# ATTACHMENT 6

## AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT

## DCA16FA217

**UTC Aerospace Systems 737NG CFM56-7B24 Southwest Airlines ESN 874112 Pensacola Fan Blade Fragments Fan Case and Inlet Trajectory Analyses dated October 31, 2018**

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# 737NG CFM56-7B24 Southwest Airlines
# ESN 874112 Pensacola
# Fan Blade Fragments
# Fan Case and Inlet Trajectory Analyses

October 31, 2018

UTC Aerospace Systems

# Conclusions

- The fan blade-out event generated multiple high-energy fan blade fragments (tip, mid, root), all which traveled forward into the inlet.
  - There is minimal damage to OGVs located aft of the fan and no fragments were recovered, which supports all fragments exited forward.
- The fan blade tip, and one mid fragment, were arrested by the inlet within the containment shield.
- The root fragment subsequently impacted the fan tip and created new fragments.
- Multiple fragments sheared the inlet inner barrel forward of the containment shield for a cumulative arc of between 112.5$^{o}$ and 210$^{o}$.

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# Summary of Fan Blade Fragments

# Trajectories and Inlet Damage

A) Tip fragment: Arrested within inlet shield at 6:30

Inlet Damage: 6” x 32” acoustic core within containment shield

B) Mid fragments: One mid fragment arrested within shield at 6:30
Mid fragments sheared 52.5$^{o}$ to 97.5$^{o}$ of inner barrel

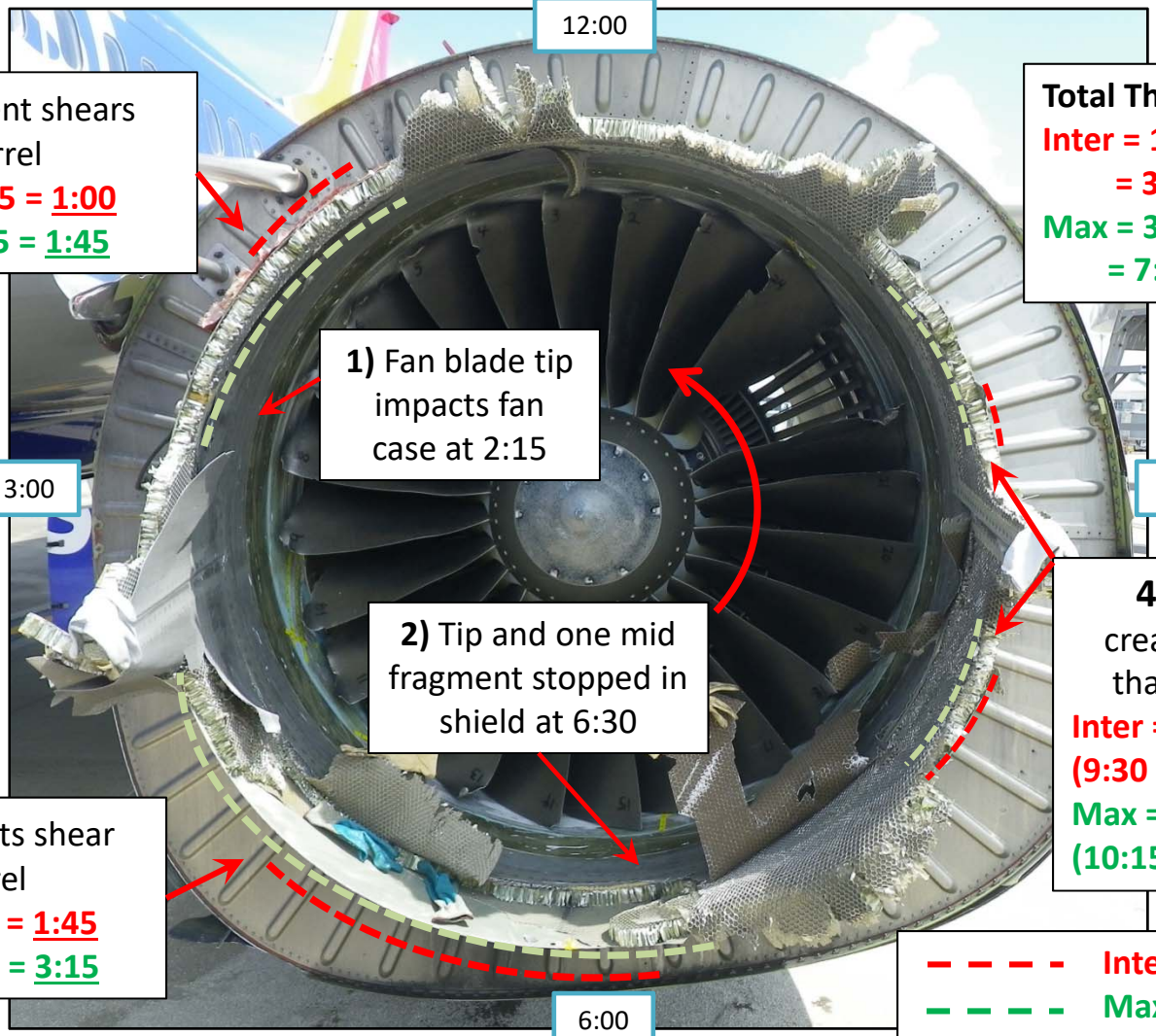
C) Root fragment: Slid a full inlet revolution, then impacted the tip fragment at 6:30 and created new fragments that sheared the inner barrel for 30$^{o}$ to 60$^{o}$

Remaining root fragment continued another full revolution and sheared an additional 30$^{o}$ to 52.5$^{o}$ of inner barrel

D) The cumulative arc of the inner barrel, sheared by fan blade fragments, was estimated to be between 112.5$^{o}$ and 210$^{o}$

# 737NG CFM56-7B24: SOUTHWEST AIRLINES ESN 874112

## Inner Barrel: Through Damage from Fan Blade Fragments




**5)** Root fragment shears inner barrel
**Inter = 1:45 - 12:45 = 1:00**
**Max = 2:30 - 12:45 = 1:45**

**1)** Fan blade tip impacts fan case at 2:15

**2)** Tip and one mid fragment stopped in shield at 6:30

**3)** Mid fragments shear inner barrel
**Inter = 6:15 - 4:30 = 1:45**
**Max = 6:45 - 3:30 = 3:15**

**4)** Root impacts tip creating new fragments that shear inner barrel
**Inter = (8:15 - 7:30) + (9:30 - 9:15) = 1:00**
**Max = (8:30 - 7:30) + (10:15 - 9:15) = 2:00**

**Total Through Damage**
**Inter = 1:45 + 1:00 + 1:00 = 3:45 = 112.5°**
**Max = 3:15 + 2:00 + 1:45 = 7:00 = 210°**

**Intermediate Damage**
**Maximum Damage**

# Fan Blade Fragments: Event Sequence Estimate

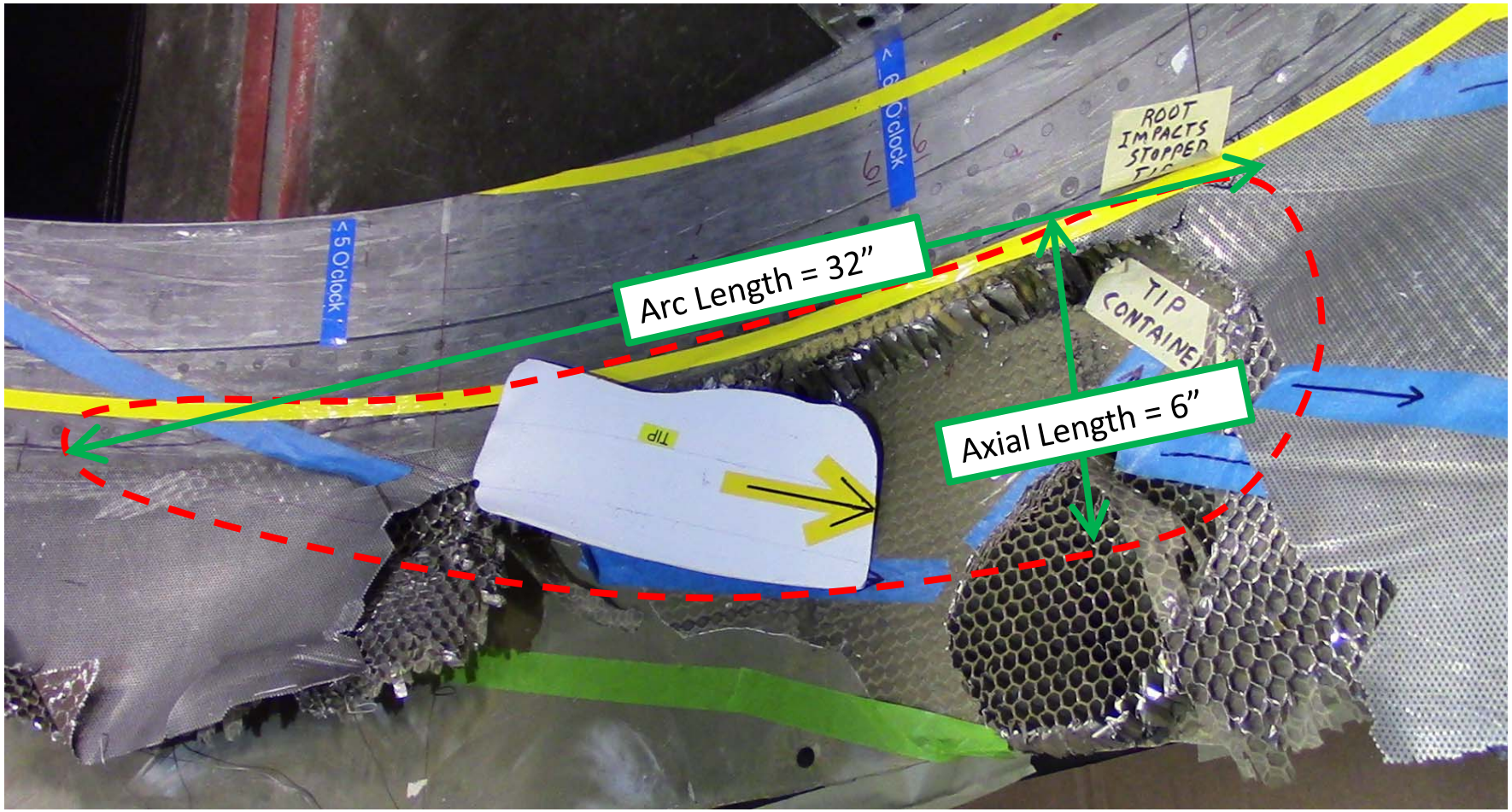
## Event

1. Fan blade impacts fan case at 2:15
2. Tip fragment is contained within shield at 6:30
3. Mid fragments lag tip fragment and shear inner barrel. One mid fragment is contained at 6:30
4. Root fragment is accelerated to fan tip velocity by trailing blade yet lags the mid fragments. After a full inlet revolution, the root impacts the stopped tip fragment creating new fragments with high velocity and energy
5. New fragments shear inner barrel
6. Remaining large root fragment continues for another full inlet revolution and shears inner barrel

# 737NG CFM56-7B24: SOUTHWEST AIRLINES ESN 874112

## INNER BARREL ACOUSTIC CORE DAMAGE

## DUE TO THE FAN BLADE TIP FRAGMENT ONLY



# A) Tip Fragment

# Fan Case and Inlet Trajectory

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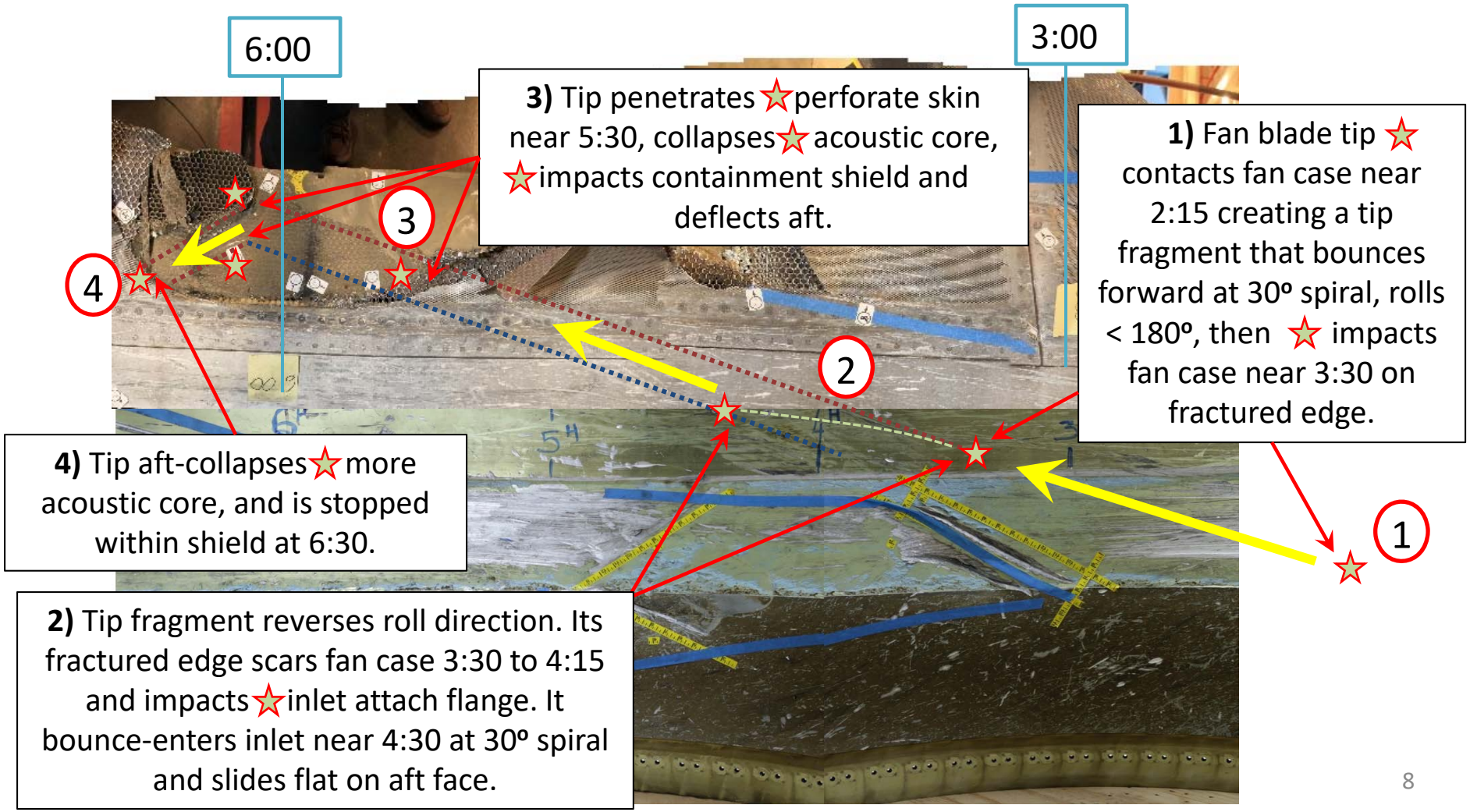
# A) Tip Fragment: Fan Case and Inlet Trajectory



# A) Tip Fragment

# Fan Case Trajectory

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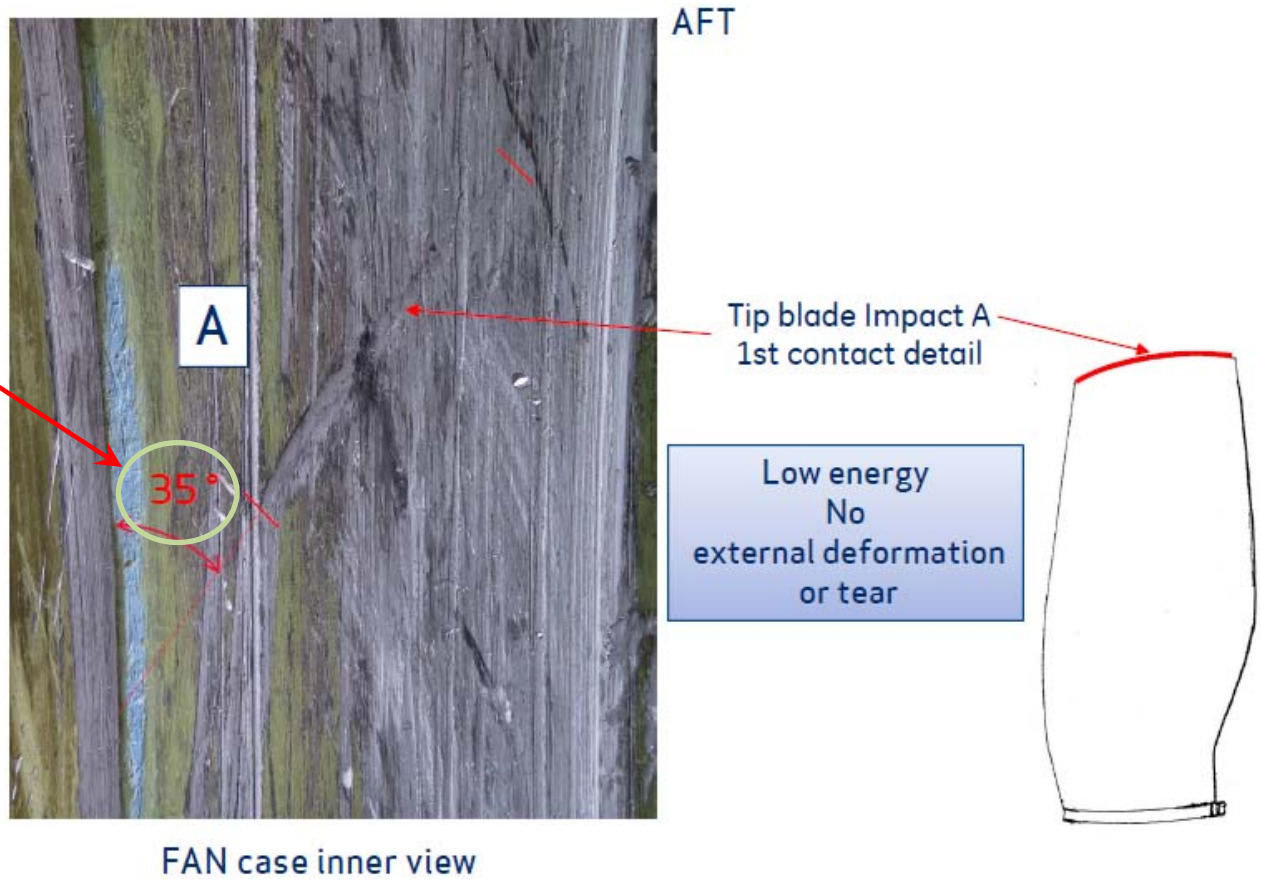
# A) Tip Fragment: Fan Case Trajectory

Fan blade tip first contacts fan case at about 2:15 with impact angle of about 35°




FAN case inner view

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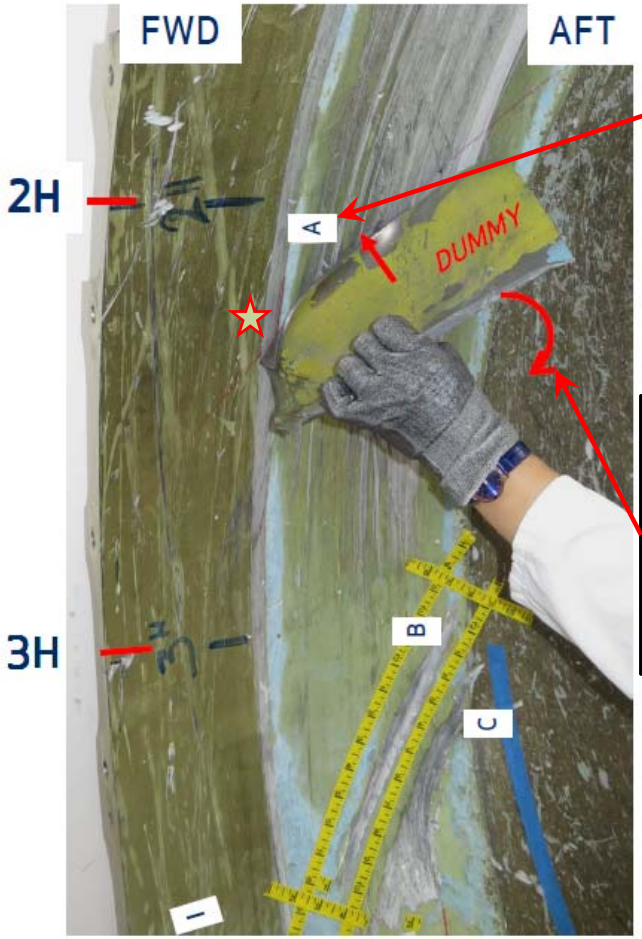
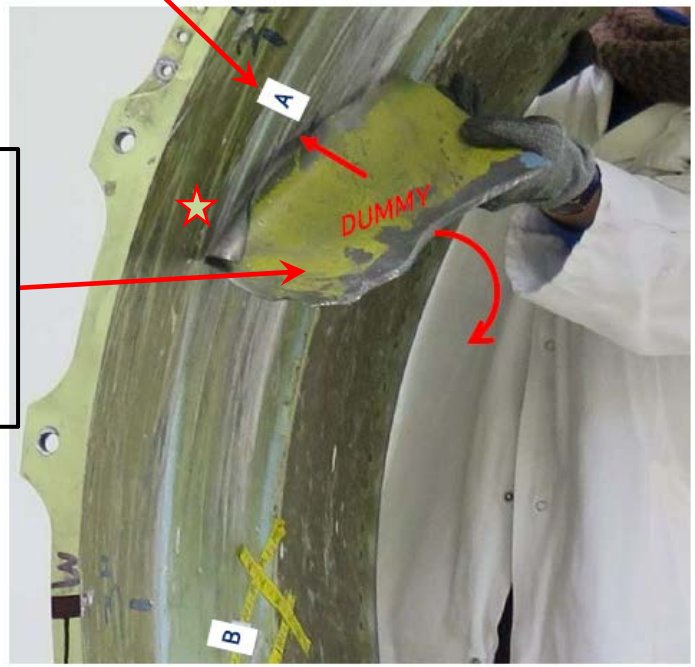
# A) Tip Fragment: Fan Case Trajectory




**1)** Fan blade initially contacts ☆ fan case at about 2:15

**2)** Between 2:15 and 3:15, the blade tip fragment is liberated, bounces off the fan case and rolls < 180°

Tip panel impact 1
1 st contact



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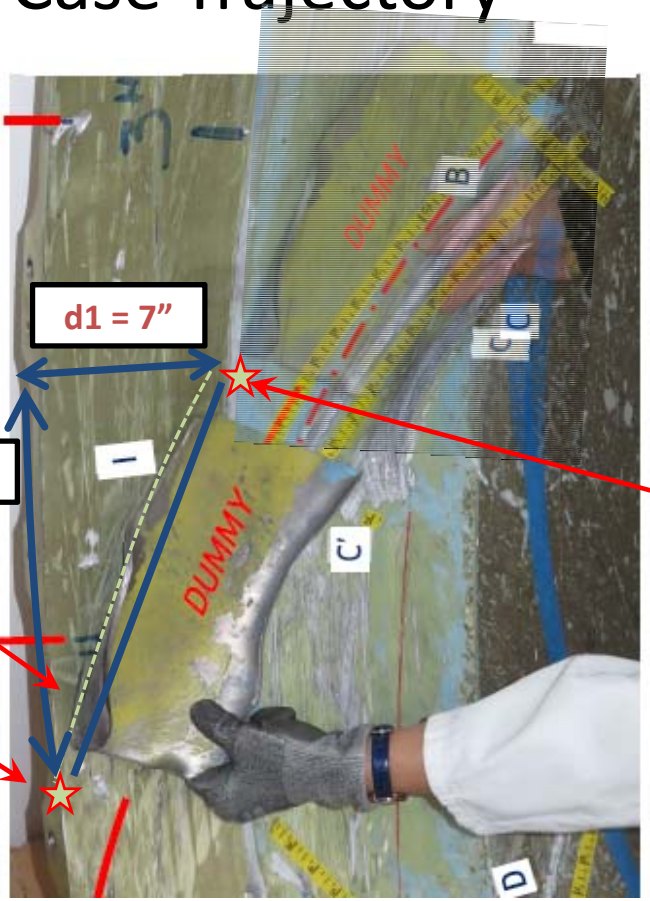
# A) Tip Fragment: Fan Case Trajectory




**2)** Tip enters inlet near 4:15

**1)** The tip fragment fractured edge impacts ☆ the fan case near 3:15 creating a large scratch that starts with a spiral angle of about 30°

$\theta = \tan^{-1}(d1/d2)$

d1 = 7”

d2 = R * Φ = 31” * [ (4:15 – 3:30) / 12:00 ] * (2*PI) = 12”

$\theta = \tan^{-1}(7/12) =$ **30°**

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# A) Tip Fragment: Fan Case Trajectory

**1)** Blade tip impacts ☆ fan case, makes distinct mark in fan case, and creates tip fragment

**2)** Tip fragment bounces off fan case, and rolls between 90° and 180° while flying through the air at about 30°

**3)** Tip fragment's fractured edge impacts ☆ fan case, reverses roll direction, and begins to make a spiral arcing scratch ☆ that initially is about 30°

**4)** While scratching ☆ fan case, tip fragment center of mass continues forward at about 30°, and rolls less than 90°, causing scratch angle to reduce to about 14°. It then impacts ☆ the inlet attach flange.

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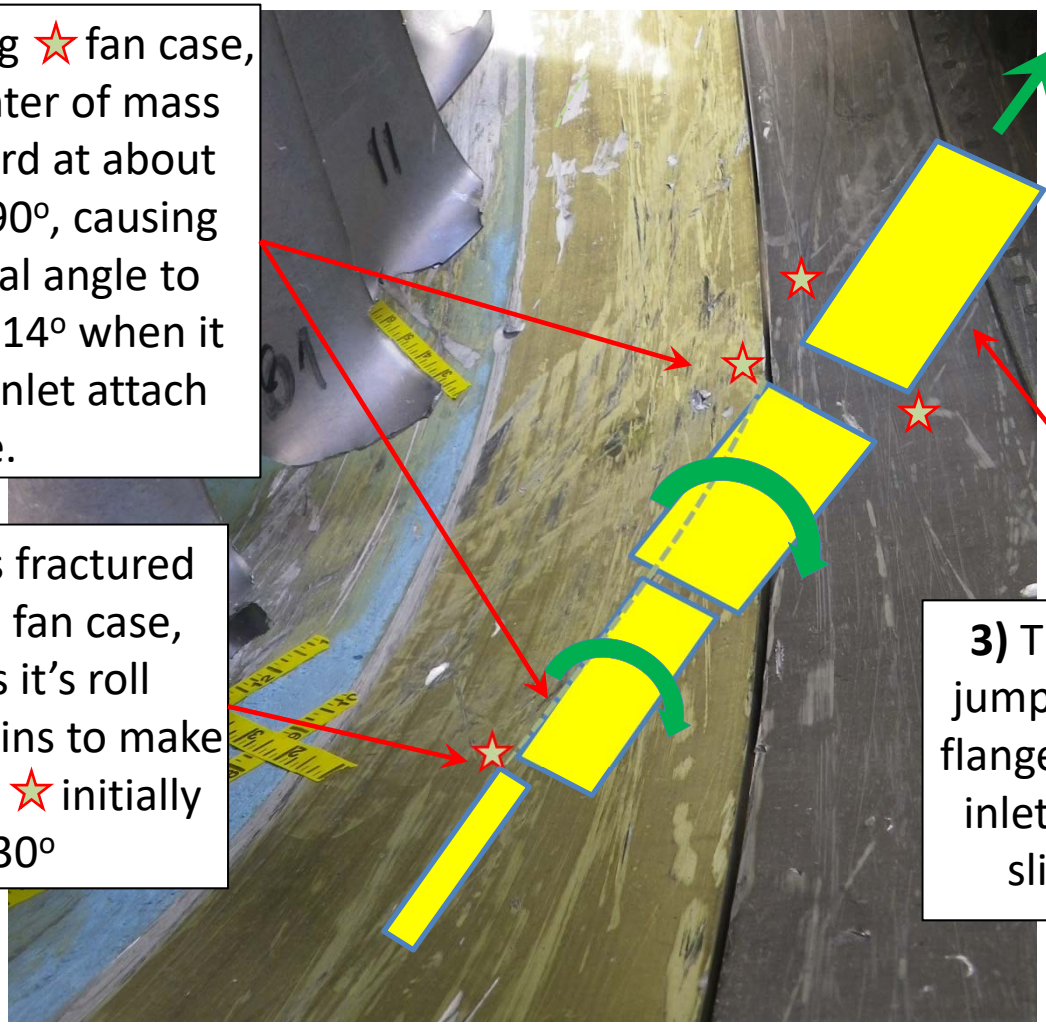
# A) Tip Fragment: Fan Case Trajectory

**2)** While scratching ☆ fan case, tip fragment center of mass continues forward at about 30°, and rolls < 90°, causing the scratch spiral angle to reduce to about 14° when it impacts ☆ the inlet attach flange.



**1)** Tip fragment's fractured edge impacts ☆ fan case, which reverses it's roll direction, and begins to make an arcing scratch ☆ initially at about 30°

**3)** Tip fragment briefly jumps ☆ the inlet attach flange, flat-impacts ☆ the inlet attach flange, and slides at about 30°

# A) Tip Fragment

# Inlet Trajectory

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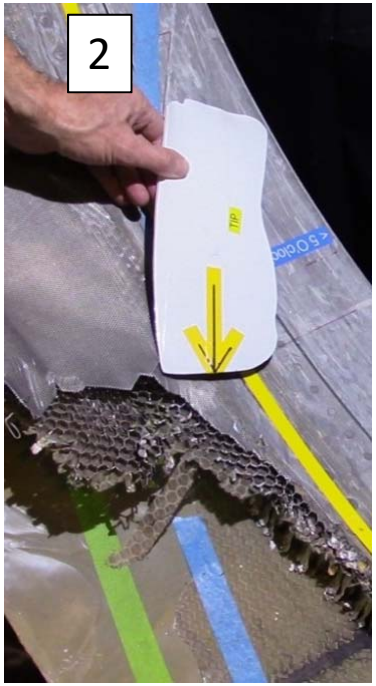
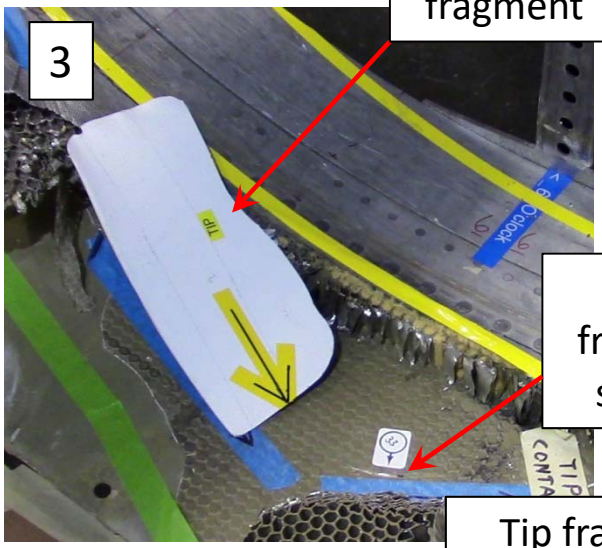
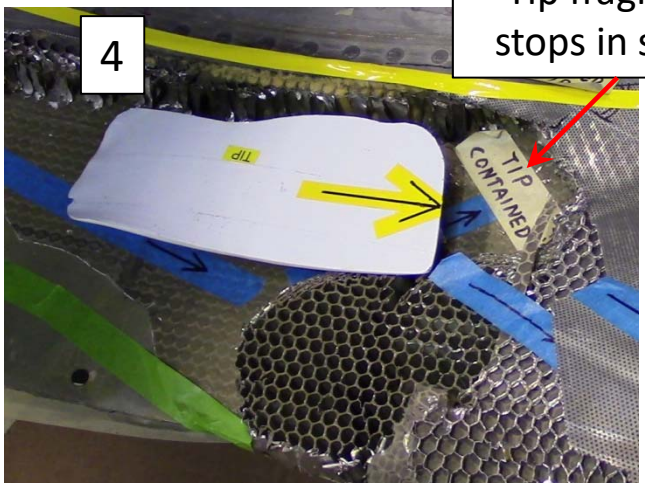
# A) Tip Fragment: Inlet Trajectory


Blue tape is tip fragment trajectory

1) Tip fragment CG enters inlet near 4:00 at 30º
2) Slides along attach flange and densified core
3) Penetrates perforate skin near 5:30, sideways collapses acoustic core, and deflects aft
4) Tip continues aft, collapsing acoustic core, and is stopped within containment shield at 6:30

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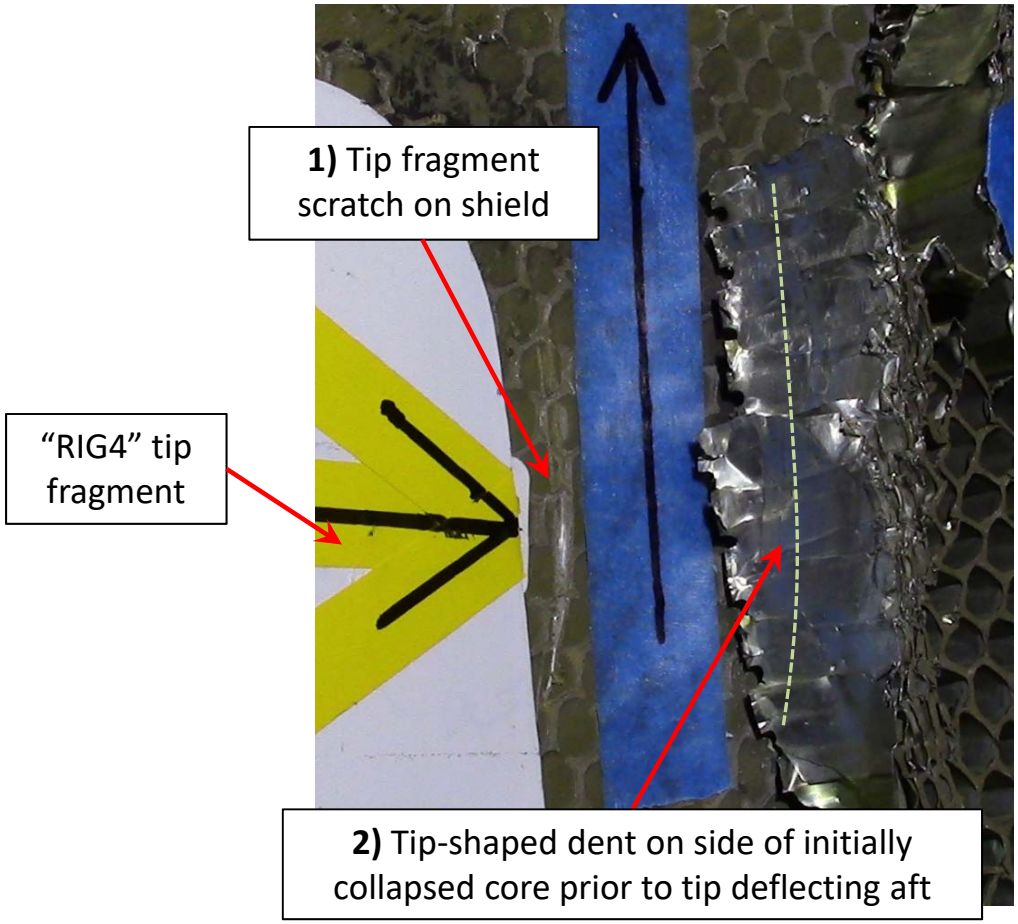
# A) Tip Fragment: Inlet Trajectory and Containment




- "Rig-4" replica tip fits nearly perfectly in initial side-of-core dent near tip-scratch

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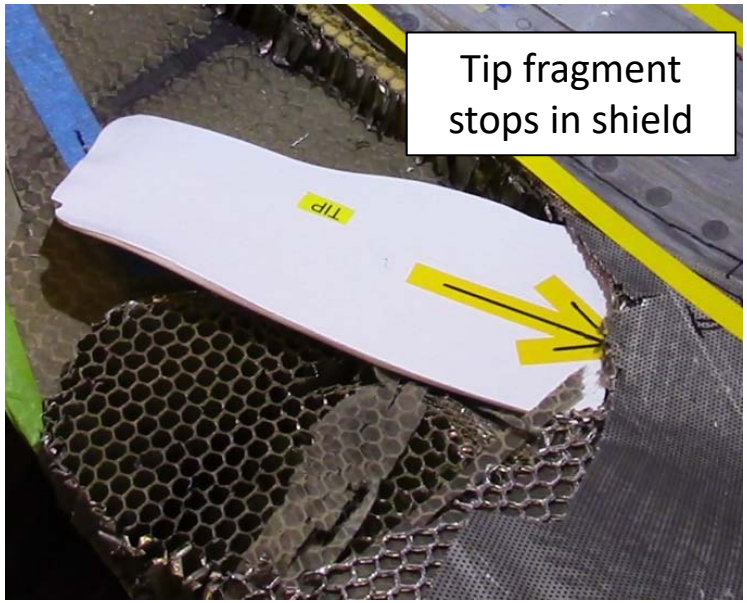
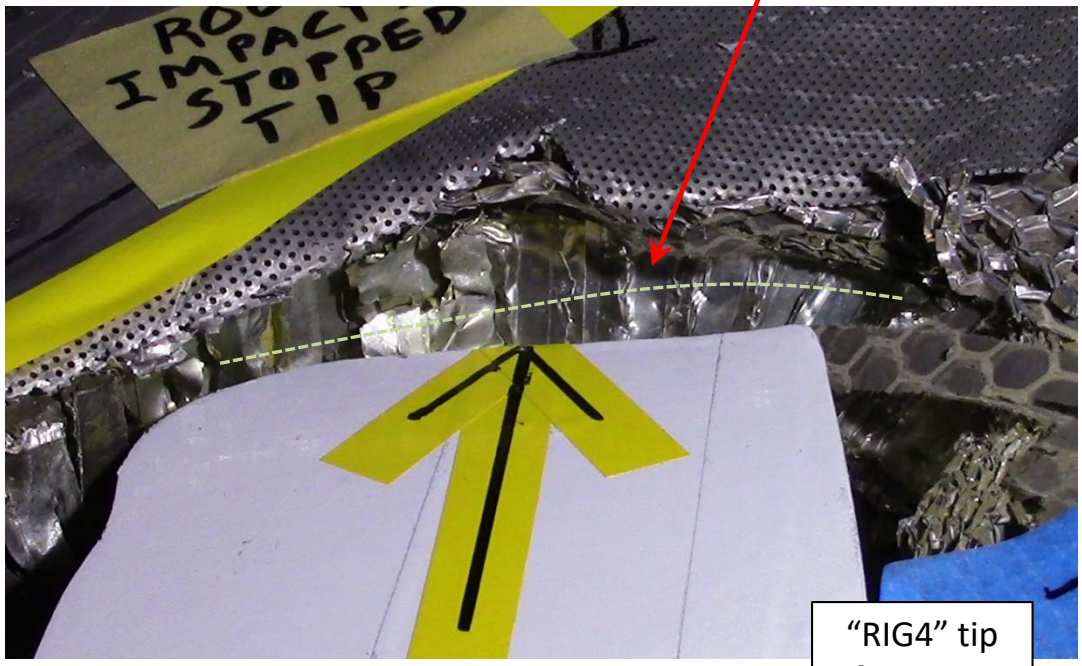
# A) Tip Fragment: Inlet Trajectory and Containment




- "Rig-4" replica tip fragment fits nearly perfectly in side-of-core dent where it stopped
- Tip fragment contained within inlet containment shield at 6:30

# B) Mid Fragments

# Fan Case and Inlet Trajectories

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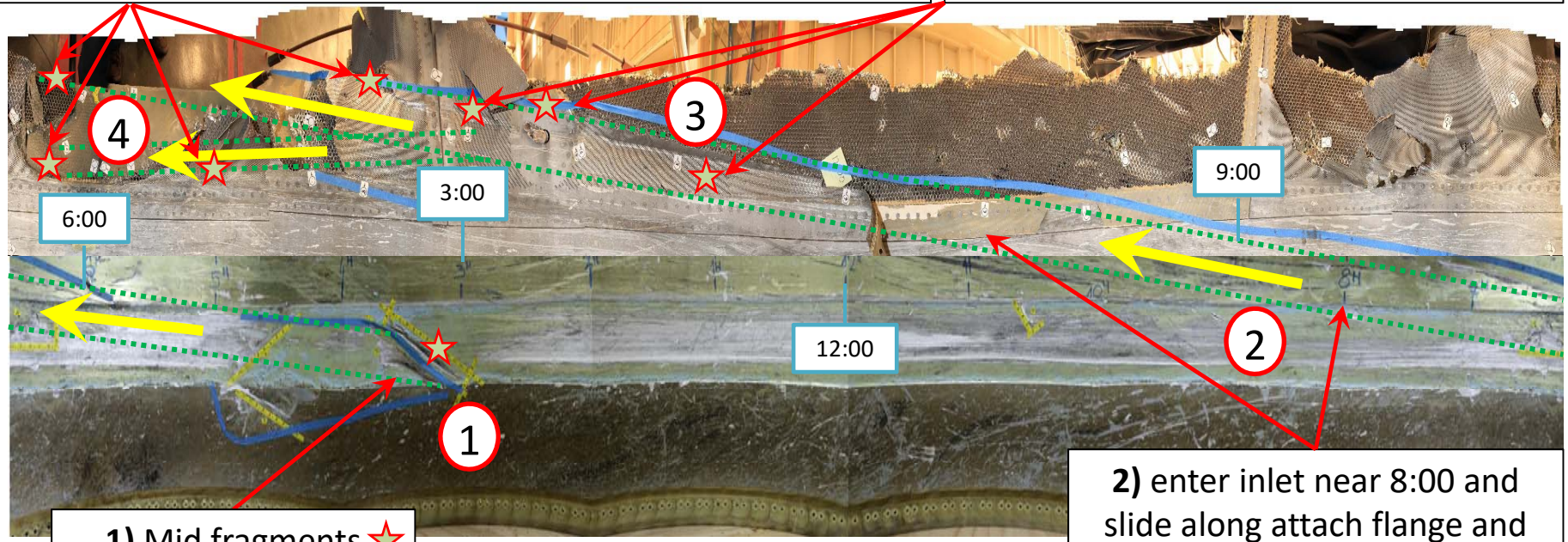
# B) Mid Fragments: Fan Case and Inlet Trajectories

**4)** ☆penetrate acoustic core and ☆shears inner barrel at containment shield edge from 3:15 to 6:45 after a full inlet revolution. A mid fragment ☆slides under the inner core, ☆ impacts/lifts the tip fragment and stops at 6:30

**3)** ☆crush acoustic core, ☆impact T12 probe, scatter, and penetrate perforate skin and ☆crush acoustic core near 3:00




**1)** Mid fragments ☆ impact fan case near 3:30

**2)** enter inlet near 8:00 and slide along attach flange and densified core at 6º - 8º

# B) Mid Fragments

# Fan Case Trajectory

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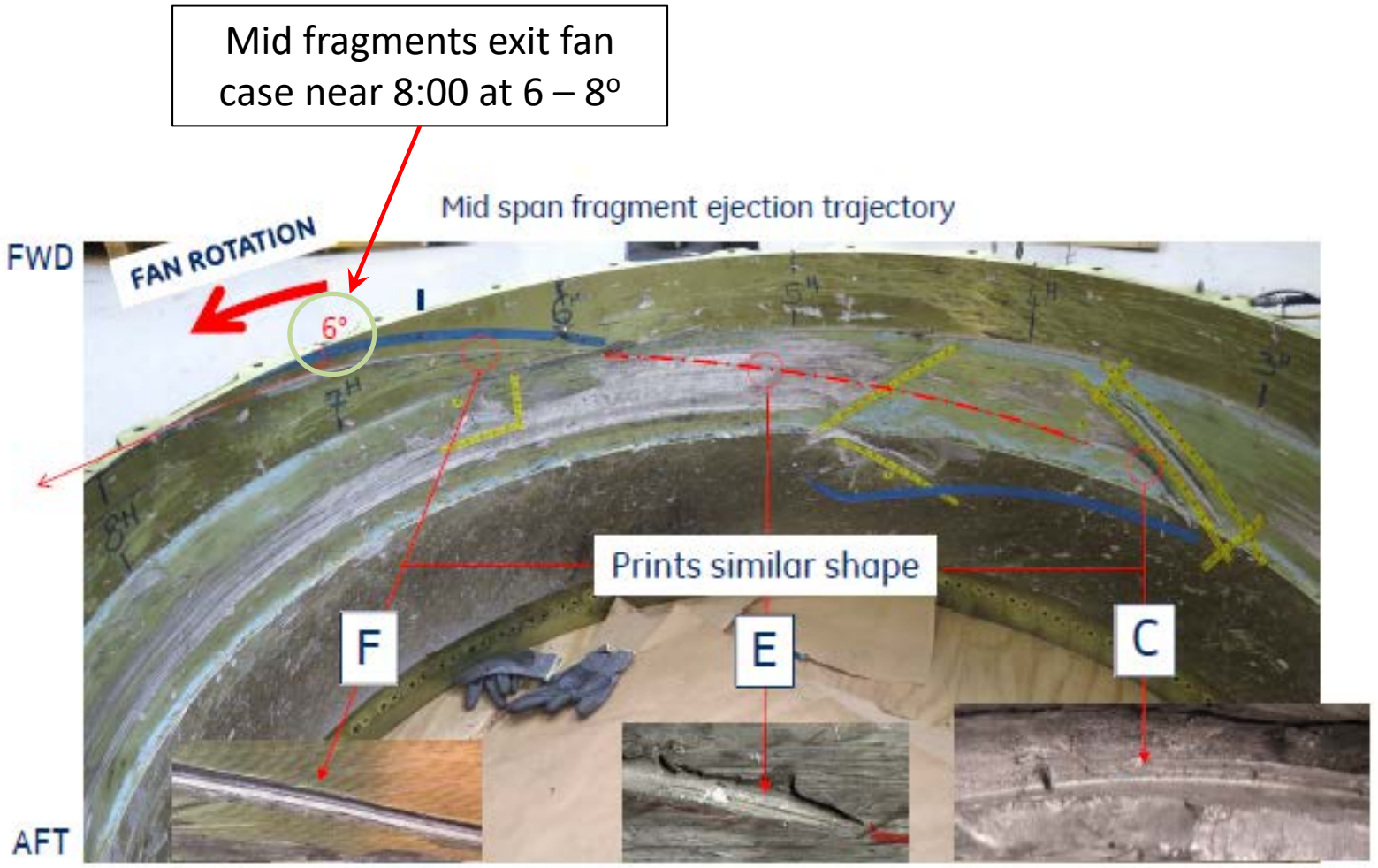
# B) Mid Fragment: Fan Case Trajectory



# B) Mid Fragments

# Inlet Trajectory

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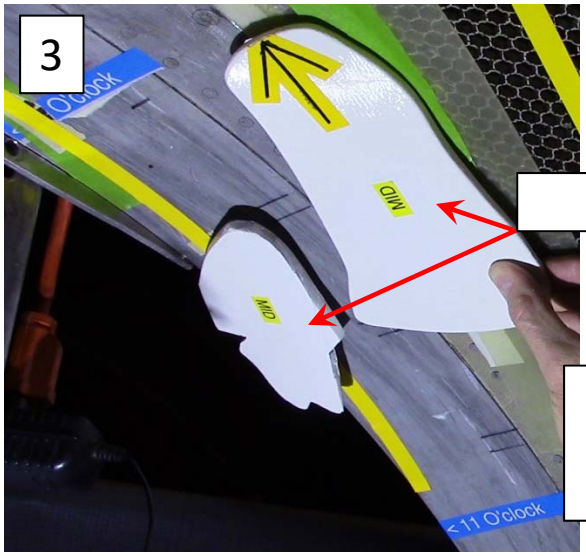
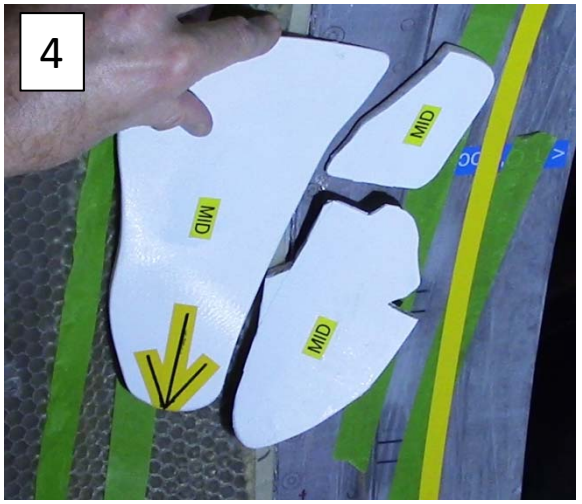
# B) Mid Fragments: Inlet Trajectory






Mid Fragments

Green tape is mid fragments trajectory




1) Mid fragments enter inlet near 8:00 at 6 - 8°
2) Slide along attach flange and densified core
3) Begin crushing acoustic core near 11:30
4) Continue to slide along and radially crush acoustic core

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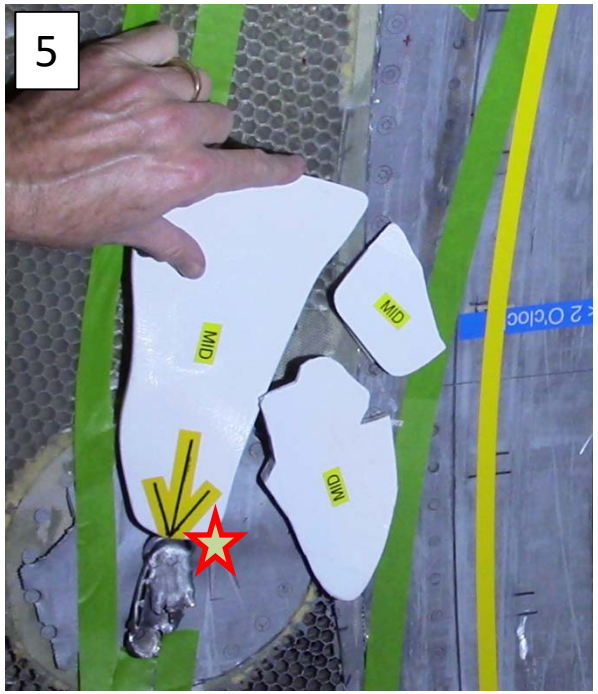
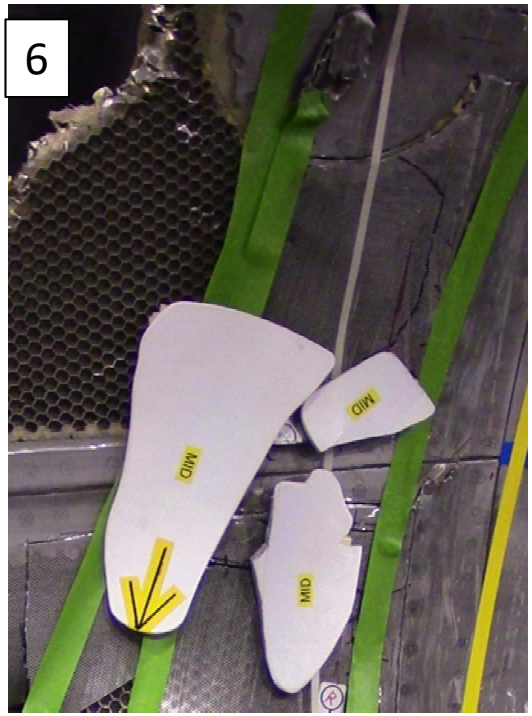
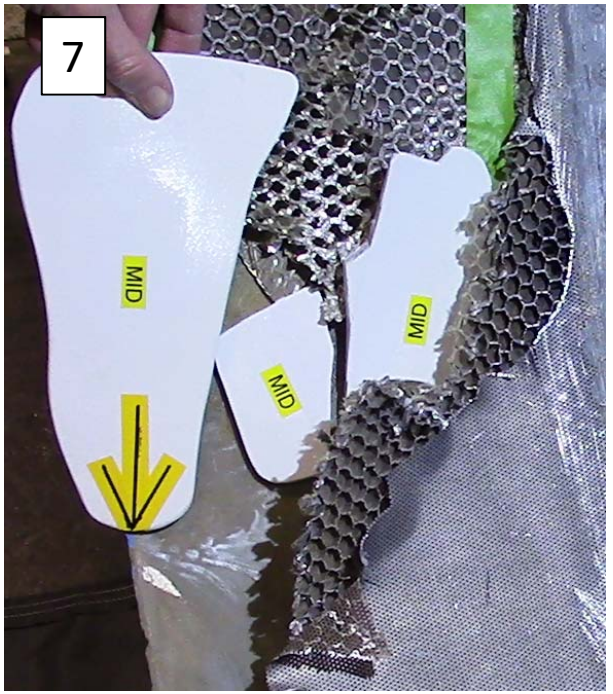
# B) Mid Fragments: Inlet Trajectory




5) Continue to crush core with some impacting T12 probe
6) Some mid fragments are deflected forward and some aft
7) All penetrate perforate skin and inner core. Some penetrate outer core. Some slide under inner core, and sideways collapse outer core, while deflecting aft

Green tape is mid fragments trajectory

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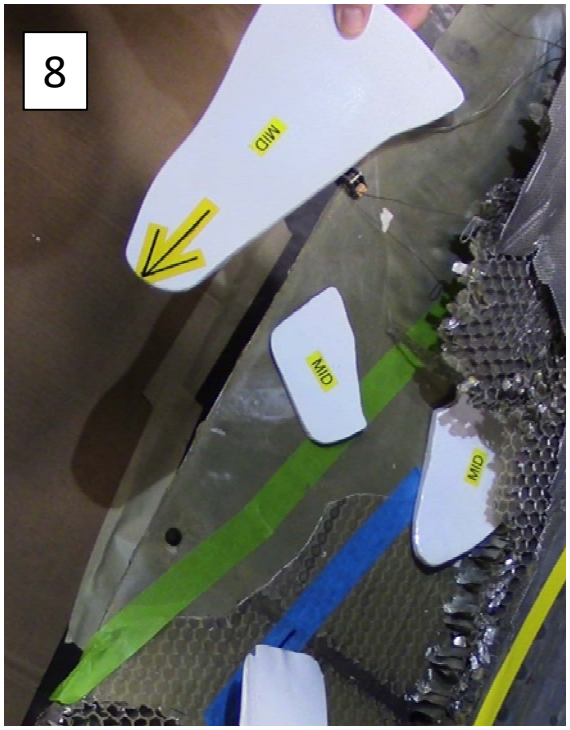
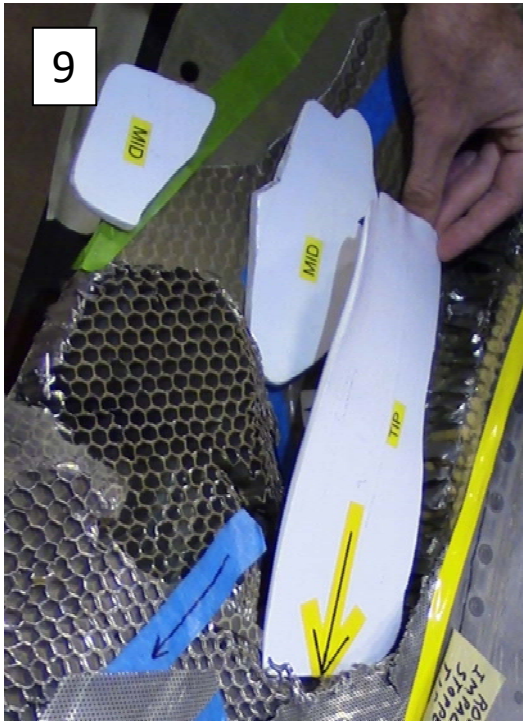
# B) Mid Fragments: Inlet Trajectory





8) Some shear inner barrel. One slides under inner core, and enters the cavity created by the tip fragment

9) Some additionally sideways collapse outer core, deflect aft, scratch back skin and slide under stopped tip fragment

10) Some are stopped as they impact ☆ and lift tip fragment

Green and blue tape shows mid fragments trajectories

# C) Root Fragment

# Fan Case and Inlet Trajectory

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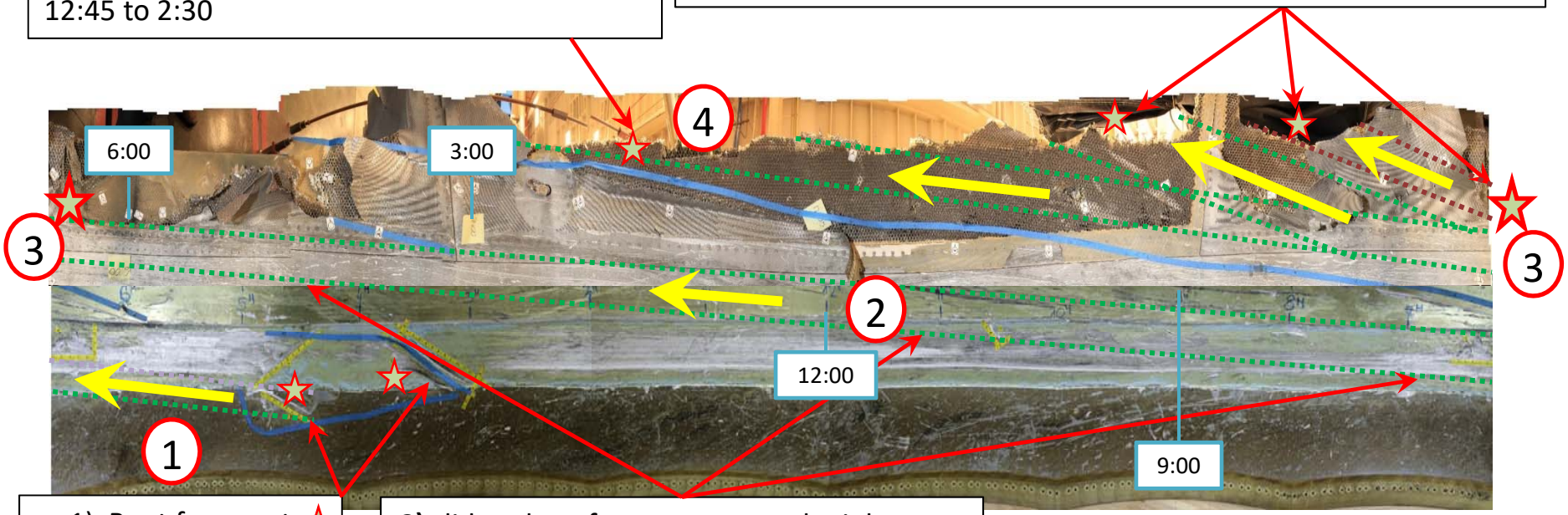
# C) Root & Tip Fragments: Fan Case and Inlet Trajectory

**4)** Remaining large root fragment continues to slide along acoustic core, penetrates ☆inner and outer core near 11:30, and shears ☆inner barrel at the containment shield edge from 12:45 to 2:30

**3)** Root impacts ☆the stopped fan tip fragment near 6:30 creating more fragments that ☆penetrate perforate skin and acoustic core and ☆shear inner barrel outer skin at containment shield edge from 7:30 to 8:30 and 9:15 to 10:15




1) Root fragment ☆ impacts fan case near 3:30 then 4:30

**2)** slides along fan case, enters the inlet near 11:00 at about 5º, and slides along attach flange and densified core for more than a full inlet revolution

# C) Root Fragment

# Fan Case Trajectory

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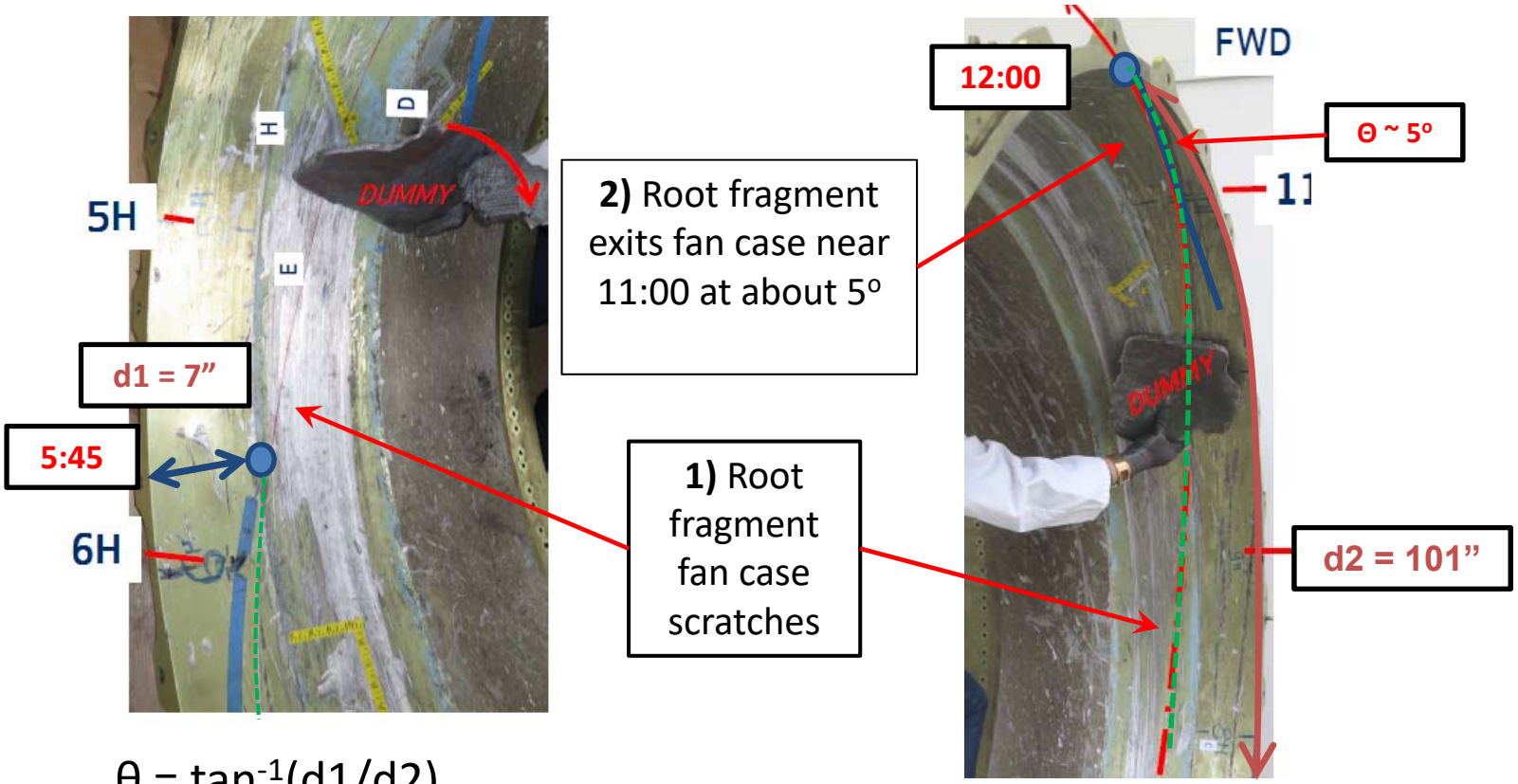
# C) Root Fragment: Fan Case Trajectory




$\theta = \tan^{-1}(d1/d2)$

$d1 = 7”$

$d2 = R * \Phi = 31 * [ (11:00 – 5:45) / 12:00 ] * (2*PI) = 101”$

$\theta = \tan^{-1}(7/85) =$ **4.7º**

# C) Root and Batted-Tip Fragments

# Inlet Trajectory

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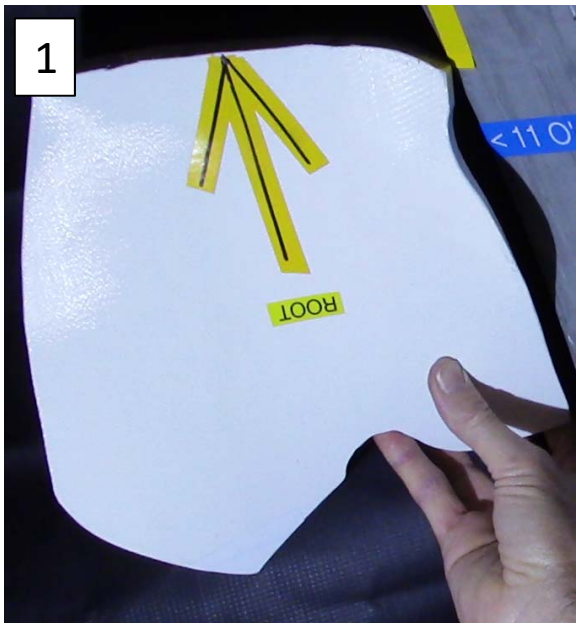
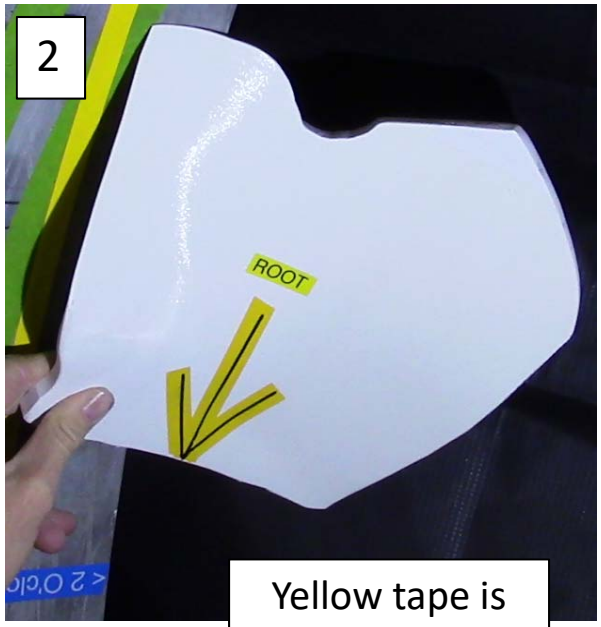
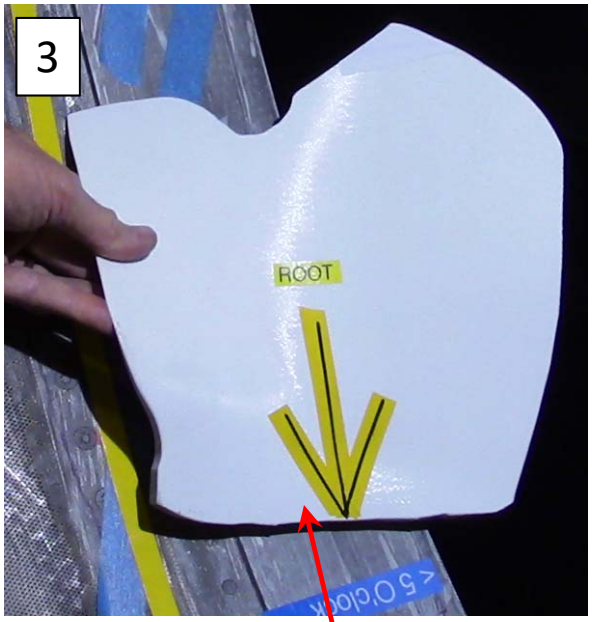
# C) Root Fragment: Inlet Trajectory




Yellow tape is root fragment trajectory




Root Fragment

1) Root fragment enters inlet near 11:00 at about 5º
2) Slides along attach flange past 2:00
3) Slides along densified core past 5:00

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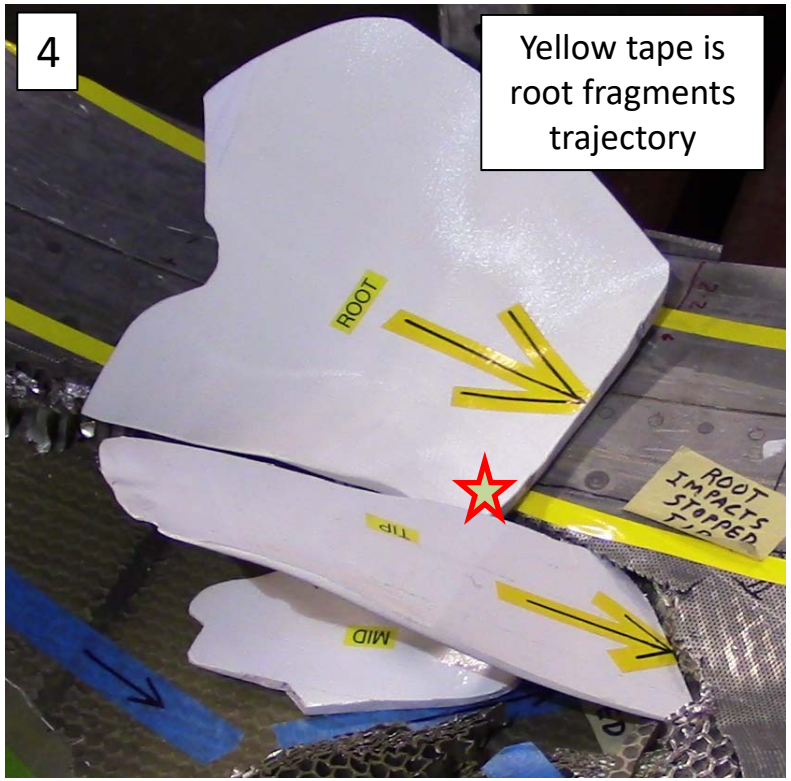
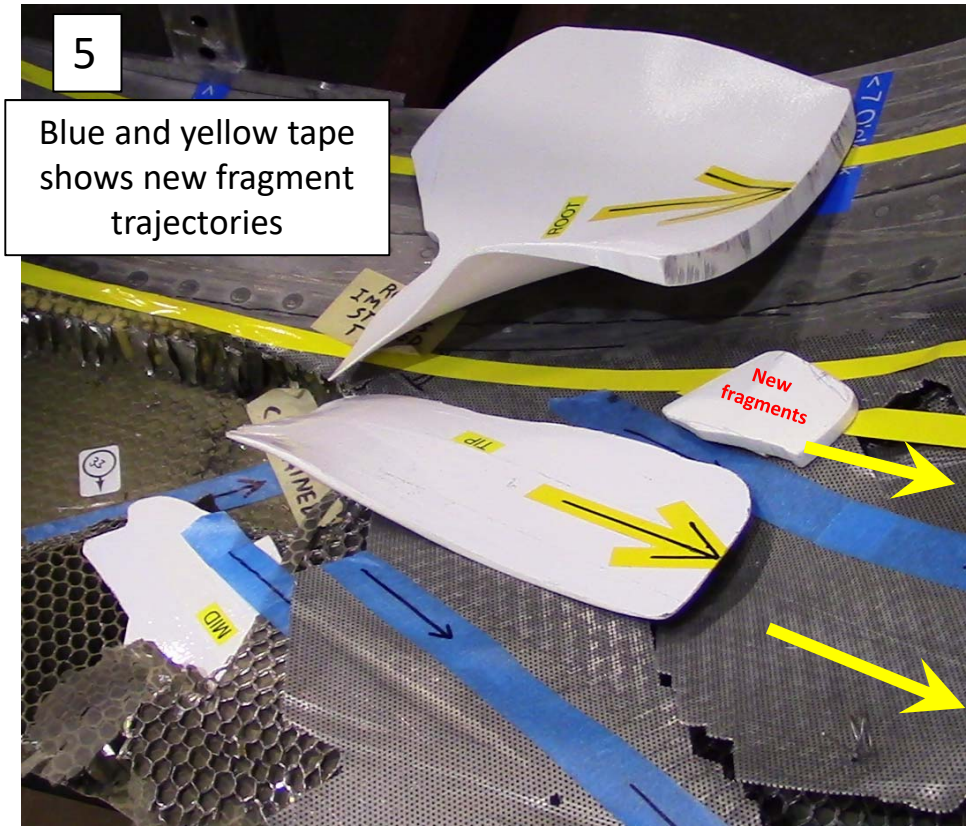
# C) Root Impacts Tip Fragment: Inlet Trajectory




4) Root fragment impacts ☆ stopped tip fragments at 6:30 creating new fragments. Remaining large root fragment continues along 5º path

5) New fragments slide between inner and outer core and across perforate skin at about 25º to 30º per scratches beginning at the impact location

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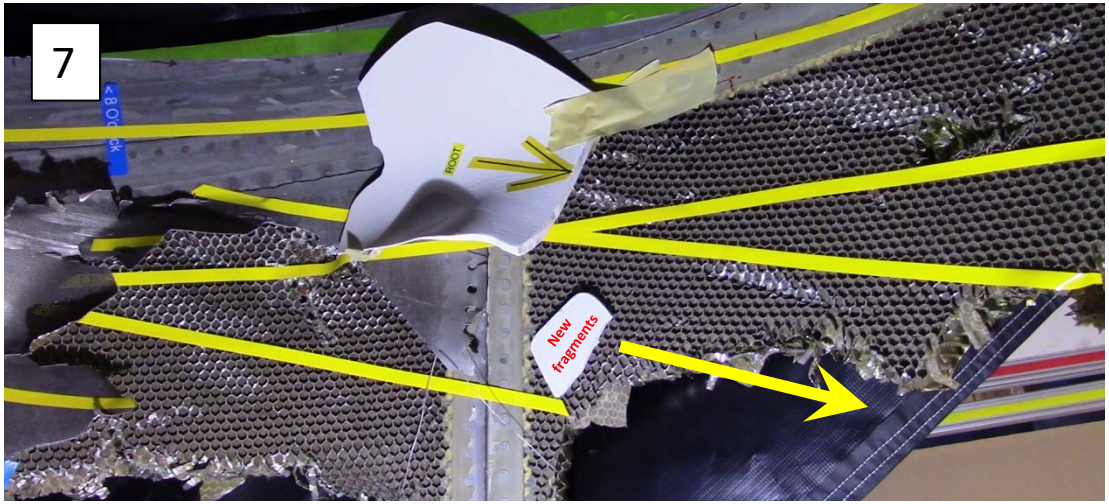
# C) Root and Tip Fragment: Inlet Trajectory


6) New fragments penetrate perforate skin, acoustic core and shear inner barrel outer skin at containment shield edge from 7:30 – 8:30

7) New fragments penetrate perforate skin, acoustic core and shear inner barrel outer skin at containment shield edge from 9:15 – 10:15




Blue and yellow tape show new fragment trajectories

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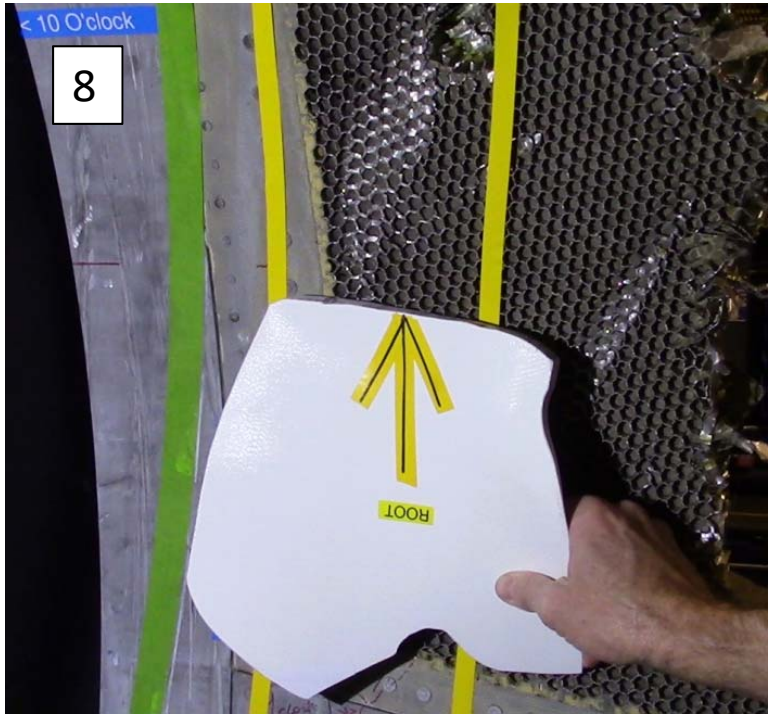
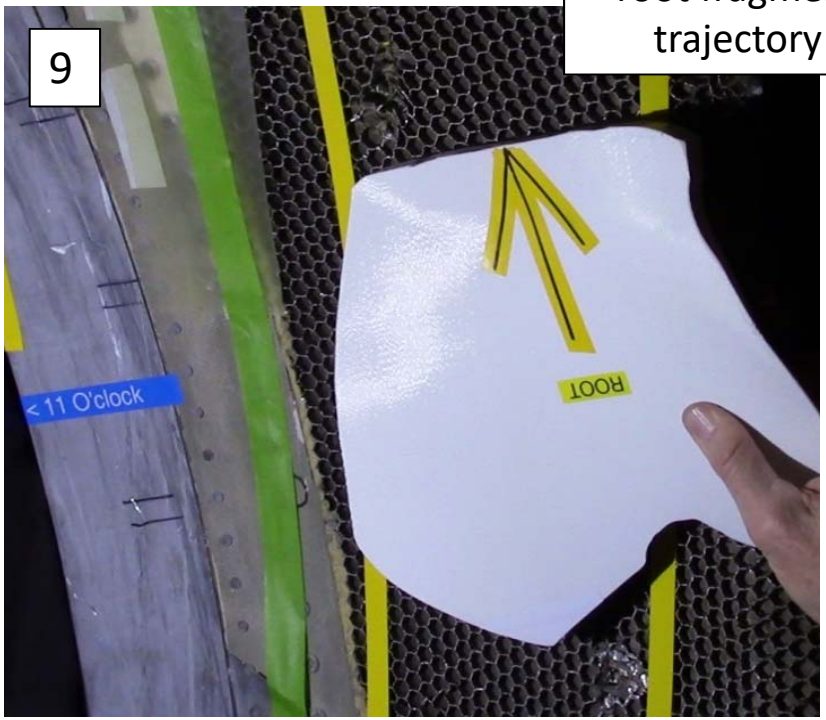
# C) Root Fragment: Inlet Trajectory

Yellow tape is root fragment trajectory




8) Remaining large root fragment slide along acoustic core past 9:00
9) Slide along acoustic core past 11:00

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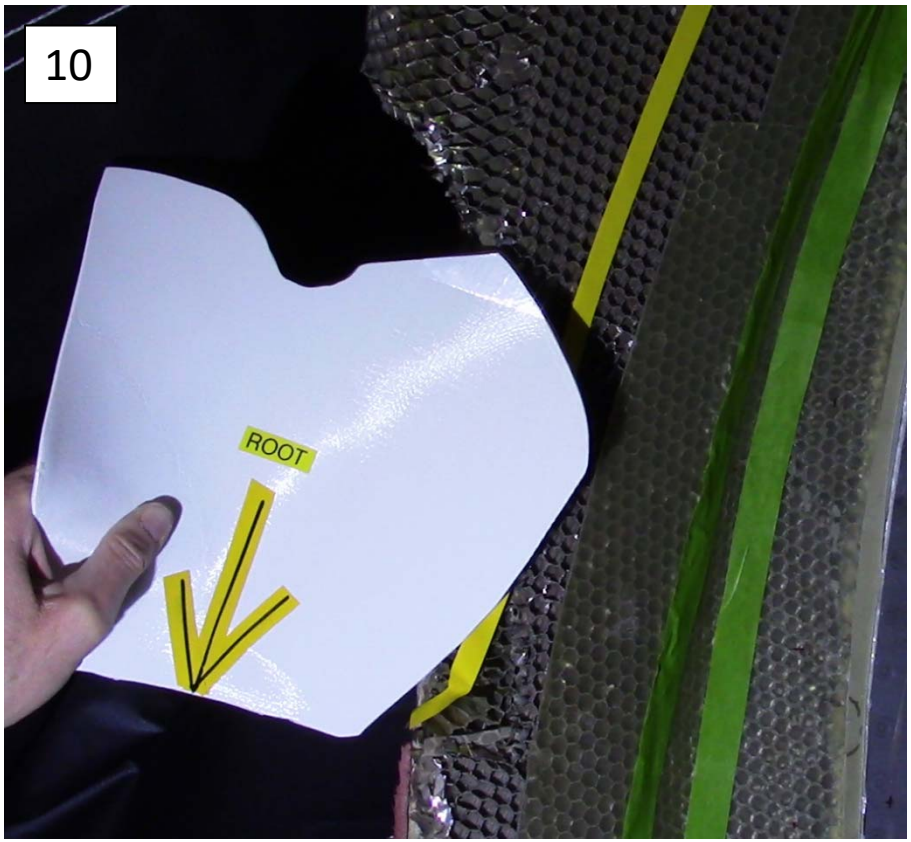
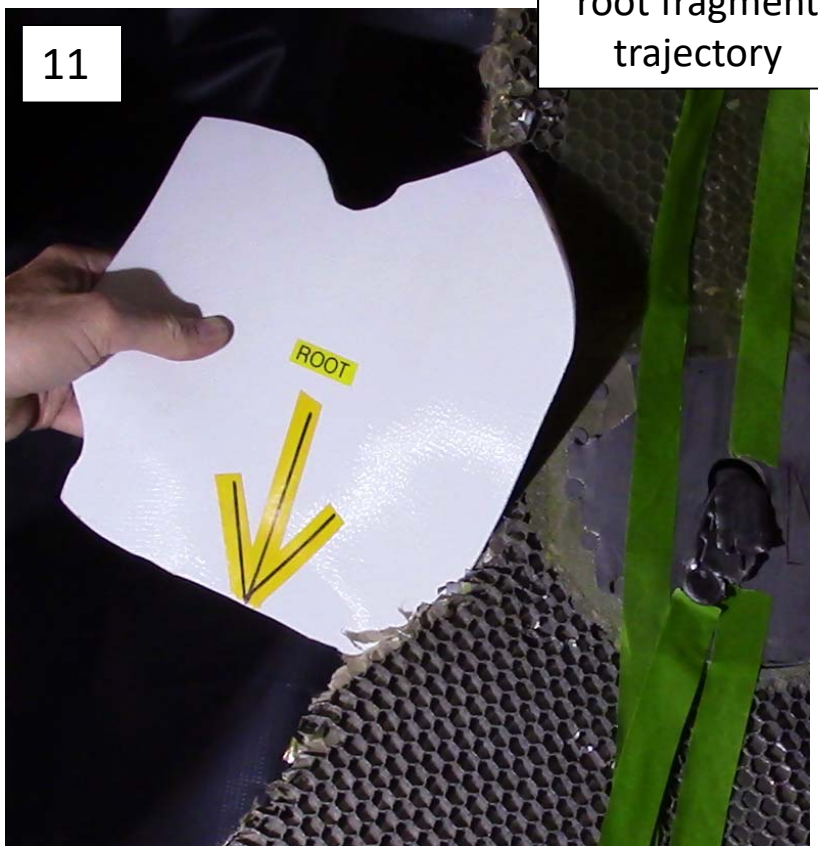
# C) Root Fragment: Inlet Trajectory

Yellow tape is root fragment trajectory




10) Penetrates inner and outer core near 12:45

11) Shears inner barrel outer skin at containment shield edge from 12:45 to 2:30

# End