NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

March 14, 2022

Group Chairman's Factual Report

AIRWORTHINESS

DCA21FA085

Appendix A – Boeing EQA Report AS13328
(203 pages)

Equipment Quality Analysis Report

Boeing Commercial Airplanes

TO: Air Safety Investigations (ASI)

EQA NUMBER:	**13328**
DATE:	January 20, 2022
MODEL NUMBER:	**777-200**
AIRPLANE NUMBER:	**N772UA, WA005, Serial Number 26930**

SUBJECT: ***Right Engine Fan Blade Out and Inlet/Fan Cowl Departure – Examination of recovered Inlet Cowl, Fan Cowls, and Thrust Reversers***

IDENTIFICATION:

Part name:	Inboard Thrust Reverser (left)
Boeing part number:	315W3001-3AA
Serial number:	000002
Supplier:	Boeing
Part name:	Outboard Thrust Reverser (right)
Boeing part number:	315W3001-4AA
Serial number:	000002
Supplier:	Boeing
Part name:	Inlet Cowl
Boeing part number:	3143080-12
Serial number:	000190
Supplier:	Boeing
Part name:	Fan Cowl Inboard (left)
Boeing part number:	314W3110-45
Serial number:	000002
Supplier:	Boeing
Part name:	Fan Cowl Outboard (right)
Boeing part number:	314W3110-4AA
Serial number:	000002
Supplier:	Boeing

Part name:	Fan Cowl Support Beam
Boeing part number:	314W3310-2AA
Serial number:	000010
Supplier:	Boeing

Part name:	Door Assembly, Center Latch Access
Boeing part number:	315W3429-9
Serial number:	Unknown
Supplier:	Boeing

REFERENCES: (a) National Transportation Safety Board (NTSB) I.D. DCA21FA085.

BACKGROUND:

As reported in the reference (a) NTSB case number, on Feb 20, 2021, a United Airlines (UAL) 777-200, variable number WA005, experienced a fan blade out (FBO) engine failure of the right engine while on climb out from Denver International Airport (DEN).

Under direction of the US National Transportation Safety Board (NTSB), Boeing Air Safety Investigation (ASI) requested Boeing Equipment Quality Analysis (EQA) to facilitate the visual examination and damage documentation of engine nacelle structure and components recovered from the airplane and from various locations on the ground near DEN.

Airplane WA005 was delivered on September 29, 1995, and was reported to have accumulated approximately 96,975 hours and 17,784 cycles at the time of the engine failure.

SUMMARY:

EQA completed photo-documentation and reconstruction of the engine nacelle structure and components as authorized by the NTSB through Boeing ASI.

Boeing Research and Technology (BR&T) performed material, metallurgical and thermographic analysis of materials related to the event as requested by the NTSB Airworthiness Group.

All details of the examination were shared with the investigative team.

EXAMINATION:

Five crates were shipped to a Boeing facility near Seattle, WA. Examination of the supplied parts commenced on March 11, 2021 under direction of the NTSB Airworthiness Group.

Photo documentation in this report shows reconstruction and examination of the supplied parts using a positional reference of aft looking forward with 12:00 at the top and 6:00 at the bottom, as seen in Figure 1.

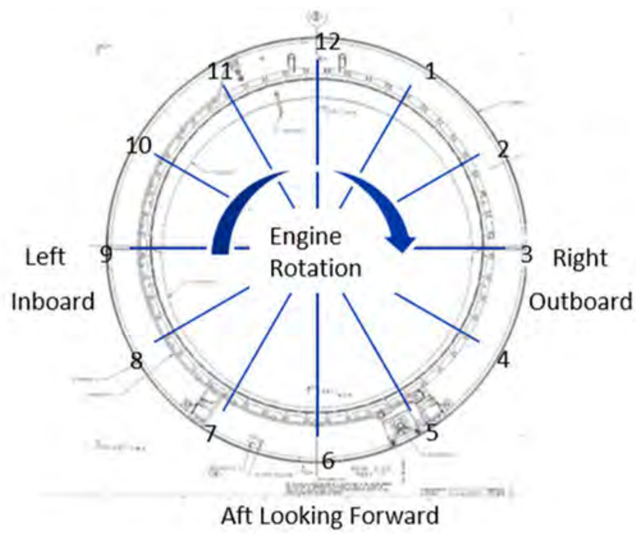


Figure 1: Positional reference

Throughout the report, the following symbols are used:

Denotes location of embedded fragments removed for examination.

Denotes location of chemical or material sampling.

Boeing Research and Technology (BR&T) Analytical Chemistry completed material analysis of areas of interest. The NTSB Airworthiness Group identified areas for material analysis. The marked areas identify the collection location of the corresponding samples in the attached BR&T report, Enclosure A.

Denotes location of metallurgical fracture sampling.

BR&T Fracture Analysis completed analysis of fracture areas of interest on thrust reverser components as determined by the NTSB Airworthiness Group. The marked areas in the images correspond to the samples in the attached BR&T report, Enclosure B.

Denotes location of thermography test results.

EXAMINATION, INLET COWL:

Inlet cowl parts and fragments were received in three crates as seen in Figure 2, Figure 3, Figure 4, and Figure 5.

Figure 2: Inlet cowl crate as arrived at Boeing.

Figure 3: Inlet cowl crate and (2) crates containing various parts upon arrival at Boeing.

Figure 4: Parts as arrived at Boeing.

Figure 5: Parts as arrived at Boeing.

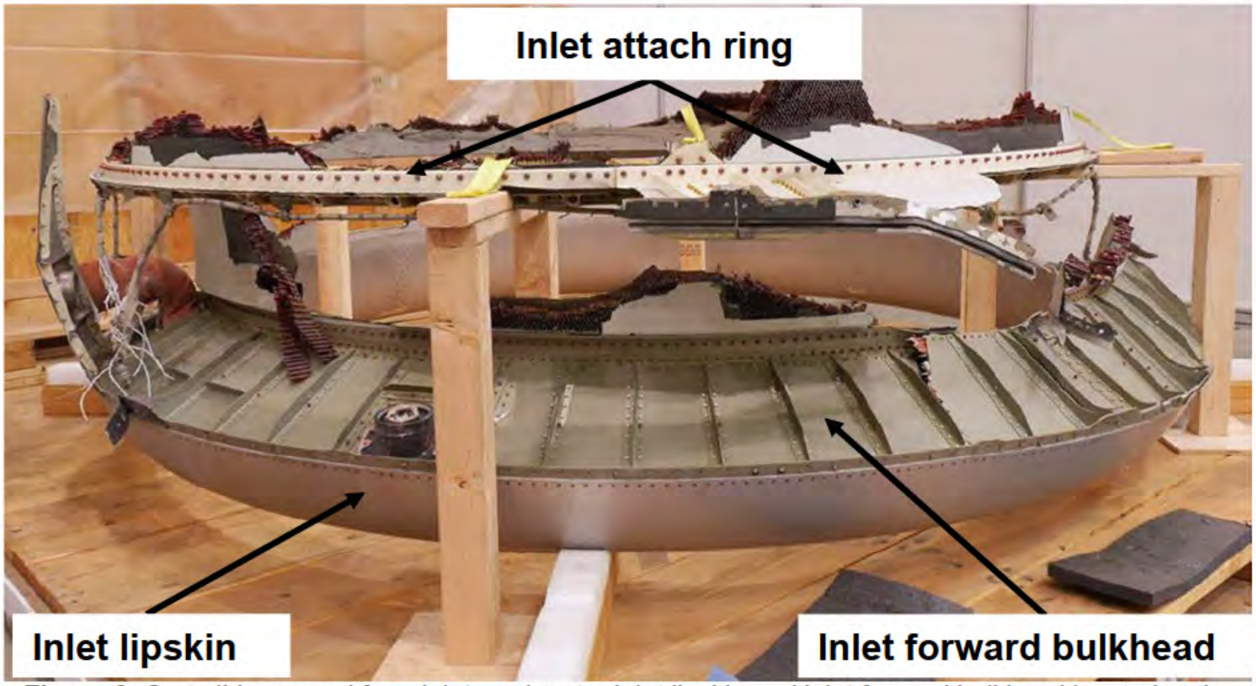


Figure 6: Crate lid removed from inlet cowl crate. Inlet lipskin and inlet forward bulkhead located at the bottom of the pallet with inlet attach ring supported above.

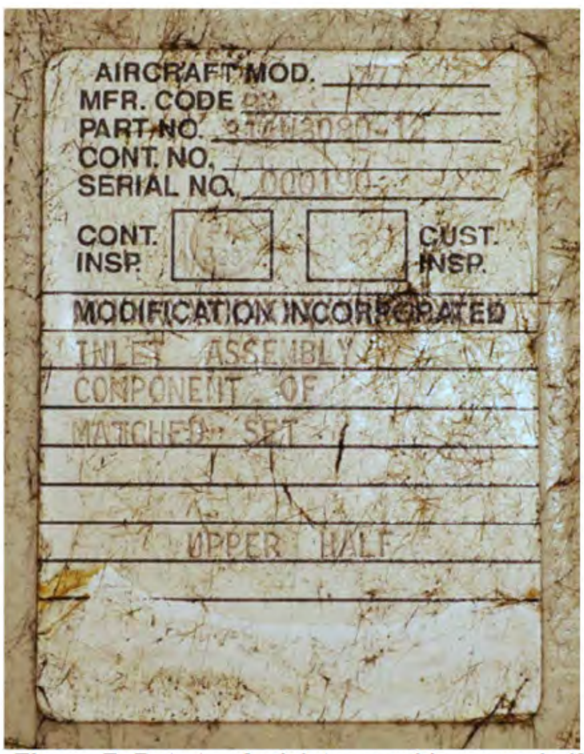


Figure 7: Data tag for inlet assembly, upper half.

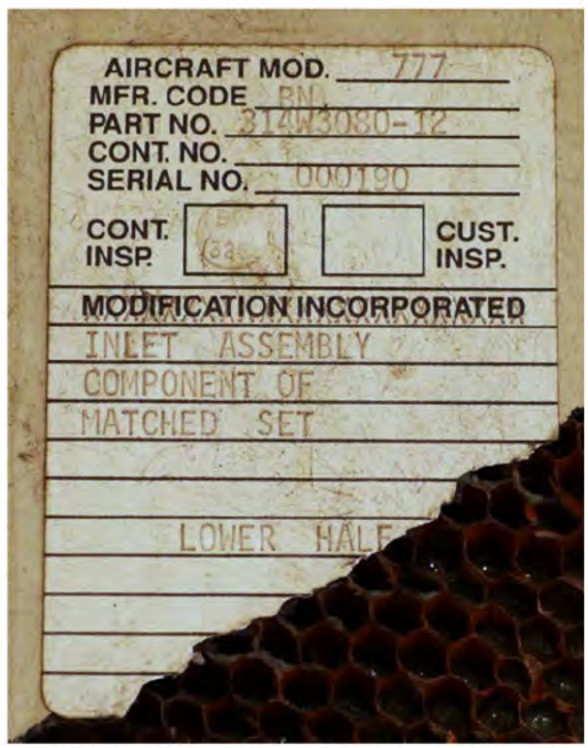


Figure 8: Data tag for inlet assembly lower half.

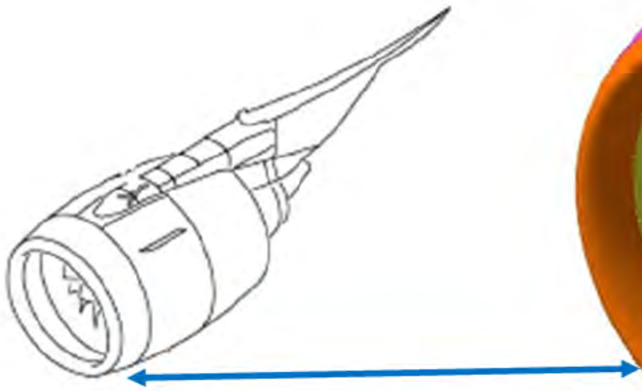


Figure 9: Engine nacelle inlet cowl location.

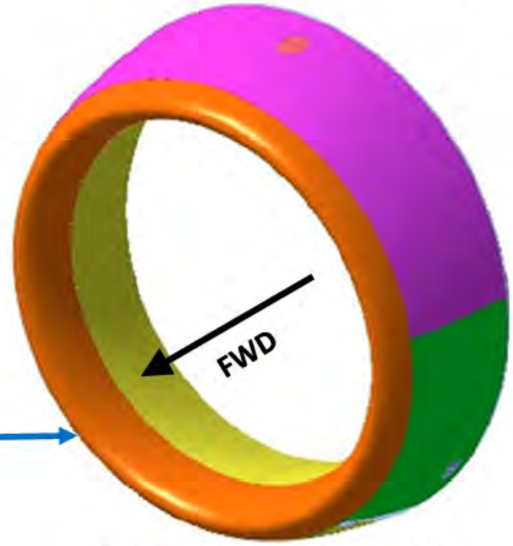


Figure 10: Inlet cowl assembly.

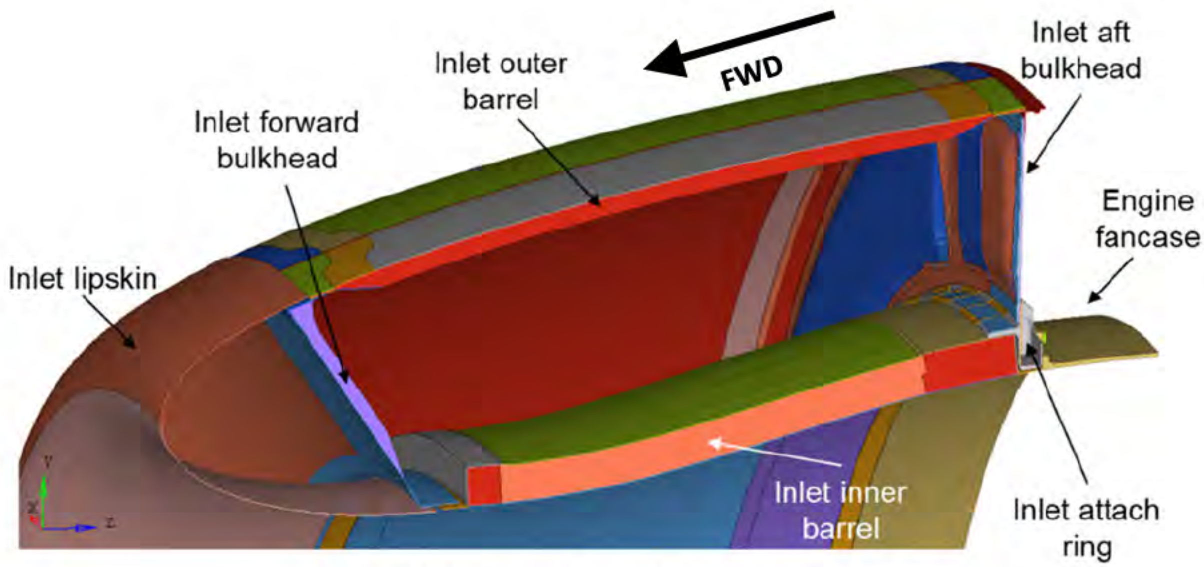


Figure 11: Inlet cowl assembly with nomenclature.

Using the base of the inlet cowl crate as a foundation, the lipskin and inlet attach ring were supported by lumber at an appropriate distance and angle to facilitate the reconstruction of the assembly, seen in Figure 13.

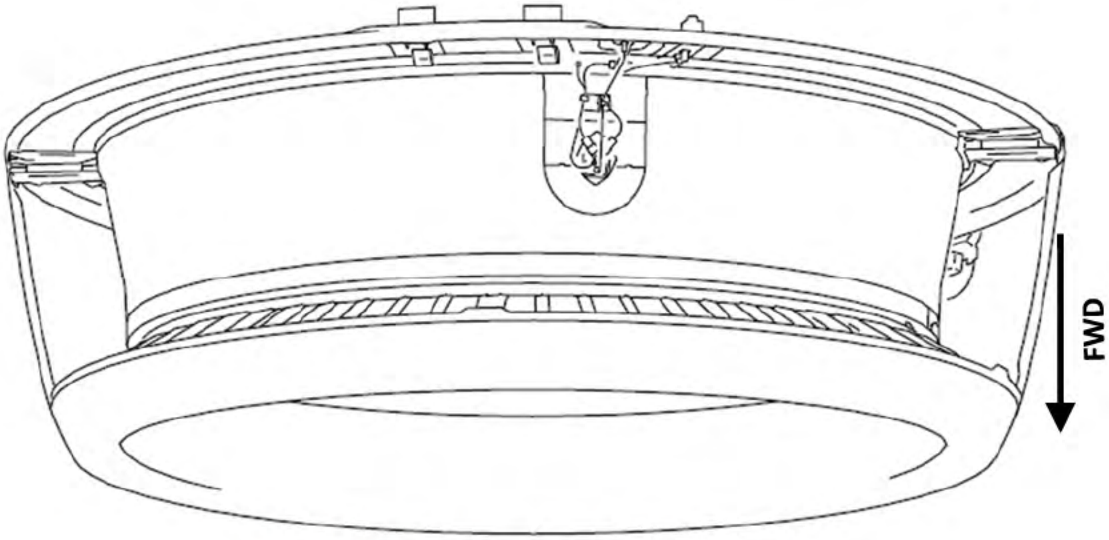


Figure 12: Inlet cowl reconstruction orientation.

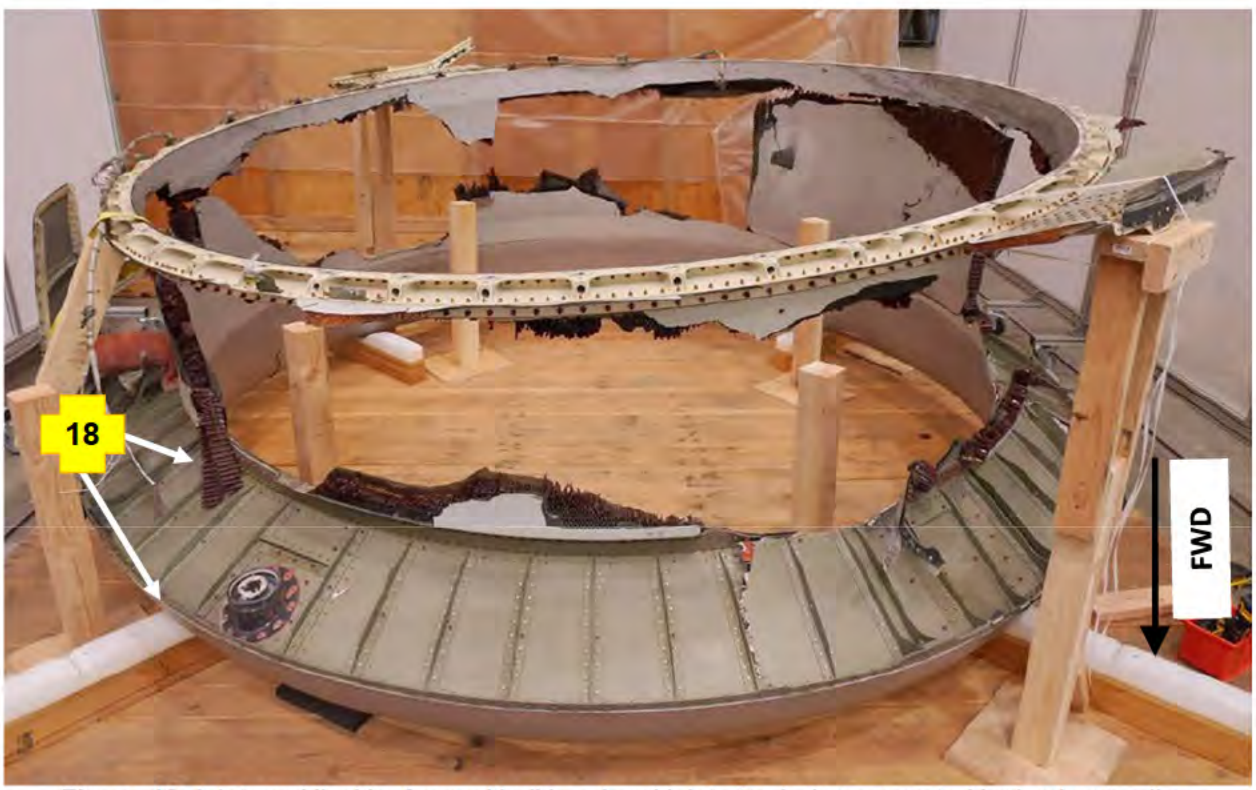


Figure 13: Inlet cowl lipskin, forward bulkhead and inlet attach ring supported by lumber to allow reconstruction of fragments recovered from the incident location.

Figure 14: Inlet cowl with fragments reassembled to assist in incident investigation.

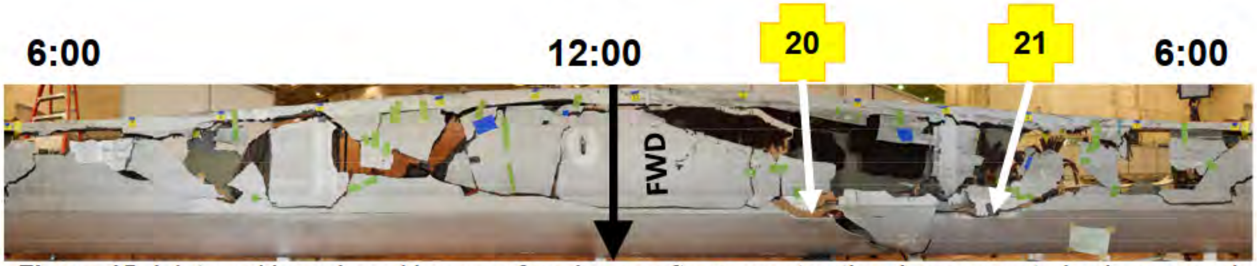


Figure 15: Inlet cowl inner barrel inner surface image after reconstruction. Image created using merged photos. Zoom to view at full resolution.

Figure 16: Inlet cowl outer barrel outer surface. Image created using merged photos. Zoom to view at full resolution.

Figure 17: Inlet cowl outer barrel inner surface. Image created using merged photos. Zoom to view at full resolution.

Two fragments were located and removed from the Inlet cowl outer barrel inner surface from locations 1 and 2, as seen in Figure 17. Detailed location is seen in Figure 18. Initial material identification using an X-ray fluorescence (XRF) analyzer found sample #1 to contain 93.6% aluminum and sample #2 82.7% titanium. These samples were sent to Pratt & Whitney for further evaluation under direction of the NTSB.

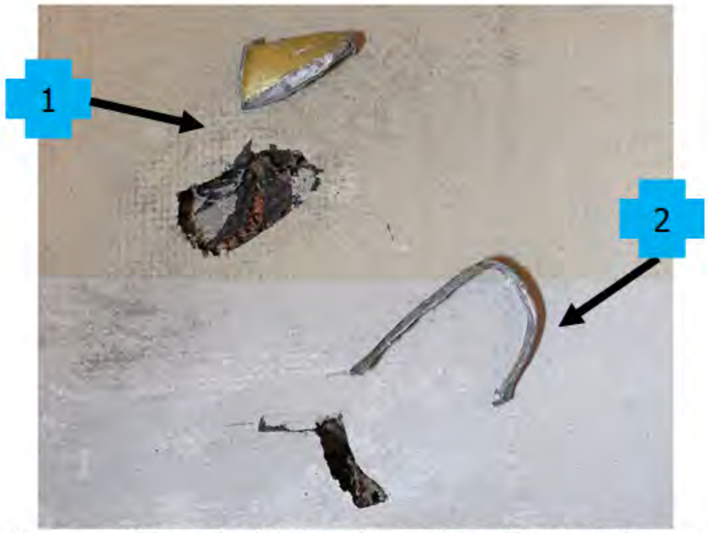


Figure 18: Fragments removed from the inlet cowl outer barrel inner surface near the 6:00 position.

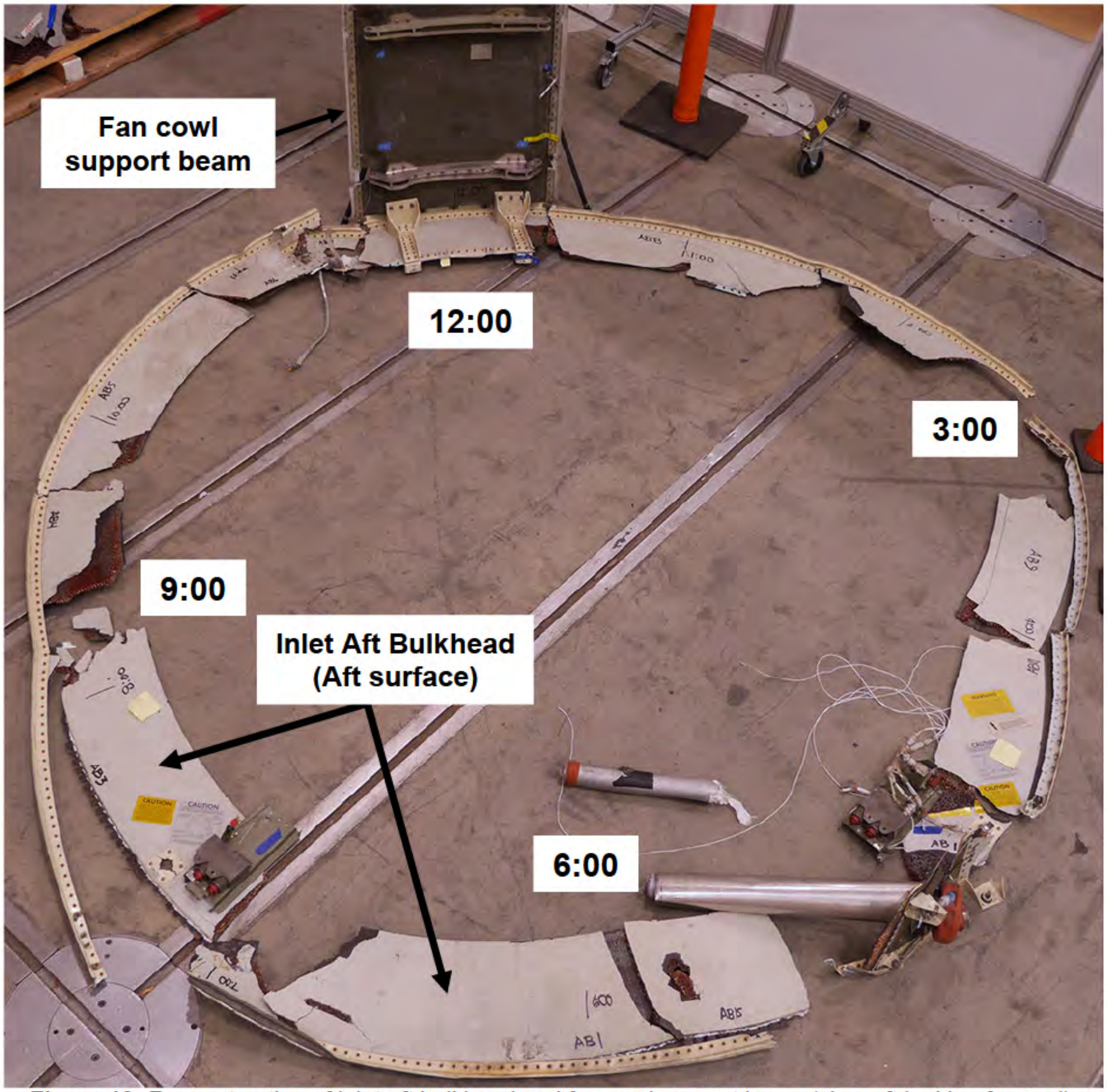


Figure 19: Reconstruction of inlet aft bulkhead and fan cowl support beam (view aft looking forward).

EXAMINATION, FAN COWL:

The fan cowl and fan cowl support beam (FCSB) parts were removed from two crates, seen in Figure 4 and Figure 5. These parts were placed into the approximate as installed orientation in coordination with the NTSB Airworthiness Team.

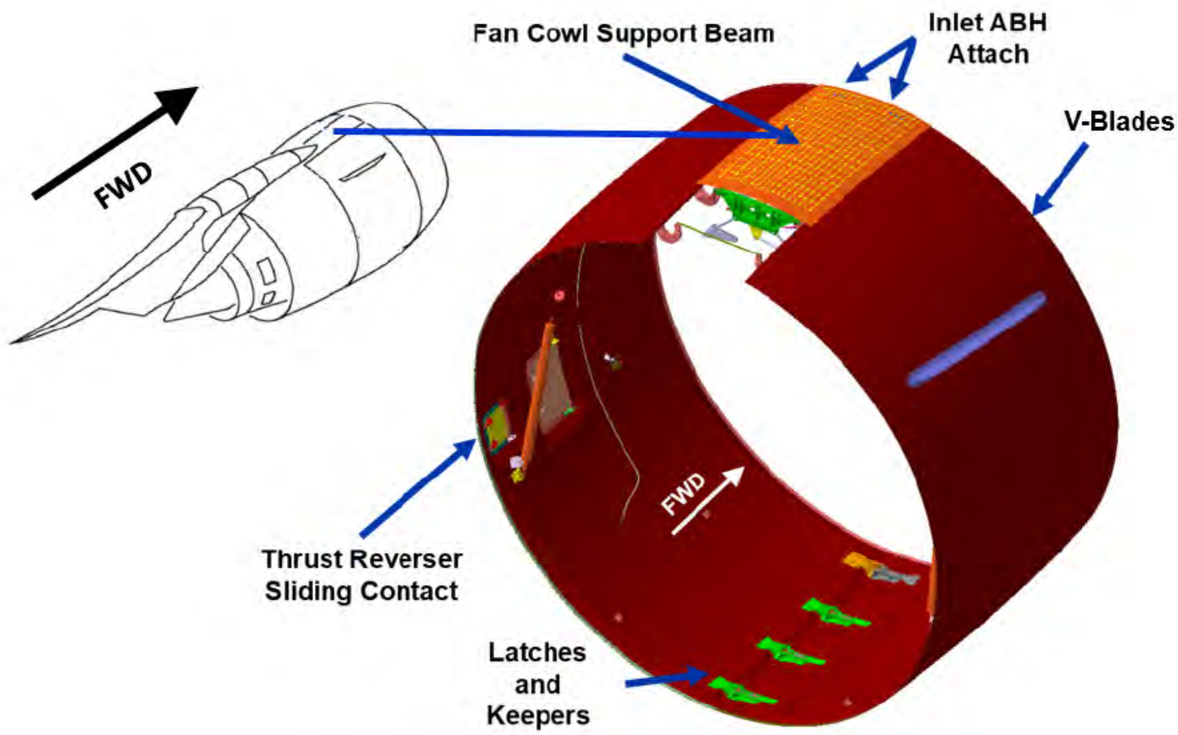


Figure 20: Fan cowl installation with nomenclature
(left engine installation shown, right installation is opposite)

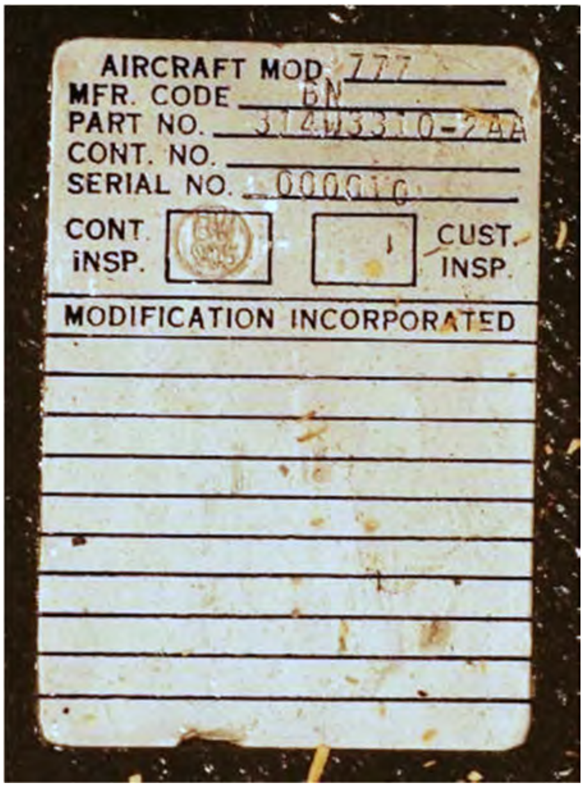


Figure 21: Data tag for outboard fan cowl assembly.
Note: Data tag for inboard fan cowl assembly was not recovered.

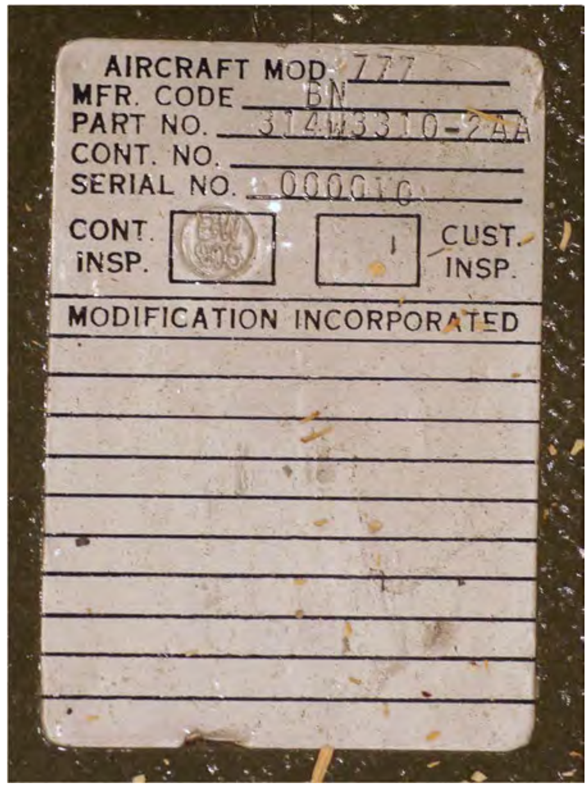


Figure 22: Data tag for fan cowl support beam assembly.

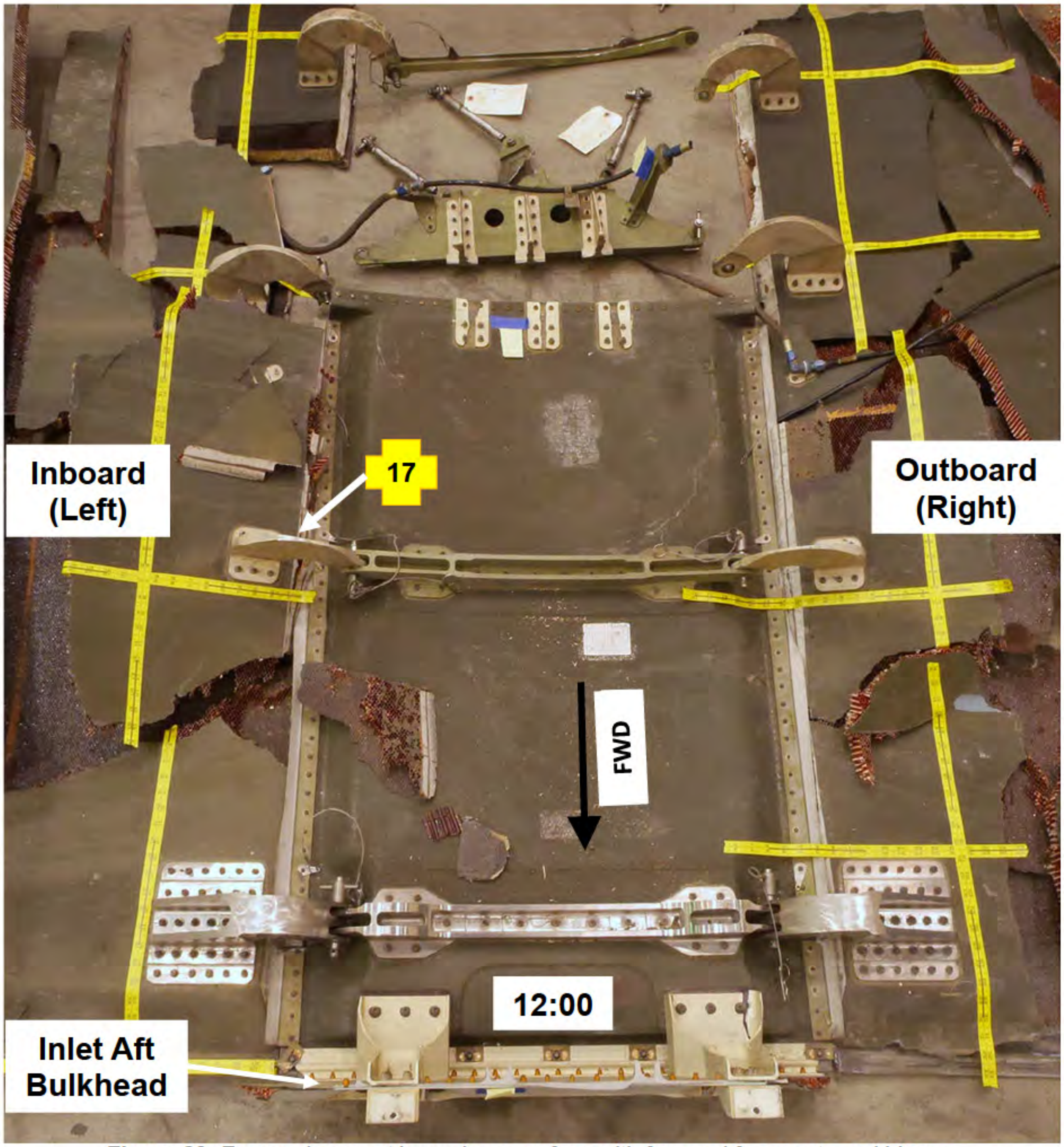


Figure 23: Fan cowl support beam inner surface with fan cowl fragments and hinges.

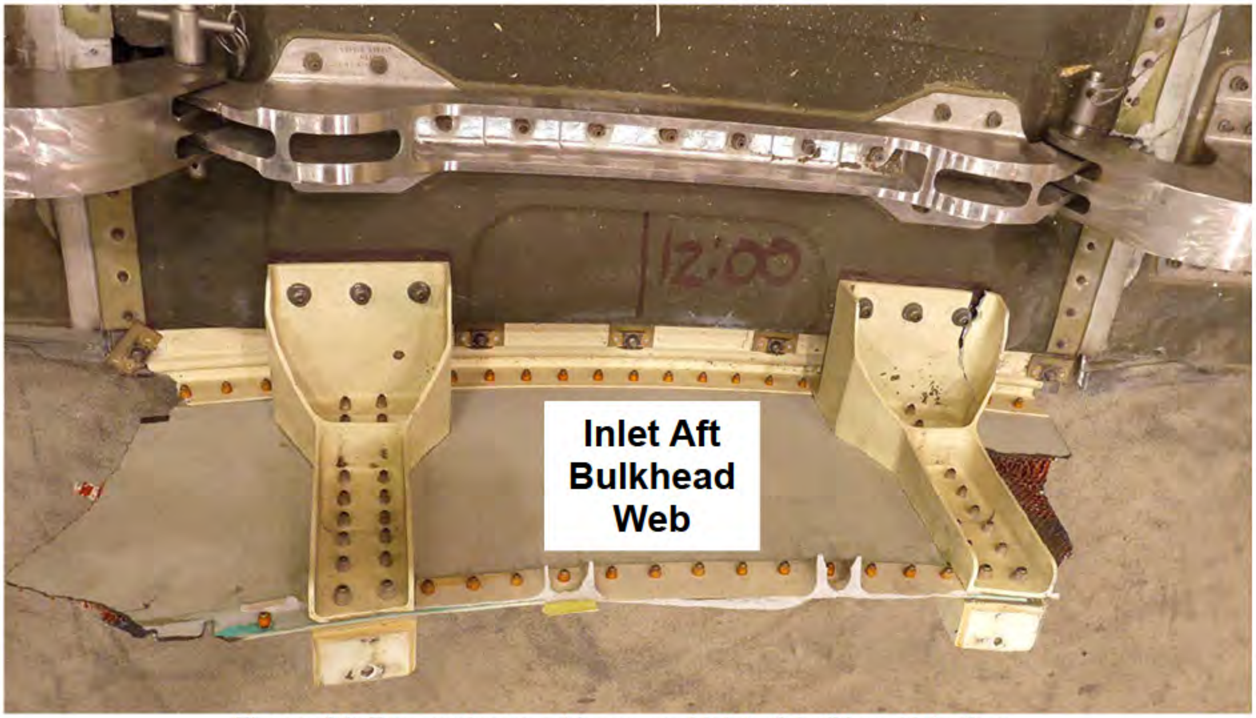


Figure 24: Fan cowl support beam and inlet aft bulkhead interface.

Figure 25: Fan cowl and fan cowl support beam inner surface reconstruction. Image created using merged photos. Zoom to view at full resolution.

Figure 26: Fan cowl and fan cowl support beam outer surface reconstruction. Image created using merged photos. Zoom to view at full resolution.

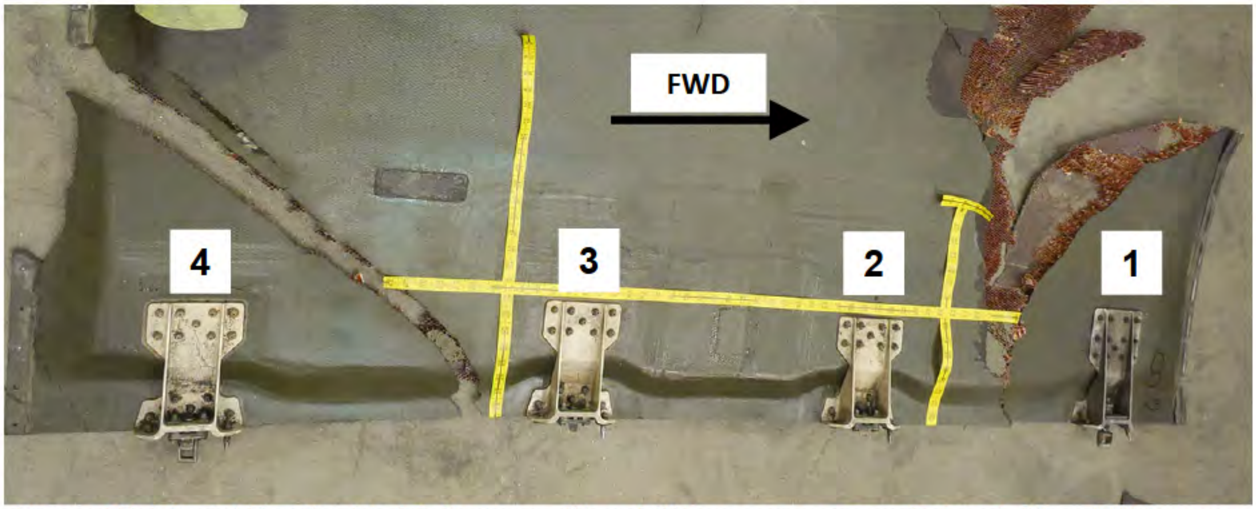


Figure 27: Inboard Fan Cowl Latch Keepers - #1 and #4 keepers were mostly intact, #2 and #3 keepers were fractured as shown in figures 29 and 30.

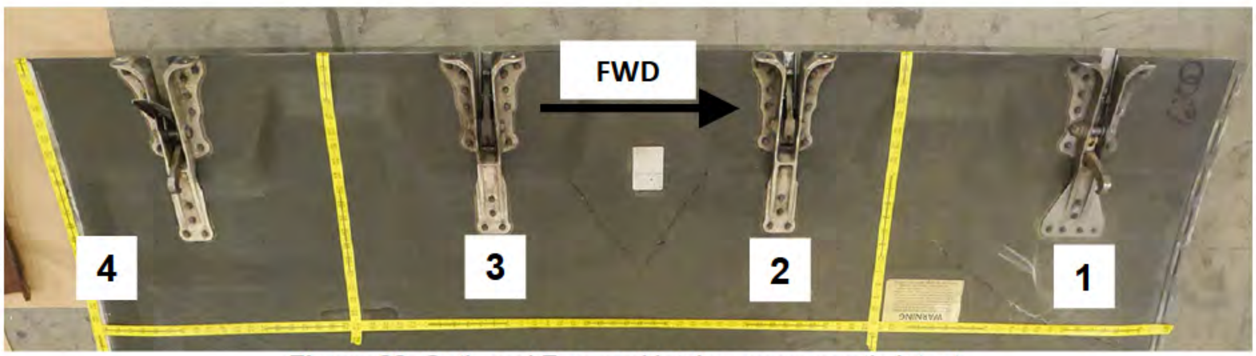


Figure 28: Outboard Fan cowl latches were mostly intact.

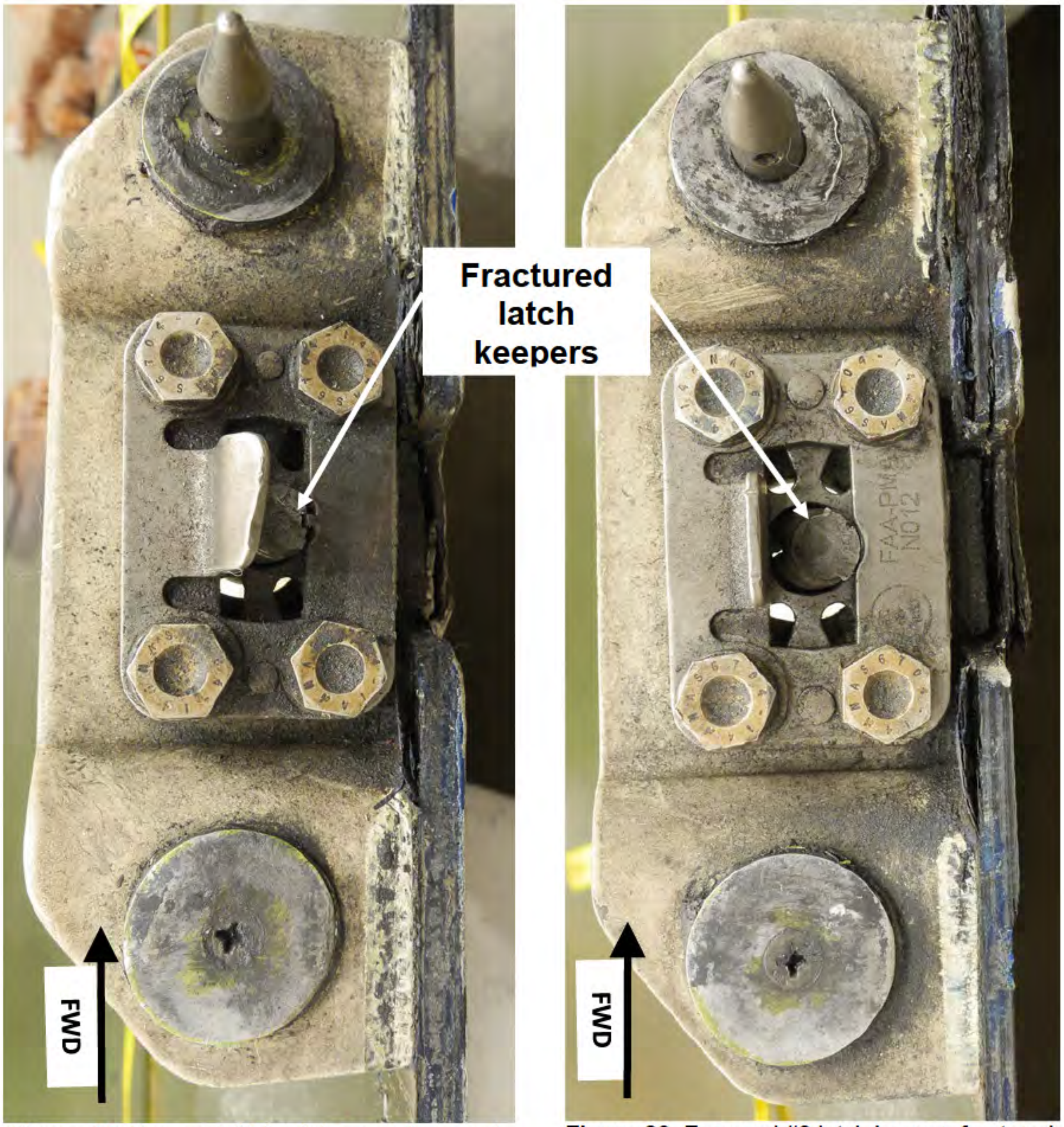


Figure 29: Fan cowl #2 latch keeper, fractured.

Figure 30: Fan cowl #3 latch keeper, fractured.

EXAMINATION, THRUST REVERSER:

Outboard and Inboard thrust reversers were received in 2 crates as seen in Figure 31and Figure 32. The covers were removed and examination performed.

Figure 31: Outboard thrust reverser crate as received at Boeing.

Figure 32: Inboard thrust reverser crate as received at Boeing.

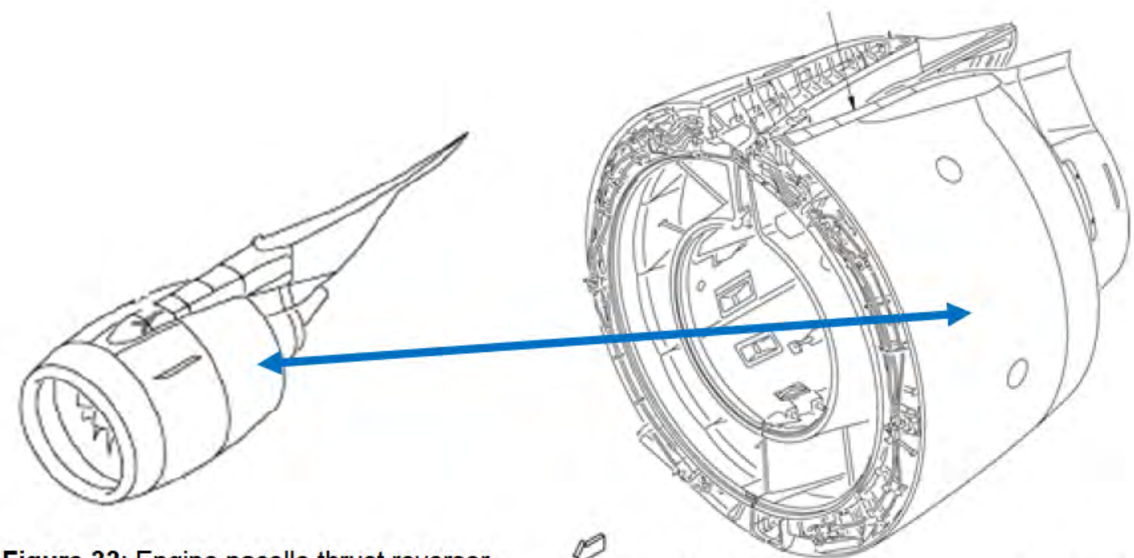


Figure 33: Engine nacelle thrust reverser location.

Figure 34: Thrust reverser assembly, left and right.

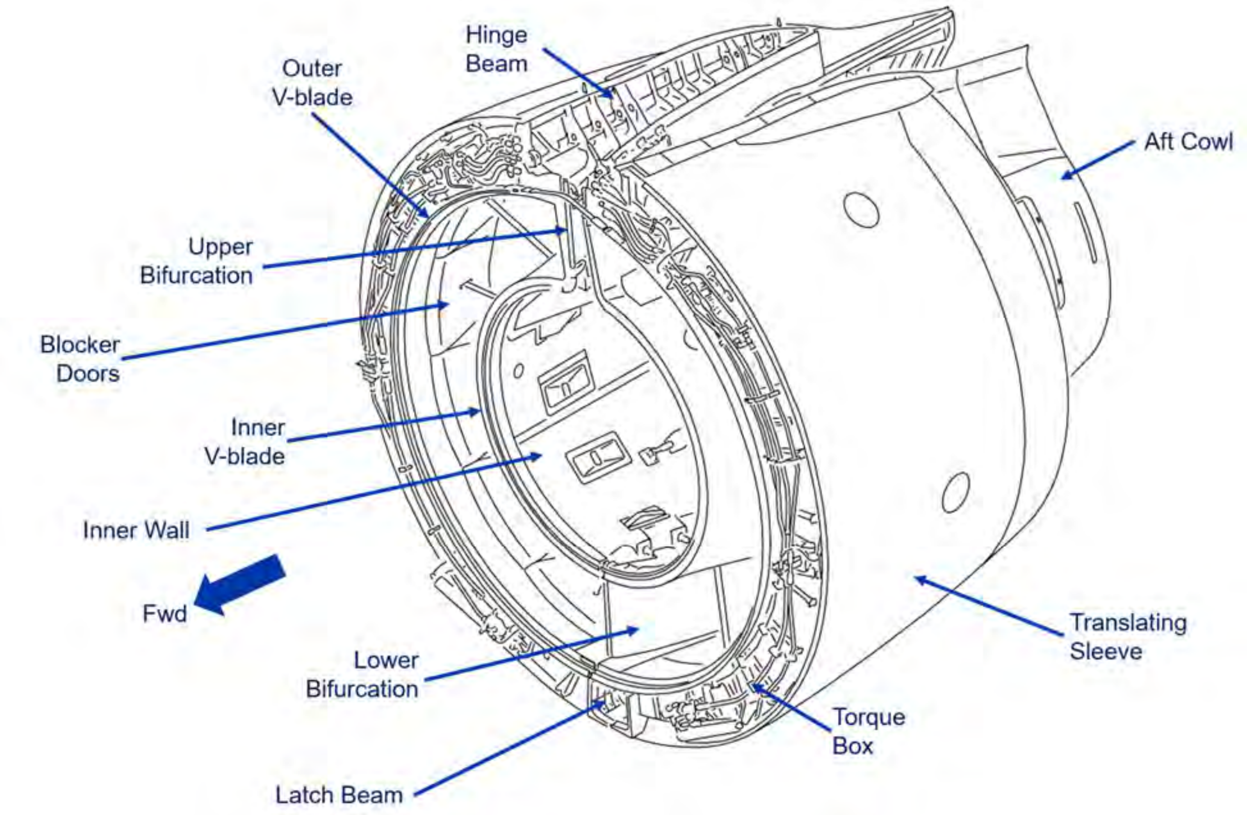


Figure 35: Thrust Reverser nomenclature (Left and Right sides).

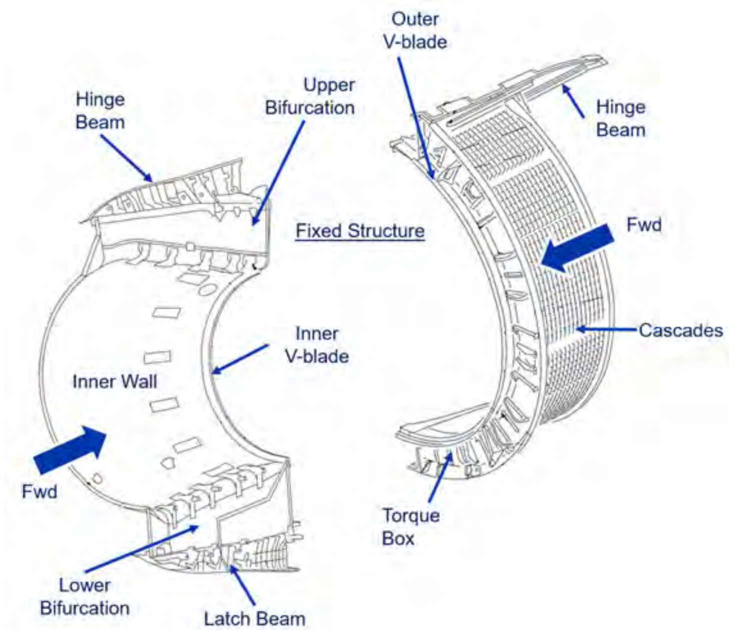


Figure 36: Thrust reverser fixed structure nomenclature (left side).

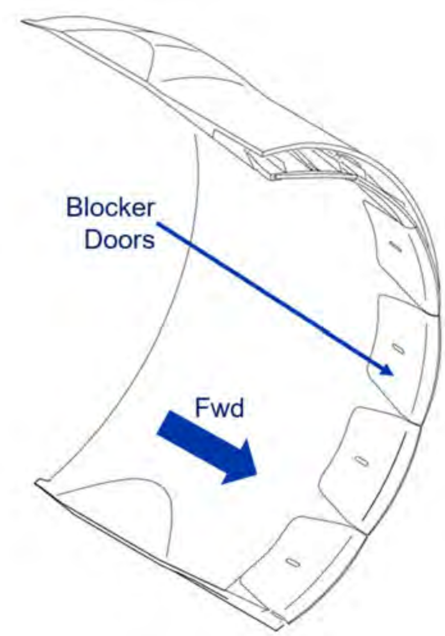


Figure 37: Thrust reverser translating sleeve (left side).

Figure 38: Outboard thrust reverser, condition as uncrated (view forward looking aft).

Figure 39: Outboard thrust reverser hinge beam and translating sleeve (view looking down).

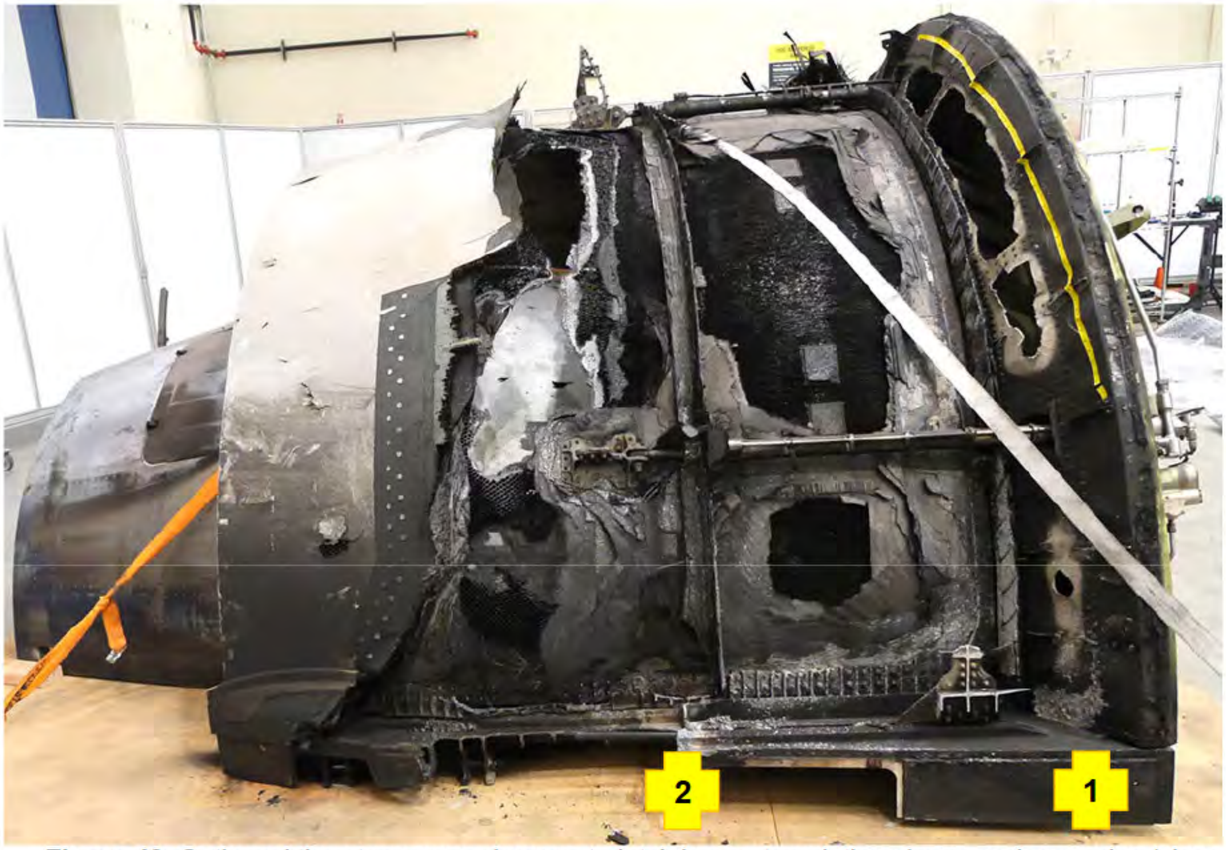


Figure 40: Outboard thrust reverser, damage to latch beam, translating sleeve and cascades (view looking up).

Figure 41: Outboard thrust reverser, aft cowl (view aft looking forward).

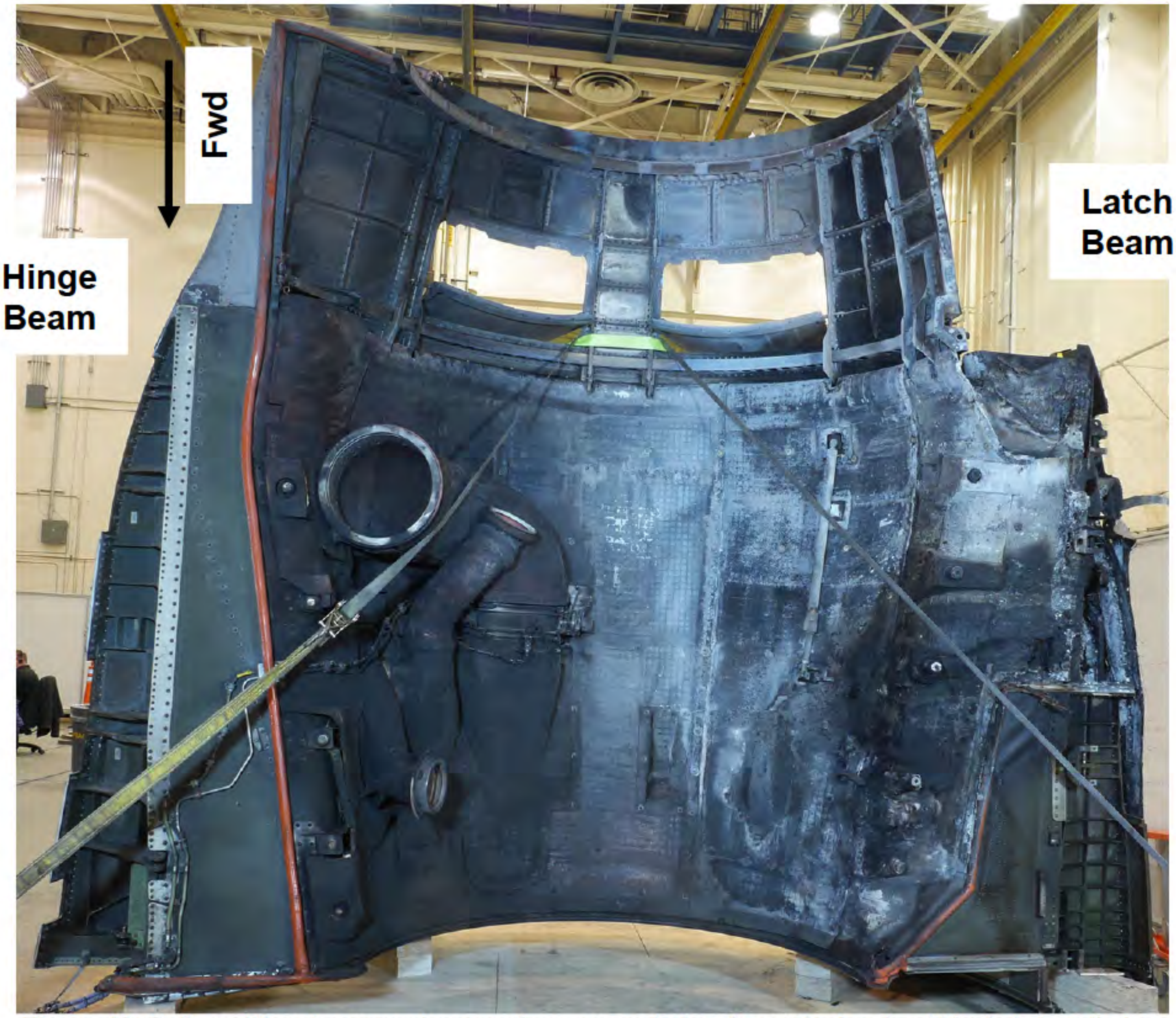


Figure 42: Outboard thrust reverser inner surface, supported on forward edge, heat blankets installed as received.

Thrust reverser heat blankets were removed in coordination with the NTSB Airworthiness Group. Figure 43 shows the outboard thrust reverser with heat blankets removed.

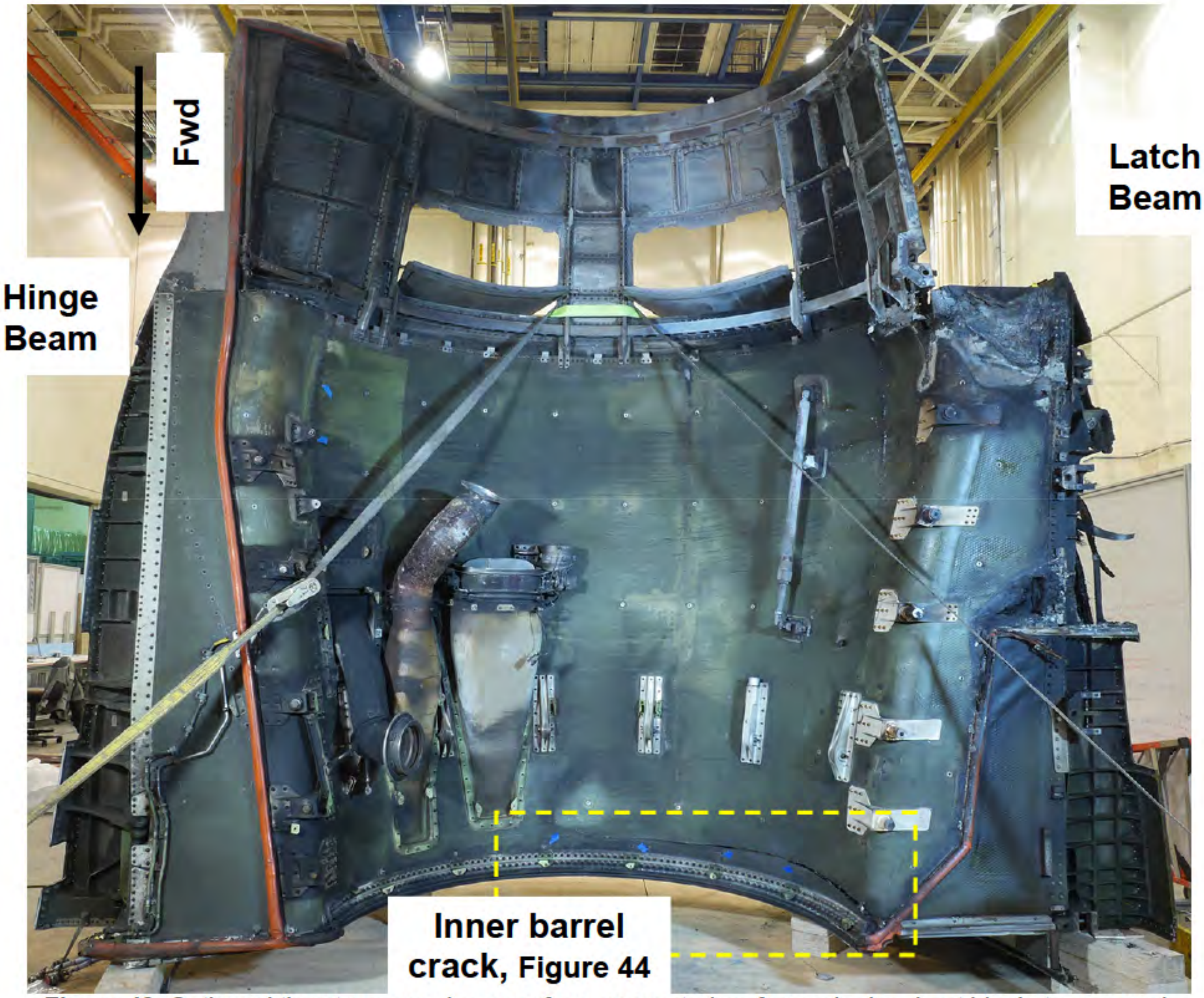


Figure 43: Outboard thrust reverser inner surface, supported on forward edge, heat blankets removed.

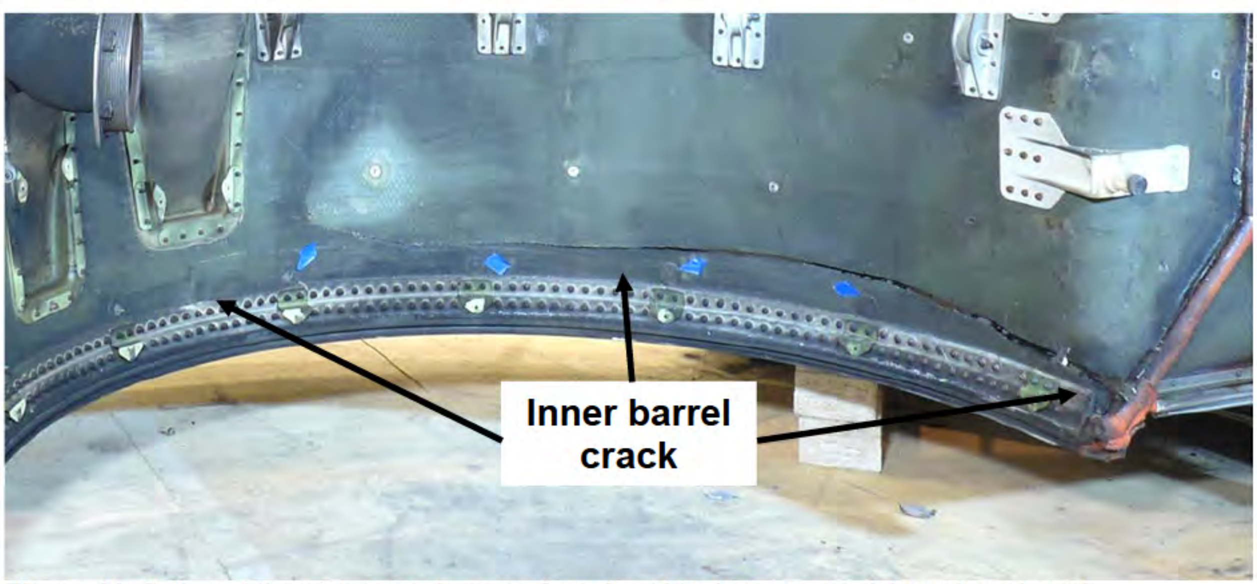


Figure 44: Outboard thrust reverser inner surface, heat blankets removed, inner barrel crack.

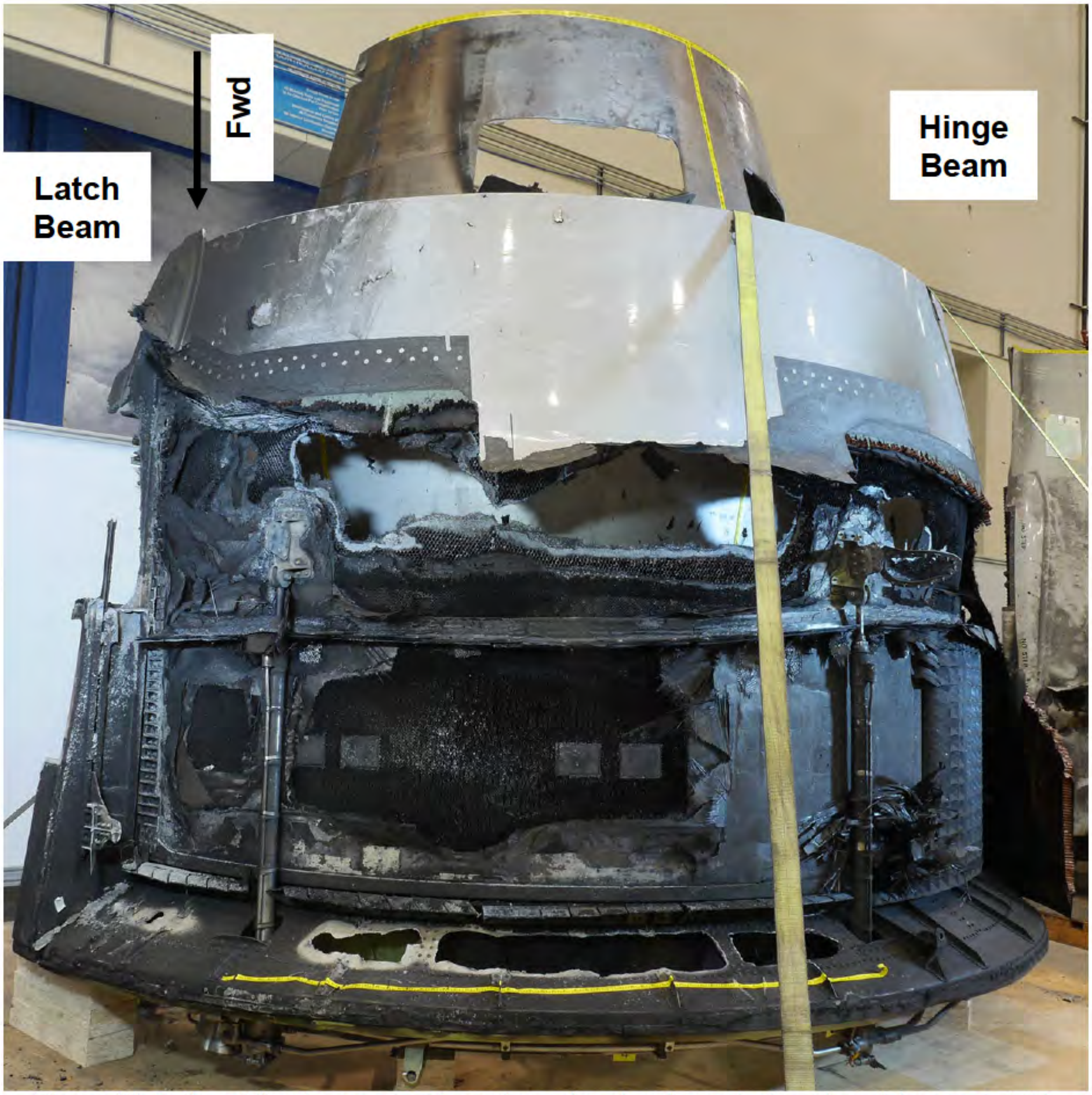


Figure 45: Outboard thrust reverser outer surface, placed on forward edge, view of damage to latch beam, translating sleeve and cascades.

A large section of the translating sleeve was recovered from the incident location. In its installed location the part was located at the lower translating sleeve in the 6:00 to 4:00 position. Figure 46 and Figure 47 show the translating sleeve fragment outer and inner surfaces, Figure 48 shows the translating sleeve section near the installed location.

Figure 46: Translating sleeve separated from outboard thrust reverser, outer surface.

Figure 47: Translating sleeve separated from outboard thrust reverser, inner surface.

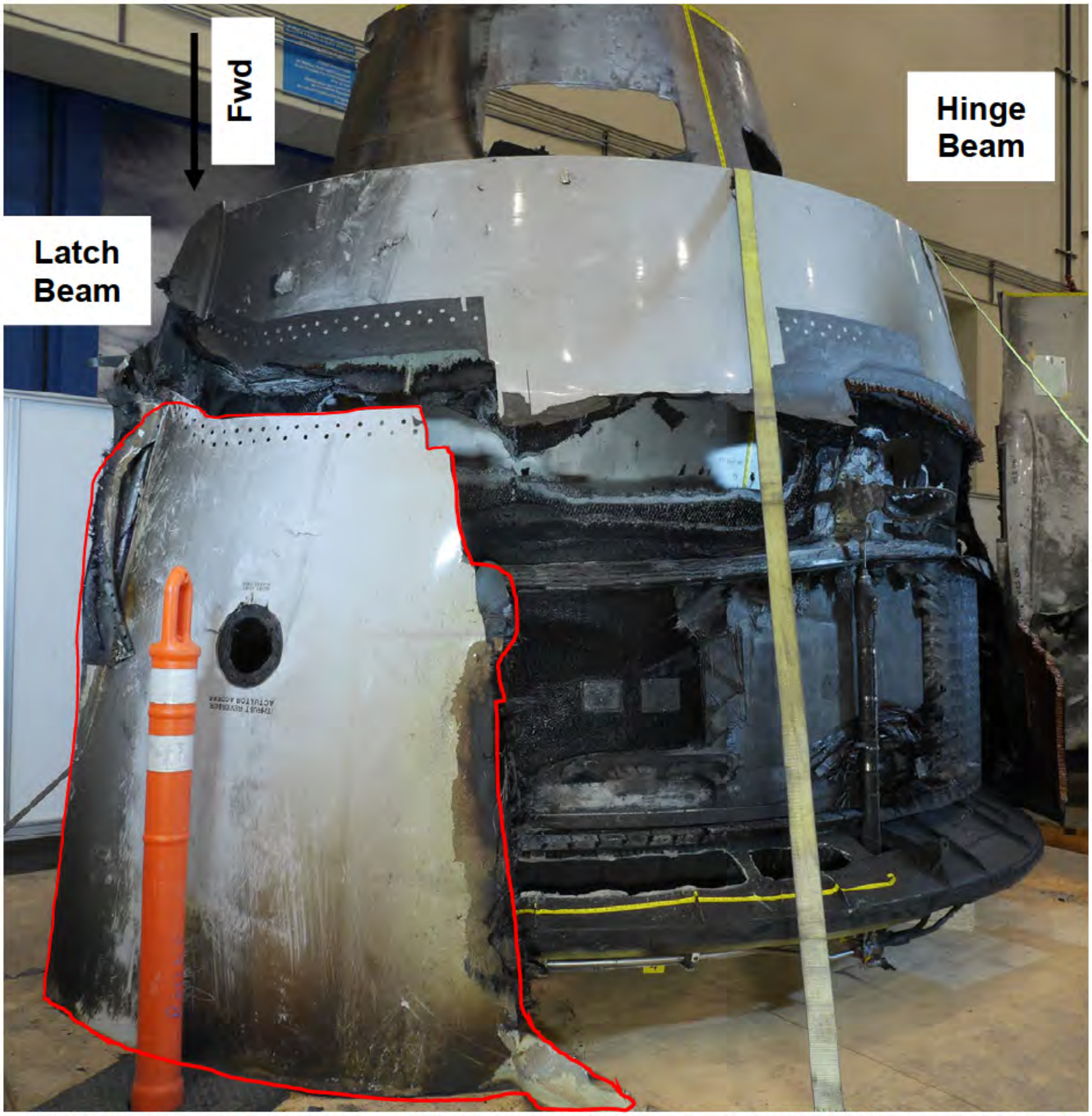


Figure 48: Outboard thrust reverser, with recovered translating sleeve (red highlight) near its installed location.

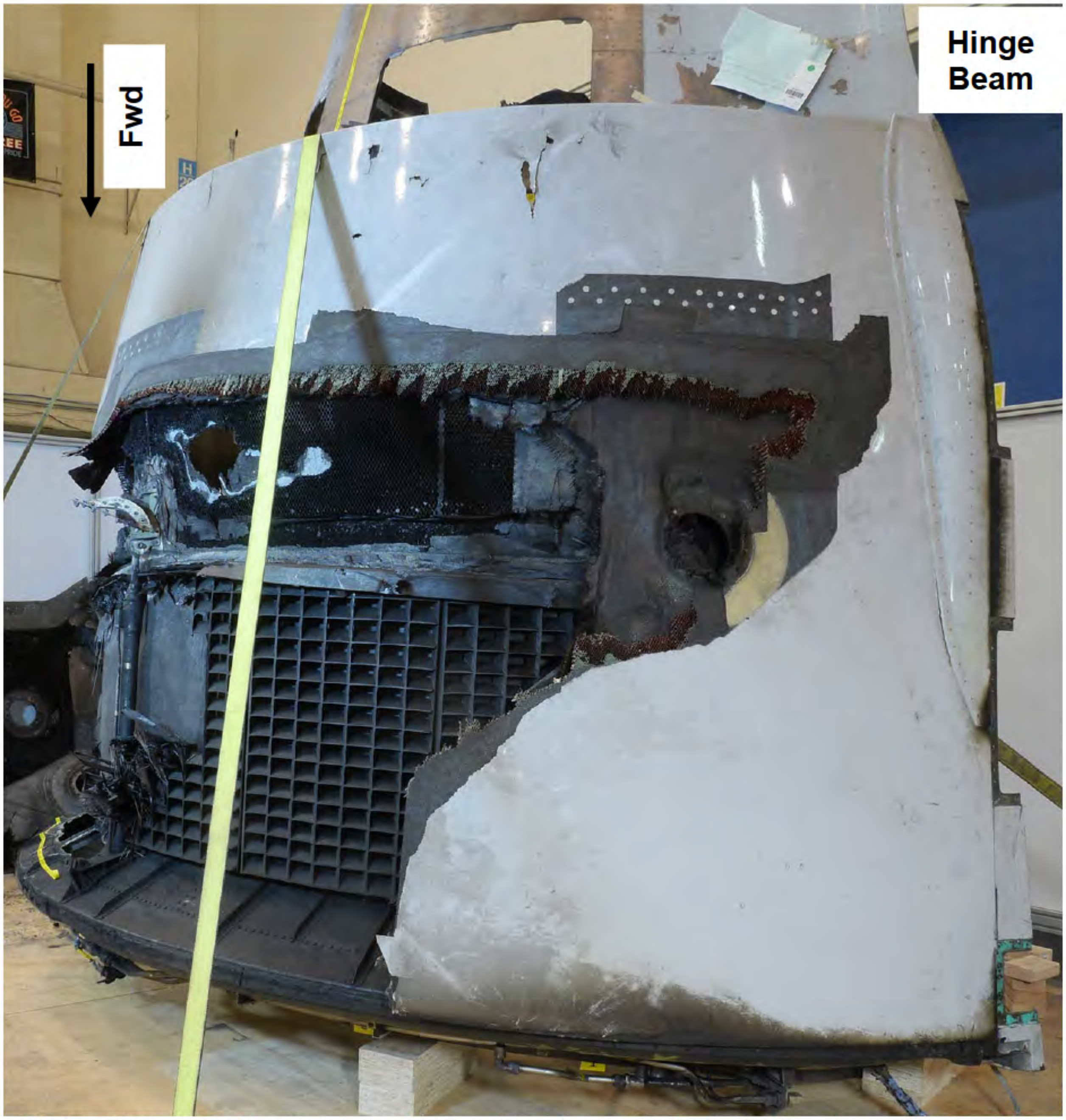


Figure 49: Outboard thrust reverser, view from hinge beam showing translating sleeve and cascades.

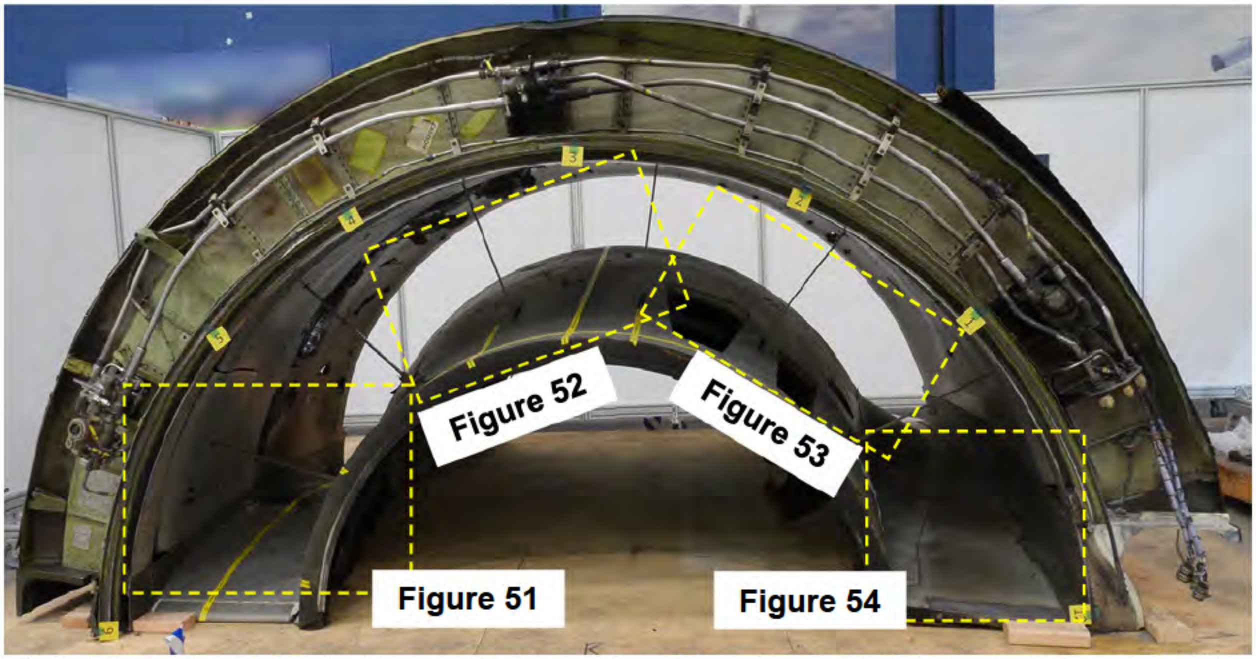


Figure 50: Outboard thrust reverser, showing location of inner barrel detail photos (view forward looking aft).

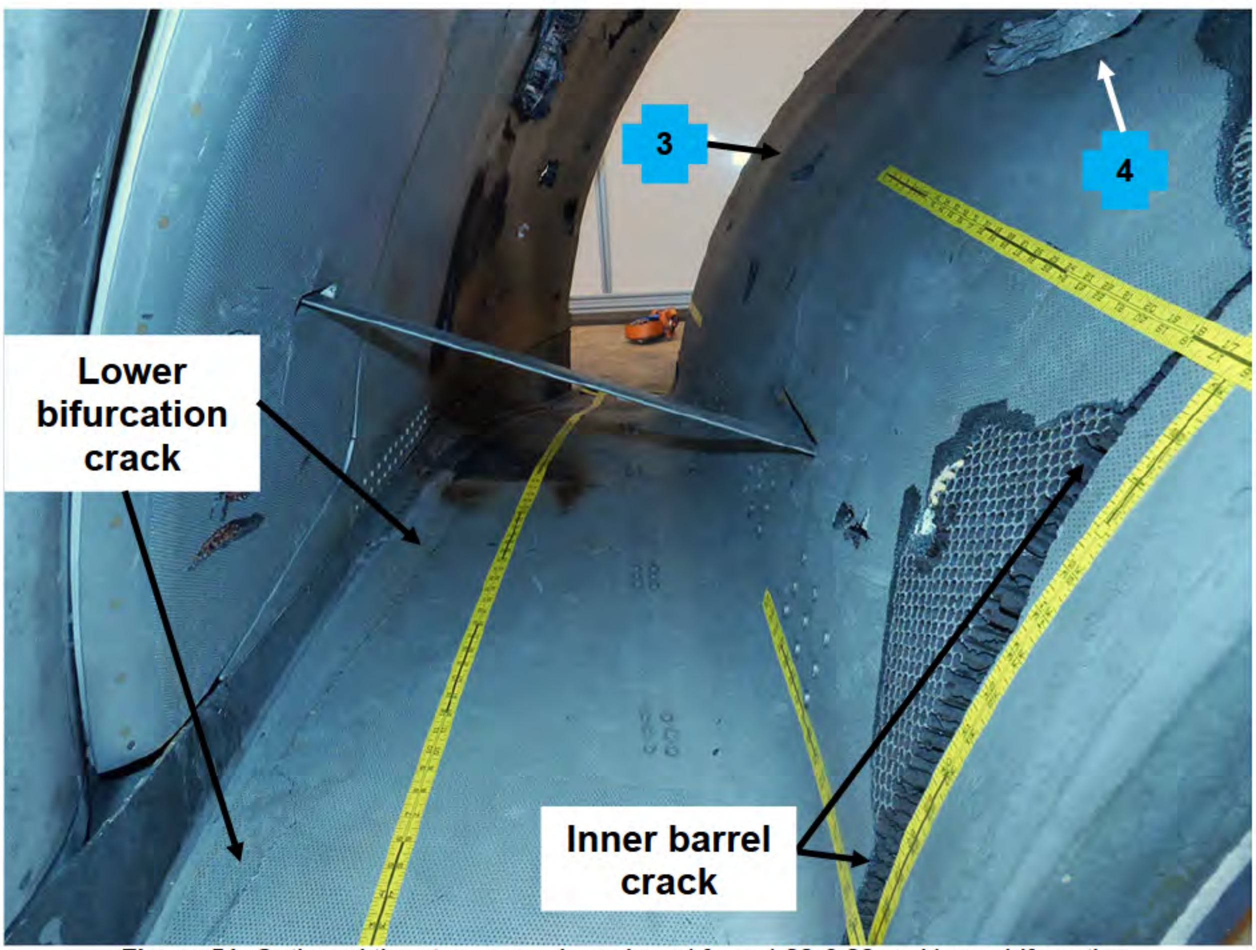


Figure 51: Outboard thrust reverser, inner barrel from 4:00-6:00 and lower bifurcation.

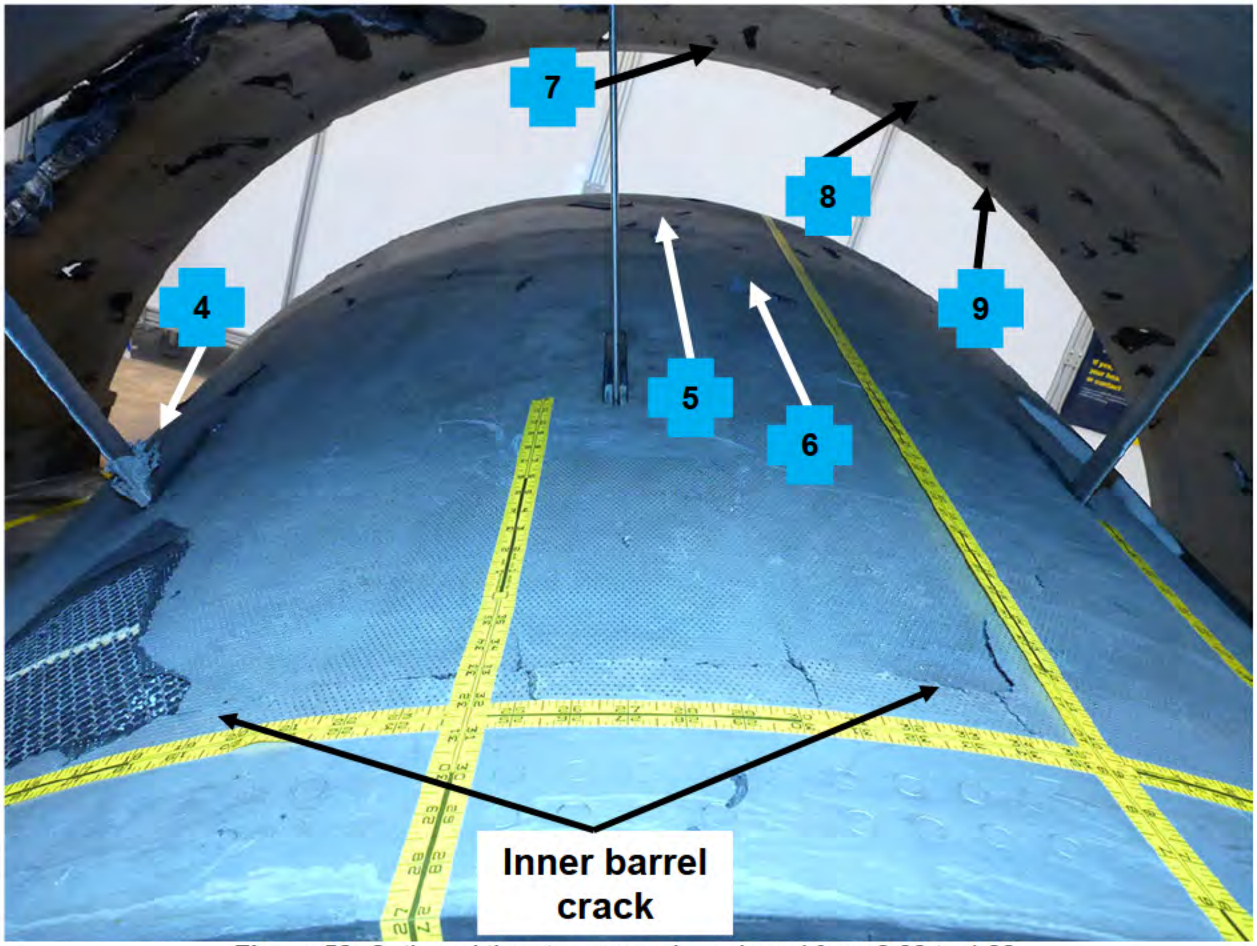


Figure 52: Outboard thrust reverser, inner barrel from 2:00 to 4:00.

Figure 53: Outboard thrust reverser, inner barrel from 1:00 to 3:00.

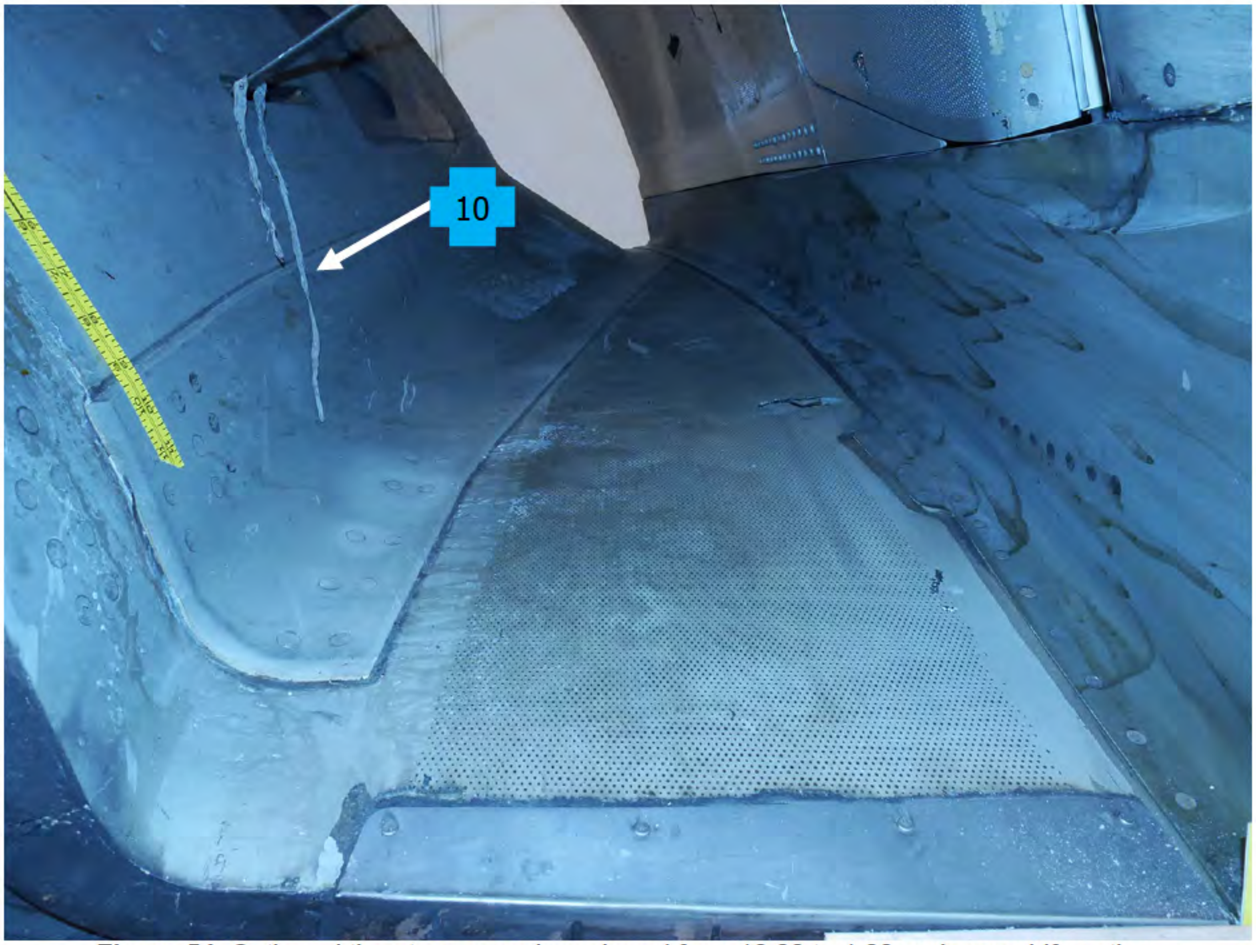


Figure 54: Outboard thrust reverser, inner barrel from 12:00 to 1:00 and upper bifurcation.

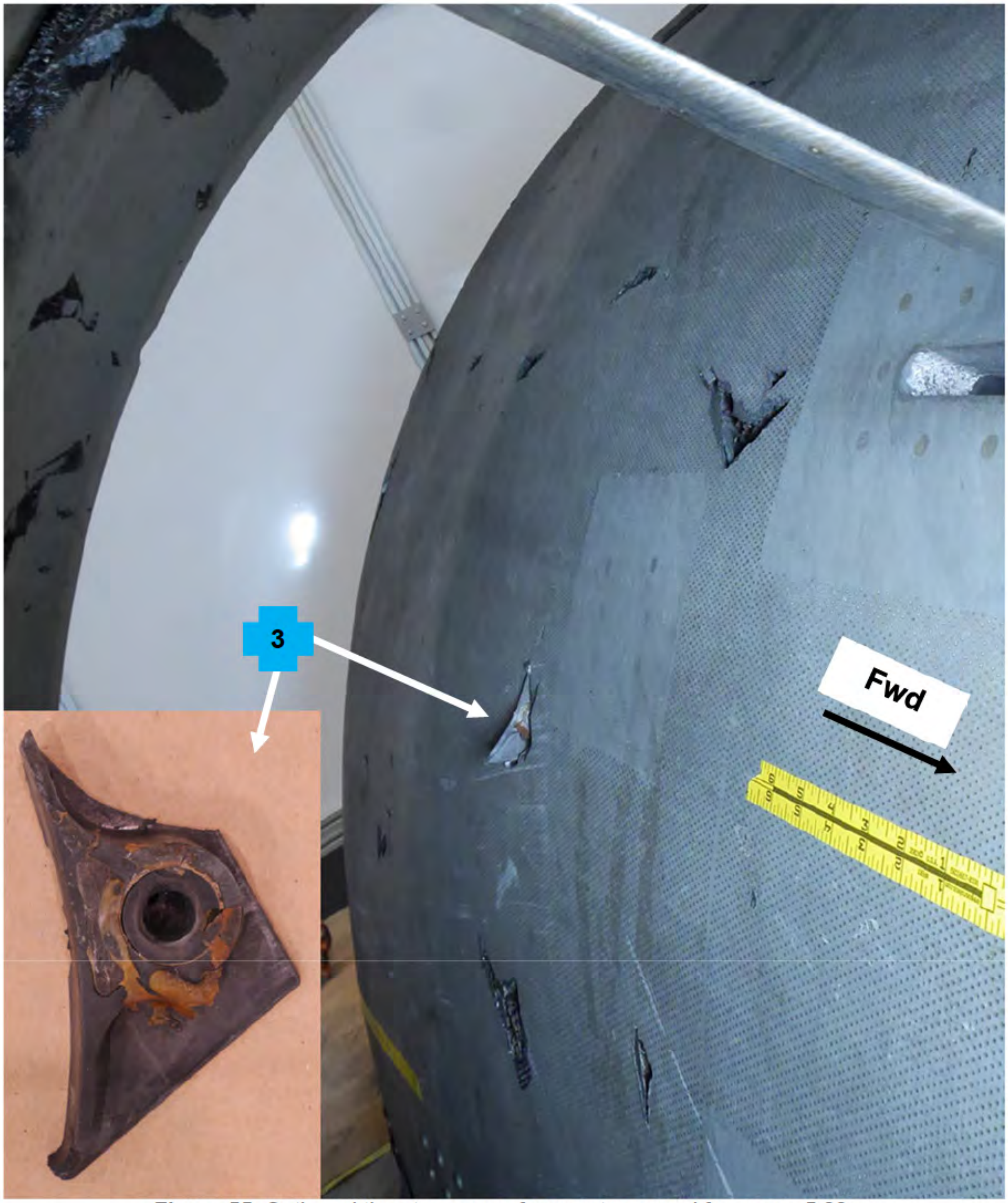


Figure 55: Outboard thrust reverser, fragment removed from near 5:00.

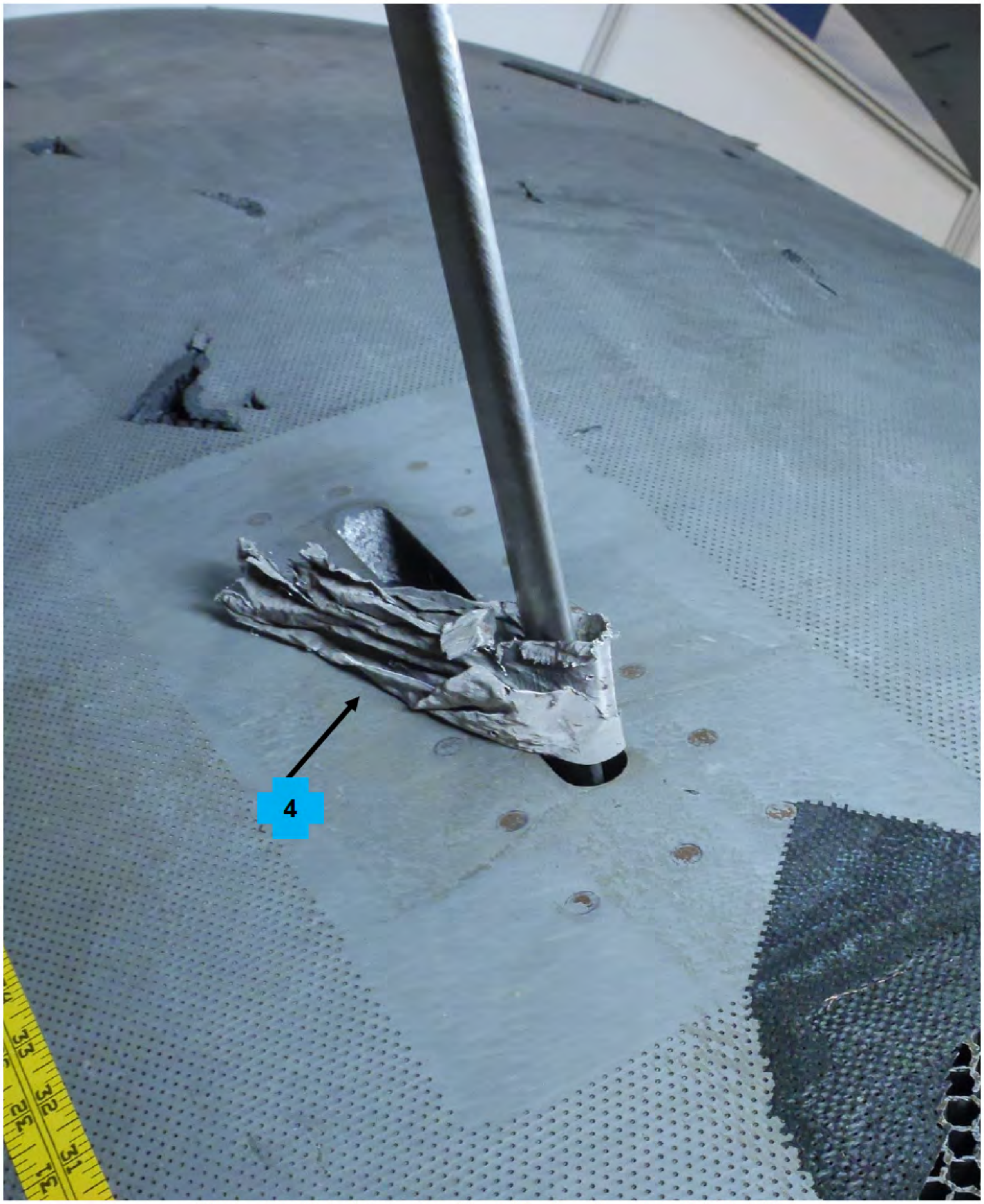


Figure 56: Material removed from blocker door drag link at 4:30.

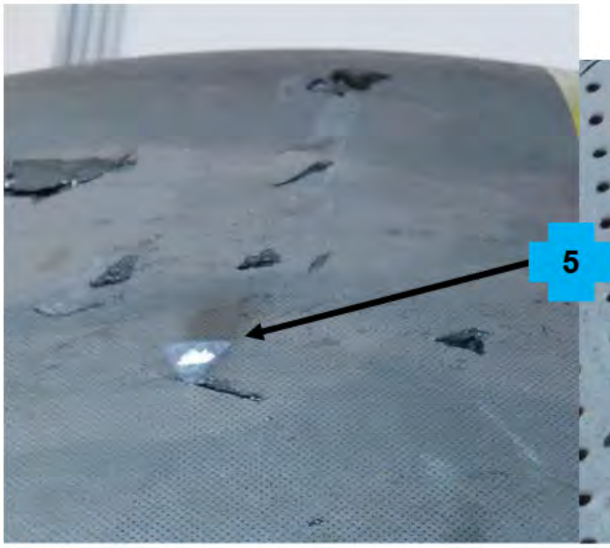


Figure 57: Outboard thrust reverser, fragment removed from near 3:30.

Figure 58: Outboard thrust reverser, fragment removed from near 3:30, detail.

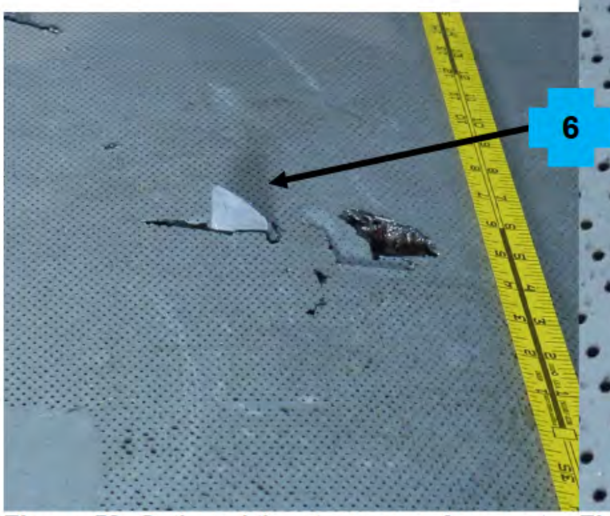


Figure 59: Outboard thrust reverser, fragment removed from near 3:00.

Figure 60: Outboard thrust reverser, fragment removed from near 3:00, detail.

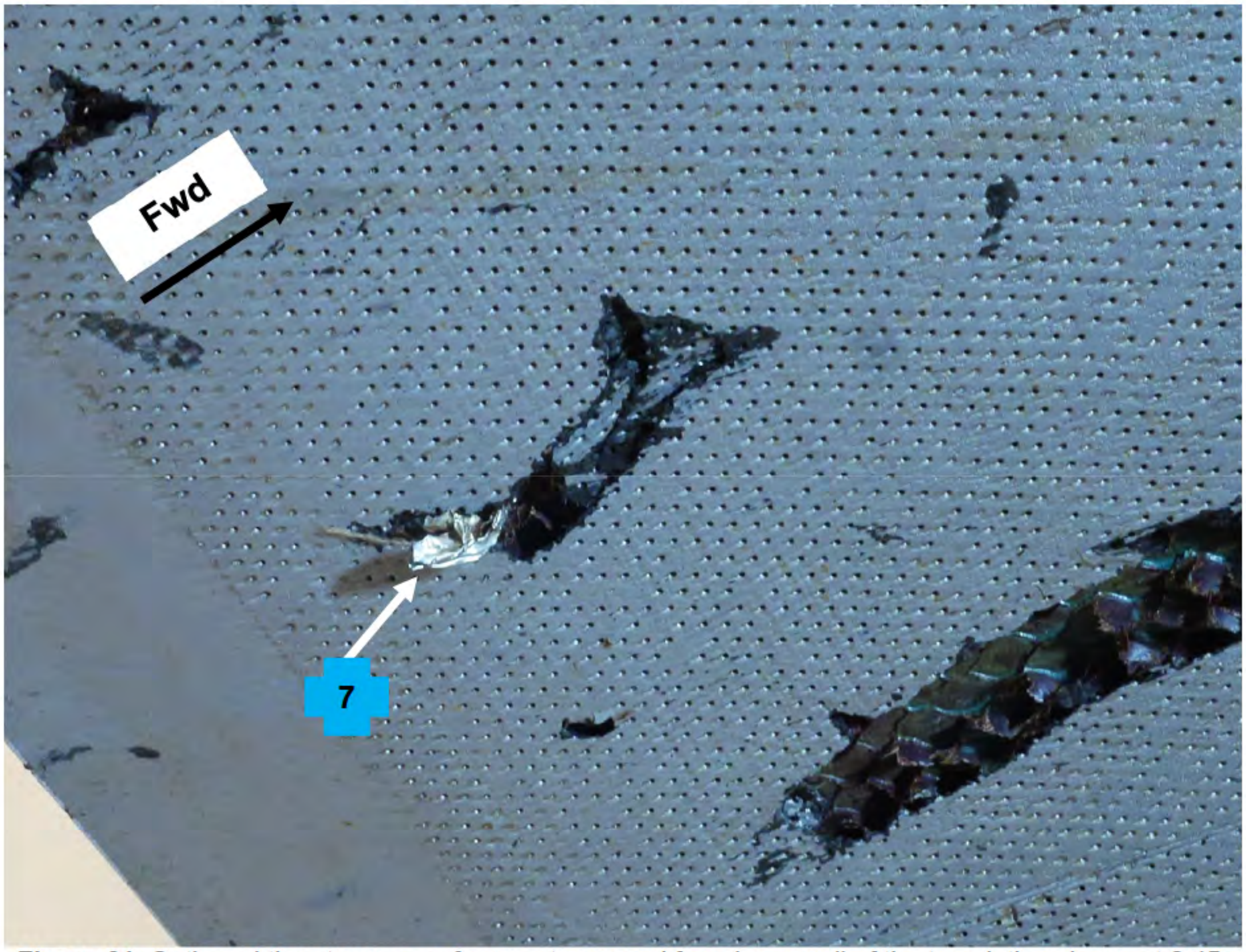


Figure 61: Outboard thrust reverser, fragment removed from inner wall of the translating sleeve at 2:45.

Figure 62: Fragment removed from inner wall of translating sleeve at 2:45.

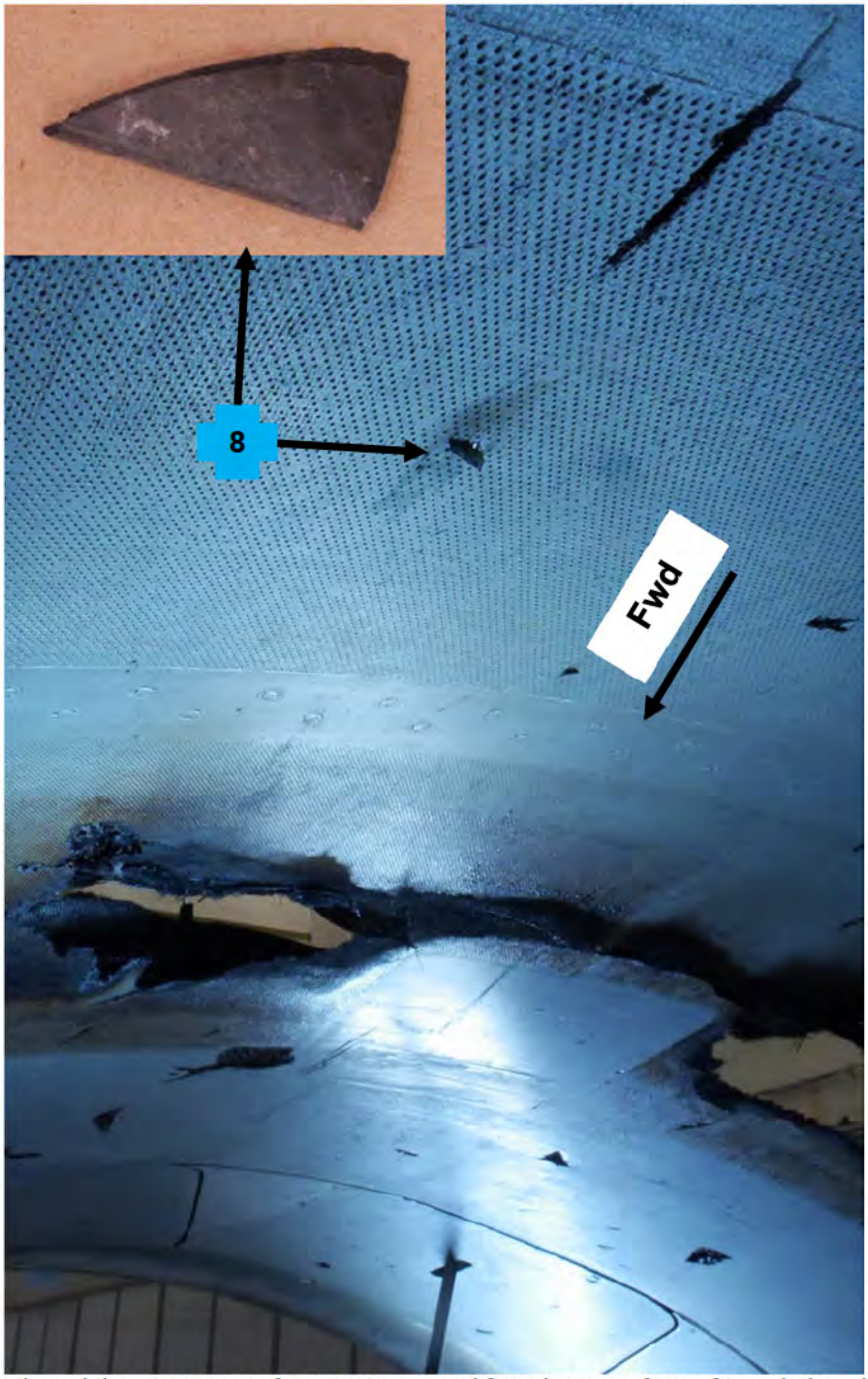


Figure 63: Outboard thrust reverser, fragment removed from inner surface of translating sleeve at 3:00.

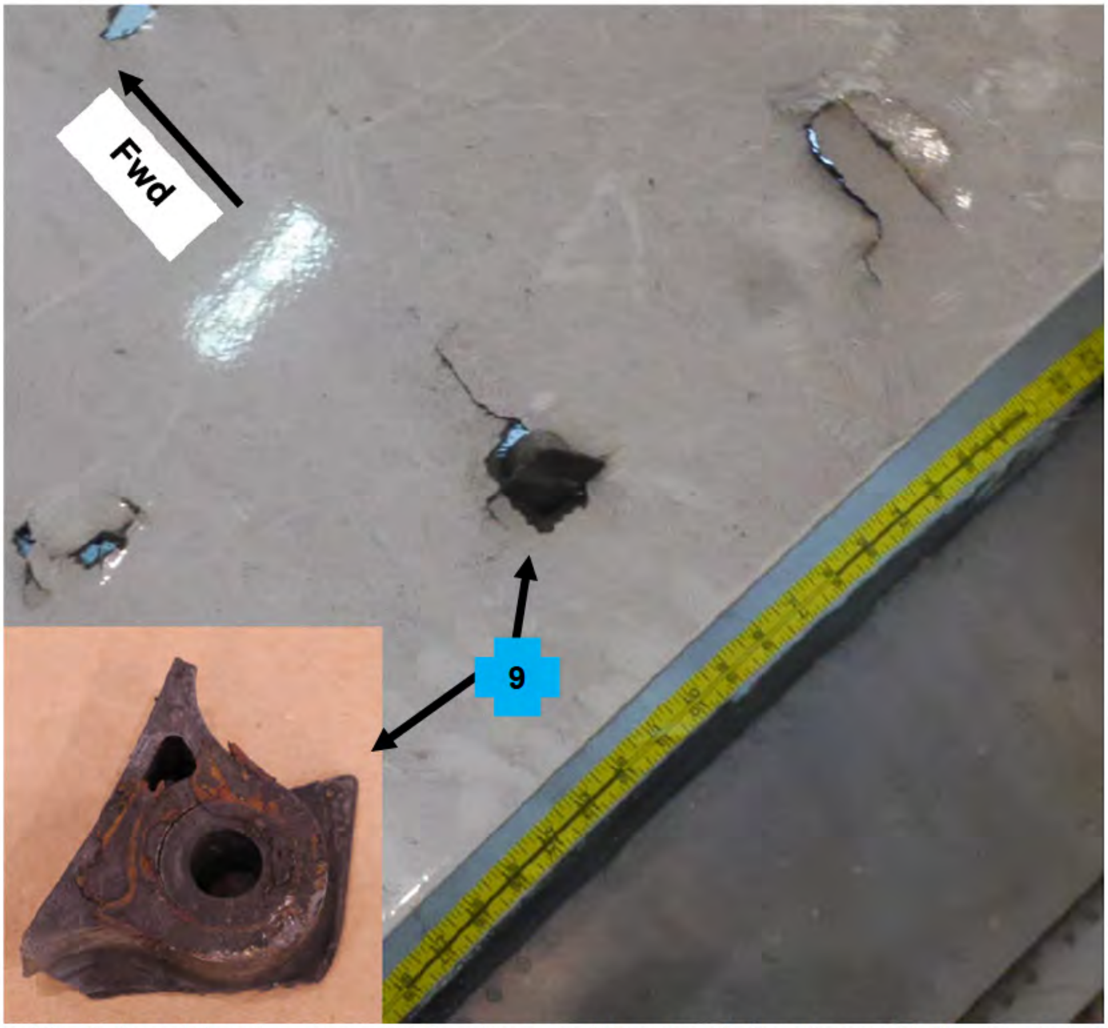


Figure 64: Outboard thrust reverser, fragment removed from translating sleeve at 2:00, penetrated both surfaces. Viewed from outer surface of translating sleeve.

Figure 65: Material removed from blocker door drag link at 12:30.

Figure 66: Inboard thrust reverser, condition as uncrated (view forward looking aft).

Figure 67: Inboard thrust reverser hinge beam, showing damage to translating sleeve and cascades (view looking down).

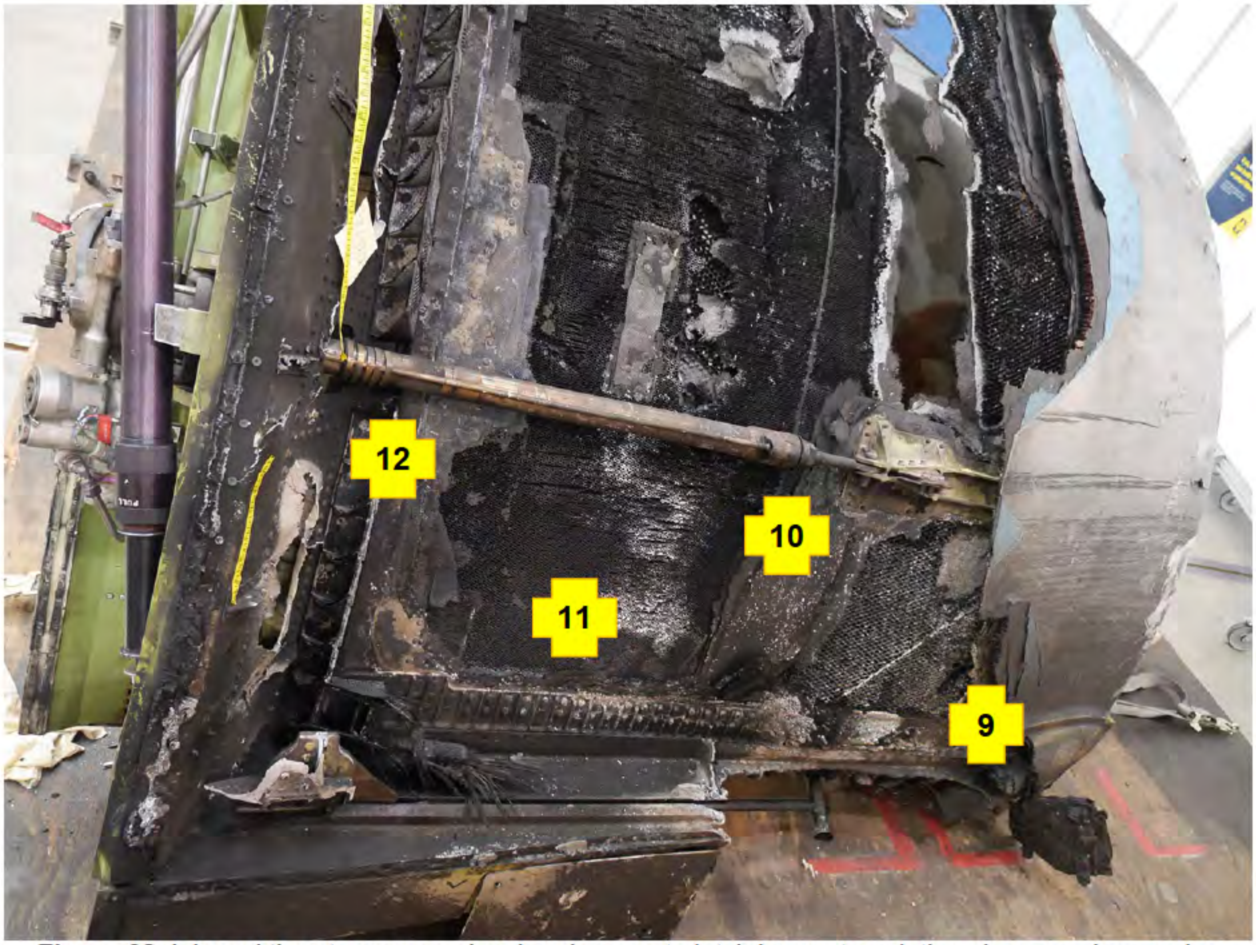


Figure 68: Inboard thrust reverser, showing damage to latch beam, translating sleeve and cascades (view looking up).

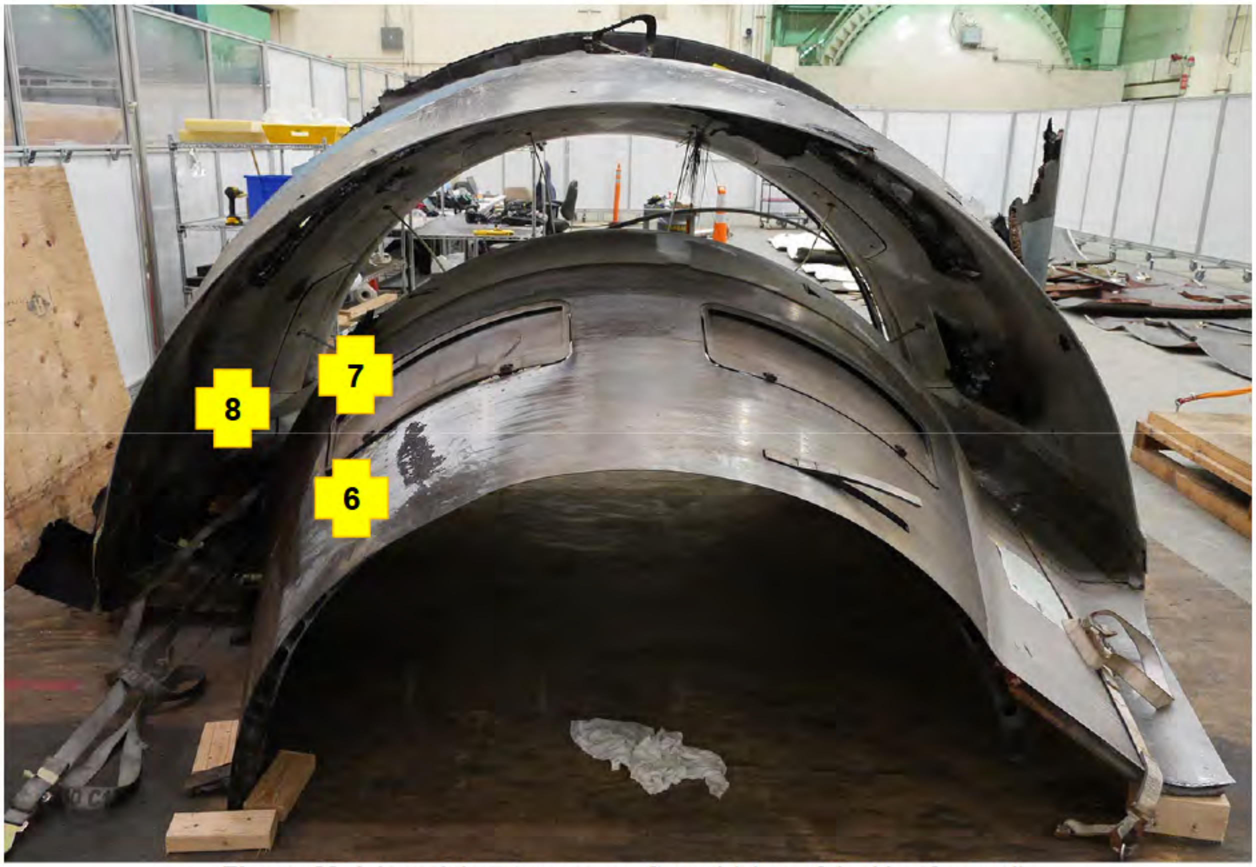


Figure 69: Inboard thrust reverser aft cowl (view aft looking forward).

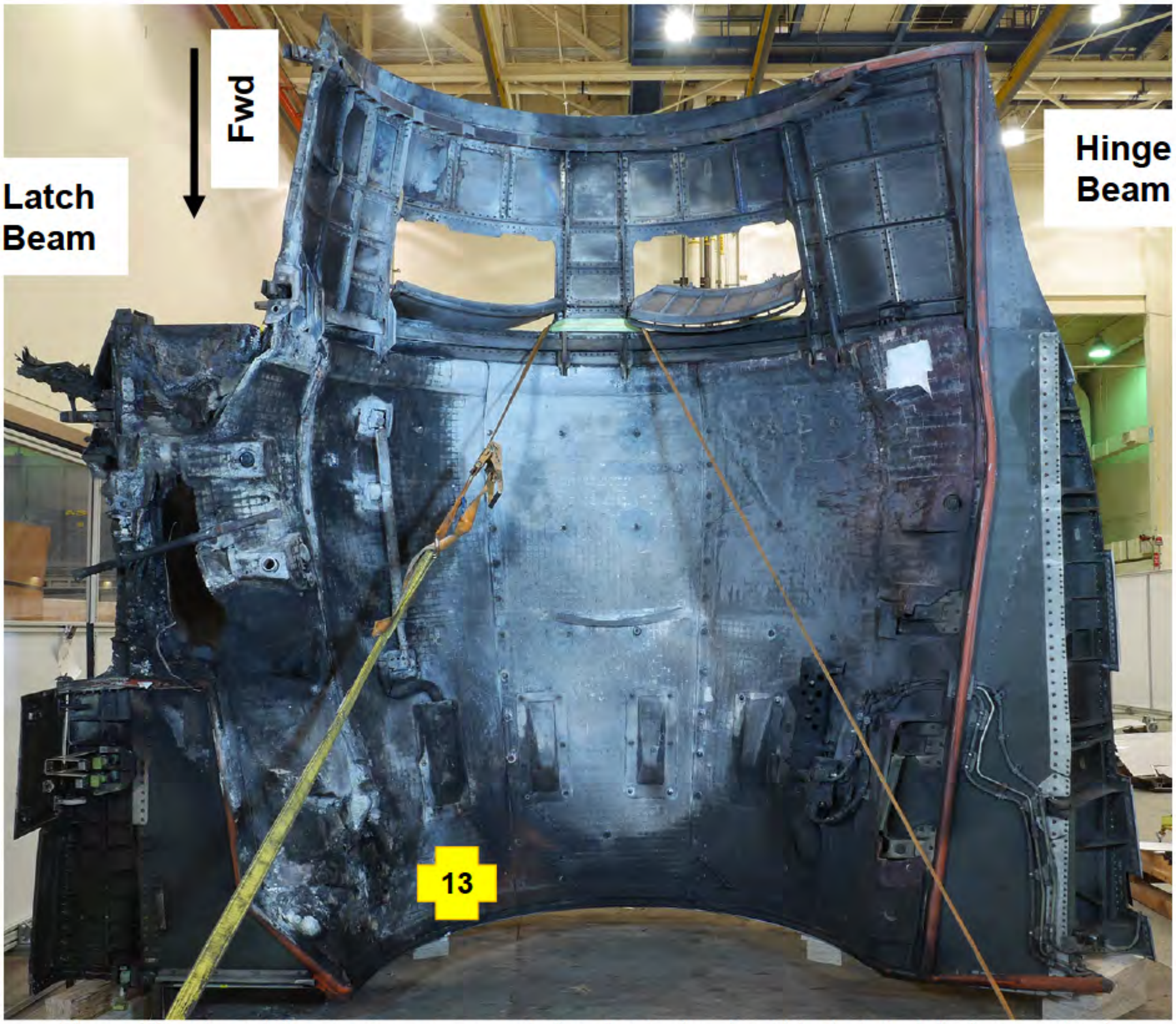


Figure 70: Inboard thrust reverser, supported on front edge, heat blankets installed as received.

Thrust reverser heat blankets were removed in coordination with the NTSB Airworthiness Group. Figure 71 shows the outboard thrust reverser with heat blankets removed.

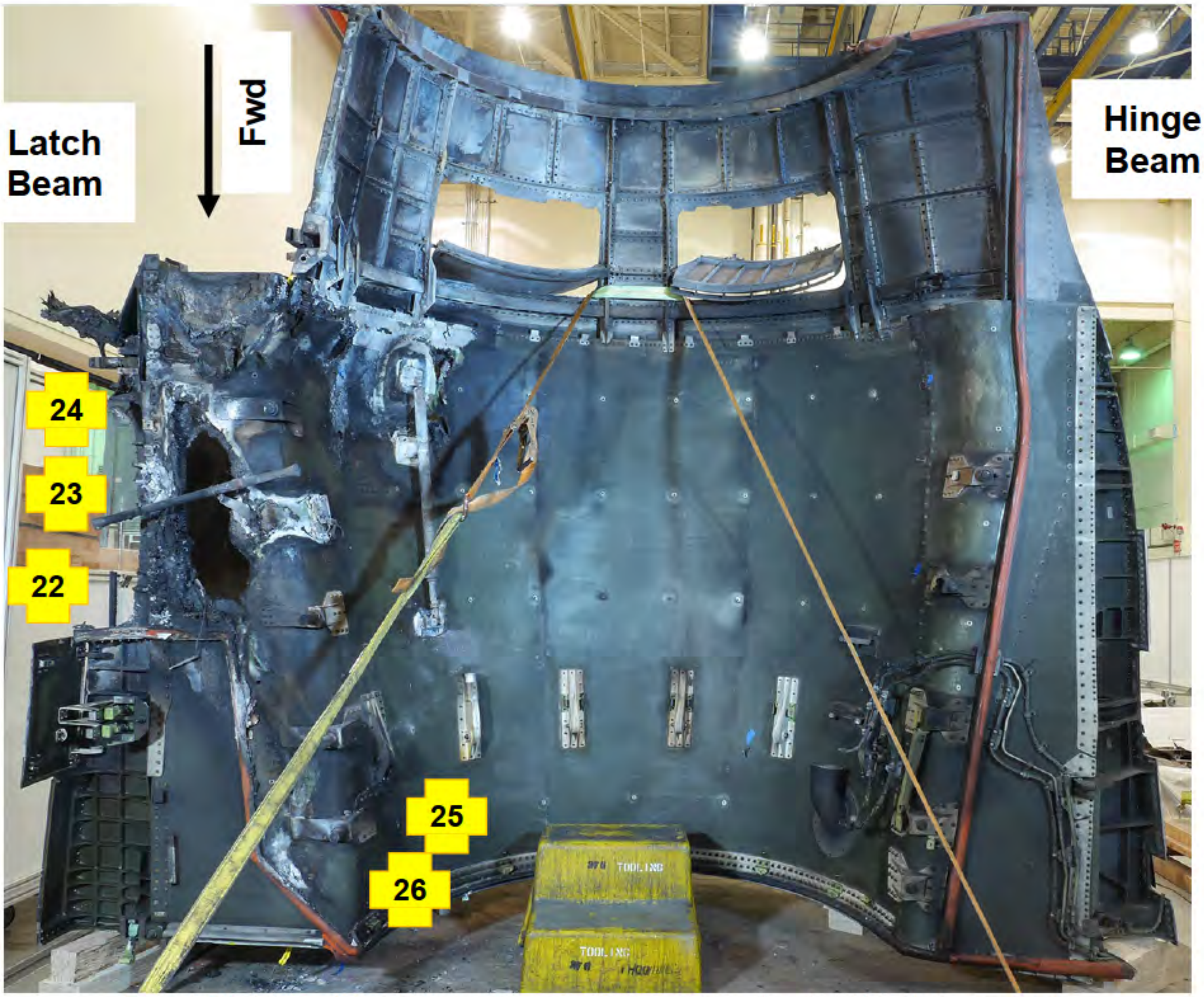


Figure 71: Inboard thrust reverser, supported on front edge, heat blankets removed.

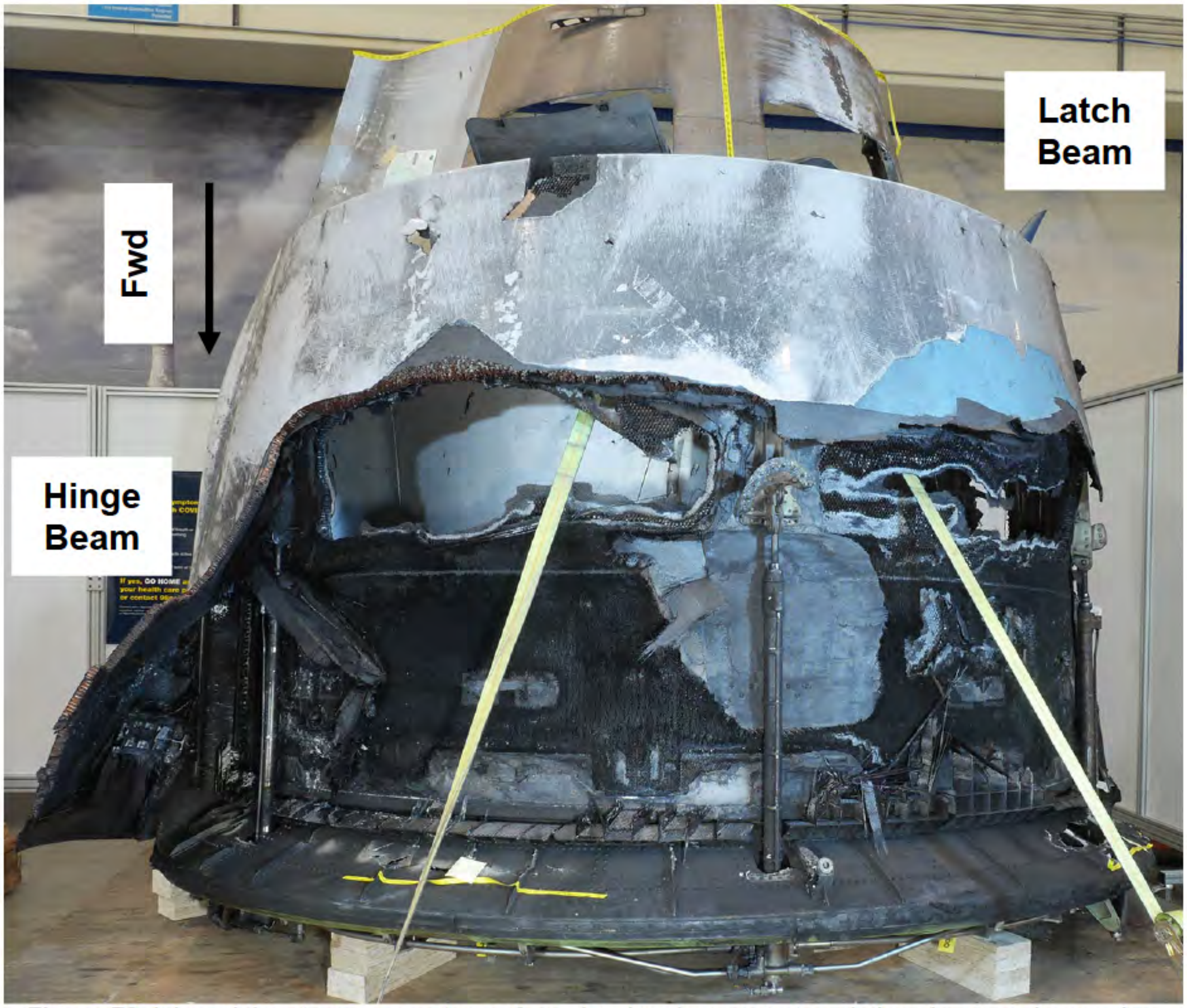


Figure 72: Inboard thrust reverser outer surface showing damage to translating sleeve and cascades.

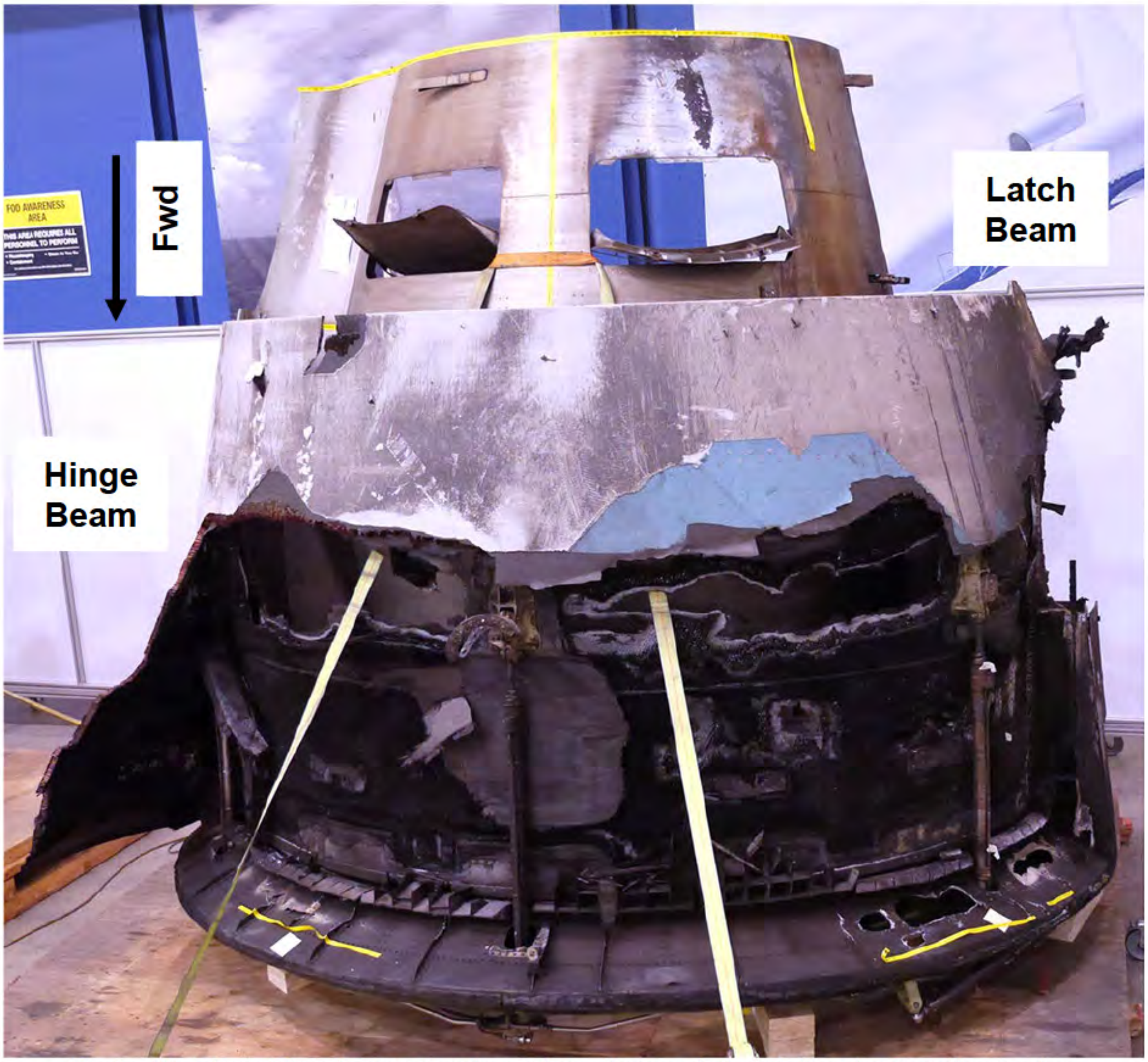


Figure 73: Inboard thrust reverser outer surface, damage to translating sleeve and cascades.

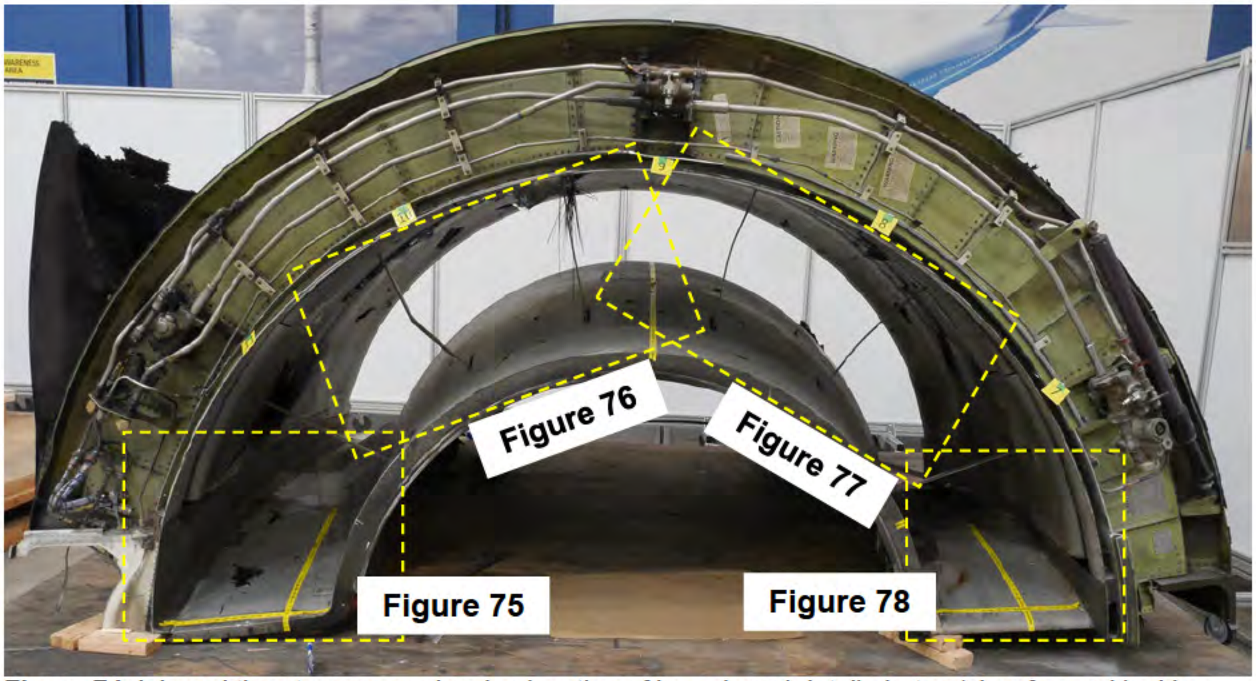


Figure 74: Inboard thrust reverser, showing location of inner barrel detail photos (view forward looking aft).

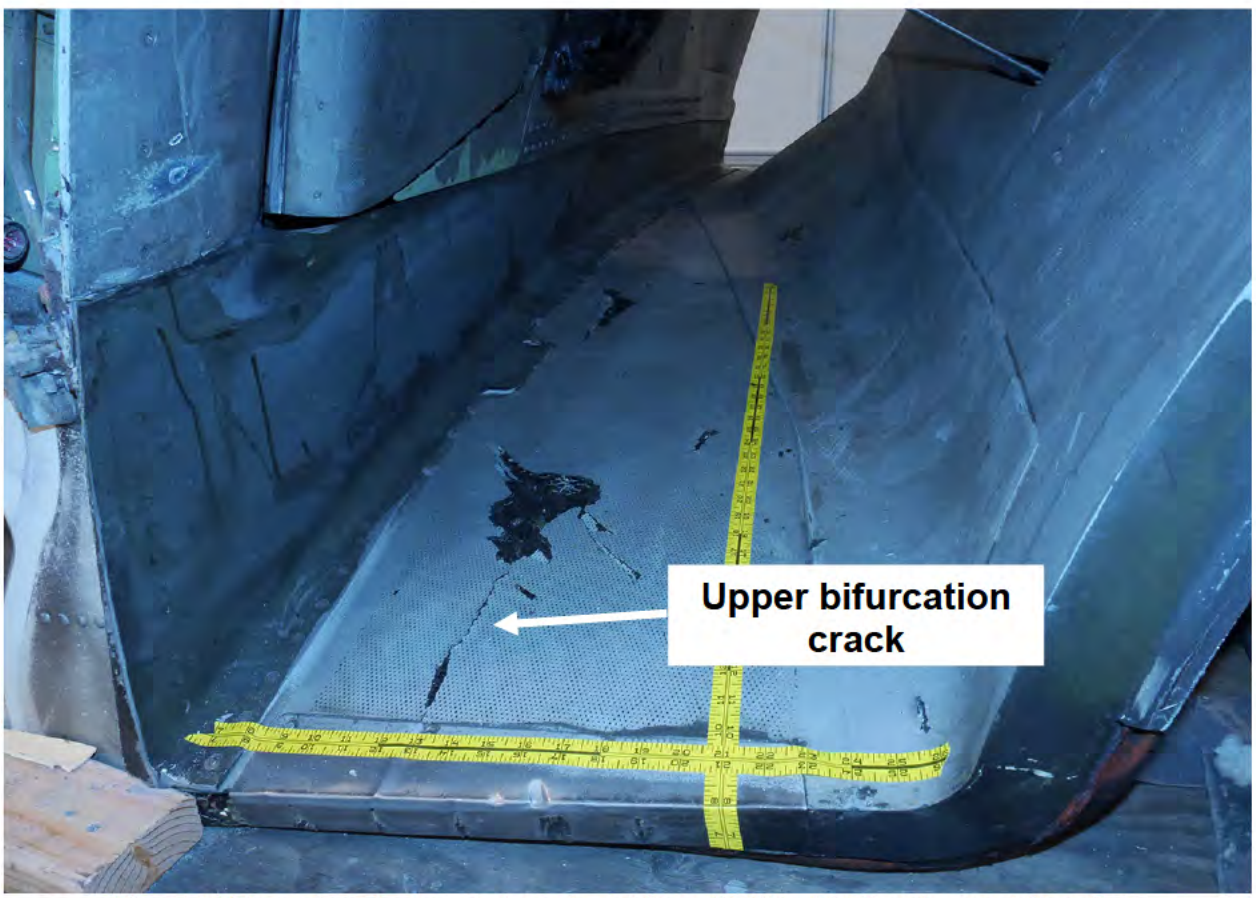


Figure 75: Inner thrust reverser, inner barrel from 12:00 to 11:00 and upper bifurcation.

Figure 76: Inboard thrust reverser, inner barrel from 11:00 to 9:00

Figure 77: Inboard thrust reverser, inner barrel from 9:00 to 7:00.

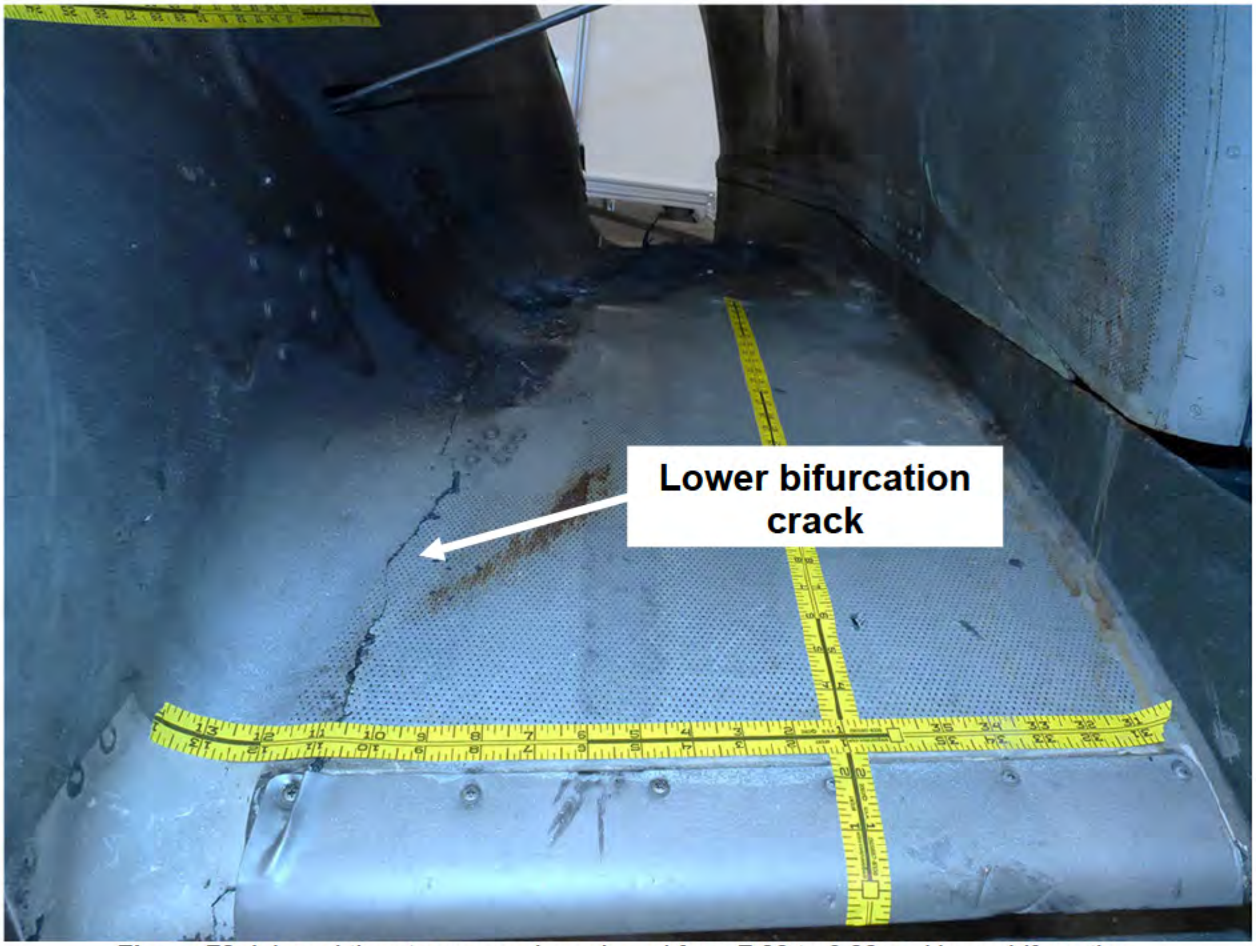


Figure 78: Inboard thrust reverser, inner barrel from 7:00 to 6:00 and lower bifurcation.

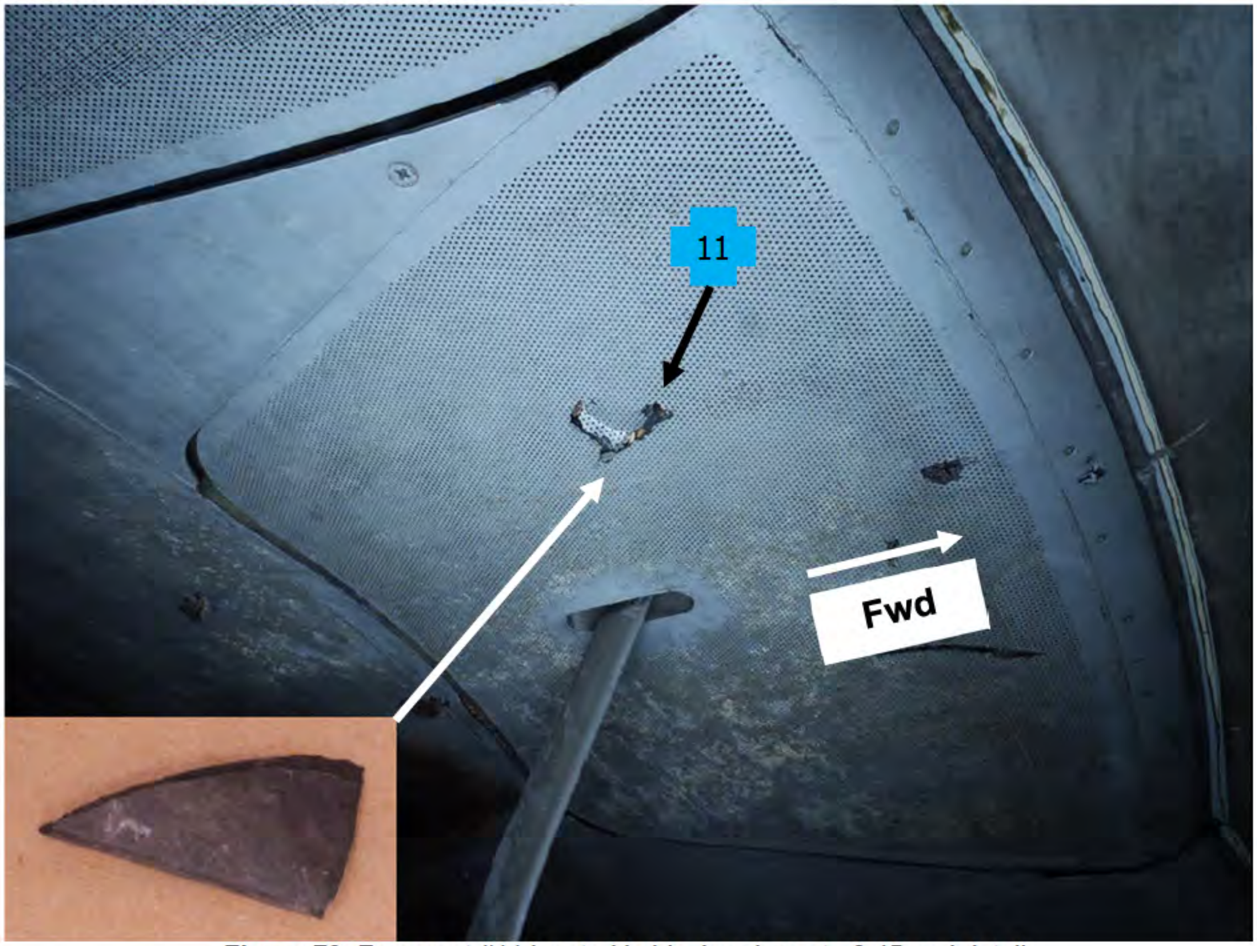


Figure 79: Fragment #11 located in blocker door at ~8:45 and detail.

DOOR ASSEMBLY, CENTER LATCH ACCESS:

Door assembly part number 314W3429-9 was recovered from the incident site. Chemical and metallurgical analyses were performed on sample areas seen in Figure 80 and Figure 81.

Figure 80: Door assembly, center latch access, outer surface.

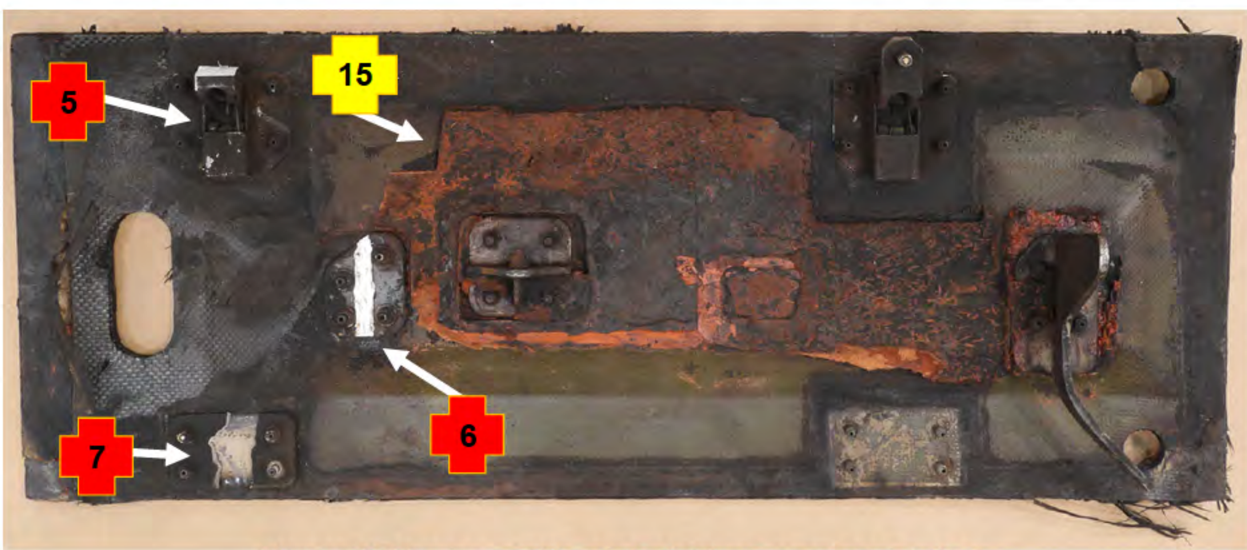


Figure 81: Door assembly, center latch access, inner surface.

ENGINE BACKUP GENERATOR (BUG)

Boeing received samples from United Airlines that were taken from the BUG, see Enclosure D for details. EQA photo-documented the condition of the parts and BR&T completed material analysis of the provided samples. BUG oil line samples of the white material near the hose connector were consistent with magnesium oxidation products. BUG oil line samples of the loose material in the hose connector threads were consistent with magnesium oxidation products. Gearbox mounted bracket samples of white material were consistent with magnesium oxidation products. Loose material samples, referred to by the investigative team as “creek rocks,” were most consistent with cast aluminum and aluminum alloys. Material samples collected from the four provided electrical connectors were consistent with corrosion products and an inorganic silicon compound.

MATERIAL AND CHEMICAL ANALYSIS:

Boeing Research and Technology (BR&T) completed material analysis of areas of interest. The NTSB Airworthiness Group identified areas for material analysis. Areas marked by in the preceding images and correspond to the samples in Enclosure A.

FRACTURE ANALYSIS:

BR&T completed material analysis of fractures areas of interest on thrust reverser components as determined by the NTSB Airworthiness Group, see Enclosure B. Areas are marked with a in the images correspond to the samples in Enclosure B.

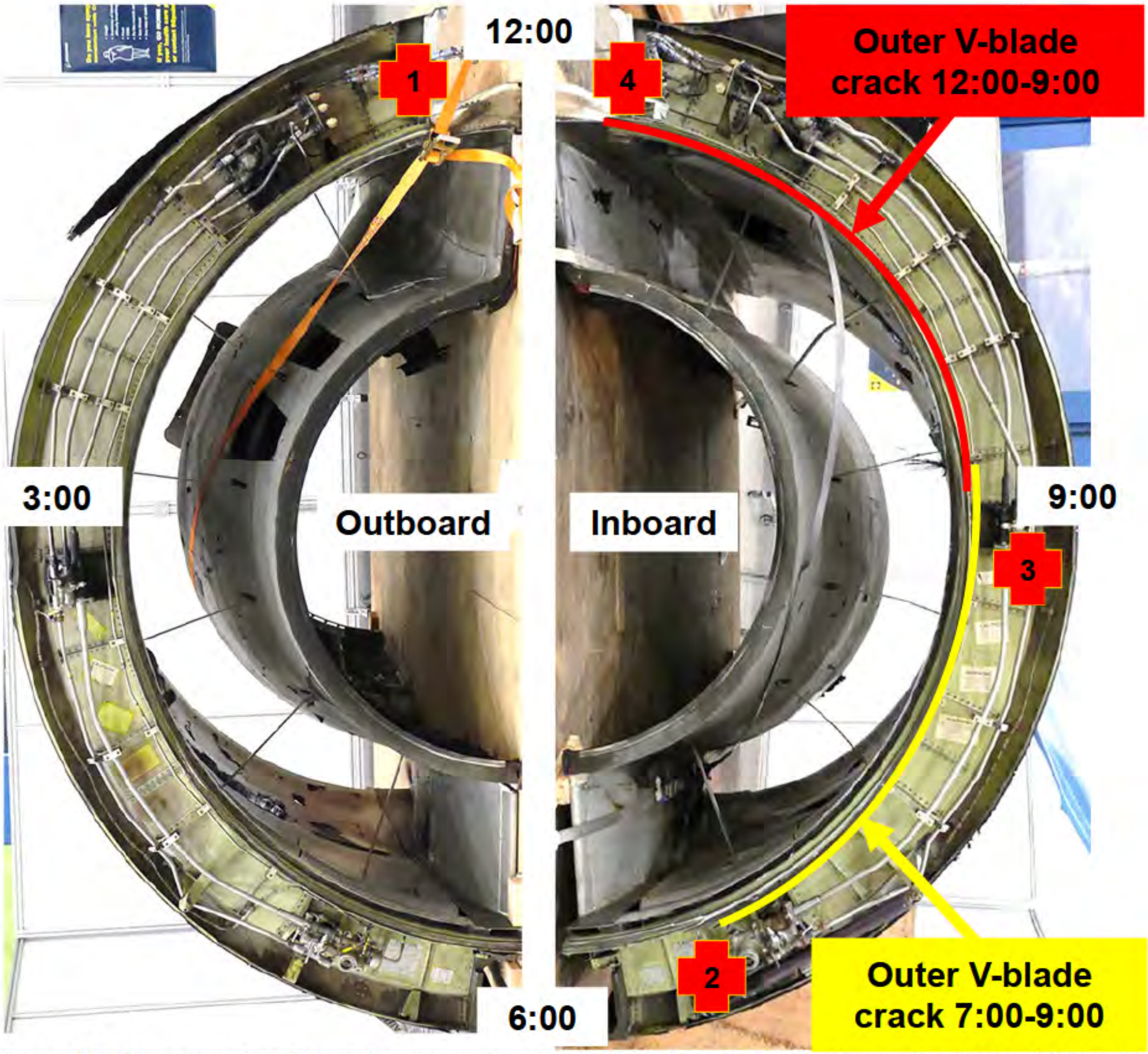


Figure 82: Inboard and outboard thrust reversers in aircraft orientation (view forward looking aft) Samples 1-4 removed for fracture analysis.

Figure 83: Outboard (right) thrust reverser crack at 12:00.

Figure 84: Outboard (right) thrust reverser crack at 12:00 removed.

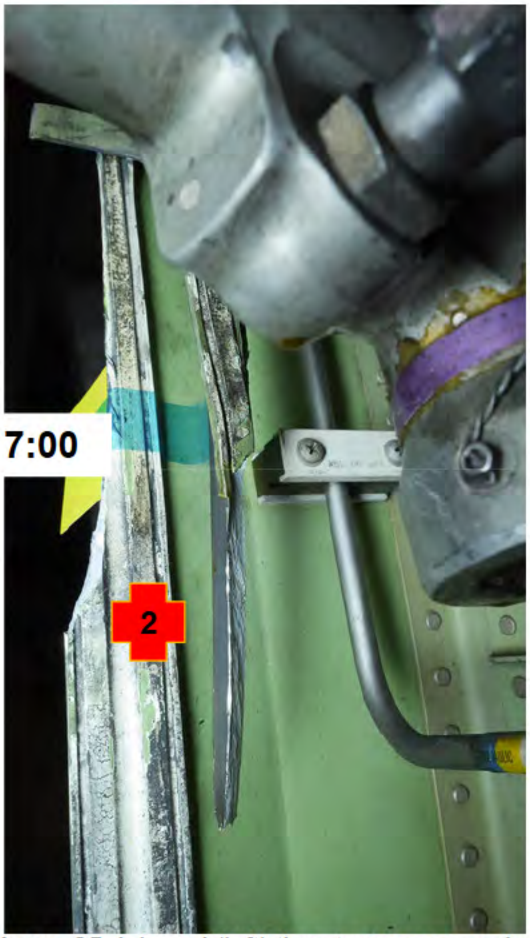


Figure 85: Inboard (left) thrust reverser crack at 7:00.

Figure 86: Inboard (left) thrust reverser crack at 7:00 removed.

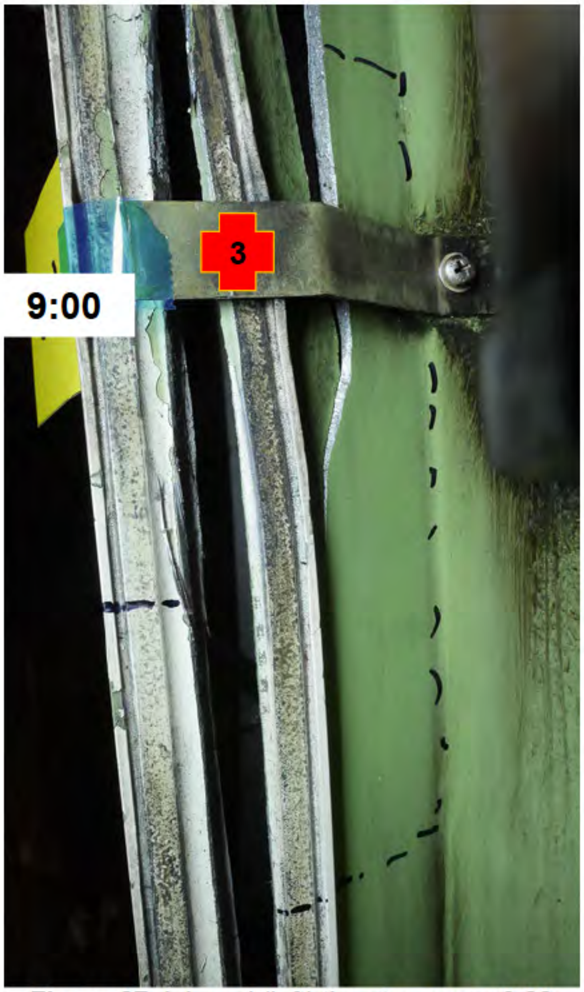


Figure 87: Inboard (left) thrust reverser 9:00 crack.

Figure 88: Inboard (left) thrust reverser 9:00 crack removed.

Figure 89: Inboard (left) thrust reverser crack at 12:00 removed.

THERMOGRAPHIC ANALYSIS:

Fluid ingression inspection was performed using a handheld infrared (IR) camera and a heat gun. Examination included parts from the fan cowl and inlet cowl outer barrel with sealed core. Areas marked with  in Figure 90 and Figure 91 indicate fluid ingression. See enclosure C for details.

Figure 90: Fan cowl thermography results.

Figure 91: Inlet cowl outer barrel thermography results.

DISPOSITION:

On August 31, 2021 the inlet cowl lipskin, attach ring and forward bulkhead were secured in the inlet cowl shipping crate as seen in Figure 2. The remaining inlet cowl parts and and fan cowl parts were packaged in the shipping crates seen in Figure 3. On September 1, 2021 both thrust reversers were secured to their respective pallets and covers lowered into place as seen in Figure 31 and Figure 32. The subject components, in as received shipping containers, are stored in a secure location near Boeing Seattle WA, pending instructions from the NTSB for final disposition.

Signatures on file.

ENCLOSURE:

A. Chemical_analysis_777_NTSB_UAL_investigations
B. UAL 777-200 FBO Thrust Reverser Fracture Analysis
C. UAL_investigation_thermography_report
D. Boeing EQA report AS13354, Backup Generator Material Samples, Denver Fan Blade Out Event.

Engineering, Test & Technology
Boeing Research & Technology

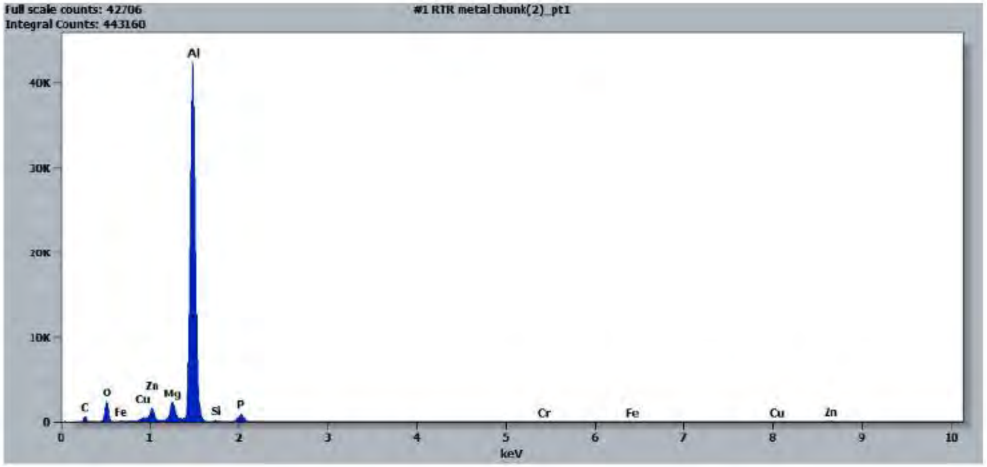
Chemical analysis for 777 NTSB UAL investigation

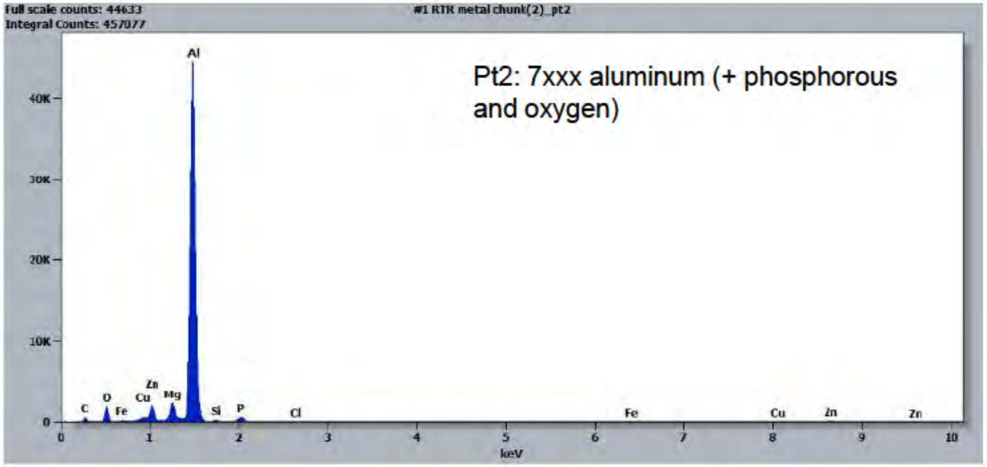
May 13, 2021

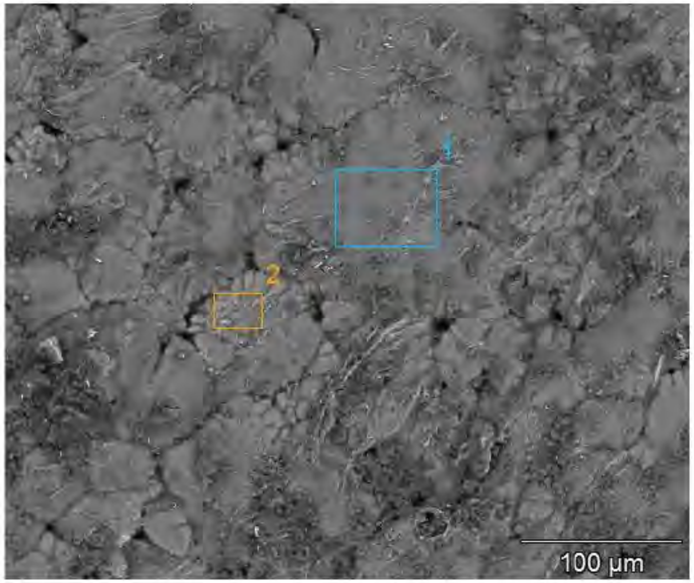
Enclosure A to EQA Reports AS13328 and AS13354

Sample #1 Right TR Metal slag aft side torque box 6:00

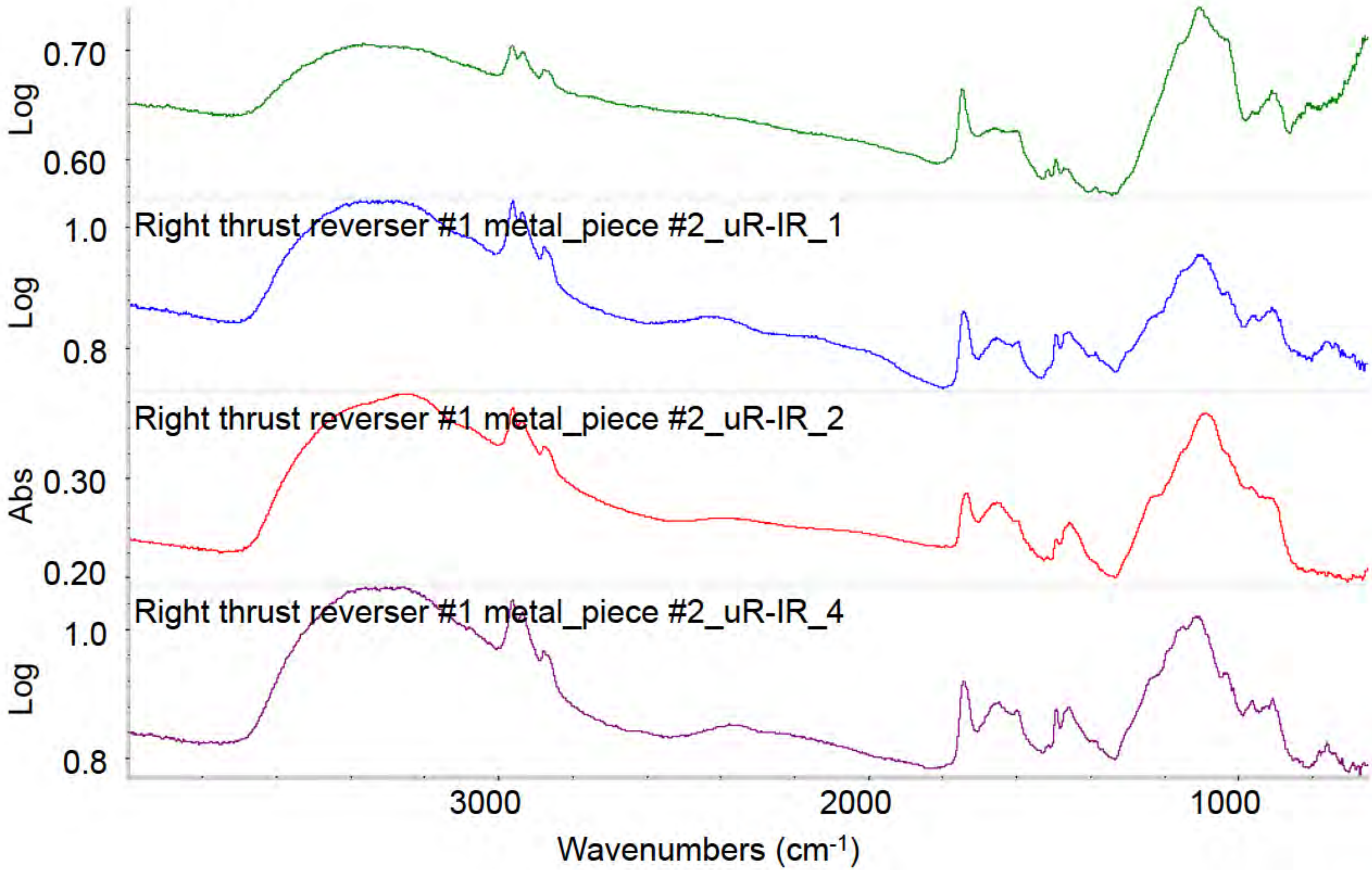
#1 RH TR metal: consistent with 7xxx aluminum, but has elevated phosphorous and oxygen content



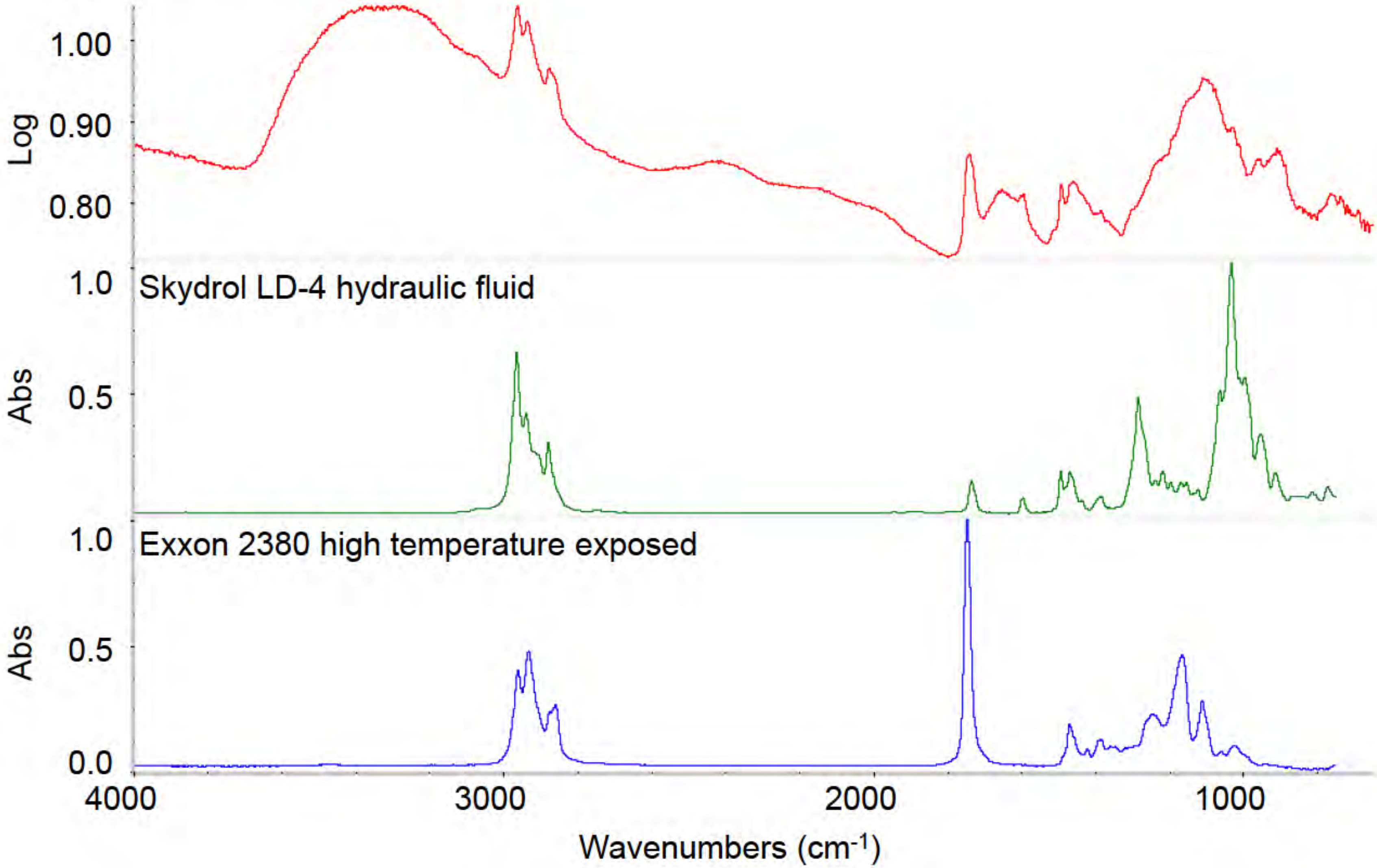




The residue on the right thrust reverser #1 metal pieces was similar. The residue was consistent with a mixture of turbine oil and phosphate ester hydraulic fluid.

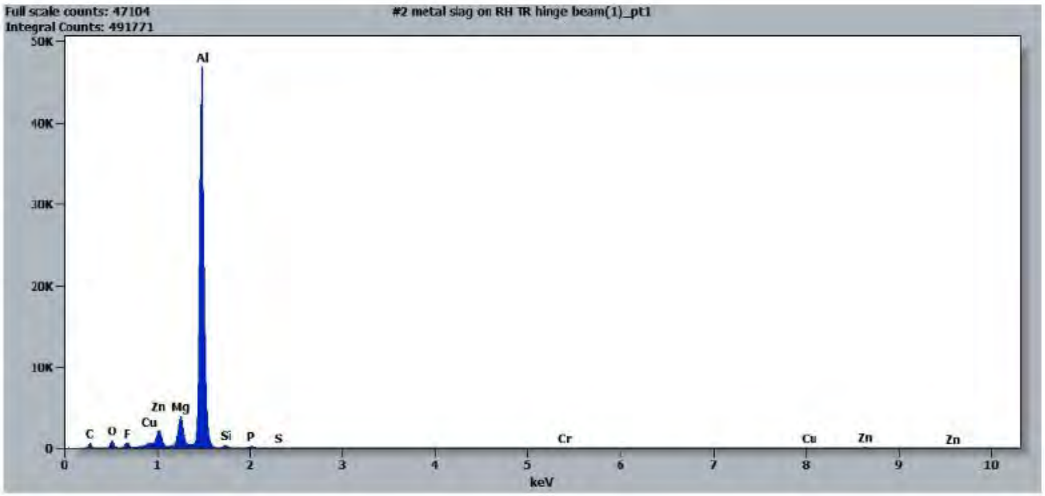


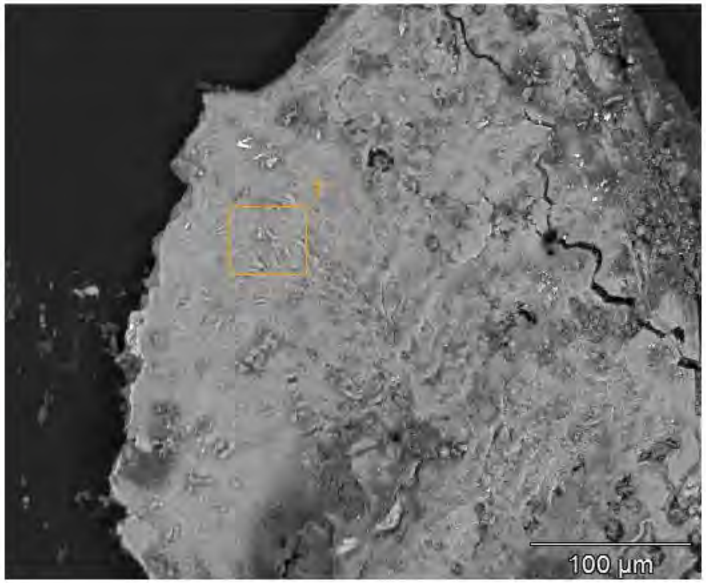
The residue on the metal surface was consistent with a mixture of turbine oil (Eastman 2380 as an example) and phosphate ester hydraulic fluid (Skydrol LD-4 as an example).



Sample #2 Right hand TR metal slag hinge beam

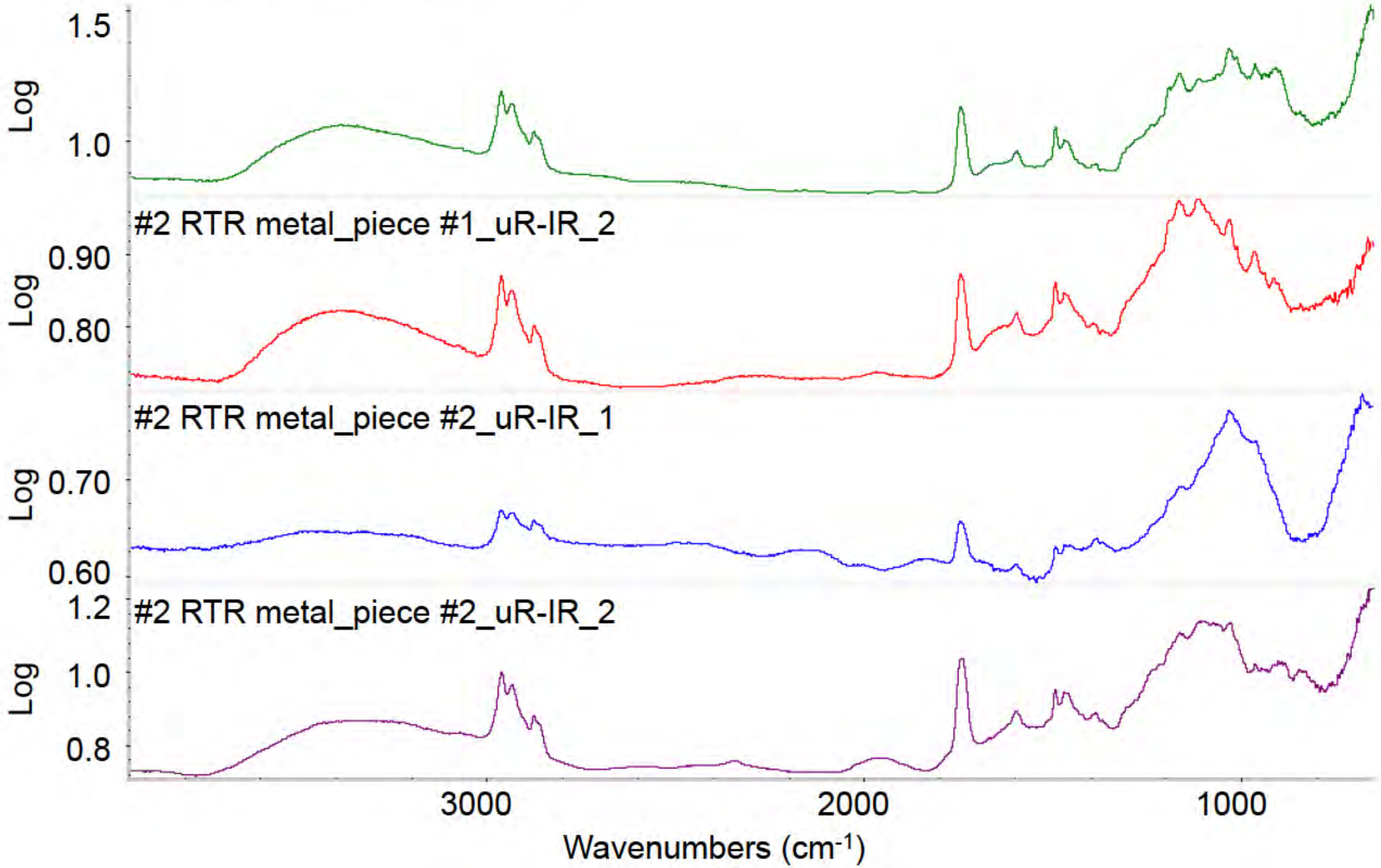
2 metal slag on RH TR hinge beam consistent with 7xxx aluminum



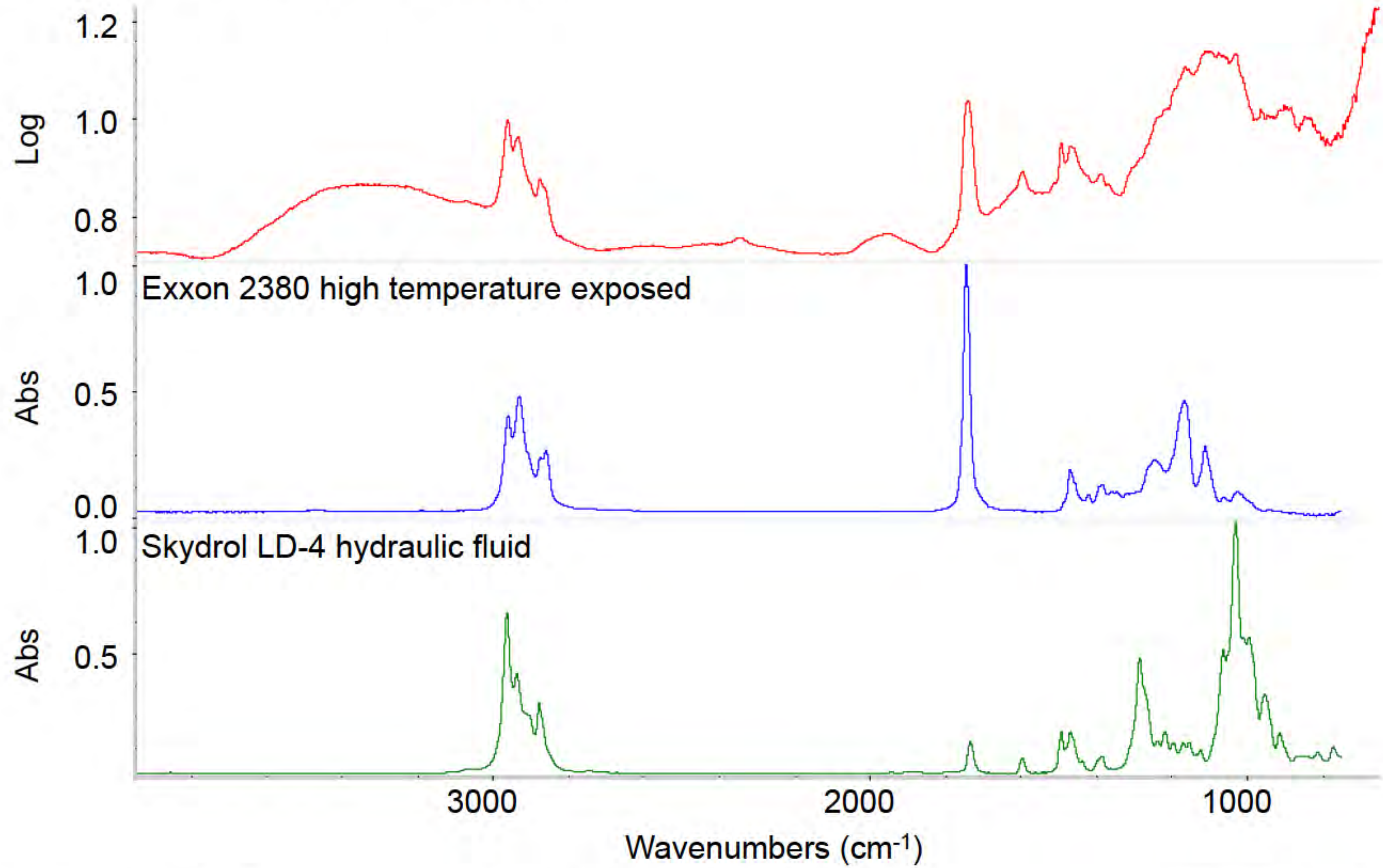


Enclosure A to EQA Reports AS13328 and AS13354

The organic residue on the #2 RTR metal pieces was similar in overall chemistry. This residue was similar to a mixture of turbine oil and phosphate ester hydraulic fluid.

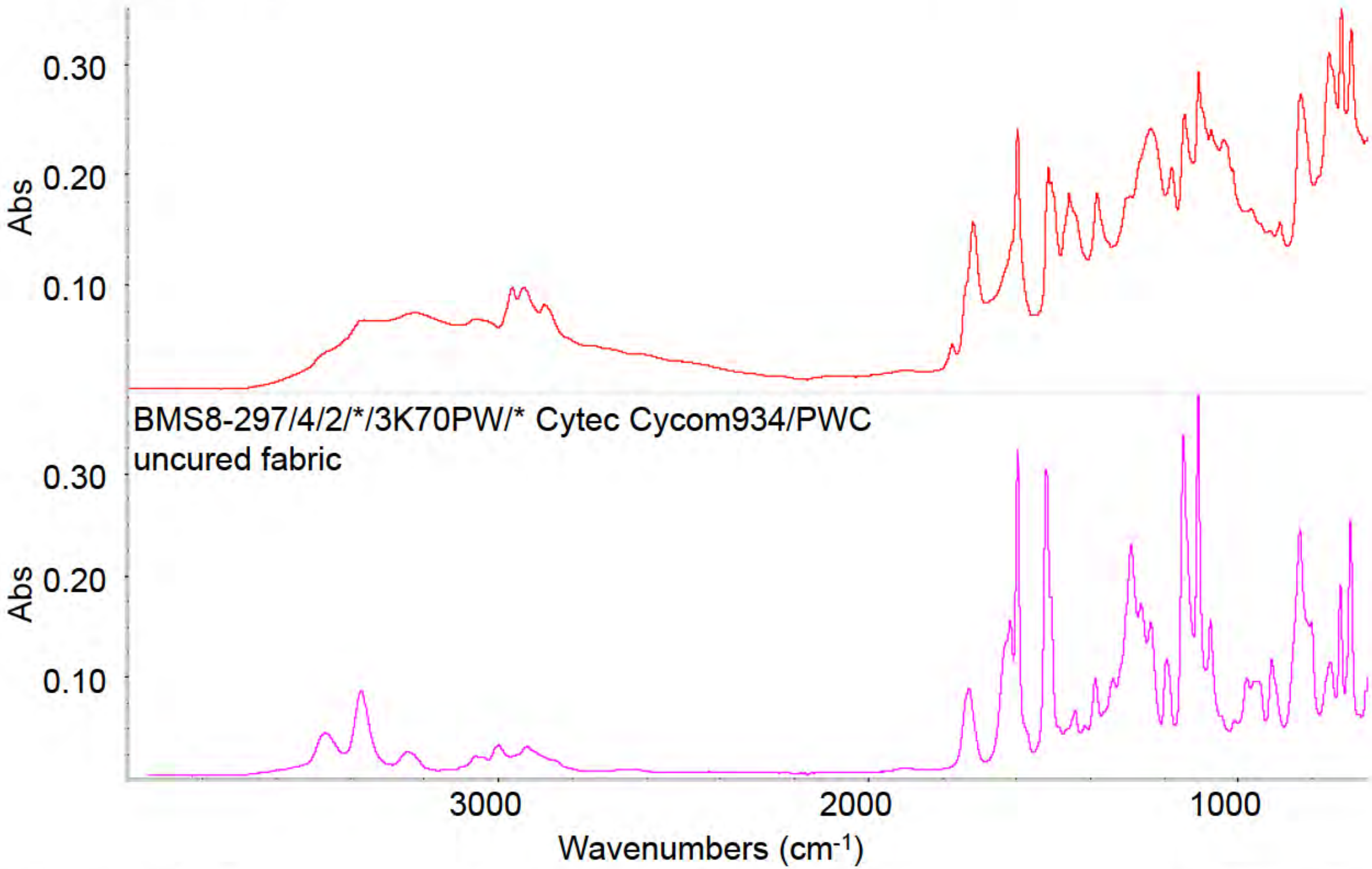


The residue on the metal surface was consistent with a mixture of turbine oil (Eastman 2380 as an example) and phosphate ester hydraulic fluid (Skydrol LD-4 as an example).



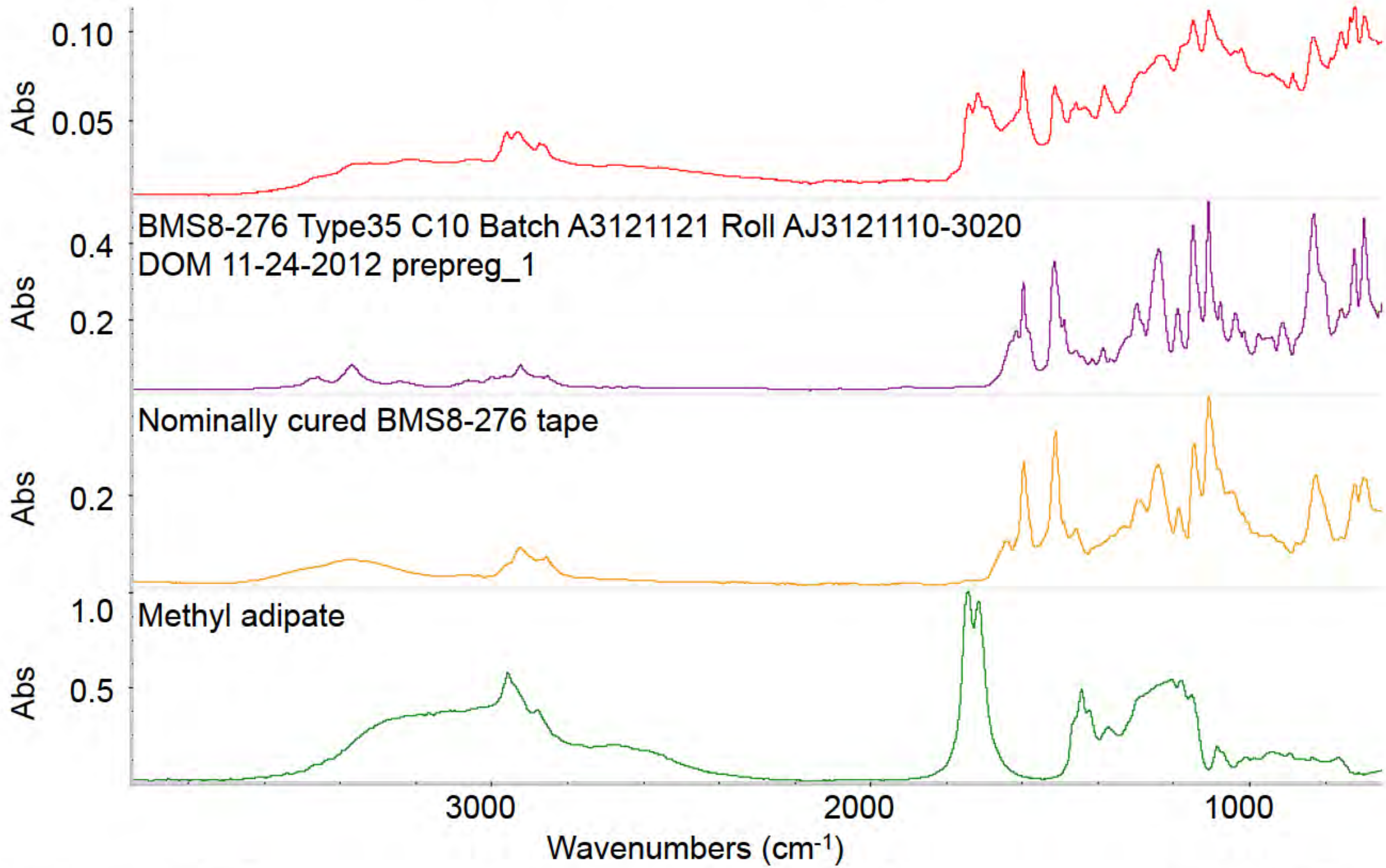
Sample #3 Right hand TR inner skin brown goo translating sleeve

#3 brown deposit on RH TR translating sleeve inner perforated skin was consistent with an epoxy resin which is likely oxidized

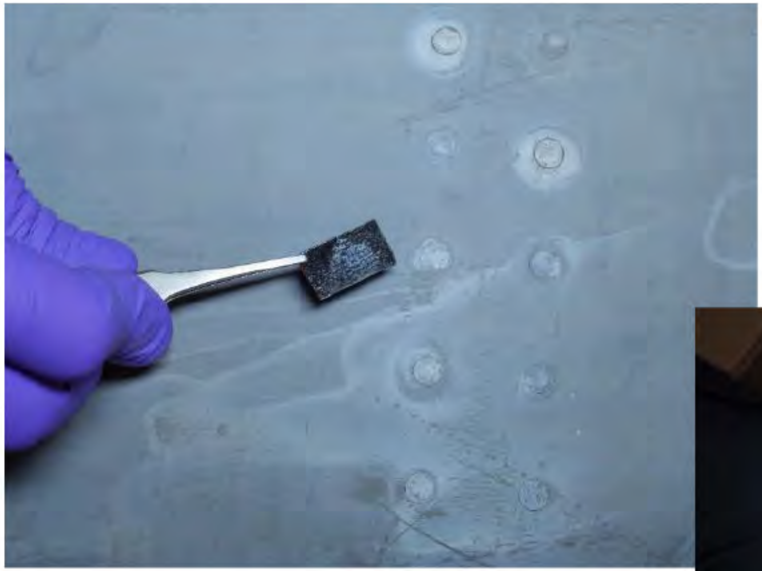


Sample #4 Right thrust reverser inner skin bifurcation brown goo

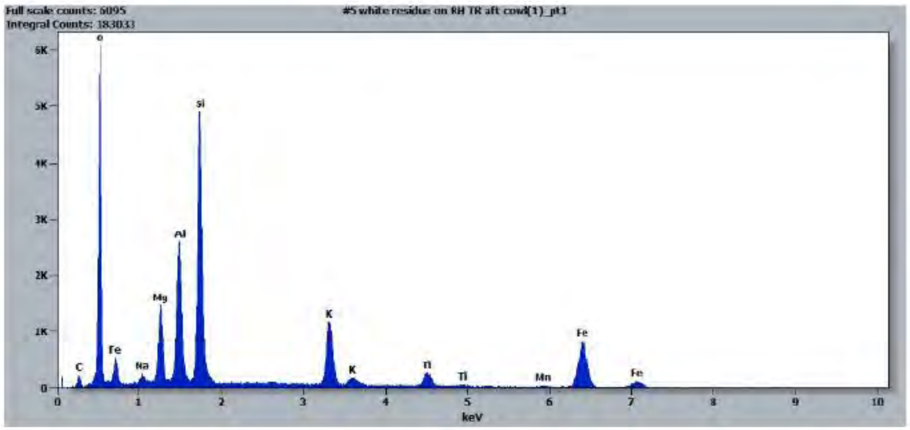
#4 brown deposit on RH TR bifurcation inner perforated skin was consistent with an epoxy resin likely in a mixture of cure / crosslinking states as well as an adipate chemistry which could be from handling or a plasticizer

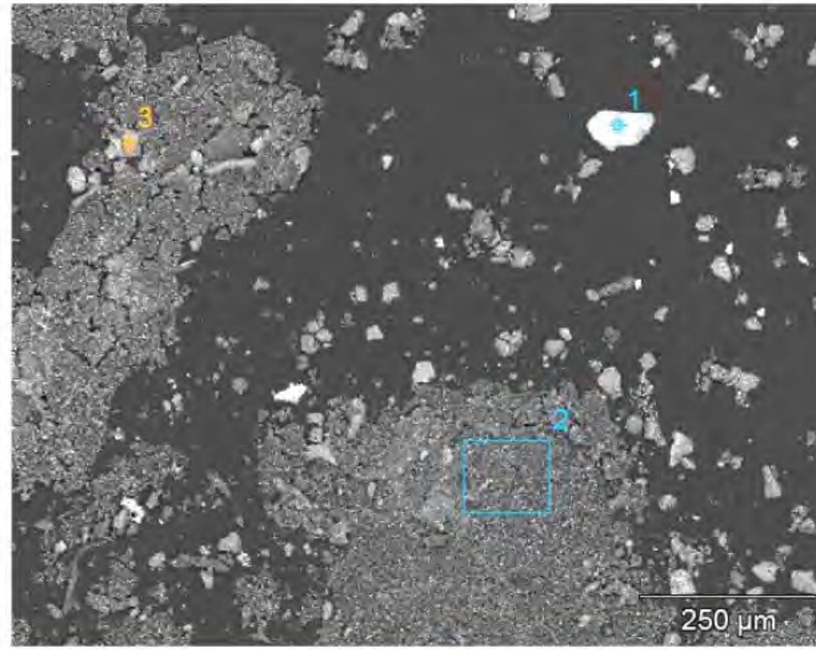


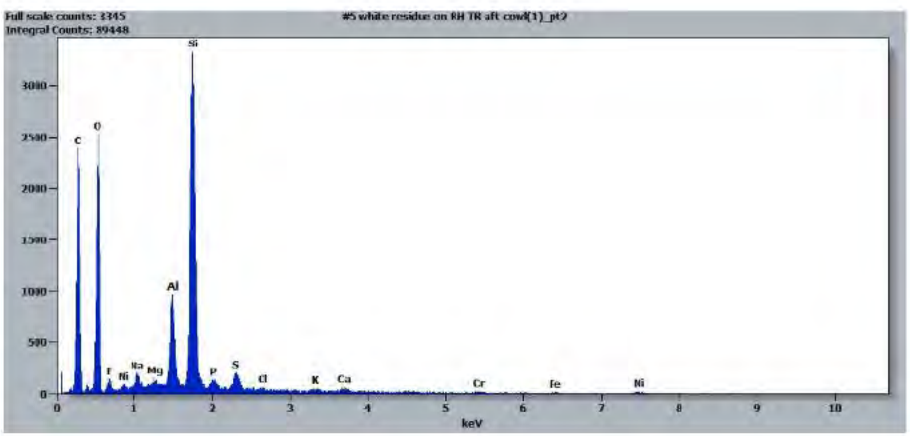
Sample #5 white residue

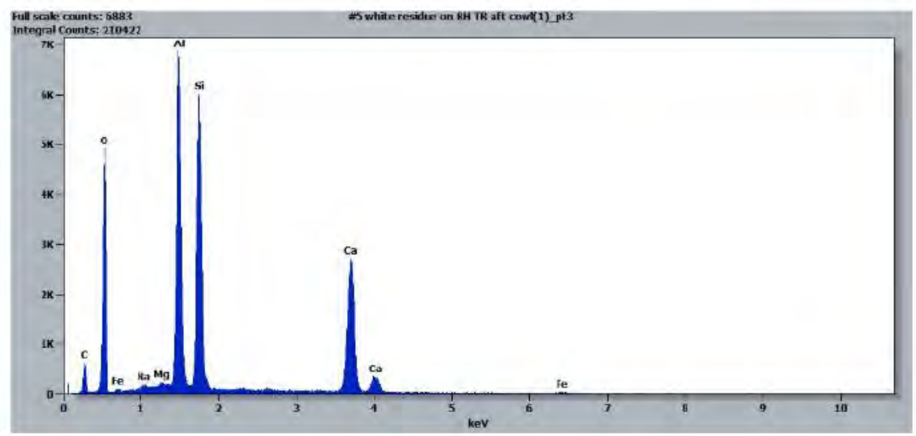


5 white residue – consistent with inorganic/mineral debris

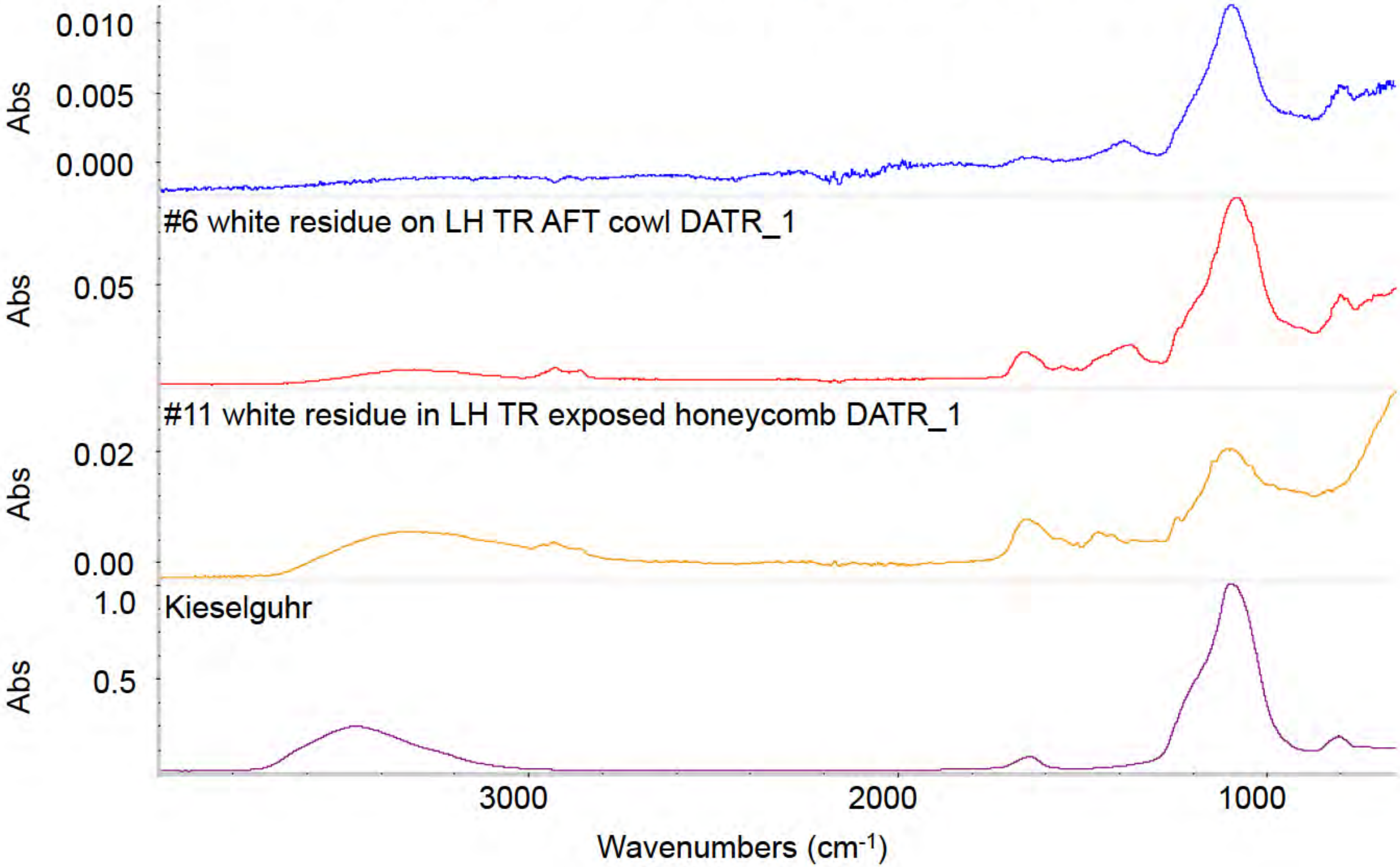






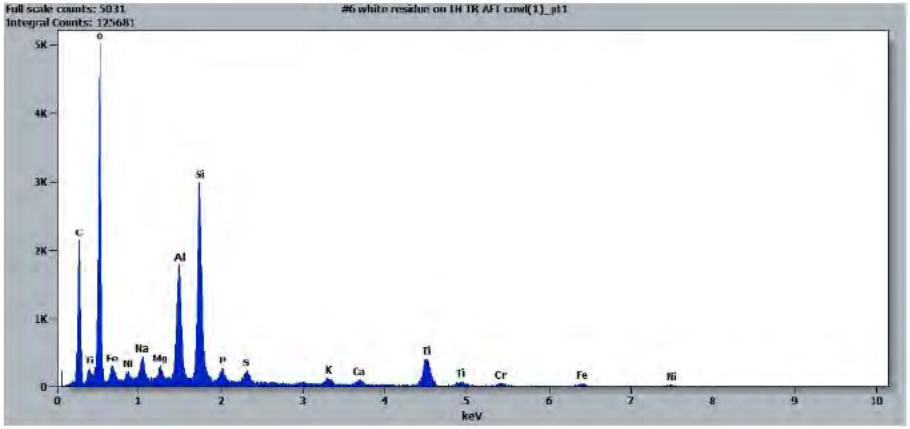


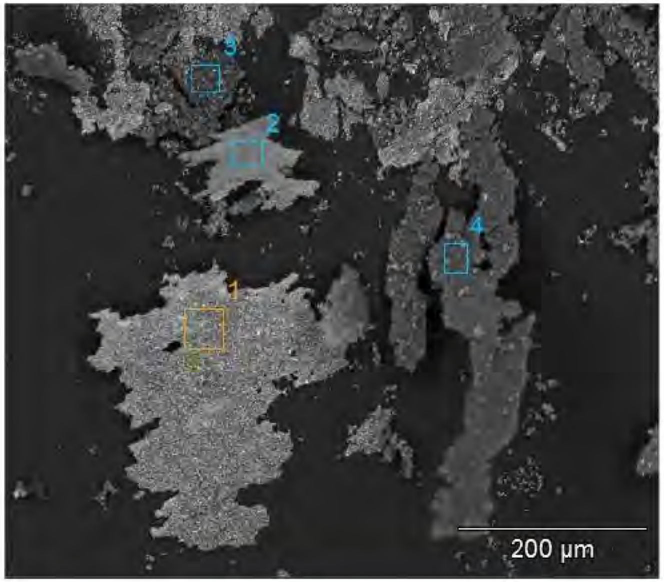
The white residues from samples #5, #6 and #11 were consistent with inorganic material, possibly silica based.

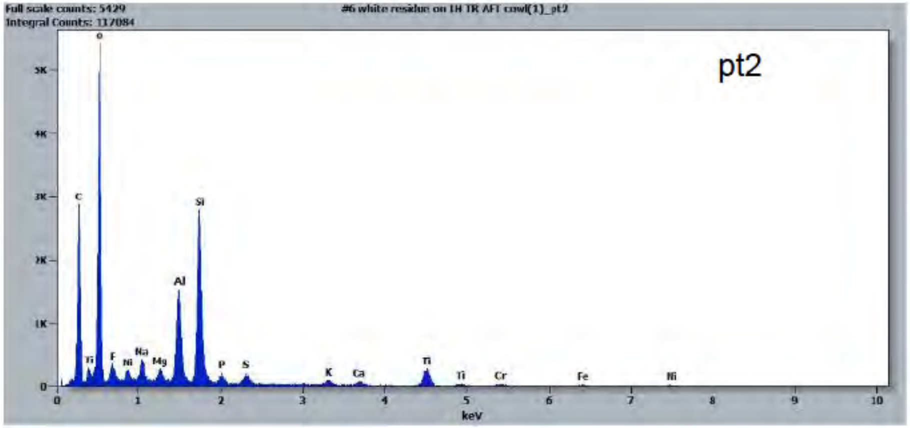


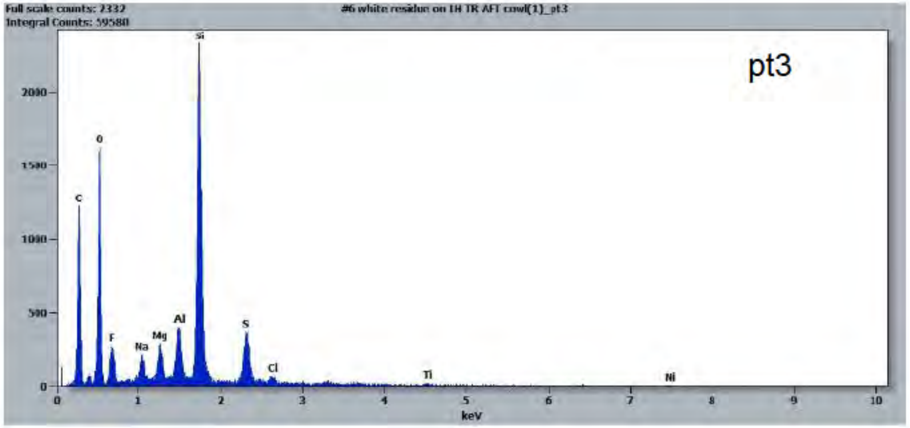
Sample #6 White residue

6 EDS white residue on LH TR AFT cowl is consistent with inorganic material



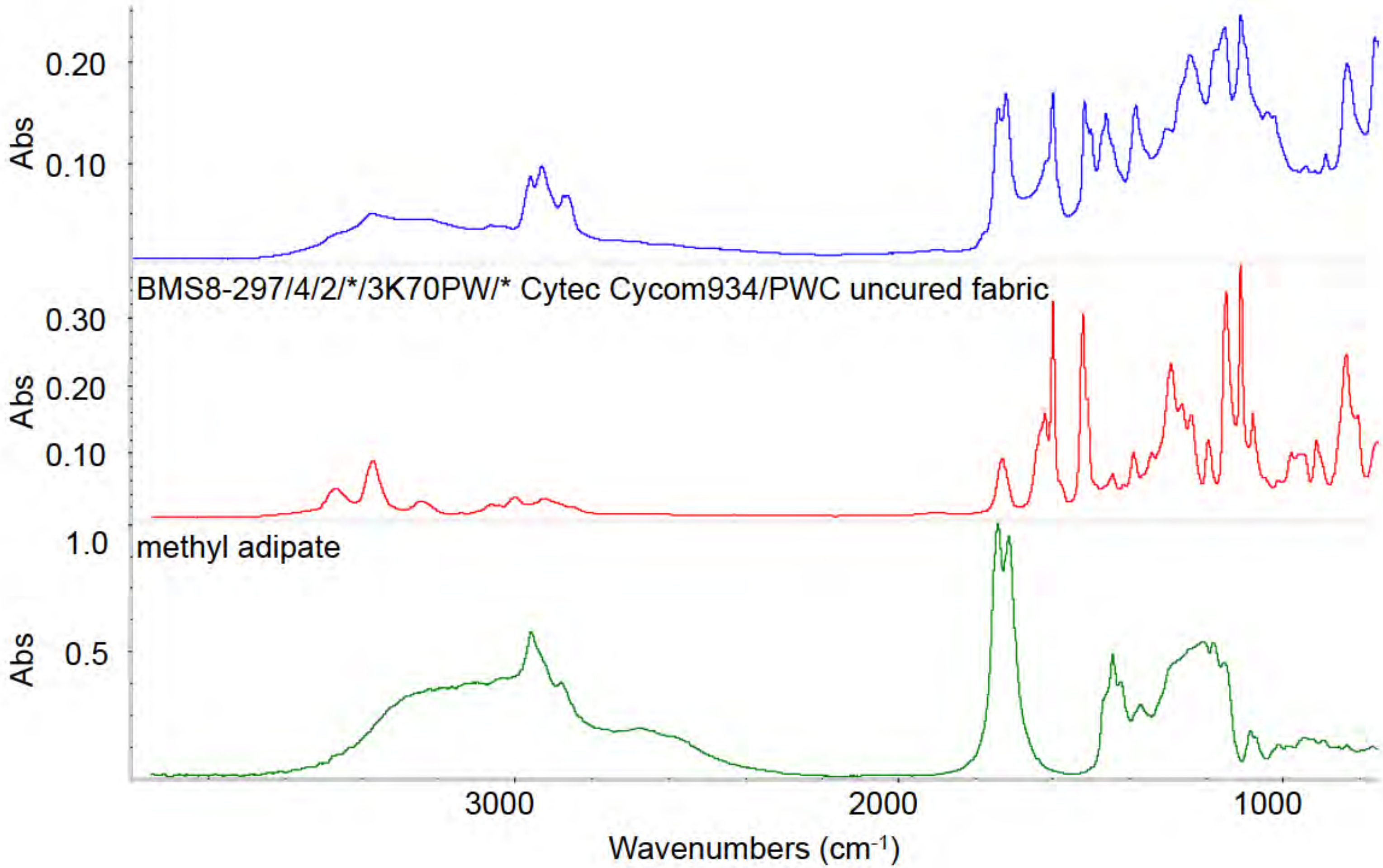






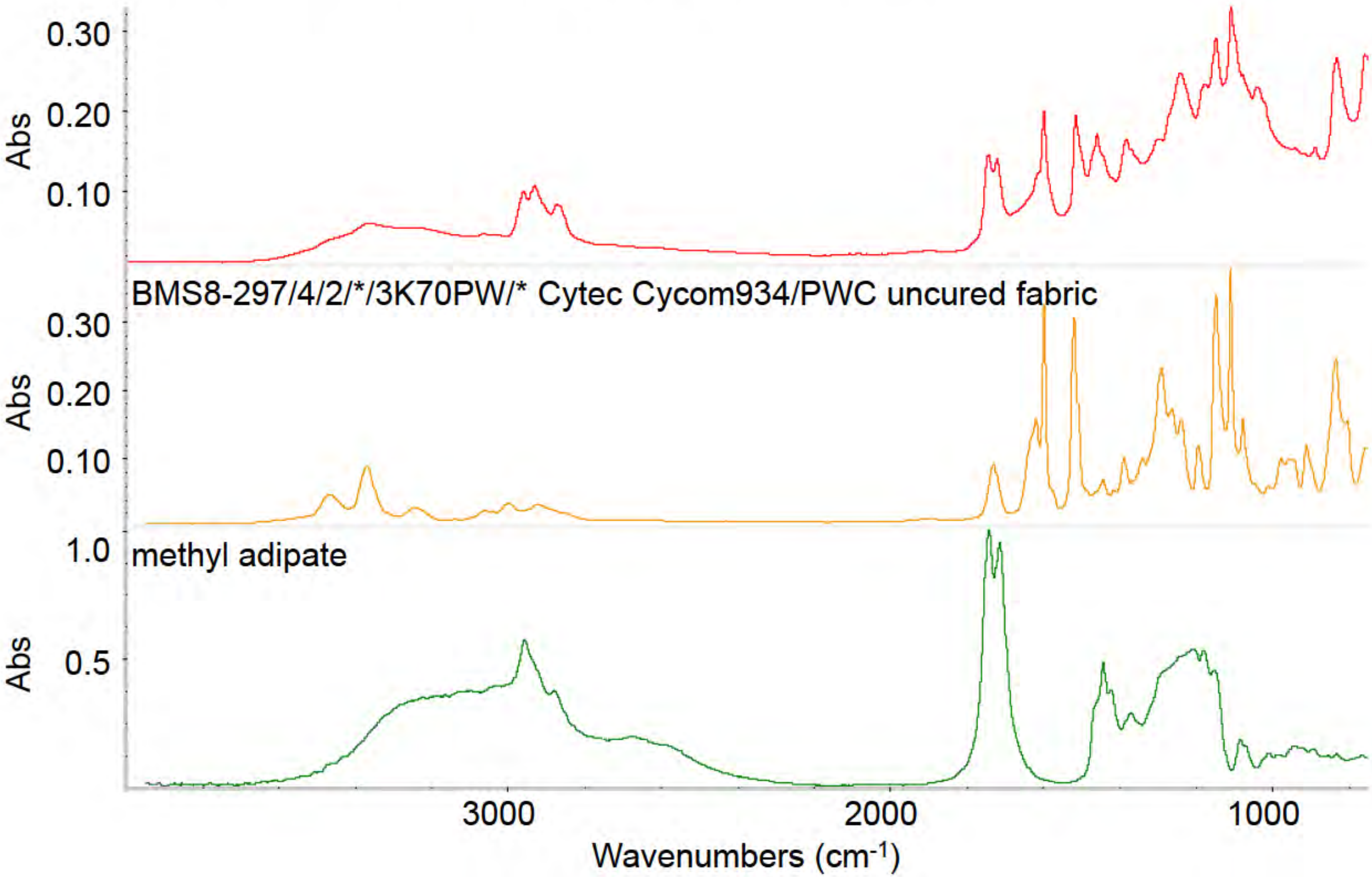
Sample #7 Left hand TR core skin brown goo

7 brown deposit on LH TR core cowl perforated skin was consistent with a mixture of epoxy resin and a chemistry similar to an methyl adipate (adipate-based chemistry could be from handling or plasticizers)



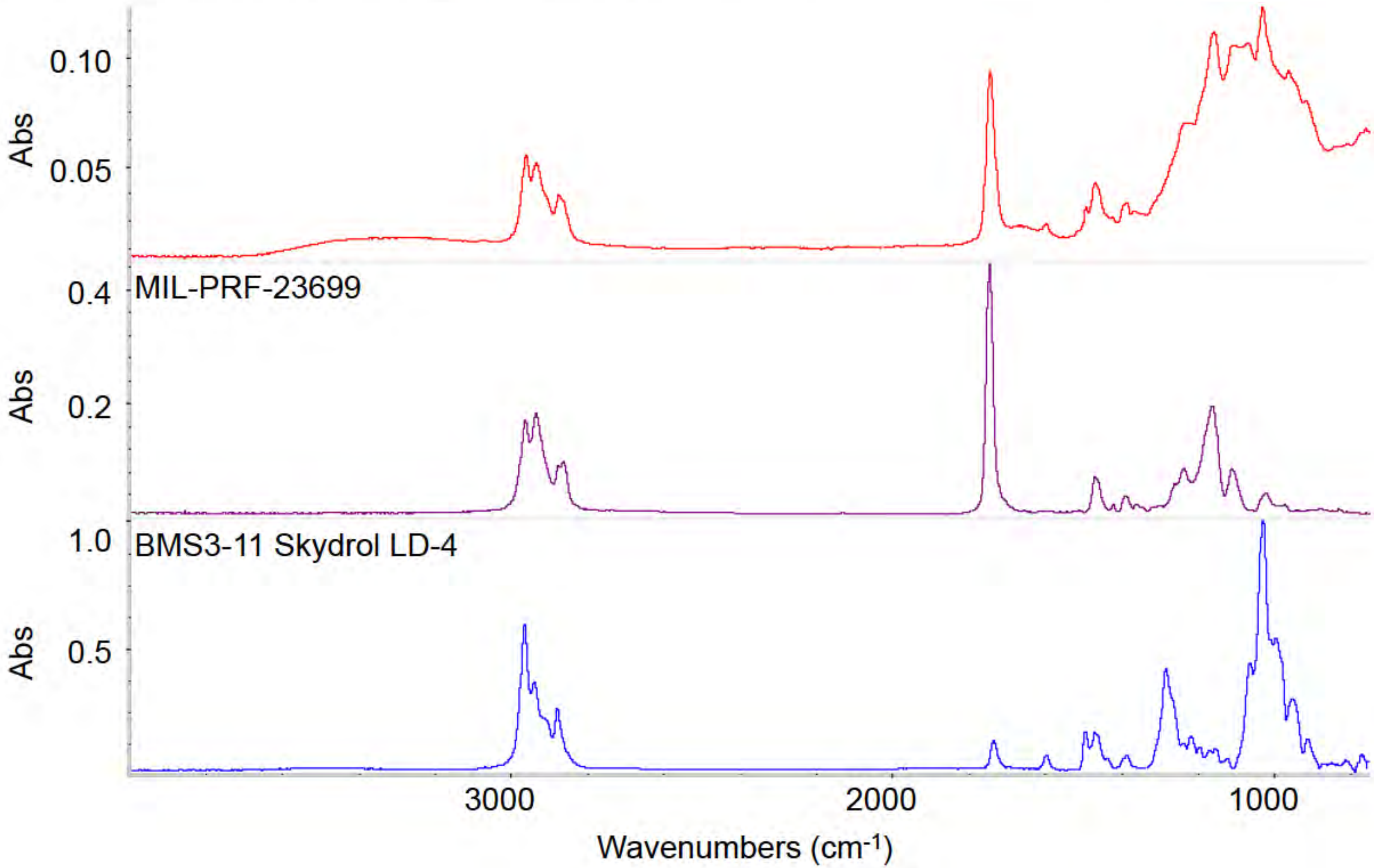
Sample #8 Left hand TR inner skin brown goo

8 brown deposit on LH TR translating sleeve inner perforated skin was consistent with a mixture of epoxy resin and adipate (adipate-based chemistry could be from handling or plasticizers)

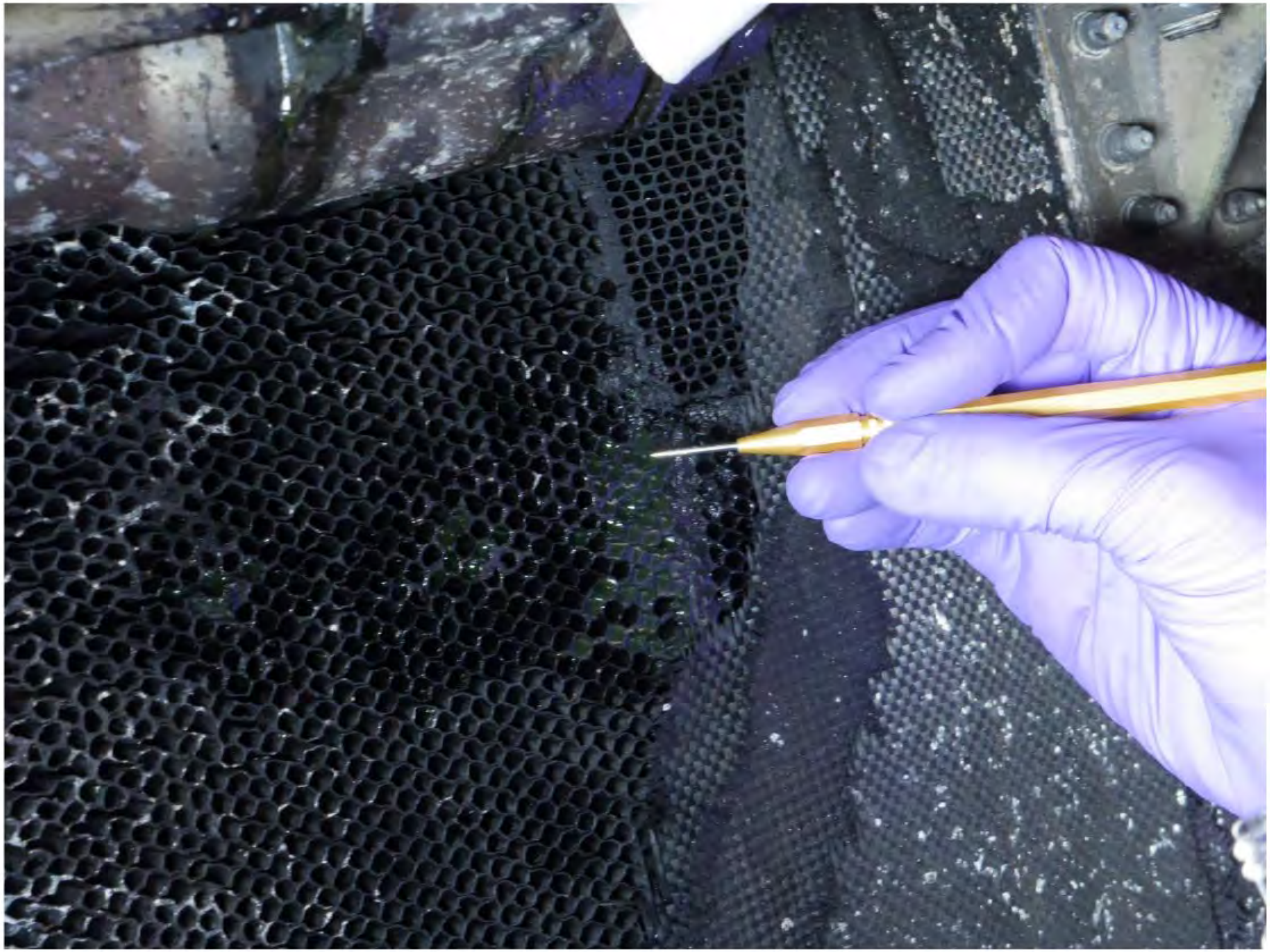


Sample #9 Left hand TR soot hinge beam

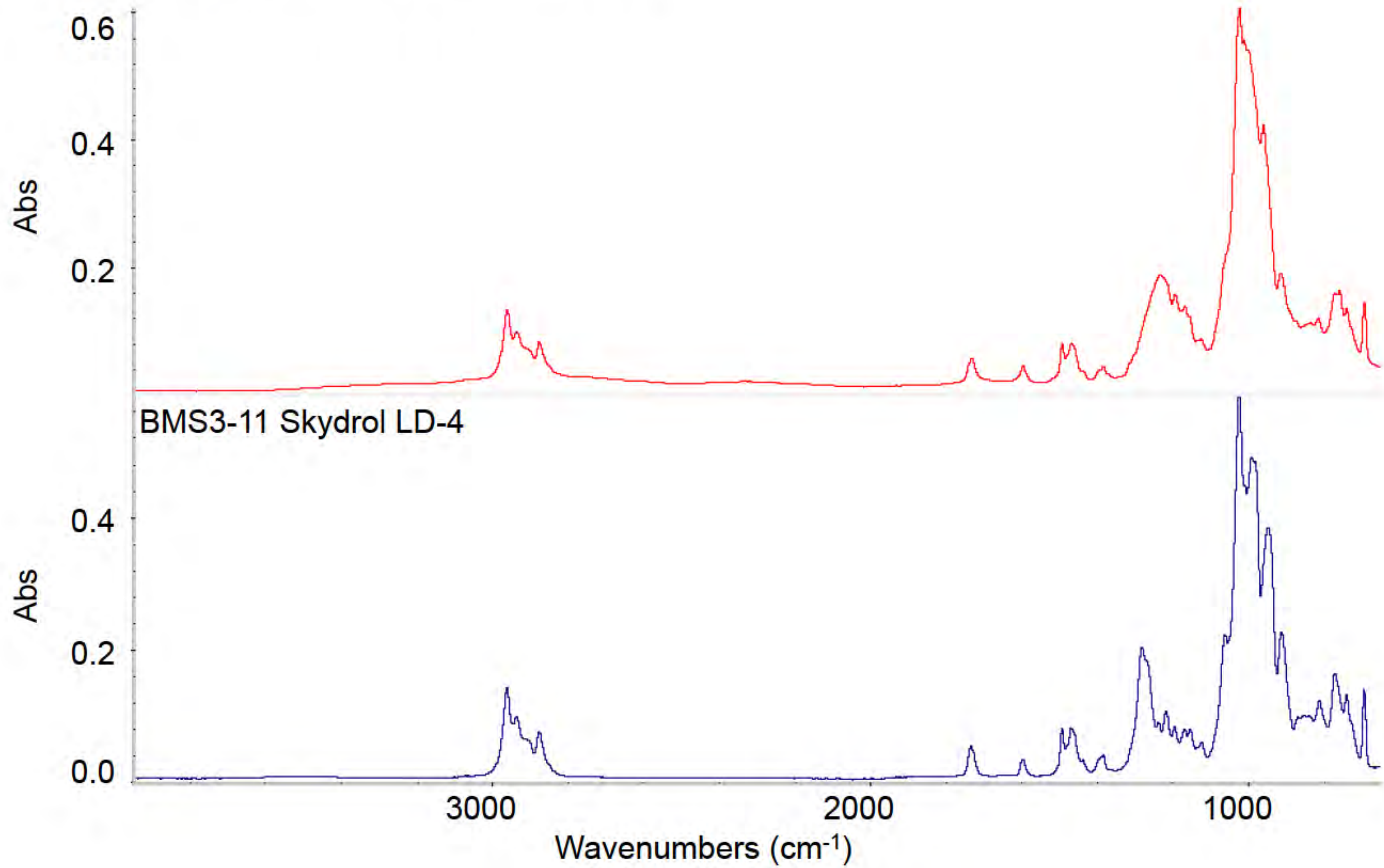
9 soot on LH TR latch beam was consistent with a mixture of synthetic oil (likely engine oil) and phosphate ester hydraulic fluid (i.e. BMS3-11)

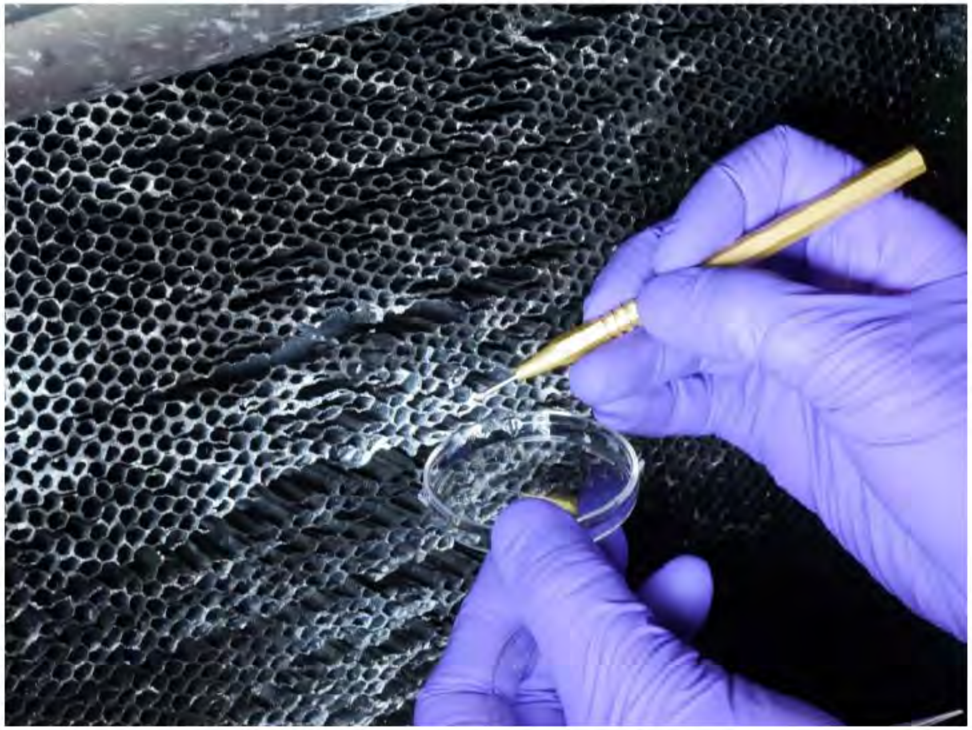


Sample #10 Fluid near actuator

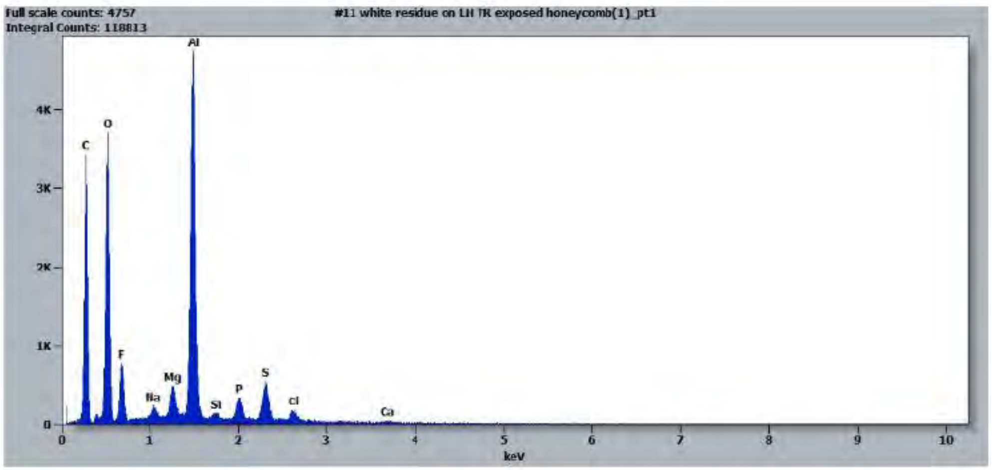


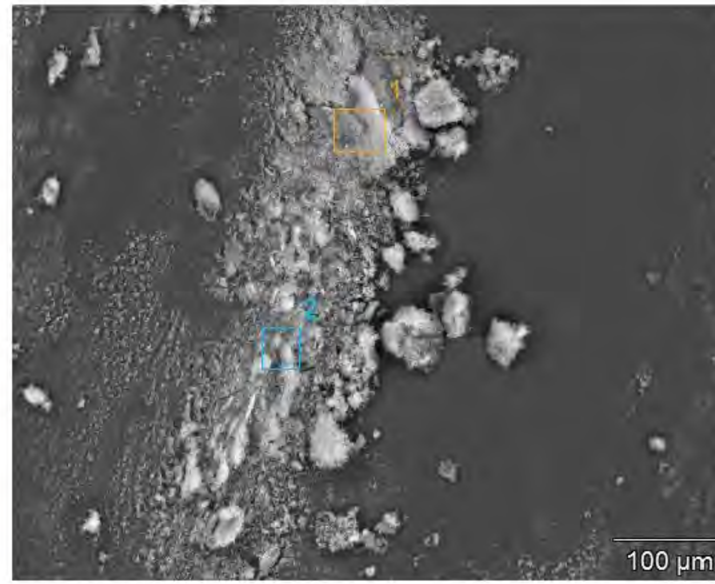
#10 fluid near actuator was consistent with BMS3-11 phosphate ester hydraulic fluid





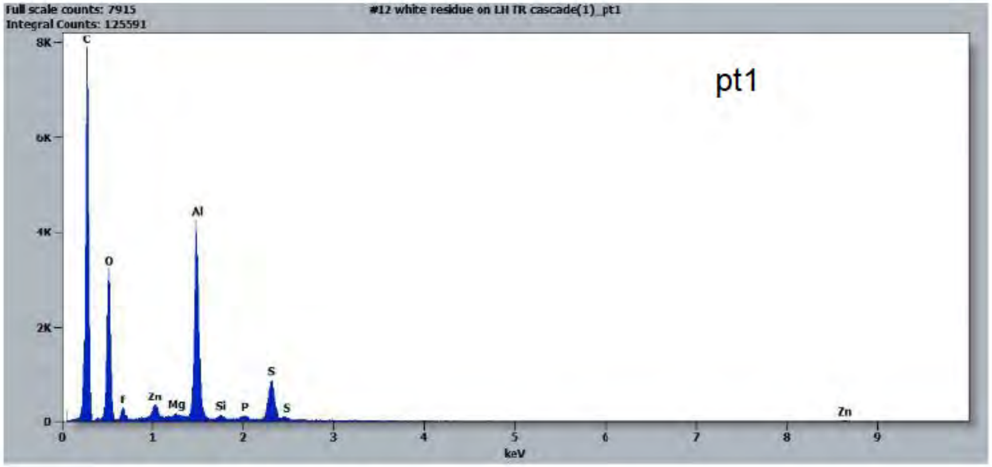
#11 white residue on LH TR exposed honeycomb consistent with inorganic material

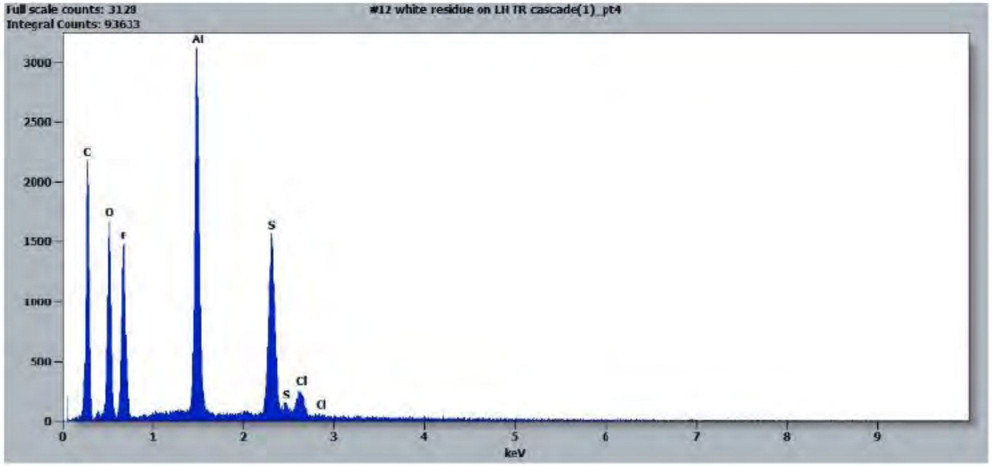


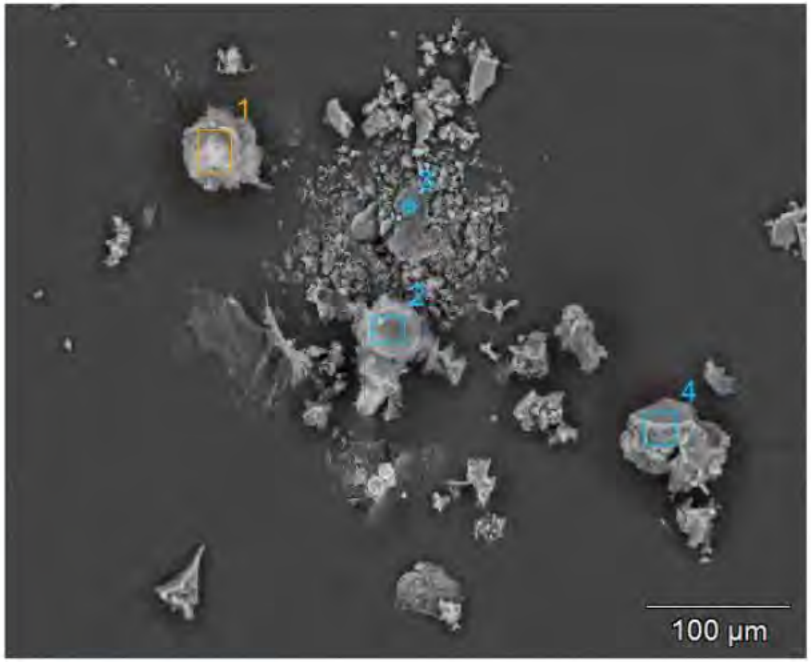


Sample #12 Left hand TR metal slag on cascade remnants

#12 white residue on LH TR cascade is consistent with an inorganic material (+ fluorine)

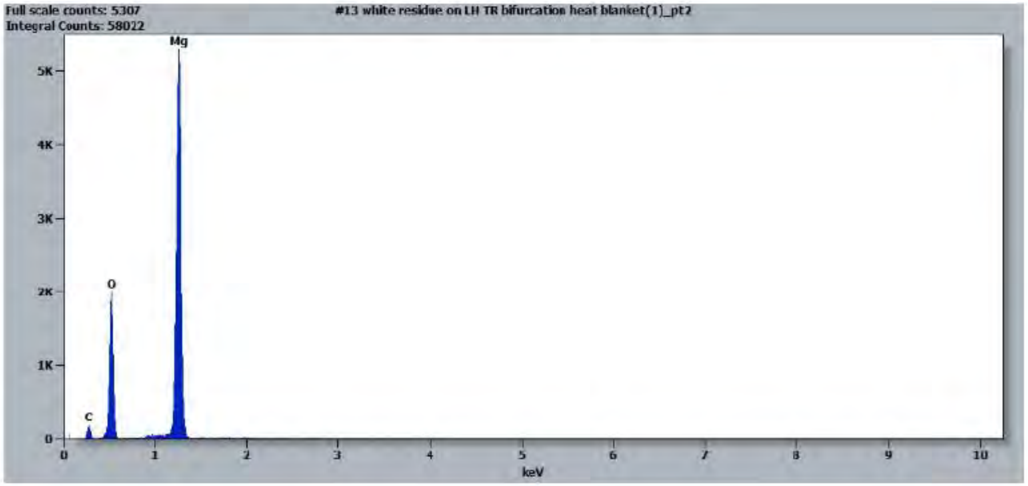


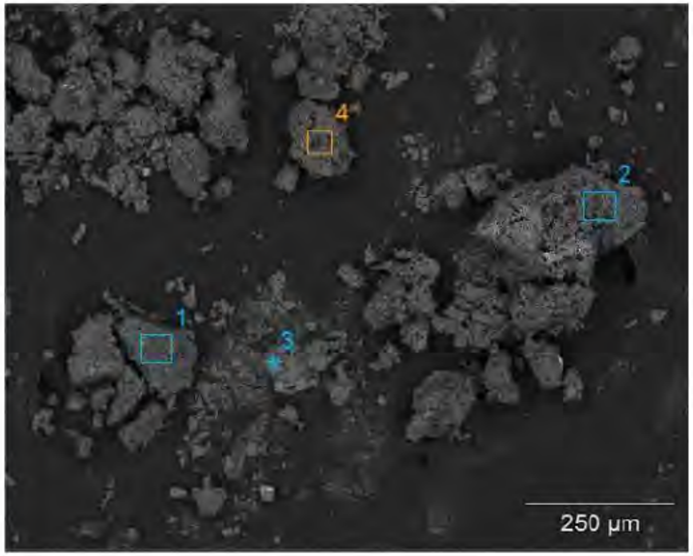




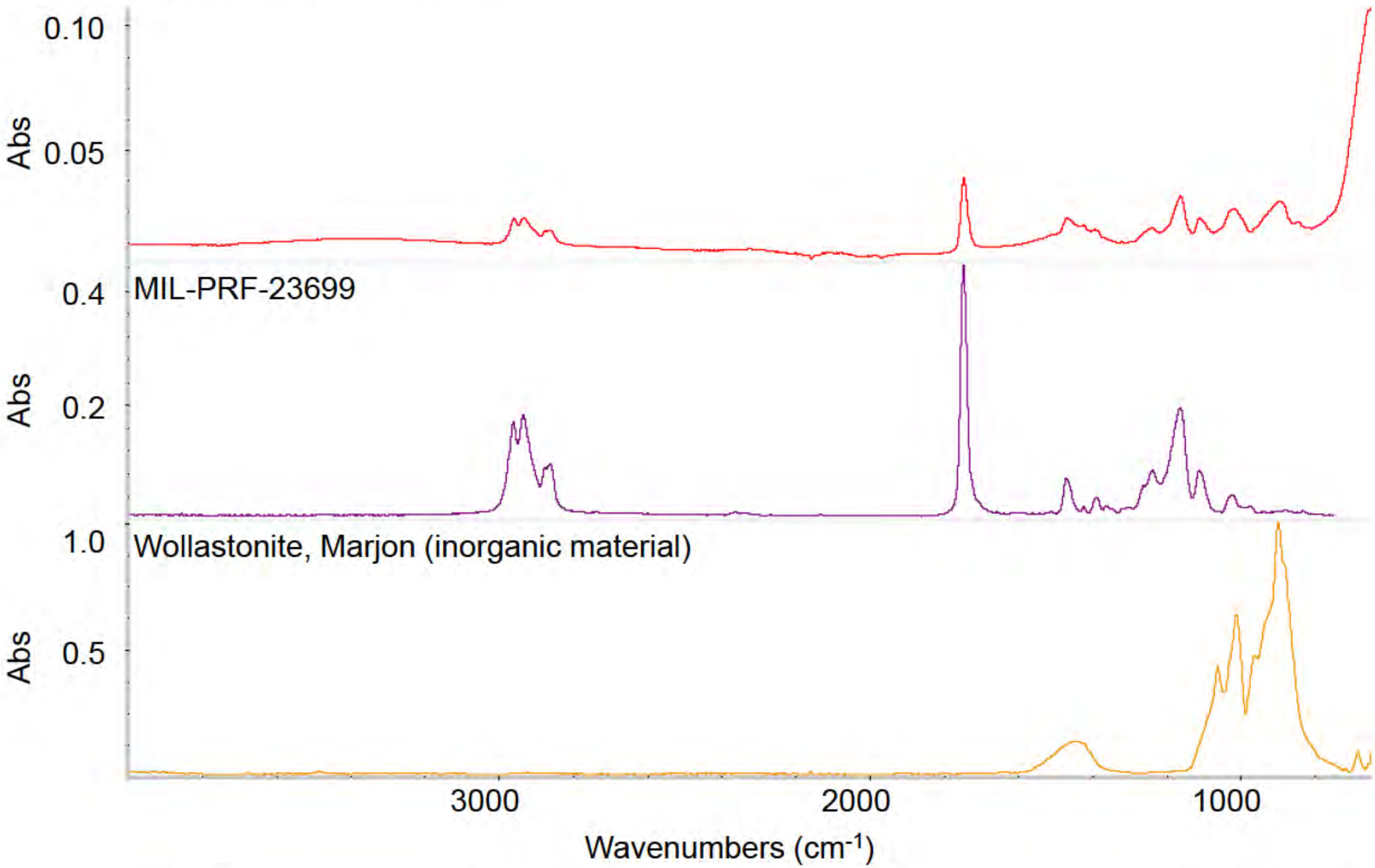
Sample #13 Left hand TR White residue on heat blanket

#13 white residue on LH TR bifurcation heat blanket consistent with a magnesium oxidation product

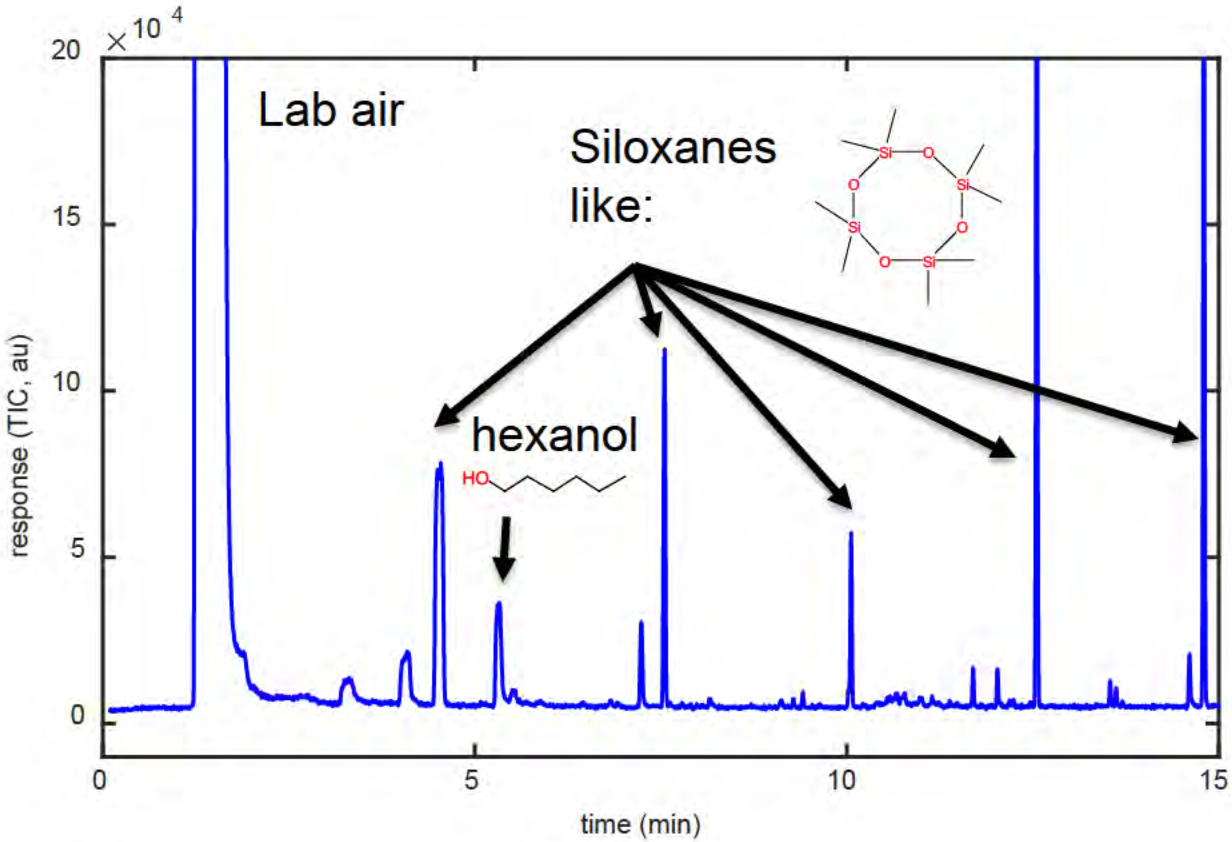




#13 white residue on LH TR bifurcation heat blanket was consistent with a mixture of synthetic oil (likely engine oil) and inorganic material



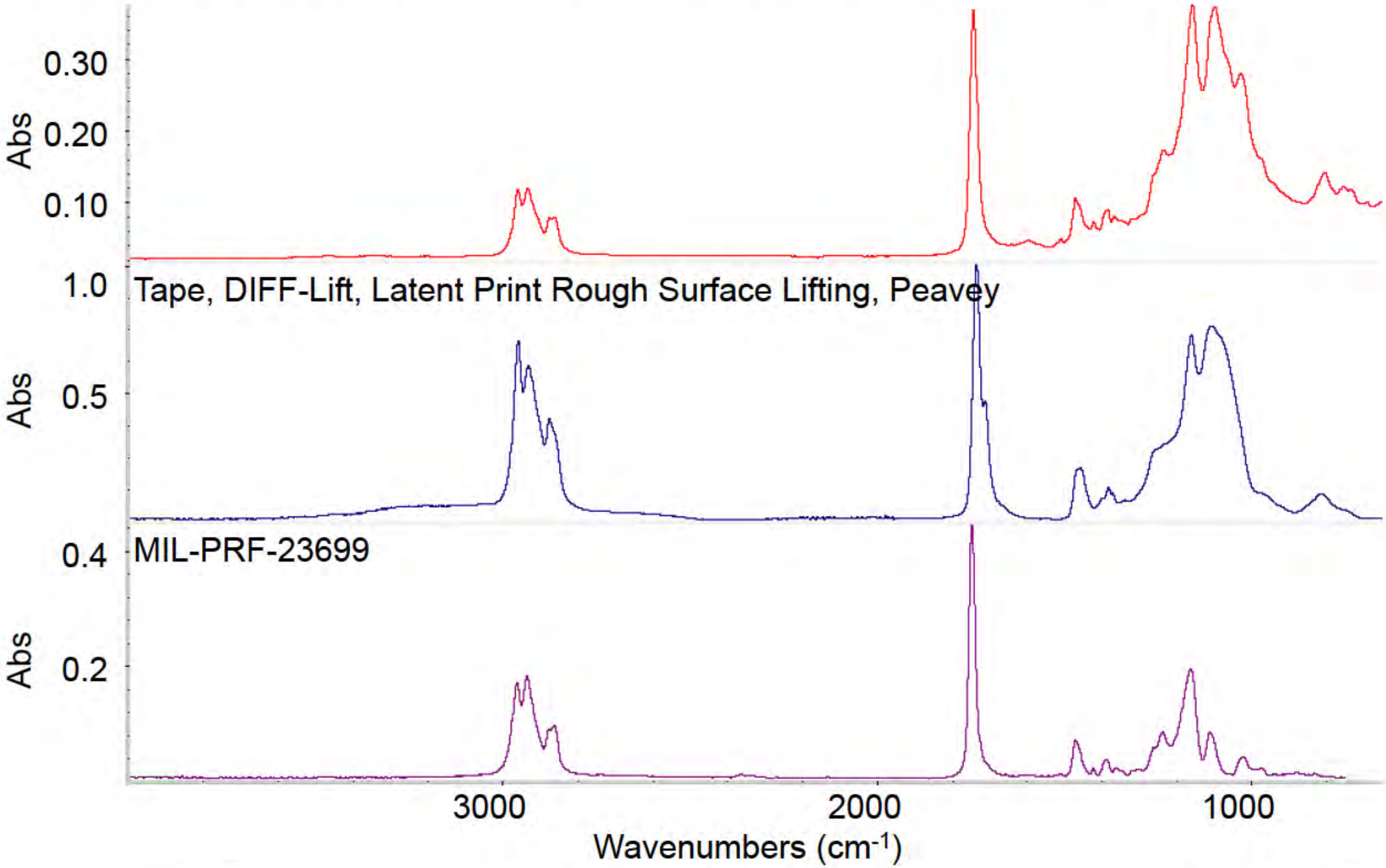
#14 red seal on nacelle drain access door – Headspace GC-MS

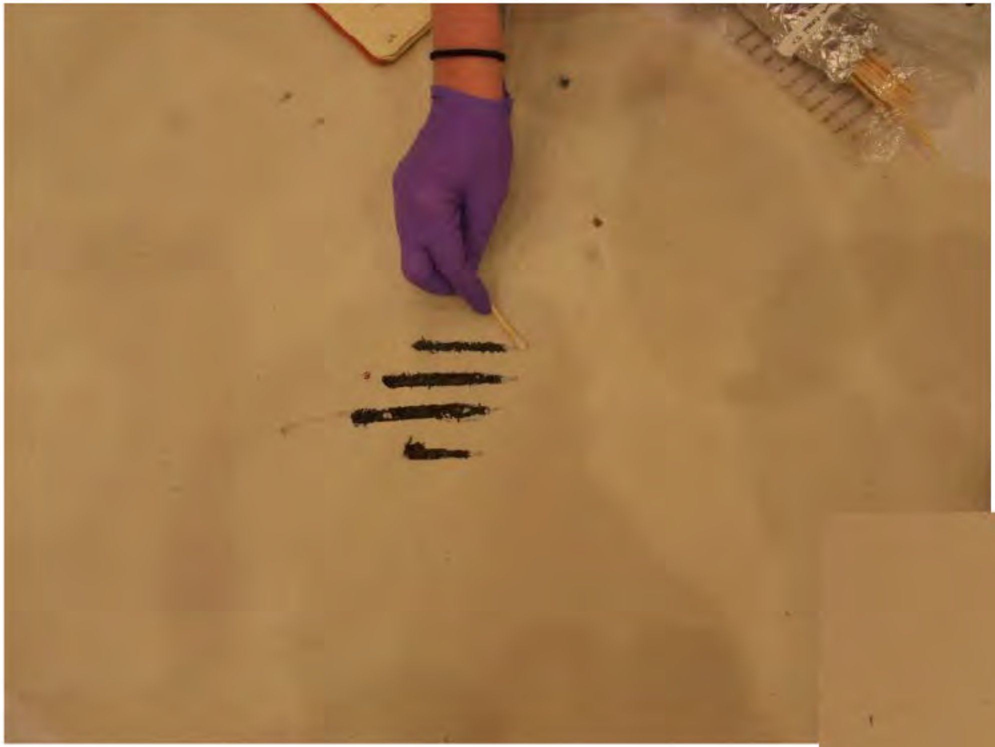


- Sample heated to 100 °C for 30 min in a sealed vial
- 1 mL of the resulting headspace gas analyzed via GC - MS

Sample #15 soot on outer surface of nacelle drain access door

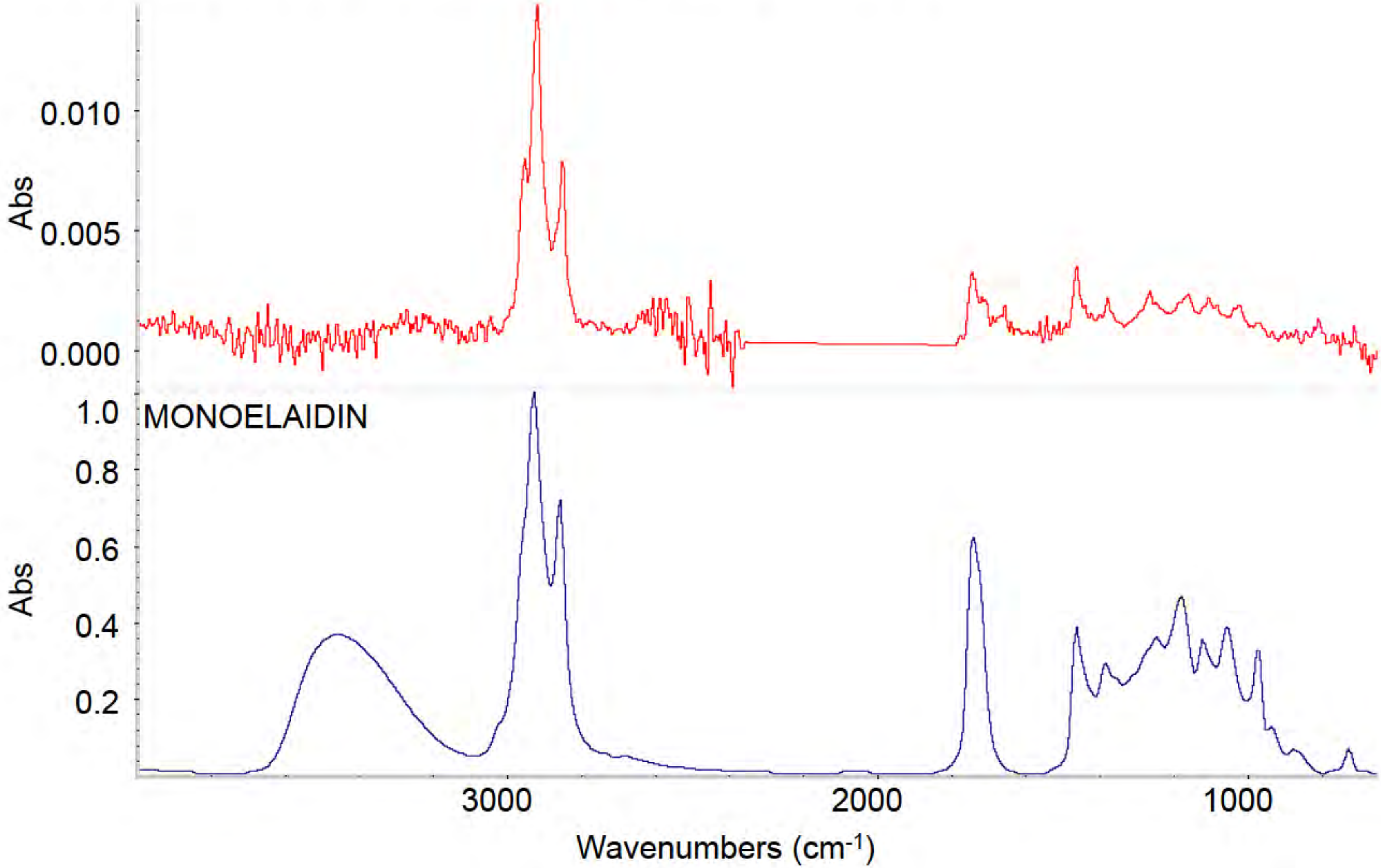
#15 soot on outer surface of nacelle drain access door was consistent with a mixture of synthetic oil (likely engine oil) and a poly(acrylate) which is likely tape residue



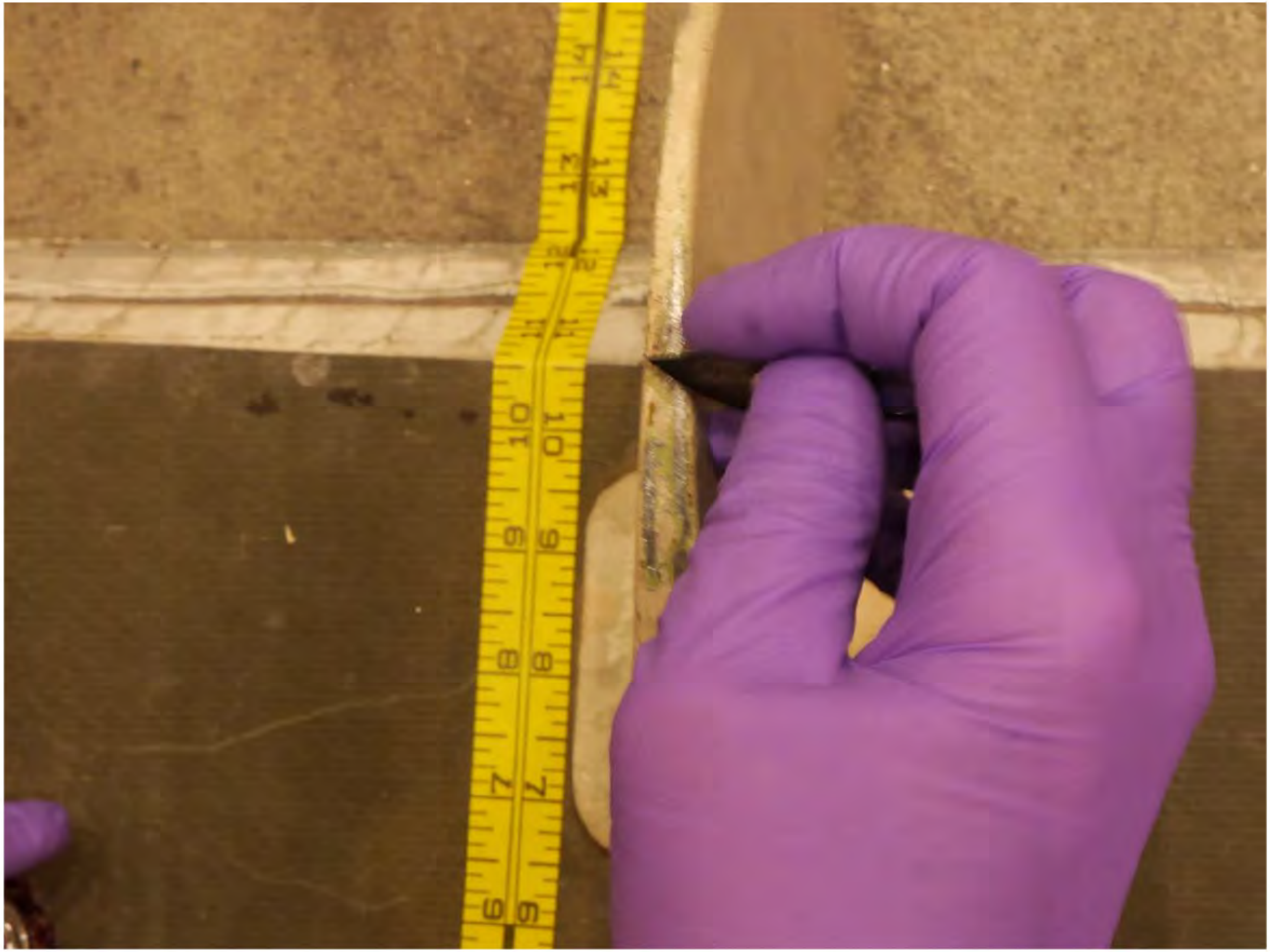


Sample #16 Inlet Cowl inside of outer barrel at 10:00

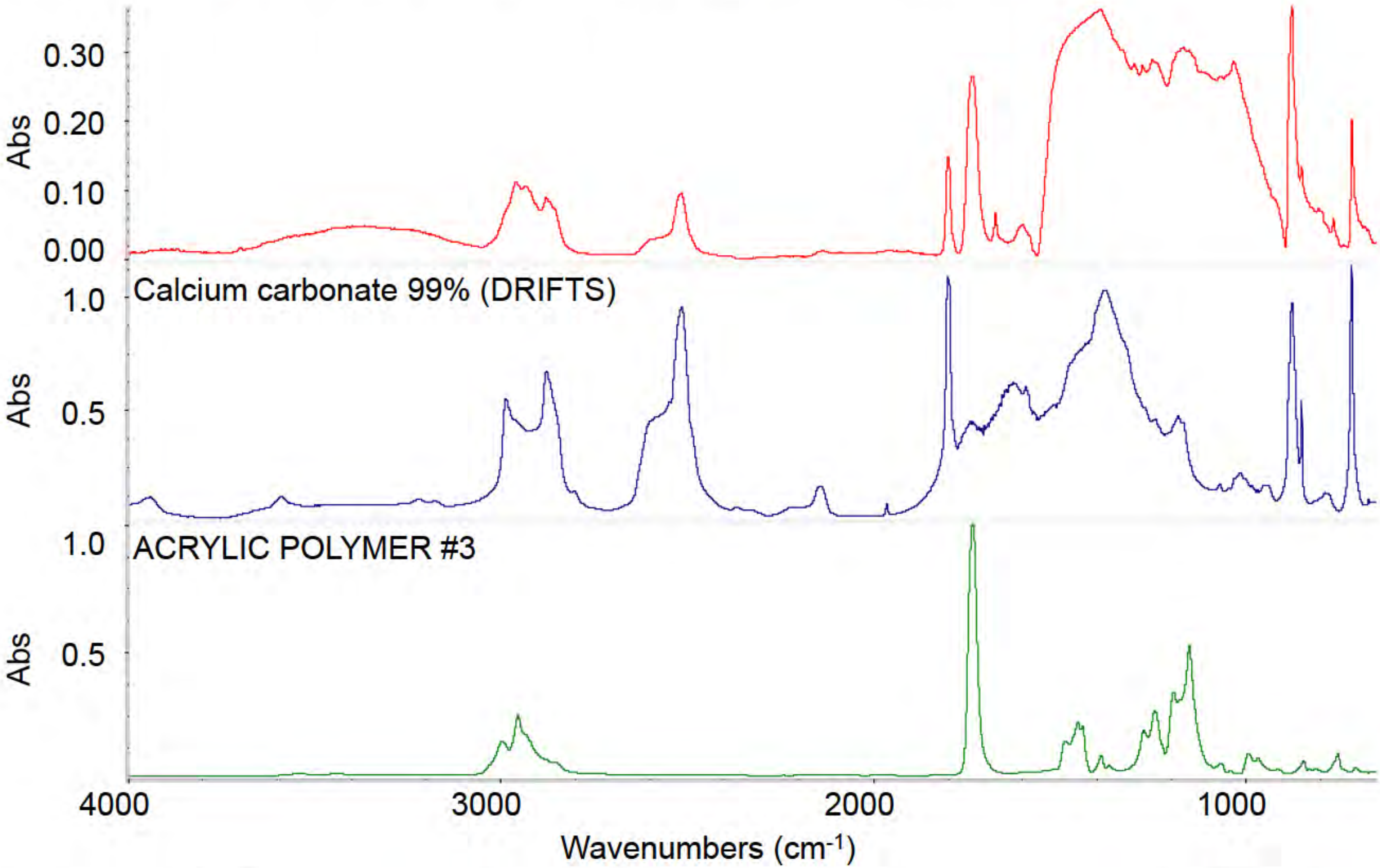
#16 hexane extraction is consistent with a stearate chemistry (ester modified hydrocarbon – fatty acid)



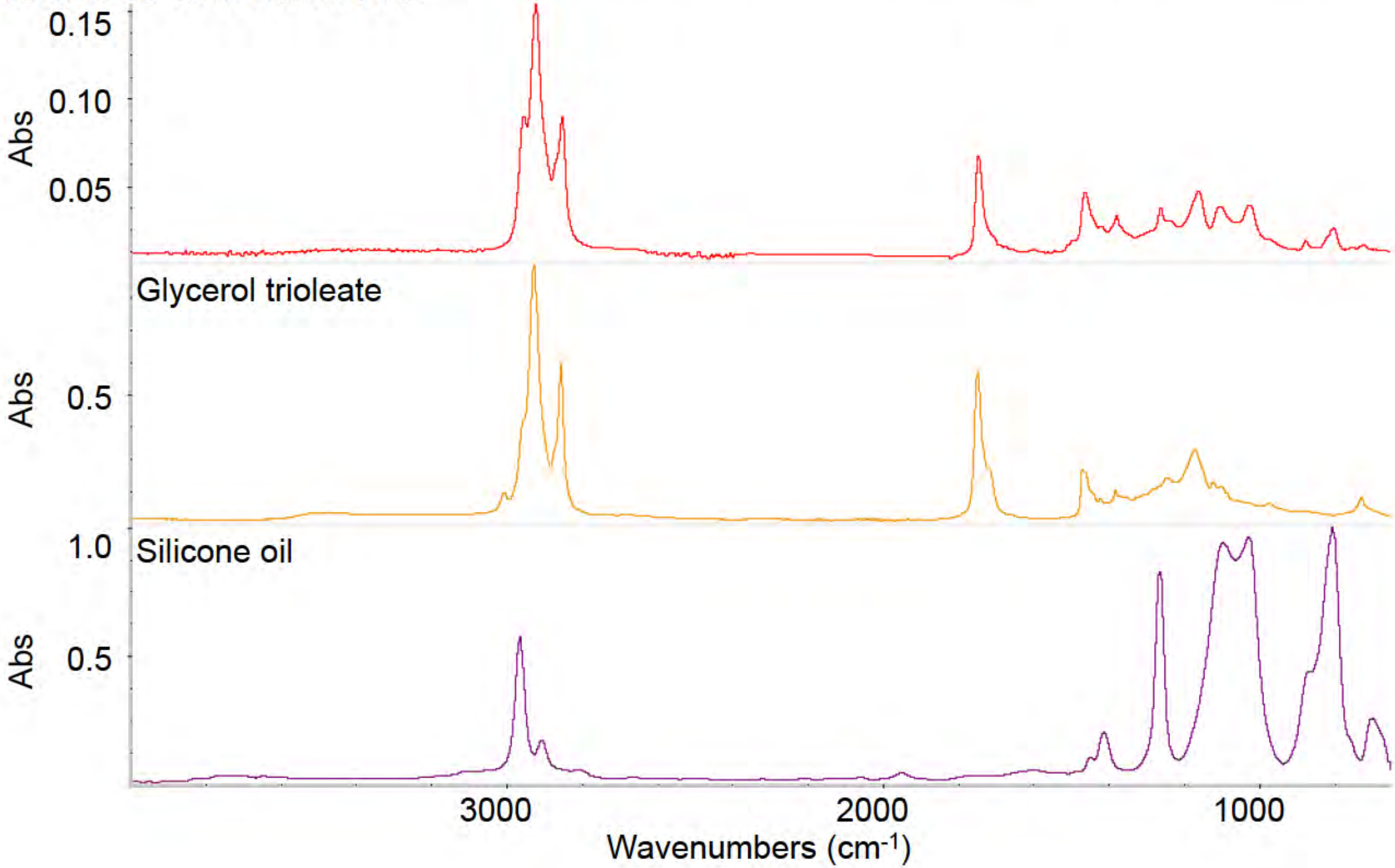
Sample #17 Left and cowls number 2 hinge



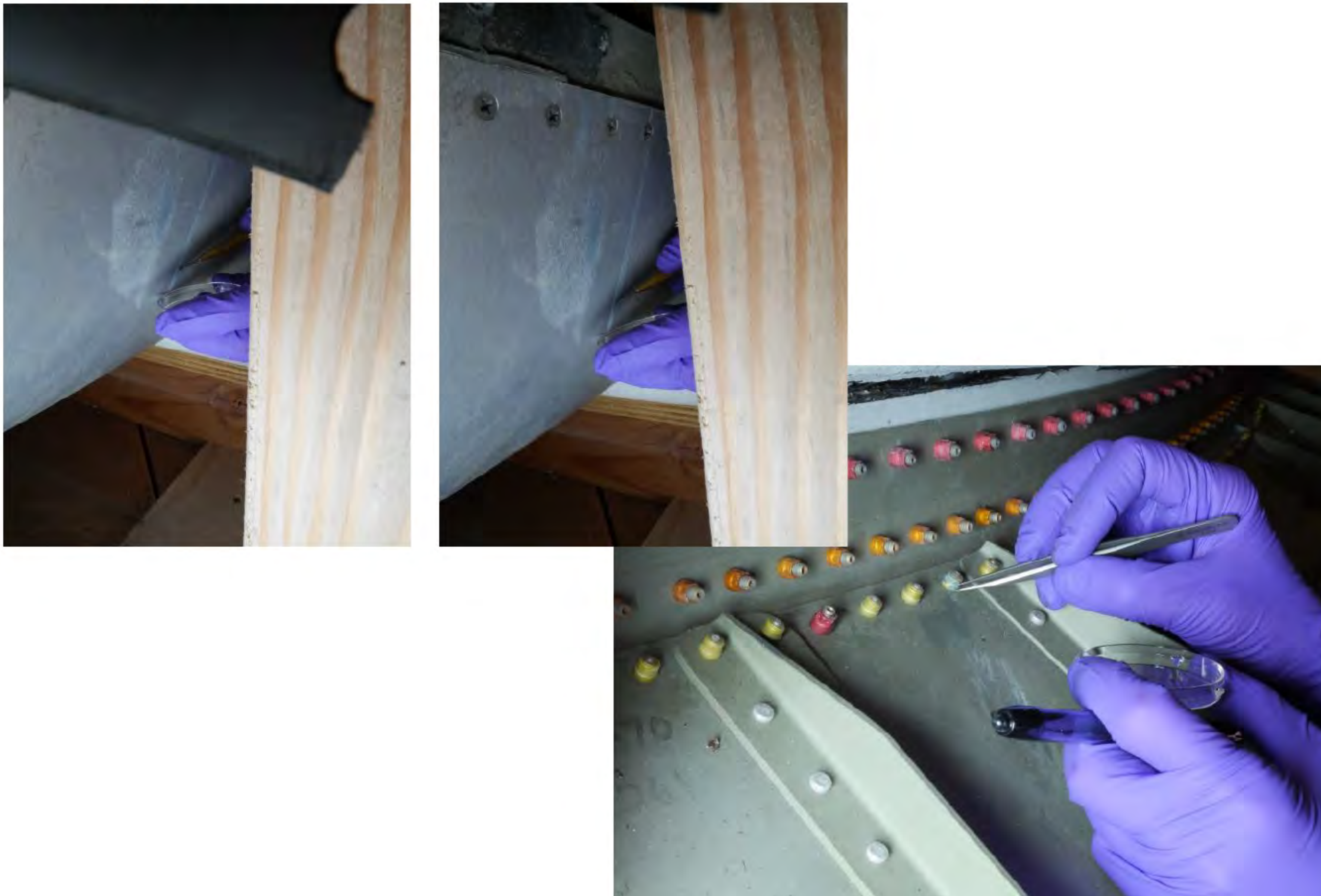
#17 residue on #2 fan cowl hinges was consistent with a mixture of calcium carbonate and an acrylic polymer, possibly an acrylic caulk? The acrylate could also be due to an adhesive residue. No Kevlar was observed.



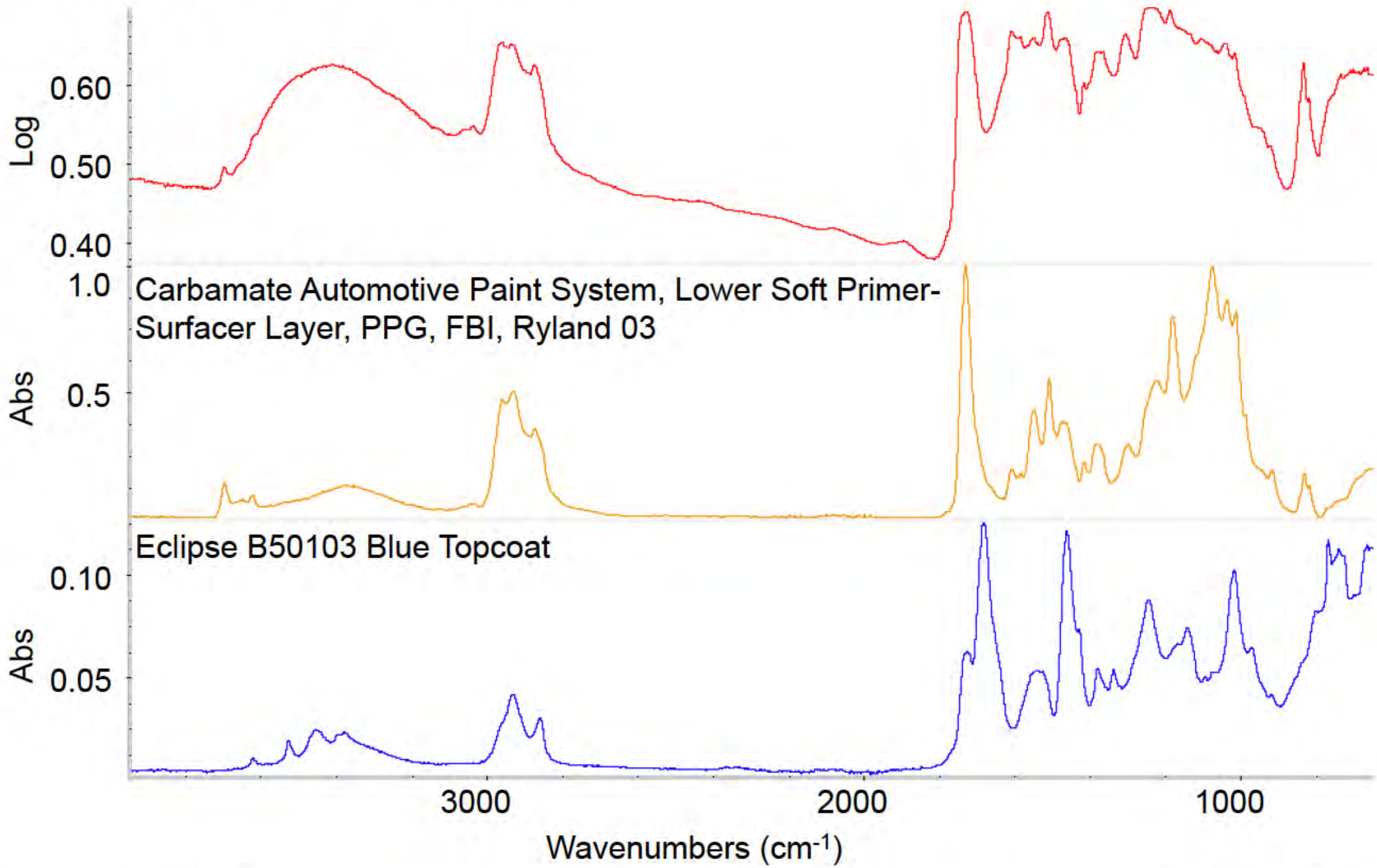
The #17b fan cowl support hinge hexane extraction was consistent with a mixture of an ester modified hydrocarbon (i.e. oleate) chemistry which could be from a variety of sources such as handling, or possibly a cutting fluid, as well as silicone. No Kevlar was observed.



Sample #18 Inlet cowl blue paint



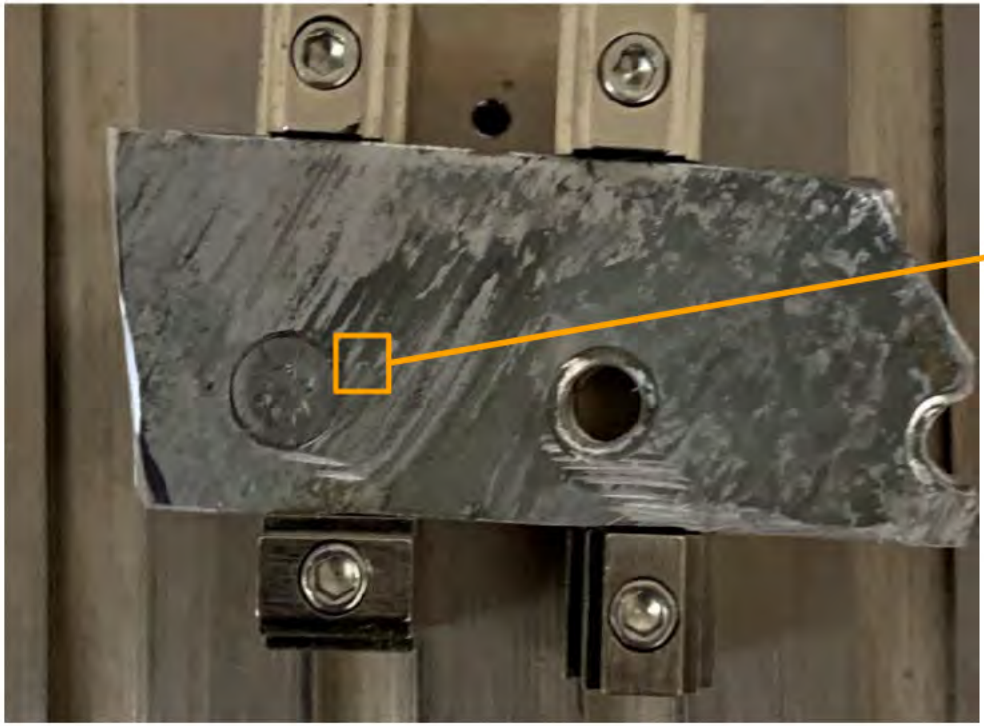
#18 blue paint on inlet lipskin near 0530 was consistent with a carbamate based paint; more similar to an automotive paint (carbamate) than an aircraft (polyurethane) topcoat

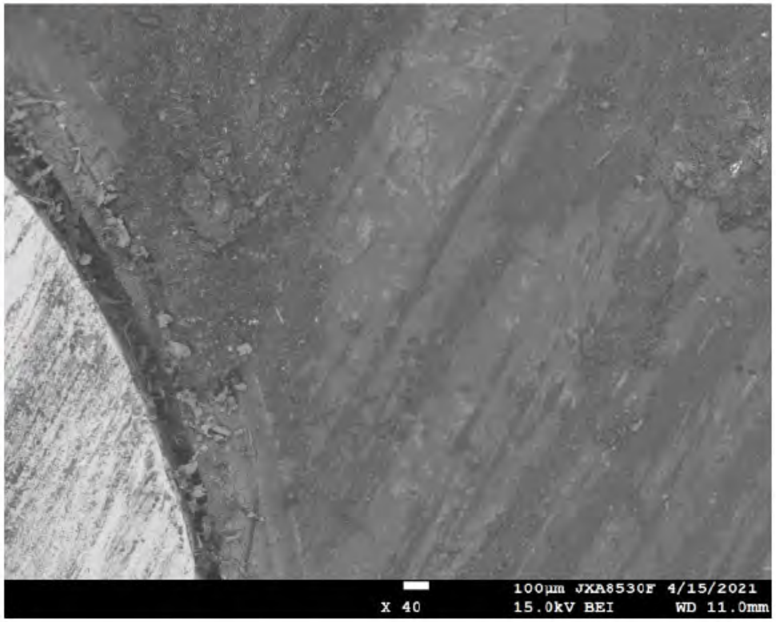


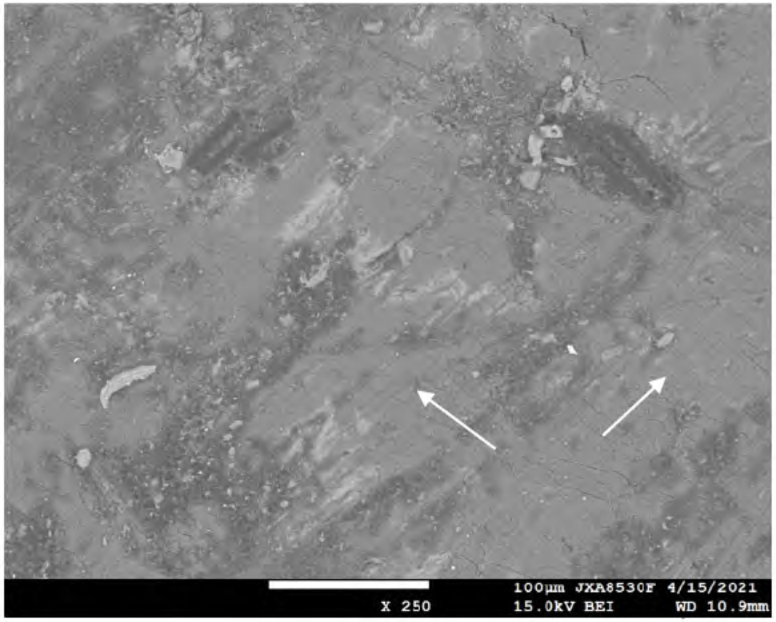
Enclosure A to EQA Reports AS13328 and AS13354

Sample #20 Inlet lipskin near 1:30

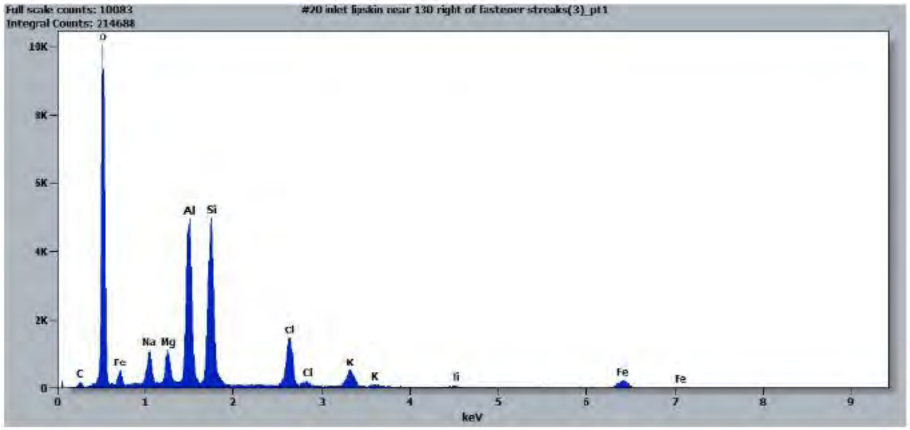
#20 Inlet lipskin near 1:30 primary analysis locations

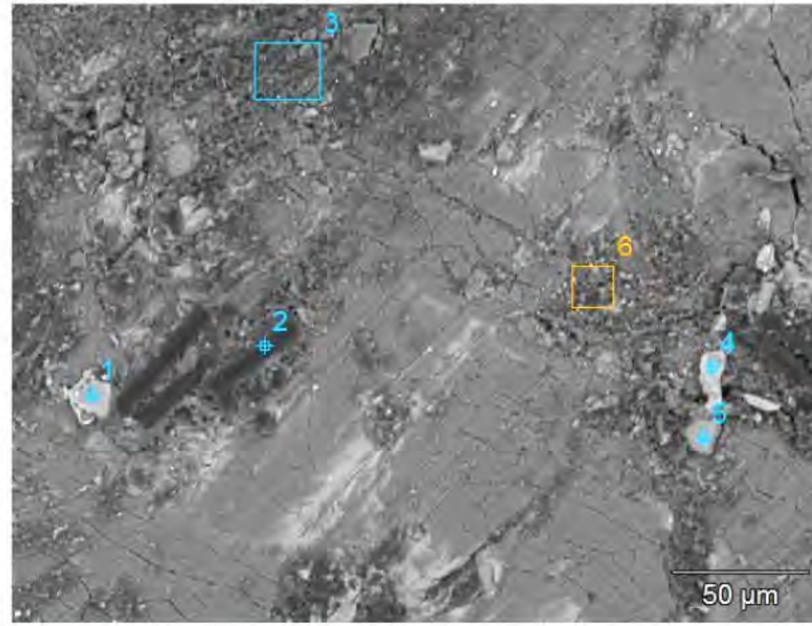


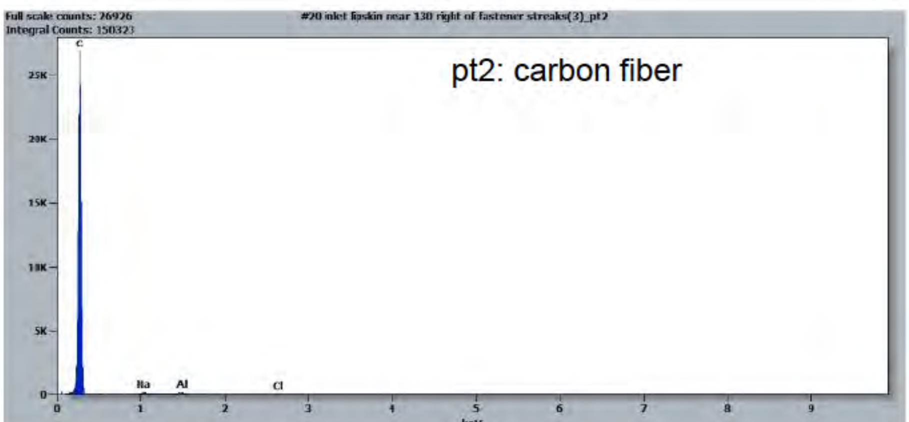




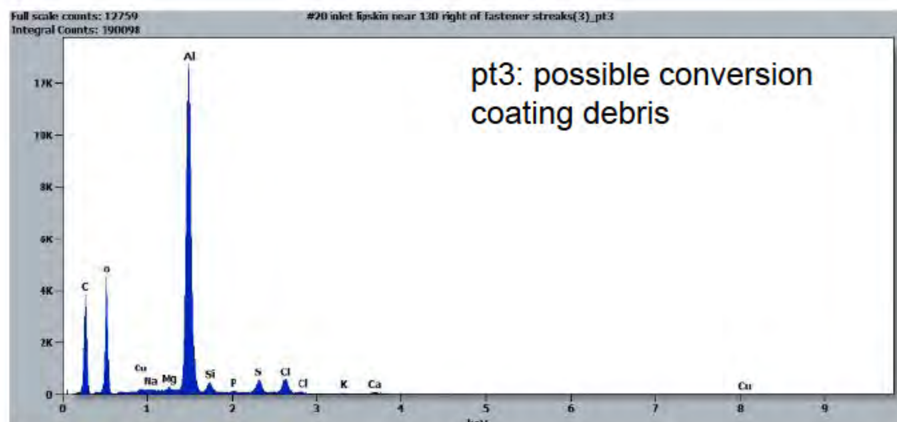
#20 Inlet lipskin near 1:30







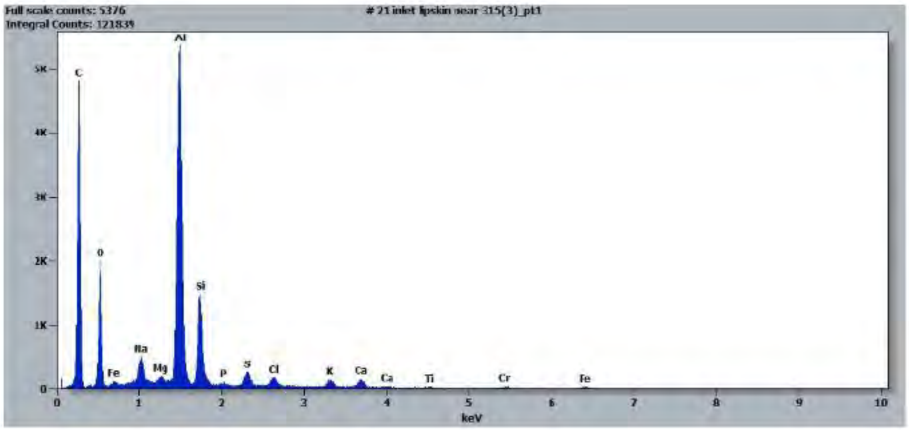
pt2: carbon fiber

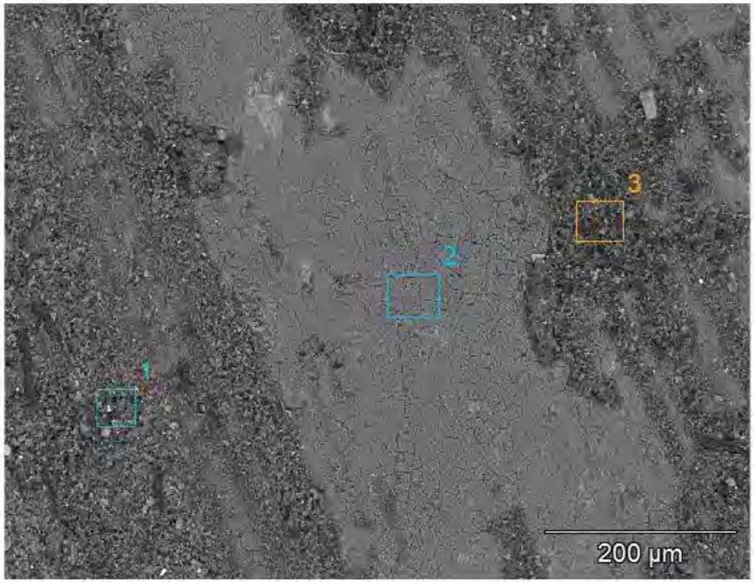


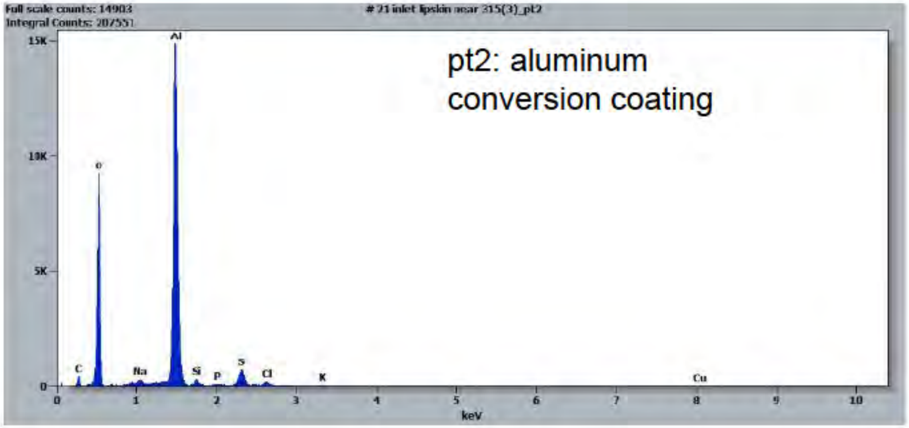
pt3: possible conversion coating debris

Sample #21 Inlet lipskin near 3:15

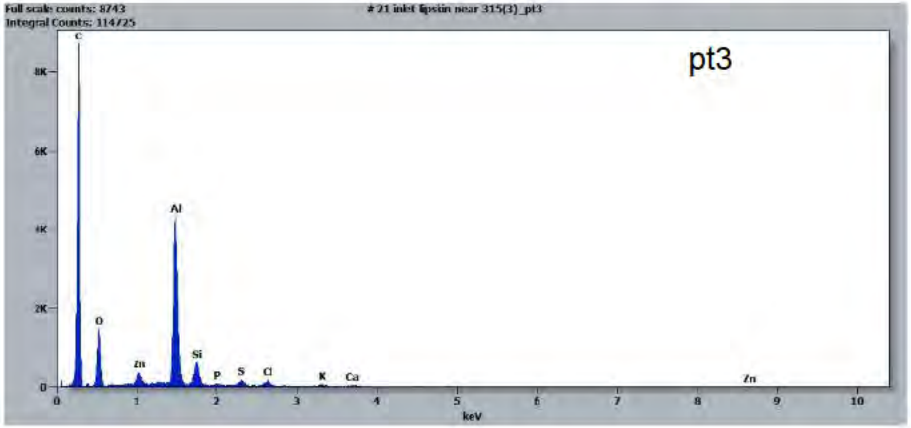
#21 Inlet lipskin near 3:15







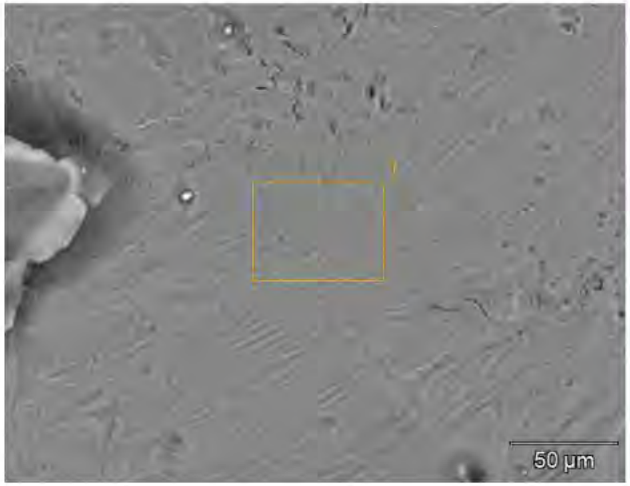
pt2: aluminum conversion coating

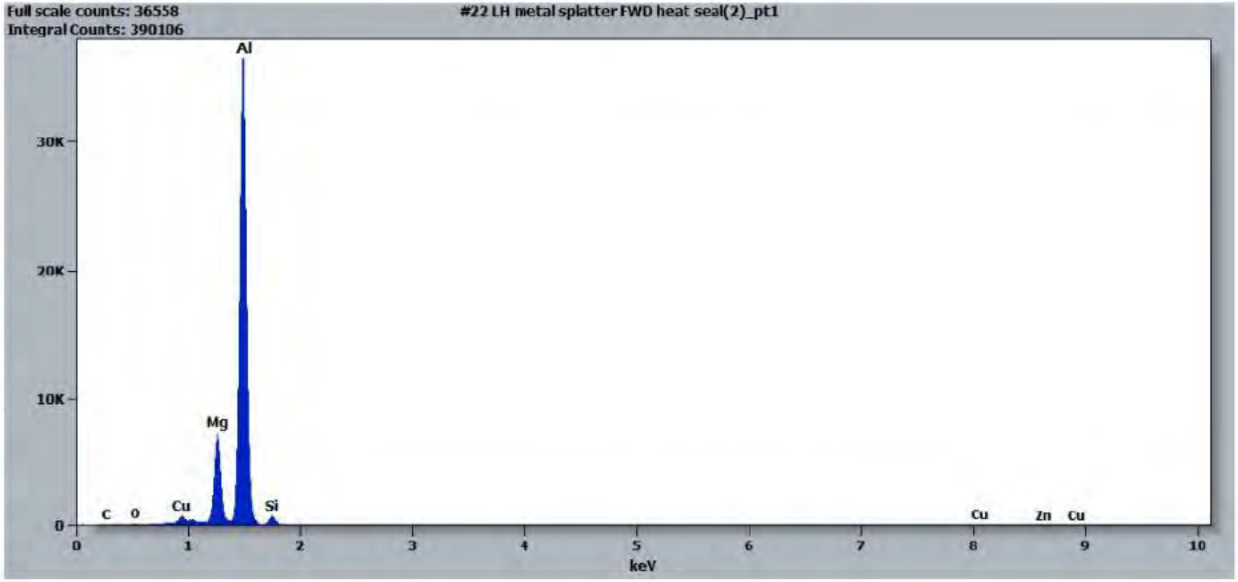


pt3

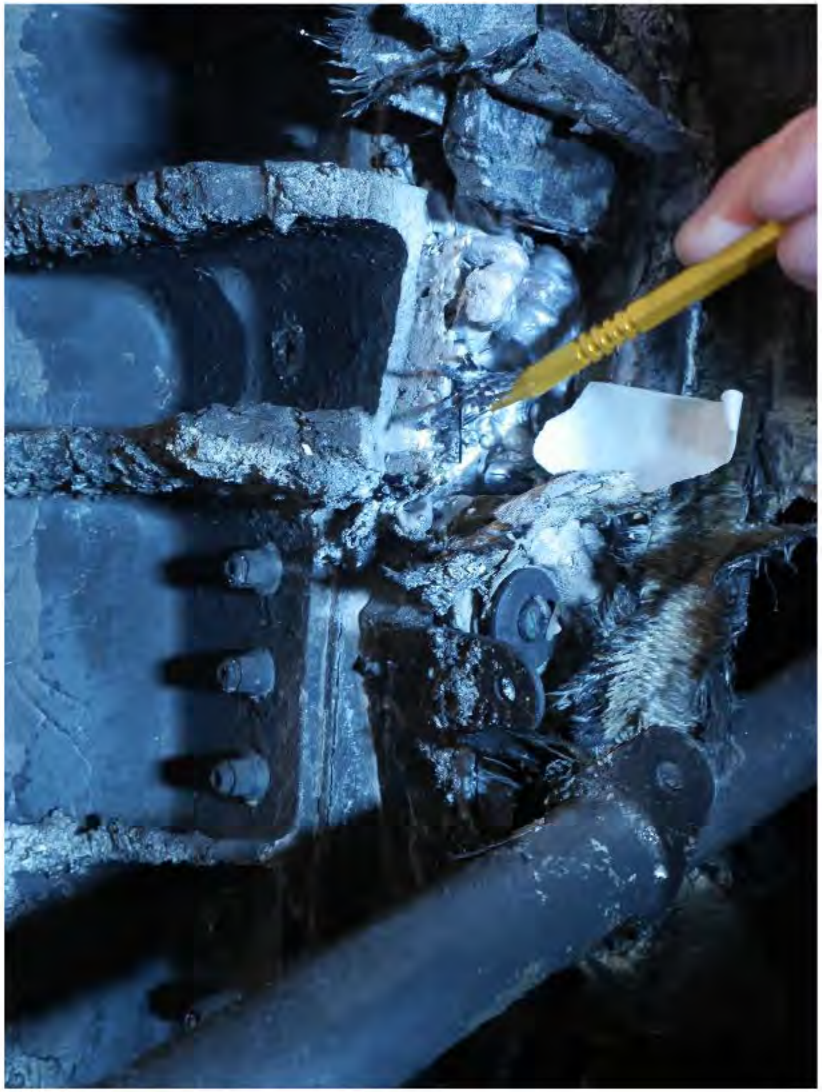
Sample #22 LH TR metal splatter FWD heat shield

#22 LH TR metal splatter FWD heat shield

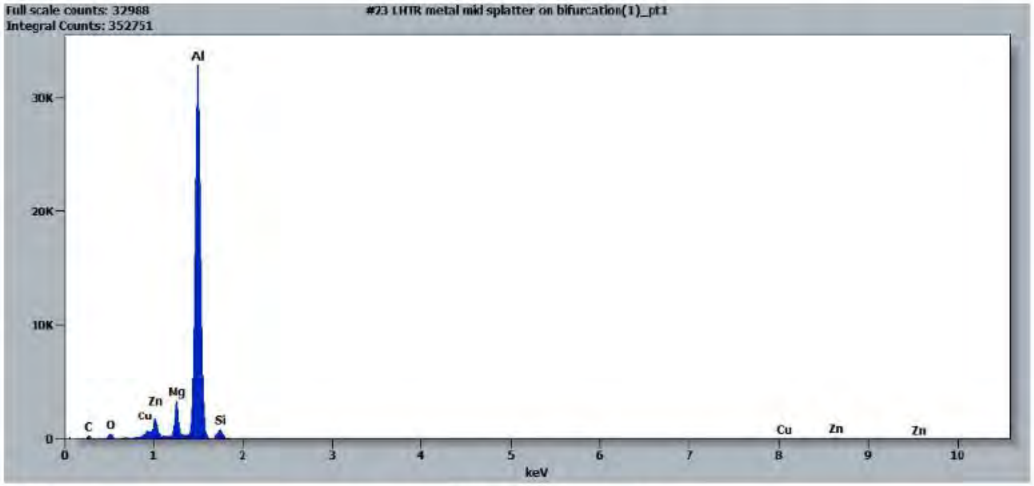


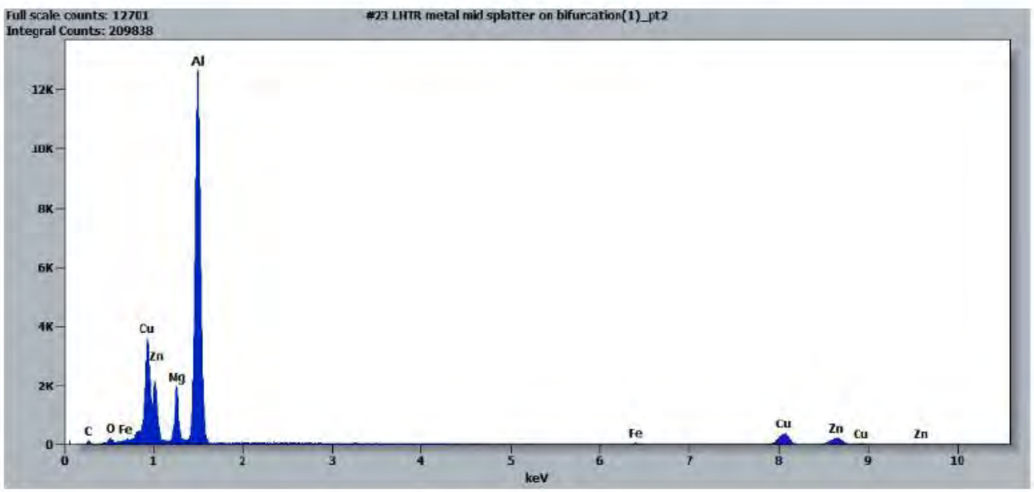


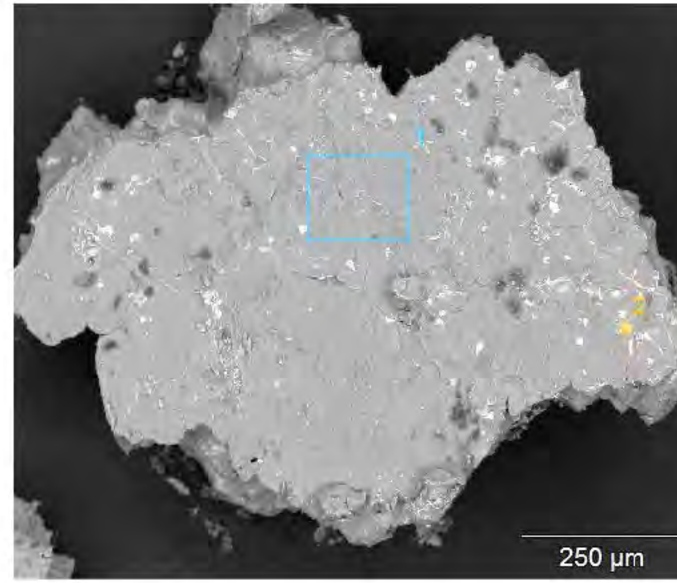
Sample #23 Left TR metal mid splatter on bifurcation near drain



#23 LHTR metal mid splatter on bifurcation is possibly a 7xxx alloy with elevated magnesium



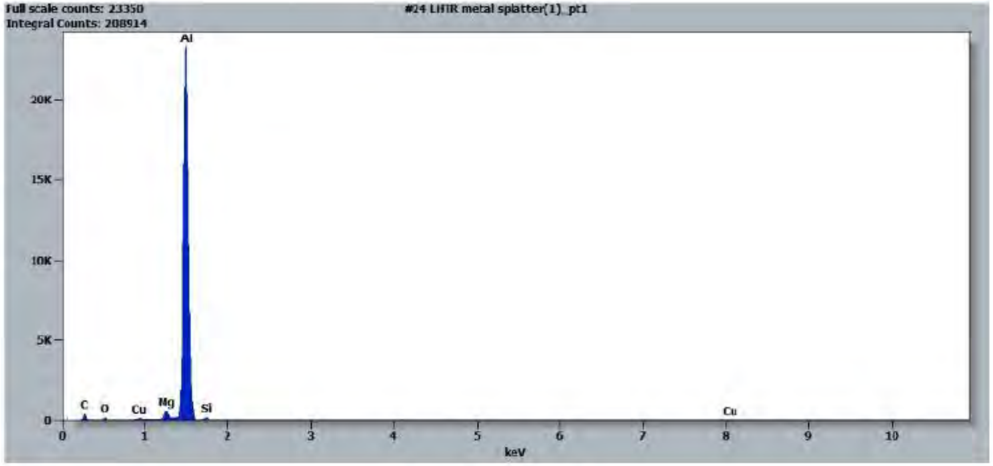


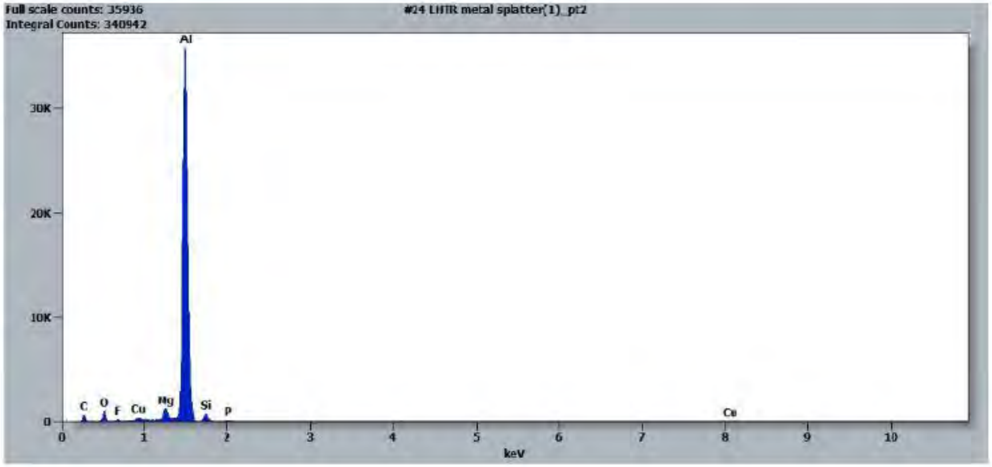


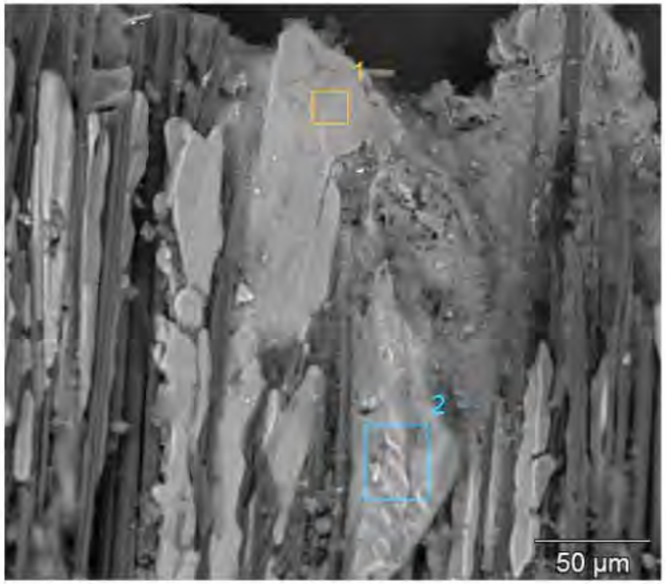
Enclosure A to EQA Reports AS13328 and AS13354

Sample #24 Left TR metal splatter on honeycomb

24 LHTR metal splatter is most similar to a 2xxx aluminum alloy

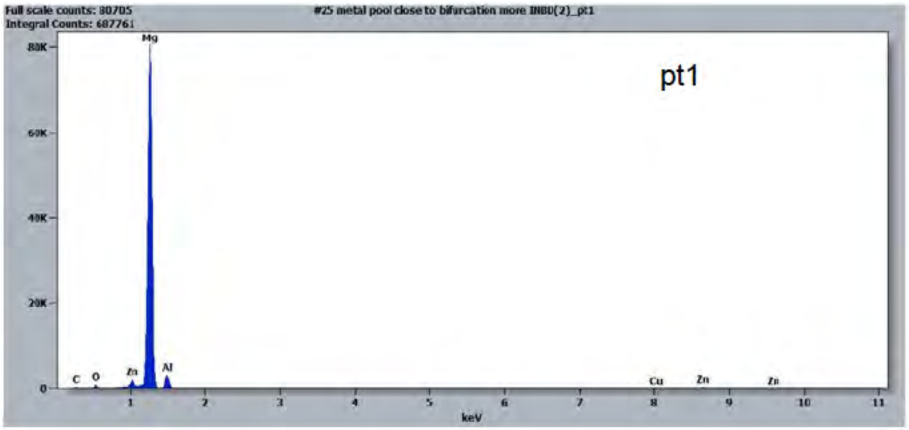


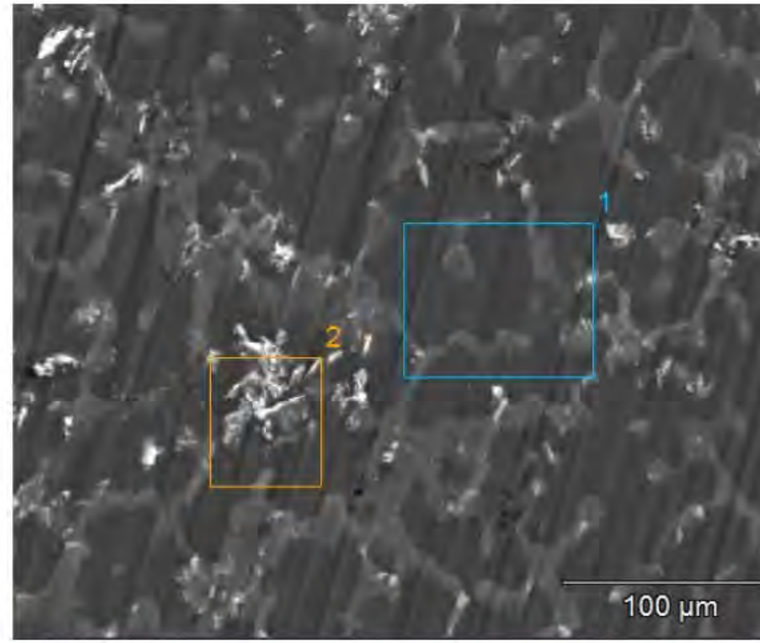


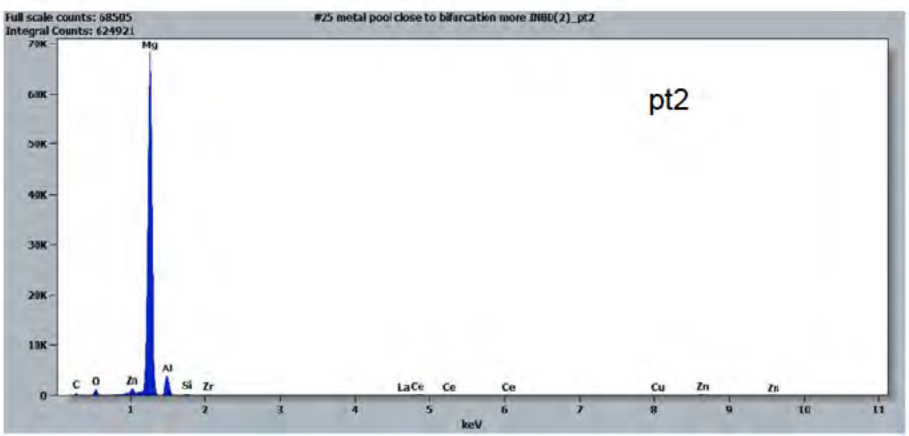


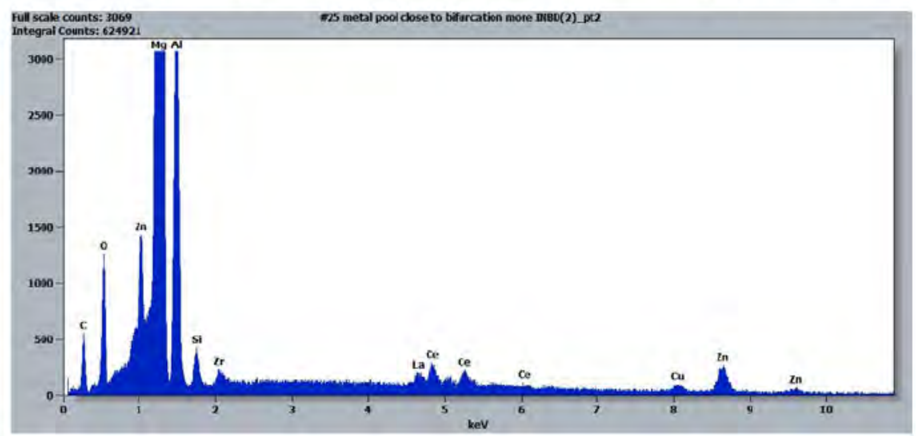
Enclosure A to EQA Reports AS13328 and AS13354

#25 melted metal near bifurcation (more INBD) – possibly 7xxx aluminum + additional Mg (remelted material)



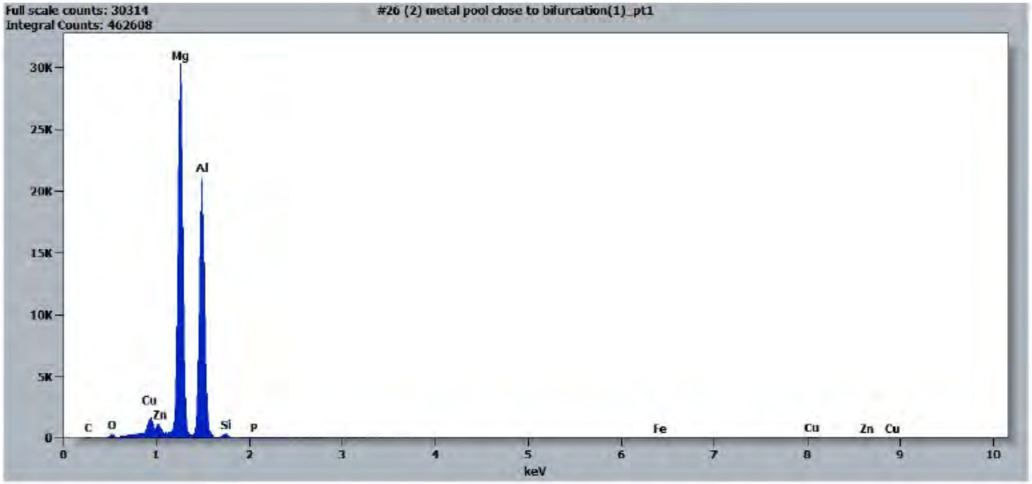


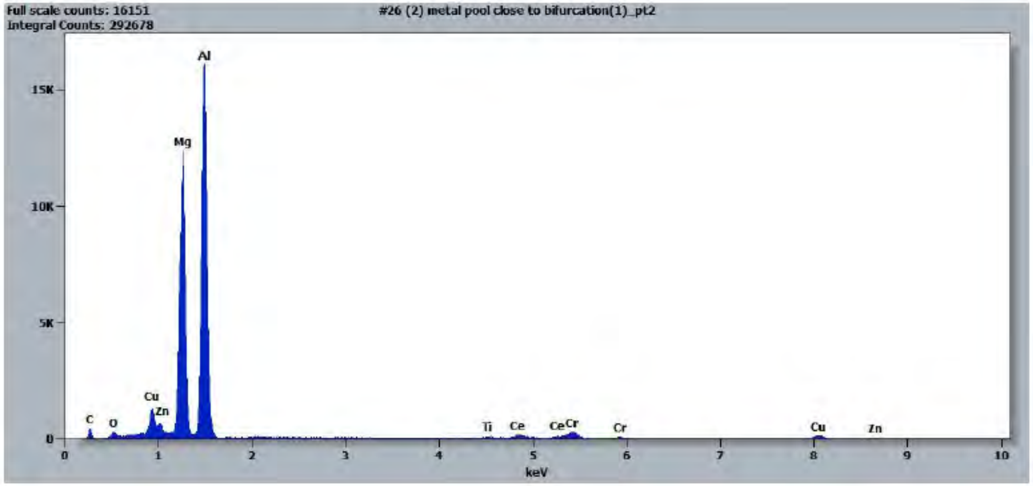


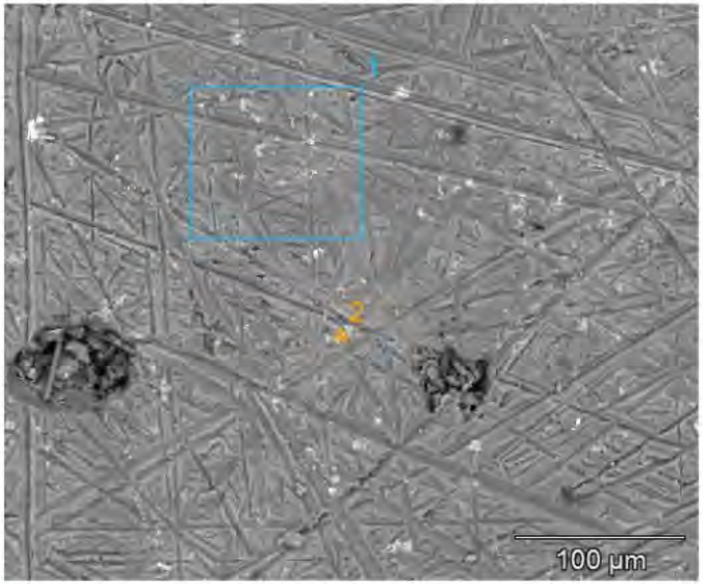


Sample #26 Left TR melted metal near bifurcation

#26 melted metal near bifurcation – possibly 7xxx Al + additional magnesium.

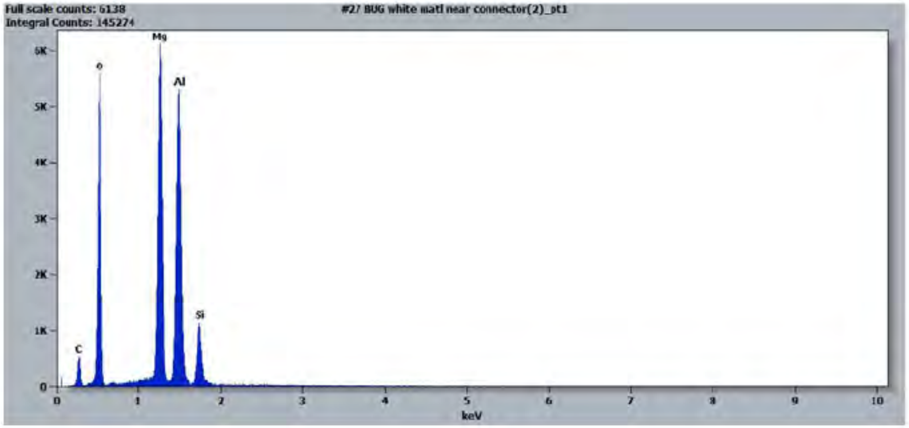


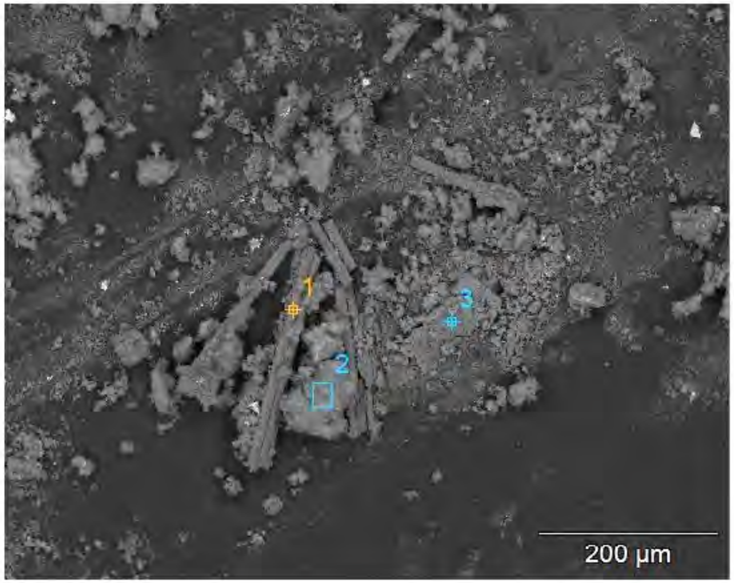


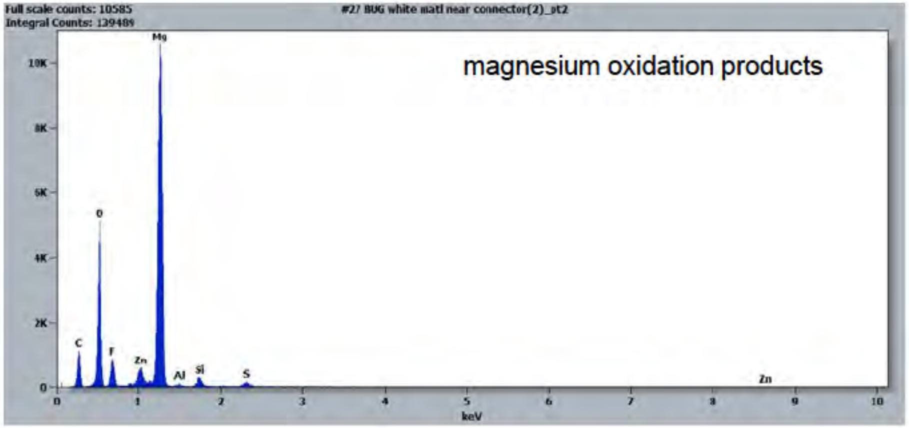


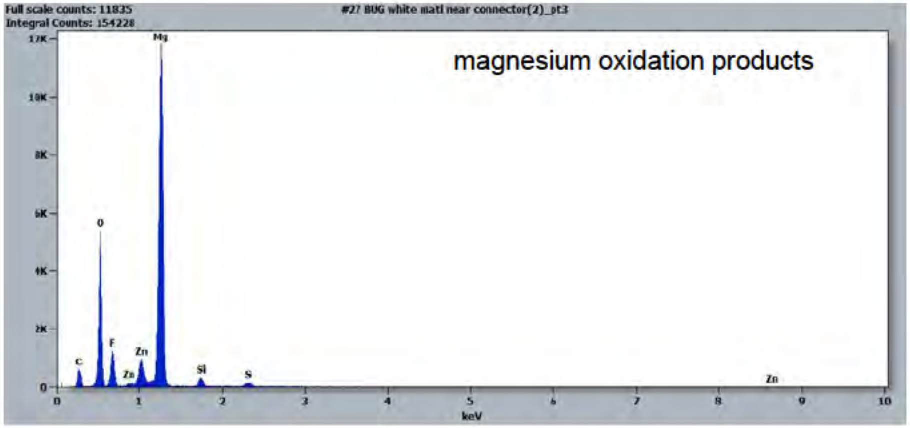
Sample #27 backup generator (BUG) white material near connector

27 backup generator (BUG) white material near connector is consistent with magnesium oxidation products



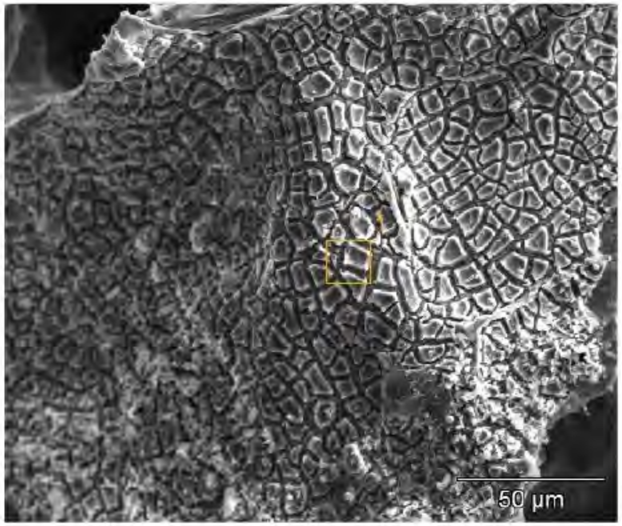


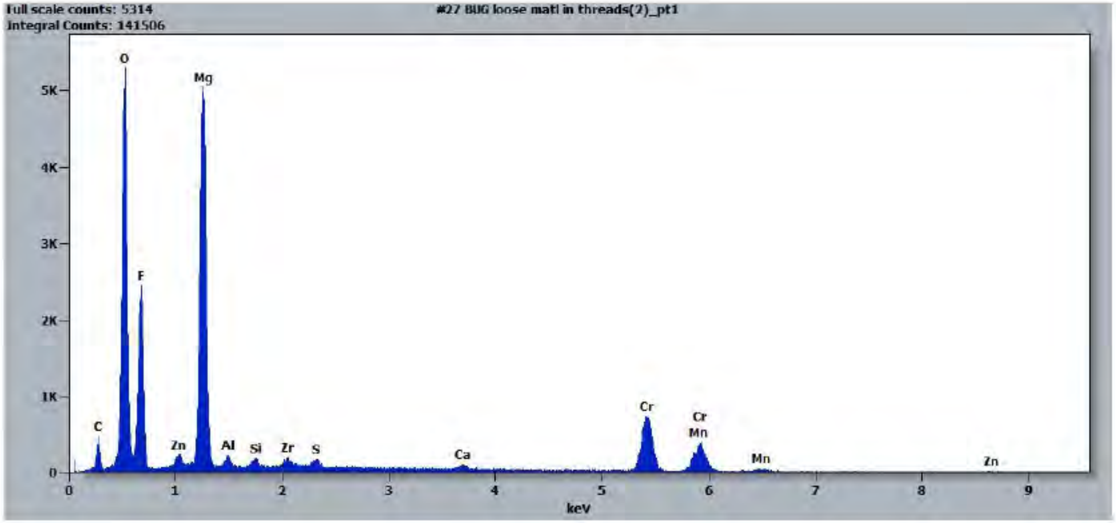




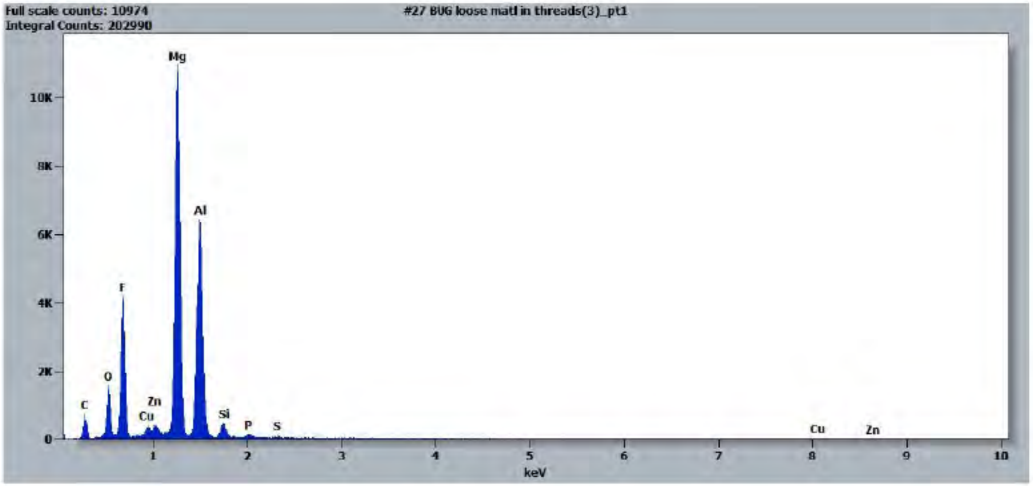
Sample #27 BUG loose material in threads

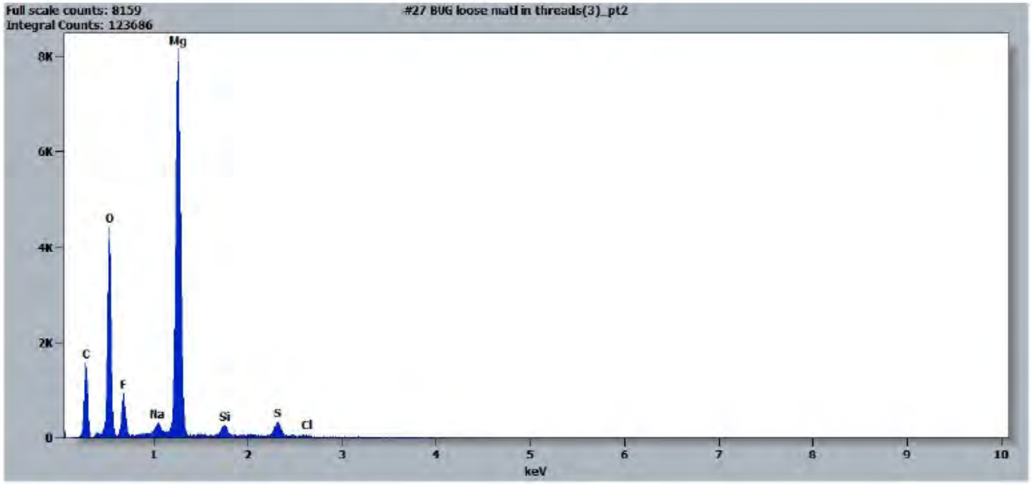
#27 BUG loose material in threads

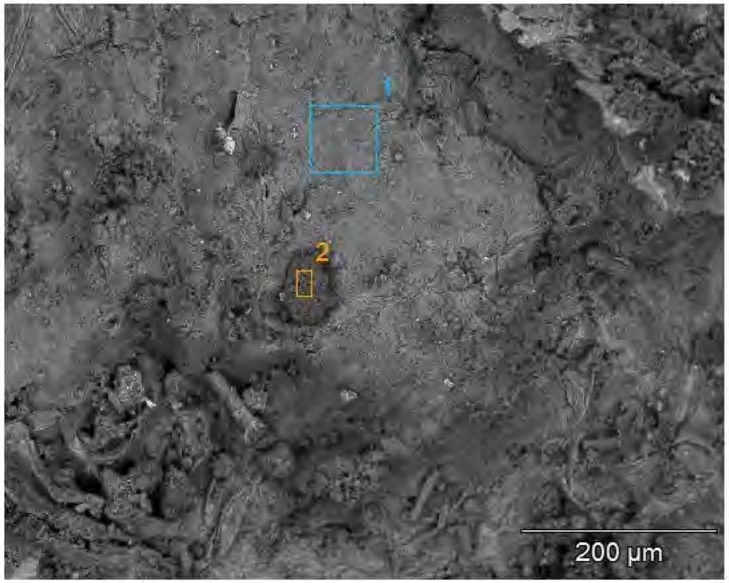




#27 BUG loose material in threads cont. – consistent with magnesium oxidation products

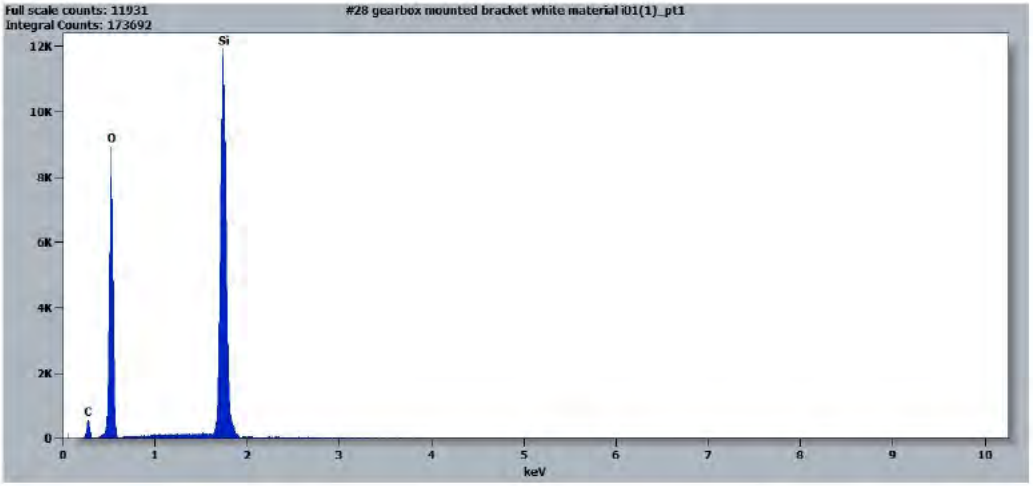


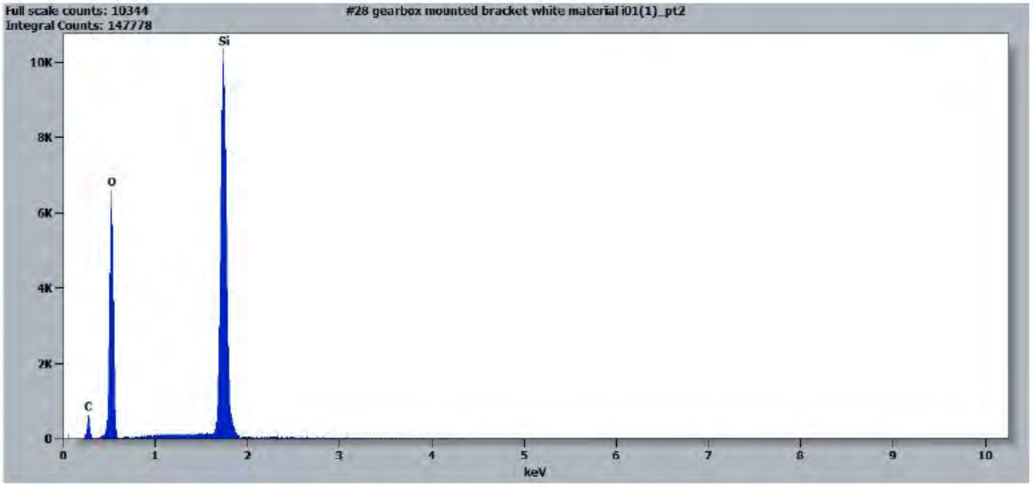


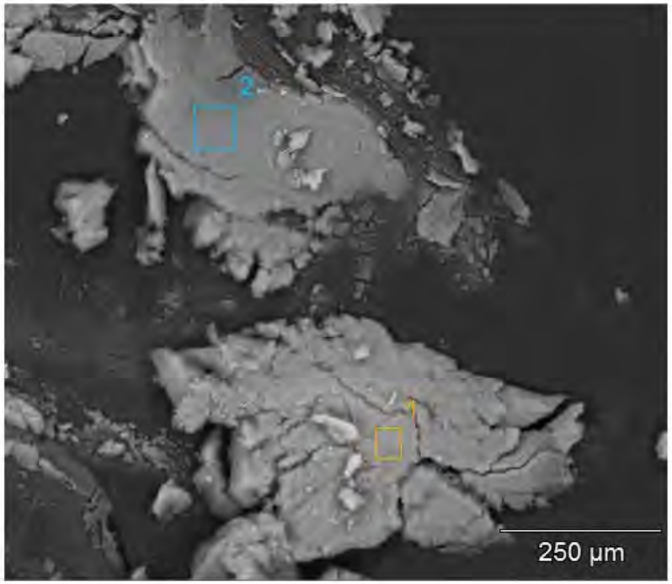


#28 Gearbox mounted bracket white material

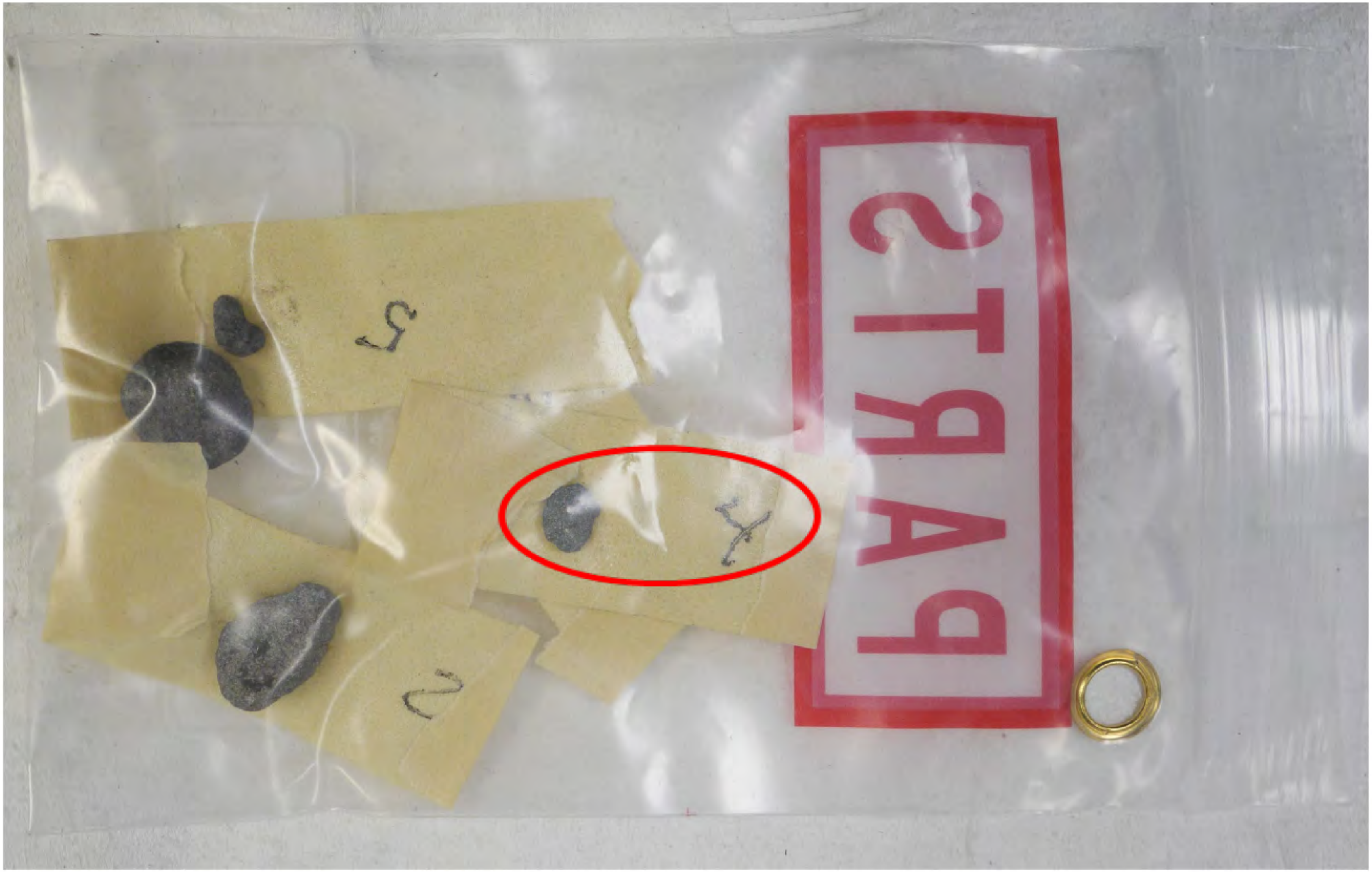
#28 Gearbox mounted bracket white material



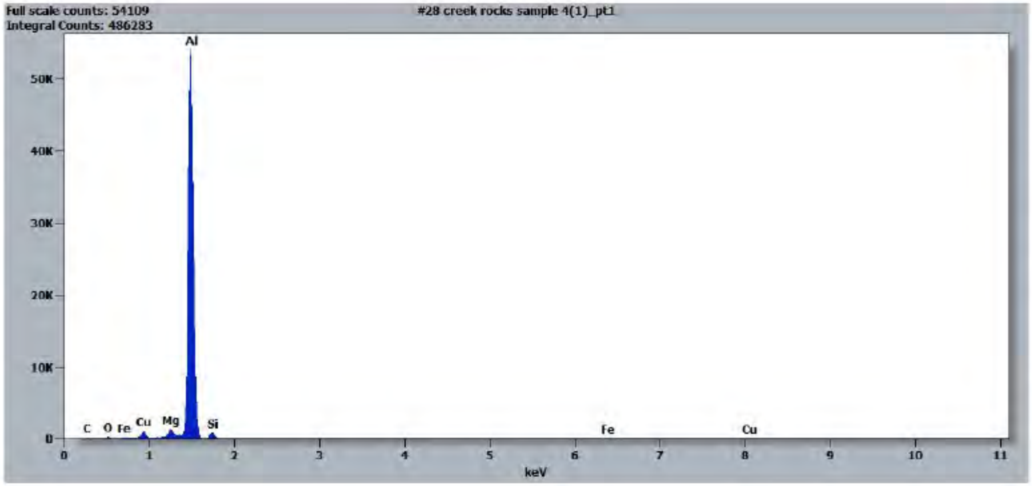


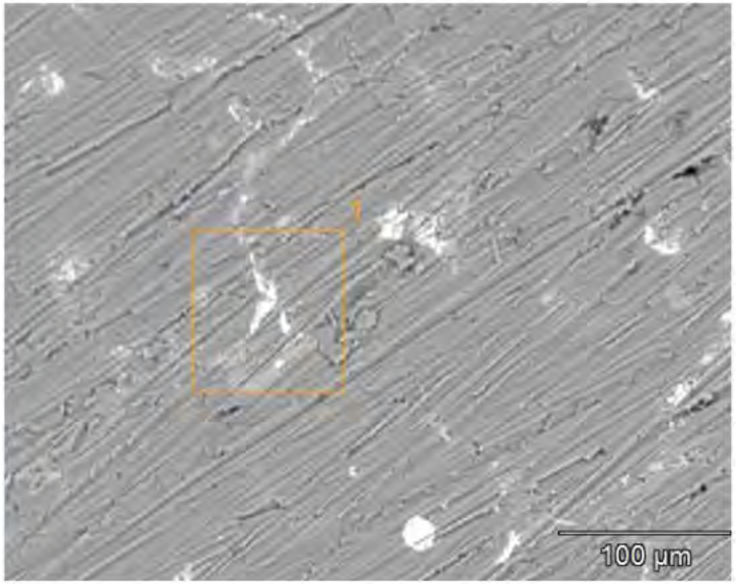


#28 ‘creek rocks’ sample 4



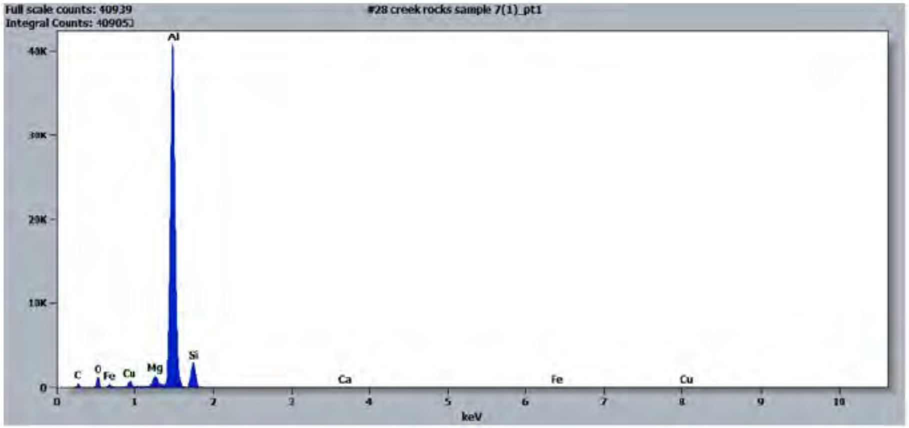
#28 'creek rocks' sample 4 – similar to 2xxx aluminum

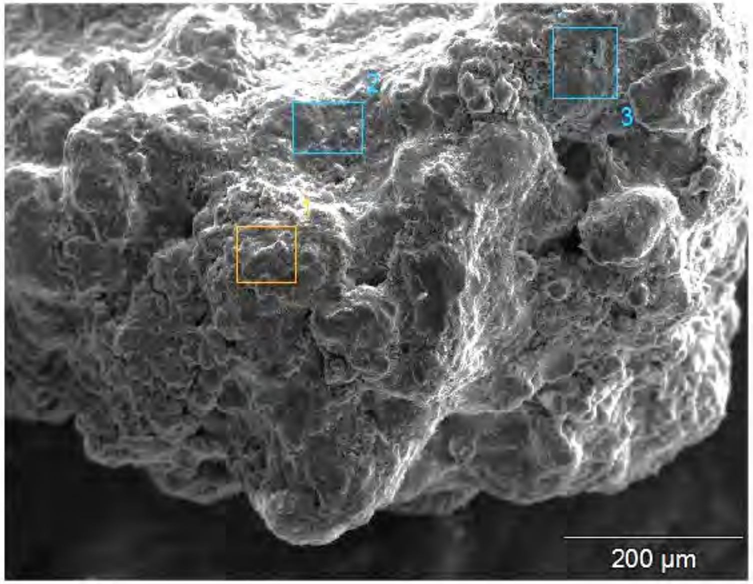


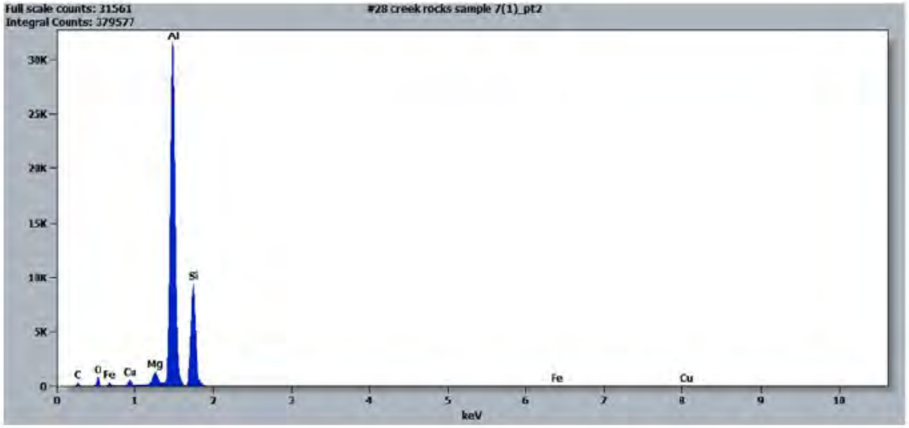


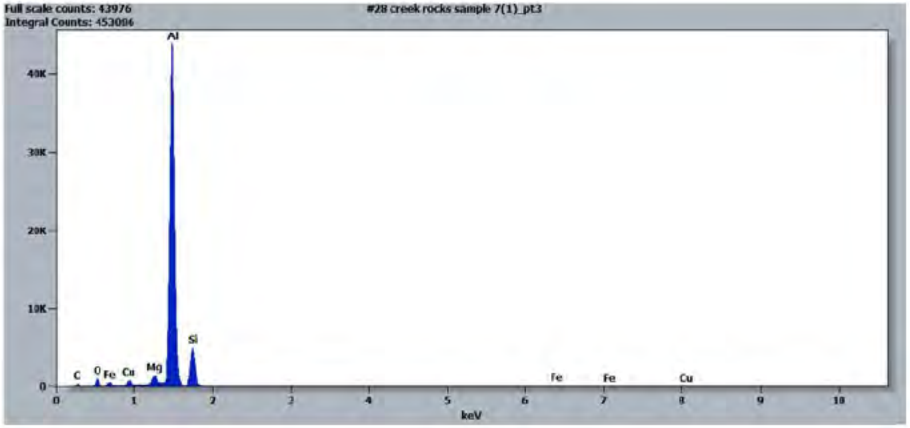
#28 'creek rocks' sample 7

#28 ‘creek rocks’ sample 7 – possibly cast aluminum.



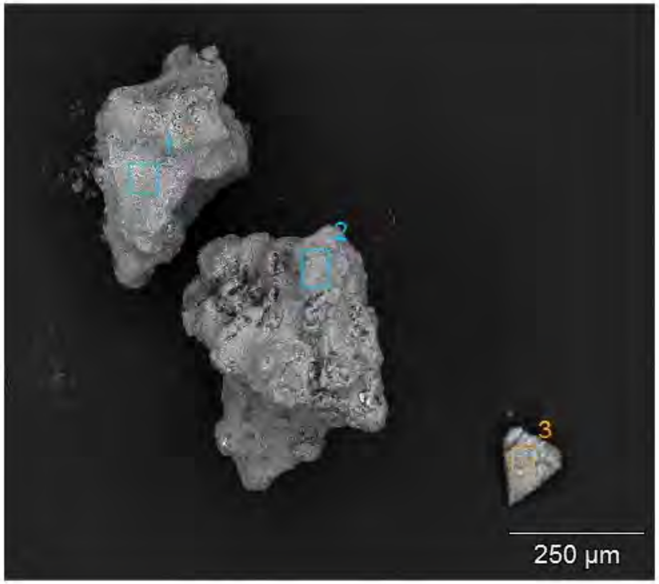


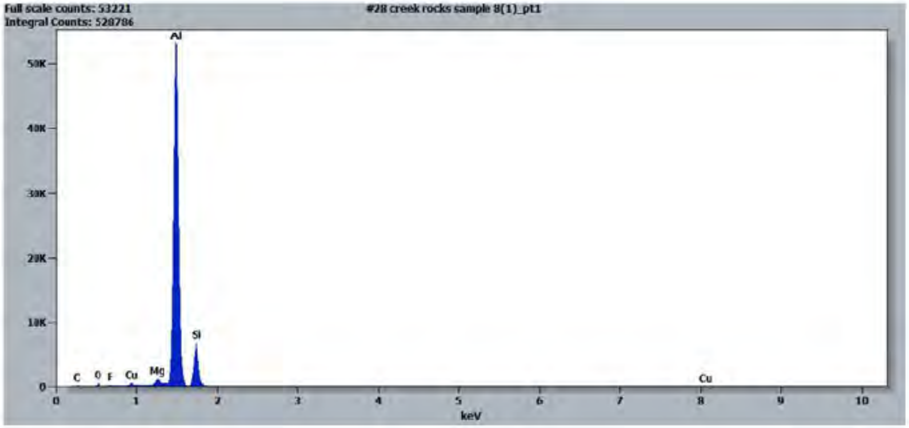


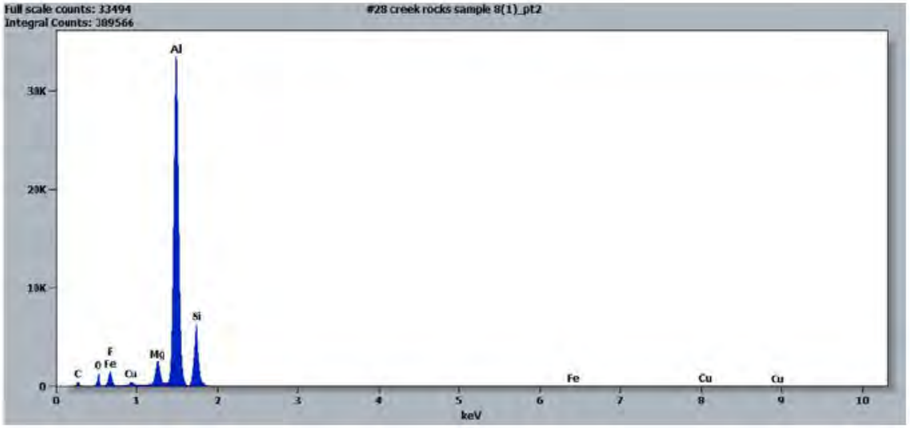


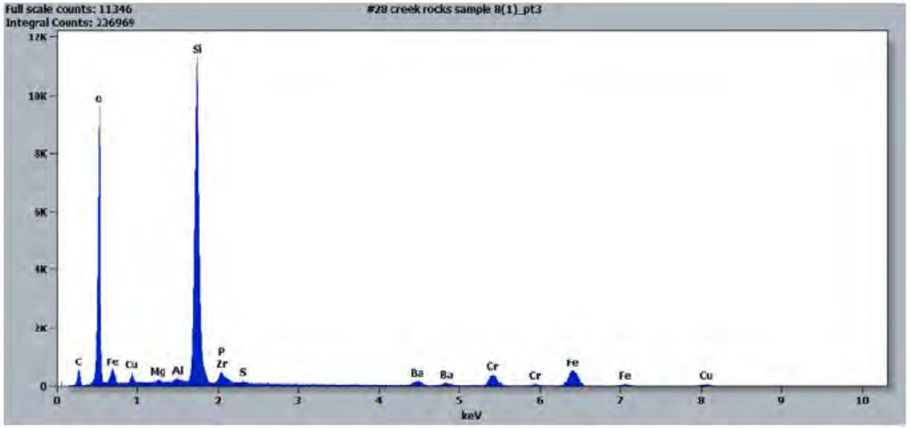
#28 'creek rocks' sample 8

#28 'creek rocks' sample 8





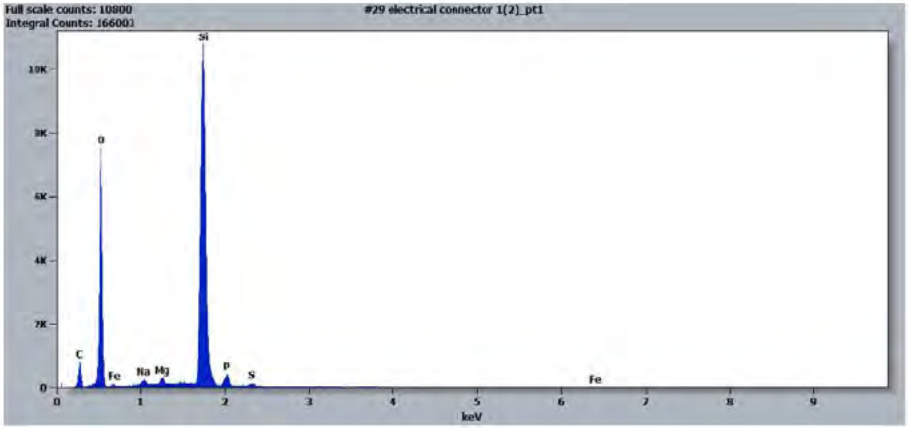


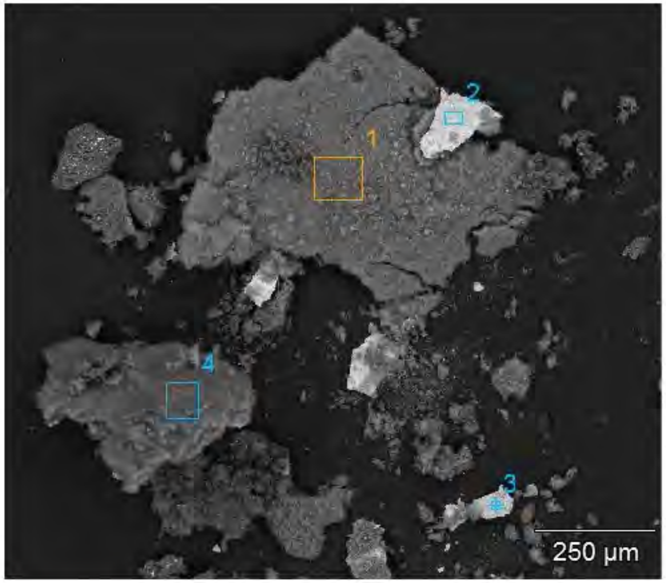


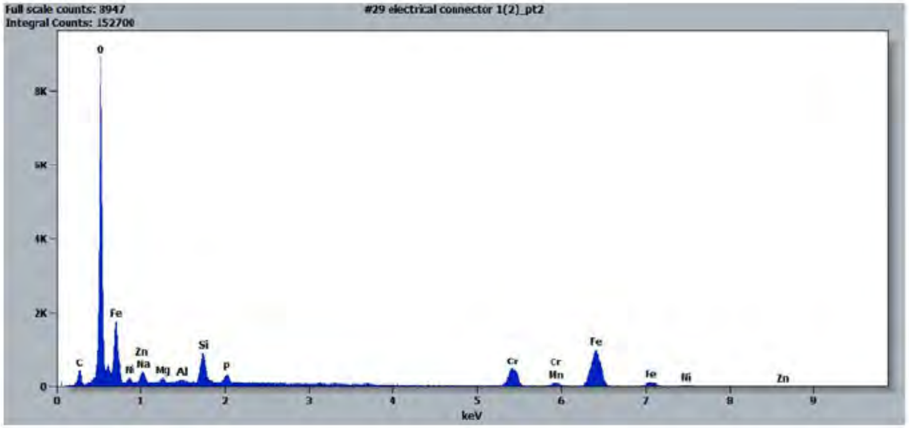
Enclosure A to EQA Reports AS13328 and AS13354

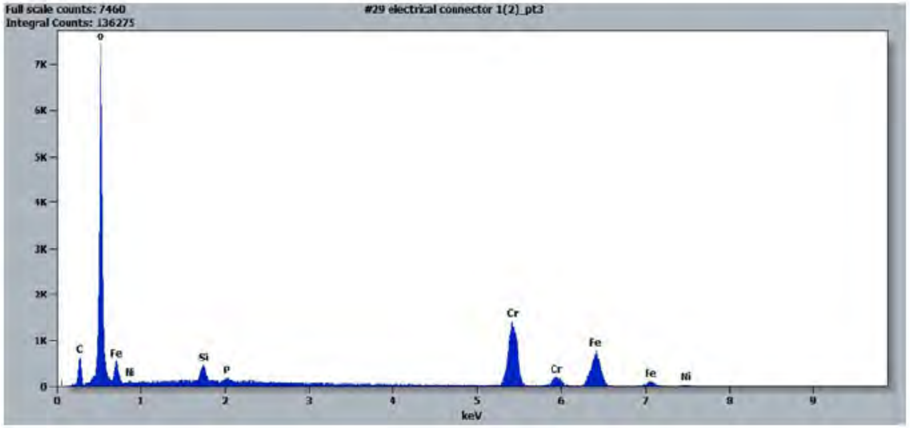
#29 electrical connectors

#29 electrical connector (1) – corrosion products and an inorganic silicon compound

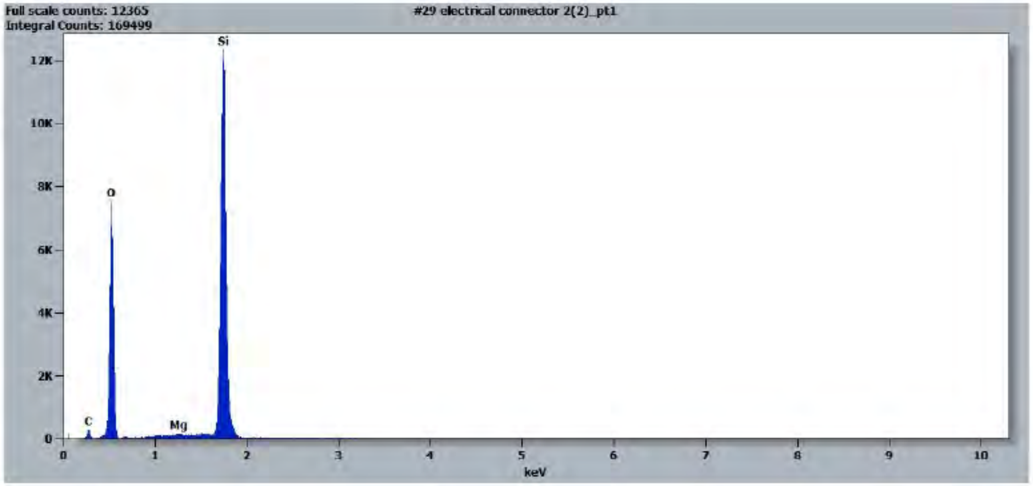


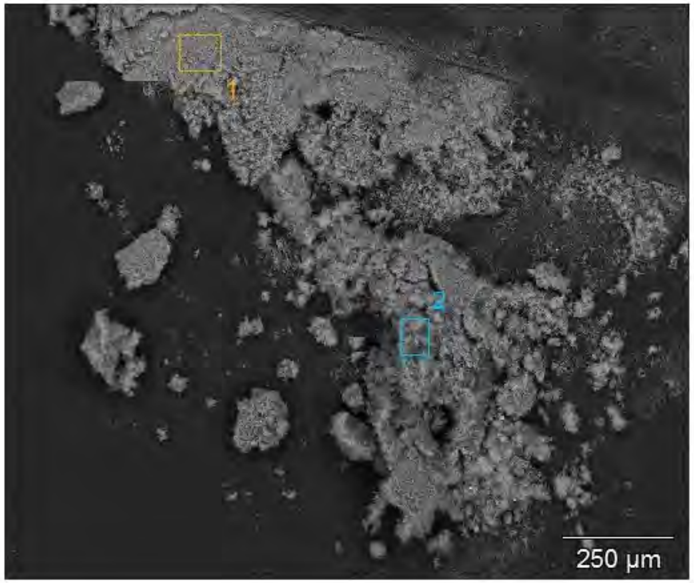


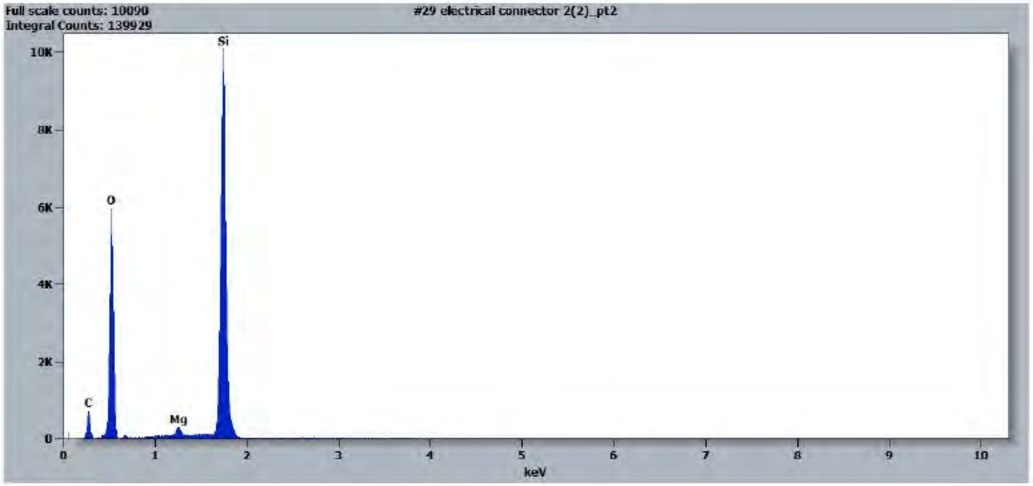




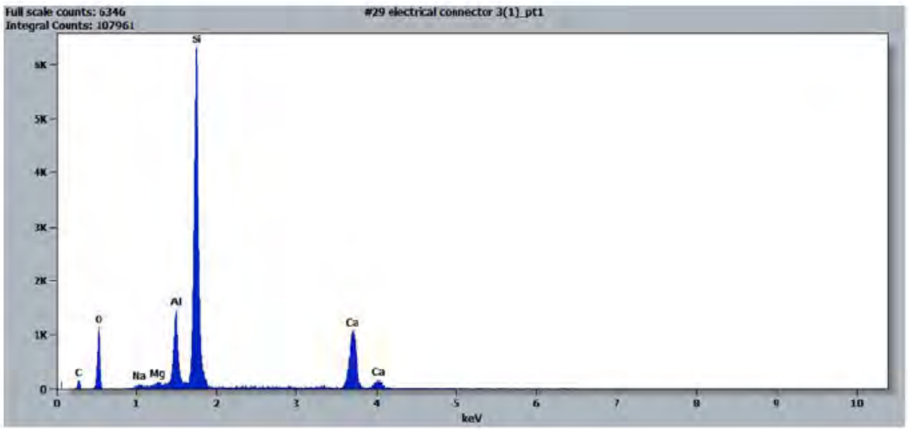
29 electrical connector (2) – inorganic silicon material

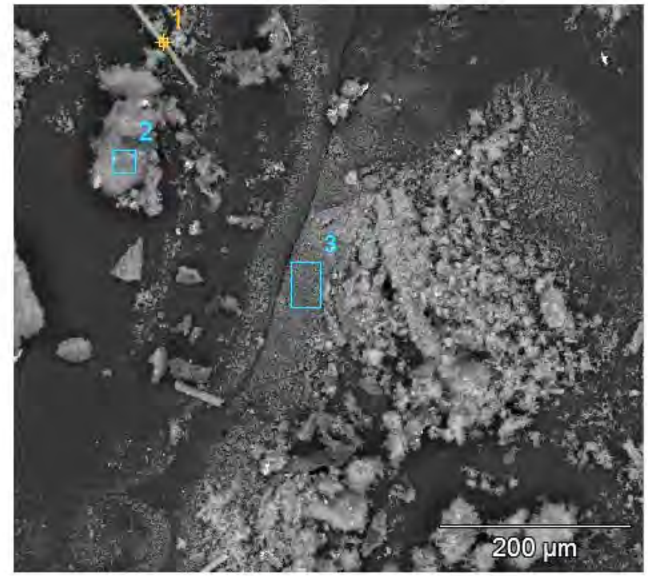


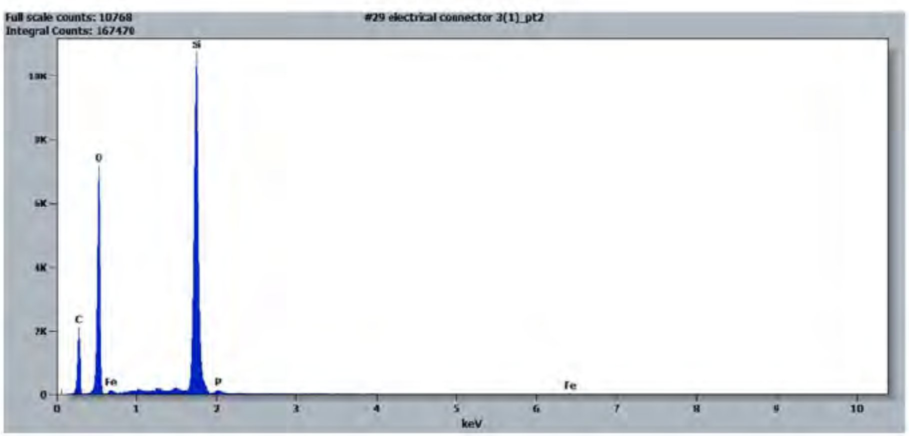


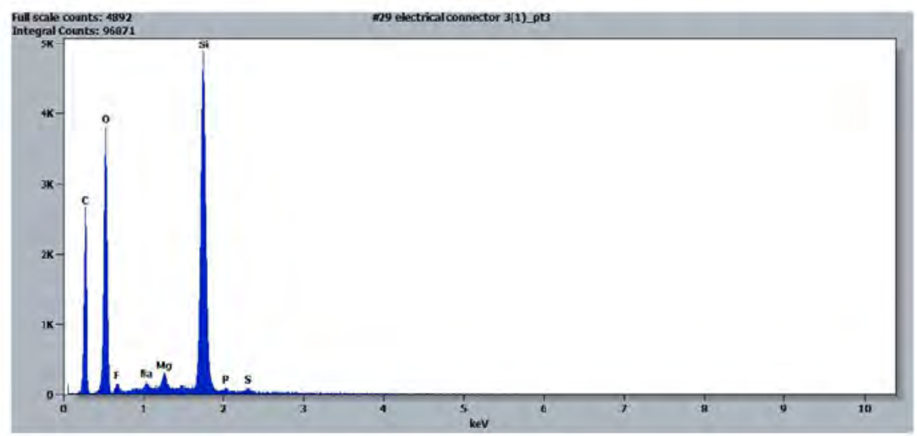


29 electrical connector (3) – consistent with an inorganic silicon material

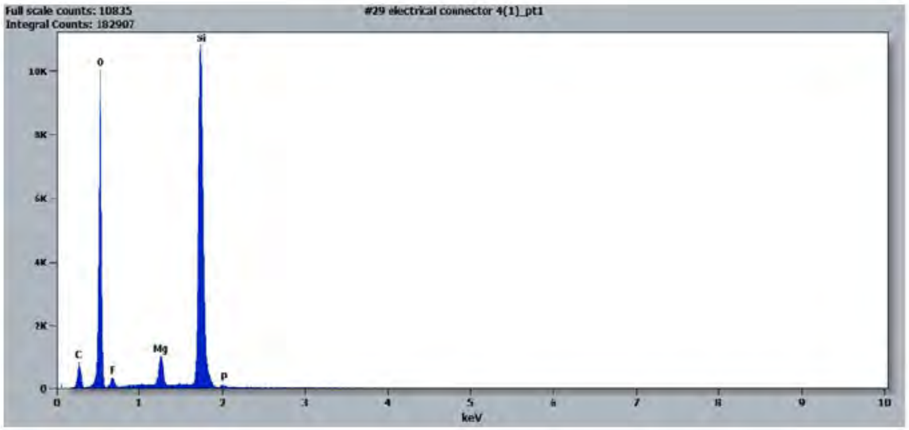


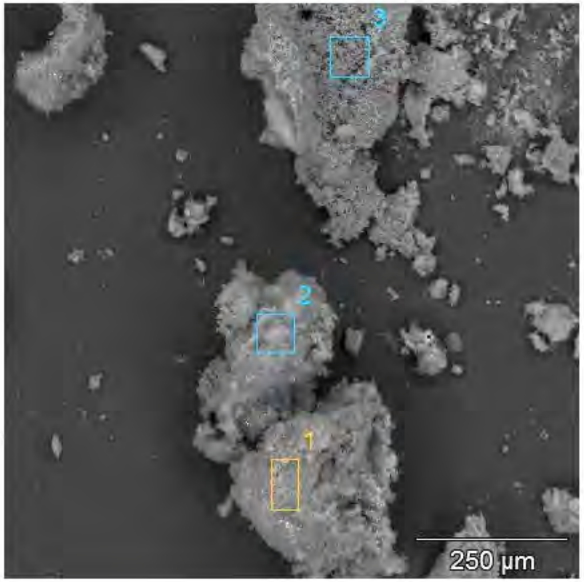


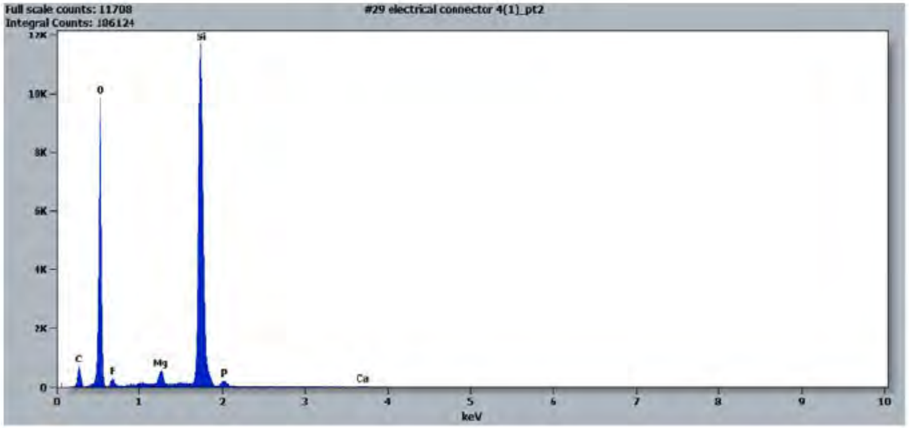


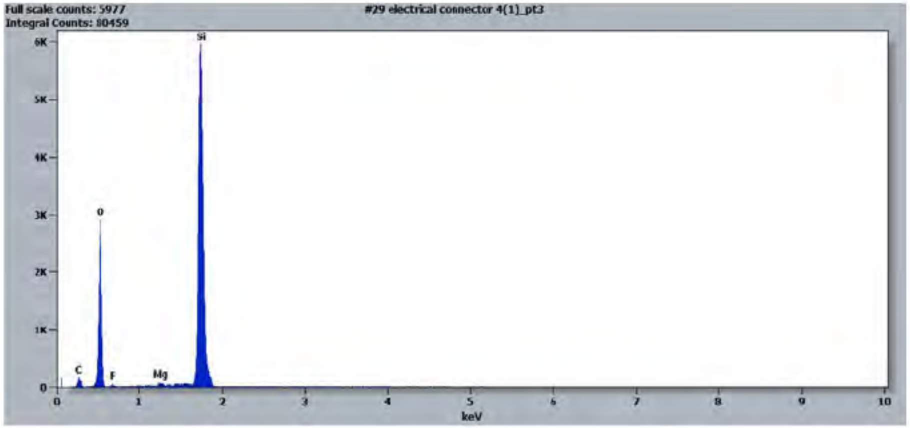


#29 electrical connector (4) – consistent with an inorganic silicon material

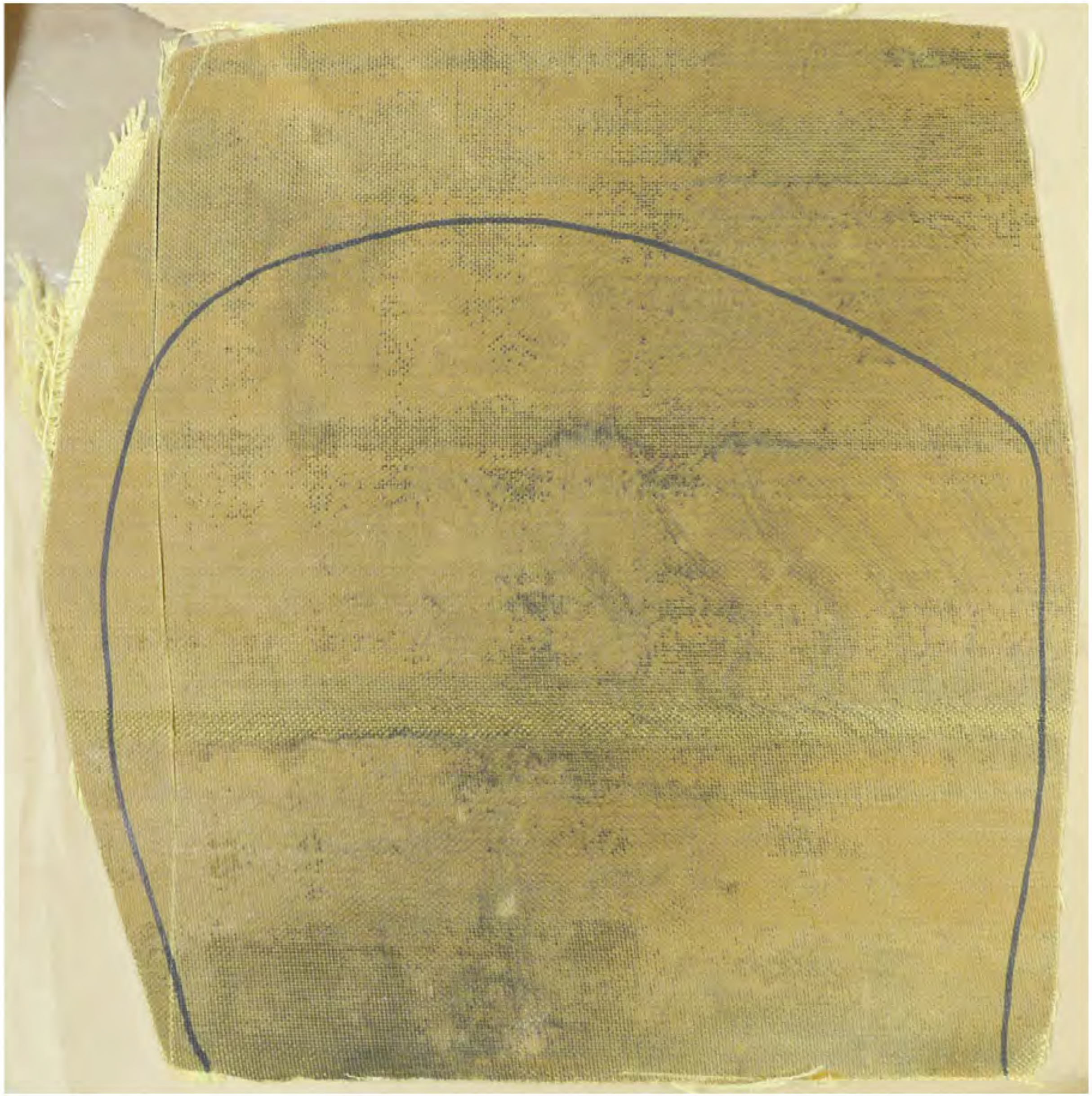




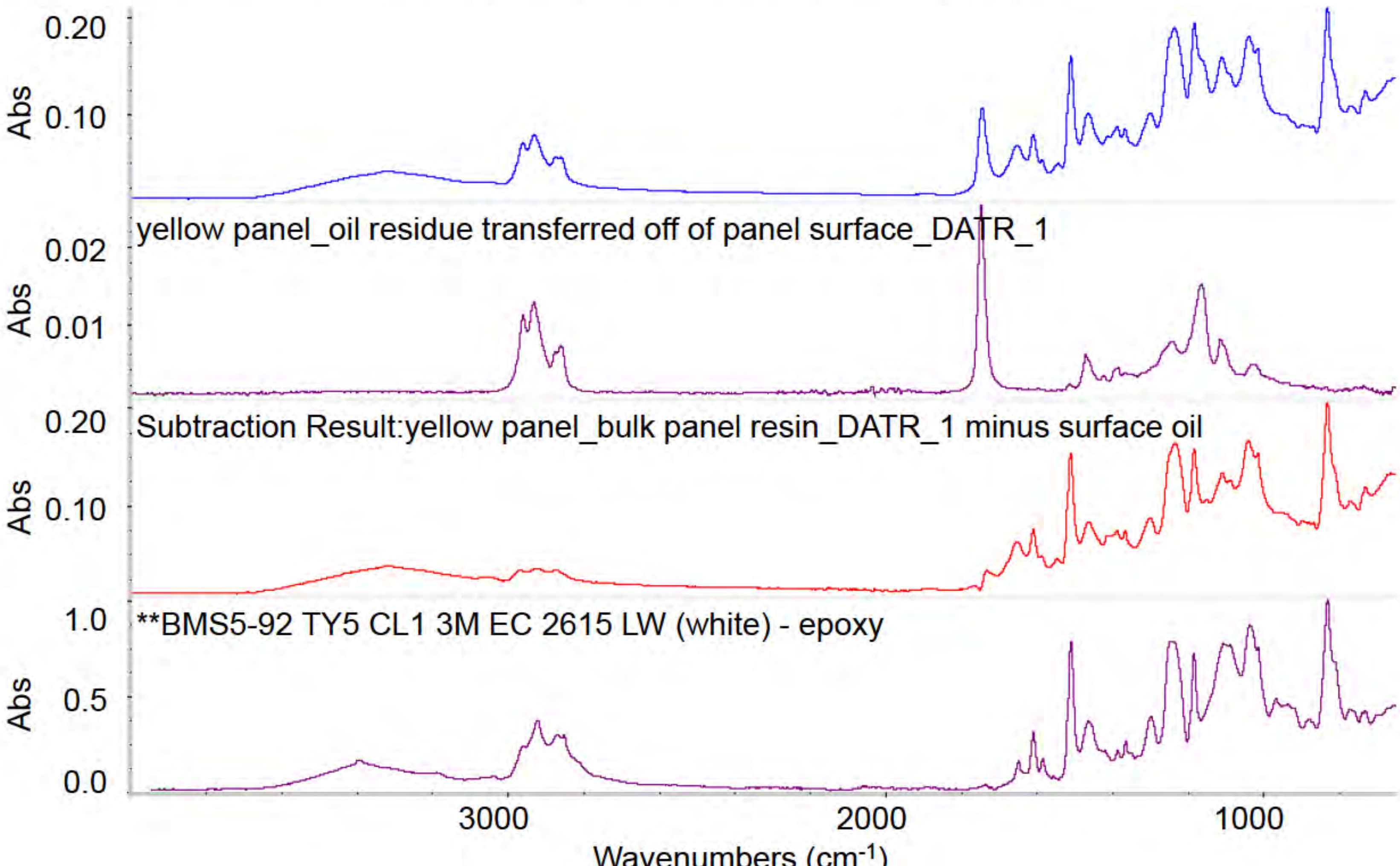




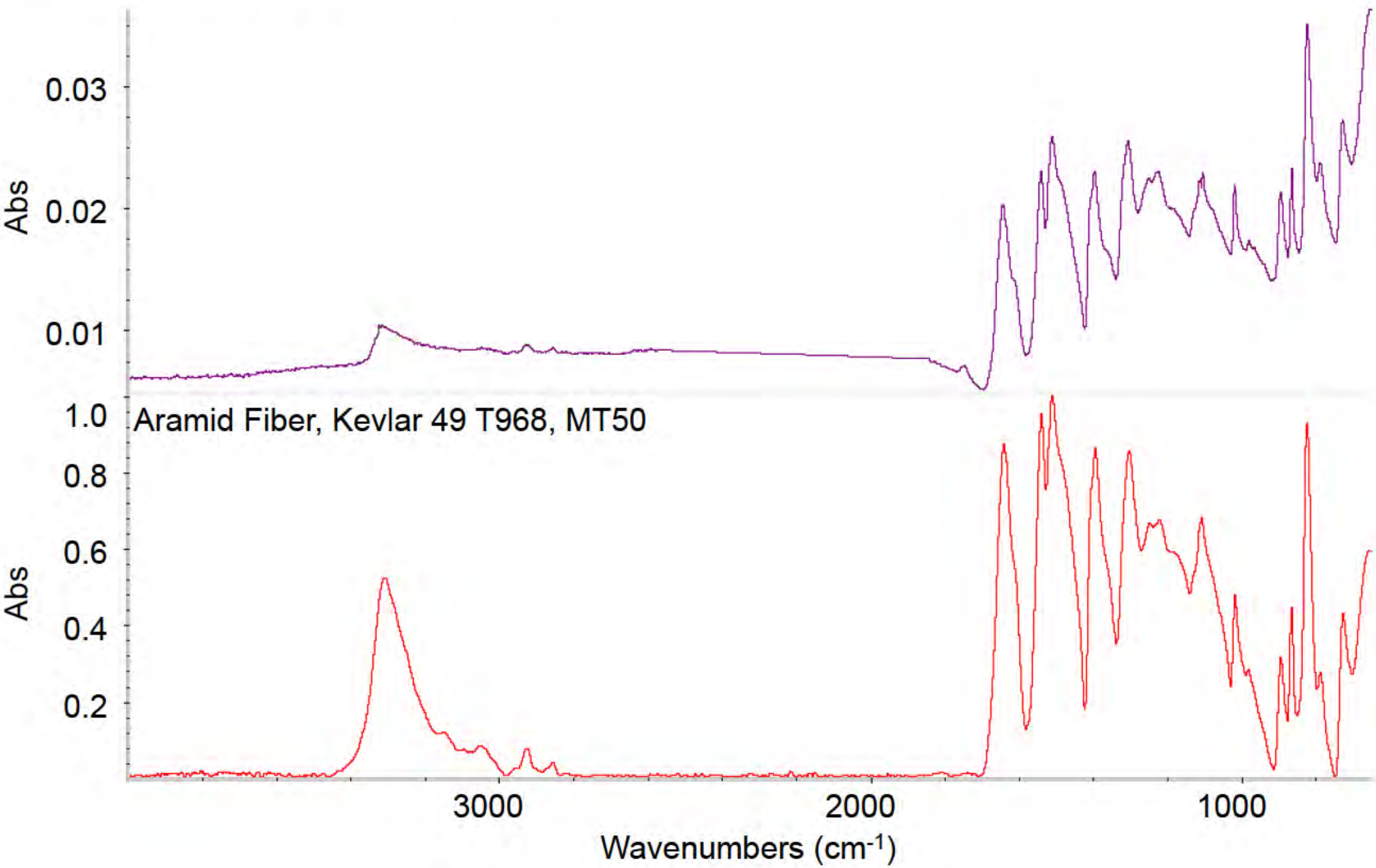
30 environmental wrap



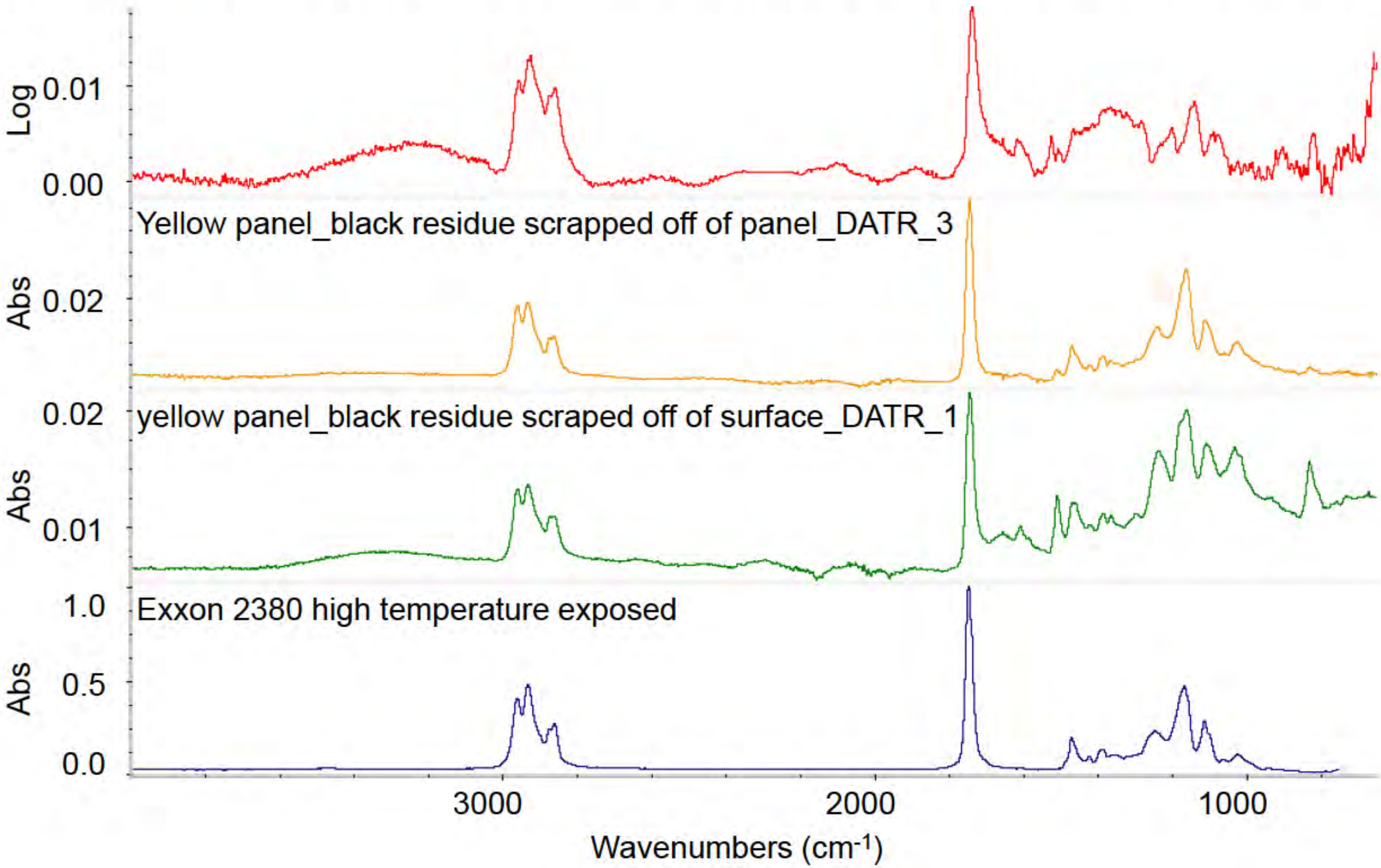
30 environmental wrap. The panel resin is consistent with epoxy. In order to assess the panel resin, the oil coating the surface of the panel needed to be subtracted.



#30 - The yellow fibers reinforcing the epoxy were consistent with aramid, such as Kevlar.



#30 - The black soot looking material on the panel was consistent with engine oil coking deposits. The deposits consisted of varying levels of thermally degraded engine oil.



Engineering, Test & Technology
Boeing Research & Technology

July 30 2021
SR 17376

To: [redacted],

Program: **Air Safety, Equipment Quality Analysis, 777 Program**

BLIS No.: [redacted]

Subject: **UAL 777-200 FBO Thrust Reverser Fracture Analysis**

Prepared by: [redacted]

Approved by: [redacted]

Background

UAL experienced a fan blade out (FBO) event on the right engine of a 777-200 WA005. Cracking was found in the left and right thrust reverser outer v-blade areas upon inspection. Portions of the cracks from the right and left thrust reverser assemblies (P/N 315W3001-4AA and 315W3001-3AA, respectively) and components from the drain access door assemblies (P/N 315W3008-9) were submitted to the BR&T Central Fracture Analysis Team for analysis.

Experimentation and Results

Upon receipt at the BR&T Fracture Analysis group, the portions of the thrust reversers and drain access panel were subjected to the following analyses:

- Visual examination of the as-received parts.
- Separating of the crack faces when necessary.
- Optical and scanning electron microscopic (SEM) examination of the fractured surfaces.
- Energy dispersive spectroscopy (EDS) of the access door components to determine the alloy.
- Hardness and conductivity checks of access door components to determine if affected by heat from fire.

Figure 1 shows the Right Thrust Reverser (P/N 315W3001-4AA) before sectioning. An approximately 1.5 inch crack extended from the edge of the part in the 12:00 region and was excised for analysis (Figures 2 – 4). Figure 5 contains SEM images of the fracture surface of this portion of the crack. Some portions of the fracture surface were obscured by post fracture damage, but in the undamaged area the fracture mode was entirely ductile separation, consistent with a single event and showing no signs of fatigue or crack advancement after the event.

Figure 6 shows the Left Thrust Reverser (P/N 315W3001-3AA) before sectioning. Significant cracking ran from the edge of the part at the 6:00 position to the 9:00 region (Figures 7 and 15) and a smaller crack was identified in the 12:00 location.

Figures 8 and 9 show the portion excised from the 9:00 location and further cut into nine sections for SEM fractography. Figures 10 – 14 show SEM images of the fracture surfaces of this portion of the crack. Some portions of the fracture surface were obscured by post fracture damage, but in the undamaged area the fracture mode was entirely ductile separation, consistent with a single event and showing no signs of fatigue or crack advancement after the event.

Figures 16 and 17 show the portion excised from the 7:00 location and further cut into five sections for SEM fractography. Figure 18 shows SEM images of the fracture surfaces of the lower portion of Section 1 from this region. The presence of striations on the fracture surface confirmed fatigue as the fracture mode in this region, propagating in a primarily downward direction. No obvious origins were found at the edge of the part, indicating the fatigue may have started at the termination of ductile separation fractures or may have been preexisting, but the cleanliness of the fracture surface indicates the fracture was a recent occurrence. Figure 19 shows SEM images of the fracture surfaces of the upper portion of Section 1 from this region, the fracture mode in this portion was entirely ductile separation.

Figures 20 – 27 show SEM images of the fracture surfaces of Sections 2 – 9 of this portion of the crack. Some portions of the fracture surface were obscured by post fracture damage, but in the undamaged area the fracture mode was entirely ductile separation, consistent with a single event and showing no signs of fatigue or crack advancement after the event.

Figure 28 shows the smaller crack from the 12:00 location excised for examination. Figure 29 contains SEM images of the fracture surface of this portion of the crack. Some portions of the fracture surface were obscured by post fracture damage, but in the undamaged area the fracture mode was entirely ductile separation, consistent with a single event.

Three fractured components from drain access door assembly (P/N 315W3008-9) were removed from the structure for further evaluation. All showed significant discoloration from heat and/or soot (Figures 30, 32, and 34). SEM fractography confirmed ductile separation as the fracture mode in all fracture surfaces in the access door components (Figures 31, 33, and 35). EDS was used to check the chemistry of the access door components on the fracture surfaces. All were found to be similar to the drawing requirements, but did not exactly match the specifications, typical of fracture surfaces exposed to temperature and environment. Hardness and conductivity measurements were taken of the door components to evaluate the heat treatment. The Latch (P/N 9476-1) met the drawing requirements for 2024-T3511 aluminum. Both the Gooseneck Assembly (P/N 315W3422-12) and Depressor (P/N 315W3419-3) did not meet the requirements, which could indicate significant exposure to heat.

Conclusions

1. All fractures investigated in this report were composed entirely of ductile separation fracture mode, consistent with a single event, with the exception of a region in the Left Thrust Reverser 9:00 position.

2. The fatigue in the Left Thrust Reverser 9:00 position section 1 was located in the lower region of the fracture and propagated in the down direction.

3. The chemical composition of the components from the drain access door assembly appear consistent with the alloys specified on the engineering drawings, but were not exact matches, likely due to the locations of the analysis on exposed fracture surfaces.

4. The hardness and conductivity of the latch met the requirements of the engineering drawing. The hardness and conductivity of the gooseneck and depressor did not meet the requirements, possibly the result of thermal exposure.

5. No other anomalies were observed contributing to the fractures.

Figure 1. Right Thrust Reverser (P/N 315W3001-4AA SN 000002). A short fracture runs from the edge of the part at the 12:00 clock position, extending for approximately 1.7 inches.

Figure 2. Right Thrust Reverser fracture at the 12:00 clock position before removal.

Figure 3. Right Thrust Reverser fracture at the 12:00 clock position after removal. The 1.5 inch long crack is indicated by the red arrow.

Figure 4. Macro photograph of the Right Thrust Reverser fracture initiation.

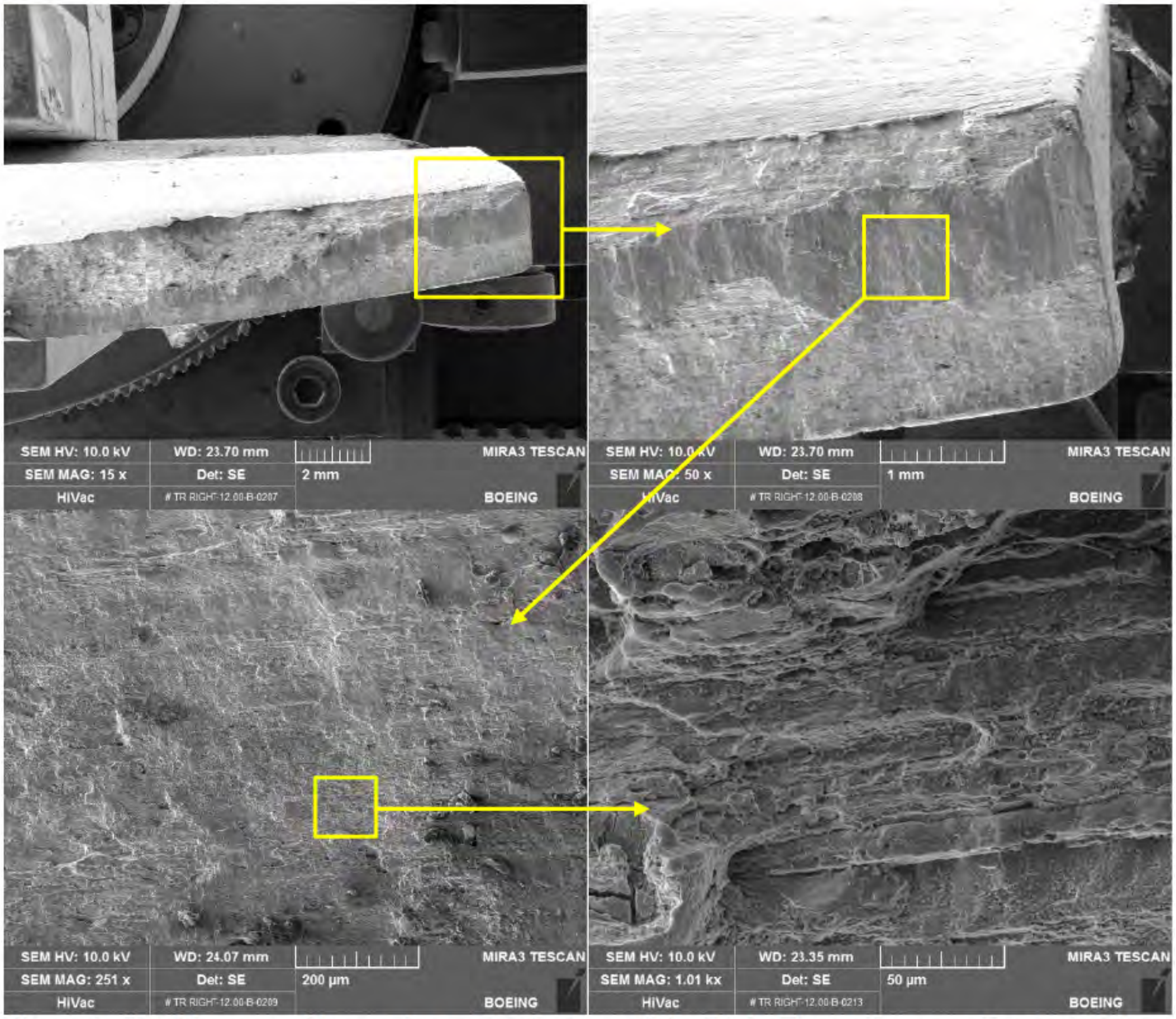


Figure 5. SEM images of increasing magnification of the Right Thrust Reverser Fracture, taken at the end of the part. Post fracture damage obscured portions of the fracture surface, the fracture mode visible was entirely ductile separation.

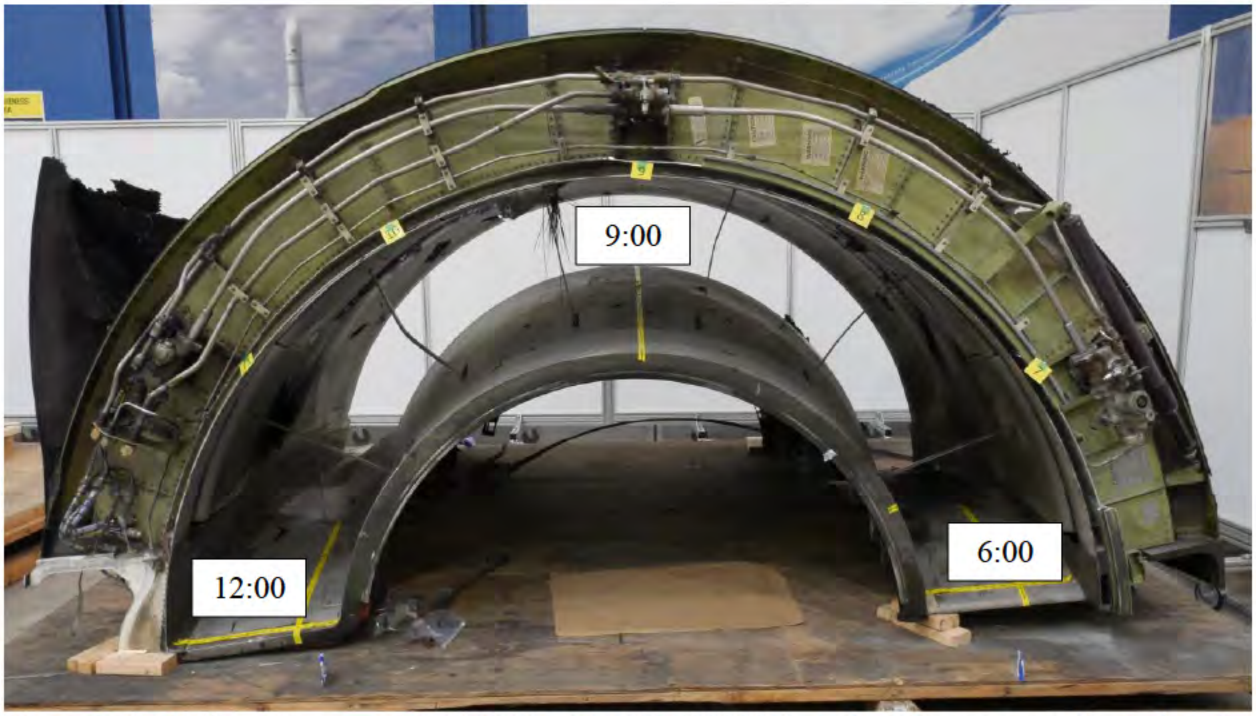


Figure 6. Left Thrust Reverser (315W3001-3AA SN 000002). A short fracture was located at the 12:00 position, a longer fracture ran from the end of the part at the 6:00 position to 9:00.

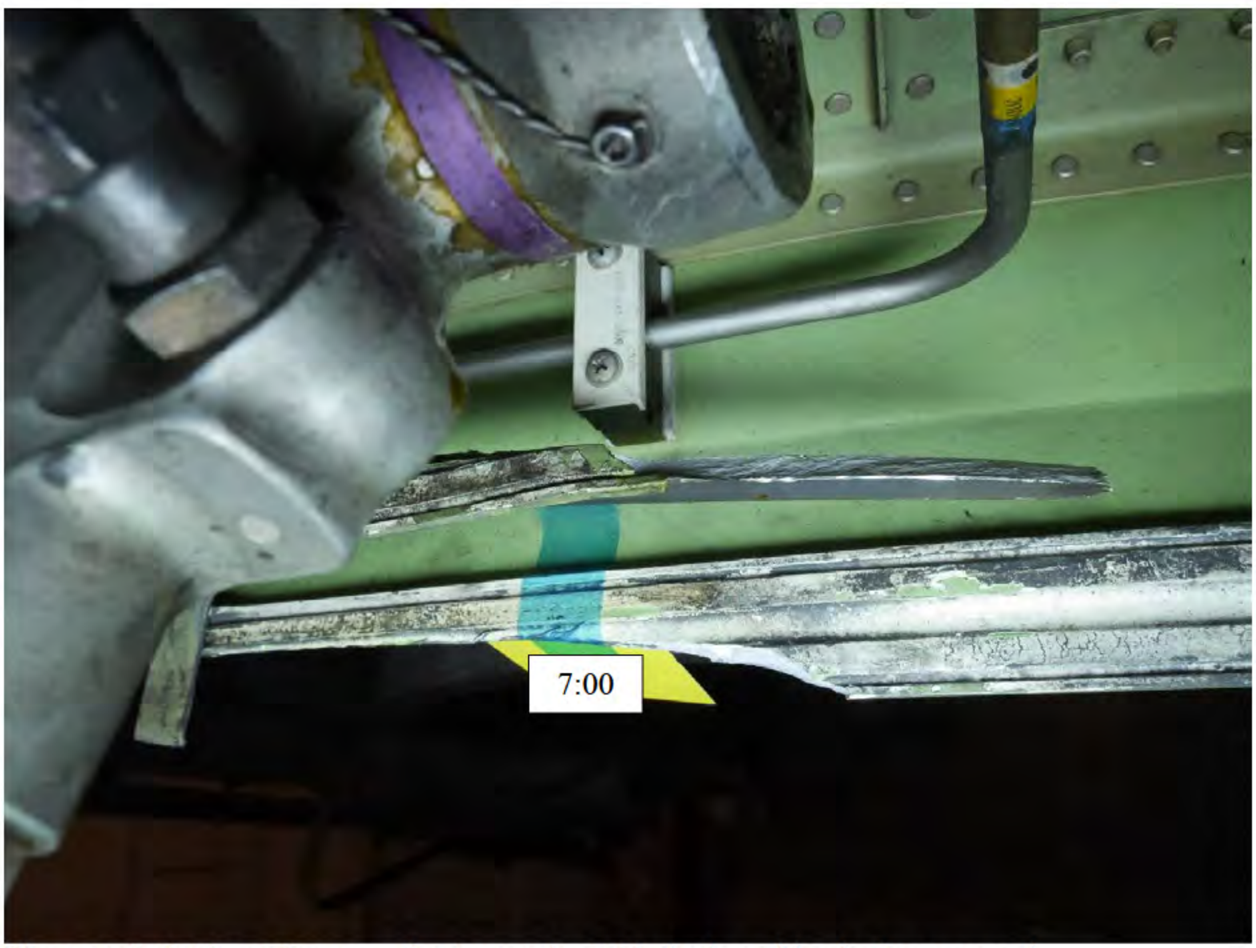


Figure 7. Left Thrust Reverser fracture at the 7:00 clock position before removal.

Figure 8. Left Thrust Reverser fracture at the 7:00 clock position after removal.

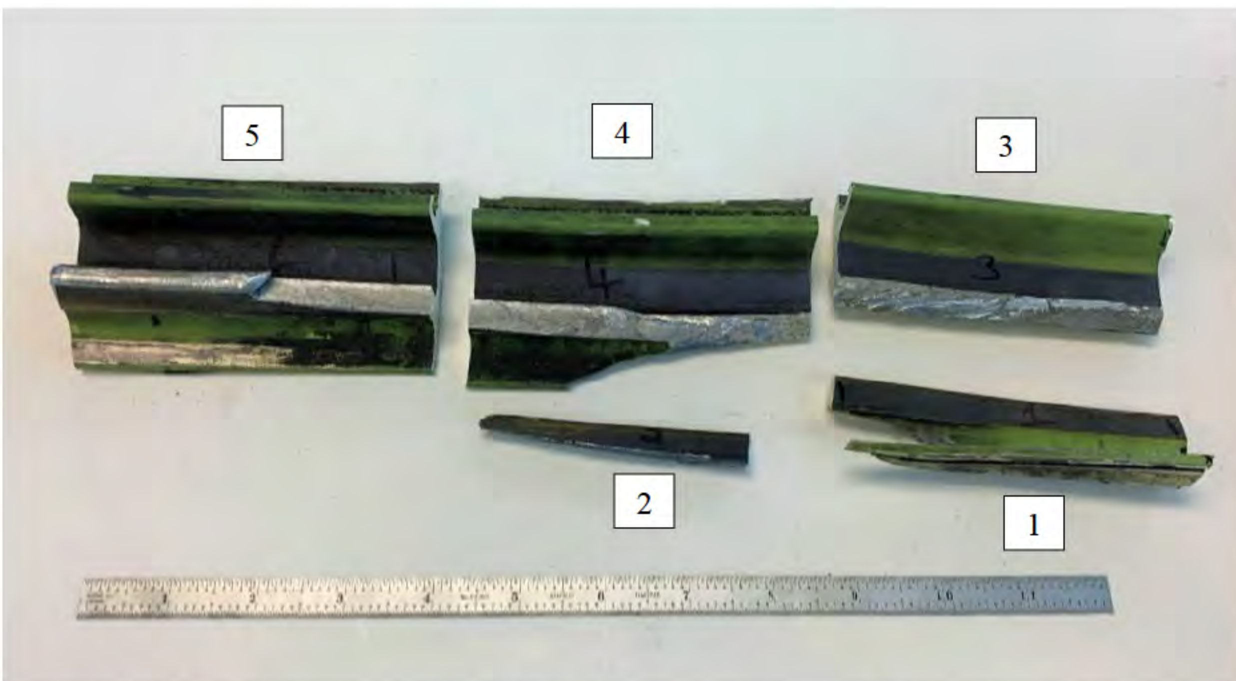


Figure 9. Left Thrust Reverser fracture at the 7:00 clock position cut into sections for SEM examination with the sections labeled.

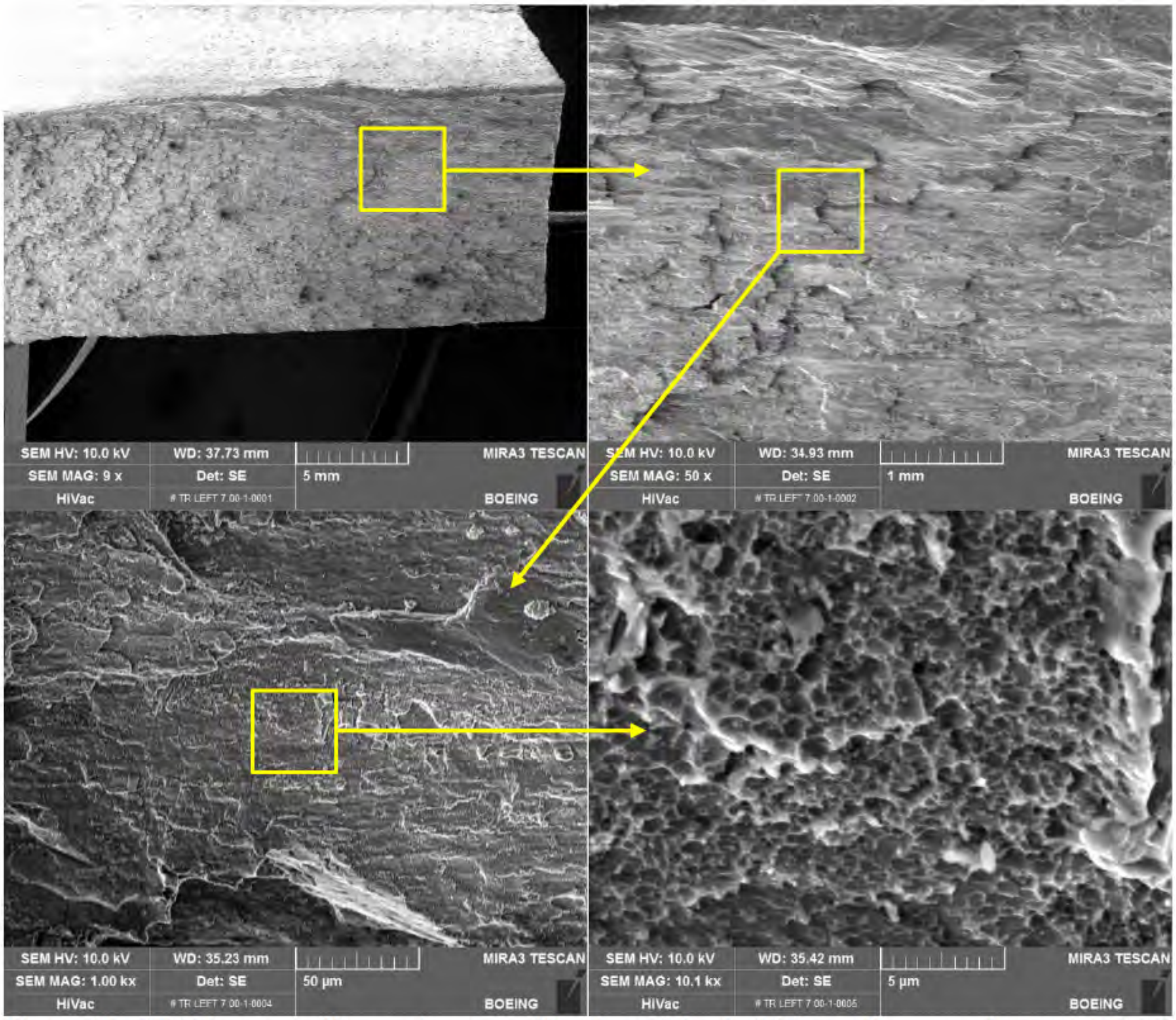


Figure 10. SEM images of increasing magnification of the Left Thrust Reverser fracture at 7:00, Section 1. Some portions of the fracture surface were obscured by post fracture damage, but where visible the fracture mode visible was entirely ductile separation.

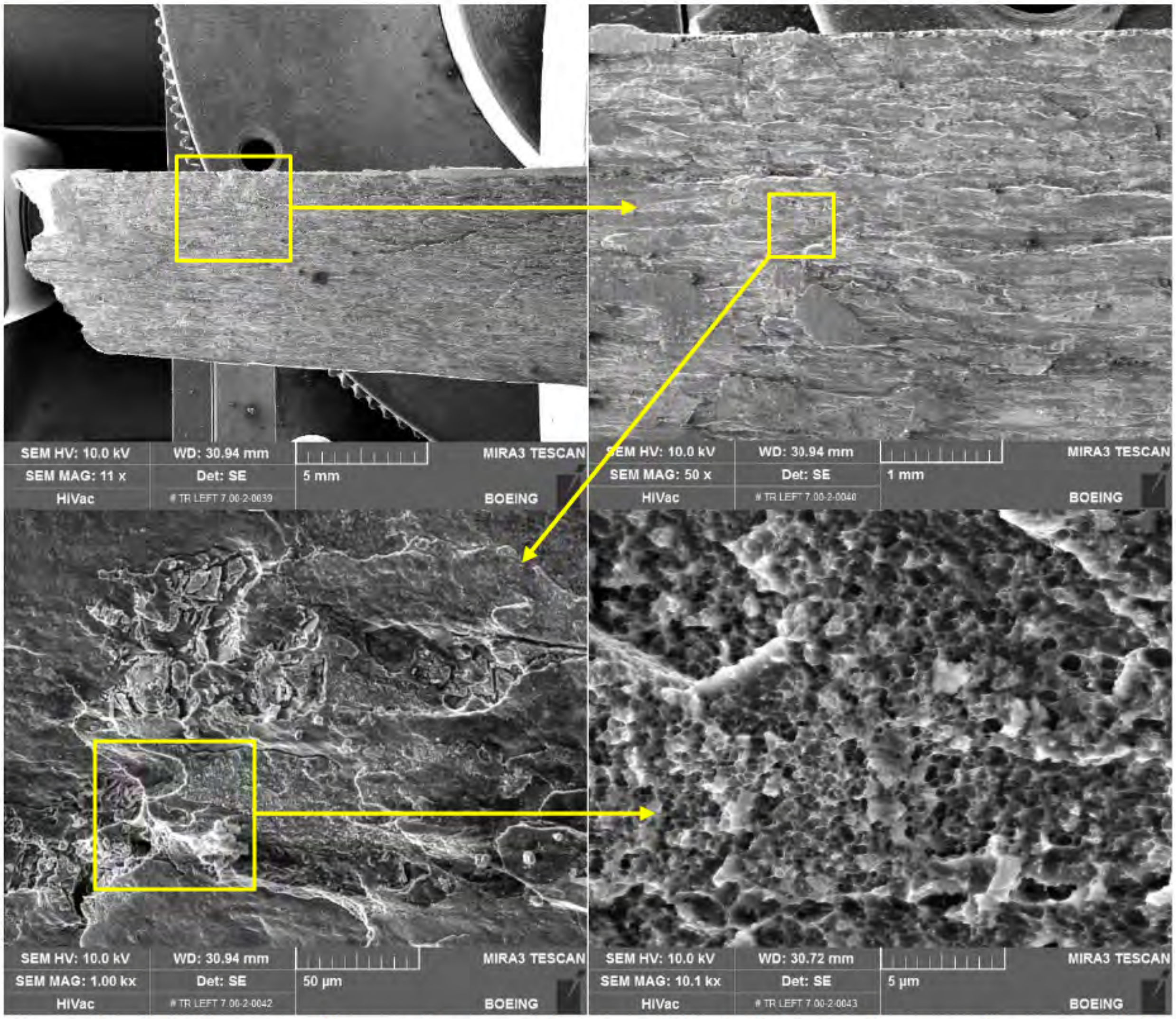


Figure 11. SEM images of increasing magnification of the Left Thrust Reverser fracture at 7:00, Section 2. Significant post fracture damage obscured portions of the fracture surface, the fracture mode visible was entirely ductile separation.

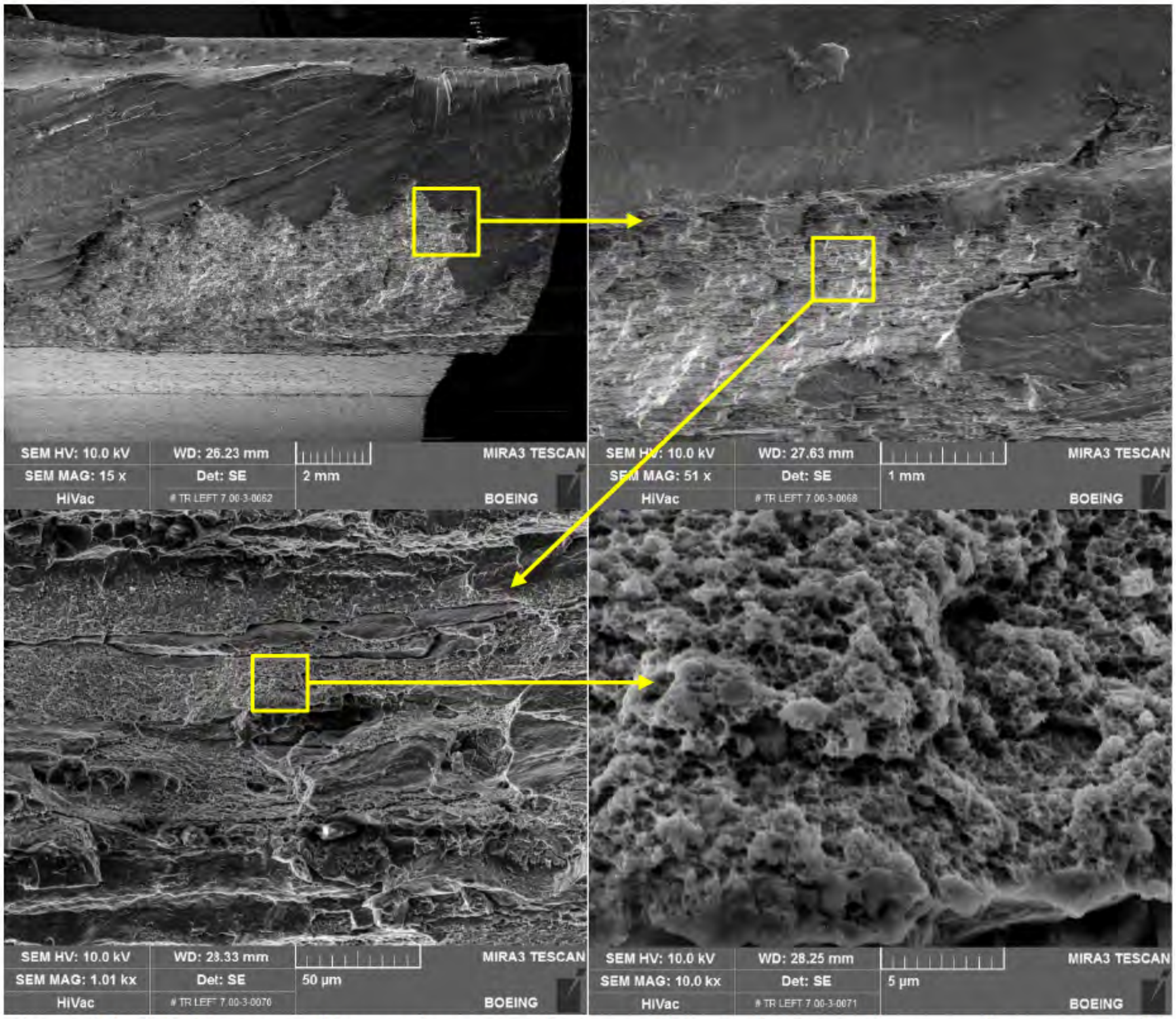


Figure 12. SEM images of increasing magnification of the Left Thrust Reverser fracture at 7:00, Section 3. Significant portions of the fracture surface were obscured by post fracture damage, but where visible the fracture mode visible was entirely ductile separation.

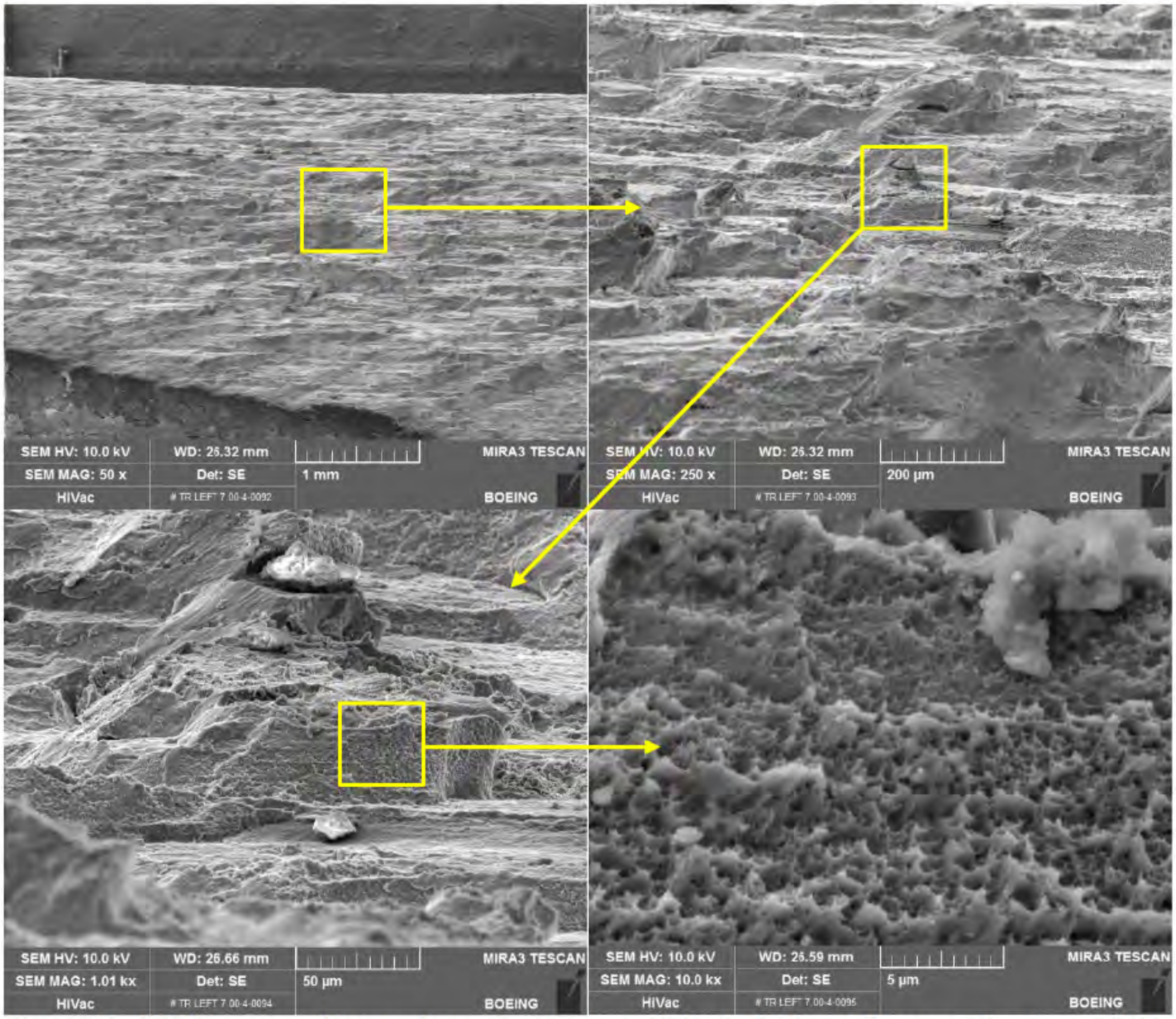


Figure 13. SEM images of increasing magnification of the Left Thrust Reverser fracture at 7:00, Section 4. The fracture mode visible was entirely ductile separation.

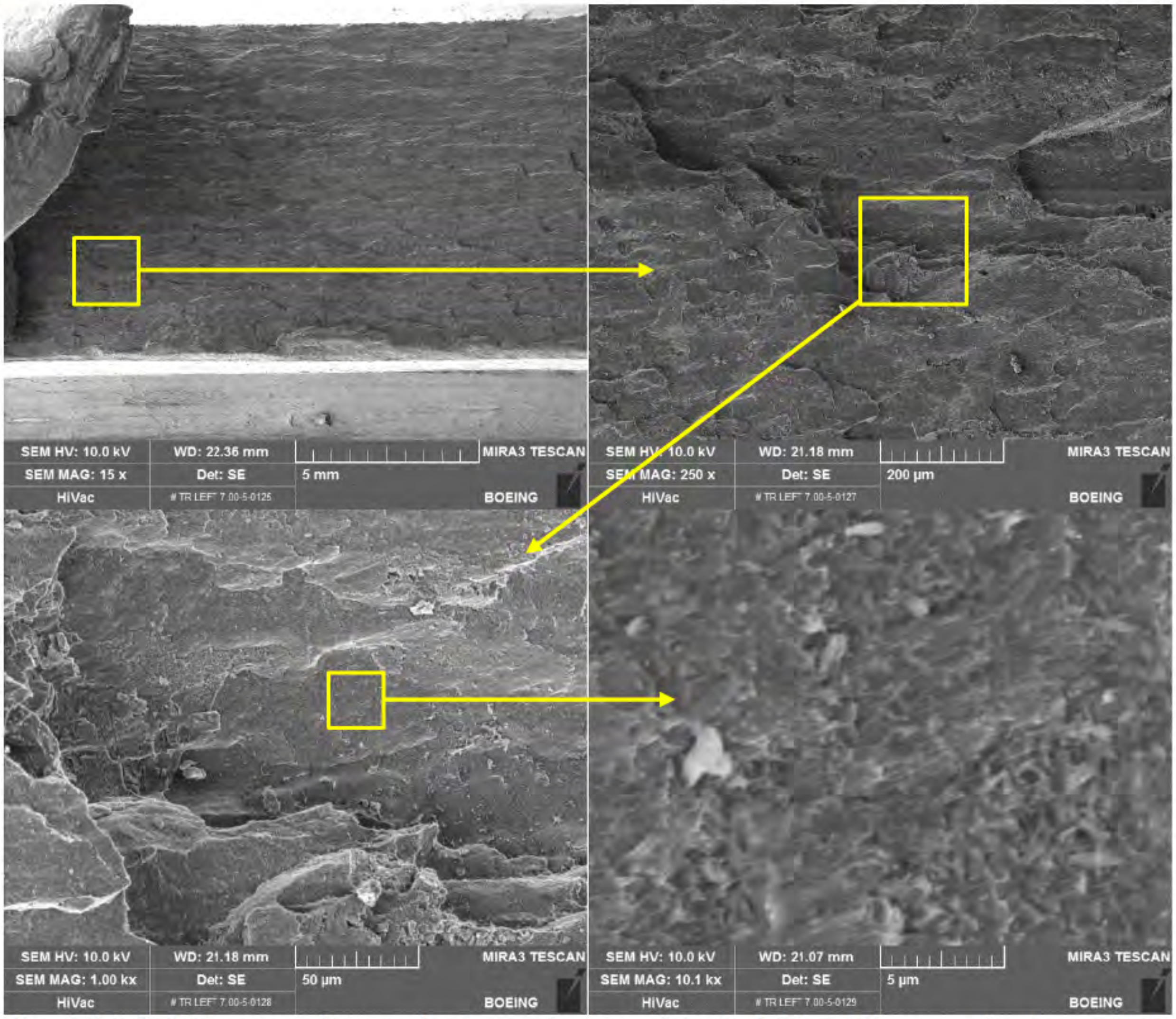


Figure 14. SEM images of increasing magnification of the Left Thrust Reverser fracture at 7:00, Section 5. The fracture surface were obscured by post fracture damage and oxidation, but appears consistent with ductile separation.

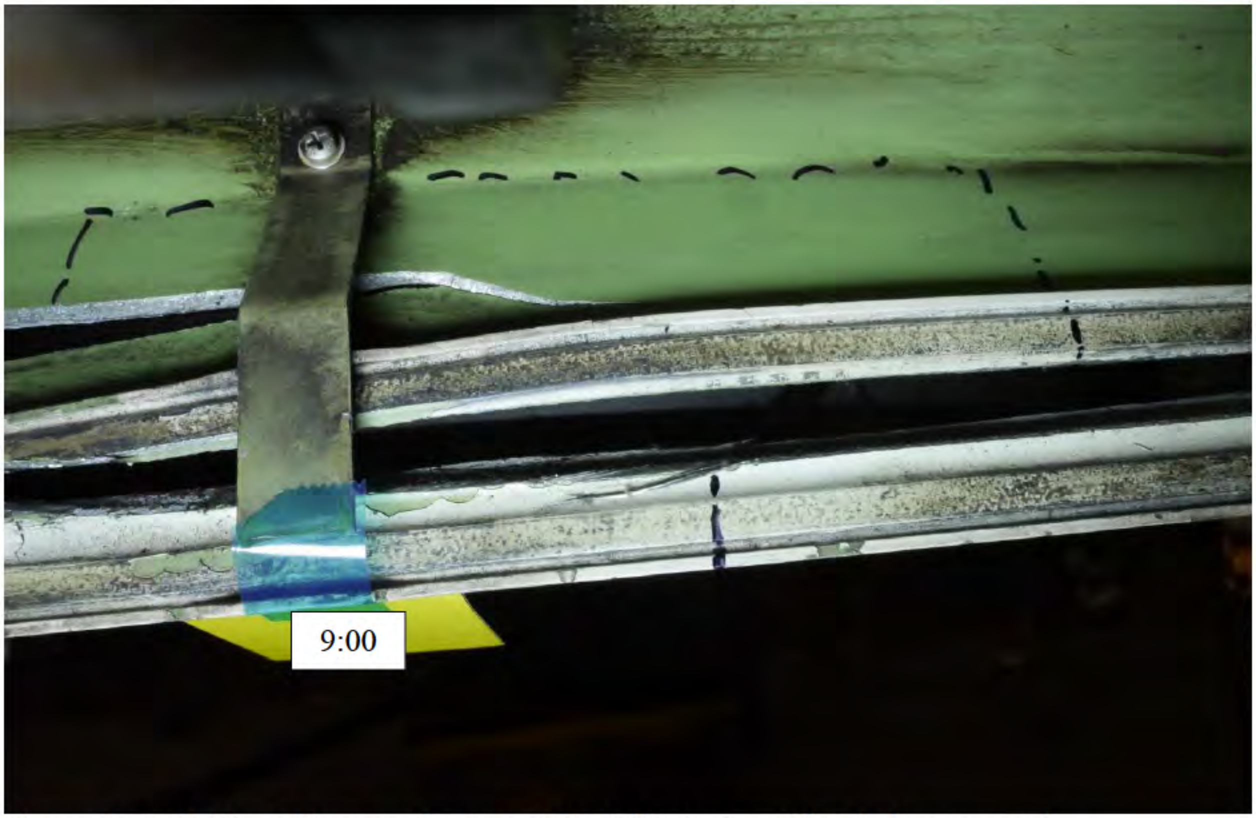


Figure 15. Left Thrust Reverser fracture at the 9:00 clock position before removal.

Figure 16. Left Thrust Reverser fracture at the 9:00 clock position after removal.

Figure 17. Left Thrust Reverser fracture at the 9:00 clock position cut into sections for SEM examination with the sections labeled.

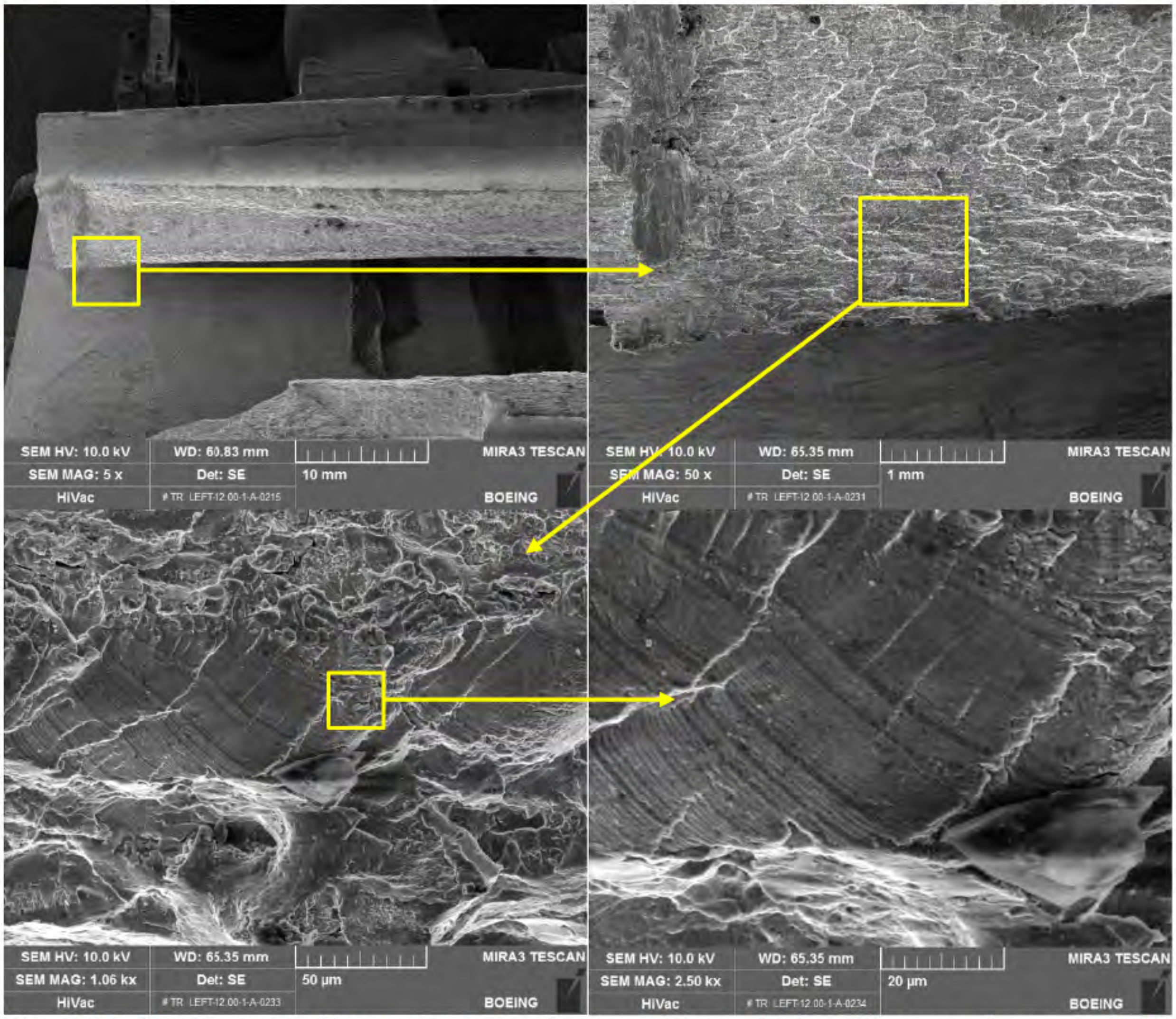


Figure 18. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 1. These images are from the lower portion of the section, striations are clearly visible in the lower images, confirming fatigue as the fracture mode in this region.

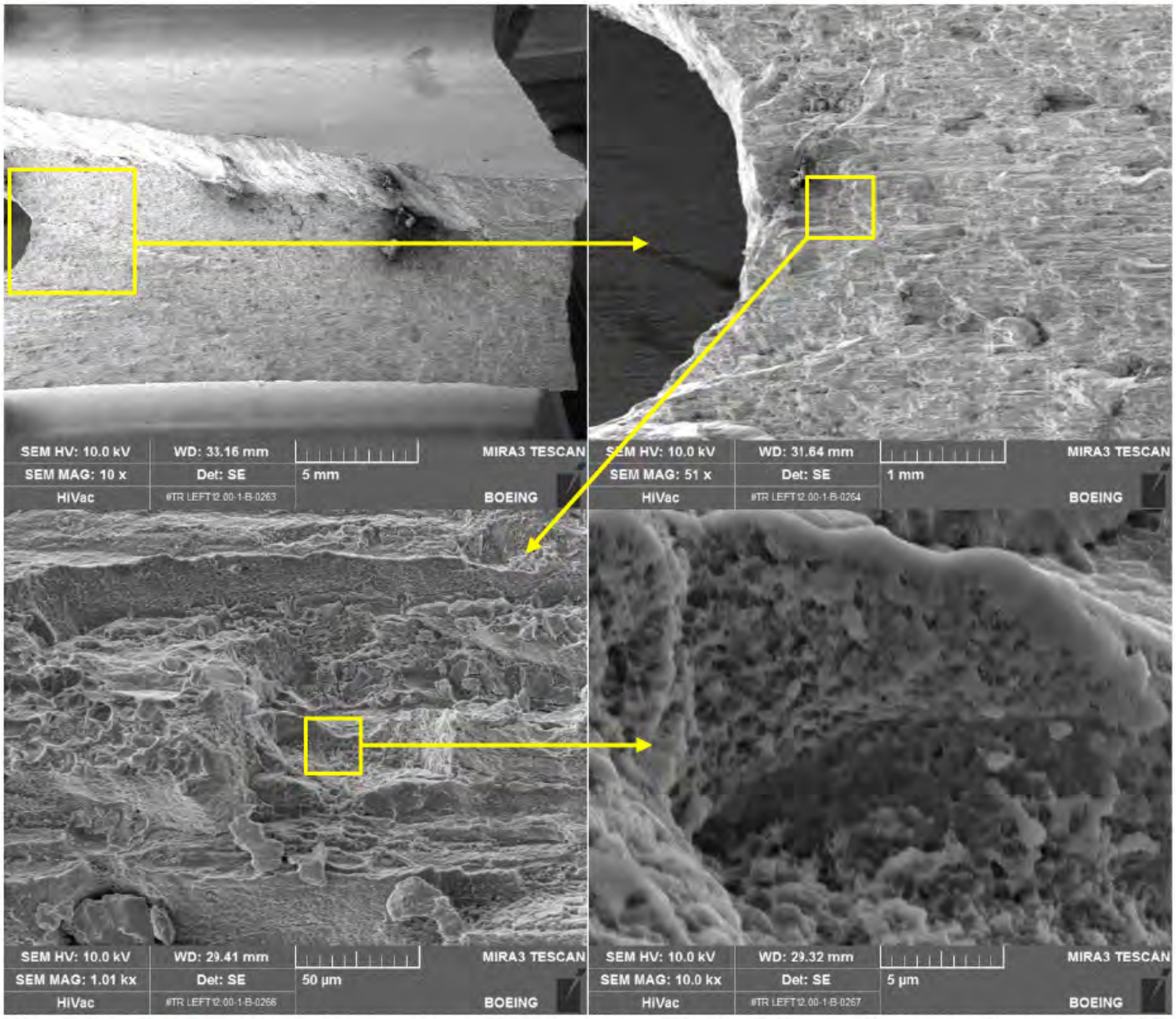


Figure 19. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 1. These images are from the upper portion region of the section, where the fracture mode was ductile separation.

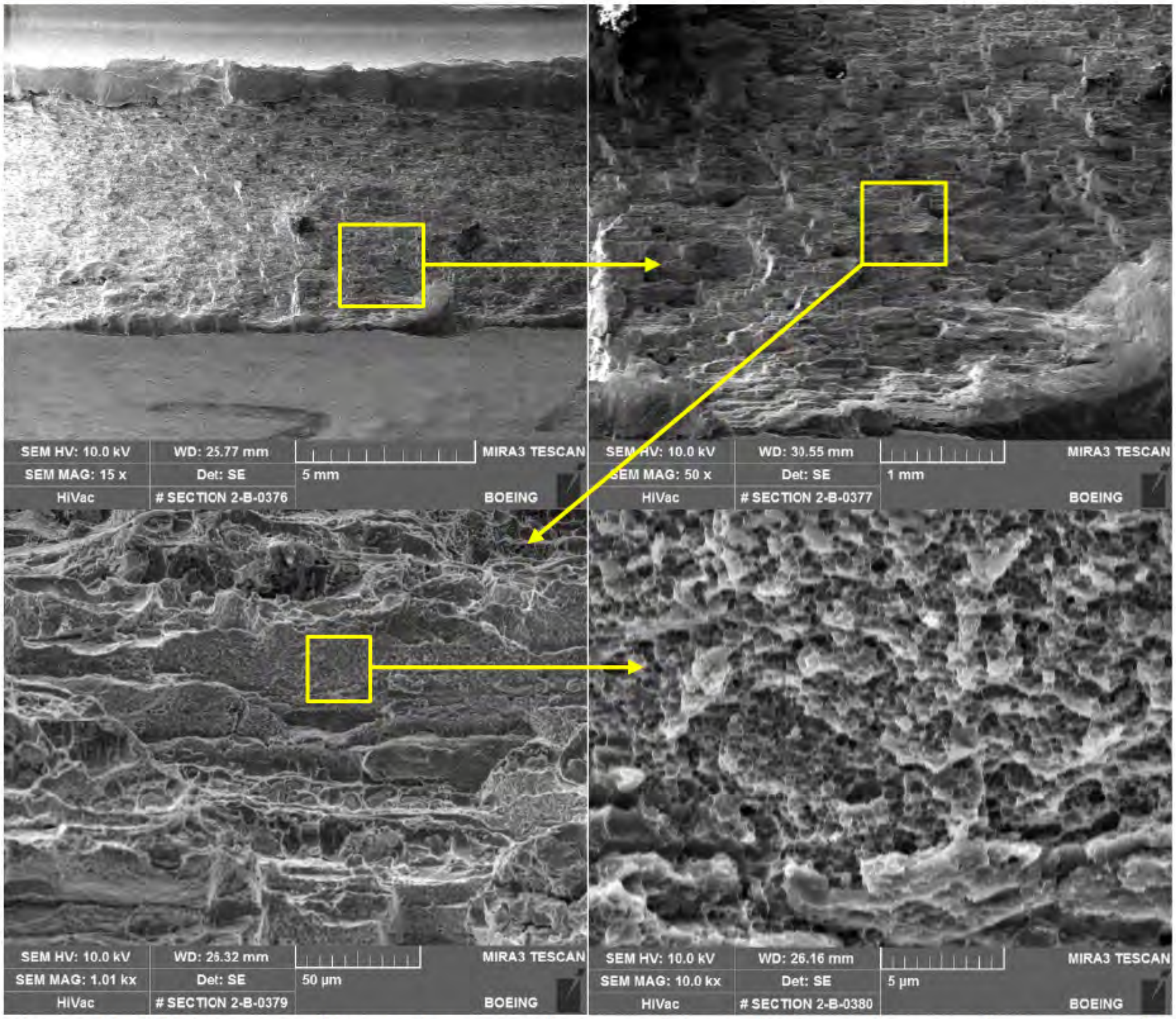


Figure 20. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 2. The fracture mode visible was entirely ductile separation.

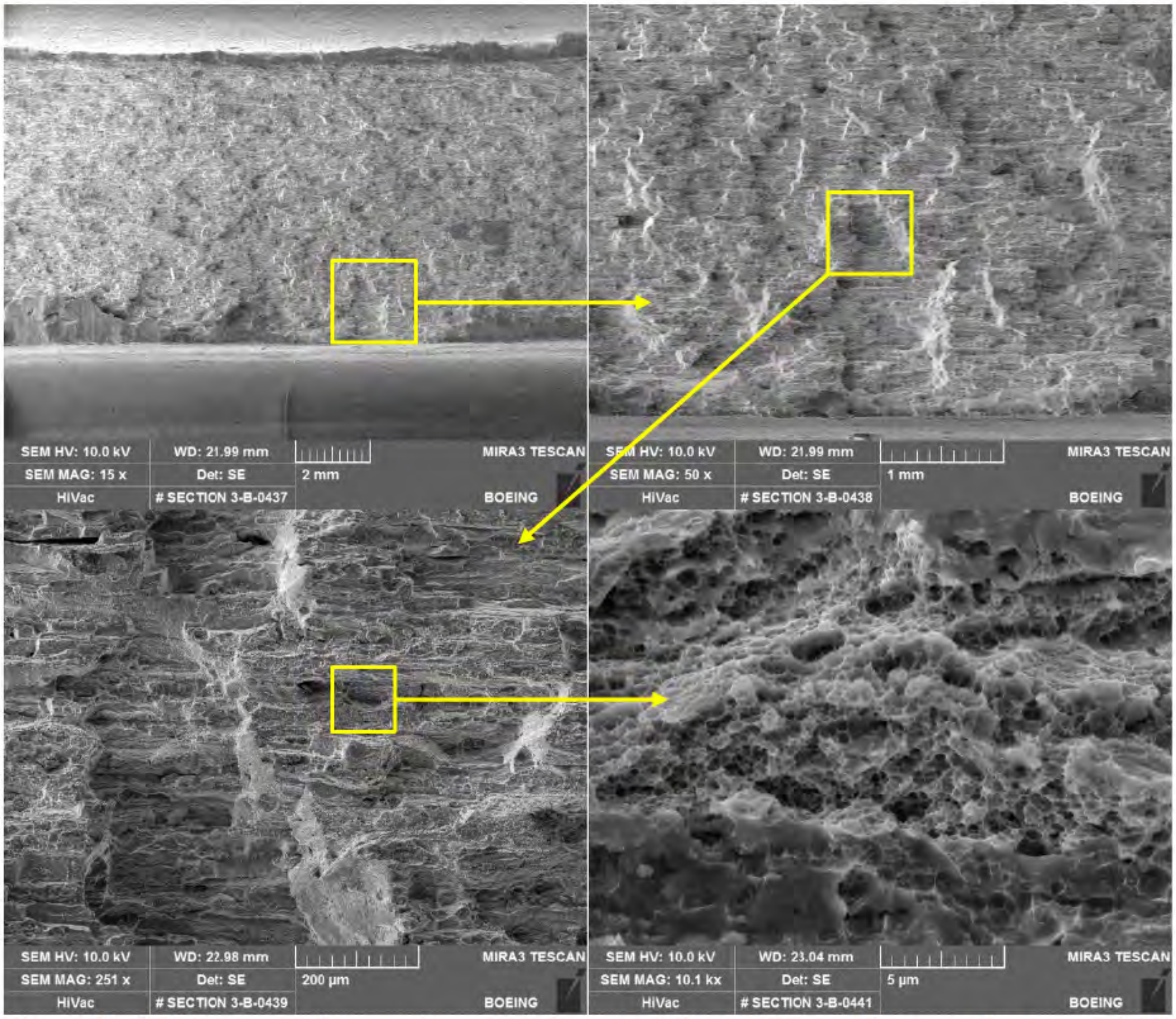


Figure 21. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 3. The fracture mode visible was entirely ductile separation.

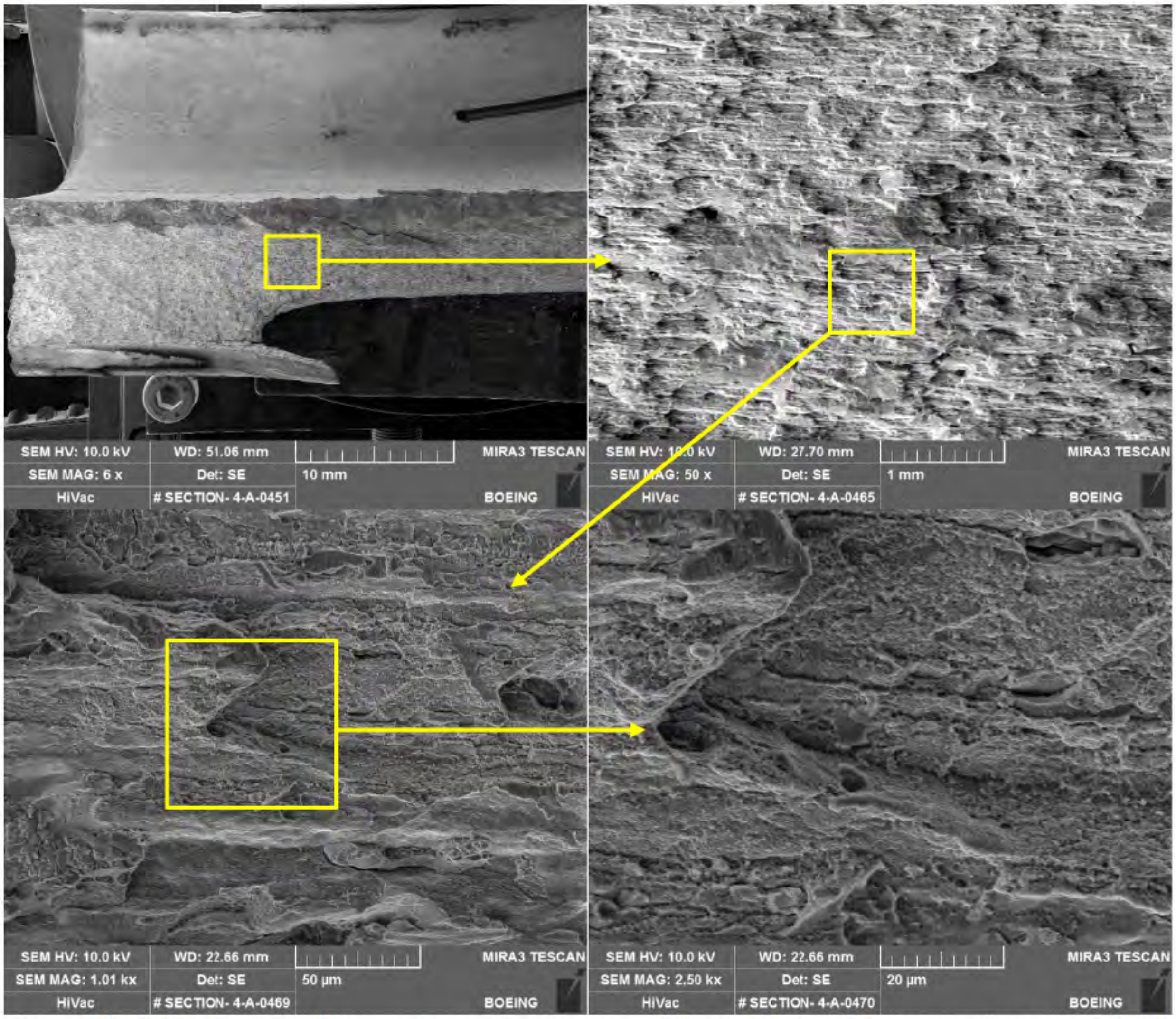


Figure 22. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 4. Some portions of the fracture surface were obscured by post fracture damage, but where visible the fracture mode visible was entirely ductile separation.

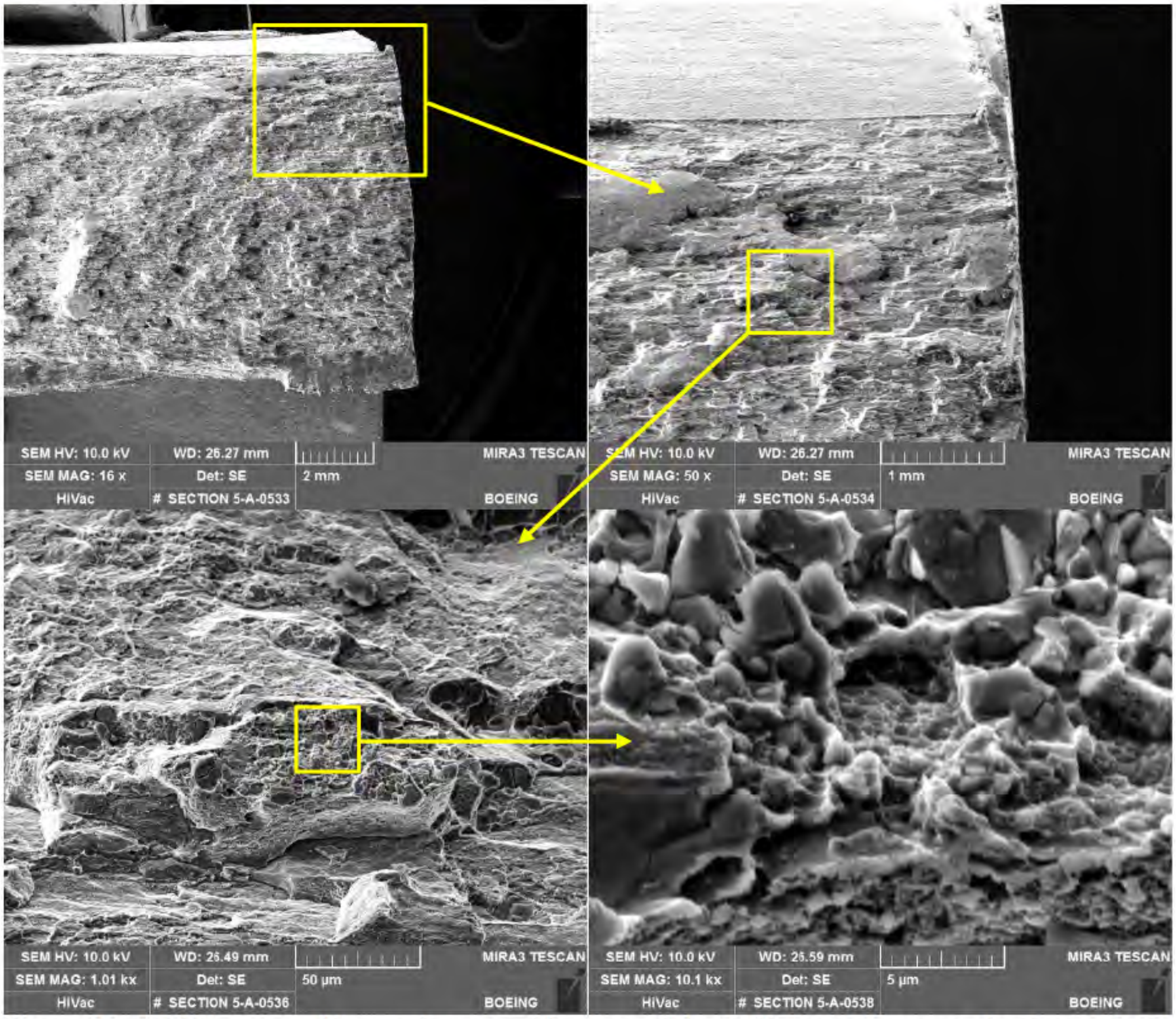


Figure 23. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 5. The fracture mode visible was entirely ductile separation.

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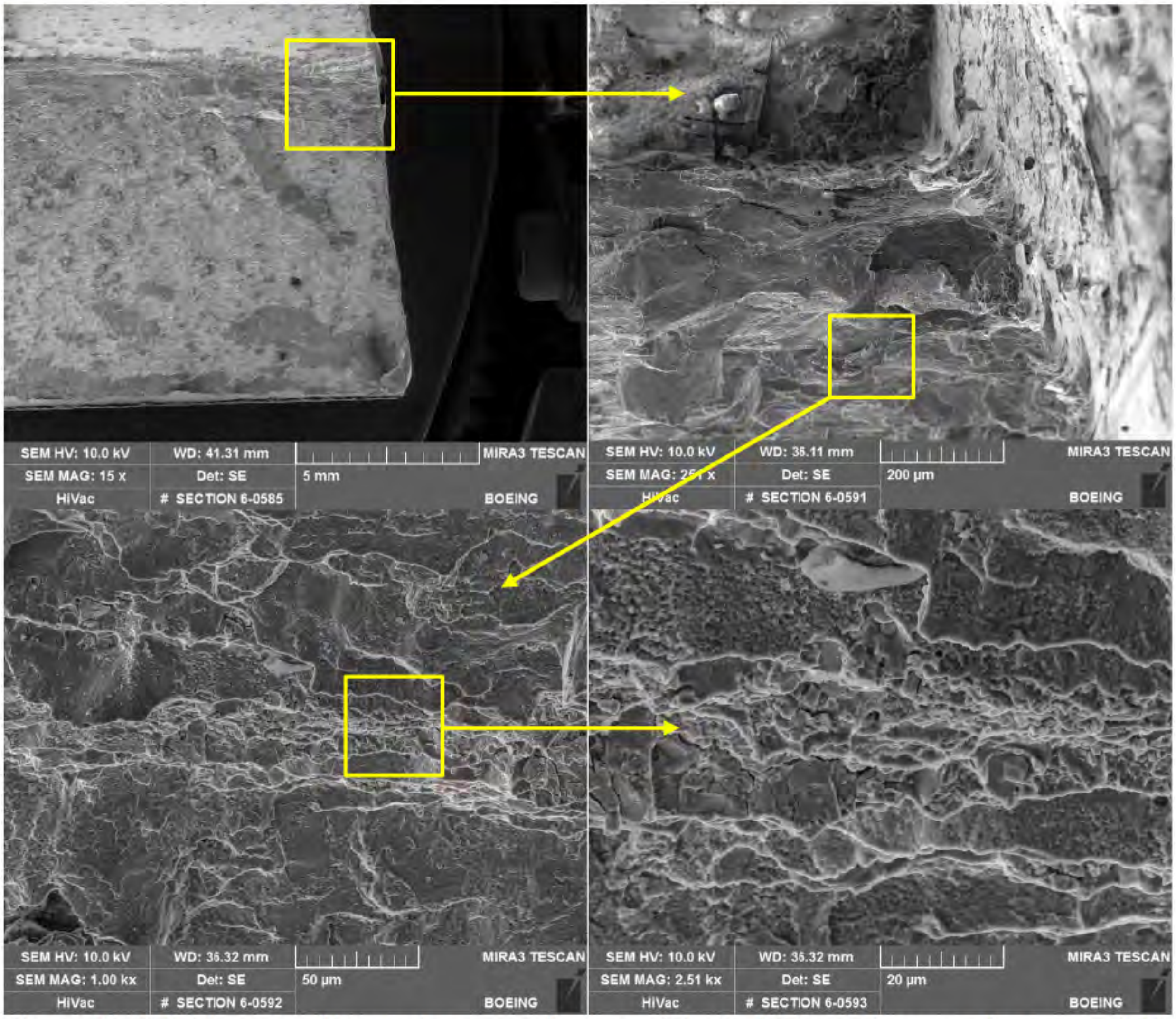

Figure 24. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 6. Some portions of the fracture surface were obscured by post fracture damage, but where visible the fracture mode visible was entirely ductile separation.

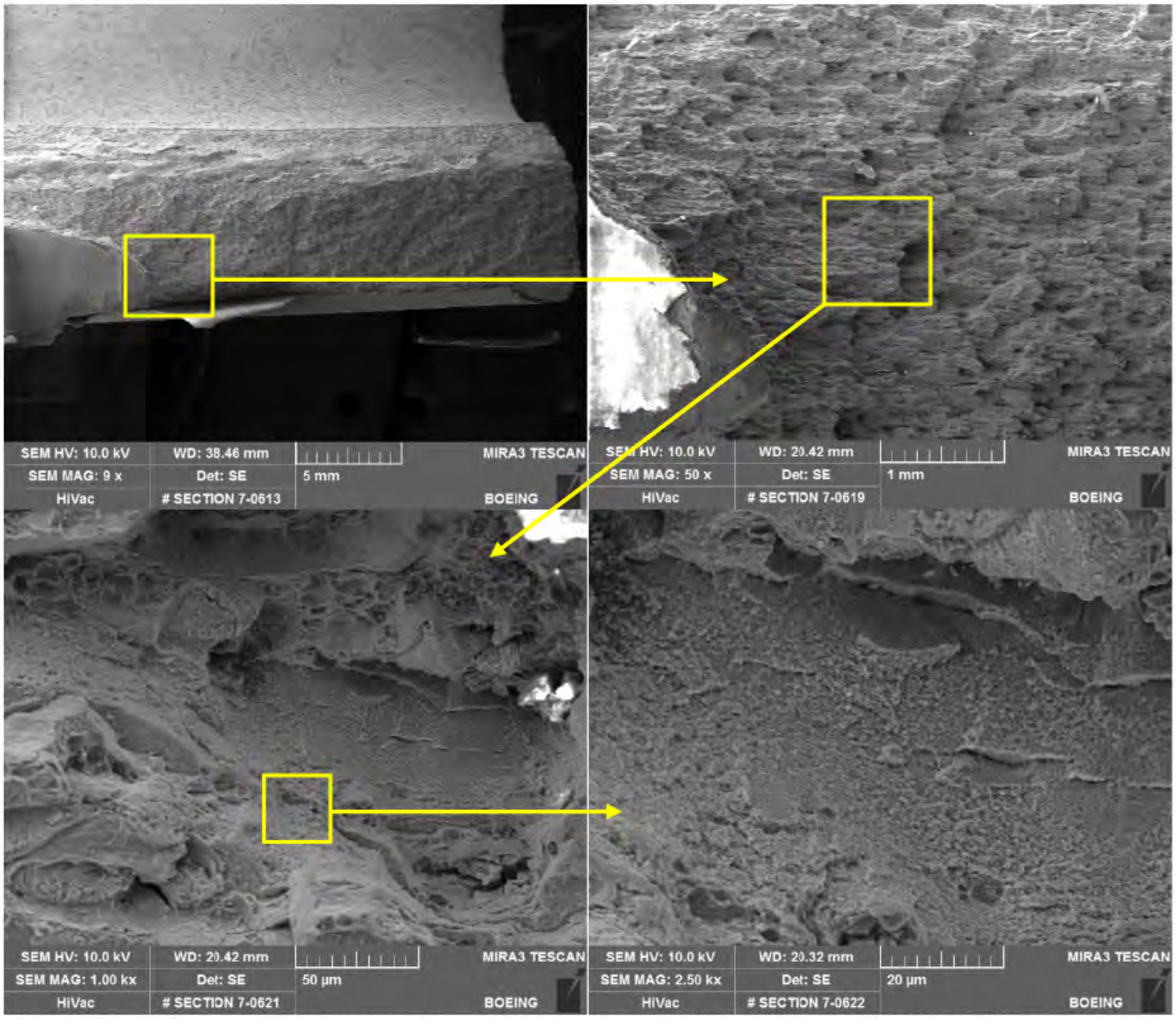

Figure 25. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 7. The fracture surface were obscured by post fracture damage and oxidation, but appears consistent with ductile separation.

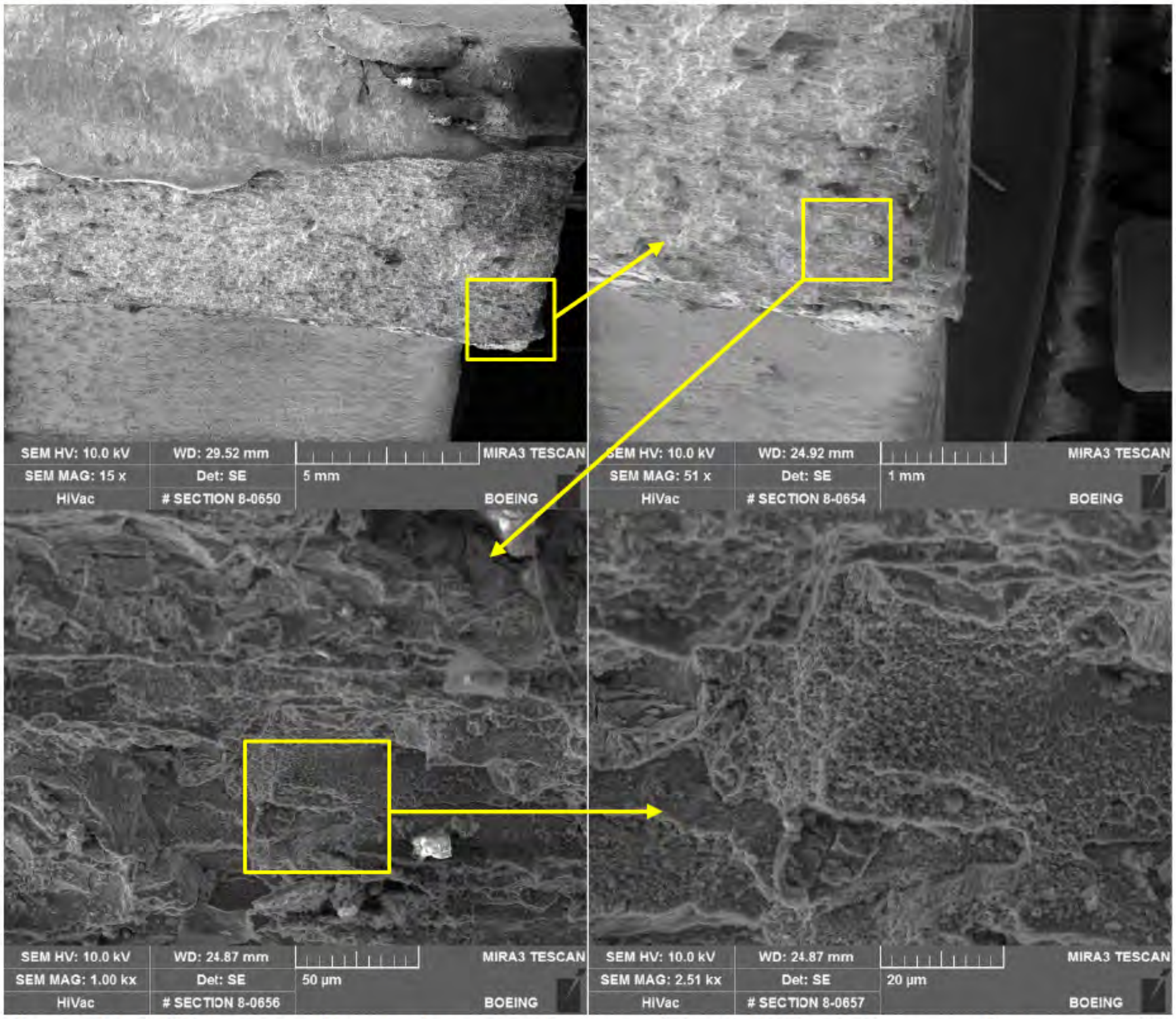

Figure 26. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 8. The fracture surface were obscured by post fracture damage and oxidation, but appears consistent with ductile separation.

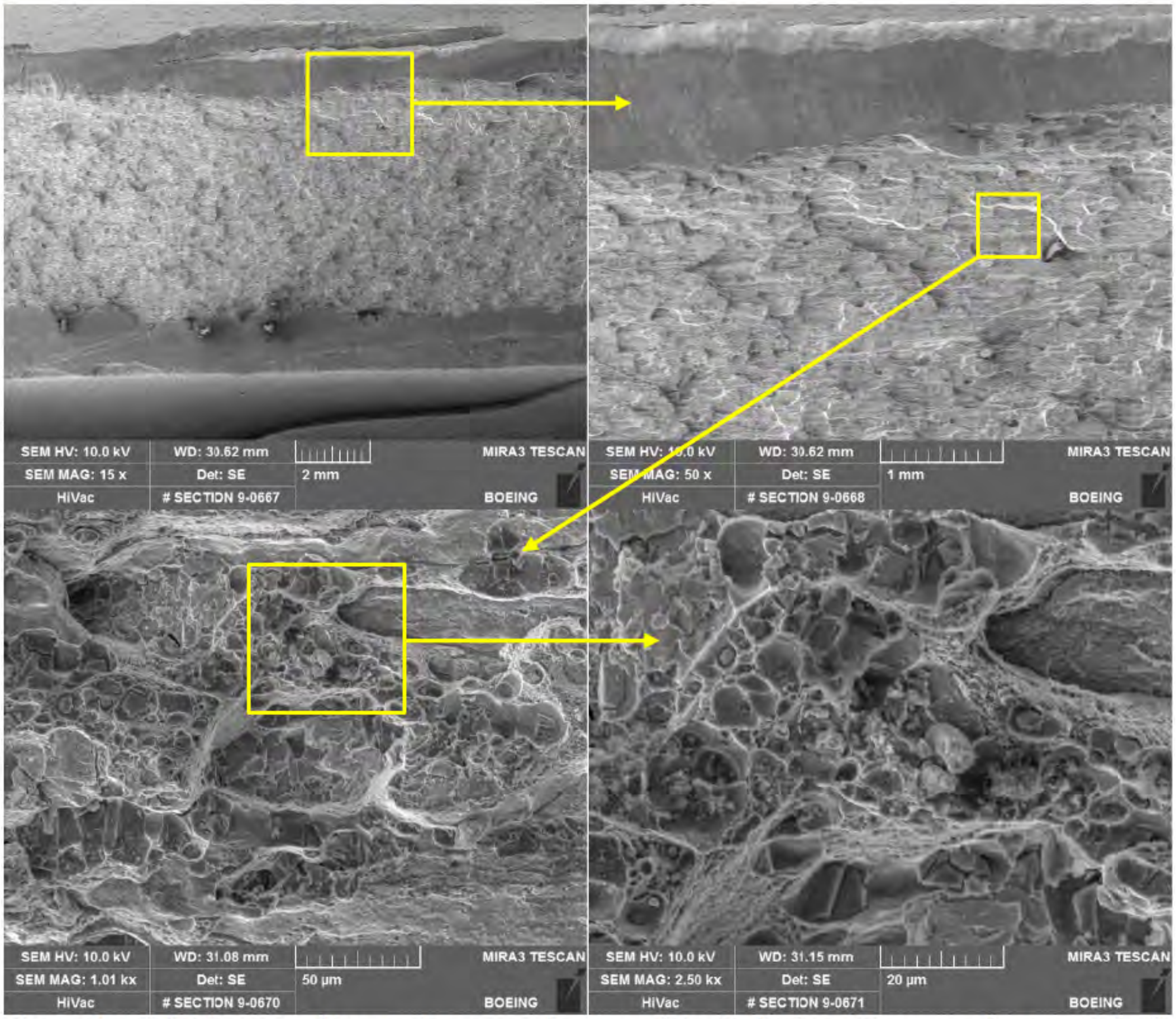

Figure 27. SEM images of increasing magnification of the Left Thrust Reverser fracture at 9:00, Section 9. Significant portions of the fracture surface were obscured by post fracture damage, but where visible the fracture mode visible was entirely ductile separation.

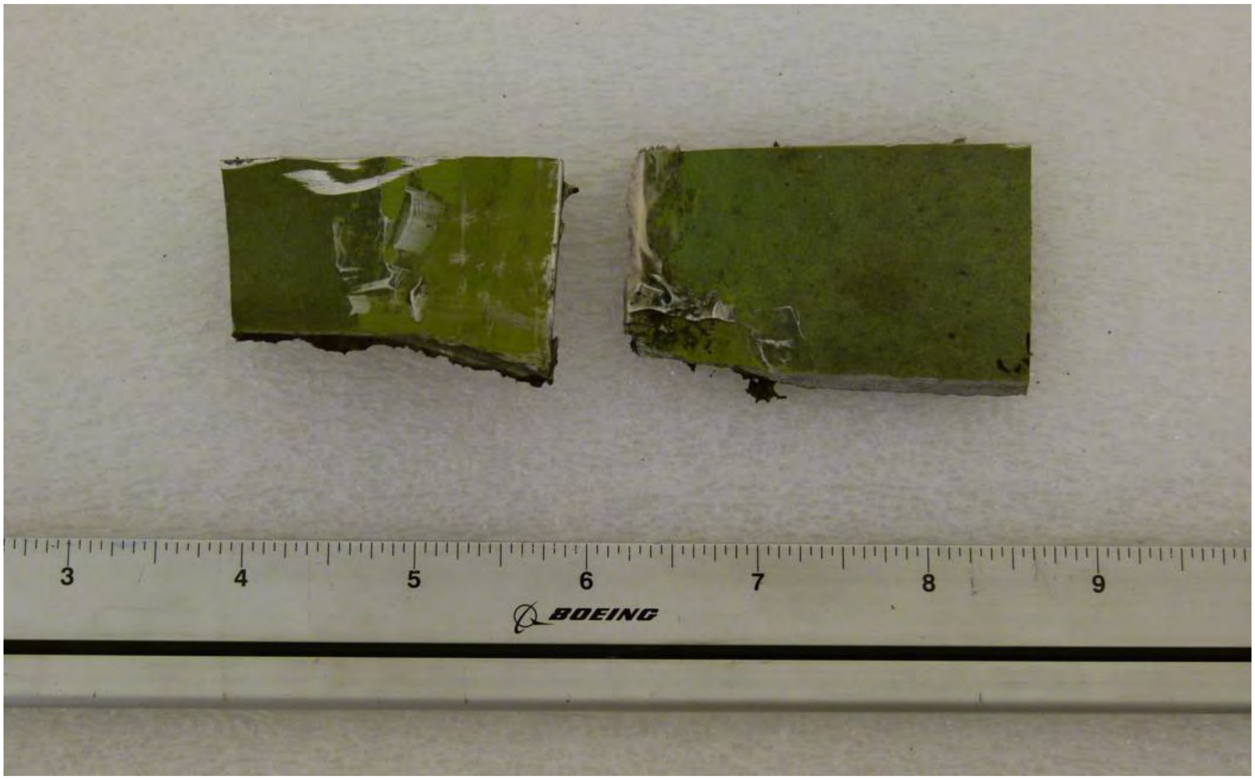

Figure 28. Left Thrust Reverser fracture at the 12:00 clock position after removal.

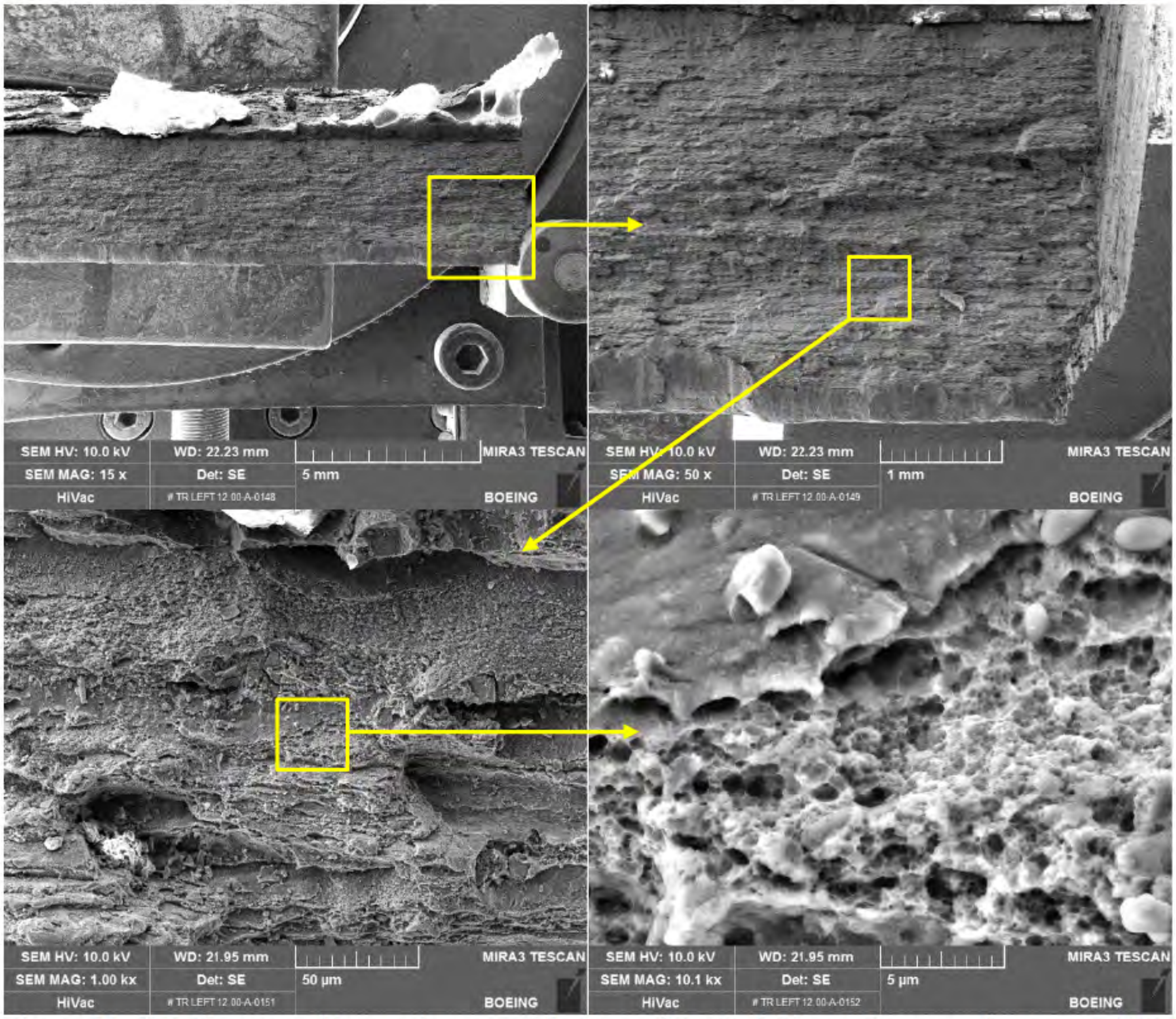

Figure 29. SEM images of increasing magnification of the Left Thrust Reverser fracture at 12:00. Some portions of the fracture surface were obscured by post fracture damage, but where visible the fracture mode visible was entirely ductile separation.

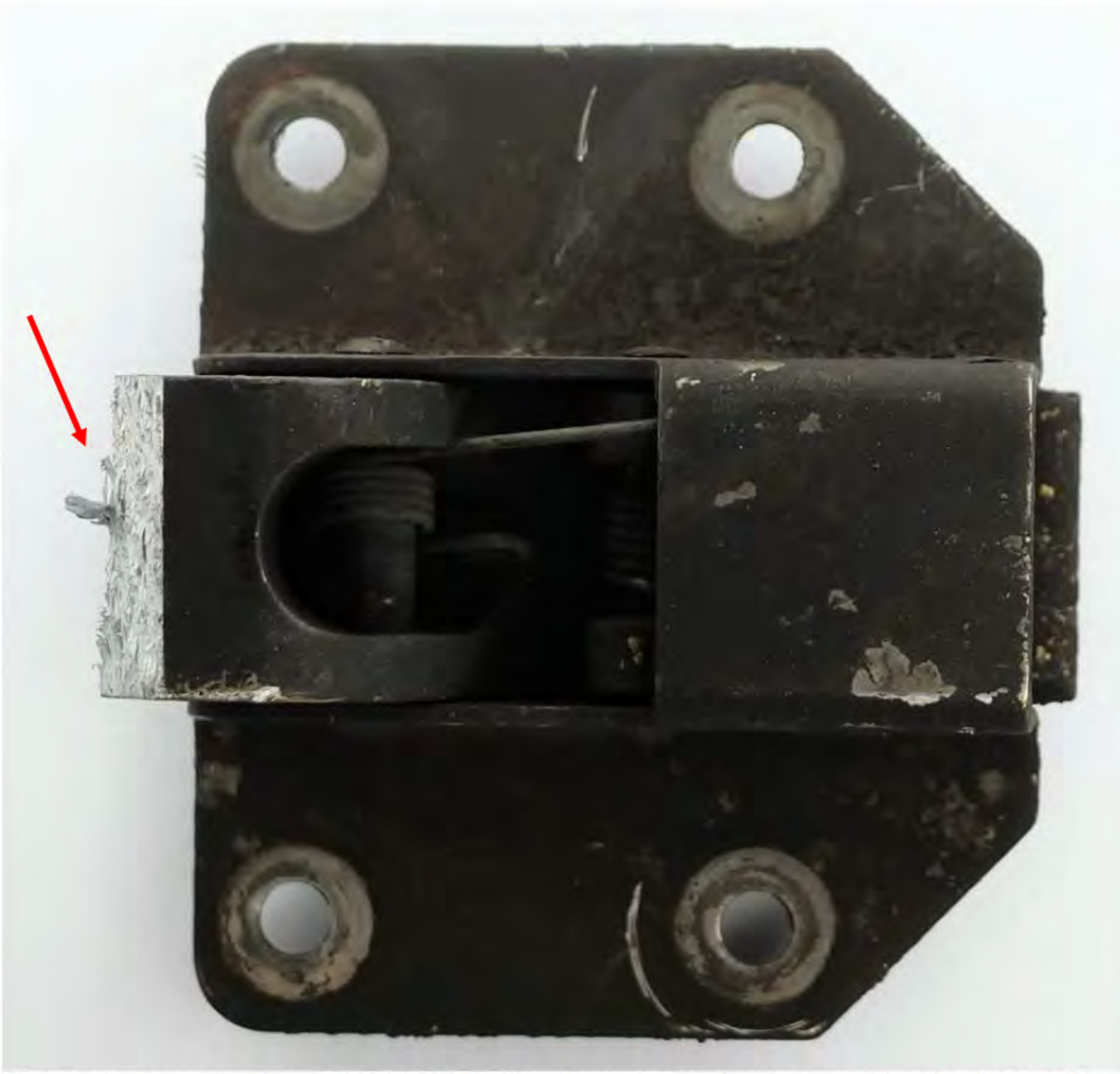

Figure 30. As received latch (P/N 9476-1) from Door Access Panel Assembly. The fracture is indicated by the red arrow.

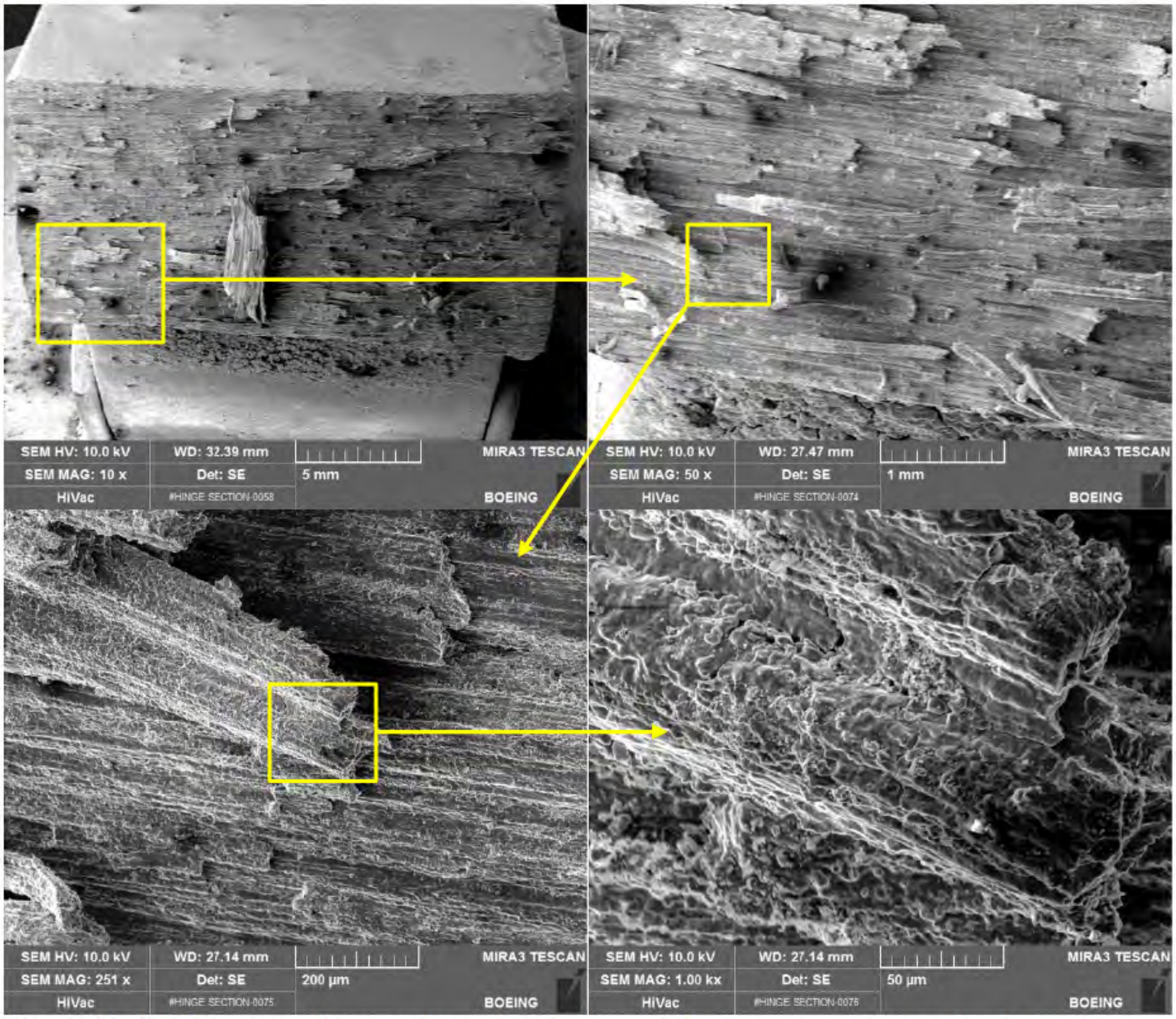

Figure 31. SEM images of increasing magnification of the fracture surface on the Door Access Panel Assembly latch. The fracture surface were obscured by post fracture oxidation, but appears consistent with ductile separation.

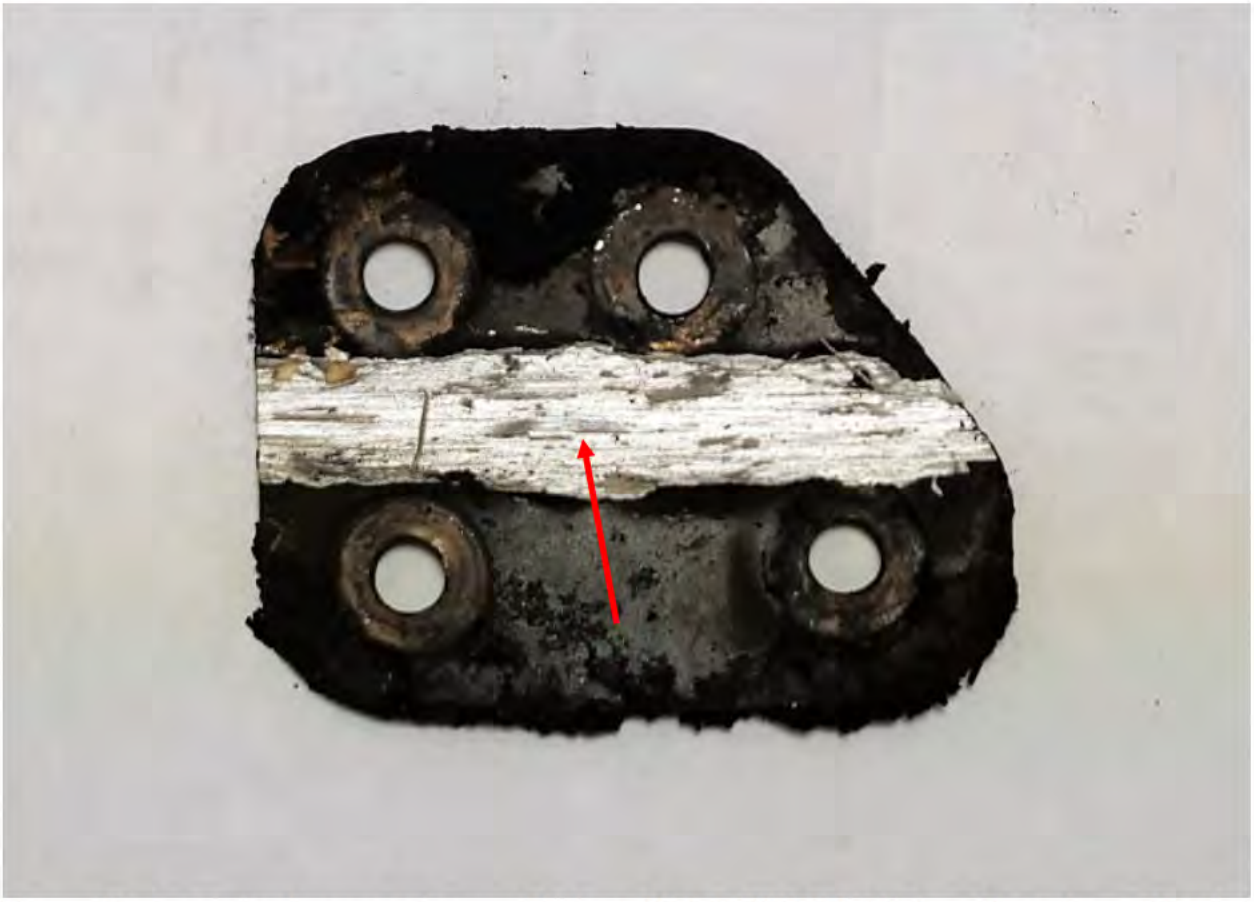

Figure 32. As received gooseneck assembly base (P/N 315W3422-13) from Door Access Panel Assembly. The fracture is indicated by the red arrow.

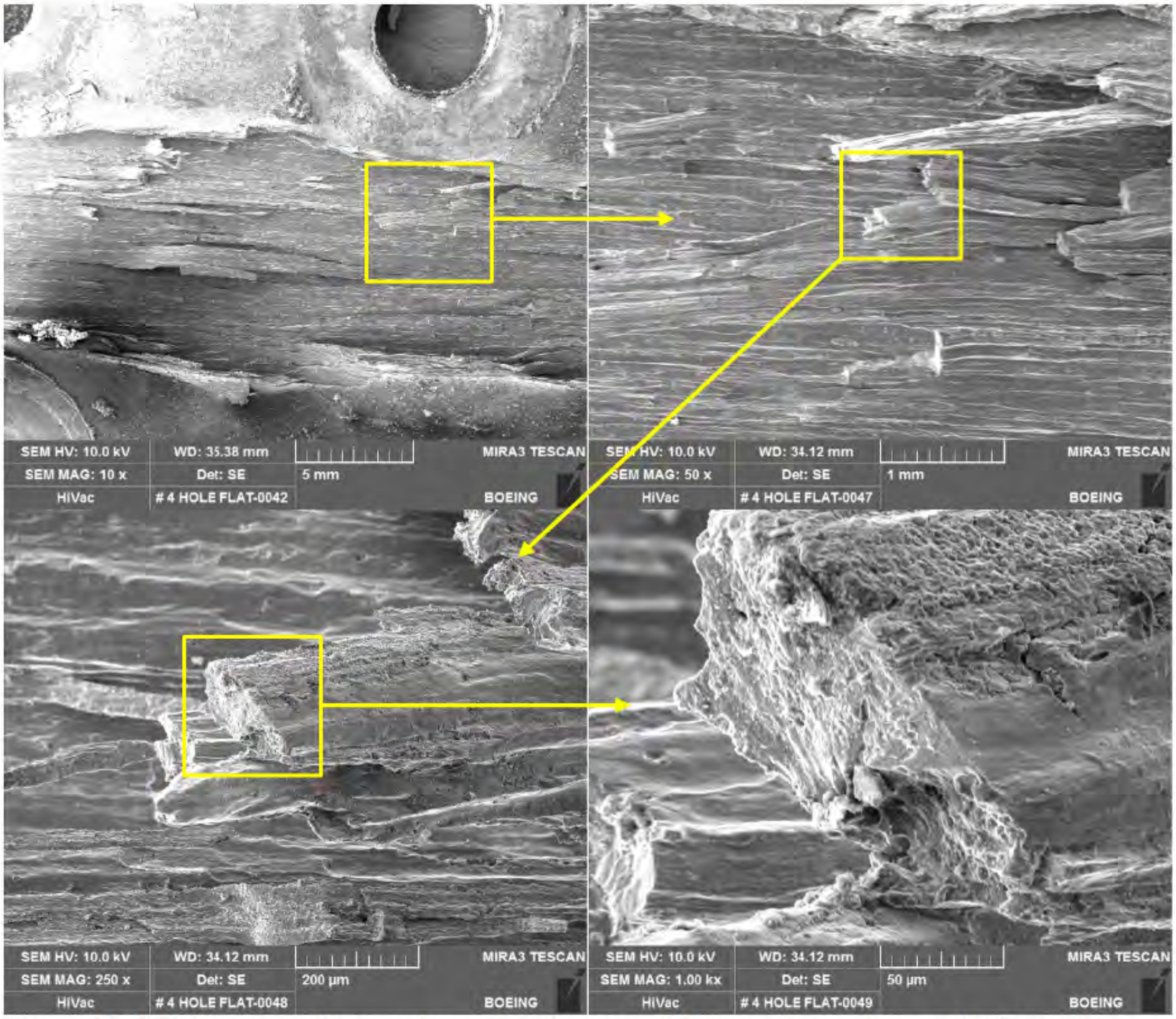

Figure 33. SEM images of increasing magnification of the fracture surface on the Door Access Panel Assembly gooseneck base. The fracture surface were obscured by post fracture oxidation, but appears consistent with ductile separation.

Figure 34. As received depressor (P/N 315W3419-3) from Door Access Panel Assembly. The fractures are indicated by the red arrows.

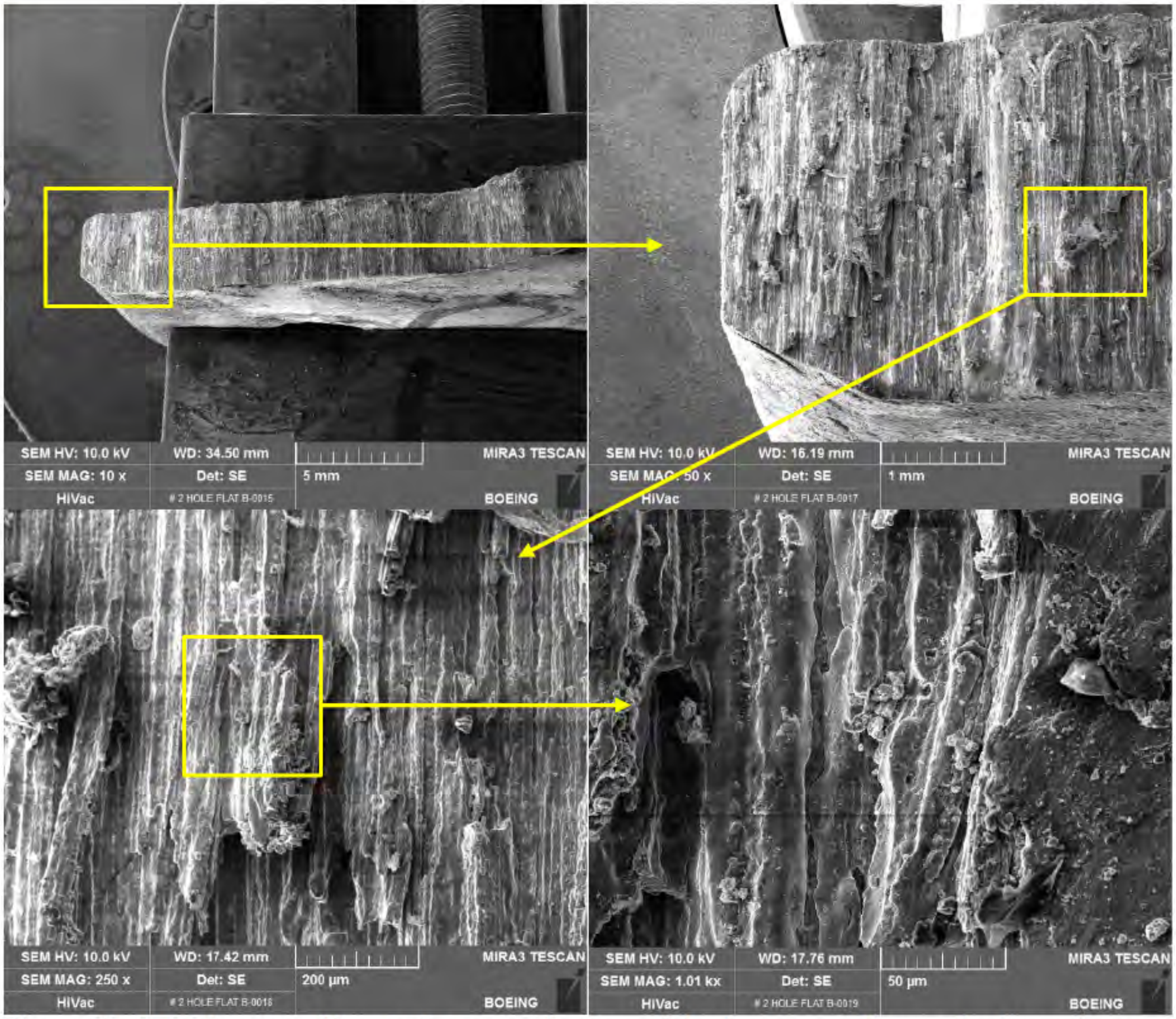

Figure 35. SEM images of increasing magnification of the fracture surface on the Door Access Panel Assembly depressor. The fracture surface were obscured by post fracture oxidation, but appears consistent with ductile separation.

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Dreaming
Collaborating
Innovating
Exploring
Trailblazing

UAL Investigation Thermography Report

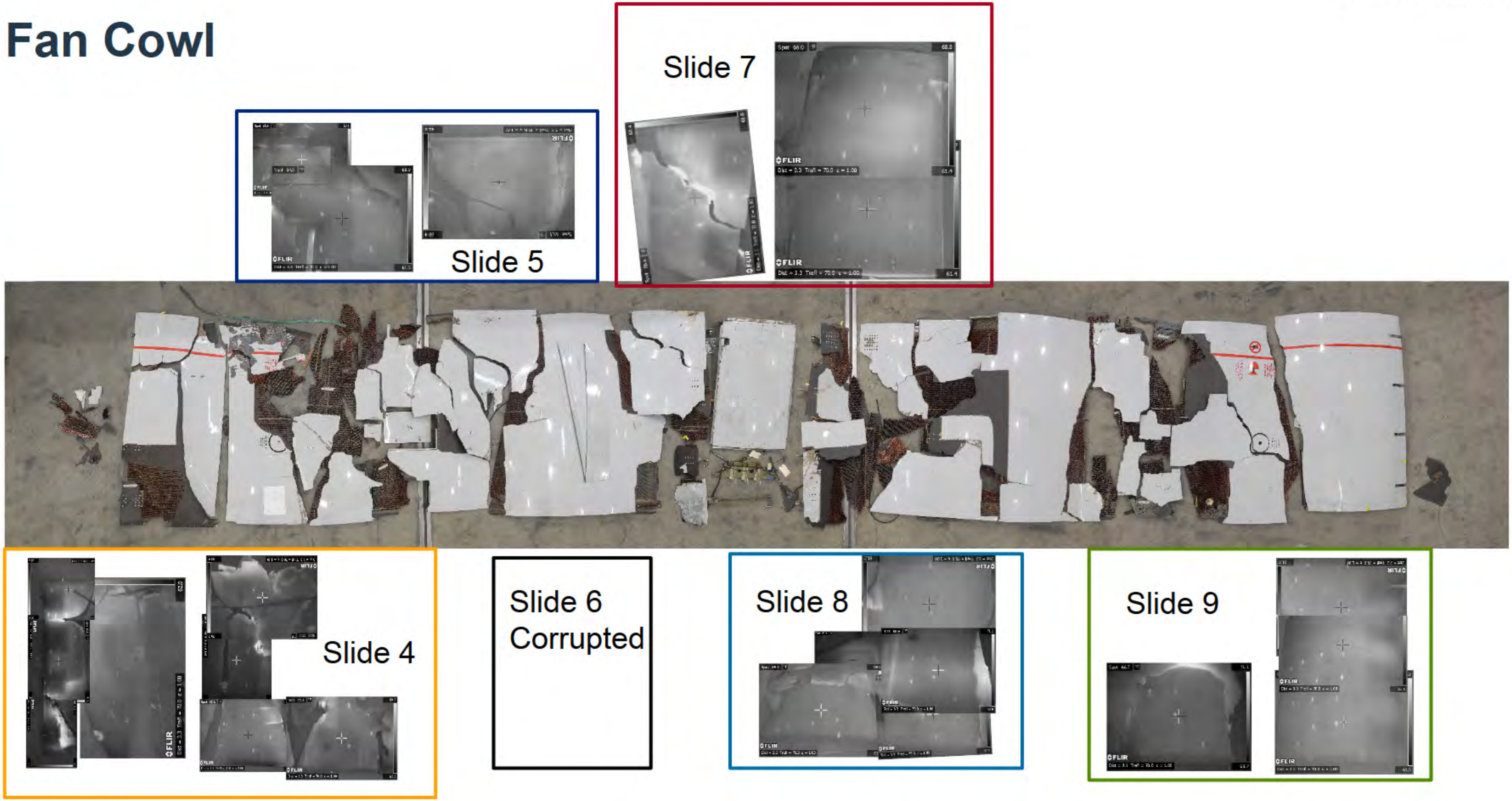
March 24, 2021

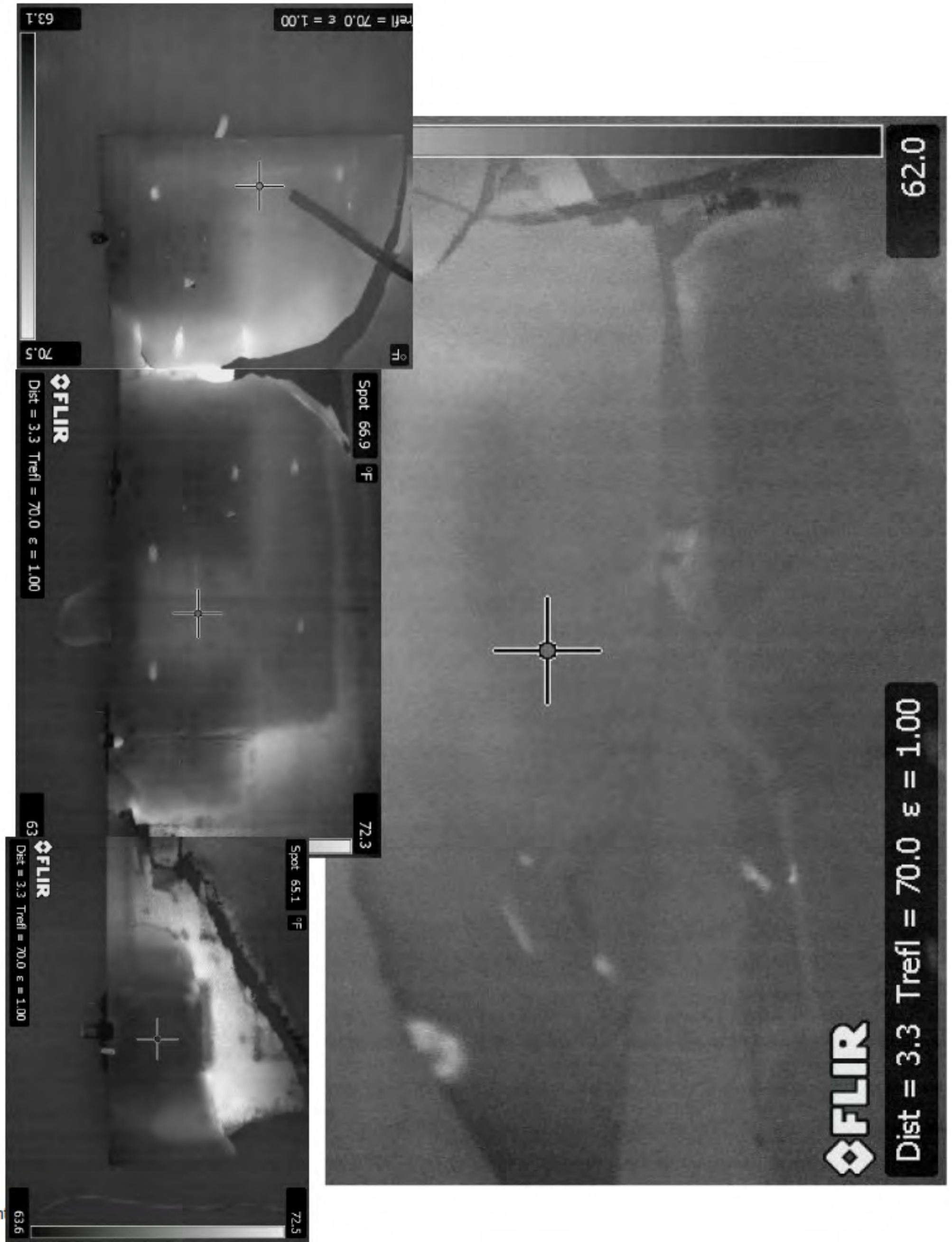
Producing
Leading
Creating
Researching
Analyzing

Information

- Fluid ingression inspection performed using a handheld IR camera and a heat gun
- Parts that were clearly just skin or had core with skin completely removed were skipped
- Locations with suspect indications that could be fluid are circled in red in this presentation

Fan Cowl

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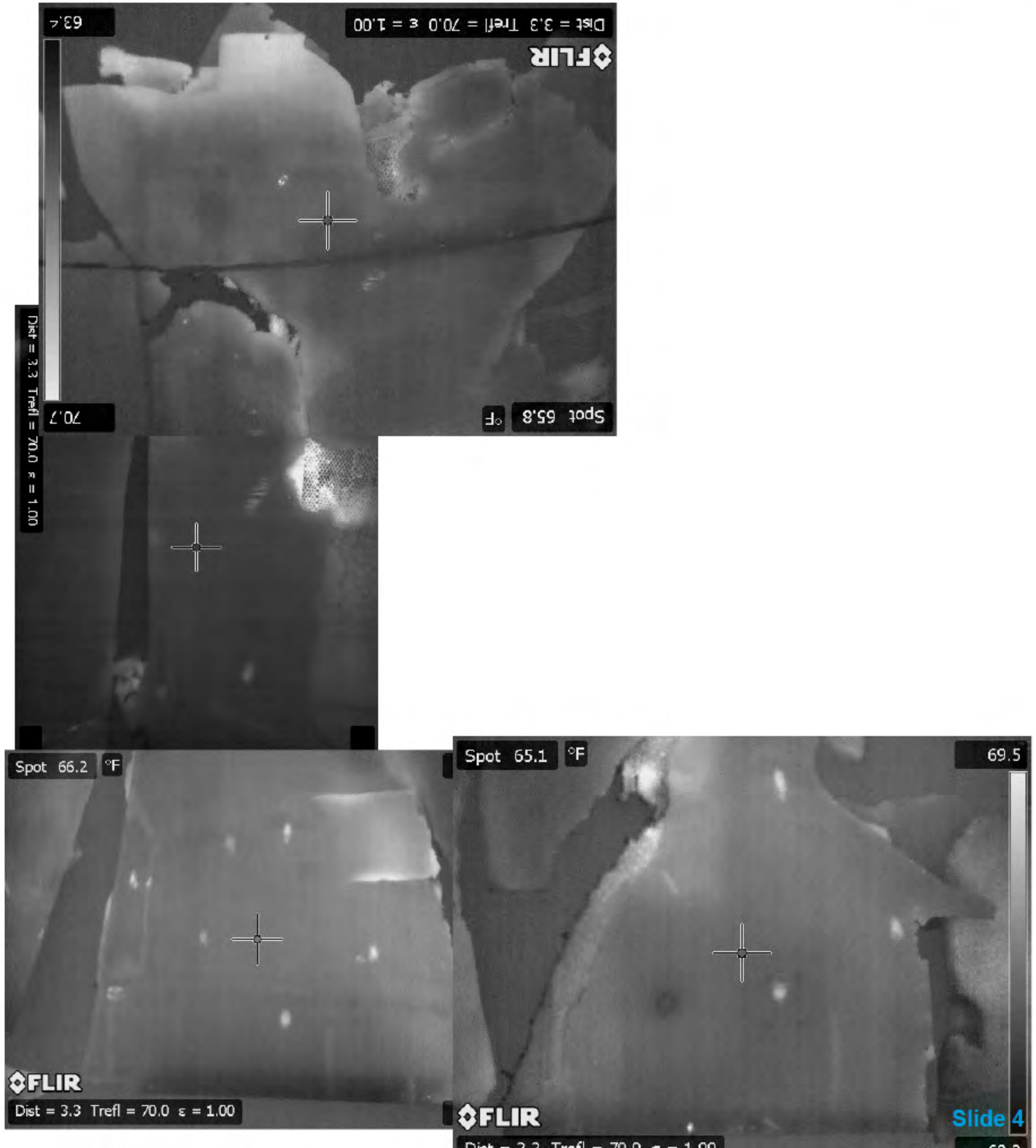
FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00


Spot 66.2 °F
FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00
Spot 65.1 °F
69.5
FLIR

Slide 4


Spot 65.8 °F
69.1
FLIR
Dist = 3.3 T
Spot 64.8 °F
68.9
FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00
61.5


Dist = 3.3 Trefl = 70.0 ε = 1.00
61.0
FLIR
Spot 65.5 °F
68.4

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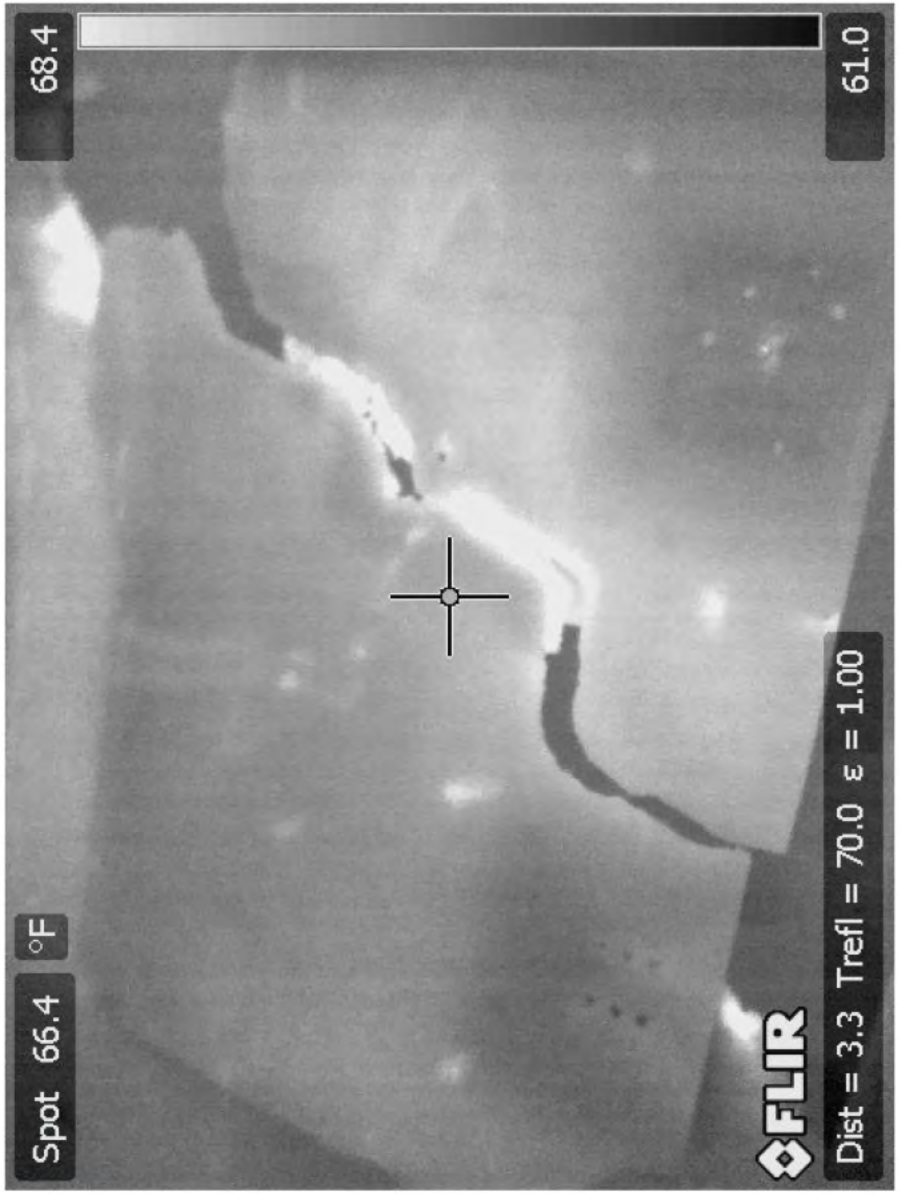
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61.0
Spot 66.4
°F
FLIR
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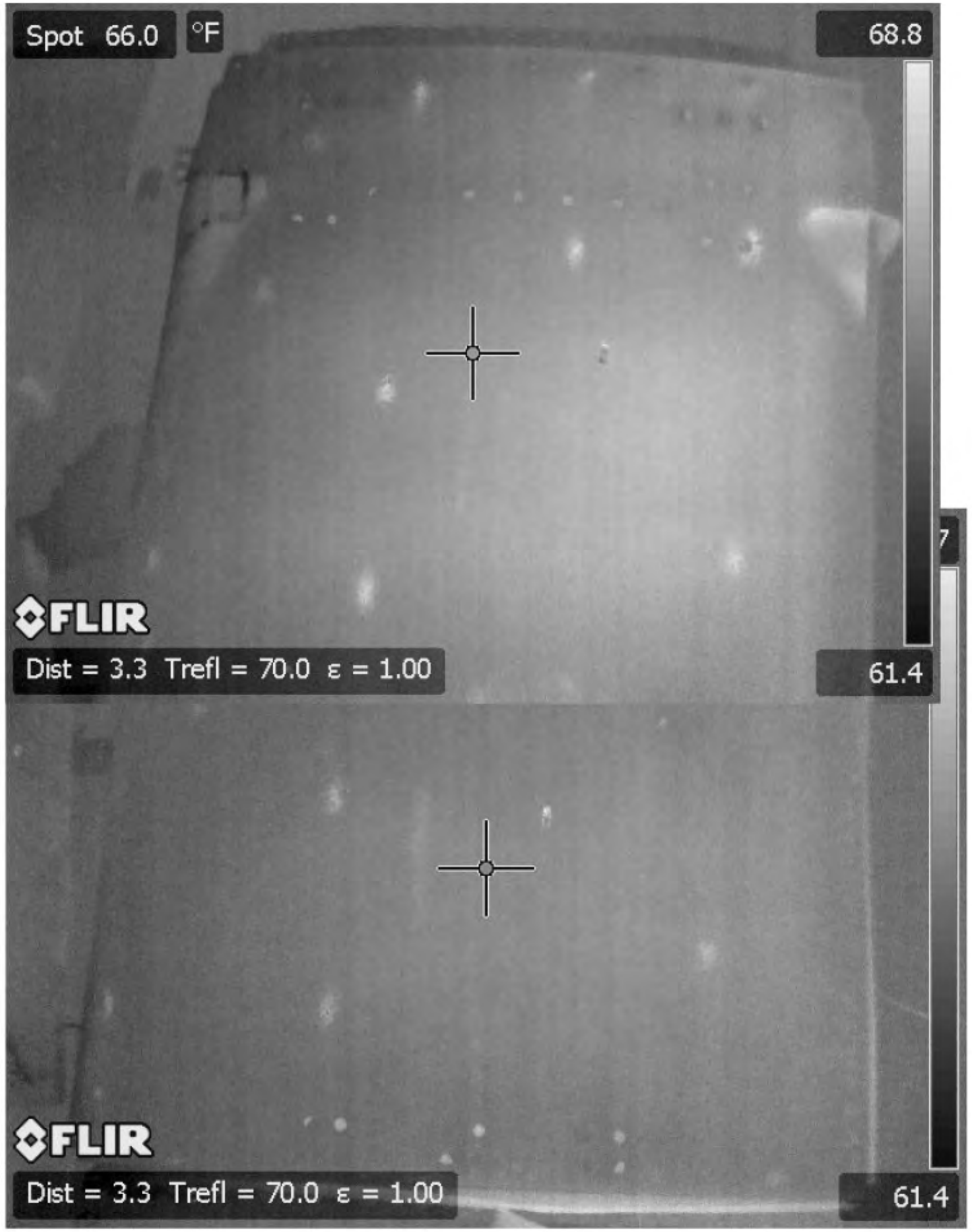
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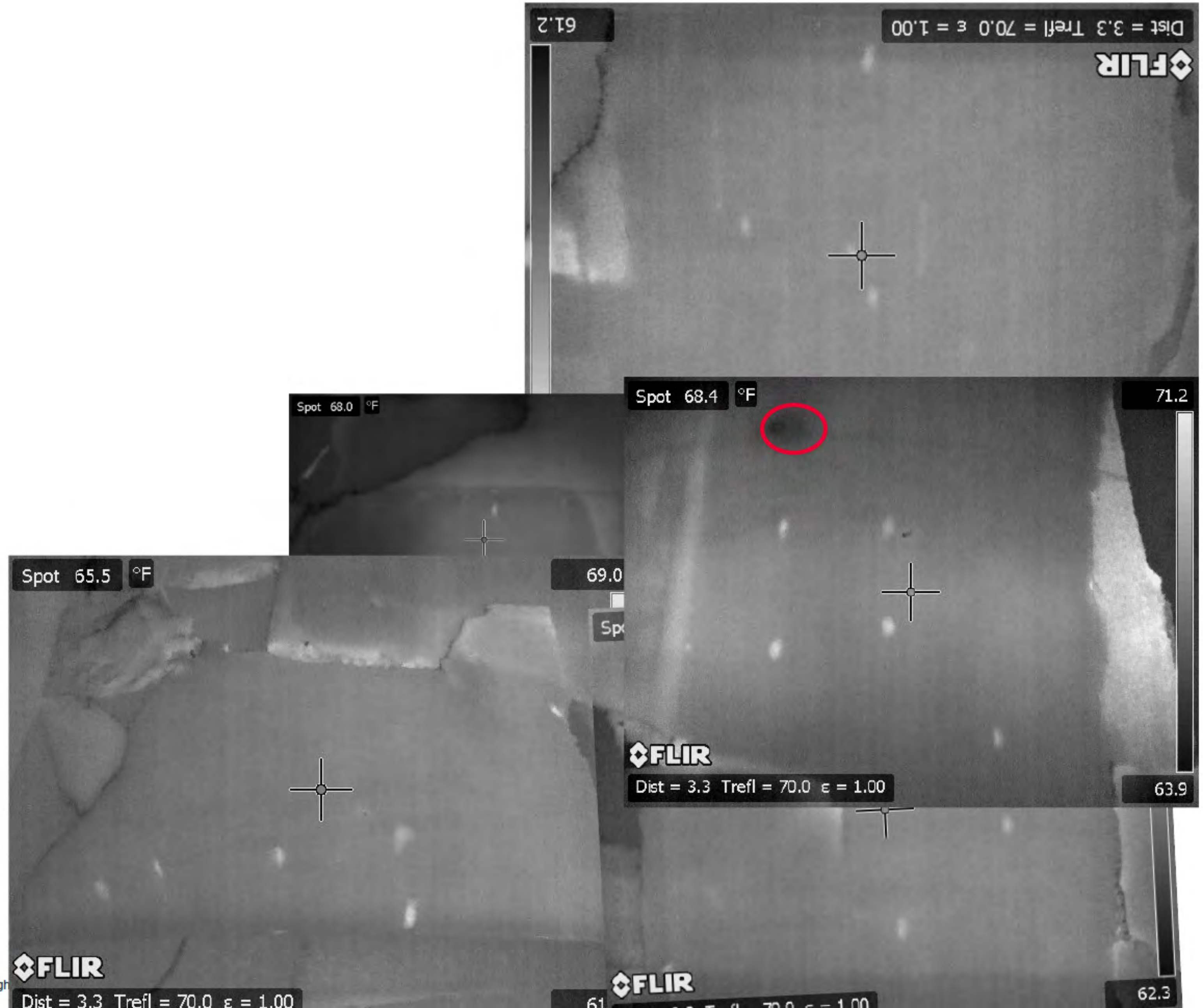
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63.9
Spot 65.5 °F
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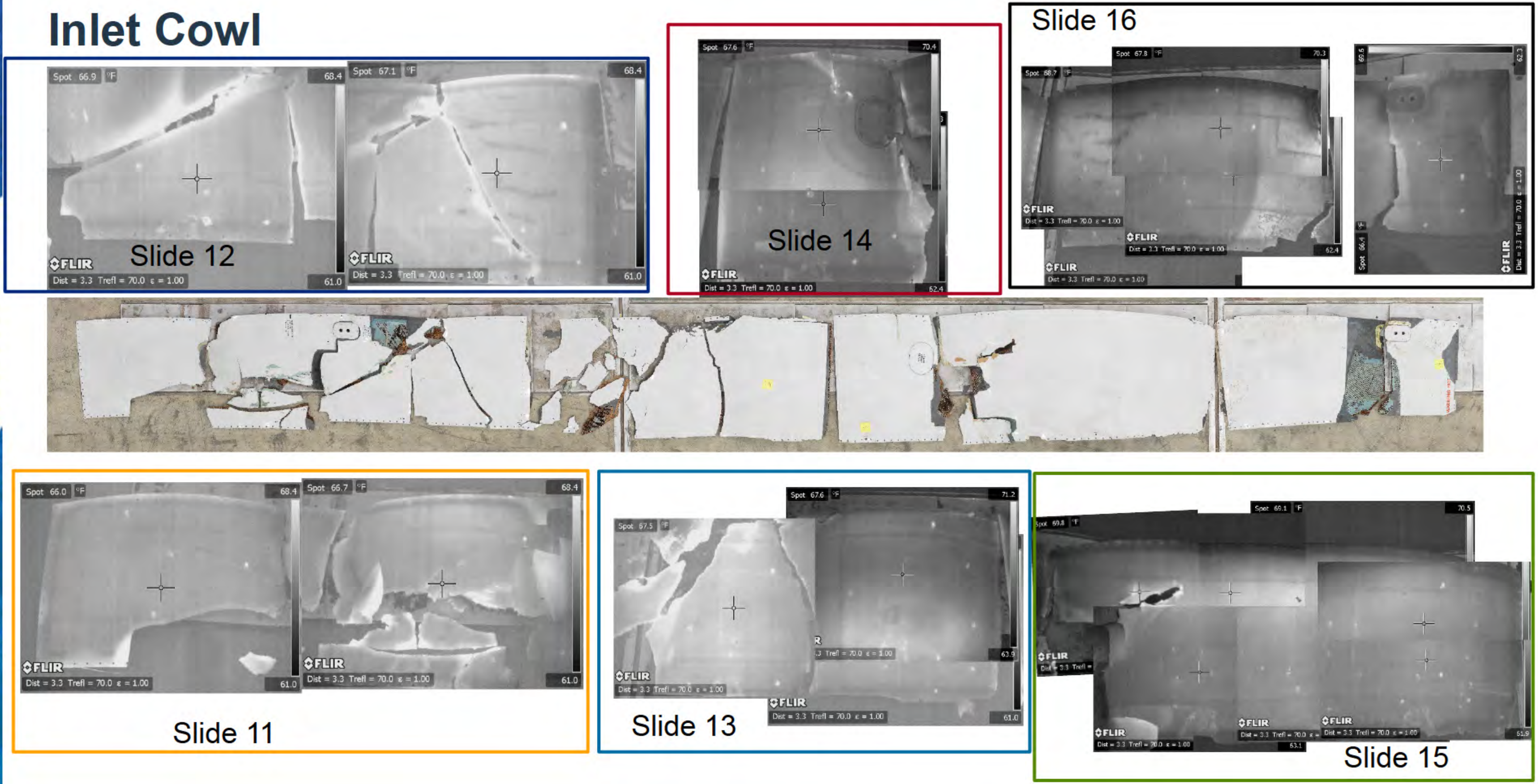
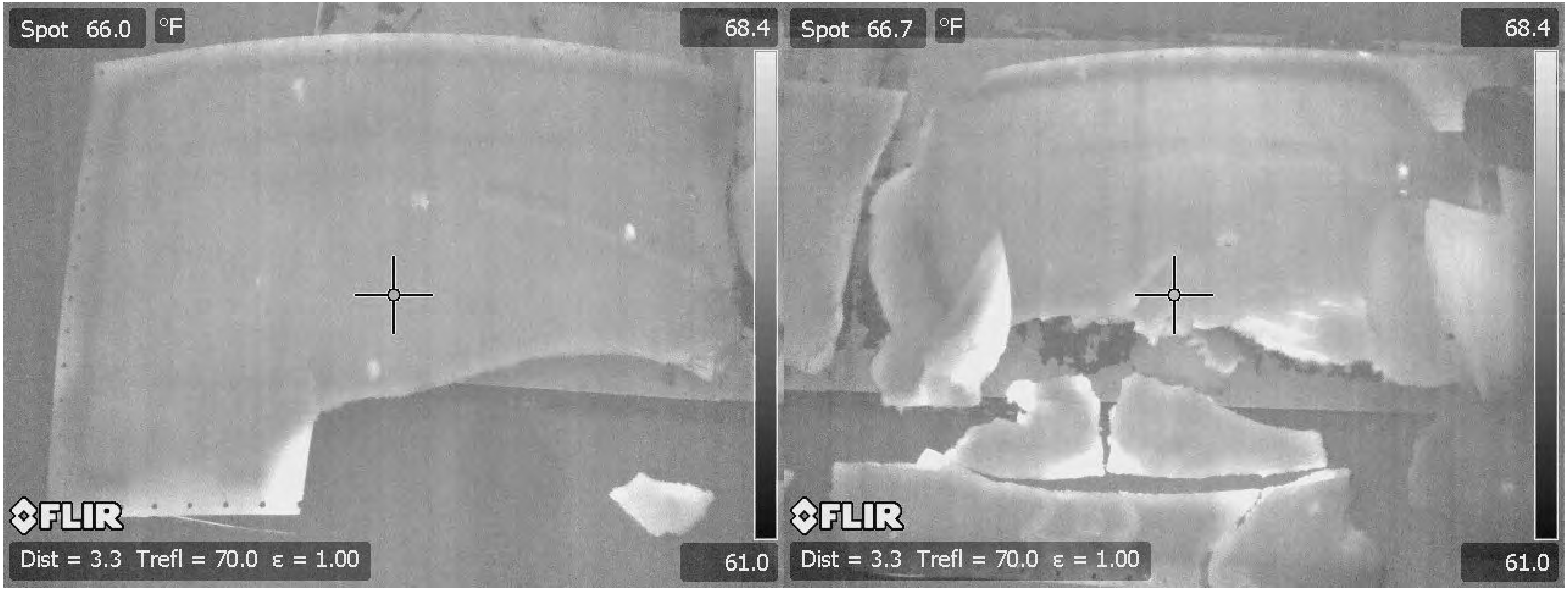
FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00
FLIR
62.3


Spot 66.7 °F
71.1
FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00
63.7


FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00
61.5
FLIR
Dist = 3.3 Trefl = 70.0 ε = 1.00
61.5

Inlet Cowl

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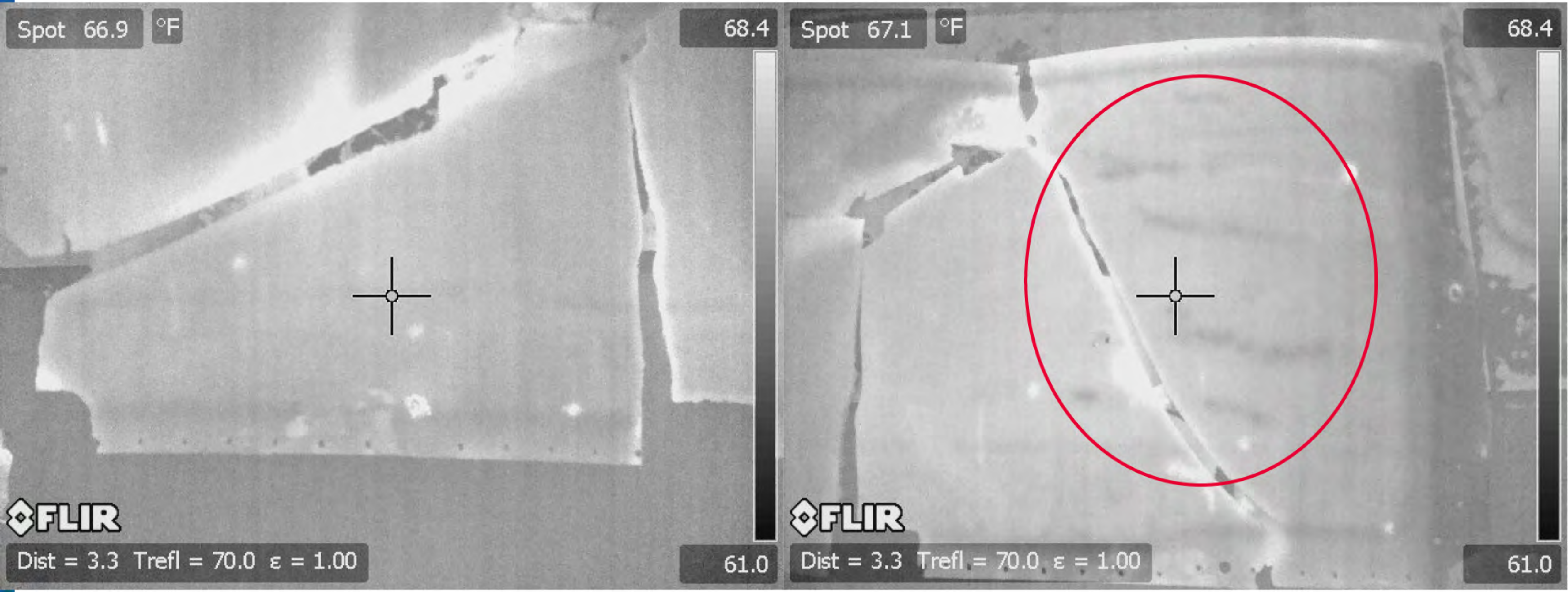
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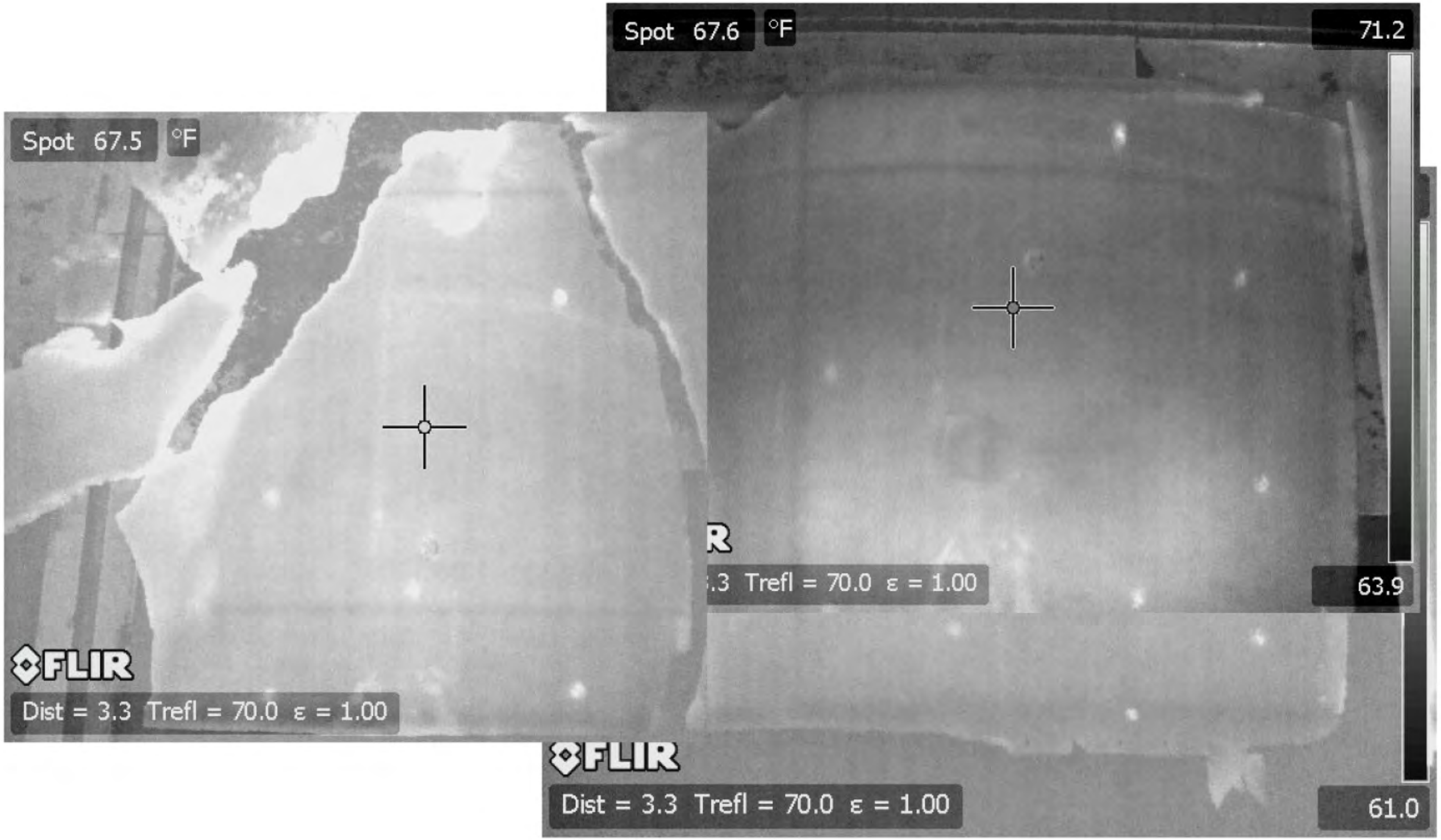
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61.9


Spot 68.7 °F
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Spot 67.8 °F
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Dist = 3.3 Trefl = 70.0 ε = 1.00
Dist = 3.3 Trefl = 70.0 ε = 1.00
69.6
62.3
Spot 66.4 °F
Dist = 3.3 Trefl = 70.0 ε = 1.00

- On the previous slide there are dark indications as well as a large area that has a clear contrast difference line. This could be due to fluid or a change in core density or skin thickness

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Equipment Quality Analysis Report

Boeing Commercial Airplanes

TO: Air Safety Investigations (ASI)

EQA NUMBER: AS13354

DATE: May 27, 2021

MODEL NUMBER: 777-200

AIRPLANE NUMBER: WA005

SUBJECT: ***Engine Back Up Generator (BUG) Material Samples – Denver Fan Blade Out (FBO) Event***

IDENTIFICATION:

Part name:	BUG Oil Supply Line
Boeing part number:	114834
Part name:	BUG Oil Return Line
Boeing part number:	AS1634B06N0140
Part name:	Gearbox Mounted Bracket
Boeing part number:	Not Provided
Part name:	Material samples in parts bags
Quantity:	4
Part name:	12”x12” fan case (environmental wrap) cut-out
Part name:	Electrical Connectors
Boeing part number:	Not Provided
Quantity:	4

REFERENCES: (a) National Transportation Safety Board (NTSB) reference DCA21FA085

BACKGROUND:

As reported in the reference (a) NTSB case number, on Feb 20, 2021, a United Airlines (UAL) 777-200, variable number WA005, experienced a fan blade out (FBO) engine failure of the right engine while on climb out from Denver International Airport (DEN).

Under direction of the US National Transportation Safety Board (NTSB), Boeing Air Safety Investigations (ASI) requested Boeing Equipment Quality Analysis (EQA) facilitate the material analysis of samples removed from the engine examination.

Aircraft WA005 was delivered on September 29, 1995, and was reported to have accumulated approximately 96,975 hours and 17,784 cycles at the time of failure.

SUMMARY:

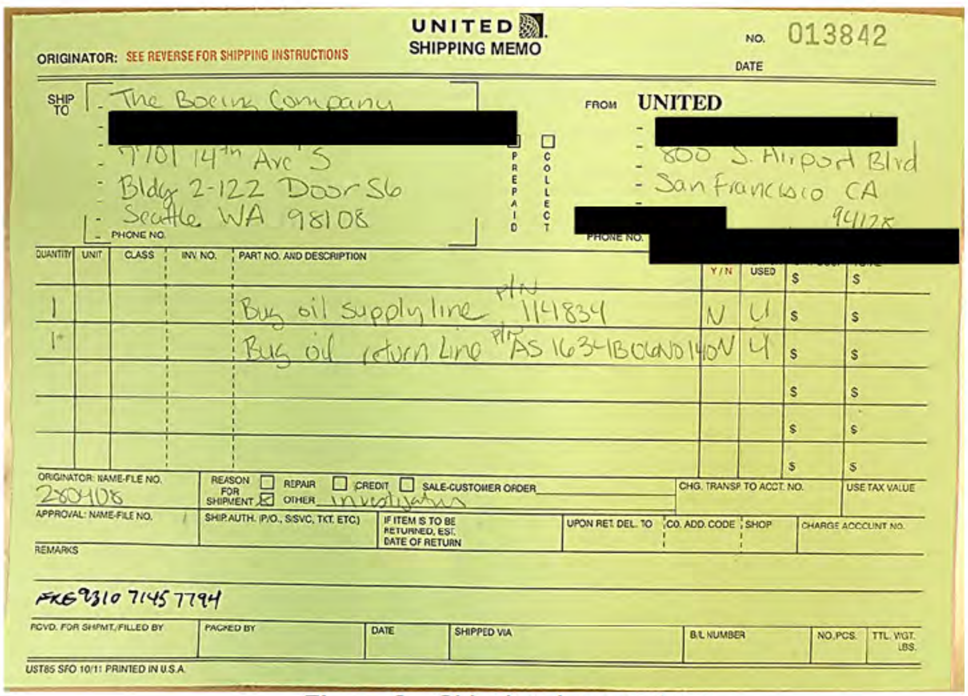
Boeing Research and Technology (BR&T) completed material analysis of the provided samples. BUG oil line samples of the white material near the hose connector were consistent with magnesium oxidation products. BUG oil line samples of the loose material in the hose connector threads were consistent with magnesium oxidation products. Gearbox mounted bracket samples of white material were consistent with magnesium oxidation products. Loose material samples, referred to by the investigative team as “creek rocks,” were most consistent with cast aluminum and aluminum alloys. Material samples collected from the four provided electrical connectors were consistent with corrosion products and an inorganic silicon compound.

EXAMINATION:

An examination of the supplied parts and samples was conducted at Boeing EQA on April 23, 2021, with Boeing ASI, Boeing Propulsion Design Engineering (DE), and BR&T Chemical Technology in attendance. An image of the shipping container as received is shown in Figure 1.

Figure 1 – Shipping container as received

Parts received and listed in the identification table were as provided in the attached shipment documents, shown in Figure 2 and Figure 3.



UNITED
SHIPPING MEMO

ORIGINATOR: SEE REVERSE FOR SHIPPING INSTRUCTIONS

NO. 013842

DATE

SHIP TO: The Boeing Company
[redacted]
9701 14th Ave S
Bldg 2-122 Door S6
Seattle WA 98108
PHONE NO.

PREPAID / COLLECT

FROM: UNITED
[redacted]
800 S. Airport Blvd
San Francisco CA
94128
PHONE NO. [redacted]

QUANTITY	UNIT	CLASS	INV. NO.	PART NO. AND DESCRIPTION	Y/N	USED		
1				Bug oil supply line P/N 114834	N	U	$	$
1				Bug oil return Line P/N AS1634B06N0140	N	U	$	$
							$	$
							$	$
							$	$

ORIGINATOR: NAME-FILE NO. 280408

REASON FOR SHIPMENT: ☐ REPAIR ☐ CREDIT ☐ SALE-CUSTOMER ORDER ☑ OTHER investigation

CHG. TRANSP. TO ACCT. NO. | USE TAX VALUE

APPROVAL: NAME-FILE NO. | SHIP AUTH. (P.O., S/SVC, TKT, ETC) | IF ITEM IS TO BE RETURNED, EST. DATE OF RETURN | UPON RET. DEL. TO | CO. ADD. CODE | SHOP | CHARGE ACCOUNT NO.

REMARKS

FXG 9310 7145 7794

RCVD. FOR SHPMT./FILLED BY | PACKED BY | DATE | SHIPPED VIA | B/L NUMBER | NO. PCS. | TTL. WGT. LBS.

UST85 SFO 10/11 PRINTED IN U.S.A.

Figure 2 – Shipping document

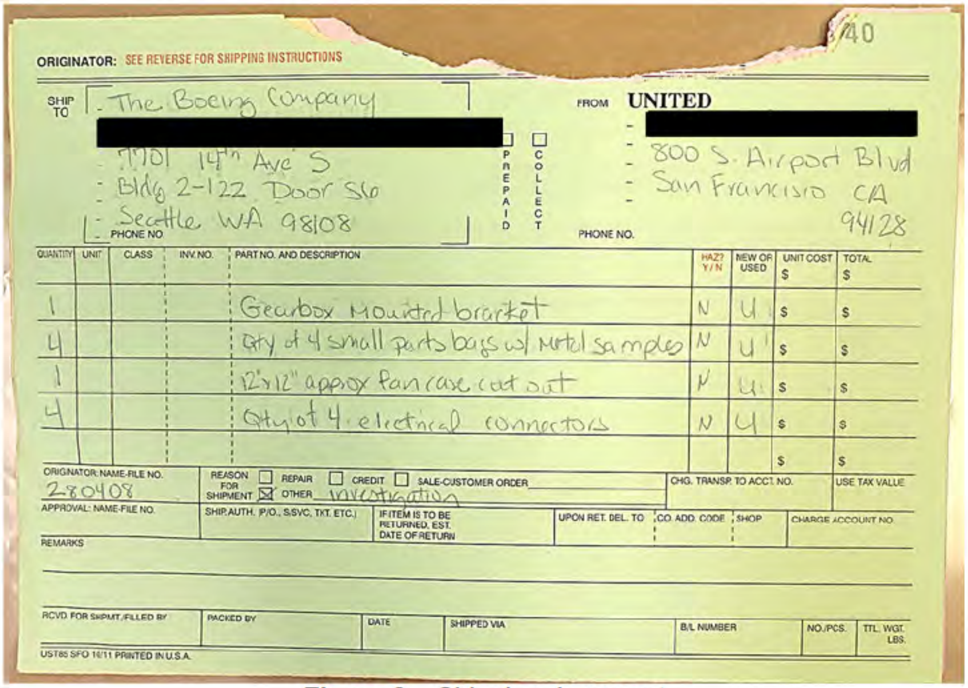


Figure 3 – Shipping document

BUG oil lines are shown as received in Figure 4 and Figure 5.

Figure 4 – BUG oil lines as received

Figure 5 – Bug Oil Lines as received

Boeing ASI and DE identified areas on the oil lines for material analysis, as shown in Figure 6. Areas of interest were loose materials on the threads of the connector fitting and white material near the connector base and on the hard line.

Figure 6 – BUG oil lines with sample areas identified

The gearbox mounted bracket and loose material samples are shown as received in Figure 7.

Figure 7 – Gearbox mounted bracket and material samples as received

Boeing ASI and DE identified areas on the gearbox mounted bracket for material analysis, as shown in Figure 8 and Figure 9. Area of interest was white material near the end of the bracket.

Figure 8 – Gearbox mounted bracket

Figure 9 – Gearbox mounted bracket

Loose material samples collected from the engine oil sump are shown in Figure 10 through Figure 12. The larger material samples were referred to by the investigative team as “creek rocks”, and this terminology was used in the material analysis. Sample 7 was stuck between the Figure 11 and Figure 12 parts bags, as shown in Figure 12.

Figure 10 – Loose material samples

Figure 11 – Loose material samples

Figure 12 – Loose material “creek rock”

BUG electrical connectors are shown as received in Figure 13 and Figure 14.

Figure 13 – BUG electrical connectors as received

Figure 14 – BUG electrical connectors as received

Boeing ASI and DE identified areas on the electrical connectors for material analysis, as shown in Figure 15 and Figure 16. Areas of interest were white material and other deposited materials on the connector backshells. The connector numbers in Figure 15 and Figure 16 are for reference to BR&T analysis only, and do not represent connector positions on the aircraft.

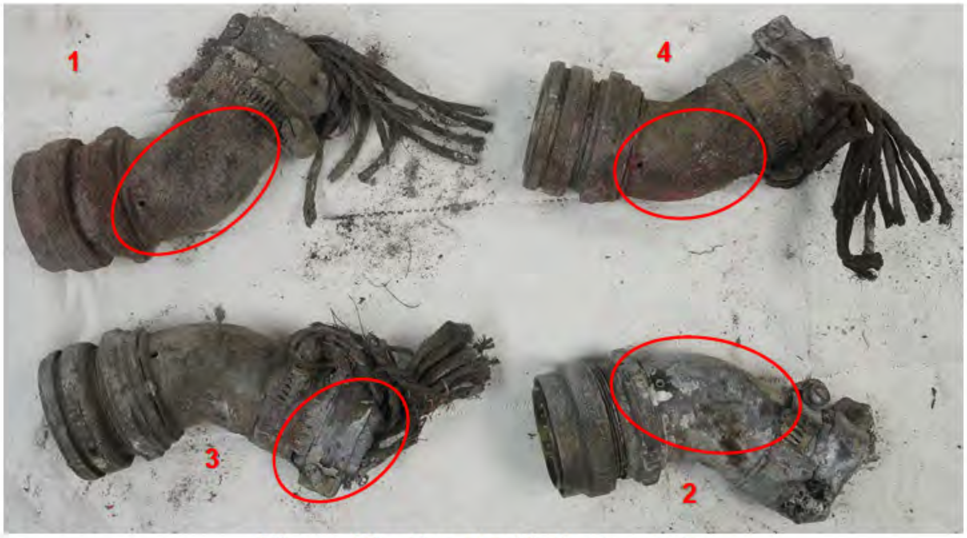


Figure 15 – Bug electrical connectors

Figure 16 – Bug electrical connectors

ANALYSIS:

Chemical analysis completed by BR&T Chemical Technology is contained in Chemical_analysis_777_NTSB_UAL_investigations, attached as enclosure A.

BUG oil line samples of the white material near the hose connector, Figure 6, were consistent with magnesium oxidation products.

BUG oil line samples of the loose material in the hose connector threads , Figure 6, were consistent with magnesium oxidation products.

Gearbox mounted bracket samples of white material, Figure 8 and Figure 9, were consistent with magnesium oxidation products.

Engine oil sump loose material samples, Figure 10, Figure 11, and Figure 12, were most consistent with cast aluminum and aluminum alloys.

Material samples collected from the four provided electrical connectors, Figure 15 and Figure 16, were consistent with corrosion products and an inorganic silicon compound.

The cutout material from the event engine fan case environmental wrap (not pictured in this report) was consistent with Kevlar. Soot sampled on the cutout surface was consistent with thermally degraded engine oil.

DISPOSITION:

The subject samples were retained by BR&T Chemical Technology.
incl

The preceding information is being submitted for information purposes.

Signature on file.

ENCLOSURE:

A. Chemical_analysis_777_NTSB_UAL_investigations