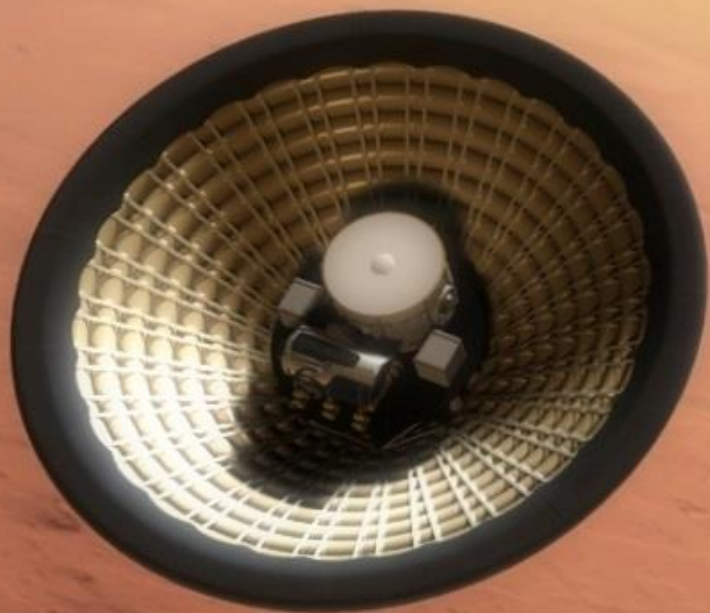




National Aeronautics and
Space Administration



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



Presented By: **Greg Swanson**
g.swanson@nasa.gov
AMA Inc. @ NASA ARC

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

Airborne Systems – Brian Gilles, Paul Anderson

Jackson-Bond Enterprises – Bruce Bond

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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

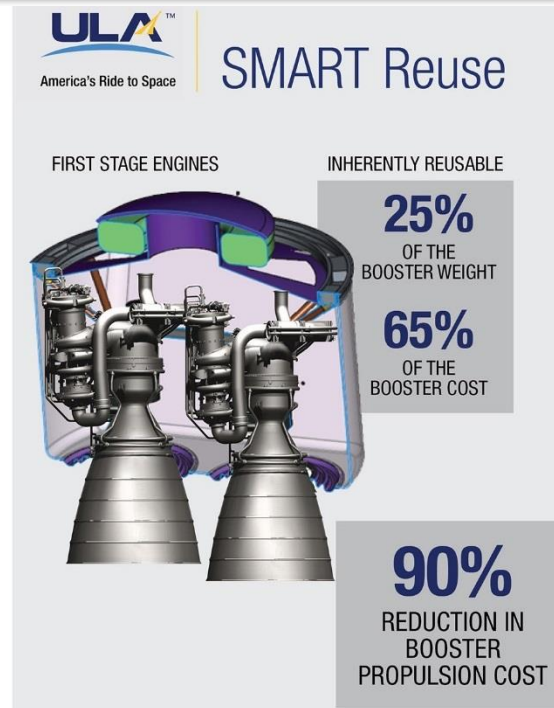


Motivation for Scaling to a 15m Class

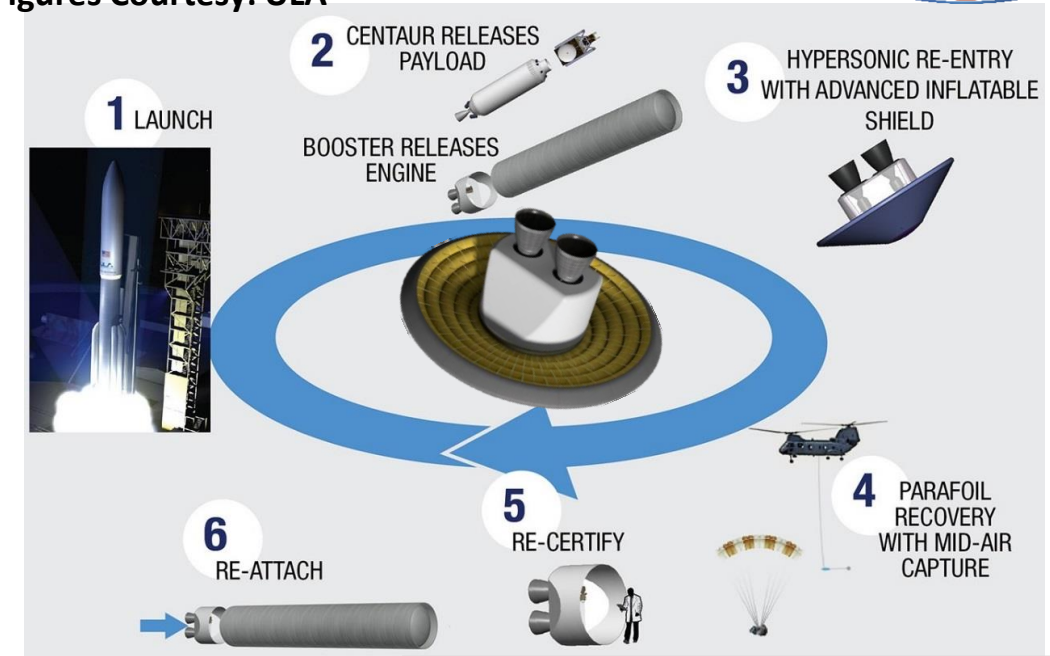
⇒ Flight Test

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.*



Critical Jump in Manufacturing / Associated Challenges



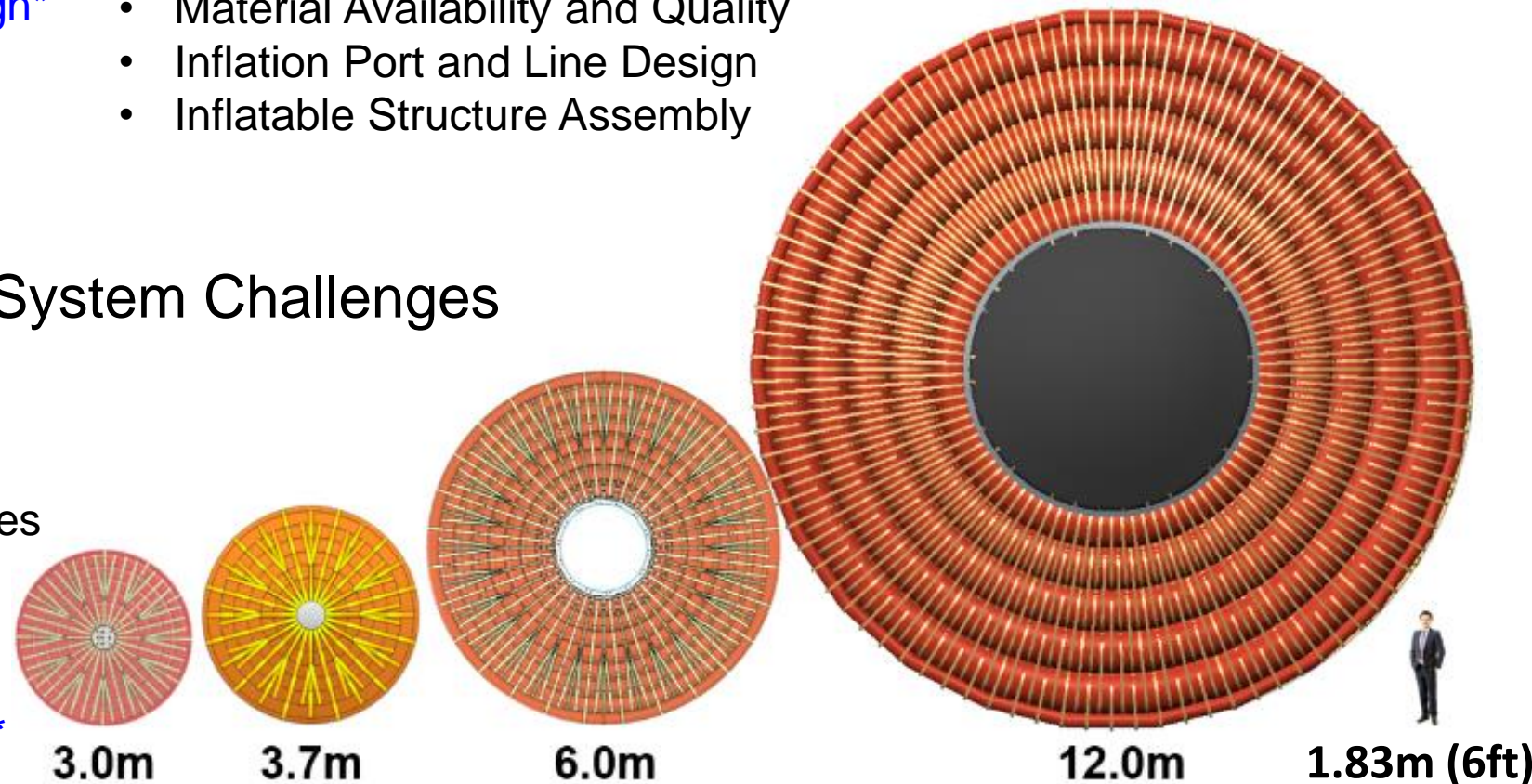
- The largest HIAD inflatable structure and flexible TPS that NASA has built to date are 6m in diameter. The HIAD team has also built 3m and 3.7m aeroshells
- 12m HIAD has 4x the cross sectional area of a 6m (a 15m has over 6x) – See Below

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

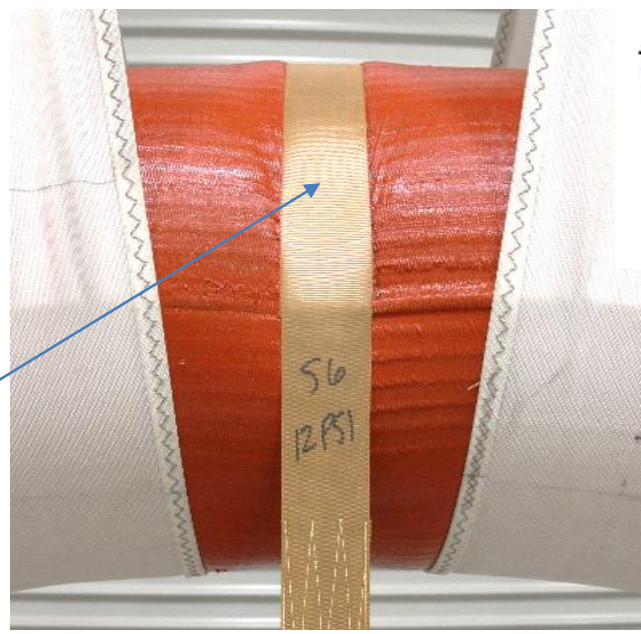
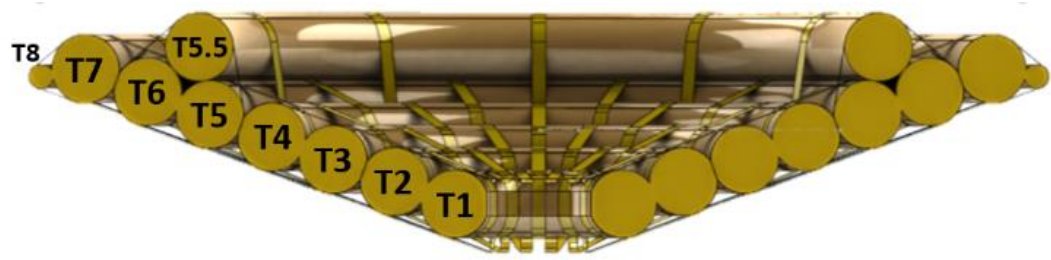
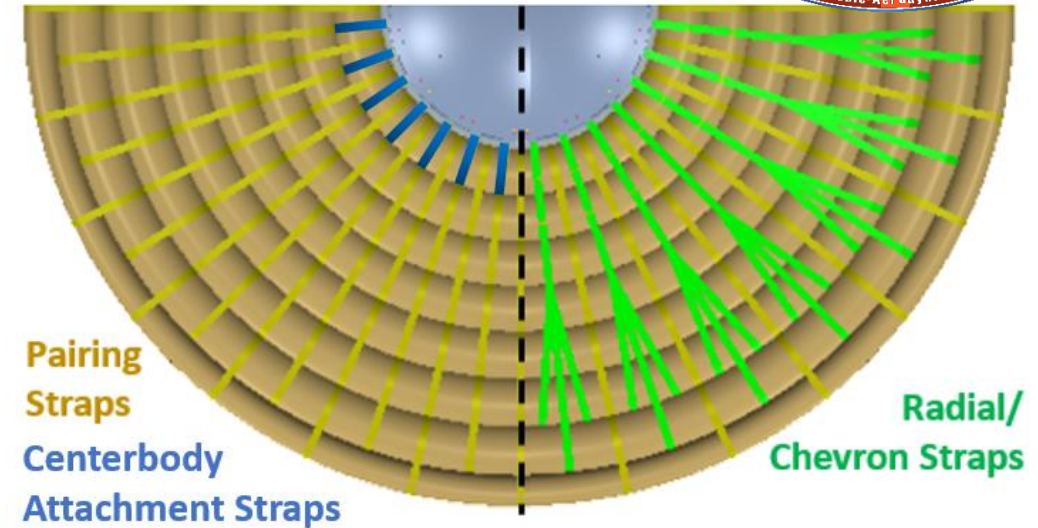
Flexible Thermal Protection System Challenges

- 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*



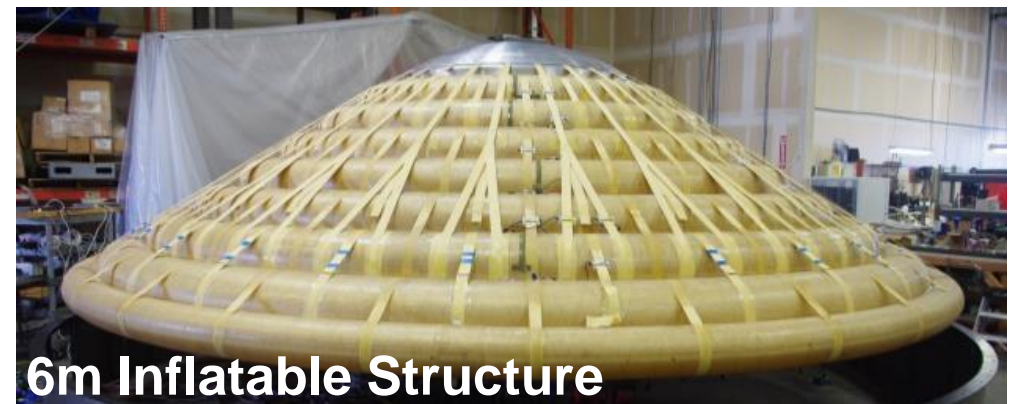
Inflatable Structure Structural Strap Layout and Design

- 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



550lbs (250kg) of Load

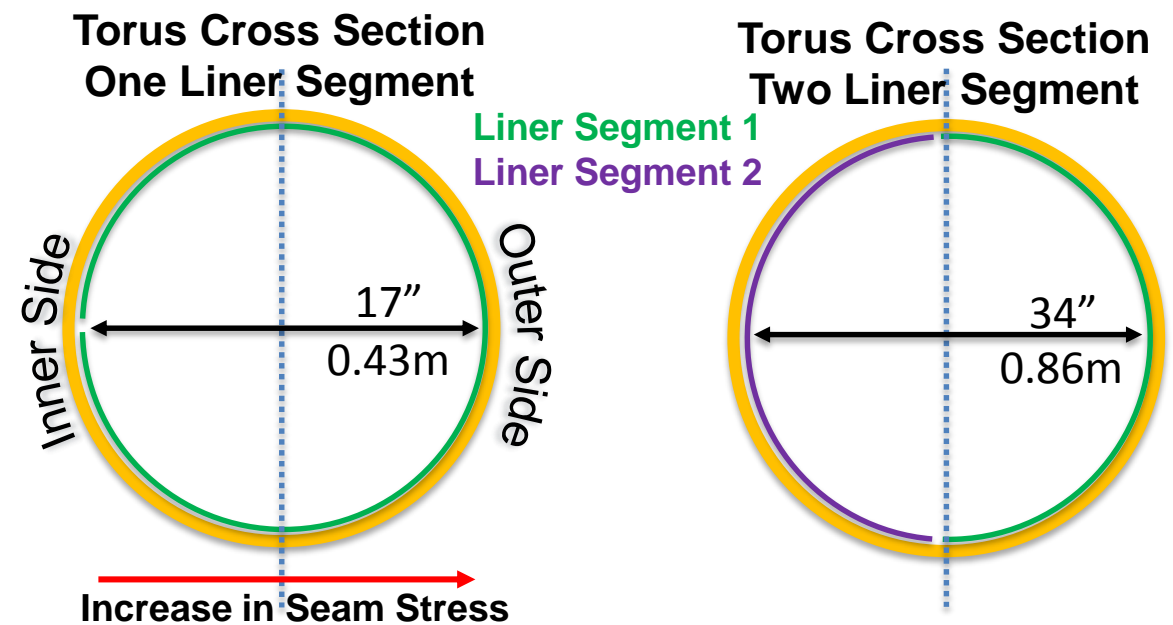
Strap Indentation – provides indication at what load the strap/torus system can no longer carry additional load



6m Inflatable Structure

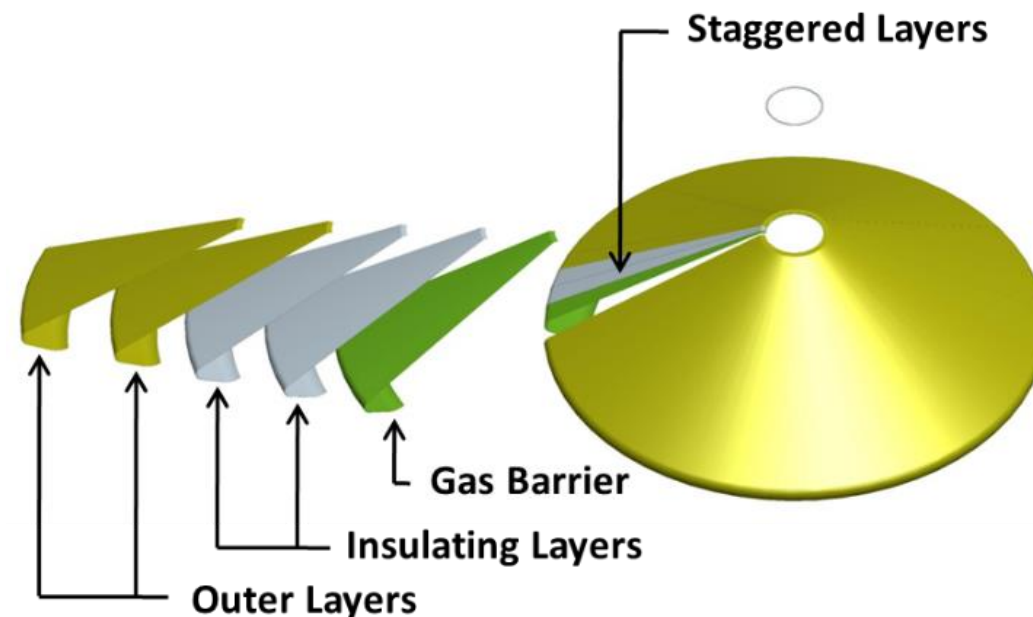
Inflatable Structure Gas Barrier Design

- 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 to 1.3m)
- Concern about seam location to be addressed
- Now have made multiple tori with 2 seams



F-TPS Gore and IS Strap Seaming/Stitching

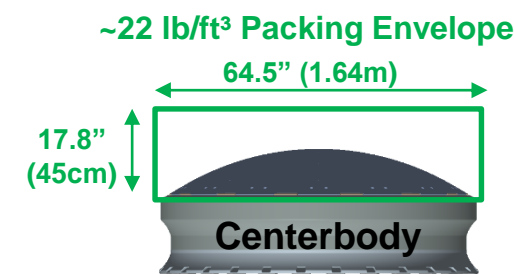
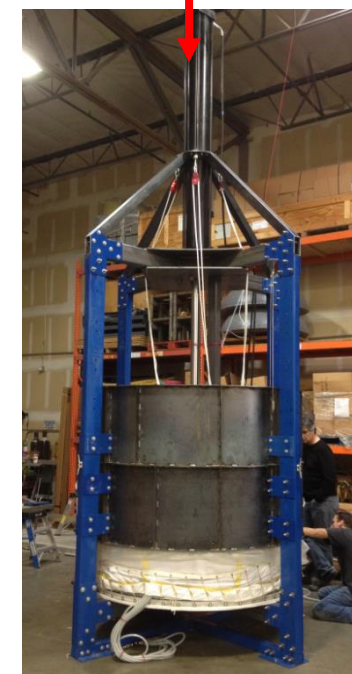
- Current components/systems have been small enough that they could be manually placed and moved, although this was challenging at the 6m scale
- 15m-class systems will require a shift in process since this approach will no longer be viable
 - Research other large scale high performance textile manufacturing
 - 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



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

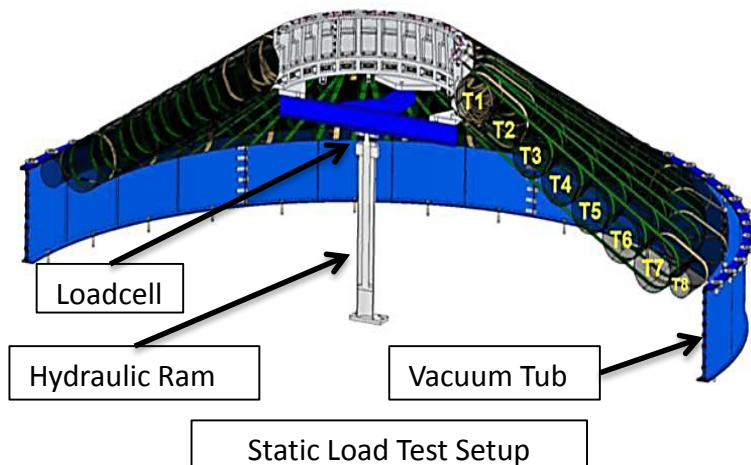
6m Aeroshell



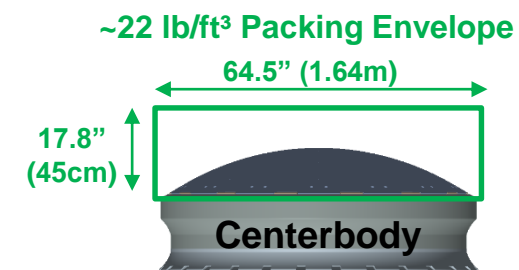
Packing and Structural Testing

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 - This was a challenge at the 6m level, will need special fixtures/lifts/slings for 15m-class system
- 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



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



Inflatable Component Testing

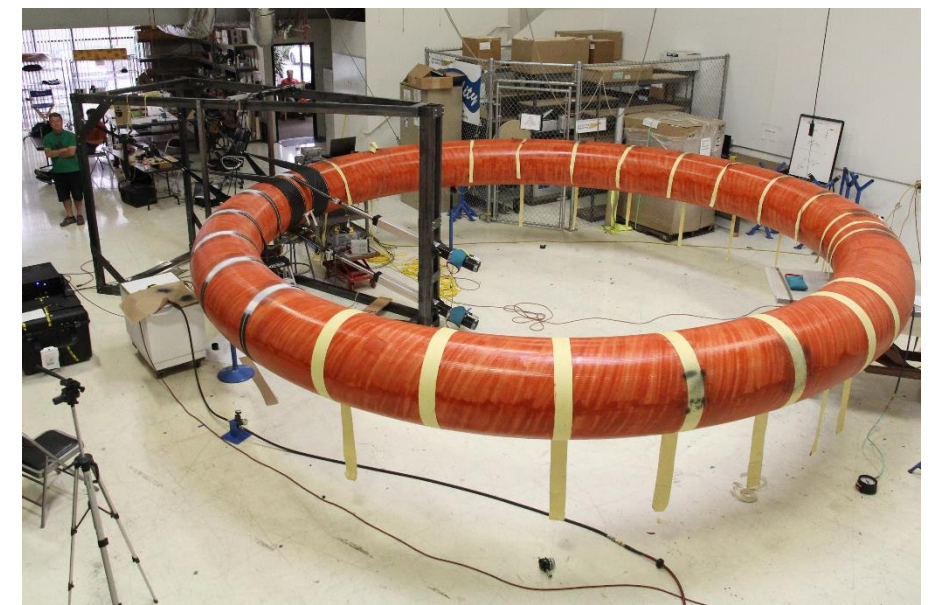


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- Strap Indentation Testing Approach Needs to Be Redesigned for Safety
 - Old approach was to manually apply weight to the strap.
 - Now that strap loads can go much higher, an automated system is required

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

9.7" Torus Pairing Strap Length 

32" Torus Paring Strap Length 



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9.7" Torus Pairing Strap Length **0.25% Accuracy**

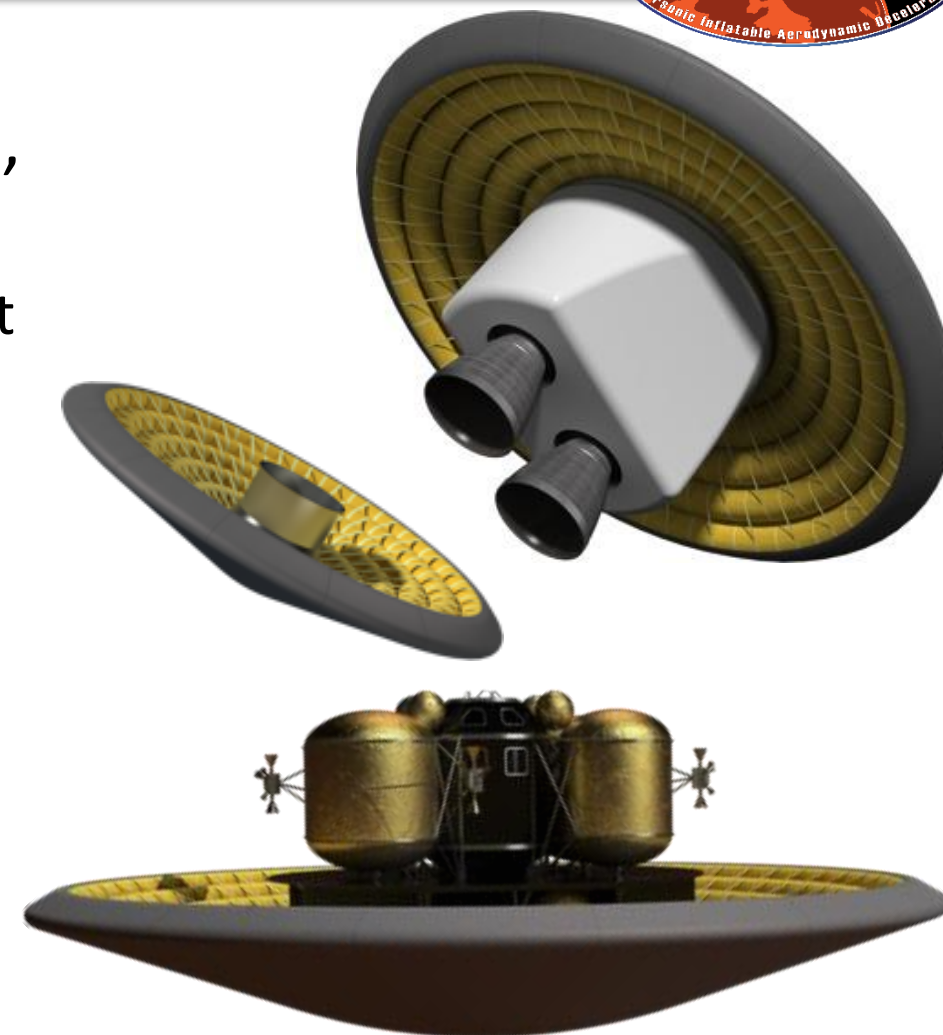


32" Torus Pairing Strap Length **0.075% Accuracy**



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.*