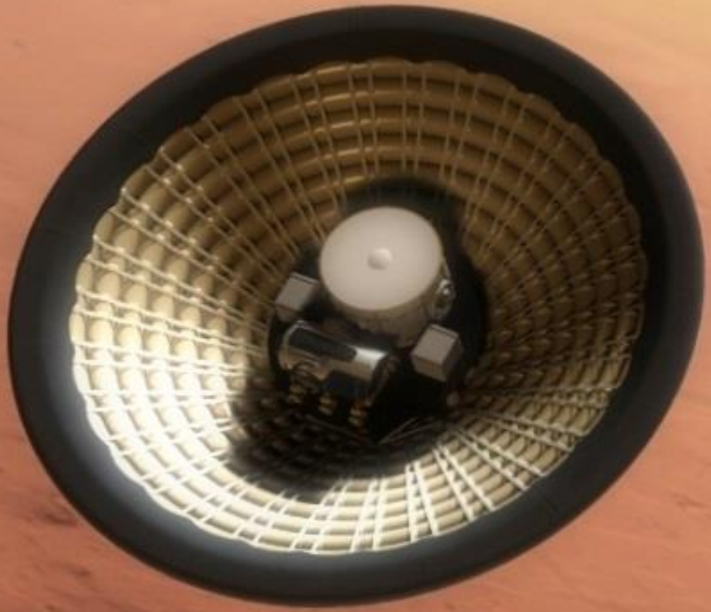
National Aeronautics and
Space Administration

Manufacturing Challenges and Benefits when Scaling the HIAD Stacked-Torus Aeroshell to a 15m-Class System



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What is a HIAD?

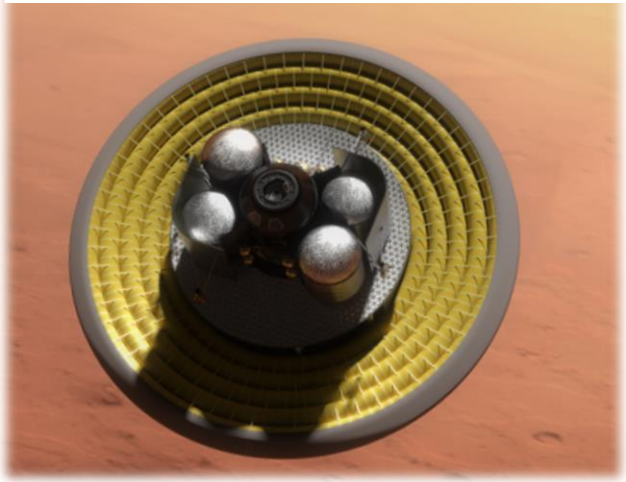
A Hypersonic Inflatable Aerodynamic Decelerator (HIAD) is a deployable aeroshell consisting of an Inflatable Structure (IS) that maintains shape during atmospheric flight, and a Flexible Thermal Protection System (F-TPS) employed to protect the entry vehicle through hypersonic atmospheric entry.


6m Aeroshell


3m Aeroshell (IRVE-3)

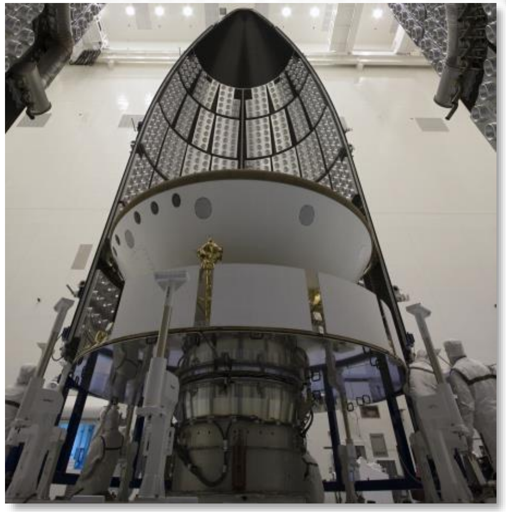
3.7m Aeroshell

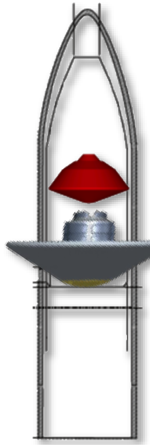

3.7m IS


~19m Journey to Mars Concept

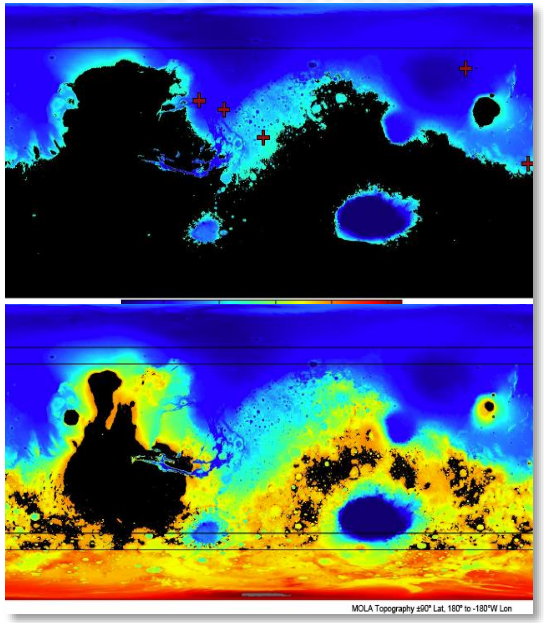
- Deployable Aeroshells are not new technologies – first conceptualized in 1960s, and built/tested through early 1970s
- Recent requirements outside the performance capabilities of traditional EDL technology, and developments in high performance materials have revitalized these technologies
- By increasing drag area without violating current launch vehicle shroud constraints you can achieve lower ballistic coefficients
- Low ballistic coefficient architectures can provide benefits in many key areas:
  - Decrease in peak heat flux
  - Increased payload mass fraction
  - Increased landing site altitude (Mars)
  - Lower deceleration loads

Launch Vehicle Fairing Constraints



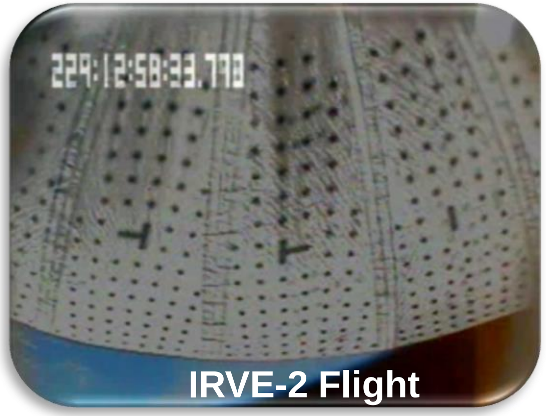


Mars Surface Access



NASA's HIAD Project History – Last 10 Years

- **Systematic and stepwise technology advancement**
  - ✓ **Ground Test**: Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE)—Softgoods technology breakthrough
  - ✓ **Flight Test**: Inflatable Reentry Vehicle Experiment (IRVE), 2007: LV anomaly—no experiment
  - ✓ **Flight Test**: IRVE-II, 2009—IRVE "build-to-print" re-flight; first successful HIAD flight
  - ✓ **Ground Test**: HIAD Project improving structural and thermal system performance (Gen-1 & Gen-2)—Extensive work on entire aeroshell assembly
  - ✓ **Flight Test**: IRVE-3, 2012—Improved (Gen-1) 3m IS & F-TPS, higher energy reentry; first controlled lift entry



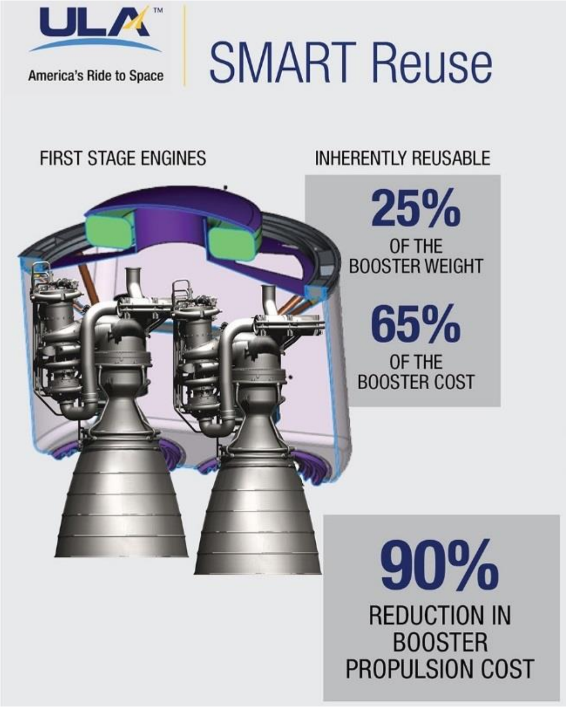
Motivation for Scaling to a 15m Class

12m T1 Torus

Current Focus:

- **Ground Effort**: *Gen-3 F-TPS, advanced structures, packing, manufacturability at scale >10m, controllability, and demonstrated staging to secondary decelerator.* **Prepares for large-scale flight test and readiness for potential Mars mission**.

- **Flight Test Possibilities**: *United Launch Alliance (ULA) flight test and/or first stage engine recovery at scale, and Mars Human EDL Pathfinder*.



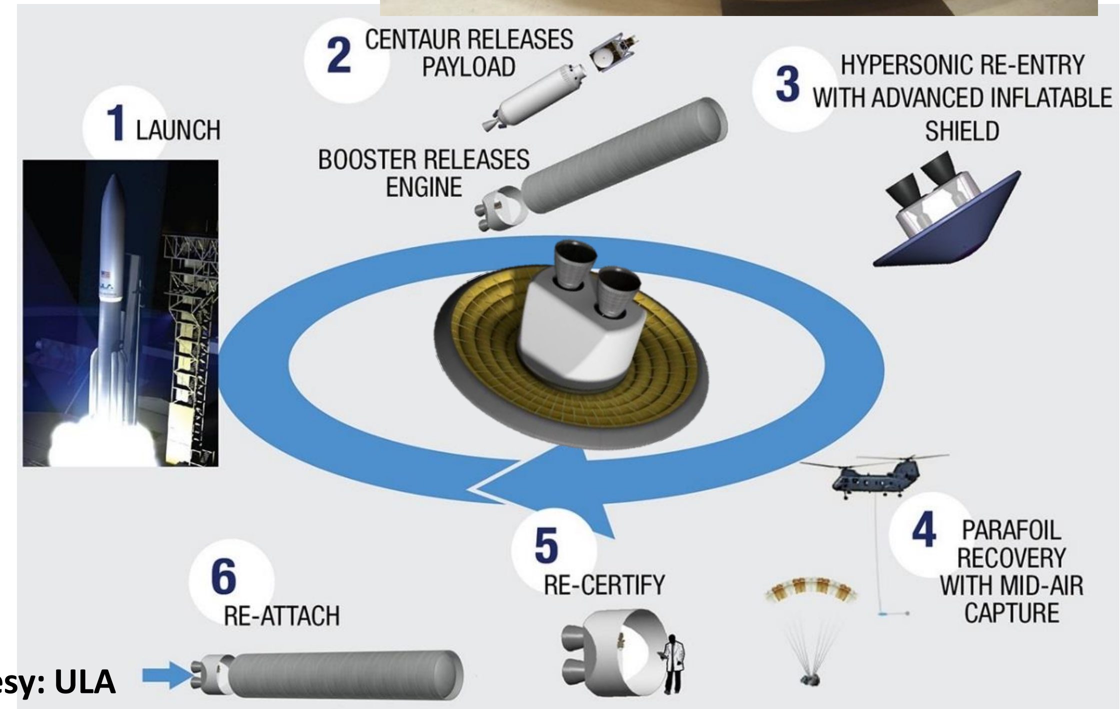
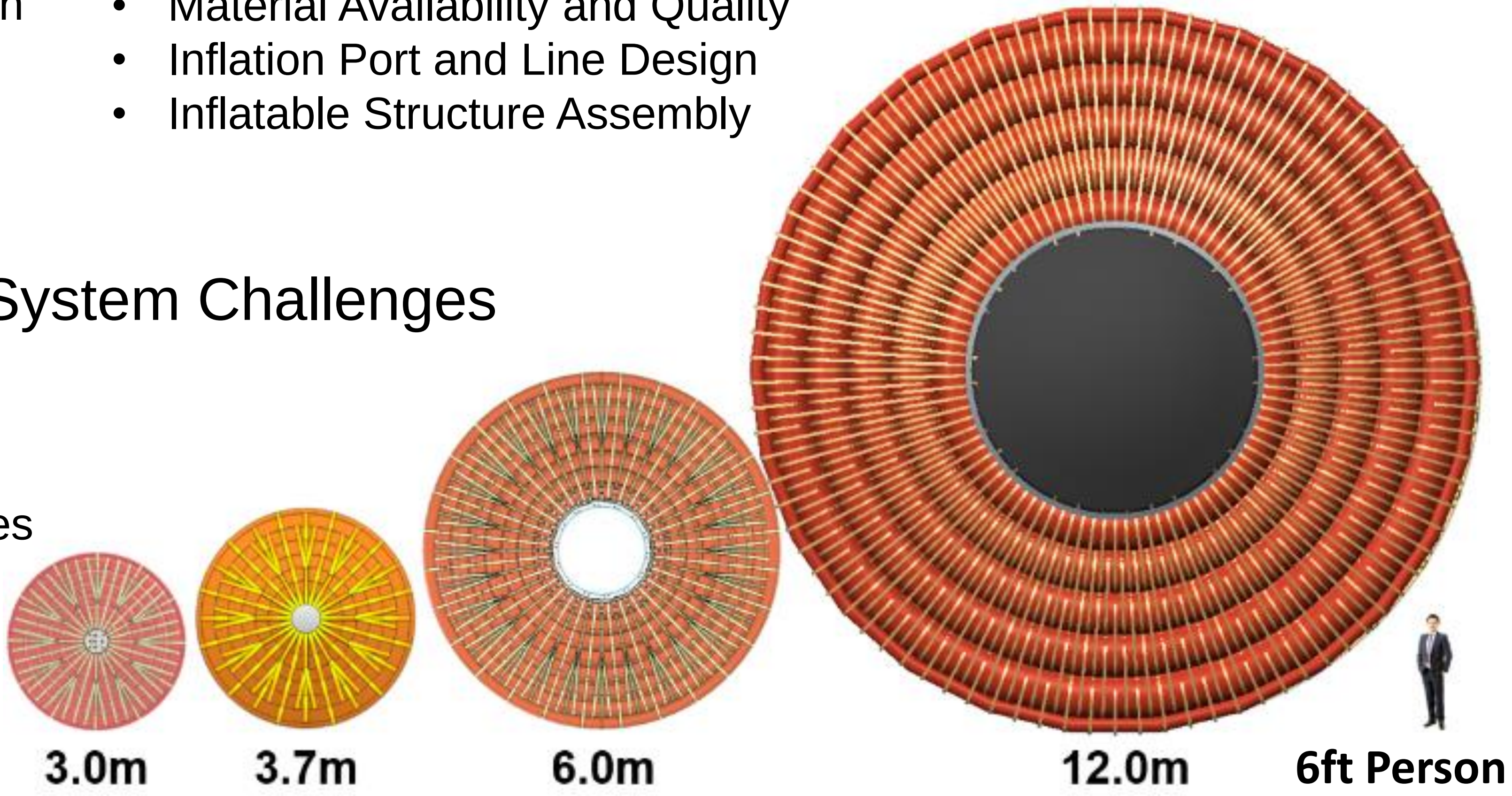


Figure Courtesy: ULA

Critical Jump in Manufacturing / Associated Challenges

- The largest HIAD inflatable structure (IS) and flexible TPS that NASA has built to date are 6m in diameter. The HIAD team has also built 3m and 3.7m aeroshells
- 12m HIAD has 4x the cross sectional area of a 6m (a 15m has over 6x) – See Below
- Inflatable Structure Challenges
  - Structural Strap Layout and Design
  - Inflatable Gas Barrier Design
  - Torus Braid Design
  - Inflatable Structure Component and System Testing
  - Material Availability and Quality
  - Inflation Port and Line Design
  - Inflatable Structure Assembly
- Flexible Thermal Protection System Challenges
  - Gore Seaming and Stitching
  - Limitations on Material Widths
  - Low-Outgassing Adhesive
  - Fabrication Equipment and Fixtures
  - Material Lifting and Handling
  - Facility Space Requirements
  - Material Inspection and QC
  - F-TPS Packing and Load Testing



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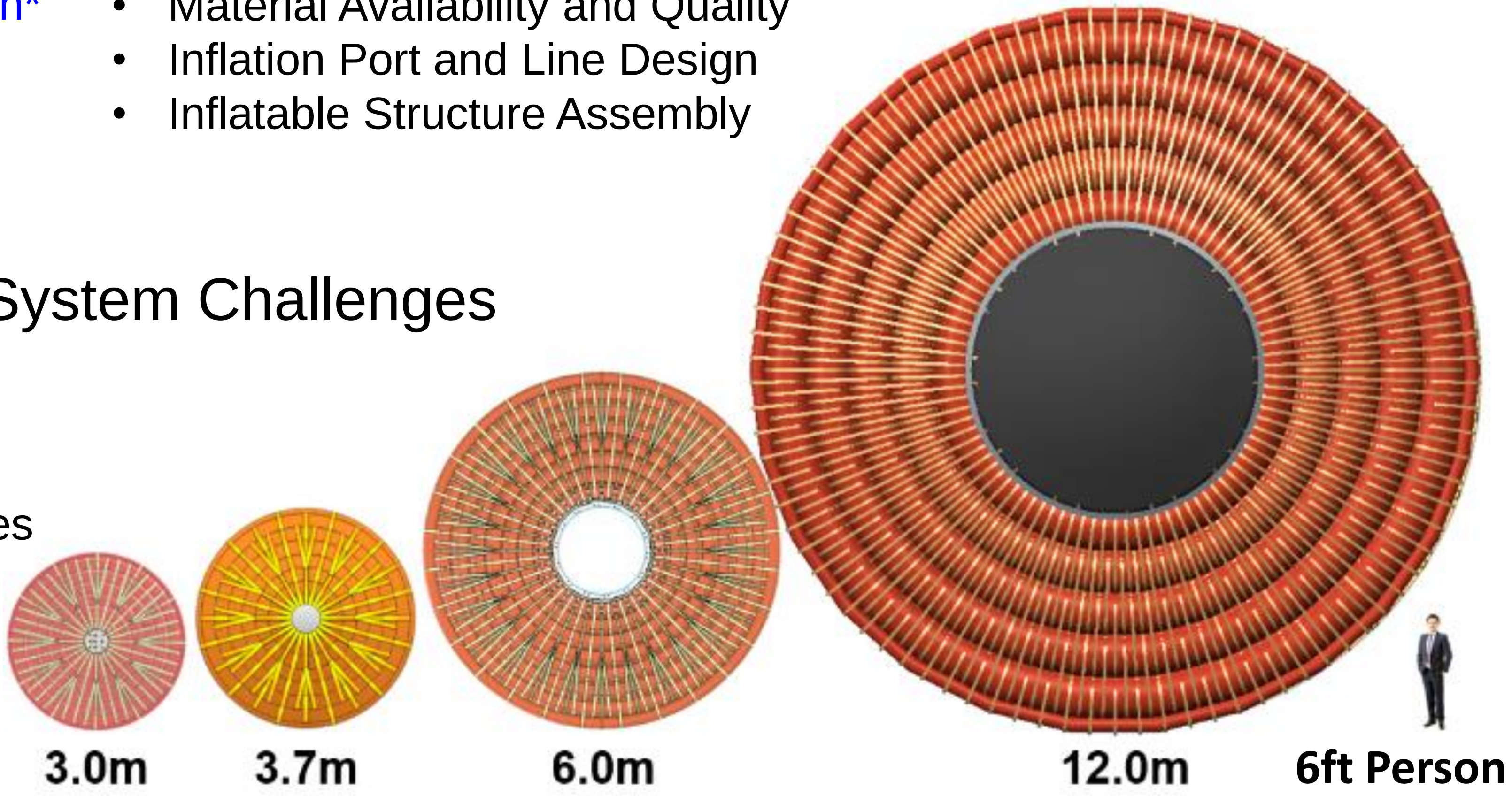
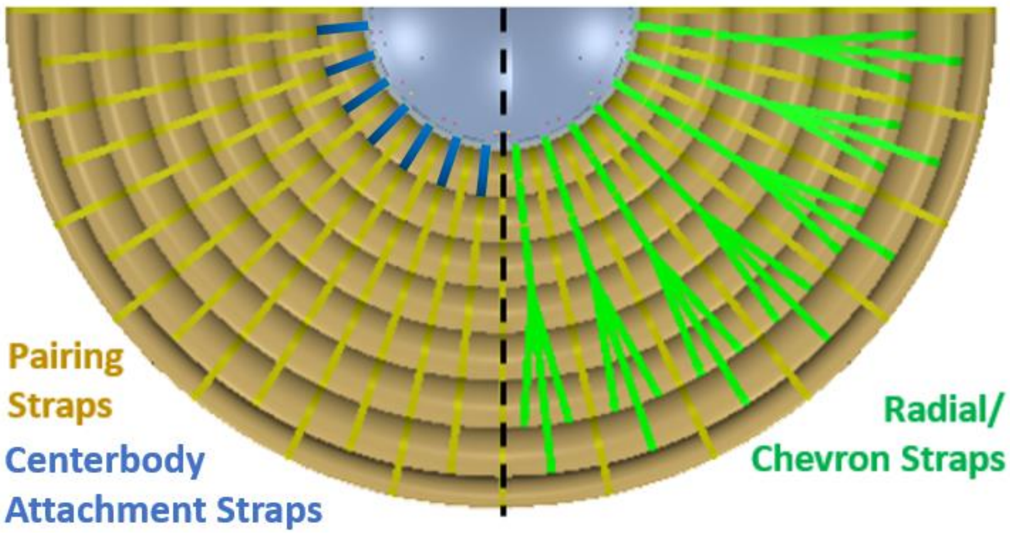
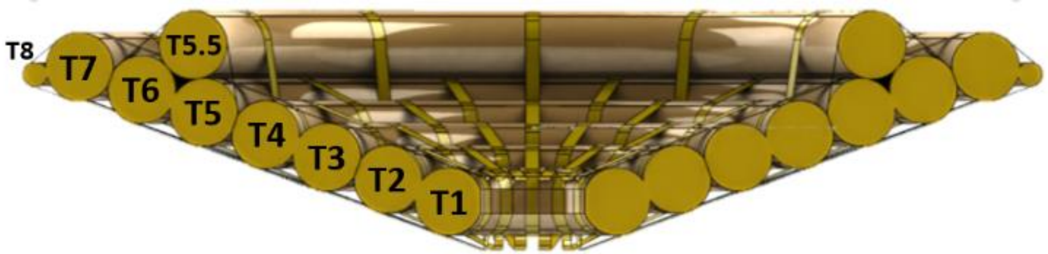
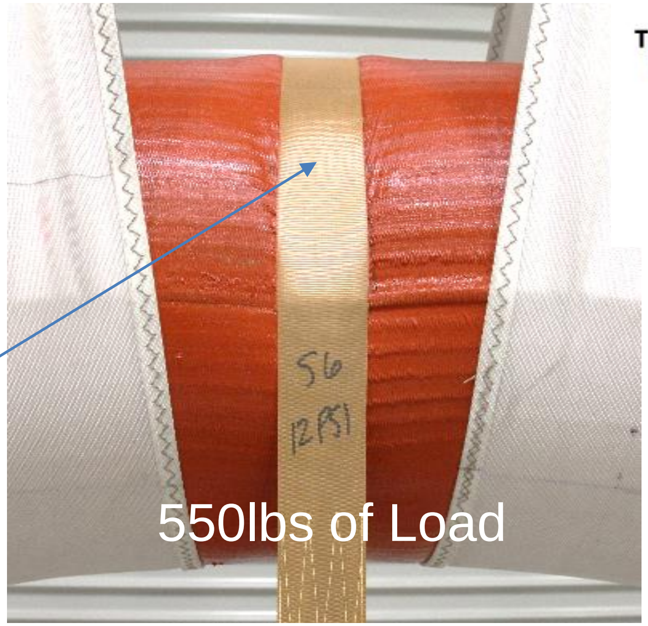


Inflatable Structure Structural Strap Layout and Design

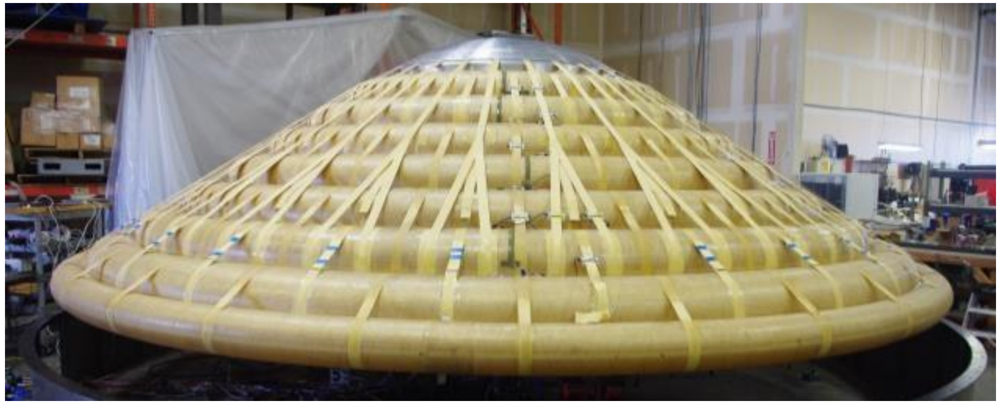
- 6m HIAD used 28 strap positions - was tested to a load of 50,000lbs w/ F-TPS
- Loads for a 15m-Class HIAD (mission specific) could be in the range of 300,000lbs
- Requires a change in strap layout and design to react load back to centerbody
- Design Options / Trade Space:
  - Strap Width
  - Number of Strap Positions
  - Number of Chevron Straps
  - Strap Design





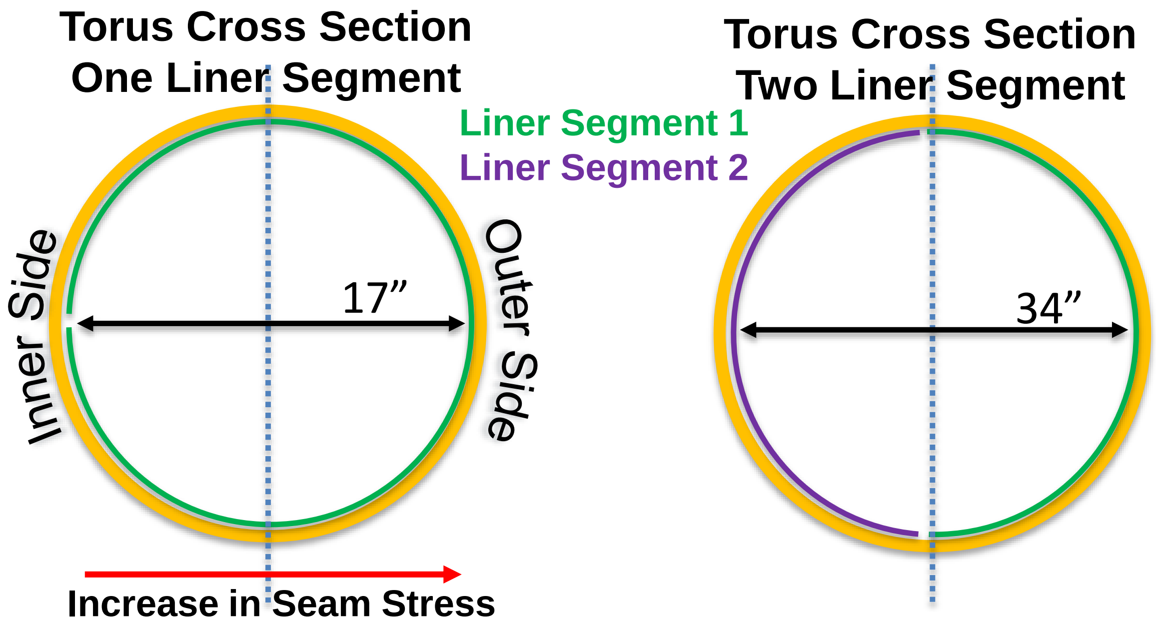


Strap Indentation – provides indication at what load the strap/torus system can no longer carry additional load



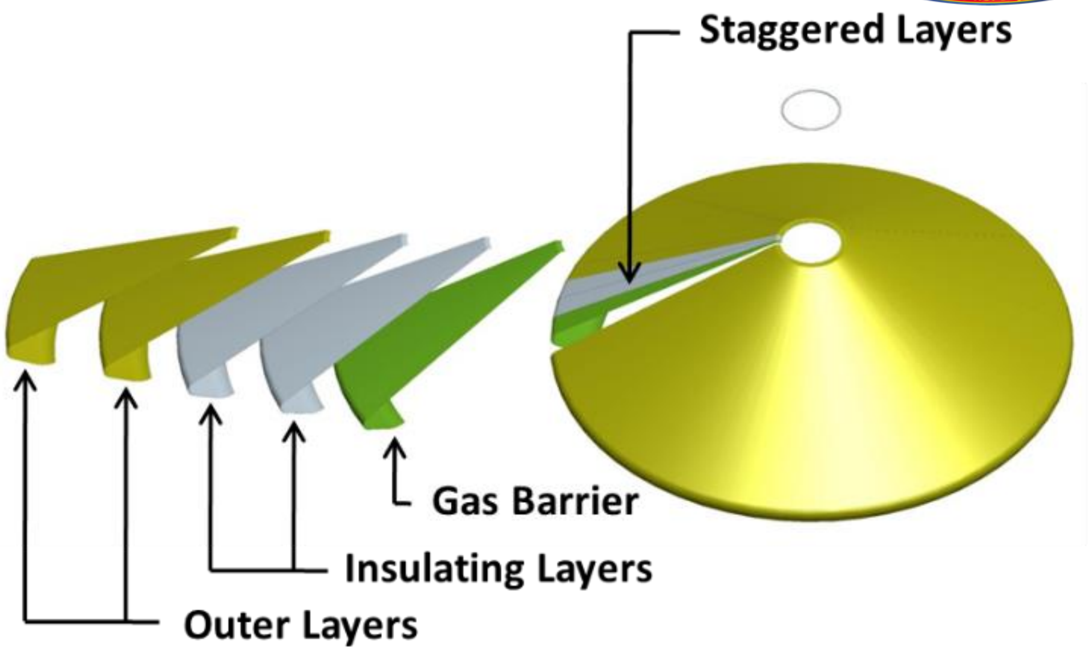
IS Gas Barrier Design

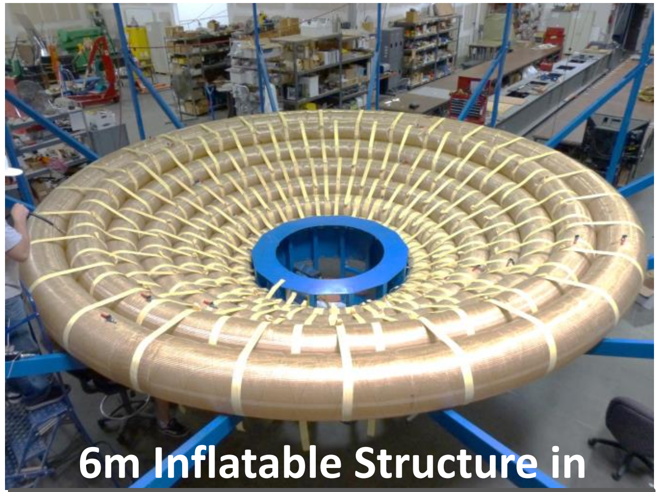
- The IS gas barrier is fabricated by forming liner material into a cylinder closed out by an axial seam located at the innermost side of the torus (least stress)
- All current HIAD inflatable structures have been built using a one liner seam system
- The current ~54in width of useable liner material limits a one seam gas barrier design to 17in diameter tori; anything larger requires an alternate design
- A two seam system can be used with 18in to 34in tori; three seam system can do 35in to 53in (~1.3m)
- Concern about seam location to be addressed



F-TPS Gore and IS Strap Seaming/Stitching

- Current components/systems have been small enough that they could be manually placed and moved, although this was challenging at the 6m scale
- 15m-class systems will require a shift in process since this approach will no longer be viable
  - Research other large scale high performance textile manufacturing
  - Special equipment will need to be designed and fabricated to move materials (if materials are not supported correctly at this size they could be damaged)
  - Tasks must now be brought to the materials when at all possible requiring an investment in new equipment. e.g. mobile sewing machines



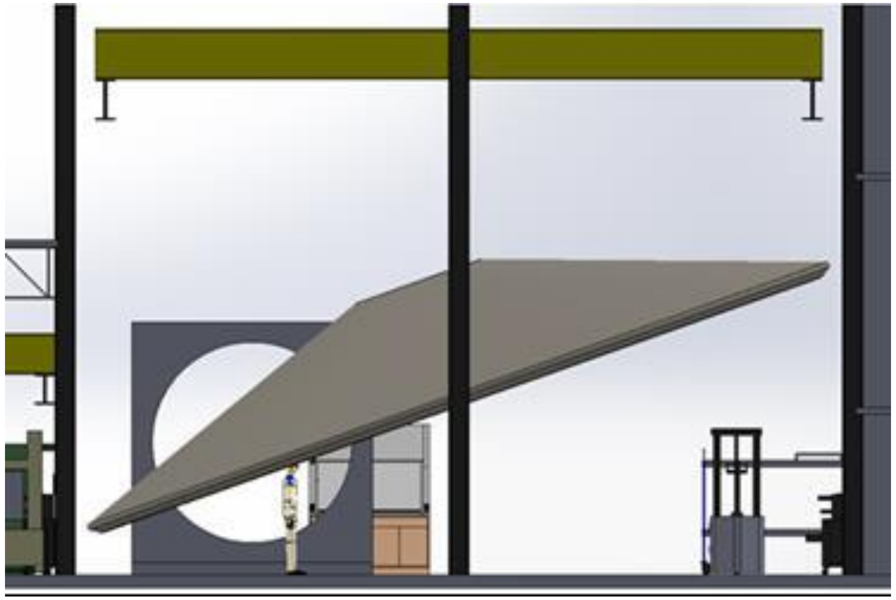


6m Inflatable Structure in Stacking Fixture

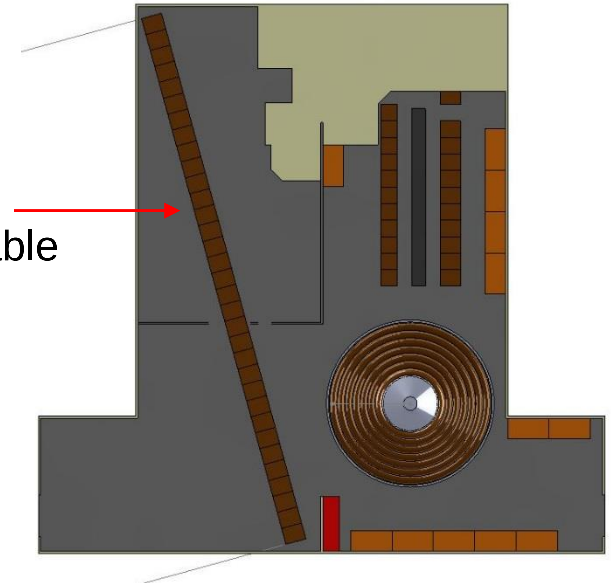
Facility Space Requirements

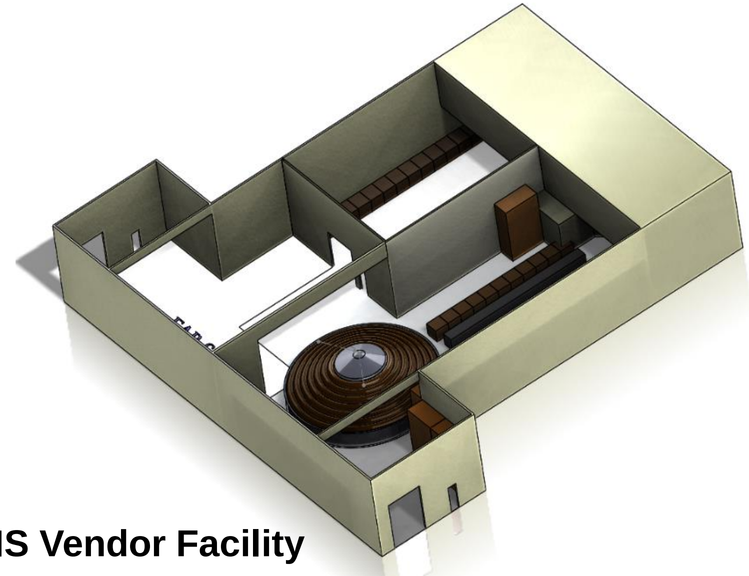
- Growing the technology to a 12m aeroshell from the current largest system (6m) requires 4x the cross sectional area in the vendor facilities
- Both facilities can accommodate the fabrication of a 12m aeroshell with some reconfiguration, but that is the maximum
- Larger than a 12m will require temporary/ permanent relocation of the vendor staff and equipment (presents its own challenges)

F-TPS Vendor Facility



~130ft Layout Table

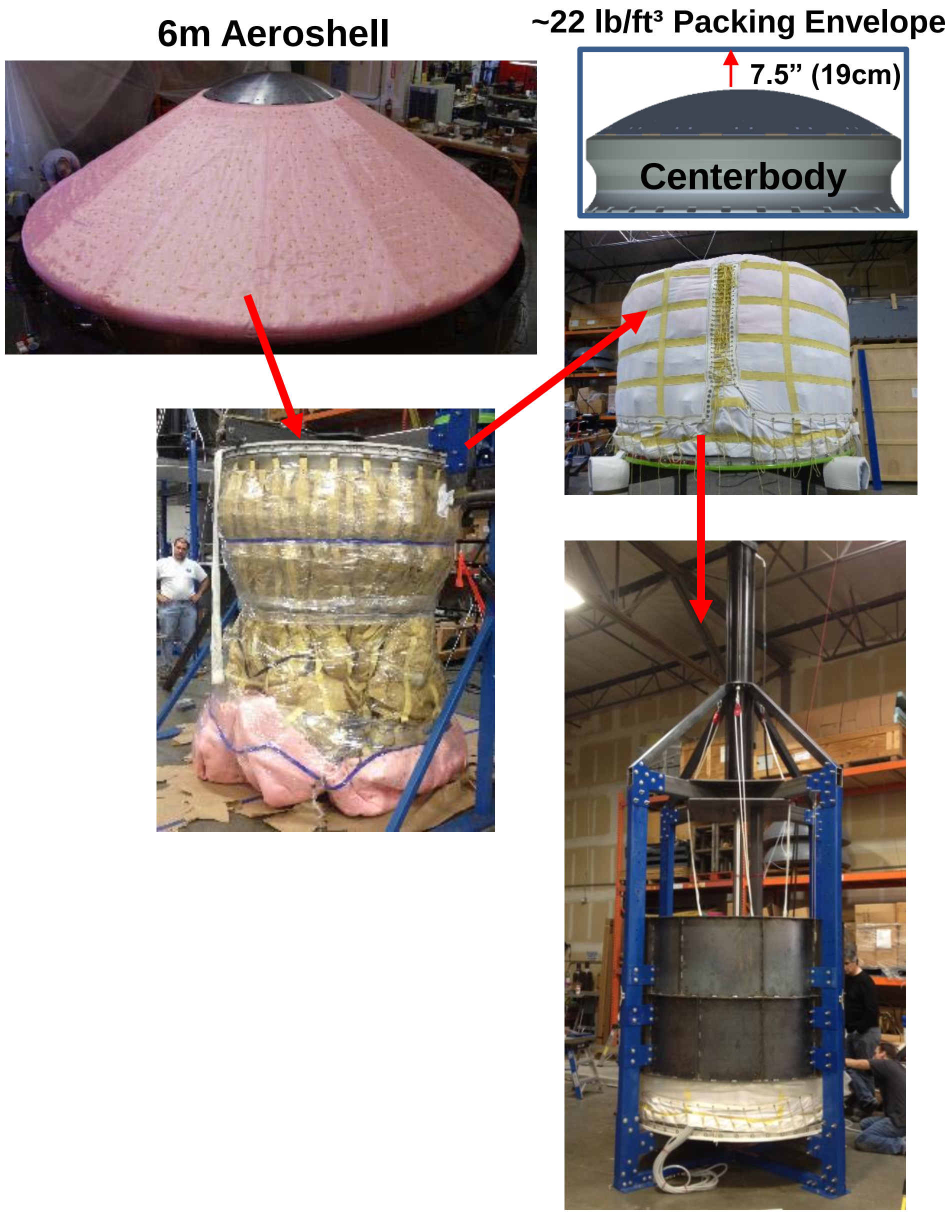




IS Vendor Facility

Packing and Structural Testing

- To date all aeroshell packing has been done by hand folding the textiles and then using a combination of vacuum and pressure to meet the required pack density
  - This was a challenge at the 6m level, will need special fixturing for 15m-class system



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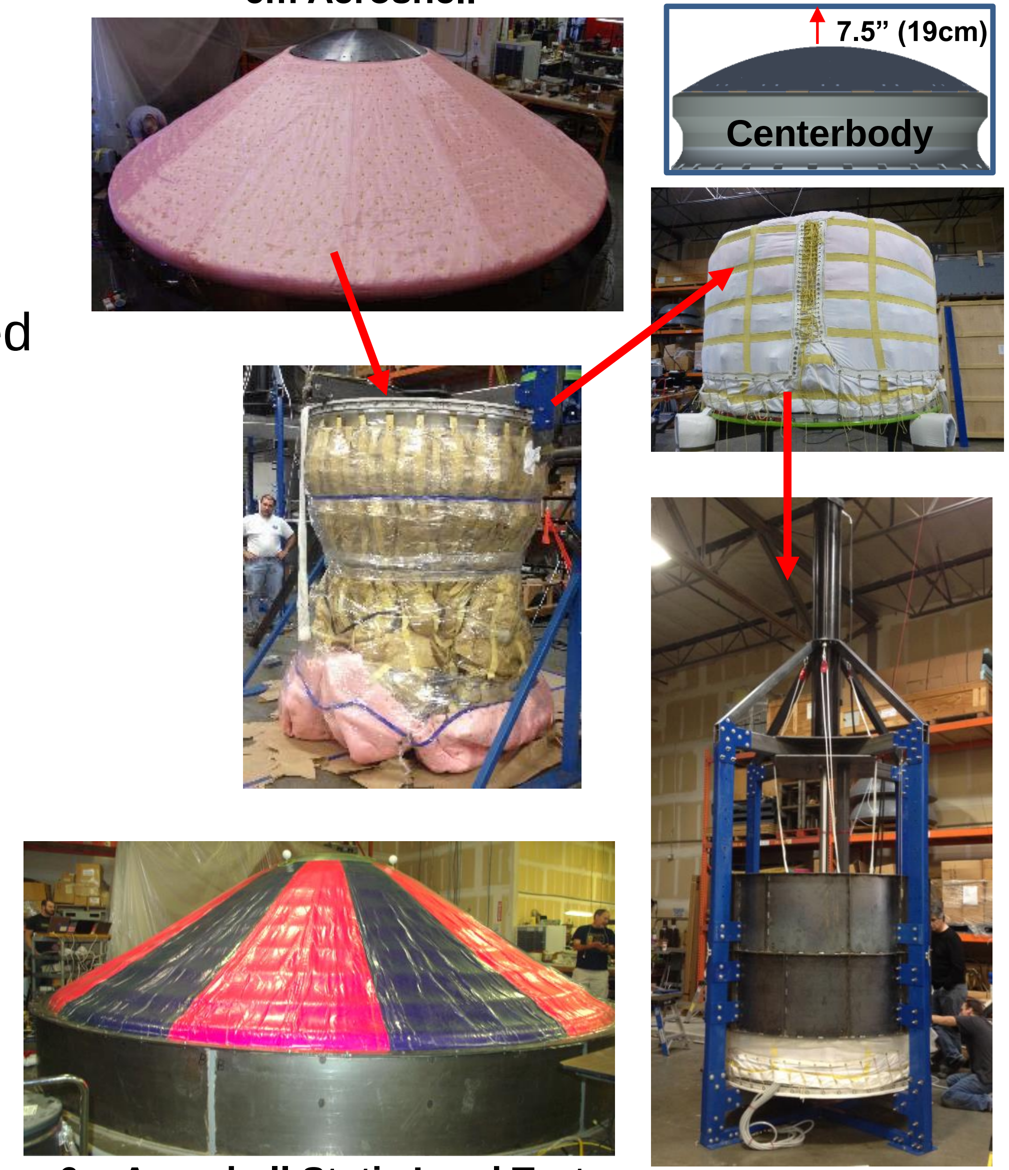
- Distributed load testing (static load testing) capability will need to be increased from the current 50,000lbs load to ~300,000lbs of load
  - Requires investment in new high capacity ram
  - Possibly reinforcing the facility

6m Aeroshell

~22 lb/ft³ Packing Envelope



6m Aeroshell Static Load Test

Packing and Structural Testing

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- Distributed load testing (static load testing) capability will need to be increased from the current 50,000lbs load to ~300,000lbs of load
  - Requires investment in new high capacity ram
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- Hydrostatic testing needs a promotion from the kiddie pool
  - Will utilize the 6m and 3.7m static load test tubs and ~3,000 gallons of water to test the 12m T1 torus

6m Aeroshell

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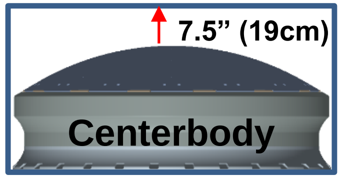
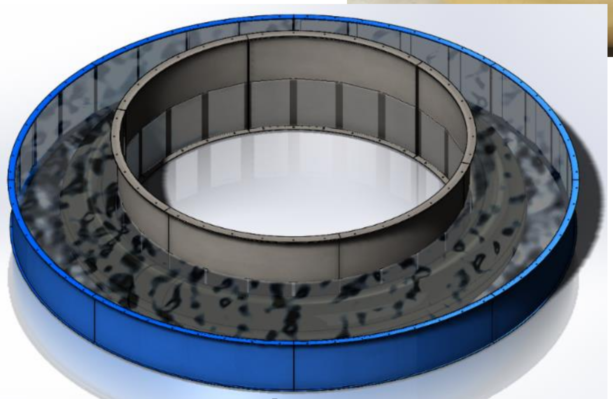
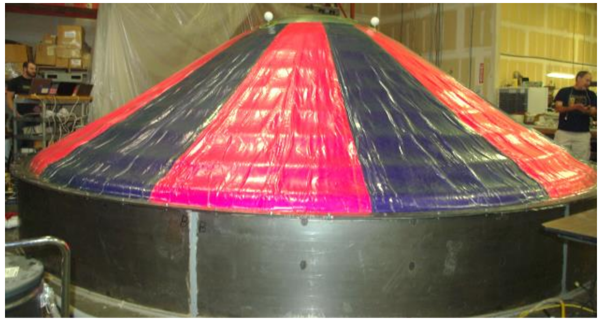




12m T1 Hydro Test Setup



6m Aeroshell Static Load Test

Benefits of Scaling the HIAD Structure to a 15m Class

- Contrary to the process of scaling high performance structures, there are a few noteworthy benefits of growing the HIAD to a 15m-class system:
    - Material Response / Design Margin
    - Handmade Textile Accuracy

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  - Material Response / Design Margin
  - Handmade Textile Accuracy*

- HIAD fabrication team comprised of expert tradespeople, but these are still handmade structures
- ~1/8” accuracy for sizing and sewing materials
- 3m aeroshell exhibited ~0.5% deviation in pairing strap length (9.7” minor diameter torus), which can cause large differences in load distribution
- Making the reasonable assumption that the accuracy of ~1/8” remains constant when scaling-up the technology, the resultant deviation would be reduced
  - i.e. a 15m-class HIAD with 32.5” minor diameter tori, would have ~0.075% variation

Conclusions / Future Work

- After a detailed study of the manufacturing process, no show-stoppers have been identified, but many challenges exist
  - Could easily throw mass/$$$ at these challenges but we are resource constrained.
  - Must continue to develop creative and innovative solutions to these new challenges.
- Some challenges have already been addressed in FY16, the rest will be worked over the next couple years during the HIAD-2 project
- All current activities are working towards the fabrication and ground testing of a 12m aeroshell, as well as the 6m HIAD on ULA test flight