

NATIONAL TRANSPORTATION SAFETY BOARD

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



August 5, 2014

MATERIALS LABORATORY FACTUAL REPORT

Report No. 14-015

A. ACCIDENT INFORMATION

Place : Burns, Oregon
Date : August 12, 2013
Vehicle : McDonnell Douglas 369E, N62PJ
NTSB No. : WPR13GA374
Investigator : Joshua Cawthra, ASI-WPR

B. COMPONENTS EXAMINED

Components from a Rolls-Royce turbine engine, model number: M250-C20B, serial number: CAE836896:

1. Fourth-stage turbine wheel;
2. First-stage turbine wheel;
3. Combustion liner;

C. DETAILS OF THE EXAMINATION

On August 12, 2013, about 1400 Pacific daylight time, a McDonnell Douglas Helicopter 369E, N62PJ, sustained substantial damage during a forced landing following a loss of engine power near Burns, Oregon. The pilot reported that during cruise flight at an altitude of about 400 feet above ground level over mountainous terrain, he heard a loud bang originate from the engine followed by an immediate loss of engine power. The pilot performed a 180-degree autorotation and landed hard on a forest service logging road.

The engine was sent to a Rolls-Royce facility in Indianapolis, IN where it was disassembled and the engine components were examined visually. During the examination, it was discovered that one of the fourth-stage turbine wheel airfoils had fractured just above the rim. Components from the turbine section, including the fourth-stage wheel, were then sent to the Rolls-Royce metallurgical laboratory for additional visual examination and documentation. The findings of the laboratory's visual examination can be found in a separate report prepared by Rolls-Royce at the request of the NTSB (Rolls-Royce 2013).

The turbine section components were then sent to the NTSB Materials Laboratory for additional visual examination and destructive testing. On January 7 and 8, 2014 a group examined the engine parts that are listed above. The group consisted of the following members:

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1. Donald Kramer, Ph.D. – Sr. Materials Engineer, NTSB
 2. Matthew Johnson – Failure Investigator – Rolls-Royce Corporation

See table 1 for part number, serial number, and usage data for each engine component. The findings from the examination, as well as some findings from additional work performed after the group examination, are described in the sections below.

1. Fourth-stage turbine wheel

The leading edge and trailing edge sides of the fourth-stage turbine wheel are shown in figures 1a and 1b, respectively. The wheel was originally cast as a single article that contained 32 airfoils; however one of the airfoils was fractured just outboard of the rim of the wheel. For convenience, the fractured airfoil was designated as airfoil #1 and the rest of the airfoils were incrementally numbered proceeding in a clockwise direction when viewing the wheel from the leading edge side, as indicated in figure 1a. The airfoils smoothly transitioned into a continuous outer shroud that ran around the circumference of the wheel. The outer shroud was fractured adjacent to airfoils #29 and #2 and was missing across the intermediate airfoils #30 – #32. The outer shroud fractures had rough appearances that were consistent with overstress fractures.

Airfoil #1 was sectioned from the wheel and first examined using an optical microscope. The fracture through airfoil #1 is shown in figure 2a. The fracture, as described below, initiated along the airfoil trailing edge and progressed by fatigue toward the leading edge, nominally following the path indicated by the yellow arrows up to the yellow-dashed line. The length of the fatigue crack, measured from the trailing edge was approximately 0.54 inch. Beyond the yellow-dashed line, the fracture surface exhibited a comparatively rough appearance that was consistent with the remaining ligament failing in overstress. A side view of the fractured airfoil trailing edge is shown in figure 2b. The fracture initiated approximately 0.025 inch above the rim where a fillet radius blended into the airfoil trailing edge. As the crack initially progressed toward the airfoil leading edge it also progressed inward toward the rim. At a distance of 0.028 inch from the trailing edge, the crack began to progress outward away from the rim as it continued its progression toward the leading edge.

The fracture surface of airfoil 1 was examined using a scanning electron microscope (SEM) and exhibited curved fatigue crack propagation features near the trailing edge as shown in figures 3 through 5. The curvature and orientation of the features were used to trace the crack path back to an initiation site along the airfoil trailing edge. An SEM image of the initiation site is shown in figure 4 and was taken at the location indicated in figure 3. The crack initiated along a straight segment of the airfoil trailing edge approximately 0.0045 inch from a curved segment on the pressure side of the airfoil. The initiation site exhibited features consistent with oxidation and mechanical rubbing/smearing.

Examination of the fracture surface in the SEM revealed a boundary at which the fatigue fracture morphology changed as the crack progressed toward the airfoil leading edge. An example of the boundary for a portion of the fracture is indicated by a yellow-

dashed line in figure 5. From the initiation site up to the boundary, the fracture surface exhibited the curved fatigue crack progression features described above. Beyond the boundary the curved crack progression features diminished in appearance and the fracture surface began to exhibit feathery features. The transition occurred as far as 0.038 inch from the trailing edge of the airfoil. The feathery features persisted as the fatigue crack progressed toward the leading edge until it reached the overstress region described above.

The Rockwell hardness of the wheel was measured in accordance with ASTM E18 on the curvic teeth on the trailing edge side of the wheel and measured 35.5 HRC, 34.0 HRC, 33.6 HRC, 34.6 HRC, and 36.4 HRC. The hardness values were in accordance with the material requirement.

After the conclusion of the group exam the wheel was sent to Rolls-Royce to inspect the other airfoil trailing edges for the presence of cracks. The wheel was cleaned with grit blast and the remaining airfoil trailing edges were inspected using a fluorescent penetrant. No additional cracks were detected.

The microstructure of the fractured airfoil was also examined by preparing a metallurgical specimen. The fractured airfoil was cross sectioned, ground, and polished in accordance with ASTM E3. The sample was then etched using a mixture of 33% acetic acid, 33% nitric acid, 33% water, and 1% hydrofluoric acid. The etched cross section is shown in figure 6. The microstructure had an appearance of a typical cast microstructure and there were no apparent microstructural anomalies at or near the trailing edge.

2. First-stage turbine wheel

Overview images of the first-stage turbine wheel are shown in figures 7a and 7b. The airfoils on the wheel were black, consistent with a carbon-based deposit. Similar deposits were observed on the rim and as far as 0.3 inch below the rim on the trailing edge side of the wheel.

One of the airfoils was cut from the wheel for the purpose of making a metallurgical cross section. A cut was made parallel and adjacent to the trailing edge and the cut face was mounted for viewing. The sample was ground and polished in accordance with ASTM E3 and etched using a mixture of 33% acetic acid, 33% nitric acid, 33% water, and 1% hydrofluoric acid. The etched cross section is shown in figure 8. The outer portion of the airfoil etched white, while the inner portion of the airfoil etched blue.¹

The axle on the leading edge side of the wheel was cut off and the hardness was measured on the cut surface of the wheel using a Rockwell hardness tester in

¹ The color of the etched surface is indicative of the presence of a precipitate formed during the processing of the wheel. Areas that etch blue have a higher concentration of the precipitate than areas that etch white. Exposure to a sufficiently high temperature can cause dissolution of the precipitate.

accordance with ASTM E18. The hardness values were 38.9 HRC, 39.3 HRC, 40.0 HRC, and 38.6 HRC. All of the measurements were in accordance with the material requirement.

3. Combustion liner

An overview image of the combustion liner is shown in figure 9. At the outlet end of the liner, there was a metal ring that was welded onto the outside of the liner by means of tabs distributed around its circumference. The weld zone on one of the tabs is indicated in figure 10a. The ring-and-tab assembly was formed in such a way that the ring and the liner formed a cylindrical groove. The groove then interfaced with a tongue on the downstream gas producer support (not shown). A piece of one of the tabs had separated from the assembly, as shown in figures 9, 10a, and 10b, and was not recovered.

The ring at the separated tab was cut out and the inside surface was visually examined. The majority of the surface exhibited varying shades of a gold or blue tint, as shown in figures 11a and 11b. However along the edge of a manufactured bend, where the base of the tab had separated, the surface had a rubbed appearance and lacked the tint, as indicated in figure 11b. The features were consistent with wear through the metal at the bend.

The fragment of the welded tab that remained attached to the liner was examined using a digital optical microscope. Two images of the fracture through the tab are shown in figures 12a and 12b at the locations indicated in figure 10a. The fracture surface radially inward (adjacent to the liner) was comparatively flat and the fracture surface radially outward was comparatively rough. Ratchet marks and thumbnail-shaped features were observed within the flat fracture region that were consistent with multi-site fatigue crack initiation along the welded interface between the liner and the tab. The comparatively rough appearance within the radially outward portion of the fracture surface was consistent with an overstress fracture of the remaining ligament.

D. REFERENCES

Rolls-Royce Corporation. (2013). *Metallurgical Investigation Report 13FA8-112: Metallurgical Investigation of a Fourth Stage Turbine Wheel, P/N 23055944 S/N X586178, Removed from an M250-C20B, Engine S/N CAE836896, Operated by PJ Helicopters*, Rolls-Royce Corporation, Indianapolis, IN.

Donald Kramer, Ph.D.
Sr. Materials Engineer

Table 1: Information about the examined components.

Engine Component	Part Number	Serial Number	Time Since New, hr	Cycles Since New
Fourth-stage turbine wheel	23055944-F	X586178	1246.8	984
First-stage turbine wheel	23073853-B	X591867	1246.8	984

Engine Component	Part Number	Date (Lot) Code	Time Since New, hr	Cycles Since New
Combustion liner	23056130	10-01-79	1246.8	984

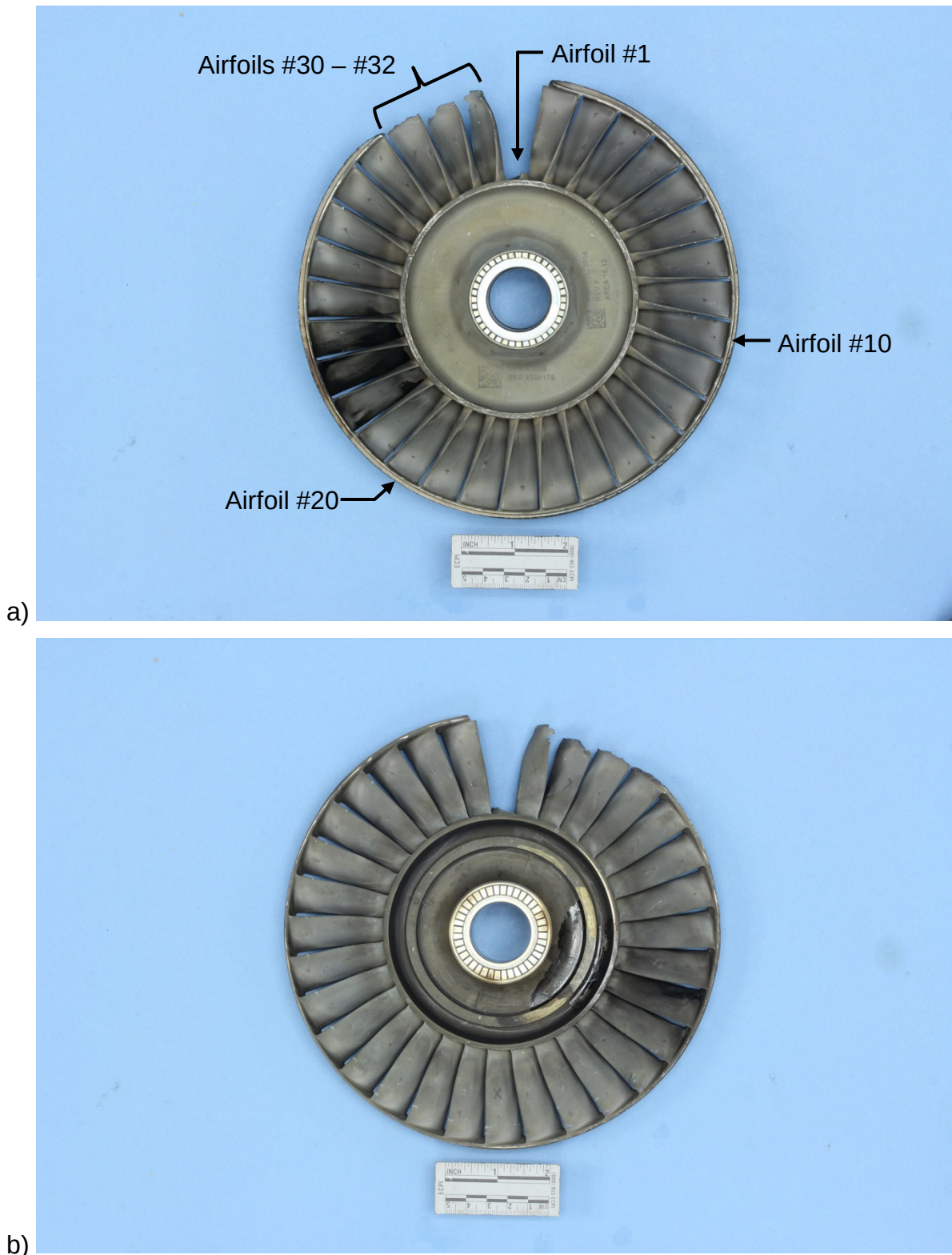


Figure 1: a) Image of the leading edge side of the fourth-stage turbine wheel and b) image of the trailing edge side of the fourth-stage turbine wheel. For convenience, the fractured airfoil was designated as airfoil #1 and the remaining airfoils were incrementally numbered proceeding in a clockwise direction when viewing the wheel from the leading edge side.

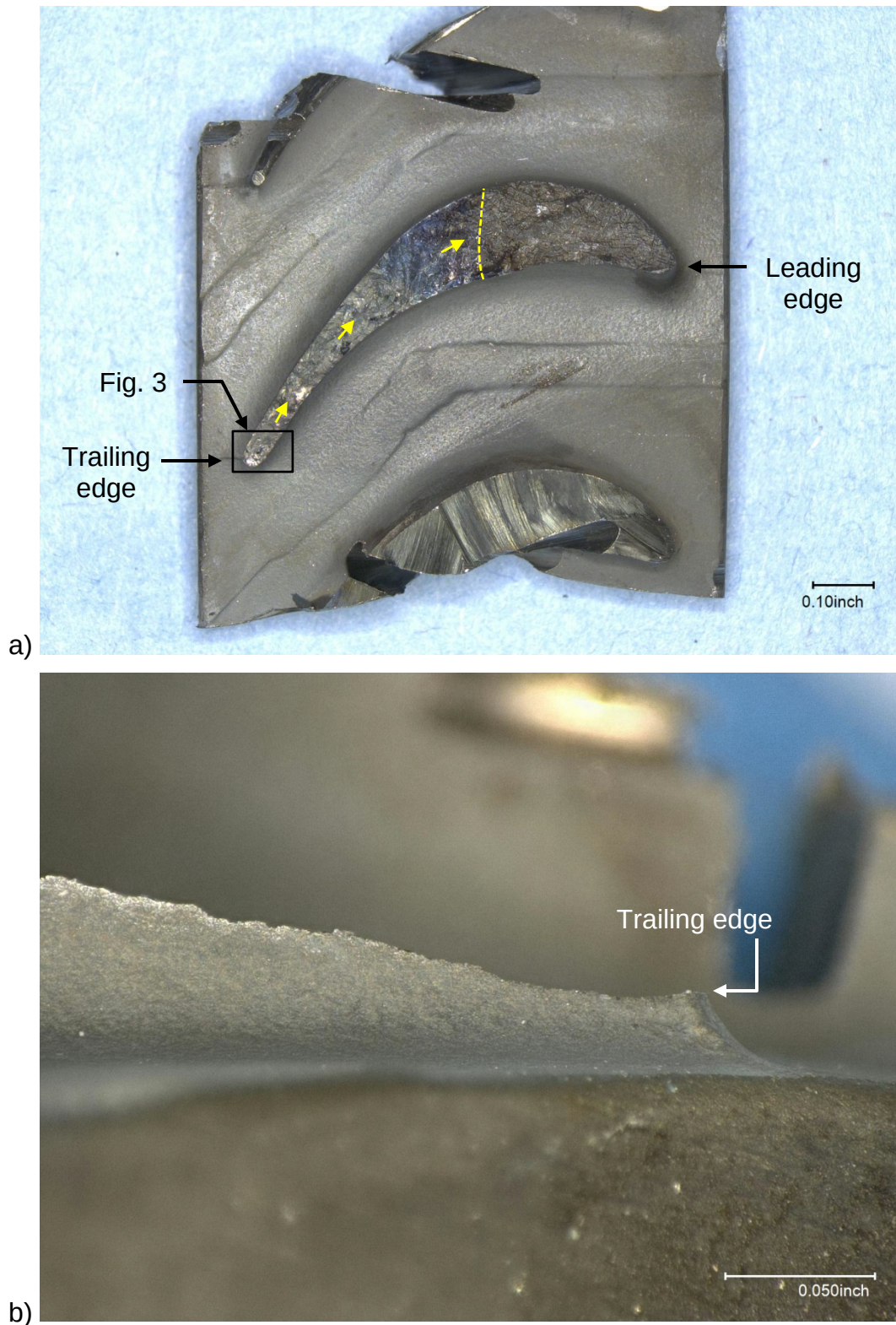


Figure 2: a) Top down image of the fractured fourth-stage wheel airfoil #1 fracture surface. A rectangle indicates the location of an SEM image shown in figure 3 and b) sideview of the fractured airfoil trailing edge.

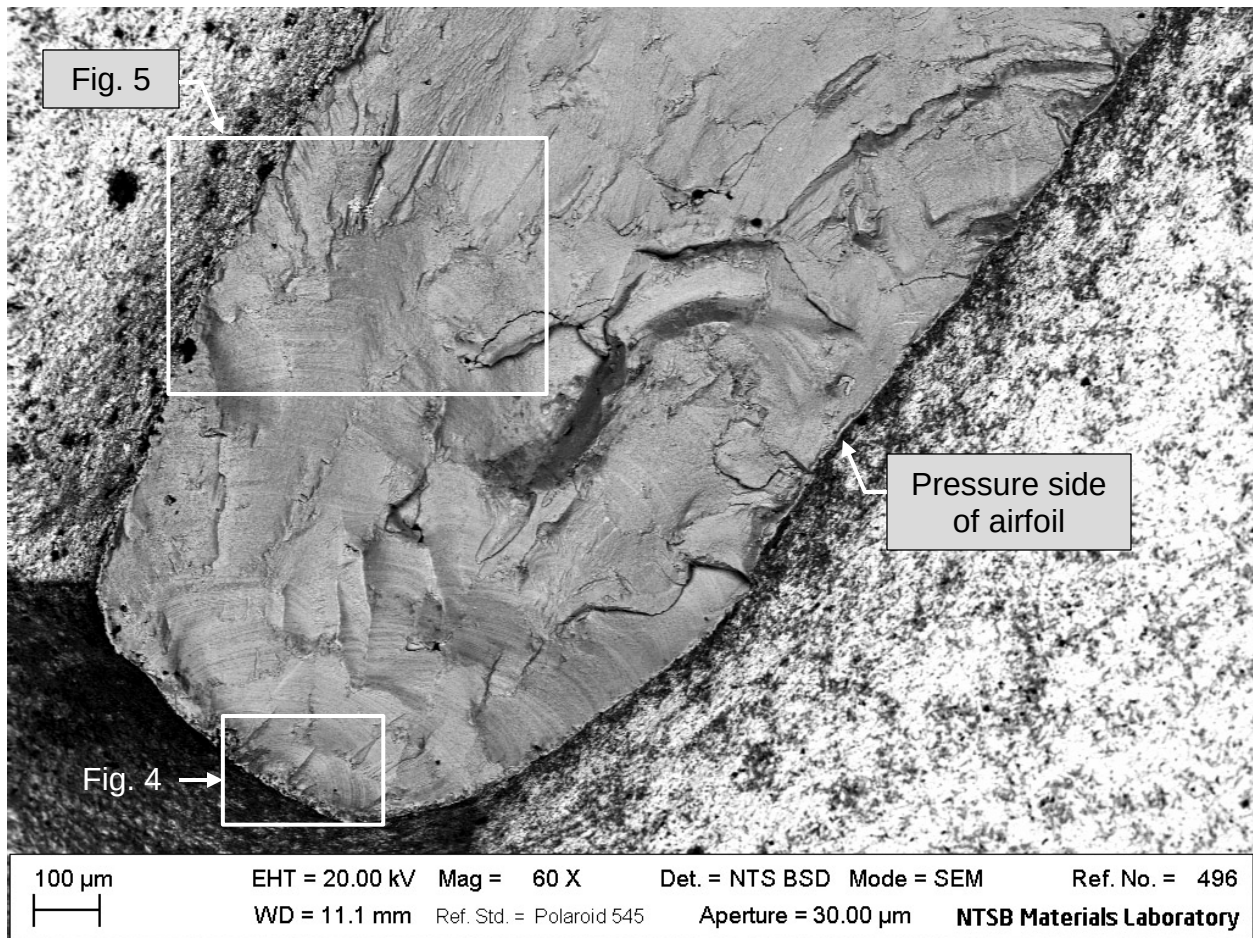


Figure 3: Overview SEM image of the airfoil #1 trailing edge fracture surface. Rectangles indicate the locations of images shown in figures 4 and 5.

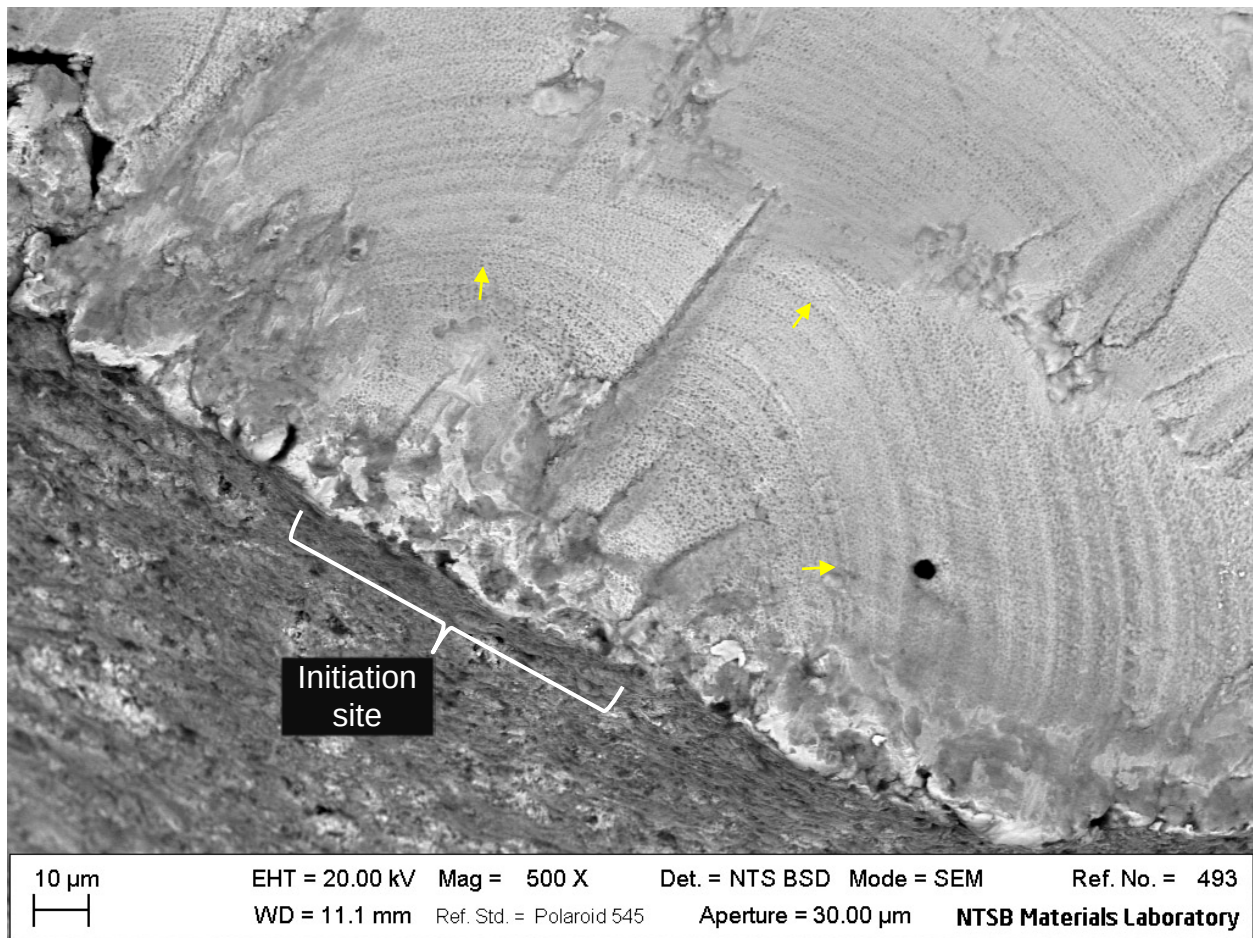


Figure 4: SEM image along the trailing edge of the airfoil #1 fracture surface. Fatigue crack propagation features radiated away from a straight segment of the airfoil trailing edge located approximately 0.0045 inch from a curved segment on the pressure side of the airfoil.

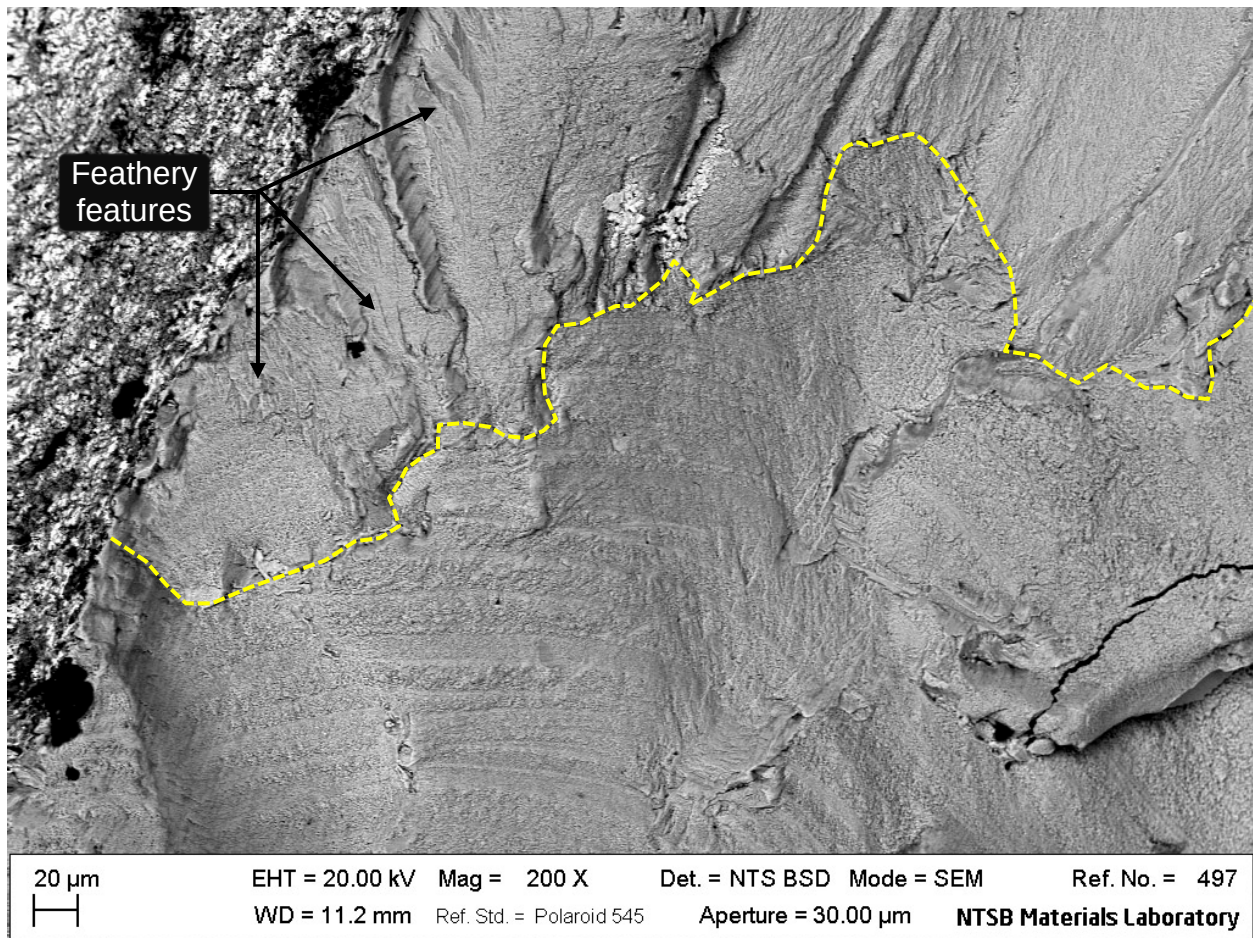


Figure 5: SEM image at the location indicated in figure 3. The yellow-dashed line indicates the boundary where curved fatigue crack propagation marks diminished in appearance and feathery features emerged.

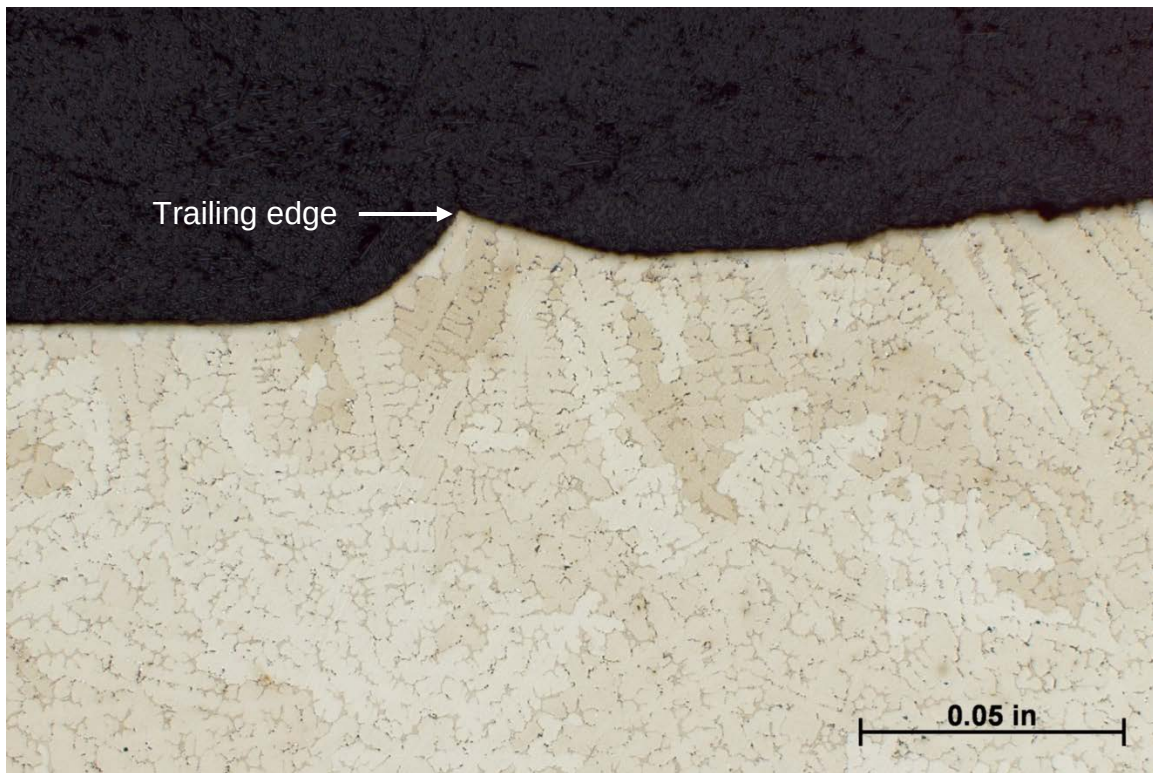


Figure 6: Metallographic cross section through the airfoil #1 trailing edge adjacent to the suction side of the airfoil.

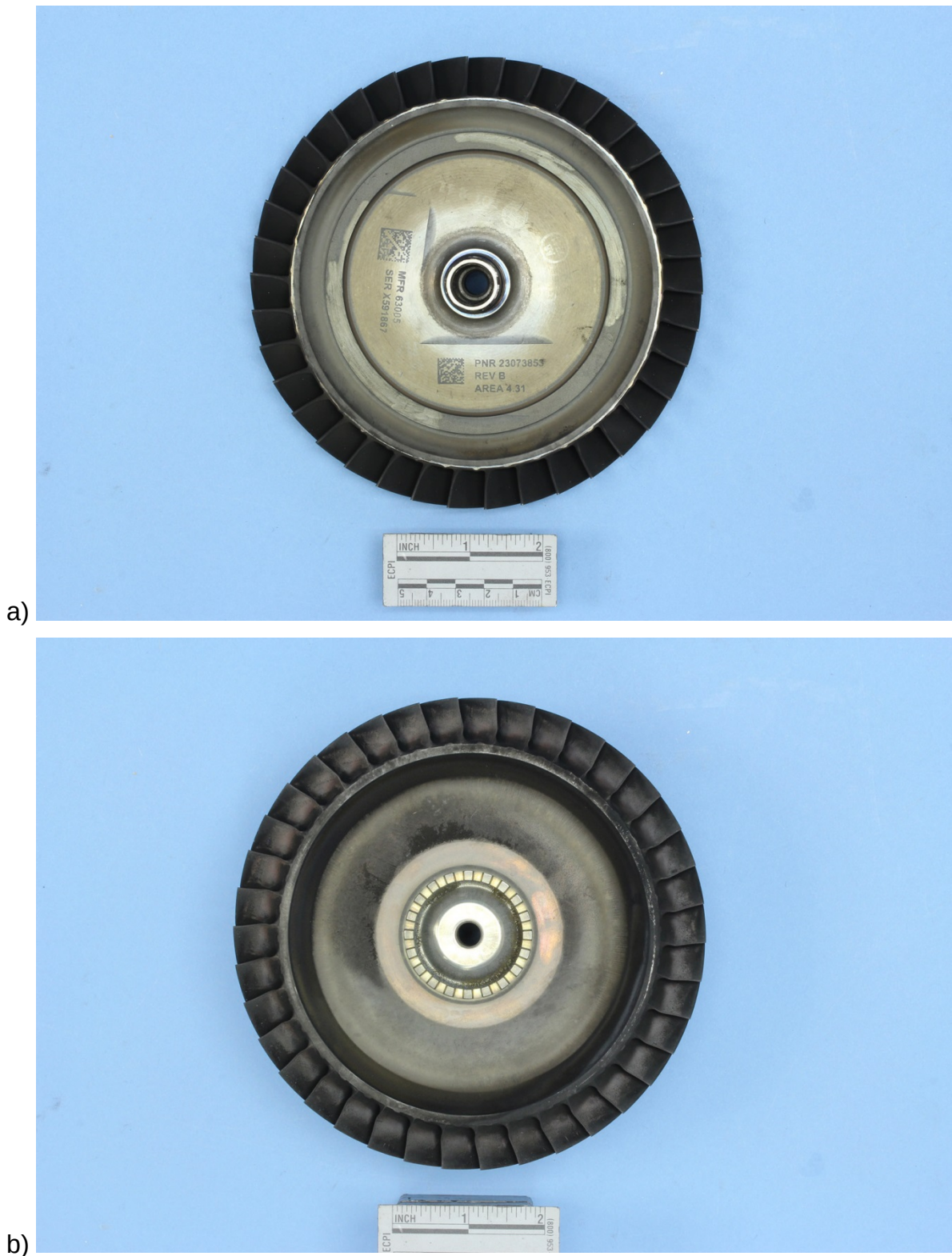


Figure 7: a) Image of the first stage turbine wheel leading edge side and b) image of the first stage turbine wheel trailing edge side.



Figure 8: Metallographic cross section of a first-stage turbine wheel airfoil adjacent and parallel to the trailing edge from the base to the tip of the airfoil.

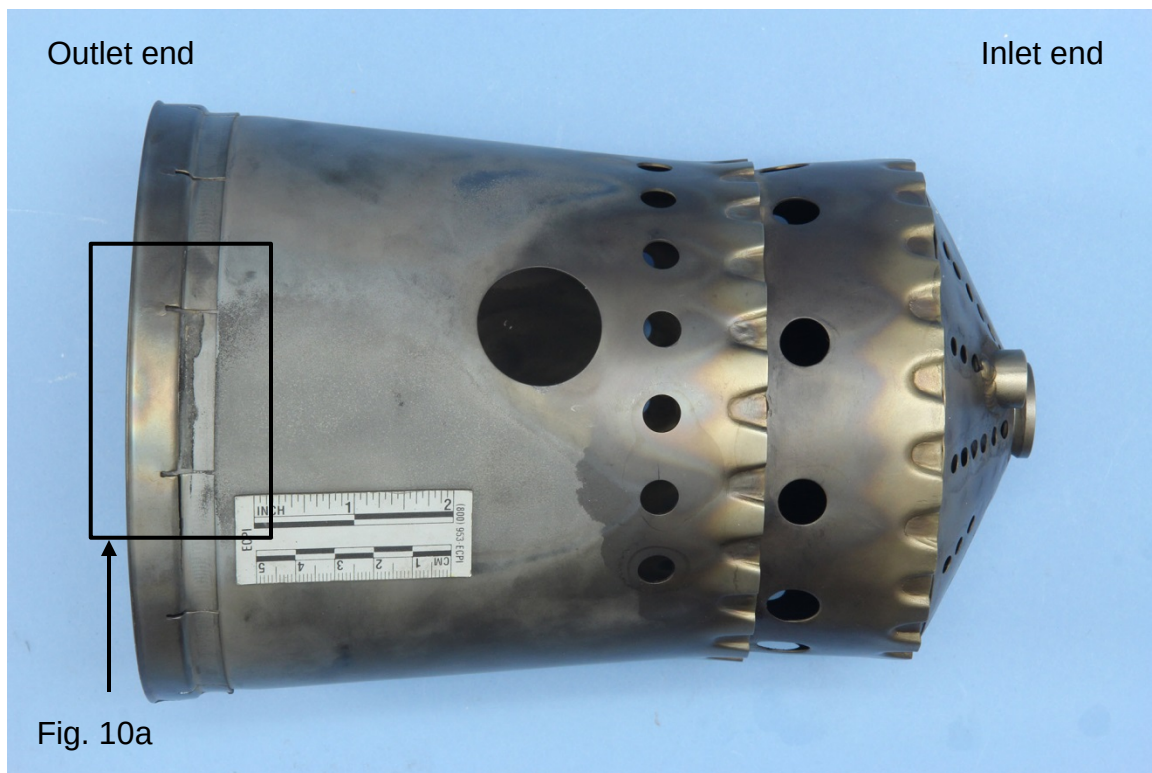


Figure 9: Overview image of the combustion liner.

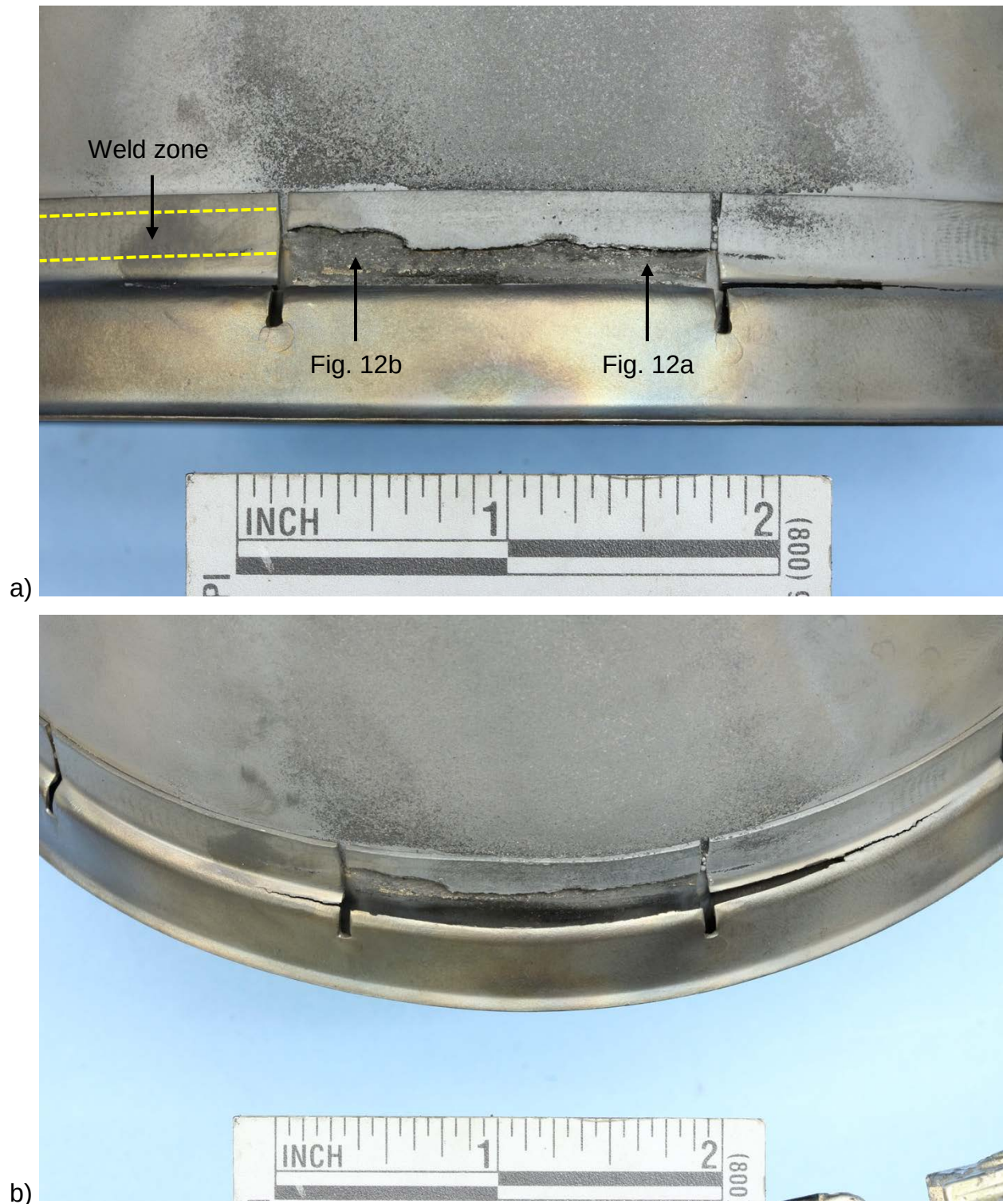


Figure 10: a) and b) Images of the combustion liner/ring assembly where a piece of a tab had separated.

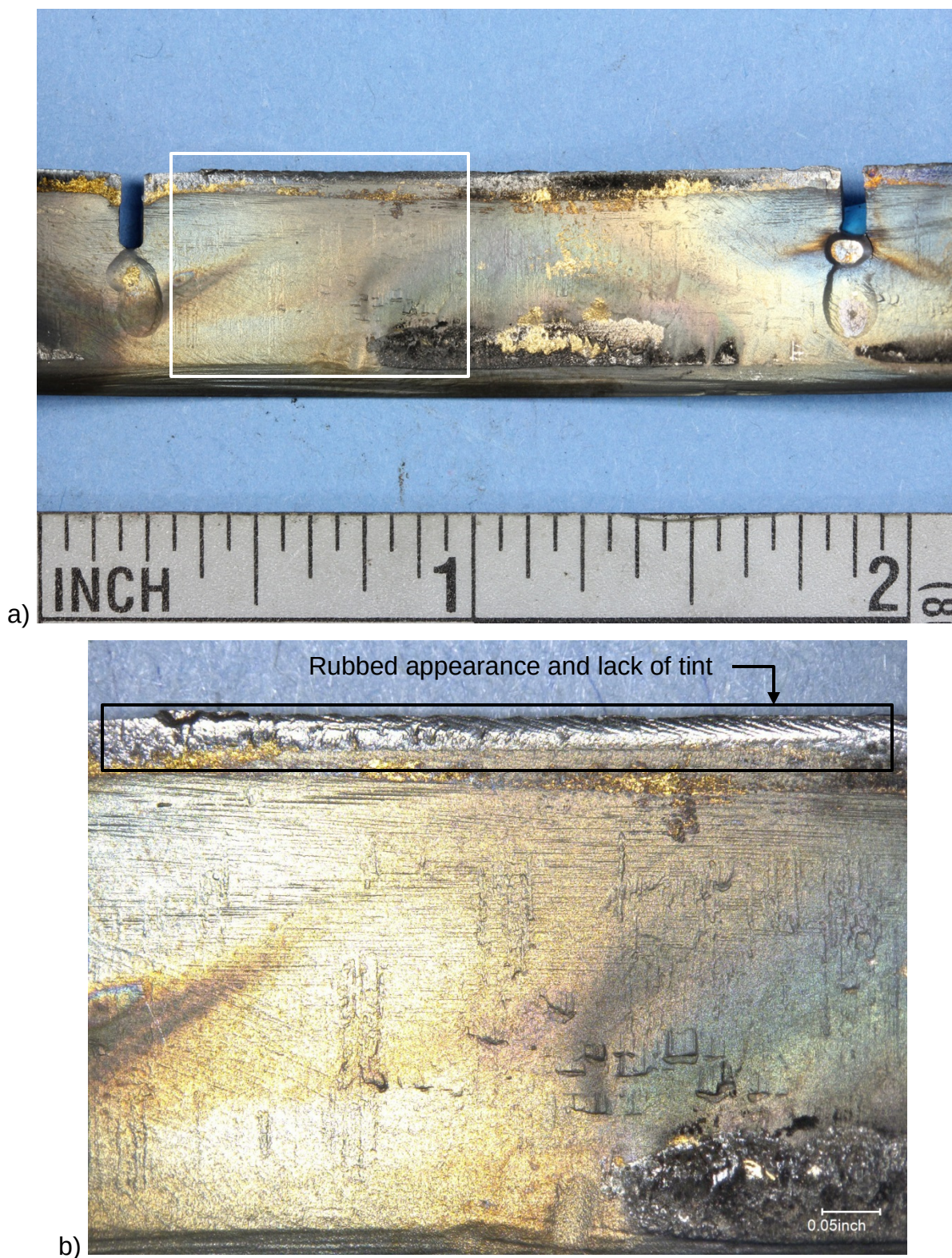


Figure 11: a) The inside surface of the ring section taken from where a piece of a tab had separated from the liner assembly and b) higher magnification image highlighting a location where the material exhibited a rubbed appearance and lack of tint.

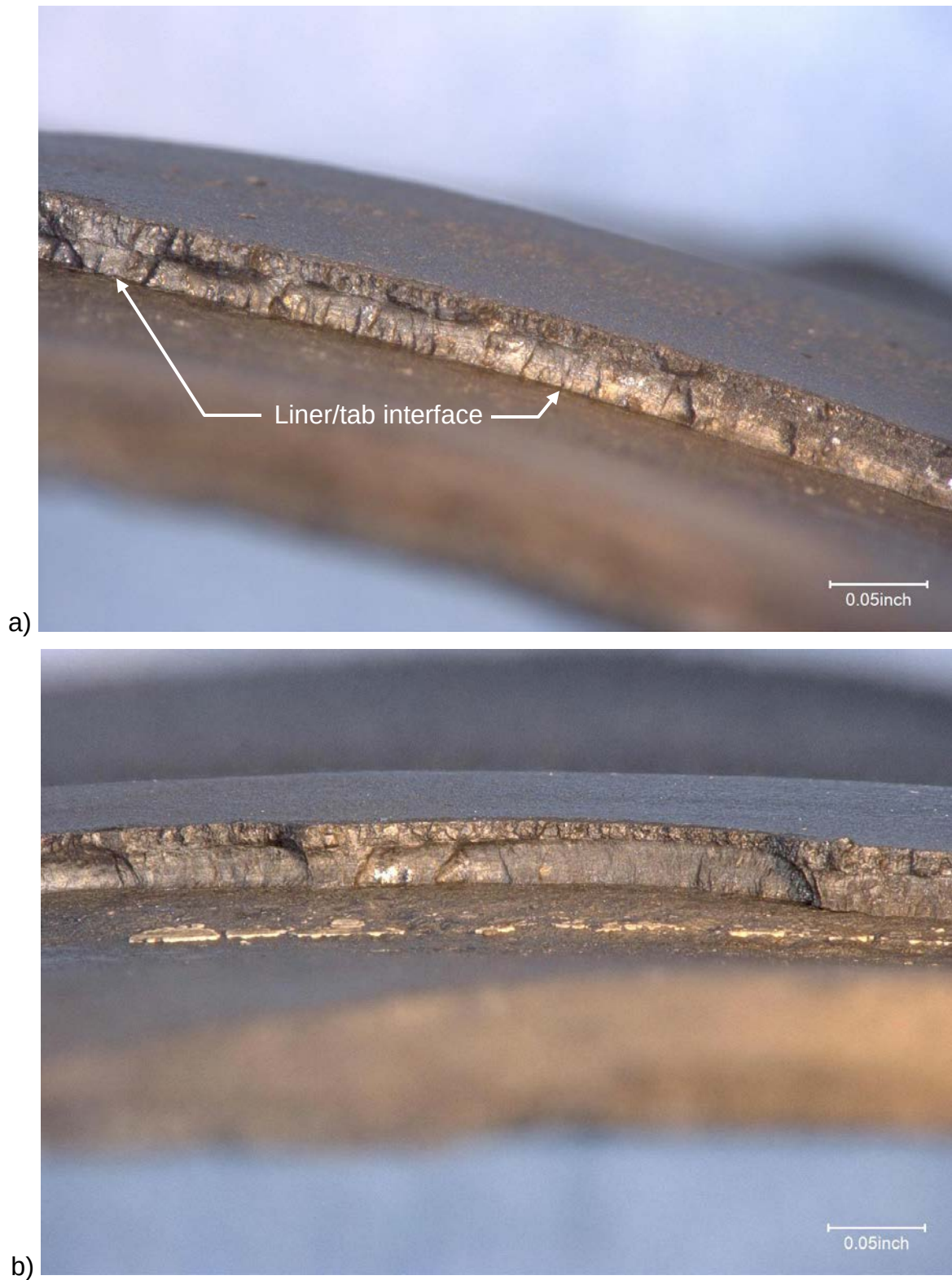


Figure 12: a) and b) Images of the fracture through the welded tab, taken at the locations indicated in figure 10a.