Composite Cryogenic Tank Research Capabilities at Langley Research Center

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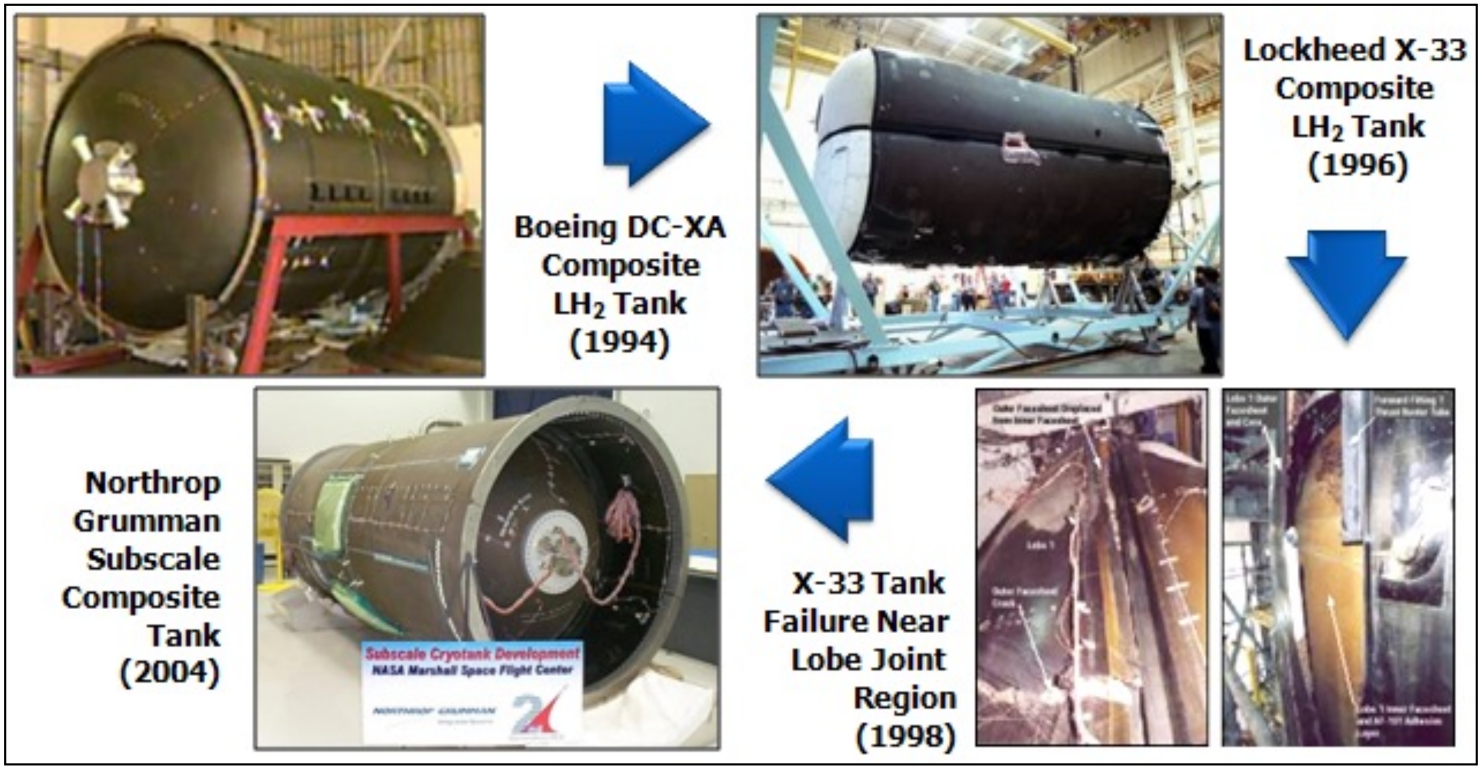
Rocket Lab Visit
NASA Langley Research Center
Hampton, VA

June 29, 2023

Outline

- History of composite liquid hydrogen (LH_2) cryotank development
- Composite Cryotank Technology Development (CCTD) Program
  - Requirements, design and analysis were led by Langley Research Center (LaRC)
- Proposed testing
- LaRC test capabilities and facilities
- Summary

History of LH_2 Tank Development



- Several research programs have fabricated and tested composite LH_2 tanks
  - DC-XA (circa 1994) first composite tank that flew
  - X-33 (circa 1999)
  - Space Launch Initiative (SLI) Composite Cryotank Program (circa 2004)
  - CCTD Project (circa 2013) (Largest structure out of autoclave ever built)

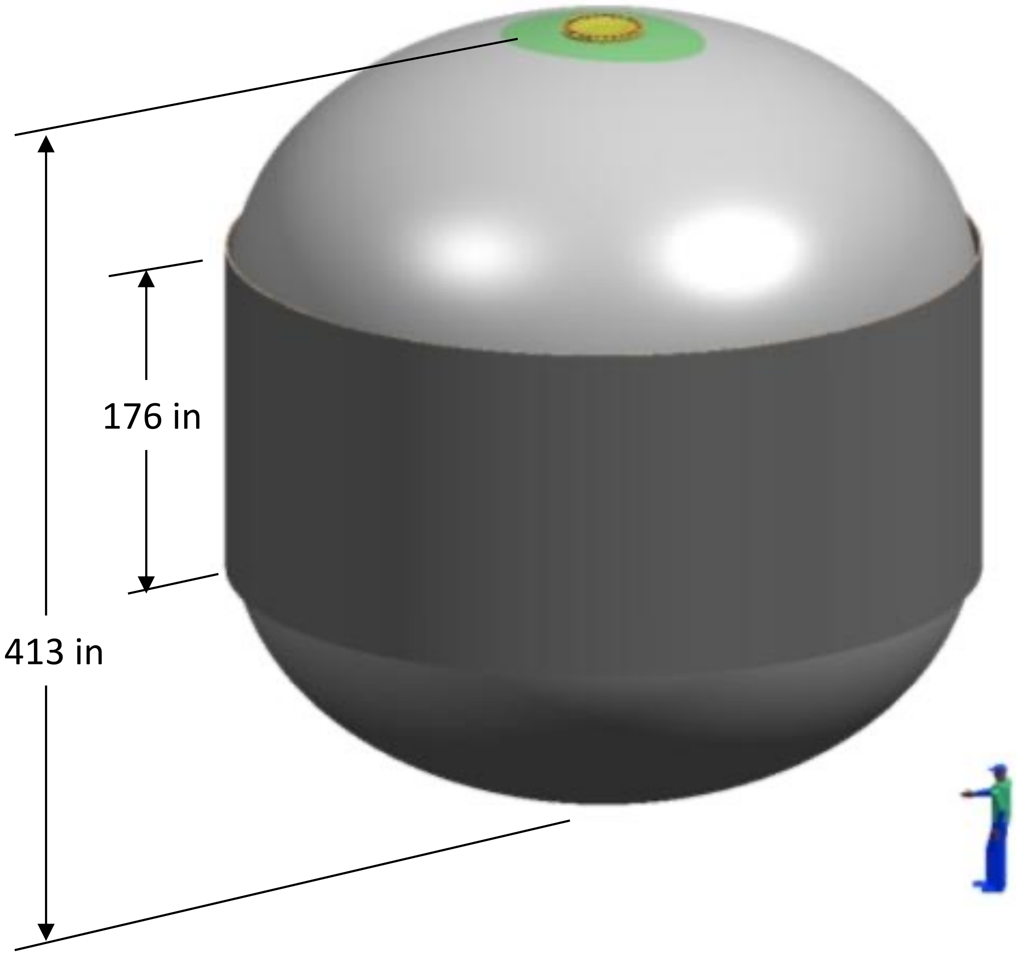
CCTD Industry Partners

- Boeing: Fluted Core Concept
- Lockheed-Martin: Externally Stiffened Concept
- Northrop Grumman: Honeycomb Sandwich Concept
- All three Industry Partners used IM7/977-2 Gr-Ep
- Each Industry Partner developed a damage tolerance plan where their material allowables could achieve 5000 µin/in

Design Requirements

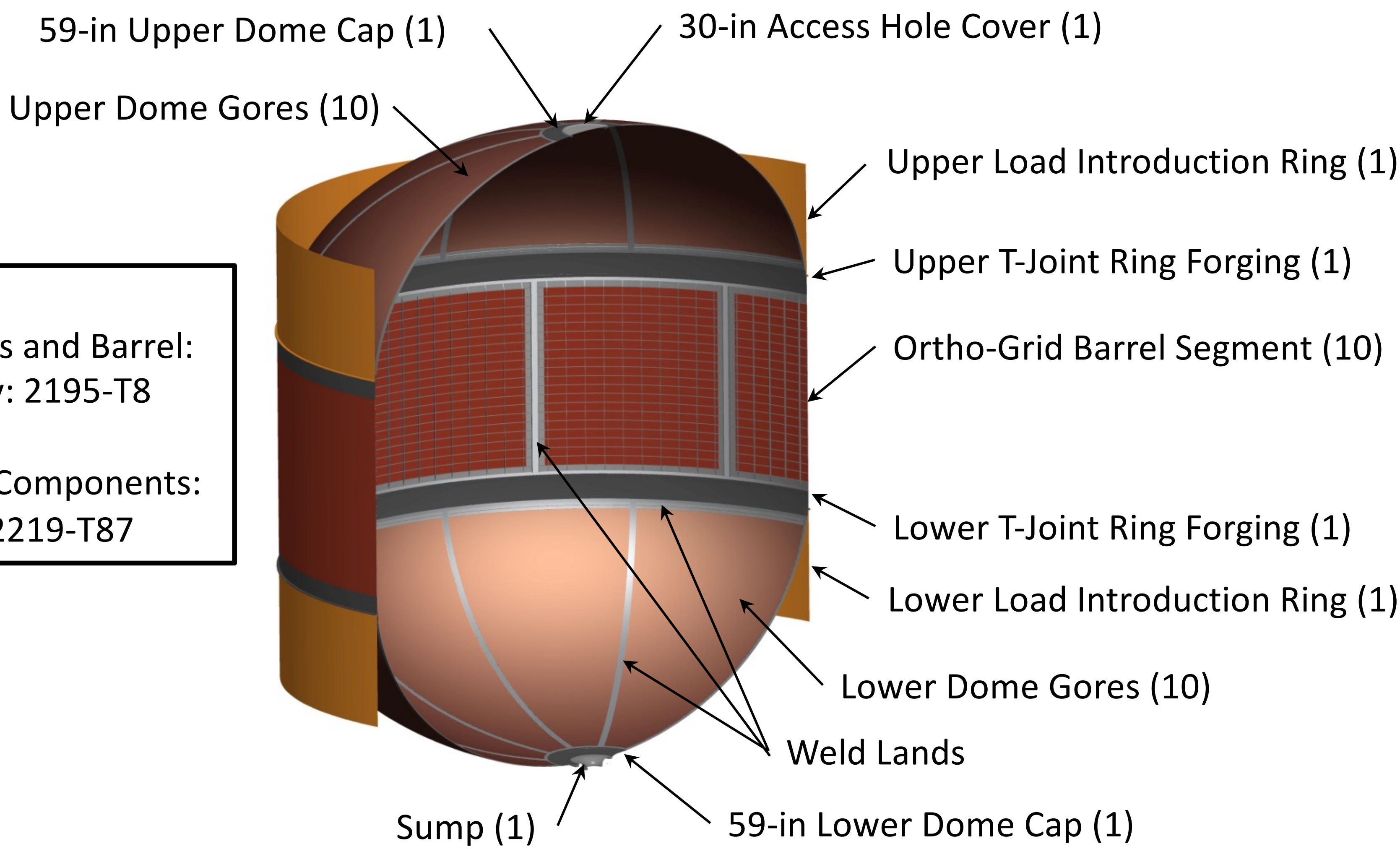
Based on Ares V and Space Launch Systems (SLS) Projects

- Diameter: 33 ft (~10 m)
- Height: 34.8 ft (10.6 m)
- Volume: 22,396 ft³ (634 m³)
  - 167,533 Gallons
- Operating Pressure: 42.6 psi (290 kPa)
- NASA-defined external loads (axial, shear, and moment)
- Factor of safety for composites
  - Tank acreage = 1.5
  - Discontinuities (joints, etc. = 2.0)
- Material IM7/977-2 Gr/Ep
- Limit lamina tensile strain = 5000 μin/in
- Two 30-inch (76-cm) diameter openings at the sump and forward dome



("Anthroman" is 5-ft, 8.5-in tall)

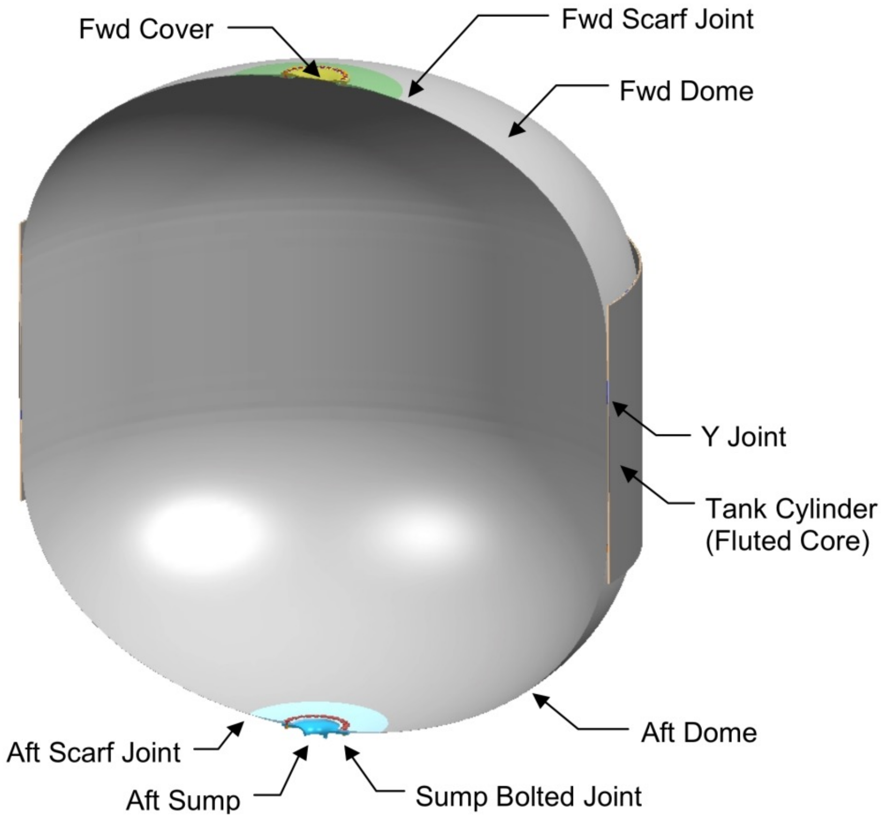
LaRC Metallic Cryotank Design

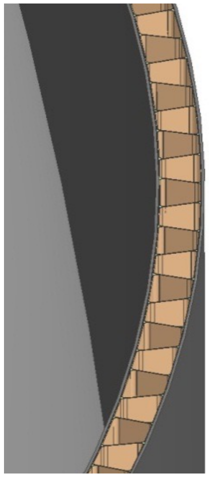


<u>Materials:</u>
Dome Gores and Barrel:
Al-Li Alloy: 2195-T8

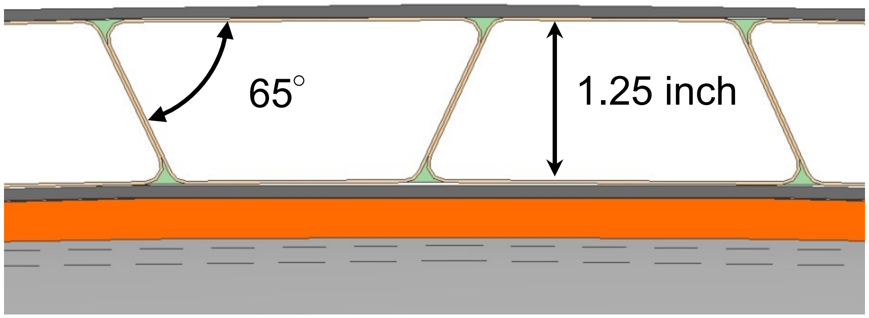
Remaining Components:
Al Alloy: 2219-T87

Boeing Fluted Core Concept
Details





Isometric Edge View

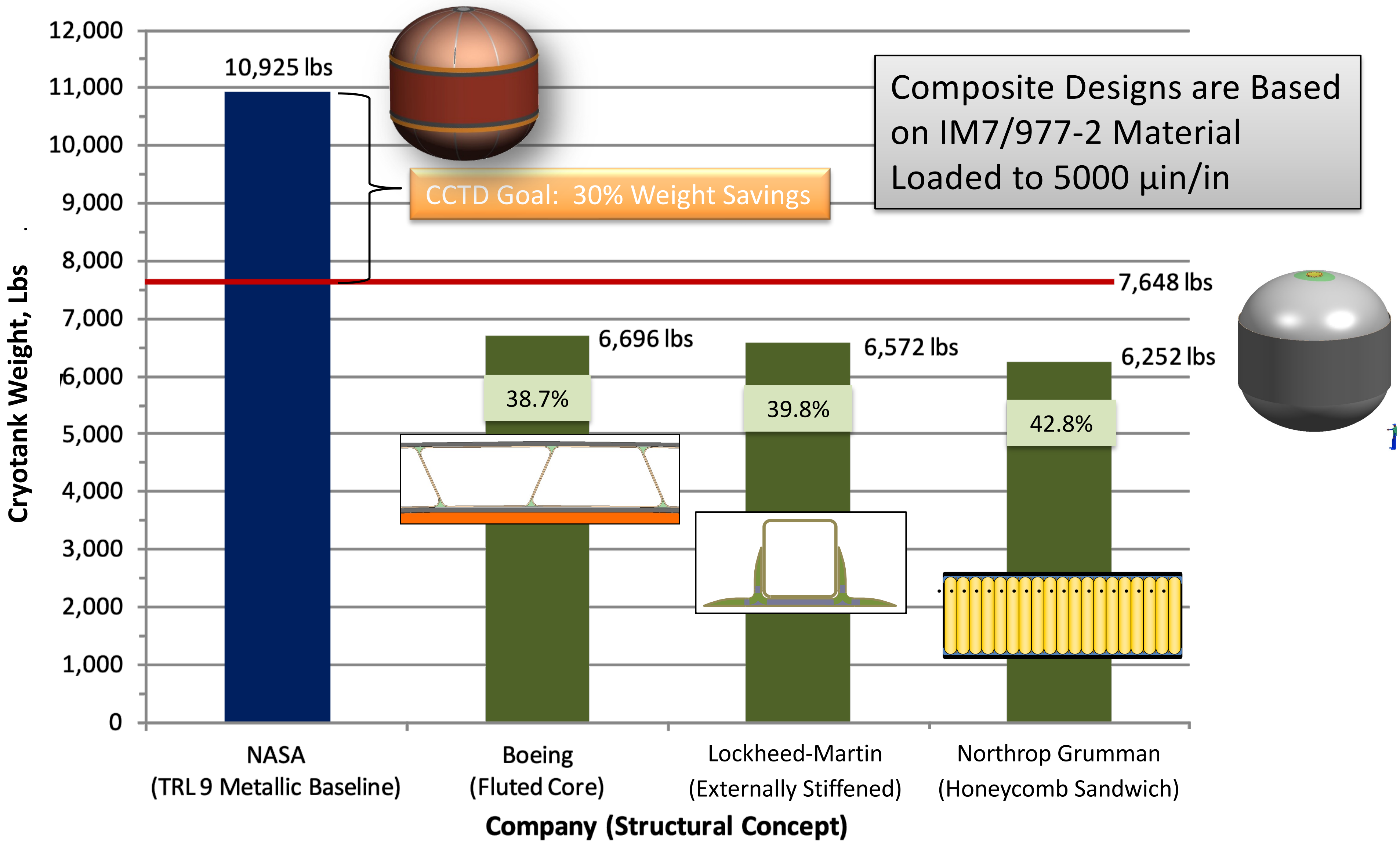


Edge Cross-Section View

- Dome profile was in between a Cassinian and elliptical shape
- Laid-up on a breakdown tool with no circumferential bellyband joint
- Six 0.0026-in thick plies were at the center to prevent hydrogen permeation
- Final weight was 6696-lbs

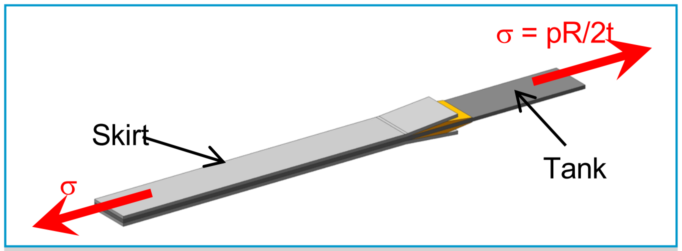
Weight Comparison

Composite Cryotank Concepts vs. Metallic Baseline

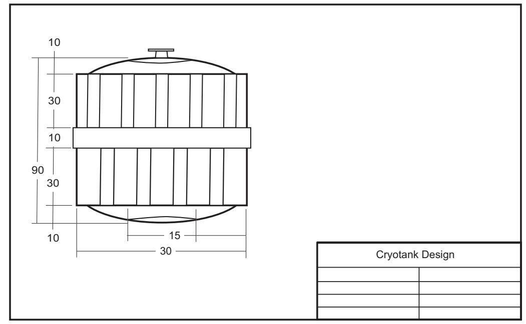


- Line at 7648-lbs represents a 30% reduction in weight from the Al-Li concept

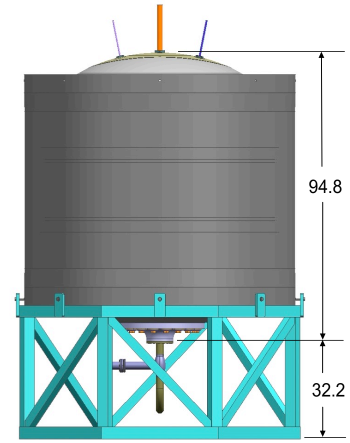
Accelerated Building-Block Analysis



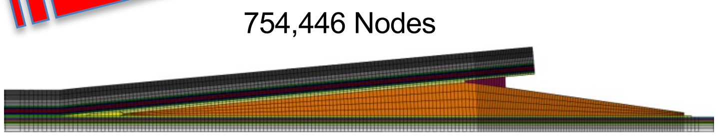
Y-Joint Test Elements



CAD Design

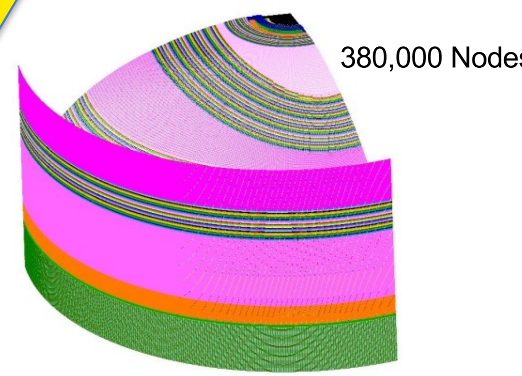


Final Test



Crack Growth FEM Model

Detail Dome Ply Drop-Off Model



90° FEM Model

- Detailed models of each test component with correlation to test results

Advanced Testing at LaRC

Mechanical properties (screening)

Strain and temperature allowables

Physical properties (permeability, thermal conductivity, glass transition)

Fatigue (Mech., Therm./Mech.)

Thermal durability

Progressive failure

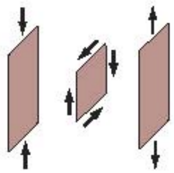
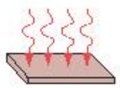
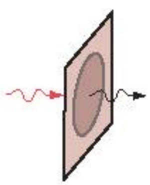
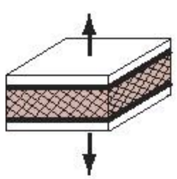
Damage tolerance

Assessment of repair (Nondestructive evaluation [NDE] and structural health monitoring [SHM])

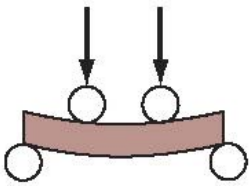
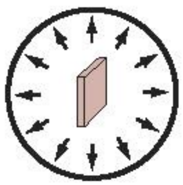
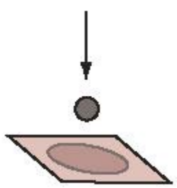
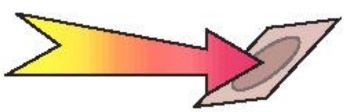
Lifecycle durability

Accelerated test methods

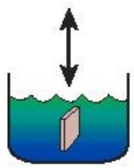
Temperature Dependent Material Characterization Tests – Coupons Level

Experiments		Task Goals
	Mechanical properties	Mechanical properties of materials at incremental temperatures Stength, stiffness, durability aging ...
	Physical properties	Physical properties of materials at incremental temperatures Thermal conductivity, glass transition ...
	H_2 Permeability tests (6-in. dia.)	Ambient/cold permeability with load Characterize max. allowable microstrain of composites
	Sandwich structure tests (2 in. x 2 in.)	Hot/cold bond strength Core strength Curing process Tension/compression/edgewise compression

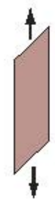
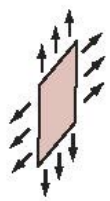
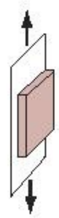
Temperature Dependent Material Characterization Tests – Coupons Level (Continued)

Experiments		Task Goals
	3-Pt. & 4-Pt. Bend tests	Flexural and shear strength for laminates and sandwich core Sandwich to core shear strength
	Vacuum tests (10^{-5} - 10^{-10} Torr) (2 in. x 8 in.)	Simulate space environments Determine outgassing potential Verify joint integrity
	Impact & Damage tolerance tests (6 in. x 6 in.)	Damage tolerance of materials Permeation and strength after impact
	HyMETS (Arcjet) (Mach 2.5-5.0 1,400°F - 2,700°F)	Characterize coatings under high temperature and load

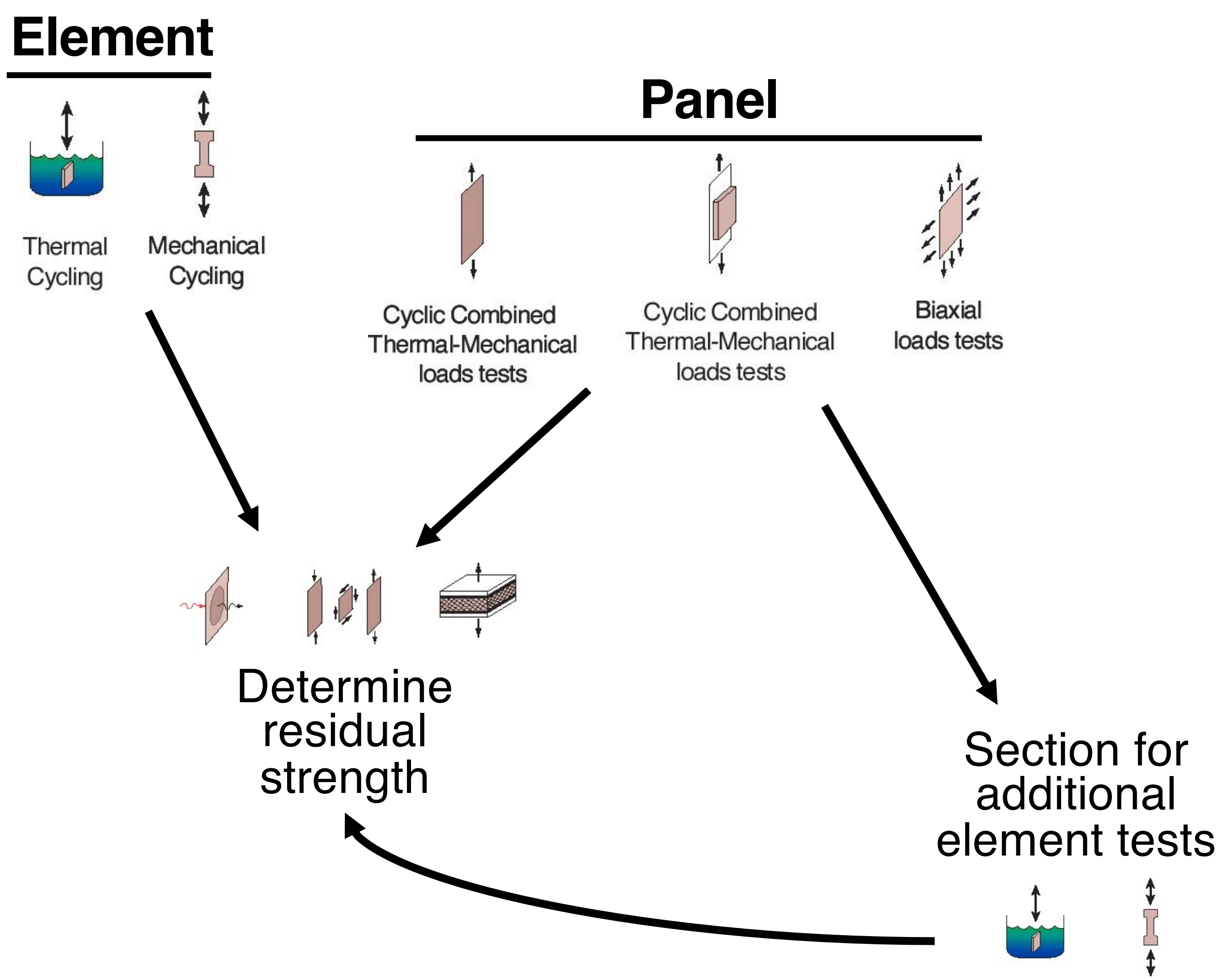
Temperature Dependent Material Characterization Tests – Element Level

Experiments		Task Goals
	Thermal Cycling	Exposure of materials to extreme temperature environments and extreme temperature changes
	Mechanical Cycling	Subject materials to life cycle loading to examine durability

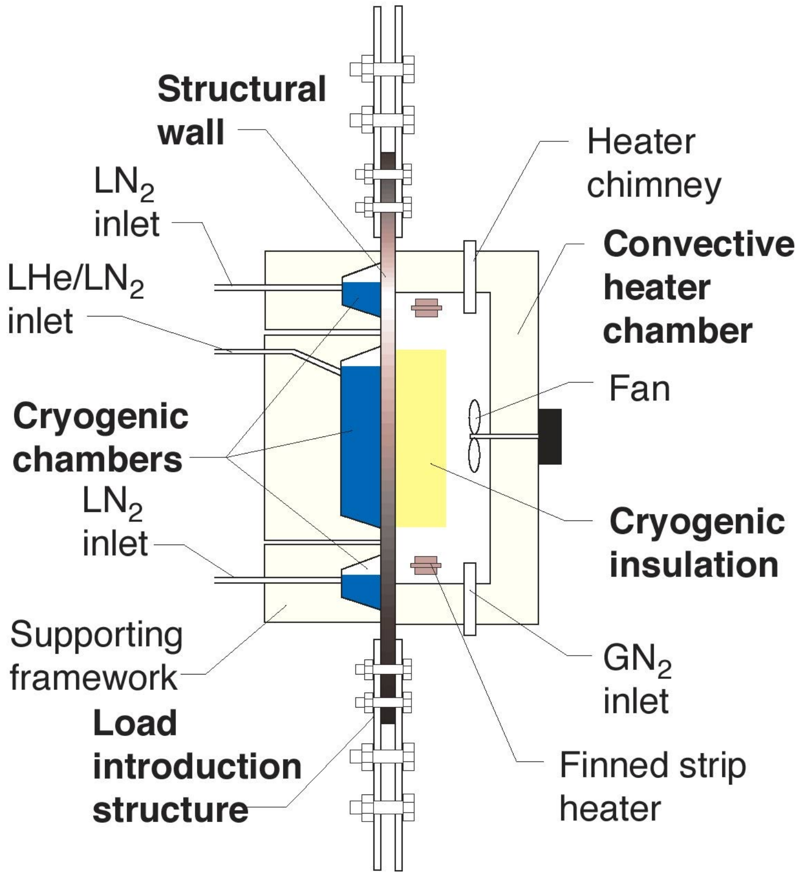
Temperature Dependent Structural and Material Characterization Tests – Panel Level

	Experiments	Task Goals
	Cyclic Combined Thermal-Mechanical loads tests (1 ft. x 4 ft.)	Thermal-mechanical cyclic Manufacturing and process Lifetime durability Simulated flight loads
	Biaxial (tension/compression + temp.) loads tests (2 ft. x 2 ft.)	Thermal-mechanical biaxial tension or compression Realistic loading of material
	Cyclic Combined Thermal-Mechanical loads tests (1 ft. x 2 ft.)	Thermal-mechanical cyclic Durability of foam/adhesive Manufacturing/fabrication details Through the thickness gradiients Global/local NDE/IHM methods verified

Materials in Structural Applications and Joint Evaluations Tests



Thermal-Mechanical Tension Test



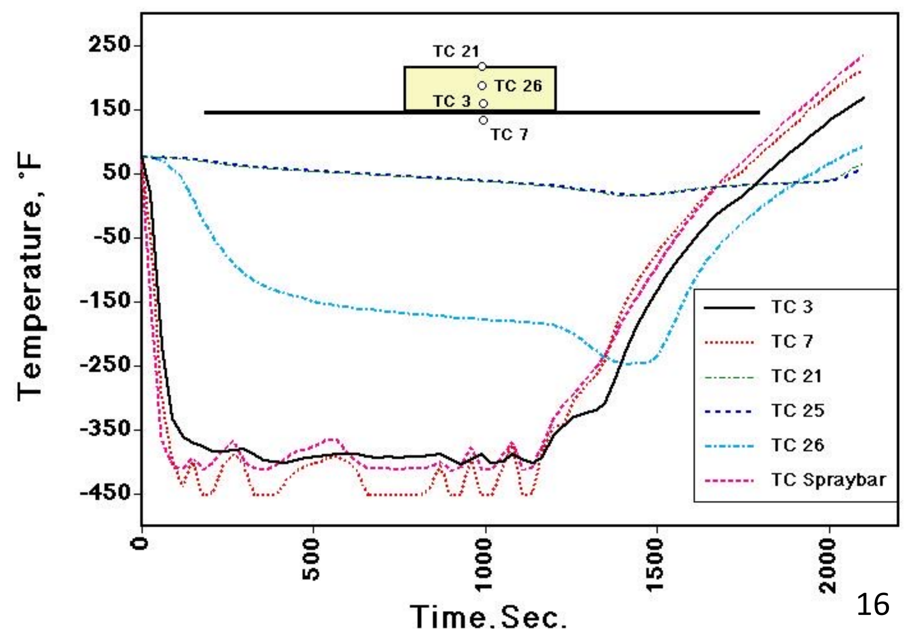
Specimens

Substrate: 1 ft by 2 ft or 1 ft by 4 ft

Min. Temp.
- -423˚F (Cryo. side)
- 10˚F (Foam surface)

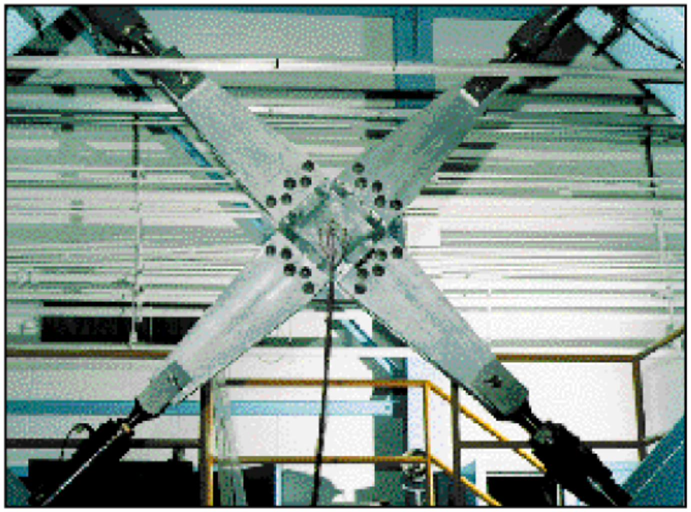
Max. Temp.
- 250˚F (Cryo. side)
- 450˚F (Foam surface)

Max. Load: 110 kips

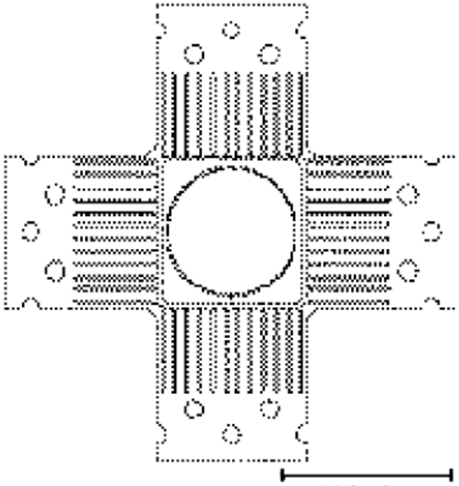


Coupon Level Thermal Biaxial Test Stand

Biaxial Test Stand



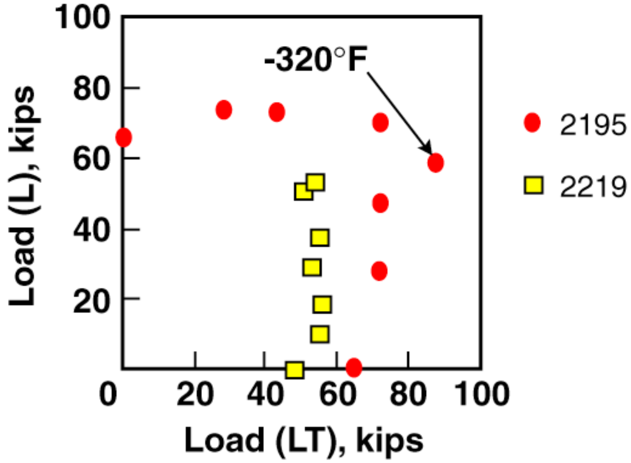
Representative Biaxial Test Specimen



Test Capabilities

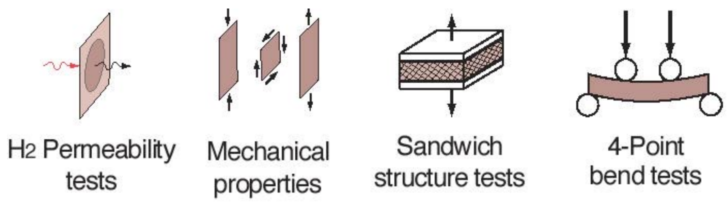
- Major axis load: 150 kips
- Minor axis load: 100 kips
- Cryogenic temperatures as low as -320°F
- Potential for elevated temperature using custom heaters

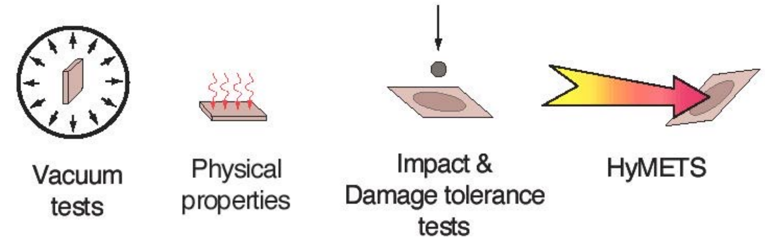
Yield Load Locus for 2219 & Al-Li 2195



Materials and Adhesives Characterization and Screening Tests

Characterization tests



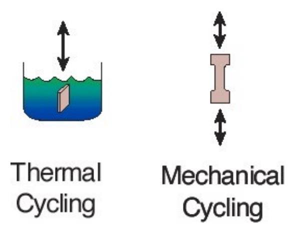


LaRC in-house capability required

Required but not throughout program

Repeated when significant improvements in technology occur

Initial screening tests

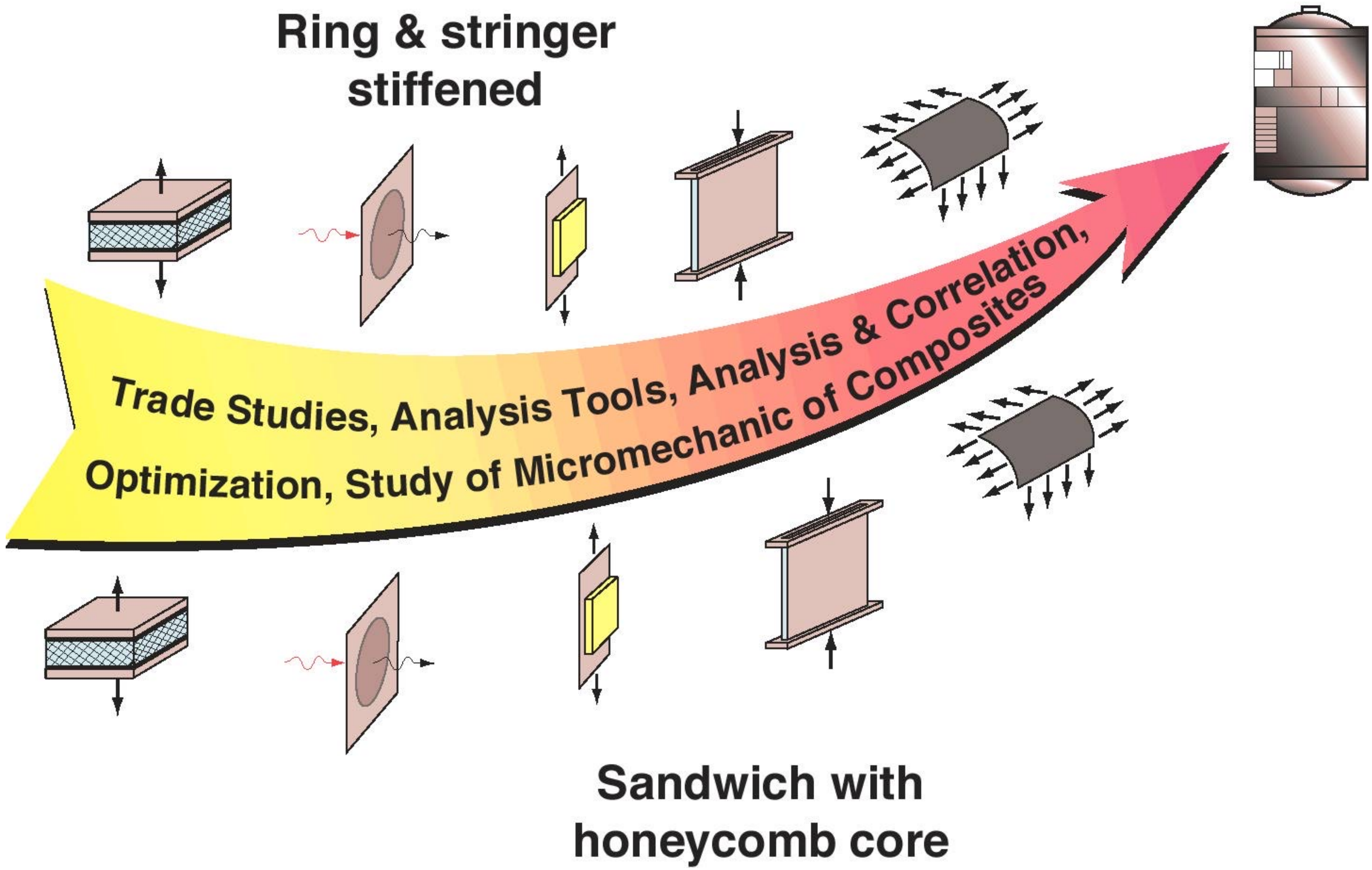


NOTE:

H2 permeability

Low temperature (below -65°F) physical property tests cannot be performed at LaRC.

Development of Cryotank Structural Concepts



Materials and Structures Experiments

Facilities and Competencies

Core Competencies:

- Composite Fabrication
- Mechanical Testing
- Thermal Analysis
- Hypersonic Material Environments Test System (HyMETS)
- 8-ft and 16-m Vacuum Chamber
- Large-scale testing on backstops
- Corporate knowledge for safe operations in our facilities

Facilities:

- James Starnes Structure and Materials Lab. (Bldg. 1148)
- Materials Research Lab (Bldg. 1205)
- Thermal Structures Lab (Bldg. 1256C)
- Composite Fabrication Lab (Bldg. 1267A)
- Advanced Materials and Processing Labs (Bldg. 1293A&C)
- Structural Dynamics Labs (Bldg. 1293B)

B1148 Thermal / Mechanical Testing Capabilities

Load Frame Test Machines

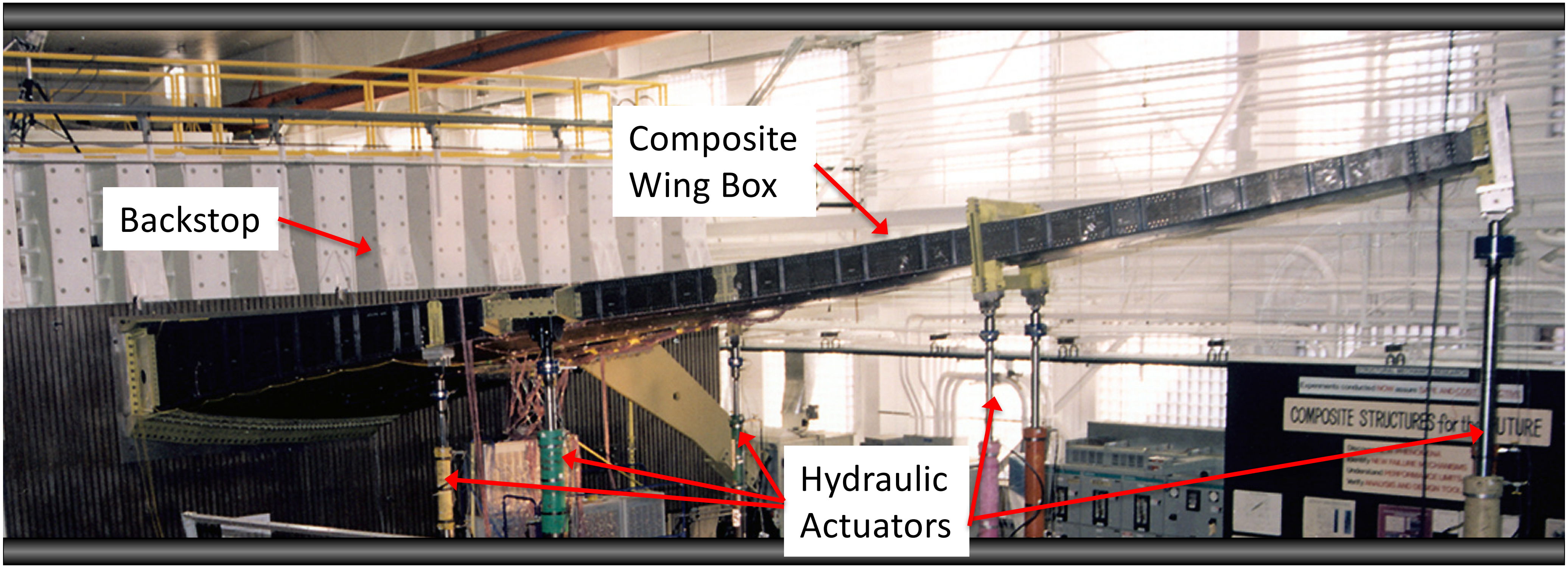
- Environmental Chambers: -420°F to 3000°F
- Specimen Size: coupon to 7 ft H by 5 ft W
- Tension / Compression / Cyclic / Creep Loading
  - 1 kip electromechanical
  - 5 kip
  - 22 kip (2)
  - 50 kip (2)
  - 100 kip inverted cyro
  - 100–120 kip (4)
  - 220 kip (3)
  - 300 kip
  - 500 kip (2)
  - 600 kip
  - 1 M lb

Impact Machines

- Drop Weight Impact
  - Max H = 7 ft
  - Max L = 25 lb
- Static Indentation: 5000 lb

1000-Kip Southwark-Emery Test Machine

B1148 Test Capabilities: Structural Backstop Facility

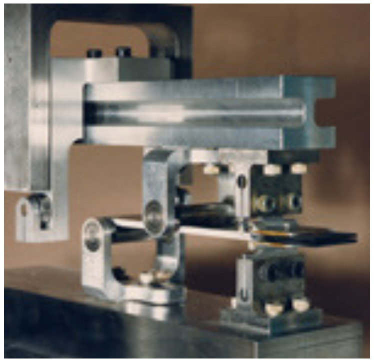


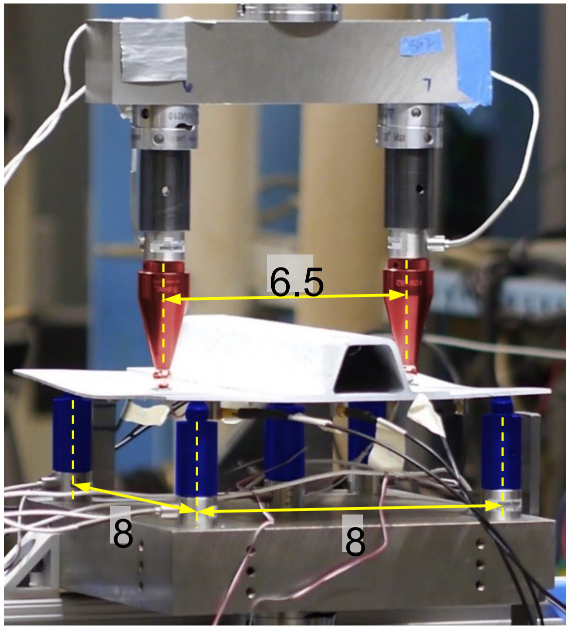
Primary Capability: 10-ft by 30-ft T-slotted steel reaction surface for testing structural components

- Steel beams embedded in floor for actuator or specimen attachment
- 3000 psi hydraulic system for actuator activation
- Actively controlled multi-actuator capability for load application

B1205 Thermal / Mechanical Testing Capabilities

- Materials Research Lab
  - ~ 40 uniaxial load frames (up to 400 kip)
  - Biaxial load frame
  - 3 tension – torsion load frames
  - Axial – Tension Bending load frame
  - Environmental chambers from -320°F to 1000°F
  - Ultrahigh vacuum chamber
  - DMA (Dynamic Mechanical Analysis)
- Digital Image Correlation
- Electron Microscopy (PFIB)
- Confocal Microscopy - FRASTA
- In-situ Inspection (UT, X-Ray, thermography)
- Materials Processing
  - Arc Melter
  - Crystal Puller





All dimensions in inches

Summary

- LaRC has performed structural and material testing for multiple cryotank programs
- Coupon screening of materials at cryogenic temperatures (-320°F and -423°F) can be accomplished
- Lifecycle testing in thermal/mechanical cyclic environments have been conducted for reusable launch vehicle (RLV) programs
- Literature searches, trade studies, design, and detailed analyses has been conducted under various programs
- Testing at cryogenic temperatures requires:
    - Cryogenic rated test fixtures
    - Cryogenic temperature controllers