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# Inspection and Teardown of Aged In-Service Bonded Repairs

2016 Technical Review

Waruna Seneviratne, John Tomblin, and Brandon Saathoff

NIAR | Wichita State University
National Institute for Aviation Research

# Inspection and Teardown of Aged In-Service Bonded Repairs

## Research Team

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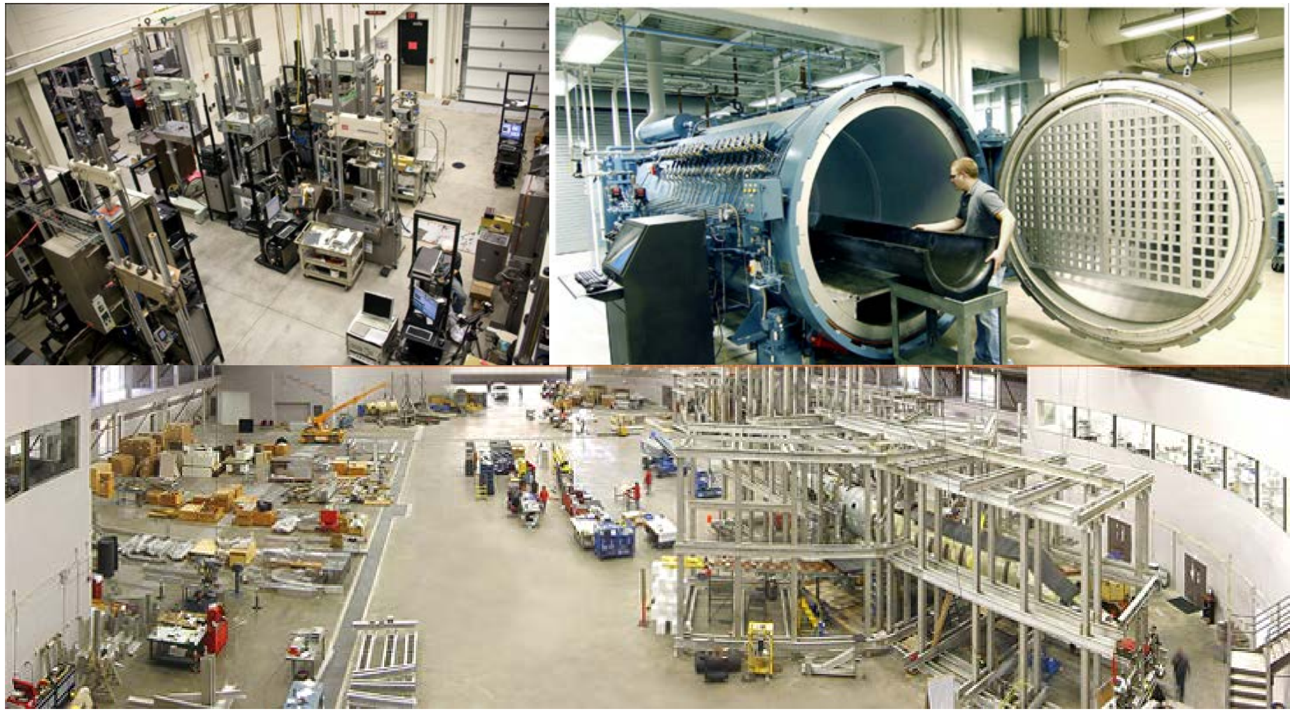


# Program Overview

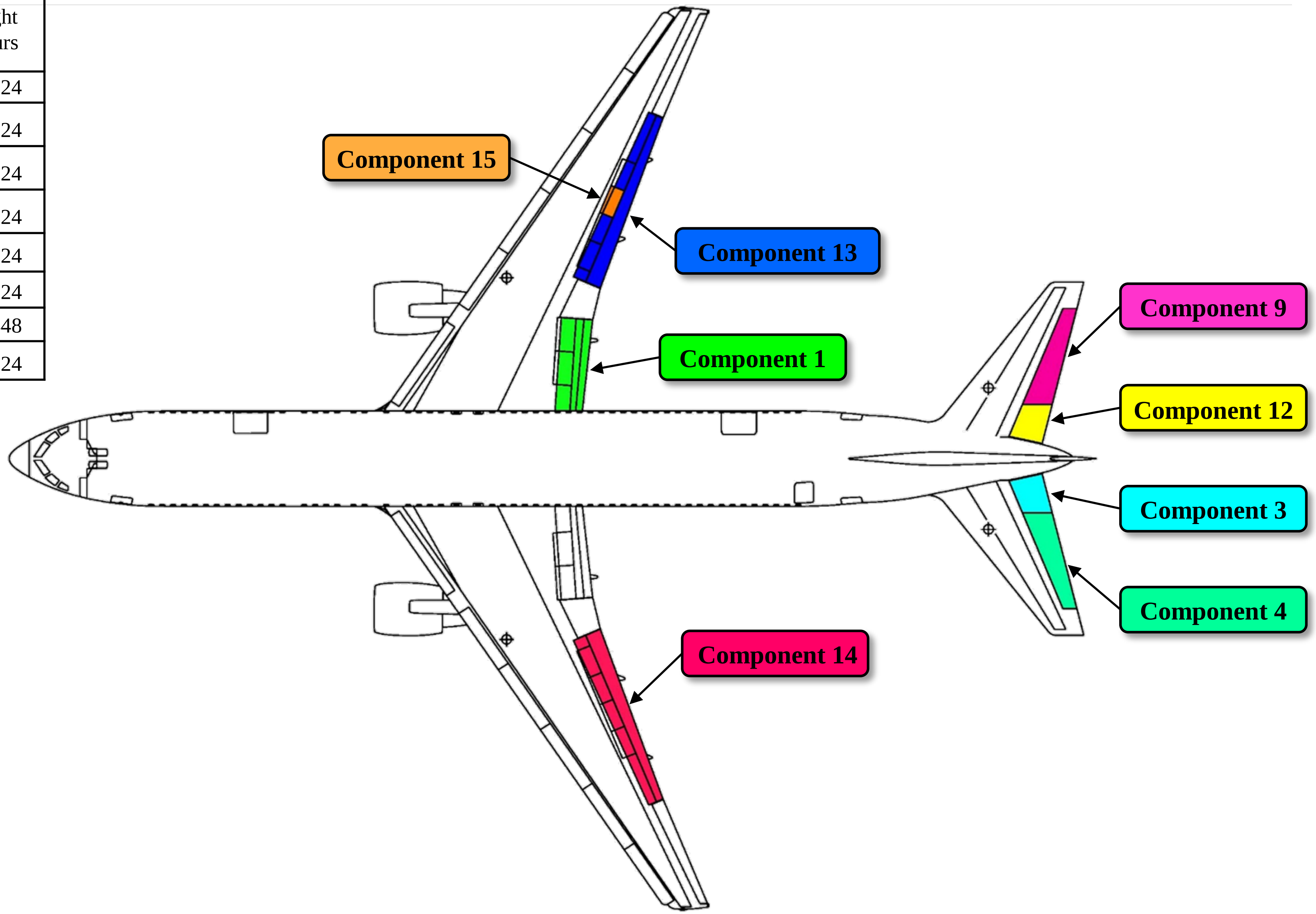
- The increased use of bonded applications in critical structures raises the concerns related to process sensitivity of the bondline, because an improperly accomplished in-service repair could become a safety threat due to weak bond that is susceptible for further degradation in an unpredictable manner due to operational environments and ground-air-ground (GAG) thermo-mechanical loads.
  - Therefore, long-term durability under operational environments and GAG loading must be understood and the aging mechanism must be investigated to support maintenance practices and to establish criteria for structural retirement.
  - Detailed nondestructive inspections (NDI), teardown inspections, and laboratory testing of bonded repairs on aircraft components that have been retired from service provide vital information related to the aging mechanism and any undetected material degradation.
  - Several decommissioned structural members, both metal and composites, with multiple repairs will be subjected to detailed inspections and cyclic loading in order to determine the remaining life of those repairs.
- The main goal of this research program is to evaluate bondline integrity and durability of in-service repairs on composite structures in commercial aircraft in order to provide guidance into AC 65-33 (Development of Training/Qualification Programs for Composite Maintenance Technicians) and AC 43-214 (Repairs and Alterations to Composite and Bonded Aircraft Structure)

# Technical Approach

- Phase 1: Acquisition of Aircraft Components with Documented Repairs
- Phase 2: Detailed inspections at Sandia National Lab (SNL)
  - Upon completion of NDI, SNL will ship components to NIAR along with detailed NDI reports.
- Phase 3:
  - Teardown inspections
    - Assess the quality of the bonded repairs
  - Document findings related to repair integrity and viability on NDI methods
  - Detailed inspections, strain surveys, and material testing during cyclic testing of component/element testing are intended to provide insight into assessing current standard inspection methods to detect material degradation/wearout.
- Phase 4: Documentation of findings
  - Research team will engage in CACRC and CMH-17 activities related to guidance materials and training/qualification programs for composite maintenance technicians and certification approaches

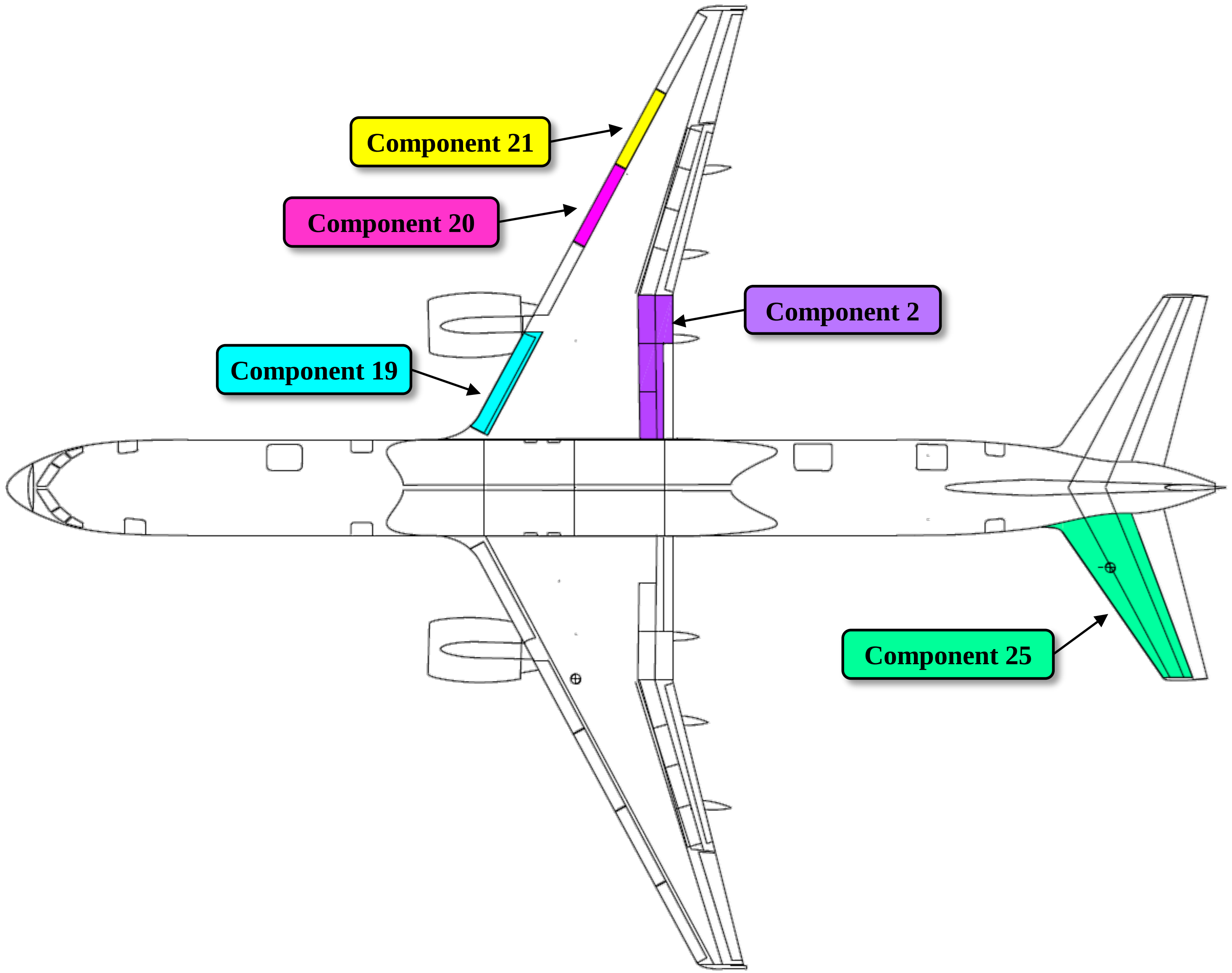
# B767-300 Components

| Component # | Tail # | Repaired Component | Flight Hours |
|---|---|---|---|
| 1 | N135DL | Elevator, Left O/B | 13,324 |
| 7 | N135DL | Elevator, Left I/B | 13,324 |
| 2 | N135DL | Elevator, Right I/B | 13,324 |
| 3 | N135DL | Elevator, Right O/B | 13,324 |
| 4 | N135DL | Spoiler, NR 11 | 13,324 |
| 5 | N135DL | Flap, Left O/B | 13,324 |
| 6 | N135DL | Flap, Right I/B | 13,448 |
| 10 | N135DL | Flap, Right O/B | 13,324 |

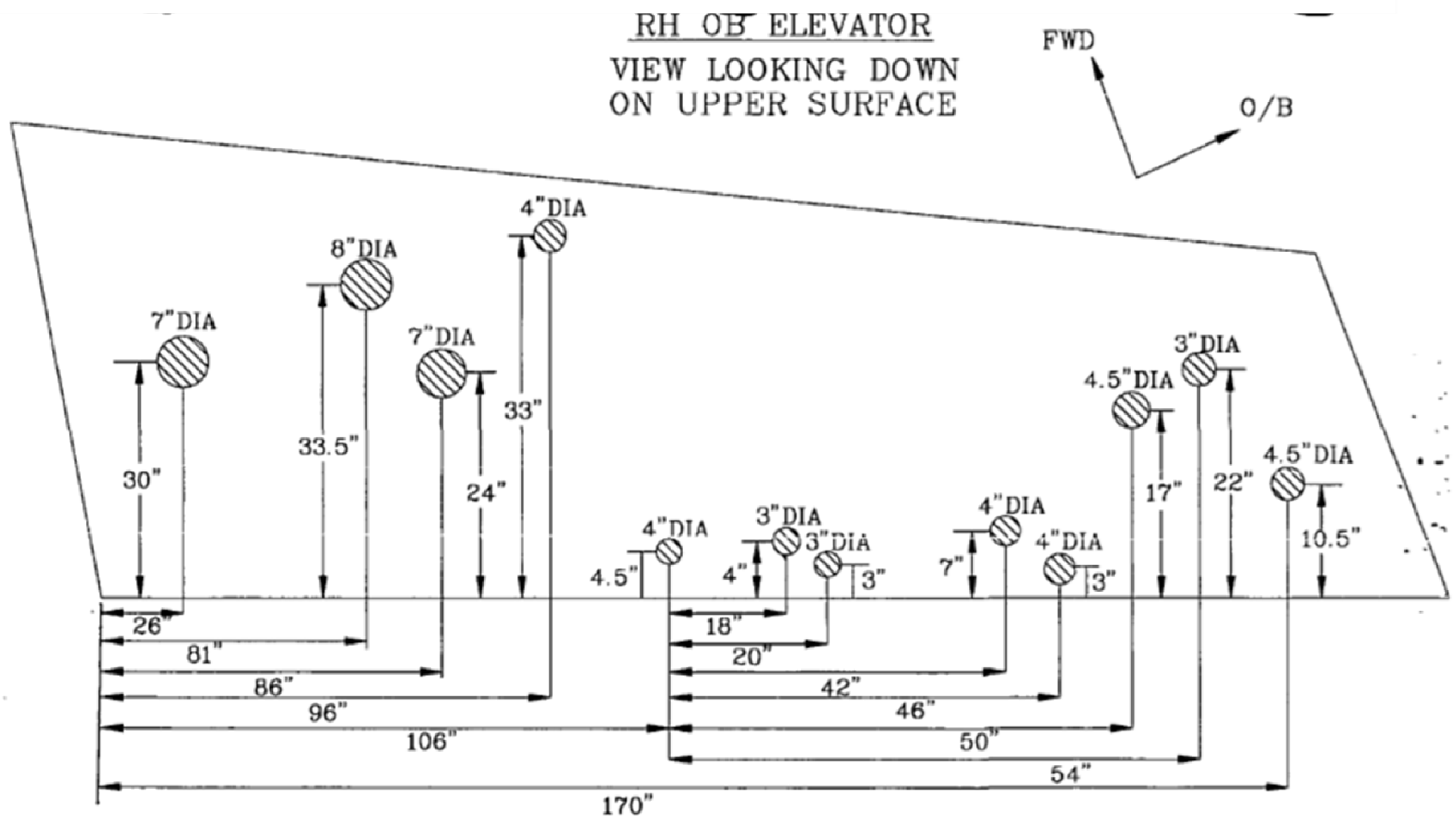


# B757-200 Components

| Component # | Tail # | Repaired Component | Flight Hours |
|---|---|---|---|
| 8 | N531US | Slat, NR 9* | 72,679 |
| 9 | N503US | Slat, NR 6 | 85,359 |
| 11 | N531US | Slat, NR 8* | 72,679 |
| 12 | N629DL | Horizontal Stabilizer | 75,316 |
| 30 | N648DL | Flap, Right I/B | |



# Review Engineering Repair Authorization Forms




| | |
|---|---|
| **Host material:** | Graphite |
| **Repair material:** | Graphite |
| **Repair structure:** | Sandwich |
| **Total Repairs:** | 11 |

# Component – 1st Shipment to NIAR

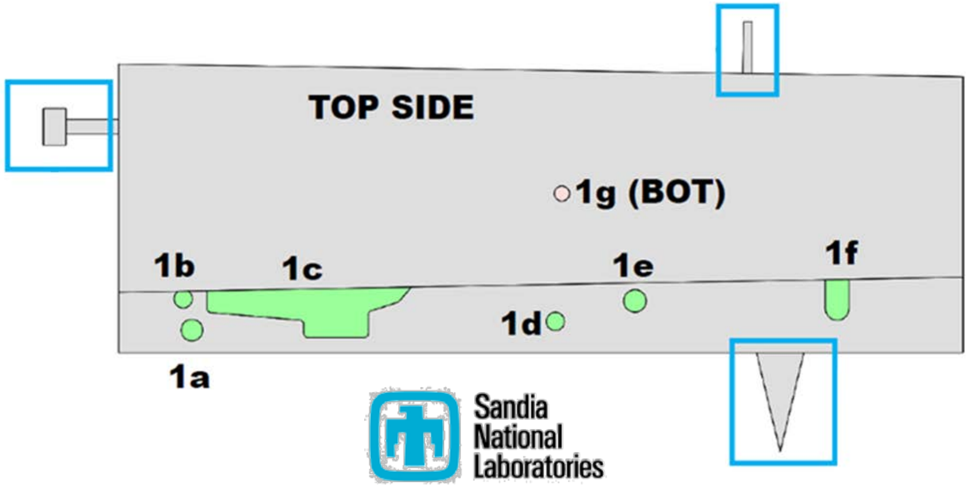
- NIAR received Components *1, 2, 13, and 14* from Sandia
  - Need to discuss receiving NDI results from Sandia on these components so that educated decisions can be made on a detailed test plan
  - Lacking SRM's for B757-200 components

| Component No. (Sandia Naming) | Tail No. | Aircraft | Aircraft Construction No. (MSN) | Aircraft Line No. | Repaired Component |
|---|---|---|---|---|---|
| **1** | **N135DL** | B767-300 | 25145 | 356 | Flap, Right I/B |
| **2** | **N648DL** | B757-200 | 24372 | 223 | Flap, Right I/B |
| **3** | **N135DL** | B767-300 | 25145 | 356 | Elevator, Left I/B |
| **4** | **N135DL** | B767-300 | 25145 | 356 | Elevator, Left O/B |
| **9** | **N135DL** | B767-300 | 25145 | 356 | Elevator, Right O/B |
| **12** | **N135DL** | B767-300 | 25145 | 356 | Elevator, Right I/B |
| **13** | **N135DL** | B767-300 | 25145 | 356 | Flap, Right O/B |
| **14** | **N135DL** | B767-300 | 25145 | 356 | Flap, Left O/B |
| **15** | **N135DL** | B767-300 | 25145 | 356 | Spoiler, NR 11 |
| **19** | **N503US** | B757-200 | 23192 | 59 | Slat, NR 6 |
| **20** | **N531US** | B757-200 | 23846 | 190 | Slat, NR 8 |
| **21** | **N531US** | B757-200 | 23846 | 190 | Slat, NR 9 |
| **25** | **N629DL** | B757-200 | 22919 | 134 | Horizontal Stabilizer Section |

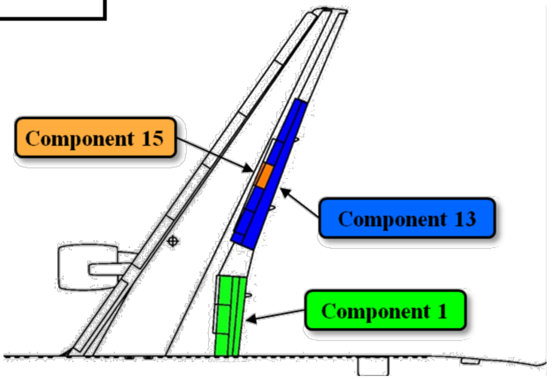
# Component 1

## B767-300 Flap, Right I/B

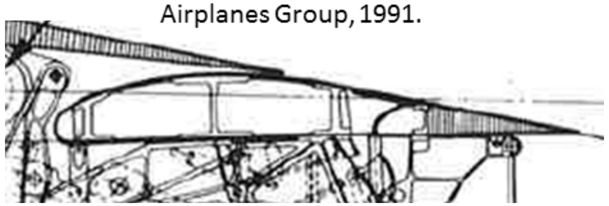
| Component 1 (767-300) | | | | | |
|---|---|---|---|---|---|
| Repair | Size | Host Skin Material | Host Core Material | Repair Material | Location |
| 1a | ≈ Ø5.00" | 2024-T3 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum | Top Side |
| 1b | ≈ Ø4.25" | 2024-T3 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum | Top Side |
| 1c | ≈ 47.5" x 11.0" | 2024-T3 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum | Top Side |
| 1d | ≈ Ø4.25" | 2024-T3 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum | Top Side |
| 1e | ≈ Ø5.25" | 2024-T3 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum | Top Side |
| 1f | ≈ 9.5" x 5.5" | 2024-T3 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum | Top Side |
| 1g | ≈ Ø3.50" | 2024-T3 Aluminum w/ Aramid Epoxy Outer Plies | Aluminum Honeycomb | 2024-T3 Aluminum w/ Aramid Epoxy Outer Plies | Bottom Side |




Sandia National Laboratories




*767 Structures*, Boeing Commercial Airplanes Group, 1991.



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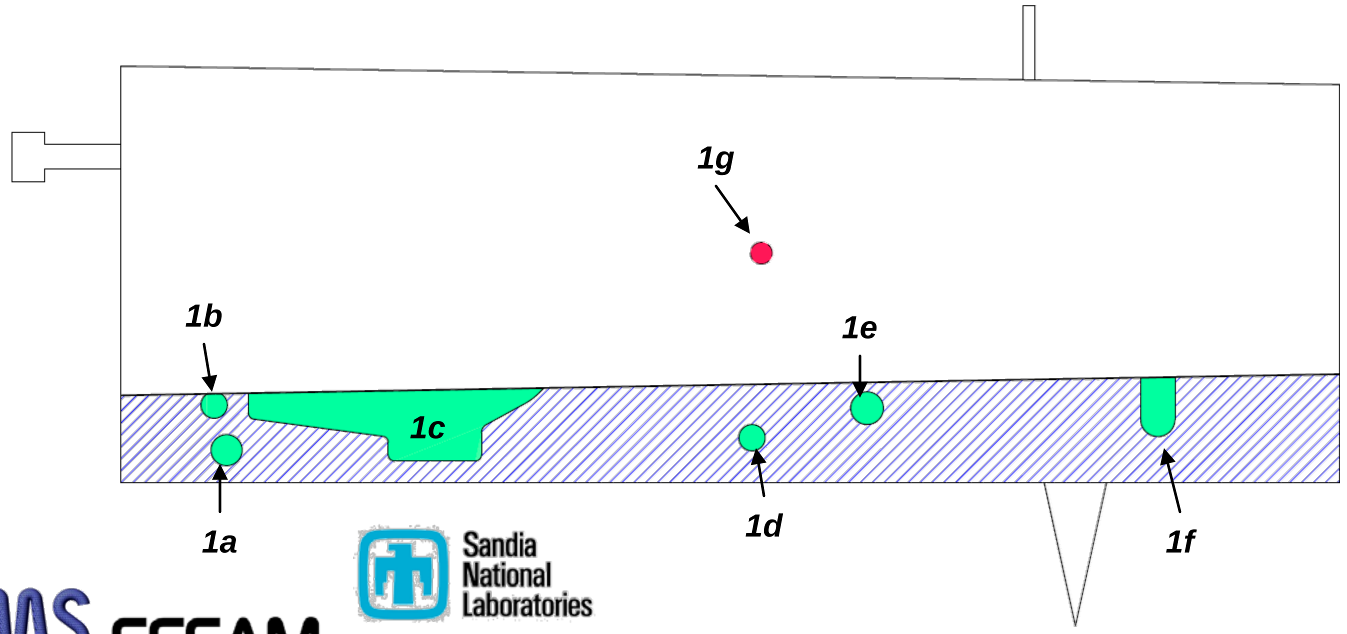
CECAM center of excellence for composites and advanced materials

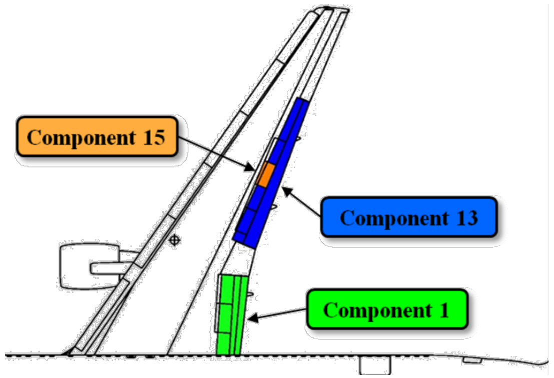
# Component 1 – B767-300 I/B Flap (RH)

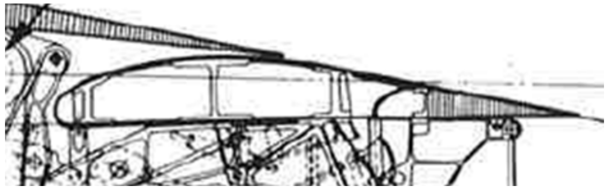
- *7 Repairs*

| Component 1 (767-300) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Repair | Location | Size | Host Skin Material | Host Core Material | Host Film Adhesive | Repair Material | Repair Core | Repair Film Adhesive |
| 1a | Top Skin | ≈ Ø5.00" | 2024-T3 Aluminum | Aluminum | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 1b | Top Skin | ≈ Ø4.25" | 2024-T3 Aluminum | Aluminum | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 1c | Top Skin | ≈ 47.5" x 11.0" | 2024-T3 Aluminum | Aluminum | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 1d | Top Skin | ≈ Ø4.25" | 2024-T3 Aluminum | Aluminum | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 1e | Top Skin | ≈ Ø5.25" | 2024-T3 Aluminum | Aluminum | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 1f | Top Skin | ≈ 9.5" x 5.5" | 2024-T3 Aluminum | Aluminum | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 1g | Lower Skin | ≈ Ø3.50" | 2024-T3 Aluminum w/ Aramid Epoxy Outer Plies | Aluminum Honeycomb | - | 2024-T3 Aluminum w/ Aramid Epoxy Outer Plies | Aluminum Honeycomb | AF163-2K / EA 9657 |




Top Skin Repair
Bottom Skin Repair
Bottom Skin Disbond
Extraction Region

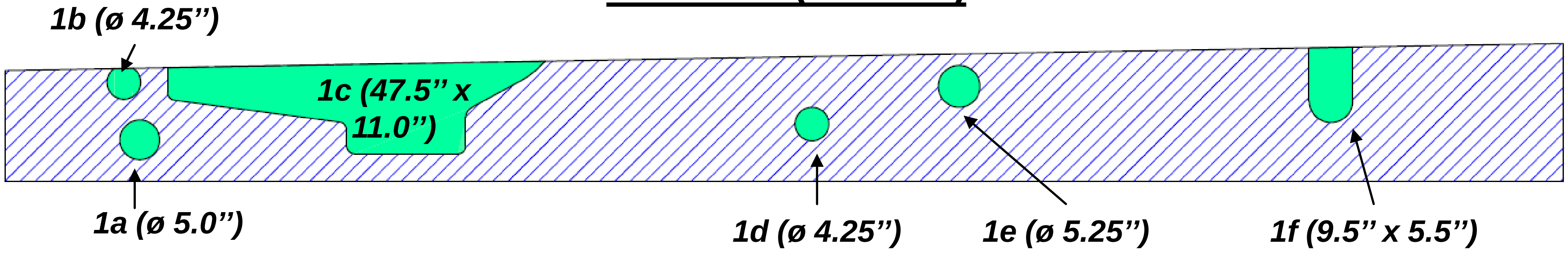


# Component 1 – Subpanel Extraction (Metallic)

- *Need to verify if Aramid/Epoxy outer ply exists on lower skin.*
  - *If this is the case, repair 1g will not be considered.*
  - *These repairs have significant curvature near leading edge.*

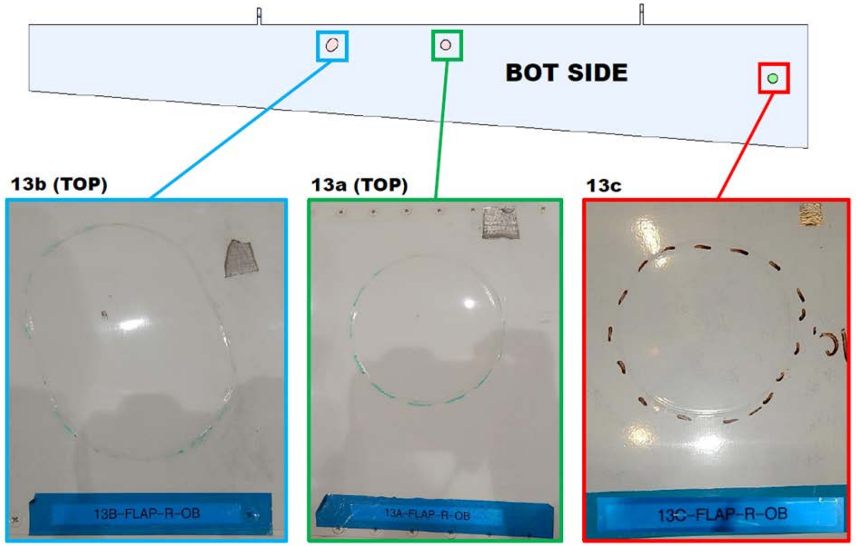
**Section 1 (Metallic)**

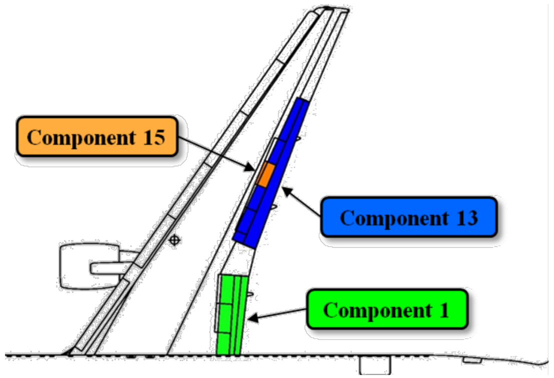


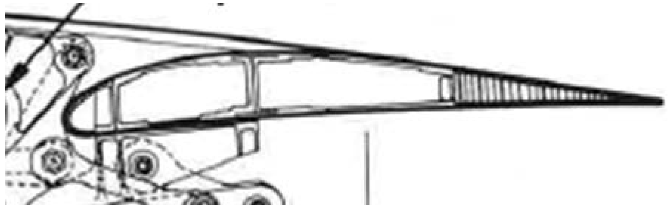
# Component 13

## B767-300 Flap, Right O/B

| Component 13 (767-300) | | | | | |
|---|---|---|---|---|---|
| Repair | Size | Host Skin Material | Host Core Material | Repair Material | Location |
| 13a | ≈ Ø4.75" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 13b | ≈ 6.5" x 4.75" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 13c | ≈ Ø4.50" | 2024-T3 Aluminum, 7075-T6 Aluminum | Aluminum Honeycomb | 2024-T3 Aluminum, 7075-T6 Aluminum (non-clad) | Bottom Side |



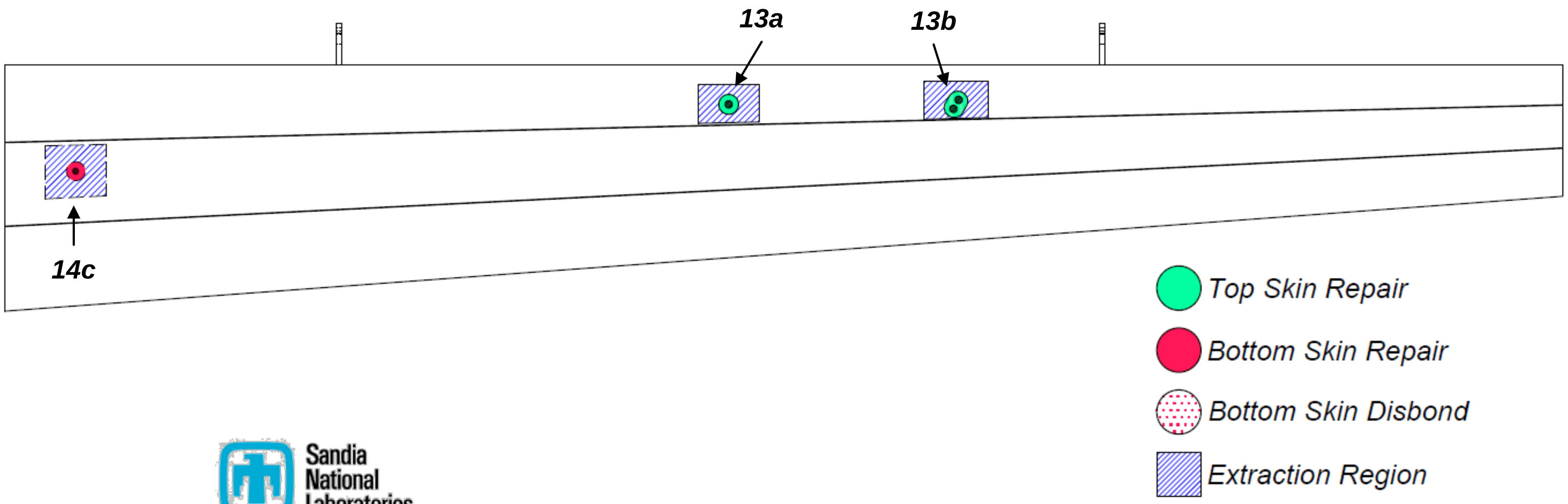



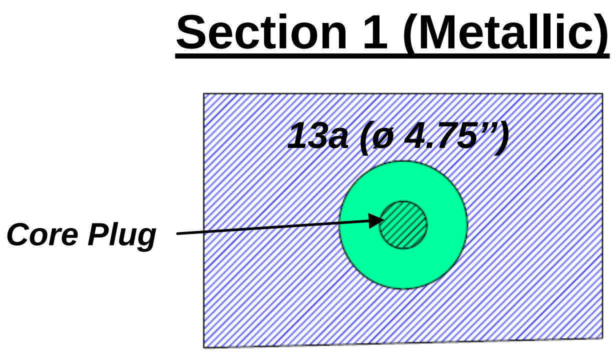
# Component 13 – B767-300 O/B Flap (RH)

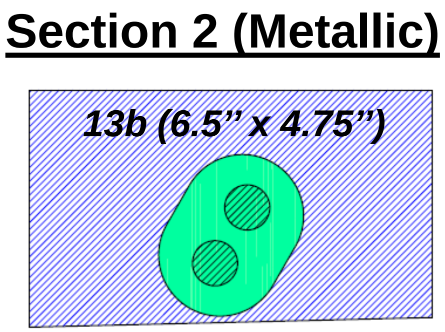
- *3 Repairs*

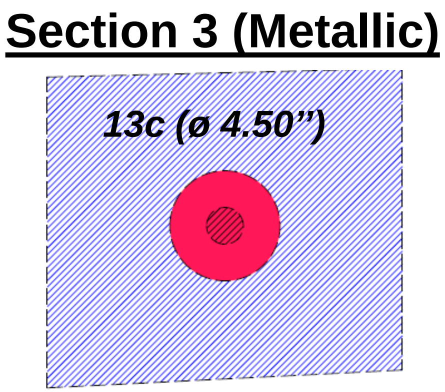
| Component 13 (767-300) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Repair | Location | Size | Host Skin Material | Host Core Material | Host Film Adhesive | Repair Material | Repair Core | Repair Film Adhesive |
| 13a | Top Skin | ≈ Ø4.75" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 13b | Top Skin | ≈ 6.5" x 4.75" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 13c | Lower Skin | ≈ Ø4.50" | 2024-T3 Aluminum | Aluminum Honeycomb | - | 2024-T3 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |



# Component 13 - Subpanel Extractions



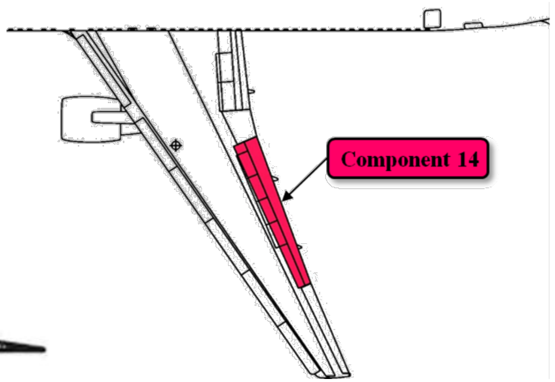



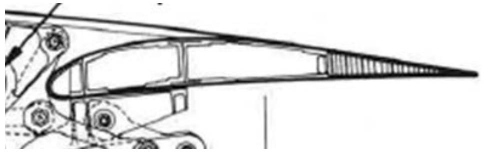



# Component 14

## B767-300 Flap, Left O/B

| Component 14 (767-300) | | | | | |
|---|---|---|---|---|---|
| Repair | Size | Host Skin Material | Host Core Material | Repair Material | Location |
| 14a | ≈ Ø5.50" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 14b | ≈ Ø6.00" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 14c | ≈ 9.5" x 6.0" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 14d | ≈ 10.5" x 7.0" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 14e | ≈ Ø7.00" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 14f | ≈ Ø6.00" | 7075-T6 Aluminum | Aluminum Honeycomb | 7075-T6 Aluminum (non-clad) | Top Side |
| 14g | ≈ 60" x 19" | Fiberglass/Epoxy (TE Wedge Assembly Only) | Nomex Honeycomb | Fiberglass/Epoxy (TE Wedge Assembly Only) | Bottom Side |
| 14h | ≈ 23" x 10" | Fiberglass/Epoxy (TE Wedge Assembly Only) | Nomex Honeycomb | Fiberglass/Epoxy (TE Wedge Assembly Only) | Bottom Side |

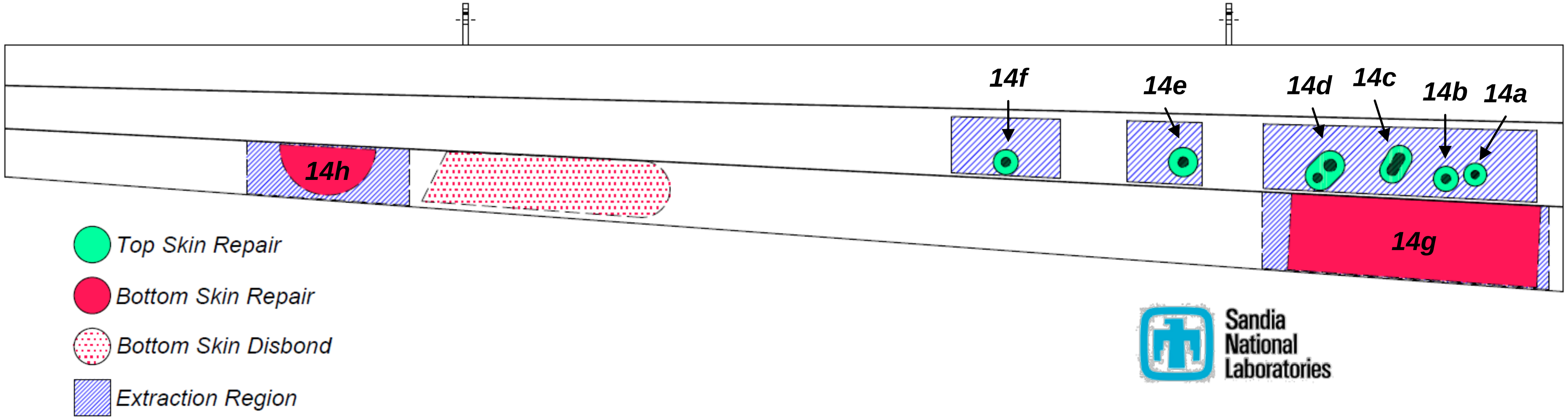



*767 Structures*, Boeing Commercial Airplanes Group, 1991.

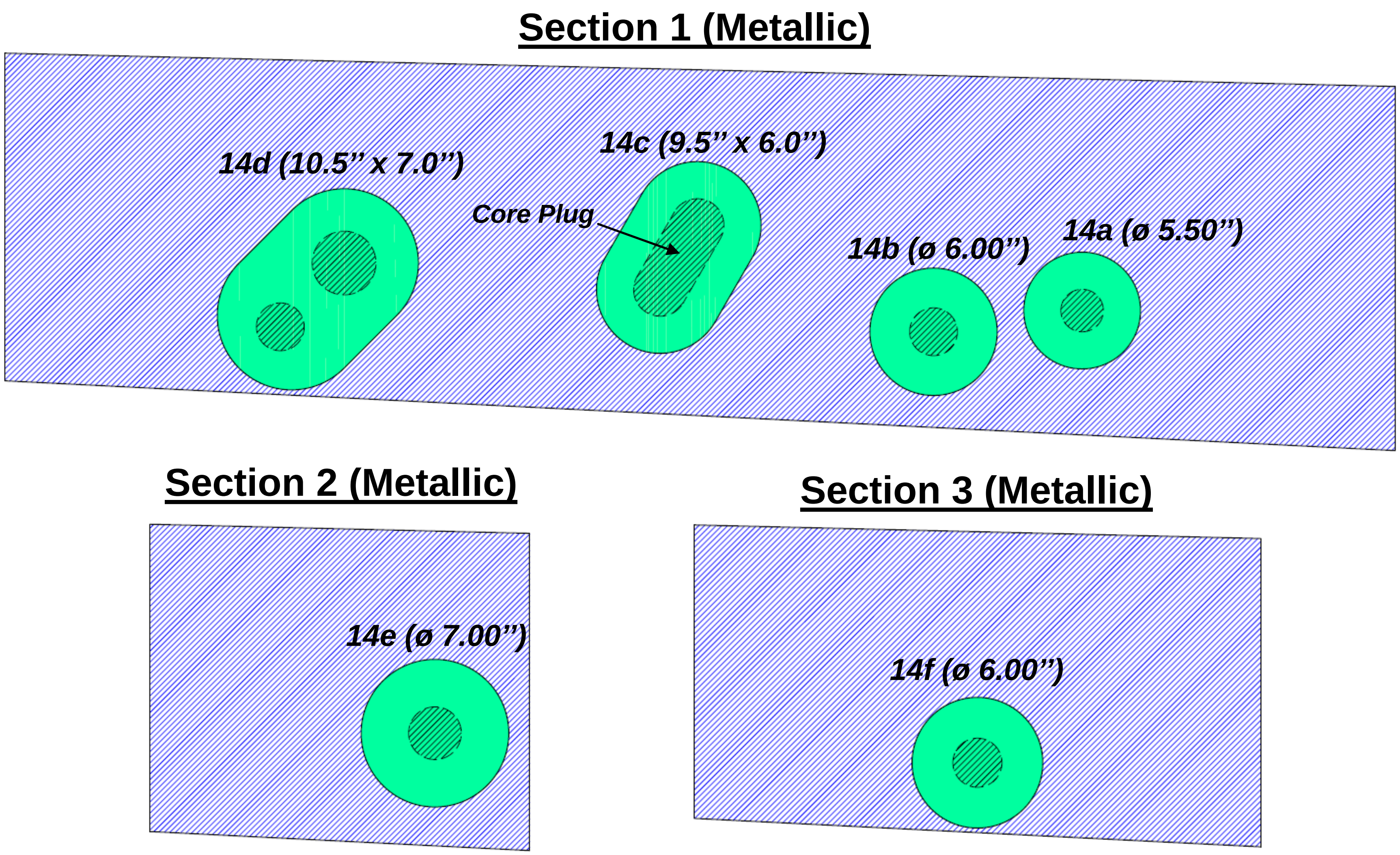
# Component 14 – B767-300 O/B Flap (LH)

- *8 Repairs*

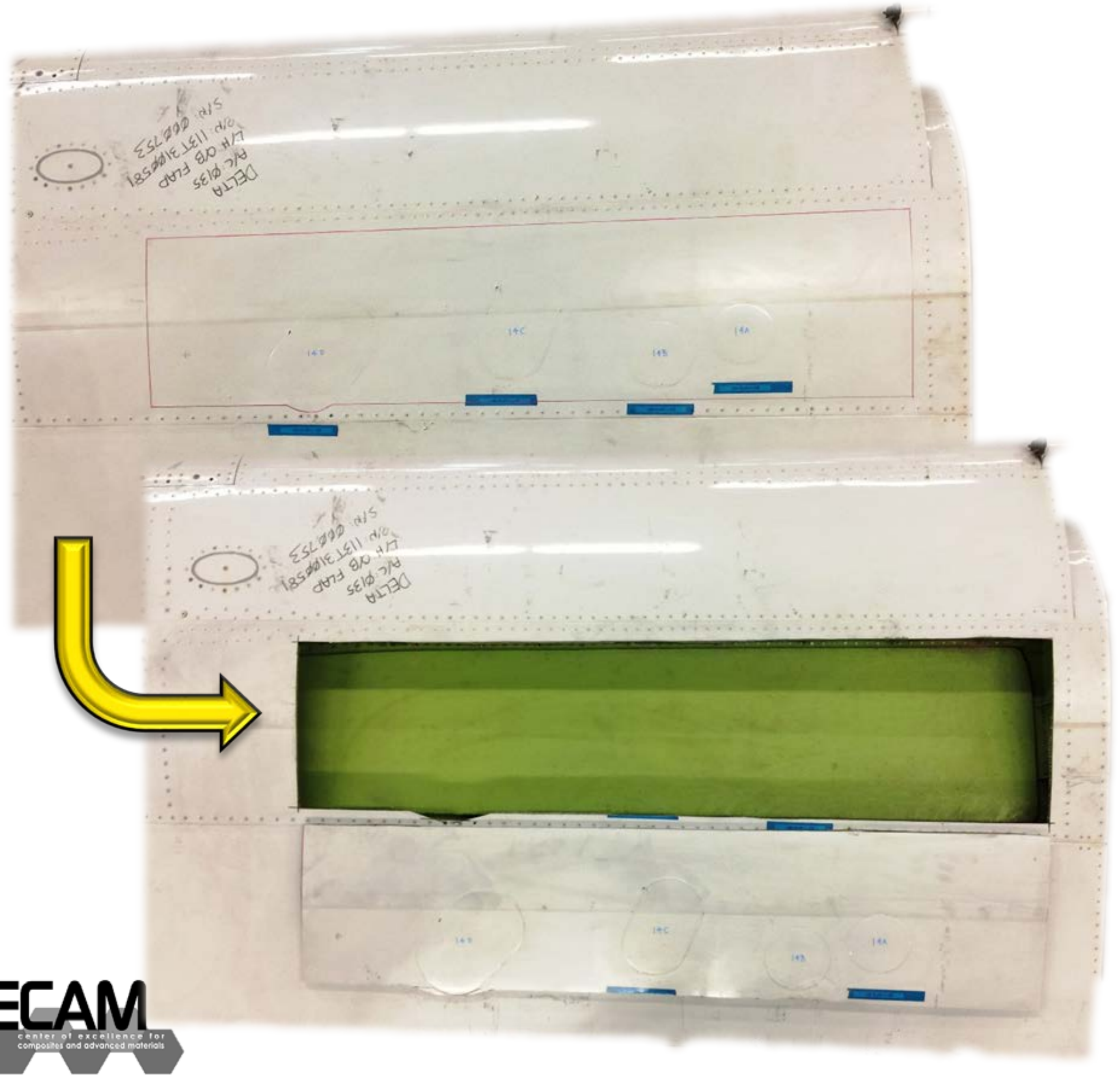
| Component 14 (767-300) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Repair | Location | Size | Host Skin Material | Host Core Material | Host Film Adhesive | Repair Material | Repair Core | Repair Film Adhesive |
| 14a | Top Skin | ≈ Ø5.50" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 14b | Top Skin | ≈ Ø6.00" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 14c | Top Skin | ≈ 9.5" x 6.0" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 14d | Top Skin | ≈ 10.5" x 7.0" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 14e | Top Skin | ≈ Ø7.00" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 14f | Top Skin | ≈ Ø6.00" | 7075-T6 Aluminum | Aluminum Honeycomb | - | 7075-T6 Aluminum | Aluminum Honeycomb | AF163-2K / EA 9657 |
| 14g | Lower Skin on TE Wedge | ≈ 60" x 19" | Fiberglass/Epoxy | Nomex Honeycomb | - | Fiberglass/Epoxy | Nomex Honeycomb | Wet Layup |
| 14h | Lower Skin on TE Wedge | ≈ 23" x 10" | Fiberglass/Epoxy | Nomex Honeycomb | - | Fiberglass/Epoxy | Nomex Honeycomb | Wet Layup |

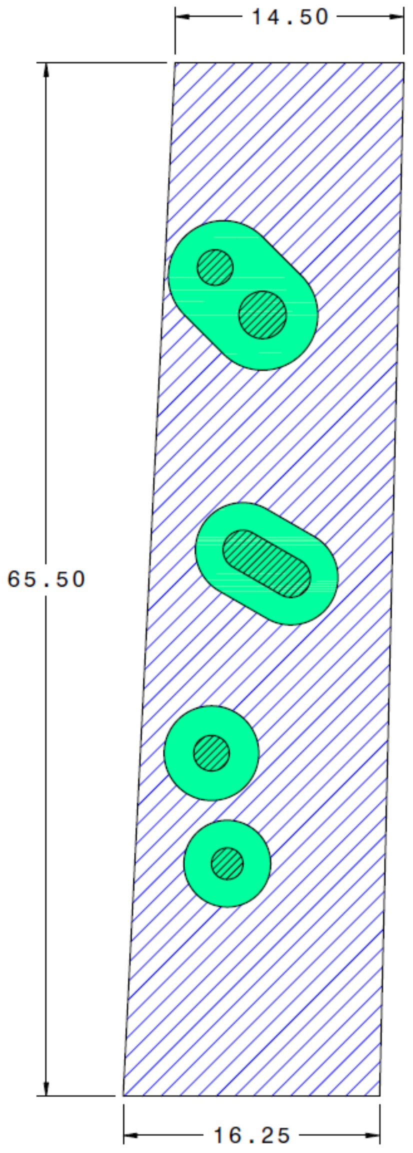


# Component 14 - Subpanel Extractions

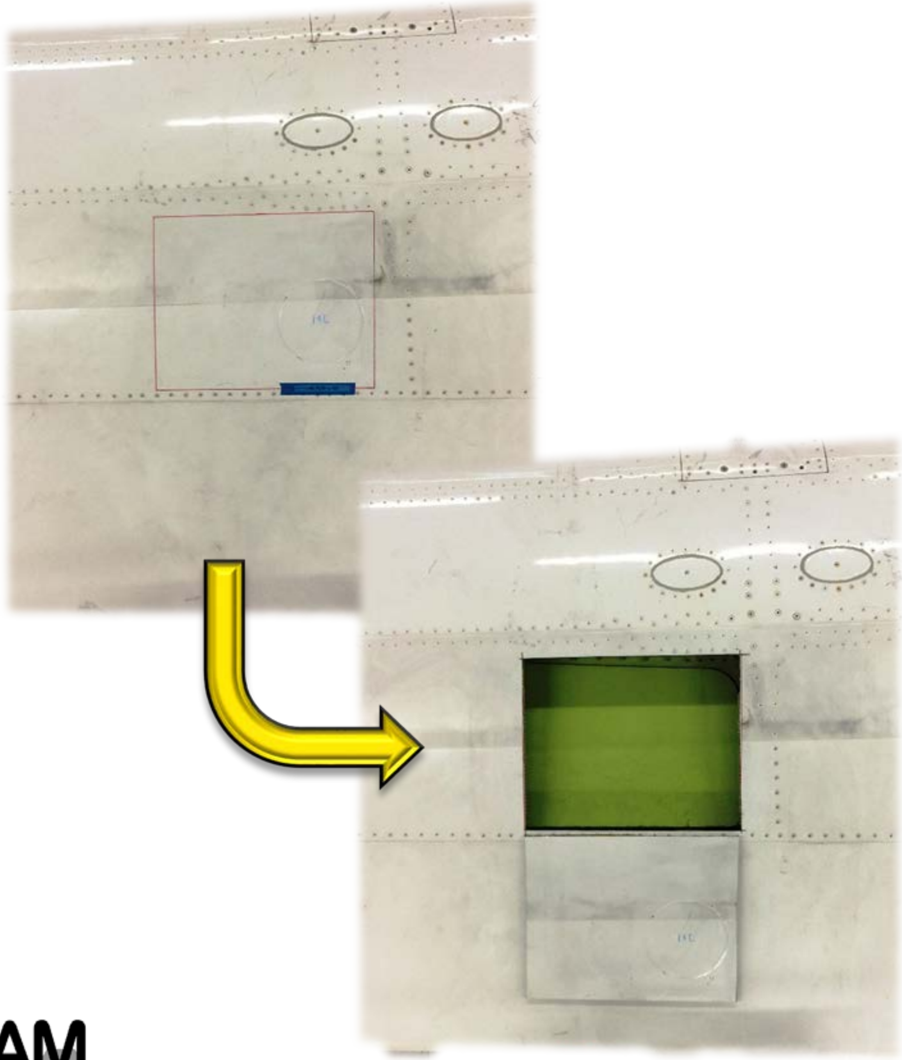


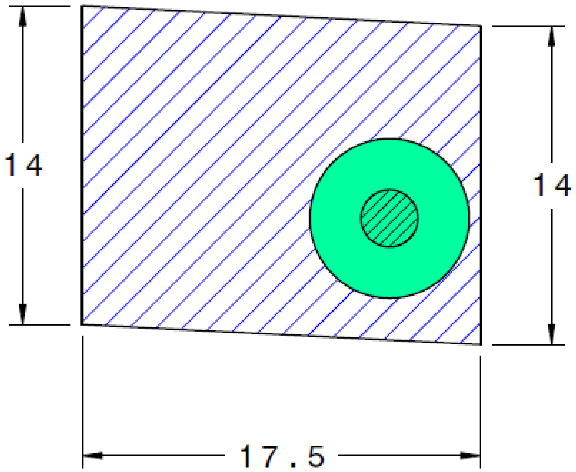
# Component 14 – Section 1



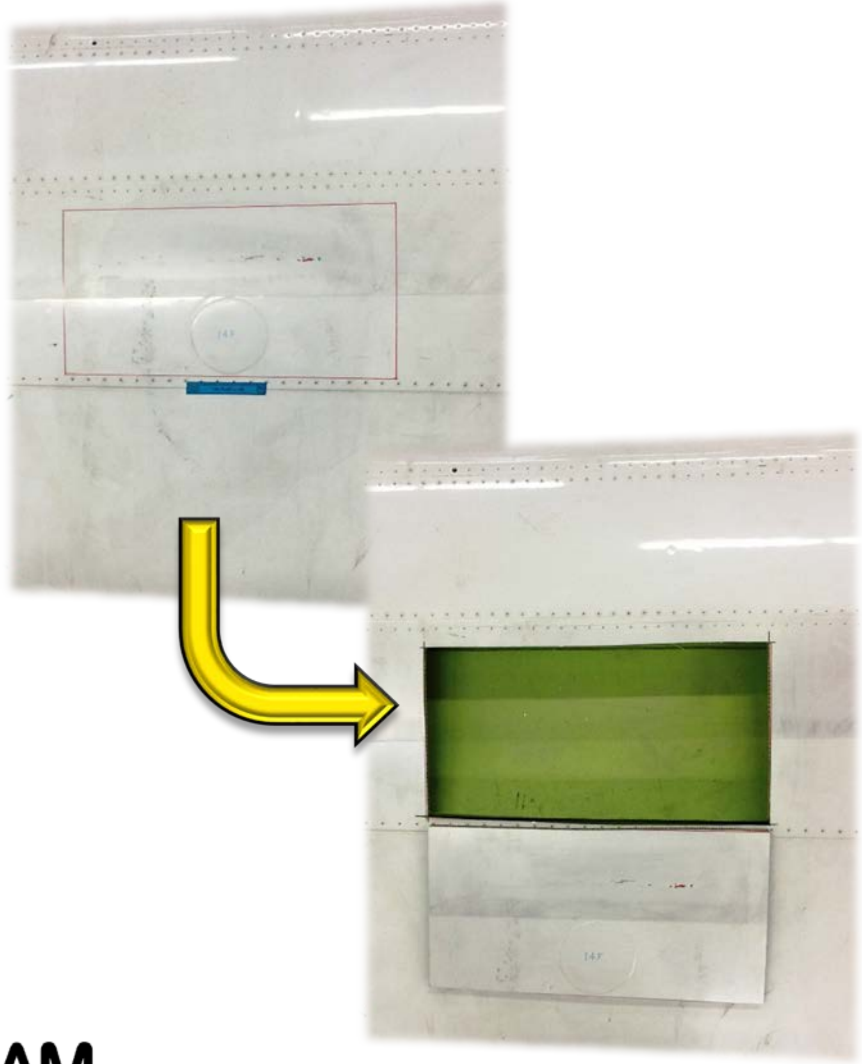


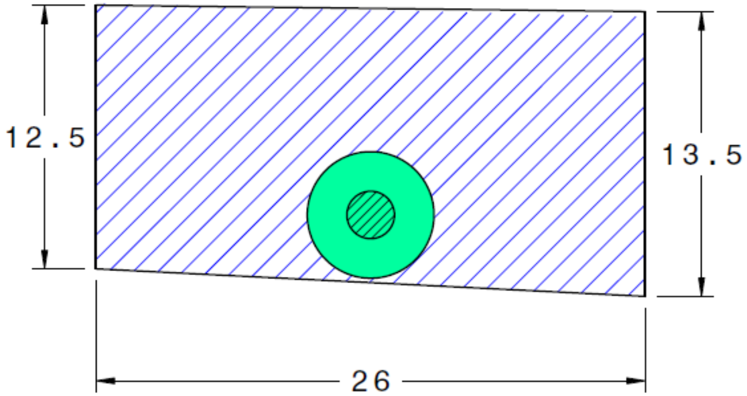
# Component 14 – Section 2



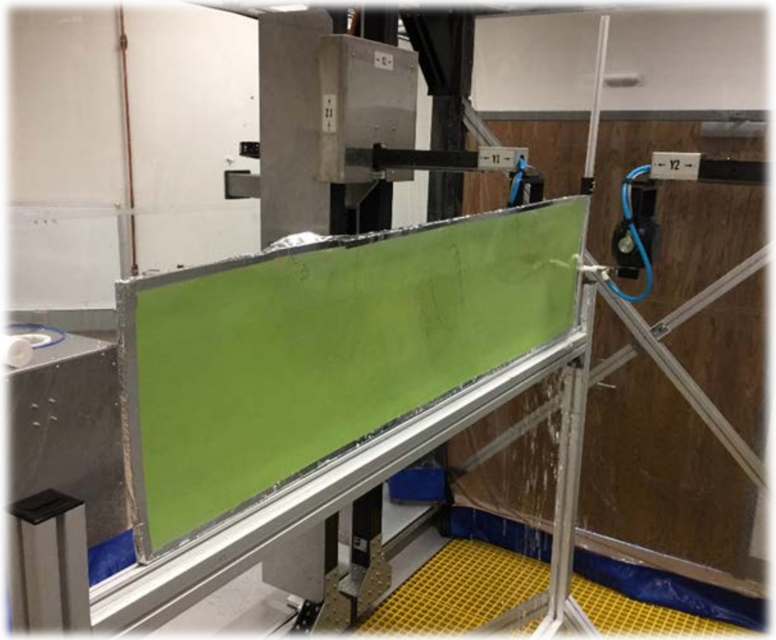


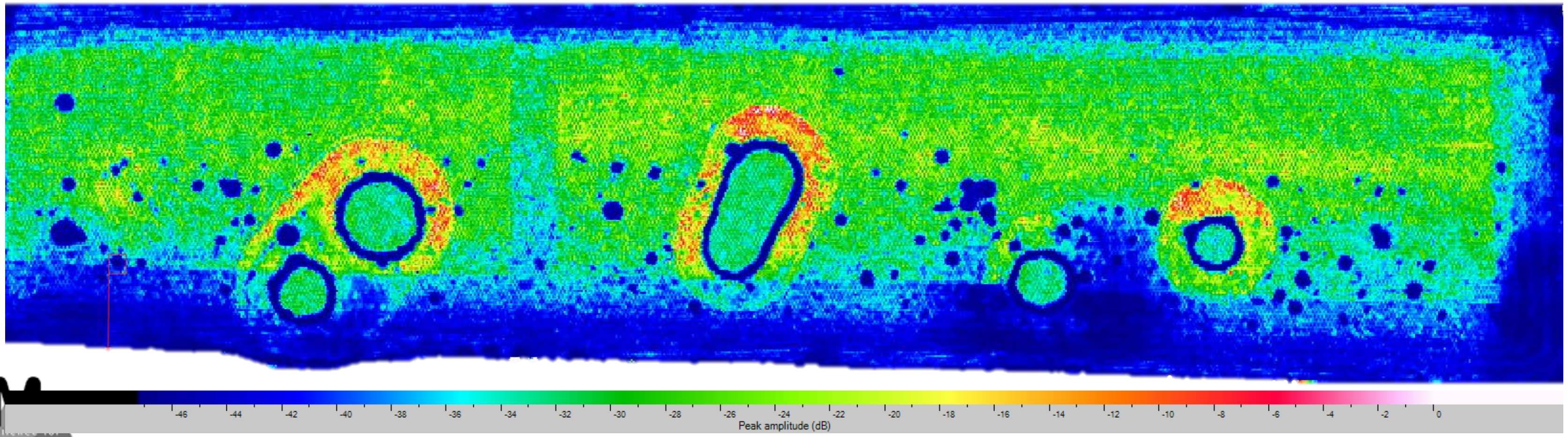
# Component 14 – Section 3





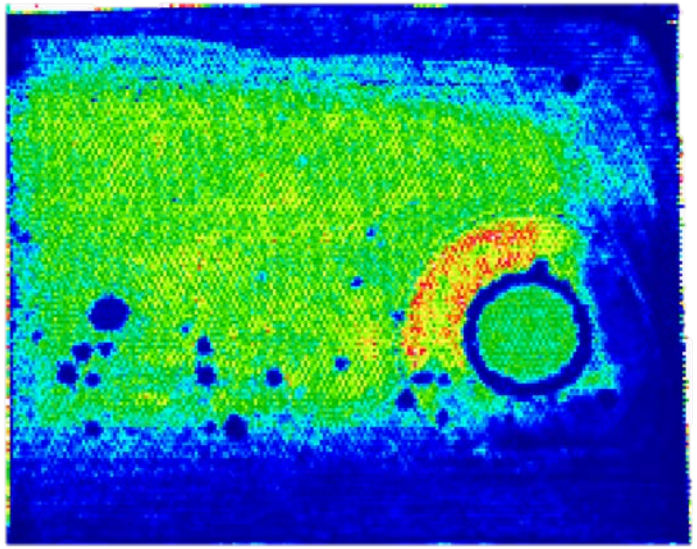
# Component 14 – Section 1 TTU C-Scan



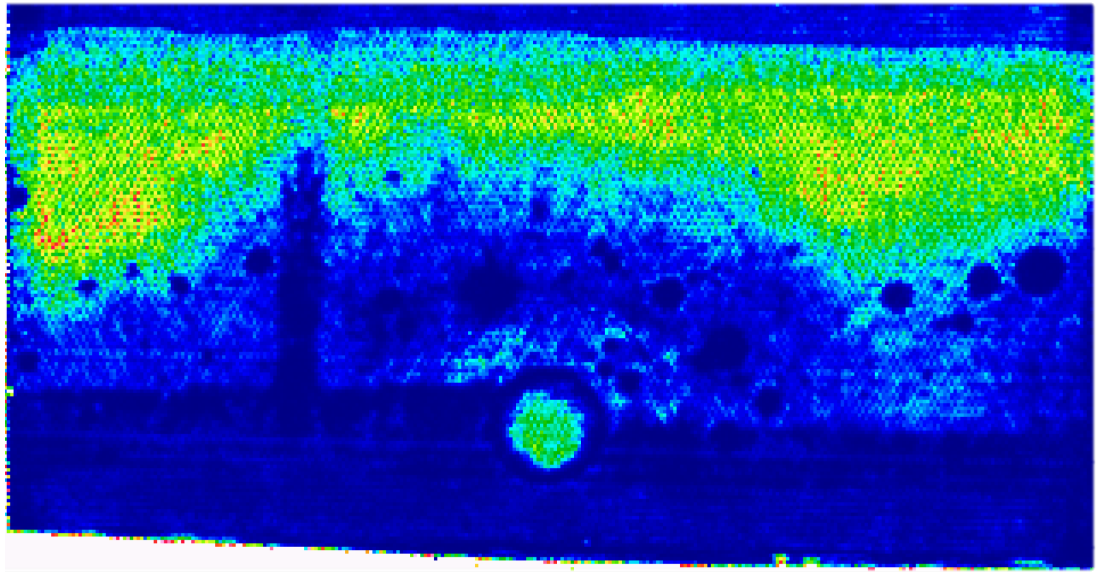


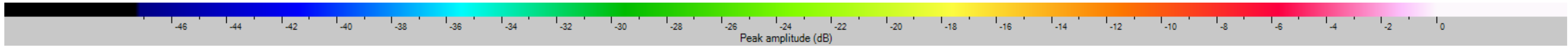
# Component 14 – Section 2 & 3 TTU C-Scans

**Section 2**

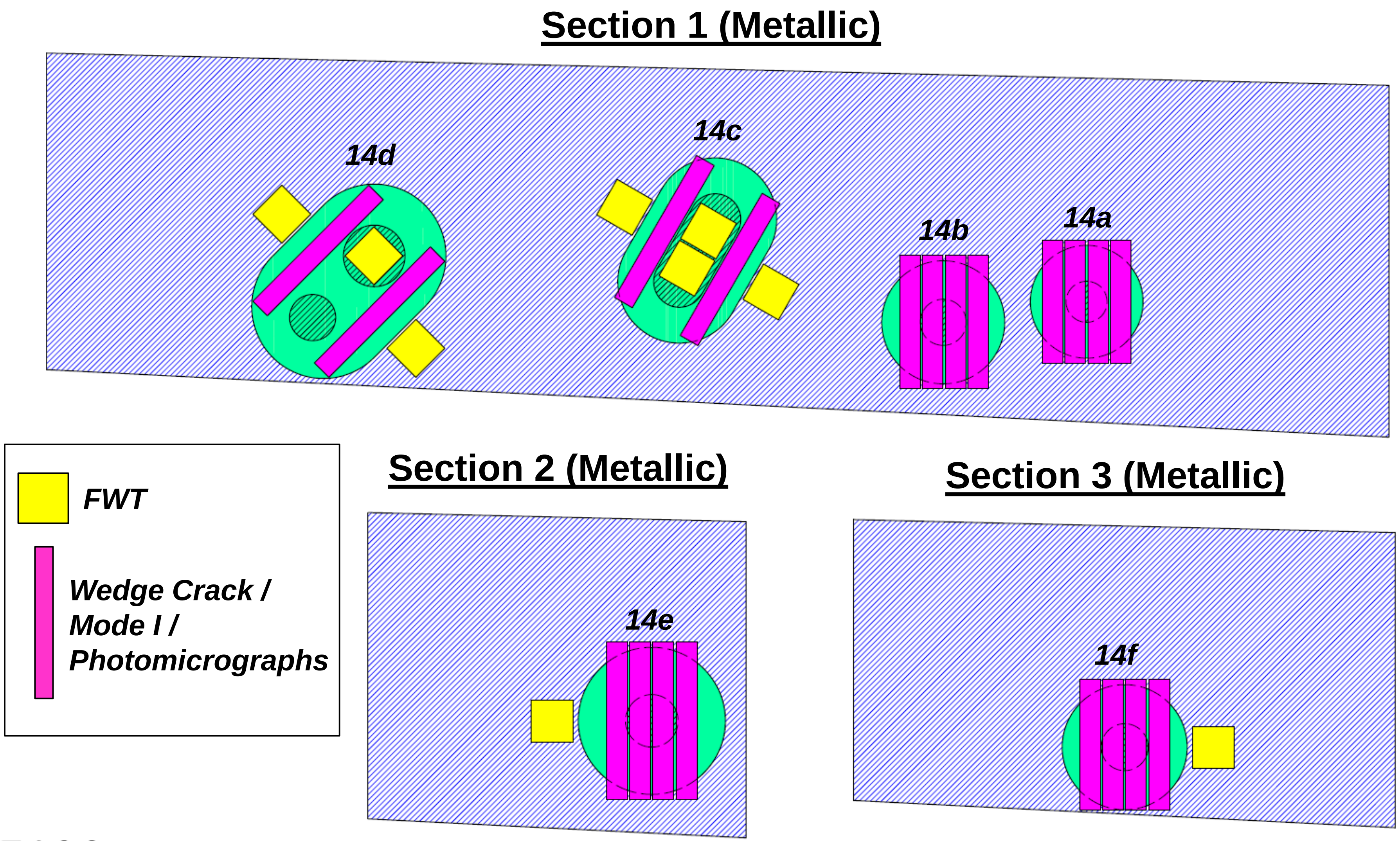


**Section 3**





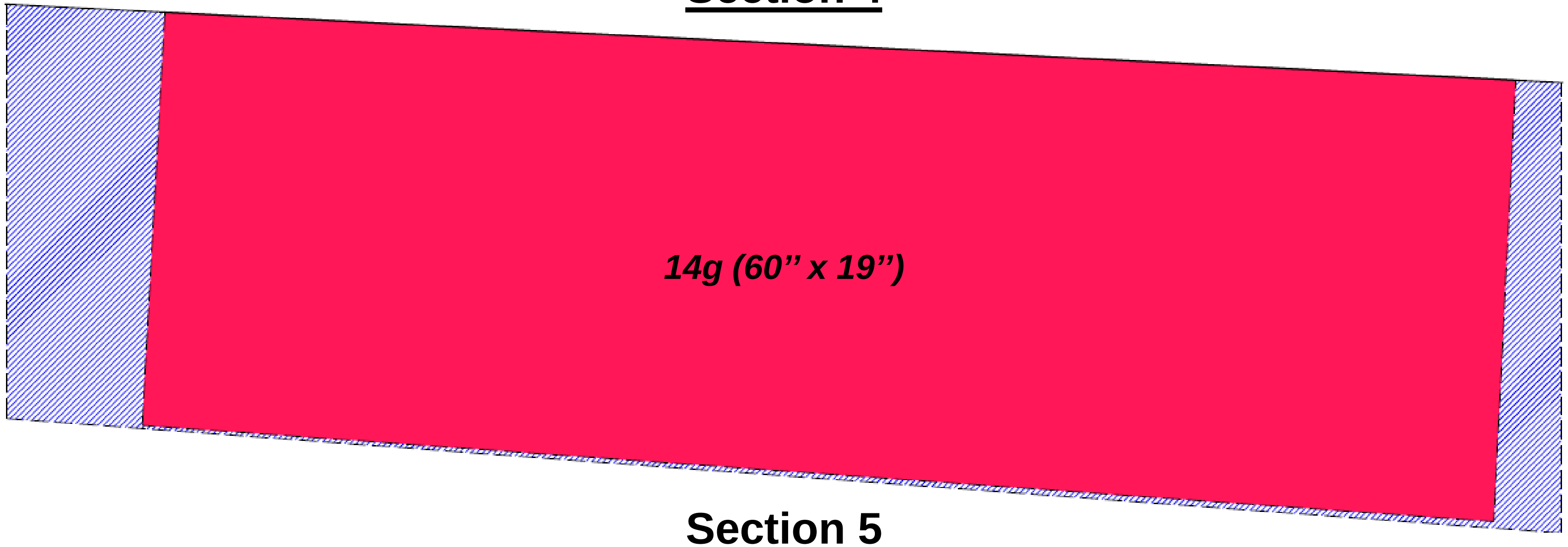
# Example Specimen Layout (Component 14)



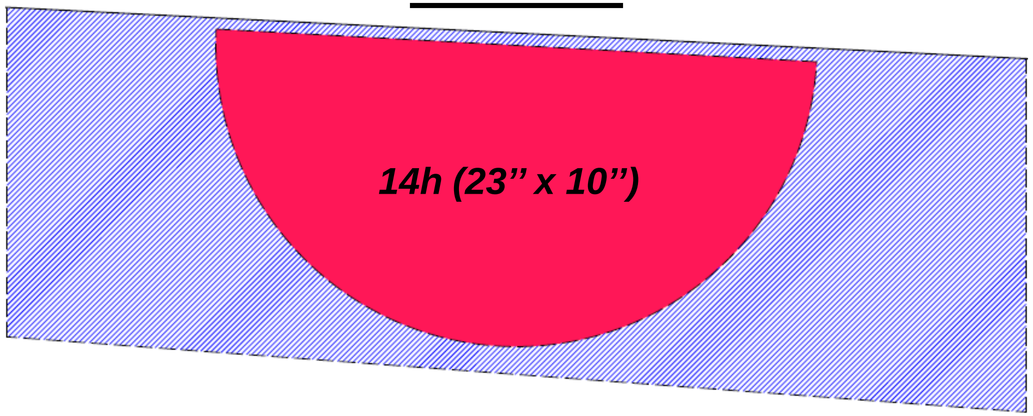

Challenge - Limited # of Specimens

# Component 14 - Subpanel Extractions (Composite)

**Section 4**




**Section 5**




- *Limited repeatability. These materials are not used on any other repairs we have.*

# NIAR Actions

- **Teardown inspections**
  - Extract sections with **repairs**
  - Inspections
    - Visual, Pulse thermography, Ultrasonic, ..
    - SEM, Photomicrographs
    - X-ray CT
  - Thermal and physical test
    - Void content/porosity
    - Glass transition temperature (DMA), degree of cure (DSC)
    - Residual moisture
  - Coupon/element extraction for mechanical tests
    - Compression, Flexure, Flatwise tensile
    - Fracture toughness
    - Picture-frame shear

- **Mechanical Testing**
  - Develop individual test plans for each component test
  - Identify test sections/areas of interest
    - Extraction strategies
  - Testing (FSFT)
    - Fixturing
    - Instrumentation
    - Whiffletrees and load spectrum Inspection intervals & techniques
    - Runout ➔ residual strength
    - Teardown inspections
- **Data reporting**
  - FAA final report
  - CMH-17, CACRC

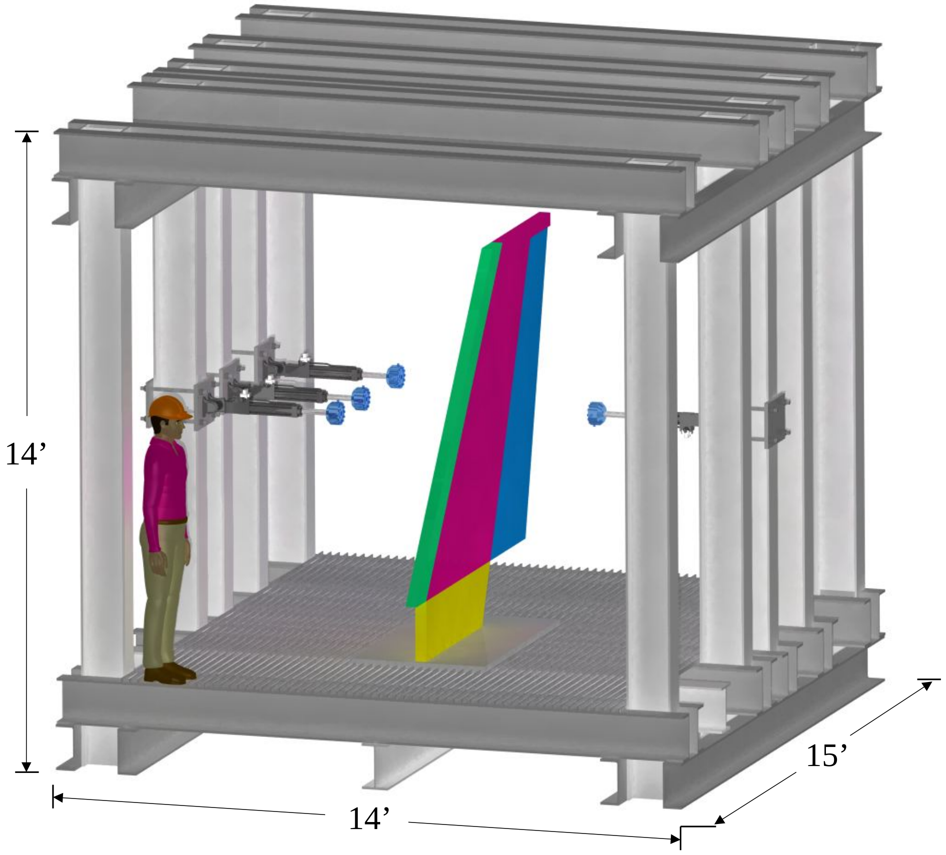
# Inspection of Large Articles


X-ray CT

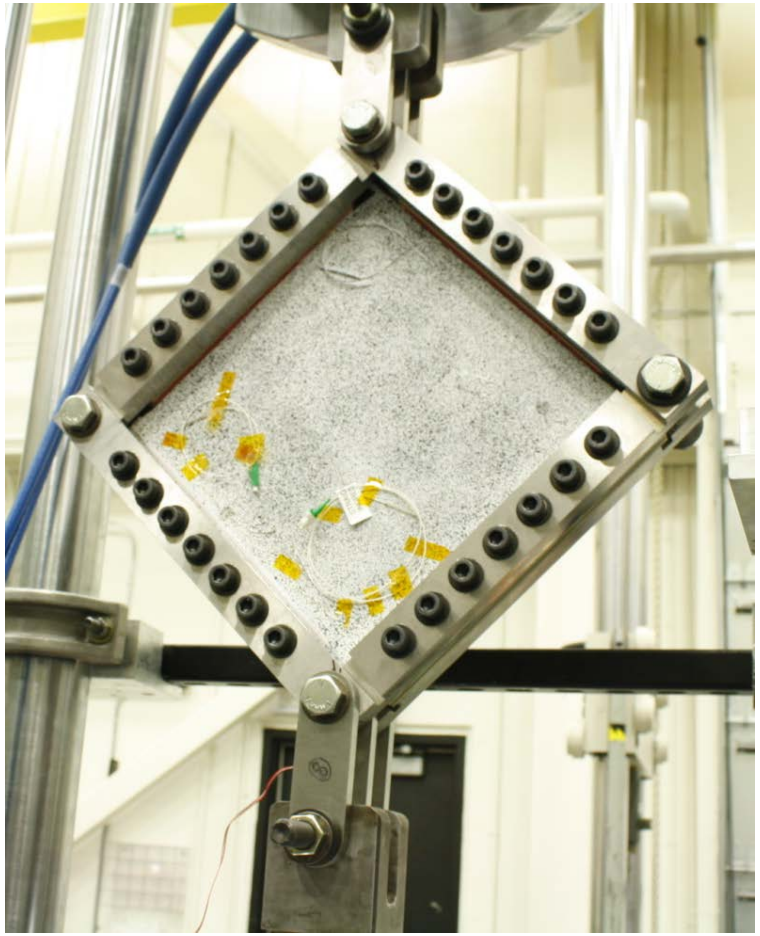
Ultrasonic C-Scan

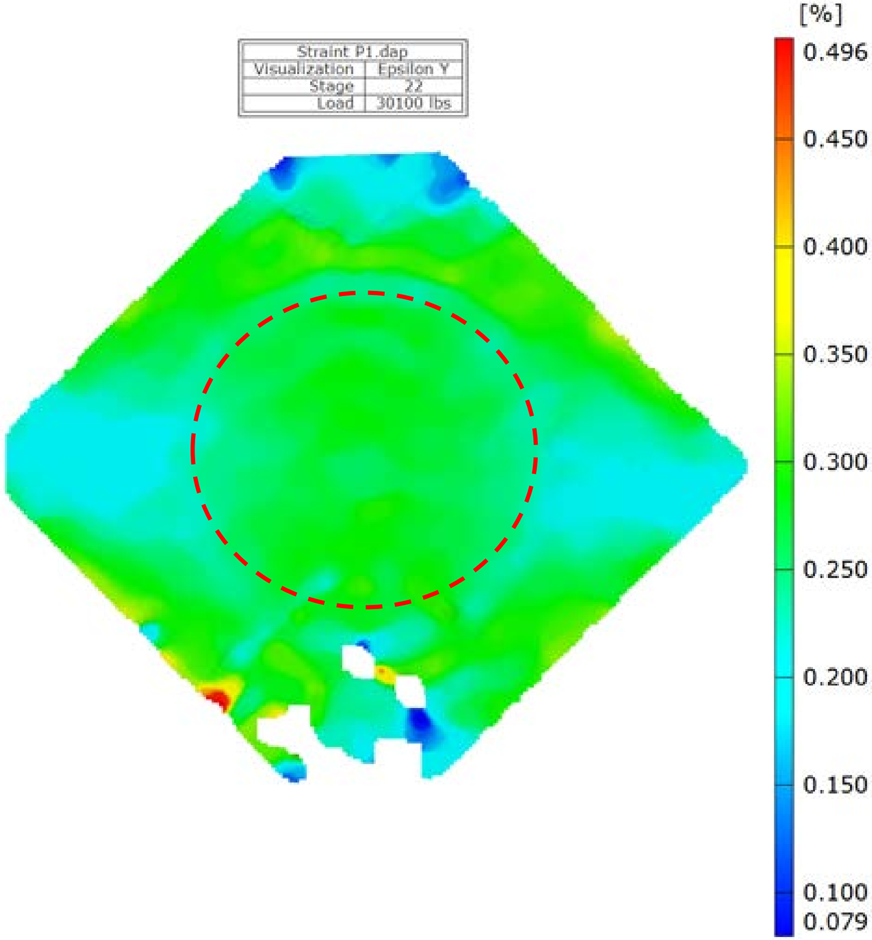
# Mechanical Testing

- Develop a test plan based on NDI findings
  - Component testing
  - Element testing
  - Coupon testing
- Teardown inspections
  - Coupons/elements will be extracted for thermal, mechanical, and physical tests
  - Various NDI techniques will be used to assess repair integrity



# Element Level Testing





# Test Methods

- **ASTM C297 –** *Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions*
  - *Standard Specimen Size: Depends on cell size of honeycomb core (likely 2” x 2”)*

**TABLE 1 Recommended Minimum Specimen Facing Area and Loading Block Dimensions**

| Minimum Cell Size (mm [in.]) | Maximum Cell Size (mm [in.]) | Minimum Loading Block Dimension W (mm [in.]) | Minimum Facing Area (mm$^2$ [in.$^2$]) |
|---|---|---|---|
| - | 3.0 [0.125] | 25 [1.0] | 625 [1.0] |
| 3.0 [0.125] | 6.0 [0.250] | 50 [2.0] | 2500 [4.0] |
| 6.0 [0.250] | 9.0 [0.375] | 75 [3.0] | 5625 [9.0] |

- **ASTM D3762 –** *Standard Test Method for Adhesive-Bonded Surface Durability of Aluminum (Wedge Test)*
- **ASTM D3433 –** *Standard Test Method for Fracture Strength in Cleavage of Adhesives in Bonded Metal Joints*
- **DSC / Tg**
- **Photomicrographs**

*Important to consider influence of the geometry of test specimens on test methodologies. This includes curvature and thickness.*

# Status

- Sandia shared the NDT results of the first batch of parts they shipped to NIAR (3/2/17).
  - This shipment included two I/B Aft Flaps (B767-300 shipset), one O/B Flap (B767-300), and one I/B Flap (B757-200)
  - NIAR visited SNL on December 13 for planning meeting
- NIAR will extract coupons from these four components
  - This exercise will provide an opportunity to identify potential technical challenges and develop solutions until new parts with composite repairs arrive
- FAA Tec Center is shipping two B767-300 spoilers to NIAR
  - Per SRM, repairs on these spoilers have graphite/epoxy prepreg fabric as surface material and nonmetallic honeycomb as core
  - Additionally, Sandia has two more spoilers from the same airplane
    - Access to the applicable SRM pages is needed to verify surface and core material of the B757 parts and the B767 aileron currently located at the FAA TC and Sandia
- Pursuing efforts to acquire additional parts with composite-on-composite repairs

# Looking Forward

- **Benefit to Aviation**
  - Evaluation of bondline integrity and durability of in-service repairs on composite structures in commercial aircraft
  - Guidance materials for AC 65-33 (Development of Training/Qualification Programs for Composite Maintenance Technicians) and AC 43-214 (Repairs and Alterations to Composite and Bonded Aircraft Structure)

- **Future needs**
  - Composite tests articles with composite repairs
  - Technical guidance on repair materials and techniques used on acquired test articles
  - Information on stress level and loading modes on repair regions