NATIONAL TRANSPORTATION SAFETY BOARD

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

February 24, 2016

MATERIALS LABORATORY FACTUAL REPORT | Report No. 16-013

A. ACCIDENT INFORMATION

Place	:	Paso Robles, California
Date	:	November 7, 2015
Vehicle	:	Cirrus SR22T, N999VX
NTSB No.	:	WPR16IA025
Investigator	:	Kristi Dunks, AS-WPR

B. COMPONENTS EXAMINED

Nose Landing Gear Strut Weldment, p/n 18633-003 s/n 1177

C. DETAILS OF THE EXAMINATION

The as-received nose landing gear (NLG) strut assembly was fractured through the strut tube adjacent to the forward edge of the gusset tube attachment welds. The fractured assembly is displayed from the left side in figure 1 and from the top in figure 2. The label affixed to the strut tube indicated the part number as 18631-405, from lot 709392 with serial number 1177 and a QA date of 8/19/14. A representative of Cirrus Aircraft indicated that this lot had contained 12 total strut assemblies.

The FAA registry database indicates that N999VX received it airworthiness certificate on October 1, 2014 with serial number 0871. The strut had a reported total of 380 service hours with an unknown number of landings at the time the strut fractured.

The NLG strut weldment was an inseparable fusion welded[1] assembly consisting of the strut tube with a spindle welded to the forward end and an upper fitting welded to the aft end. Two gusset tubes are welded between the upper fitting and the strut tube along with tabs to connect the oleo strut and lower fairing welded to the strut tube. The material of all components was specified as AISI[2] 4130[3] alloy steel in the normalized condition. The strut was quench and temper heat treated[4] after welding to a specified hardness of HRC 40 to 44.

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[1] Per CDC Specification 90497, class A.
[2] American Iron and Steel Association.
[3] Per various Military specifications.
[4] Per MIL-H-6875, Military Specification HEAT TREATMENT OF STEEL, PROCESS FOR (version H, 1 MAR 1989) [S/S BY SAE-AMS-H-6875]

As shown in figure 2, the fracture through the strut tube was located at the forward edges (toes) of the gusset tube welds to the strut tube. Visual examinations of the fracture faces found multiple fracture regions on multiple fracture planes with various features within each region as identified on the aft fracture face displayed in figure 3. All of the fracture regions were oriented on slanted planes through the wall thickness of the strut tube.

Most prominent, were opposed reflective (shiny) regions at the right and left sides of the fracture, as denoted in figure 3. Both shiny regions were approximately centered at the weld intersections of the respective gusset tubes with the strut tube. Magnified stereoscopic examinations revealed wide spread and extensive mechanical surface damage within these regions consistent with repeated mutual crack face recontact damage during crack closure. The damage was indicative of preexistent cracks present prior to total strut separation.

The reflective region on the right side (image left) of the strut measured approximately 2.2 inches around the circumference of the strut tube. Crack arrest markings visible in the left side image of figure 4, indicated initial through the wall propagation from the forward toe of the right side gusset tube weld bead. The through the wall penetration area was on an approximate 45 degree plane through the strut tube wall. At the margins of the though the wall area fracture (red arcs in figures 3 and 4) markings indicated circumferential progress in both the upward and downward directions as denoted by arrows in figure 3 and the left view of figure 4.

The left side reflective region (image right) was much smaller measuring only 0.5 inch circumferentially. Similar to the right side, fracture markings indicated through the wall thickness crack penetration from the forward toe of the respective gusset tube weld bead. However, unlike the right side region, the crack area did not penetrate though the strut wall (terminus denoted in figure 4 by dashed red line) and no circumferential progression was noted on the right side.

The fracture regions between the two reflective regions were matte in coloration with surface textures and deformation patterns and marking indicative of overstress separations. The overstress regions were also on multiple slant planes through the strut tube wall.

With the paint mostly removed, the weld beads and surrounding surfaces were visually inspected at low magnification with a stereo microscope. The surfaces had fine mottled textures consistent with grit blasting prior to painting. The weld puddle solidification ripple pattern indicated that both gusset tube-to-strut tube-welds were made in a counter-clockwise direction when the individual welds are viewed looking at the strut tube. The start / stop points of the welds were not clearly apparent. The forward surfaces of the weld beads had been ground after welding in the area adjacent to the through the wall portions of both reflective regions. The left side gusset weld shown in figure 5 is typical of both sides.

Additionally, a crack was visible at higher magnification at the aft toe of the weld on the left gusset tube as denoted by the red bracket in figure 5. Scanning electron microscope (SEM) examinations confirmed the presence of the crack as shown in figure 6. The crack was sharply delineated at the surface indicating its formation after the surfaces were grit blasted.

Scanning electron microscope examinations of the aft fracture face found the recontact mechanical damage to be extensive in the reflective regions, obliterating almost all of the fine fracture features within the left and right reflective regions. Small areas of intact features were located in the through the wall area of the right reflective region that were highly suggestive of high stress fatigue propagation. These are shown in the upper view of figure 7. Identifiable ductile dimples were found starting about midway in the circumferential progression areas and continuing to the termini. Indicating that this portion of the fracture was overstress in nature. These are shown in the lower image of figure 7. Ductile dimples were also found in the overstress regions between the reflective fracture regions.

The aft fracture face along with the gusset tubes welds was transversely saw cut from the strut and then sectioned along the horizontal plane through the approximate center lines of the gusset tubes as shown in figure 8. The pieces shown were then mounted and metallographically prepared. Figures 9 and 10 display the as-polished welds at the forward (top) and aft (bottom) sides of the right and left gusset tubes, respectively.

Sectioning revealed a dark brown organic coating on all of the interior surfaces of the strut and gusset tubes, see figure 8. A representative of Cirrus described the coating as LPS Hardcoat. The coating was bubbled adjacent to the weld regions but still covered the surfaces. No internal corrosion was noted.

The fracture was at the forward toes of the forward gusset tube welds as shown in the upper views of figures 9 and 10. Also note the slanted nature of the fracture through the strut tube wall thickness.

The welds were specified on the engineering drawings as full circumferential fillet weld in accordance with Cirrus Design Corporation (CDC) specification 90497 class A[5] by GTAW (gas tungsten arc weld).

As shown in the upper image of figure 9, the weld bead at the forward edge of right gusset tube completely melted the end of the tube and incorporated it into the fusion zone. The left tube weld, shown in the upper view of figure 10, did not completely melt the tube section but incorporated most into the fusion zone. Both welds satisfied the welding specification requirements for complete root penetration plus 10%. The measured weld sizes for both leg lengths “L” and throat depths “K” were near the middle of the size range specified by the process specification.

The welds on the aft sides of the gusset tubes displayed incomplete penetration to the root of the joint as shown in the lower images in figure 9 and 10. Figure 4.5.3-4 of the weld specification allows for incomplete root penetration for angled tube joints where the acute angle between the tube is 45 degrees or less. The measured angle between the strut and gusset tubes was measured between 55 and 60 degrees.

When etched with 2% Nital[6], the welds and surrounding tube structures showed tempered martensitic structures consistent with the post welding specified quench and tempered heat treatment, see figure 11. The strut tube microstructure showed an elongated structure consistent with the drawing direction of the original tube. Partial decarburation was also noted on the inner diameter of the strut tube as shown in figure 10. The decarburization both complete and partial was visually measured to be about 0.003 inch in depth. The outer diameter of the strut tube, the welds and gusset tube surfaces did not display any decarburation. Heat treating is required to be in accordance with MIL-H-6875H which limits decarburization for this hardness level to 0.005 inch or less as determined by a micro hardness survey.

Examinations of the metallographic sections also uncovered three small (< 0.005 inch) surface cracks in the surface of the left weld fusion zone as shown in figure 13. The cracks were oxide-filled indicating their presence during heat treatment. The cracks were located away from the weld toe.

Microhardness traverses across the fusion zone base metal interfaces of the forward welds showed a uniform hardness and no significant gradients.

[5] CDC Process Specification Welding –Ferrous- Alloys current revision F dated 4/12/02. Class A indicates critical applications “where a failure of any portion would cause loss of system…”.
[6] 2% concentrated nitric acid in ethanol.

As the aft fracture was sectioned from the strut, a ring section was also removed from the strut tube about 1.5 inches aft of the fracture. The ring section was ground to ensure parallel surfaces and measurements were made using an optical comparator[7]. The inner diameter measured 1.6805 inches and the outer diameter was 1.9339 inches. Cirrus reports the nominal diameters at this location as 1.938 inch outer diameter with a 0.010 inch profile tolerance and 1.687 inch inner diameter. The wall thickness measured at 8 approximately equal spaced circumferential locations ranged from 0.1349 inch to 0.1140 inch for a maximum variation of 0.0209 inch. The inner and outer diameters were visually non concentric as reflected in the large variations in wall thickness around the strut tube.

Direct HRC[8] hardness measurements were made on the ring cross section averaging 40.1 HRC for 9 measurements. Meeting the 40 HRC specified by the engineering drawing.

The strut and both gusset tubes were confirmed to be AISI 4130 alloy steel using a hand held x-ray fluorescence spectrograph[9].

Joe Epperson
Senior Metallurgist

[7] Opticom Qualifier 14B by OGP (Optical Gaging Products)
[8] Hardness Rockwell “C” scale.
[9] Thermo Scientific Niton XL3t-980 x-ray fluorescence (XRF) alloy analyzer

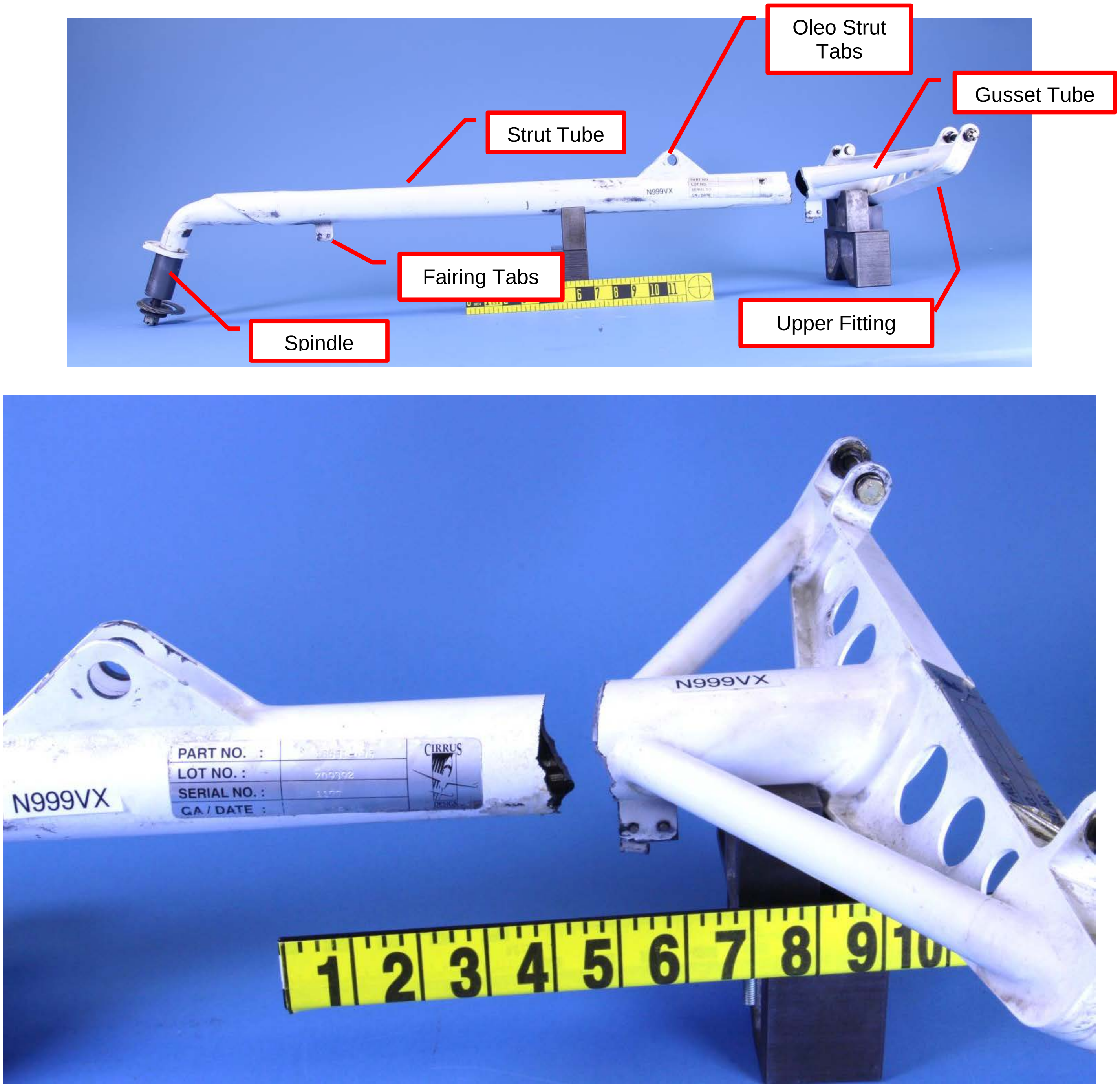


Figure 1. Left side views of the fractured strut assembly overall at top and closer view of the fracture area below. Aircraft forward at left.

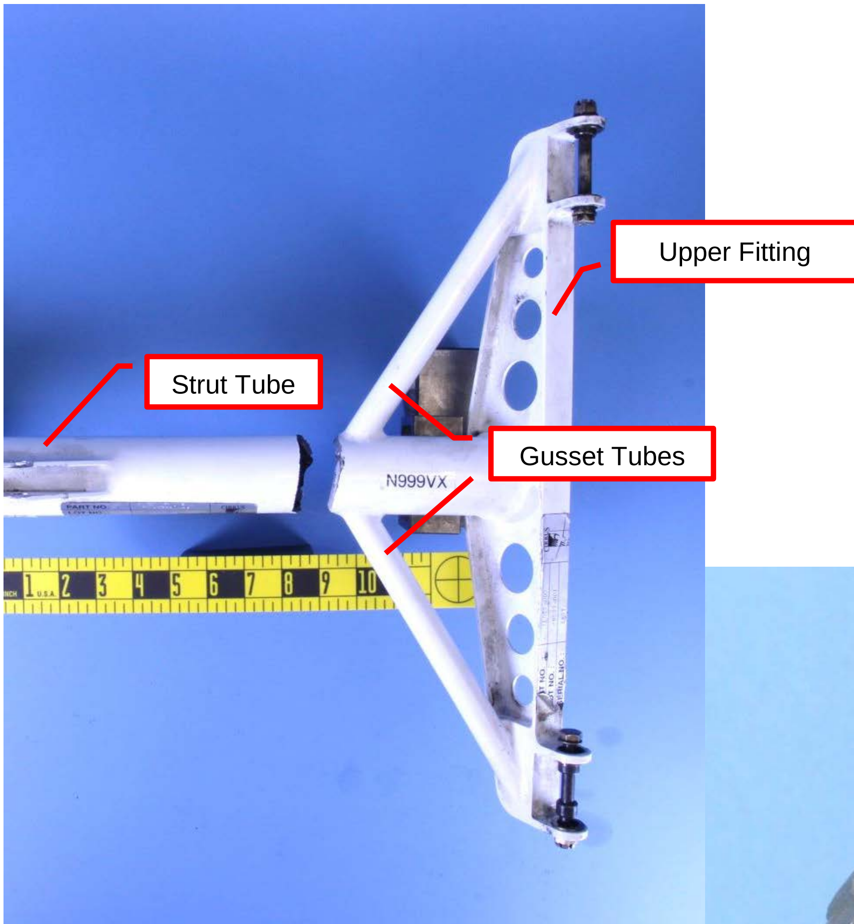


Figure 2. Upper surface views of the fracture area showing the fracture location at the forward edges of the gusset tube welds identified by brackets at right. Aircraft forward at left.

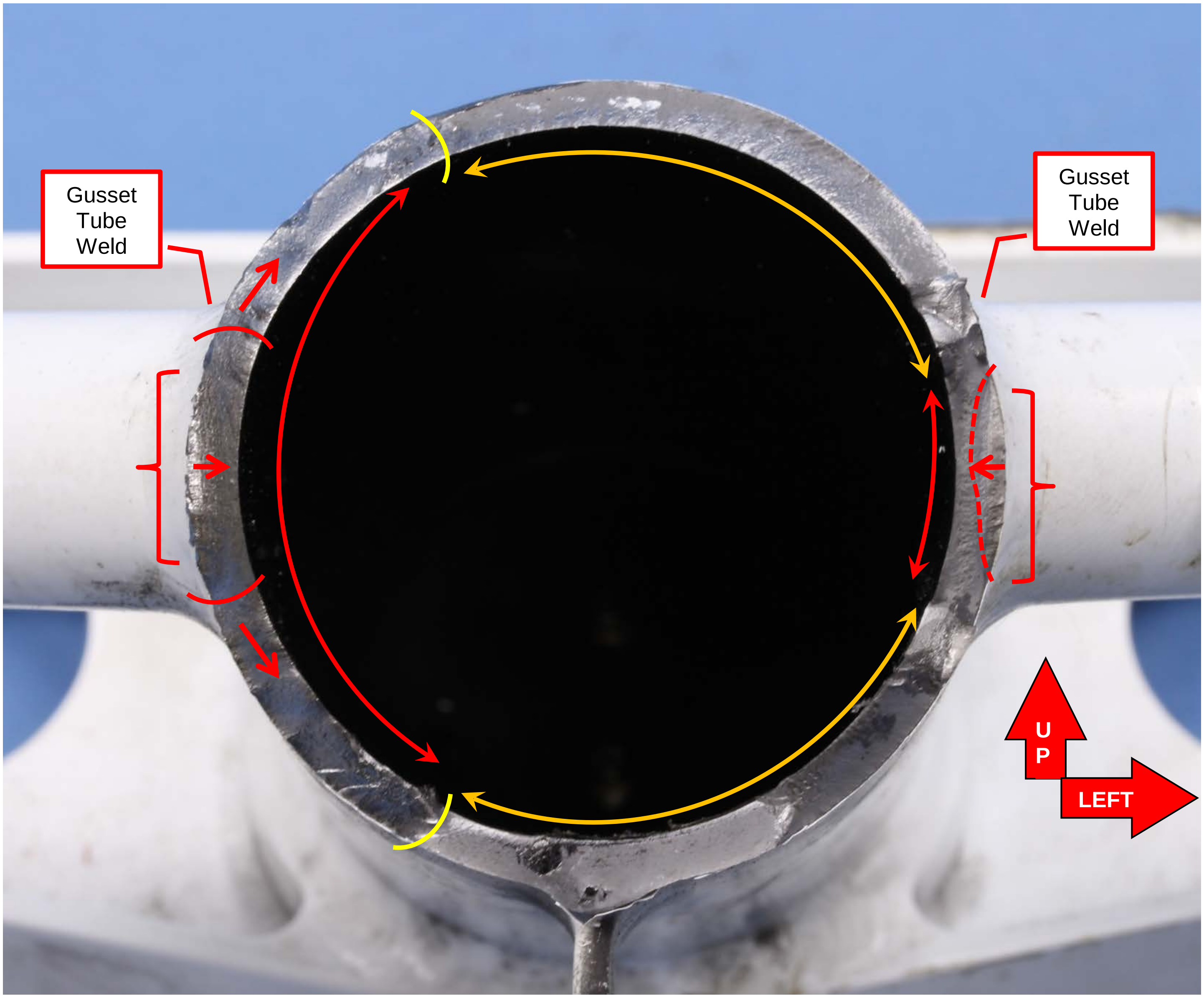


Figure 3. Looking aft at the aft fracture face. Double headed red arrows denote the reflective regions and orange arrows the overstress areas. Red brackets denote initiation locations of through the wall crack portions at the toes of the gusset tube welds. Circumferential extensions (two directions) of the right crack are between the red and yellow arcs. Arrows indicate local crack propagation directions.

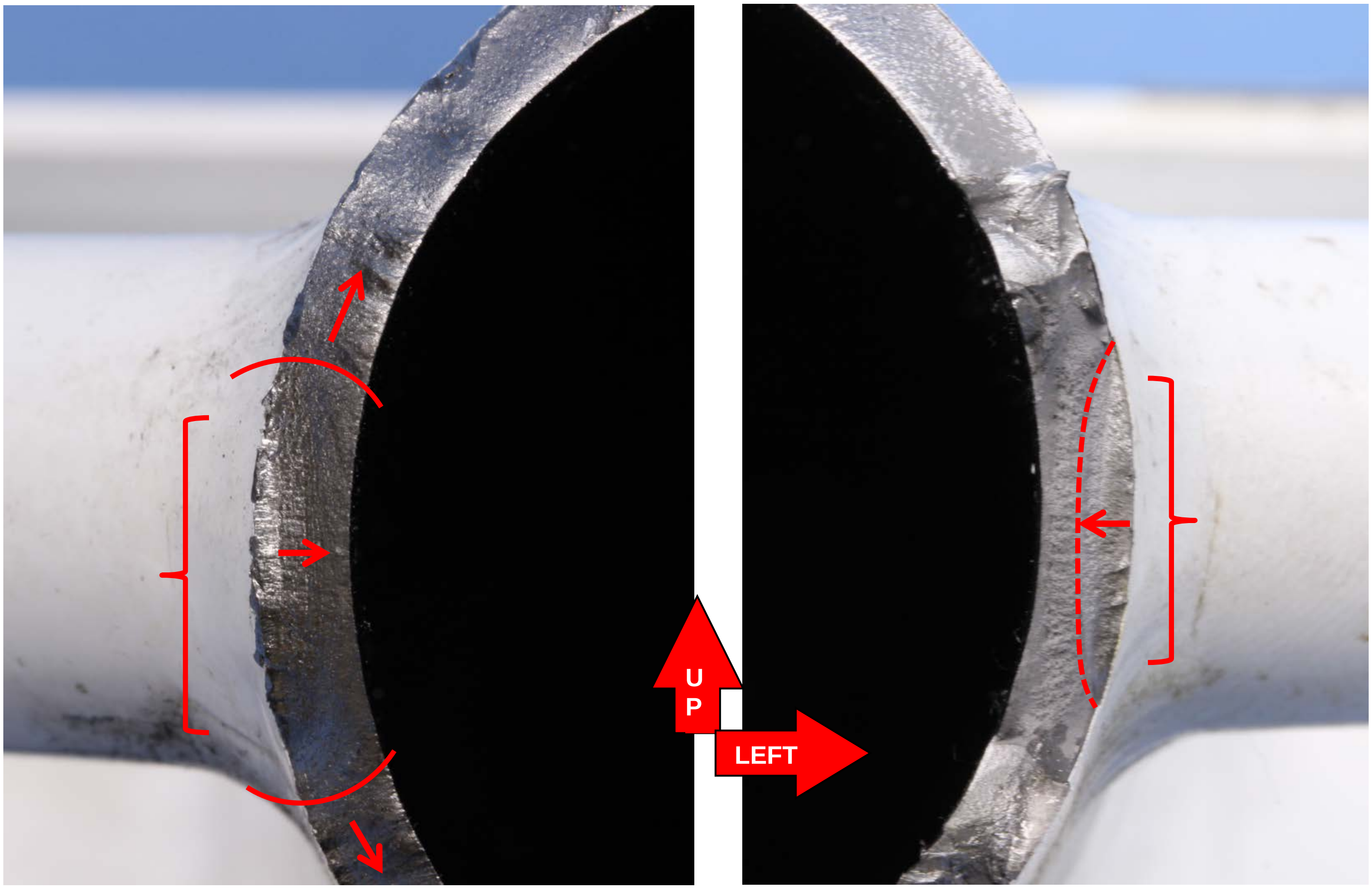


Figure 4. Closer views of the left and right crack initiations and through the wall portions. Arrows indicate local crack propagation directions. Arcs denote the approximate extent of the through the wall portion of the right regions. The terminus of the left region is indicated by the dashed line.

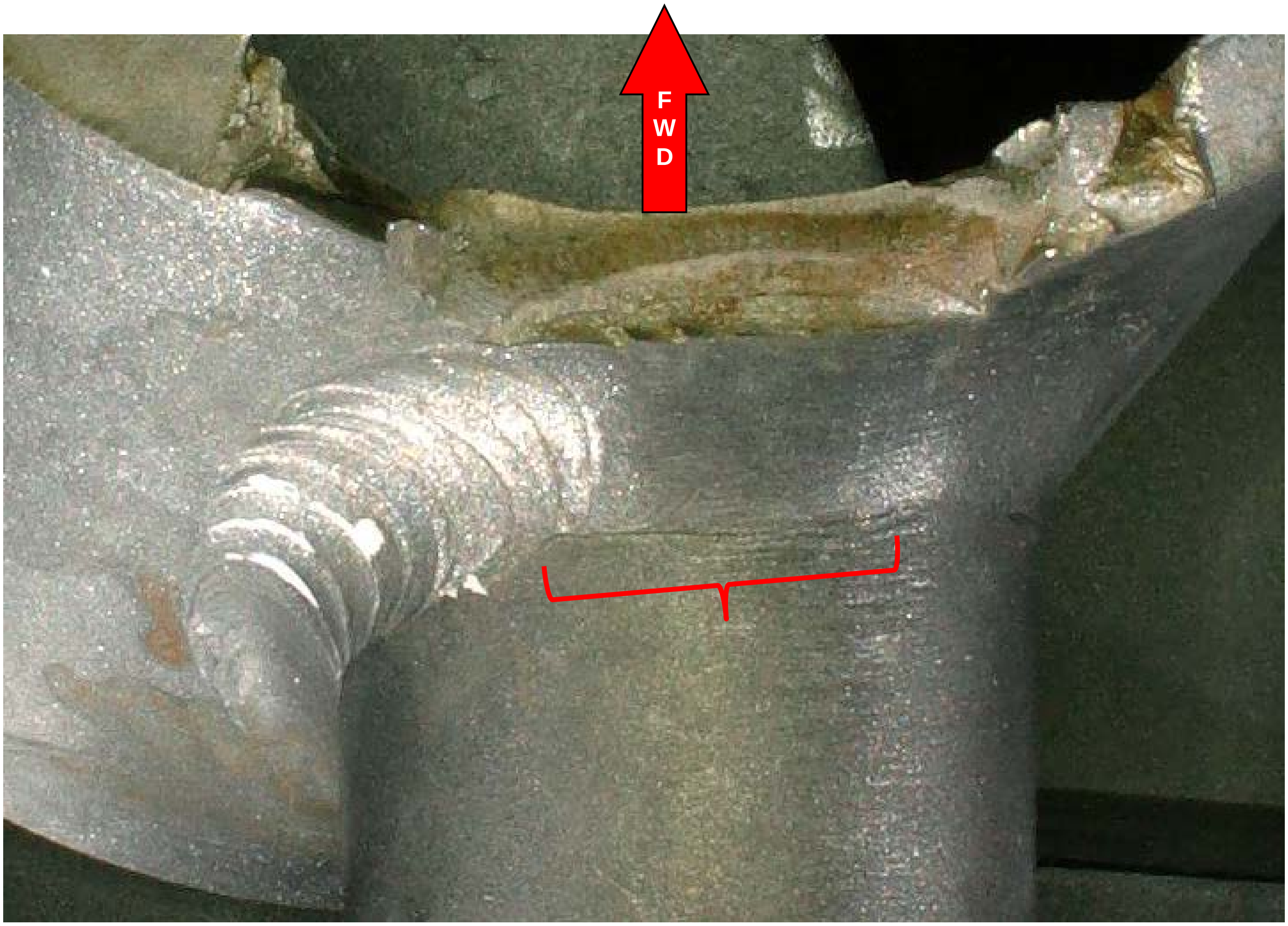
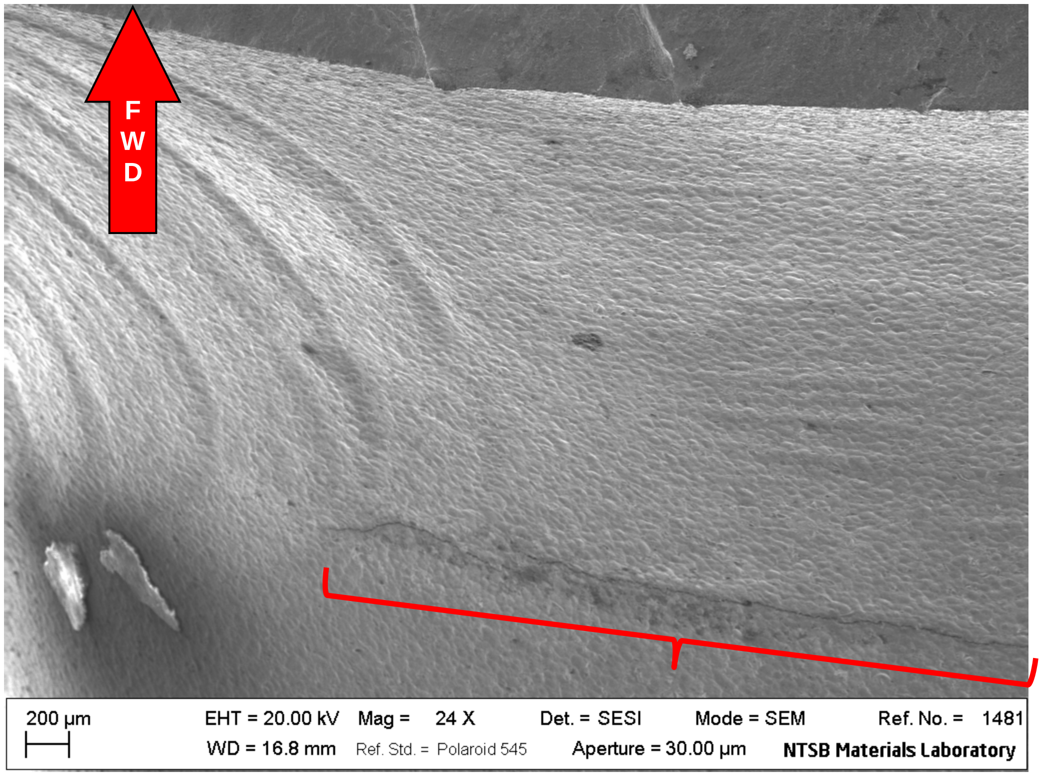


Figure 5. Optical view of the left gusset tube to strut weld showing a crack (bracket) at the aft toe of the weld. Also note the post weld grinding of the weld bead surface at the forward edge.



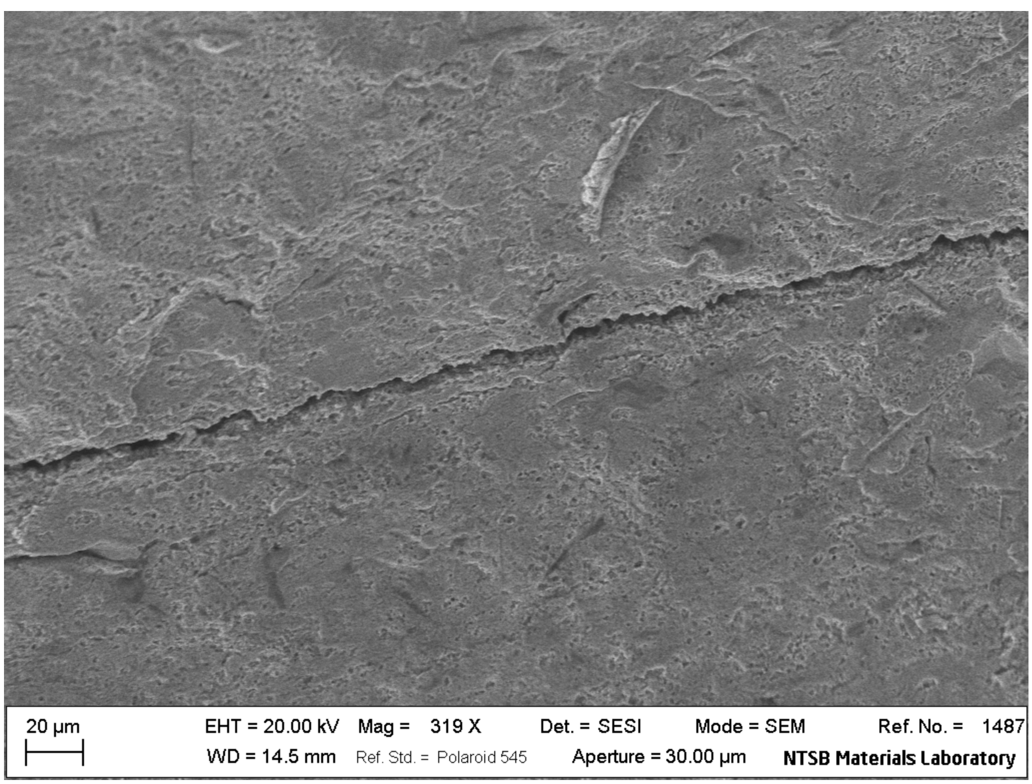
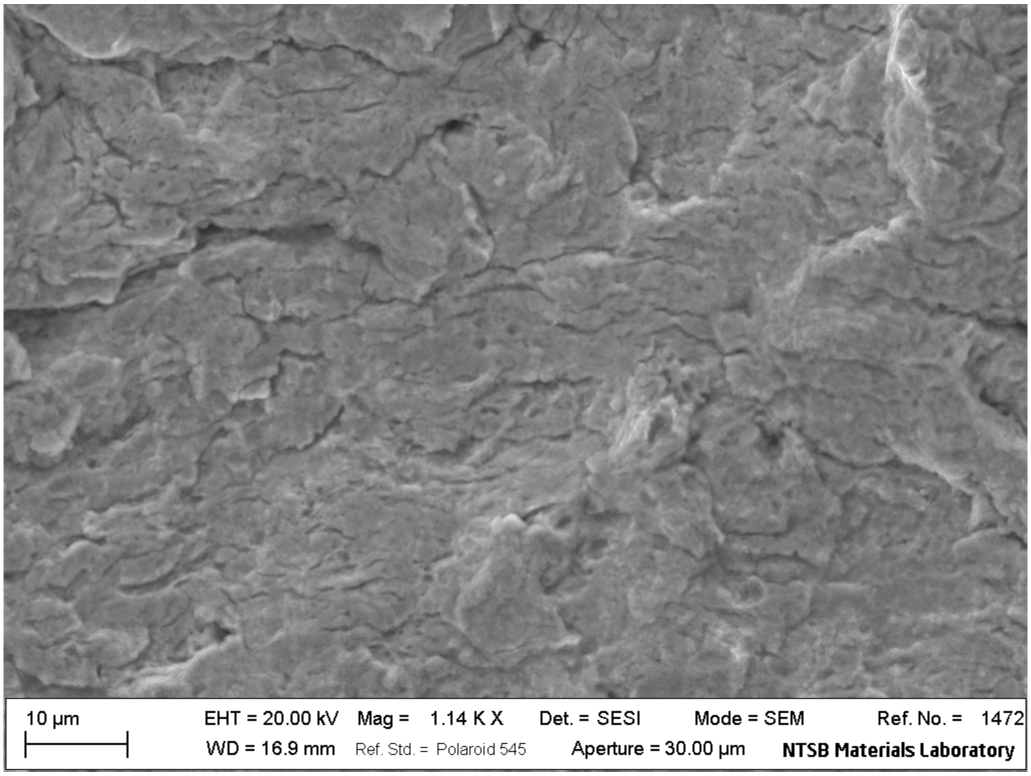


Figure 6. SEM views of the left gusset tube crack from figure 5 at low (top) and high (bottom) magnifications.



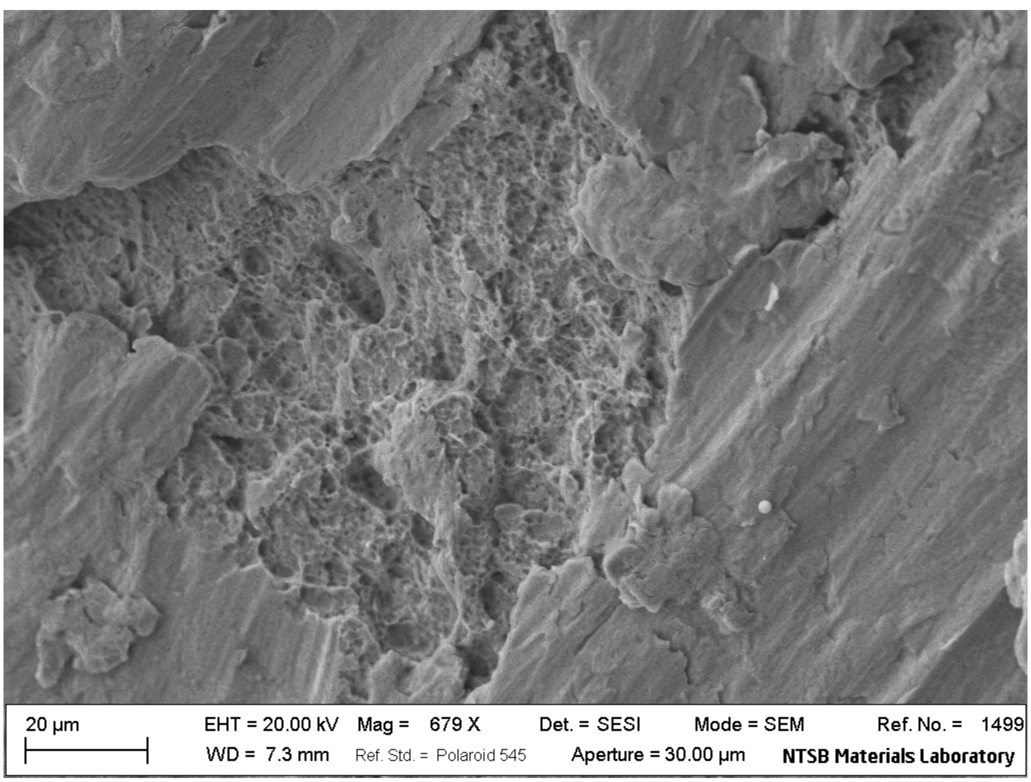


Figure 7. At top an SEM image showing of striations indicative of high stress fatigue propagation in the through the wall region of the left reflective band. The lower view displays typical ductile dimples uncovered about midway in the circumferential propagations of the left reflective region.

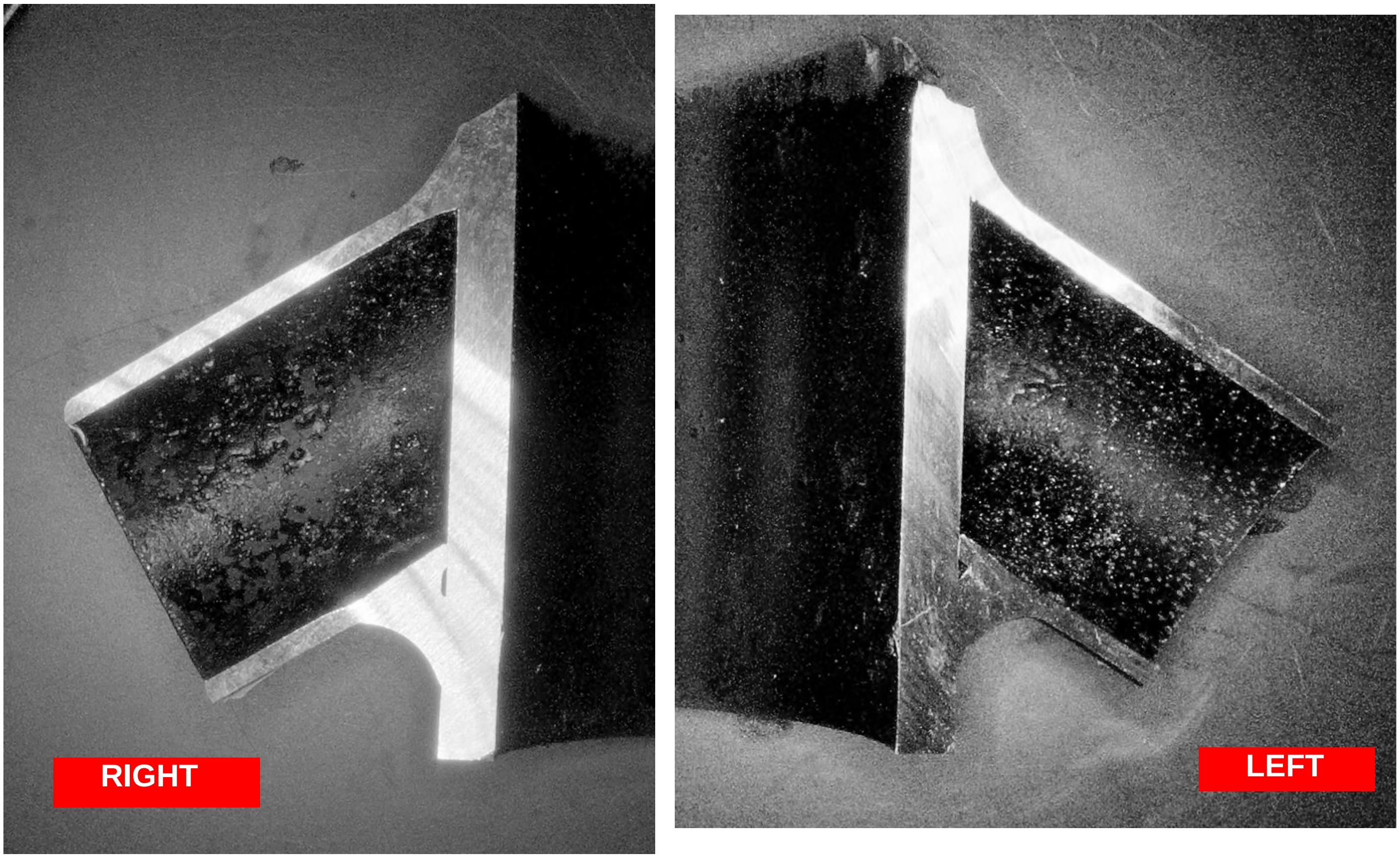
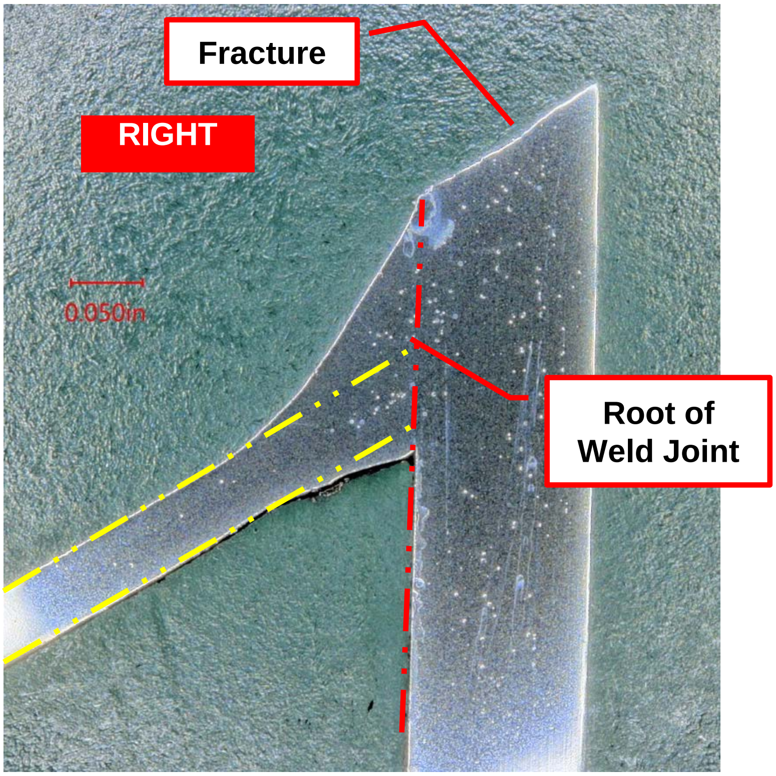


Figure 8. An overall view of the sectioned intersections of the left and right gusset tubes with the strut tube showing the welds in cross section and further shown below. Aircraft forward is at top. Interior tube surfaces coated with a dark brown material.



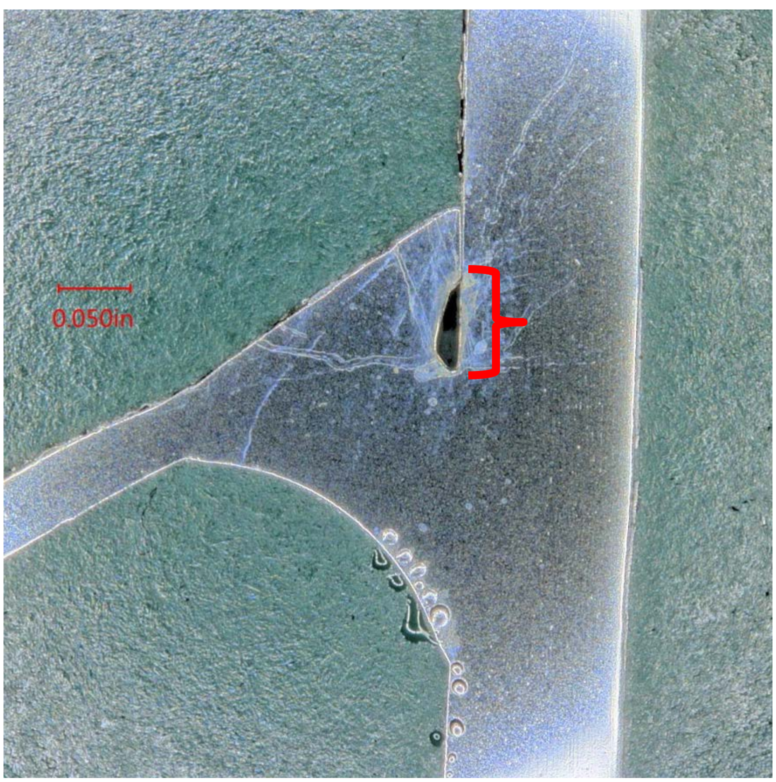


Figure 9. Metallographic views of the forward and aft portions of the fillet weld on the right gusset tube weld. Forward portion at top shows more than 100% root penetration. Yellow and red lines denote the approximate original gusset and strut tube surfaces. Note the slant profile of the fracture plane at top. Lower view shows the aft portion of the weld with the red bracket denoting the area of incomplete root penetration.

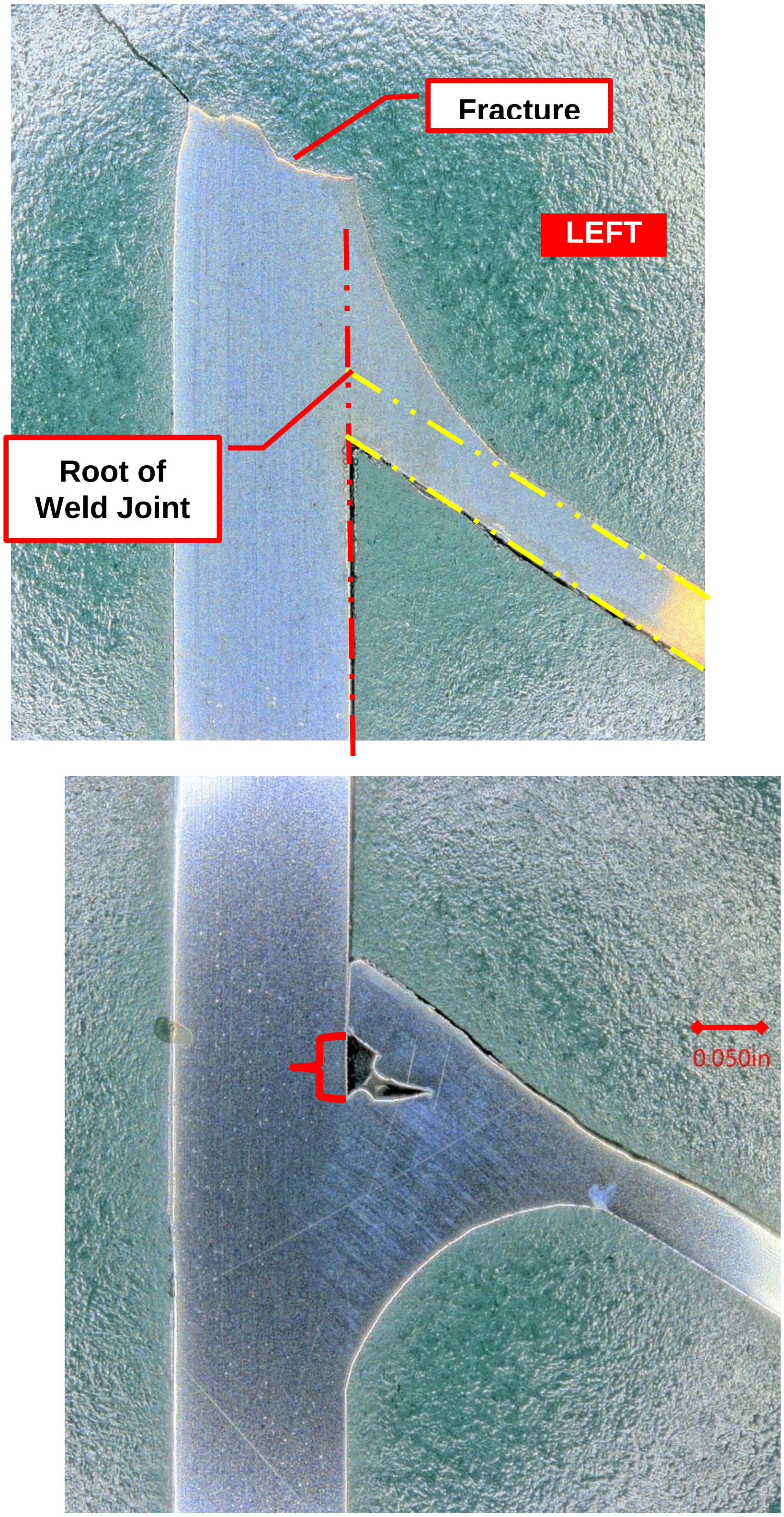


Figure 10. Metallographic views of the forward and aft portions of the fillet weld on the left gusset tube weld. Forward portion at top shows more than 100% root penetration. Yellow and red lines denote the approximate original gusset and strut tube surfaces. Note the slant profile of the fracture plane at top. Lower view shows the aft portion of the weld with the red bracket denoting the area of incomplete root penetration.

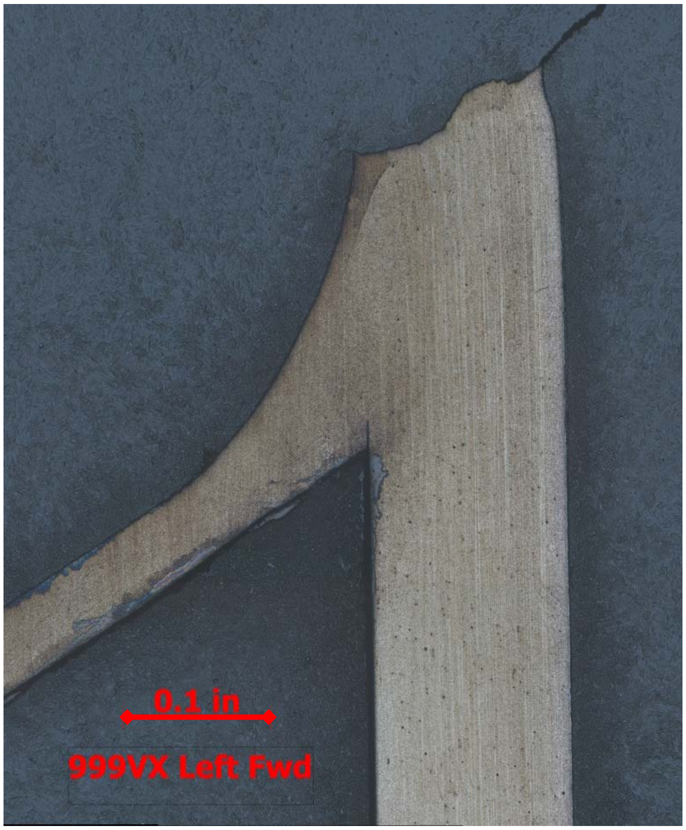


Figure 11. The etched microstructures of the forward welds of the left and right gusset tubes showing a fully martensitic microstructure except at inner diameter of strut tube. See Figure 13. Images mirrored from figures above.

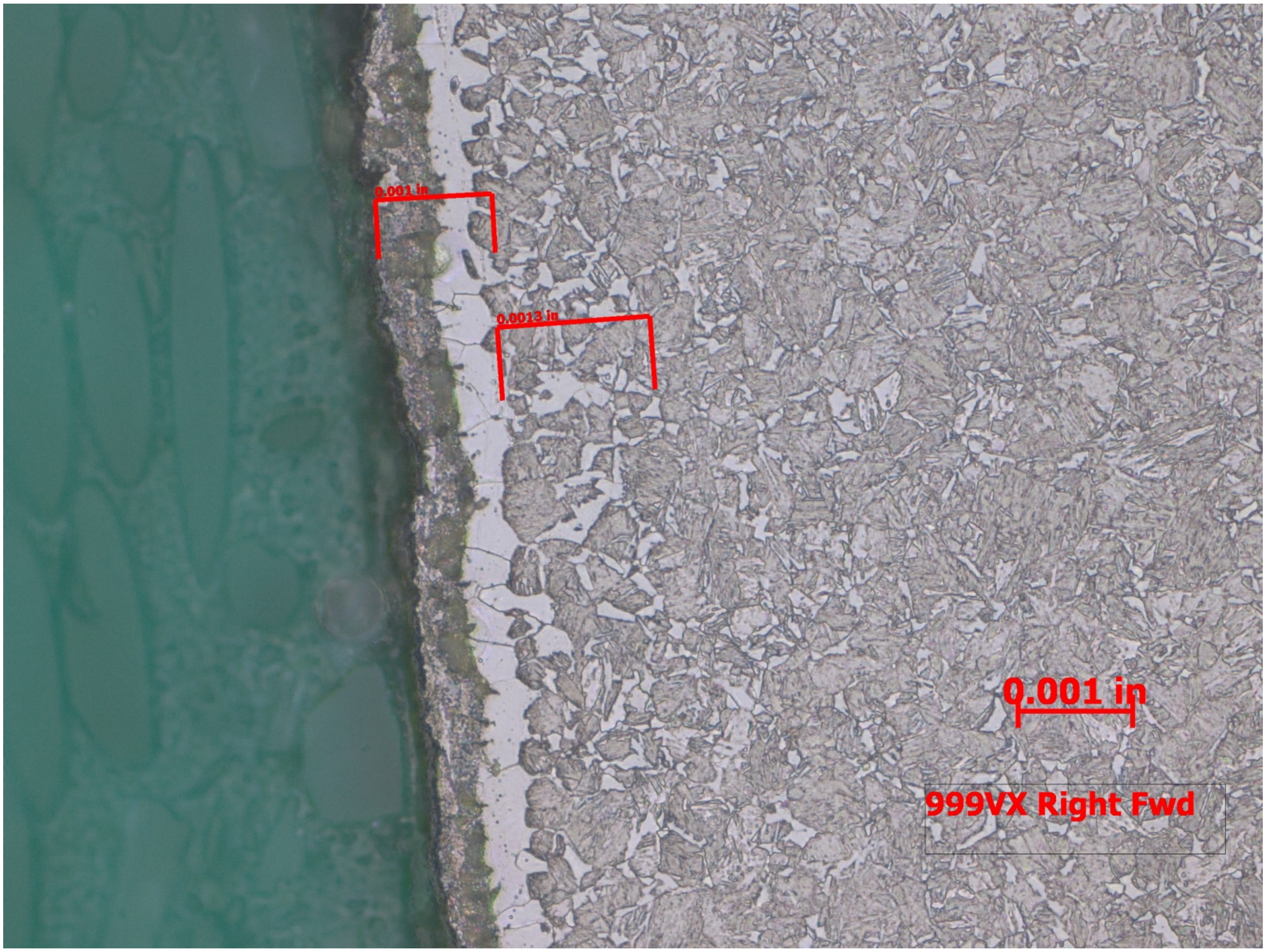


Figure 12. Closer view showing decarburized layer at inner diameter surface of strut tube. Visually measured about 0.003 inch at this location.

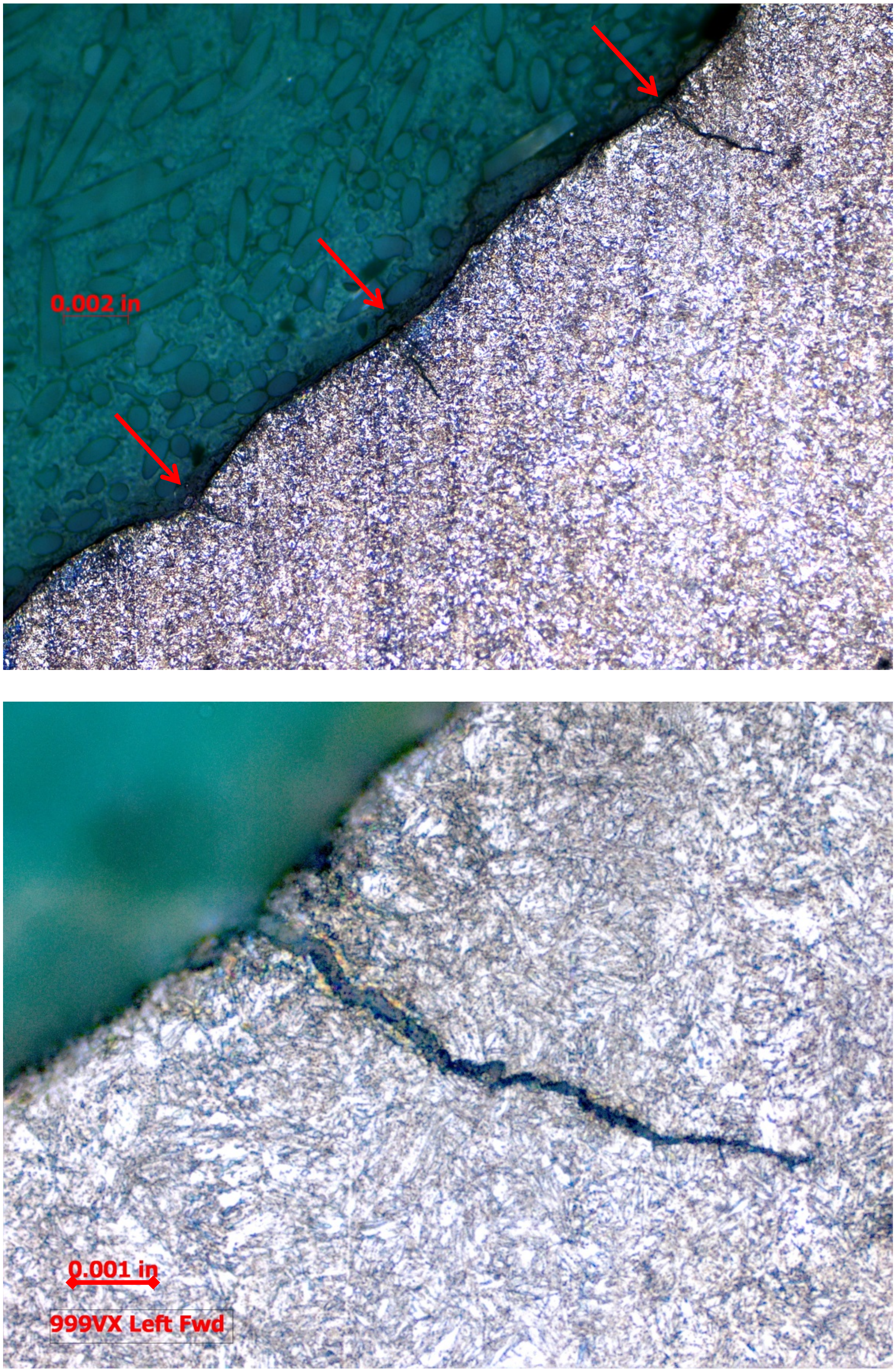


Figure 13. Two metallographic views of the forward portion of the left gusset tube weld showing the three cracks (red arrows) at top. The oxide filled largest one is show at bottom.