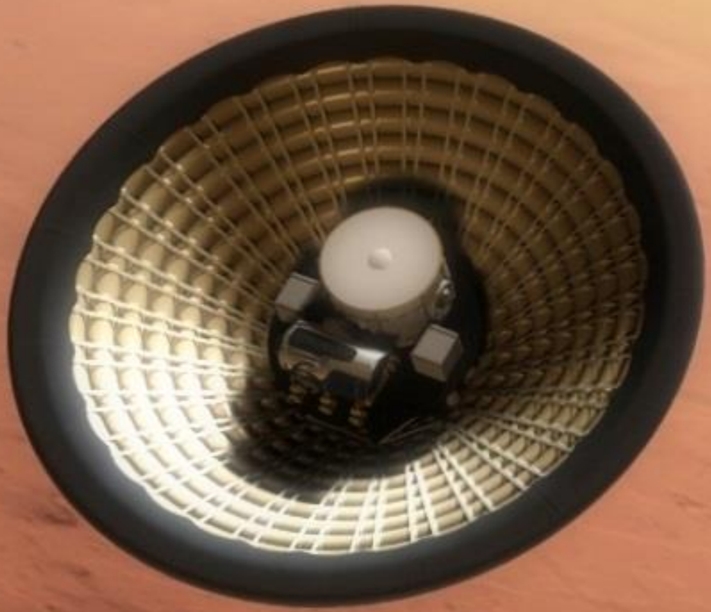
National Aeronautics and
Space Administration

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



Presented By: Greg Swanson
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AMA Inc. @ NASA ARC

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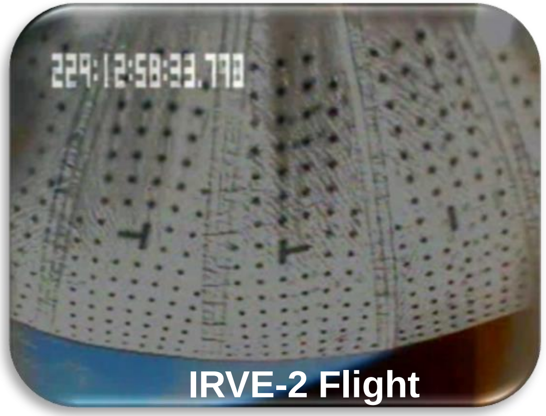
NASA LaRC – Neil Cheatwood, Keith Johnson, Steve Hughes, Anthony Calomino

Airborne Systems – Brian Gilles, Paul Anderson

Jackson-Bond Enterprises – Bruce Bond

NASA's HIAD Project History – Last 10 Years

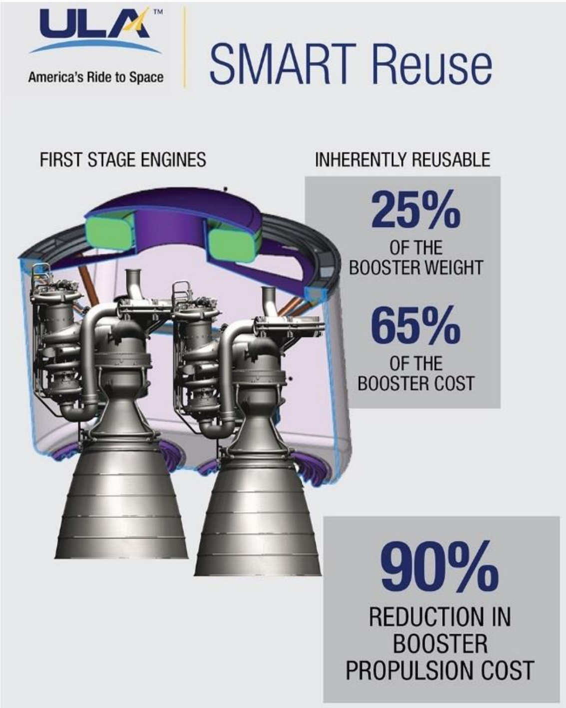
- **Systematic and stepwise technology advancement**
  - ✓ **Ground Test**: Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE)—Softgoods technology breakthrough
  - ✓ **Flight Test**: Inflatable Reentry Vehicle Experiment (IRVE), 2007: LV anomaly—no experiment
  - ✓ **Flight Test**: 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)— 3m and 6m systems tested
  - ✓ **Flight Test**: IRVE-3, 2012—Improved (Gen-1) 3m IS & F-TPS, higher energy reentry; first controlled lift entry



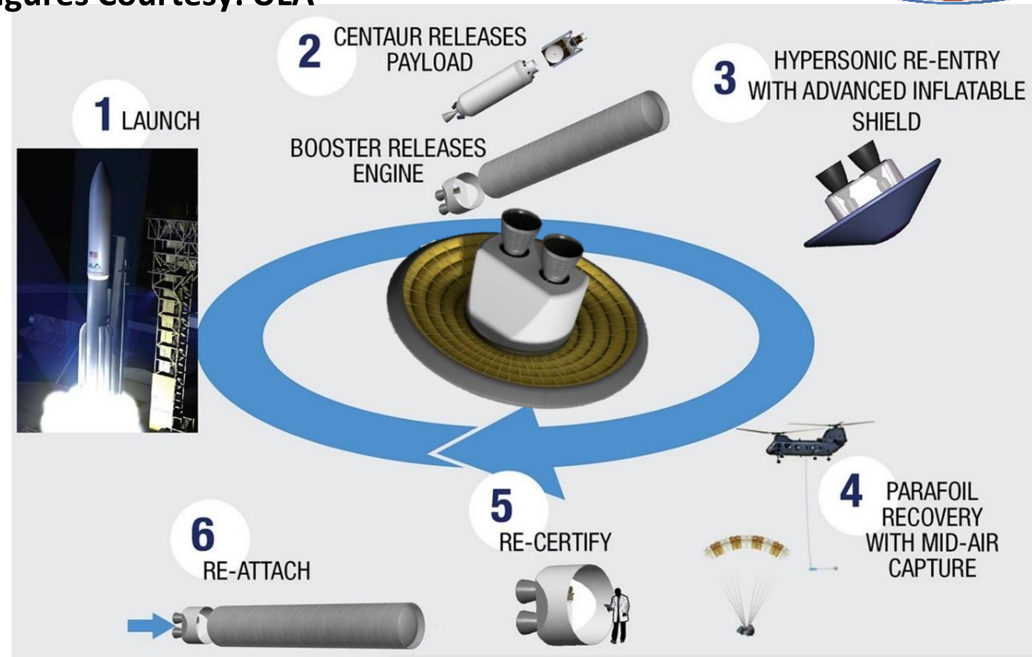
Motivation for Scaling to a 15m Class

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

**John DiNonno's Talk Earlier Today*



Figures Courtesy: ULA



Current Focus:

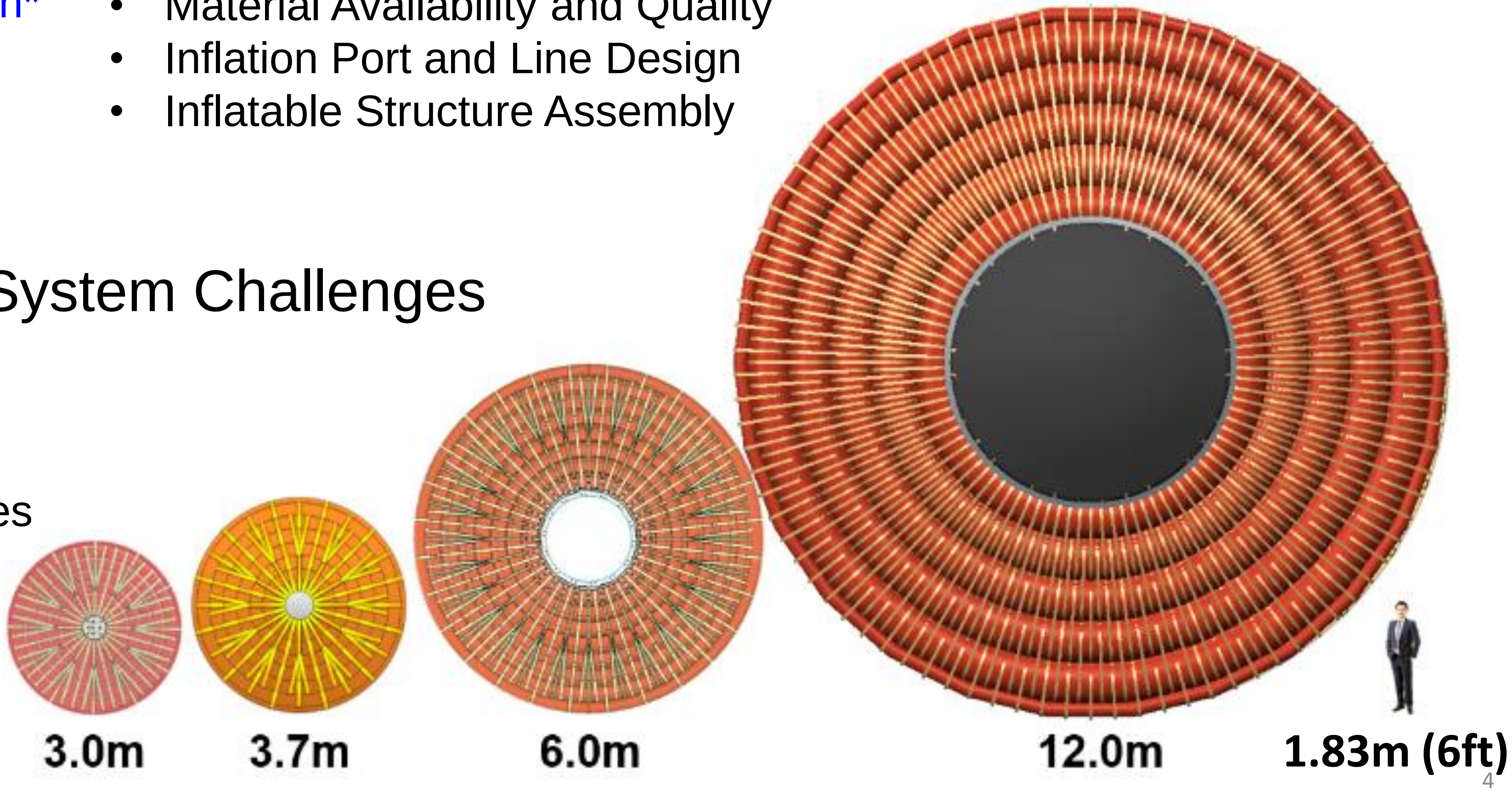
- ⇨ **Ground Effort**: *advanced structures, packing, manufacturability at scale >10m, controllability, and demonstrated staging to secondary decelerator.* **Prepares for large-scale flight test and readiness for potential Mars mission**.

5.3m Major Dia., 0.6m Minor Dia.

Smallest Torus for 12m Aeroshell
(Only 24lbs (11kg) After Coating!)

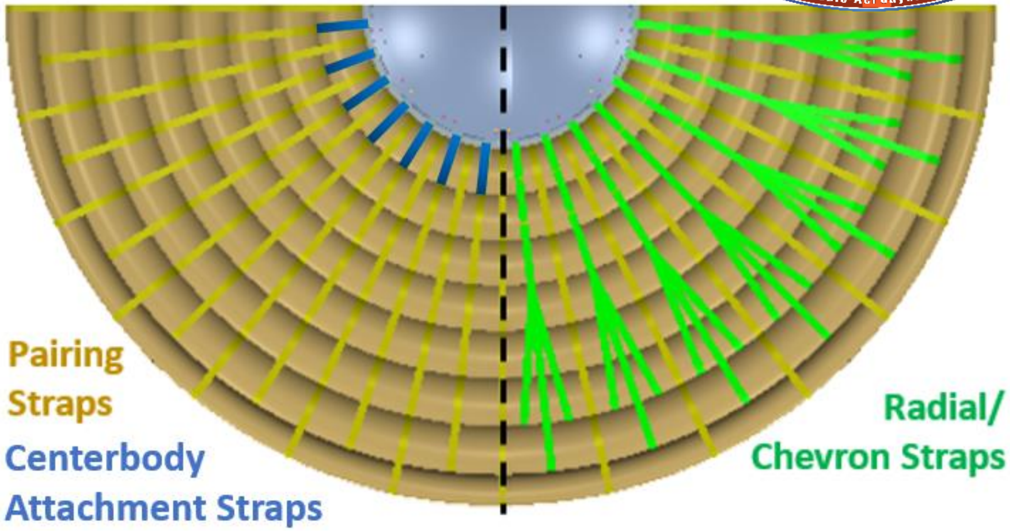
Critical Jump in Manufacturing / Associated Challenges

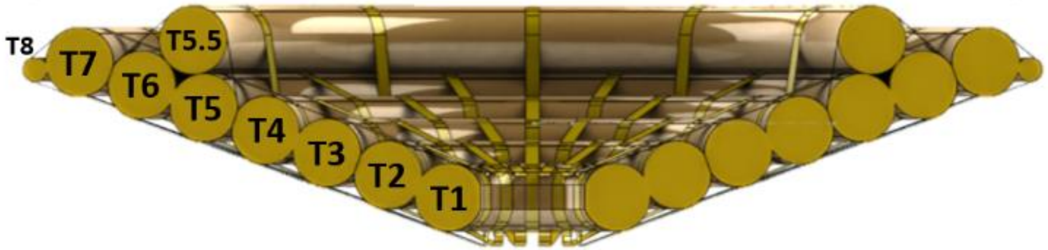
- The largest HIAD inflatable structure and flexible TPS that NASA has built to date are 6m in diameter. The HIAD team has also built 3m and 3.7m aeroshells
- 12m HIAD has 4x the cross sectional area of a 6m (a 15m has over 6x) – See Below
- Inflatable Structure Challenges
  - Structural Strap Layout 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*



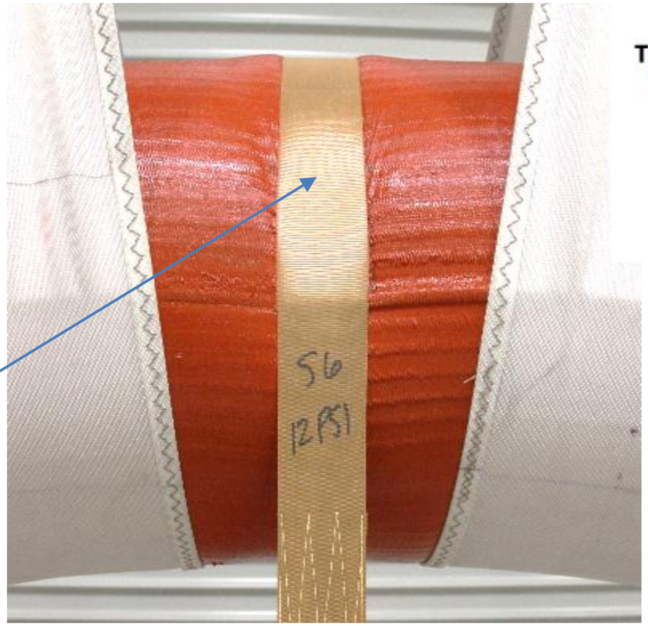
Inflatable Structure Structural Strap Layout and Design

- 6m HIAD used 28 strap positions - was tested to a load of 50,000lbs (22,700kg) w/ F-TPS @ 10psi
- Loads for a 15m-Class HIAD (mission specific) could be in the range of 300,000lbs (136,000kg)
- 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

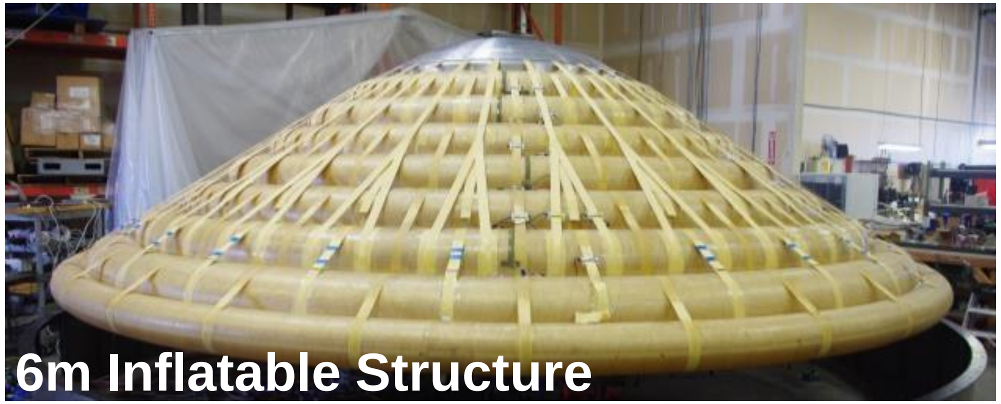




Strap Indentation – provides indication at what load the strap/torus system can no longer carry additional load



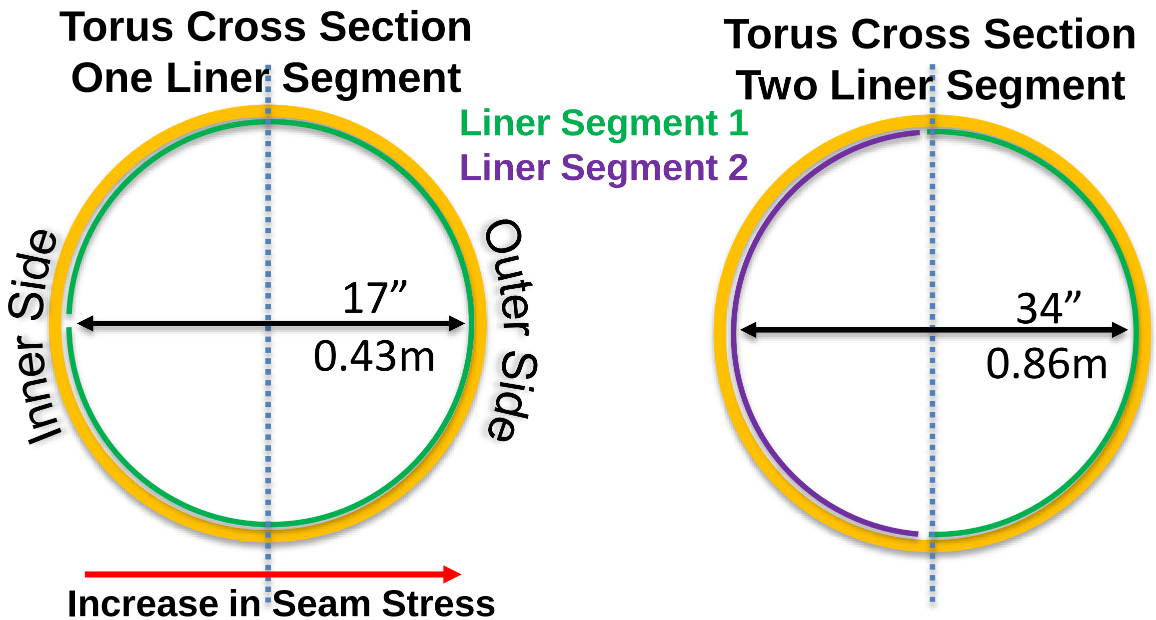
550lbs (250kg) of Load



6m Inflatable Structure

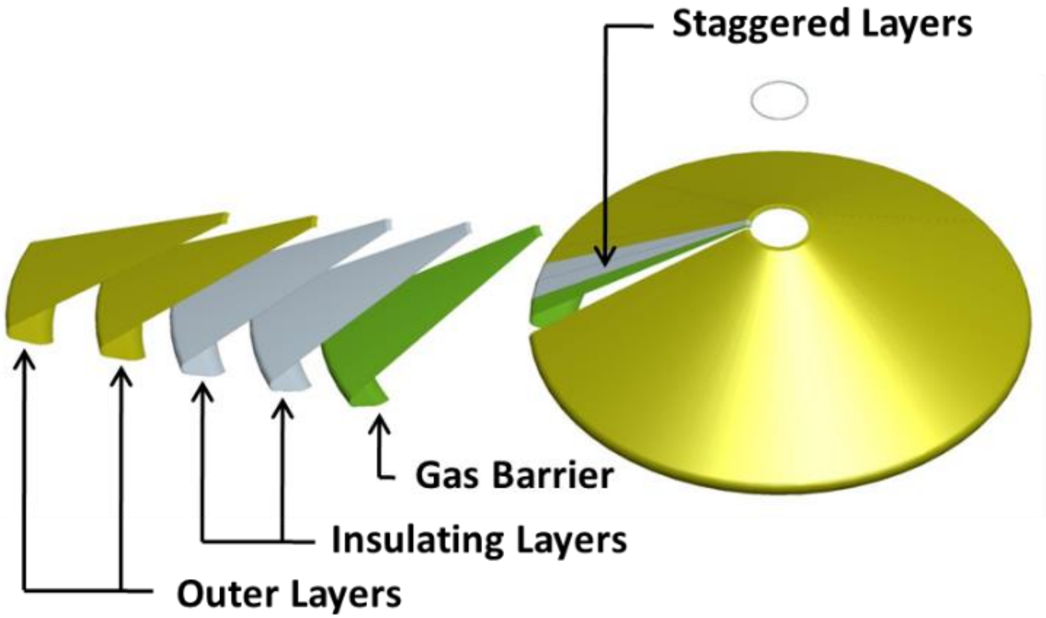
Inflatable Structure Gas Barrier Design

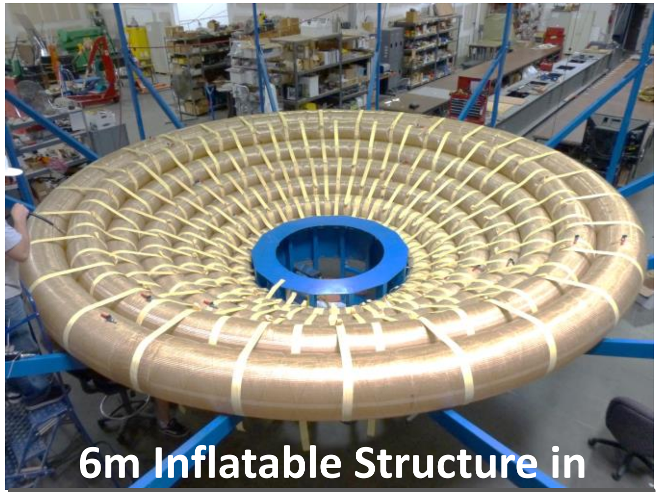
- The IS gas barrier is fabricated by forming liner material into a cylinder closed out by an axial seam located at the innermost side of the torus (least stress)
- All current HIAD inflatable systems have one liner seam design
- 54in (1.37m) max width of available liner material limits a one seam gas barrier design to 17in (0.43m) minor diameter tori; anything larger requires alternate design
- A two seam system can be used with 18in to 34in (0.45m to 0.86m) tori; three seam 35in to 53in (0.89m to1.3m)
- Concern about seam location to be addressed
- Now have made multiple tori with 2 seams



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



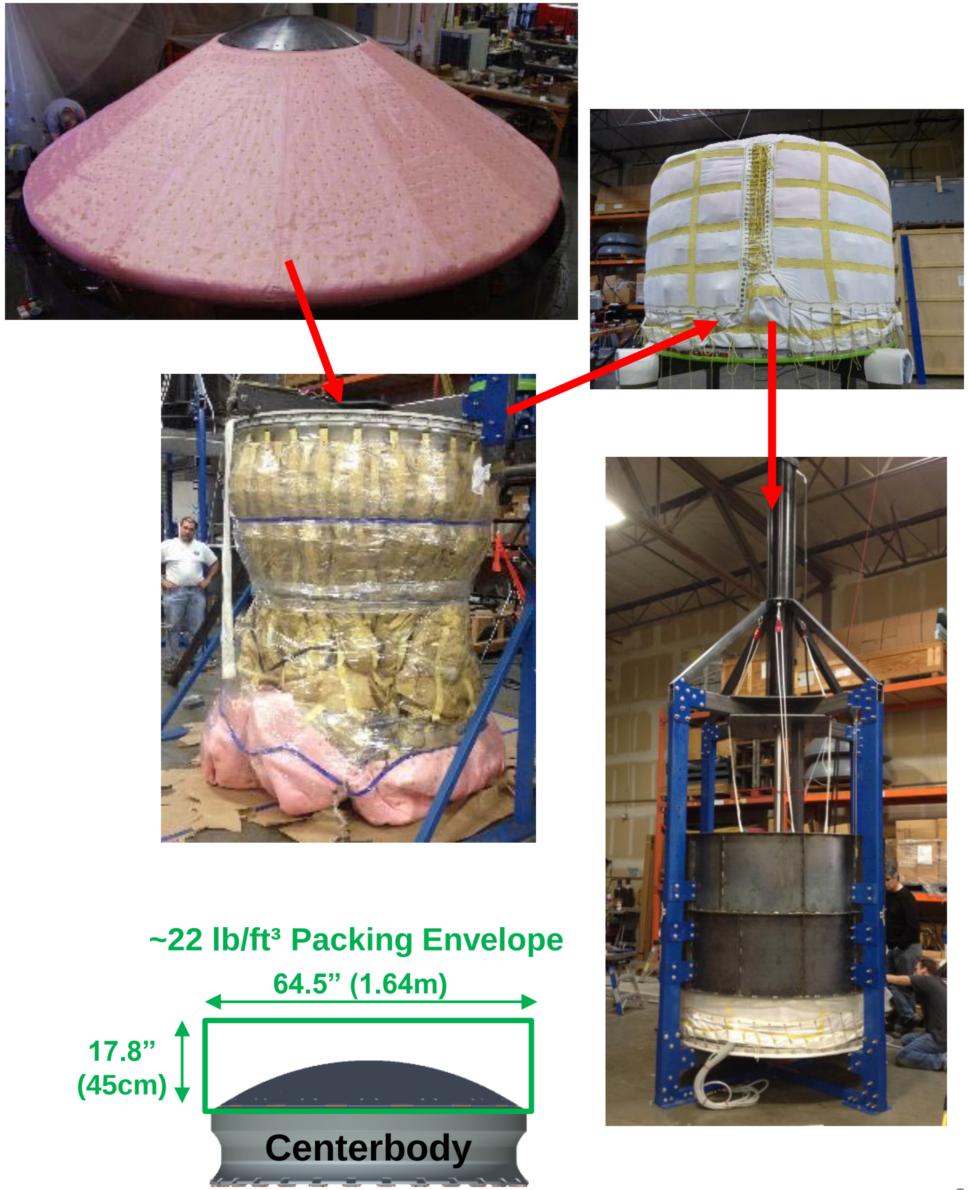


6m Inflatable Structure in Stacking Fixture

Packing/Deployment 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 fixtures/lifts/slings for 15m-class system

6m Aeroshell



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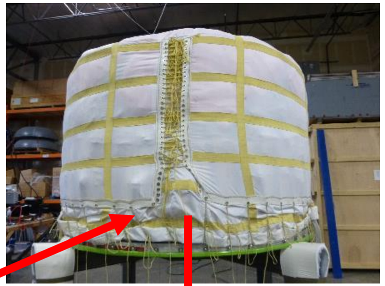
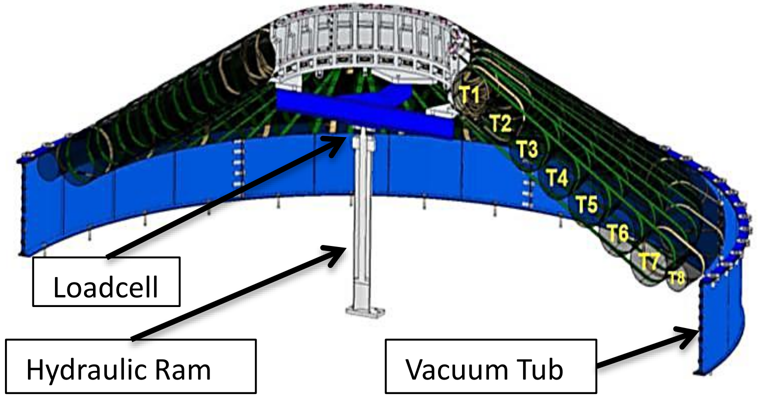
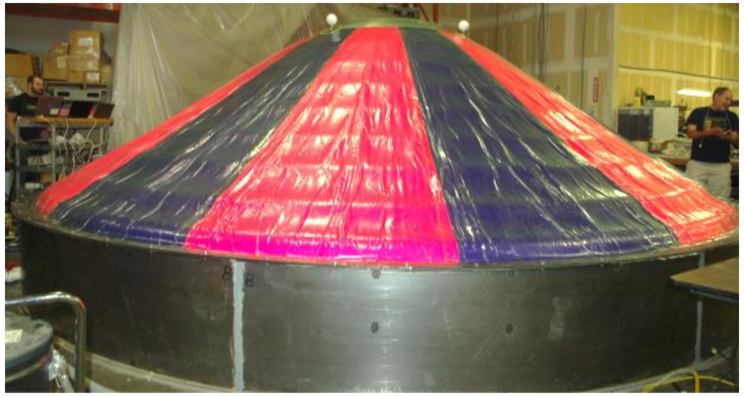
- Distributed load testing (static load testing) capability will need to be increased from the current 50,000lbs (22,700kg) load to ~300,000lbs (136,000kg) of load
  - Requires investment in new high capacity ram
  - Possibly reinforcing the facility, stronger tub walls

6m Aeroshell

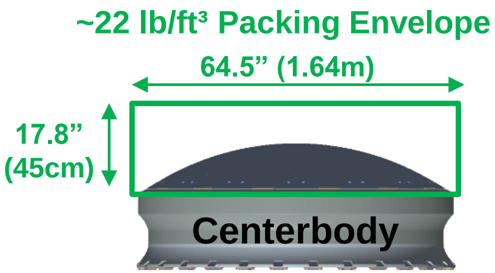




Static Load Test Setup



6m Aeroshell Static Load Test



Inflatable Component Testing

- Hydrostatic testing needs a promotion from the kiddie pool
  - Will utilize the 6m and 3.7m static load test tubs and ~3,000 gallons (11,350 liters) of water to test the 12m T1 torus

3.7m T5

12m T1

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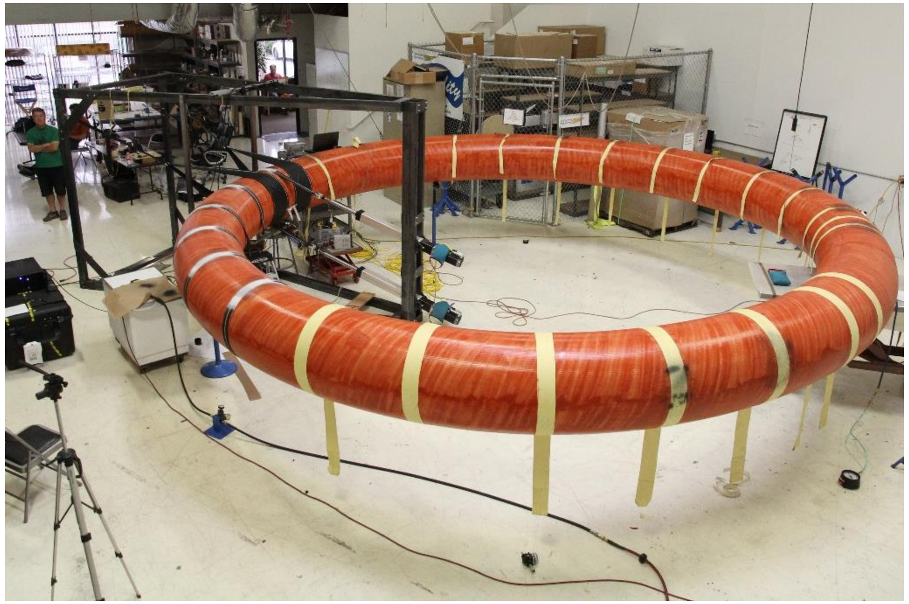
- Strap Indentation Testing Approach Needs to Be Redesigned for Safety
  - Old approach was to manually apply weight to the strap.
  - Now that strap loads can go much higher, an automated system is required

3.7m T5

12m T1



Some Aspects Actually Get Easier!

- There are a couple noteworthy benefits of growing the HIAD to a 15m-class system:
  - Material Response / Design Margin
  - Handmade Textile Accuracy*

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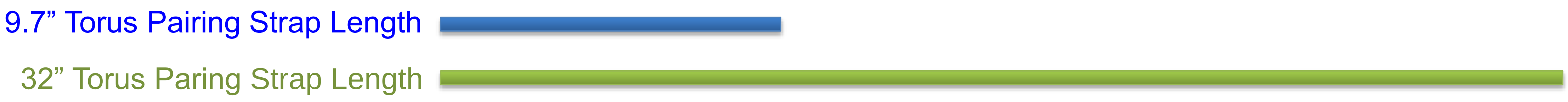
- HIAD fabrication team comprised of expert tradespeople, but these are still handmade structures
- ~1/8” (3.18mm) accuracy for sizing and sewing materials
- 3m aeroshell exhibited ~0.25% deviation in pairing strap length (9.7” minor dia. torus), which can cause large differences in load distribution (seen in initial HIAD work)
- 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” minor diameter tori, would have ~0.075% variation



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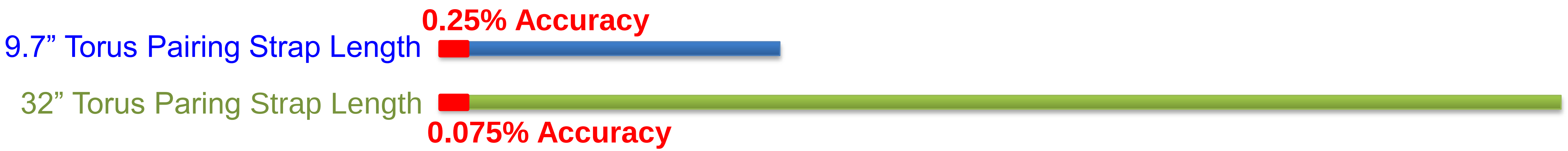

Conclusions / Future Work

- 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 (HULA) flight test

The Full Publication Is Available Online: 'Manufacturing Challenges and Benefits when Scaling the HIAD Stacked-Torus Aeroshell to a 15m-Class System' IEEE Aerospace Conference, March 2016.