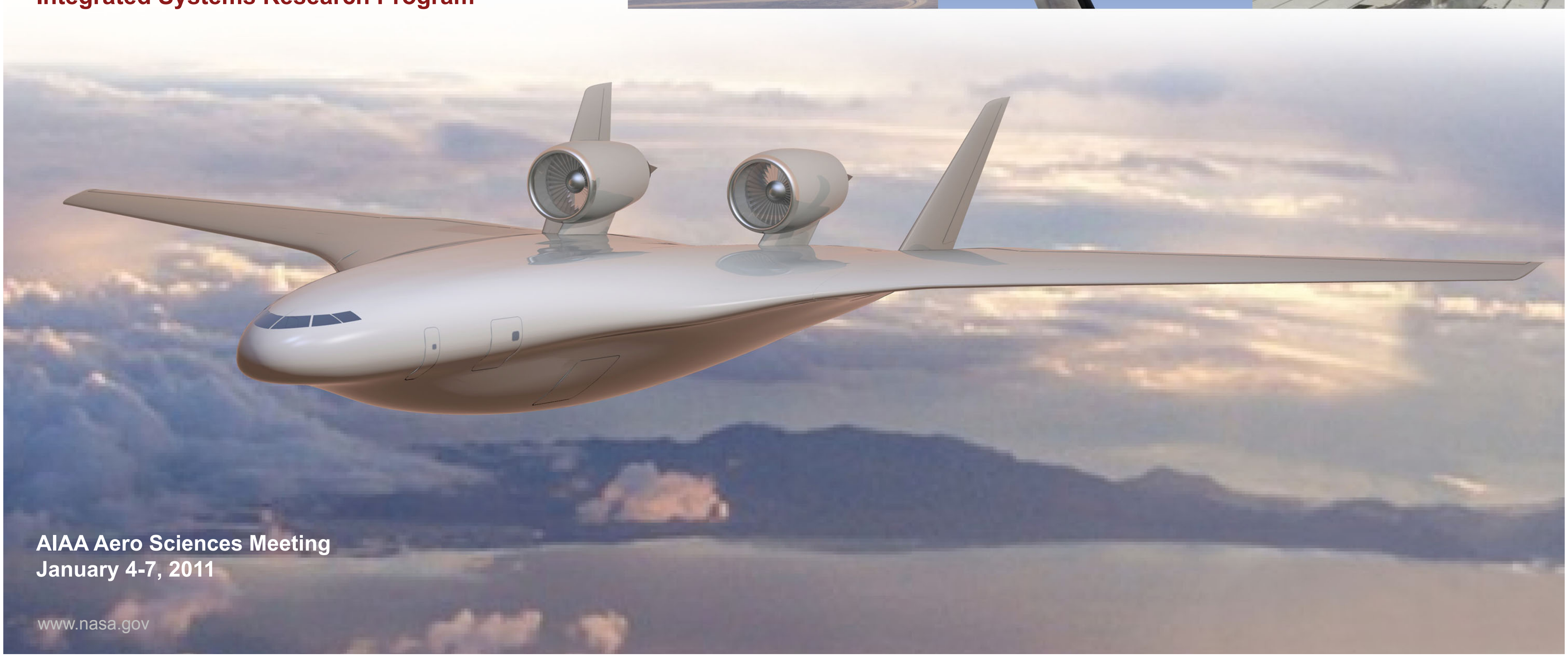
National Aeronautics and Space Administration

Status of Advanced Stitched Composite Aircraft Structures

Dawn Jegley
NASA Structures Lead
Environmentally Responsible Aviation
Integrated Systems Research Program

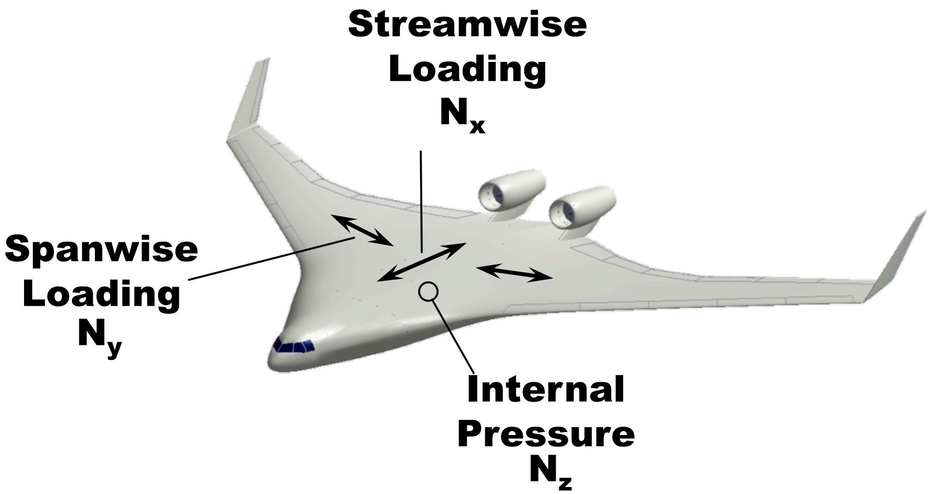
Alexander Velicki
Boeing PI



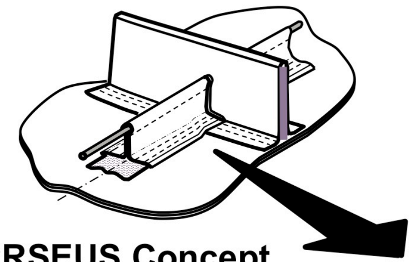
AIAA Aero Sciences Meeting
January 4-7, 2011

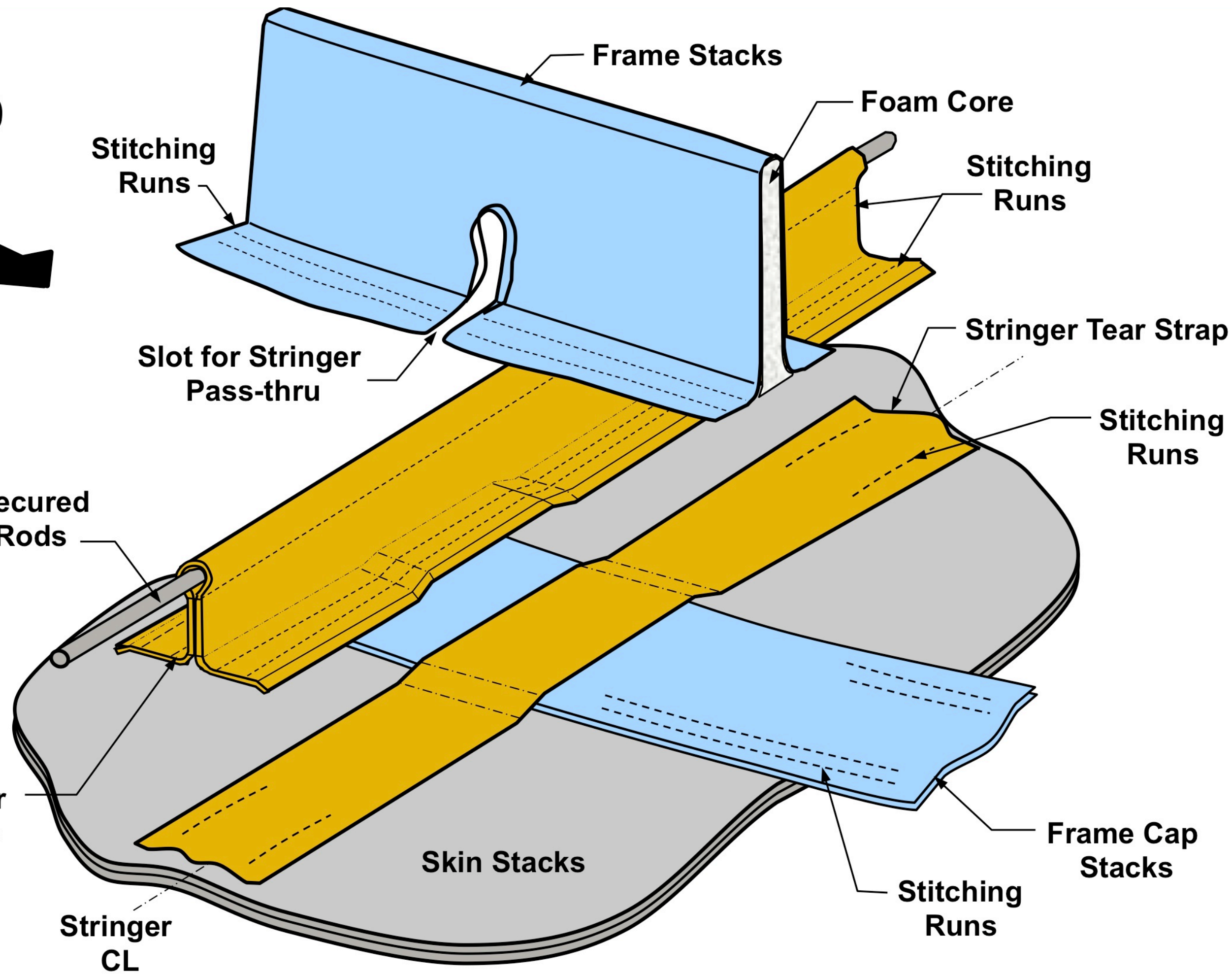
Challenges of Hybrid Wing Body Center Section

- Pressurized non-circular center section
  - Compound curvature
  - Almost 90-degree angles at joints
  - Fatigue
- Bi-directional in-plane loading
  - Continuous load paths in both direction
  - Integral design without shear clips
- Manufacturable
  - Large integral components
  - Out-of-autoclave process
- Economical
  - Hard metal tooling on OML only
  - Simplified bagging process for IML
  - Fabricate entire cover panel in one cure
- Damage Tolerant
  - Arrest damage resulting from discrete source damage
  - Minimal delamination
- Acceptable acoustic response



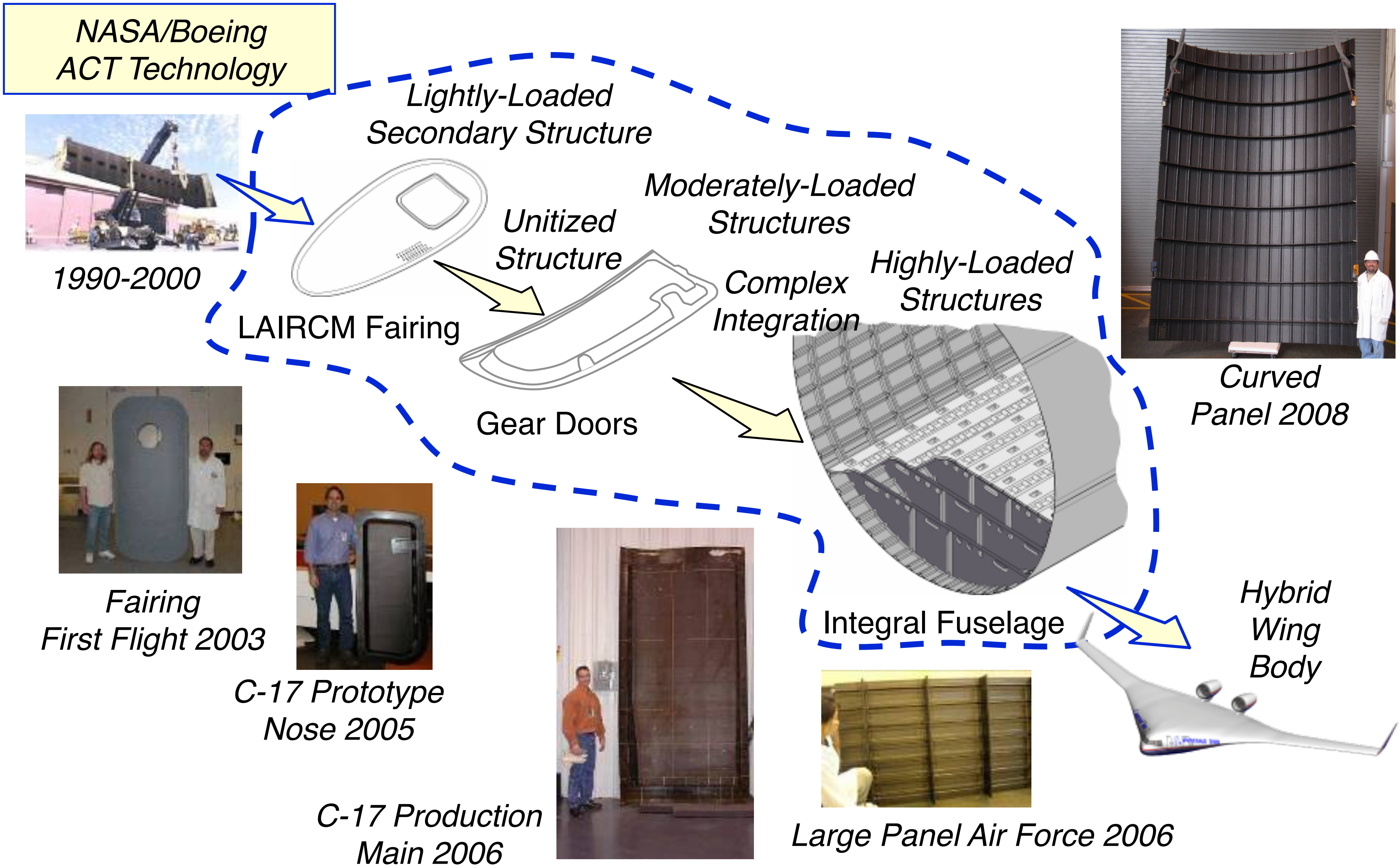
Pultruded Rod Stitched Efficient Unitized Structure





Exploded View of Preform Assembly

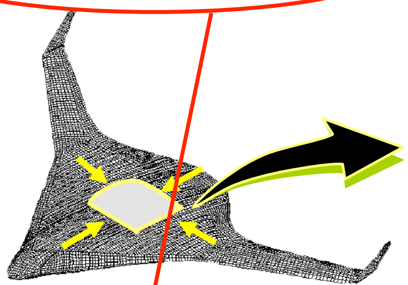
Stitched Structure Development



Initial Objective: Develop concept for HWB center

TRL 3 - Proof of Concept

Trades Studies



Combined Load:

- Spanwise Axial

- Chordwise Axial

- Internal Pressure

Verify improvements with vehicle-level analysis and refine analysis codes

- *Test Loads*
- *Panel Geometry*

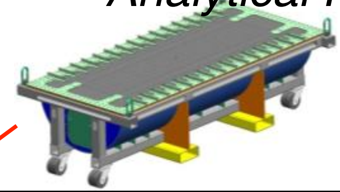
TRL 4 - Validation by Test

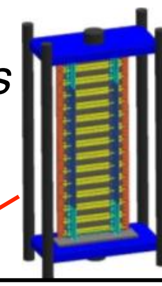
Element-level Specimens

- *Stringer and Frame Directions*
- *Static Axially Loaded*
- *Analytical Predictions*

Subcomponents

- *Stringer and Frame Directions*
- *Static Axially Loaded (Fx and Fy)*
- *Pressure Box (Fn)*
- *Analytical Predictions*



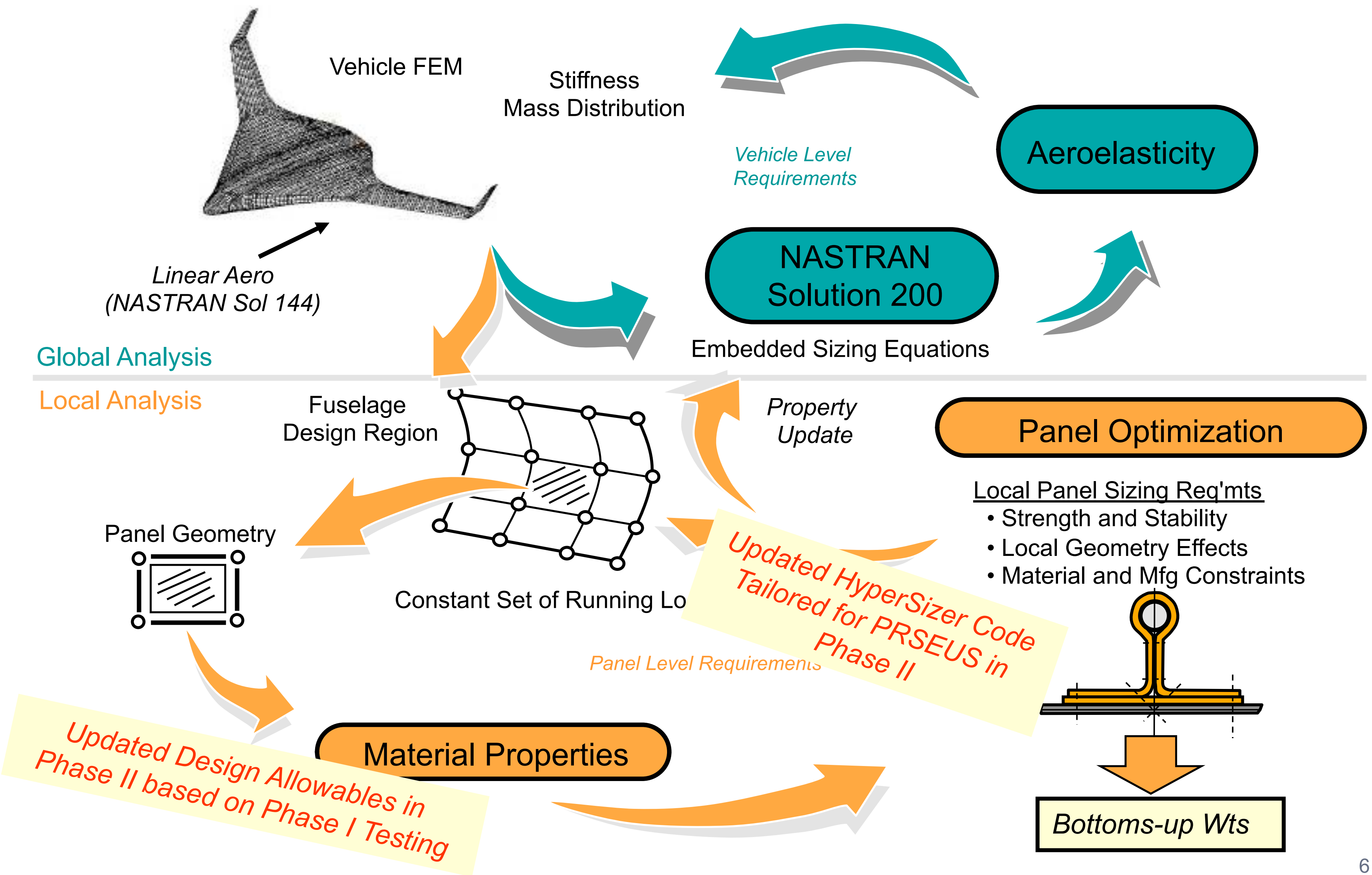


Bending and out-of-plane loading for minimum gauge panels

Buckling of large unsupported spans

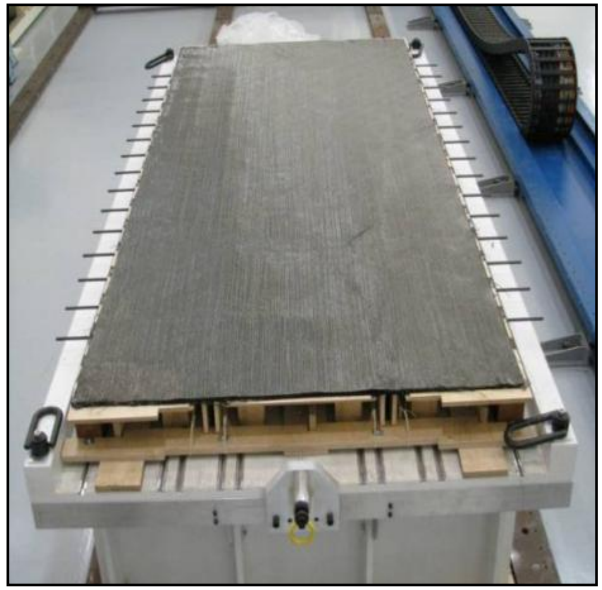
Damage arrestment for minimum gauge panels

HWB Vehicle Sizing



Flat PRSEUS Panel Fabrication

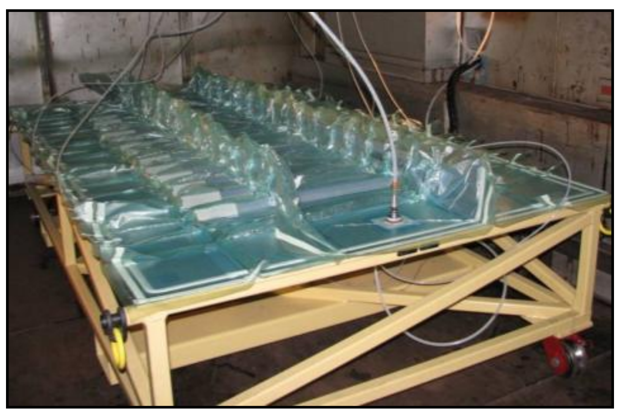
Tear Straps Placed



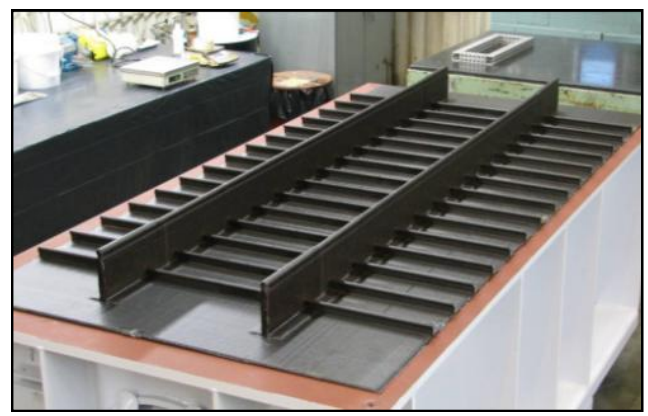
Skins Placed

Automated Preform Stitching

Preform on Mold Tool



Resin Infusion

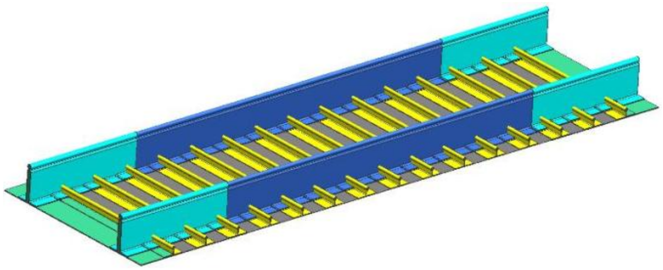


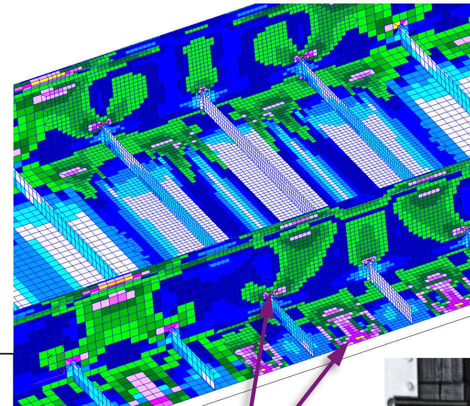
Cured Panel

Manufacturing, Coupons, Design and Mechanics

- Material characterization
- Thermal effects on properties
- Fatigue studies
- Rod-wrap interface improvements
- Positioning aids to improve dimensional tolerance
- Ideal stitching pattern
- Improved bagging methodology
- Simplified analysis methodologies

Compression Panel



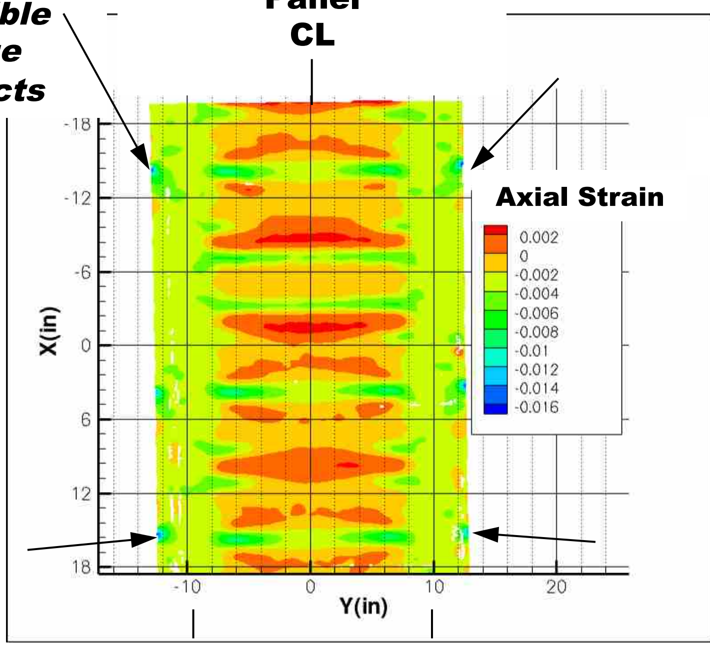


Predicted Critical Locations

Max Strains

Possible Edge Effects

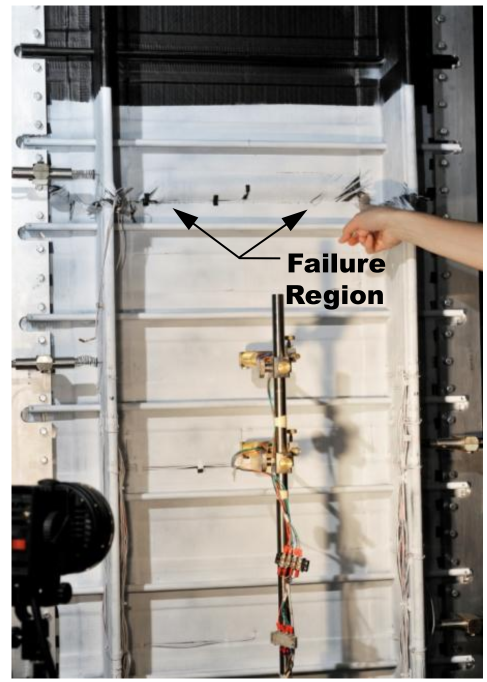
Panel CL



Frame CL

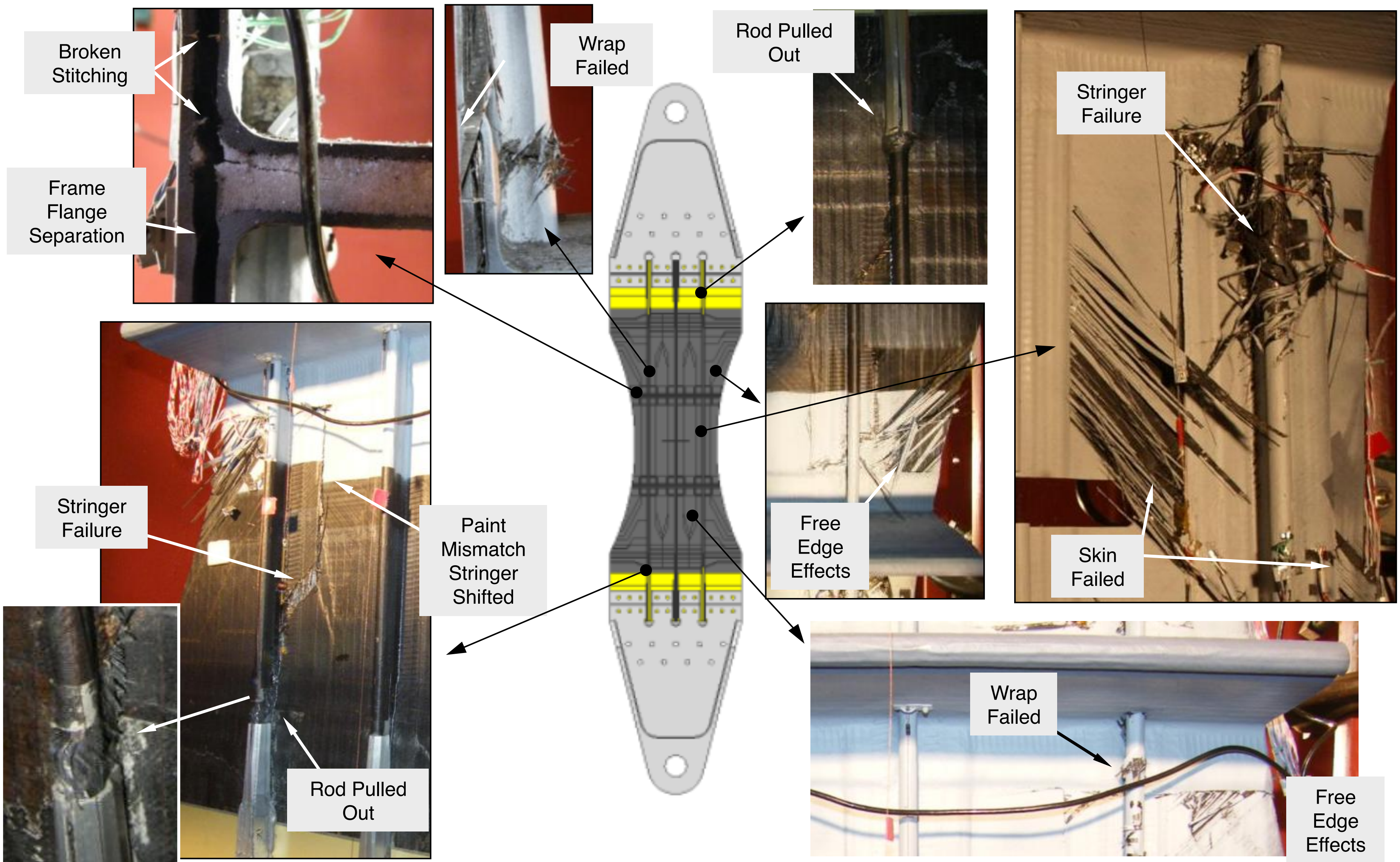
Frame CL

Measured Full Field Axial Strain



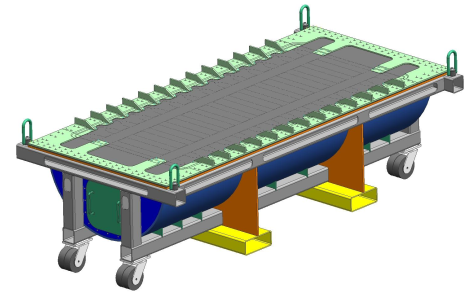
IML Specimen Surface

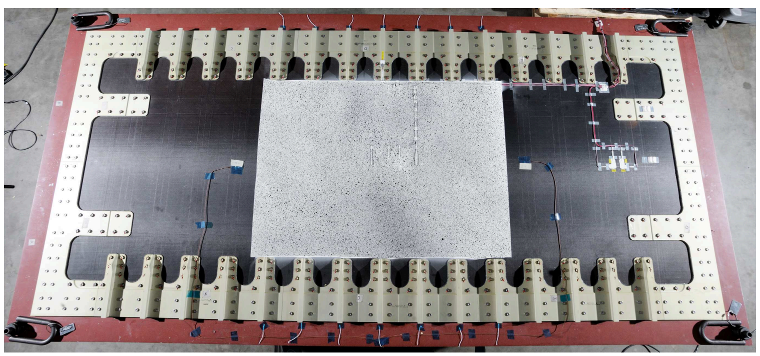
Damaged Tension Panel Test

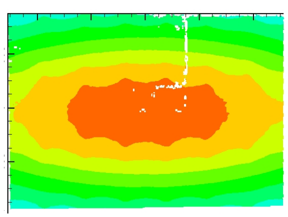


Flat PRSEUS Pressure Panel

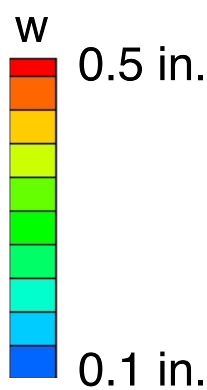
- Minimum gage skin (.052 in.)
- Met 2P (18.4 psi) requirement with no damage
- 20 ft-lb internal damage to rod-stiffener
- Sustained 3P with damage
- Failure in rod-stiffener but continued to hold pressure to 30 psi



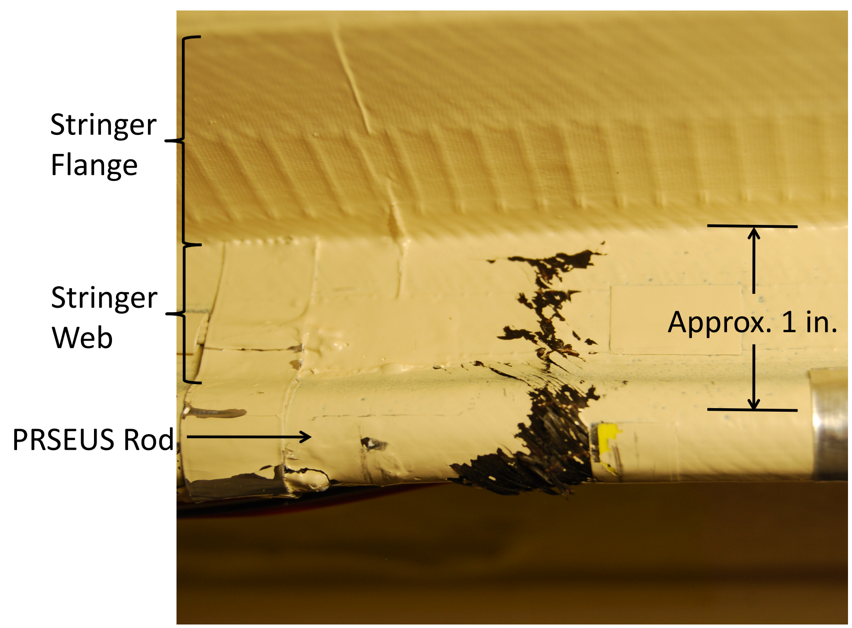




18 psi



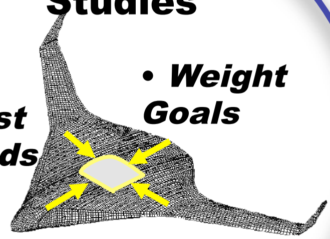
Failure Site



PRSEUS Progress

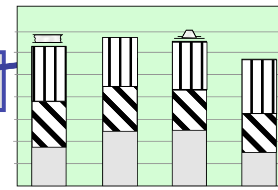
Trades Studies

- Test Loads
- Weight Goals
- Panel Geometry



10% better than sandwich.

NRA Phase I Trades



PRSEUS 10.4% lighter.

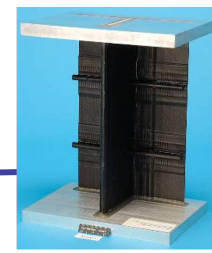
improved buckling stability.

NRA Phase I Specimens

test stability failure 75% higher than strength design allowable.

within 5% of static results after 2 fatigue lives.

Stringer

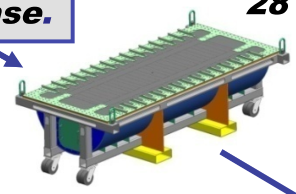


Frame

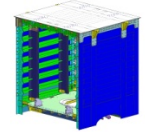
fatigue failures within 5% of static test results.

withstand 2P (18.4 psi) load case.

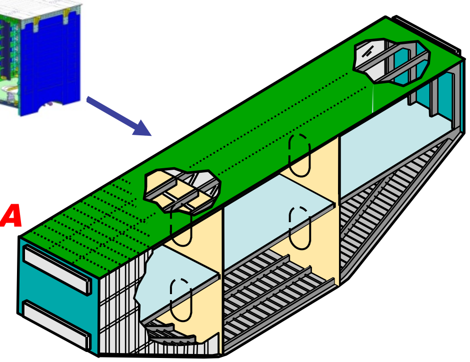
28 psi with no damage



Pressure Cube



Multi-bay Box

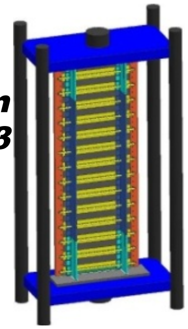


arrested damage at 1.5 times initiation load.

Arrested damage at 3 times higher than initiation load level.

general panel buckling at -5,000 lbs/in.

Compression panel test 73 kips/frame.



Combined axial & pressure loading test at NASA COLTS Facility

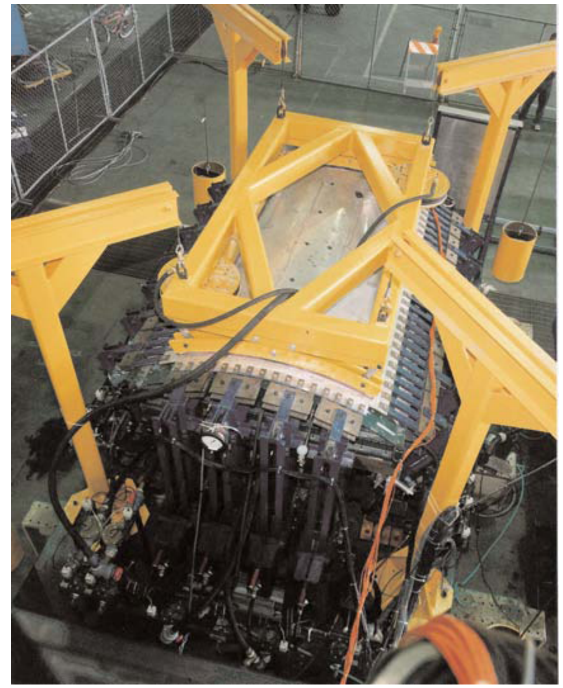
Curved Pressure Panel

- IM7-VRM-34
- 127 inches long
- 75 inches wide (with doublers)
- 90-inch radius
- 24-inch frame spacing
- 7.8-inch rod-stiffener spacing

Panel delivered to NASA Dec. 2010
Testing scheduled for summer 2011

Curved Pressure Panel Test

- Pristine panel
  - apply 18.4 psi
  - apply 9.2 psi and DLL tension
- Panel with barely visible damage
  - apply 9.2 psi and DLL tension
  - apply 13.8 psi and DUL tension
- Panel with Discrete Source Damage
  - apply 9.2 psi with DLL
  - apply axial load to failure with no pressure
- Tests planned for summer 2011



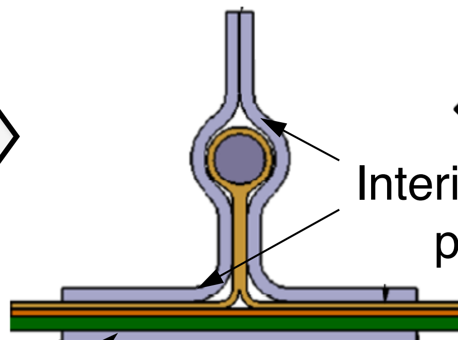
FAA FASTER Facility

(**F**ull scale **A**ircraft **S**tructure **T**est **E**valuation and **R**esearch facility)

Repair Concepts

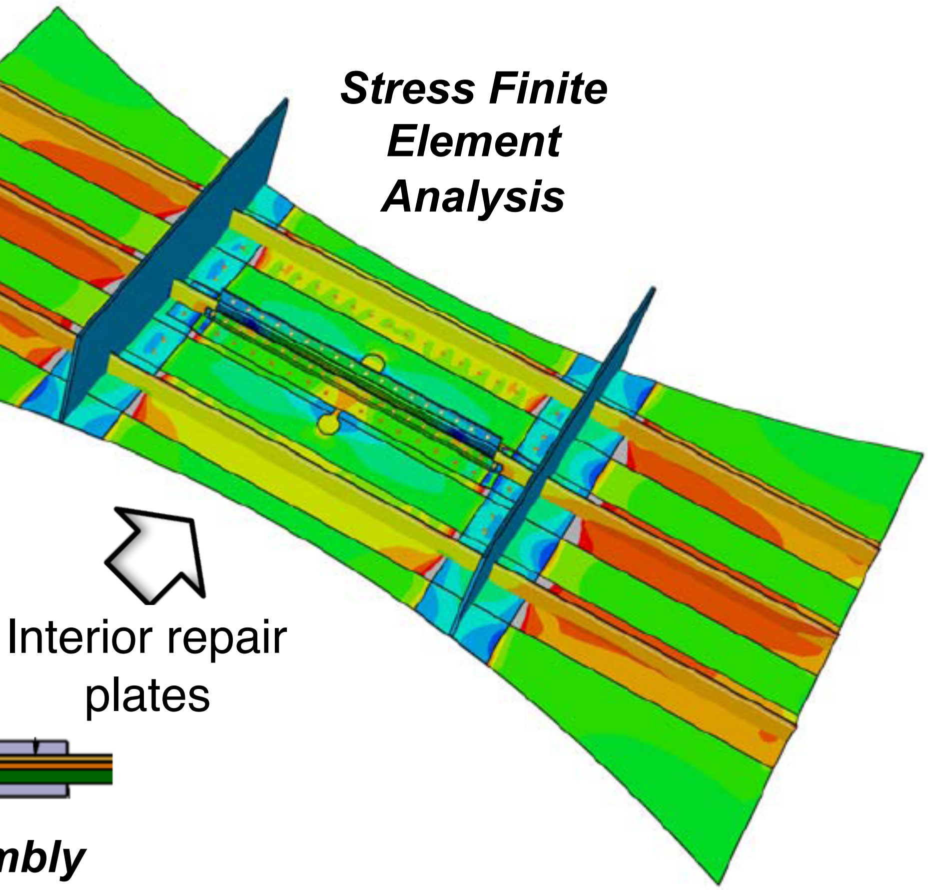
- Design, Testing and Analysis
  - Requirements: (1) Restore load carrying capability of a pristine structure (2) Minimize need for specialized equipment/methods
  - Bolted metallic repair;
  - DSD tension panel used as a baseline

Tension-Loaded Crack-Arrestment Test Panel Baseline



Repair Assembly

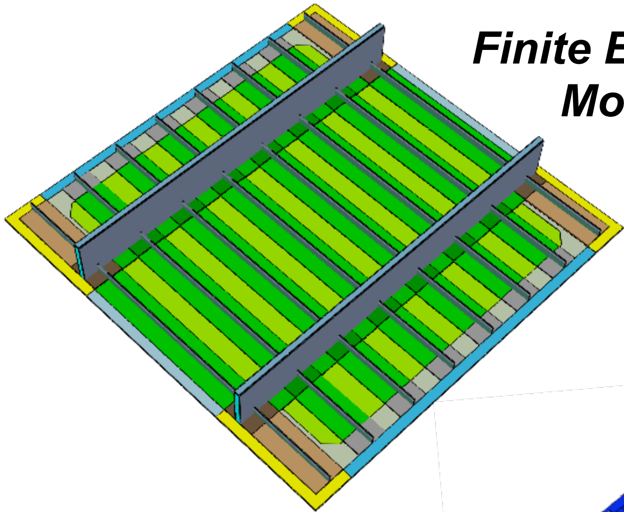
Stress Finite Element Analysis



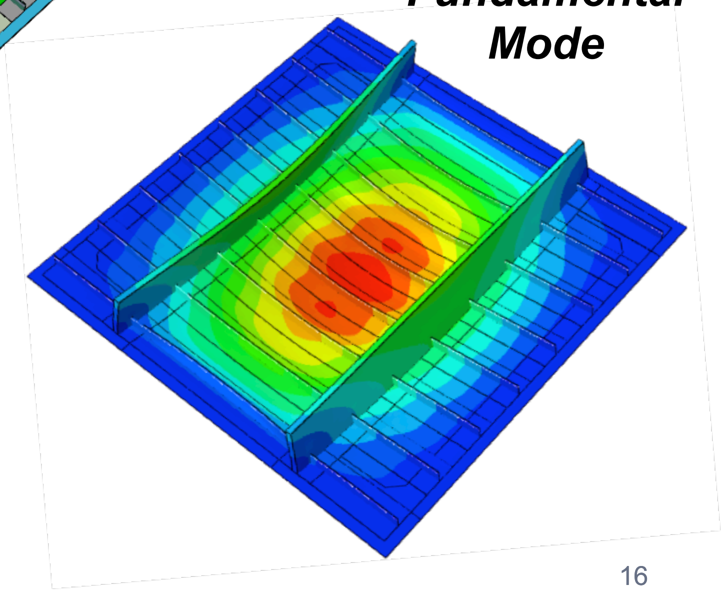
Acoustics

- Experimentally characterize PRSEUS panel without acoustic treatment
- Validate finite element (low freq.) and statistical energy (high freq.) analyses
- Propose effective acoustic treatment with minimal weight penalty

LaRC SALT facility



Finite Element Model



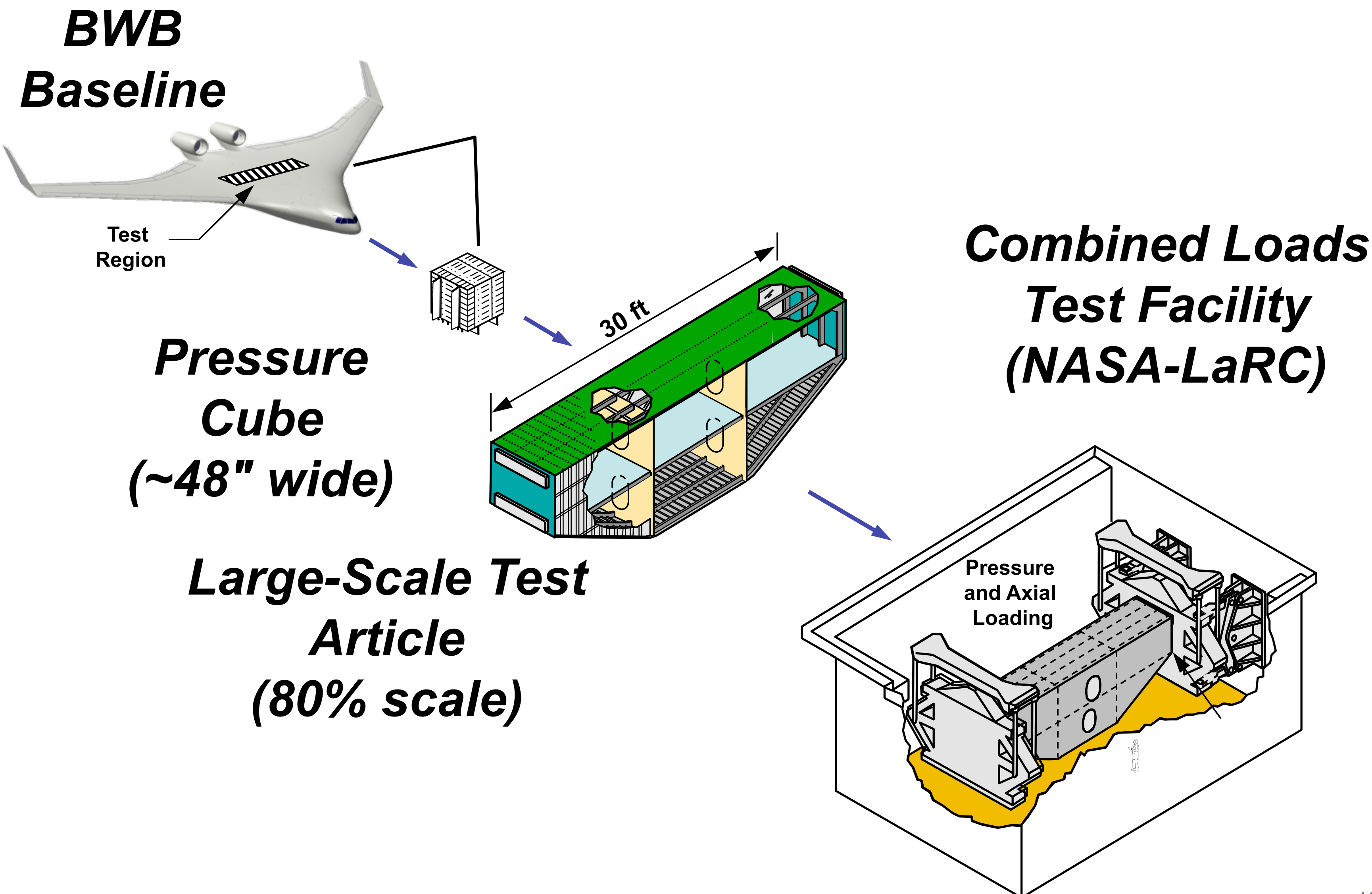
Fundamental Mode

Panel test in 2011

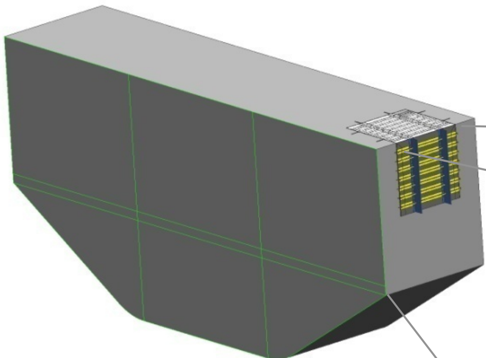
Damage

- Damage arrestment at stitch lines
  - experimental evidence
  - corresponding analytical predictions
- Structural Health Monitoring
  - damage around stitches
  - Rod-overwrap region
- Fatigue and damage growth
- Stitching/damage suppression and arrestment opens the door to more efficient design

Multi-bay Test Article Development Approach

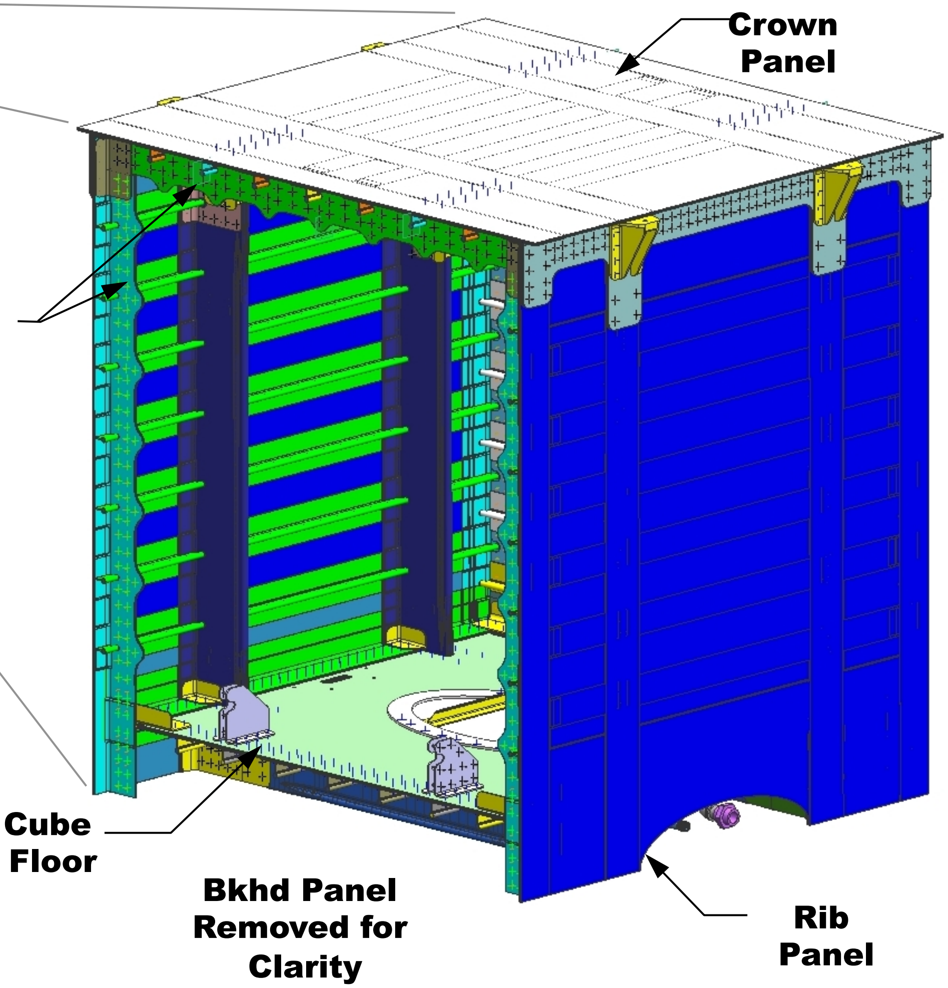


Pressure Cube - Risk Reduction



Large-scale Test Article

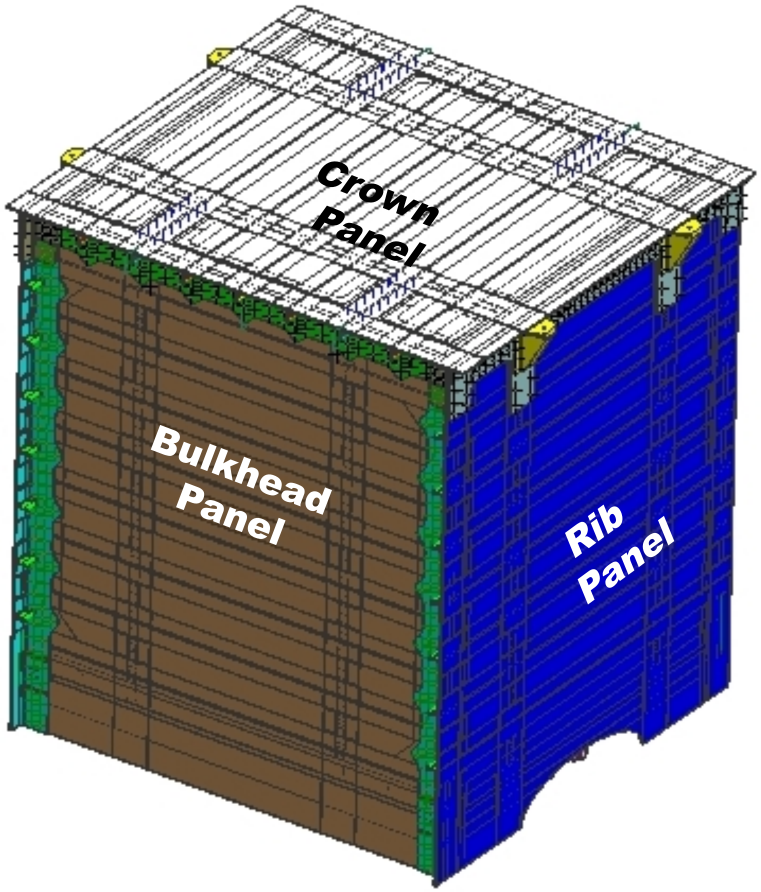
Pressure Cube Design (52" x 48" x 56" Tall)



- PRSEUS panels on all sides
- Evaluate joint behavior
- Load in pressure only to 2P (18.4 psi)
- Impact at critical joint location
- Supports multi-bay box design

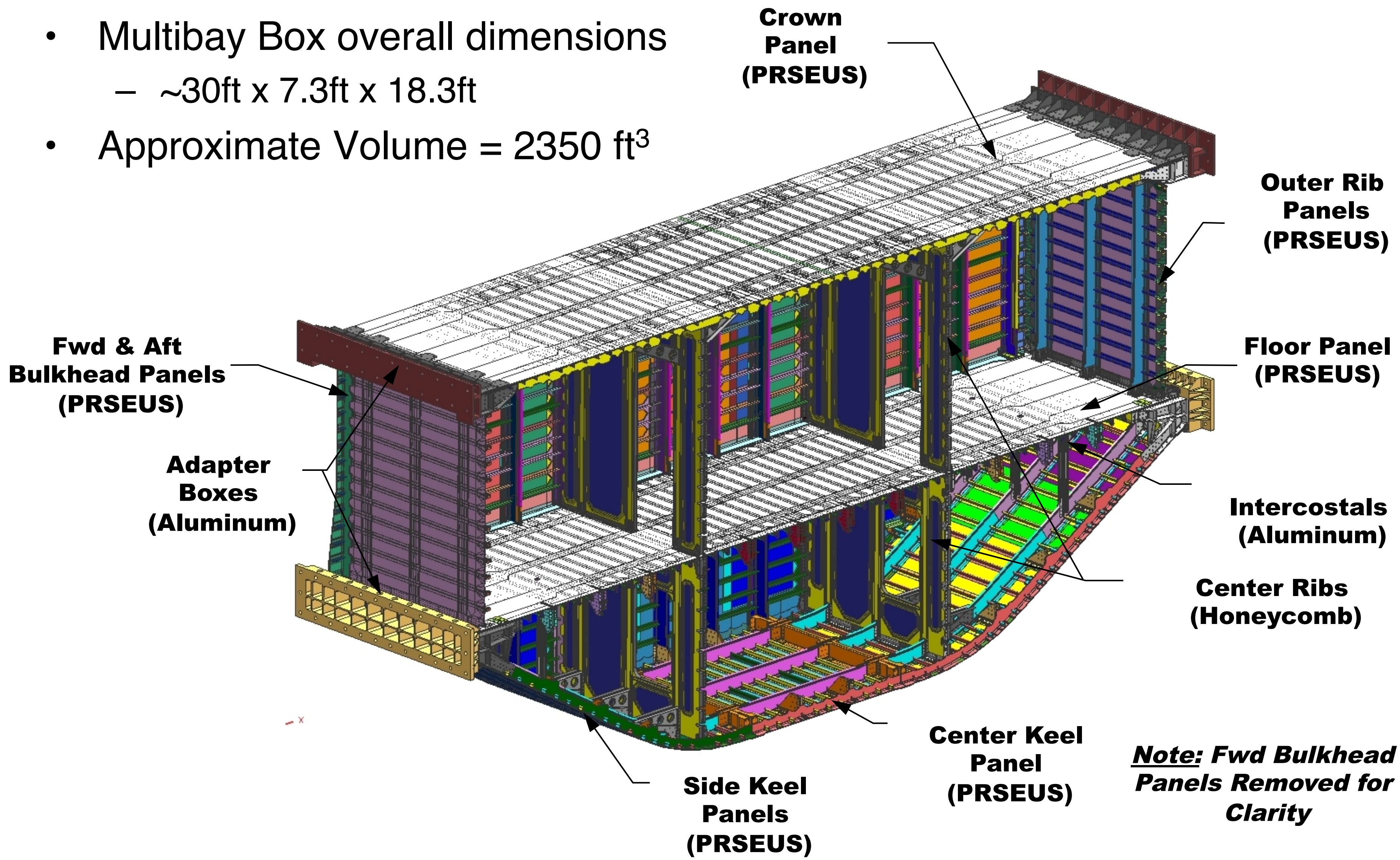
Pressure Cube Benefits

- A build up of highly integrated structural panel assemblies
- Integrated structures eliminates fit-up issues during assembly
- Stitching increased pull-off capability and enables a fail-safe design approach
- PRSEUS concept reduces panel fabrication tooling costs
- No final assembly tooling required
- Drastic part reduction
- Reduced assembly time



Multi-bay Box Overview

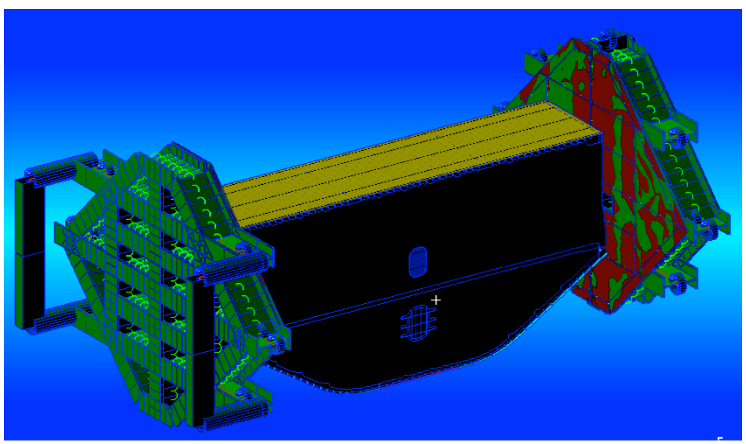
- Multibay Box overall dimensions
  - ~30ft x 7.3ft x 18.3ft
- Approximate Volume = 2350 ft^3

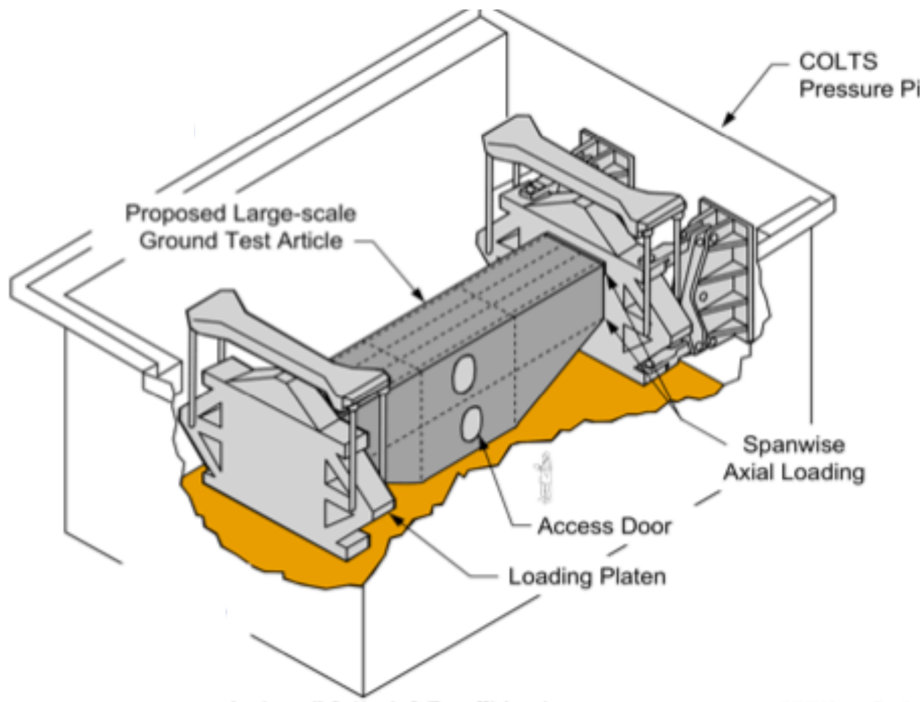


***Note:* Fwd Bulkhead Panels Removed for Clarity**

Multi-bay Test in NASA LaRC COLTS Facility

- Test conditions
  - Pressure loading to 2P (18.4 psi)
  - Axial Bending to 2.5G
  - Combined Axial loading and 1P (9.2 psi)
- Analysis including loads as applied by COLTS
- Delivered and tested in 2010





Future Plans

- Pressure cube test: April 2011
- Multi-bay box test: 2012
- Circular fuselage development 2011-2015
- Damage tolerance studies 2011-2015
- PRSEUS wing development
- Flight vehicle

Summary of PRSEUS development

- PRSEUS development supported by NASA, Boeing, FAA and AFRL
- Stitching is used to suppress interlaminar failures, arrest damage and turn cracks
- Damage arrest design principles already demonstrated in flat panels
- PRSEUS allows for non-circular pressurized center section to withstand repeated pressure and flight loads
- Unitized structure simplifies final assembly
- Out-of-autoclave processing allows for cheaper fabrication and quicker and easier changes to designs
- Validation of predictions for built-up structure still needed
- Combined axial and pressure loading will be achieved by a near-full-scale 30-foot multi-bay box representing the center section of a HWB vehicle