

Metallurgical Investigation Final Report



Subject: Metallurgical Investigation of Swiss International Air Lines PW1524G Engine No. 736195

Date: October 23rd, 2019

Summary and Conclusions:

The 1st stage low pressure compressor (LPC R1) integrally bladed rotor fractured due to high cycle fatigue (HCF) progression from a primary origin area at the pressure side leading edge (PSLE) root radius of blade no. 16. There was no evidence of any anomalies observed in the vicinity of the origin area.

Fatigue progressed from a primary sub-surface origin area located 0.0033 inch in depth from the flow path surfaces thru the thickness of the rim. The fracture mode subsequently transitioned to progressive overstress/tearing prior to final overstress fracture through the web and bore. No additional crack indications were identified in the vicinity of the PSLE root radius region of the remainder of the blades from a fluorescent penetrant inspection (FPI) of the recovered portion of LPC R1.

The general and surface microstructure conformed to the quality requirements for rotor grade Ti-6Al-4V titanium alloy. The chemical composition was found to conform to the material specification requirements. The root radius measurements conformed to the part drawing requirements. There were no material or processing abnormalities detected.

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1.0 Background

PW1524G engine serial number (ESN) 736195 was installed in the number 1 (left) position on an A220-300 aircraft HB-JCA operated by Swiss International Air Lines (SWR). On September 17th, 2019, the subject engine experienced an in-flight shutdown (IFSD) during climb. An “L Eng Stall” message was posted in the cockpit. The engine was shut down and the aircraft was diverted to Geneva Airport (GVA) where it made an uneventful landing. There was no penetration of the nacelle or metal in the tailpipe reported.

The aircraft was impounded (quarantined) in Geneva for investigation. A portion of the 1st stage low pressure compressor (LPC R1) integrally bladed rotor was recovered in the nacelle in the fan bypass. The recovered portion of LPC R1 was returned to Pratt & Whitney (P&W) East Hartford for investigation. A joint metallurgical investigation was conducted with representatives from Pratt & Whitney Materials and Processes Engineering (P&W-MPE), the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), and Airbus. This report serves to document the results of the metallurgical investigation.

2.0 Details of Examination

A metallurgical investigation plan was reviewed and approved by the joint investigation team. The metallurgical investigation was executed in accordance to the details outlined in the investigation plan. The following sections document the non-destructive and destructive evaluations performed on the portion of LPC R1 recovered from P736195.

2.1 Visual Examination of LPC R1

A visual review of the recovered portion of LPC R1 was conducted in the as-received condition in order to identify any potential primary modes of distress and to determine the fracture origin area (**Figure 1**).

The part identification markings (part number: 5315291, serial number: LBDUA42469, and heat code: XAAFT 0007) were located on the OD surface of the LPC R1 aft spacer (**Figure 2**). An “X” marking located on the OD surface of the spacer identifies the location of blade (airfoil) no. 1. The blade position number is determined by starting at blade no. 1 and counting in the clockwise direction as viewed aft looking forward. The mass of the recovered portion of LPC R1 was determined to be [REDACTED], indicating that approximately 73.8% (by mass) of the LPC R1 was recovered.

The recovered portion of the LPC R1 exhibited mating fracture halves of the bore region, indicating that the full bore of the rotor was recovered. A portion of the rim containing blade nos. 12 thru 15 was not recovered. Additionally, a portion of the aft spacer was not recovered as indicated by the lack of mating fracture halves.

Significant secondary distress was noted resulting from the fracture and release of LPC R1. The recovered portion of LPC R1 was severely distorted (elongated). Several of the blades were bent

opposite the direction of rotation and exhibited airfoil cracks and/or fractures consistent with rapid tensile-shear overstress.

The recovered portion of LPC R1 exhibited a primary radial fracture thru the rim and bore adjacent to blade no. 16. Only one-half of the primary radial fracture was recovered. The fracture direction was assessed by the presence of river lines and shear lip formation. Progressive features indicated that the fracture progressed from an origin area located at the pressure side leading edge (PSLE) root radius of blade no. 16 (**Figure 3**).

2.2 Binocular Microscope Examination of Primary Origin Area

The recovered portion of LPC R1 was sectioned to extract blade no. 16 and the adjacent blade (blade no. 17) in order to evaluate the primary origin area optically at higher magnifications under the binocular microscope.

Binocular microscope examination confirmed fatigue progression from a primary origin area at the PSLE root radius of blade no. 16 (**Figure 4**). The origin area was located in the region of the rim/flow path side of the root radius run-out.

Fatigue progressed in the radial/thru-thickness direction toward the forward balance flange, and along the rim in the forward and aft directions. The fracture mode subsequently transitioned to progressive overstress/tearing prior to final overstress fracture thru the remaining rim section and in the radial direction through the web and bore.

The fracture surface did not exhibit any evidence of discrete cyclic markers (macro-arrest lines) in the region of fatigue based on the optical examination. Evidence of remnant machining (milling) lines and slight dimples/indentations from shot peening were observed in the root radius region of blade 16. There was no unusual surface damage noted, with the exception of secondary damage associated with the fracture event.

2.3 Scanning Electron Microscope (SEM) Examination of Primary Origin Area

The primary fracture surface region was further sectioned to obtain a sample size suitable for direct SEM evaluation. The sample was cleaned in an alkaline cleaning solution in an ultrasonic cleaner, followed by immersion in solvent prior to SEM examination.

SEM evaluation in the region of fatigue identified cleavage fracture features that were consistent with a high cycle mode of fatigue initiation and progression. The early stages of fatigue exhibited predominantly faceted growth consistent with high cycle fatigue (HCF). There were no areas of striated growth observed. The faceted growth direction thru primary alpha grains was used to determine the crack growth direction and identify the fatigue origin (initiation site).

The initiation site was determined to be located 0.0033 inch (85 μ m) below the surface (**Figure 5 - 6**). Faceted growth was observed progressing away from the sub-surface initiation site in all directions including toward the flow path surface. The sub-surface initiation site was located

within the zone of the expected compressive residual stress die-out from peening. There was no evidence of any anomalies observed in the vicinity of the origin area.

A crack growth assessment could not be performed based on fractographic observations. There were no fracture features (discrete cyclic markers or arrest lines) observed for correlation to crack growth. The zone of fatigue was mapped at high resolution using a mapping routine that collects a series of image tiles, which were stitched together to form a map. The fracture map was used to assess the directionality of faceted alpha grains.

The extent (zone) of stable fatigue progression was determined from both binocular microscope and SEM evaluations. The stable fatigue progression was determined to extend up to 0.275 inch in the aft axial direction along the flow path surface and up to 0.190 inch in the radial (thru thickness) direction measured from the origin area (**Figure 7**). The aspect ratio of the fatigue crack was estimated to be approximately 2.9:1. A narrow zone exhibiting mixed fatigue and dimple rupture overstress fracture features was observed beyond the zone of stable fatigue progression. The fracture terminated in final ductile dimple overstress.

The bore fracture region was examined under the SEM for documentation and confirmation of the fracture direction and mode. SEM examination of the bore region revealed ductile dimple overstress fracture features (**Figures 8 - 9**). The formation of shear lips and the presence of ductile dimple fracture features indicated that the radial fracture terminated in the region of the bore.

2.4 Metallographic Examination of Blade No. 17

Three (3) metallographic sections were prepared through blade no. 17 in order to evaluate the general and surface microstructure (**Figure 10**). Transverse sections were taken spanwise through the leading edge (LE) root radius, chordwise through the pressure side root radius, and in the axial direction through the platform/flow path surface.

The general microstructure consisted of alpha-beta processed Ti-6Al-4V titanium alloy (**Figure 11**). There was no evidence of any distorted surface microstructure (bent grain or white etching layer) associated with abusive machining (**Figure 12**). The microstructure conformed to the quality requirements for rotor grade Ti-6Al-4V titanium alloy. There were no material or processing abnormalities detected.

2.5 Wet Chemistry Analysis

A complete quantitative elemental analysis using wet chemistry analysis was performed on a sample of the recovered LPC R1 extracted from the region of the bore. Analysis of all major, minor, and interstitial elements was performed. The chemical composition was found to conform to the material specification requirements.

2.6 Root Radius Measurement of Blade No. 16

Rubber replicas were taken at the pressure and suction side root radius locations on blade no. 16 (**Figure 13**). The root radius at the pressure and suction side of blade no. 16 was determined to be [REDACTED] (typical) at both locations from measurement of the rubber replicas using a digital microscope. The radius measurements conformed to the part drawing requirements.

2.7 Three-Dimensional (3D) Fracture Surface Scanning

A non-contacting optical measurement system was used to generate a three-dimensional rendition of the primary fracture surface region in order to illustrate the changes in fracture surface morphology with fracture mode transitions (**Figure 14**). A blue light dimensional scan of the primary fracture surface was also performed in order to assess the location of the origin area relative to reference datums/geometric features on the airfoil and rim. The axial location of the origin area was estimated to be located approximately 0.511 inch aft from the edge (forward face) of the platform. The tangential location of the origin area was estimated to be approximately 0.050 inch from the point of tangency between the airfoil fillet and the platform surface.

2.8 Fluorescent Penetrant Inspection of the Recovered Portion of LPC R1

The recovered portion of LPC R1 (with blade nos. 16 and 17 extracted) was processed through an aqueous cleaning procedure and a fluorescent penetrant inspection (FPI) was performed using ultra high sensitivity fluid. No crack indications were identified in the vicinity of the PSLE root radius region. Blade nos. 2, 3, 7, and 8 exhibited crack indications at the airfoil trailing edge root radius run-out (airfoil side), **Figure 15**. Additional crack indications were identified on the aft spacer (**Figure 16**). The crack indications were reviewed optically (visually and under the binocular microscope). The crack indications appeared consistent with secondary distress (tearing) resulting from the fracture and release of the LPC R1 fragment.

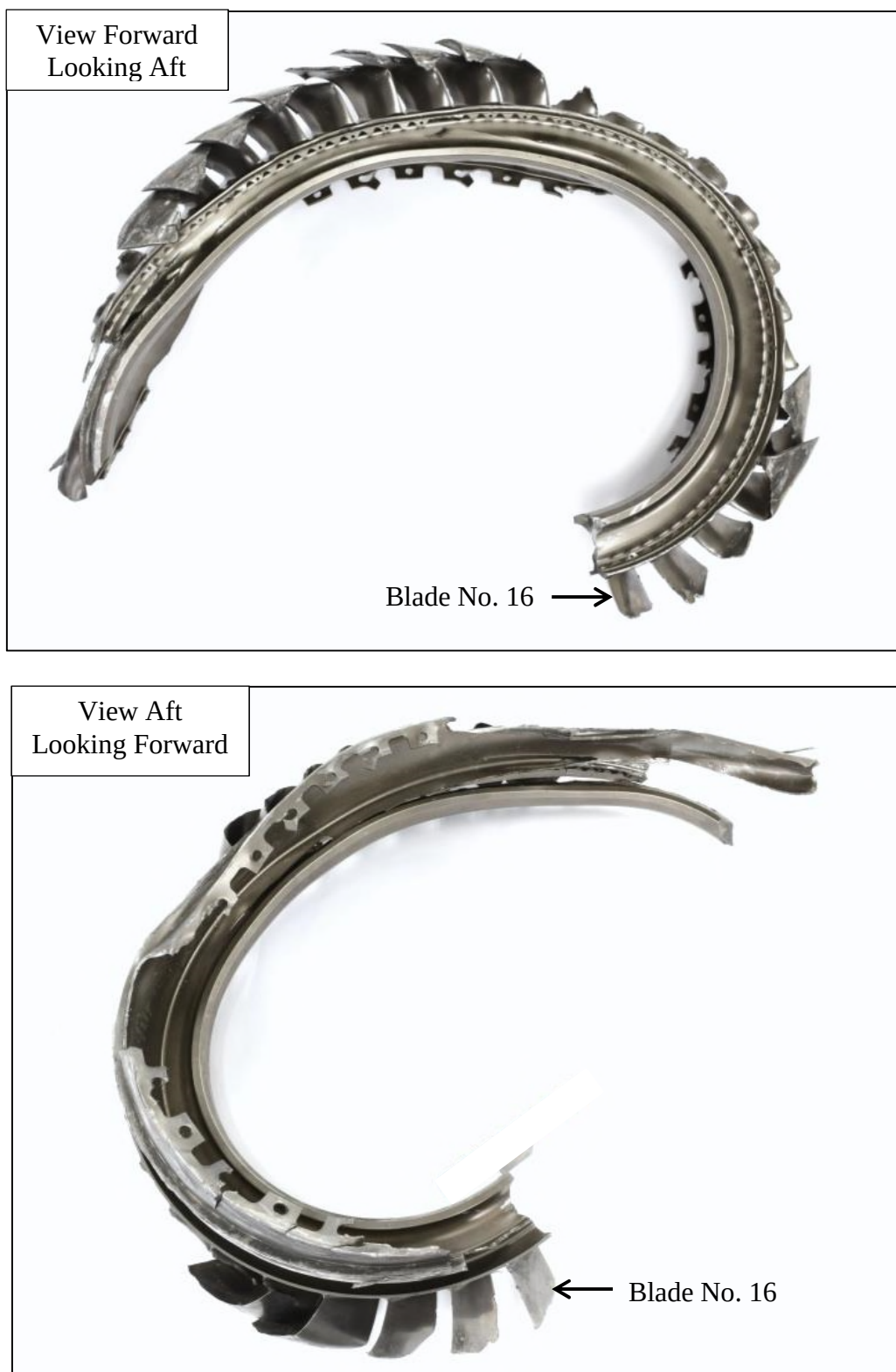


Figure 1. Views of the recovered portion of LPC R1 in the as-received condition.

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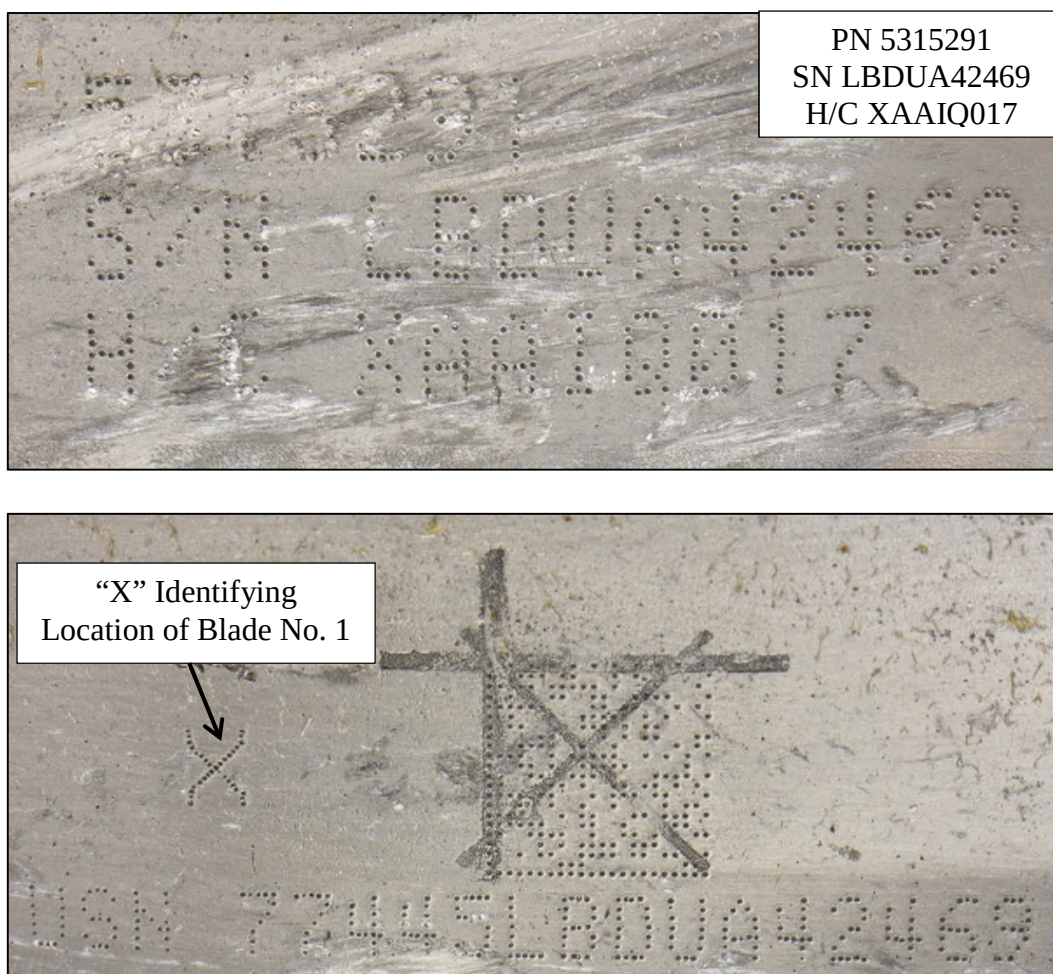


Figure 2. Views showing the LPC R1 part identification markings.

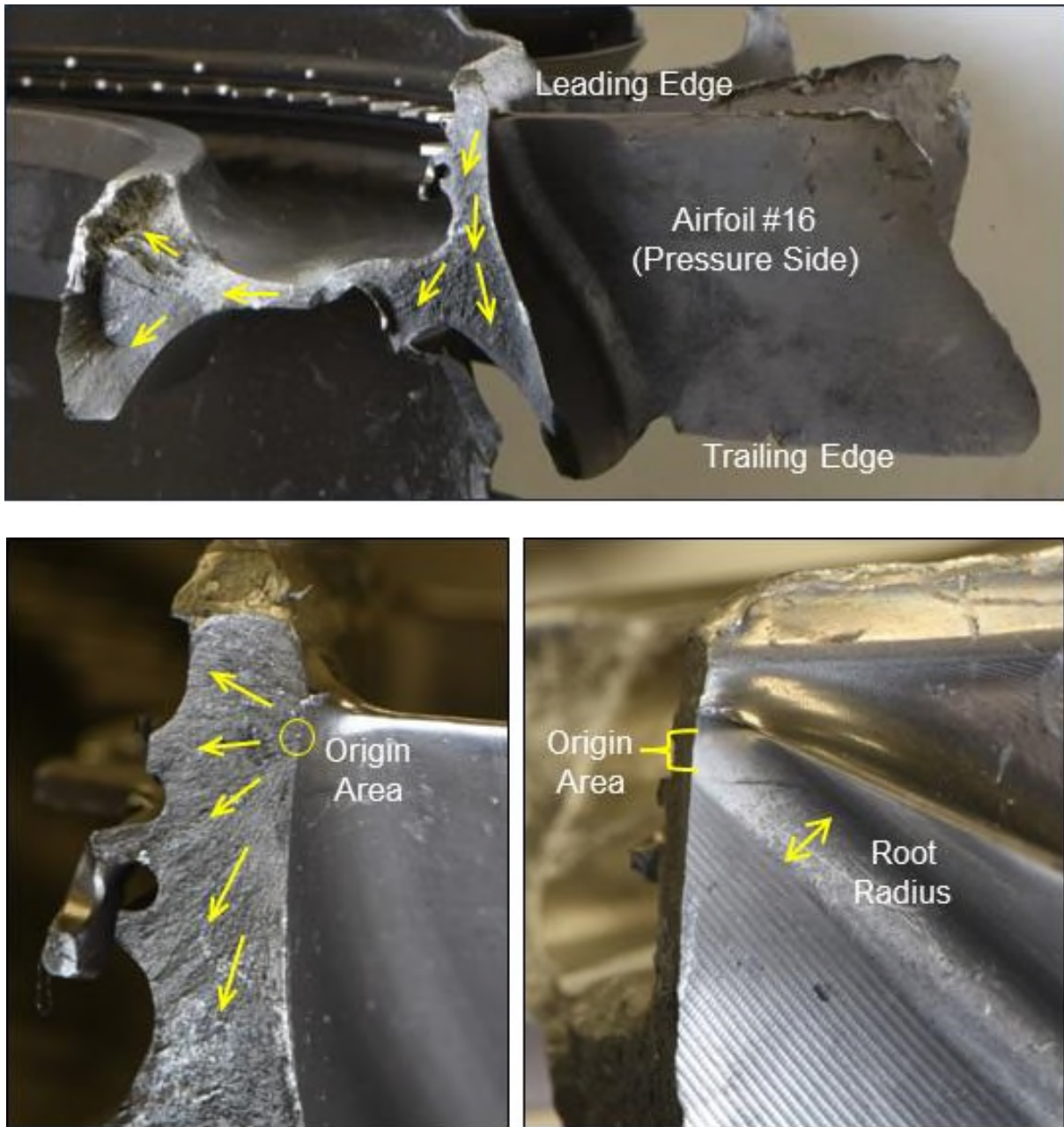


Figure 3. Views showing the direction of fracture progression from a primary origin area at the pressure side leading edge (PSLE) root radius of blade no. 16.

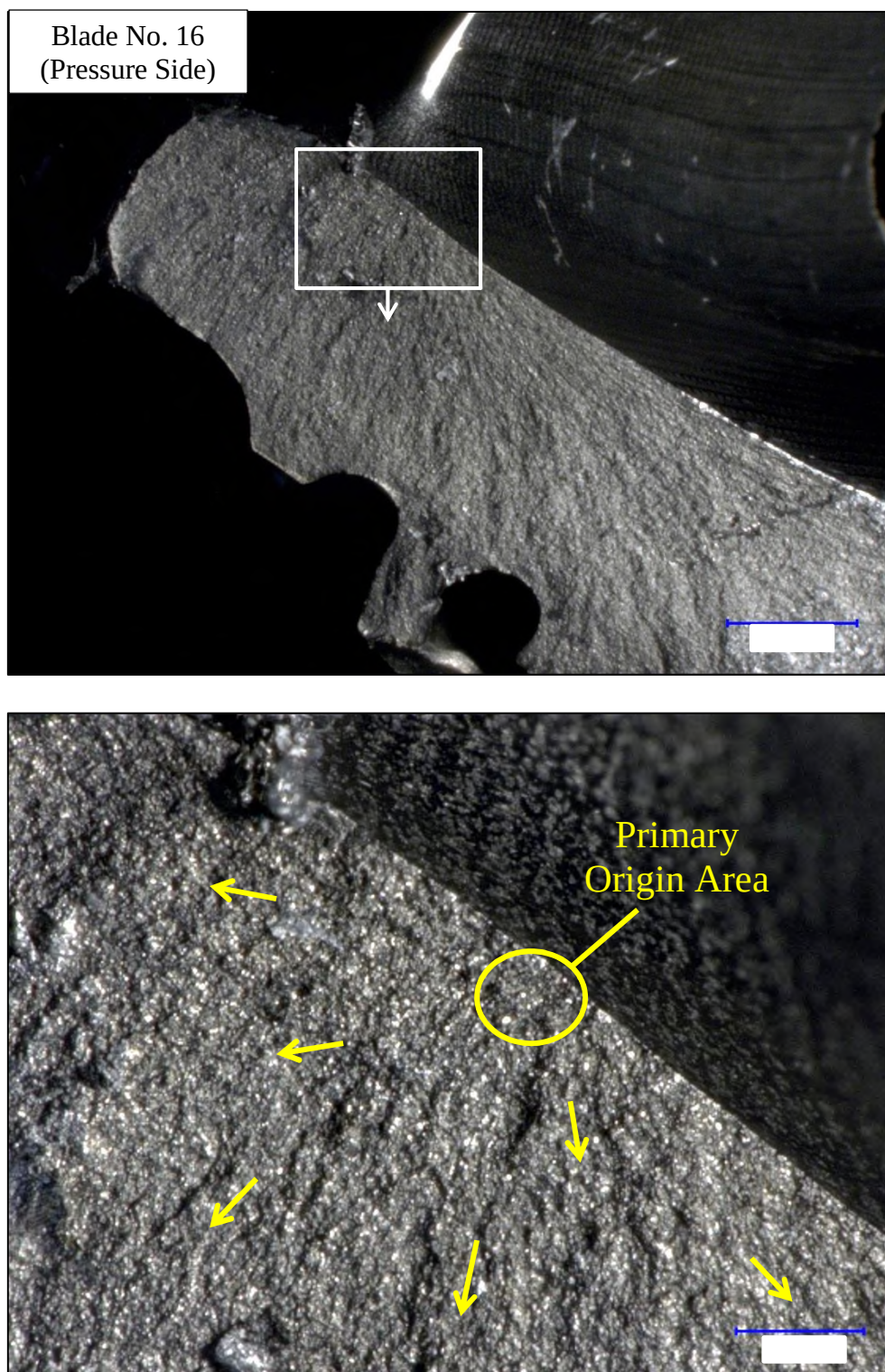


Figure 4. Views showing fatigue progression from a primary origin area at the PSLE root radius of blade no. 16.

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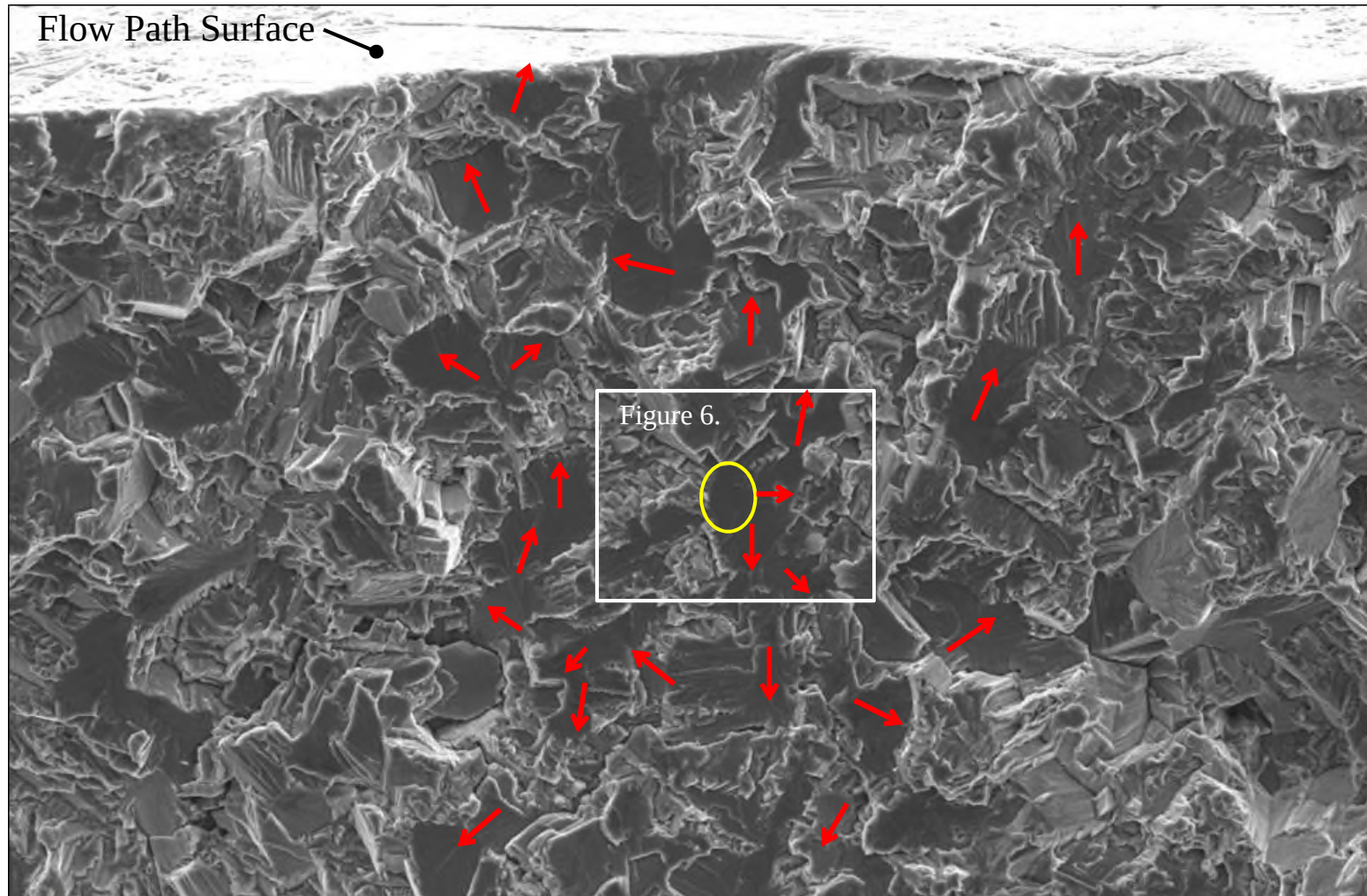


Figure 5. SEM view showing the direction of fatigue progression (arrows) from the primary origin area (ellipse).

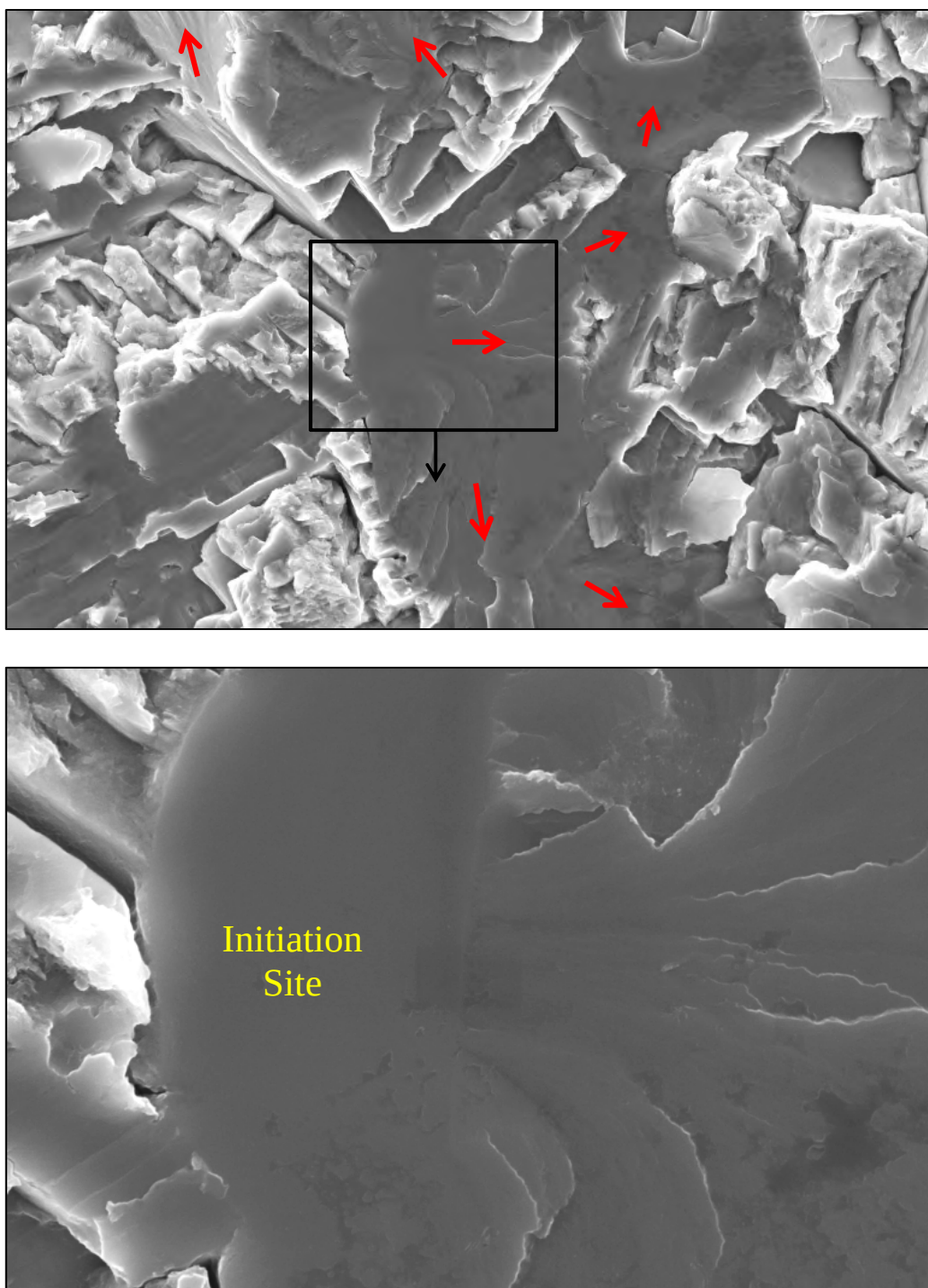


Figure 6. SEM views showing a sub-surface initiation site located 0.0033 inch below the flowpath surface.

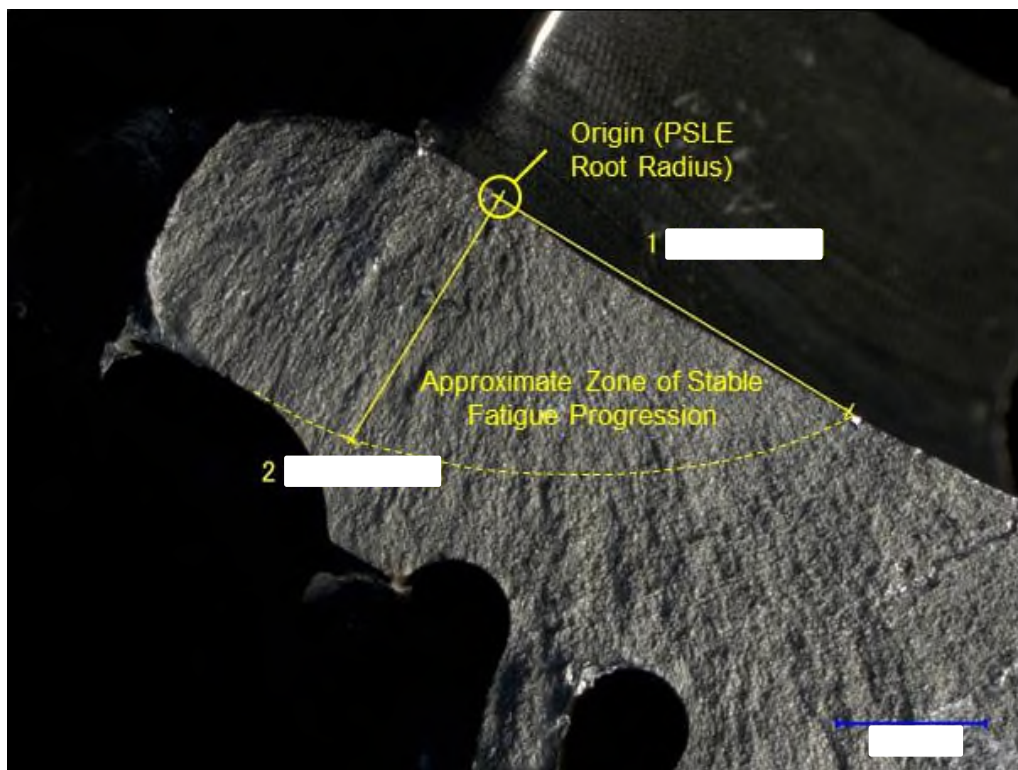


Figure 7. View showing the extent of stable fatigue progression.

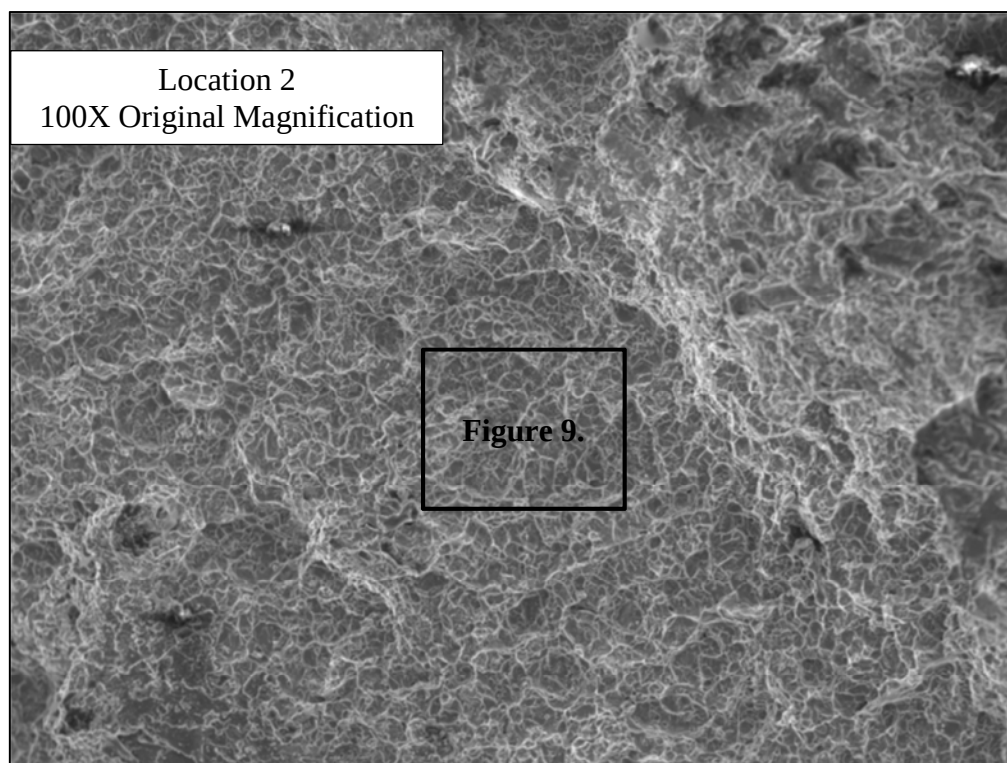
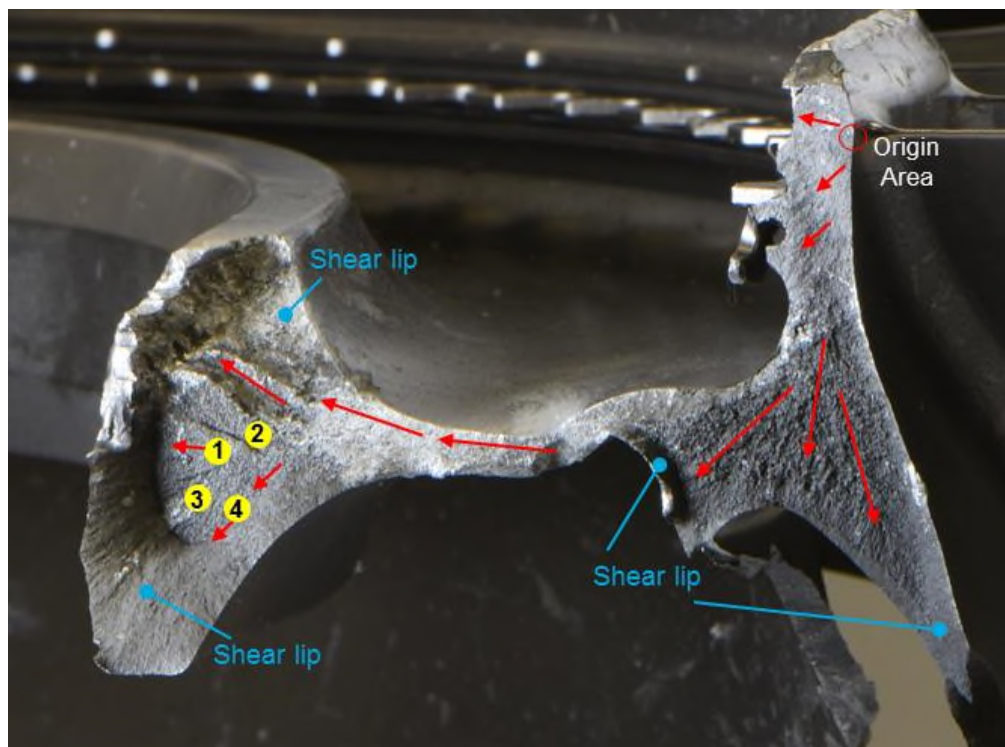


Figure 8. SEM view in the bore fracture region.

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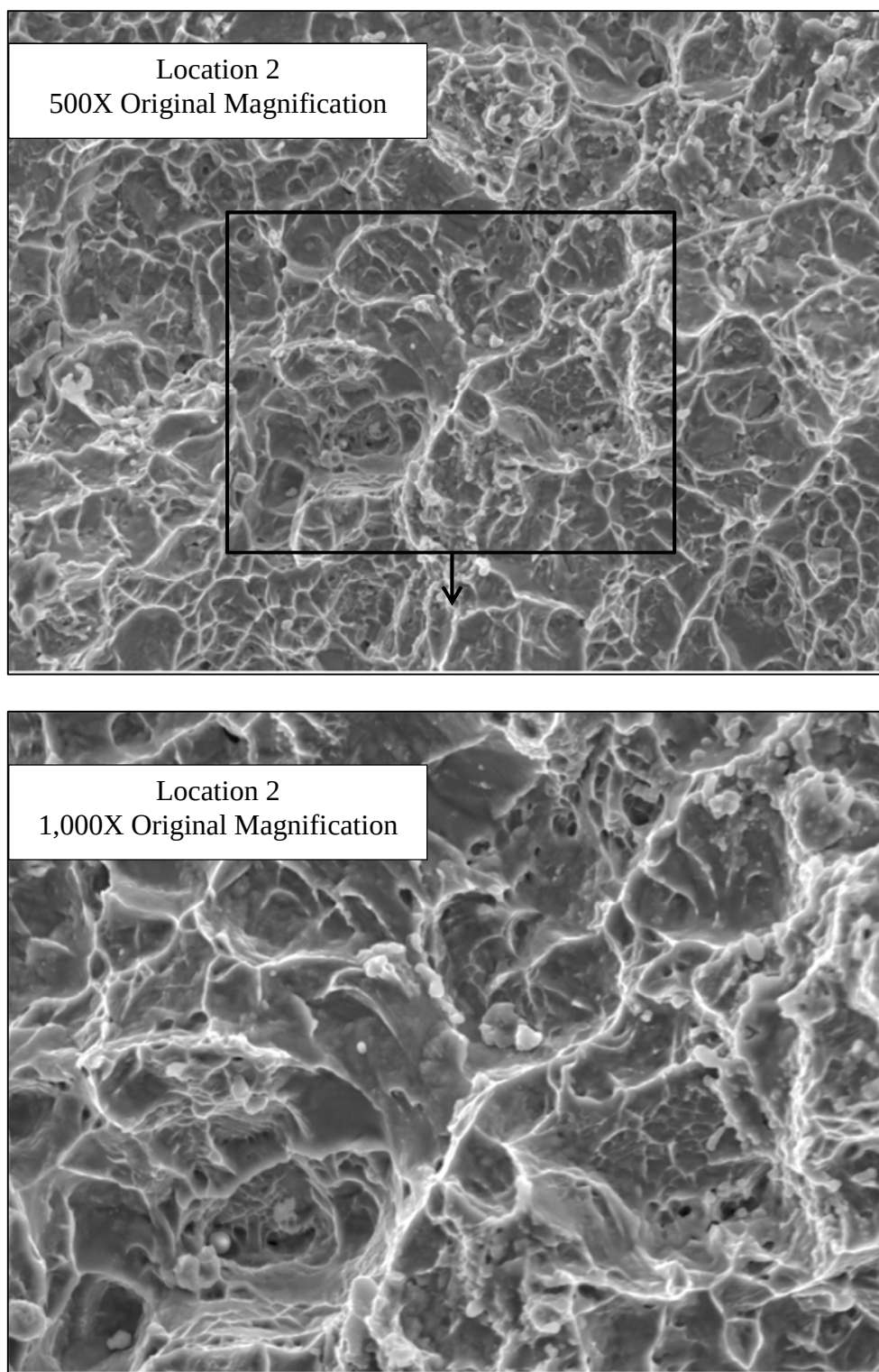


Figure 9. SEM views in the bore fracture region showing ductile dimple overstress features.

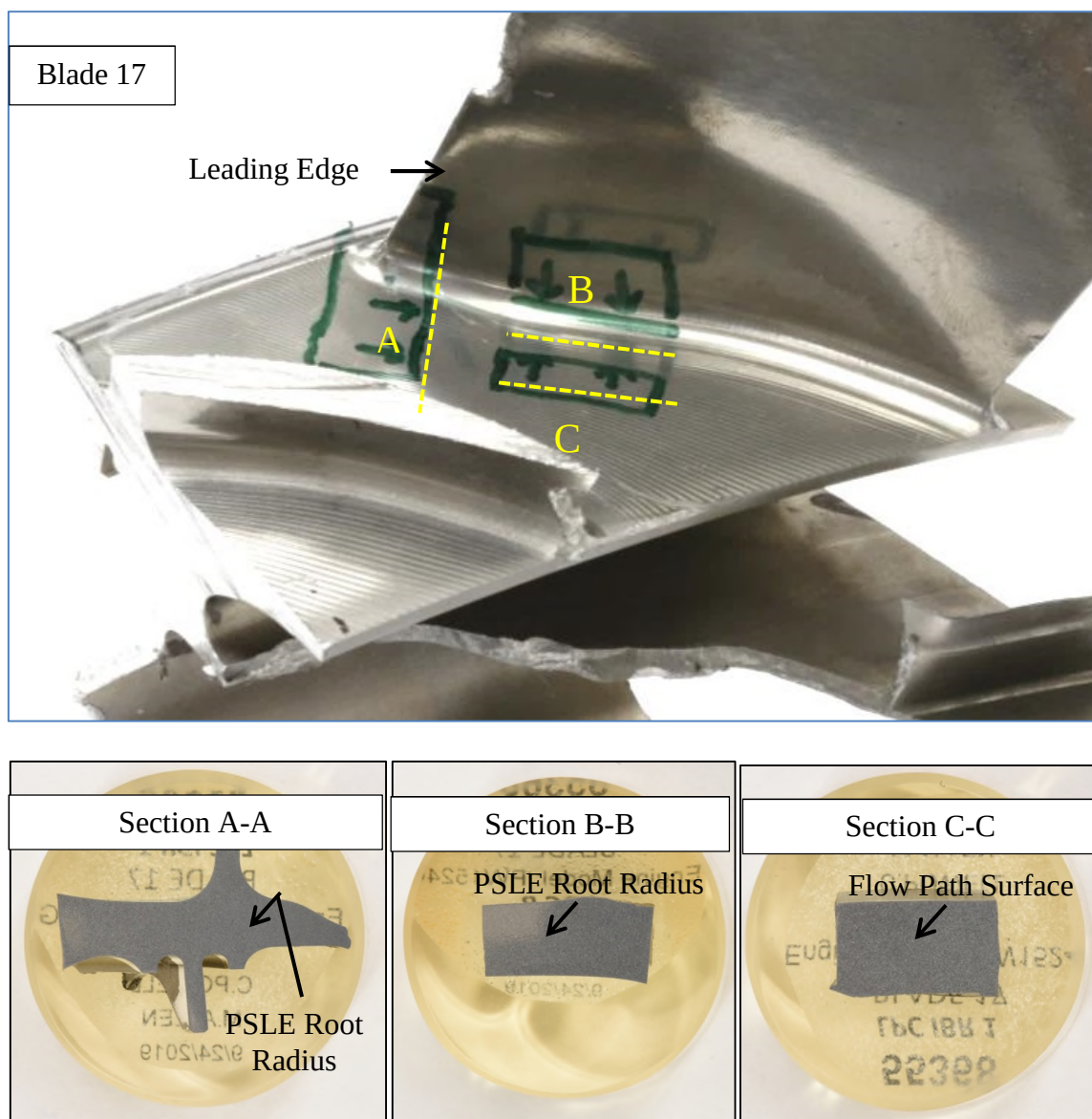


Figure 10. Views showing the location of metallographic sections taken thru blade no. 17 (upper image) and the metallographic mounts (lower image).

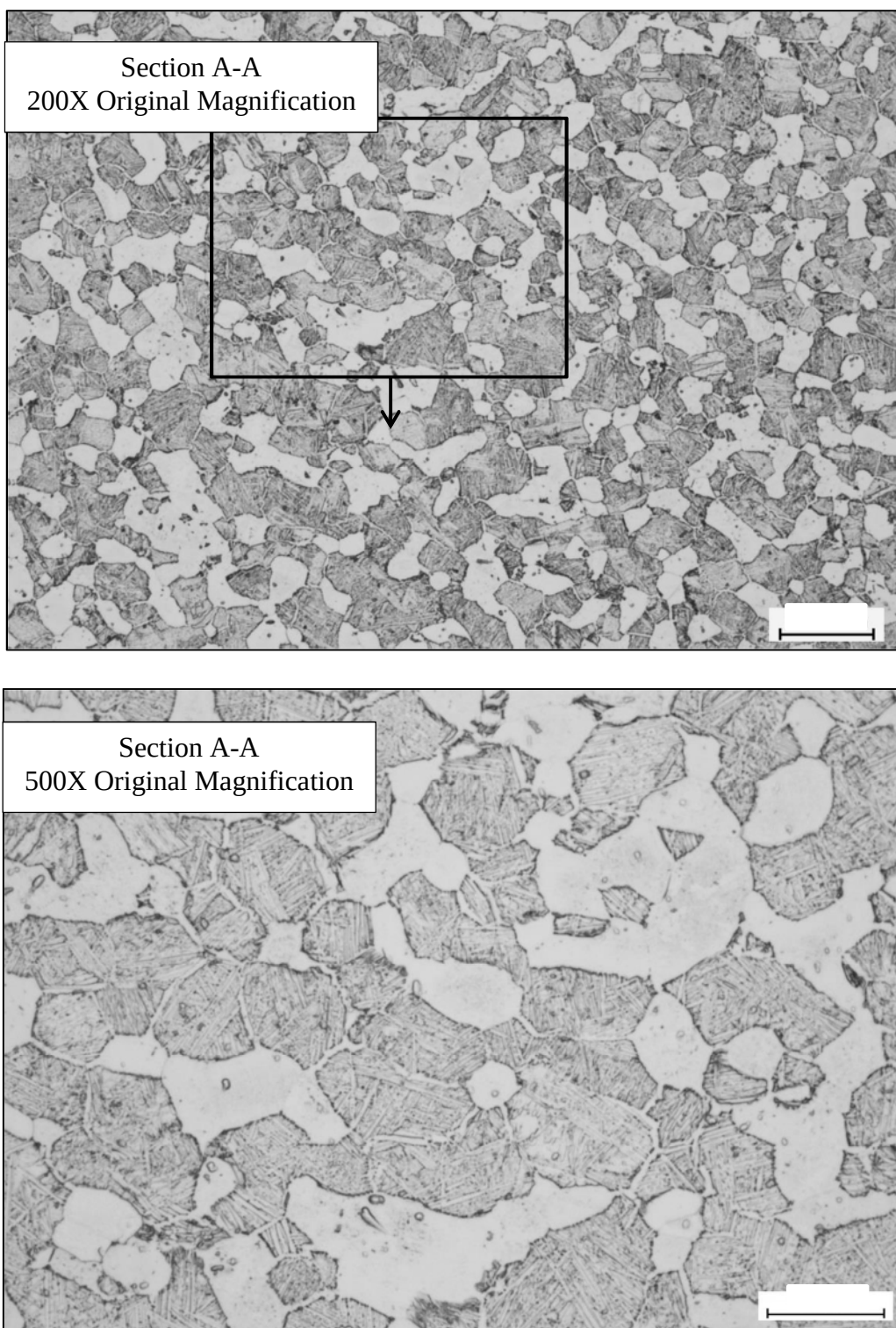


Figure 11. Photomicrographs showing the general microstructure (typical) consisting of alpha-beta processed Ti-6Al-4V titanium alloy.

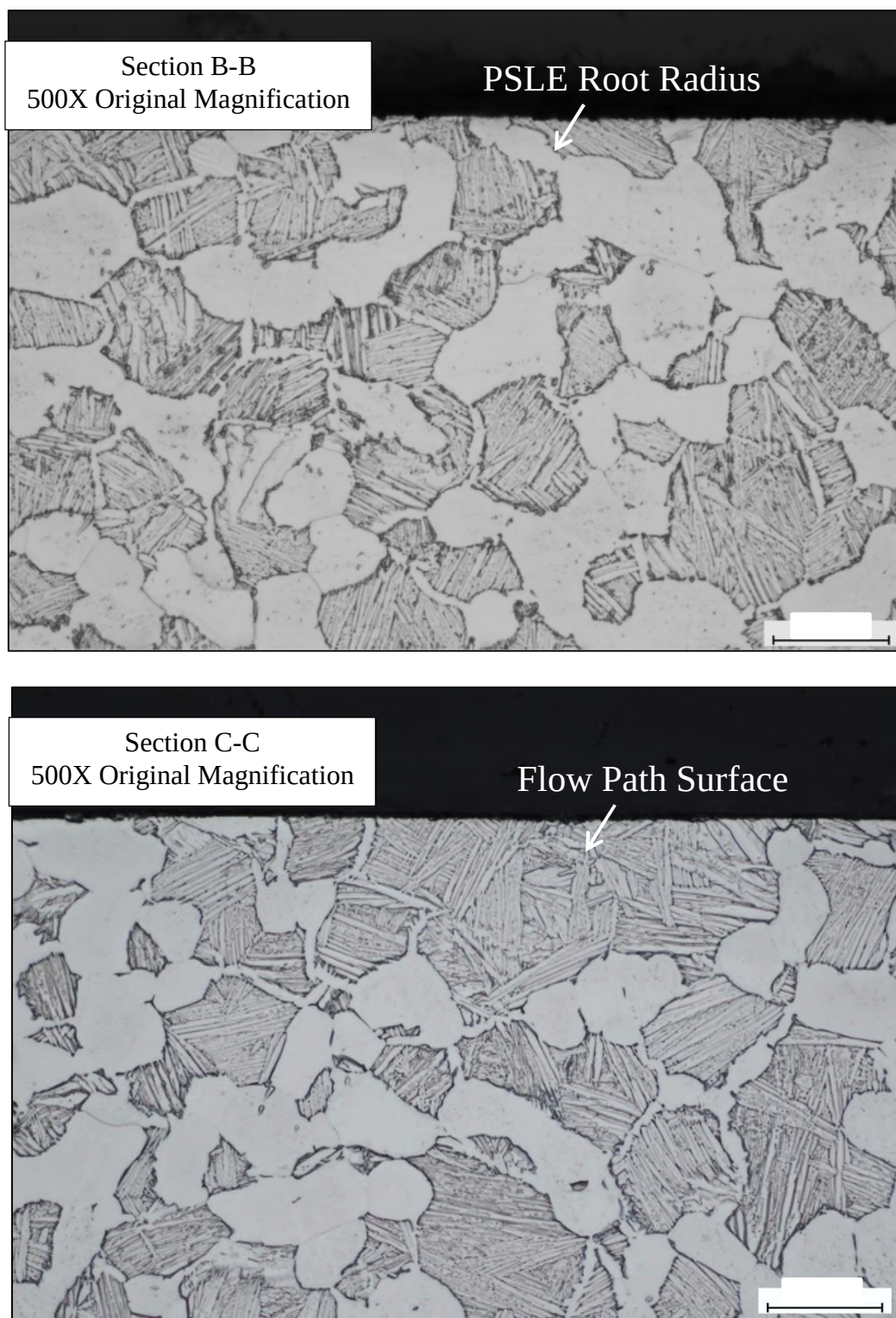


Figure 12. Photomicrographs showing the surface microstructure at the PSLE root radius (upper image), and the platform (lower image).



Figure 13. Views showing the root radius measurement at the pressure and suction side leading edge of blade no. 16.

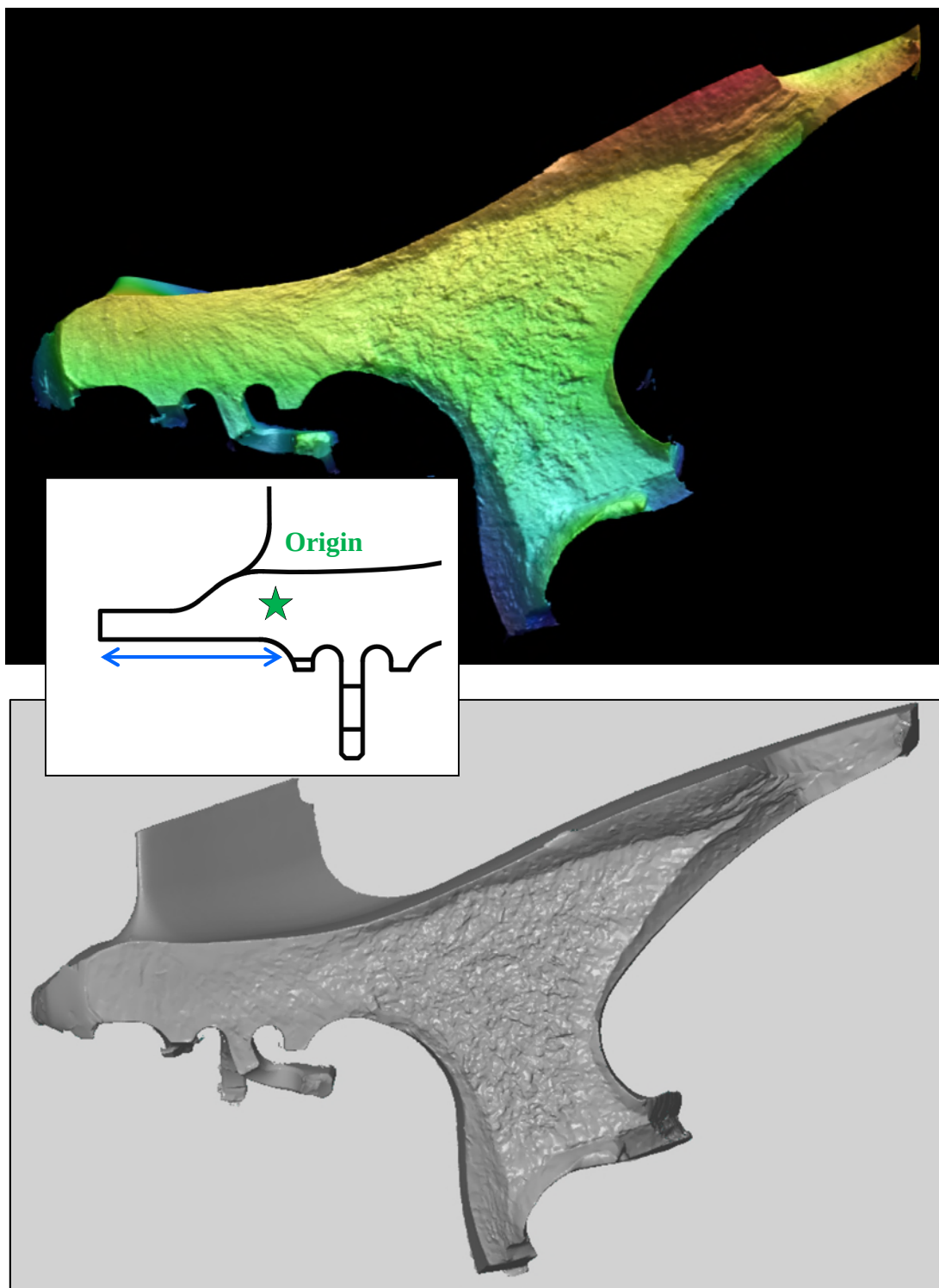


Figure 14. Views showing three-dimension renditions of the primary fracture surface region using a non-contacting optical measurement system (upper image) and a blue light dimensional scan (lower image).

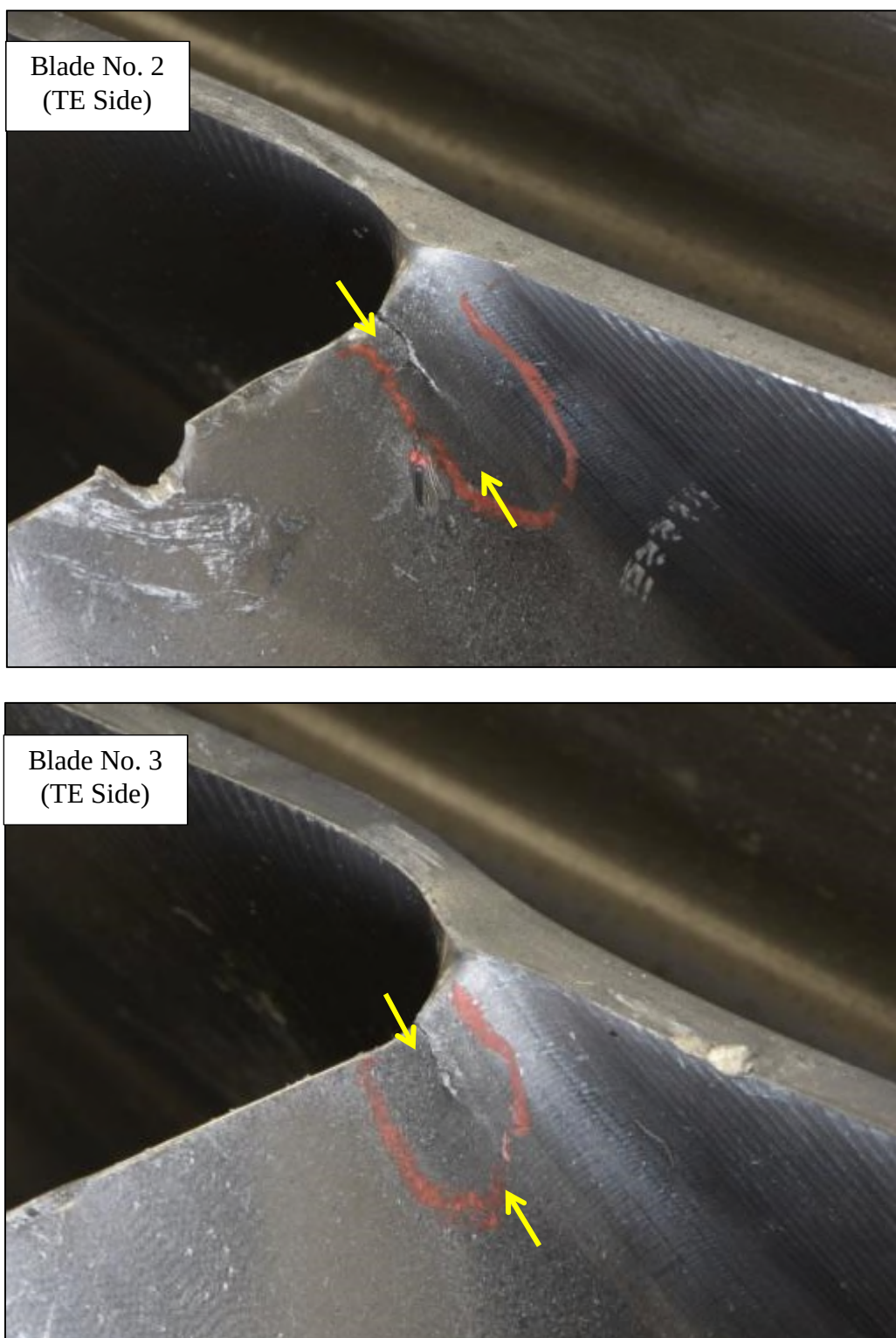


Figure 15. Views showing crack indications (arrows) at the trailing edge root radius runout (airfoil side) of blade nos. 2 and 3.

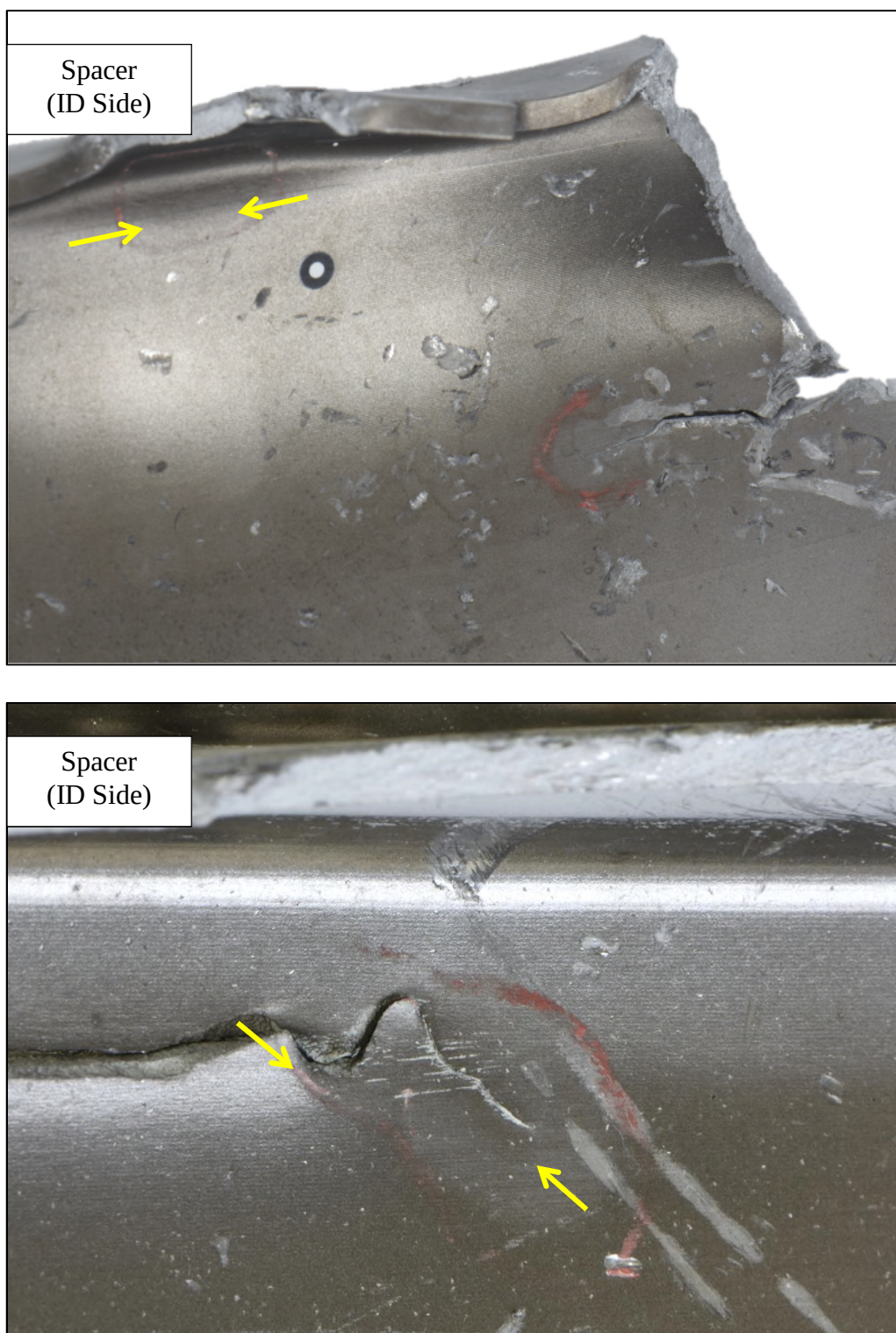


Figure 16. Views showing crack indications (arrows) at the ID side of the aft spacer.