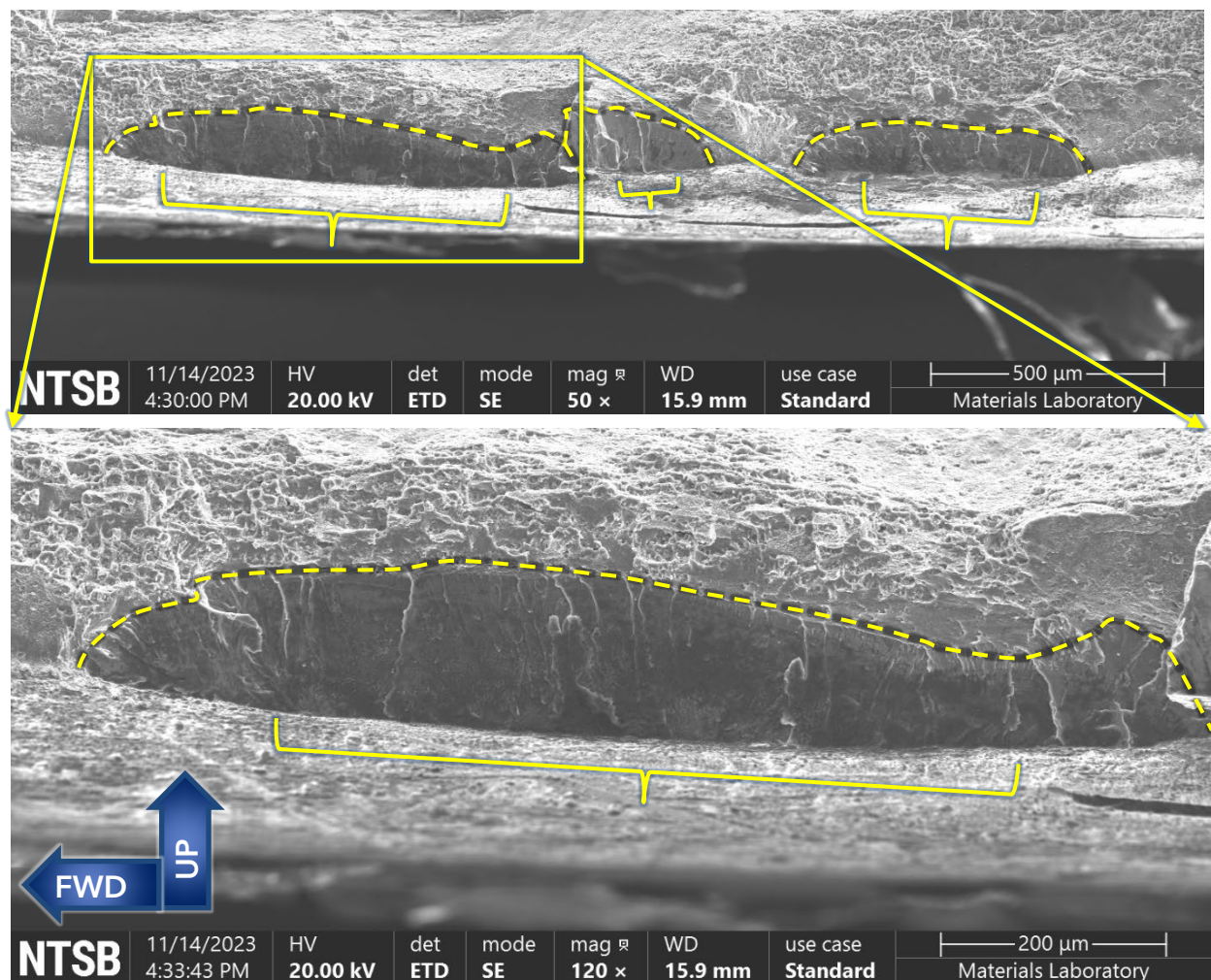


Figure 12. SEM image of the laboratory fracture outboard of hole RC1. Dashed lines indicate the fatigue boundaries, and brackets indicate the fatigue origin areas.

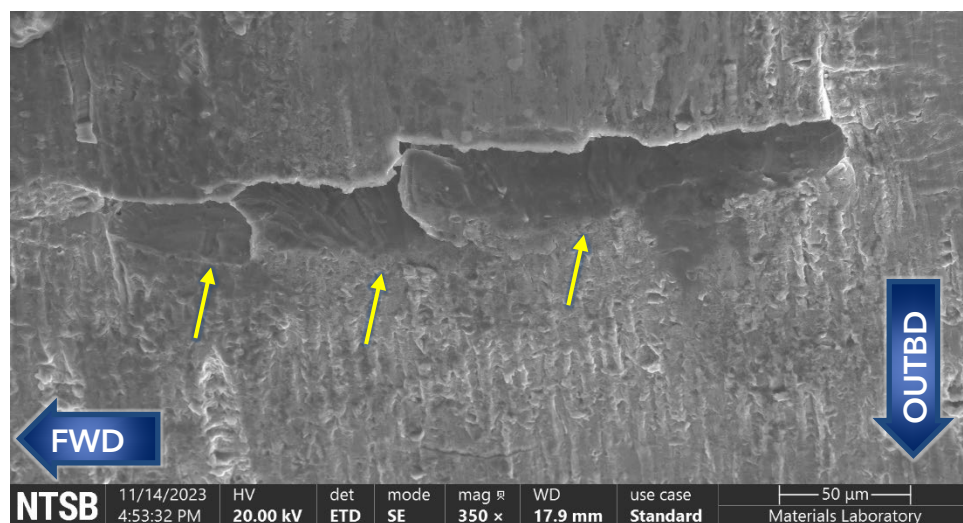


Figure 13. SEM image of a secondary fatigue crack located outboard of the laboratory fracture near hole RC1. Arrows indicate origin areas.

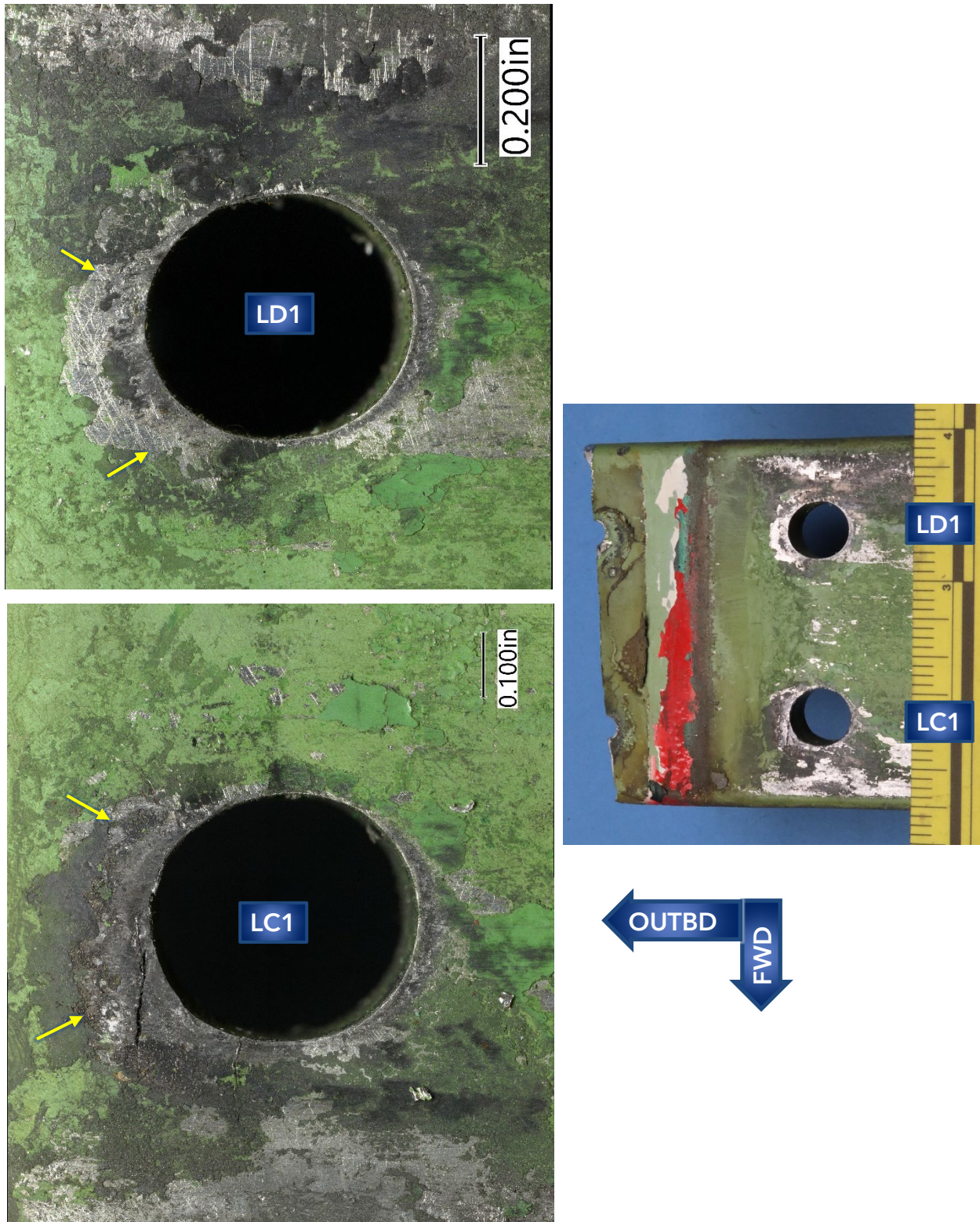


Figure 14. Left wing main spar lower cap showing the lower surface inboard of the fracture with closer views of the areas around attachment holes LC1 and LD1. Arrows in the left images indicate areas of fretting damage adjacent to the holes.



Figure 15. Oblique views of holes LC1 (upper image) and LD1 (lower image). Unlabeled arrows indicate visual crack indications emanating from the lower corner of hole LC1, and the circled crack was opened by lab fracture. A bracket indicates a series of relatively prominent circumferential imprints on the outboard side of the hole bore.

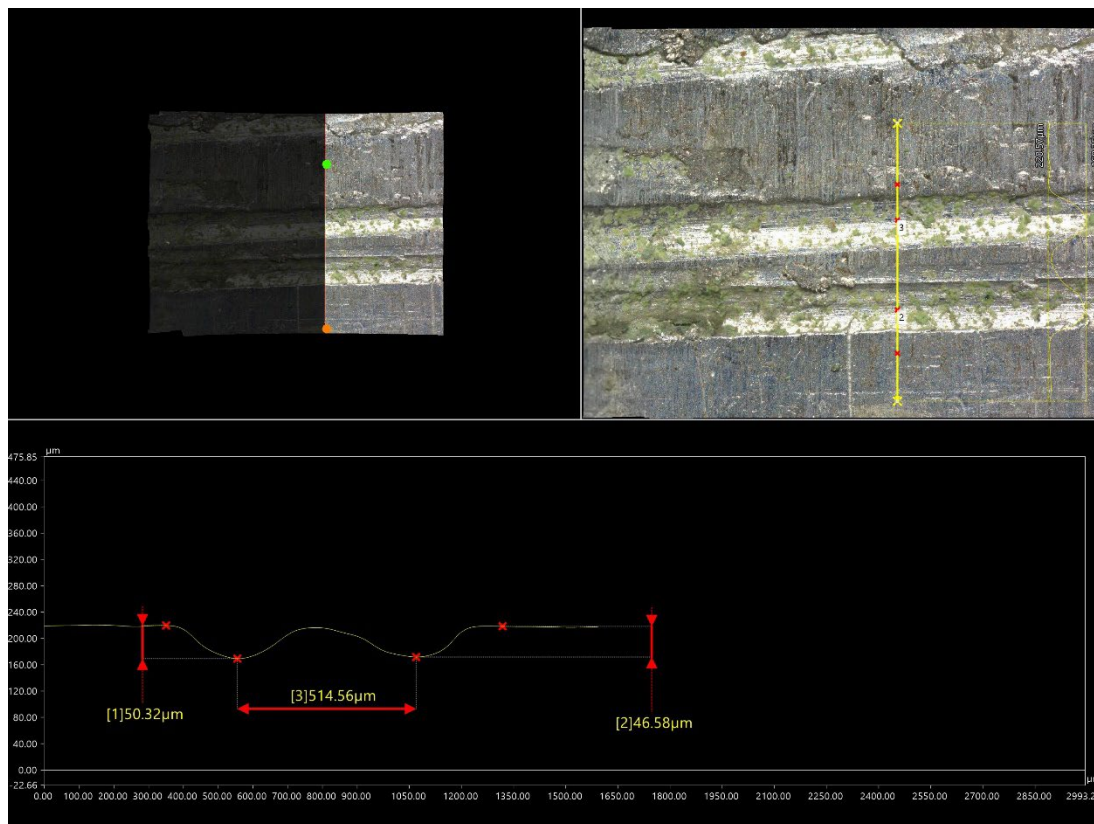
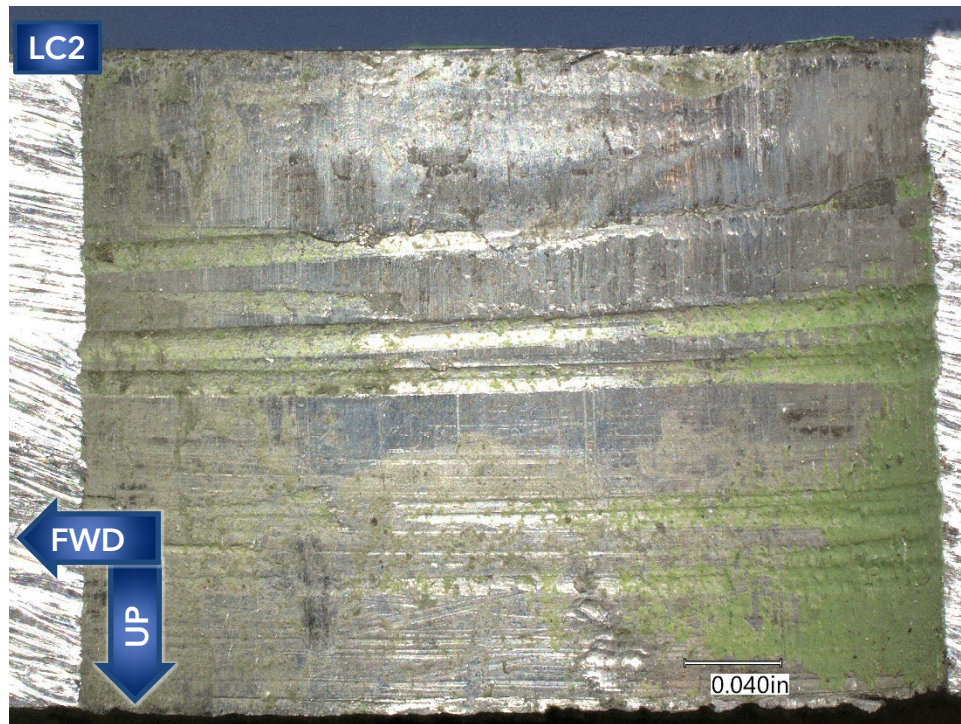


Figure 16. Outboard side of hole LC2 showing circumferential grooves in the surface (upper image). The lower image shows a relative depth profile scan obtained across two of the grooves using a Keyence VHX-7000 optical microscope with a 100x objective lens.

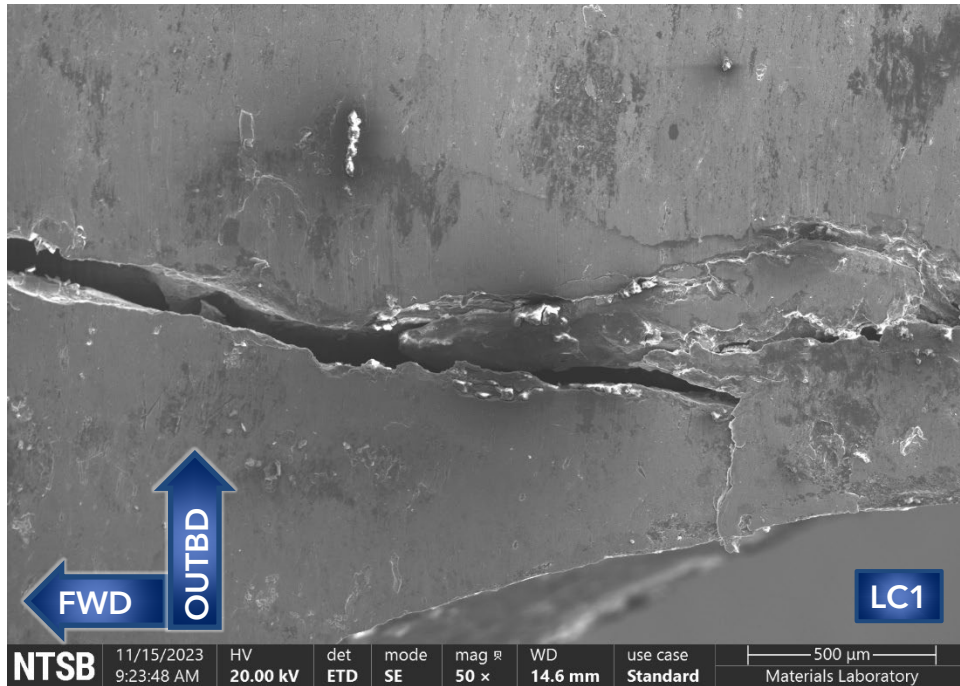


Figure 17. SEM image of the lower surface of the cap from the left wing showing the crack just outboard of hole LC1.

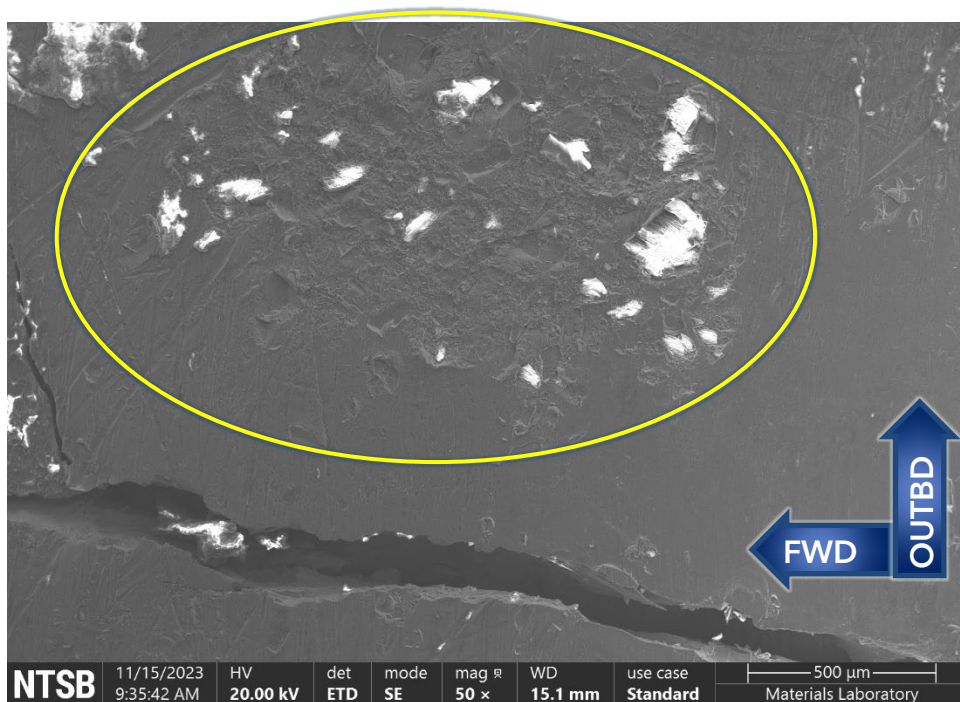


Figure 18. SEM image of a cluster of angular imprints and embedded nonconductive faceted particles (circled area) on the lower surface of the cap from the left wing outboard of the crack near hole LC1.

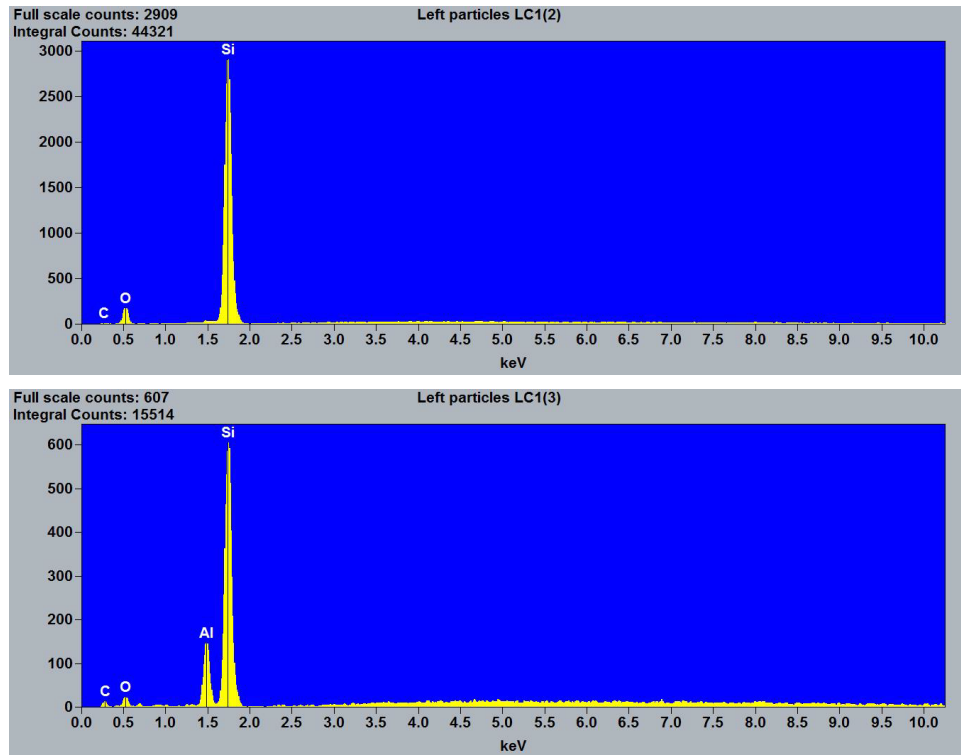


Figure 19. Typical EDS spectra of faceted particles shown in figure 18.

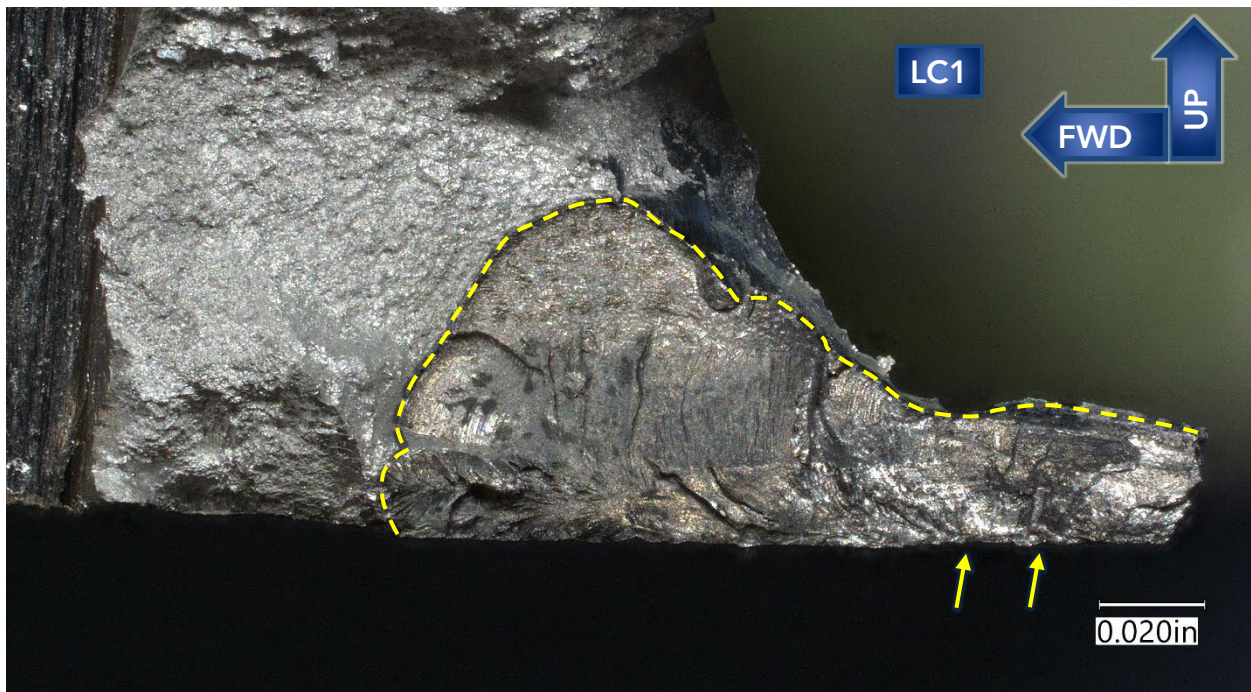


Figure 20. Inboard side of the laboratory fracture outboard of hole LC1 after opening the crack shown circled in figure 15. A dashed line indicates the fatigue boundary, and arrows indicate fatigue origin areas.

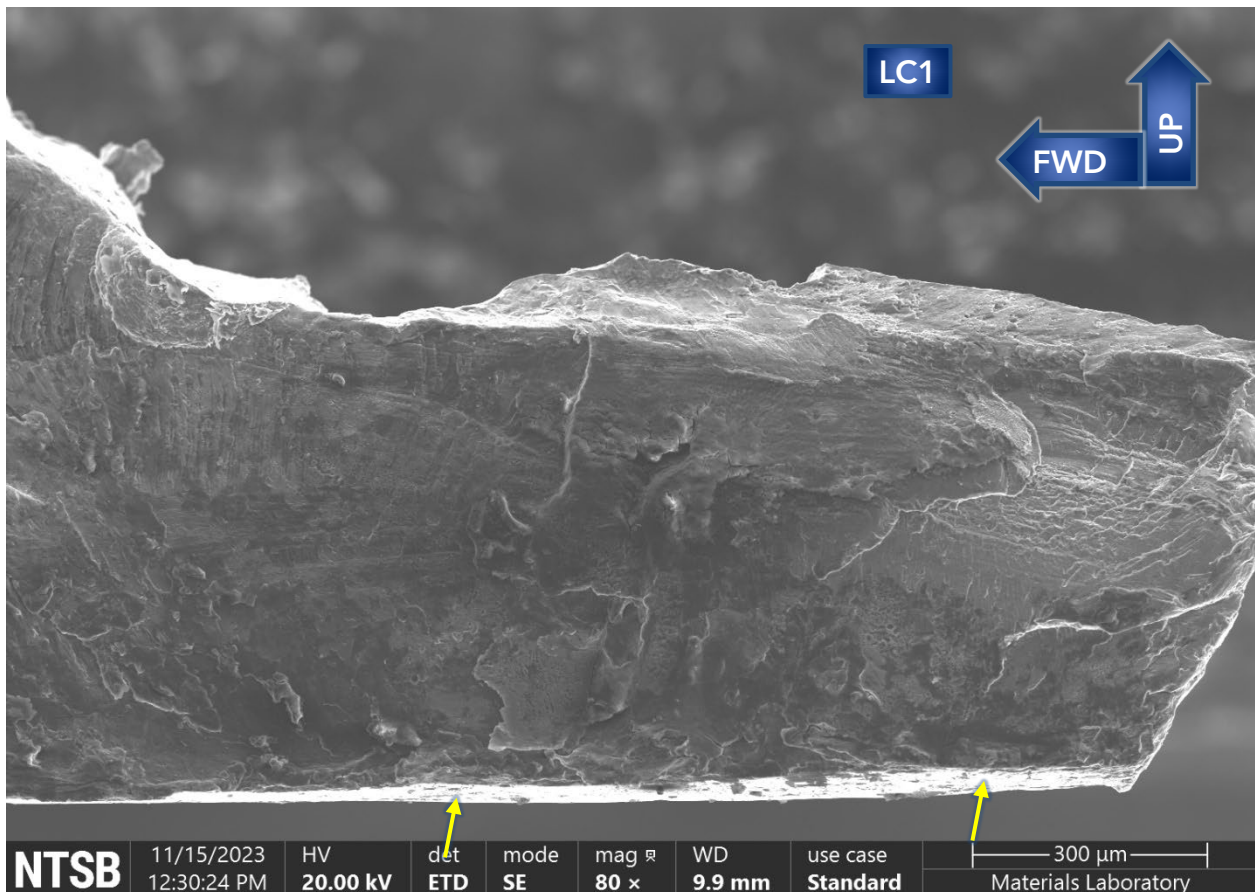
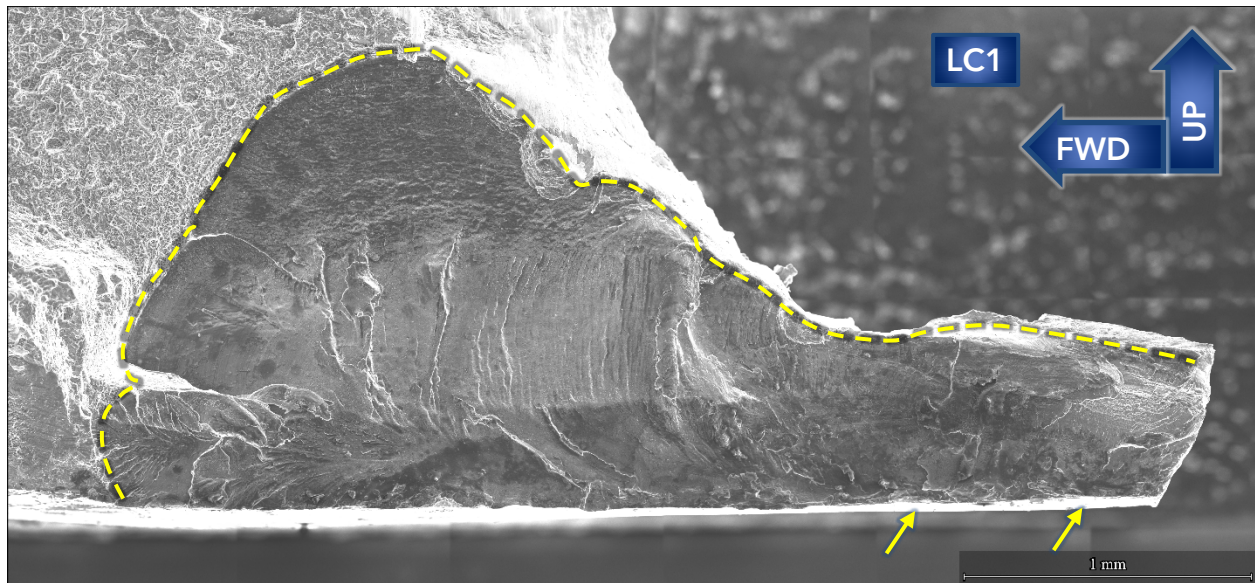


Figure 21. SEM image of the inboard side of the laboratory fracture outboard of hole LC1 after opening the crack shown circled in figure 15 (upper image) with a closer view of the origin areas (lower image). A dashed line indicates the fatigue boundary, and arrows indicate fatigue origin areas.

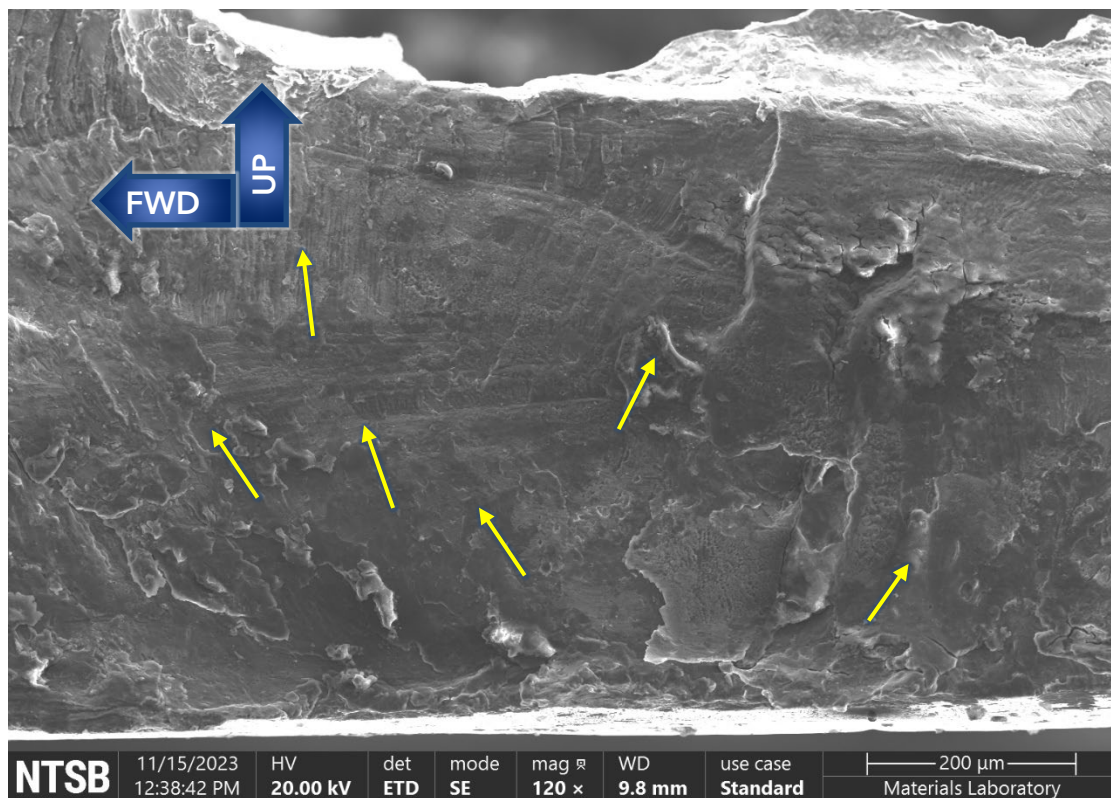
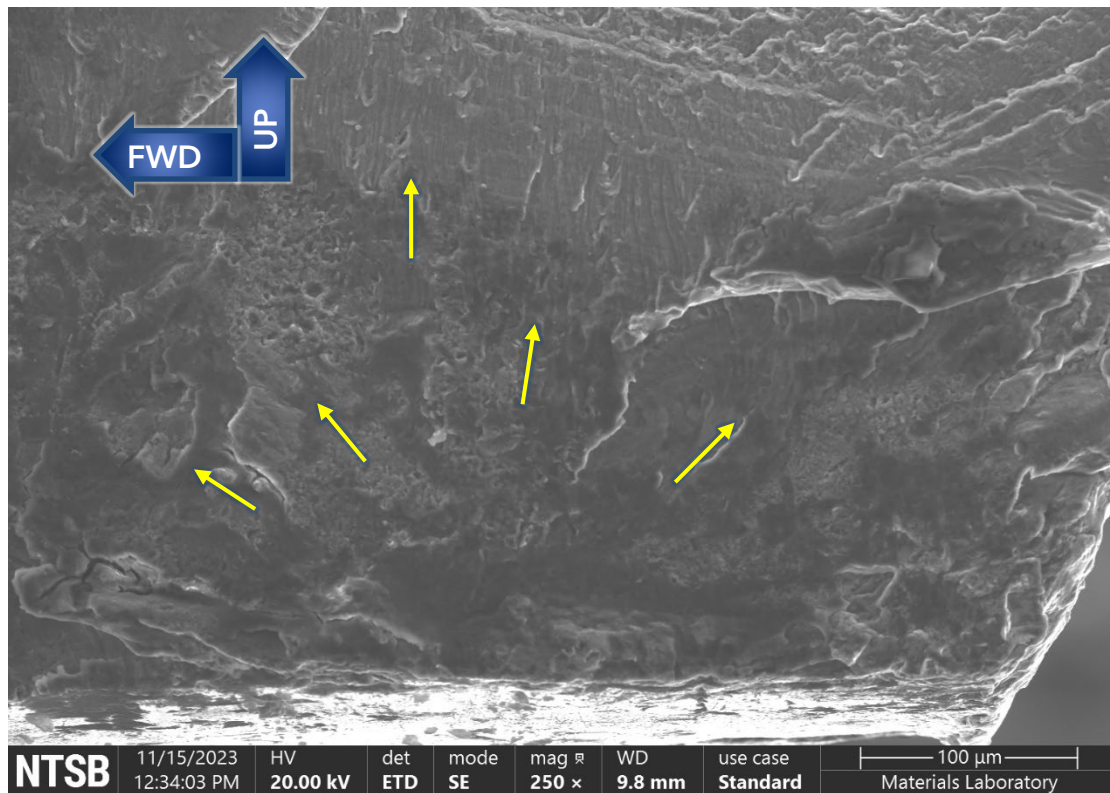


Figure 22. SEM images of the origin areas shown in figure 21. Unlabeled arrows indicate the local direction of fatigue propagation emanating from the origin areas.

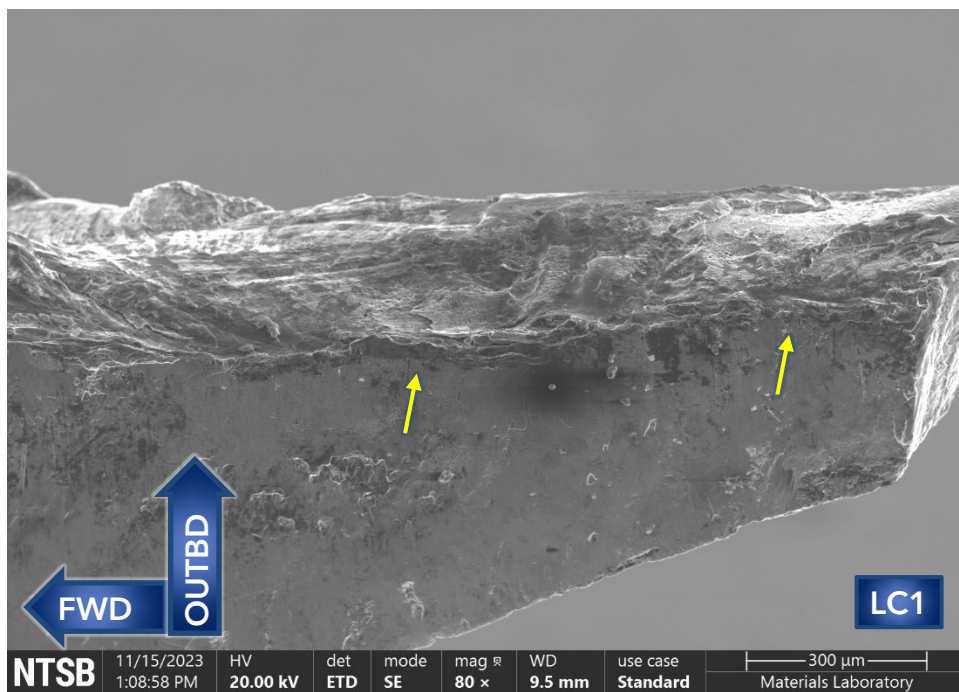


Figure 23. SEM image of the lower surface of the cap from the left wing after lab fracture to open the crack where unlabeled arrows point to the lower surface adjacent to the fatigue origins.