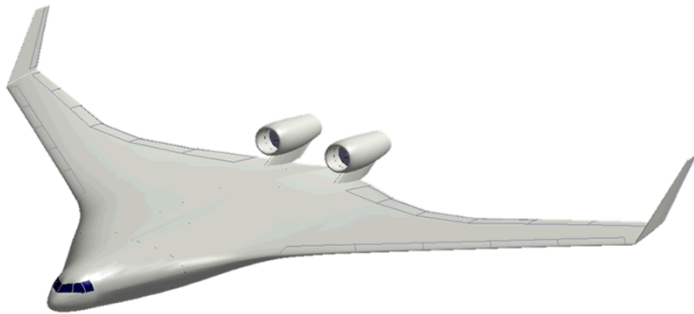


PRSEUS Structural Concept Development (Part 2)

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**Structural Mechanics and Concepts Branch
NASA Langley Research Center
May 18, 2018**



Outline

- Summary of previous talk (February 2014)
 - Background
 - PRSEUS (Pultruded Rod Stitched Efficient Unitized Structure)
 - Concept and fabrication
 - Building blocks
- Multi-bay box test article
- Alternate designs
- Stitching at Mississippi State University
- Stitching at NASA Langley Research Center (LaRC)

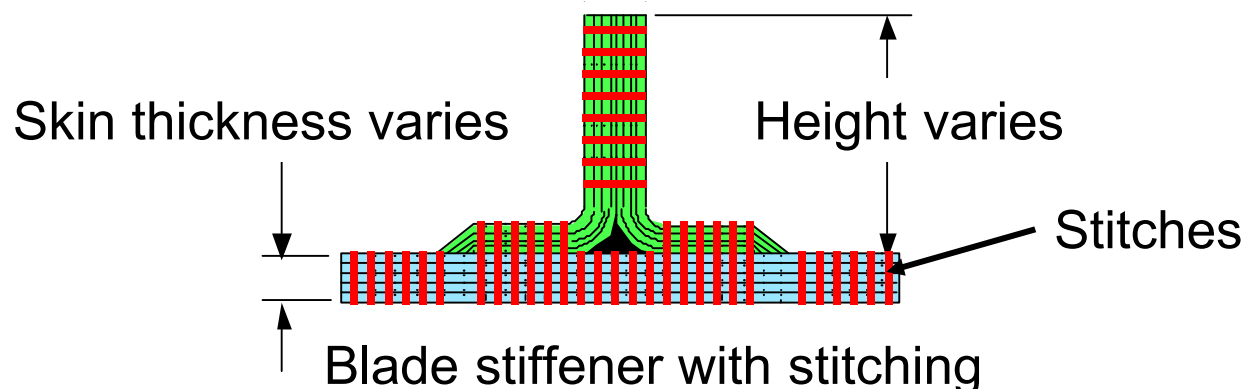
Traditional Composites

Current State-of-the-Art

- Material characteristics
 - Lighter and stiffer than aluminum
 - Layered material with unidirectional fibers connected by epoxy resin
 - Weak in the through-the-thickness direction
 - Out-of-plane deformation and impact can lead to delaminations/disbonds
 - Non-visible damage can be severe and lead to catastrophic failure
- Fabrication and assembly characteristics
 - Prepreg has limited shelf-life
 - Autoclave cure requires high temperature and pressure
 - Fasteners and clips attach many stiffeners to skins
 - Large mouseholes at stiffener intersections disrupt load paths

Structural Benefits of Stitched Structure

- Through-the-thickness stitching changes the design space
 - Prevents separation between plies and between flange and skin
 - Allows repeated buckling cycles and pressurizations
 - Turns cracks
 - Suppresses failure modes and minimizes the spread of damage
 - Reduces or eliminates the need for fasteners and their associated holes and doublers



Advanced Composites Technology (~1990-2000)

- Goals: 25% weight and 20% cost reduction compared to aluminum
- Concept: Composite with stitching for transport wing structure
- Approach: Hundreds of building blocks culminating in a 40-foot-long wing
- Conclusions
 - Reduced part count, pad-ups, and assembly time
 - Demonstrated exceptionally high stiffener pull-off loads
 - Suppressed interlaminar failures, turned cracks
 - Wing supported 97% design ultimate load (DUL)
 - Achieved program goals



Leaving Boeing



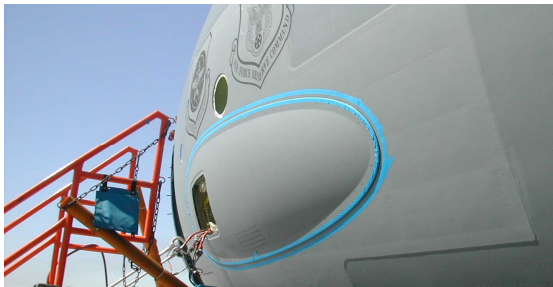
Final Test at LaRC

Next Step

Environmentally Responsible Aviation (~2007-2015)

- Goal: Reduced fuel burn and fewer pollutants
- Approach: Technologies applicable to wings, barrel fuselages and non-traditional fuselages
- Concept: Since traditional composites not living up to their initial promise, continue to develop through-the-thickness reinforcement in the form of stitching

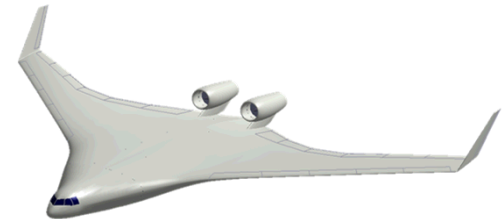
Damage Arresting Composites Technology Demonstration



C-17 Stitched Fairing
(2009)

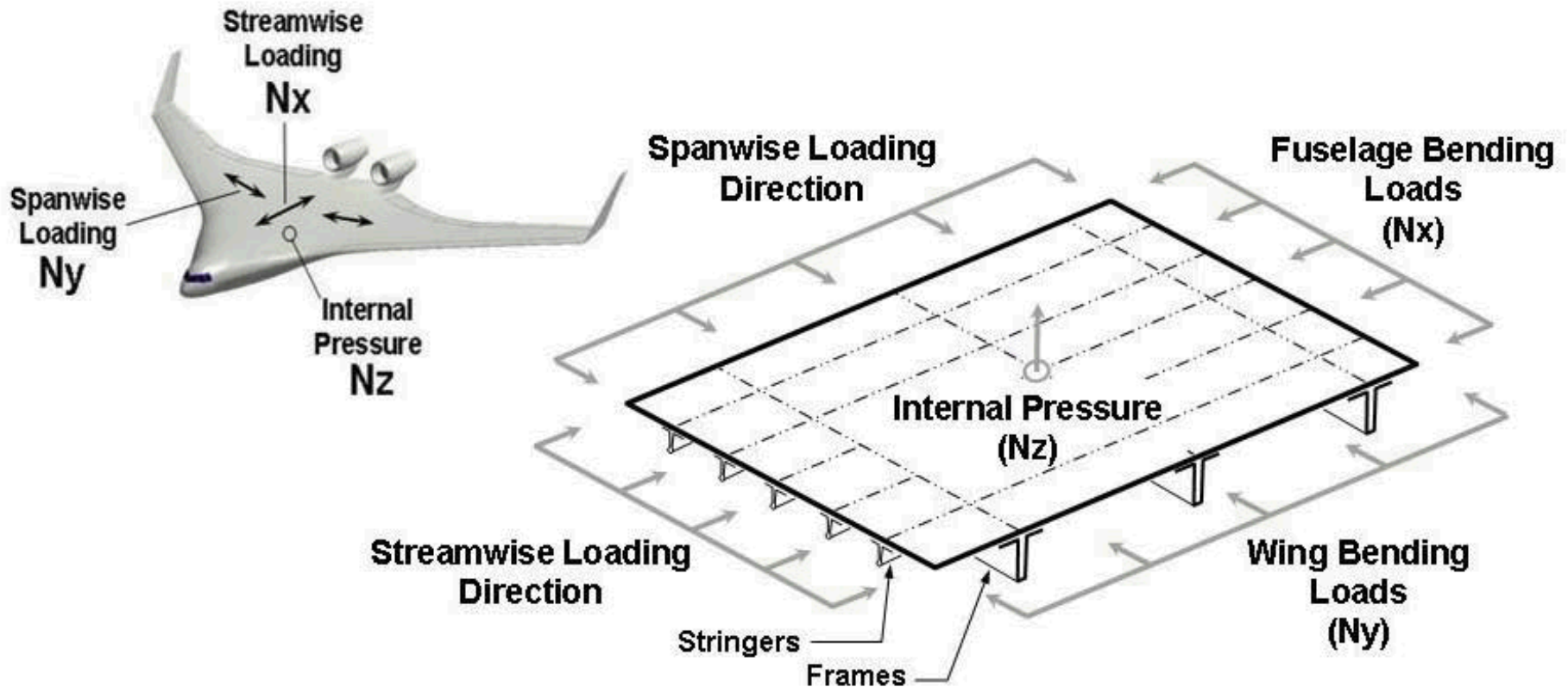


Traditional



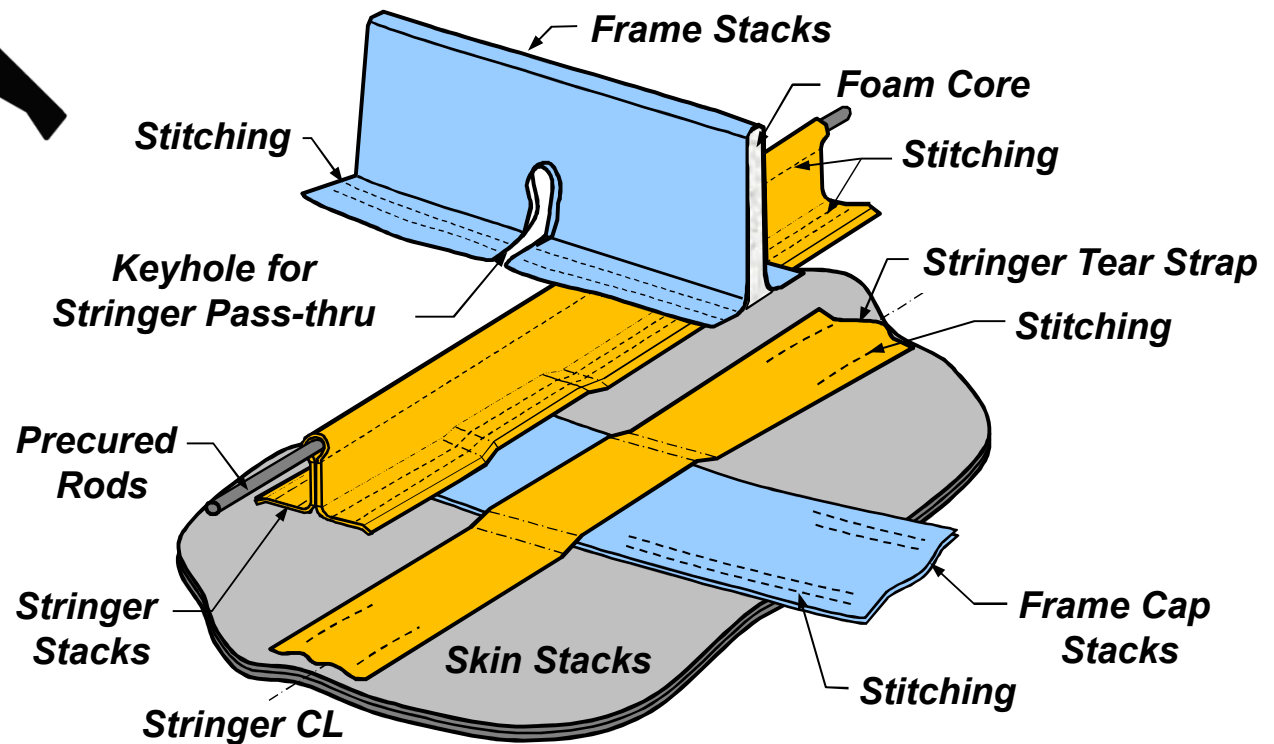
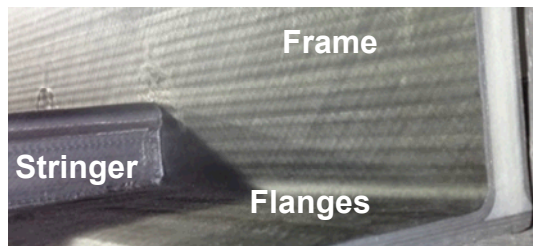
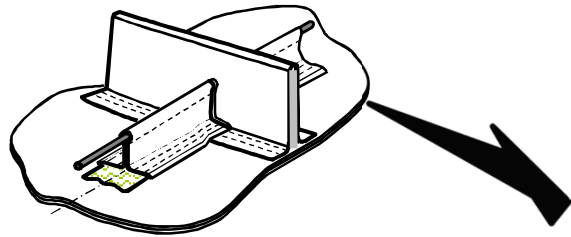
Hybrid Wing Body

Advanced Configuration Hybrid Wing Body (HWB)



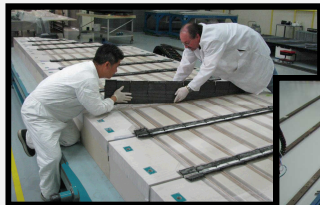
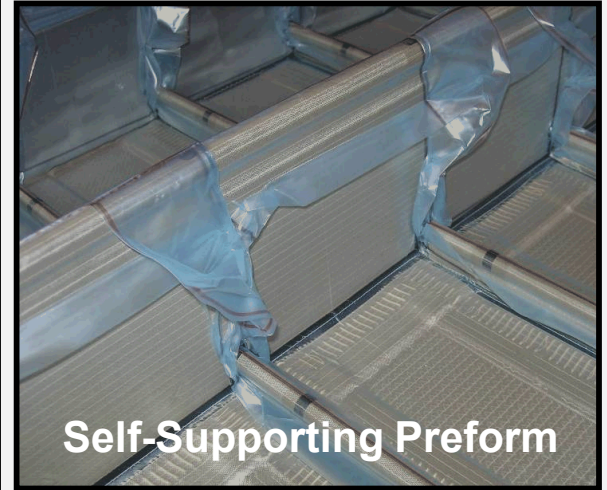
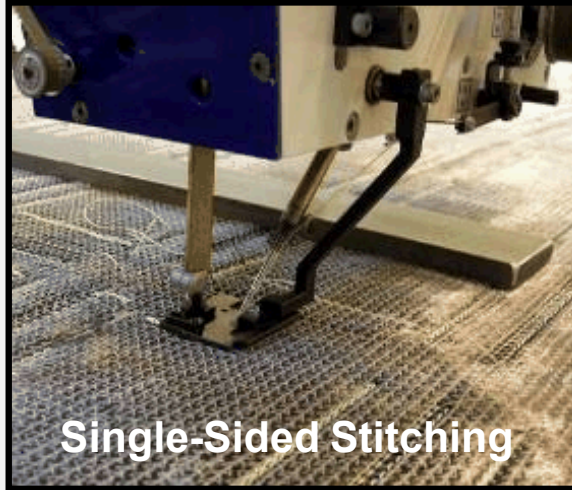
- Suppressing the skin-flange separation failure mode caused by repeated pressure cycles on nearly flat panels means that stitching is enabling technology for HWB center section

Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)



Stacks of 44/44/12 percent 0/45/90 lay-up
One stack is 0.052 inches thick
Typical frame spacing is 20 inches to 24 inches
Typical stringer spacing is 6 inches

PRSEUS Fabrication



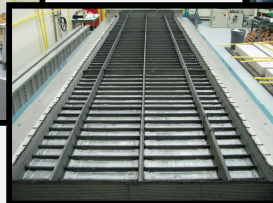
**Place
Stiffeners**



**Build Up
Preform**



**Stitch
Single-Sided**



**Self-Supporting
Preform**



**Infuse and
Oven Cure**



**Remove
Bag Film**

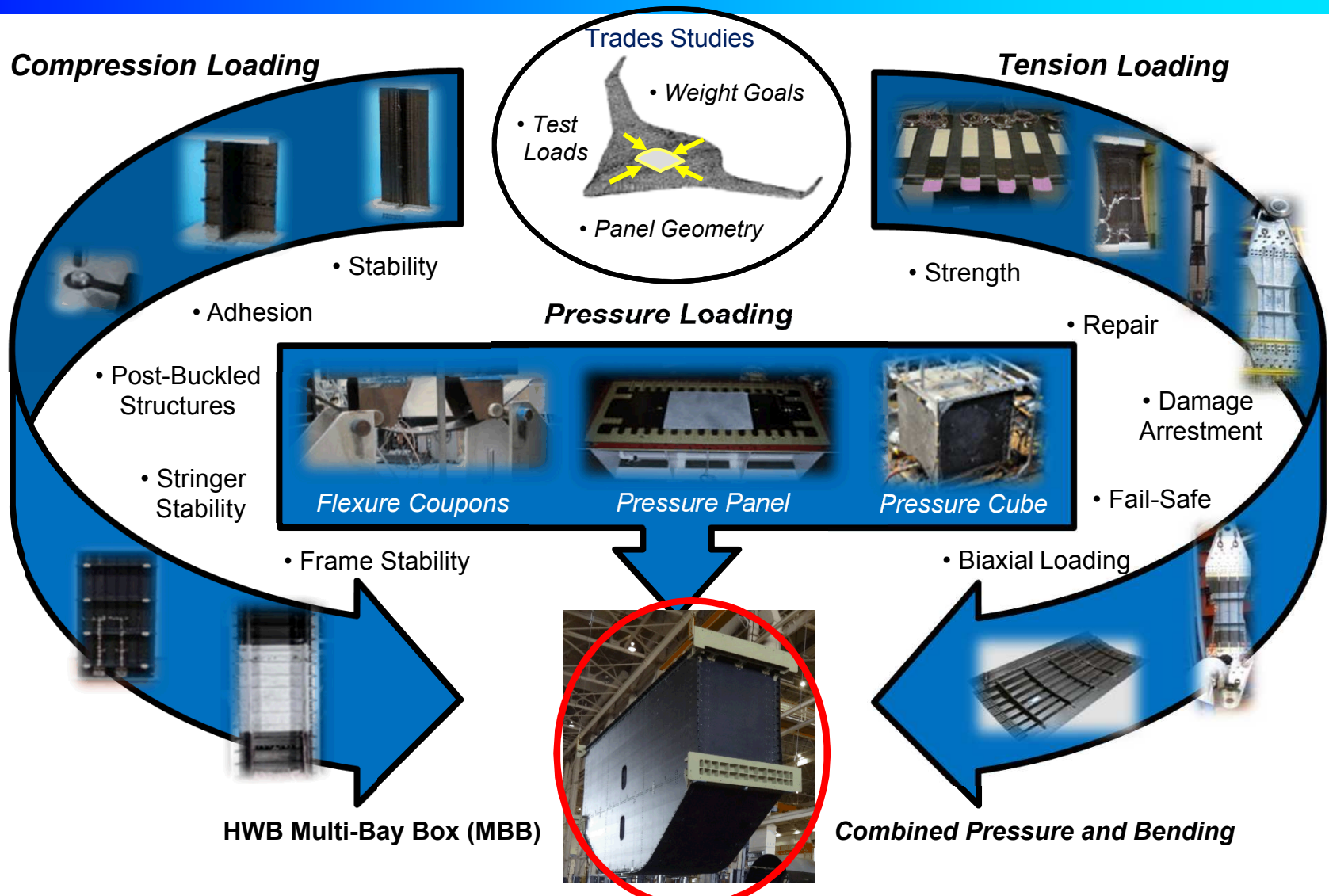


**Edge Trim
Cured Panel**

Basic Steps in Fabricating a PRSEUS Panel



Building Block Testing

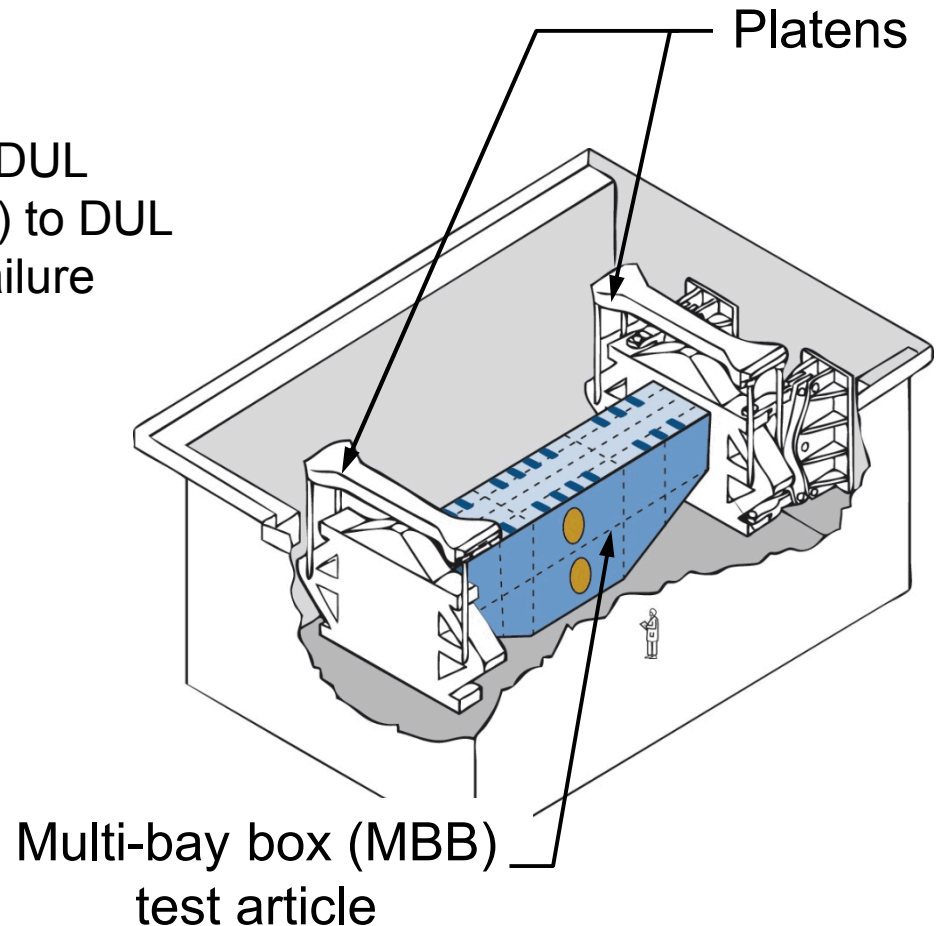


Combined Loads Testing at LaRC

Load Cases and Conditions

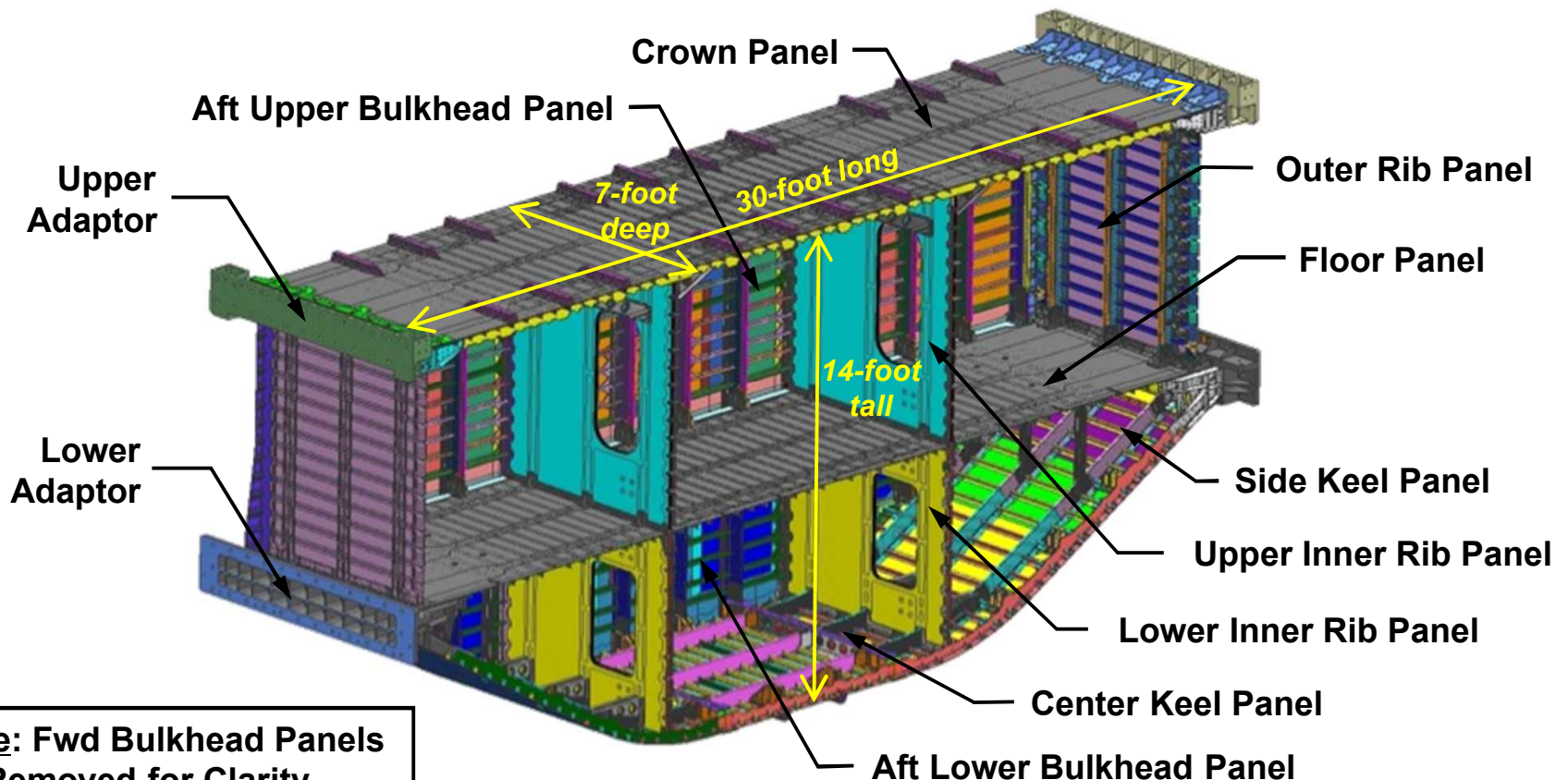
- Internal pressure alone to 18.4 psi
- 2.5 G Upbending to DUL
- 1 G Downbending to DUL
- Combined pressure and bending to DUL
- Barely visible impact damage (BVID) to DUL
- Discrete source damage (DSD) to failure

Combined Loads Test System (COLTS)



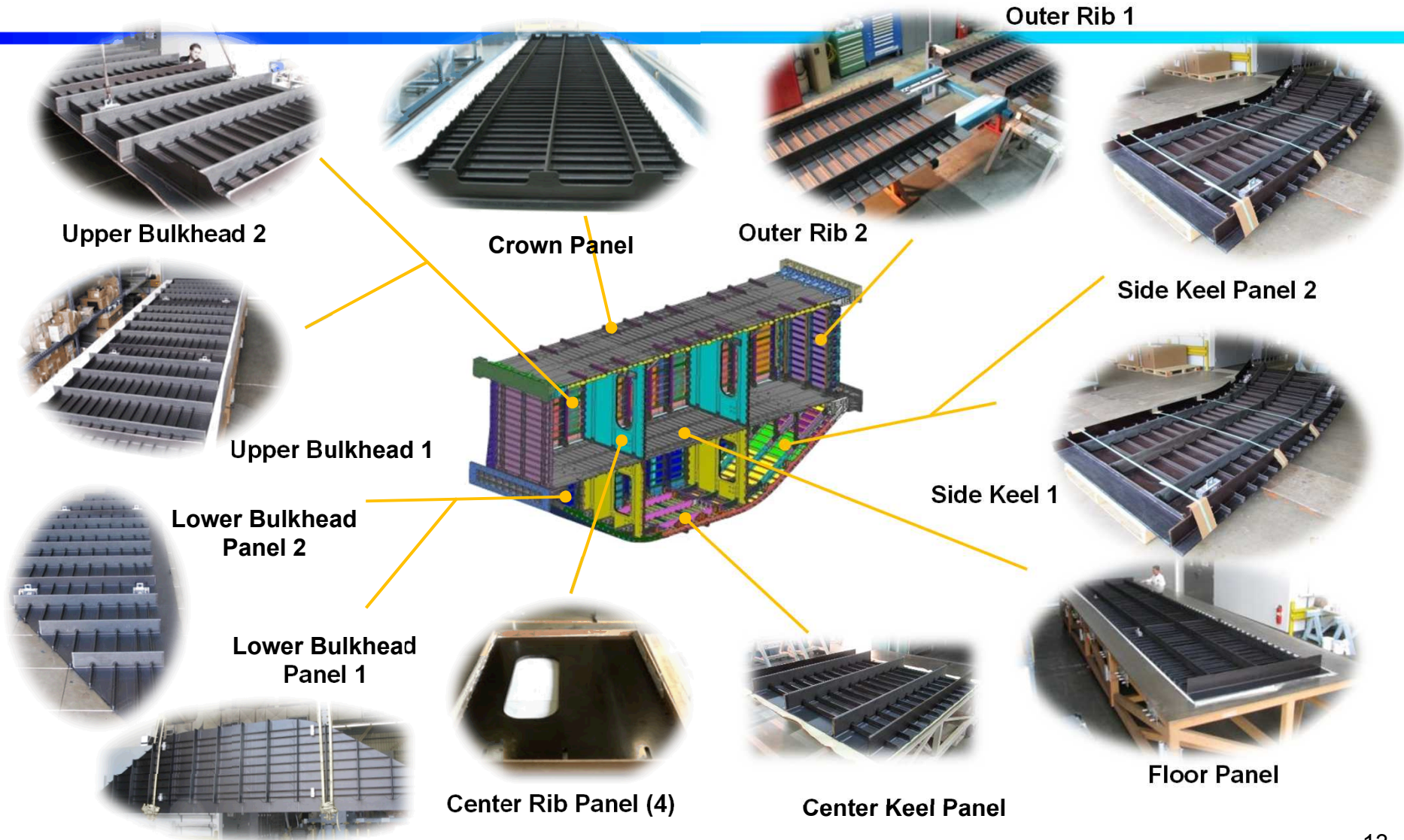
MBB Schematic

- 11 PRSEUS panels and 4 composite sandwich panels

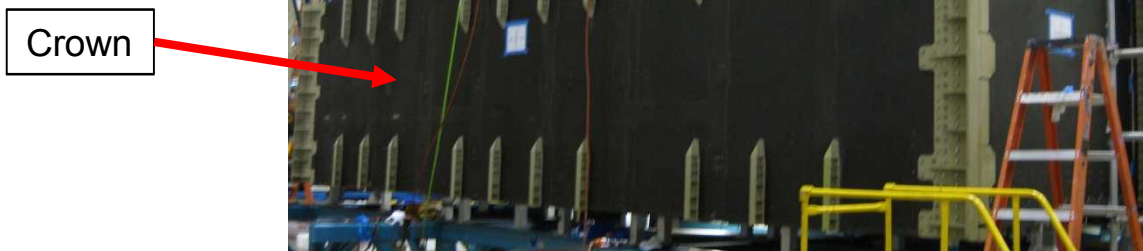
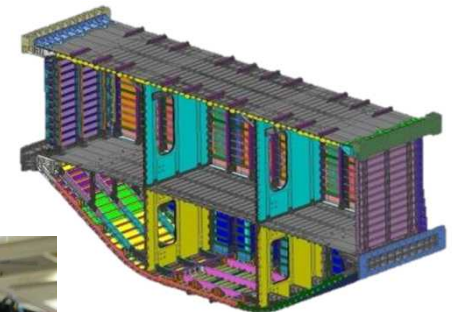
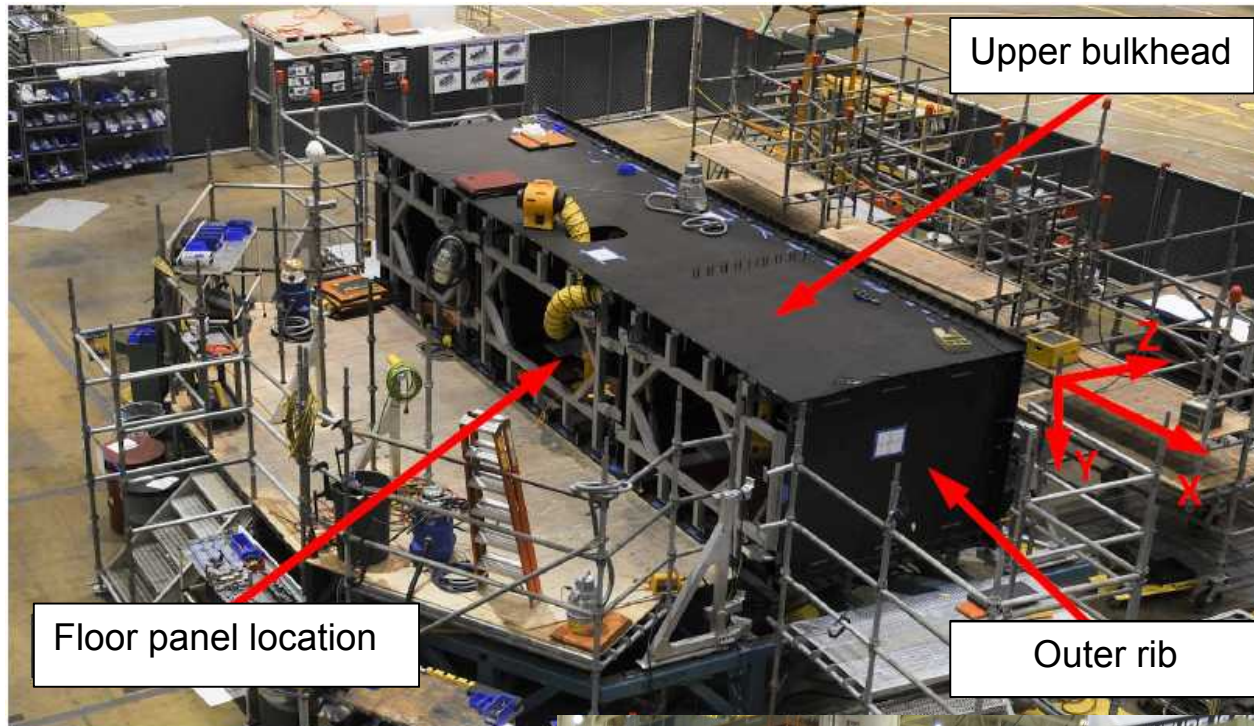


Note: Fwd Bulkhead Panels
Removed for Clarity

MBB Panels



Assembly of the MBB



Long Beach, CA to Hampton, VA



MBB loaded on K-Loader
at Boeing Long Beach



MBB loaded into
Super Guppy at Boeing

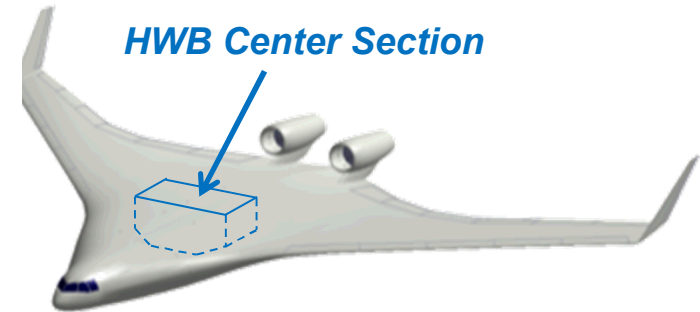
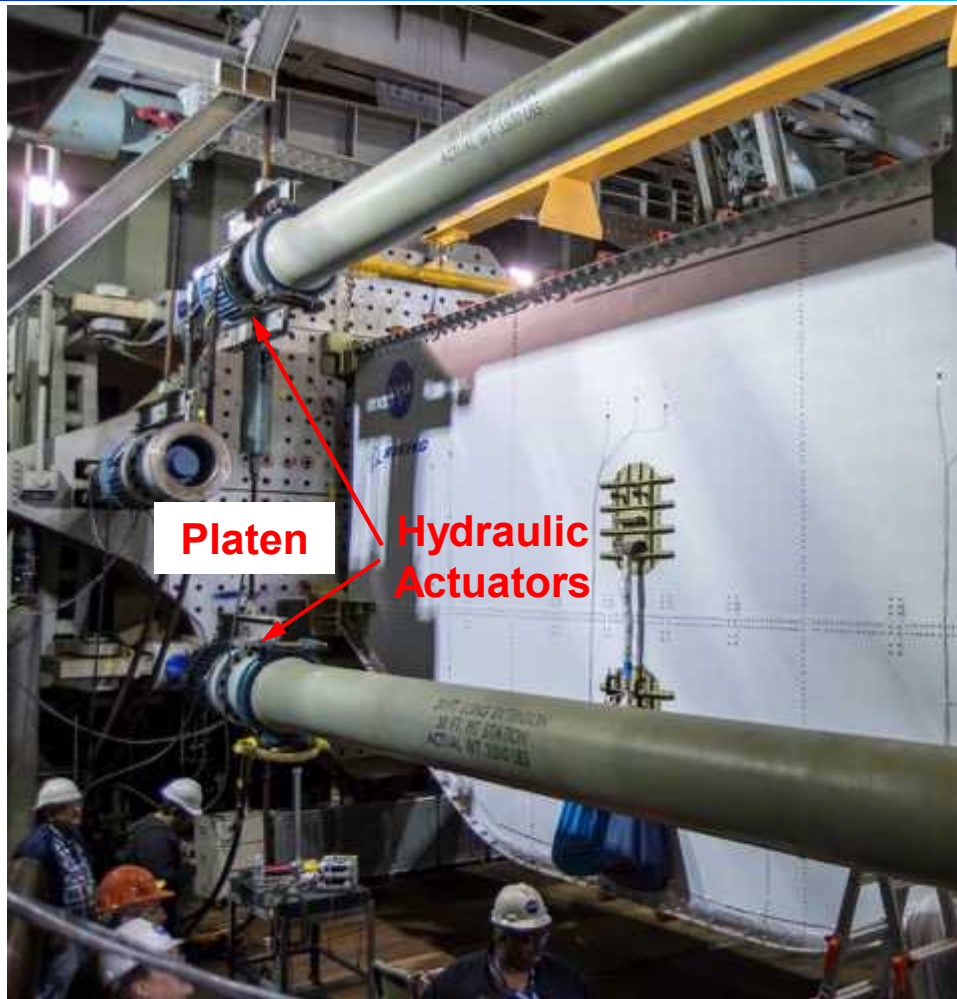


MBB unloaded from
Super Guppy at NASA LaRC



MBB unloaded from
K-Loader at NASA LaRC

Inside the COLTS Test Chamber



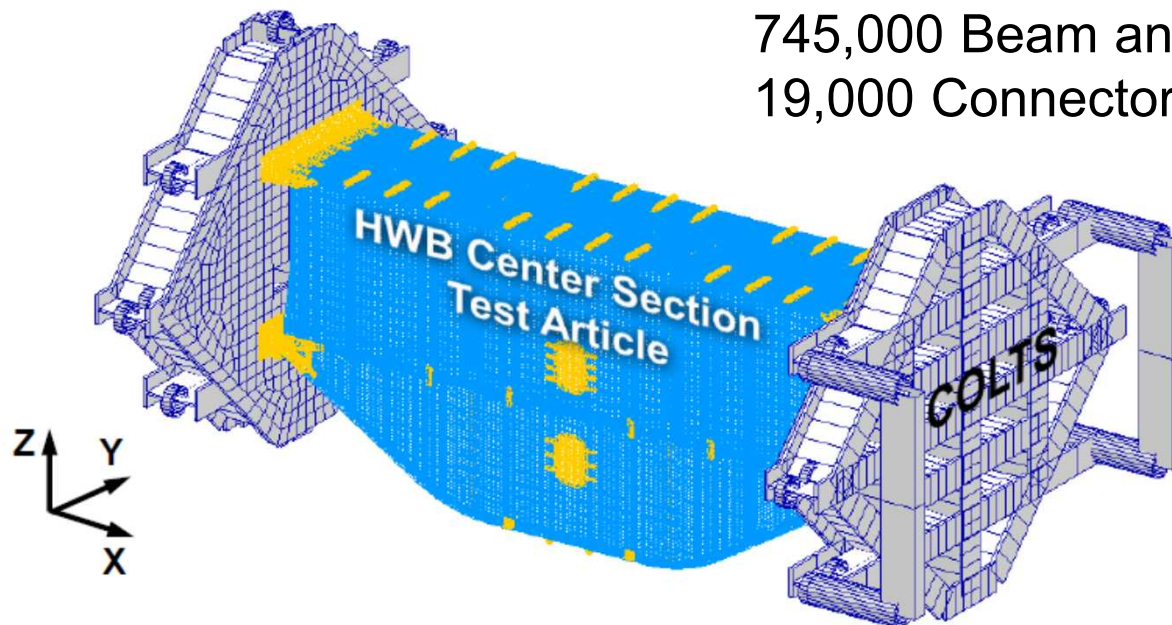
Finite Element Model

- Shell, bar, and connector elements
- Typical element size approximately 1 in.
- Total model size approximately 4.5-million degrees of freedom

746,000 Nodes

745,000 Beam and Shell Elements

19,000 Connector Elements

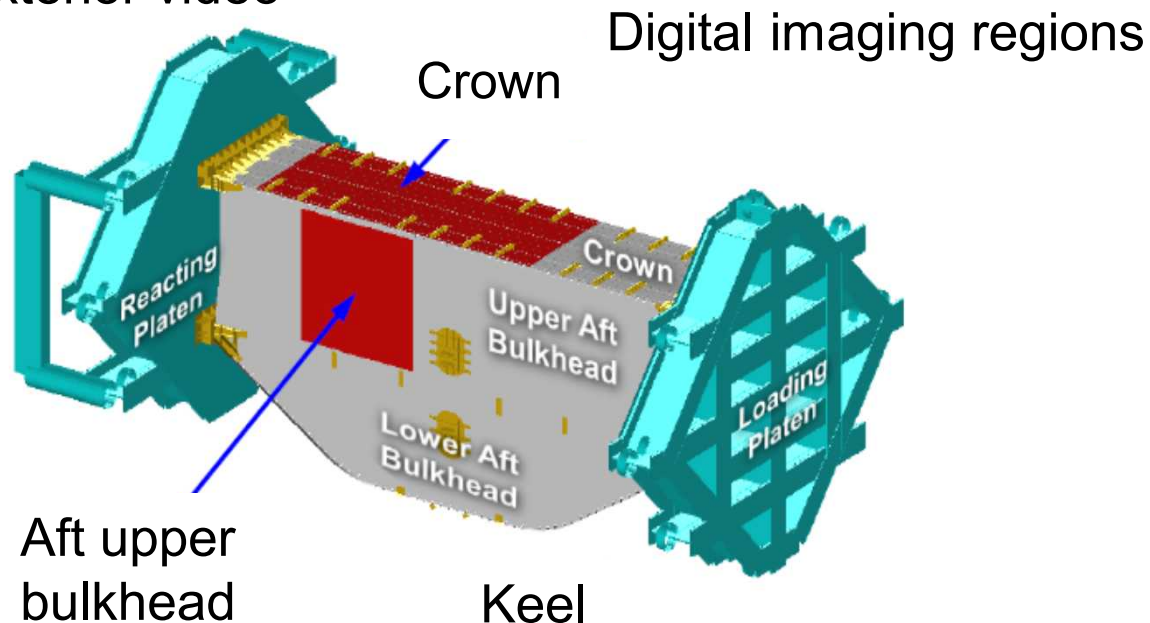


Load Cases and Conditions

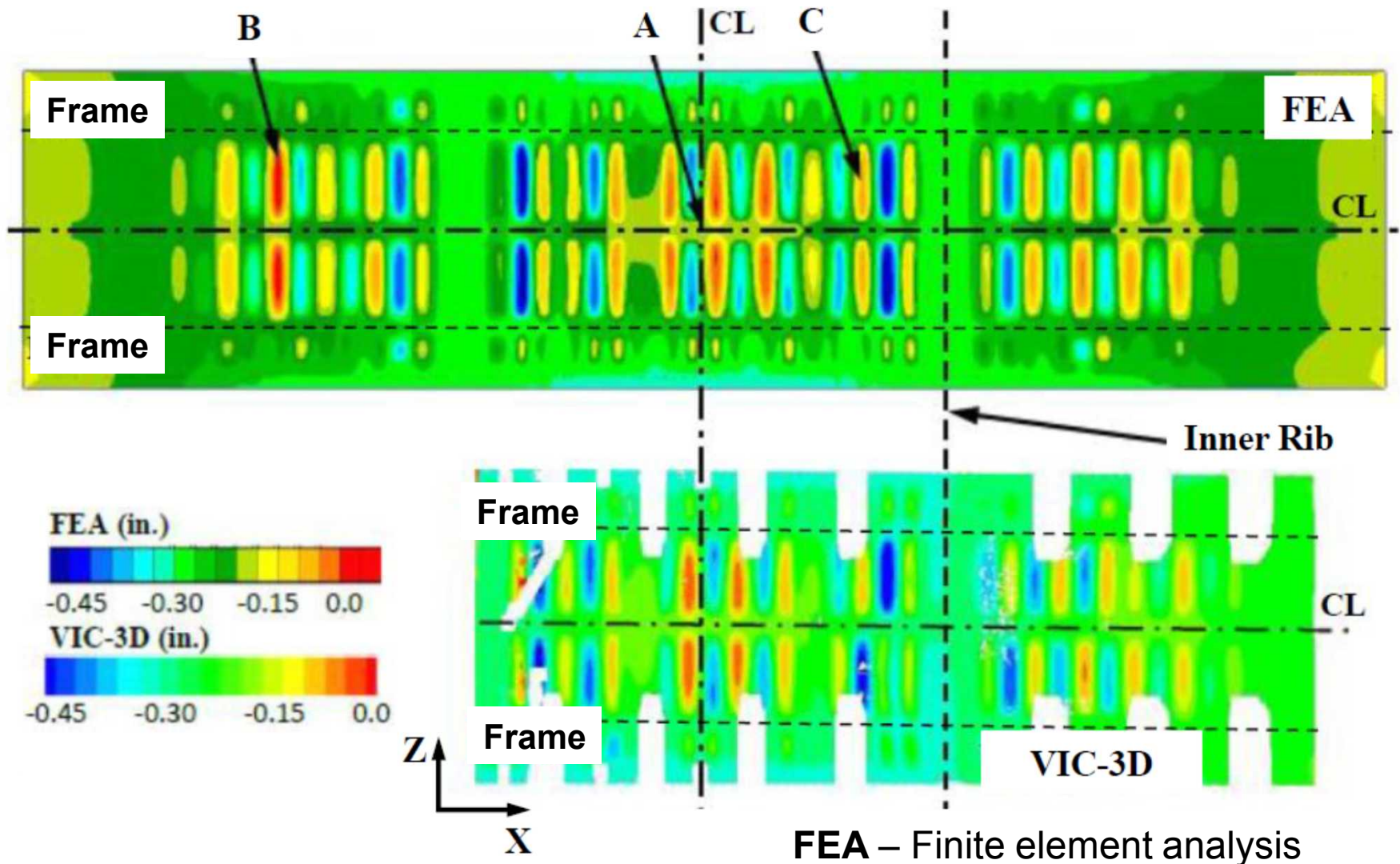
- Internal pressure
- 1 G Downbending
- 2.5 G Upbending
- Combined Internal pressure and downbending
- Combined Internal pressure and upbending
- All with barely visible impact damage (BVID)
- Upbending with discrete source damage (DSD) to crown

Instrumentation

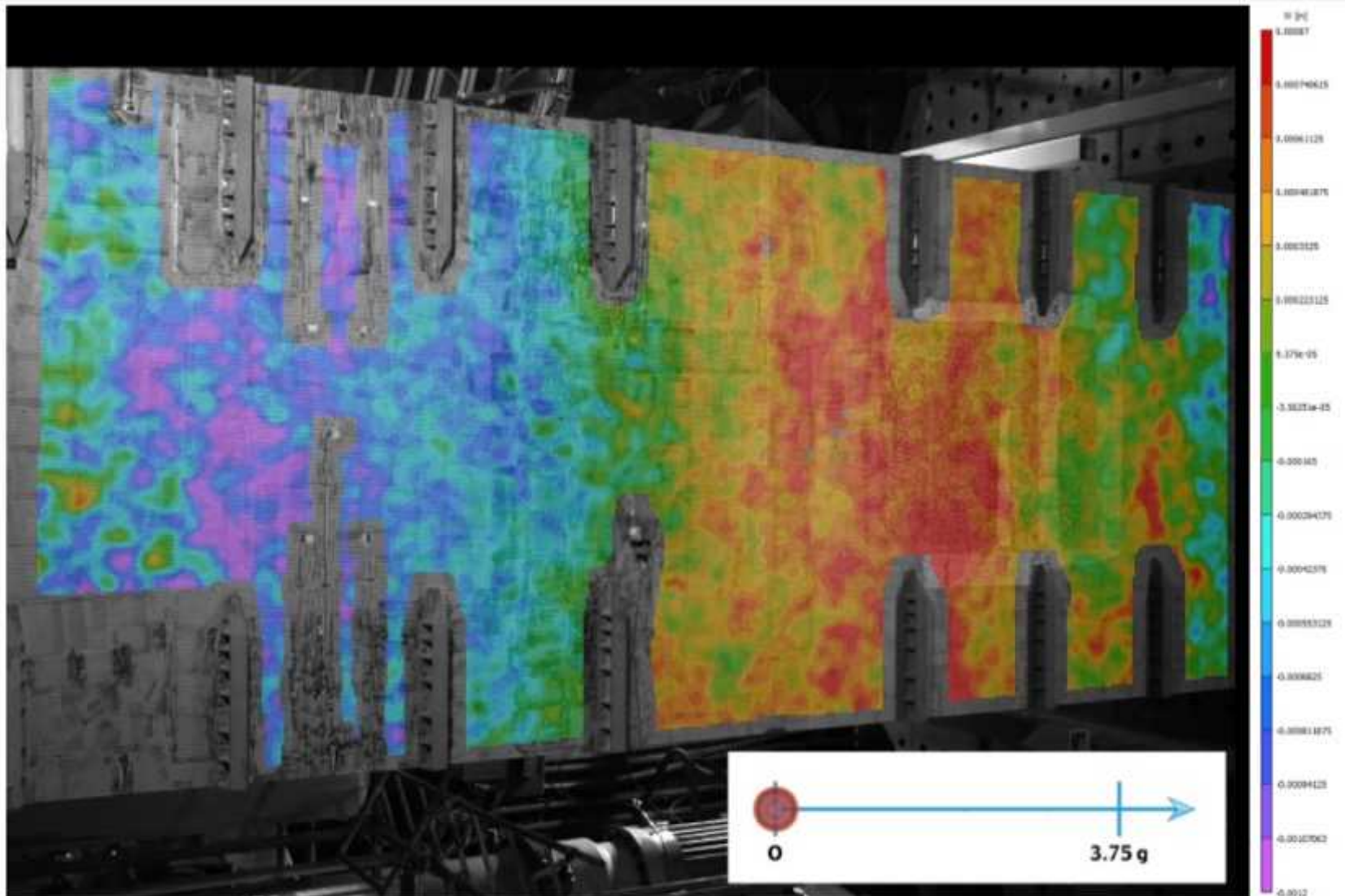
- Strain gauges on every panel
- Digital image correlation (aka VIC-3D) for full field displacement and strains on outer surfaces of crown, keel and upper bulkhead panels
- Displacement transducers
- Interior and exterior video



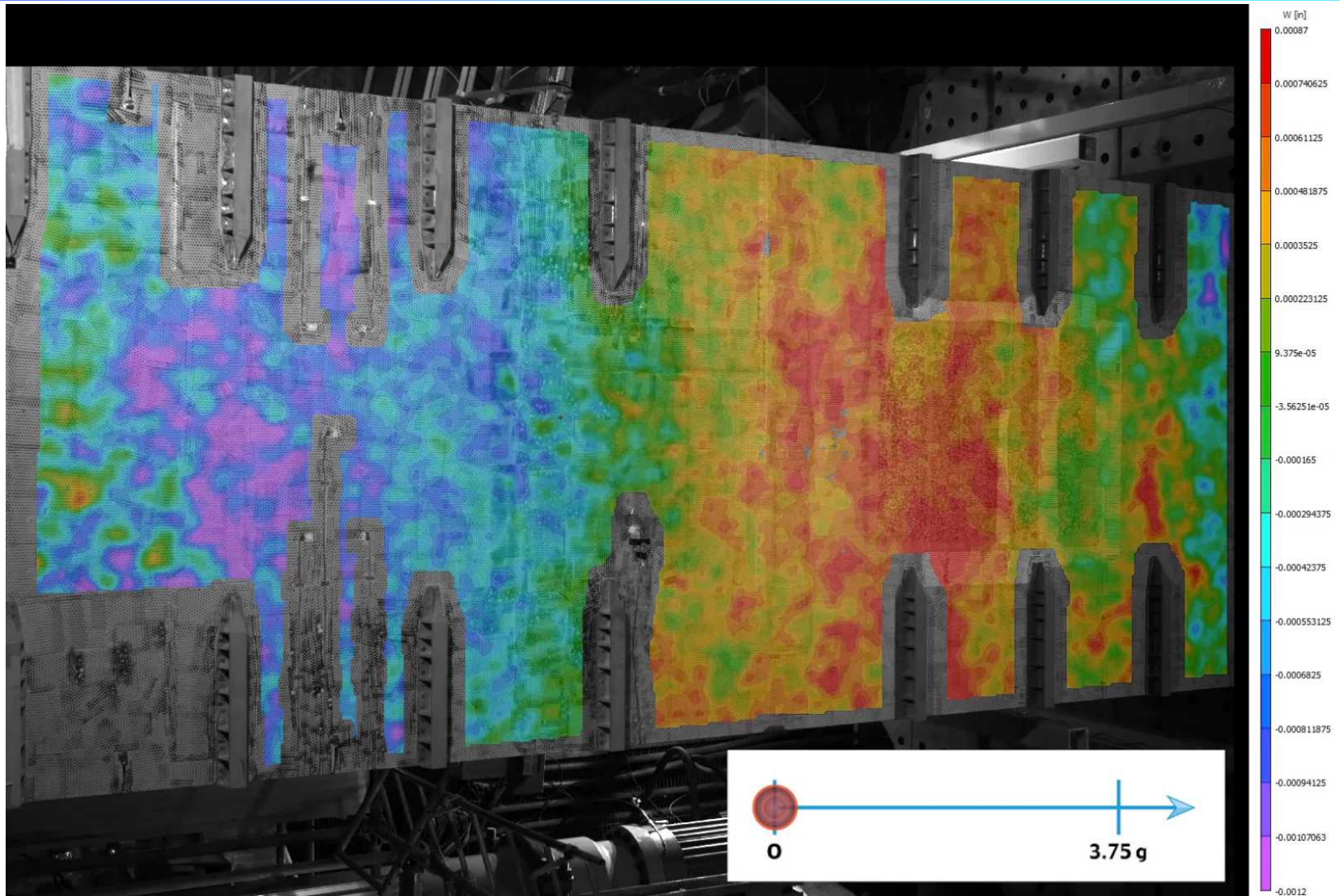
Out-of-Plane Displacement at DUL Crown



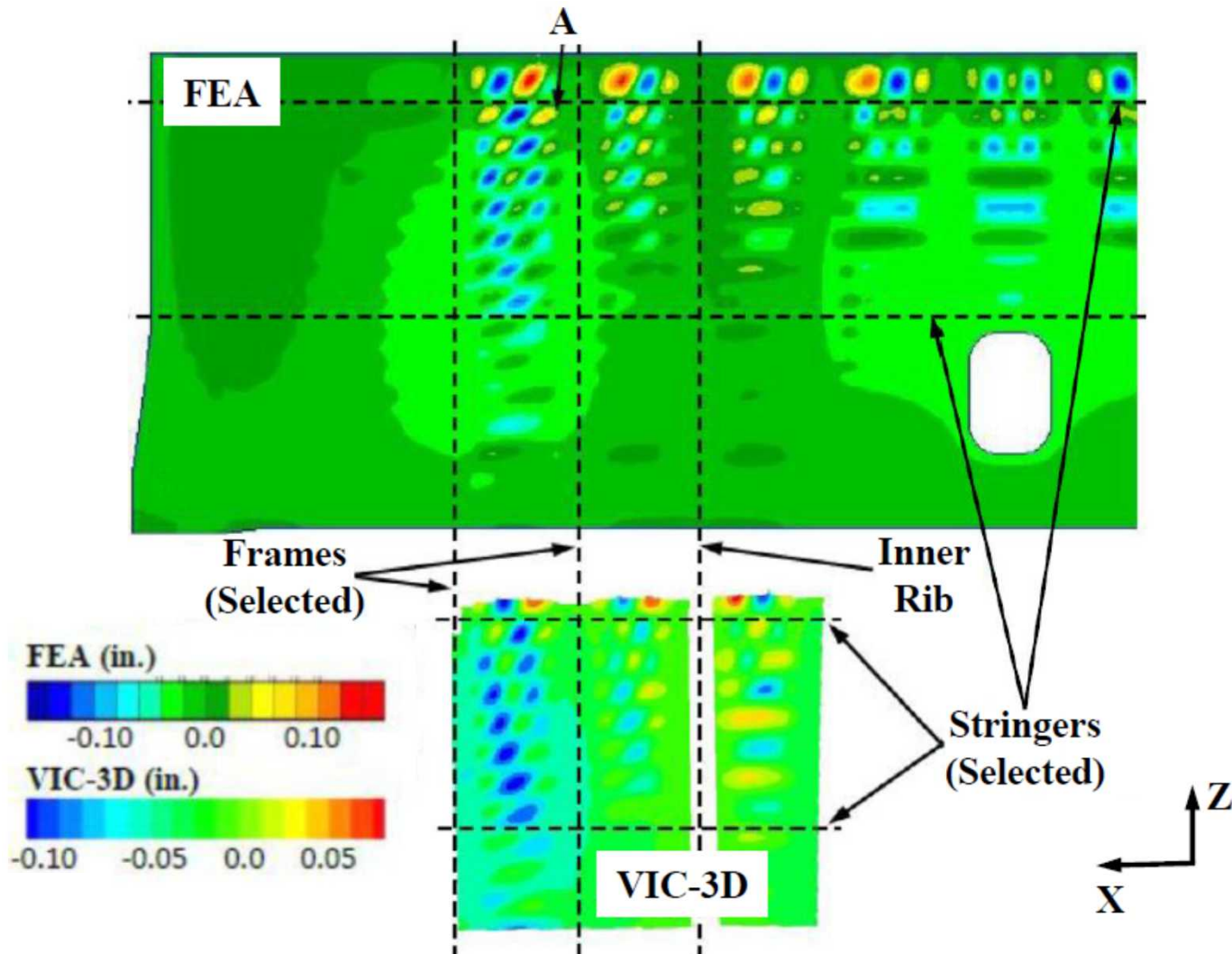
Crown Out-of-Plane Displacement Full Field (Test)



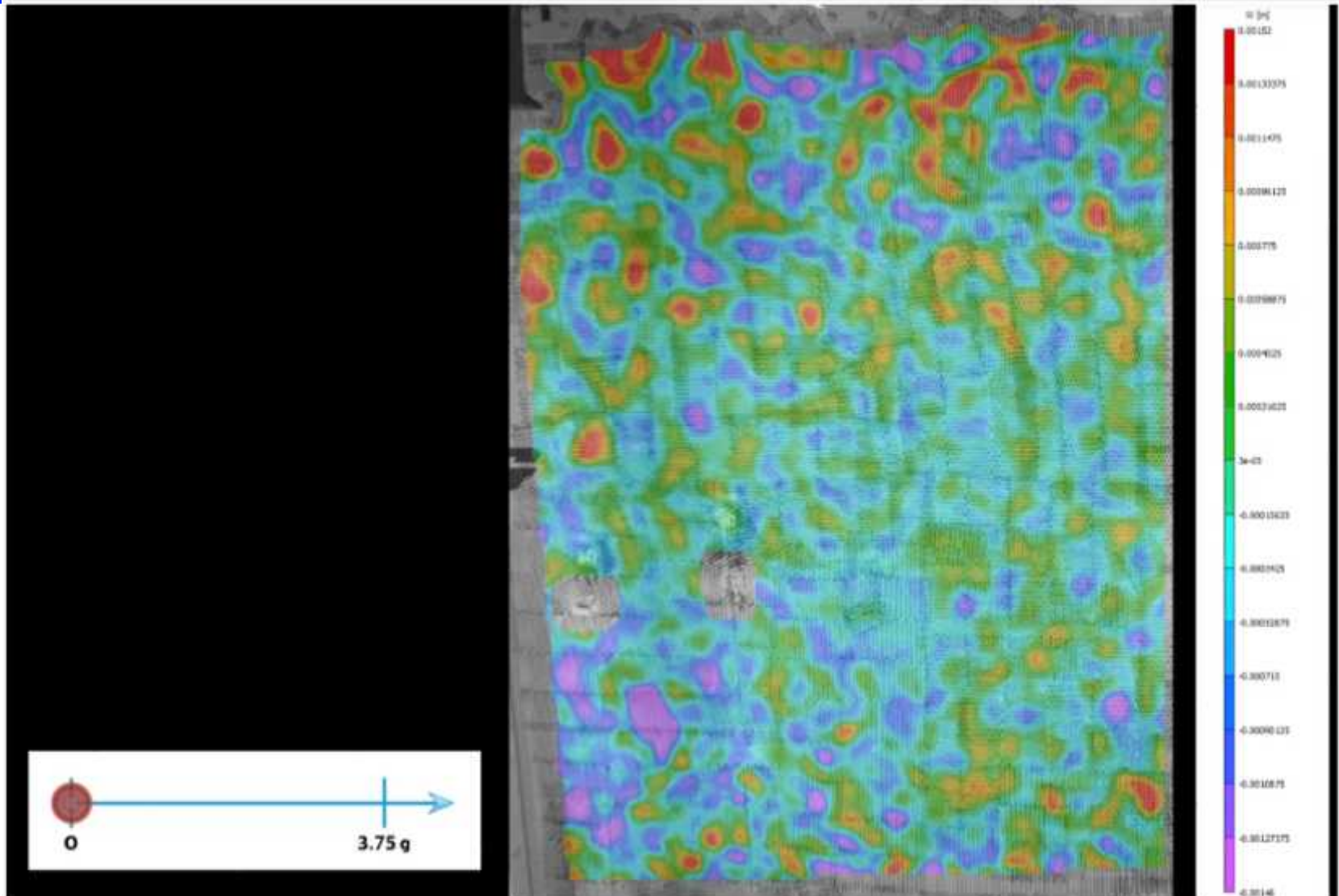
Crown Out-of-Plane Displacement Full Field (Test)



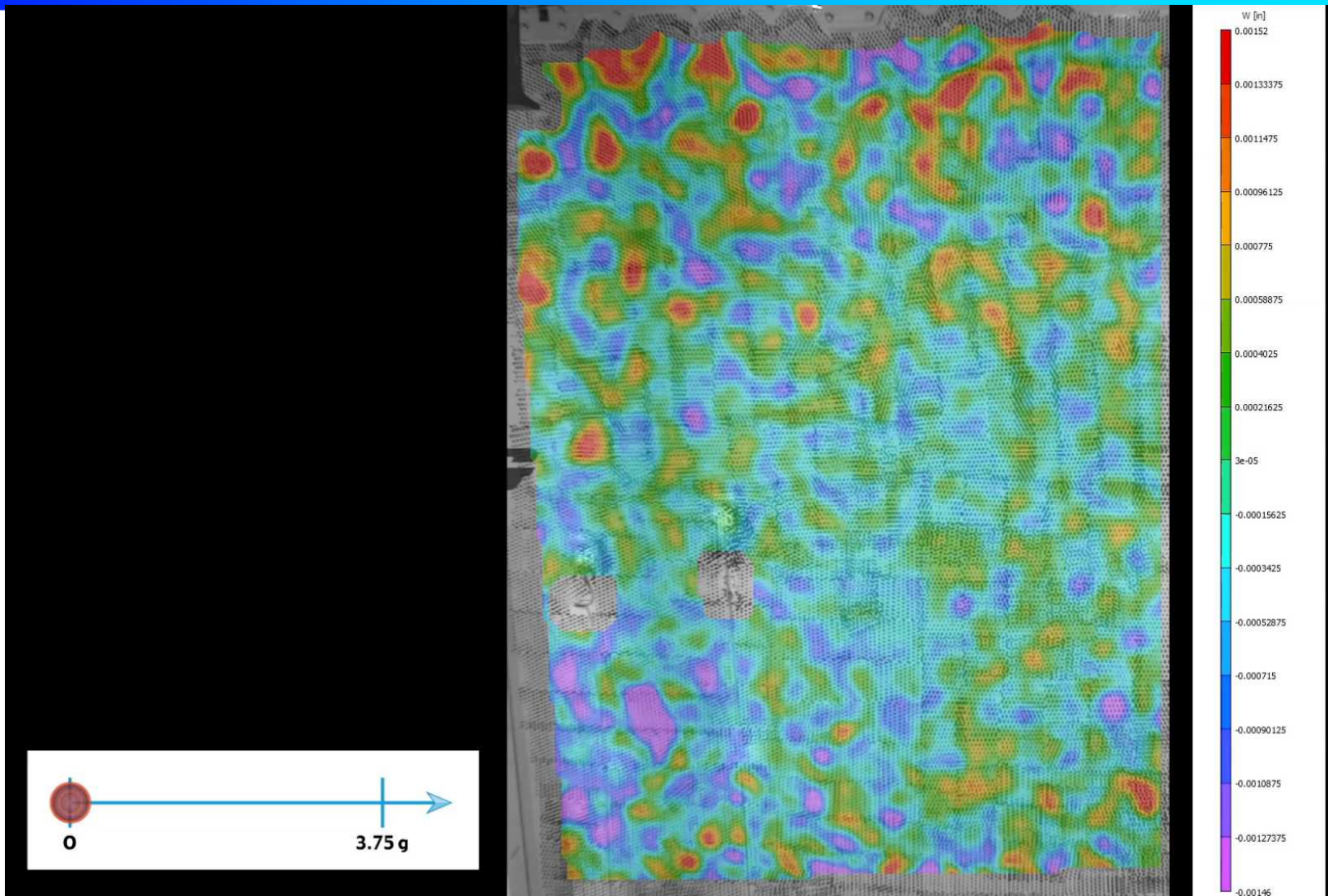
Out-of-Plane Displacement Upper Bulkhead at DUL



Bulkhead Out-of-Plane Displacement Full Field (Test)



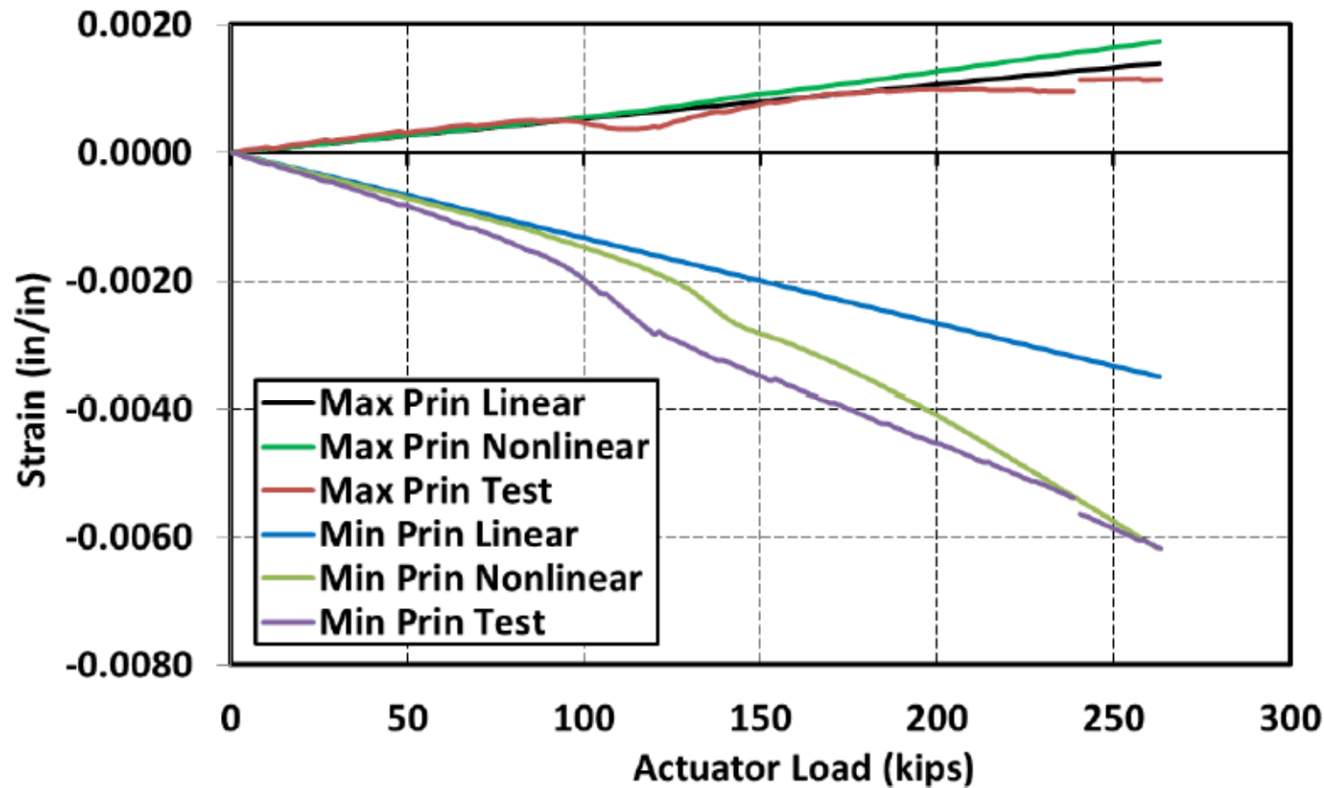
Bulkhead Out-of-Plane Displacement Full Field (Test)



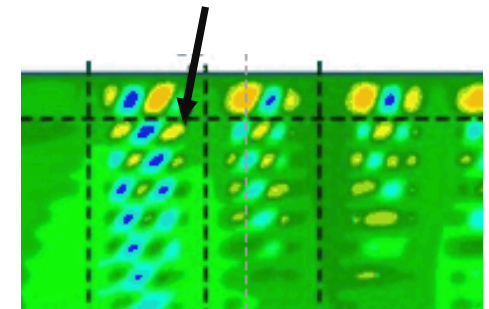
Value of Nonlinear Analysis

Upper Bulkhead Skin Strain

Minimum gauge skin, principal strain



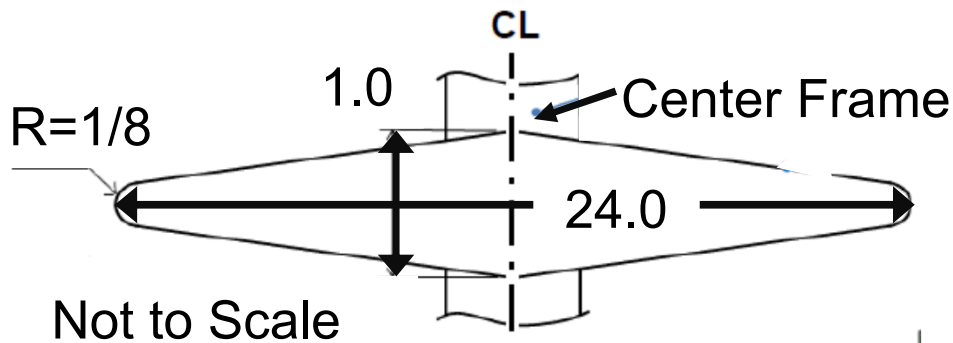
Strain gauge rosette



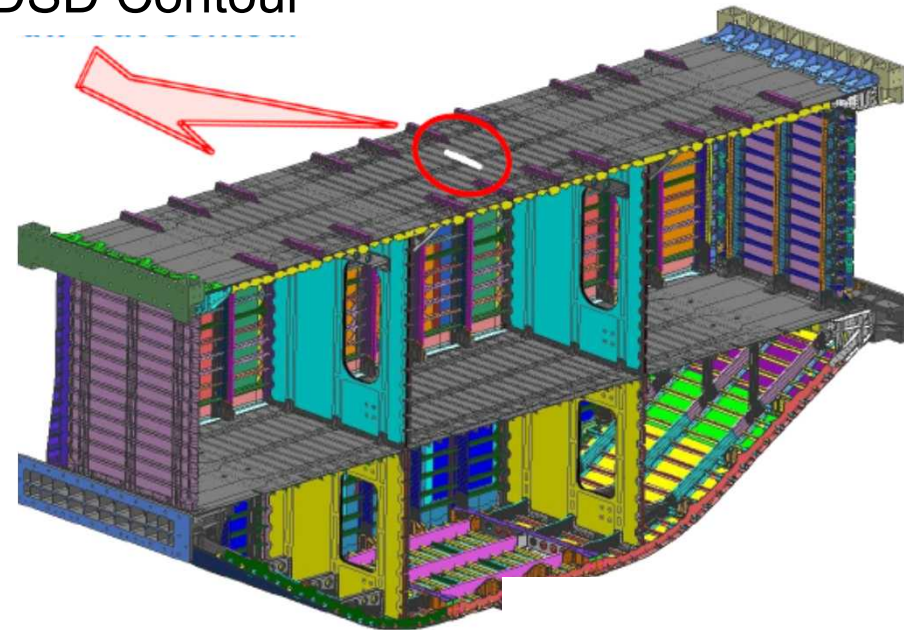
DSD

- Crown panel
- Diamond-shaped cut
- Mid-bay to mid-bay including cutting the center frame
- Nonlinear analysis without damage progression conducted

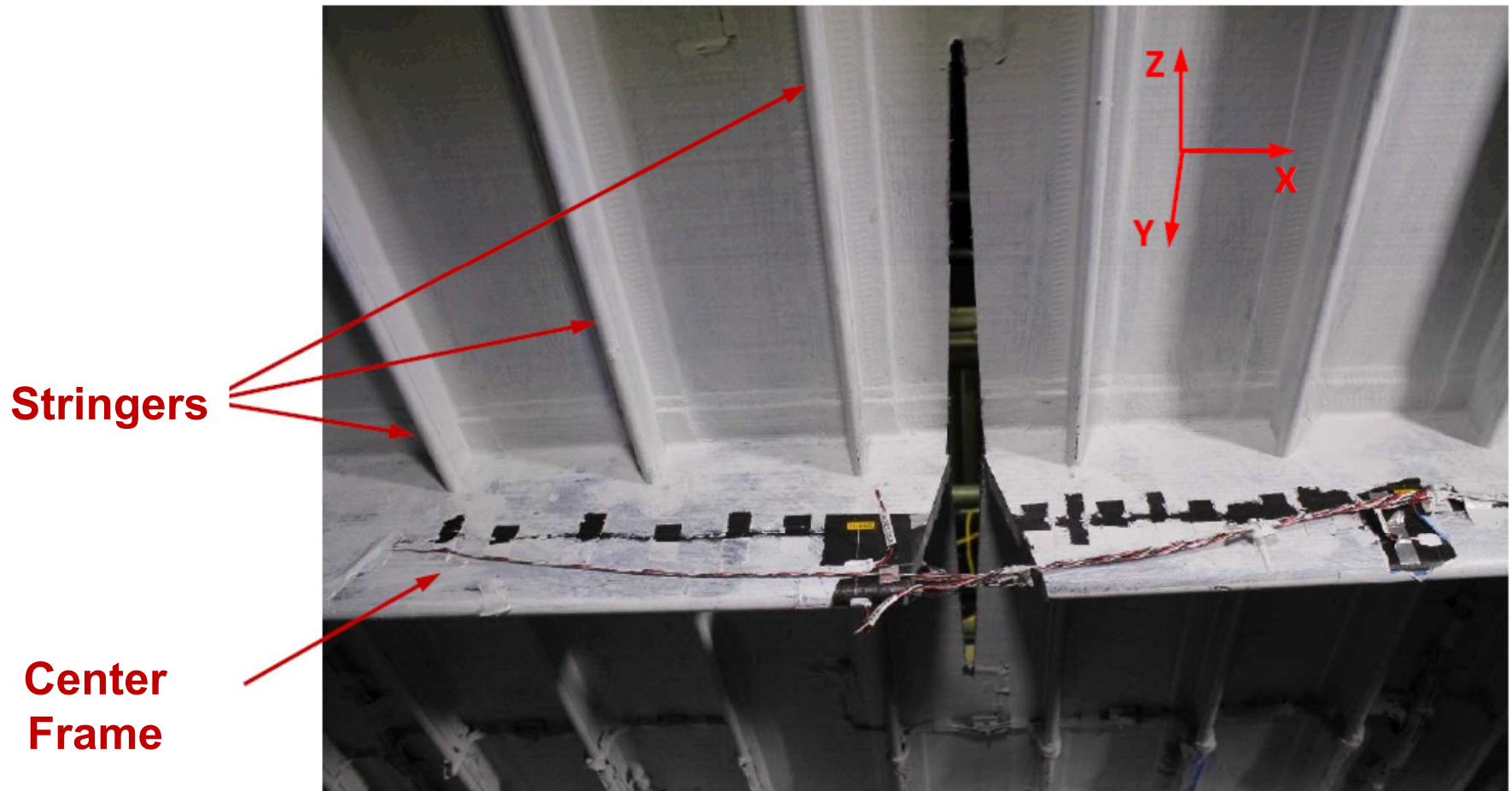
DSD Contour



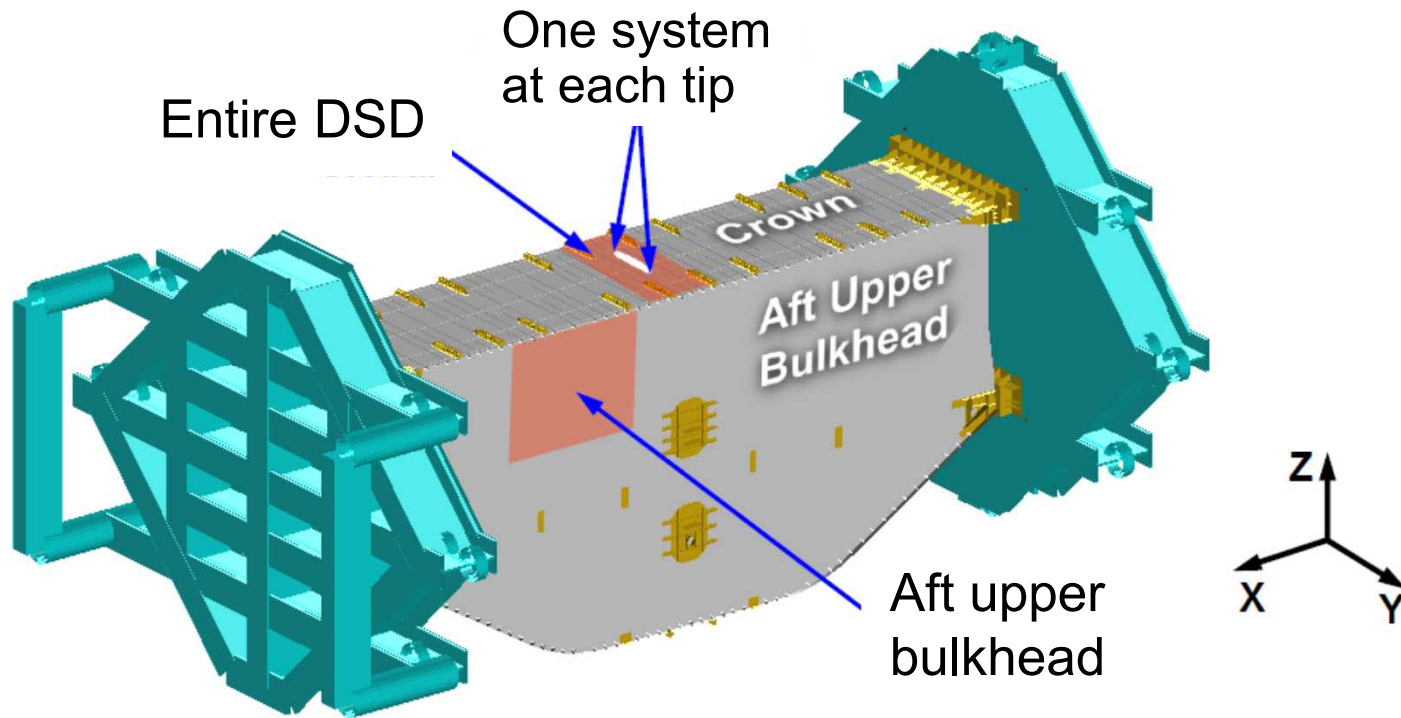
Dimensions in inches



DSD from inside the MBB

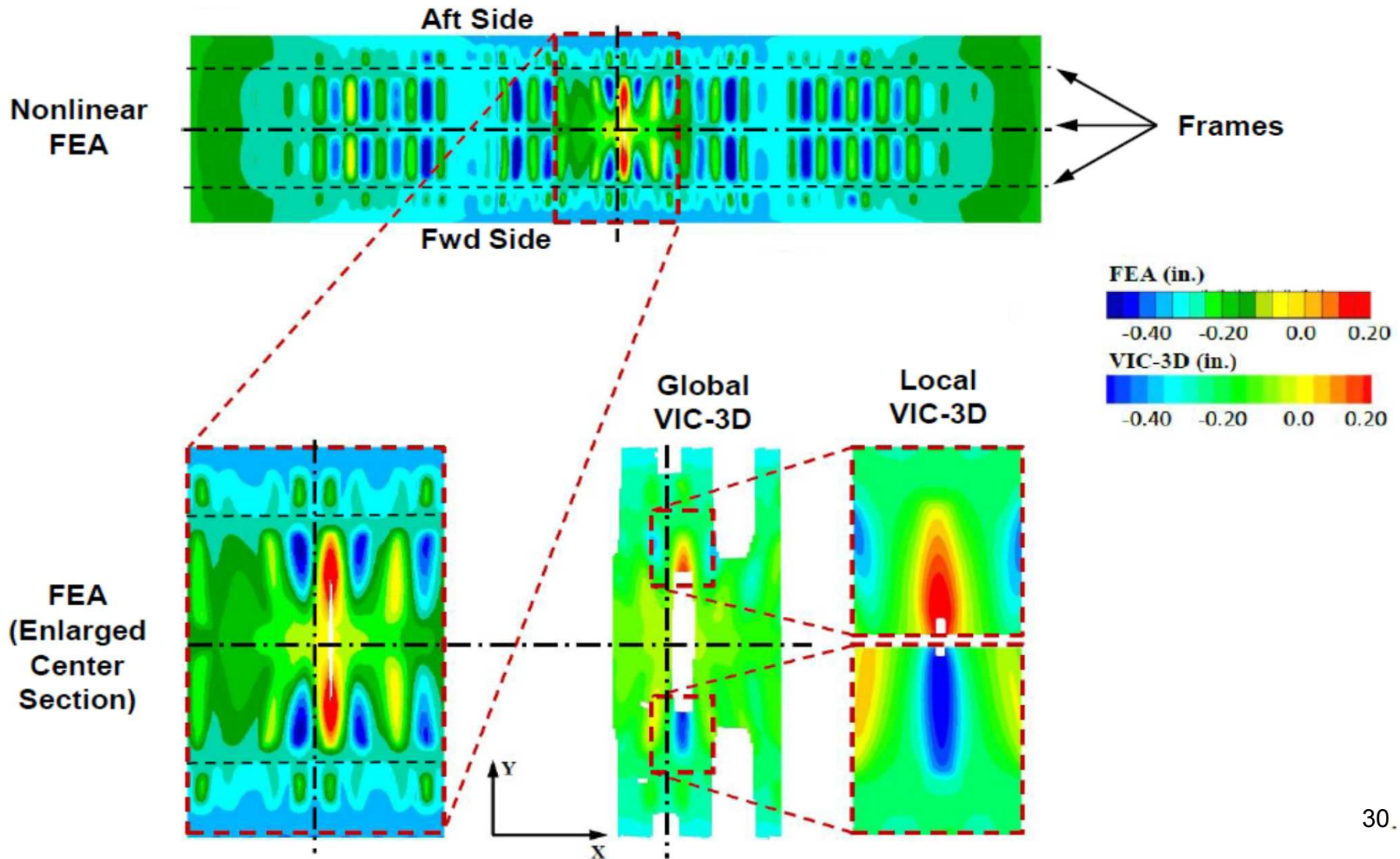


Digital Imaging Regions for DSD Loading

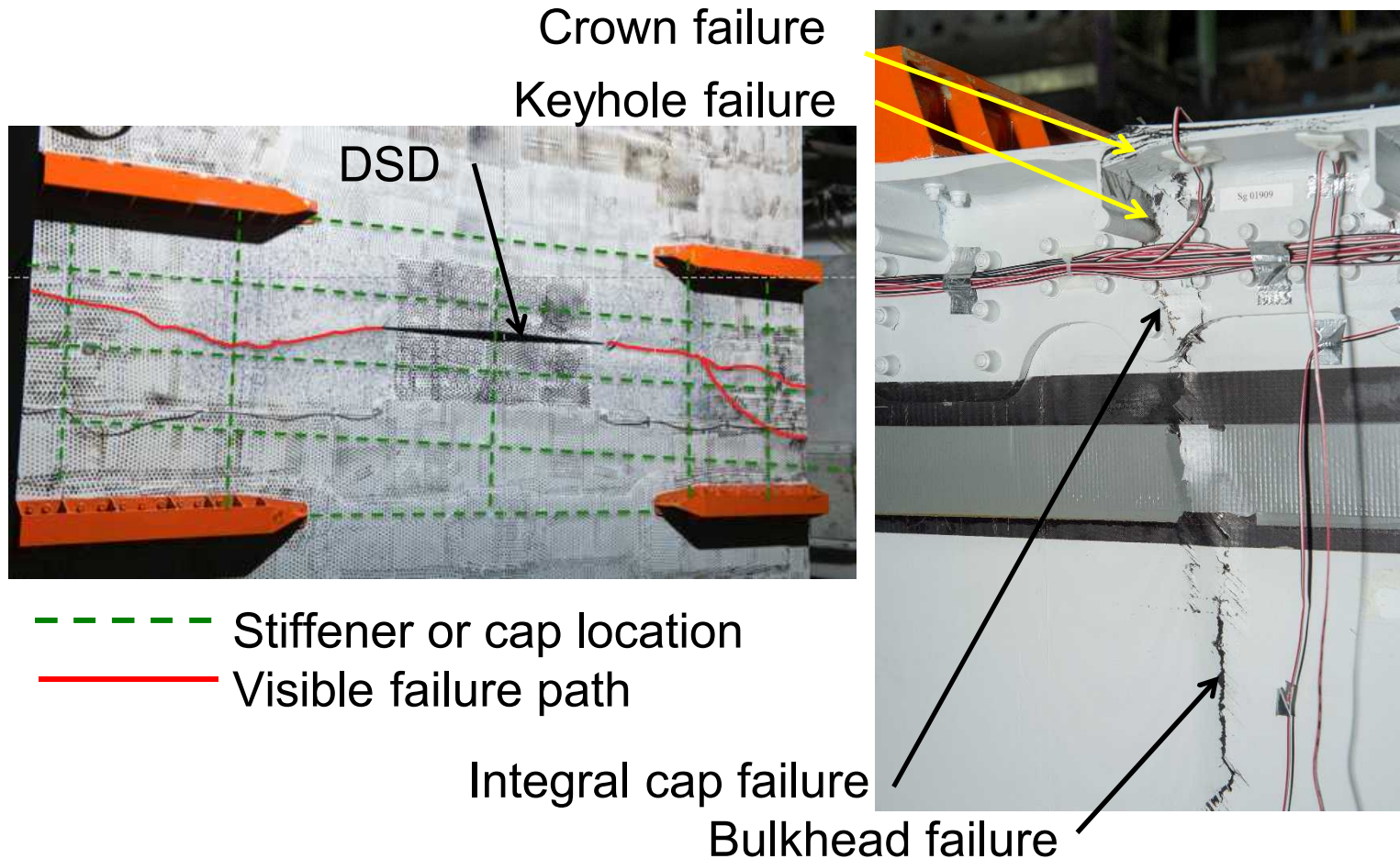


Crown Panel with DSD

Out-of-Plane Deformation



Final Failure at 152% DLL



MBB Conclusions

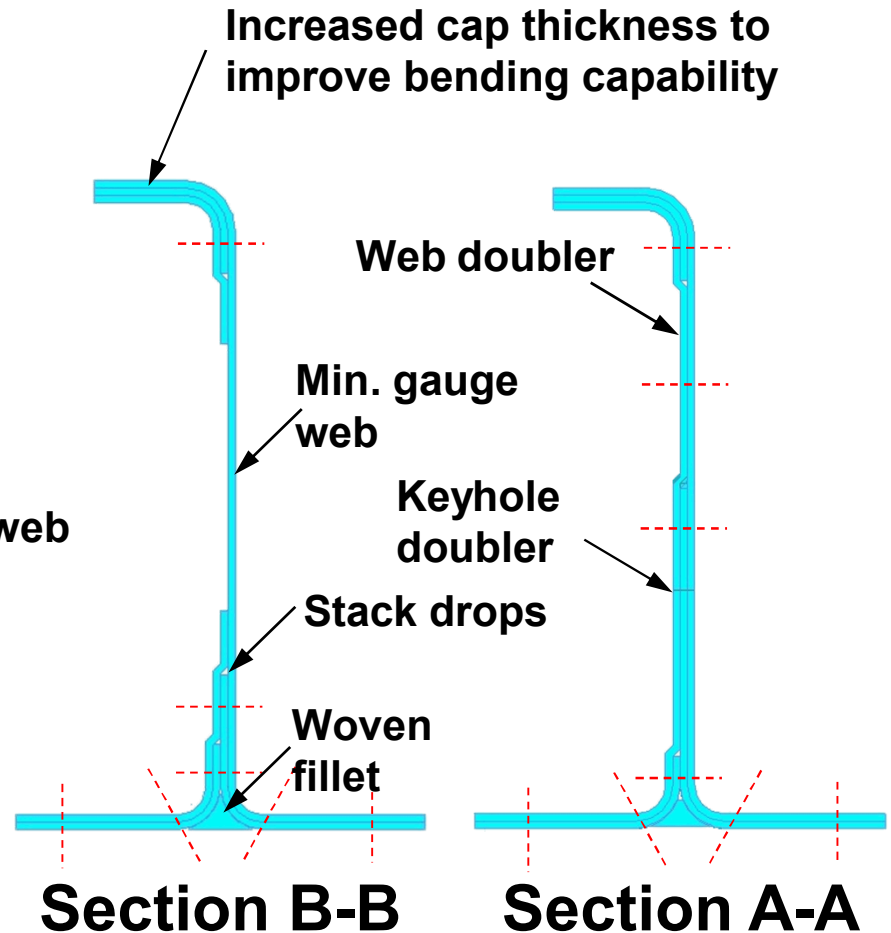
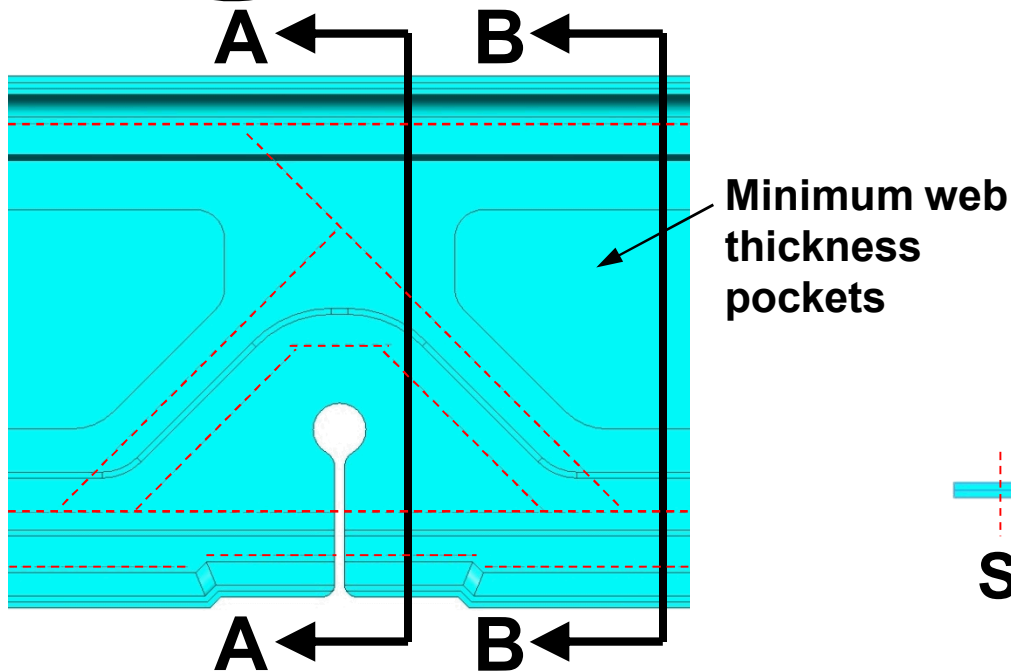
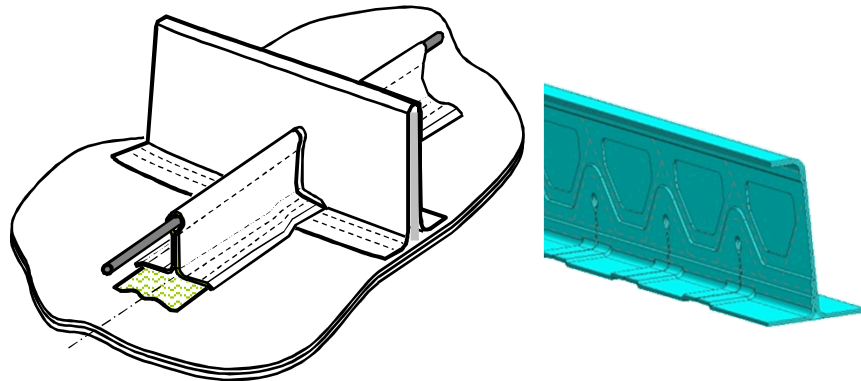
- Upbending, downbending, pressure, and combinations of pressure and mechanical loads applied
- Supported DUL for all load cases in pristine and BVID conditions
- Supported DUL+10% for upbending condition with and without pressure
- Supported DUL in upbending condition without pressure with DSD (approximately double FAA requirement)
- Damage was contained by stitching
- Favorable comparison of test data and nonlinear analysis
- Technology Readiness Level (TRL) 5 for HWB fuselage structure demonstrated

Damage Arresting Composites Conclusions

- Eliminating fasteners in acreage removes the need for pad-ups, removes stress concentrations, and removes the need for inspections at holes
- Stitching suppresses interlaminar failures, arrests damage, and turns cracks
- Post-buckling capability has been demonstrated
- Stitching and out of autoclave manufacturing process successfully created high-quality parts
- Need analysis capability to support the design and tailoring of damage arresting features
- PRSEUS structures can support design load requirements in the pristine state, with impact damage, and with a severed stiffener
- The PRSEUS concept has the potential to reduce the weight of aircraft structure by 10% or more compared to conventional composites
- Viability of the PRSEUS concept for non-conventional primary airframe structure demonstrated and is enabling technology for the HWB center section

Post MBB

Tapered Solid Frame Configuration



Mississippi State University (MSU)

Marvin B. Dow

Advanced Composites Institute

Mission:

Facilitate and promote research in the field of aerospace composite structures leveraging resin infusion and stitching technology

- Collaborate with Boeing, US Government Agencies, and other industry partners
- Develop advanced structural design architectures with improved performance beyond conventional approaches
- Develop processes and equipment to enable low cost/high rate manufacturing
- Support technology transition into production
- Serve as a training center for strategic suppliers

Collaborative nature of center enhances visibility with industry partners to spawn new research opportunities

Institute Operational March 2018



Institute Features

- Facility
 - 40,000 square foot facility
 - Access to airport runway
- Stitched structure fabrication
 - Single- and double-sided stitching
 - Purchasing 20-foot wide, 50-foot long oven
 - Automated resin infusion processing
 - Invar molds
 - Cutting tables and CNC ply cutter
- Additional capabilities
 - Tufting machine
 - Traditional industrial sewing machines
 - Student project areas
 - 5-axis CNC machining system



Integrated Structural Assembly of Advanced Composites (ISAAC) at LaRC

Mission:

Facilitate and promote research in automated composite manufacturing to support NASA goals

- Explore new manufacturing methods and designs in a research environment
- Develop technology on a small scale and move to a larger scale in-house
- Transfer knowledge to industry for application to flight hardware

Working with industry and university partners to advance composites technology for aerospace applications

ISAAC Capabilities

Initial capability Automated Fiber Placement (AFP)

- Flat panels
- Cylinders
- Complex shapes

Additional features

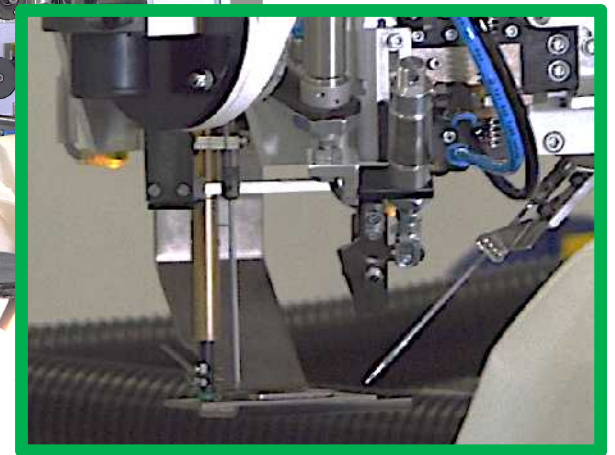
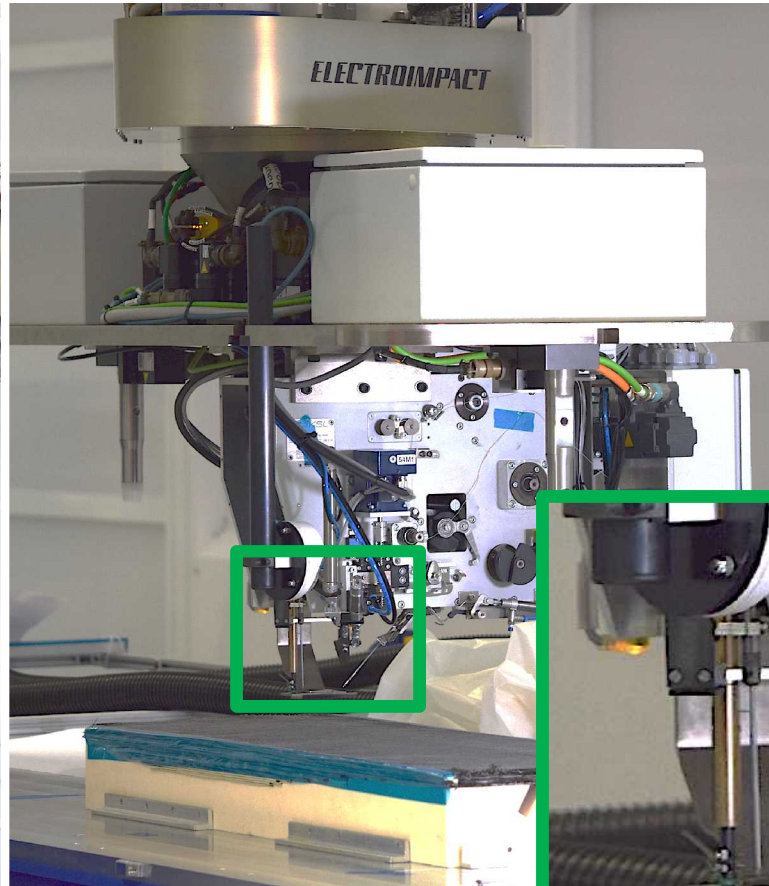
- Laser projector
- Ultrasonic knife
- In situ thermography for quality control
- Clean room (ISO 7)

New features

- **Single- and double-sided stitching**



AFP and Stitching



Questions?

