

NATIONAL TRANSPORTATION SAFETY BOARD

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



December 16, 2019

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-074

1. ACCIDENT INFORMATION

Place : Covington, Tennessee
Date : September 1, 2018
Vehicle : JetEZ Experimental, N815EY
NTSB No. : ERA18FA240
Investigator : Adam Gerhardt, AS-ERA

2. COMPONENTS EXAMINED

Sections of left-wing upper wing skin
Pieces of left-wing upper wing spar

3. DETAILS OF THE EXAMINATION

On September 1, 2018, about 1720 central daylight time, an experimental amateur-built JetEZ was destroyed when it experienced an in-flight breakup and impacted terrain while maneuvering at low altitude near Covington Municipal Airport, Covington, TN. The airline transport pilot was fatally injured. According to FAA airworthiness records, the airplane was a two-seat original design composite, canard style airplane, manufactured by the pilot. The airplane was designed with blended composite winglets that were integral to a C-channel wing spar.

According to a one of the accident witnesses, after the airplane flew over the airport, he noticed a "wave like movement" or "wiggle" in the left wing and then the "left wing failed at mid-span." The wreckage was recovered and retained for further examination by the NTSB, and sections of the upper spar cap and upper wing skin from the left wing were sent to the NTSB Materials Laboratory for examination.

Figure 1 shows the components received from the left wing by the Materials Laboratory, viewed from below looking upward as re-assembled to show the relative positions of the pieces prior to the accident. The components received included three spar cap sections, two sections of excised out upper wing skin, and three tattered plies of wing skin from just below the outermost skin. Several of the received components had been marked after the accident. Based on the markings, the components in this report will be referred to as the following (and are shown in Figure 2 through Figure 10):

- Upper Spar cap sections
 - Outboard spar cap – No 1 spar cap section
 - Middle spar cap section – A/B spar cap section
 - Inboard spar cap section – C spar cap section
- Upper wing skin
 - Outboard wing skin – No 2 wing skin section
 - Inboard wing skin – A/B/C wing skin section
- Wing skin plies
 - Outboard ply – Ply fragment 5
 - Middle ply fragment – Ply fragment 4
 - Inboard ply fragment – Ply fragment 3

As demonstrated in Figure 1 through Figure 2, the two outer wing skin sections mated, the three wing skin plies mated with each other on the outboard region of the upper wing skin, and the upper spar cap upper surfaces mated with the skin along an approximately 3-inch wide strip shown in Figure 2. This strip was visible on Figure 2, Figure 4, Figure 6, and Figure 8 and exhibited a lighter yellow color in contrast to the darker color present on most of the rest of the lower facing surfaces of the spar and wing skin. This strip on the skin corresponded to where the three spar cap sections had been positioned and was consistent with a resin-starved or dry laminate. The mating upper faces of the spar cap sections exhibited the dark amber color, consistent with the cured resin used in the construction of the composite spar cap. These faces were generally smooth in texture with a faint imprinted pattern consistent with the mating unbalanced plain-weave fabric of the wing skin visible in Figure 9. These mating upper faces of the spar cap sections were absent loose or broken fiber remnants.

The three loose wing skin ply pieces (3, 4, and 5) were delaminated from the upper wing skin. Shown best in Figure 4, these separated skin plies were oriented at a 45° to the upper wing skin and spar cap. They had delaminated at the same ply layer on the upper and lower sides. In addition, these loose plies exhibited the same 3-inch strip on the lower surfaces corresponding to the position to which the spar cap section upper surfaces mated.

Of note was the condition of the three spar cap pieces. The upper surface of all three pieces exhibited a generally smooth surface with a dark yellow-brown color, consistent with cured epoxy resin. Figure 9 and Figure 11 show a closer view of a typical area of the upper surface of the spar cap pieces. In general, this surface was smooth, exhibiting an imprint of the mating 45° unbalanced plain-weave fabric of the upper wing skin and wing skin plies. As shown in Figure 12, there was no significant amount of fiber pullout or breakage on the upper spar cap upper surfaces.

In contrast, the lower surfaces of the inboard spar cap pieces exhibited a rougher appearance. The lower surfaces, as typified in Figure 13, exhibited fracture of fibers in both woven (warp and fill) directions. These sets of fibers had fractured in multiple, rather than just one, layer. In areas where fiber fracture occurred, the fiber lengths varied. Figure 14 shows a closer area with fracture of the matrix. In this figure, small hackles were visible

in the cured resin between parallel fibers. These fracture features were consistent with an angled translamellar fracture of the inboard spar sections.

Figure 15 shows one of the mating faces of the wing skin plies that faced the upper spar cap. As shown in the figure, the unbalanced plain weave of the glass fibers was visible, most of them absent of resin infiltration. Figure 15 shows several resin globules, present on the lower surface of the one of the plies that faced the upper spar cap upper surface. These resin globules, which exhibited a general bead shape, were consistent with a lack of wetting and impregnation of the fabric by the resin.

In contrast, the opposite side of this ply, which faced the upper wing skin, exhibited a flatter orientation of some of the resin. This face exhibited a higher degree of wetting/impregnation characteristics of the resin, as exemplified in the lower left of Figure 16. However, much of the fabric still exhibited areas with bare fibers, consistent with a lack of impregnation of the resin into the fabric.

These features on the 3-inch strip of the wing skins pieces and the upper surfaces of the upper spar cap sections were consistent with an adhesive disbond between the respective faying surfaces. Had the fracture been cohesive within the laminate structure, the features would be more consistent with the fracture on the lower surface of spar cap section C (shown in Figure 10). Had the fracture been cohesive within the adhesive bond between the upper surfaces of the upper spar cap and the wing skin pieces, there would be evidence of adhesive/resin remnants still adhered to both faying surfaces. This adhesive disbond was consistent with a lack of impregnation and interfacial interaction of the resin into and with the glass fiber fabric, creating a lack of strong adhesion between the wing skin and the spar cap. These issues were consistent with a fabrication problem at manufacturing of the layup, rather than an in-service or environmental degradation failure.

Figure 9 shows the upper surface of the spar cap segment C, and Figure 10 shows the lower surface. The upper surface of this spar segment exhibited the flatter, smoother surface present on the other spar segments. The lower surface exhibited a rougher texture and consisted of fiber fracture among multiple layers and fracture in the matrix resin. The general orientation of the lower surface of spar cap segment C was angled downward from inboard to outboard (i.e., cross sectional thickness of the submitted fragment increased from inboard to outboard). Adjacent the fracture surface on the upper side was a rectangular-shaped area that was inconsistent with the smooth upper surface. This area was consistent with localized delamination and pullout of an individual ply.

Figure 17 shows the inboard surface of spar cap section A/B. This surface was flat, consistent with having been cut or sectioned after the accident. The surface exhibited several cracks internal to the spar segment, oriented along the length of the spar. Figure 18 shows this same spar segment A/B inboard surface, but with the mating outboard cut surface of spar cap section C in place. The lower surface of the C segment, which had fractured, was consistent with the internal cracking present on the inboard side of segment

A/B. Therefore, the internal cracking on segment A/B was consistent with a continuation of the fracture of spar cap segment C.

Examination of the spar cap segment C fracture surface found two general features. All along the fracture surface was fiber fracture. The fiber fracture near the upper surface was generally flat and the fibers were located close to the fracture surface (Figure 19). The fibers on the lower surface exhibited longer lengths away from the fracture surface, which were typically varied in length (Figure 20). These features were consistent with fiber pullout on the lower surface and fiber crushing or shearing on the upper surface. This fiber fracture pattern, along with the upper surface local delamination, were consistent with fracture of the spar cap section in upwards bending.

Figure 21 and Figure 22 show the upper (outer) surface of the inboard upper wing skin section. This surface still had the outer paint of the airplane adhered, which had cracked. In general, these cracks branched as one moved outboard from the inboard fracture. This branching orientation was consistent with crack propagation in the paint from the inboard fracture of the skin. Figure 22 shows a closer view of the inboard fracture surface of the skin section. For the most part, the paint was absent approximately 0.5 inches from the underlying composite fracture, which exhibited fiber pullout on the lower surface. This absence of paint was consistent with local paint peeling away from the outer skin surface. This fracture pattern was analogous to that of the C spar cap section, shown in Figure 18 and Figure 19. These features were all consistent with a bending fracture upward of this area of the wing, with the compressive stress side on the upper surface of the wing.

Specimens of the fiber weave cloth from ply 4, the upper surface of spar cap section C, and resin on the side of spar cap section A/B were examined using a Fourier Transform Infrared (FTIR) spectrometer with a diamond attenuated total reflectance (ATR) accessory in accordance with ASTM E1252-98.¹

The fiber cloth had a yellow rigid residue attached to areas on one side. A spectrum of the resin-free side and a spectrum of the one of the areas with residue present were collected. The spectrum for the resin-free side of the fiber cloth contained only one significant peak: a broad peak at $\sim 1100\text{ cm}^{-1}$, indicative of a silicon-oxygen (Si-O) bond. This was consistent with presence of silicon oxides such as those found in silica glass and glass fibers.

The spectrum for the residue on the fiber mat and the spectrum taken of the spar cap shared matching spectra indicating that both samples were the same material. Both spectra contained the following combination of spectral peaks corresponding to particular functional groups found within the molecular structure of the material:

- The presence of a low broad peak between $\sim 3300\text{ cm}^{-1}$, indicative of an oxygen-hydrogen (O-H) functional group.

¹ ASTM E1252-98 – *Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis*. ASTM International, West Conshohocken, PA.

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- The presence of a strong doublet peak between $\sim 2960\text{ cm}^{-1}$ and $\sim 2930\text{ cm}^{-1}$, indicative of a carbon-hydrogen (C-H) single stretching bond.
 - The presence of a doublet peak at $\sim 1675\text{ cm}^{-1}$ and $\sim 1675\text{ cm}^{-1}$, indicative of double bonded carbon (C=C) stretching bond (aromatic).
 - The presence of a single peak $\sim 1500\text{ cm}^{-1}$, indicative of a carbon-carbon (C-C) bending bond (aromatic).
 - The presence of a single peak $\sim 1450\text{ cm}^{-1}$, indicative of a carbon-hydrogen₃ (C-H₃) asymmetric stretching bond.
 - The presence of a single peak $\sim 1360\text{ cm}^{-1}$, indicative of a carbon-hydrogen₃ (C-H₃) symmetric stretching bond.
 - The presence of a single peak $\sim 1230\text{ cm}^{-1}$, indicative of a carbon-carbon-oxygen-carbon (C-C(O)-C) (ether) stretching bond.
 - The presence of a single peak $\sim 1170\text{ cm}^{-1}$, indicative of a carbon-oxygen (C-O) aromatic stretching bond.
 - The presence of a doublet peak at $\sim 1100\text{ cm}^{-1}$ and $\sim 1030\text{ cm}^{-1}$, indicative of a carbon-oxygen-carbon (C-O-C) stretching bond.
 - The presence of a single peak $\sim 820\text{ cm}^{-1}$, indicative of a carbon-hydrogen₃ (C-H₃) bending bond.

This combination of functional groups was consistent with an epoxide. A spectral library search was performed using the spectrum from the residue on the fiber mat. The search found a very strong match to several commercial epoxy resin formulations.

The spectrum for an additional unknown resin on the side of spar cap section A/B contained the following combination of spectral peaks corresponding to particular functional groups found within molecular structure of the material:

- The presence of a doublet peak at $\sim 3080\text{ cm}^{-1}$ and $\sim 3050\text{ cm}^{-1}$, indicative of a carbon-hydrogen functional group double bonded (stretching) to another molecule ($=\text{C-H}$) (alkene).
- The presence of a strong doublet peak between $\sim 2920\text{ cm}^{-1}$ and $\sim 2850\text{ cm}^{-1}$, indicative of a carbon-hydrogen (C-H) single stretching bond.
- The presence of multiple peaks at $\sim 1600\text{ cm}^{-1}$, $\sim 1490\text{ cm}^{-1}$, and $\sim 1450\text{ cm}^{-1}$, indicative of a carbon-carbon double (C=C) stretching bond (aromatic).
- The presence of a single peak $\sim 1020\text{ cm}^{-1}$, indicative of a carbon-hydrogen (C-H) (alkene) bending bond.
- The presence of a single peak $\sim 750\text{ cm}^{-1}$, indicative of a carbon-hydrogen₂ (C-H₂) bending bond.

This combination of functional groups is consistent with an epoxide. In addition, an additional single peak at $\sim 690\text{ cm}^{-1}$ was found, which was indicative of a carbon-hydrogen functional group double bonded (bending) to another molecule ($=\text{C-H}$), or alkene. A spectral library search performed on this spectrum found a very strong match to styrene/butadiene copolymer.

Erik M Mueller
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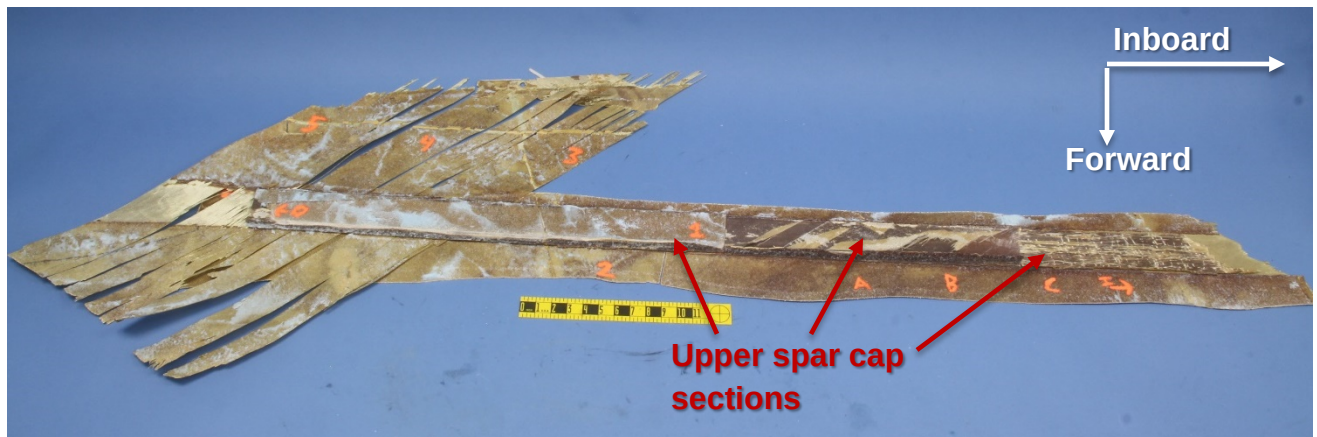


Figure 1 – The sections of the upper wing skin and spar cap from the left wing, reconstructed in their relative positions prior to the accident.

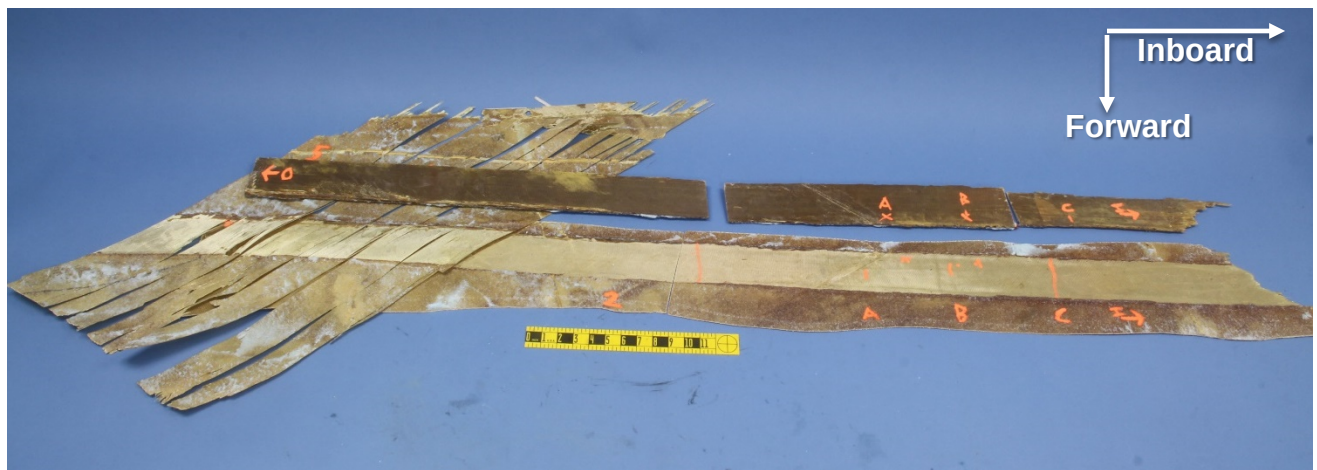


Figure 2 – The section of the wing skin and the upper spar cap sections from Figure 1, with the cap sections inverted and removed from their position on the wing skin.

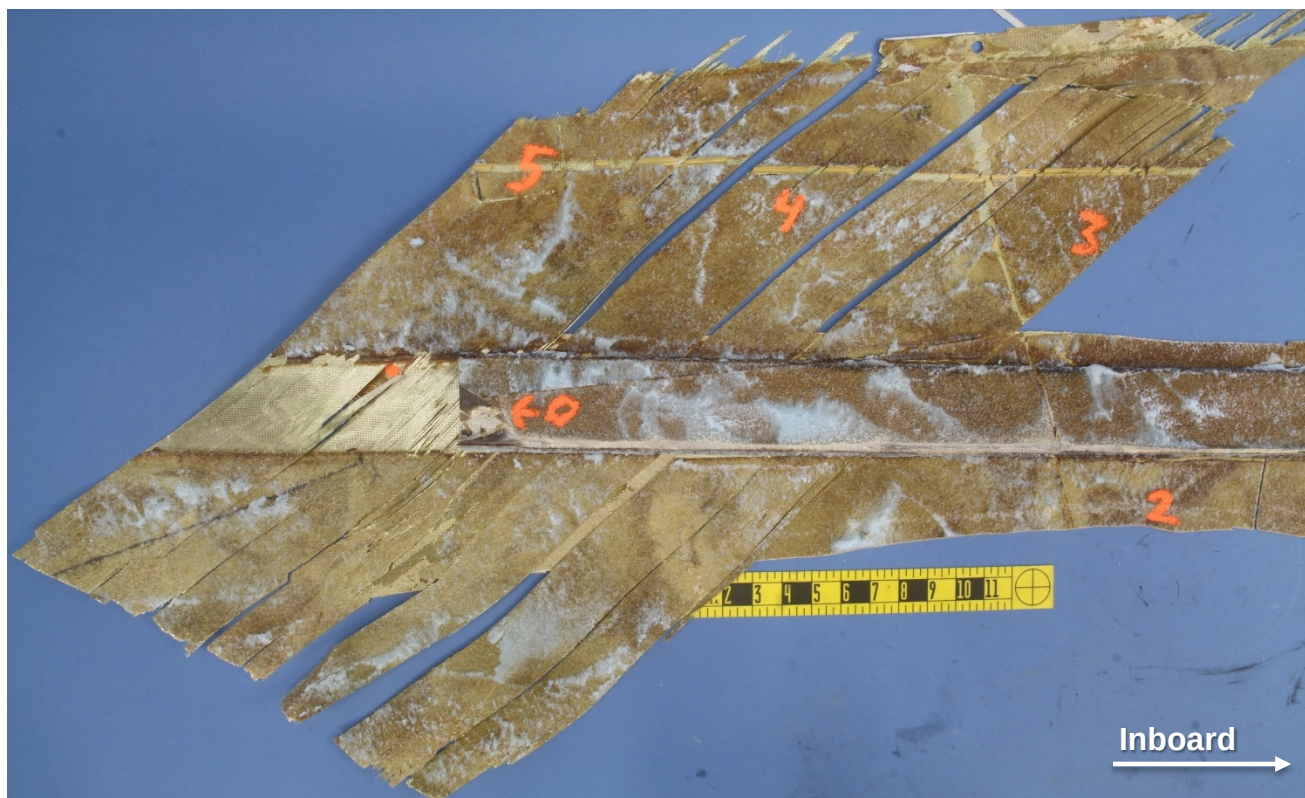


Figure 3 – View of the outboard side of the spar cap and wing skin pieces, reassembled.

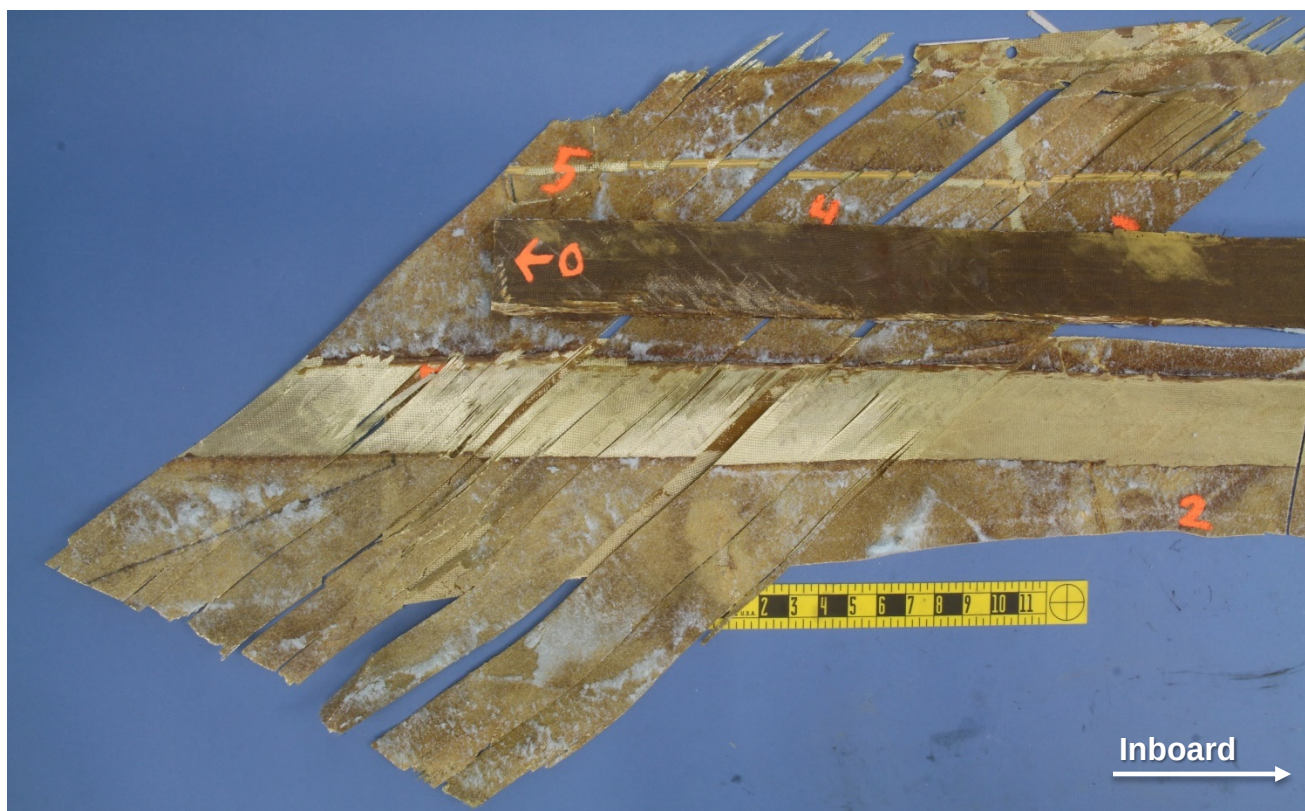


Figure 4 – View of Figure 3, with the spar cap segment removed and inverted in place.

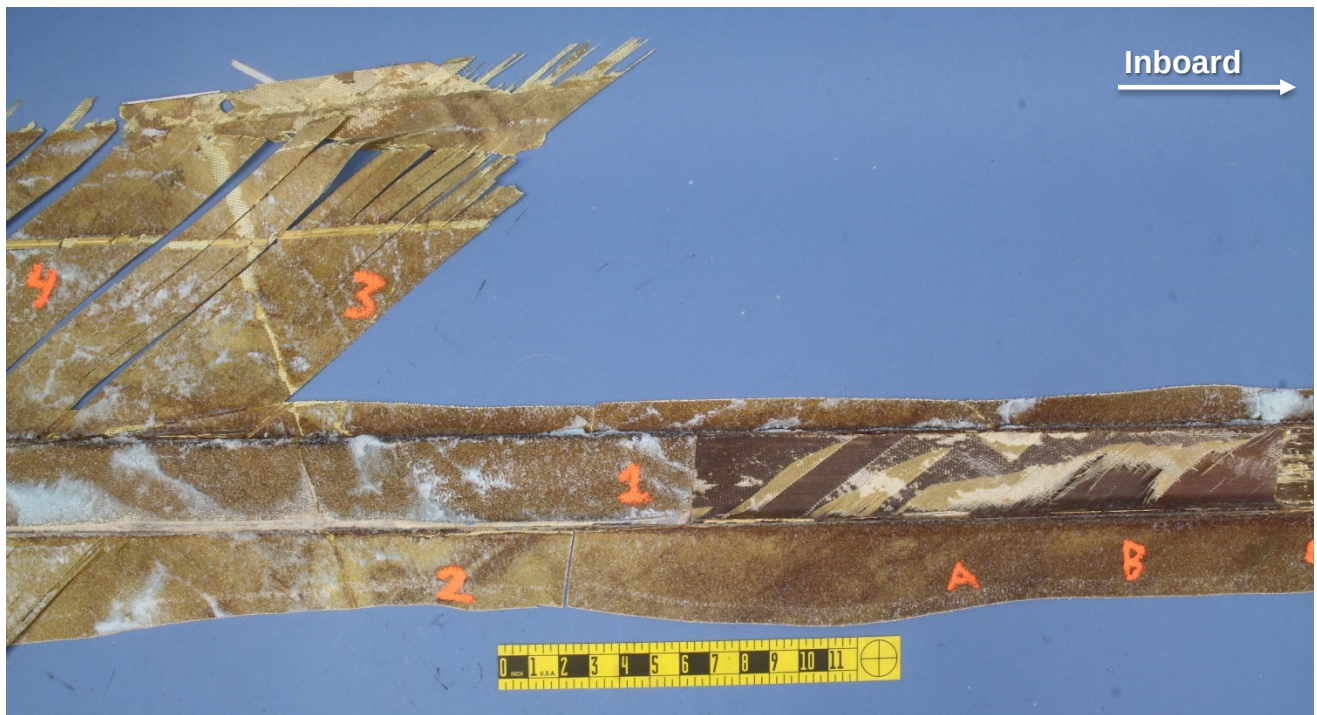


Figure 5 – View inboard of Figure 3, showing the cap segments and wing skin remnants.

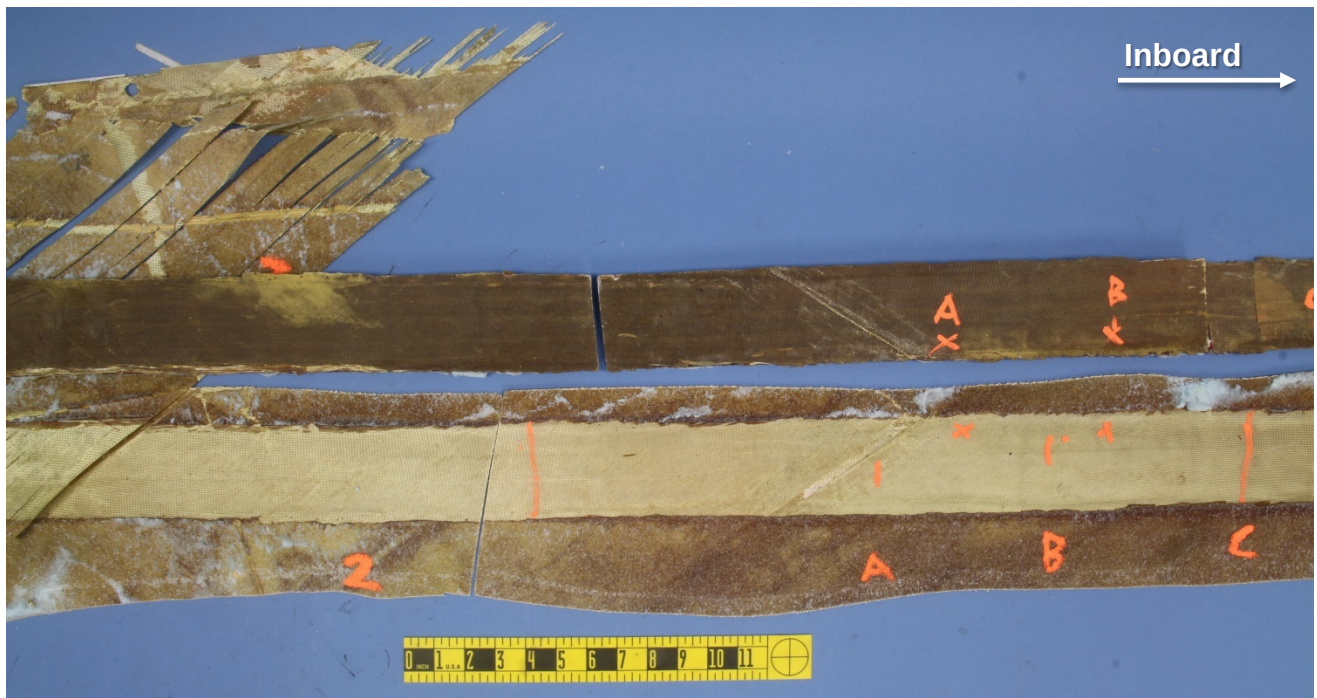


Figure 6 – View inboard of Figure 4, showing the cap segments and wing skin remnants.



Figure 7 – The inboardmost area of the spar cap and wing skin segments, reassembled.



Figure 8 – View of Figure 7, with the spar cap segment removed and inverted in place.



Figure 9 – The upper surface of spar cap segment C.

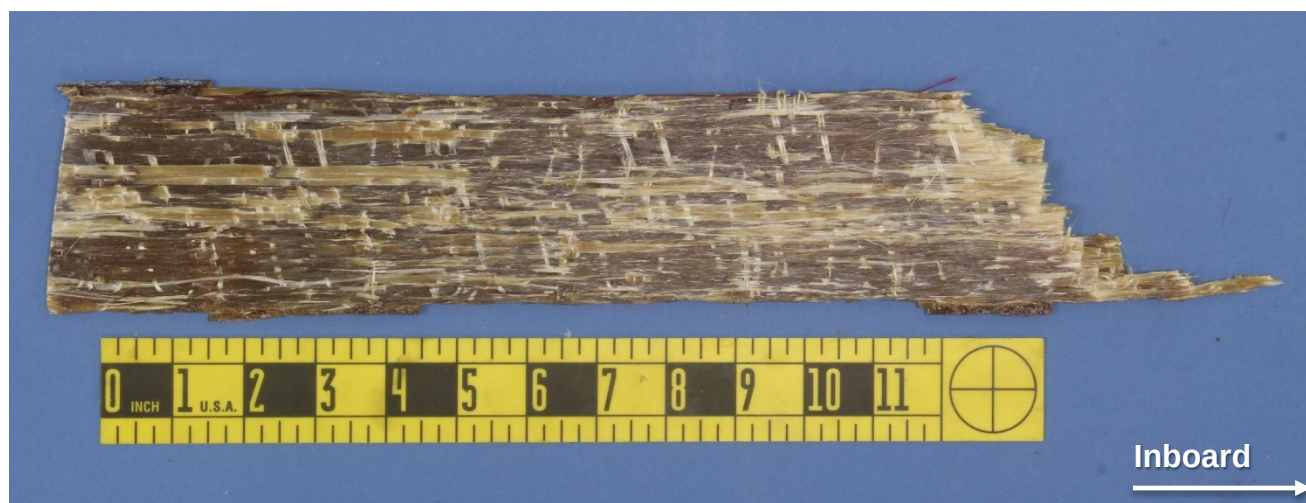


Figure 10 – The lower side of the spar cap segment C, showing intra-component fracture.

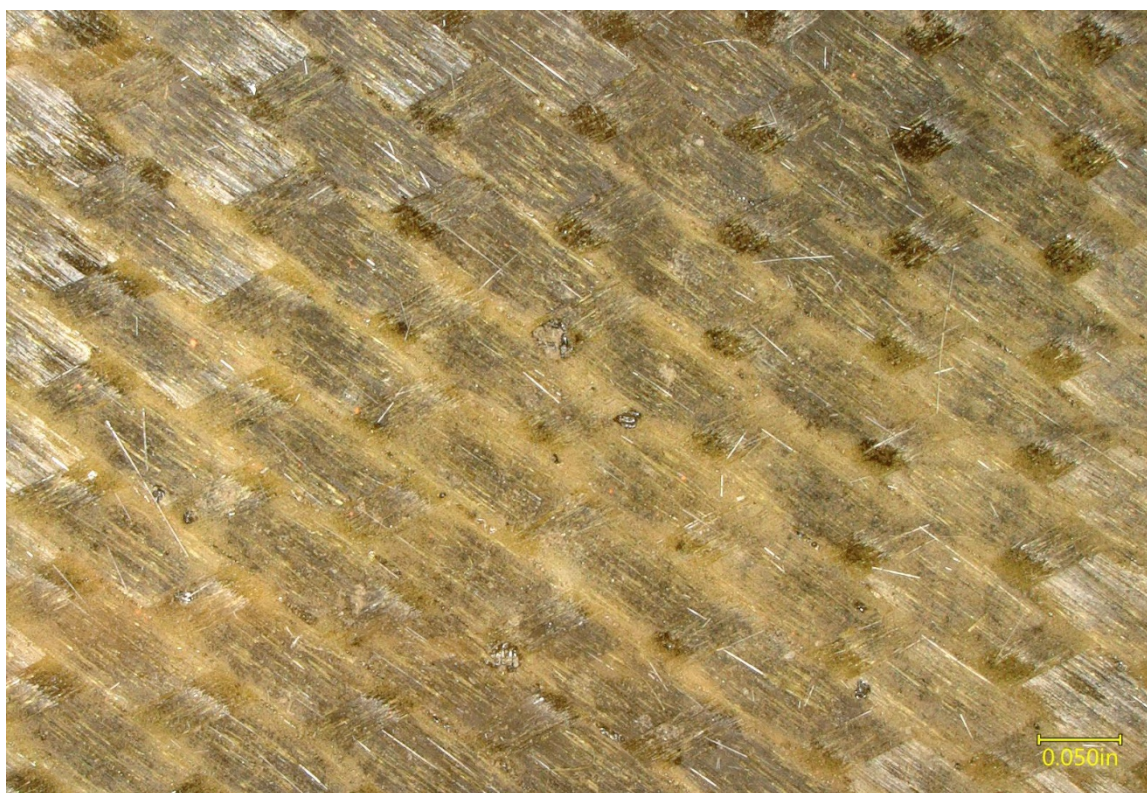


Figure 11 – Spar cap section C upper face, showing a flat surface with the underlying woven structure of the spar cap composite.

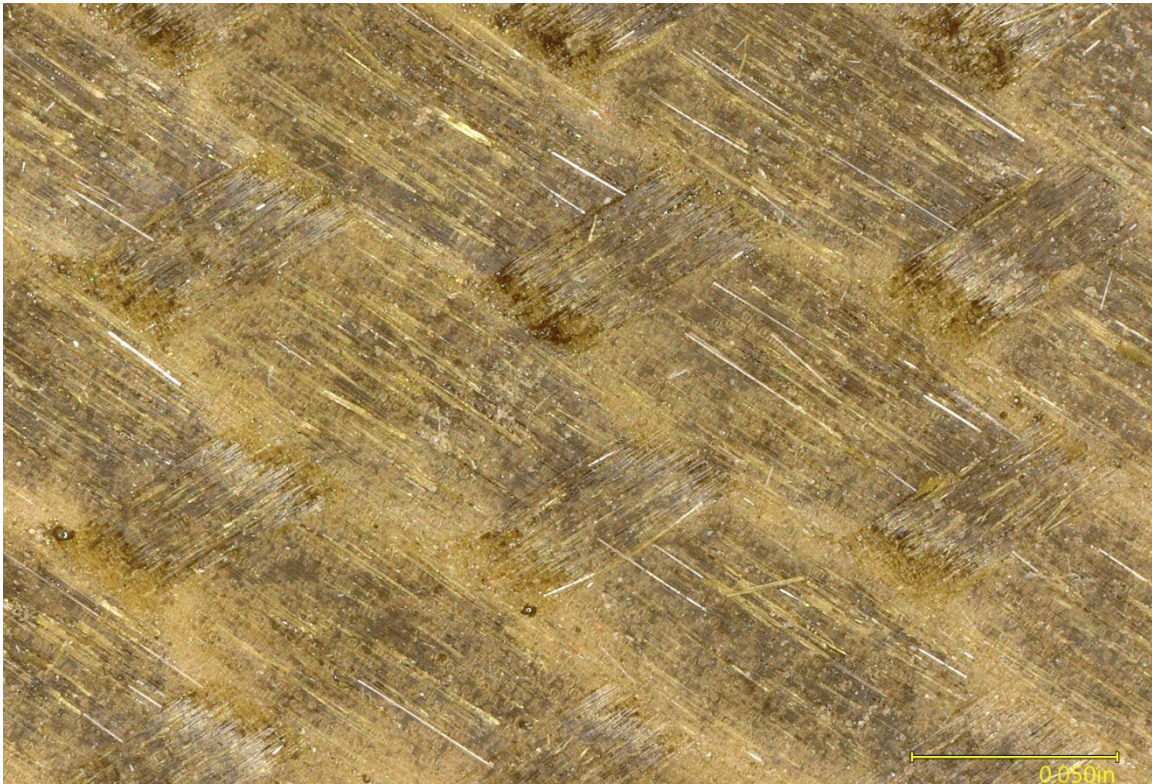


Figure 12 – Closer view of the spar cap section C surface in Figure 11.



Figure 13 – Spar cap section C lower surface face, fractured fibers and resin fracture features.

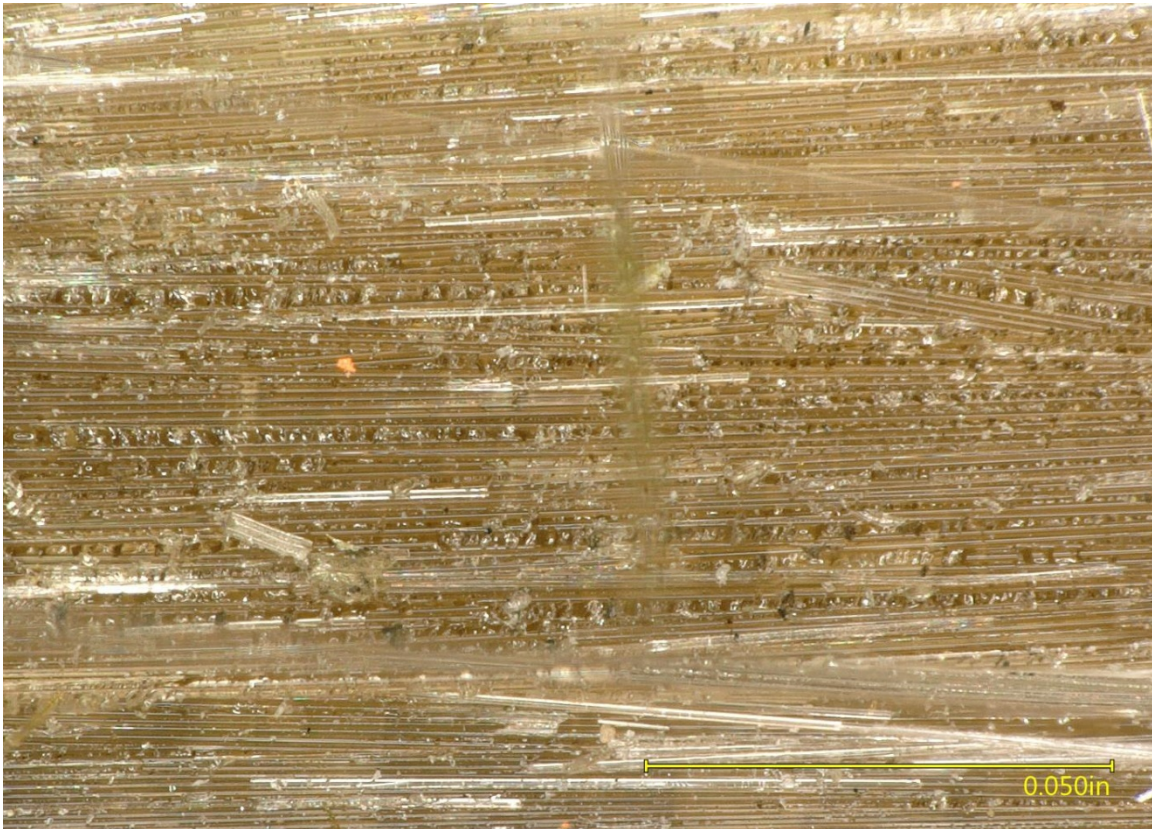


Figure 14 – Closer view of the spar cap section C lower surface, showing hackles and matrix fracture between fibers.

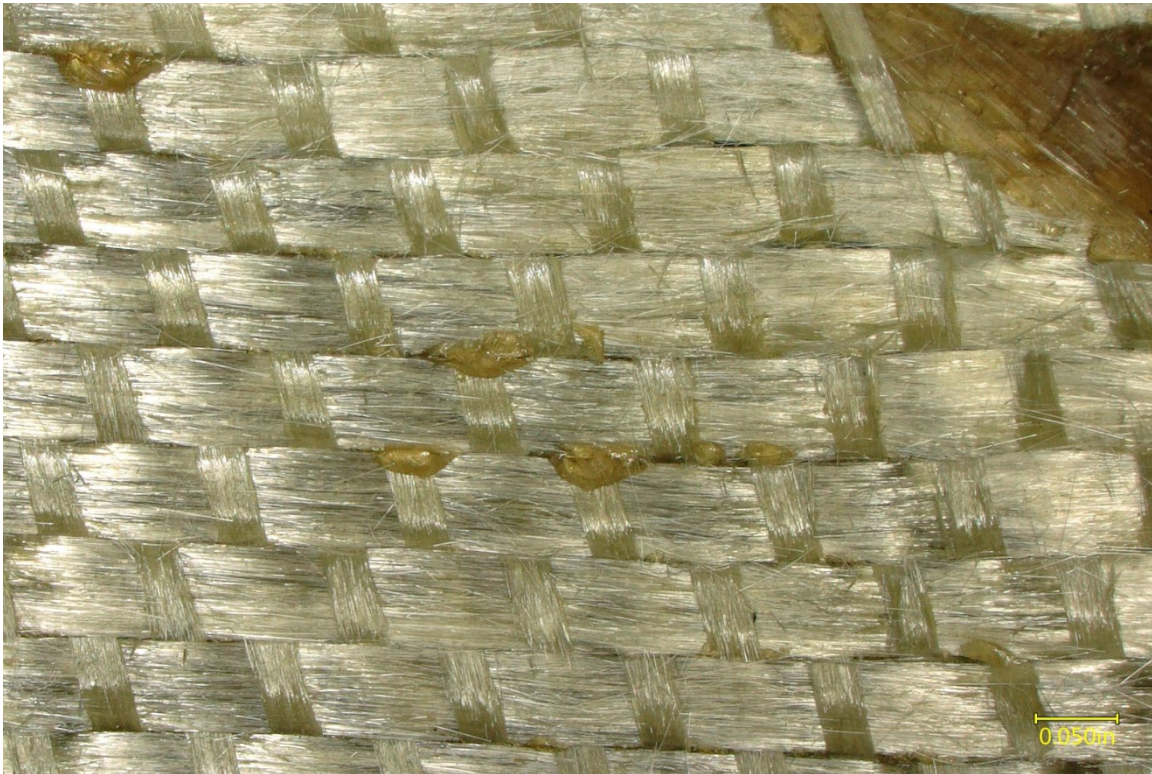


Figure 15 – The lower surface of loose ply 5 at the spar cap location, showing “dry fiber” weave and globules of resin between the weave gaps.

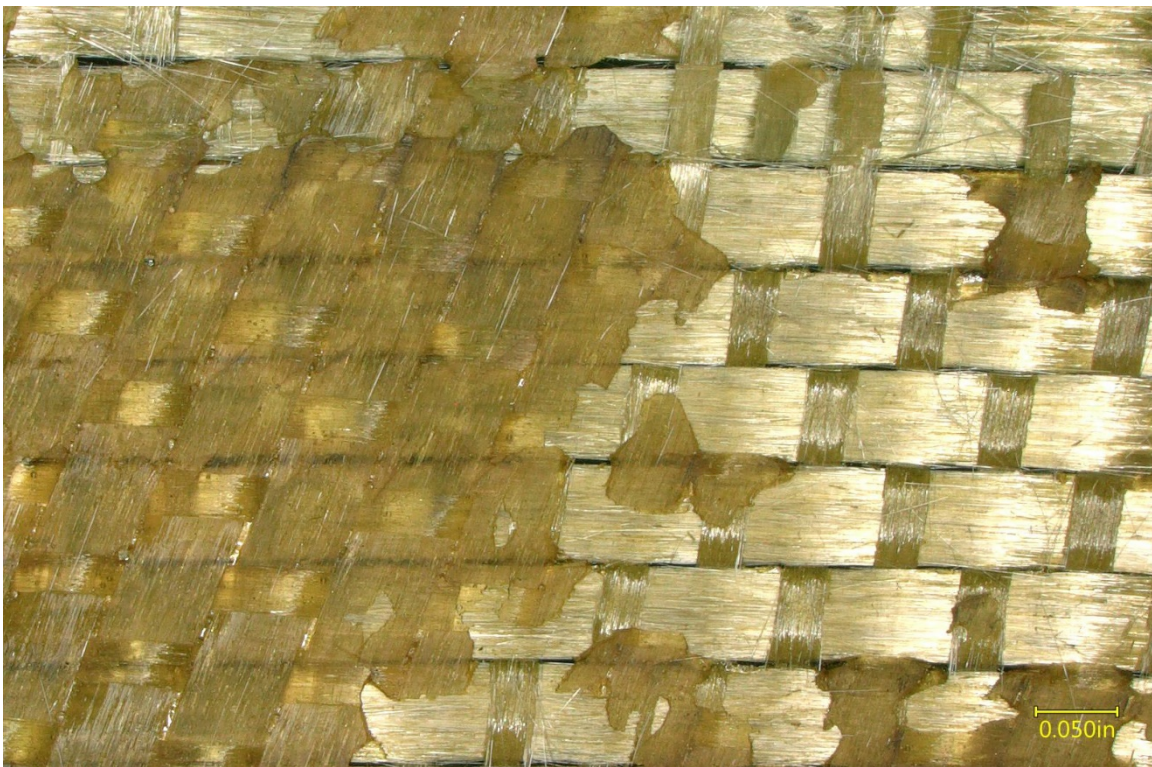


Figure 16 – Lower face of the ply 5, showing resin fracture away from the spar cap location.



Figure 17 – The A/B section of the upper spar cap, looking outboard at the inboard section.



Figure 18 – The A/B section of the upper spar cap, looking outboard with the inboard C section positioned to show the locations of the internal cracks and lower fracture surface.

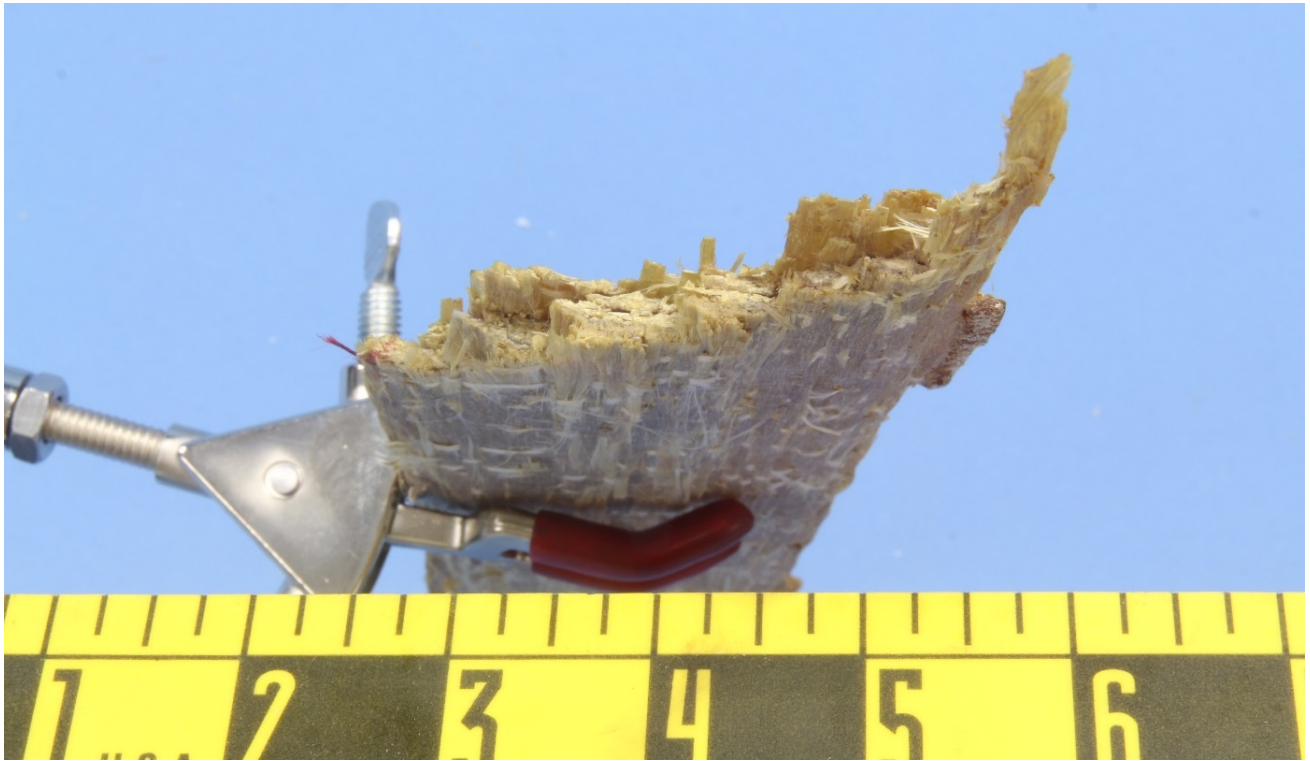


Figure 19 – Angled view of the underside of the inboard fracture of the spar cap C segment.

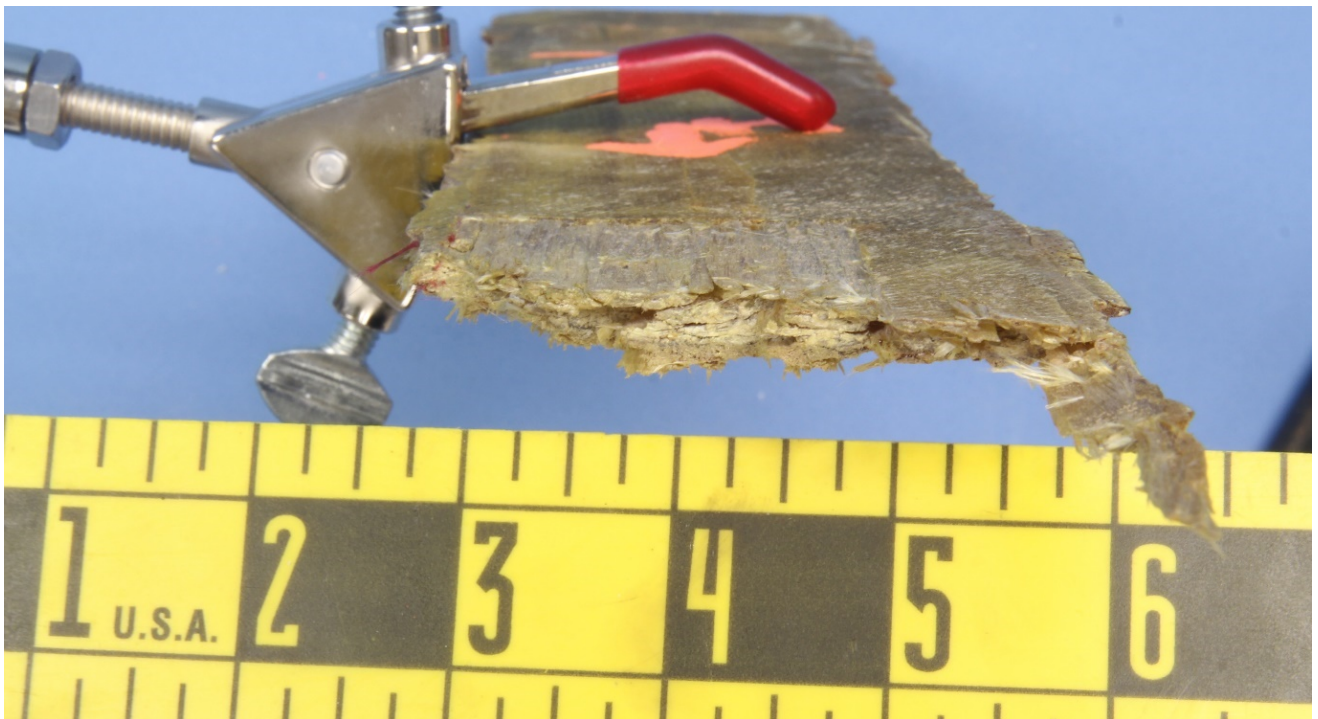


Figure 20 – Angled view of the upper face of the inboard fracture of the spar cap C segment.

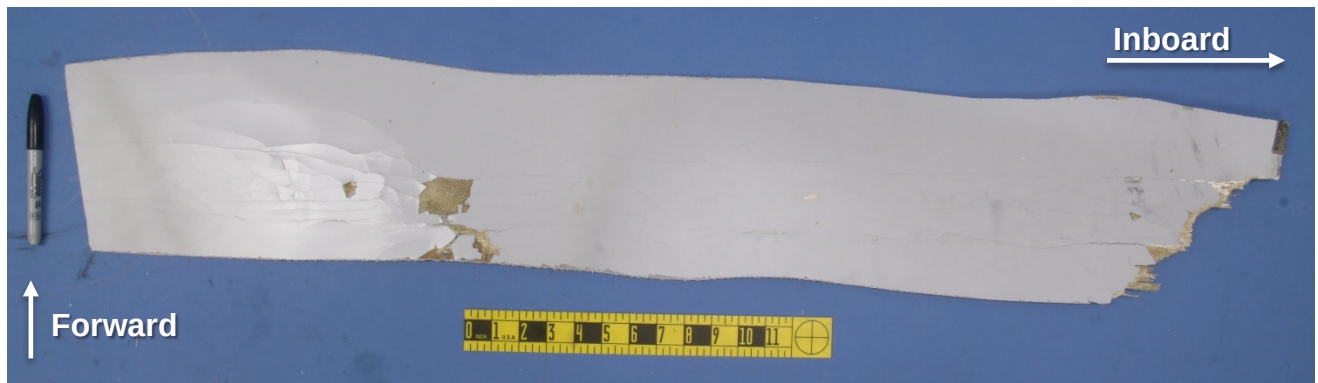


Figure 21 – The upper surface of the inboard left wing skin, as received.



Figure 22 – Closer view of the inboard area of the wing skin section in Figure 21, showing paint cracking and absence adjacent to the fracture.