

# BACKGROUND

On April 17th, 2018 SWA 1380 experienced a fan blade out (FBO) event at FL 320. The FBO event resulted in portions of the inlet and fan cowl departing the aircraft, specifically the inlet d-duct, inlet outer barrel, forward sections of the inlet inner barrel and large sections of the fan cowl. In support of the NTSB, Collins Aerospace (Collins) documented the condition of the inlet and fan cowl components that remained on the aircraft as well as the recovered hardware that departed the A/C. The recovered hardware and the remaining portions of the inlet and fan cowl were removed from the aircraft and were shipped to the Collins facility in Chula Vista, California.

Under the authority of the NTSB, Collins established a dedicated facility and team to reconstruct the inlet and fan cowl hardware, as closely as possible, to the aircraft orientation. In support of the NTSB, a forensic metallurgical investigation of the inlet and fan cowl was conducted. This investigation was coordinated with the other investigation parties (Boeing, CFM, Southwest and the FAA) and examined the hardware for evidence of fan blade fragment trajectories and damage to the inlet and fan cowl. Collins excised over 60 metallurgical sections which were evaluated using optical and scanning electron microscopes (SEM) and metallographic mounts to determine fracture mode(s) and evidence of material transfer.

The key findings, in addition to the trajectory analysis, are summarized in the following report which were presented to the NTSB and investigation parties on March 5, 2019, at the GE facility in Cincinnati OH (4/18/19 report version herein includes minor updates).

This report provides:

- An overall Collins inlet damage assessment map associated with fan blade debris
- Criteria used by Collins to associate inlet damage caused by fan blade debris
- Collins established fan blade fragment trajectories associated with inlet damage
- Collins metallurgical findings supporting fan blade debris damage to the inlet
- Engine fan blade platform potential trajectories and damage to the inlet
- Supplemental findings associated with parts departing the aircraft

This report concludes:

- The inlet damage caused by fan blade debris was established based on fan case and inlet trajectory, metallurgical findings and observed evidence:
  - Fan blade fragments trajectories entering the inlet exceeded design specifications
  - Fan blade debris mass entering the inlet, exceeded the design specification, resulting in inner barrel damage forward of the containment shield resulting in 180° degrees of inner barrel back skin damage and 240° of perforated skin damage.

**APRIL 18, 2019**

# Fan Blade Fragment Trajectories and Inlet Damage

# COLLINS INLET FAN FRAGMENT DAMAGE ASSESSMENT

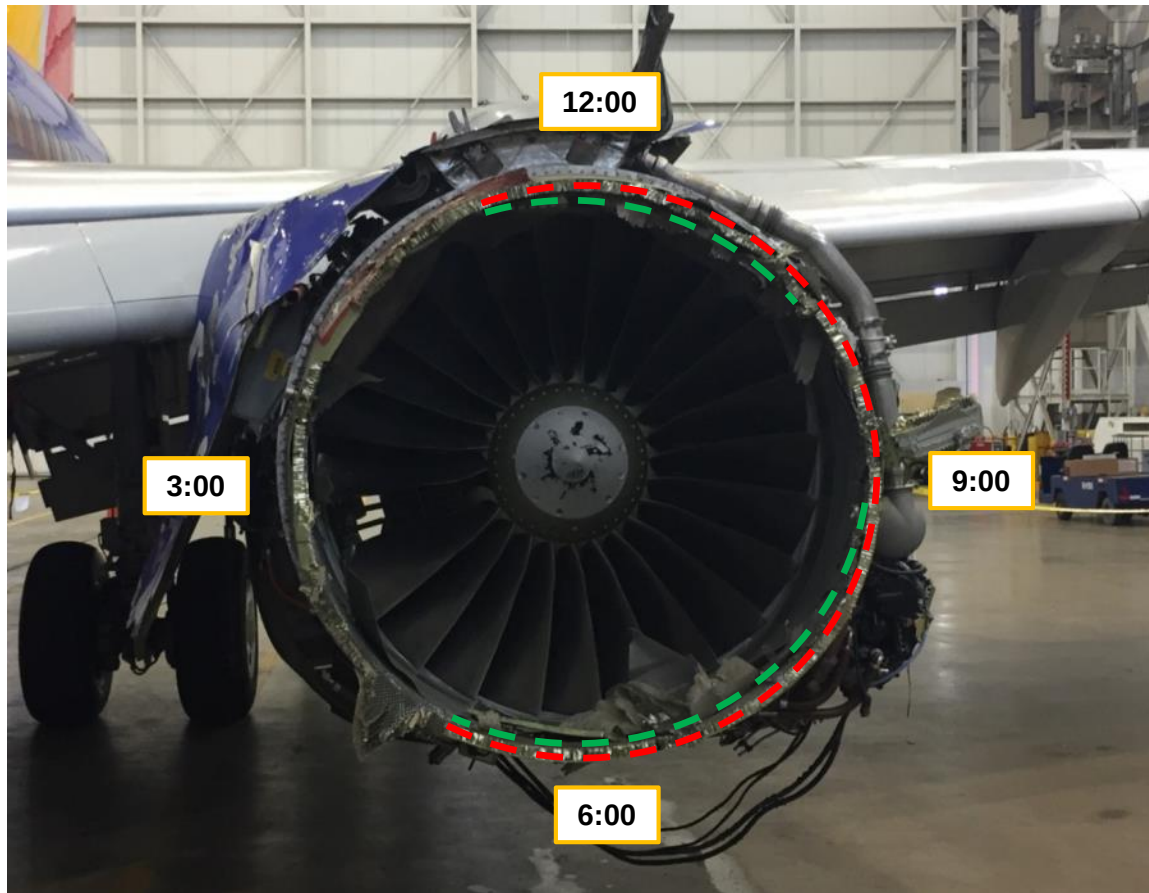
## SUMMARY

- Collins has established an updated inlet inner barrel damage associated with fan blade fragments based on the latest trajectory and metallurgical evidence. The damage is approximately 180° of back-skin and 240° of perforate skin.
- This assessment is based on additional evidence that has been evaluated since the Oct 9-11, 2018 party meeting that, with the evidence available at that time, established a minimum inner barrel damage definition of approximately 70° of back-skin and 150° of perforate skin.

# INNER BARREL BLADE FRAGMENT DAMAGE

| Clock (ALF) | Oct 9-11, 2019 Party Meeting |                      | Collins Analysis |                  |
|-------------|------------------------------|----------------------|------------------|------------------|
|             | Perf Skin Damage             | Min Back Skin Damage | Perf Skin Damage | Back Skin Damage |
| 5:00        |                              |                      |                  |                  |
| 6:00        |                              |                      |                  |                  |
| 7:00        | 150°                         |                      |                  | 105°             |
| 7:30        |                              |                      |                  |                  |
| 8:00        |                              |                      |                  |                  |
| 8:30        |                              |                      |                  |                  |
| 8:45        |                              |                      |                  |                  |
| 9:00        |                              |                      | 240°             |                  |
| 9:30        |                              |                      |                  |                  |
| 10:00       |                              |                      |                  |                  |
| 10:30       |                              | 70°                  |                  |                  |
| 11:00       |                              |                      |                  | 75°              |
| 11:30       |                              |                      |                  |                  |
| 12:00       |                              |                      |                  |                  |
| 12:30       |                              |                      |                  |                  |
| 1:00        |                              |                      |                  |                  |

# INNER BARREL BLADE FRAGMENT DAMAGE



**240°** Perforate skin damage

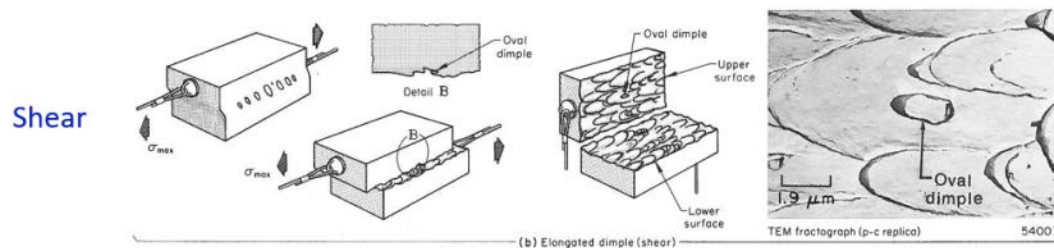
**180°** Back skin shear damage  
(75° + 105°)

# CRITERIA USED TO ASSOCIATE FAN BLADE FRAGMENTS WITH INLET DAMAGE

1. Fan Case, Inlet and Outer Barrel - Damage used to define blade fragment trajectories
2. Core and Back Skin - Planer fracture surface coincident with Containment Shield forward edge and blade fragment loading
3. Back Skin - Shear fracture surface topography consistent with blade fragment loading
4. Ti-6Al-4V - Particles embedded on Inner Barrel Core, Back Skin, Outer Barrel, and Containment Shield leading edge consistent with blade fragment material
5. Inner Barrel Core - Folded core damage consistent with blade fragment loading
6. Outer Barrel - Damage consistent with blade fragment trajectory

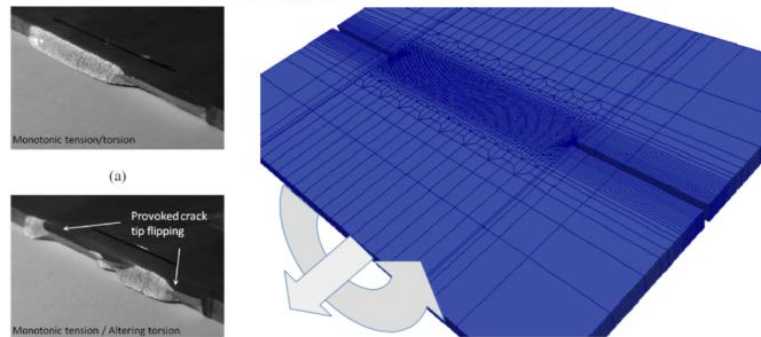
# BACK SKIN FRACTURE SURFACE MODES

- Fracture Surface Indications
  - Radially outboard and clockwise shearing consistent with fragment loading
  - Alternating Mode I/III tearing/shearing consistent with back skin:
    - axial static tension load (pressurized inlet)
    - radial outboard displacement (high velocity spiraling fragment)
    - radial oscillating free response following fragment penetration



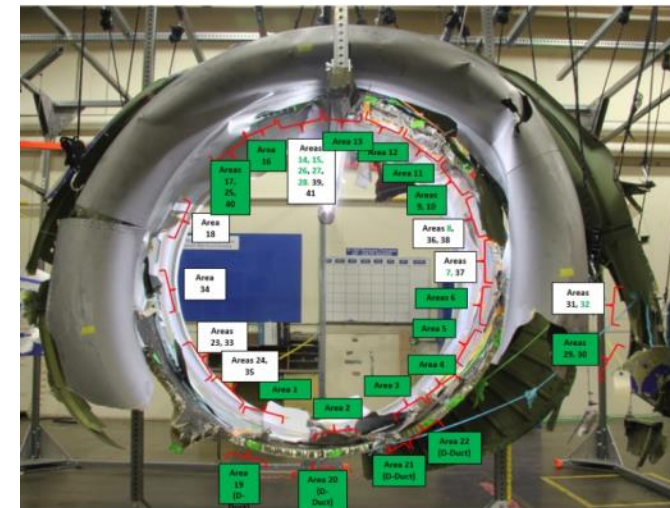
(b) Elongated dimple (shear)  
ASM Handbook Vol. 12: Fractography; Section: Mode of Fractures; Copyright © 2012, ASM International

## Crack Tip Flipping Under Mode I/III Tearing



**Crack Tip Flipping Under Mode I/III Tearing;** C. L. Felner, L. Jensen and K. L. Nielsen; *Department of Mechanical Engineering, Solid Mechanics, Technical University of Denmark and Mechanical Engineering Division, Burmesiter & Wain Energy*

# BACK SKIN FRACTURE MODE MAP



First Group (Complete): 1, 5, 8, 11, 12, 16, 19, 21, 25, 27, 30  
Second Group (Complete): 3, 6, 7, 13, 14, 15, 17, 26, 28, 32  
Third Group (Complete): 2, 4, 9, 10, 20, 22, 29, 40, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 54, 56, 57, 58, 59, 61, 62  
Not Investigated: 18, 23, 24, 31, 33, 34, 35, 36, 37, 38, 39, 41

## Areas Evaluated

# BACK SKIN DAMAGE CRITERIA MAP

| Position | 1                               | 2                             | 3                         | 4                                 | 5                | 6                           | Overall |
|----------|---------------------------------|-------------------------------|---------------------------|-----------------------------------|------------------|-----------------------------|---------|
|          | Blade<br>Fragment<br>Trajectory | Planer<br>Fracture<br>Surface | Shear Fracture<br>Surface | Ti 6Al-4V                         | Core<br>Deformed | Outer Barrel<br>Penetration |         |
| 5:00     | X (38-40)                       | X                             | Alt (41)                  | Core (42)                         |                  | Large Hole (53-54)          | 105°    |
| 6:00     |                                 | X                             | Alt (43)                  | Core (44)                         | Folded (44)      |                             |         |
| 6:30     |                                 | X                             | Alt (45)                  | Core (45)                         | Folded (45)      |                             |         |
| 7:00     |                                 | X                             | Tensile (46)              |                                   |                  |                             |         |
| 7:30     |                                 | X                             | Alt (47)                  | Back Skin (48)<br>Core (49,50)    | Folded (49)      |                             |         |
| 8:00     |                                 | X                             | Radial Out (51)           | Outer Barrel (53,54)              |                  |                             |         |
| 8:30     |                                 | X                             | Radial Out (52)           |                                   |                  |                             |         |
| 9:00     |                                 |                               |                           |                                   |                  |                             |         |
| 9:30     |                                 |                               |                           |                                   |                  |                             |         |
| 10:00    |                                 |                               |                           |                                   |                  |                             |         |
| 10:30    | X (23-25)                       | X                             | Radial Out (26)           |                                   |                  |                             | 75°     |
| 11:00    |                                 | X                             | Radial Out (27)           | Shield (28)                       |                  |                             |         |
| 11:30    |                                 | X                             | CW Rad Inbd (29)          |                                   |                  |                             |         |
| 12:00    |                                 | X                             | Radial Out (30)           | Core (31)<br>Outer Barrel (35,36) | Folded (31)      | Two Penetrations<br>(34)    |         |
| 12:30    |                                 | X                             | Radial Out (32)           |                                   |                  |                             |         |
| 1:00     |                                 | X                             | Alt (33)                  |                                   |                  |                             |         |

---

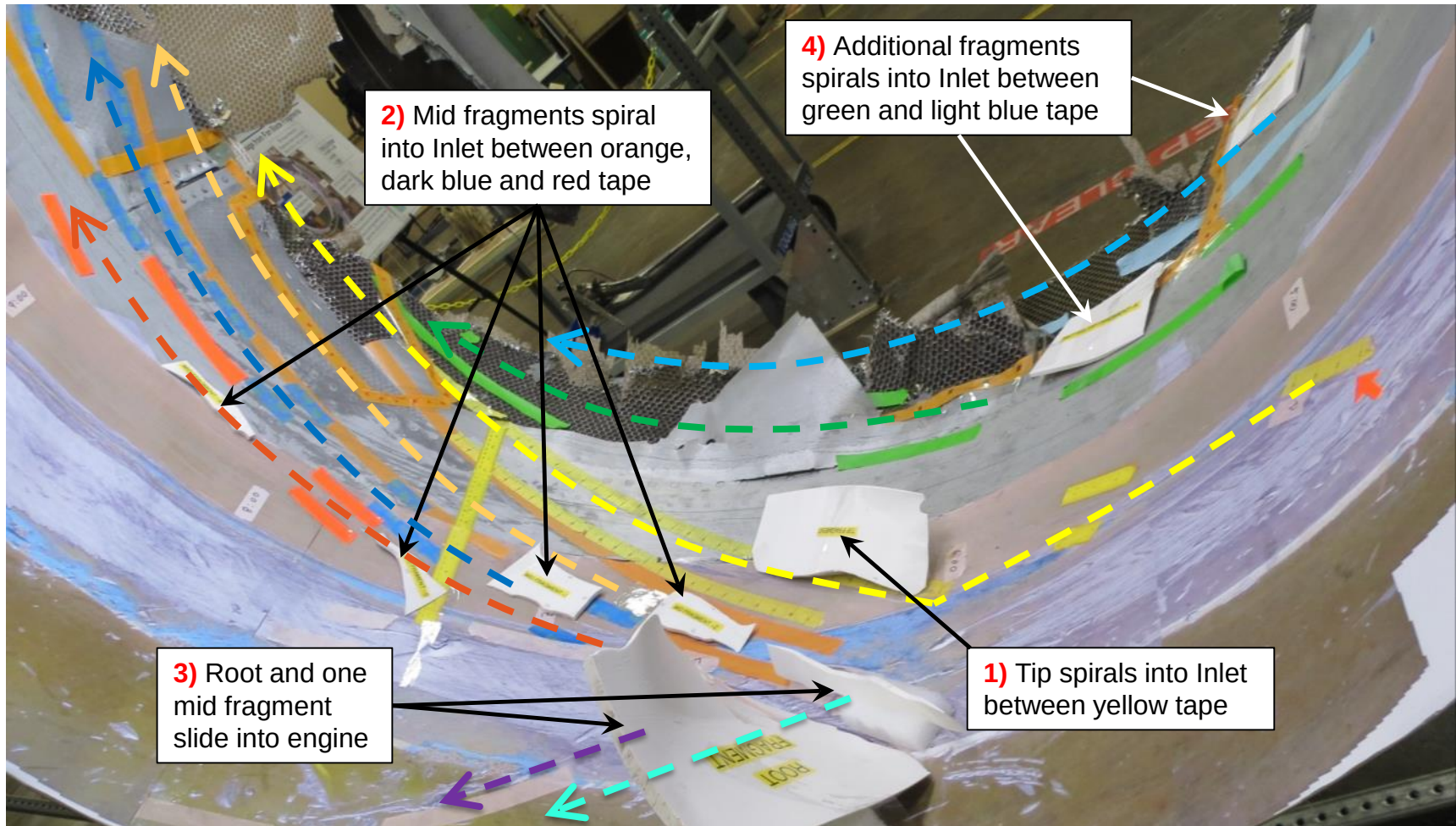
# FRAGMENT TRAJECTORY AND INNER BARREL DAMAGE SUMMARY

# SUMMARY OF FAN BLADE FRAGMENT TRAJECTORIES AND INLET DAMAGE

- The tip and multiple mid fragments spiraled forward of the Inlet containment shield, and were not recovered
- The root and one mid fragment did not enter the Inlet, and were recovered in engine
- One fan blade platform was liberated and not recovered
- The inner barrel damage by fan blade fragments was established based on fan case and Inlet trajectory indications, metallurgical data and observed evidence:
  - Perforate skin damage zone is defined as a  $240^{\circ}$  arc with its axial length beginning at the aft end of the acoustic core and ending 2.0" forward of containment shield
  - Back skin shear damage zone are defined as a  $75^{\circ}$  arc and  $105^{\circ}$  arc ( $180^{\circ}$  total) that are 1.0" wide and located just forward of the containment shield

# FAN BLADE FRAGMENT TRAJECTORIES

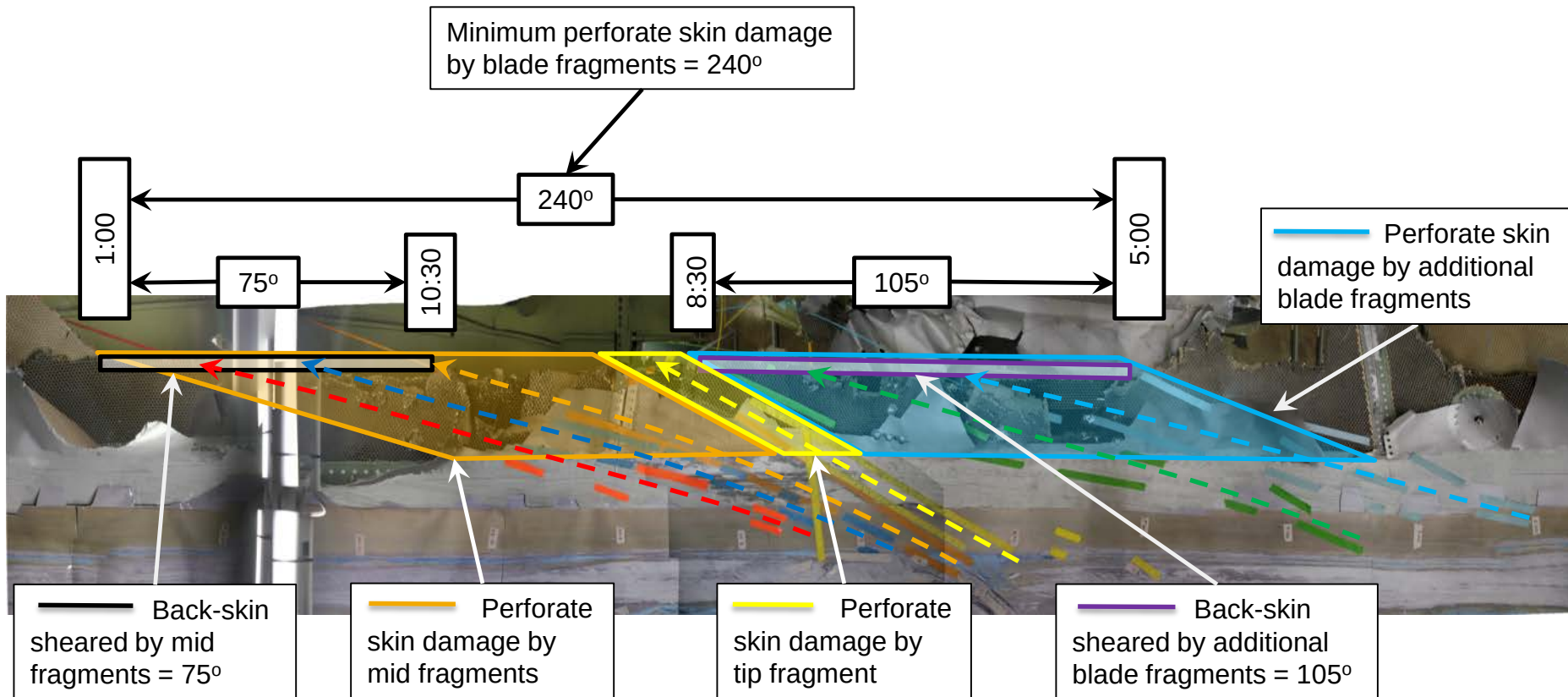
## FAN CASE AND INLET DAMAGE DEFINES TRAJECTORIES



View Looking Forward

# BLADE FRAGMENT INNER BARREL DAMAGE

## PERFORATE SKIN AND BACK SKIN DAMAGED BY FAN BLADE FRAGMENTS

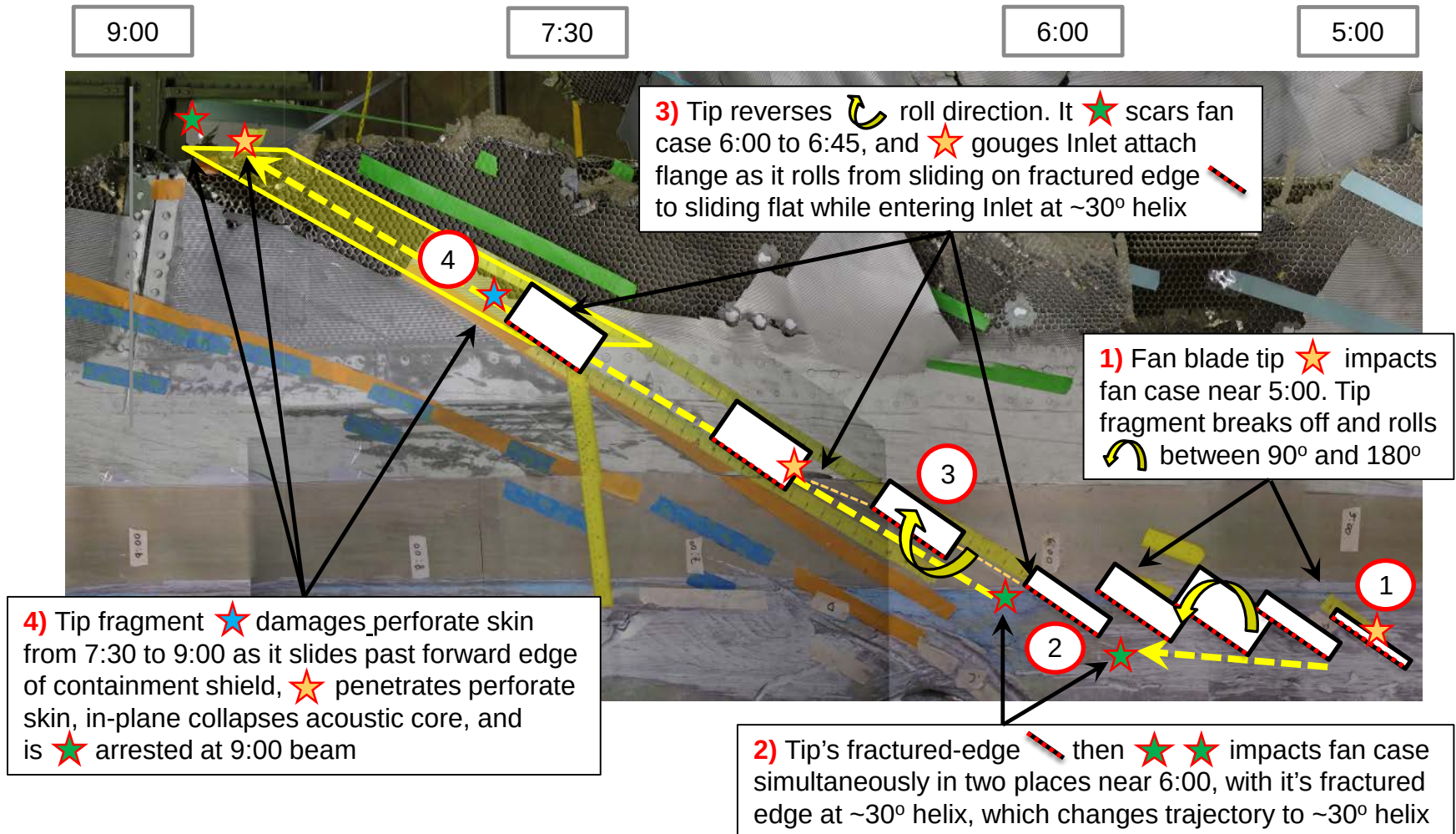


---

# FAN BLADE TIP FRAGMENT TRAJECTORY AND DAMAGE TO INLET ATTACH RING, INNER BARREL PERFORATE SKIN, AND 9:00 BEAM

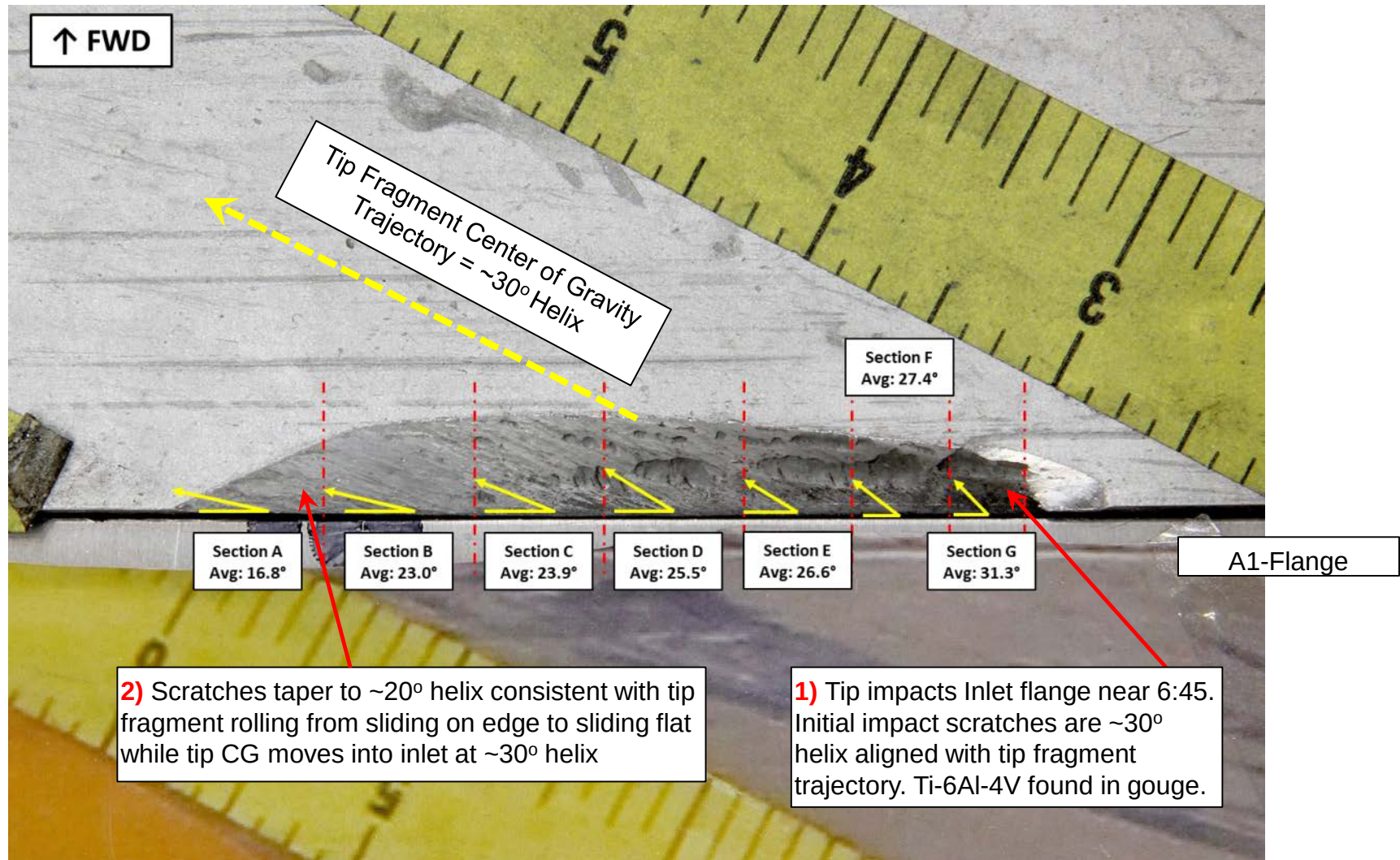
# FAN BLADE TIP FRAGMENT TRAJECTORY

TIP FRAGMENT DAMAGES ATTACH RING, PERFORATE SKIN, AND IMPACTS 9:00 BEAM



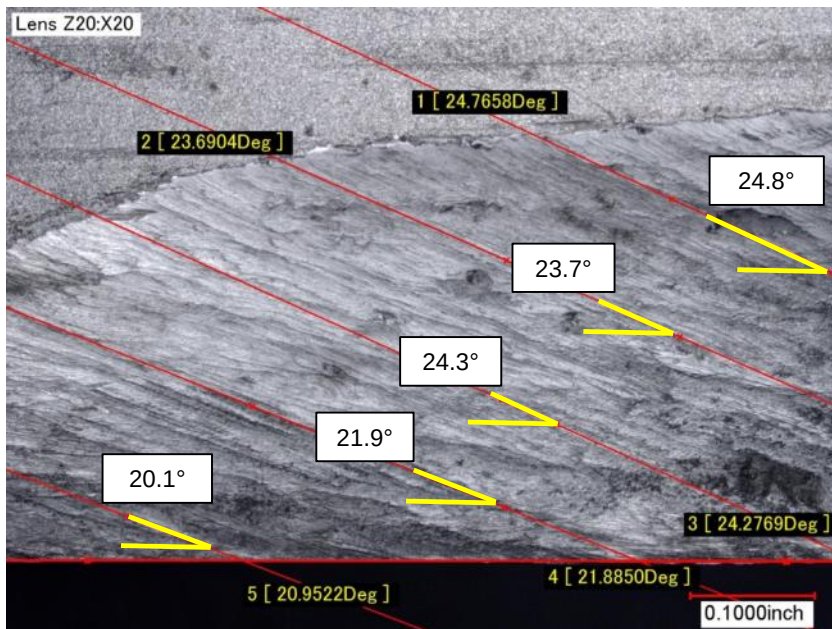
# FAN BLADE TIP FRAGMENT TRAJECTORY

TIP FRAGMENT CAUSED  $\sim 20^\circ$  TO  $\sim 30^\circ$  SCRATCHES IN GOUGE

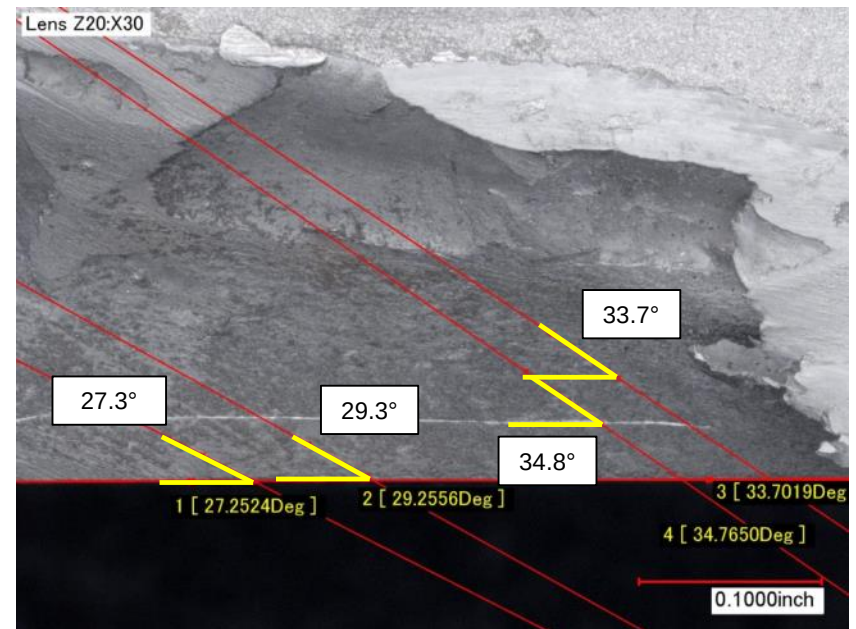


# FAN BLADE TIP FRAGMENT TRAJECTORY

TIP FRAGMENT CAUSED  $\sim 20^{\circ}$  TO  $\sim 30^{\circ}$  SCRATCHES IN GOUGE



Section B (Avg:  $23.0^{\circ}$ )



Section G (Avg:  $31.3^{\circ}$ )

# TIP FRAGMENT TRAJECTORY

TIP DAMAGES PERFORATE SKIN AND CORE WHILE IMPACTING 9:00 BEAM

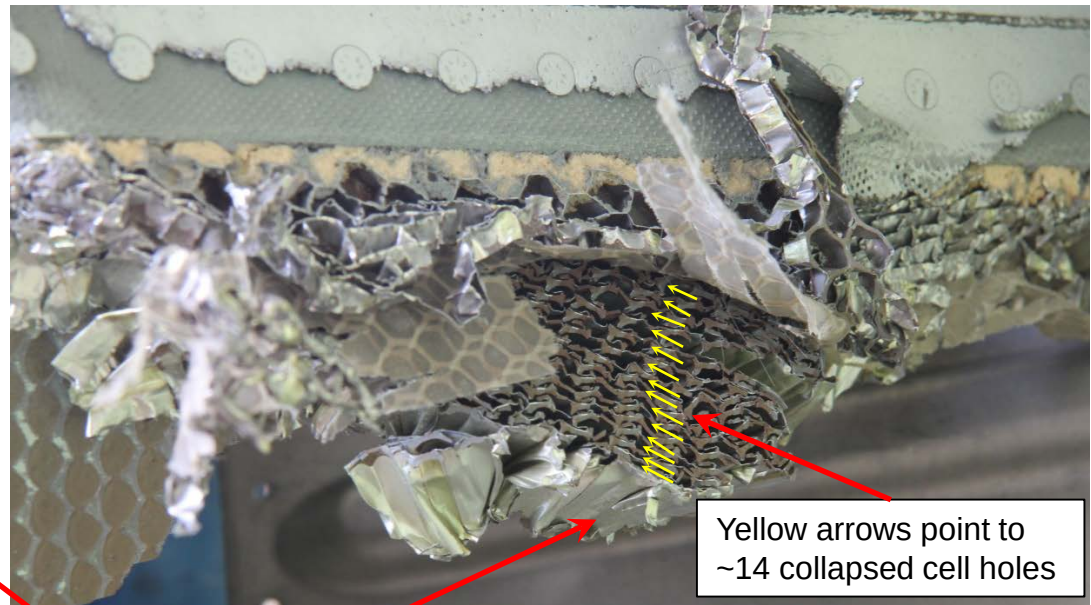
**2)** Tip in-plane folds and collapses outer core, impacts 9:00 beam, and deflects forward

**1)** Tip penetrates perforate skin, and removes inner core and septum, as it slides forward of containment shield at 30° helix

Inner core and septum missing

# TIP FRAGMENT TRAJECTORY

TIP FRAGMENT COLLAPSES ACOUSTIC CORE AND IS ARRESTED AT 9:00 BEAM

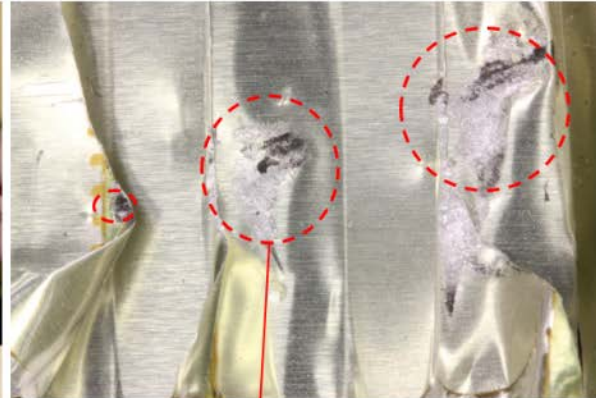


~14 cells (~5") of acoustic core was in-plane collapsed into 9:00 beam

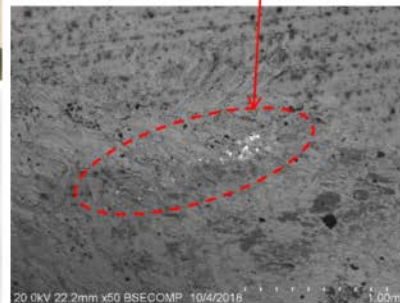
# TIP FRAGMENT METALLURGICAL FINDINGS

## TITANIUM FOUND IN 9:00 BEAM CORE

- 9:00 Core Crease – Ti-6Al-4V Particles



- Titanium Alloy particles found impacted and imbedded in the Core sheet metal

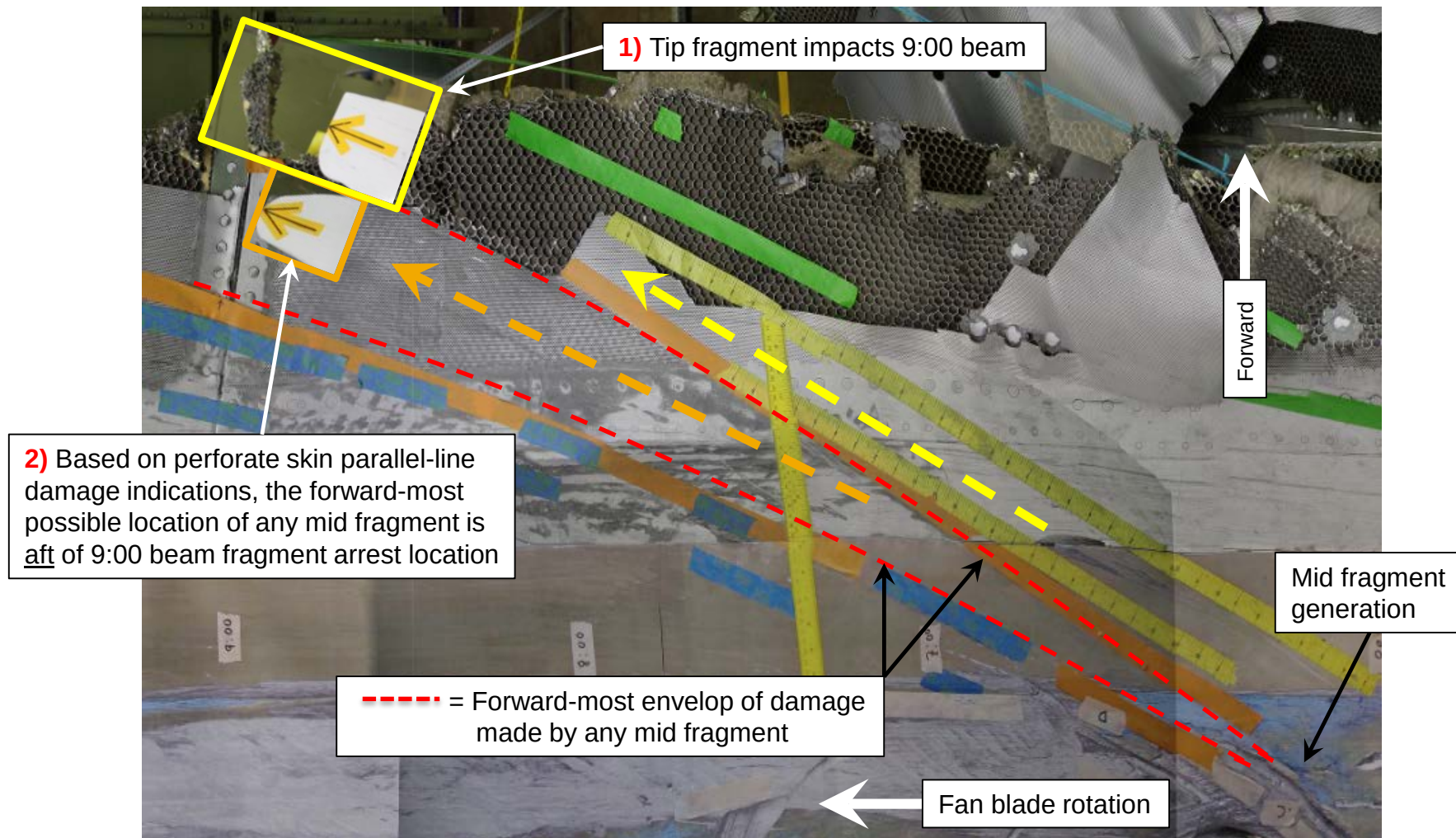


| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 17.43 | 36.18 |
| AlK     | 12.85 | 15.82 |
| TiK     | 66.05 | 45.78 |
| TK      | 01.74 | 01.13 |

Titanium Alloy  
Particles Impacted  
and Imbedded

# FAN BLADE TIP FRAGMENT TRAJECTORY

MID FRAGMENT WAS NOT ARRESTED AT 9:00 BEAM



---

# MID FAN BLADE FRAGMENT TRAJECTORIES AND DAMAGE TO INNER BARREL PERFORATE SKIN, ACOUSTIC CORE, BACK SKIN, AND OUTER BARREL

# FAN BLADE MID FRAGMENTS TRAJECTORIES

## MID FRAGMENTS DAMAGE PERFORATE SKIN AND BACK-SKIN

4) Mid fragments penetrate outer barrel at two locations near 12:00

1:00

4

10:30

7:30

6:30

3

2

1

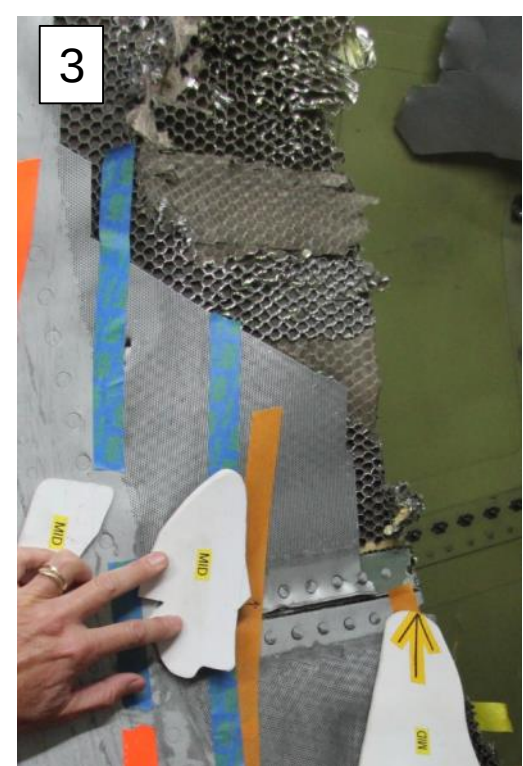
3) Mid fragments shear inner barrel back-skin at containment shield forward end from 10:30 to 1:00

2) Mid fragments slide into Inlet at 20° to 30° helix trajectory damaging perforate skin from 7:30 to 1:00

1) Remaining fan blade ★ impacts fan case near 6:30 creating multiple mid fragments and a root fragment

# MID FAN BLADE FRAGMENTS TRAJECTORIES

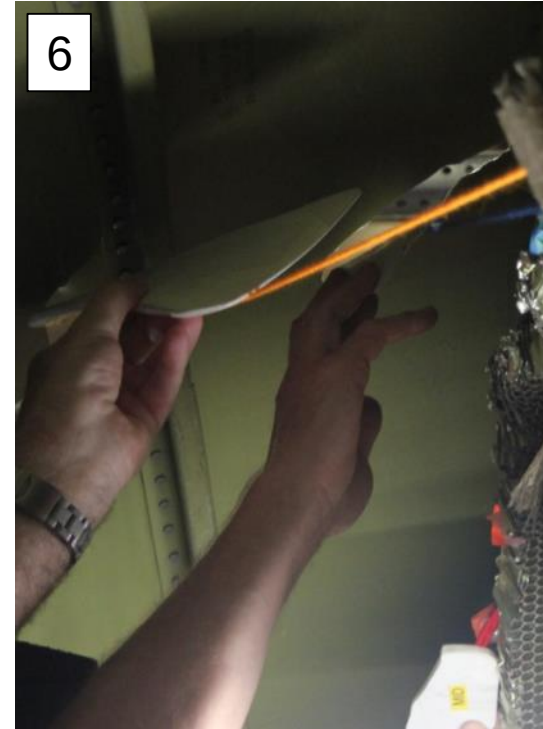
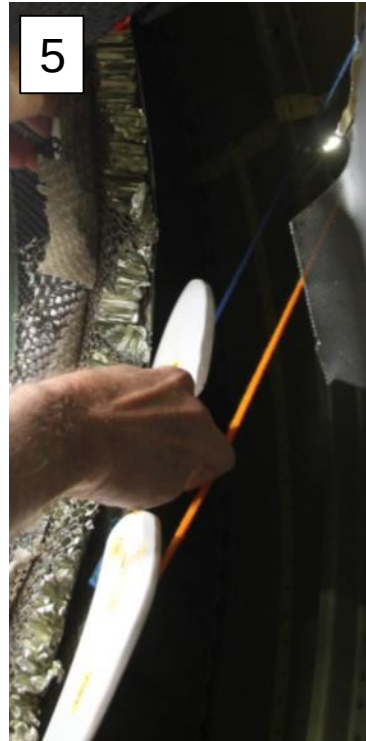
## MID FRAGMENTS DAMAGE PERFORATE SKIN



1), 2), 3) Mid fragments spiral into Inlet at  $20^{\circ}$  -  $30^{\circ}$  helix trajectory damaging perforate skin from 7:30 to 1:00

# MID FAN BLADE FRAGMENTS TRAJECTORIES

## MID FRAGMENTS DAMAGE BACK-SKIN AND OUTER BARREL

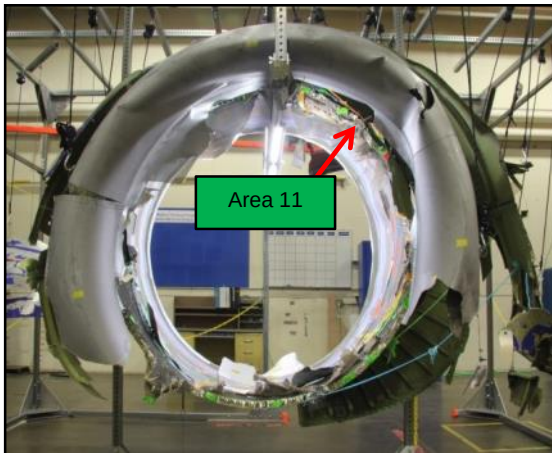


- 4) Penetrate perforate skin and shear back-skin just forward of containment shield from 10:30 to 1:00. Ti-6Al-4V was found in acoustic core, back-skin and containment shield between 11:00 and 12:00
- 5) Traverse from inner barrel to outer barrel
- 6) Penetrate outer barrel in two locations near 12:00

# MID FRAGMENT METALLURGICAL FINDINGS

## AREA 11: BACK SKIN RADIAL OUTBOARD SHEAR

- 10:30 Back-Skin – Radial Outboard



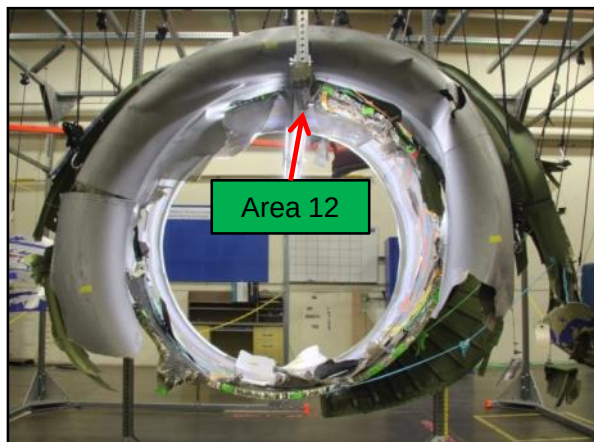
↑ FWD Skin Shear  
| Radial Outboard



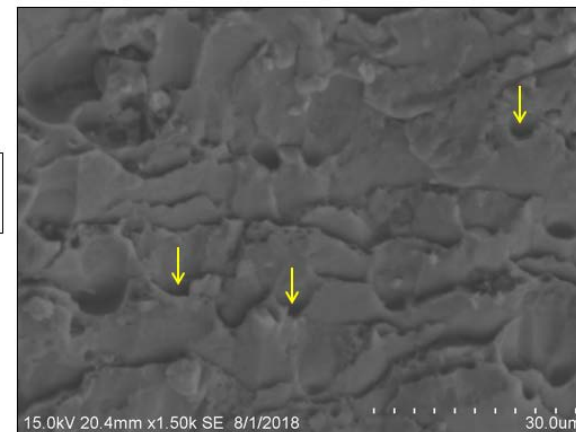
# MID FRAGMENT METALLURGICAL FINDINGS

## AREA 12: BACK SKIN RADIAL OUTBOARD SHEAR

- 11:00 Back Skin Radial Outboard



↑ FWD Skin Shear  
Radial Outboard



AFT (Back Skin) Microvoid Coalescence

# MID FRAGMENT METALLURGICAL FINDINGS

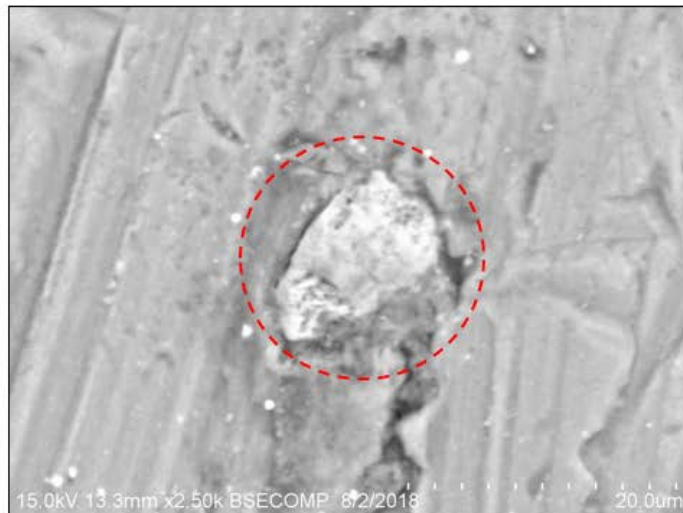
## AREA 12: TITANIUM ON CONTAINMENT SHIELD

- 11:00 Containment Shield – Titanium Particle



| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 34.86 | 59.54 |
| CuL     | 01.19 | 00.51 |
| NaK     | 00.73 | 00.87 |
| AlK     | 06.82 | 06.90 |
| TiK     | 56.41 | 32.18 |
| VK      | 00.00 | 00.00 |

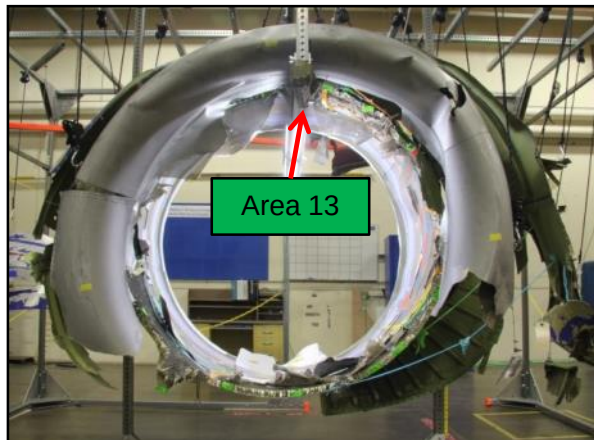
Titanium Alloy  
Particles Imbedded



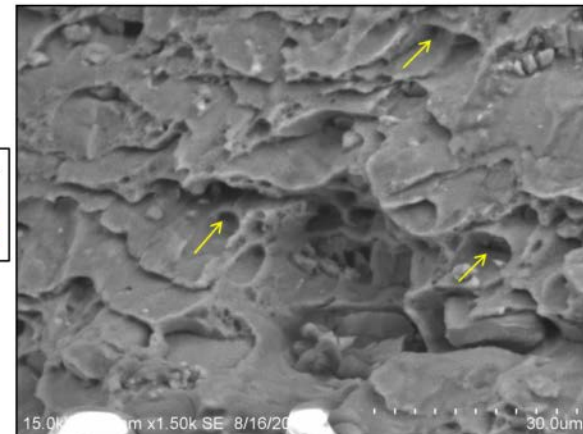
# MID FRAGMENT METALLURGICAL FINDINGS

## AREA 13: BACK SKIN TANGENTIAL CLOCKWISE RADIAL INBOARD SHEAR

- 11:30 Back Skin Tangential CW Radial Inboard



FWD Skin Shear  
↙ Tangential CW  
Radial Inboard

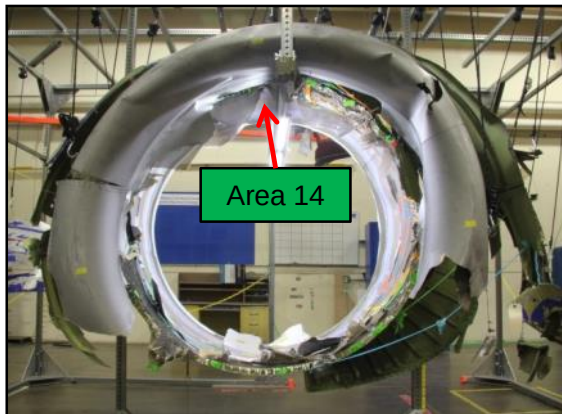


AFT (Back Skin) Microvoid Coalescence

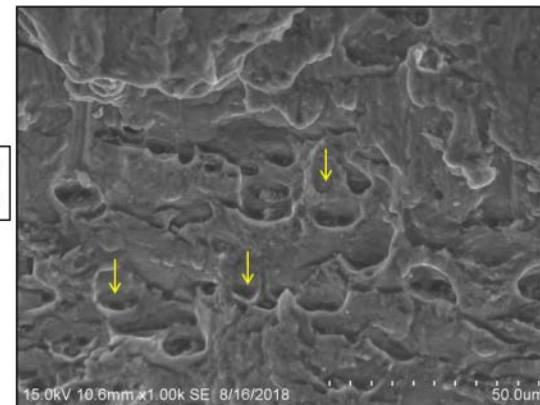
# MID FRAGMENT METALLURGICAL FINDINGS

## AREA 14: BACK SKIN RADIAL OUTBOARD SHEAR

- 12:00 Back Skin - Radial Outboard



↑ FWD Skin Shear  
Radial Outboard

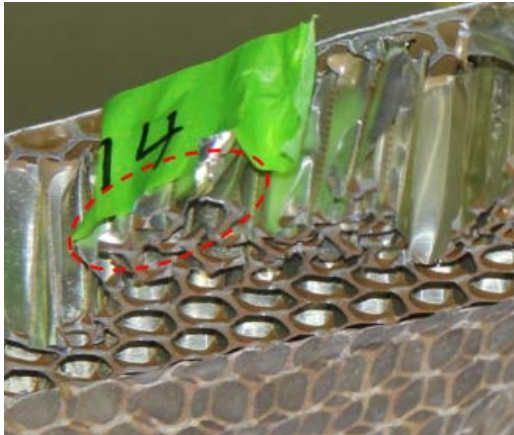


AFT (Back Skin) Microvoid Coalescence

# MID FRAGMENT METALLURGICAL FINDINGS

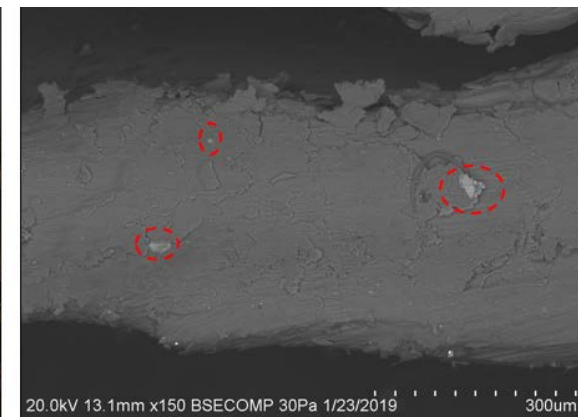
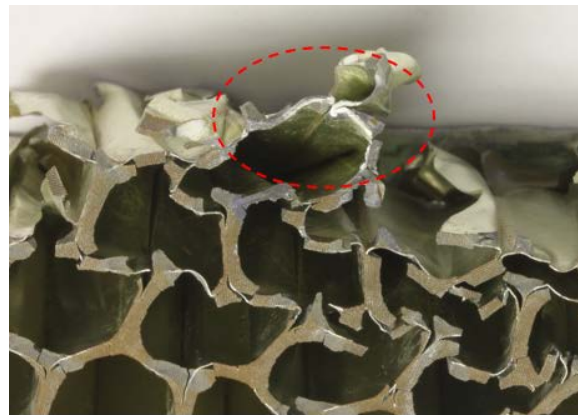
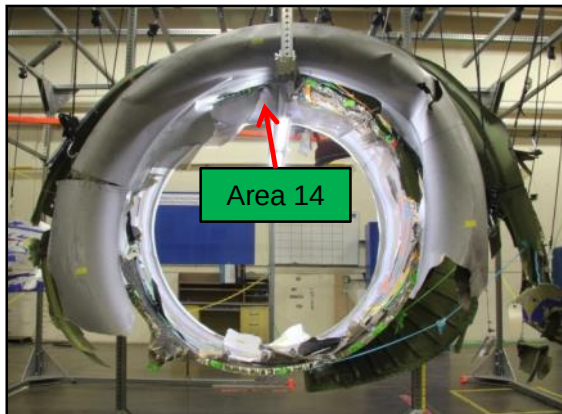
## AREA 14: FOLDED CORE WITH TITANIUM

- 12:00 Back Skin – Folded Core – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 10.24 | 22.53 |
| OK      | 09.00 | 14.85 |
| MgK     | 01.52 | 01.65 |
| AlK     | 40.89 | 40.04 |
| TiK     | 34.93 | 19.26 |
| VK      | 01.15 | 00.60 |
| FeK     | 02.27 | 01.08 |

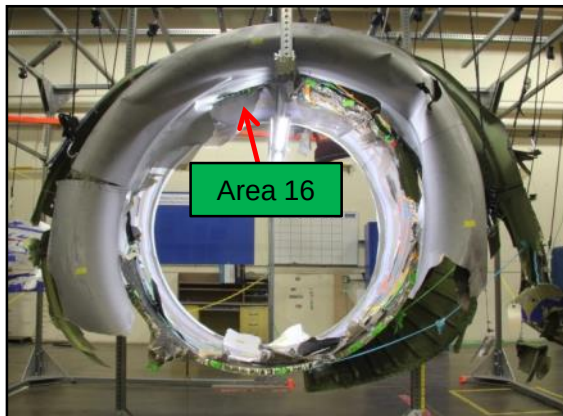
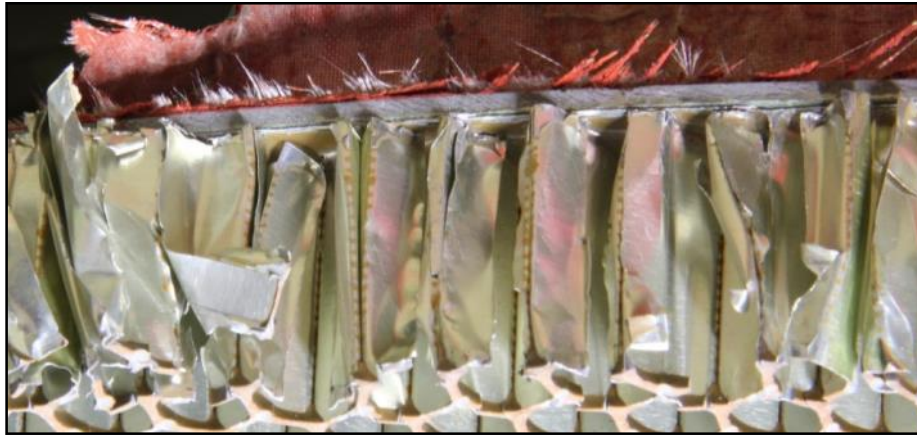
Titanium Alloy  
Particles Impacted  
and Imbedded



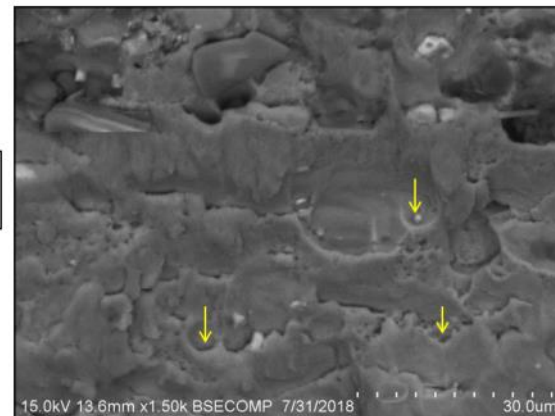
# MID FRAGMENT METALLURGICAL FINDINGS

## AREA 16: BACK SKIN RADIAL OUTBOARD SHEAR

- 12:30 Back Skin - Radial Outboard



↑ FWD Skin Shear  
Radial Outboard

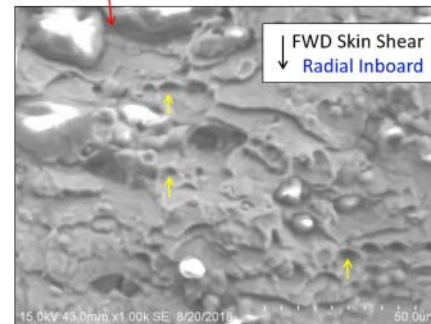
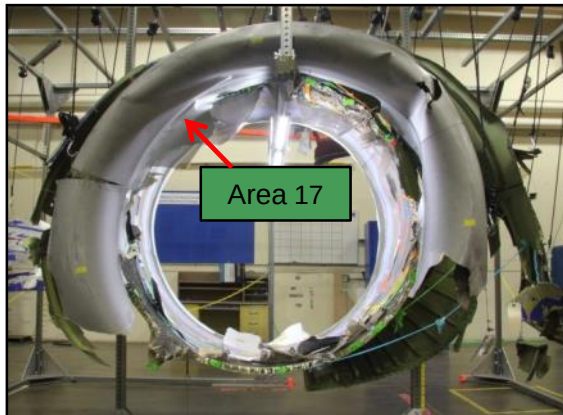
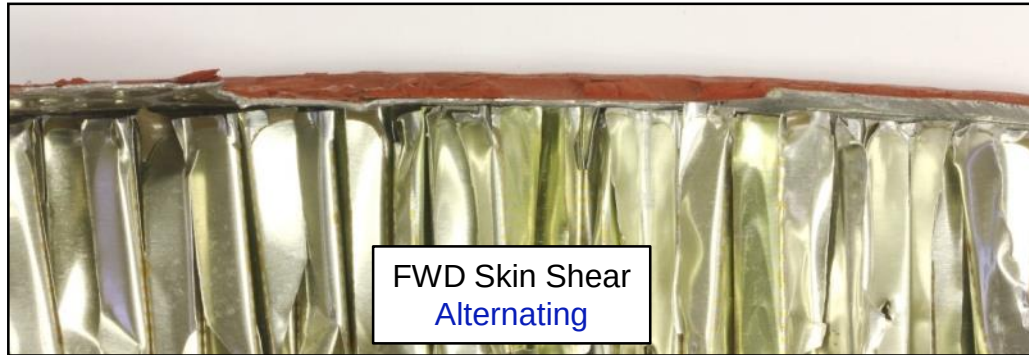


AFT (Back Skin) Microvoid Coalescence

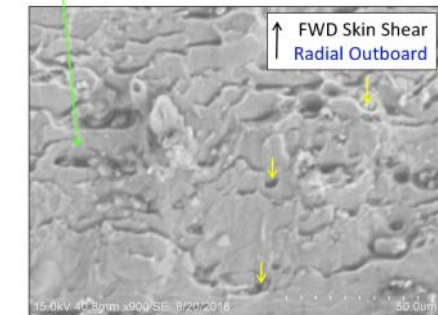
# MID FRAGMENT METALLURGICAL FINDINGS

## AREA 17: BACK SKIN ALTERNATING SHEAR

- 1:00 Back Skin – Alternating Shear



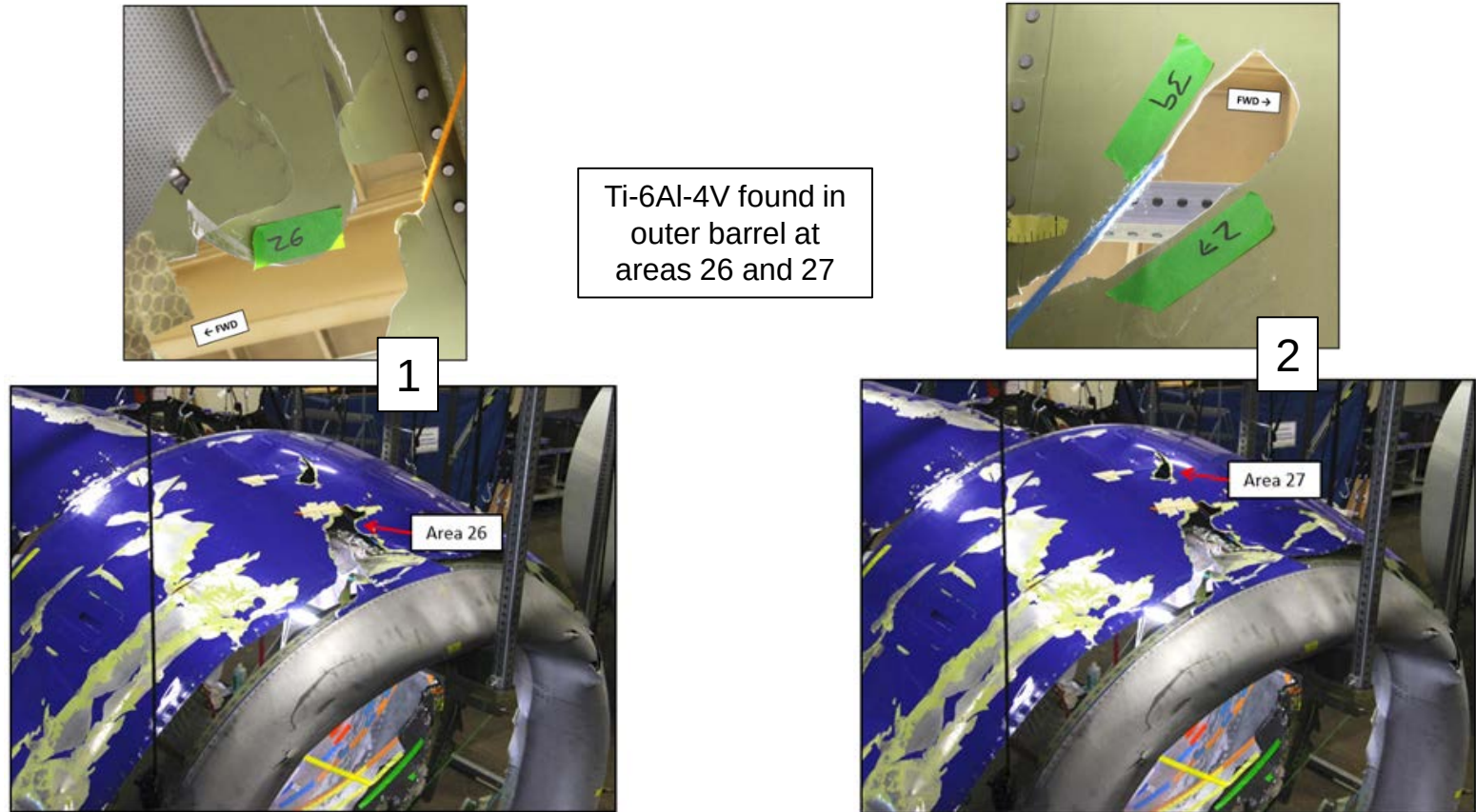
AFT (Back Skin) Microvoid Coalescence



AFT (Back Skin) Microvoid Coalescence

# MID FRAGMENTS TRAJECTORIES

## MID BLADE FRAGMENTS SHEAR OUTER BARREL

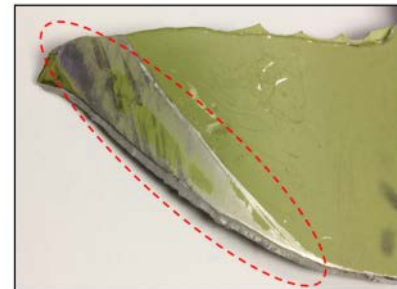
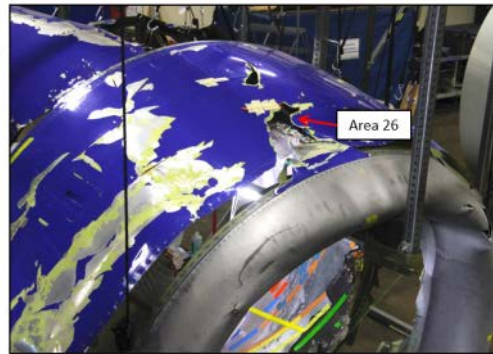
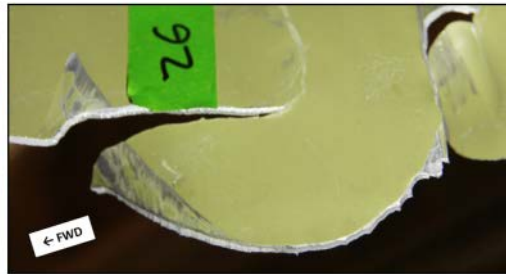


- 1) First mid fragment penetrates outer barrel near 12:00 (Area 26: forward of first mid fragment penetration)
- 2) Second mid fragment penetrates outer barrel near 12:00 (Area 27: just forward of containment shield)

# MID FRAGMENT METALLURGICAL FINDINGS

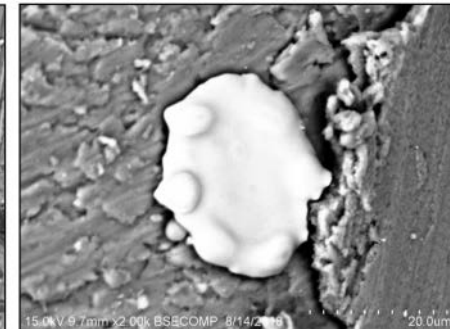
## AREA 26: OUTER BARREL DAMAGE WITH TITANIUM

- Outer Barrel Damage – 12:00 – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 04.36 | 12.70 |
| OK      | 08.94 | 19.55 |
| AlK     | 07.96 | 10.31 |
| SiK     | 00.96 | 01.19 |
| SrL     | 00.83 | 00.33 |
| TiK     | 72.31 | 52.79 |
| TK      | 02.72 | 01.87 |
| CrK     | 01.29 | 00.87 |
| FeK     | 00.62 | 00.39 |

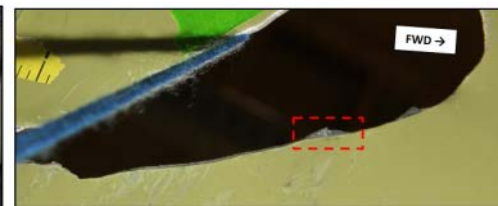
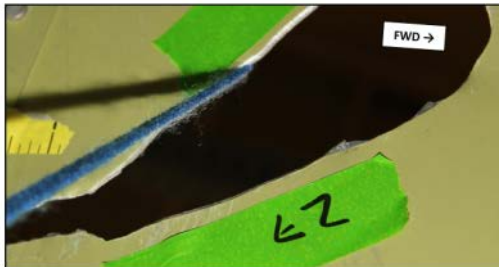
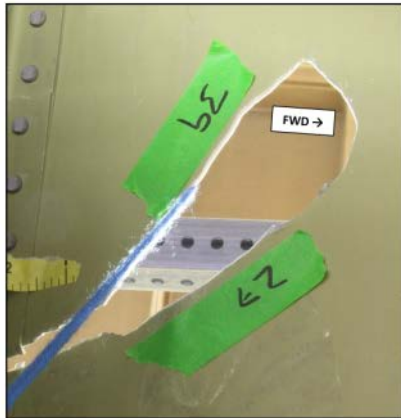
Titanium Alloy  
Particles Impacted  
and Imbedded



# MID FRAGMENT METALLURGICAL FINDINGS

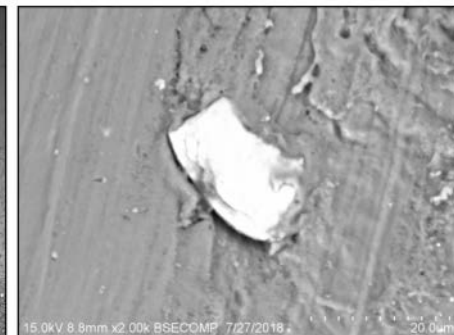
## AREA 27: OUTER BARREL DAMAGE WITH TITANIUM

- Outer Barrel Damage – 12:00 – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 06.44 | 20.26 |
| AlK     | 09.81 | 13.75 |
| TiK     | 81.45 | 64.29 |
| IK      | 02.30 | 01.71 |

Titanium Alloy  
Particles Impacted  
and Imbedded

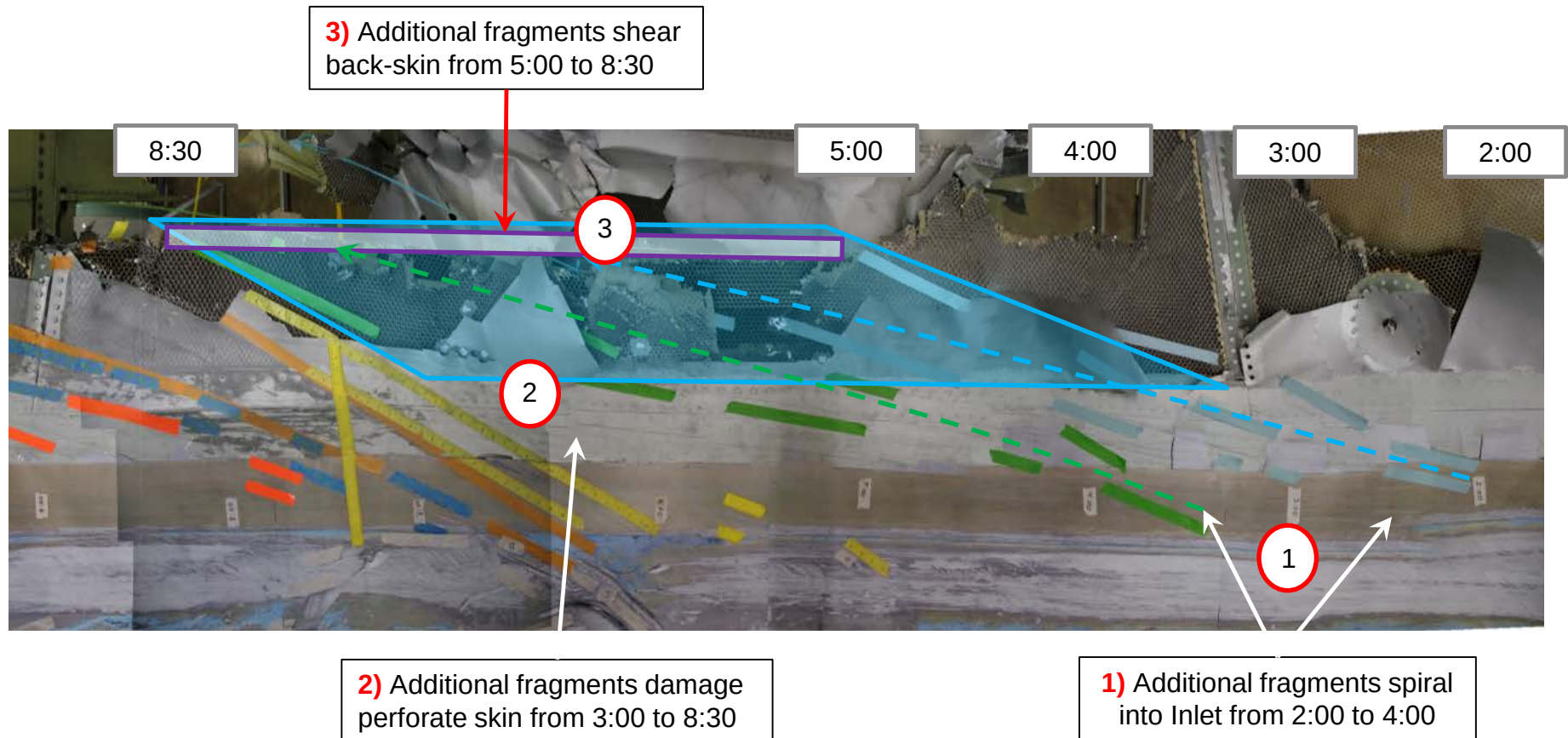


---

# ADDITIONAL FAN BLADE FRAGMENTS TRAJECTORIES AND DAMAGE TO INNER BARREL PERFORATE SKIN, ACOUSTIC CORE, BACK SKIN, AND OUTER BARREL

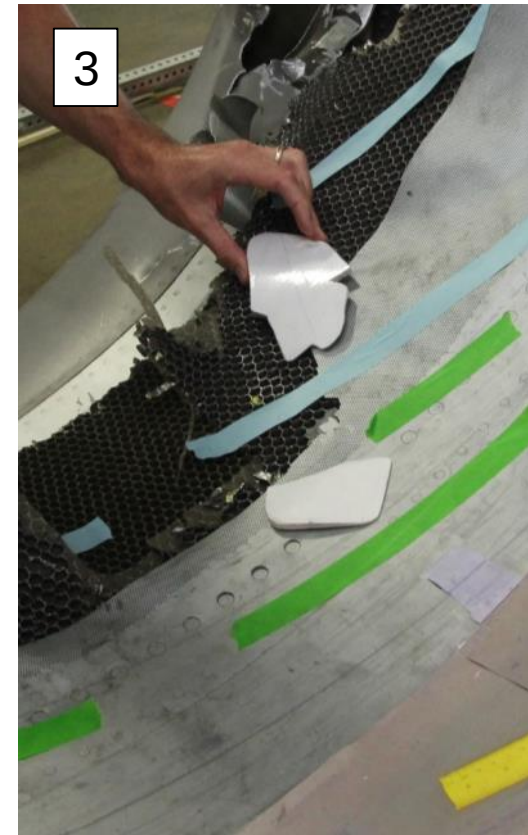
# ADDITIONAL FAN FRAGMENTS TRAJECTORIES

## ADDITIONAL BLADE FRAGMENTS DAMAGE PERFORATE SKIN AND BACK-SKIN



# ADDITIONAL FAN FRAGMENTS TRAJECTORIES

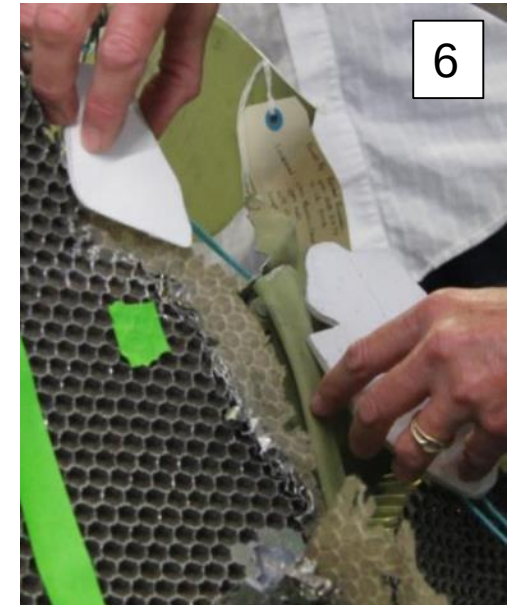
## ADDITIONAL FAN BLADE FRAGMENTS DAMAGE PERFORATE SKIN



1), 2), 3) Additional fan fragments spiral into Inlet from 2:00 to 4:00 damaging perforate skin

# ADDITIONAL FAN FRAGMENTS TRAJECTORIES

## ADDITIONAL FAN BLADE FRAGMENTS DAMAGE PERFORATE SKIN



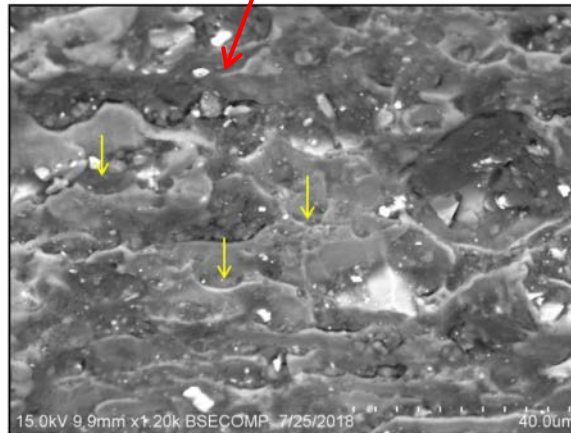
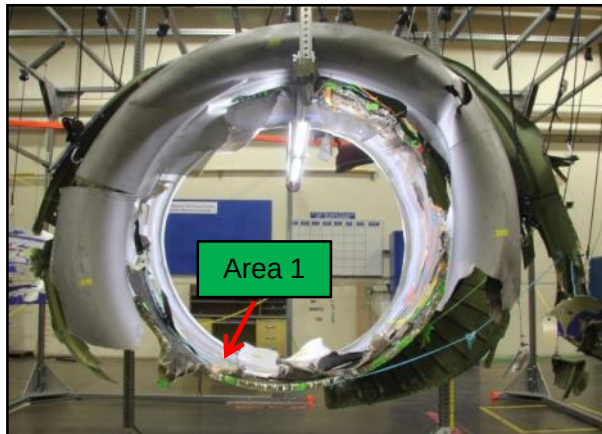
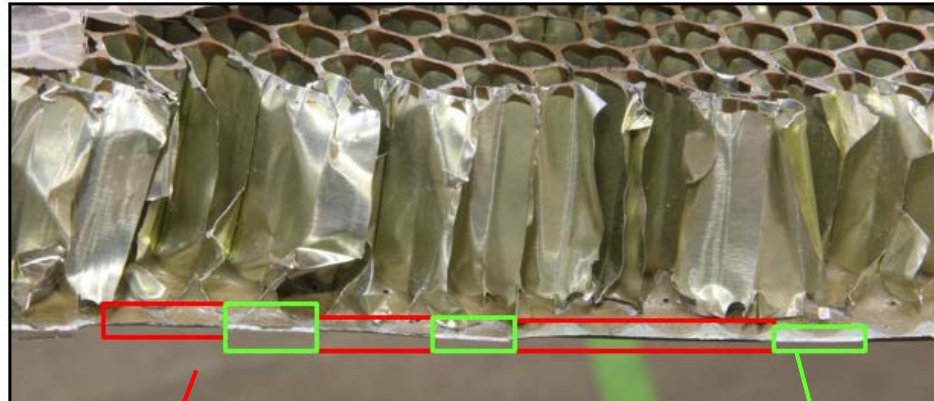
4), 5), & 6) Additional fan fragments damage perforate skin from 3:00 to 8:30

Ti-6Al-4V found in core and back-skin between 5:00 and 7:30

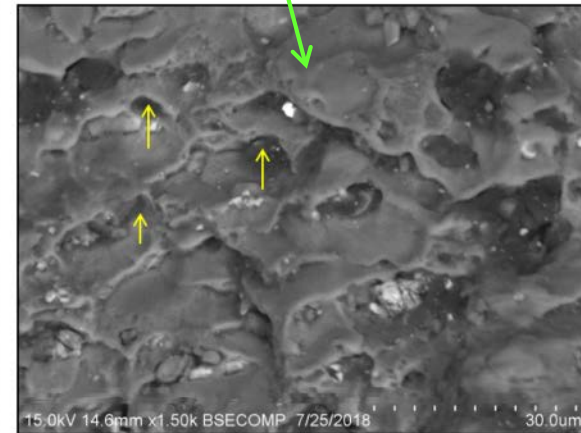
# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 1: BACK SKIN ALTERNATING SHEAR

- 5:00 Back-Skin – Alternating



↑ FWD Skin Shear  
Radial Inboard

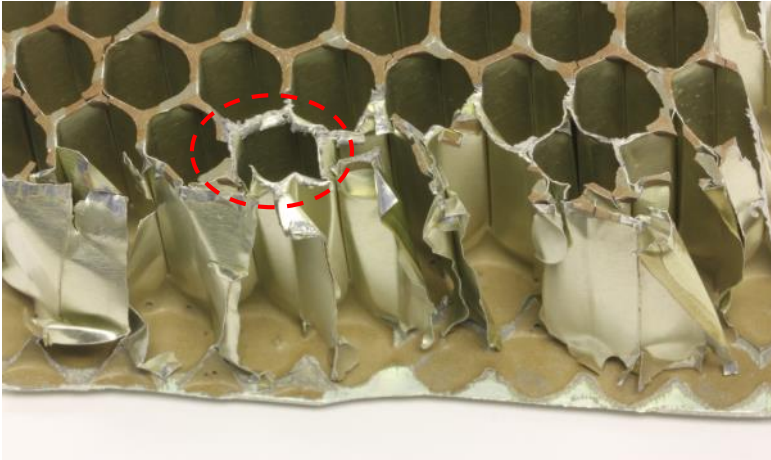


↓ FWD Skin Shear  
Radial Outboard

# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

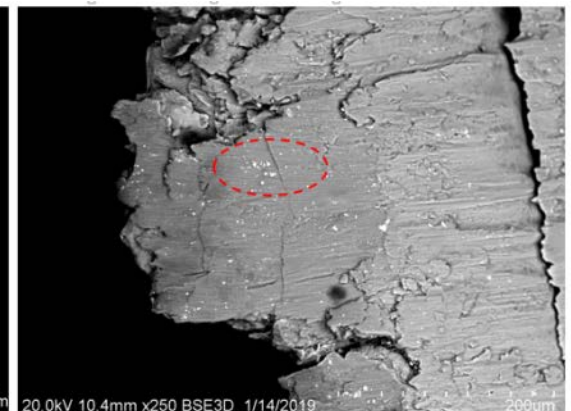
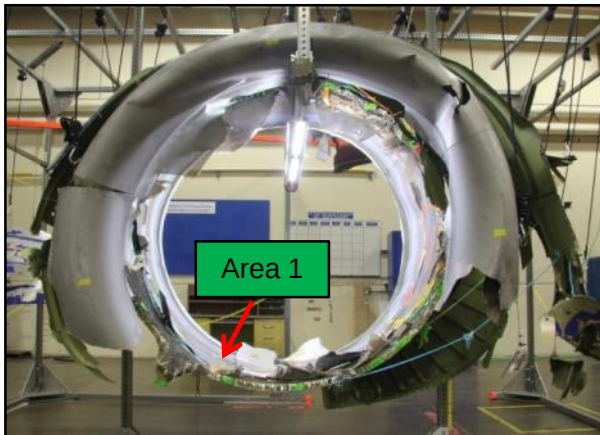
## AREA 1: TITANIUM ON CORE

5:00 – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 07.27 | 17.29 |
| OK      | 06.79 | 12.14 |
| MgK     | 01.70 | 02.00 |
| AlK     | 40.96 | 43.39 |
| SiK     | 00.12 | 00.12 |
| TiK     | 34.38 | 20.51 |
| VK      | 01.07 | 00.60 |
| FeK     | 07.71 | 03.95 |

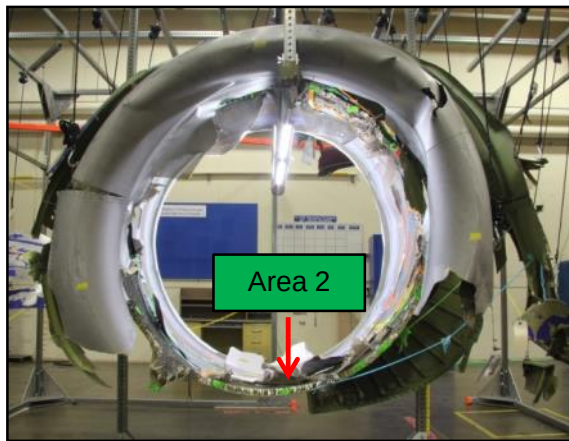
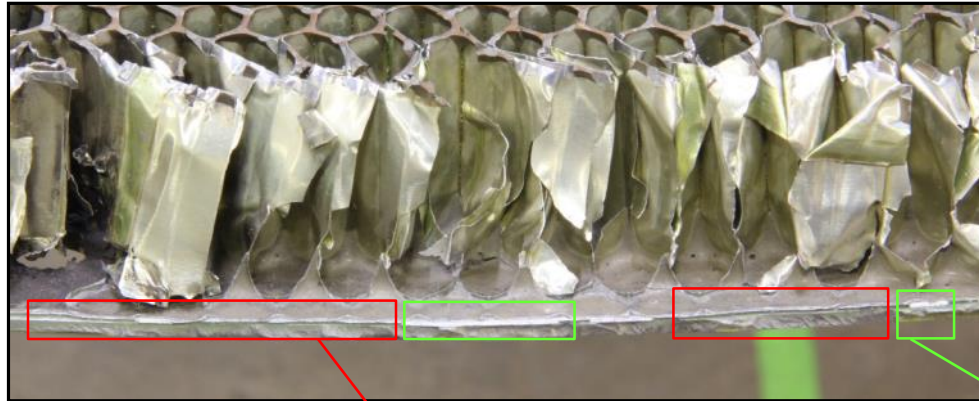
Titanium Alloy  
Particles Impacted  
and Imbedded



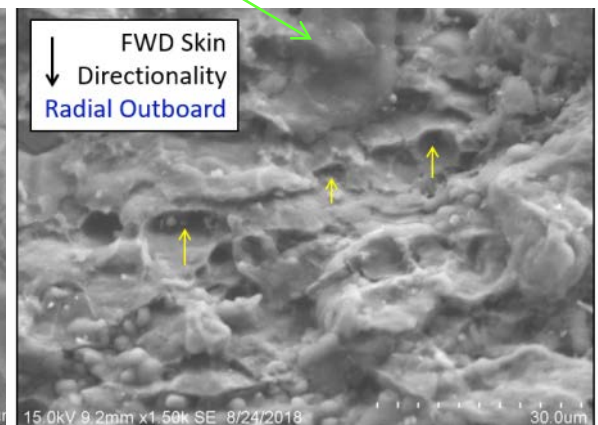
# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 2: BACK SKIN ALTERNATING SHEAR

- 6:00 Back-Skin – Alternating



FWD (Back Skin) Microvoid Coalescence



AFT (Back Skin) Microvoid Coalescence

# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

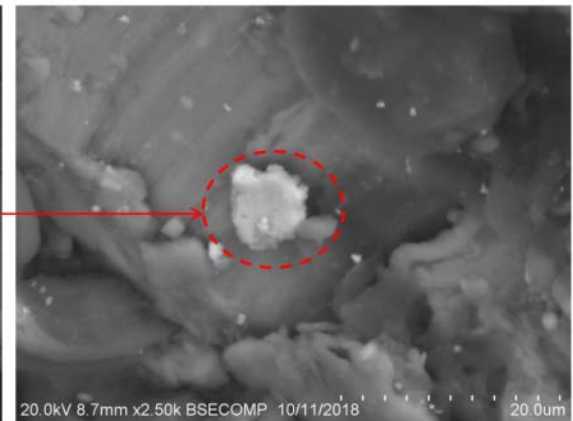
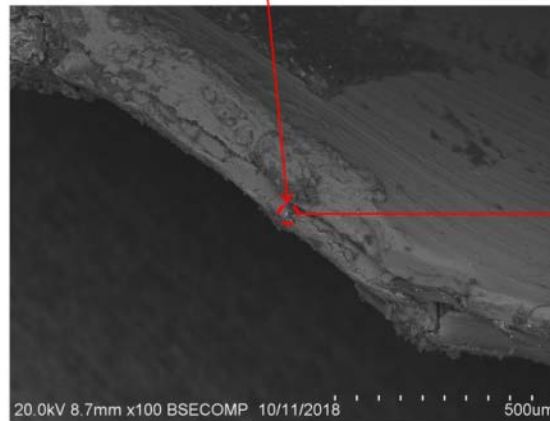
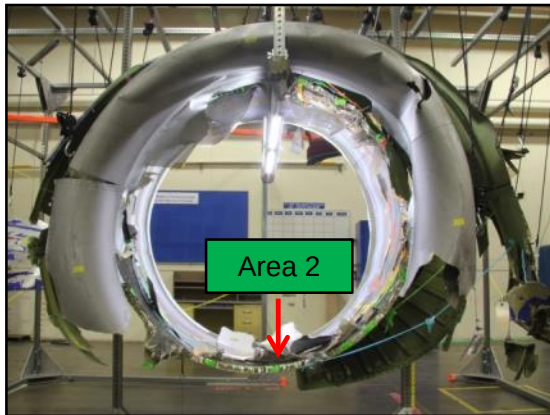
## AREA 2: TITANIUM ON FOLDED CORE

- 6:00 Folded Core – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 05.98 | 15.14 |
| AlK     | 08.61 | 12.92 |
| TiK     | 80.88 | 68.35 |
| UK      | 04.52 | 03.59 |

Titanium Alloy  
Particles Impacted  
and Imbedded



# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 61: TITANIUM ON FOLDED CORE, BACK SKIN ALTERNATING SHEAR

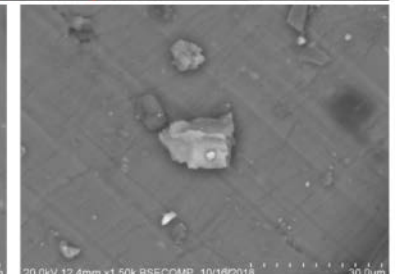
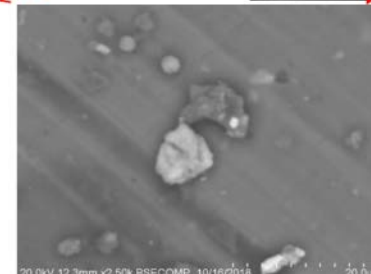
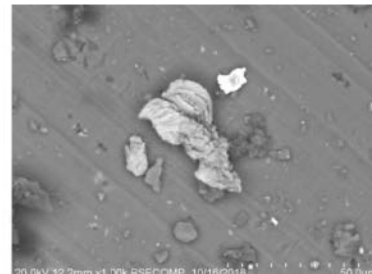
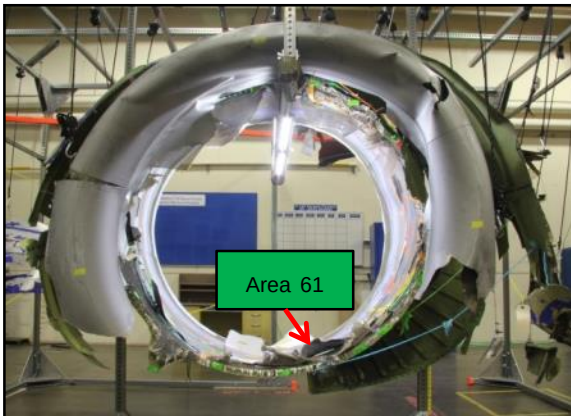
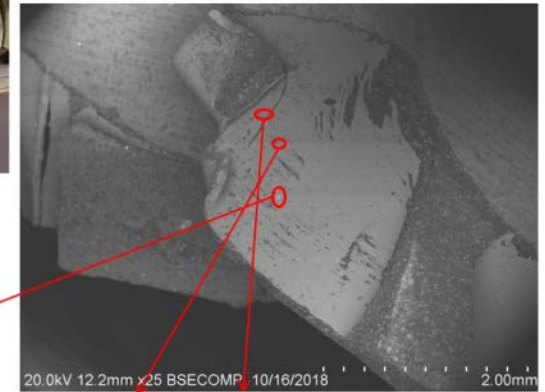
- 6:30 Folded Core – Ti-6Al-4V Particles



Back Skin Alt Shear

| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 17.18 | 36.62 |
| MgK     | 00.24 | 00.34 |
| AlK     | 07.29 | 09.21 |
| SiK     | 00.45 | 00.55 |
| PK      | 00.20 | 00.23 |
| TiK     | 72.22 | 51.43 |
| FK      | 02.42 | 01.62 |

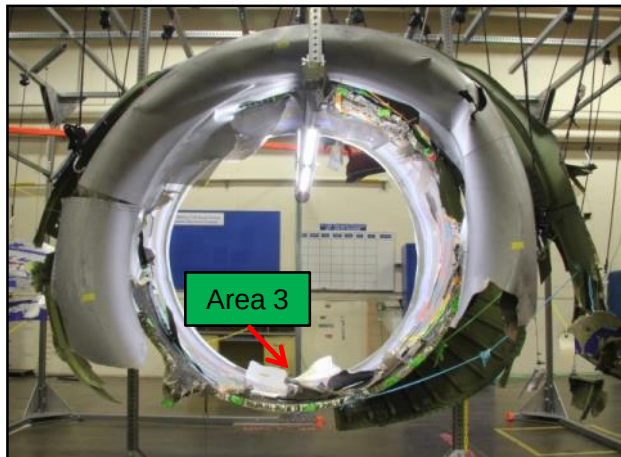
Titanium Alloy  
Particles Impacted  
and Imbedded



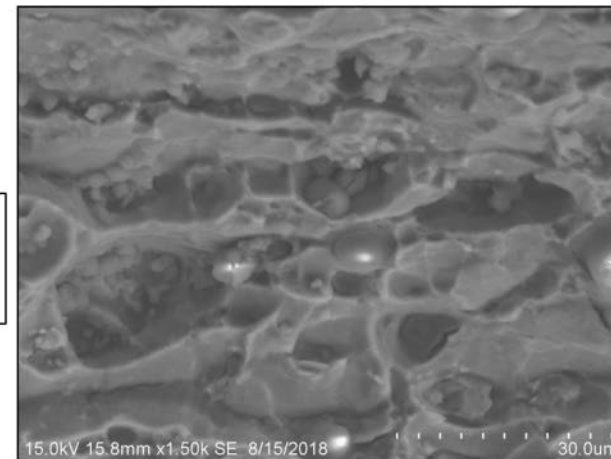
# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 3: AXIAL TENSILE OVERLOAD

- 7:00 Back-Skin – Tensile



FWD Skin  
Directionality  
Axial Tensile  
Overload

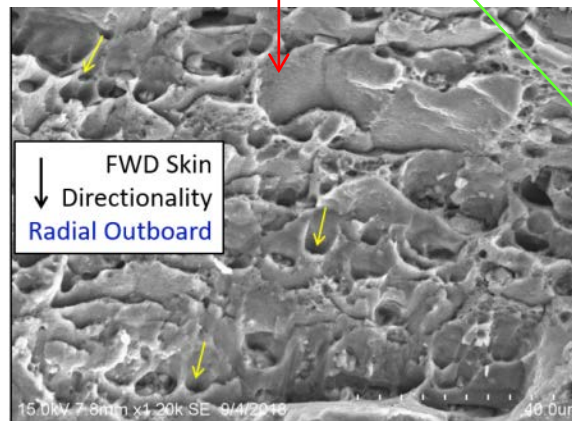
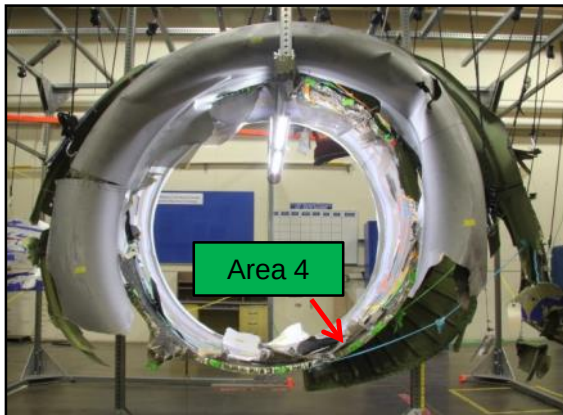
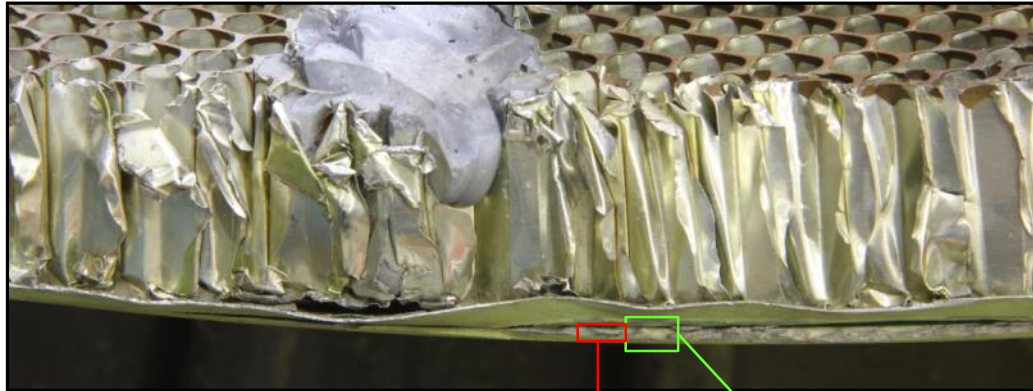


AFT (Back Skin) Microvoid Coalescence

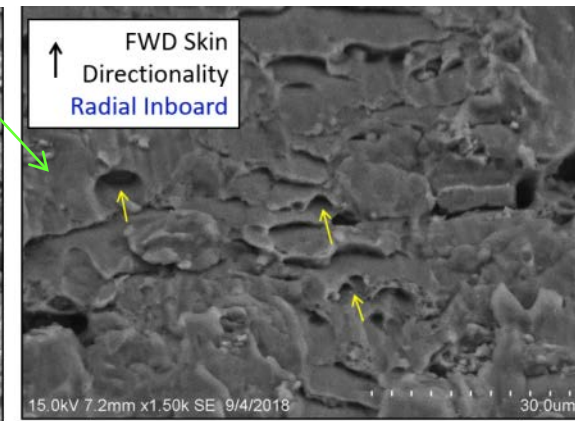
# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 4: BACK SKIN ALTERNATING SHEAR

- 7:30 Back-Skin – Alternating



FWD (Back Skin) Microvoid Coalescence

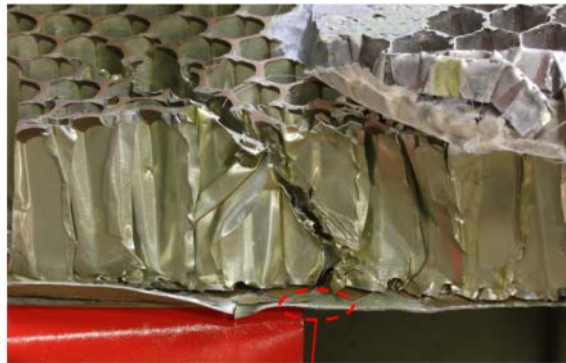
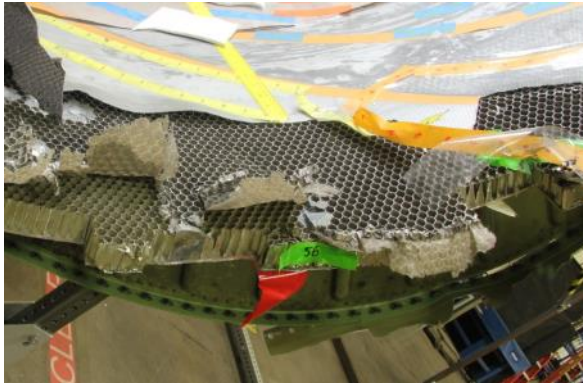


FWD (Back Skin) Microvoid Coalescence

# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

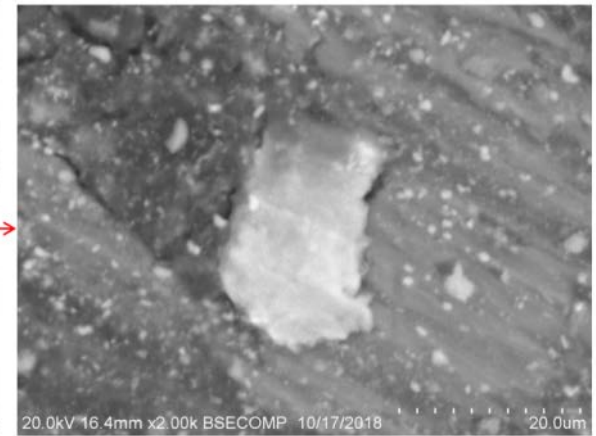
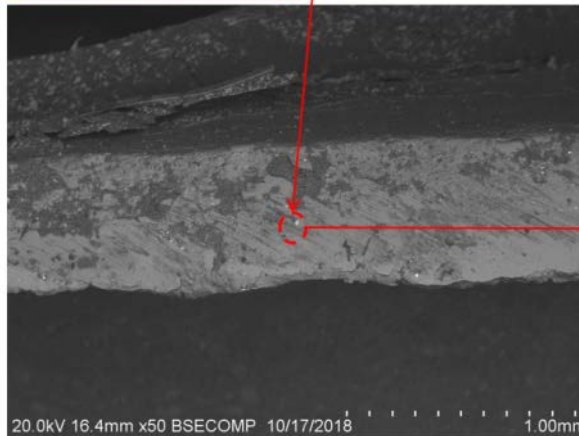
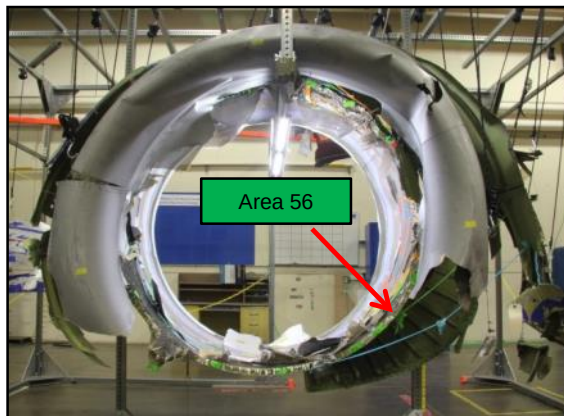
## AREA 56: TITANIUM ON BACK SKIN

- 7:30 Back Skin – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| AlK     | 28.03 | 41.20 |
| TiK     | 65.51 | 54.23 |
| VK      | 02.34 | 01.82 |
| CrK     | 00.27 | 00.21 |
| FeK     | 01.56 | 01.11 |
| CuK     | 02.29 | 01.43 |

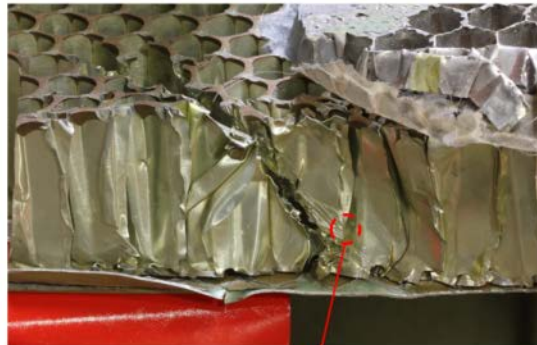
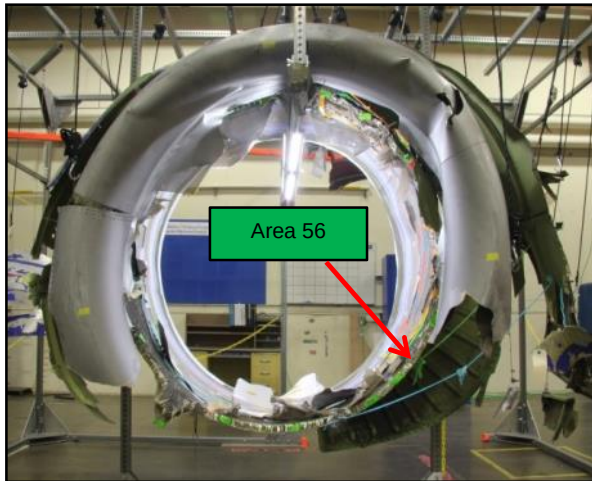
Titanium Alloy Particles  
Impacted and Imbedded



# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

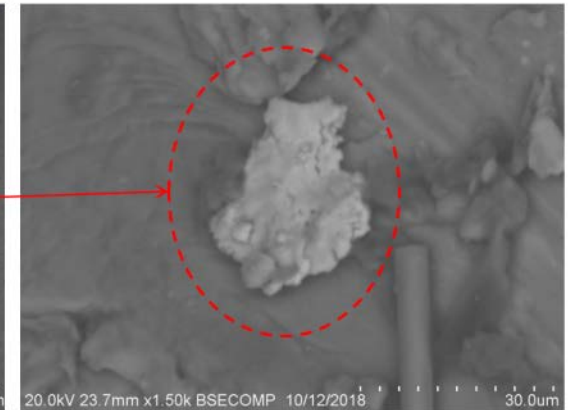
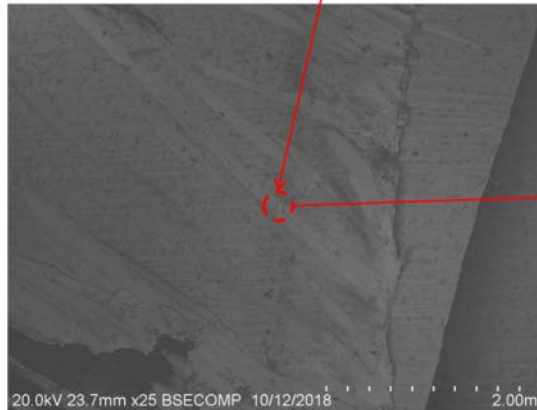
## AREA 56: TITANIUM ON FOLDED CORE

- 7:30 Folded Core – Ti-6Al-4V Particles



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 24.08 | 54.01 |
| AlK     | 07.28 | 07.27 |
| TiK     | 65.67 | 36.93 |
| IK      | 02.59 | 01.37 |

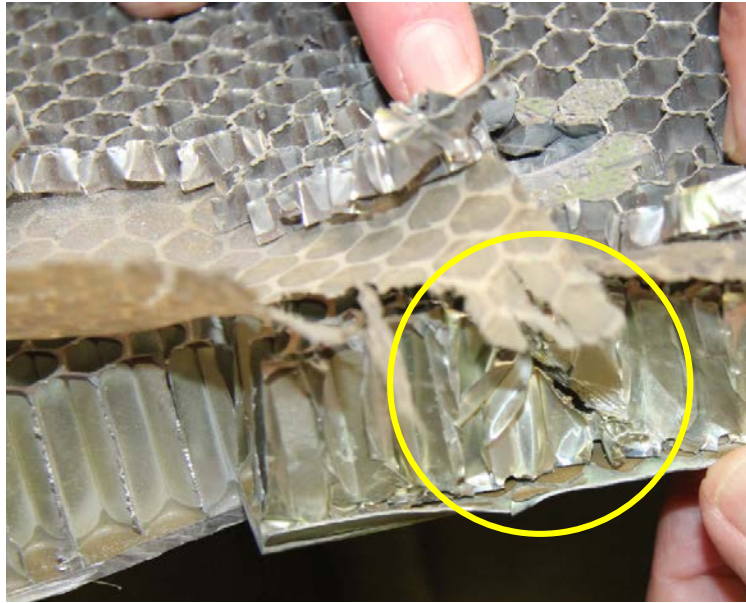
Titanium Alloy  
Particles Impacted  
and Imbedded



# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 56: TITANIUM ON FOLDED CORE

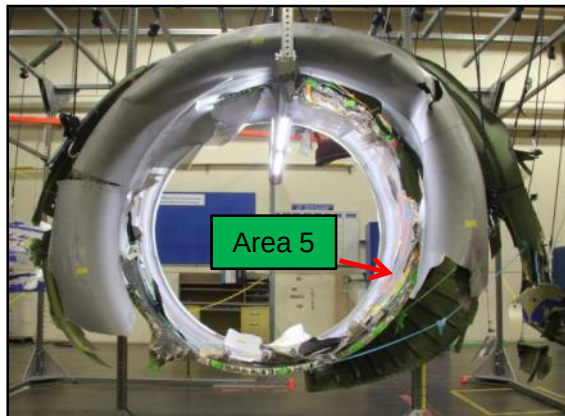
- 7:30 Core Slice



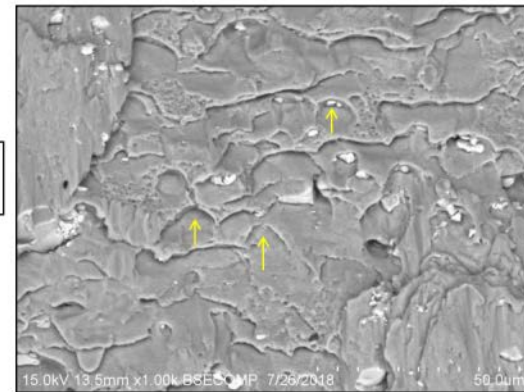
# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 5: BACK SKIN RADIAL OUTBOARD SHEAR

- 8:00 Back-Skin – Radial Outboard



↓ FWD Skin Shear  
↓ Radial Outboard

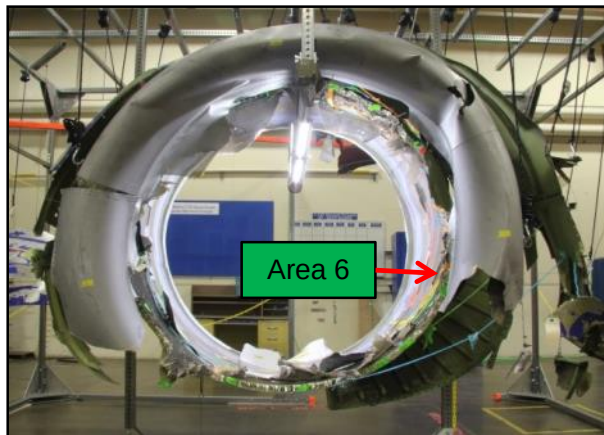


AFT (Back Skin) Microvoid Coalescence

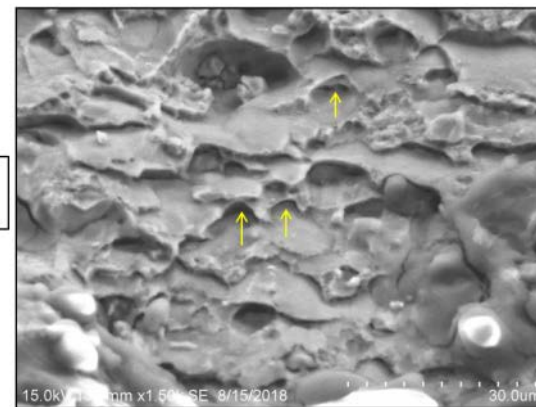
# ADDITIONAL FAN BLADE FRAGMENTS METALLURGICAL FINDINGS

## AREA 6: BACK SKIN RADIAL OUTBOARD SHEAR

- 8:30 Back-Skin – Radial Outboard



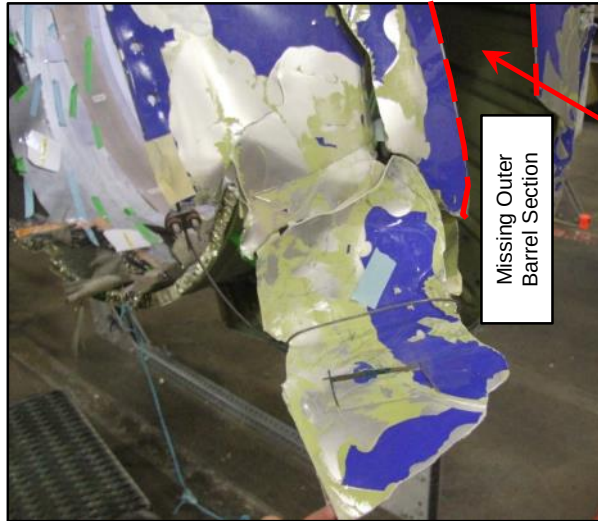
FWD Skin Shear  
Radial Outboard



AFT (Back Skin) Microvoid Coalescence

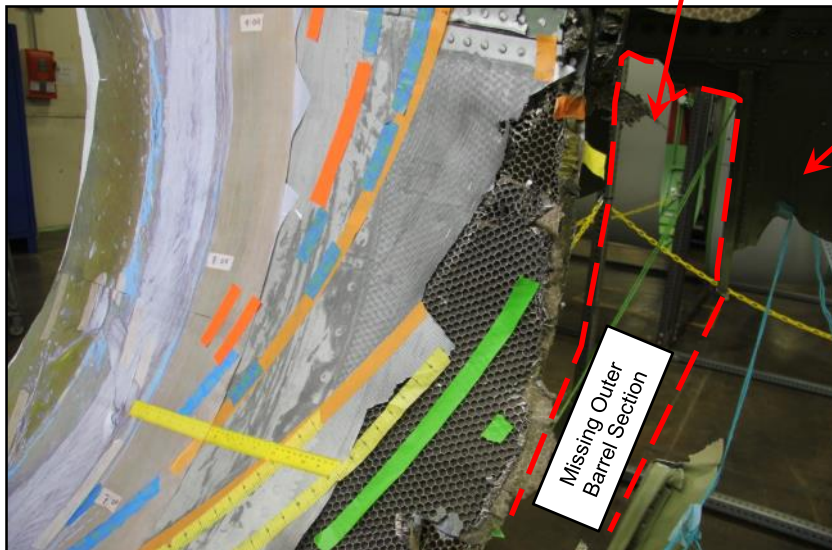
# ADDITIONAL FAN FRAGMENTS DAMAGE

## ADDITIONAL FAN BLADE FRAGMENTS IMPACT OUTER BARREL



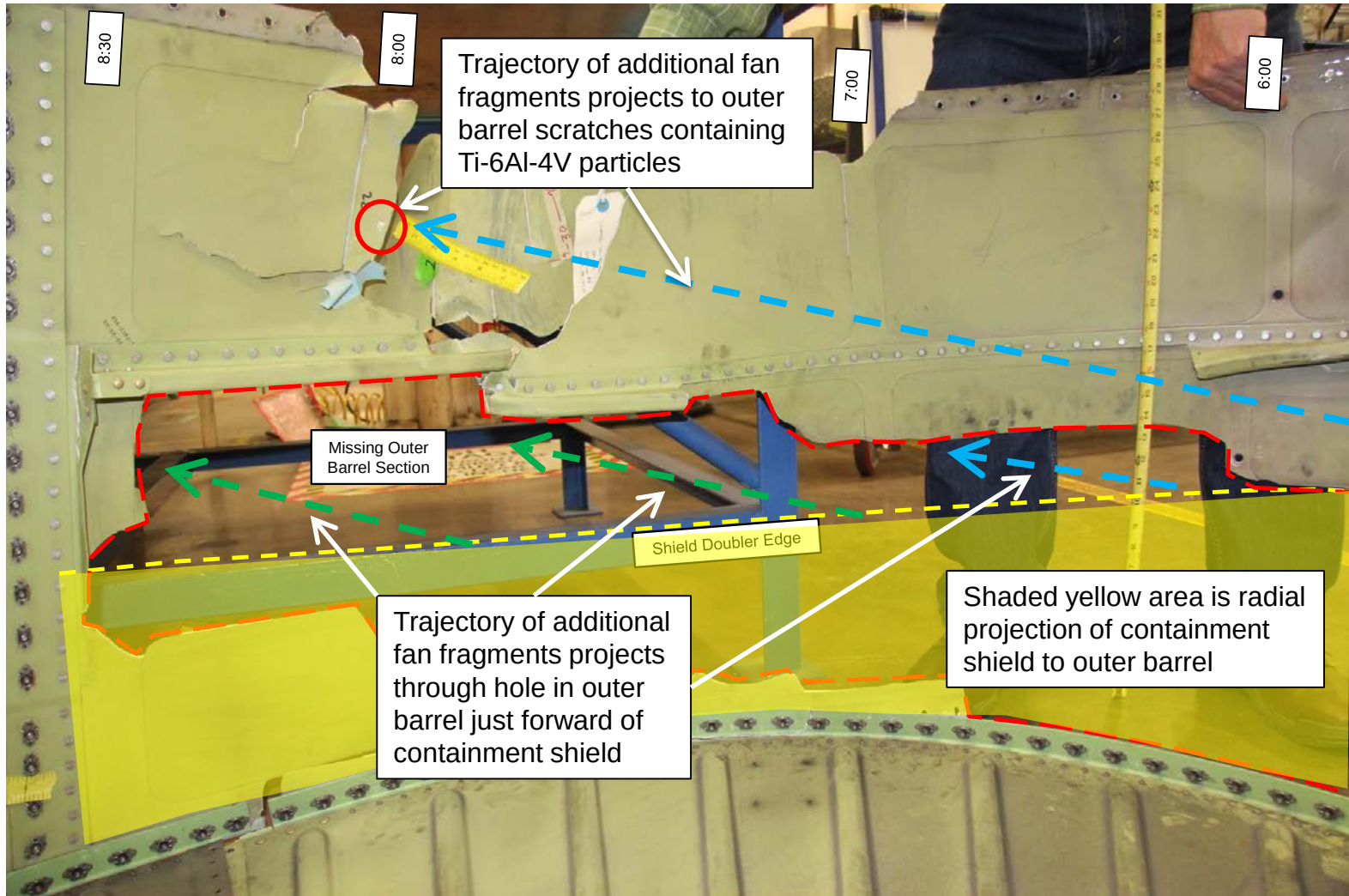
Trajectory of additional fan fragments projects through hole in outer barrel just forward of containment shield

Trajectory of additional fan fragments projects to outer barrel scratches containing Ti-6Al-4V particles



# ADDITIONAL FAN FRAGMENTS DAMAGE

## ADDITIONAL FAN BLADE FRAGMENTS IMPACT OUTER BARREL



---

# POTENTIAL ENGINE PLATFORM TRAJECTORIES AND INLET DAMAGE

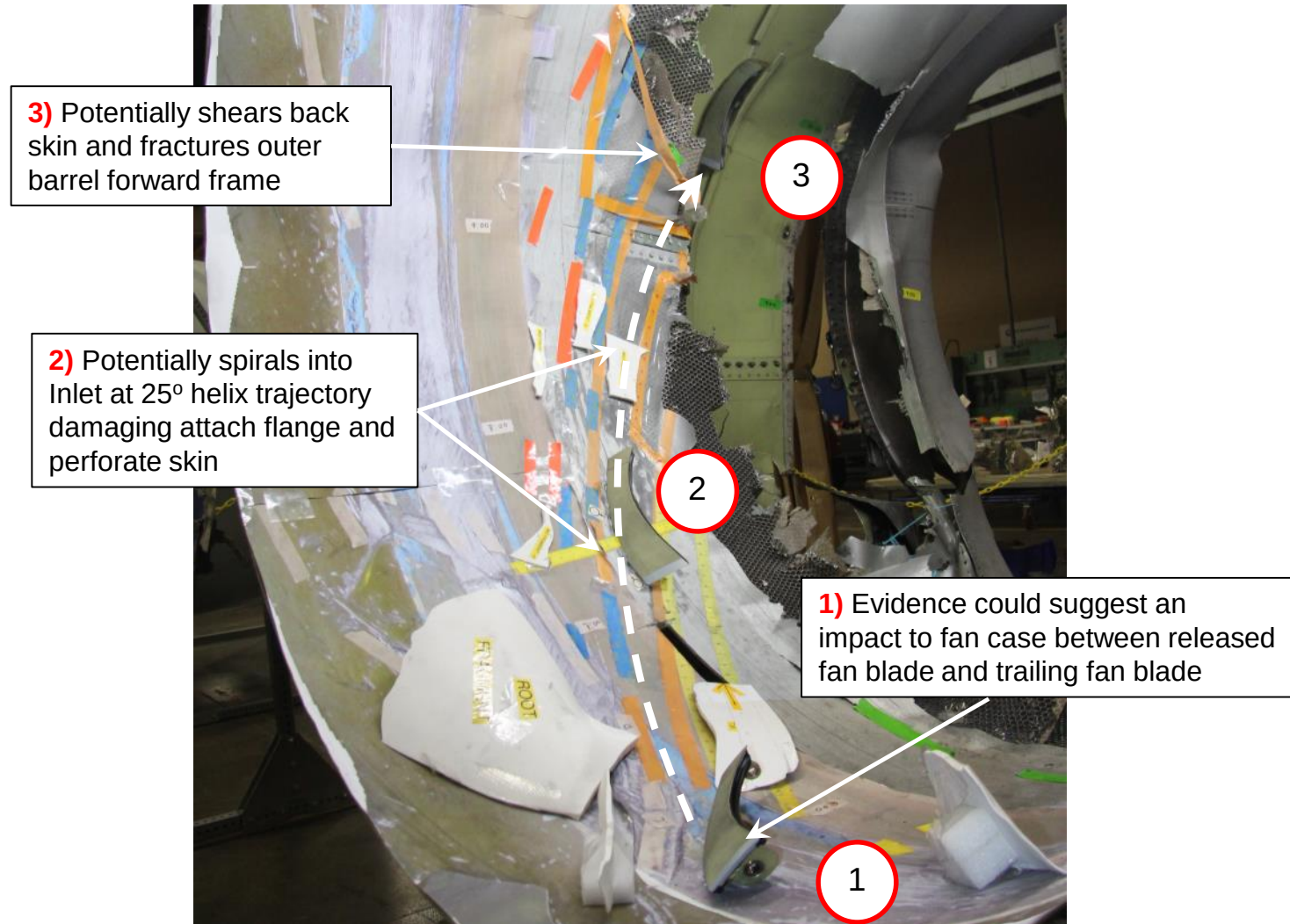
# POTENTIAL INLET DAMAGE DUE TO RELEASED ENGINE PLATFORM

## SUMMARY

- Collins has identified Inlet damage, potentially associated with the released engine platform, based on fan case and Inlet trajectory indications and observed evidence:
  - Potential perforate skin damage zone is defined as a 90° arc with its axial length beginning at the aft end of the acoustic core and ending 2.0" forward of containment shield
  - Potential back skin shear damage zone are defined as a 45° arc that is 1.0" wide and located just forward of the containment shield

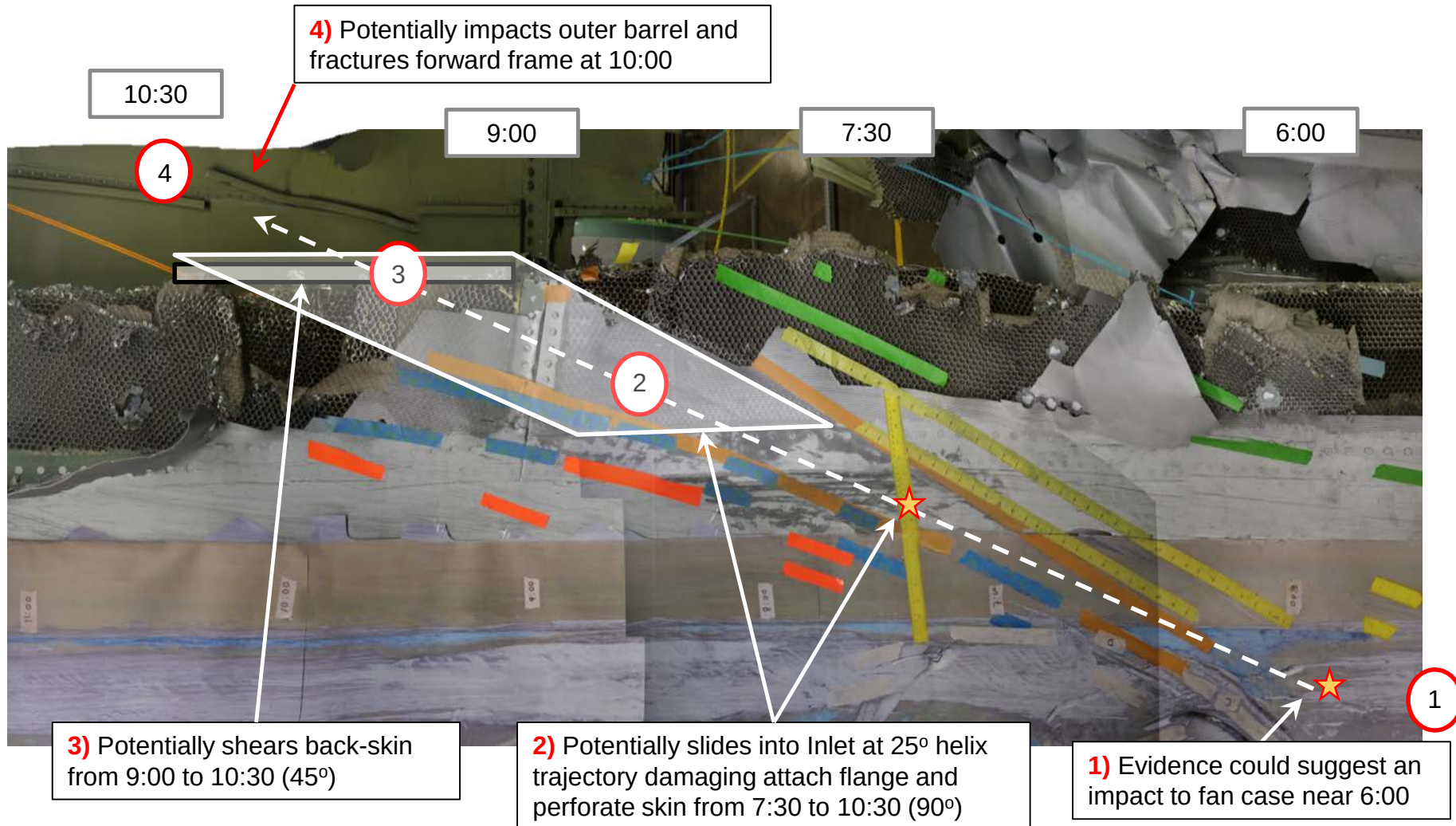
# POTENTIAL PLATFORM TRAJECTORY

**PLATFORM POTENTIALLY DAMAGES INLET ATTACH FLANGE, PERFORATE SKIN, BACK-SKIN AND OUTER BARREL**



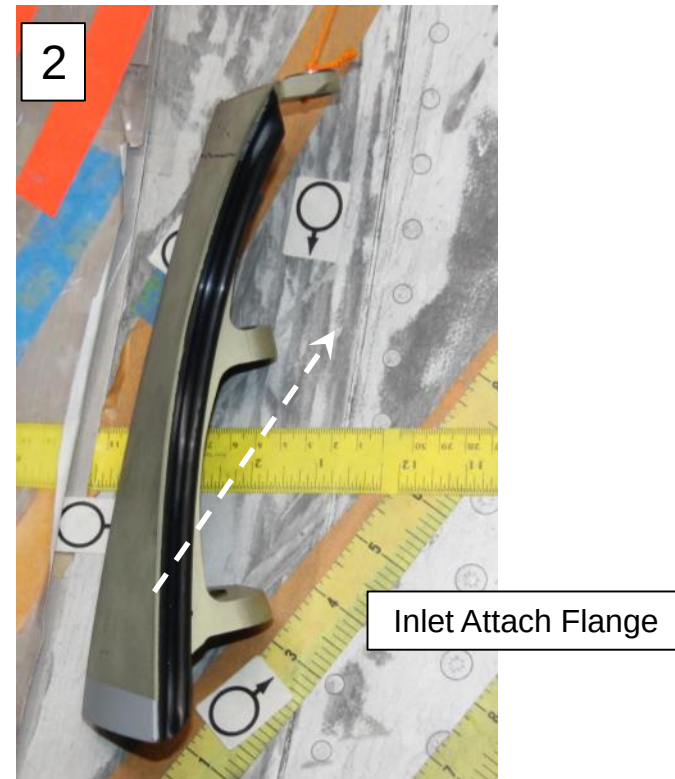
# POTENTIAL PLATFORM TRAJECTORY

PLATFORM POTENTIALLY DAMAGES INLET ATTACH FLANGE, PERFORATE SKIN, BACK-SKIN AND OUTER BARREL



# POTENTIAL PLATFORM TRAJECTORY

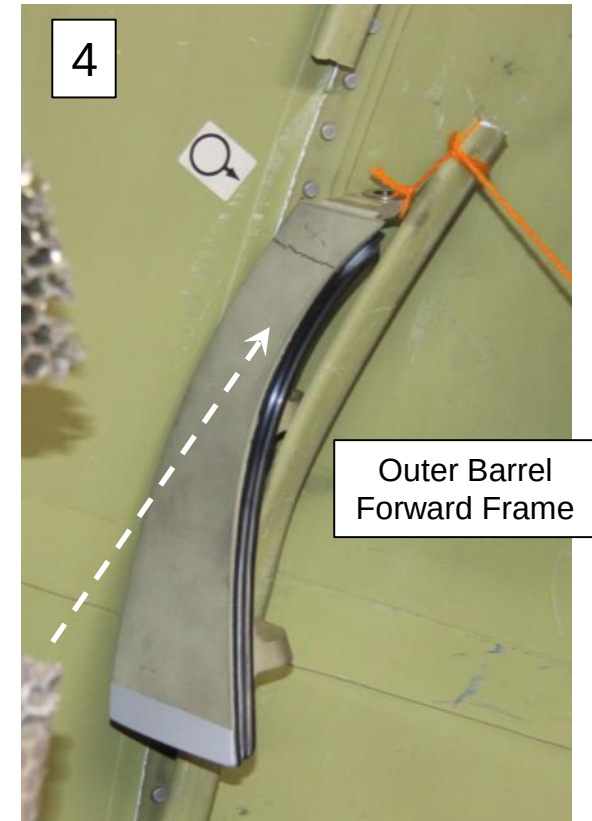
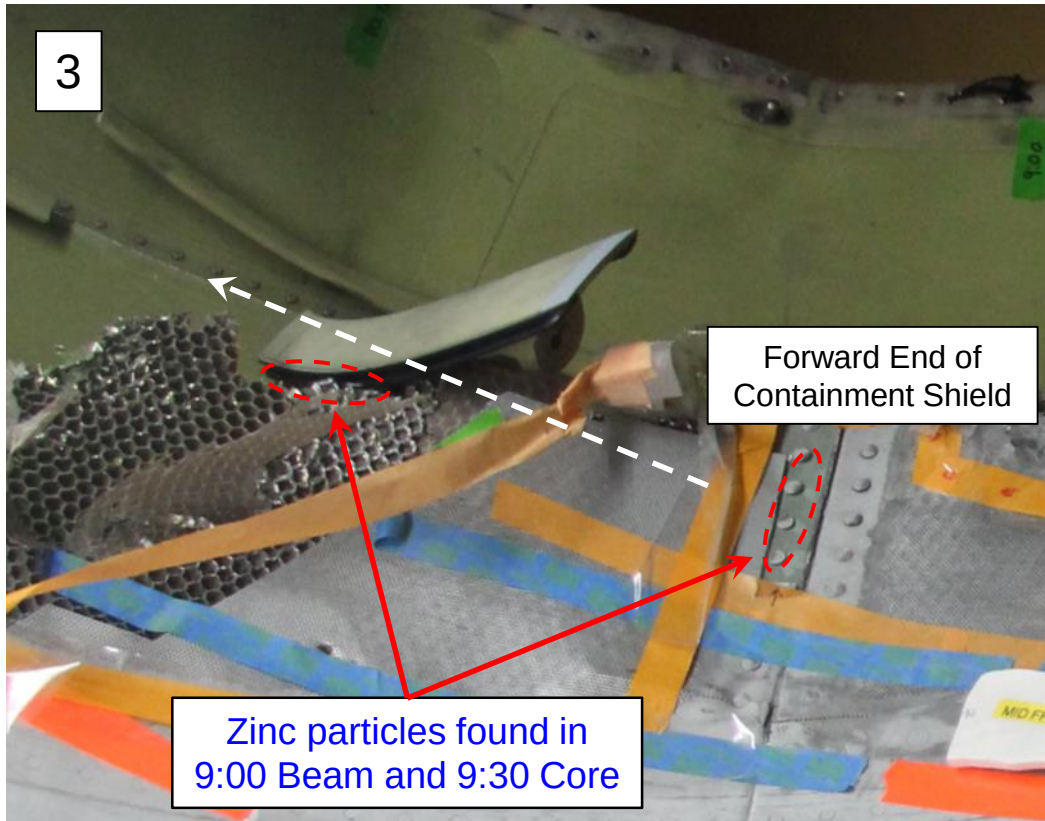
PLATFORM POTENTIALLY DAMAGES FAN CASE AND INLET ATTACH FLANGE



- 1) Scratches and gouges in fan case at 6:00 potentially align with platform edge and tangs
- 2) Scratches and gouges in Inlet attach flange at 7:30 potentially align with platform edge and tangs

# POTENTIAL PLATFORM TRAJECTORY

## PLATFORM POTENTIAL DAMAGES OUTER BARREL FORWARD FRAME

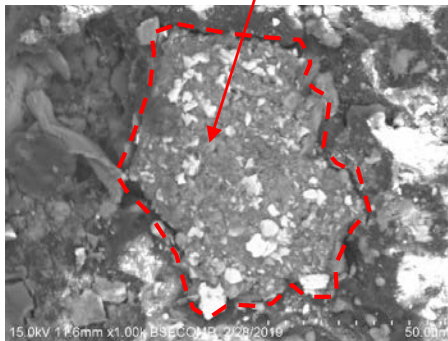
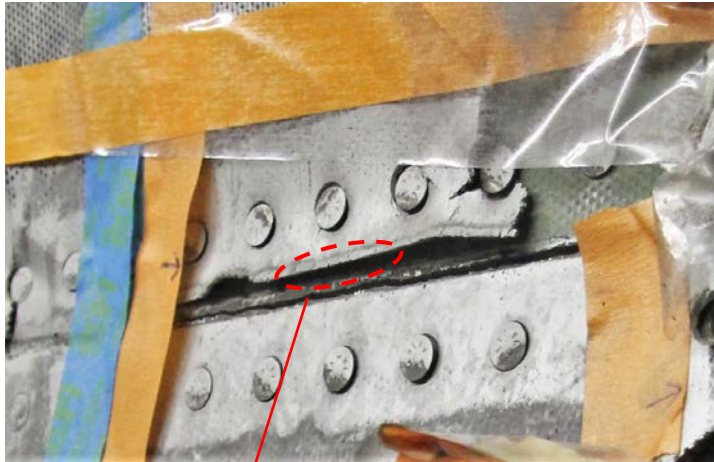


- 3) Potential trajectory projects through sheared Back Skin from 9:00 to 10:30 at forward end of Shield
- 4) Potential trajectory projects to fractured frame and scratches on Outer Barrel at 10:00

# POTENTIAL PLATFORM MATERIAL

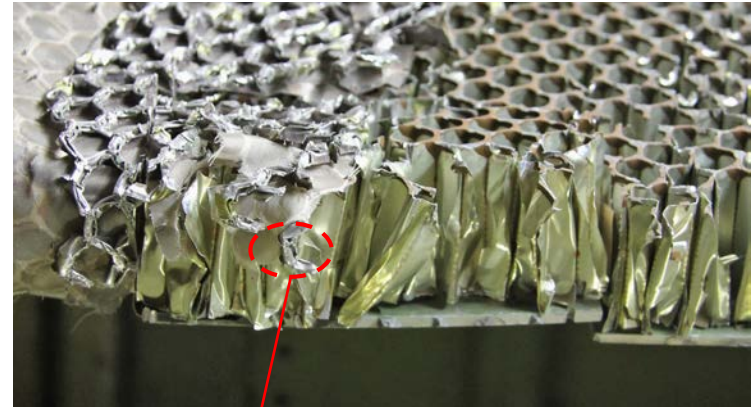
## ZINC PARTICLES FOUND IN 9:00 BEAM AND ACOUSTIC CORE

Area 64 (Beam Splice) – Position: 9:00



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 26.19 | 45.65 |
| OK      | 20.02 | 26.20 |
| FK      | 00.48 | 00.53 |
| MgK     | 00.68 | 00.58 |
| AlK     | 06.76 | 05.24 |
| SiK     | 02.22 | 01.65 |
| PK      | 07.94 | 05.36 |
| MoL     | 10.68 | 02.33 |
| SK      | 07.82 | 05.11 |
| ClK     | 00.31 | 00.19 |
| KK      | 00.18 | 00.10 |
| CaK     | 07.02 | 03.67 |
| TiK     | 01.67 | 00.73 |
| FeK     | 00.70 | 00.26 |
| NiK     | 01.31 | 00.47 |
| ZnK     | 06.04 | 01.93 |

Area 8 (Core) – Position: 9:30



| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 27.23 | 47.70 |
| OK      | 17.32 | 22.78 |
| NaK     | 00.32 | 00.29 |
| MgK     | 00.74 | 00.64 |
| AlK     | 18.27 | 14.25 |
| SiK     | 00.94 | 00.71 |
| PK      | 00.22 | 00.15 |
| MoL     | 00.24 | 00.05 |
| SK      | 00.60 | 00.40 |
| ClK     | 00.67 | 00.40 |
| KK      | 00.19 | 00.10 |
| CaK     | 00.73 | 00.38 |
| FeK     | 30.35 | 11.44 |
| ZnK     | 02.18 | 00.70 |

Zinc particles embedded

# CONCLUSIONS

- The Inlet damage likely caused by fan blade fragments was established based on Fan Case and Inlet trajectory indications, metallurgical data and observed evidence:
  - Fan blade fragments Inlet trajectories exceeded design specifications
  - Fan blade fragments damaged the inner barrel forward of the containment shield where it is critical to maintain structural continuity

---

# SUPPLEMENTAL SLIDES

# NACELLE PARTS DEPARTING A/C

# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

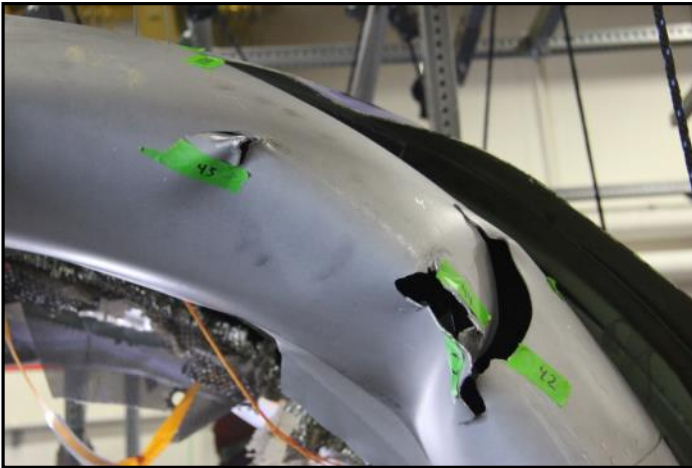
- D-Duct – Inlet Skin Embedded in Wing Top Surface



# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

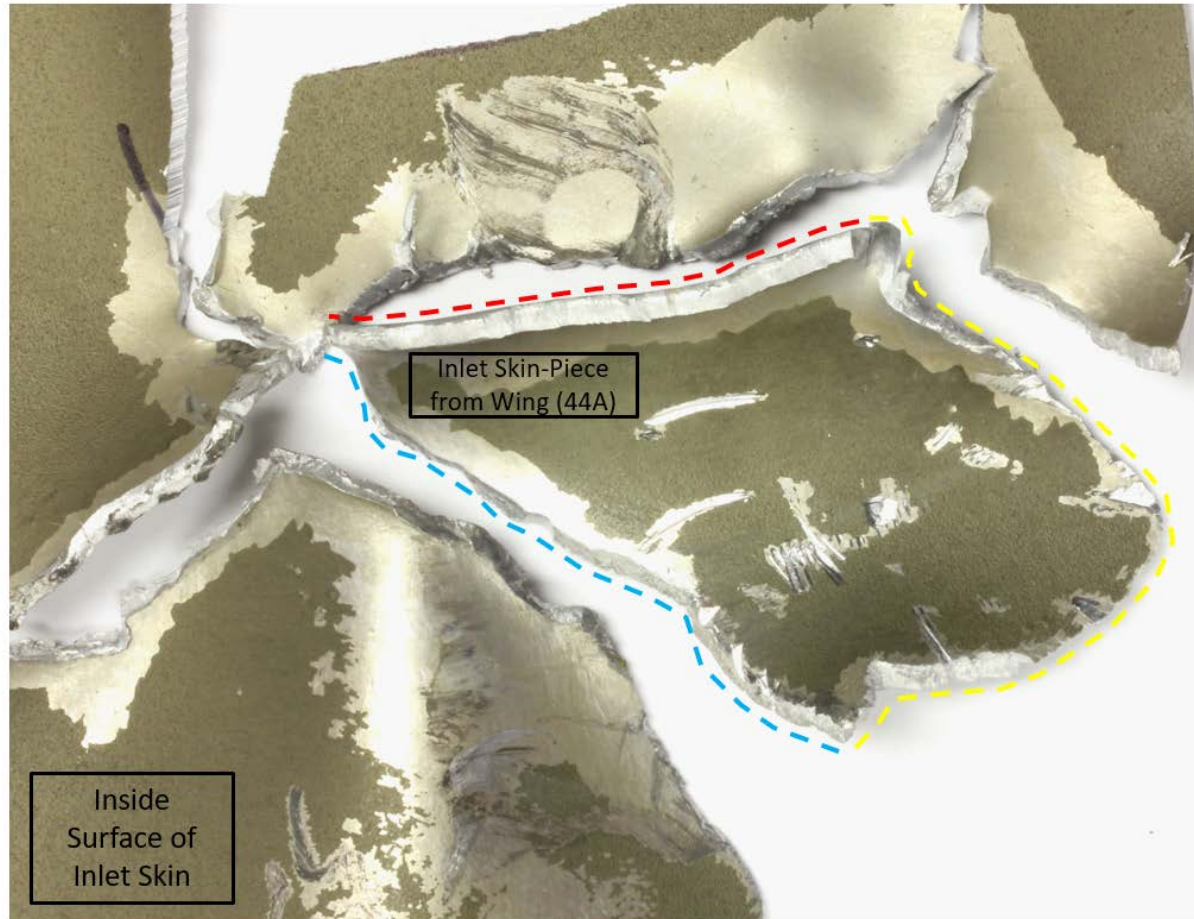
- D-Duct – Inlet Skin (Flow Surface)



# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

- D-Duct – Inlet Skin (Inside Surface )



# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

- D-Duct – Inlet Skin Flow Surface 11:00



Inlet Skin



Area 45

# SWA 1380 METALLURGICAL FINDINGS

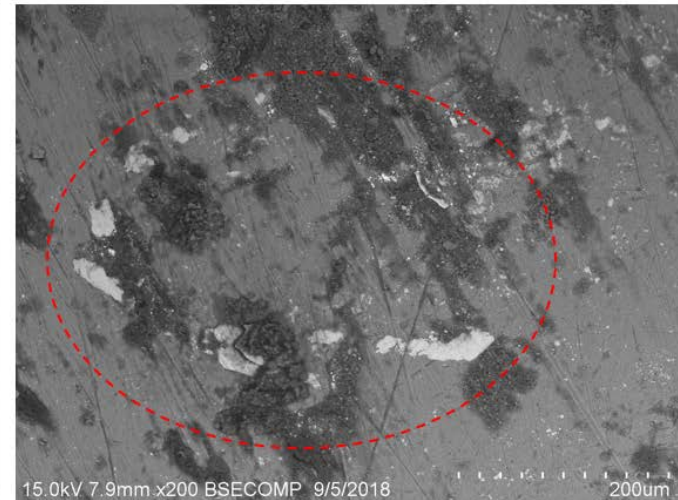
## NACELLE PARTS DEPARTING A/C

- D-Duct – Inlet Skin Flow Surface – (Piccolo Tube (Cp Ti))



| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 18.88 | 39.44 |
| NaK     | 02.84 | 04.14 |
| MgK     | 00.24 | 00.33 |
| AlK     | 03.07 | 03.80 |
| SiK     | 00.65 | 00.78 |
| YL      | 00.34 | 00.13 |
| MoL     | 00.71 | 00.25 |
| TiK     | 73.26 | 51.14 |
| TK      | 00.00 | 00.00 |

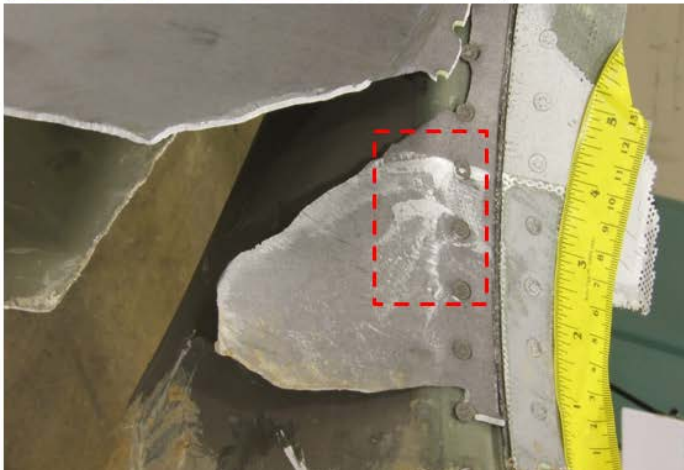
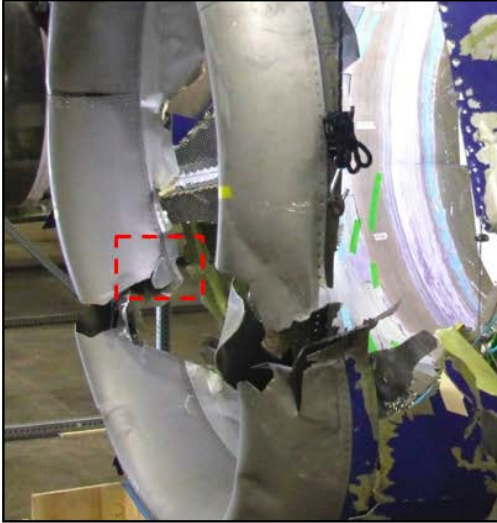
CP Titanium Particles  
Impacted and Imbedded



# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

- D-Duct – Inlet Skin 3:30 (9 O'clock Splice Plate Contact)



# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

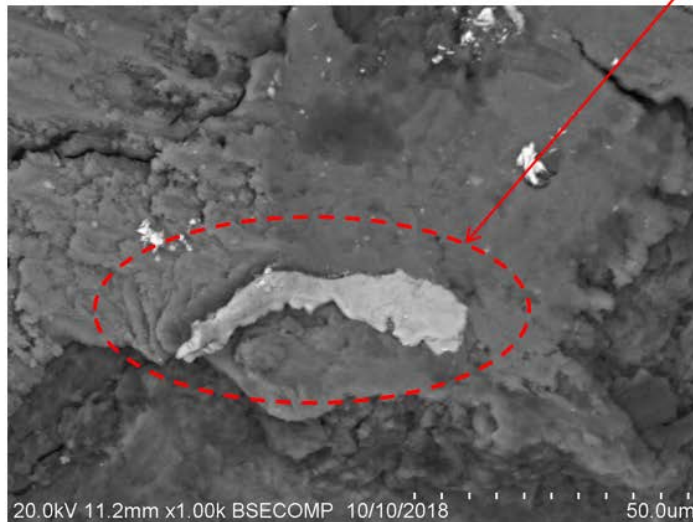
- D-Duct – Inlet Skin 3:30 (9 O'clock Splice Plate)



Titanium Alloy Particles  
Impacted and Imbedded

| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 07.41 | 18.15 |
| AlK     | 09.03 | 13.12 |
| SiK     | 00.81 | 01.13 |
| TiK     | 80.09 | 65.55 |
| VK      | 02.67 | 02.05 |

| Element | Wt%   | At%   |
|---------|-------|-------|
| CK      | 04.03 | 09.44 |
| OK      | 28.28 | 49.80 |
| AlK     | 02.13 | 02.22 |
| TiK     | 64.63 | 38.02 |
| VK      | 00.94 | 00.52 |



# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

- D-Duct – Inlet Skin 4:00 (Wing Slat Material)



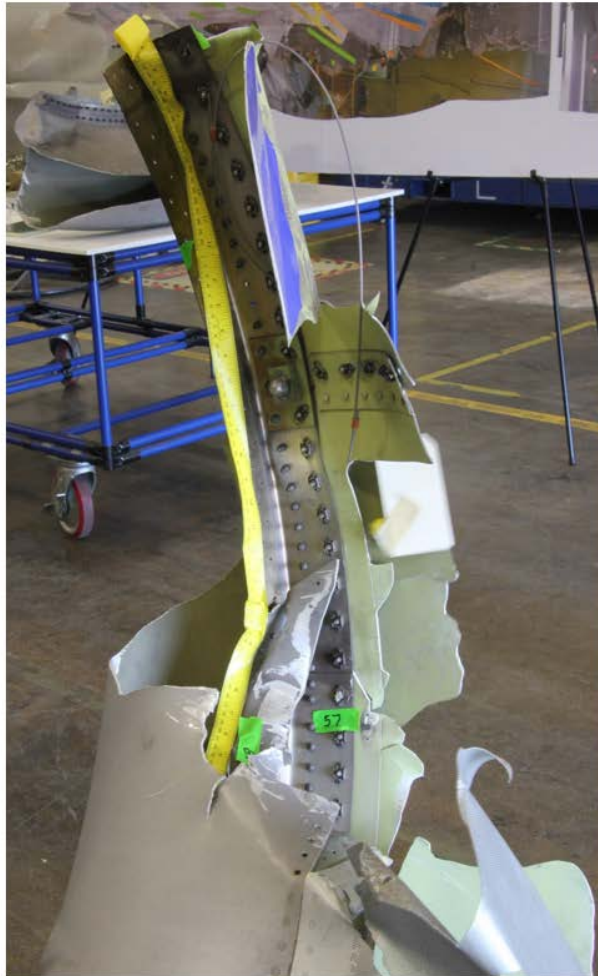
| Element    | Wt%   | At%   |
|------------|-------|-------|
| <i>MgK</i> | 02.80 | 03.25 |
| <i>AlK</i> | 89.01 | 93.19 |
| <i>CuK</i> | 01.95 | 00.87 |
| <i>ZnK</i> | 06.24 | 02.70 |

Al7075 Material Impacted  
and Imbedded

# SWA 1380 METALLURGICAL FINDINGS

## NACELLE PARTS DEPARTING A/C

- D-Duct – Inlet Skin 4:00 (Wing Slat Material)



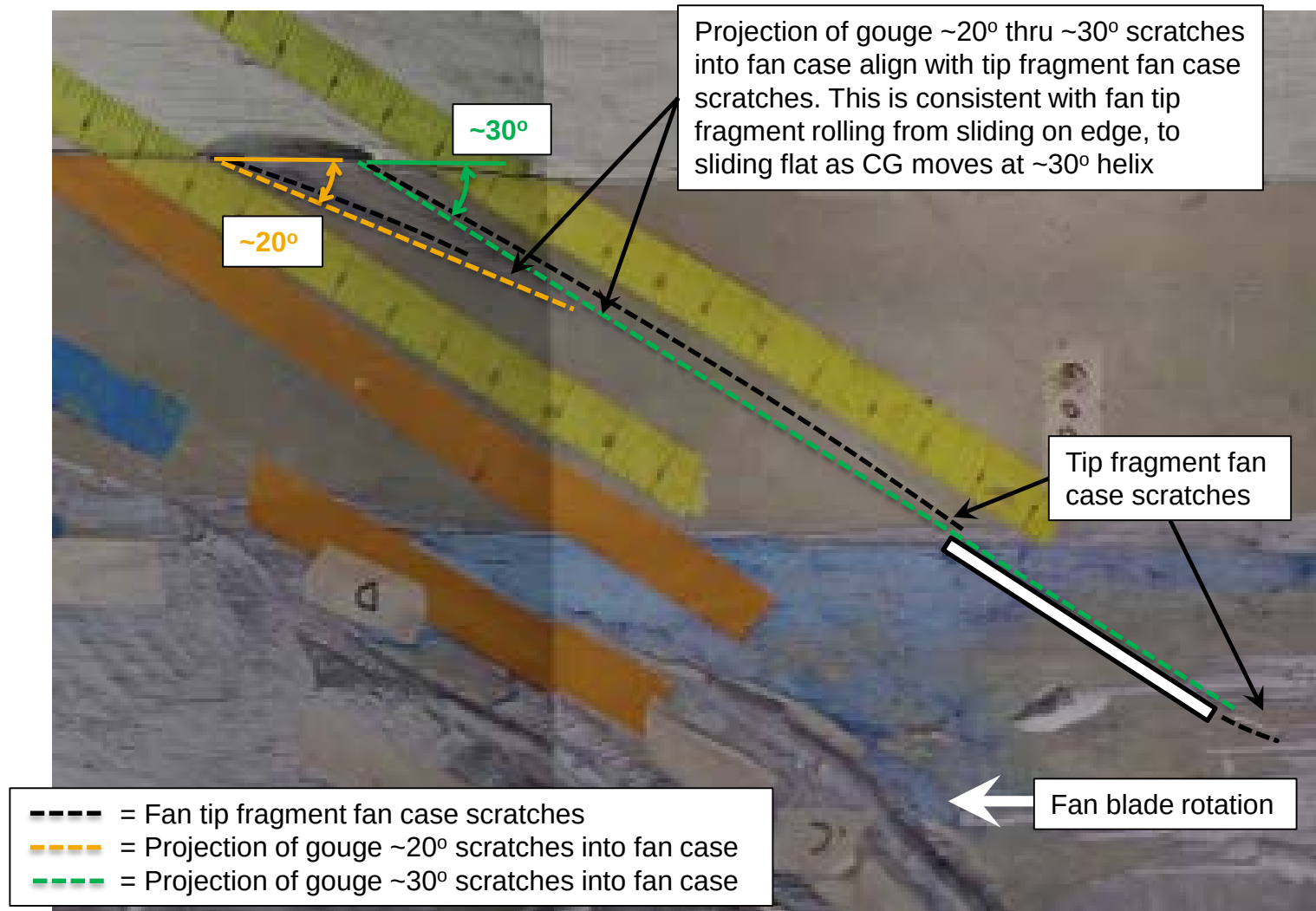
| Element | Wt%   | At%   |
|---------|-------|-------|
| OK      | 02.57 | 04.42 |
| MgK     | 02.86 | 03.23 |
| AlK     | 87.17 | 88.96 |
| TiK     | 01.63 | 00.94 |
| CuK     | 01.28 | 00.56 |
| ZnK     | 04.49 | 01.89 |

Al7075 Material  
Impacted and  
Imbedded

# TIP TRAJECTORY DETAILS

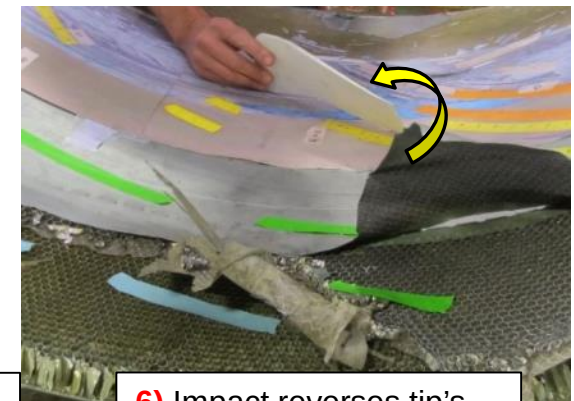
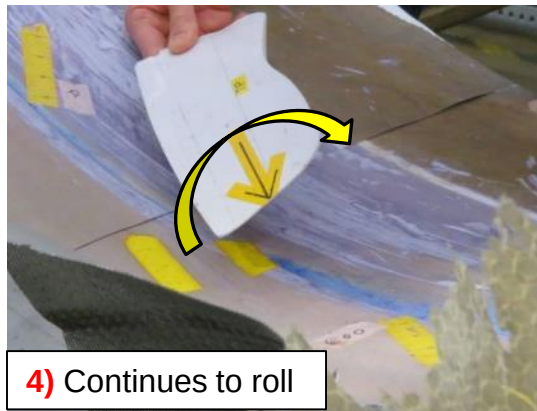
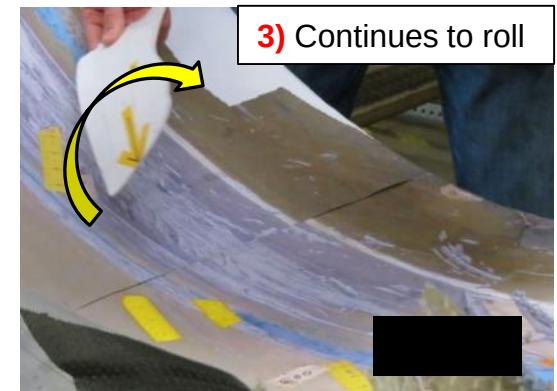
# FAN BLADE TIP FRAGMENT TRAJECTORY

## TIP FRAGMENT CAUSED SCRATCHES LEADING INTO ATTACH RING GOUGE



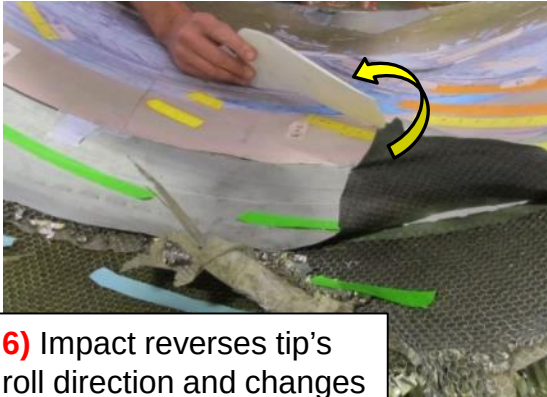
# TIP FRAGMENT TRAJECTORY

TIP FRAGMENT FRACTURED-EDGE IMPACT CHANGES ITS TRAJECTORY



# TIP FRAGMENT TRAJECTORY

## TIP FRAGMENT DELAMINATES PERFORATE SKIN



**6)** Impact reverses tip's roll direction and changes its trajectory to  $\sim 30^\circ$  helix



**7)** Tip rolls in reversed direction while its fractured-edge creates fan case scratches that begin with  $\sim 30^\circ$  helix

**8)** Tip's fractured-edge creates gouge scratches that change from  $\sim 30^\circ$  to  $\sim 20^\circ$  helix while tip rolls from sliding on fractured edge to sliding flat



**9)** Tip slides flat at  $\sim 30^\circ$  helix



**10)** Tip slides at  $\sim 30^\circ$  helix delaminating perforate skin



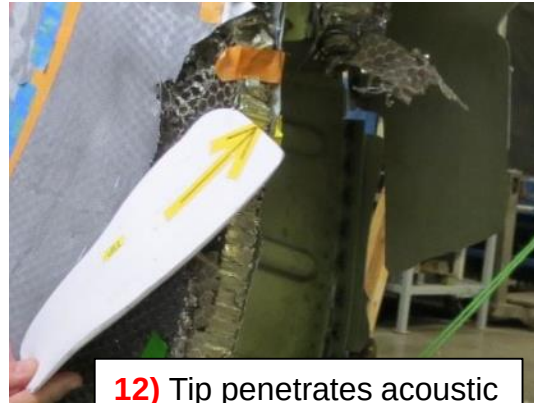
**11)** Tip slides at  $\sim 30^\circ$  helix delaminating perforate skin

# TIP FRAGMENT TRAJECTORY

TIP FRAGMENT DELAMINATES PERFORATE SKIN AND IMPACTS 9:00 BEAM



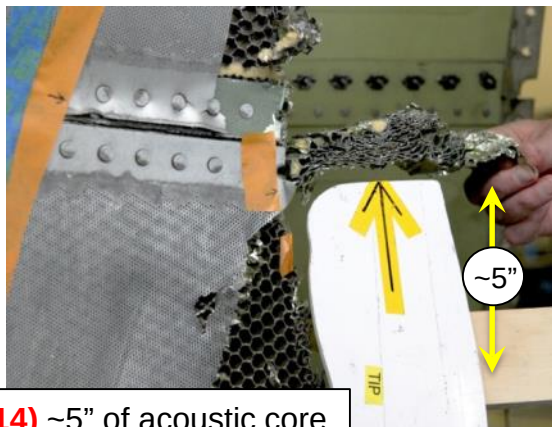
**11)** Tip slides at  $\sim 30^\circ$  helix delaminating perforate skin



**12)** Tip penetrates acoustic core and begins to in-plane collapse acoustic core



**13)** Tip collapses acoustic core and impacts 9:00 beam



**14)**  $\sim 5"$  of acoustic core in-plane collapsed



**15)** Collapsed acoustic core mates with 9:00 beam



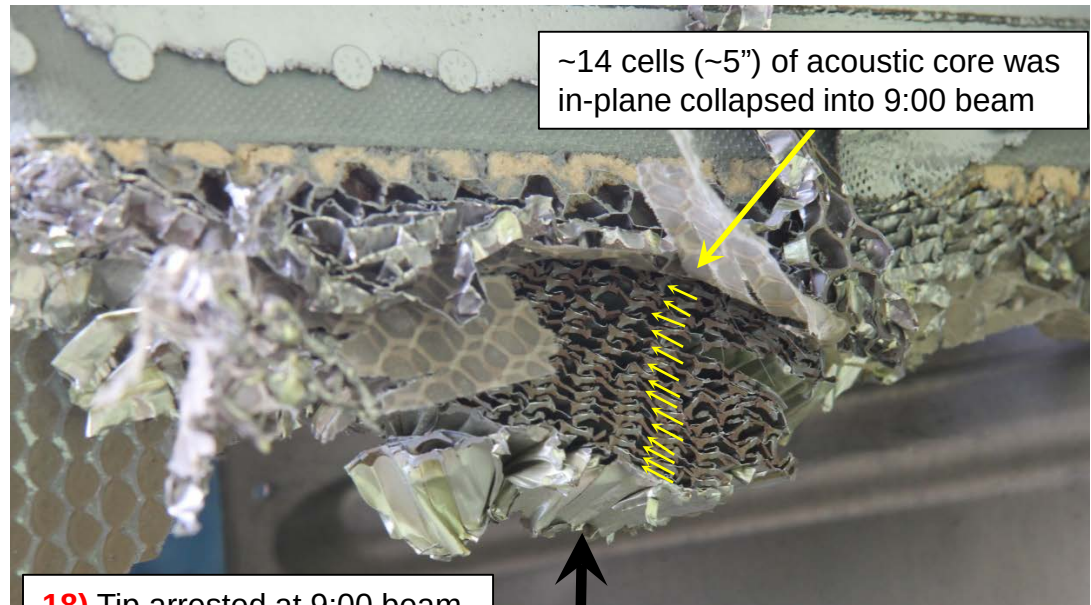
**16)** Tip fragment leading edge fits in dents of collapsed acoustic core. Ti-6Al-4V found in dents.

# TIP FRAGMENT TRAJECTORY

TIP FRAGMENT COLLAPSES ACOUSTIC CORE AND ARRESTED AT 9:00 BEAM



**17)** Tip continues to in-plane collapse  
~5" of acoustic core into 9:00 beam



**18)** Tip arrested at 9:00 beam

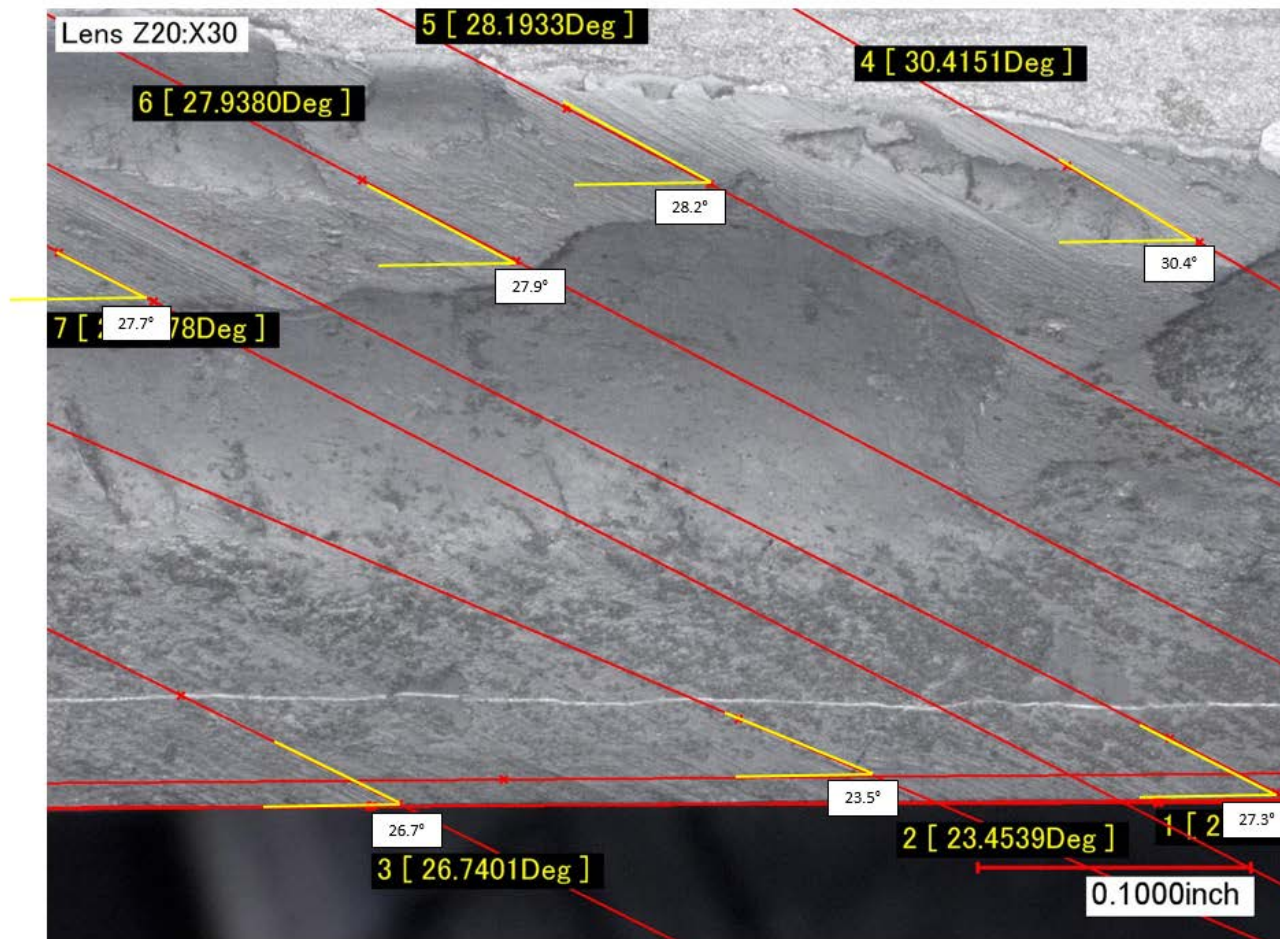
# ATTACH RING GOUGE METALLURGY

# METALLURGICAL FINDINGS

## TIP GOUGE IN ATTACH RING

### Blade Tip Impact – Section F (Avg: 27.4°)

U.S. Export Classification: 9E991

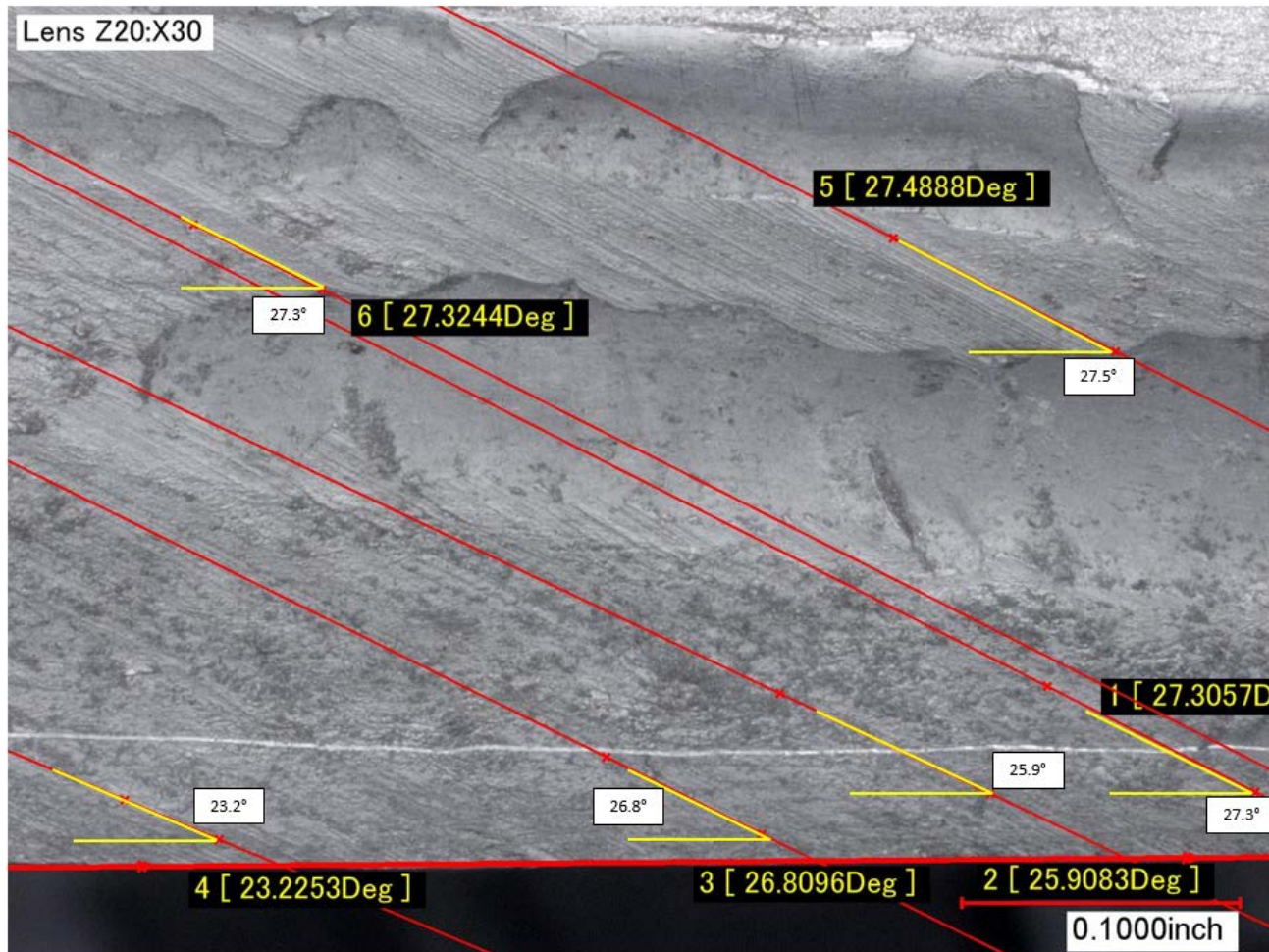


# METALLURGICAL FINDINGS

## TIP GOUGE IN ATTACH RING

### Blade Tip Impact – Section E (Avg: 26.6°)

U.S. Export Classification: 9E991



# METALLURGICAL FINDINGS

## TIP GOUGE IN ATTACH RING

### Blade Tip Impact – Section D (Avg: 25.5°)

U.S. Export Classification: 9E991

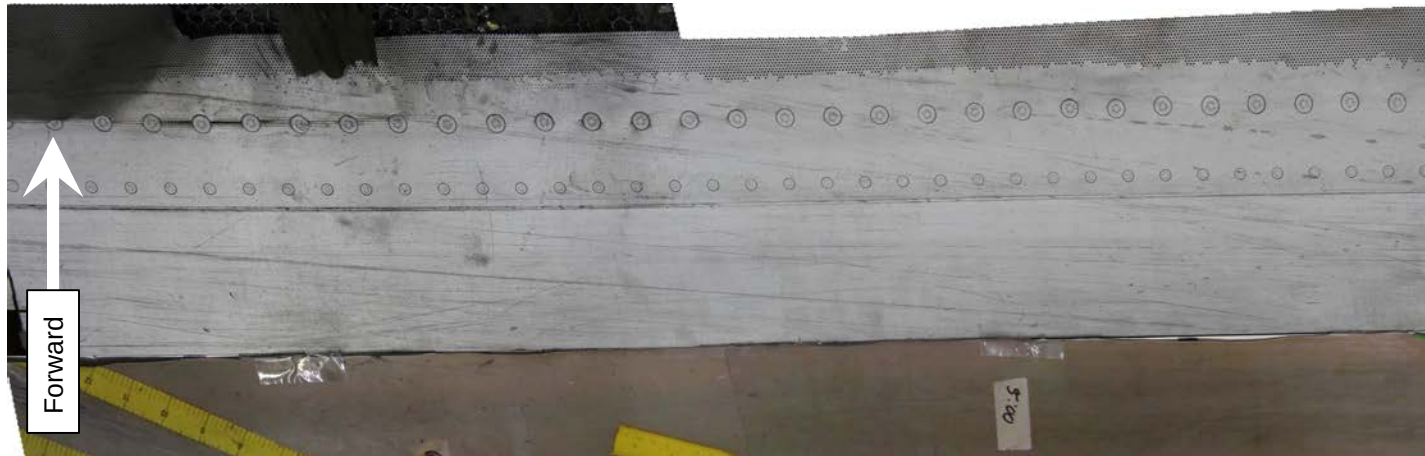


# ADDITIONAL FAN FRAGMENTS INNER BARREL SCRATCHES

# METALLURGICAL FINDINGS

## ADDITIONAL FAN FRAGMENT SCRATCHES IN INNER BARREL

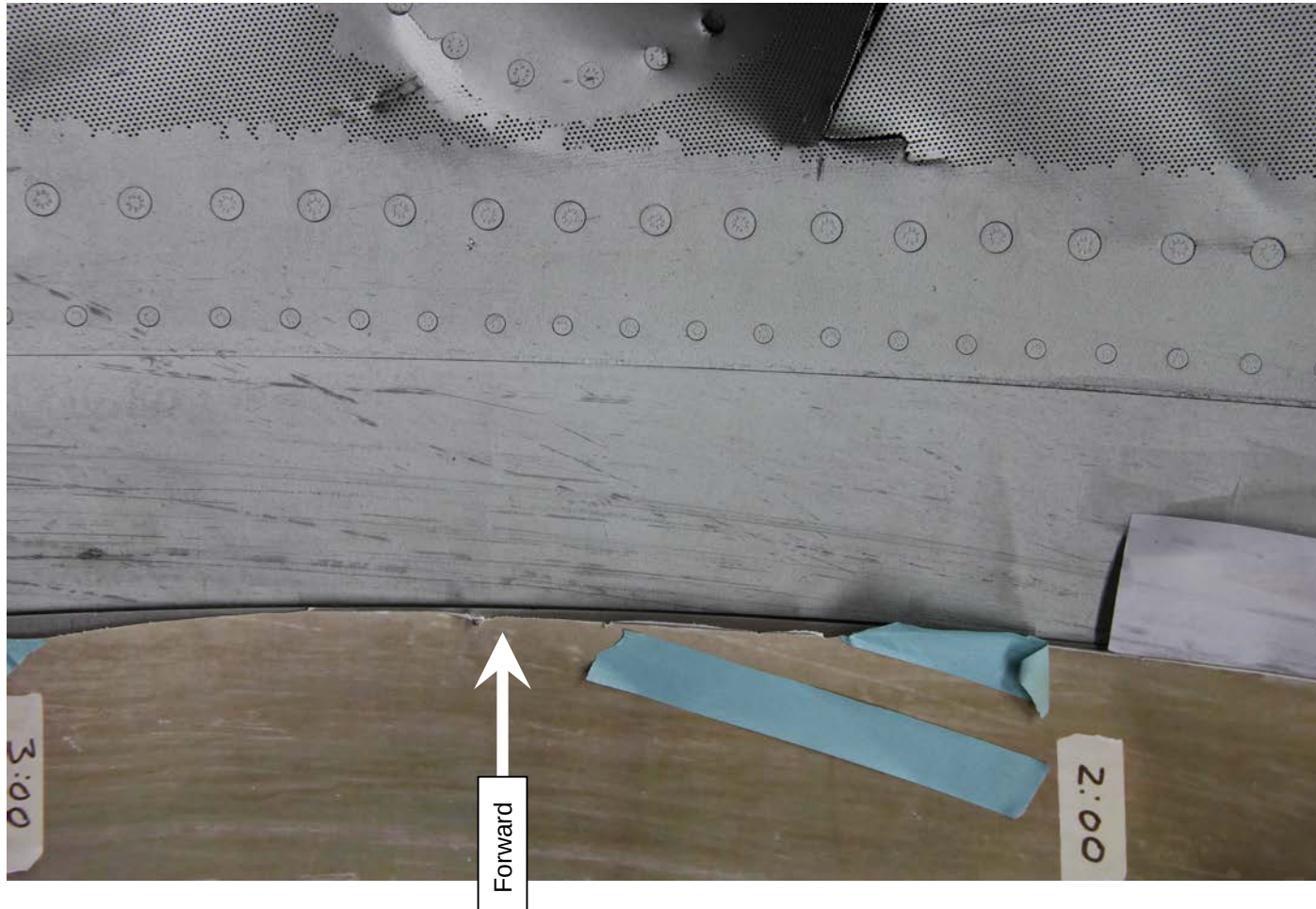
### Inner Barrel Scratch Marks 2:00-6:00



# METALLURGICAL FINDINGS

## ADDITIONAL FAN FRAGMENT SCRATCHES IN INNER BARREL

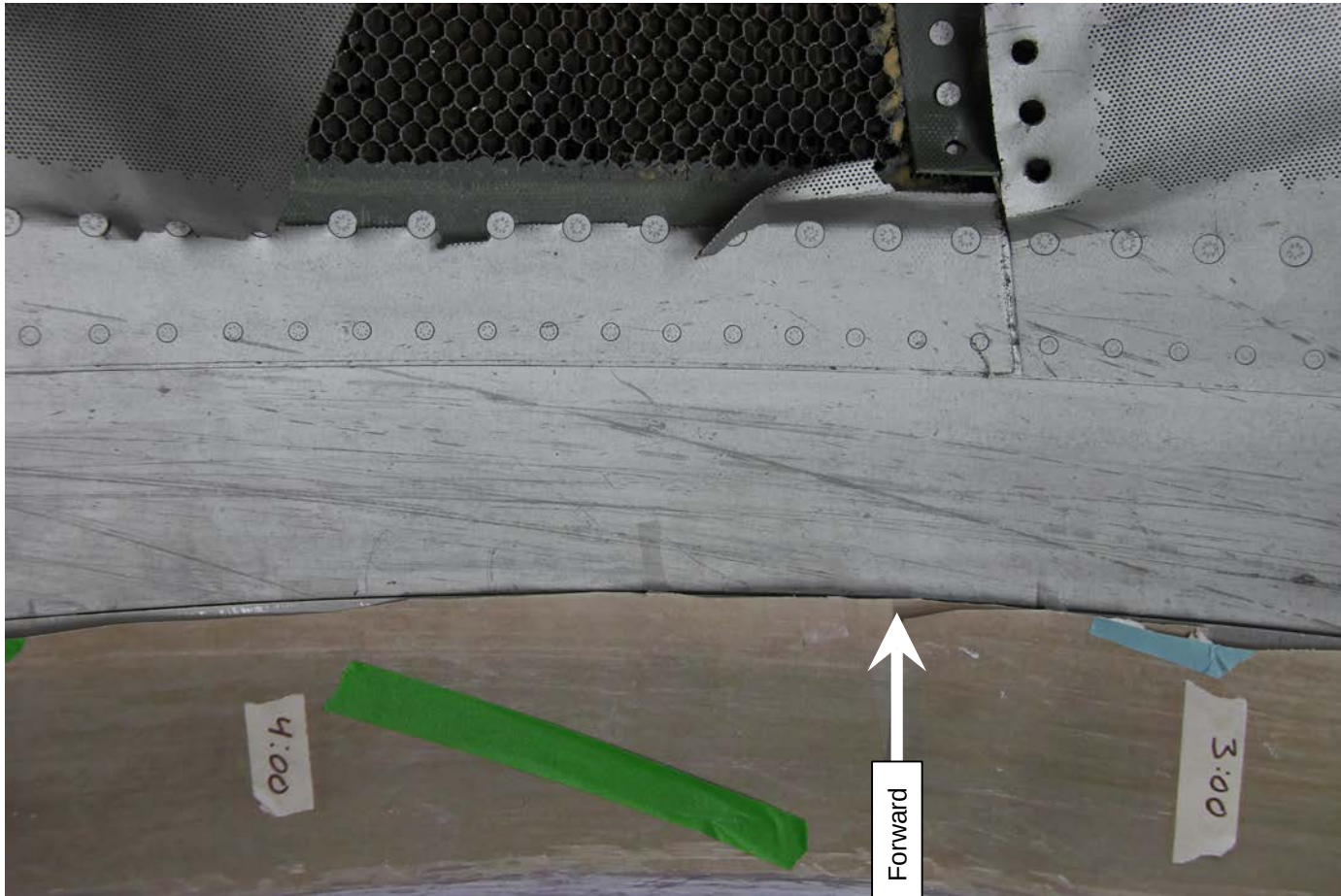
### Inner Barrel Scratch Marks 2:00-3:00



# METALLURGICAL FINDINGS

## ADDITIONAL FAN FRAGMENT SCRATCHES IN INNER BARREL

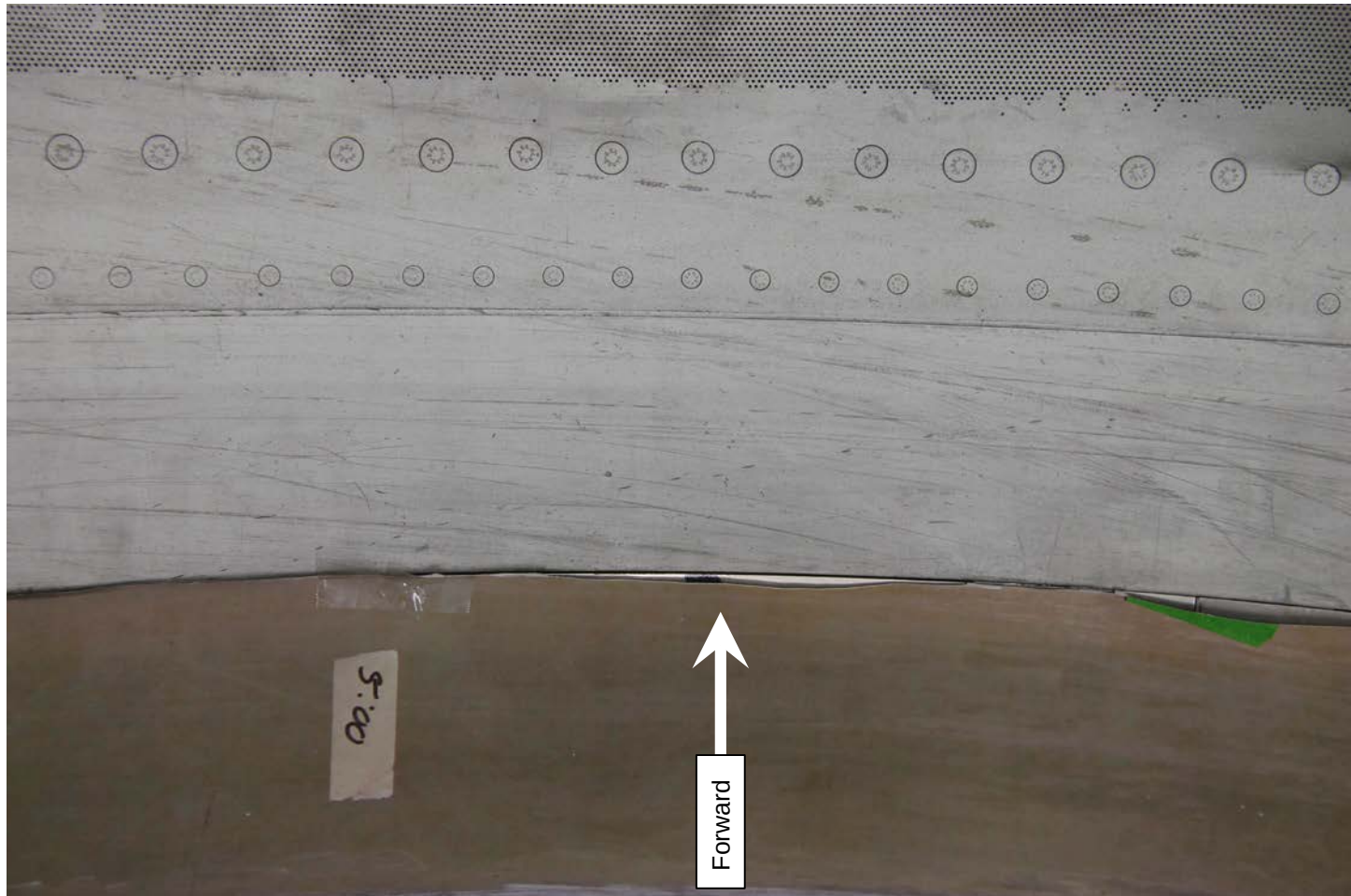
### Inner Barrel Scratch Marks 3:00-4:00



# METALLURGICAL FINDINGS

## ADDITIONAL FAN FRAGMENT SCRATCHES IN INNER BARREL

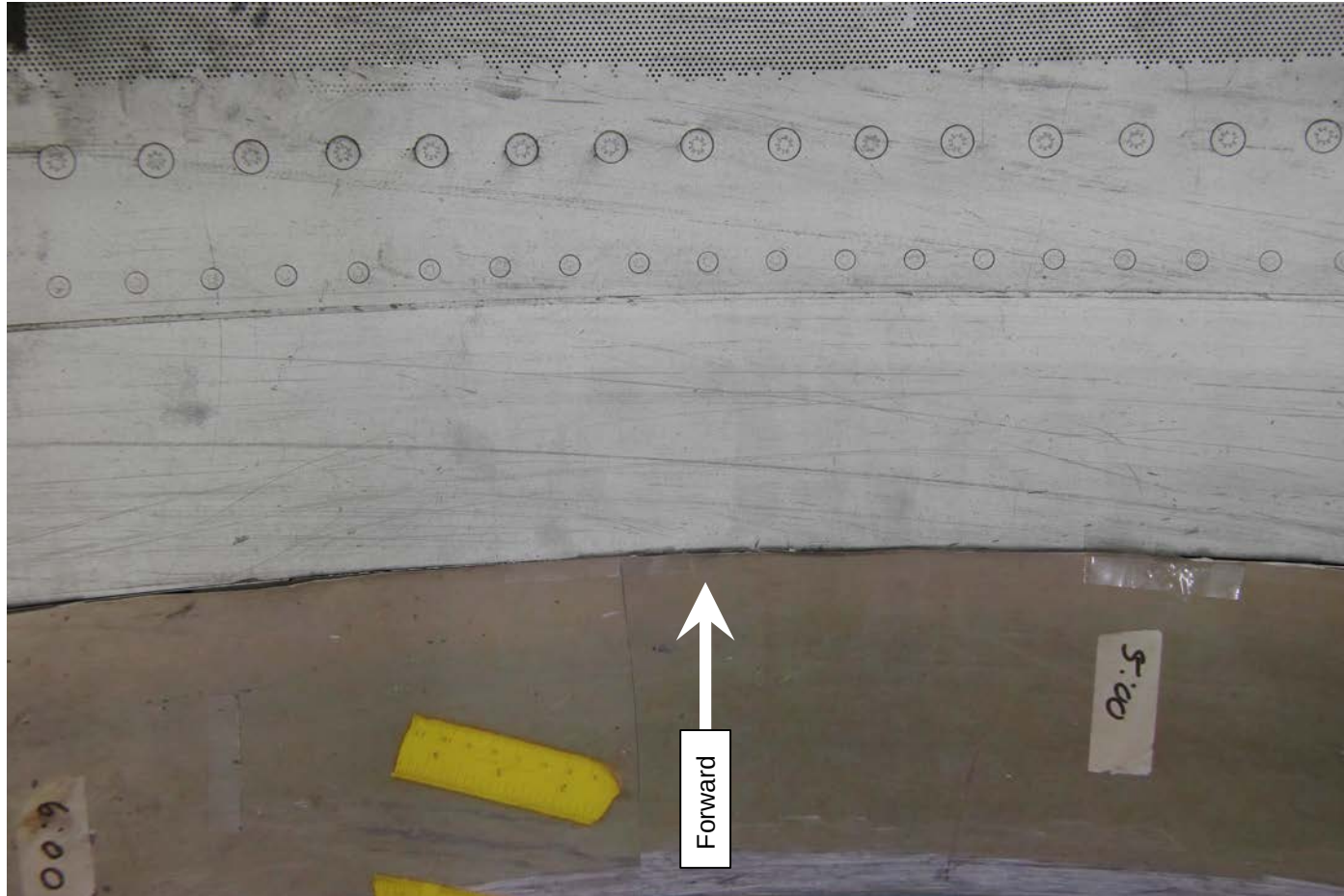
### Inner Barrel Scratch Marks 4:00-5:00



# METALLURGICAL FINDINGS

## ADDITIONAL FAN FRAGMENT SCRATCHES IN INNER BARREL

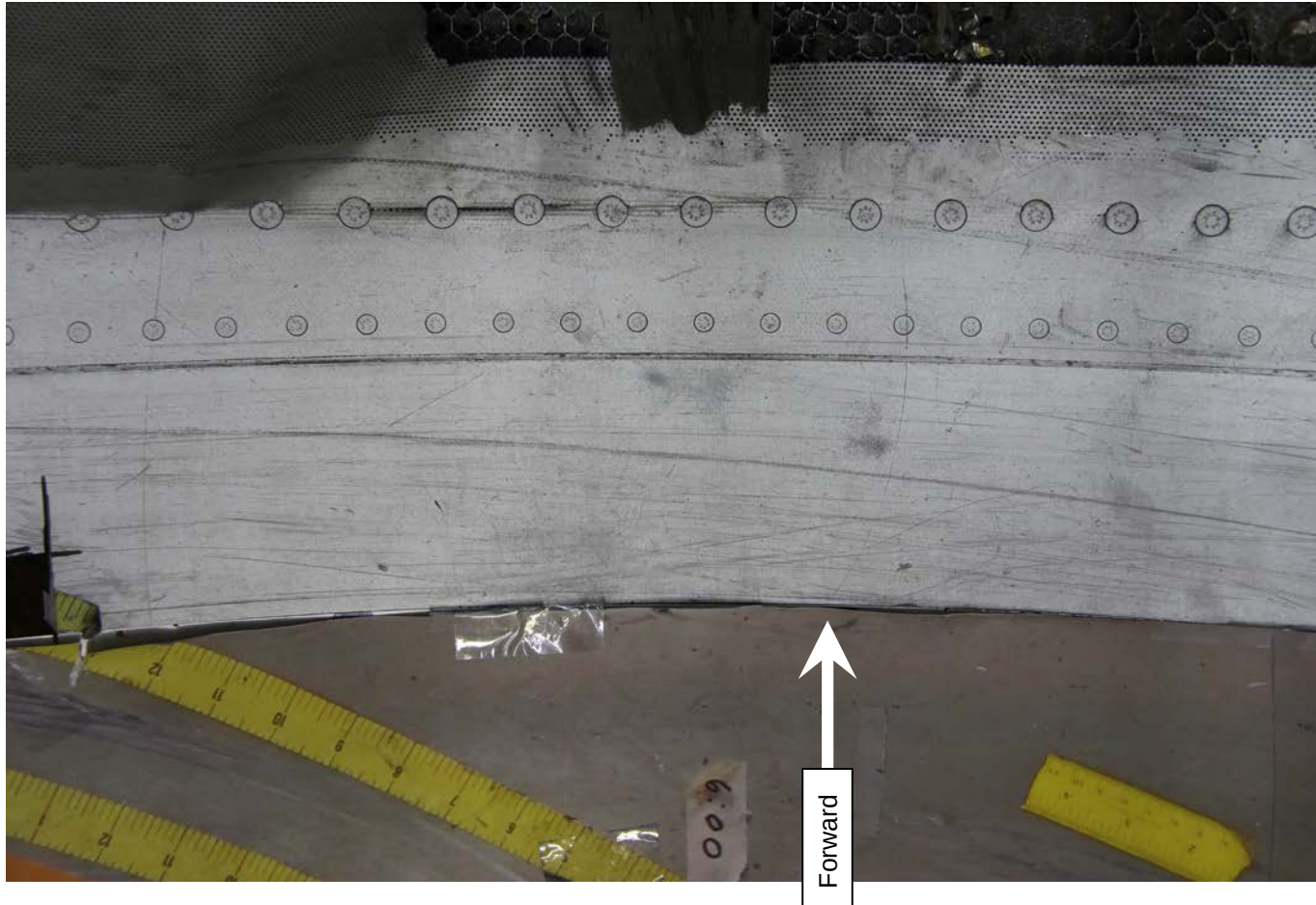
### Inner Barrel Scratch Marks 5:00-6:00



# METALLURGICAL FINDINGS

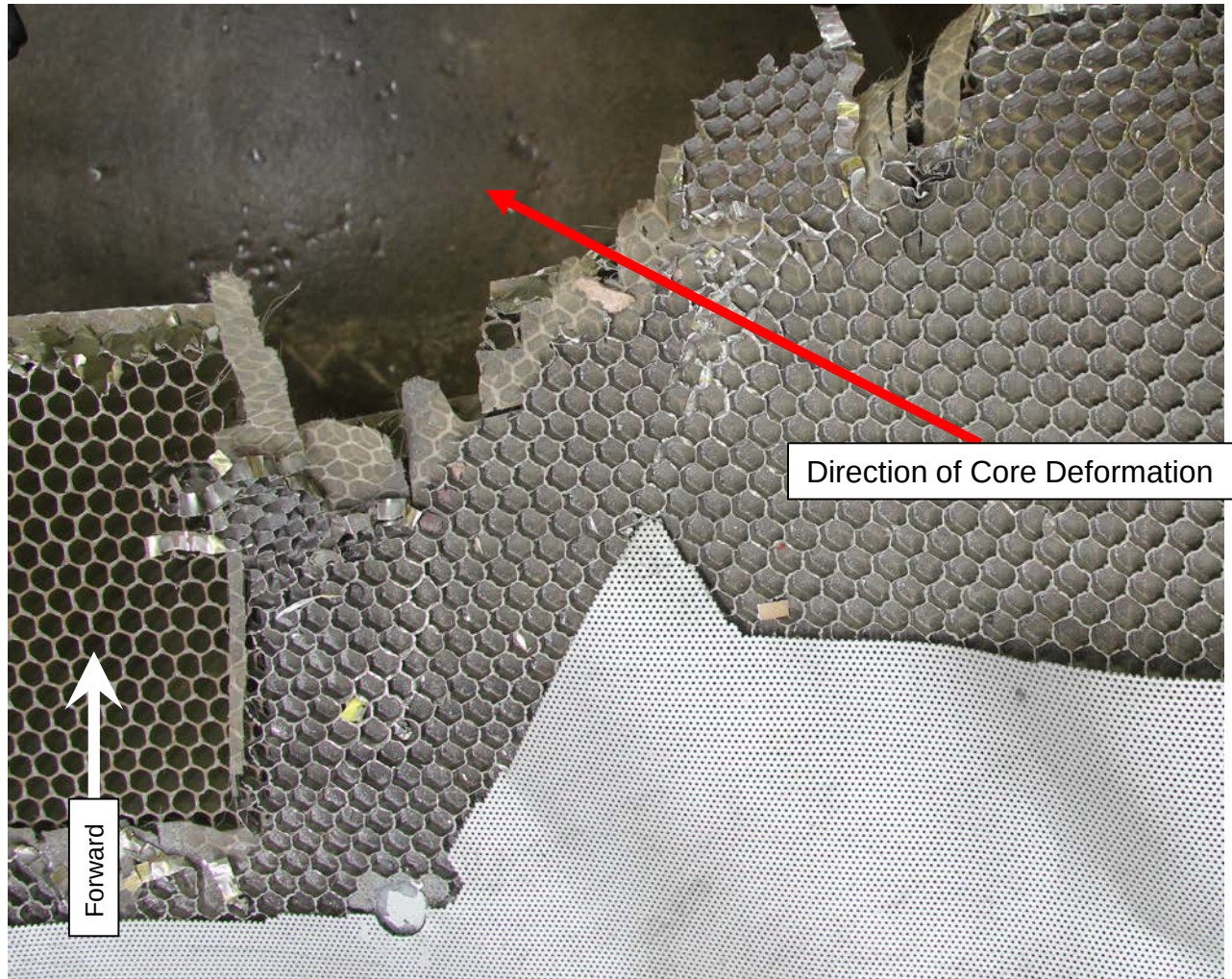
## ADDITIONAL FAN FRAGMENT SCRATCHES IN INNER BARREL

### Inner Barrel Scratch Marks 5:30-6:30



# METALLURGICAL FINDINGS

## ADDITIONAL FAN FRAGMENT CORE CRUSH AT 5:00



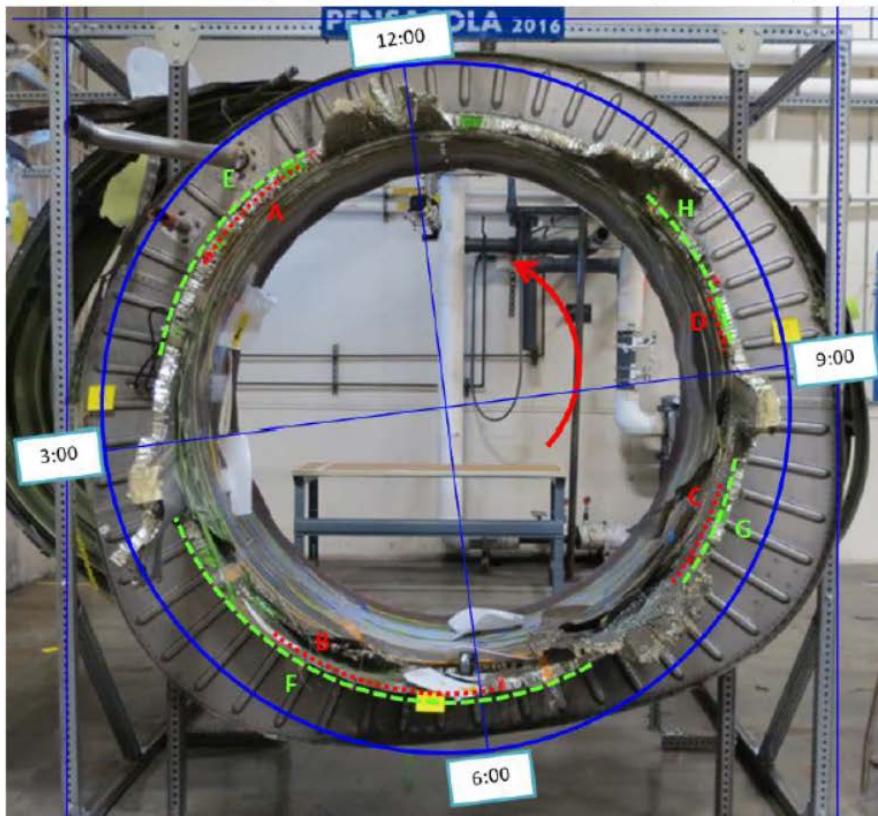
---

# PENSACOLA SW-3572 INNER BARREL BLADE FRAGMENT DAMAGE

# PENSACOLA SW-3572 (NTSB: DCA16FA217, pg 120) INNER BARREL BLADE FRAGMENT DAMAGE

## SW-3572 DAMAGE SIMILAR TO PHILADELPHIA SW-1380

### — Min/Max Inner Barrel Through Damage from Fan Blade Fragments



#### — — — Min Damage

##### Min Damage Segments

A - 12:45-1:45,  $\Delta = 1:00$

B - 4:30-6:15,  $\Delta = 1:45$

C - 7:30-8:15,  $\Delta = 0:45$

D - 9:15-9:30,  $\Delta = 0:15$

##### Min Total $\Delta$ Damage

$= 1:00 + 1:45 + 0:45 + 0:15$

$= 3:45$

$= 112.5^\circ$

#### — — — Maximum Damage

##### Max Damage Segments

E - 12:45 to 2:30,  $\Delta = 1:45$

F - 3:30 to 6:45,  $\Delta = 3:15$

G - 7:30 to 8:30,  $\Delta = 1:00$

H - 9:15 to 10:15,  $\Delta = 1:00$

##### Max Total $\Delta$ Damage

$= 0:15 + 1:45 + 3:15 + 1:00 + 1:00$

$= 7:15$

$= 210^\circ$

Clocking is based on nacelle coordinate system and is in alignment with blue tape clocking on ID of attach ring

PHOTO 129: INLET INNER BARREL DAMAGE ASSESSMENT