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# Damage Growth of Sandwich Structures under Ground-Air-Ground Cycles

2015 Technical Review

Waruna Seneviratne

Wichita State University/NIAR

# Fatigue Damage Growth Rate of Sandwich Structures using Single Cantilever Beam Test

- **Motivation and Key Issues**
  - Fluid ingression phenomenon and the progressive damage growth due to entrapped fluids in sandwich structures
  - Thermo-mechanical loads during ground-air-ground (GAG) cycling result in localized mode I stresses that cause further delamination/disbond/core fracture growth creating more passageways for fluid migration.
- **Objective**
  - The influence of sandwich parameters such as core size, density, and facesheet/core stiffness ratio on the onset and damage growth rate of sandwich composite
  - Understand the Ground-air-ground effect on onset and damage growth
- **Approach**
  - Damage growth in sandwich structures
    - Core types, core densities (24, 32 and 48kg/m$^3$) & F/C thicknesses
  - Mechanics of different damage sources
    - Fluid ingression (GAG effects)
    - Impact damages
    - Repairs (improper repairs and process deviations)

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# Fatigue Damage Growth Rate of Sandwich Structures using Single Cantilever Beam Test

- **Principal Investigators & Researchers**
  - John Tomblin, *PhD*, and Waruna Seneviratne, *PhD*
  - Upul Palliyaguru, Caleb Saathoff, Kevin Booze, Shawn Denning
- **FAA Technical Monitor**
  - Lynn Pham
- **Other FAA Personnel Involved**
  - Larry Ilcewicz, *PhD* and Curtis Davies
- **Industry Participation**

AIRBUS
BOMBARDIER LEARJET
SPIRIT AEROSYSTEMS
Beechcraft Cessna Hawker TEXTRON AVIATION
NIAR
Kansas Aviation Research and Technology (KART)

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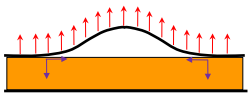
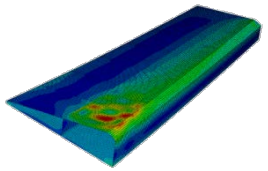
# Approach



Stress Analysis



Failure Analysis

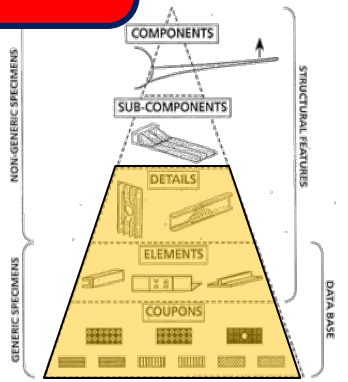
Experimental Data

Analytical Tools

Service Findings

Validation

Guidelines

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# Research Overview on Sandwich Disbond Growth [2009 – 2015]

- Single-cantilever beam (SCB) testing
  - Test/conditioning procedures (2009 – 2010)
  - Static **(2010 – 2012)**
  - Fatigue **(2011 – 2013)**
  - Supplemental damage growth studies (2013 – 2014)
- Ground-air-ground (GAG) simulations
  - Edgewise compression **(2014 – 2015)**
    - Static
    - Fatigue
- Further studies **(2015 – ……..)**
  - GAG testing with large flex test
  - Sandwich damage growth simulations

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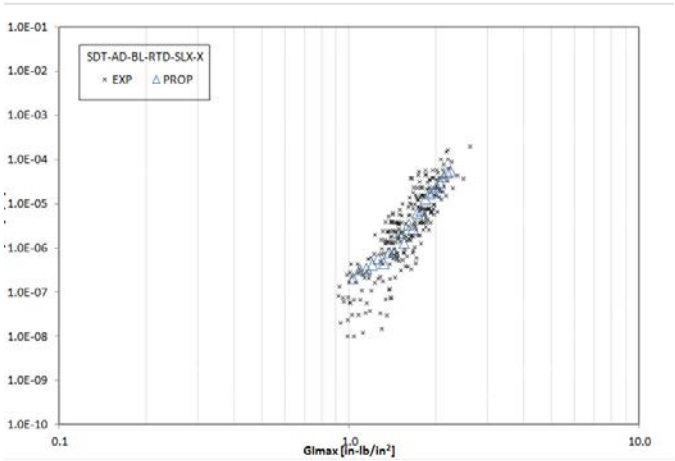
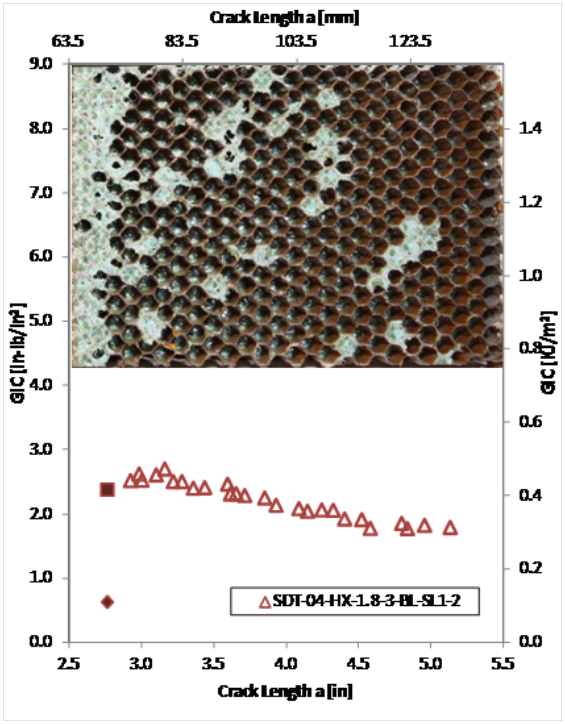
# Accomplishments year to date…

- **FAA Final Reports**
  - Volume 1: ***Damage Growth in Fluid-Ingressed Sandwich Structures***
  - Volume 2: ***Fatigue Damage Growth Rate of Sandwich Structures***
  - Volume 3: ***Damage Growth in Sandwich Structures***

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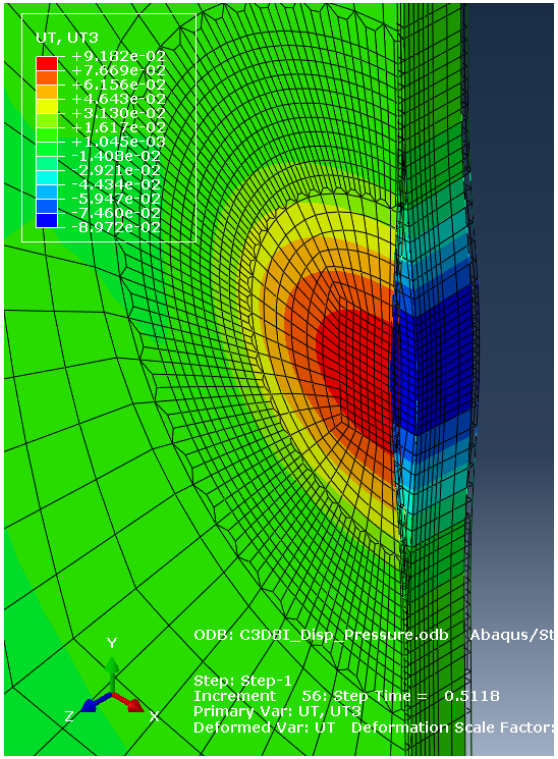
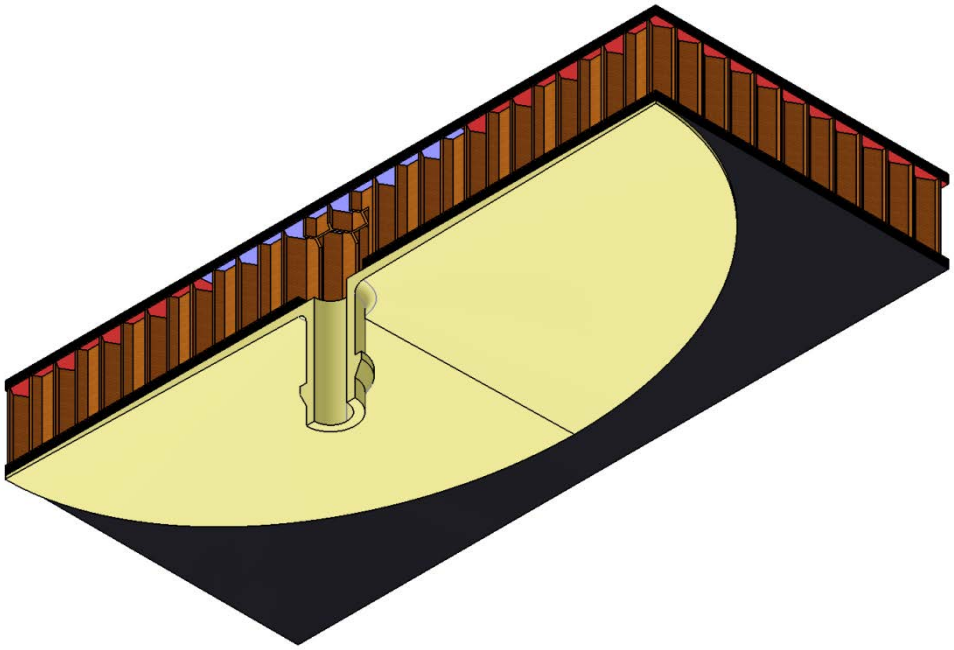
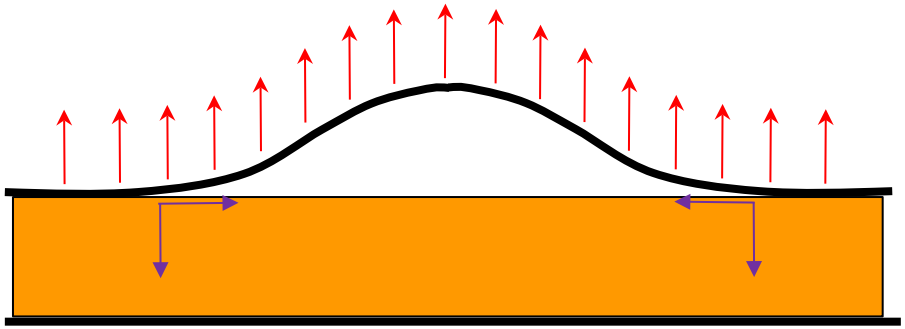
# GAG TESTING





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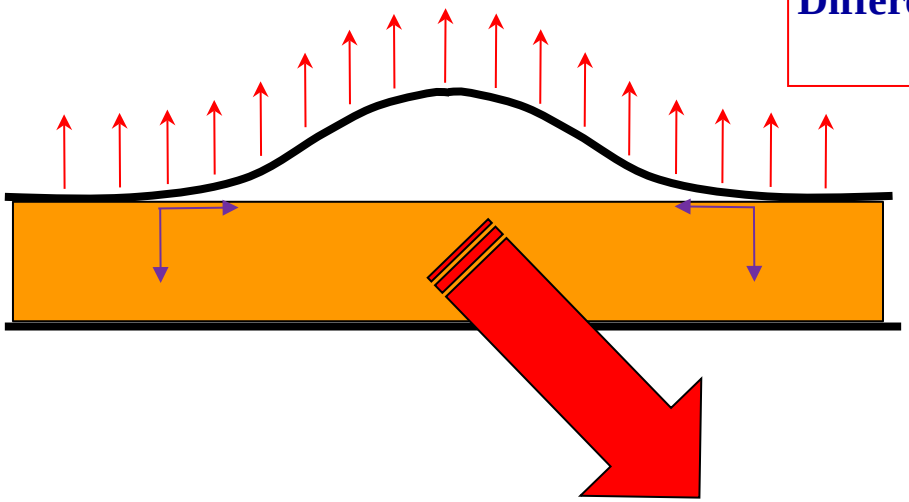
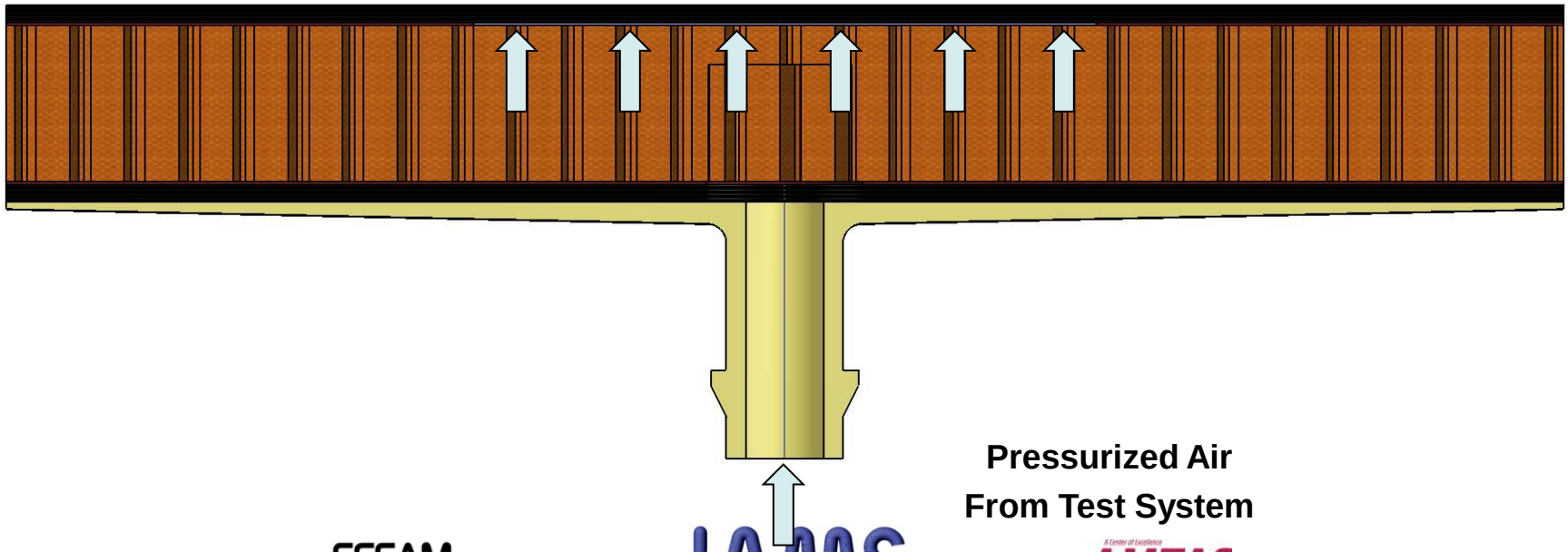
# Edgewise Compression Pressure Application

**Differential Pressure Effects**



**Simulated Differential Pressure Effects**



**Pressurized Air From Test System**

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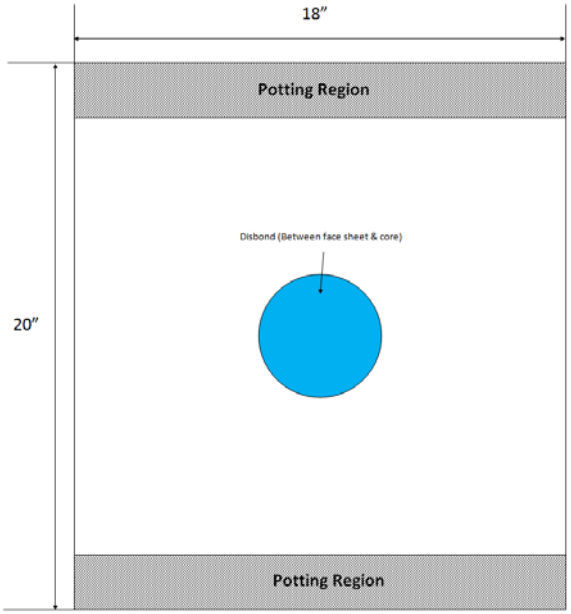
# Edgewise Compression Test Specimen



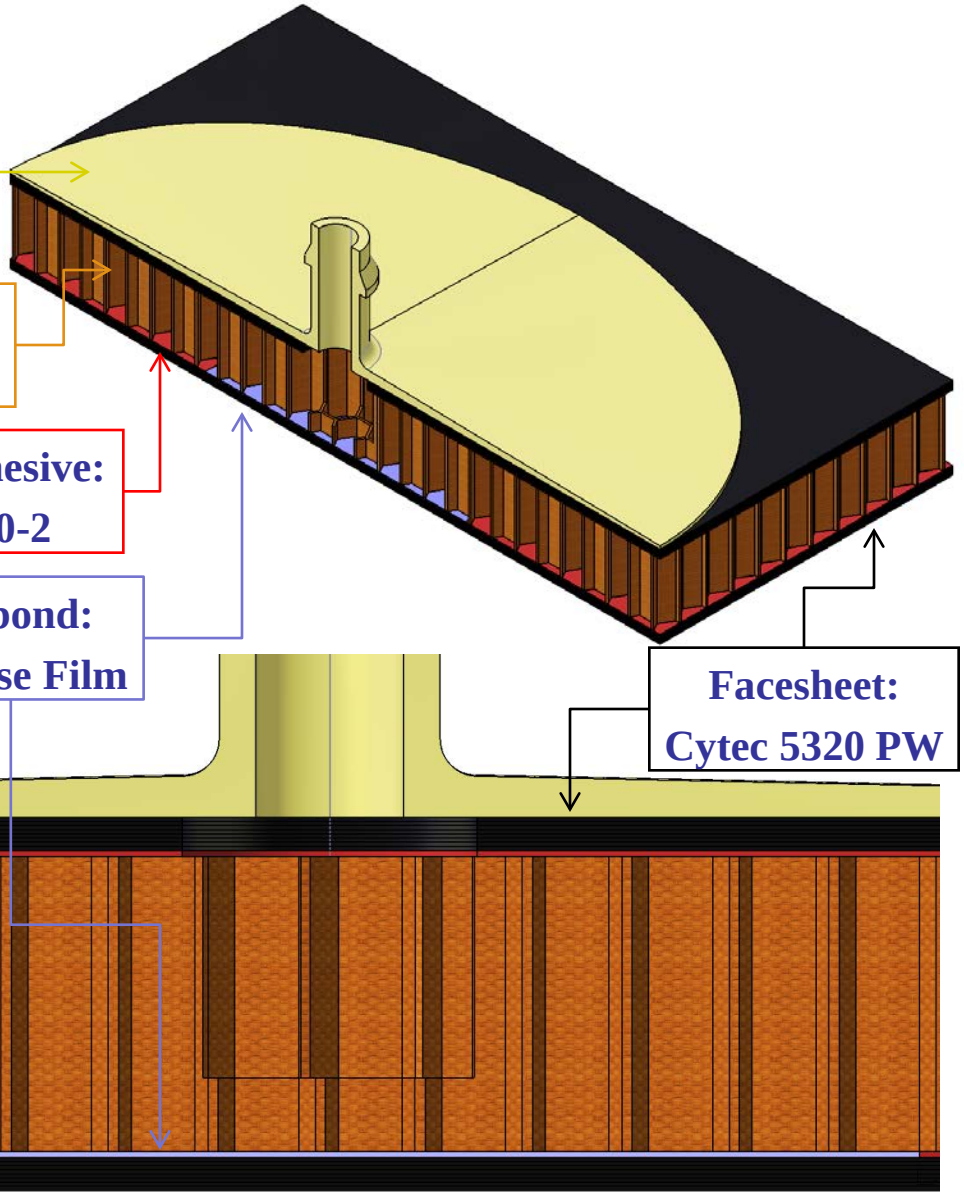

Pressure Port:
3D Printed

Honeycomb Core:
HRH-10

Film Adhesive:
FM300-2

Disbond:
Release Film

Facesheet:
Cytec 5320 PW



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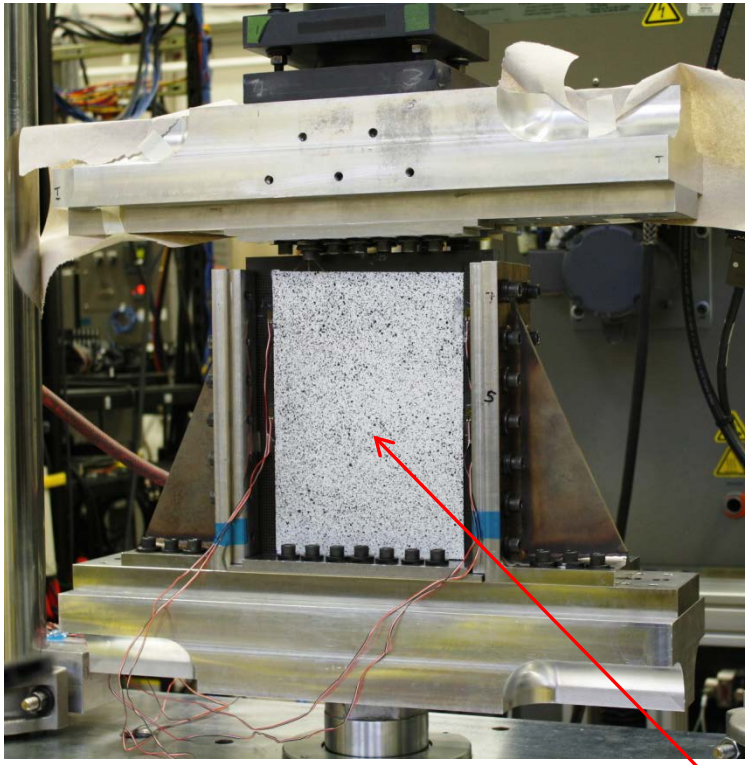
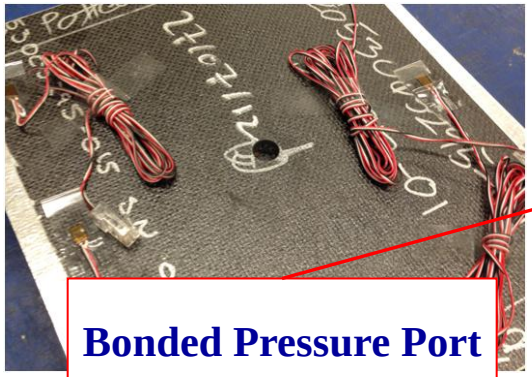
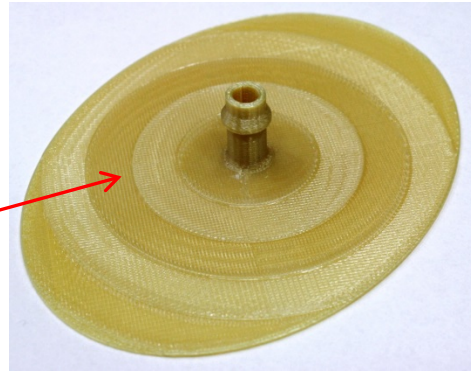
# Edgewise Compression Test Setup

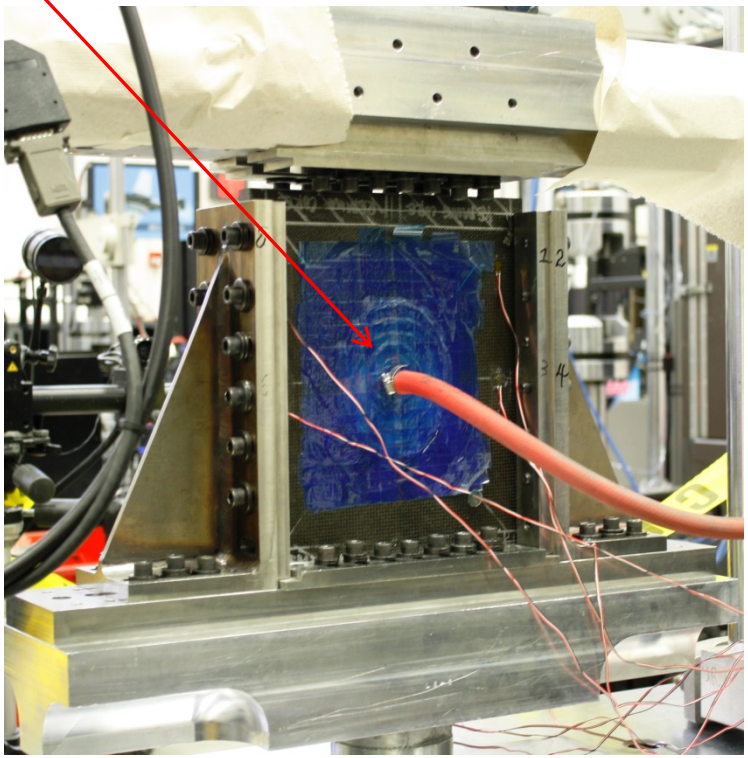


DIC speckle pattern on Damage Side





Bonded Pressure Port



**Ability to accommodate various specimen sizes**

- **Test Specimen 18x20-inch**

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# Test Matrix

- Facesheet
  - Cytec 5320/T650 3K 8HS
- Core
  - 3 lb HexWeb HRH-10
- Adhesive
  - FM300-2 Film Adhesive

| Edgewise Compression Specimen Test Matrix (Preliminary Revised Test Matrix) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| General Parameters | | | | Facesheet Thickness: 3 Ply | | | | Facesheet Thickness: 4 Ply | | | | |
| Damage Configuration | Cell Size | Damage Size | Loading Conditions | Static | | Fatigue | | Static | | Fatigue | | |
| | | | | RTA | CTW | RTA | CTW | RTA | CTW | RTA | CTW | |
| Disbond | 1/8 | N/A (Baseline) | - | - | - | - | - | - | - | - | - | |
| | | 4 | Pressure Only | - | - | 1 | 1 | - | - | 1 | 1 | |
| | | | Load Only | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | |
| | | | Pressure + Load | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | |
| | | 8 | - | - | - | - | - | - | - | - | - | |
| | 3/16 | N/A (Baseline) | - | - | - | - | - | - | - | - | - | |
| | | 4 | - | - | - | - | - | - | - | - | - | |
| | | 8 | - | - | - | - | - | - | - | - | - | |
| | 3/8 | N/A (Baseline) | - | - | - | - | - | - | - | - | - | |
| | | 4 | - | - | - | - | - | - | - | - | - | |
| | | 8 | - | - | - | - | - | - | - | - | - | |

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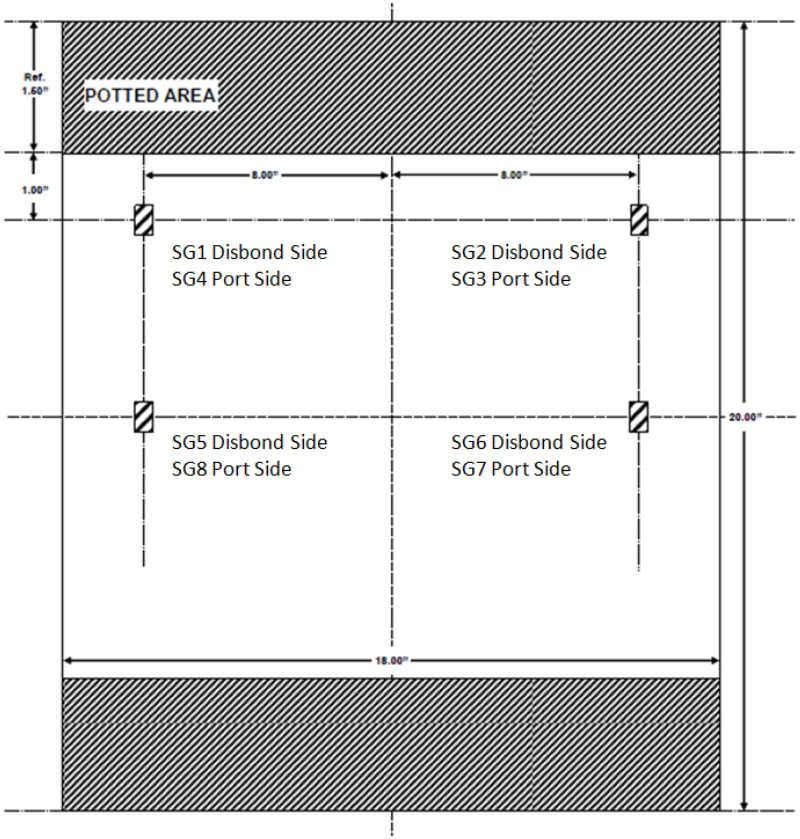
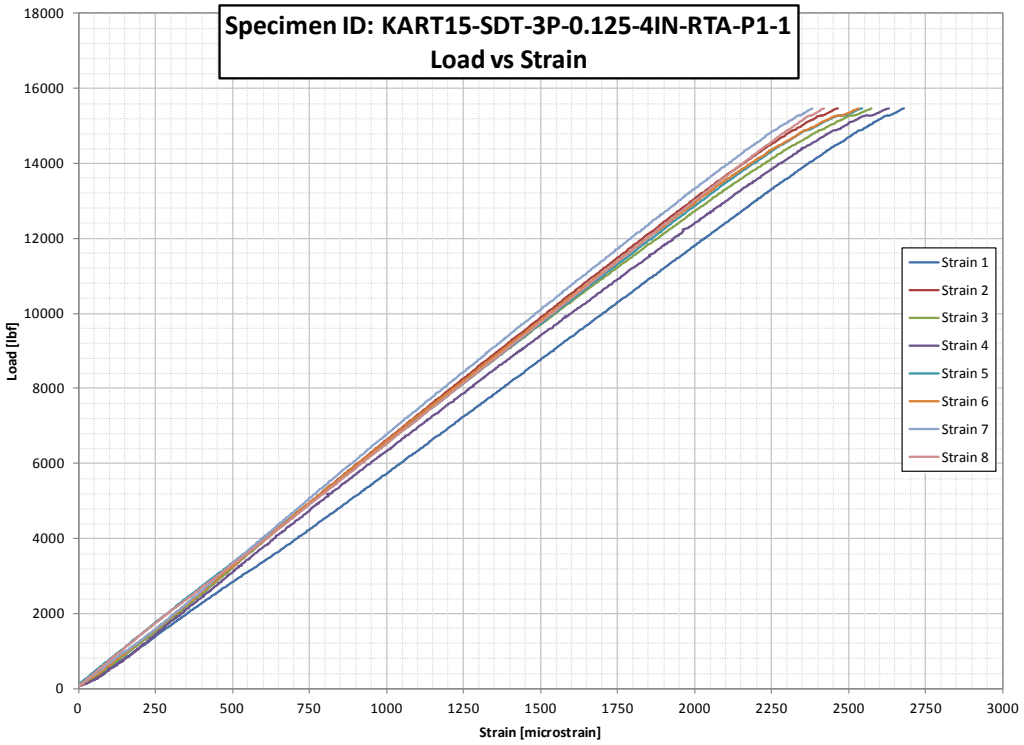
# Static Test

- Ultimate Load: 15,478 lbf
- Peak Strains: 2587 με (Top); 2469 με (Middle)

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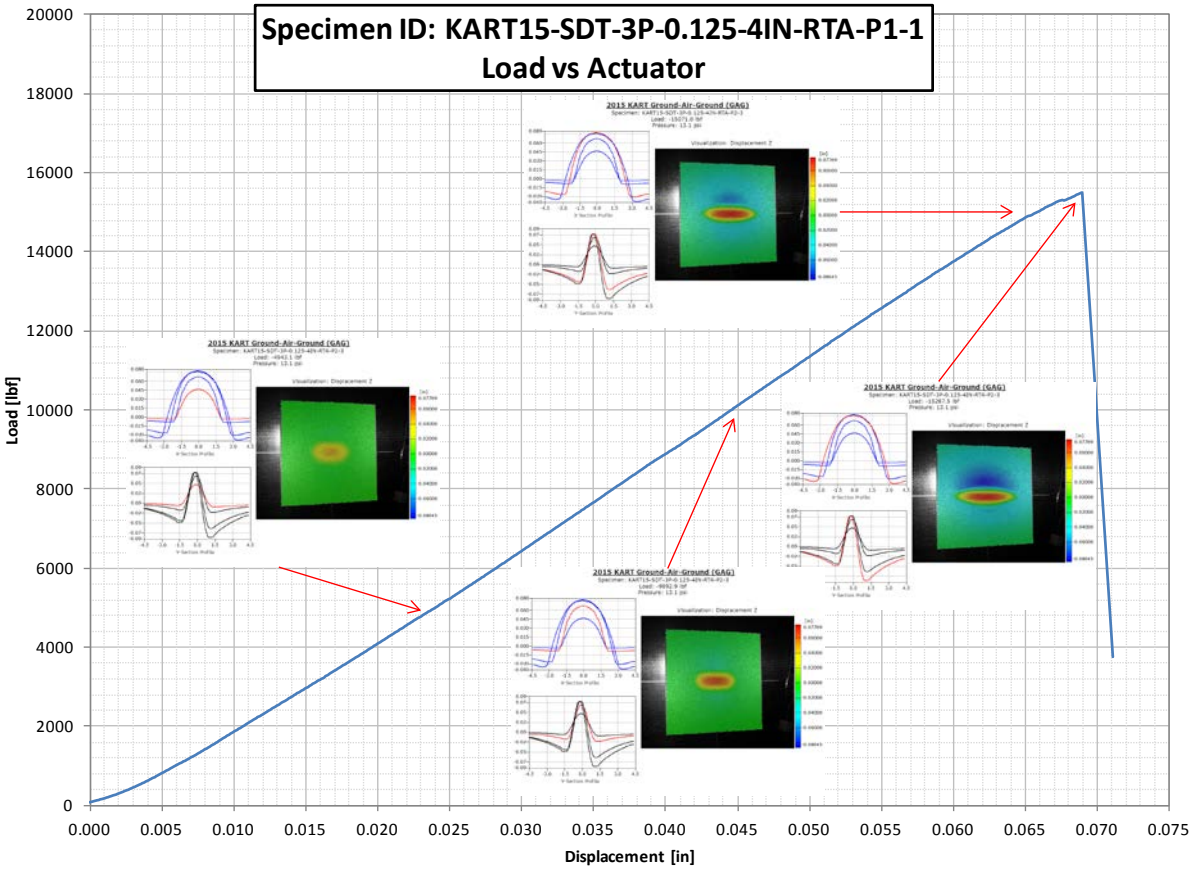
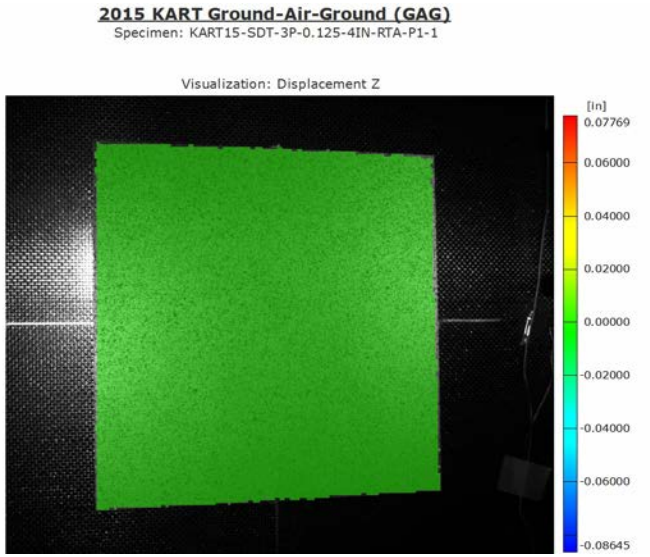
# Damage Growth During Static Test

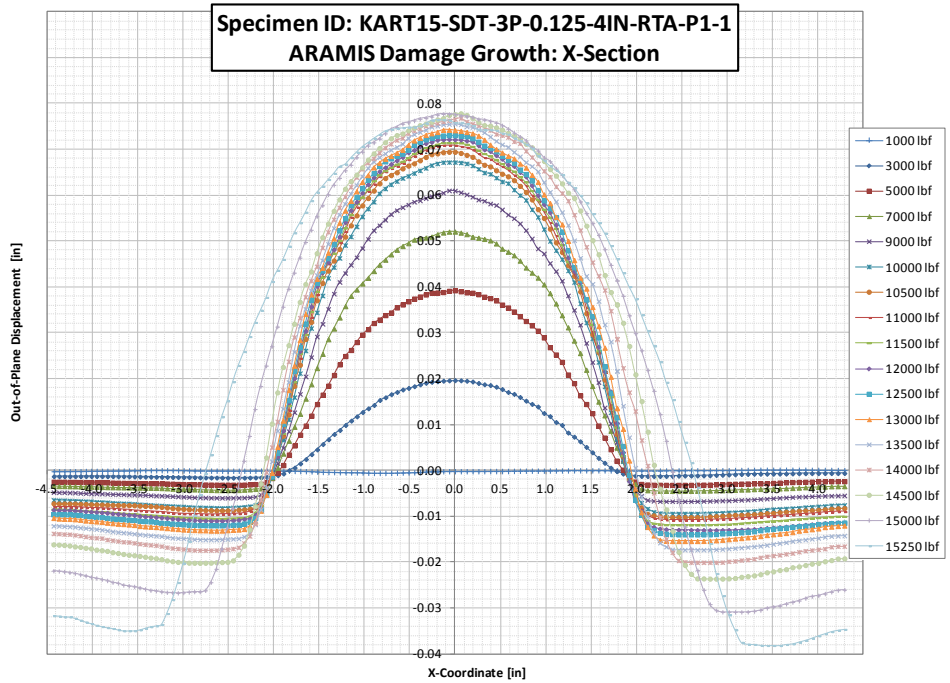
Max pressure of 13.1 psi was applied prior to load application.

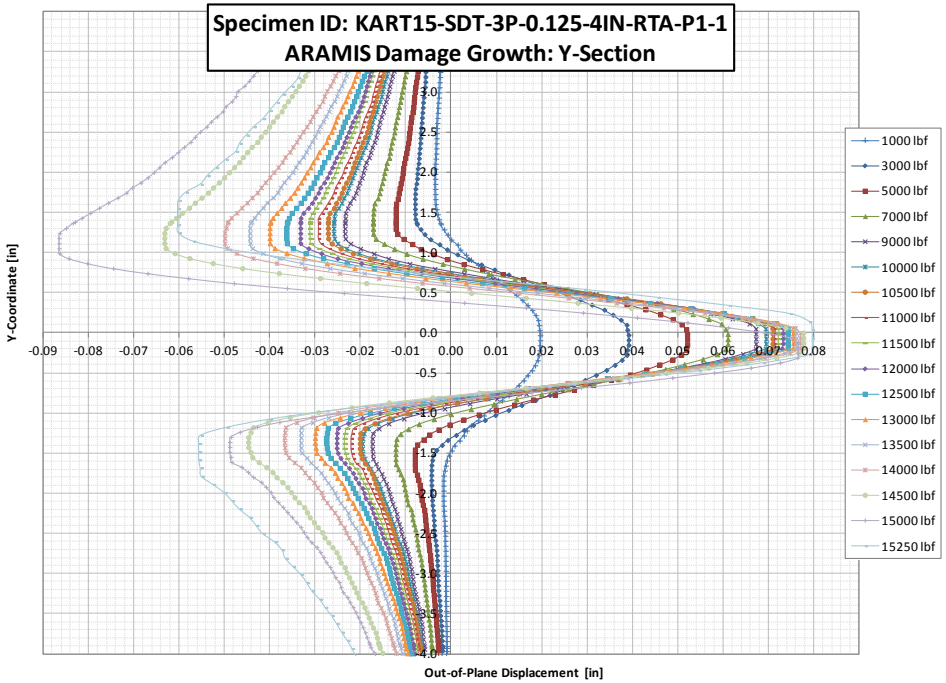


# Out-of-Plane Displacement

- ARAMIS: Utilized to capture progression of damage growth by monitoring out-of-plane displacements.




- Notable damage growth in last 1000 lbf of loading

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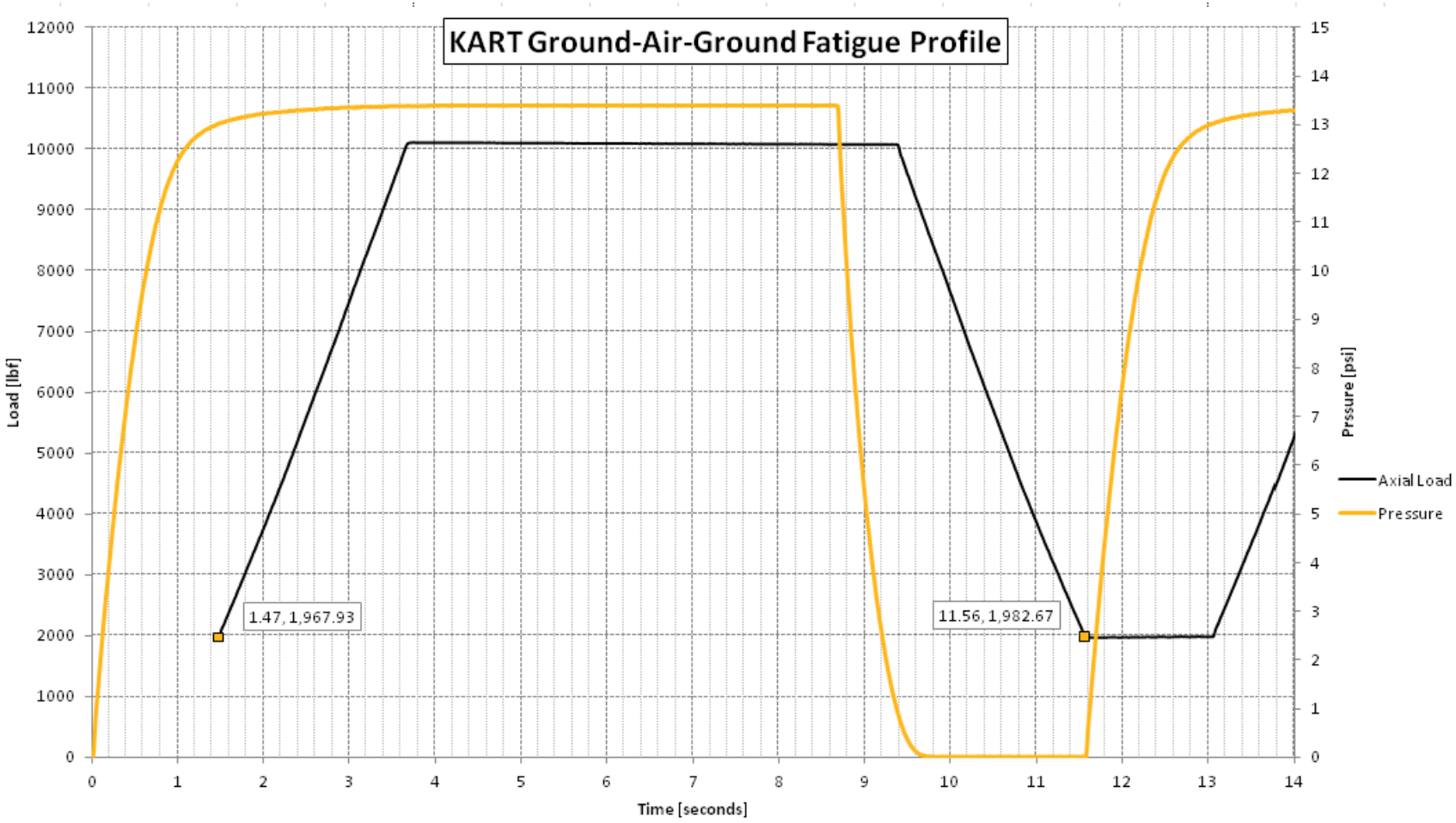
# GAG Fatigue Profile

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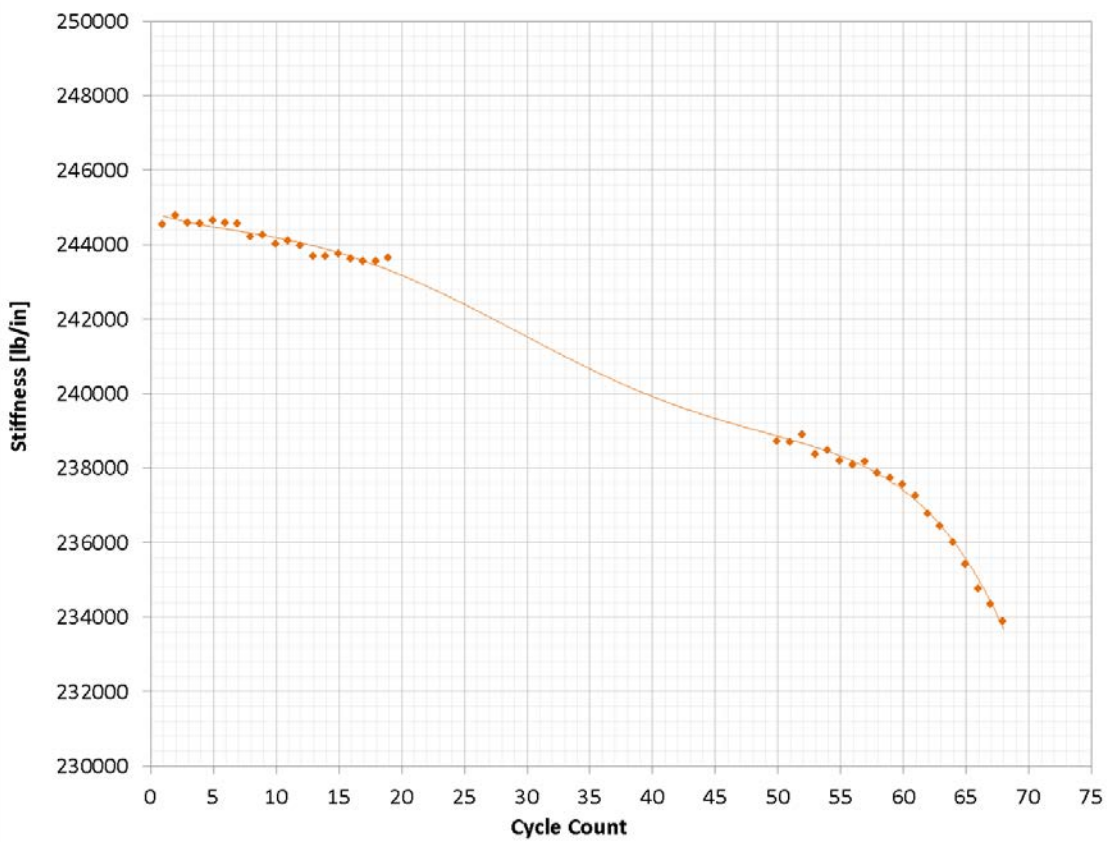
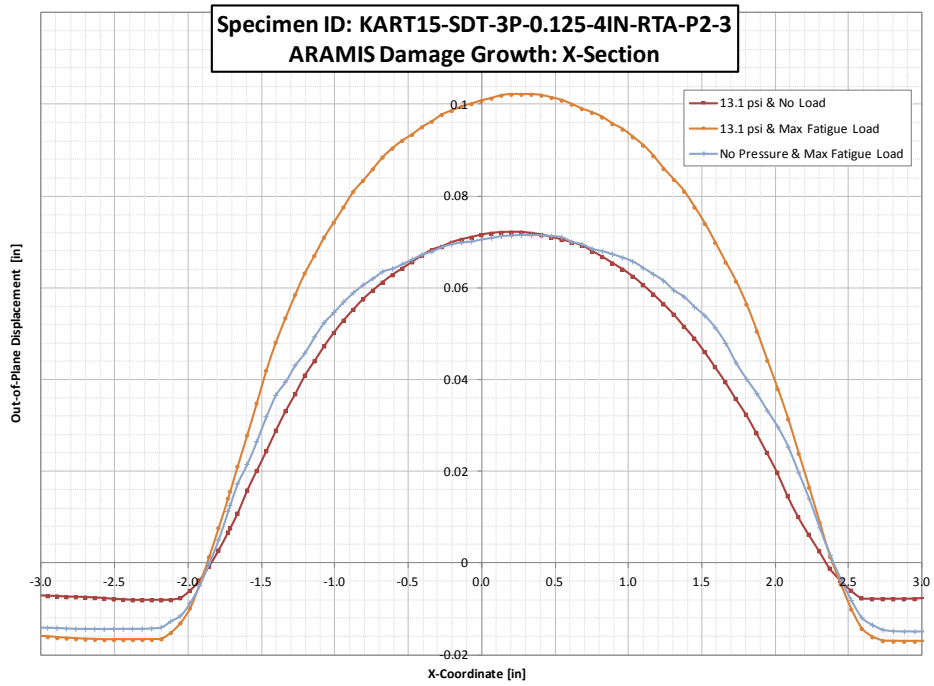
# GAG Cycling [Pressure + Load]

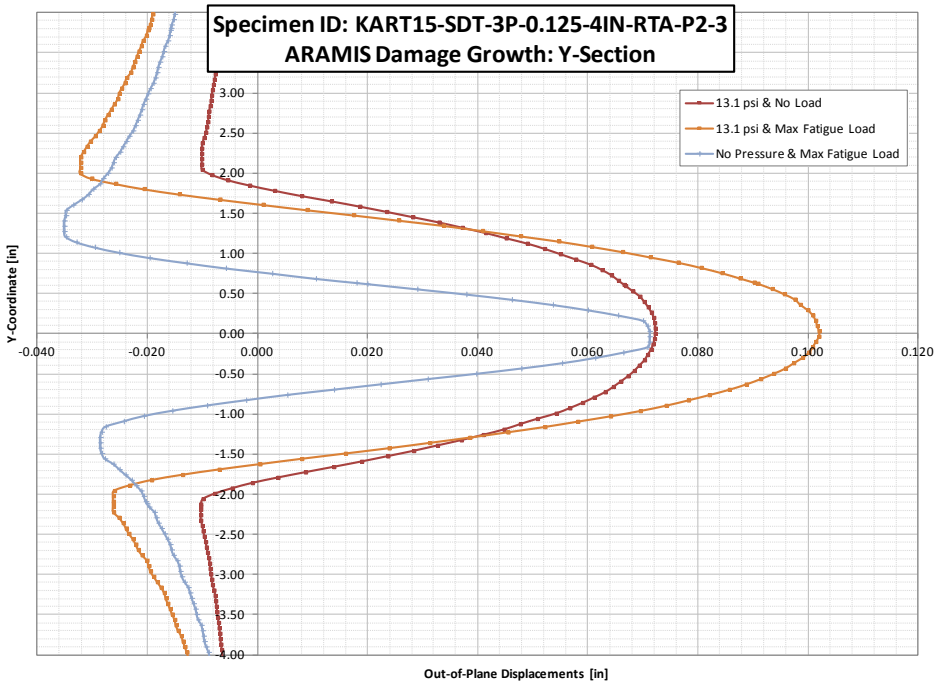
- Max fatigue load: Load corresponding to 70% of static strength
- Max fatigue load: -10,834 lbf; Min fatigue load: -2167 lbf
- Pressure: 13.1 psi
- Avg. Strain ~ 1,875 με
- Cycles until failure: 73



# Out-of-Plane Displacement

- Fatigue Test Data
  - ARAMIS: Utilized to capture progression of damage growth by monitoring out-of-plane displacements.




  - Low cycle count ➔ Only data at 0 Cycles

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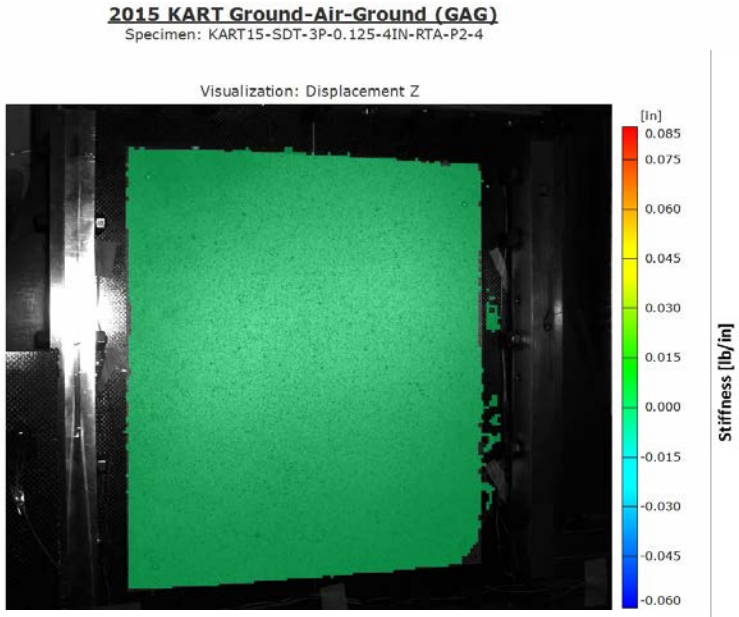
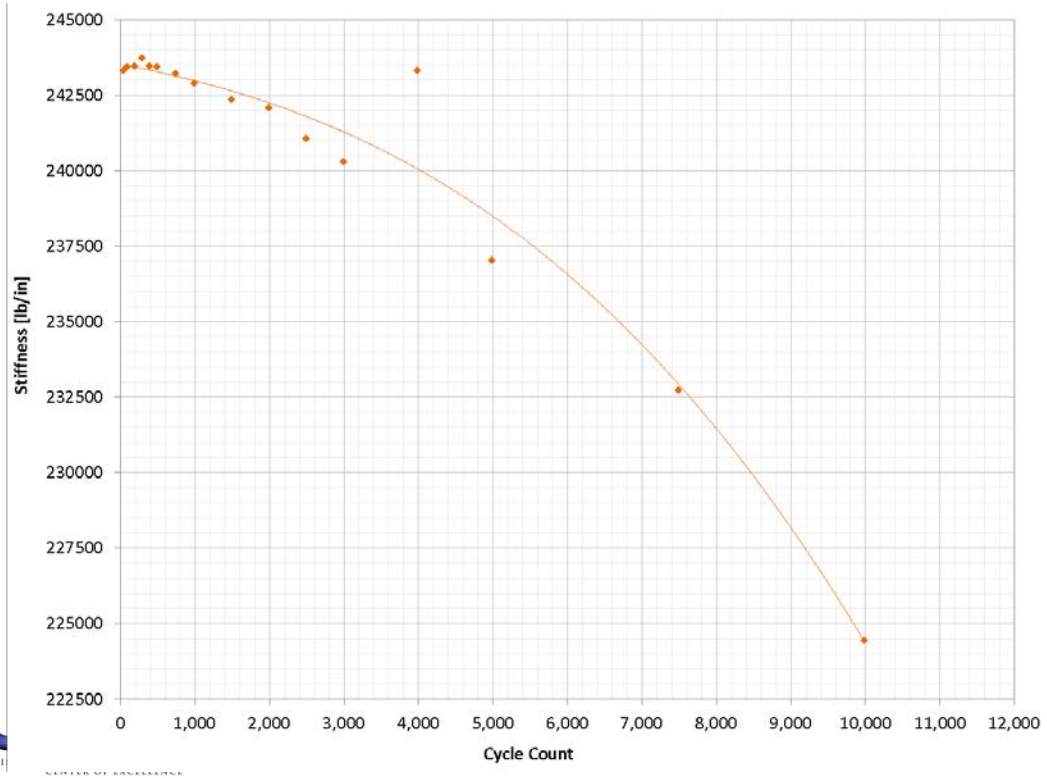
# GAG Cycling [Load Only]

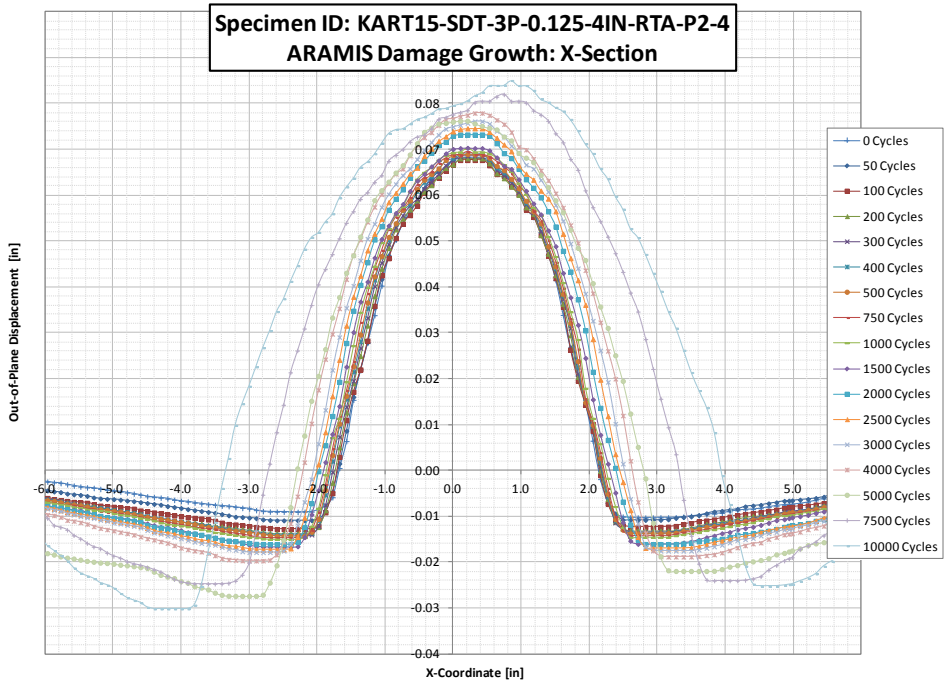
- Max fatigue load: Load corresponding to 70% of static strength
- Max fatigue load: -10,834 lbf; Min fatigue load: -2167 lbf
- Pressure: 0.0 psi
- Cycles until failure: 11,955

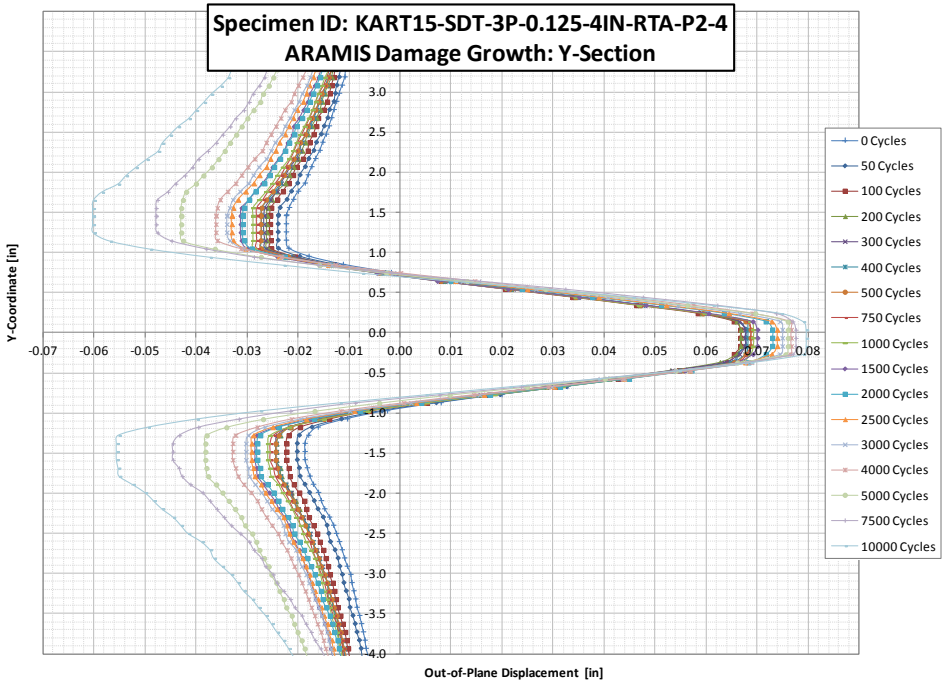


# Out-of-Plane Displacement

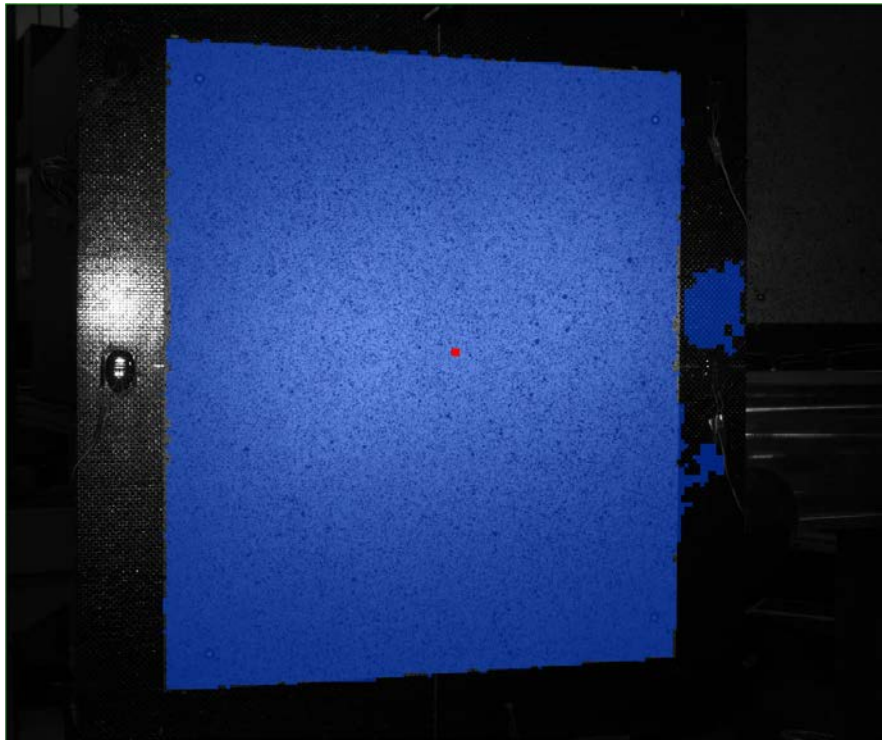
- Fatigue Test Data
  - ARAMIS: Utilized to capture progression of damage growth by monitoring out-of-plane displacements.



# GAG Cycling [Pressure Only]

- Max fatigue load: No Load
- Pressure: 13.1 psi
- Cycle Count: 30,000+



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# Out-of-Plane Displacement

- Fatigue Test Data
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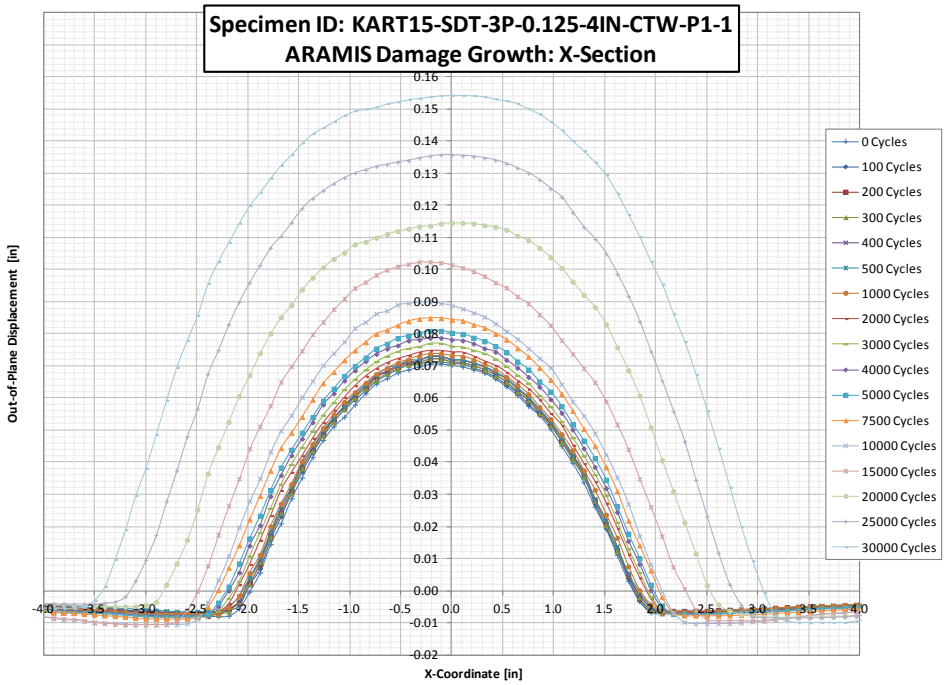


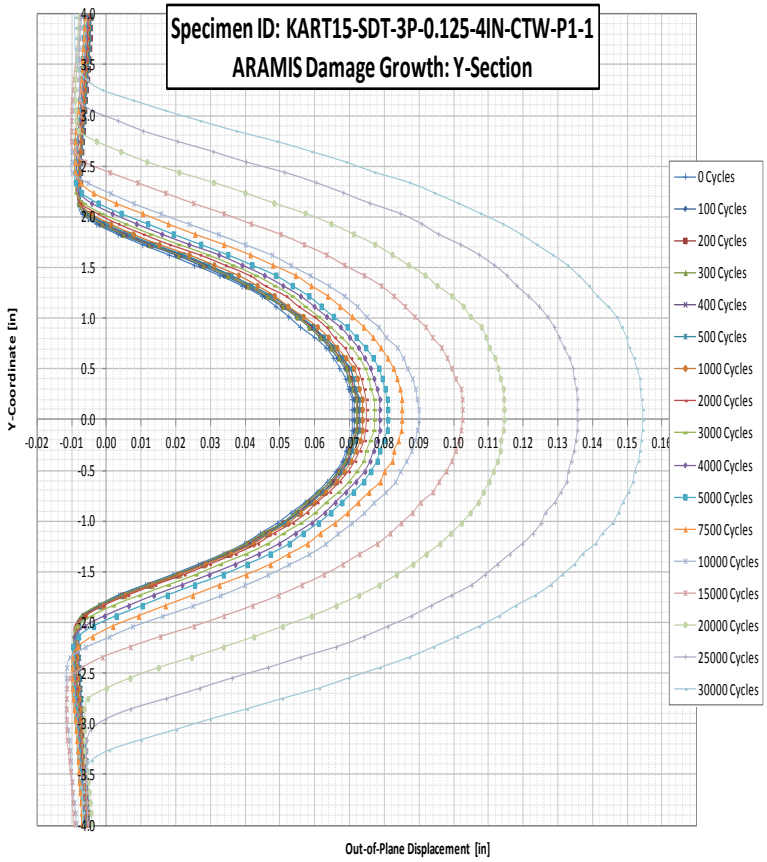


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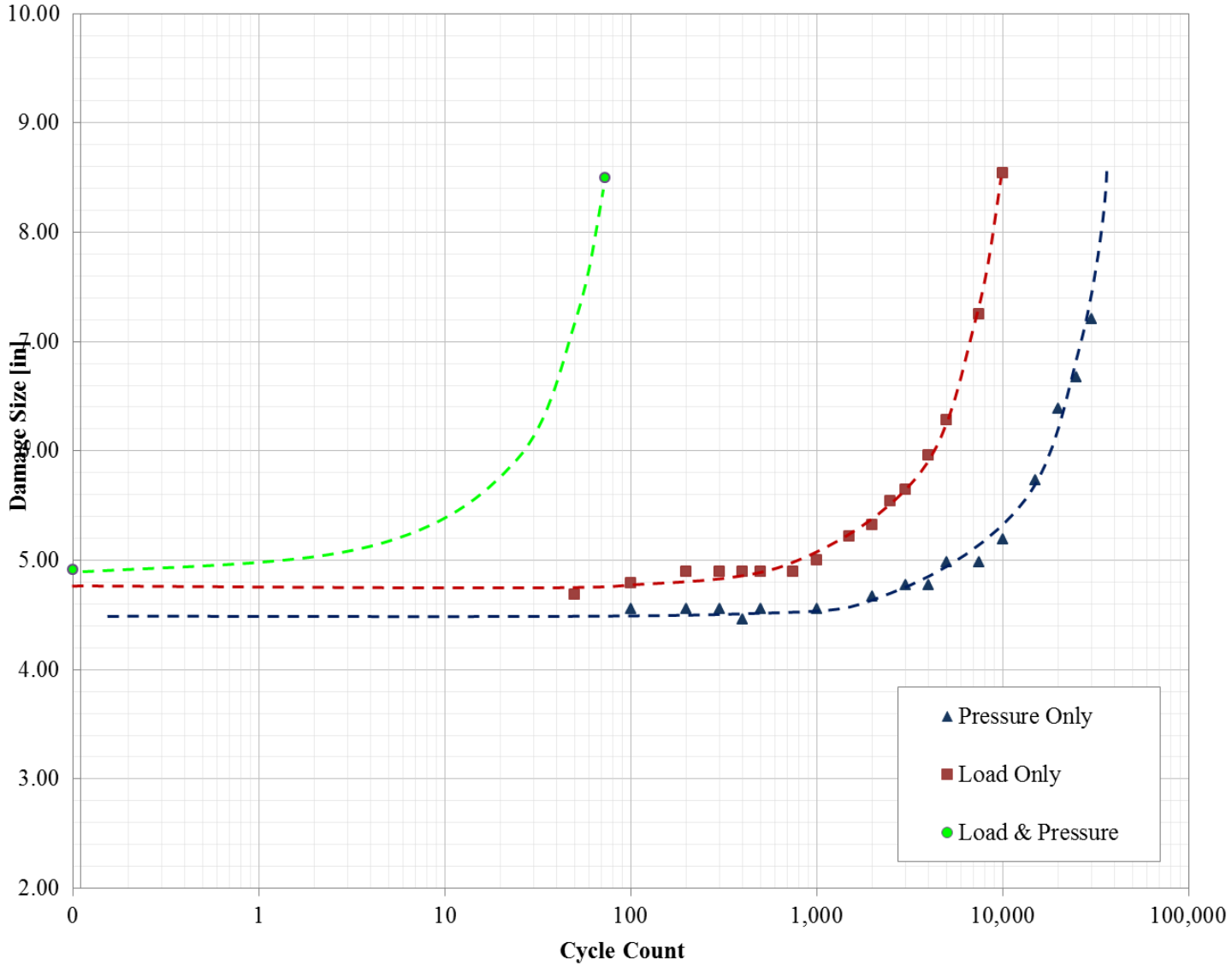
# 3-Ply GAG Test Summary

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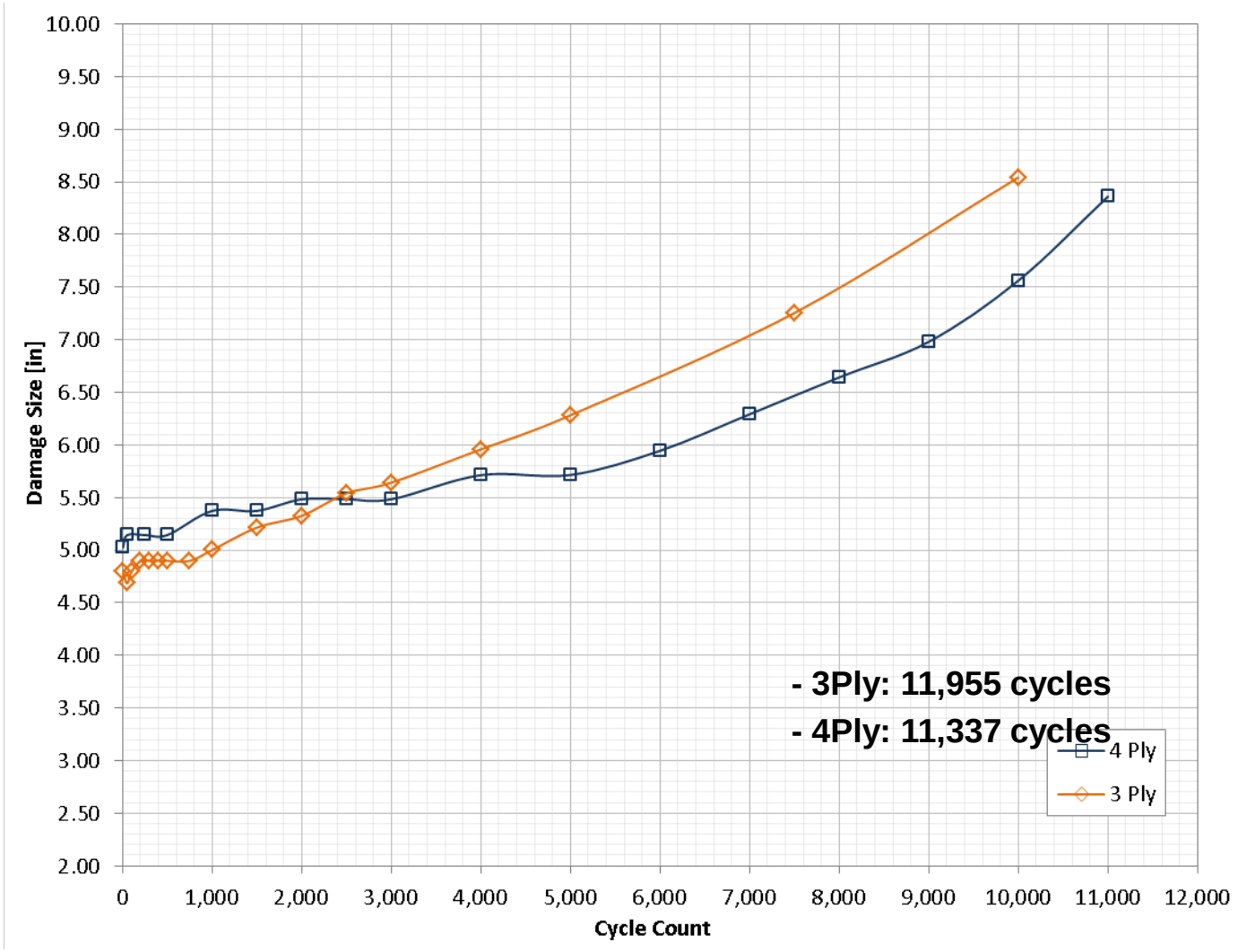
# Comparison of 3- and 4-Ply Facesheets

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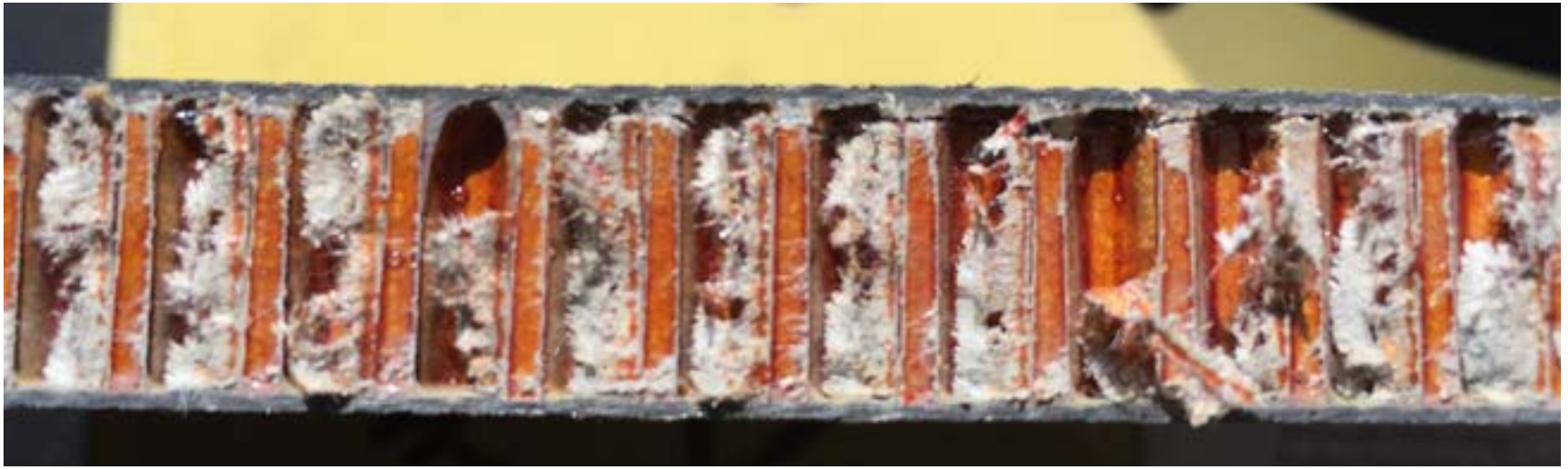
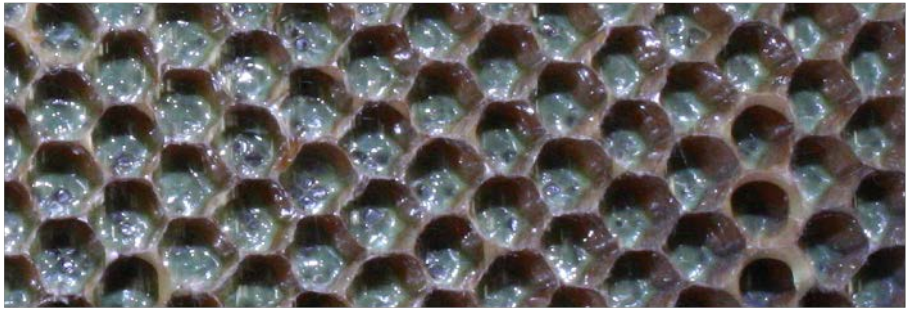
# Failure Mode

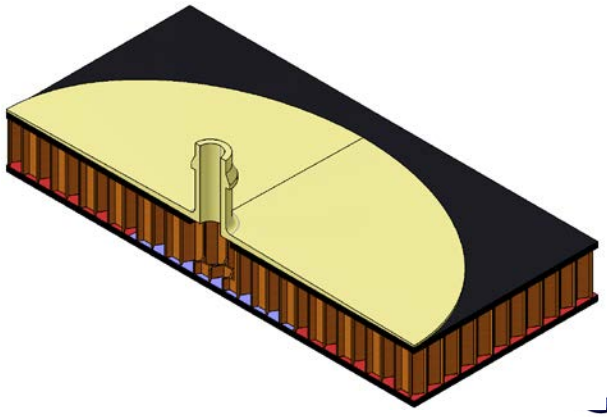


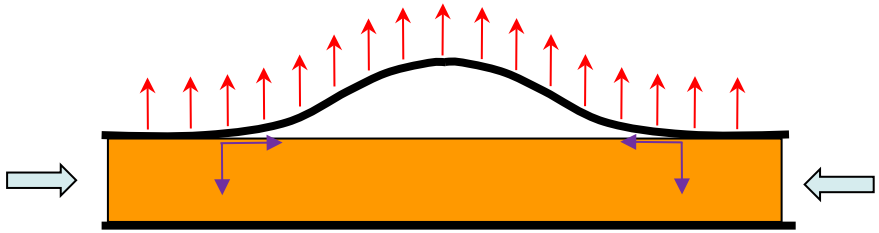
SCB Failure mode ➔



# FEA – Methodology
# GAG Sandwich Panel

- GAG Sandwich Panel Testing and Simulation
  - FEA modeling
    - Use of $G_{IC}$ facture toughness values from SCB testing
    - Model setup using methods determined from SCB test verification
    - Verify FEA model matches tested panels
      - Load – Displacement Curves
      - Strain Measurements
      - Out-of-plane displacements from ARAMIS
      - Damage growth
    - Validate FEA model by using the methods above to predict behavior of test specimen prior to physical testing





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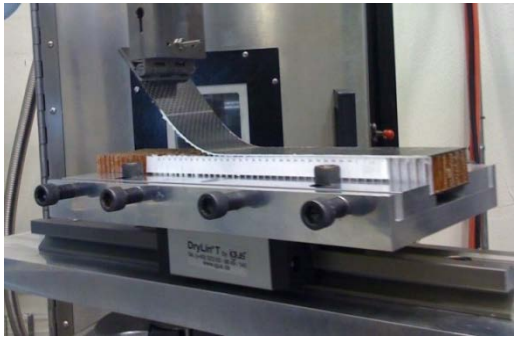
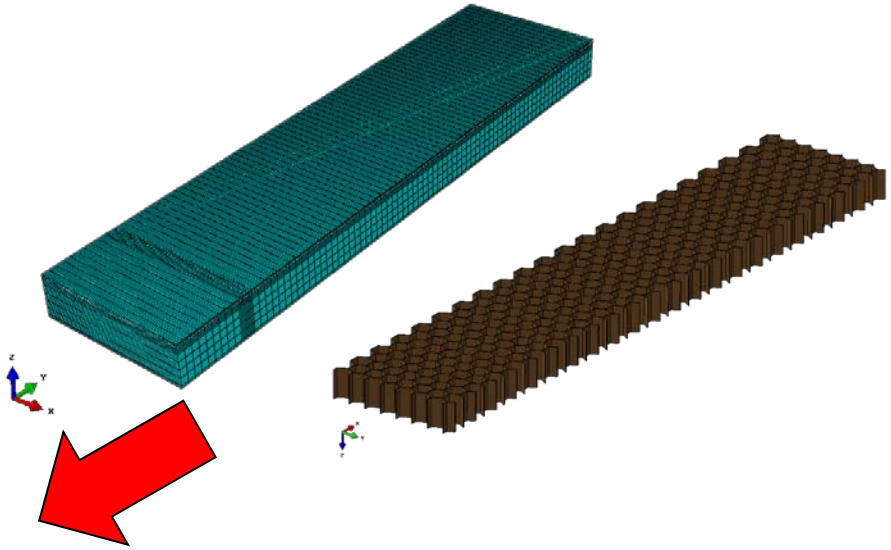
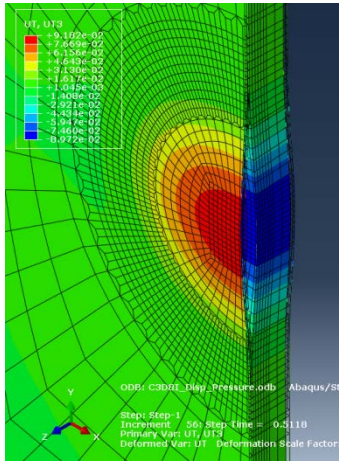


Validation





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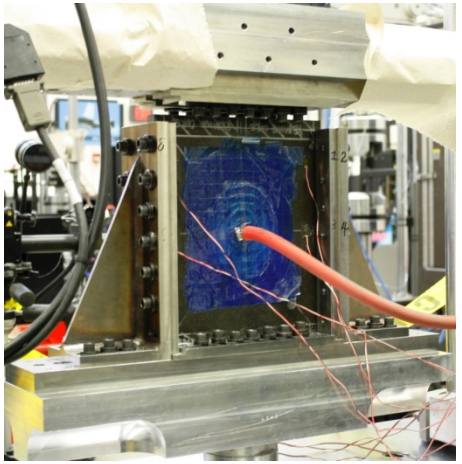

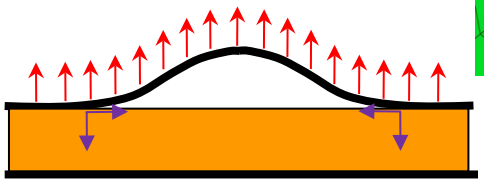

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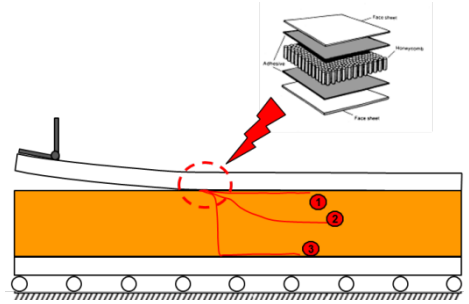
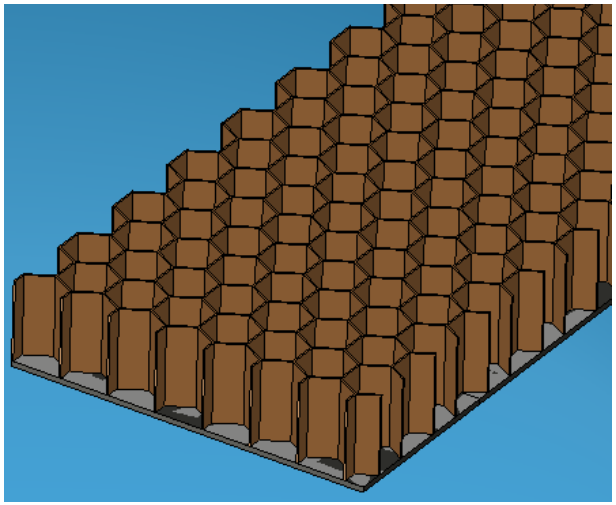
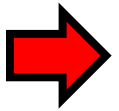
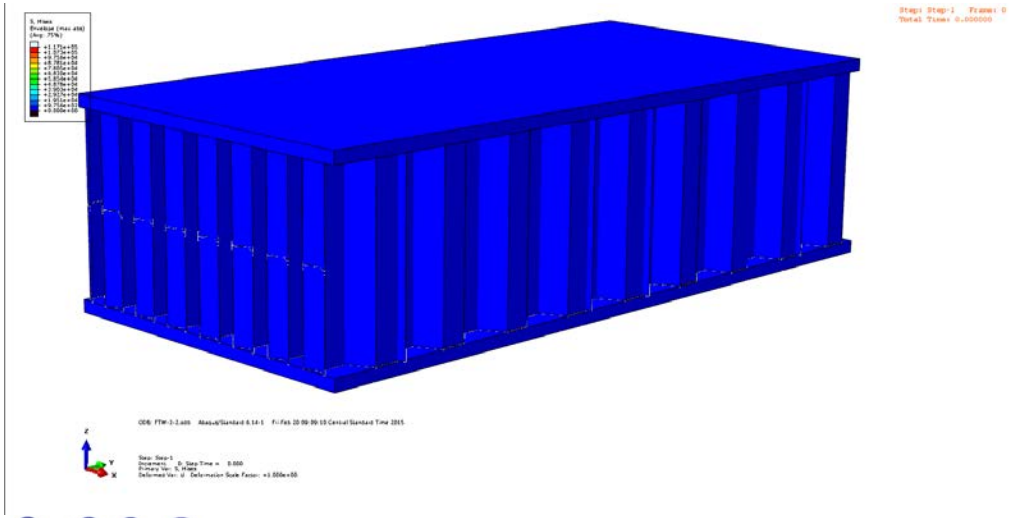
# FEA - XFEM





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# Summary of SCB Testing

- **FAA Final Reports**
  - Volume 1: ***Damage Growth in Fluid-Ingressed Sandwich Structures***
  - Volume 2: ***Fatigue Damage Growth Rate of Sandwich Structures***
  - Volume 3: ***Damage Growth in Sandwich Structures***

    **[Draft copies are available upon request]**

  -- Volume 4: ***Damage Growth of Sandwich Structures Subjected to Ground-Air-Ground Simulations***

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# Looking Forward

- **Benefit to Aviation**
  - Guidelines for substantiating sandwich structures
    - Fluid ingression phenomenon
    - GAG effects on damage growth
    - Effects of geometry and sandwich parameters on fracture toughness and damage growth rates
- **Future needs**
  - Field history data related to sandwich data growth phenomenon
  - Validated analytical methods
  - Standardized test procedures

# End of Presentation.

# Thank you.

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