

NATIONAL TRANSPORTATION SAFETY BOARD

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



February 5, 2020

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-071

1. ACCIDENT INFORMATION

Place : Ft. McDowell, Arizona
Date : April 16, 2019
Vehicle : Bell 206B, N61PH
NTSB No. : WPR19FA109
Investigator : Andrew Swick, AS-WPR

2. COMPONENTS EXAMINED

Sections of main rotor blades
Main rotor hub remnants
Sections of tail rotor assembly

3. DETAILS OF THE EXAMINATION

On April 16, 2019, a Bell 206B experimental helicopter crashed into an alfalfa field near Fort McDowell, AZ while performing autorotations at gross maximum weight. The purpose of the flight was to evaluate developmental main rotor blades. The main rotor blades, tail rotor blades, separated hub, and tail rotor were recovered and sent to the NTSB Materials Laboratory for additional examination. The parts were investigated during a group examination on November 6 and 7, 2019.

Figure 1 shows the crate with the parts from the accident, as received. The blades and other components were carefully removed and laid out in the NTSB basement laboratory on the floor in order to accommodate all of the fragments (Figure 2). Figure 3 shows all the major pieces laid out from end to end, in sequential figures. The first blade remnants, shown in Figure 3a – Figure 3g, were labeled “Blade B”, and the pieces in Figure 3h – Figure 3m were labeled “Blade A” for the purposes of this report. Prior to the accident, Blade A had been instrumented with strain gages to record measurements for the developmental tests—many of these pieces of equipment were still attached. Blade B did not exhibit any instrumentation or measurement devices.

The rotor blades had fractured in multiple locations. The two most prominent fractures were located several feet from the blade roots where the blade remnants were still attached to their respective grip plates. Figure 4 shows the measurements underneath the Blade A, and Figure 5 shows the measurements under Blade B. These fractures were

through fractures with pieces of skin having completely liberated from the structures. The liberated remnants of skin exhibited triangular shapes consistent with the $\pm 45^\circ$ plain-weave fabric orientation, with the narrow tip facing the leading edges and the wide side facing the trailing edges. Both blade tips had also fractured, exhibiting crushing and separation of the tip abrasion strip from Blade A (Figure 3m and Figure 6).

Most of the interior of the blades were absent internal material. The majority of the interior foam was not present inside the blade cores upon receipt. Much of the recovered foam remnants were in a separate bag found inside the crate. Thin, rough layers of foam remnants were still adhered to most of the interior surfaces of the blade skins. The features of these remnants were consistent with cohesive failure of the foam core, and the foam fracture features were inconsistent with adhesive failure or disbonding of the foam with the blade skins (see Figure 7).

As seen in the upper portions of Figure 3j – Figure 3l, the trailing edge strip had separated from the Blade A assembly. A closer view of the separated strip next to the interior surface of the Blade A trailing edge is shown in Figure 8. According to the Planform from the 20635000-501 drawing, the trailing edge strip was a unidirectional carbon fiber piece. The interior of the blade skin was a 45° plain-weave. The blade skin and strip were co-cured together during manufacturing.

Figure 9 and Figure 10 show a typical surface of the strip fragment. This surface exhibited the 45° plain-weave pattern visible on the mating blade skin. When intentionally split open in the laboratory examination, the strip interior exhibited a unidirectional orientation of the fibers (see Figure 11). Sections of the strip were taken for later microscopic and materialographic examination.

Figure 12 shows a portion of the cross-sectioned and mounted trailing edge strip. Figure 13 shows a closer view, showing the 90° cross section of the carbon fibers in an epoxy matrix. In both views, the carbon fibers were oriented 90° to the cross section. None of the strip interior showed fibers with a 45° , 0° , or other angle orientation.

The features observed on the surface of the separated strip were consistent with fracture of the blade skin and were inconsistent with adhesive separation of the strip from the blade skin or fracture/delamination of the strip. Figure 8 and Figure 11 show adhered foam on the inboard surface of the trailing edge strip, consistent with cohesive fracture of the foam core at the trailing edge.

Figure 14 shows the Blade B tip remnant. The tip abrasion strip exhibited paint transfer marks consistent with impact with another object. The pattern of fracture, buckling near the fracture, and tearing in the lower blade surface was consistent with composite skin fracturing upward and aft, toward the trailing edge of the blade.

Figures 15 through Figure 17 show the leading edge, top, and bottom views of the inboard fracture of the Blade A. The location of this fracture, approximately 40 inches from the grip plate or 44–51 inches from the blade root. This fracture location corresponded

with the location where an internal doubler stack terminated. Figure 15 shows fracture of the metallic leading edge abrasion strip. The strip exhibited indications of bending downward on the lower side, buckling inward on the inboard side and tensile tearing in the middle. These fracture features were consistent with fracture under multiple loading directions.

The upper blade skin surface exhibited a triangular shaped fragment, consistent with the $\pm 45^\circ$ plain-weave fabric orientation. The fracture surfaces of this fragment were relatively straight, with the outer paint remaining present adjacent to the fracture surface. In contrast, the lower skin fractures exhibited a more jagged orientation, mirroring the jagged orientation and underlying skin's 45° plain-weave pattern. The lower black paint was absent approximately 1 inch away from the fracture surface on this side. These features were consistent with tensile fracture on the upper blade surface and compressive fracture on the lower surface. This fracture pattern was consistent with Blade A having been bent downward at fracture.

Figure 18 through Figure 20 show the fracture surfaces of the inboard fracture of Blade B (the blade that had not been instrumented). These surfaces were separate from the combined reconstruction, viewed from the trailing edge and bottom side, shown in Figure 3e. On these figures, the leading-edge metallic abrasion strip was buckled inward with a slight downward bend. The woven composite fibers on the bottom blade skin showed some crushing and buckling on the leading edge, but they exhibited pullout along the leading portion of the fracture surface. While the middle section of the blade skin surface showed some paint peeling in the middle, much of the paint pattern was still present adjacent to the fracture surface on the leading and trailing edge sides (see Figure 19).

On the top side of Blade B, the fracture pattern on the skin was generally wavy, with paint absent 1 to 2 inches from the skin fracture (see Figure 20). The metallic leading-edge abrasion strip exhibited S-shaped compressive buckling on the upper face. In addition, the paint on the outboard section of the trailing edge had cracked. All of these features were consistent with compression on the upper surface and tension on the lower surface, with some evidence of twisting or torsion. This pattern was consistent with upward bending of Blade B at this fracture location. This fracture location was also consistent with the location of the doubler termination, approximately 37.5 inches from the grip plate, or 48-50 inches from the blade root.

The main rotor mast had fractured approximately 2.75 inches from the bottom of the housing, shown in Figure 21. The mast exhibited a general bend along the location of the fracture. Some paint was absent on the mast surface, shown facing the reader in Figure 21. As shown in Figure 21 through Figure 27, the mast exhibited thinning or necking near the fracture surface. This fracture surface was oriented at an inward-facing 45° angle relative to the mast direction. The fracture surface exhibited a lull, flat luster. The portion of the fracture surface on the concave side of the bend exhibited a change in orientation, although still angled. This feature suggested that this area was under compression at the

fracture. These features were consistent with a bending load at the fracture location of the mast, in the direction of the compressive fracture section.

Figure 25 and Figure 26 show the lower mast fragment. This fragment had been sectioned in the splined area, located on the left of Figure 25. Orange-painted instrumentation had been affixed to this section of the mast. Figure 26 shows the lower mast fragment after removal of the instrumentation. Using digital measurement techniques, the bend was calculated as being 15.5° downward in Figure 26.

The fracture surface of the rotor mast, depicted in Figure 26, was sectioned for microscopic analysis. Figure 27 shows this sectioned fracture surface, which exhibited a general 4° slant angle orientation in relation to the mast direction. Figure 28 shows an area of the mast fracture surface from a flat view. This section of the fracture surface exhibited chevron marks, consistent with overstress fracture of a thin-walled tube (plane stress conditions). The mast fracture surface was examined using a scanning electron microscope (SEM). As illustrated in Figure 29, the fracture surface exhibited dimple rupture, consistent with overstress fracture.

Selected measurements of the mast were taken. As the fractured mast was ovoid in shape, the part exhibited two diameters: the longer diameter was 1.627 inches wide and the shorter diameter being 1.526 inches wide, as measured from the inner diameter.

A portion of the mast wall was sectioned, mounted, and polished. The chemical composition of the mast section was examined using energy dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). The chemical composition was consistent with a 4340 alloy steel. Figure 30 shows a typical area of the mast microstructure. The microstructure exhibited tempered martensite. The hardness was measured per ASTM E18.¹ The hardness averaged 41 HRC, which was consistent with the observed microstructure and composition of the alloy for the mast.

Figure 31 through Figure 33 show the upper rotor hub assembly, specifically the bearings located at 90° to the blade roots. The covers of the bearings were removed, as demonstrated in Figure 32 and Figure 33. These roller bearings had been well greased, and the cage and the rollers still maintained suction on the inner race from installation. The bearings rotated readily, and there were no indications of scratches, gouging, loose debris, or wear on the surface on the inner race (see Figure 33).

Figure 34 shows the tail rotor assembly, as received. The tail rotors had fractured outboard of the blade roots, with heavy splintering and separation of the blades. One outer fragment of one of the tail rotor blades was received with the shipment.

Several of the attachment bolts for the tail rotor gear box housing had fractured. Four of the threaded bolt remnants are shown in Figure 35. As exemplified in Figure 36, the bolts exhibited indications of outward pullout and bending. The fracture surfaces

¹ ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

exhibited rotational features, with shear lips on one side. The fracture surfaces were dull in luster, with a rough surface texture. The fracture surfaces were all located at thread roots of the bolts. These features were all consistent with overstress fracture of the bolts.

The leading edge blade tip abrasion strips were examined further, as displayed in Figure 37 through Figure 40. Figure 37 shows the lower side of the tip from Blade B, and Figure 38 shows an edge-on view. In both figures, the underside of the metallic tip had been indented in an upward manner. The indented area exhibited a linear paint transfer mark. This paint transfer mark exhibited a pattern of alternating white and black colors. Angled scrape marks were present, consistent with having moved away from the banded paint transfer area. The width of these colors corresponded to the alternating white and black paint stripes on the tail rotor blade remnant. The matrix and the received tail rotor blade fragment were positioned together for comparison in Figure 37.

The blade tip abrasion strip of Blade A is shown in Figure 39 and Figure 40. This tip exhibited features consistent with an impact with another object. The tip had been torn and ripped at the location of the fracture. The outboard portion, while still attached to the rest of the tip, was bent aft and slightly upward. The inboard fracture surface was crumpled in an inboard direction, with the bottom section bent downward. At the outboard portion, a rounded dent was present. Blue paint transfer was present along the leading edge of the tip. Paint transfer and scrape marks emanated aft along the top of the tip.

The chemical composition of the tip abrasion strip was inspected using XRF. The composition was consistent with a nearly pure nickel alloy. The abrasion strip was also inspected using XRF. The abrasion strip composition was consistent with a 321 stainless steel. These respective compositions were consistent with the prescribed material specifications for the components.

Figure 41 show components from the collar set and lever assembly, after disassembly and removal from the mast. Of note was the collar had fractured. Figure 42 shows a closer view of the collar fracture surface. This surface exhibited river patterns and was generally rough with a dull luster. Later examination of the fracture surface using a SEM found dimple rupture on the fracture surface. These features were consistent with overstress fracture in an outward bending direction. The chemical composition of the collar was inspected using XRF. The collar composition was consistent with an AA 7075 aluminum alloy.

Erik M Mueller
Materials Research Engineer

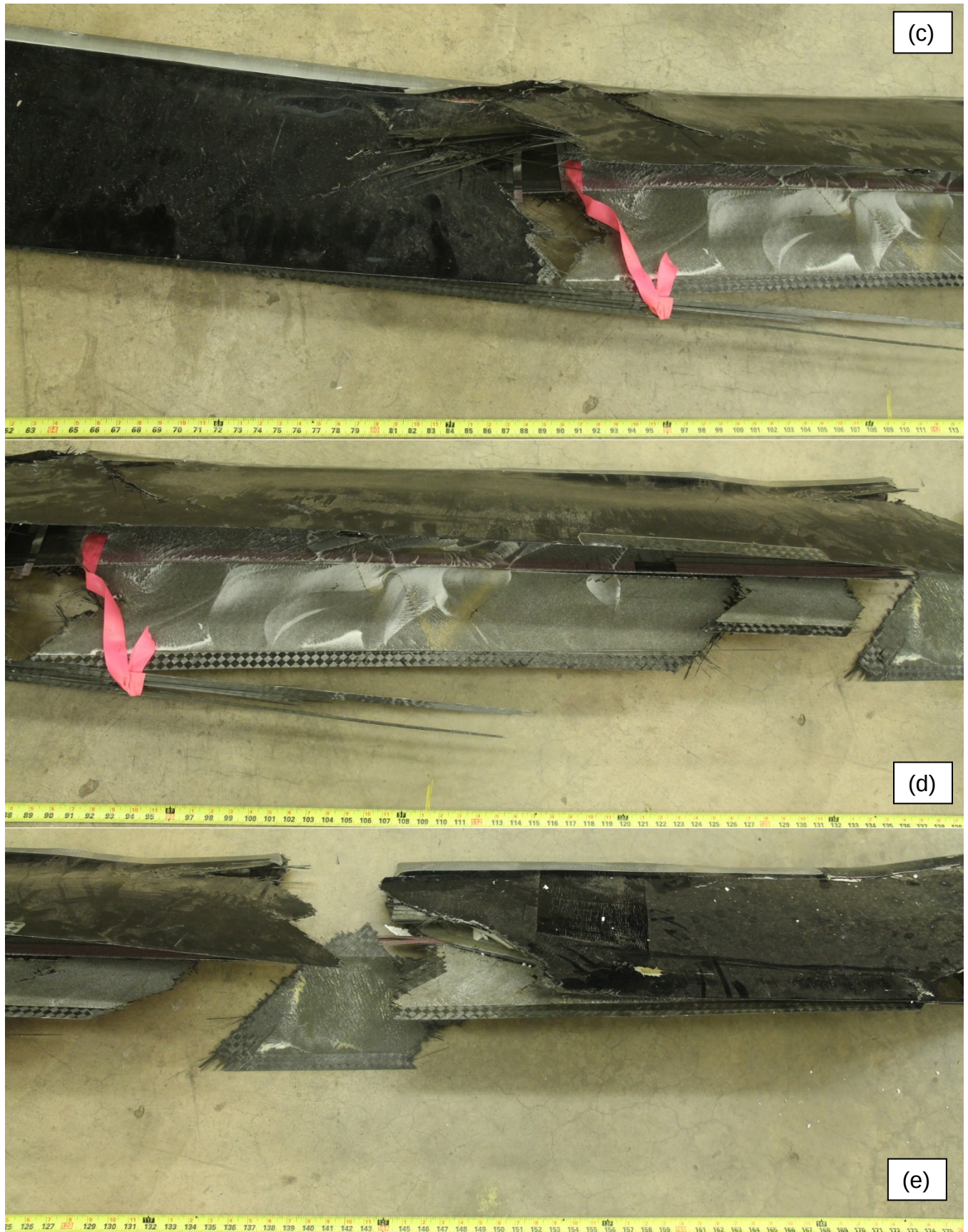


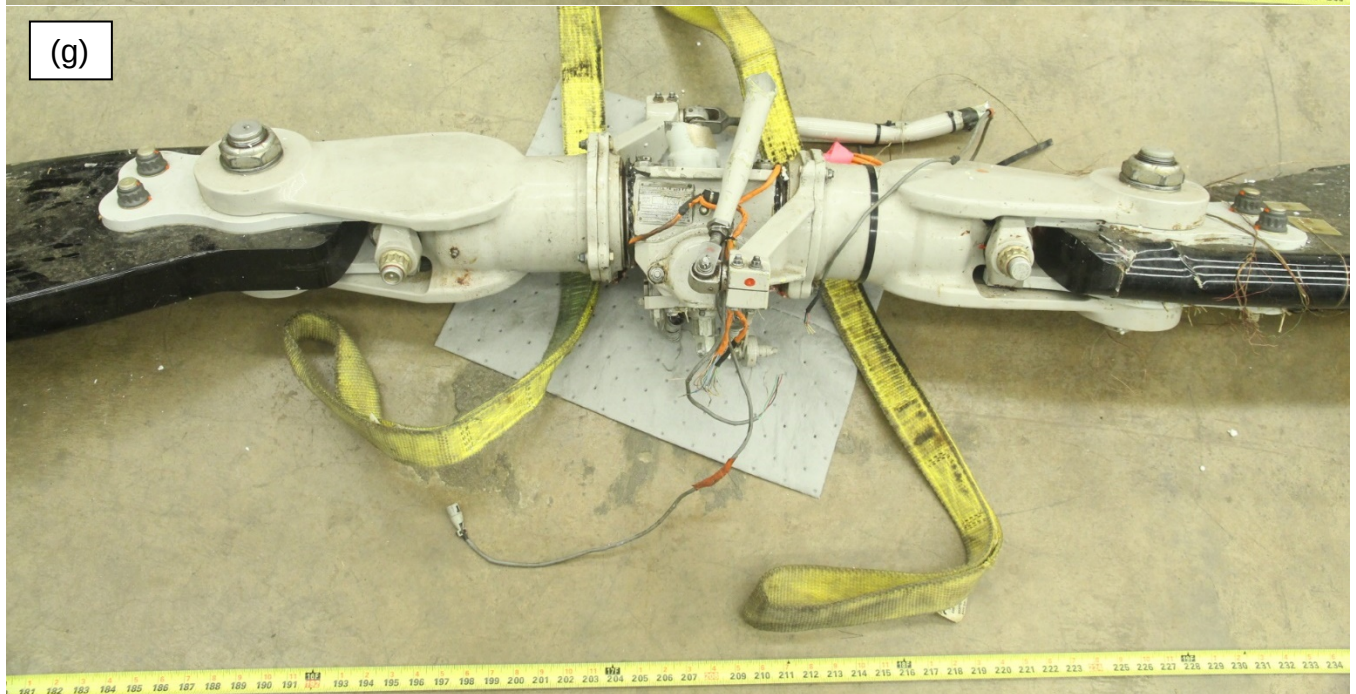
Figure 1 – Components recovered from the accident site, in the crate, as received after opening the top lid.



Figure 2 – One section of the main rotor blade fragments laid out in positions consistent with their positions prior to fracture. This is viewed from the tip of Blade B, the blade without instrumentation.

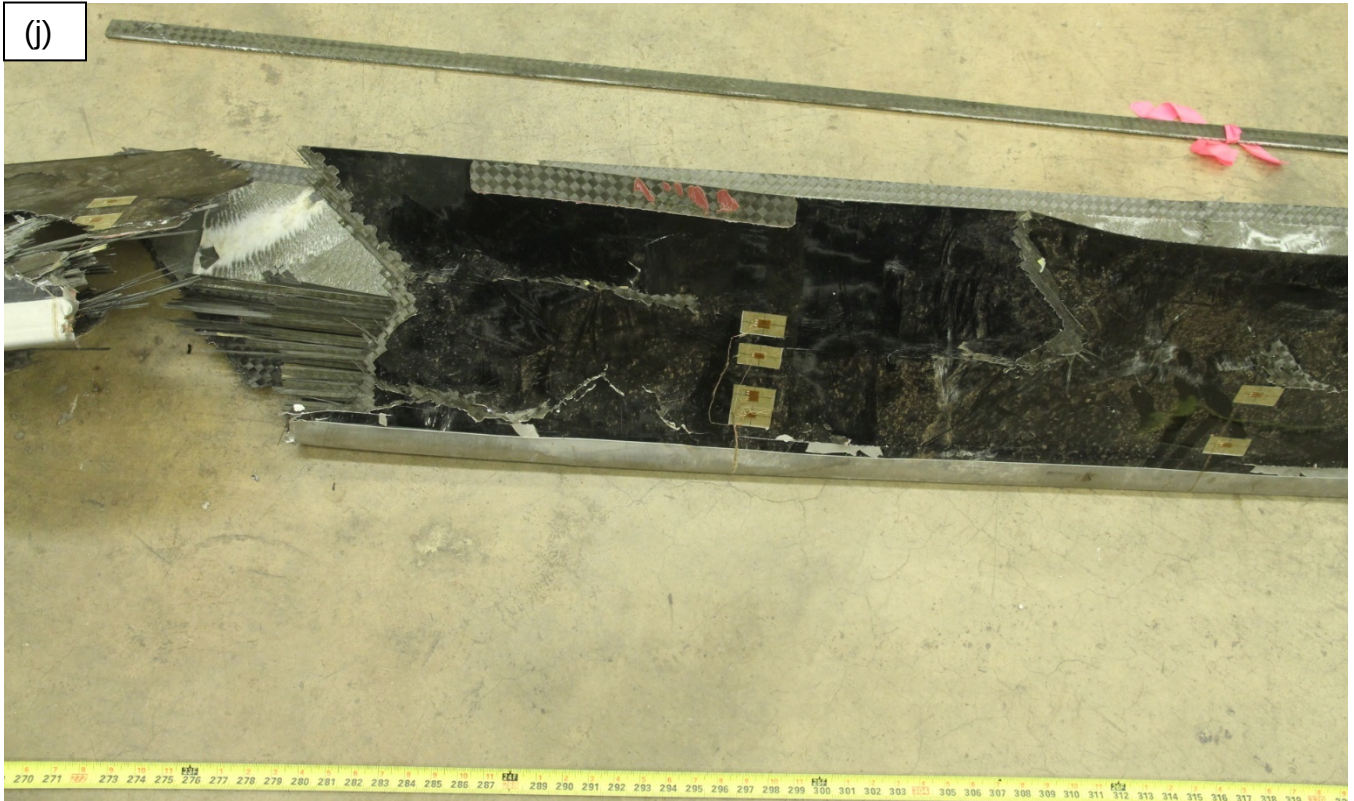




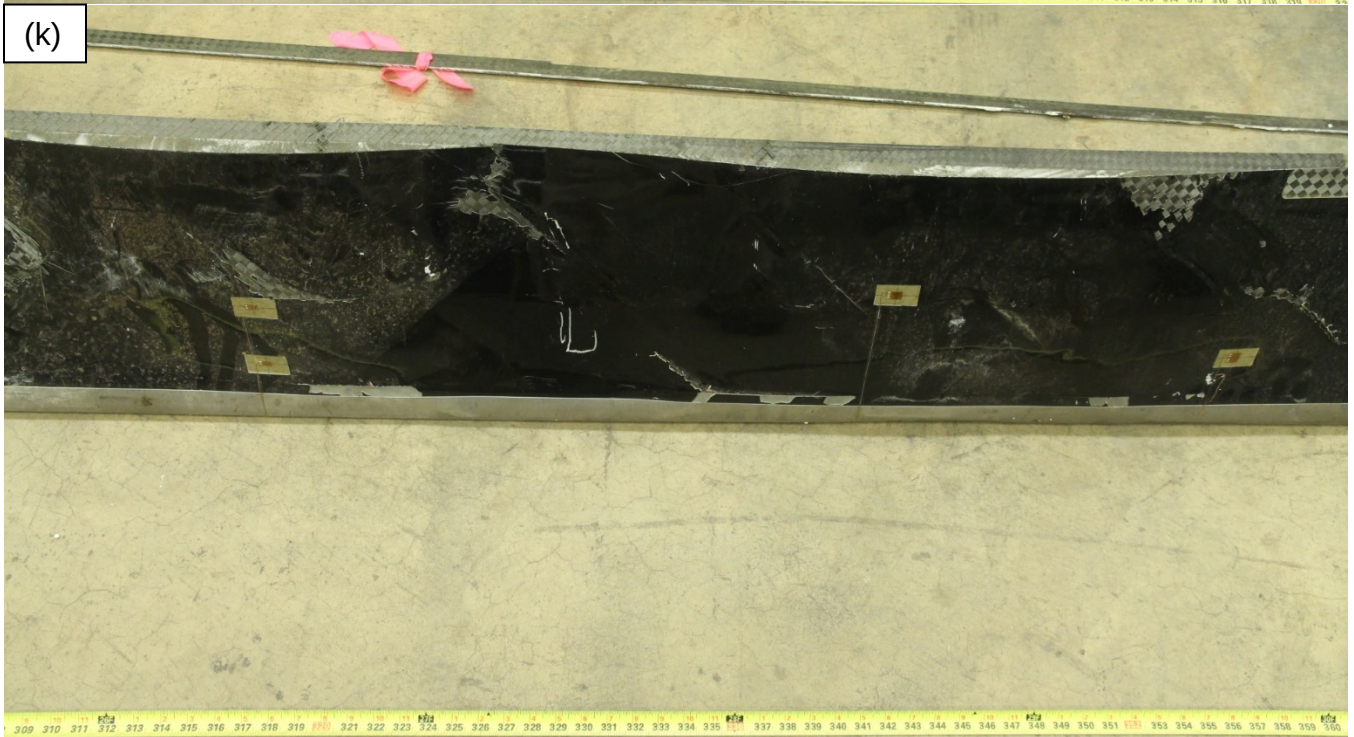




(i)



(k)



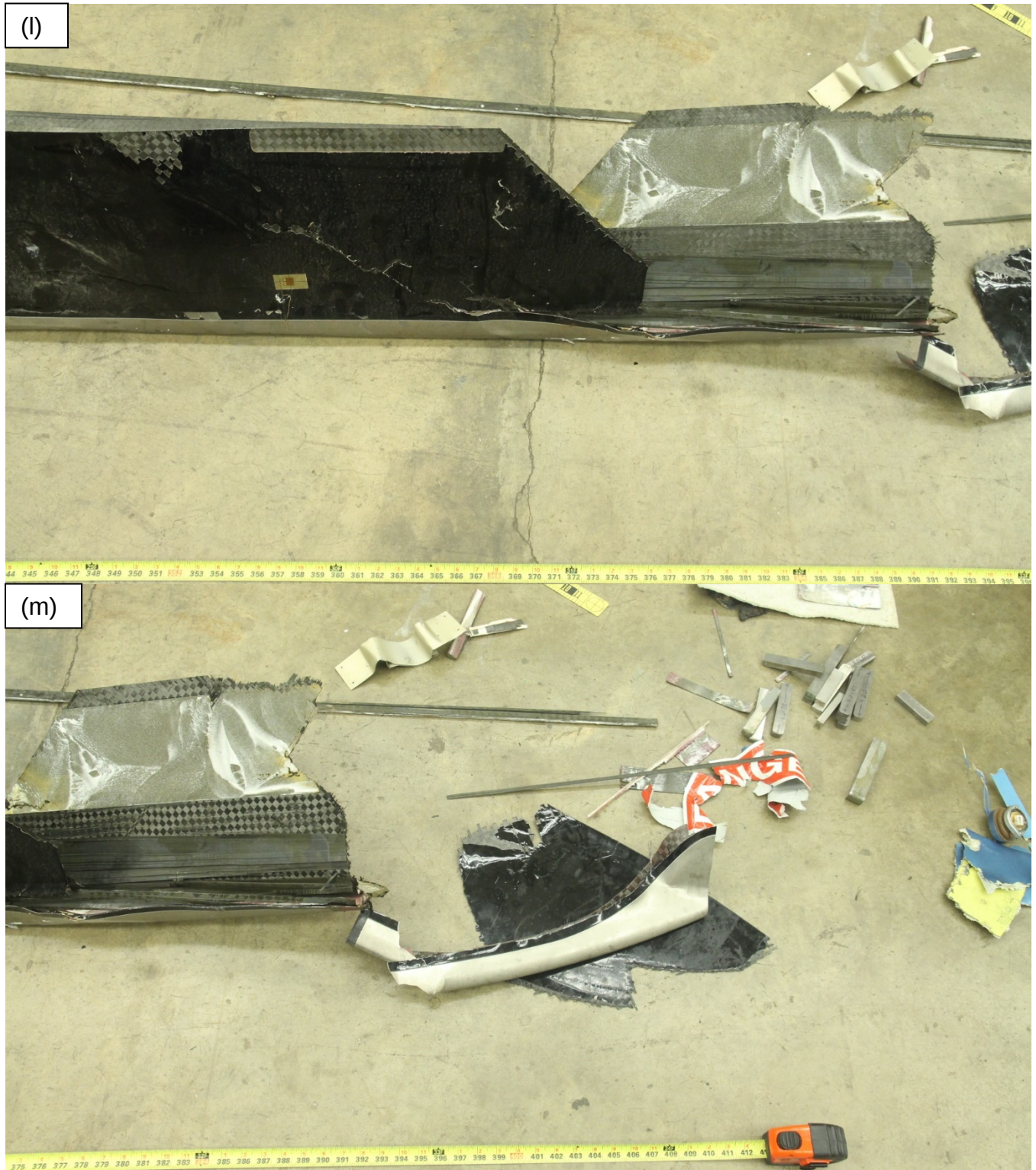


Figure 3 – The major fragments of the main rotor blades and the rotor hub, laid out from one side to the other in order from Blade B tip (a-g) to Blade A tip (h-m).

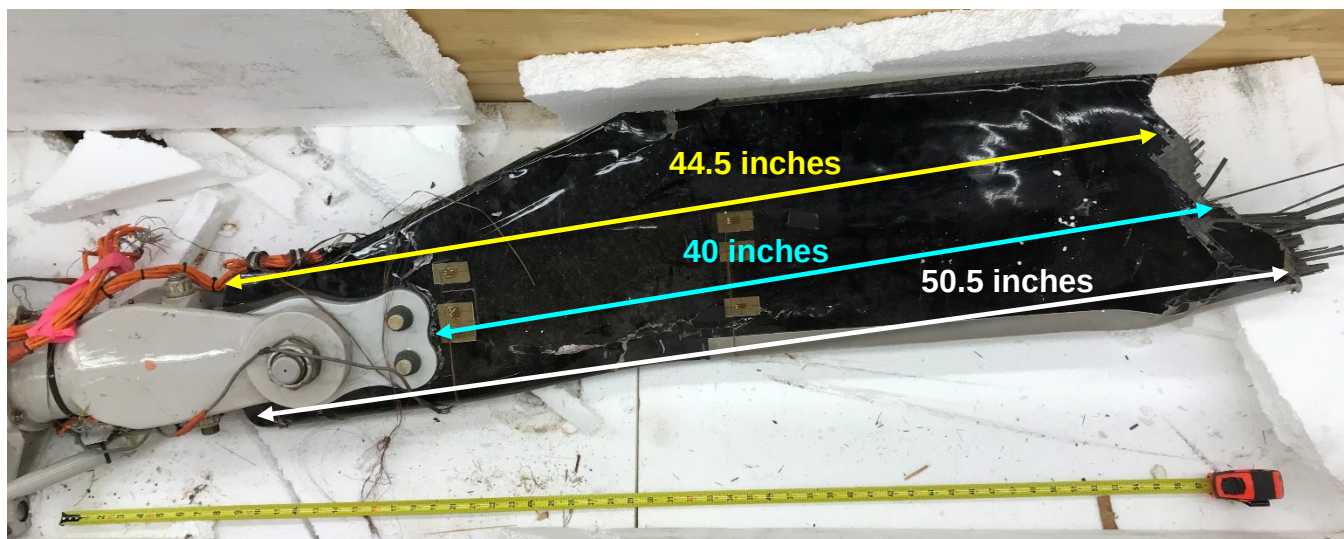


Figure 4 – Underside of Blade A at the blade root. Measurements of the fracture distance to root features are annotated.

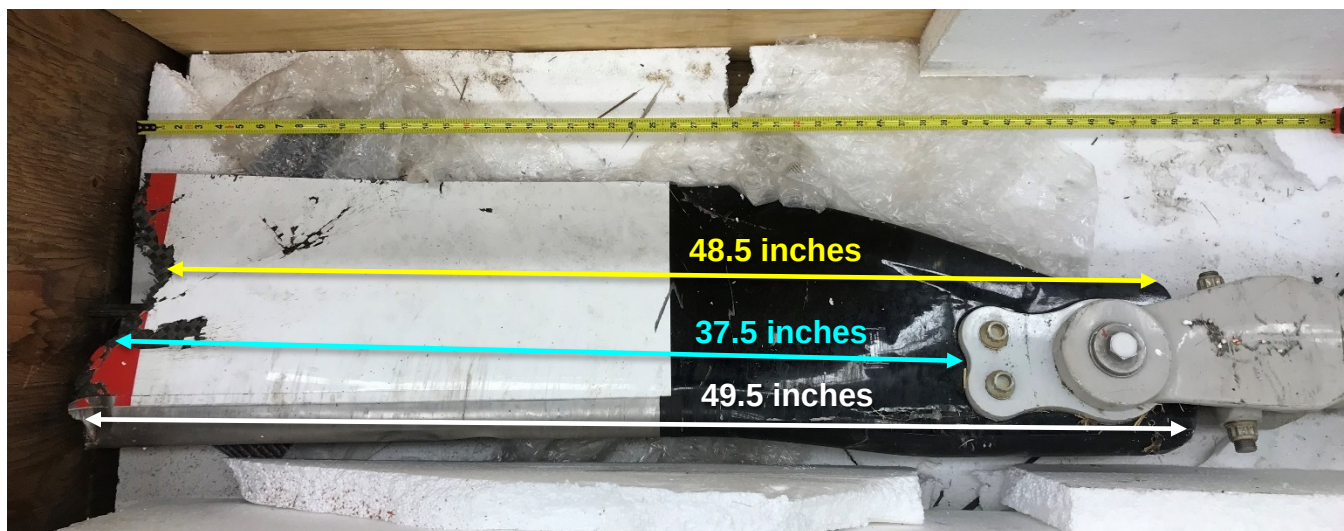


Figure 5 – Underside of Blade B at the blade root. Measurements of the fracture distance to root features are annotated.



Figure 6 – View of the Blade A tip, viewed from the trailing edge side.



Figure 7 – View of the interior of Blade A by from the trailing edge, showing foam remnants on the interior surfaces.

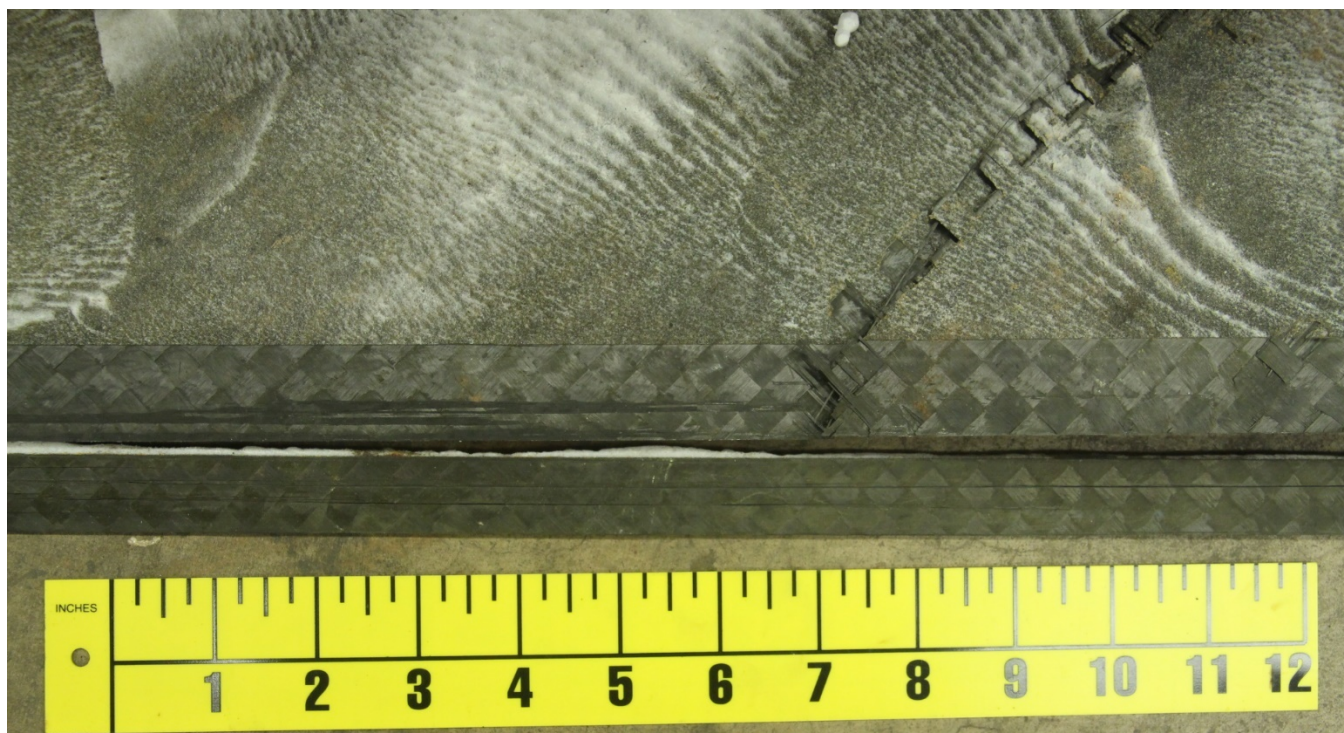


Figure 8 – View of the separated trailing edge strip beneath the trailing edge of the rotor skin interior of Blade A. Both faces show the 45° plain-weave pattern of the skin layup.

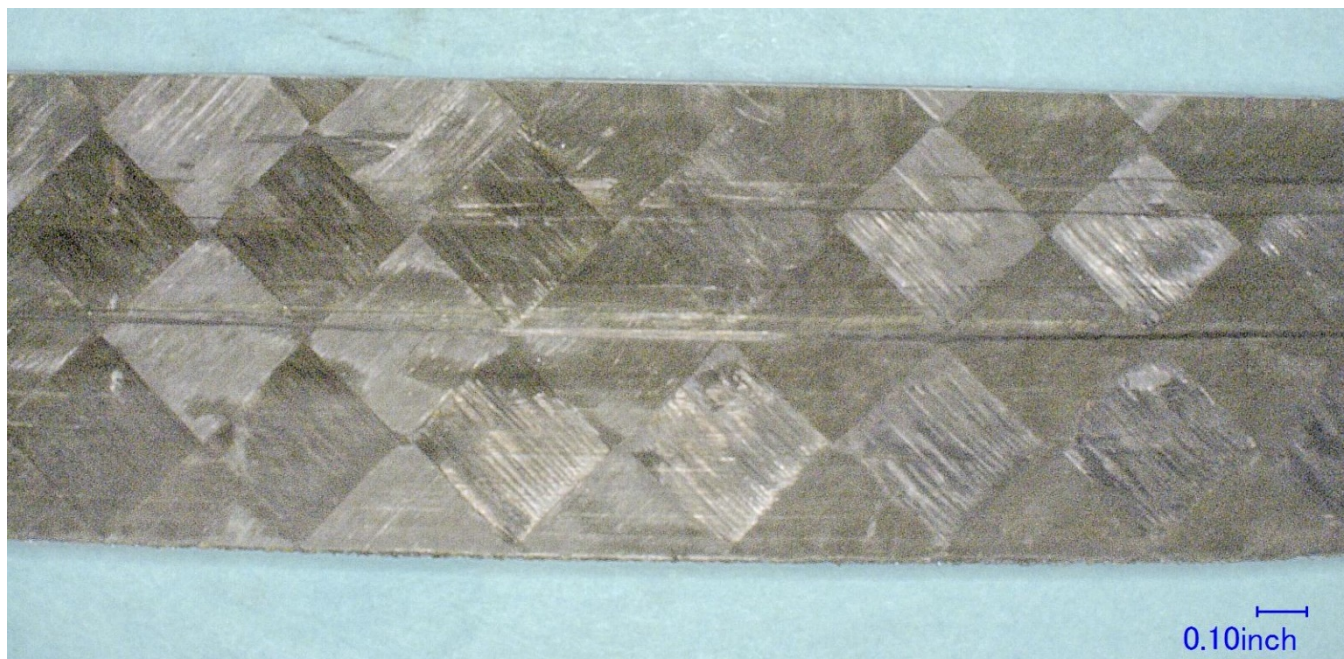


Figure 9 – Closer view of the Blade A trailing edge strip surface, showing the 45° plain-weave pattern on the exposed surface (~10X).

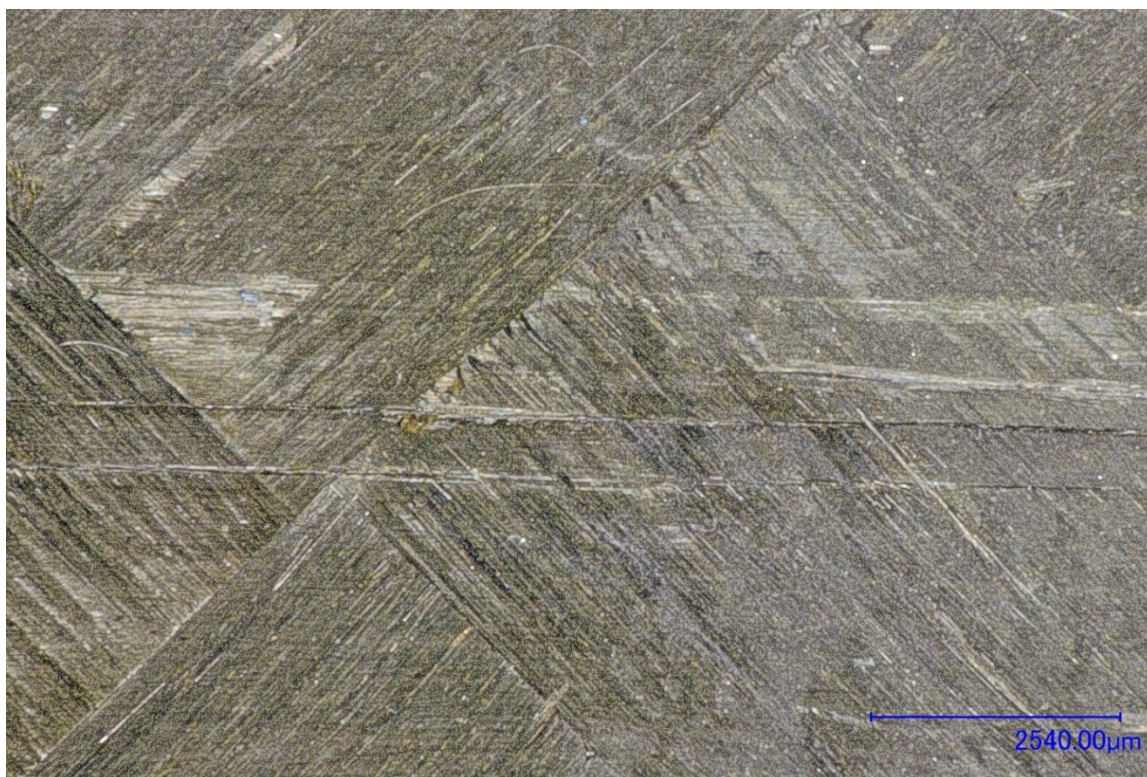


Figure 10 – Closer view of the outer surface of the trailing edge strip, showing the 45° plain-weave pattern (~30X).

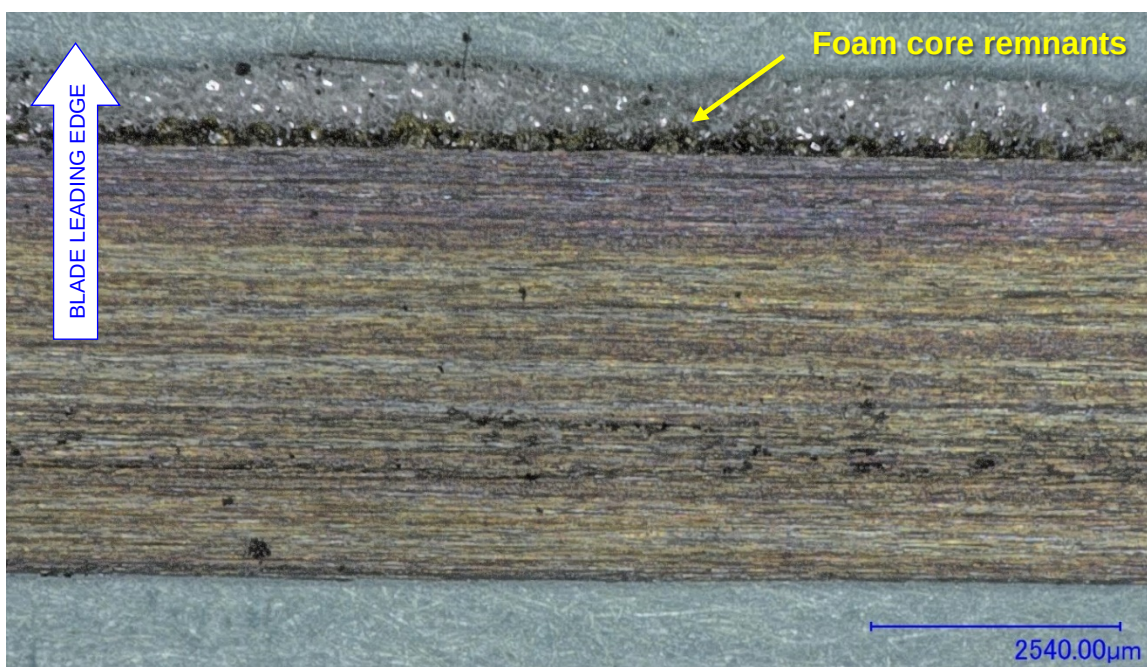


Figure 11 – Closer view of the inner surface of the trailing edge strip, showing the unidirectional fiber pattern of the interior strip composite and residual foam core still adhered (~30X).

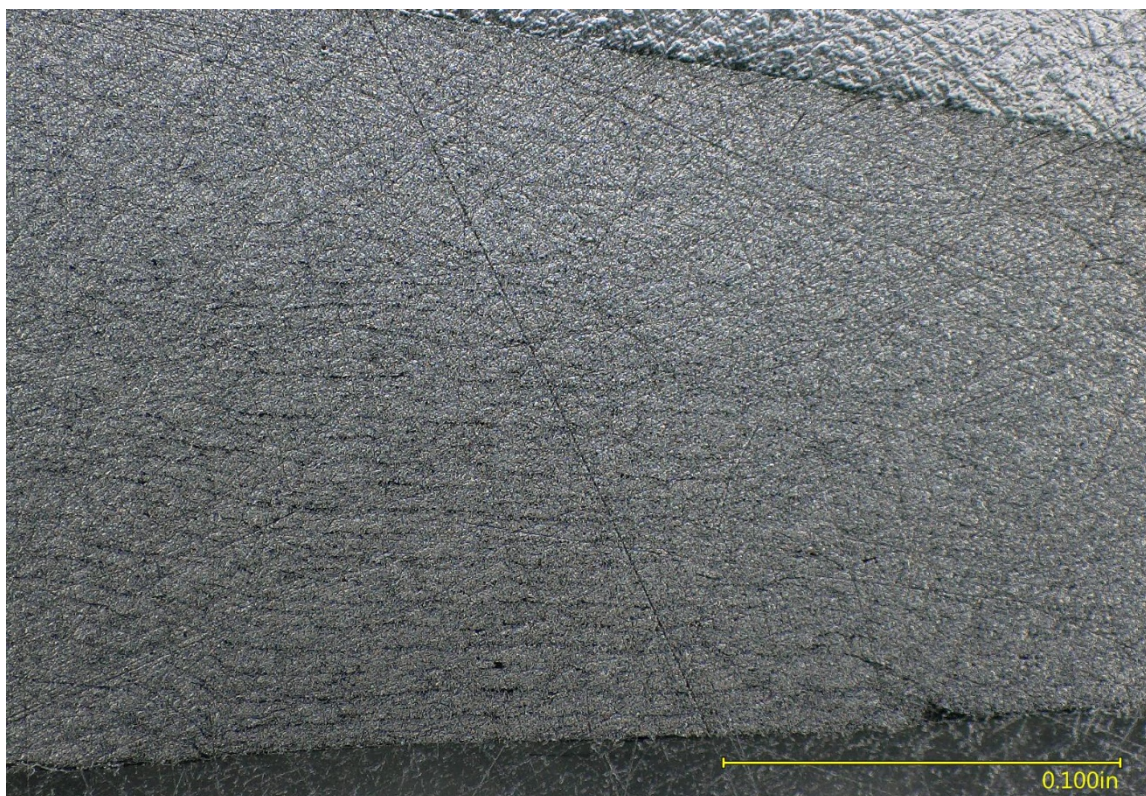


Figure 12 – View of the mounted, polished trailing edge strip in cross section.

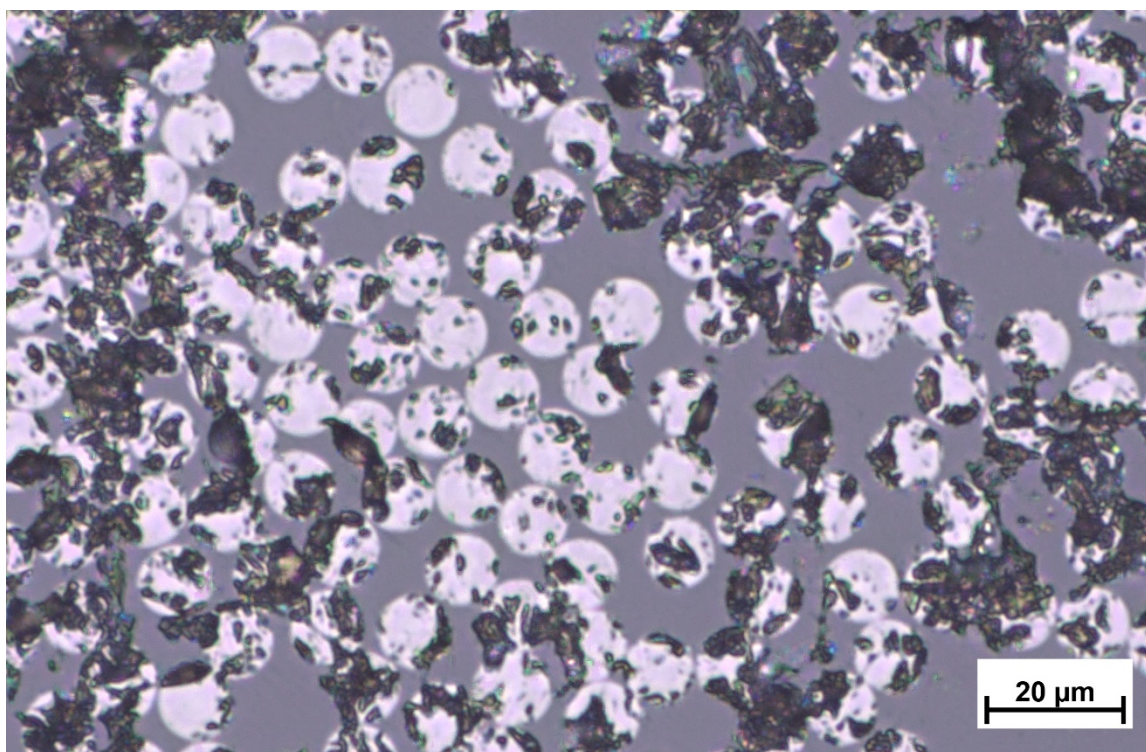


Figure 13 – Bright field (BF) view of the trailing edge strip in cross section, showing carbon fibers (white) in an epoxy matrix (gray). The dark material was an artifact of the polishing process (~as polished, ~1000X).



Figure 14 – View of the Blade B tip from the underside (leading edge faces downward).

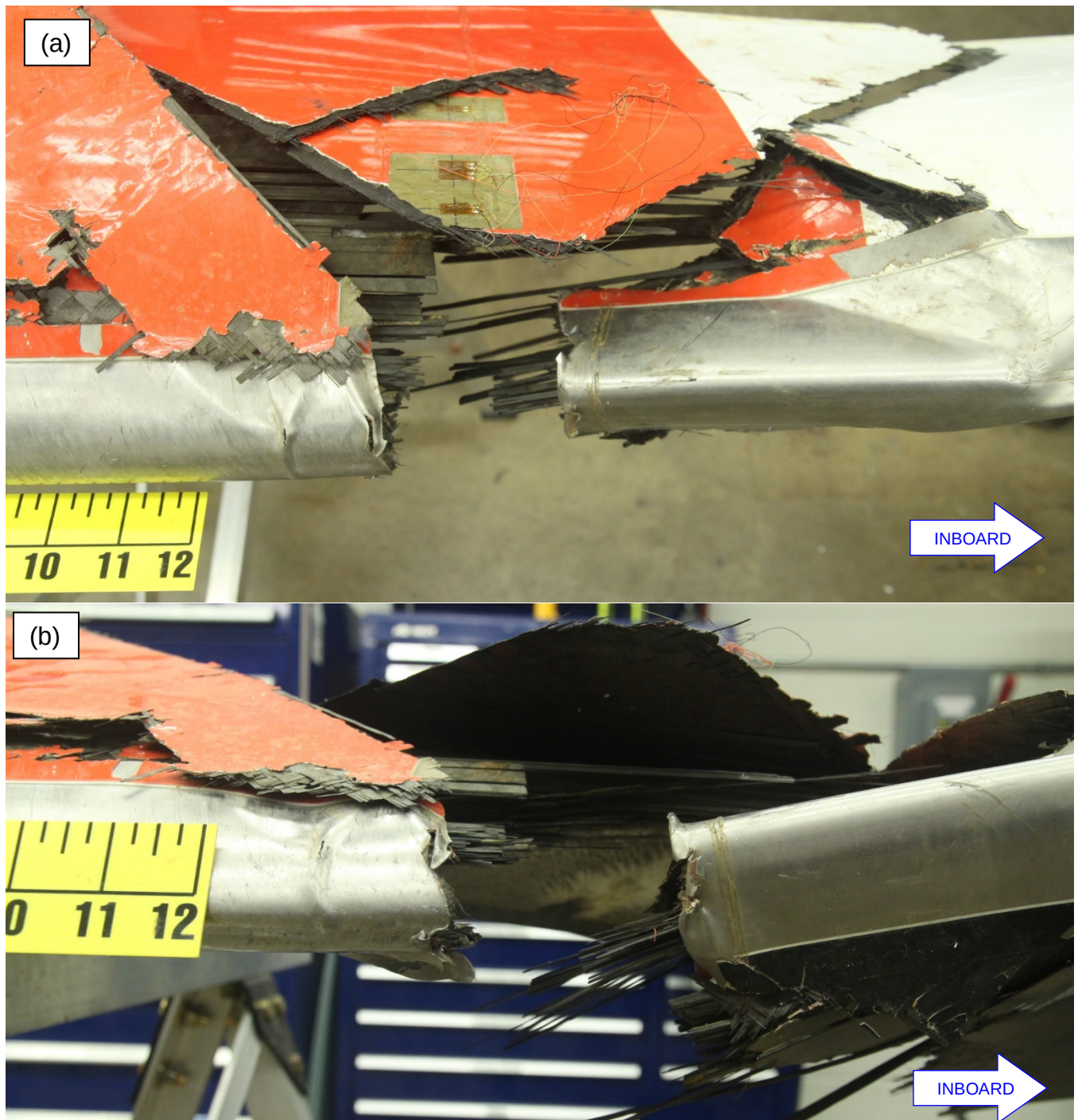


Figure 15 – The upper side of the inboard fracture on Blade A from (a) a top angled view and (b) a view of the leading edge.

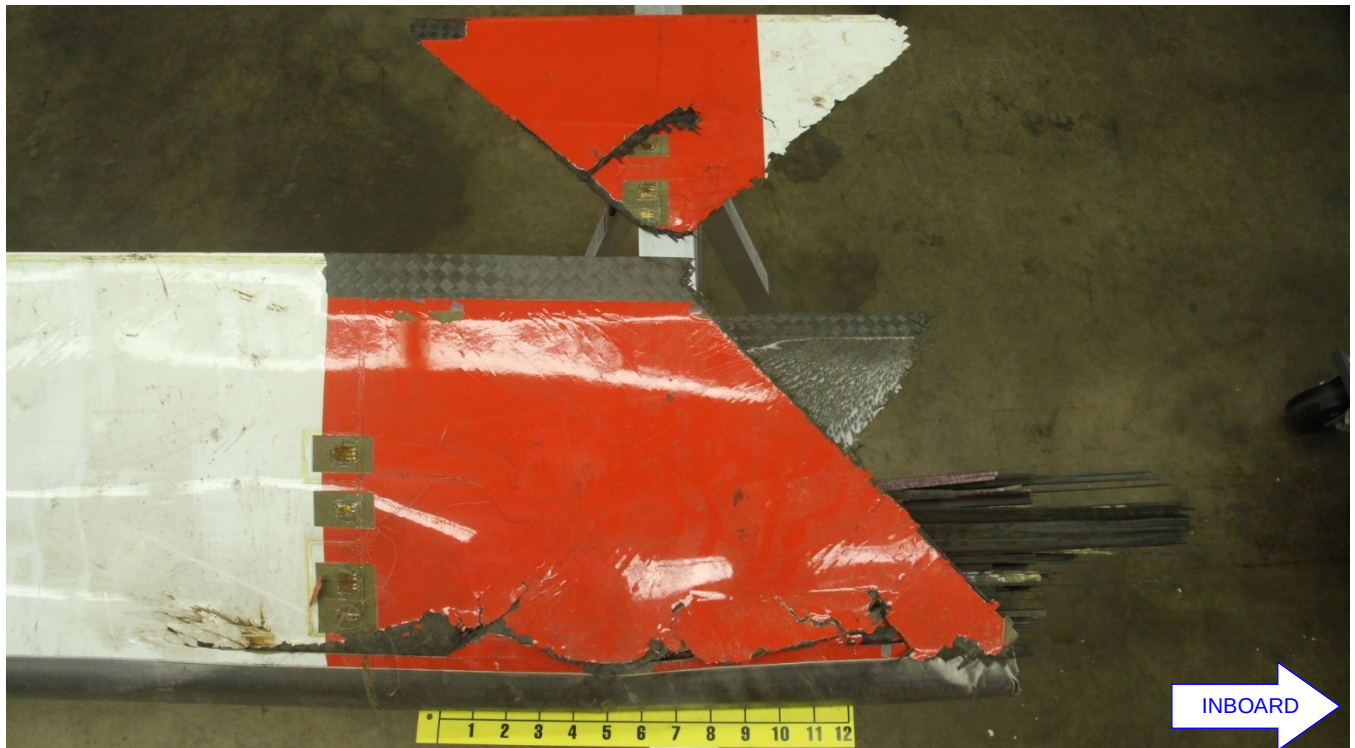


Figure 16 – Top view of the inboard fracture of Blade A, showing mating skin fragments.

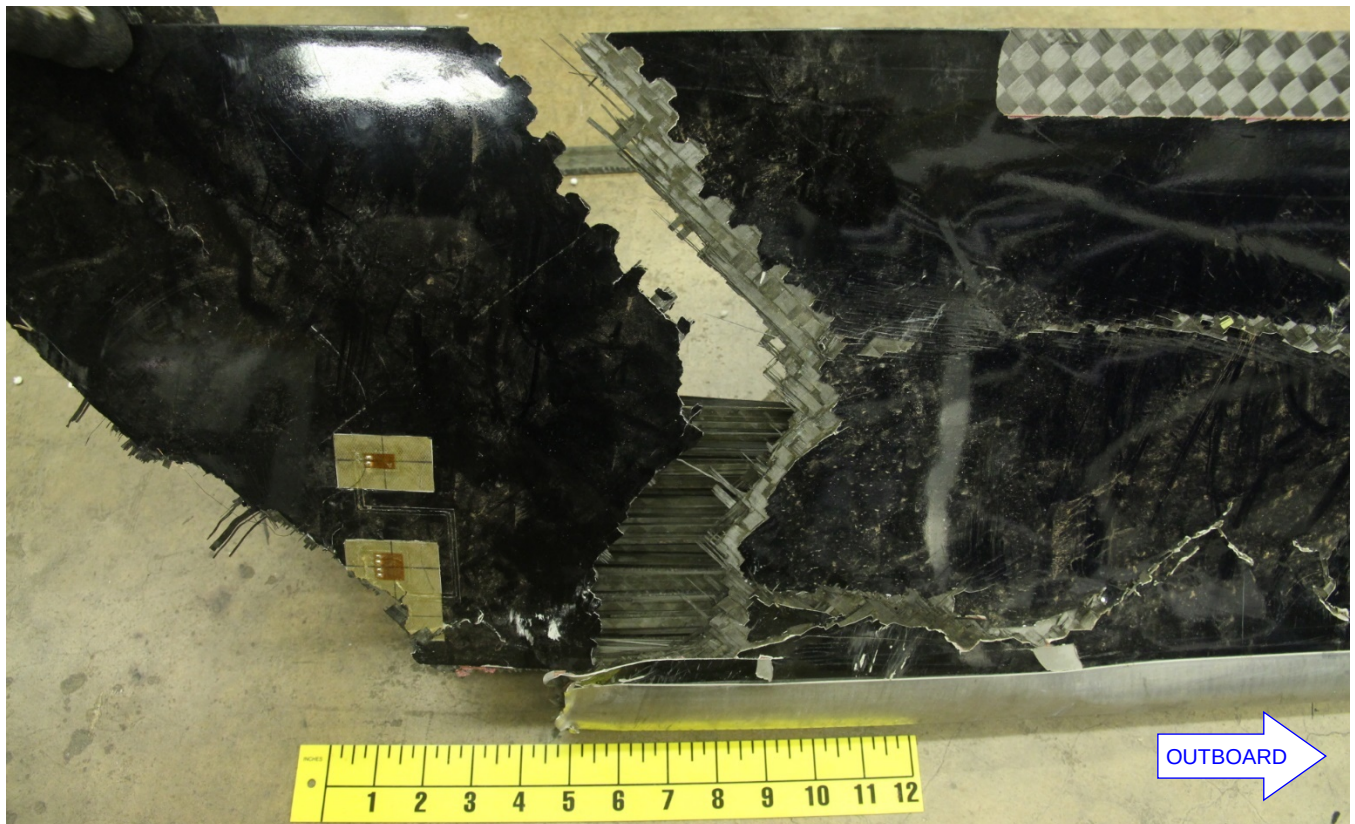


Figure 17 – Bottom view of the inboard fracture of Blade A, showing mating skin fragments.

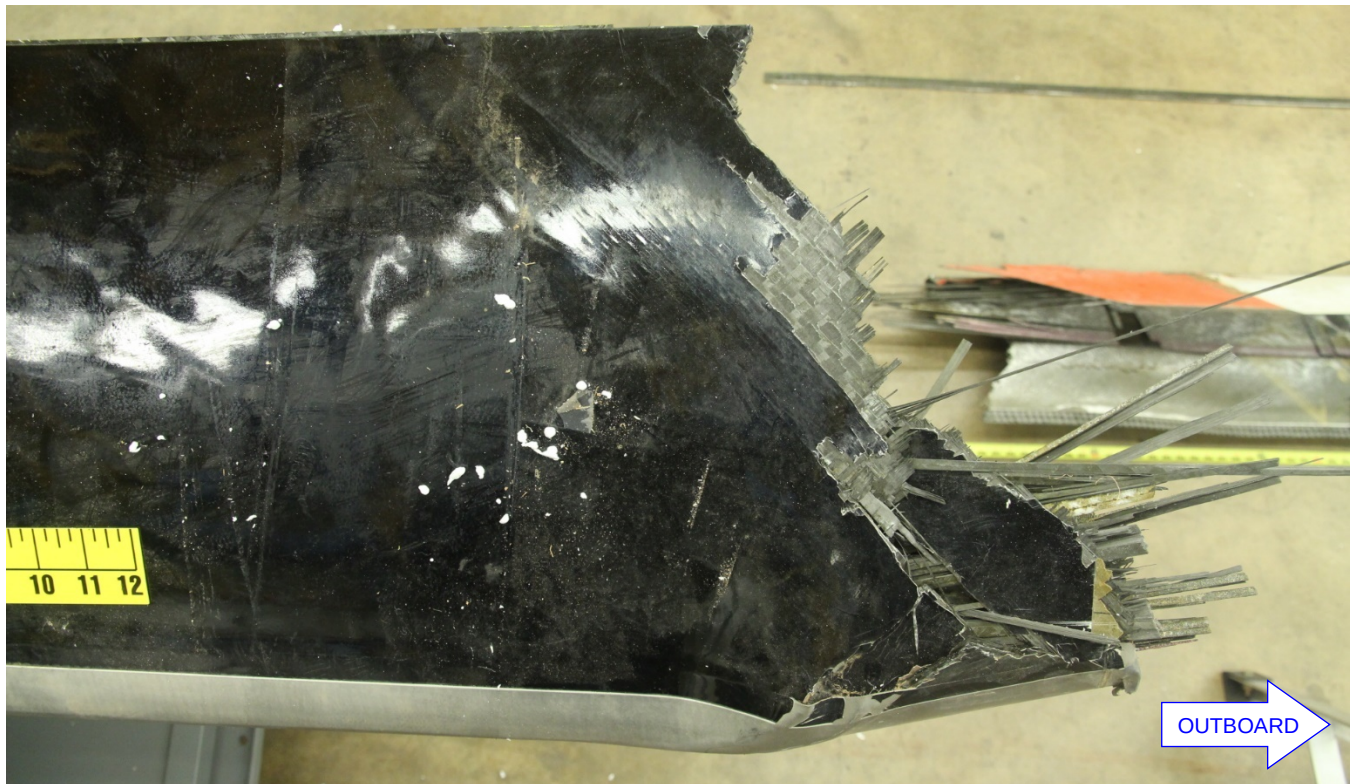


Figure 18 – Bottom view of the outboard fracture of Blade B.



Figure 19 – Mating fracture surface of Blade B from Figure 18.

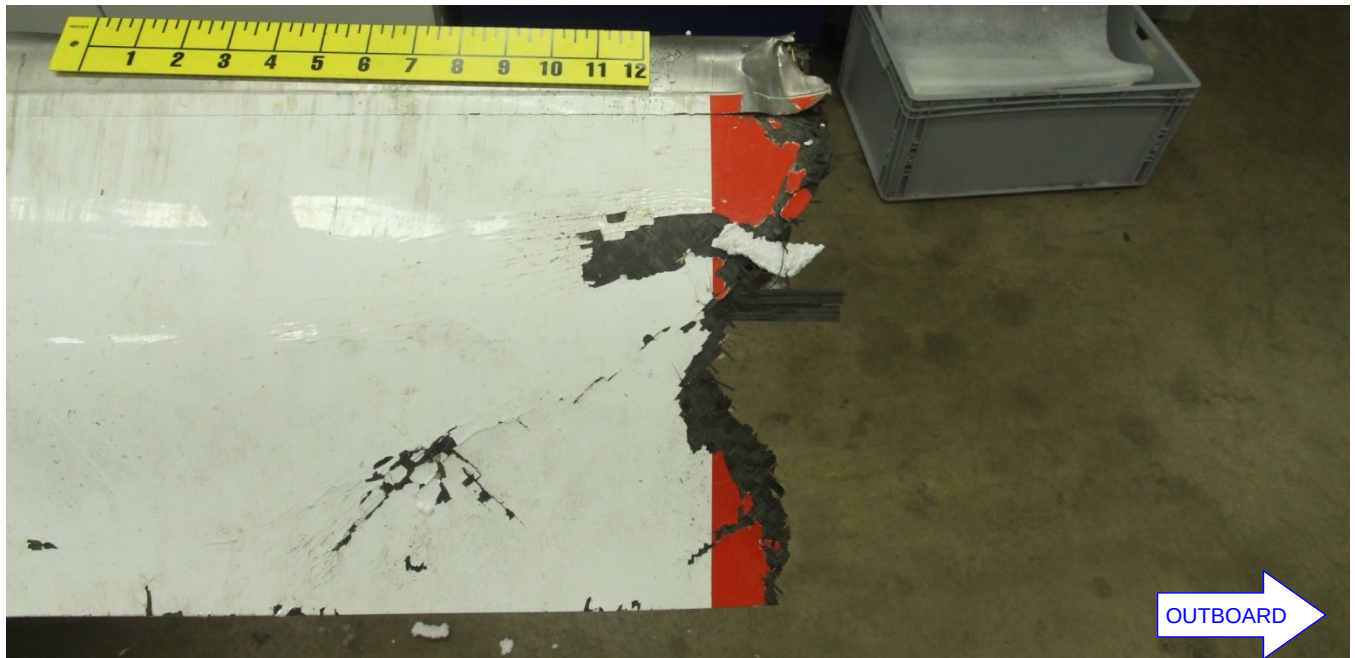


Figure 20 – Top view of the inboard fracture of Blade B.



Figure 21 – View of the mating sides of the fractured main rotor mast.

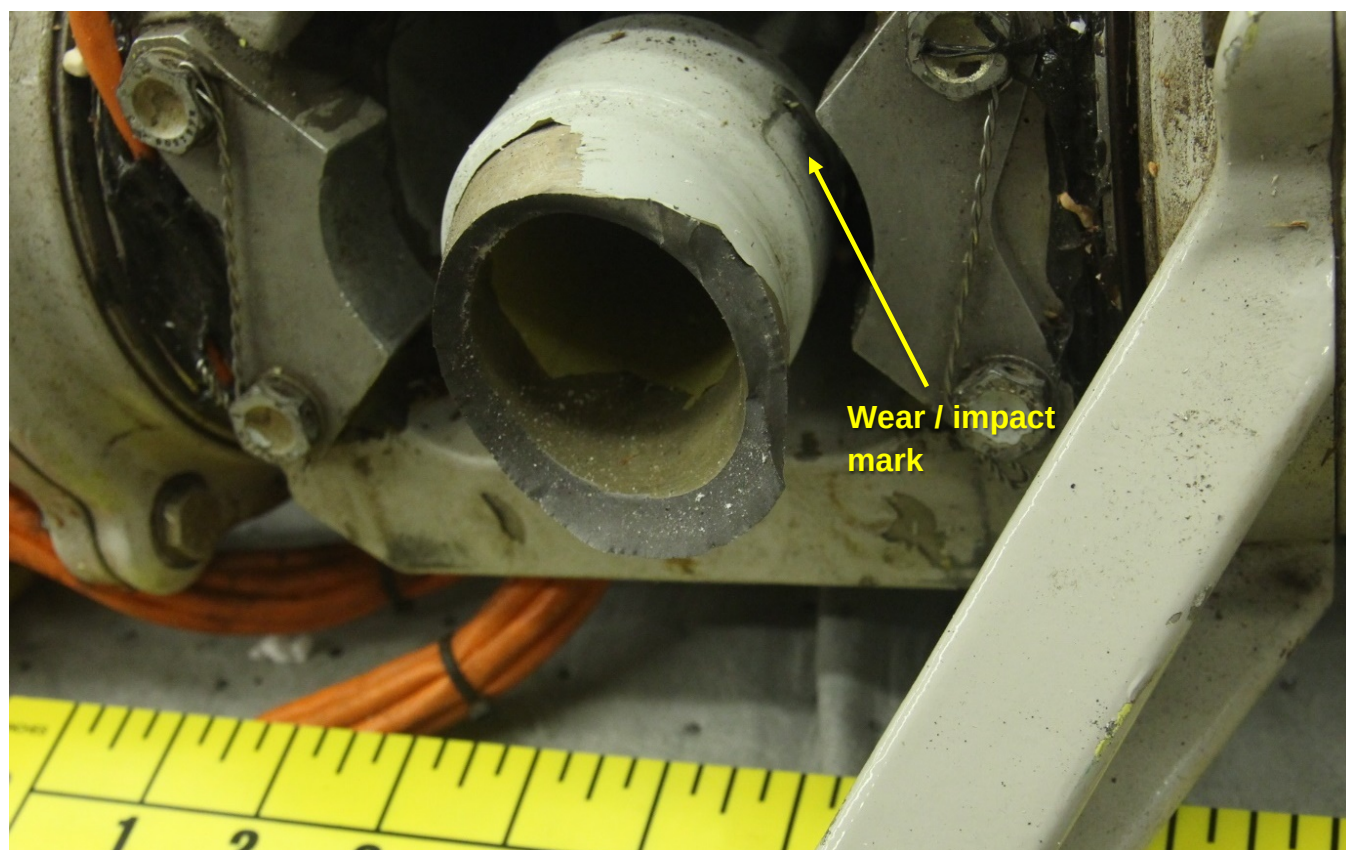


Figure 22 – Side view of the upper mast fragment, showing impact marks in the paint on the side wall.

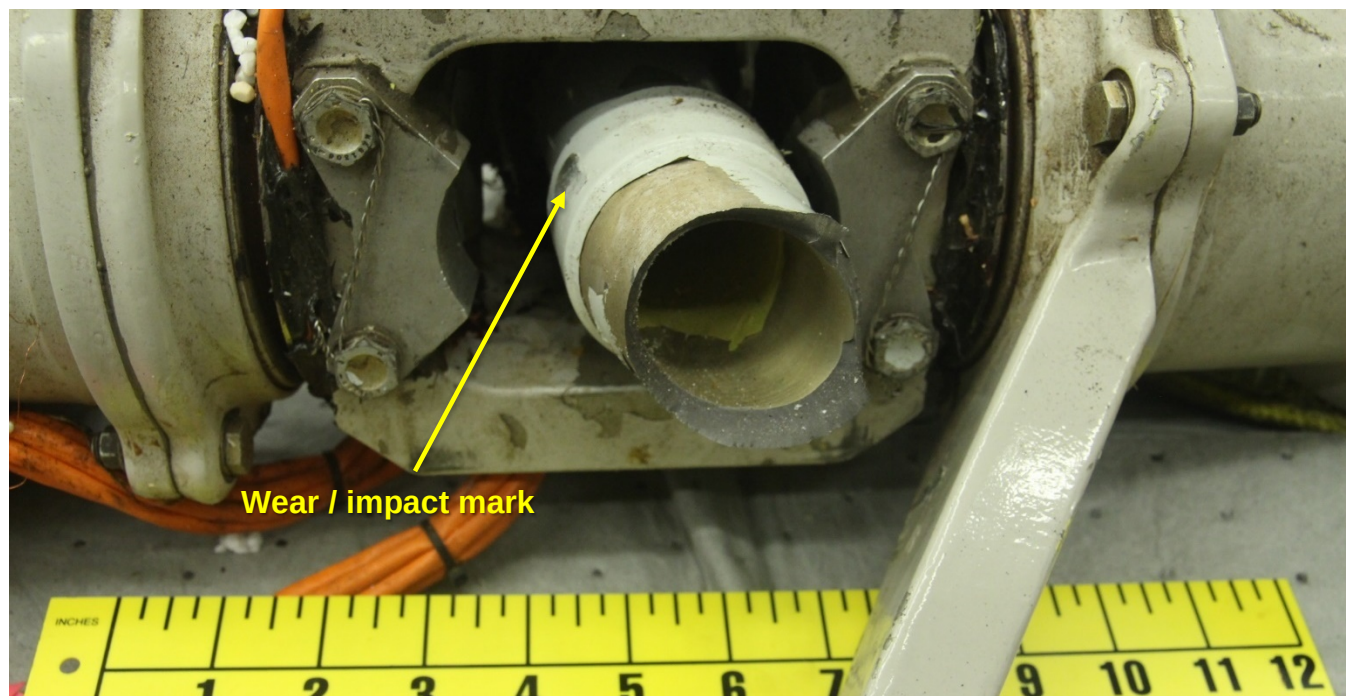


Figure 23 – Side view of the upper mast fragment opposite Figure 22, showing impact marks in the paint on the side wall.



Figure 24 – The lower mast fracture surface viewed facing the reader.



Figure 25 – View of the lower fragment of the main rotor mast (with orange instrumentation affixed). The fracture surface is to the right.



Figure 26 – Side view of the lower mast fracture, after removal of the orange instrumentation.



Figure 27 – View of the mast fracture surface, after sectioning.

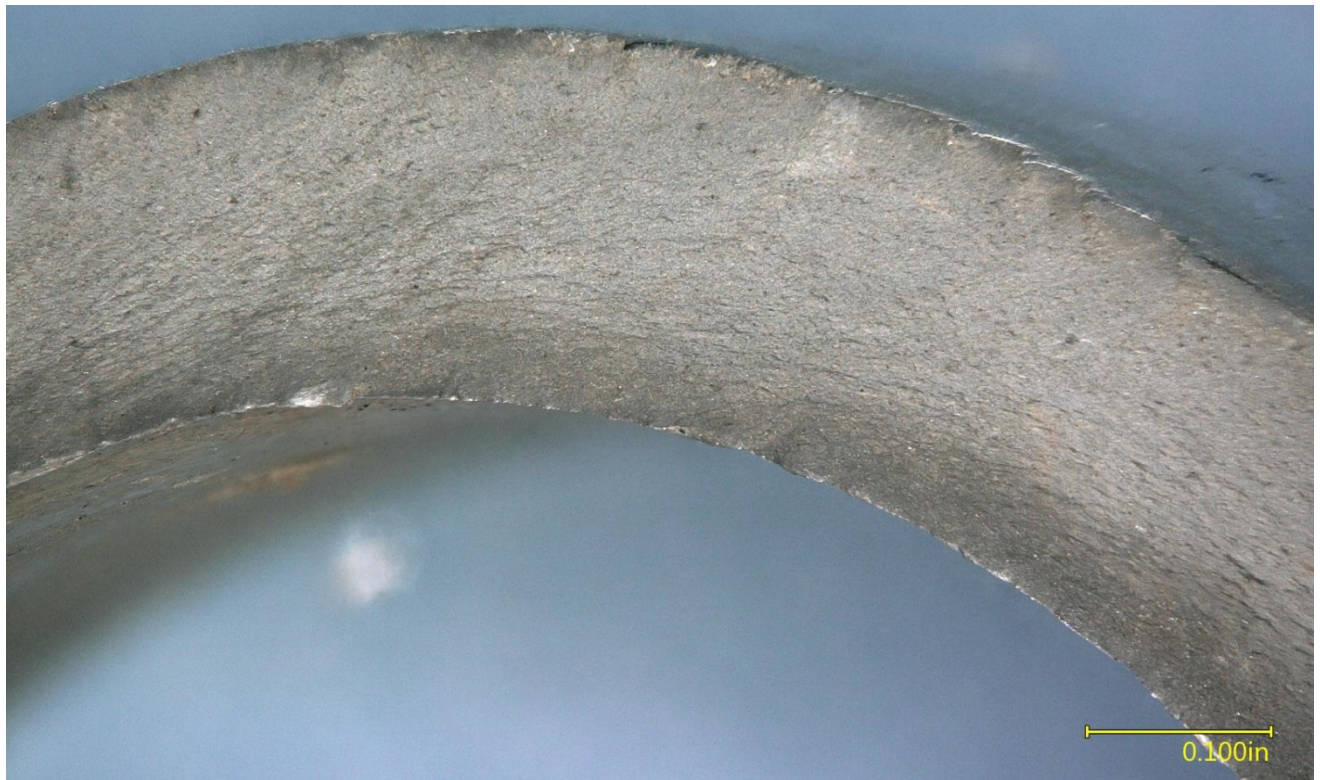


Figure 28 – Top view of the sectioned mast fracture surface, showing chevron marks.

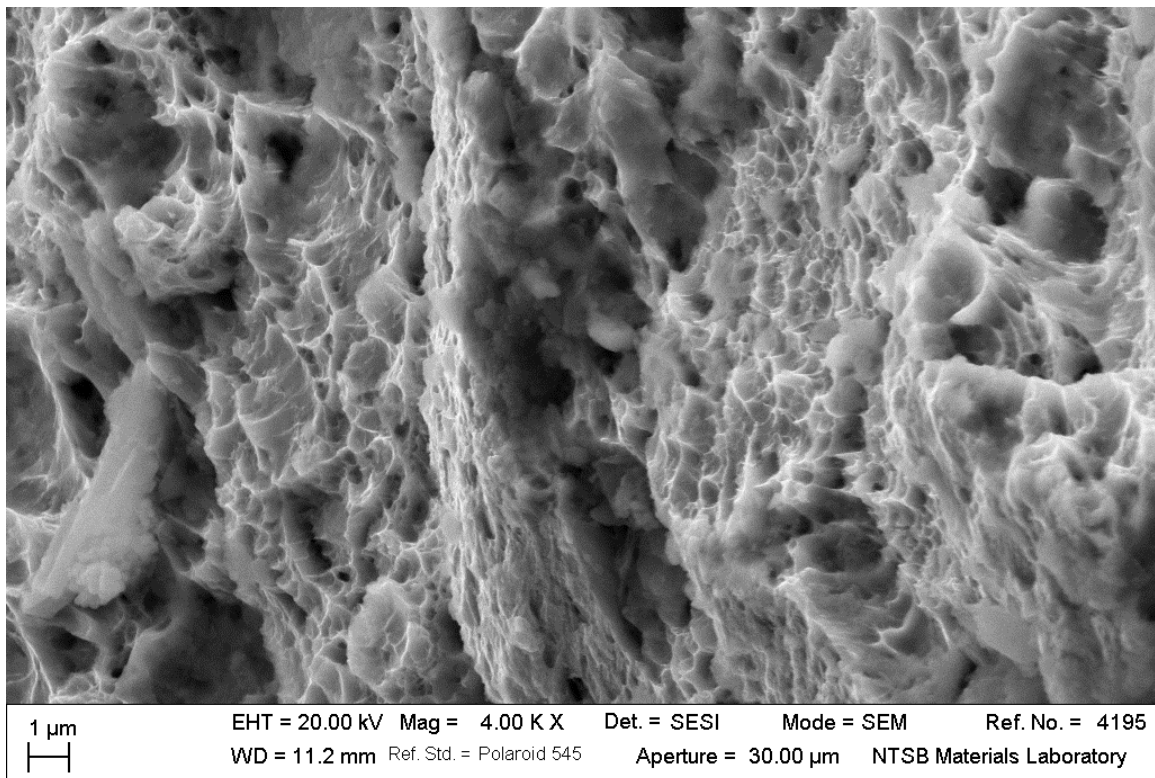


Figure 29 – Secondary electron (SE) micrograph of the mast fracture surface, showing dimple rupture.



Figure 30 – Bright-field (BF) optical micrograph of the mast microstructure (~500X, etched 2% Nital).

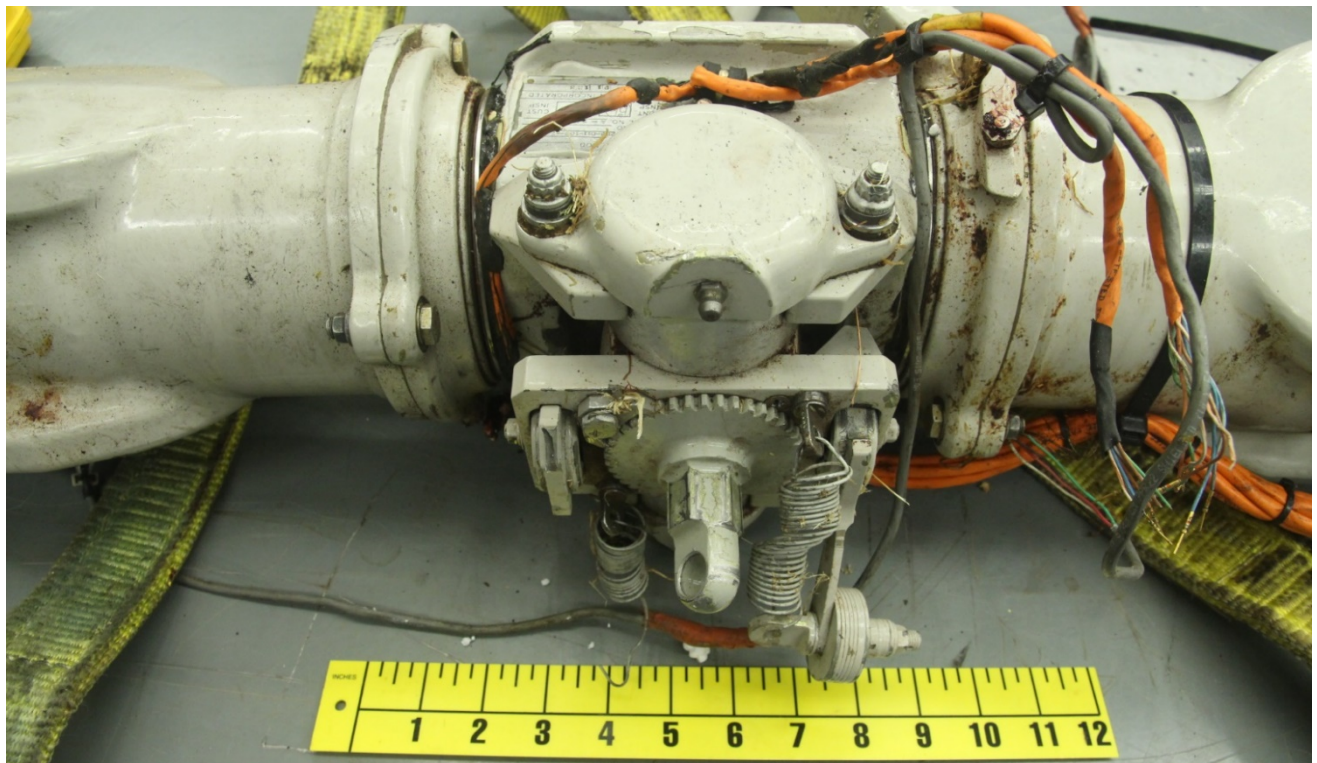


Figure 31 – An angled view of the upper main rotor hub as received, showing the bearing cover on this side.



Figure 32 – View of Figure 31, after the bearing cover on this side was removed.

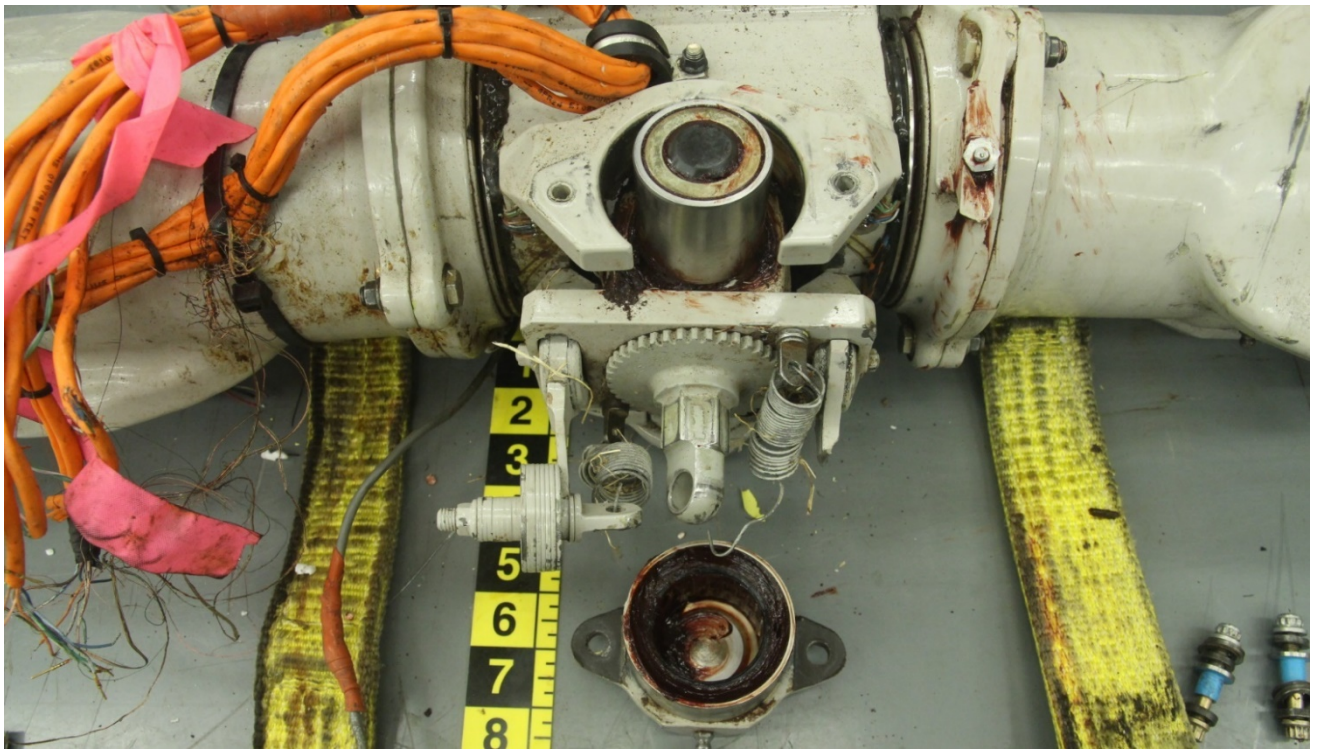


Figure 33 – The opposite bearing from that in Figure 31 and Figure 32, with the cover removed.



Figure 34 – The tail rotor assembly, as received.

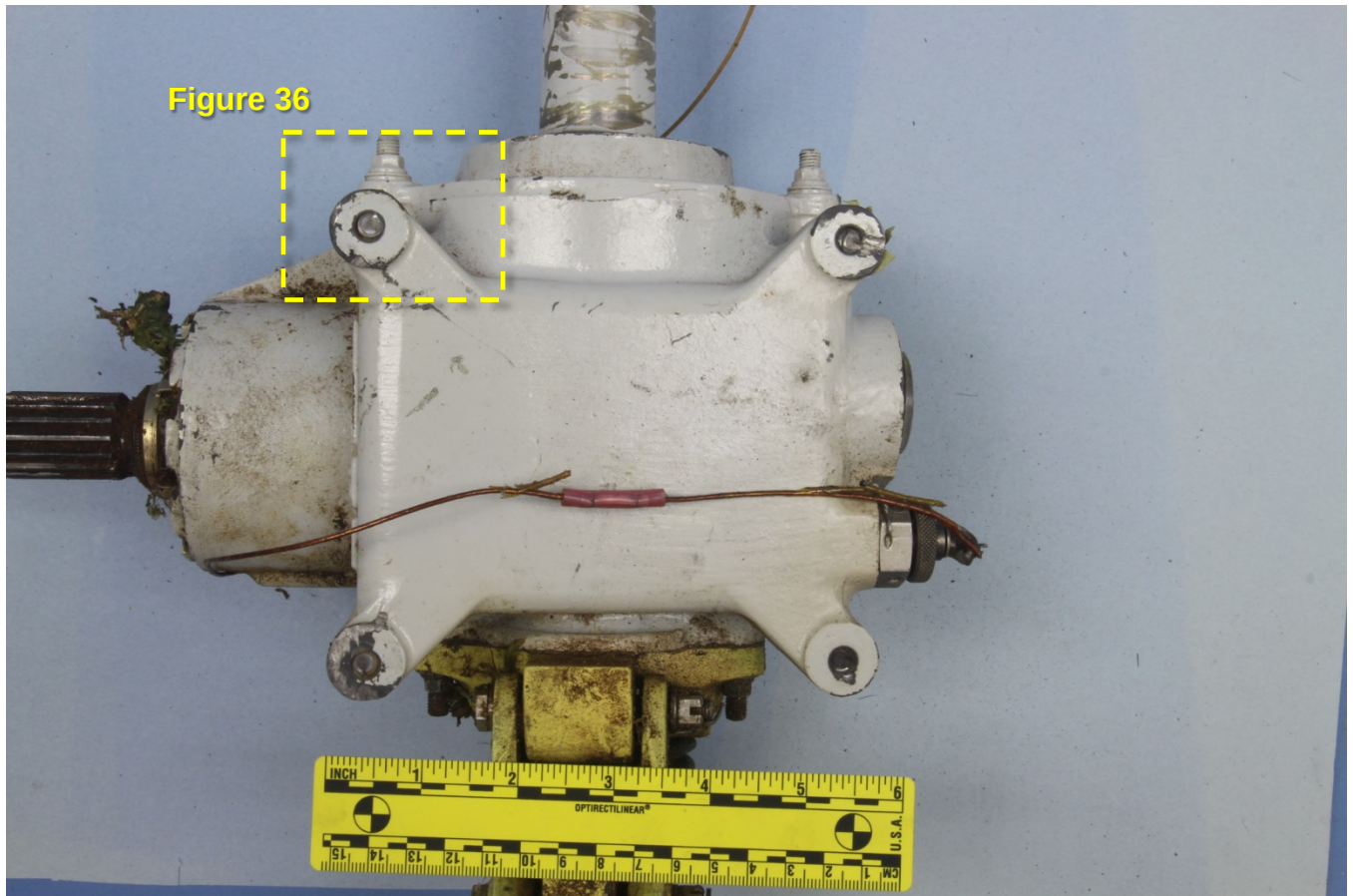


Figure 35 – Fractured bolts of the tail rotor gear assembly.



Figure 36 – Closer view of one of the fractured bolts in Figure 35.

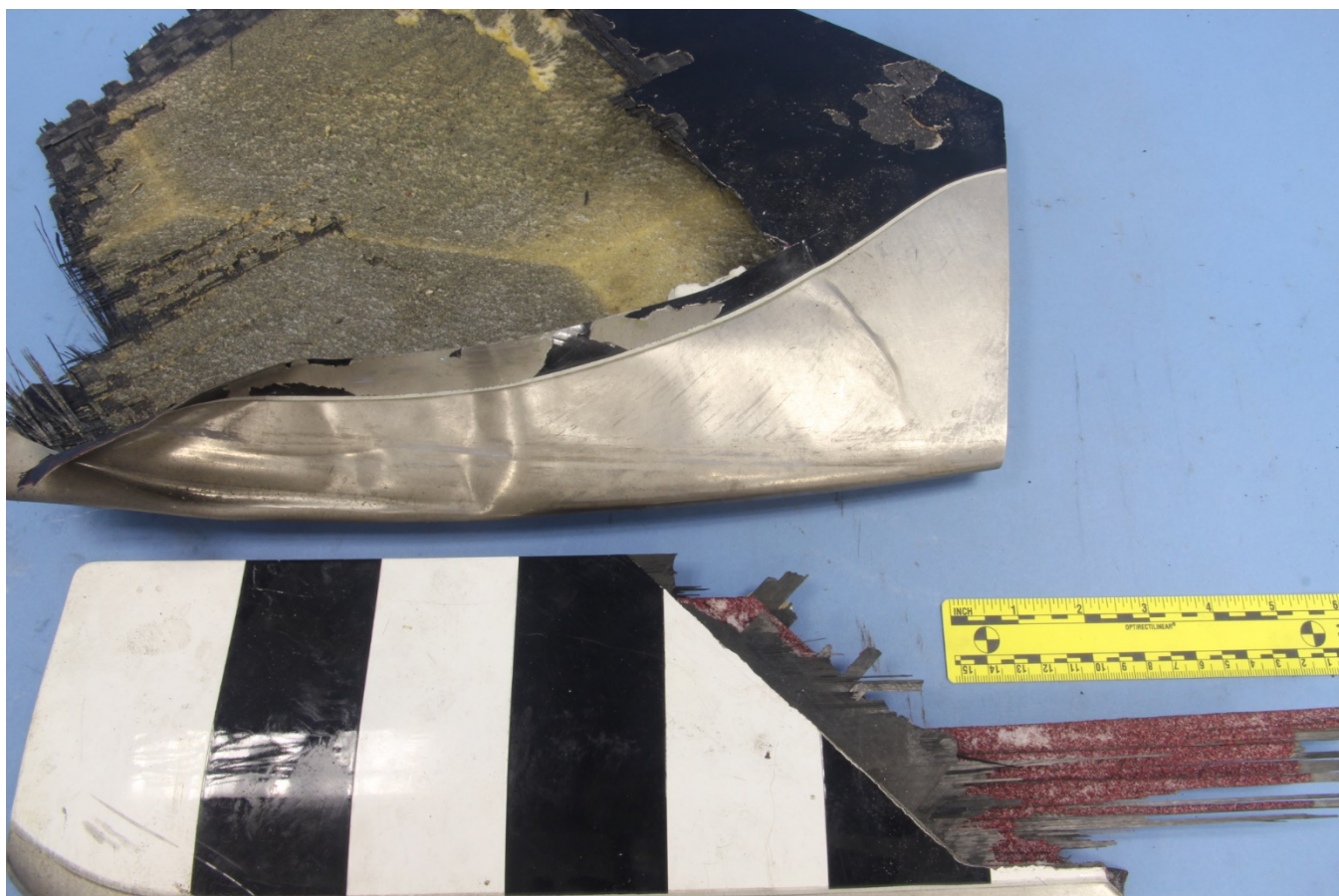


Figure 37 – View of the Blade B tip abrasion strip, showing corresponding black and white paint transfer consistent with the widths of the paint pattern of the below tail rotor blade fragment.

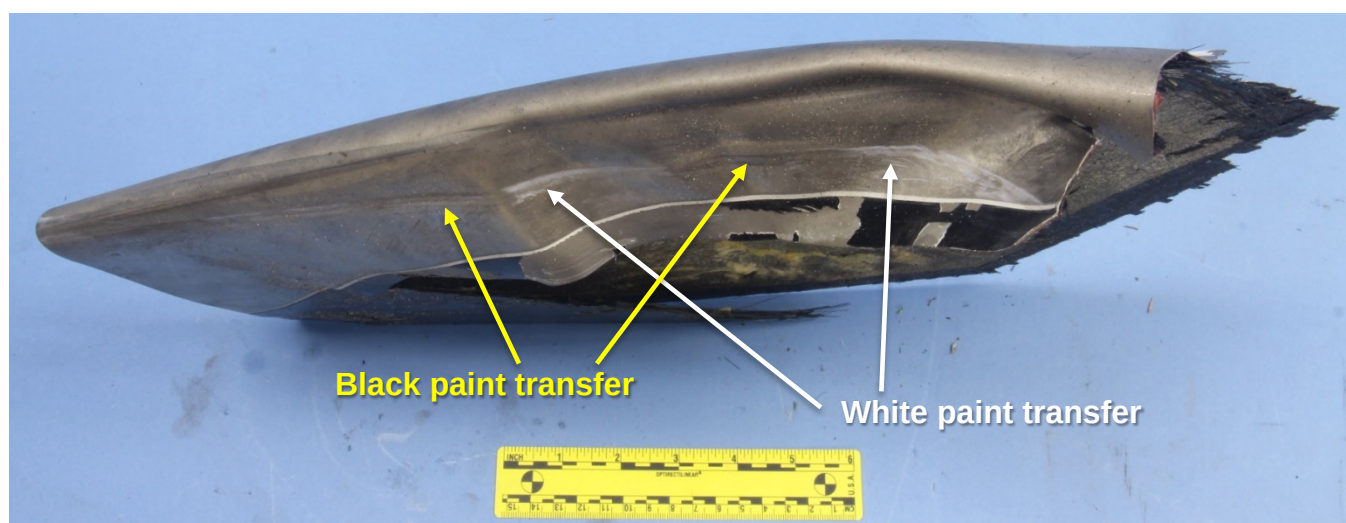


Figure 38 – View of the leading edge of the Blade B tip abrasion strip, showing impact on the lower side and alternating white and black paint transfer, as demonstrated in Figure 37.



Figure 39 – Top view of the blade A tip abrasion strip remnant.

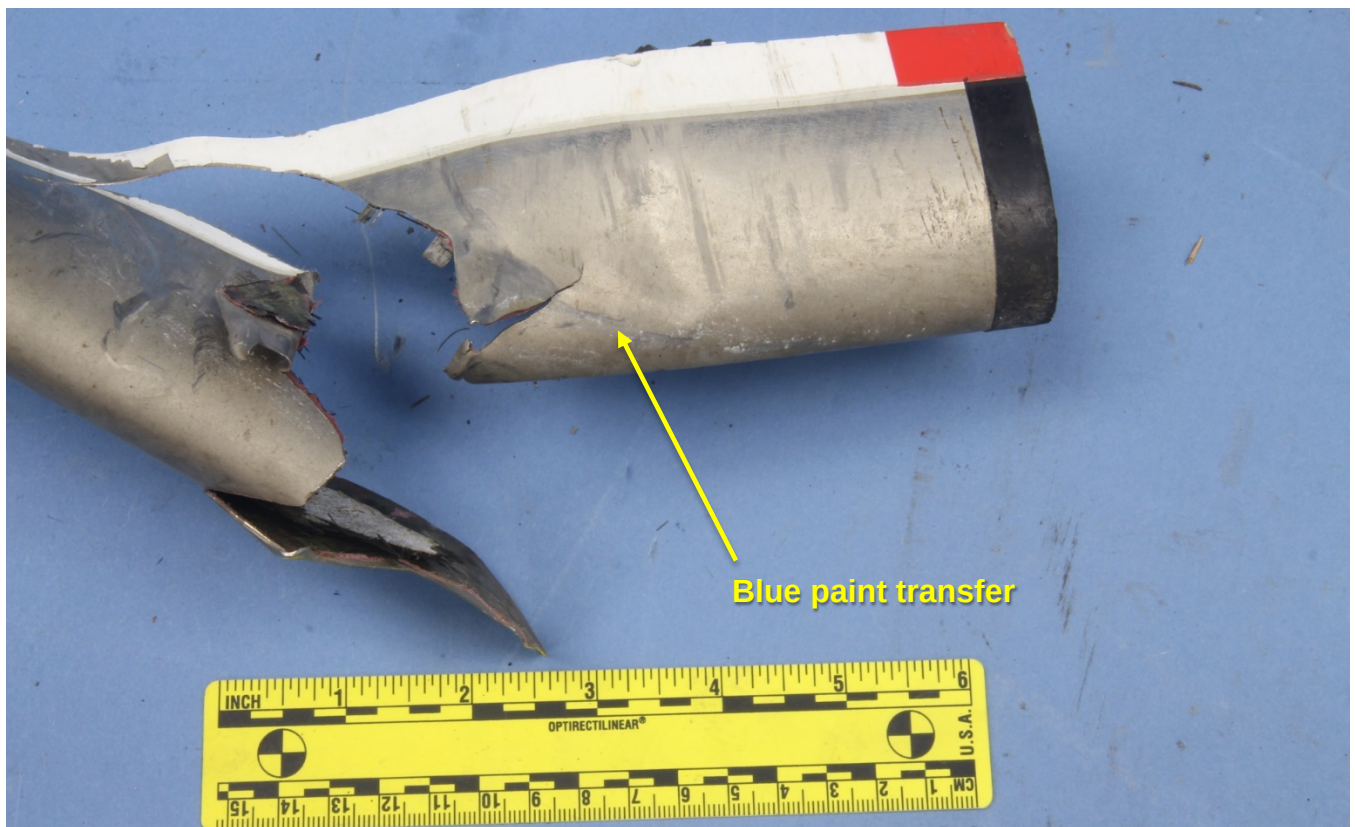


Figure 40 – View of the fracture/tear on the Blade A tip abrasion strip, showing blue paint transfer at the fractured indent.



Figure 41 – Components from the collar set assembly and lever assembly, after removing from the rotor.

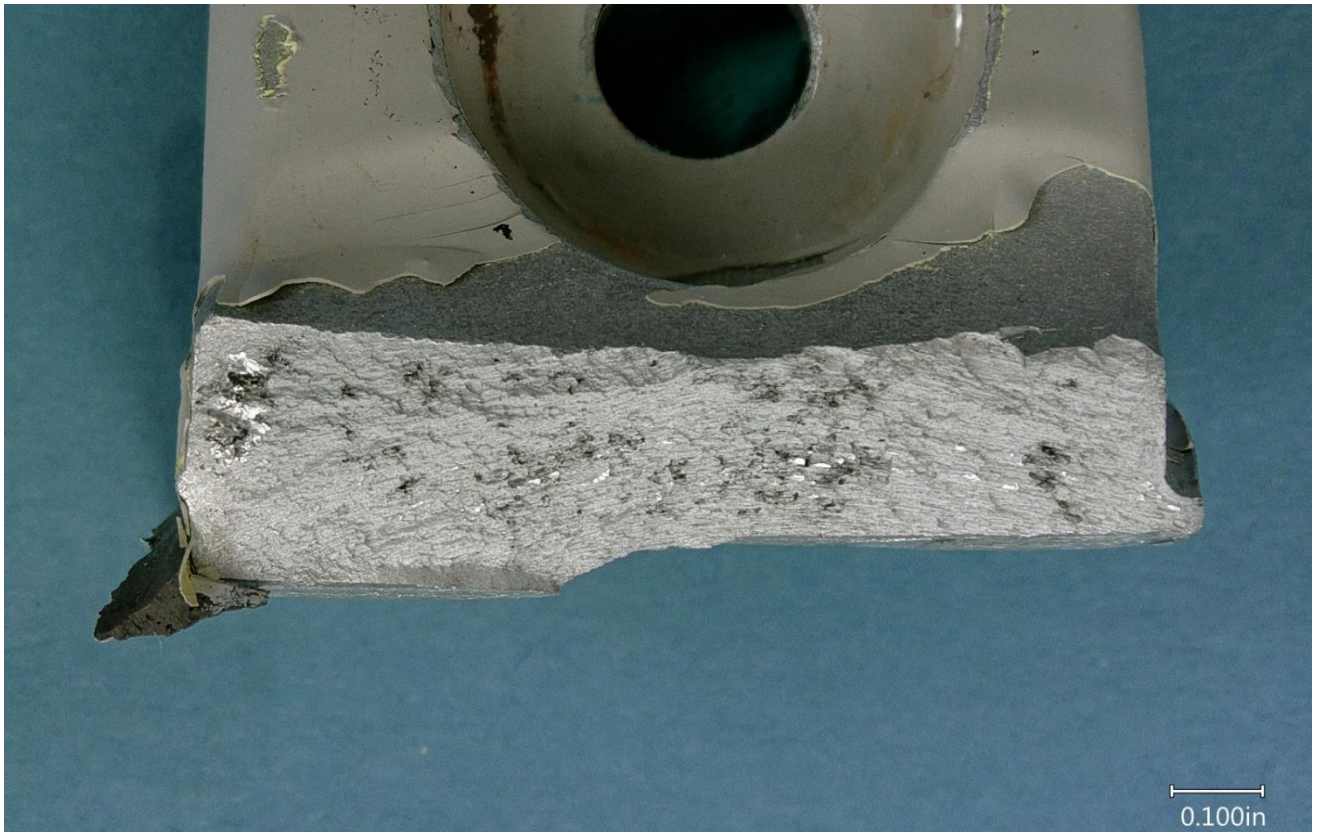


Figure 42 – Closer view of the collar fracture surface, showing river patterns and paint spall.