Design and Execution of the Hypersonic Inflatable Aerodynamic Decelerator Large-Article Wind Tunnel Experiment

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Outline

• HIAD Overview
• Test Design
• Assembly & Integration
• Testing Operations
• Instrumentation & Data Products
• Summary

Photo credit: Dominic Hart
HIAD Overview

Inflatable Aeroshell Structures Development

Large-Scale Manufacturability & Material Development

Development of large-scale manufacturing capabilities and advanced, high-temperature capable inflatable structure materials.

Large-Scale Static Load Testing & Model Development

Ground test to demonstrate HIAD scalability and initial structural model development.

Large-Scale Wind Tunnel Testing & Instrumentation Development

Ground tests to characterize HIAD performance under flight-like aerodynamic loading.

3 – 15-meter HIAD Class

- Mars robotic (SMD & ESMD)
- Venus missions (SMD)
- LEO/ISS missions (SMD & SOMD)
- NEO return-robotic (SMD & ESMD)
- Lunar return-robotic (SMD & ESMD)
- Terrestrial robotic missions (DoD)
- Technology development & risk reduction for Human Mars missions (ESMD)
HIAD Overview

The HIAD Mission Concept - HEART

Launch Configuration
- Stowed HEART HIAD Module (LaRC)
- Enhanced Antares Fairing (Orbital Sciences)
- Interstage to PCM Separation Plane (Orbital Sciences)
- Antares to Cygnus Separation Plane (Orbital Sciences)

Cruise Configuration (to and from ISS)
- Pressurized Cargo Module (PCM, Orbital Sciences)
- Interstage Structure (Orbital Sciences)
- Cygnus Service Module (Orbital Sciences)

Reentry Configuration
- Flexible Thermal Protection System (LaRC)
- Inflatable Structure (LaRC)
HIAD Overview

HEART Trajectory

Unmargined aerothermal environments
National Full-Scale Aerodynamics Complex

**40 ft x 80 ft (12 m x 24 m) Test Section Operating Specifications**

- Semi-Elliptical Profile
- Maximum Velocity: 300 knots (154 m/s)
- Max Dynamic Pressure: 262 psf (12.5 kPa)
- *Max Drag Load: 32,000 lbs*
Test Article Descriptions

6 m Baseline

Rigid Centerbody

6 m Tri-Torus

Rigid Centerbody

6 m
## Test Design

### Test Matrix

<table>
<thead>
<tr>
<th>6m Tri-Torus Configuration</th>
<th>6m Baseline Configuration</th>
<th>3m without TPS</th>
<th>3m with TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I2 Inflation State</strong></td>
<td><strong>I2 Inflation State</strong></td>
<td><strong>I1 Inflation State</strong></td>
<td><strong>I1 Inflation State</strong></td>
</tr>
<tr>
<td>Q (psf)</td>
<td>Q (psf)</td>
<td>Q (psf)</td>
<td>Q (psf)</td>
</tr>
<tr>
<td>0/8</td>
<td>0/8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>X</td>
<td>80</td>
<td>X</td>
</tr>
<tr>
<td>50</td>
<td>X</td>
<td>120</td>
<td>X</td>
</tr>
<tr>
<td>64</td>
<td>X</td>
<td>160</td>
<td>X</td>
</tr>
</tbody>
</table>

**I3 Inflation State**

| Q (psf)                    | Q (psf)                    | Q (psf)         | Q (psf)     |
| 0/8                        | 0/8                        | 8               | 8           |
| 35                         | 35                         | 40              | 40          |
| 40                         | X                          | 80              | X           |
| 50                         | X                          | 120             | X           |
| 64                         | X                          | 160             | X           |

**I4 Inflation State**

| Q (psf)                    | Q (psf)                    | Q (psf)         | Q (psf)     |
| 0/8                        | 0/8                        | 8               | 8           |
| 35                         | 35                         | 40              | 40          |
| 40                         | X                          | 80              | X           |
| 50                         | X                          | 120             | X           |
| 64                         | X                          | 160             | X           |

### Testing Approach

- Test from highest to lowest inflation setting
- Stabilize tunnel condition $q$, then do AoA sweeps
- ~60 sec dwell time at each point for data acquisition
- Slew rate for turntable (0.5 deg/sec)
- 379 total test points (with repeats) obtained
Test Article Preparations

6 m HIAD on Handling & Integration Fixture

3 m HIAD Initial Inspection
Key Features:

- Tilt via Facility Cranes to Transfer/Integration Positions
- Manually Rotatable via Bearing
- Radial Rotation Lock

Allows:

- Facile Access- Fore & Aft
- Rapid Instrumentation & Pneumatic Line Integration
- Transfer to/from Test Section
Instrumentation & Pressure Line Set-Up

Instrumentation Feed-thrus

Developmental Instrumentation

Inflation Manifold

Routing Instrumentation & pneumatic lines

Sting/Test Article Interface

Thin film bend sensor

Distribution manifolds

Instrumentation Junction Panel

Deformation Measurement System

To Model
Assembly & Integration

6 m Aerocover Install

Aerocover Transferred from Integration Fixture to 6 m HIAD using overhead crane in NFAC high bay

Aerocover Secured to 6 m Test Article
Custom Support System Hardware

- Model Capture Hooks
- Sting Arm Interface
- Photogrammetry Reference Targets
- Strakes run along struts
- 2 Rear Struts - ~2,000 lbs each
- Front Strut - ~12,000 lbs

Assembly & Integration
Assembly & Integration

Model Installation

Clam shells door open

Test Article Captured onto Hook

HIAD Lowered towards Support Hardware

Crane jogged to position HIAD
Final Assembly in Test Section

Inflation hoses and instrumentation lines routed from beneath turntable, through front strut and sting arm to test article.
Test Operations

Test Articles Installed in Wind Tunnel

6 m, 0 deg Yaw

3 m with Aerocover

6 m, -25 deg Yaw

3 m with TPS
Test Operations

HIAD Video Compilation
Instrumentation & Data Overview

Photogrammetry System

Top View

Side View

Summary Table

<table>
<thead>
<tr>
<th>Pair</th>
<th>Location</th>
<th>Distance</th>
<th>Model Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>East High</td>
<td>45.47</td>
<td>6m at -15 deg or higher</td>
</tr>
<tr>
<td>2</td>
<td>East Low</td>
<td>45.47</td>
<td>6m at -15 deg or higher</td>
</tr>
<tr>
<td>3</td>
<td>Ceiling Dome</td>
<td>46</td>
<td>Upper portion of HIAD for most solutions</td>
</tr>
<tr>
<td>4</td>
<td>Mic Stands</td>
<td>53</td>
<td>Solutions used in all data</td>
</tr>
</tbody>
</table>
Instrumentation & Data Overview

Photogrammetry System

Further details on Photogrammetry System can be found in Kushner et al, AIAA, 22nd Aerodynamic Decelerator Systems and Technology Conference

Pair #1- East Wall High
Pair #2- East Wall Low
Camera pair 1&2 controller box access panel
Lights
Pair #3- Upstream Ceiling Port
6 m HIAD Model
Pair #4- Floor Cameras
Instrumentation & Data Overview

Photogrammetry Data

Overlay of Baseline (Dark Grey) on Tri-Torus
-15 deg AoA, 50 psf, I3 Inflation Setting

Further details on Photogrammetry Data can be found in Kazemba et al, AIAA, 22nd Aerodynamic Decelerator Systems and Technology Conference

3 m Aerocover

3 m w/ TPS

Deflected surface data ready for CFD grid generation
Instrumentation & Data Overview

Test Article Surface Pressures

105 Embedded Pressure Taps

Flexible Tubing

Tap Orifice

Low Profile Design
Surface Pressure Data

Tri-Torus: i2, 50psf, 0°

Baseline i2, 50psf, 0°

Tri-Torus - Baseline
Load Pins & Load Cells

Instrumentation & Data Overview

Further details on Strap Load Measurements can be found in Swanson et al, AIAA, 22nd Aerodynamic Decelerator Systems and Technology Conference.

Load Pins- Yellow Bars

Strap Load Cells- Stars
Results Overview

Summary:

- Very successful test series- all primary test objectives were met
- Two 6 m configurations and two 3 m configurations tested.
- Comprehensive set of data products- ~ 400 data channels monitored
- Ability to investigate Aero/Structural performance over a wide range of conditions
- Full 3-d imaging of forward surface for CFD & FEA model development
- Characterization methodology for structural strap materials
- Embedded instrumentation development for pressure and localized state measurements

<table>
<thead>
<tr>
<th>Model Configuration</th>
<th># Test Points</th>
<th>Primary Data Products</th>
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<tr>
<td></td>
<td></td>
<td>Photogrammetry</td>
</tr>
<tr>
<td>6 m Tri-Torus</td>
<td>151</td>
<td>Full Model Coverage</td>
</tr>
<tr>
<td>6 m Baseline</td>
<td>106</td>
<td>Full Model Coverage</td>
</tr>
<tr>
<td>3 m</td>
<td>94</td>
<td>Full Model Coverage</td>
</tr>
<tr>
<td>3 m w/ TPS</td>
<td>28</td>
<td>Full Model Coverage</td>
</tr>
</tbody>
</table>
Acknowledgements- Core Test Team

Pictured (left to right)
- Laura Kushner
- Greg Swanson
- Justin Littell
- Alan Cassell
- Keith Johnson
- Anthony Calomino
- Neil Cheatwood
- Bill Quach
- Steve Hughes
- Brian Gilles
- Sean Hancock
- Paul Anderson
- Leo Lichodziejewski

Not Pictured
- Jeff D. Brown
- Cole Kazemba
- Lin Li
- Kevin Tran
- Vinh Tran
- Tim Schmidt
Acknowledgements - Test Team Photo
Questions?