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

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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*

**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.**
• 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*

• 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*
  • Material Availability and Quality
  • Inflation Port and Line Design
  • Inflatable Structure Assembly
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
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.
• 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.
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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
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
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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
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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  - Handmade Textile Accuracy*

- 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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*Handmade Textile Accuracy: ~1/8” (3.18mm) precision in sizing and sewing materials.
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.