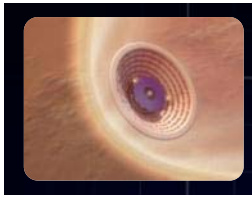


# Design and Execution of the Hypersonic Inflatable Aerodynamic Decelerator Large-Article Wind Tunnel Experiment

**Alan M. Cassell**

**NASA Ames Research Center, Entry Systems and Vehicle Development Branch**

10th International Planetary Probe Workshop, 17-21 June 2012, San Jose, CA, USA

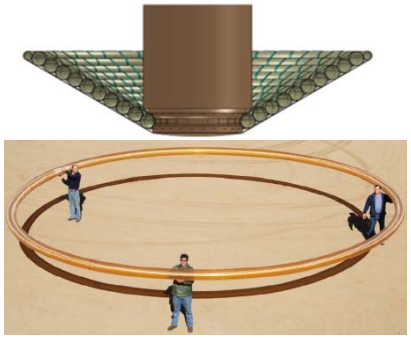
# Outline

- HIAD Overview
- Test Design
- Assembly & Integration
- Testing Operations
- Instrumentation & Data Produ
- Summary


# HIAD Overview

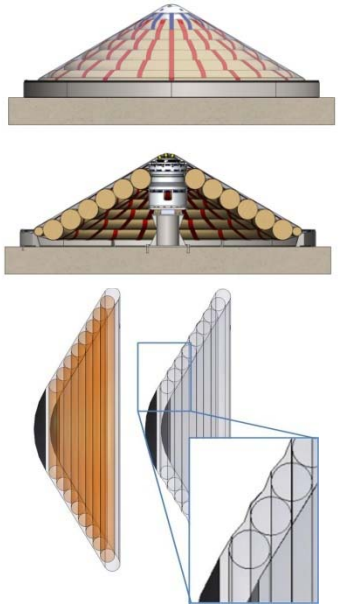
## Inflatable Aeroshell Structures Development

***Large-Scale Manufacturability & Material Development***



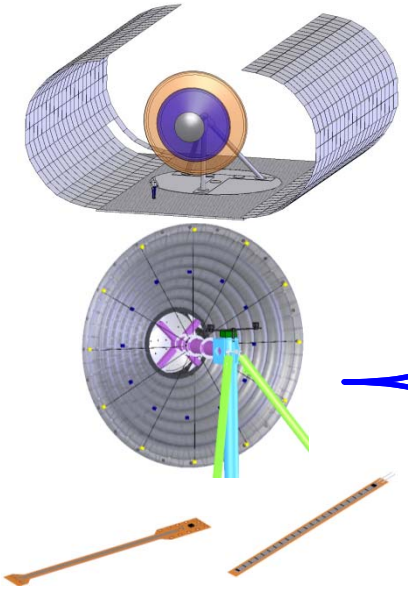
**Development of large-scale manufacturing capabilities and advanced, high-temperature capable inflatable structure materials.**

***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)*

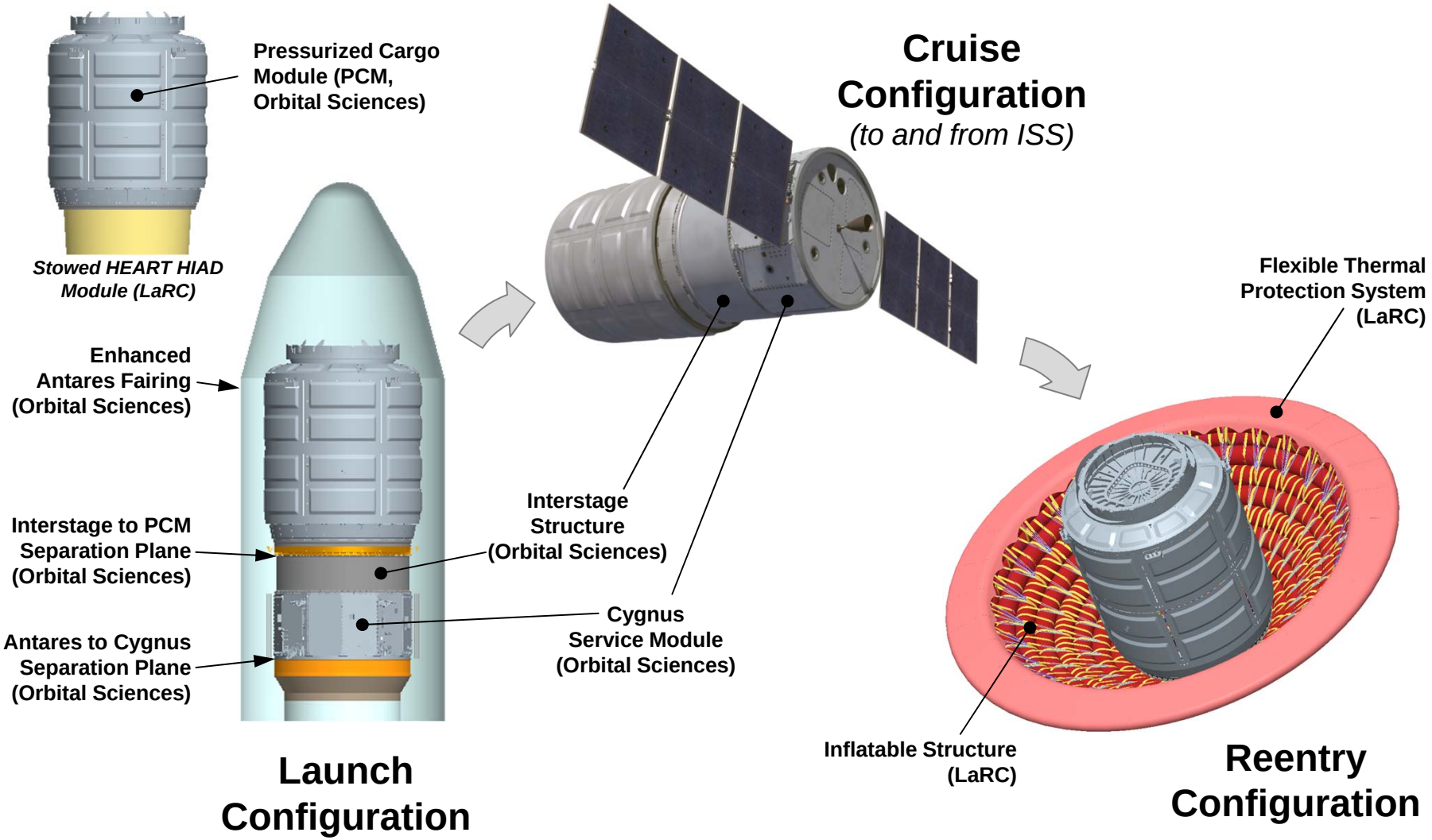
*Lunar return-robotic (SMD & ESMD)*

*Terrestrial robotic missions (DoD)*

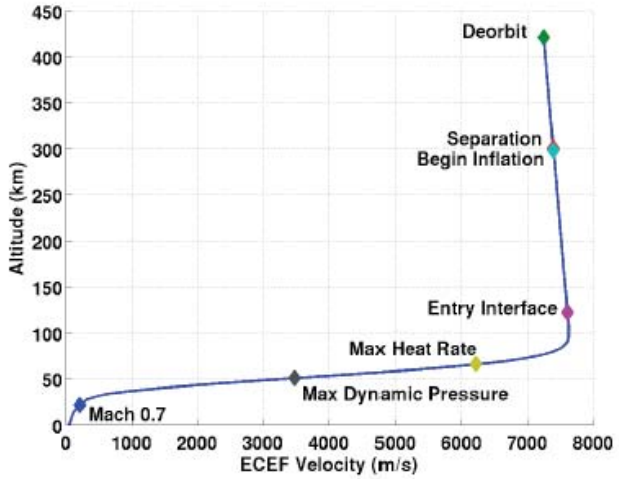
*Technology development & risk reduction for Human Mars missions (ESMD)*

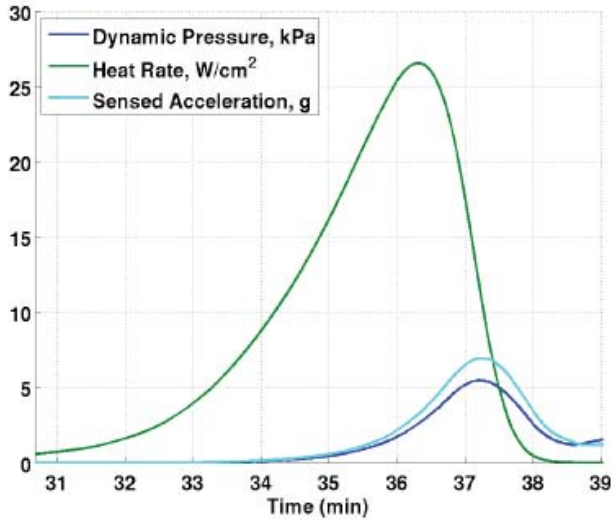
# HIAD Overview

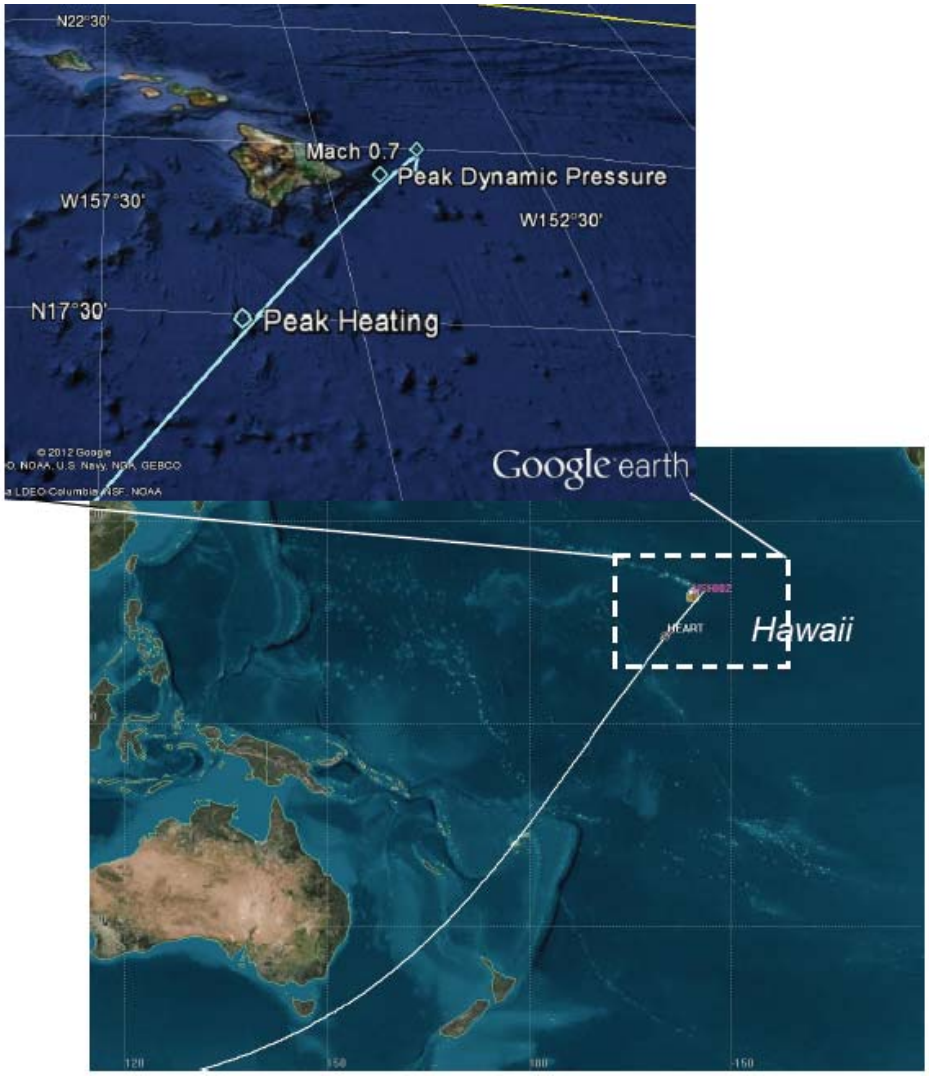
## The HIAD Mission Concept- HEART



## HEART Trajectory



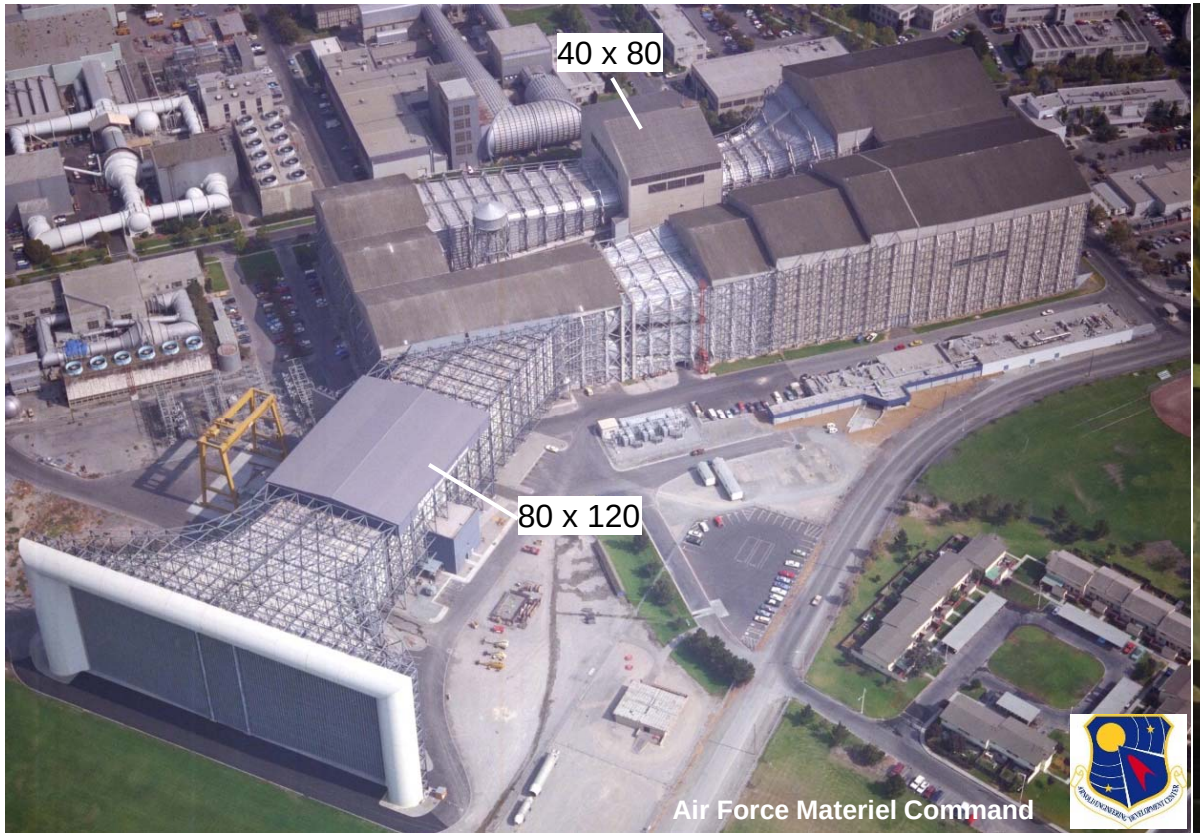



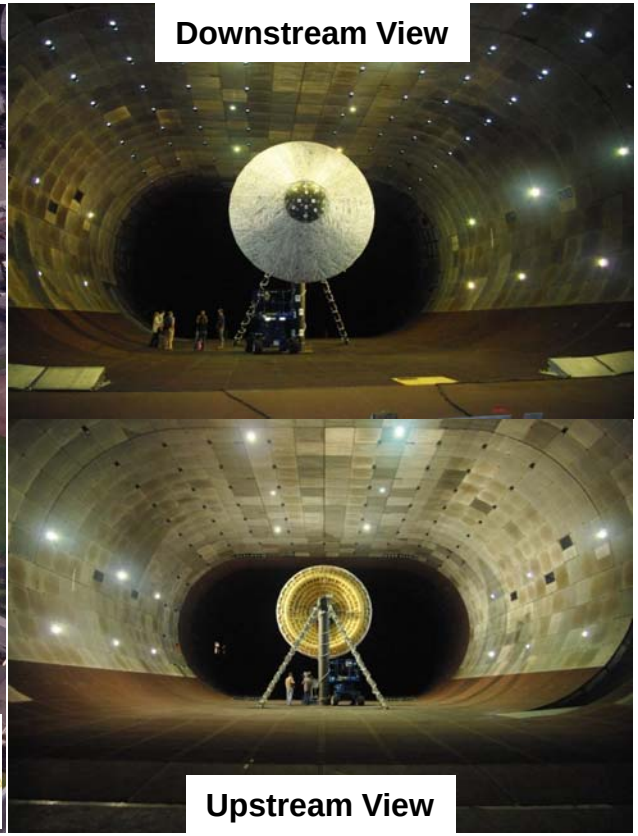




**Unmargined aerothermal environments**

# Test Design

## National Full-Scale Aerodynamics Complex



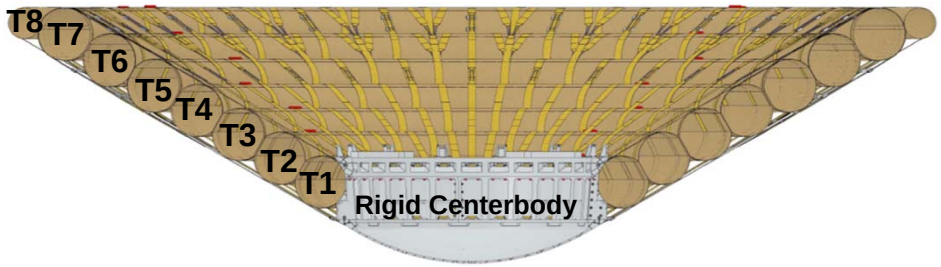

**<u>40 ft x 80 ft (12 m x 24 m) Test Section Operating Specifications</u>**

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

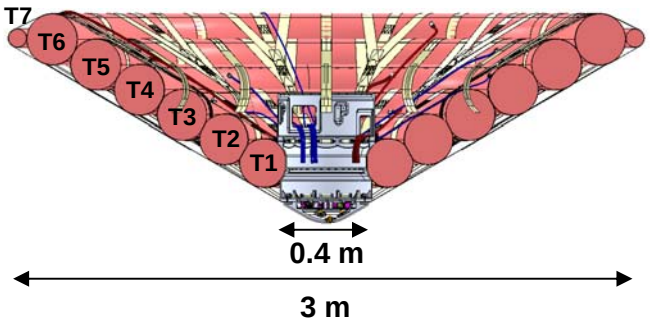
# Test Design

## Test Article Descriptions

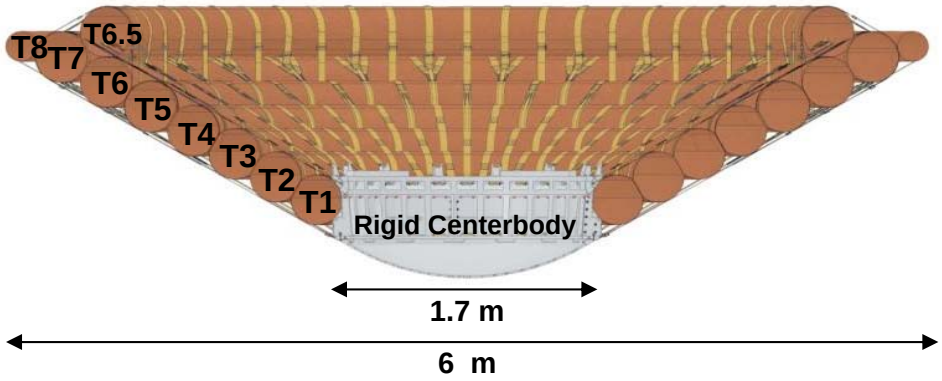
6 m Baseline

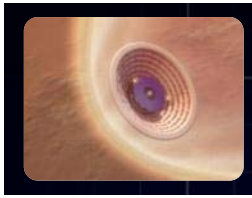



3 m




6 m Tri-Torus





# Test Design

## Test Matrix

**6m Tri-Torus Configuration**

**I2 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 |
| 0/8 | | | | | | X | | |
| 35 | | | | | | X | | |
| 40 | X | | X | | X | X | X | X |
| 50 | X | | X | X | X | X | X | X |
| 64 | | | X | | X | X | | |

**I3 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 |
| 0/8 | | | | | | X | | |
| 30 | | | | | | X | | |
| 40 | X | X | X | X | X | X | X | X |
| 50 | X | X | X | X | X | X | X | X |
| 64 | | X | X | X | X | X | X | X |

**I4 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 |
| 0/8 | | | | | | X | | |
| 30 | | | | | | X | | |
| 40 | | | X | X | X | X | X | X |
| 50 | | | X | X | X | X | X | X |
| 64 | | | | | | X | | |

**6m Baseline Configuration**

**I2 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 |
| 0/8 | | | | | | X | | |
| 35 | | | | | | X | | |
| 40 | X | | X | | X | X | | |
| 50 | X | | X | | X | X | X | X |
| 70 | X | | X | | X | X | | |

**I3 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 |
| 0/8 | | | | | | X | | |
| 35 | | | | | | X | | |
| 40 | X | | X | | X | X | | |
| 50 | X | | X | | X | X | X | X |
| 70 | X | | X | | X | X | | |

**I4 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 |
| 0/8 | | | | | | X | | |
| 35 | | | | | | X | | |
| 40 | X | | X | | X | X | | |
| 50 | X | | X | | X | X | X | X |
| 70 | X | | X | | X | X | | |

**3m without TPS**

**I1 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | |
|---|---|---|---|---|---|
| | -10 | -5 | 0 | 5 | 10 |
| 8 | X | X | X | X | X |
| 40 | X | X | X | | |
| 80 | X | X | X | X | X |
| 120 | X | X | X | X | |
| 160 | | | | | |

**I2 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | |
|---|---|---|---|---|---|
| | -10 | -5 | 0 | 5 | 10 |
| 8 | X | X | X | X | X |
| 40 | X | X | X | | |
| 80 | X | X | X | X | X |
| 120 | | X | X | X | X |

**I4 Inflation State**

| Q (psf) | Angle of Attack (deg) | | | | |
|---|---|---|---|---|---|
| | -10 | -5 | 0 | 5 | 10 |
| 8 | X | X | X | X | X |
| 40 | X | X | X | | |
| 80 | X | X | X | | |
| 120 | X | X | X | | |

**3m with TPS**

**I1 Inflation State**

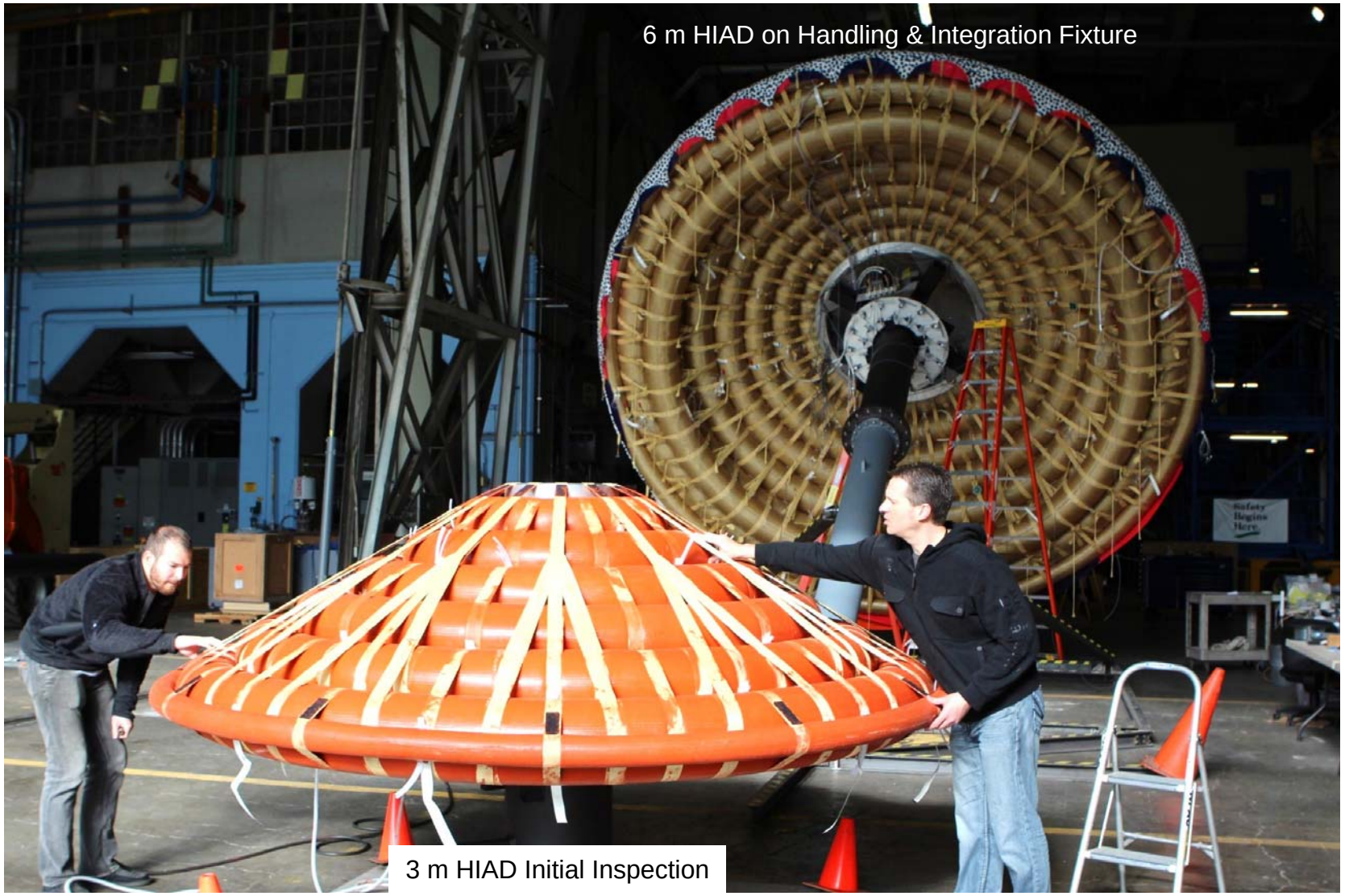
| Q (psf) | Angle of Attack (deg) | | | | |
|---|---|---|---|---|---|
| | -10 | -5 | 0 | 5 | 10 |
| 8 | X | X | X | X | X |
| 40 | X | X | X | | |
| 80 | X | X | X | X | X |
| 120 | X | X | X | X | X |
| 160 | | X | X | | |

**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

# Assembly & Integration

## Test Article Preparations



# Assembly & Integration

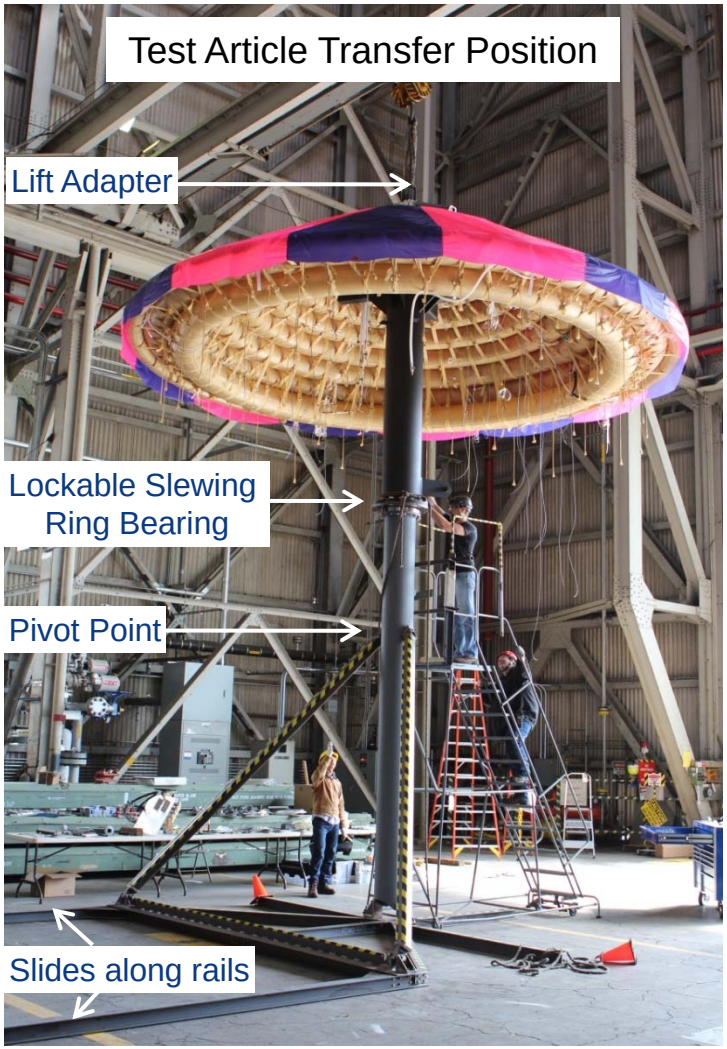
## Custom Handling & Integration Fixture

**Key Features:**

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

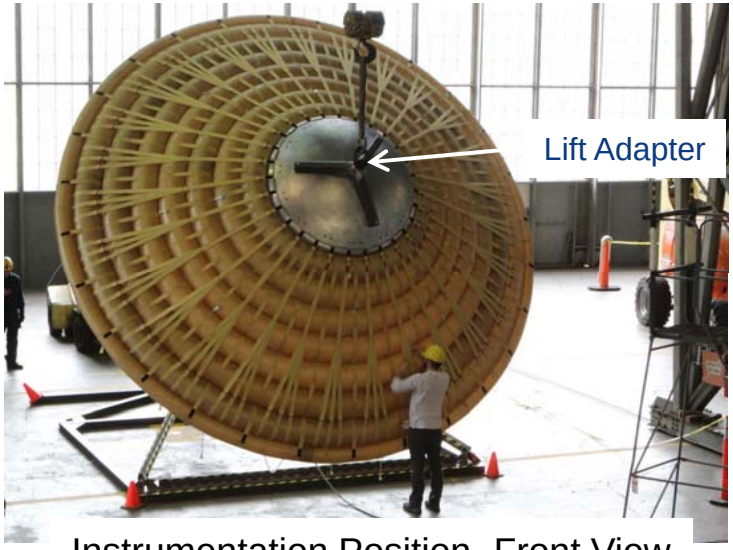
**Allows:**

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





Instrumentation Position- Rear View



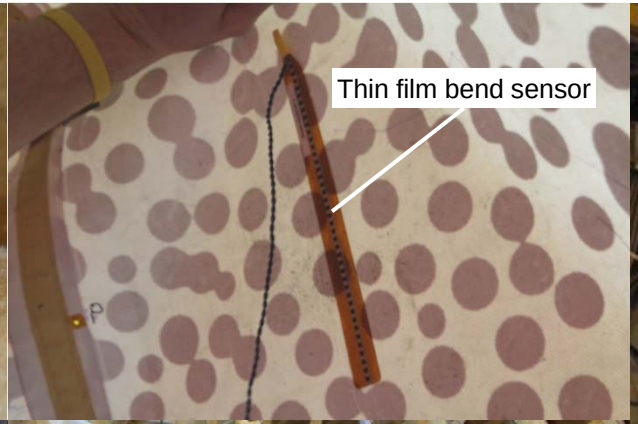

Instrumentation Position- Front View

# Assembly & Integration

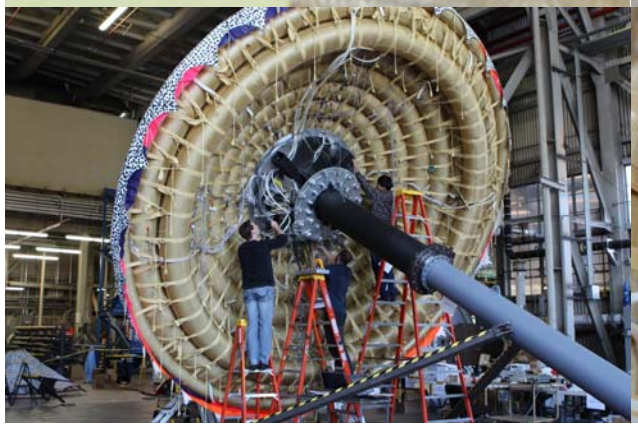
## Instrumentation & Pressure Line Set-Up

Instrumentation Feed-thrus

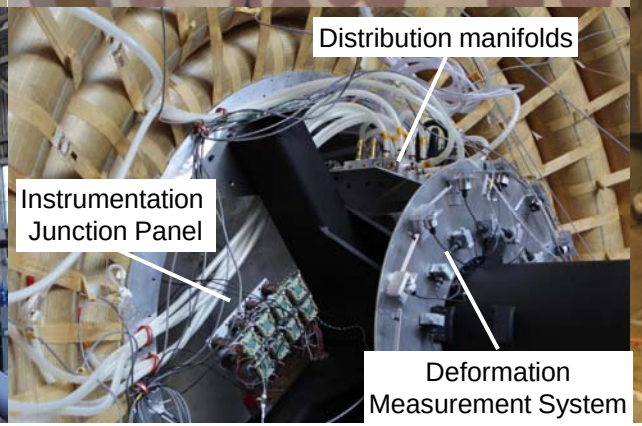
Developmental Instrumentation




Inflation Manifold

Routing Instrumentation & pneumatic lines




Sting/Test Article Interface

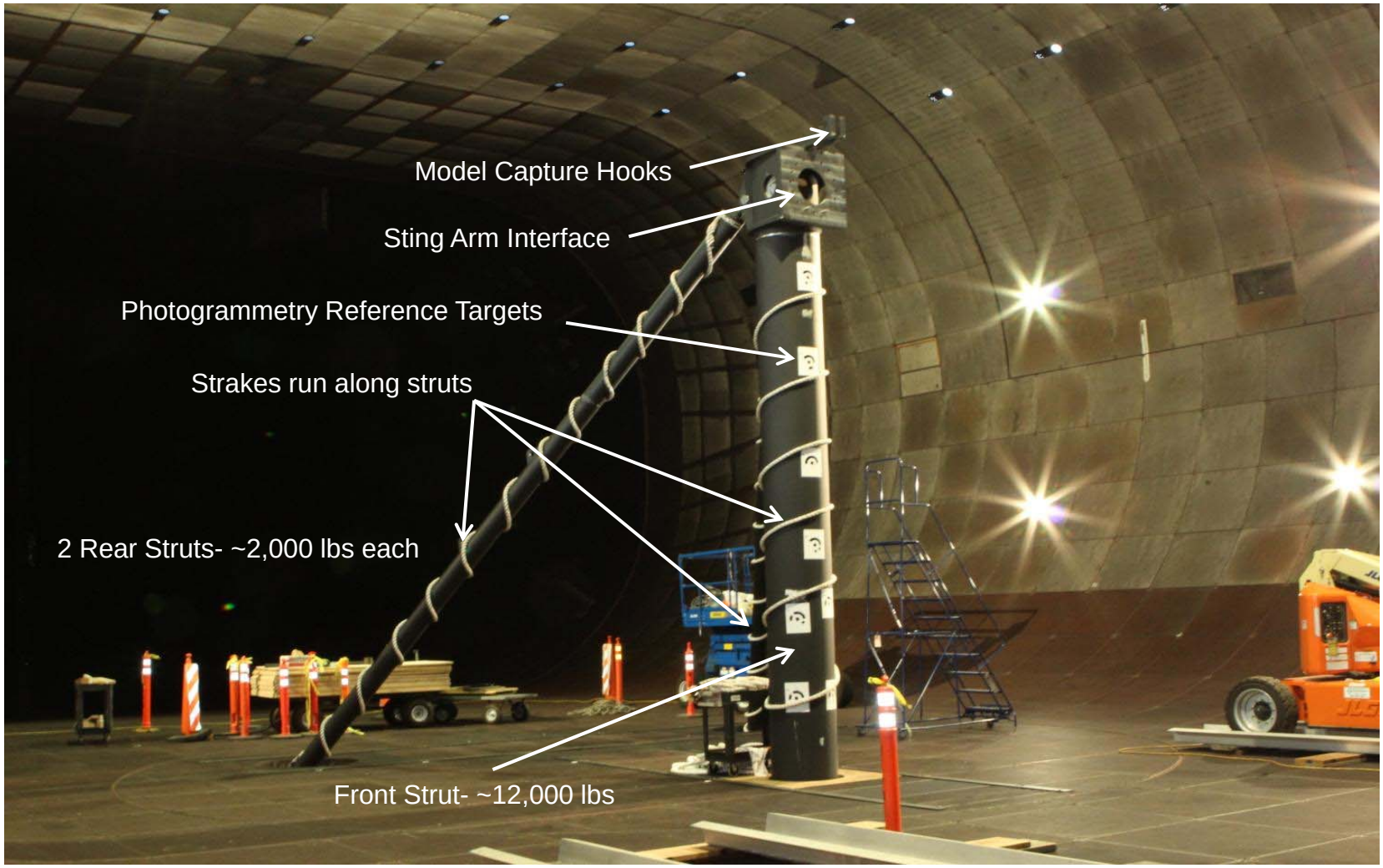
# Assembly & Integration

## 6 m Aerocover Install

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

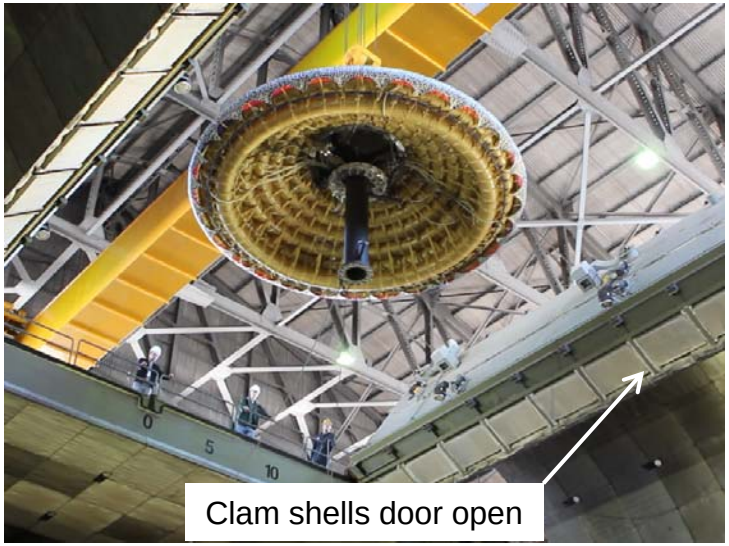
**Aerocover Secured to 6 m Test Article**

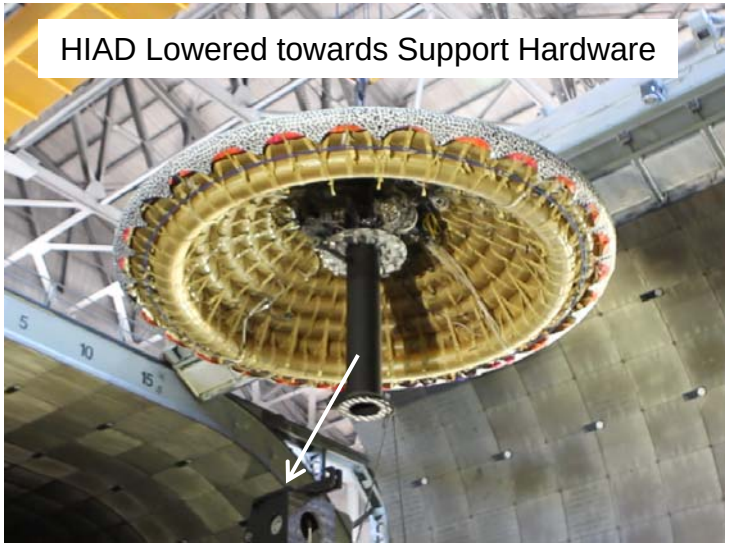
## Custom Support System Hardware

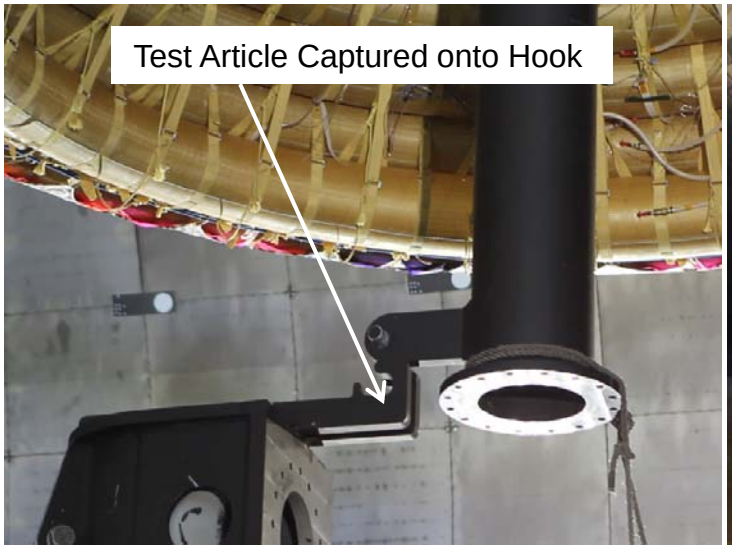


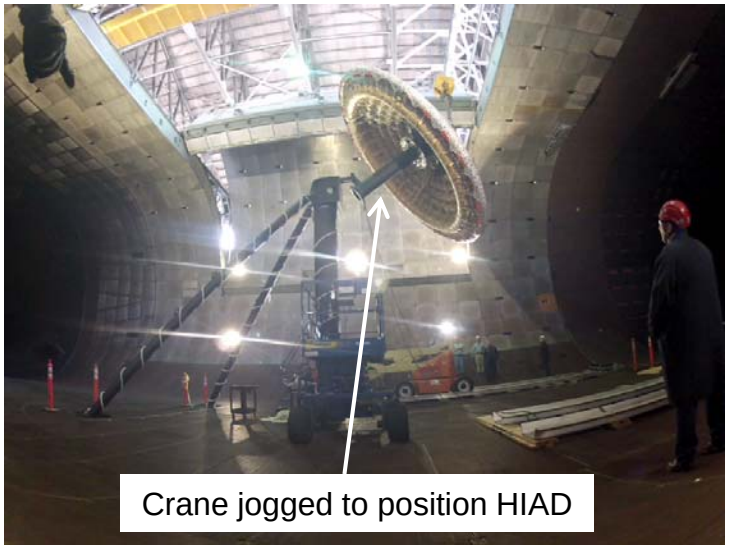
# Assembly & Integration

## Model Installation



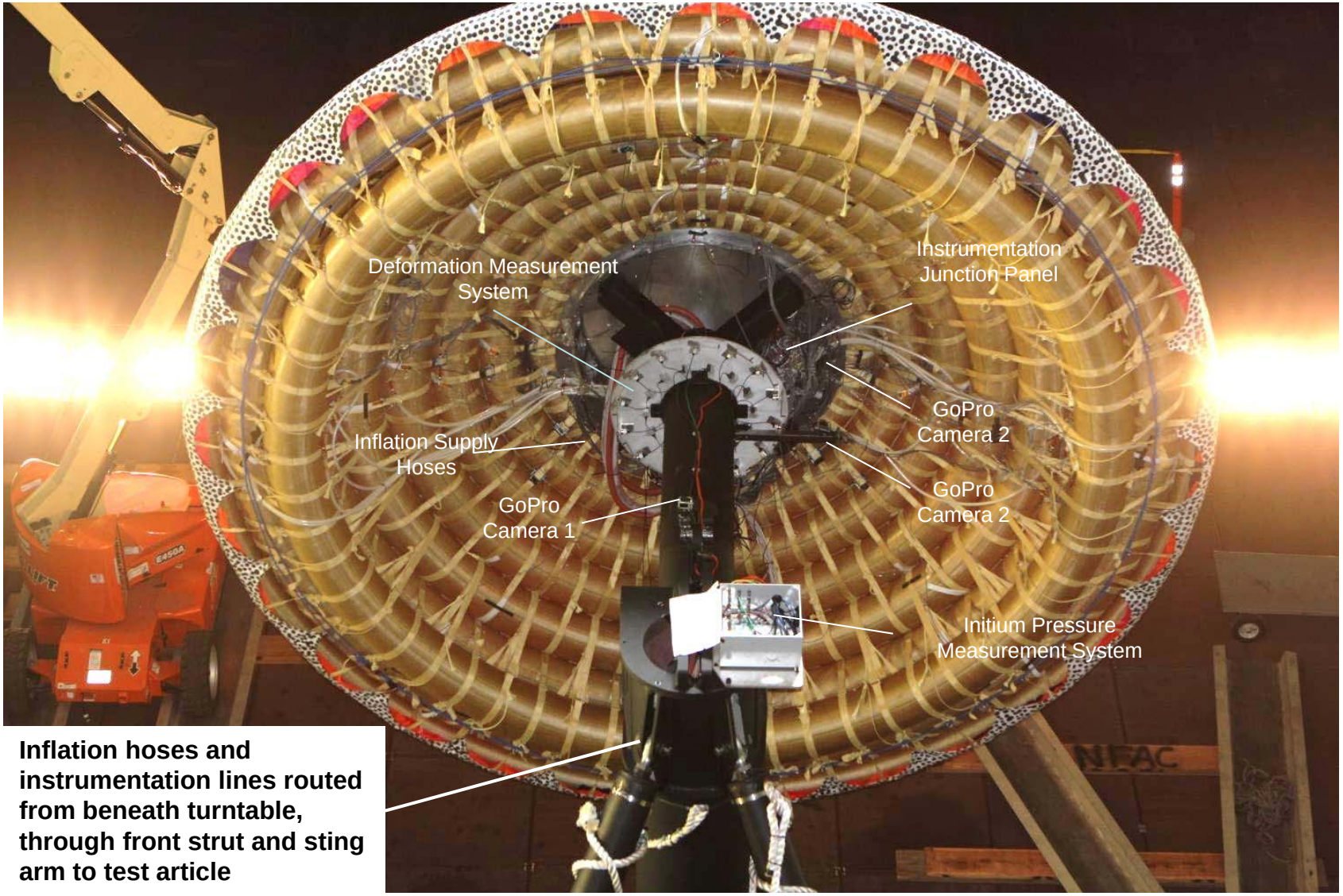



# Assembly & Integration

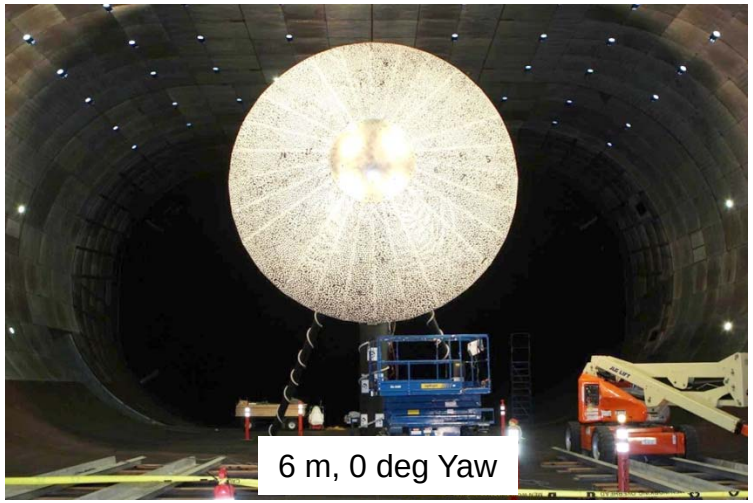
## Final Assembly in Test Section

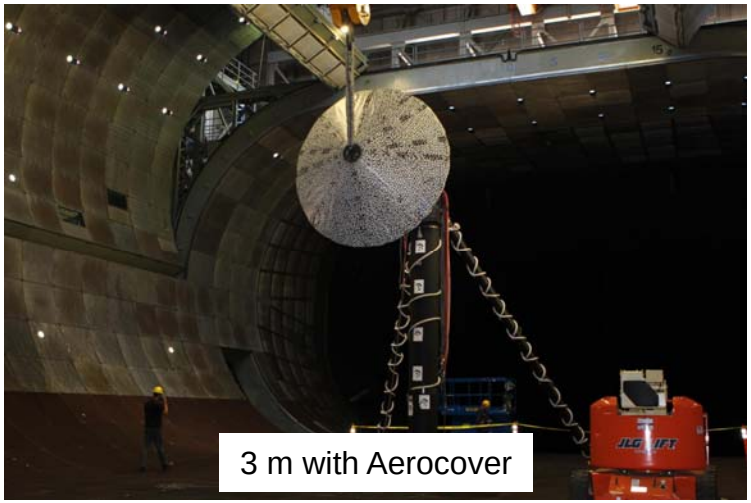



**Inflation hoses and instrumentation lines routed from beneath turntable, through front strut and sting arm to test article**

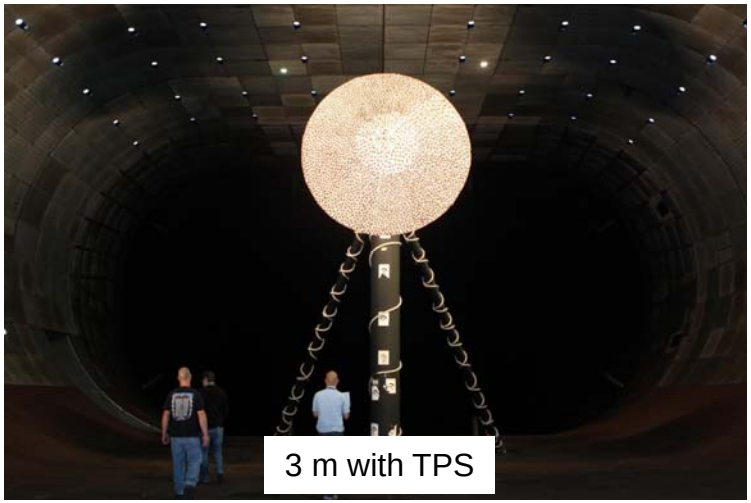
# Test Operations

## Test Articles Installed in Wind Tunnel


6 m, 0 deg Yaw


3 m with Aerocover

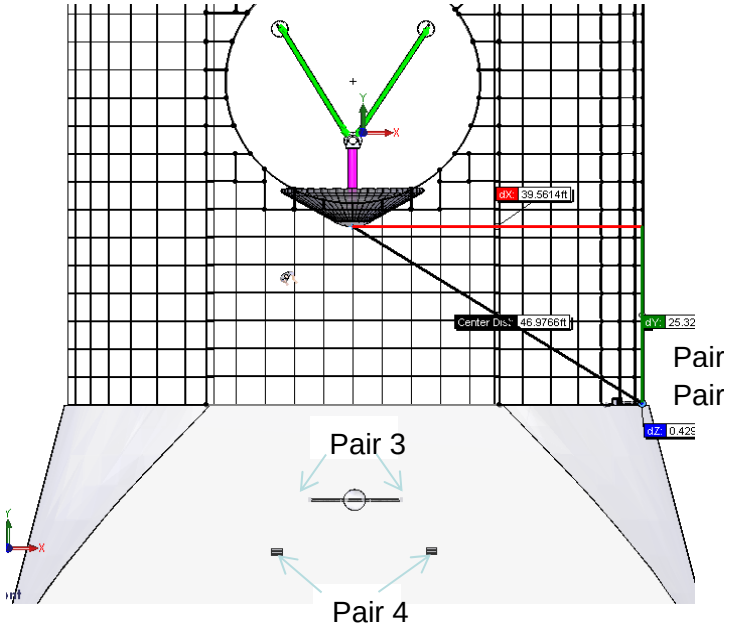

6 m, -25 deg Yaw


3 m with TPS

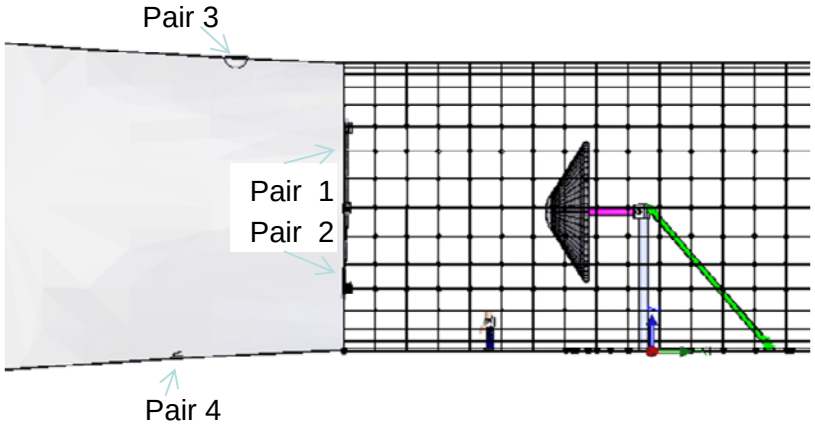
## HIAD Video Compilation

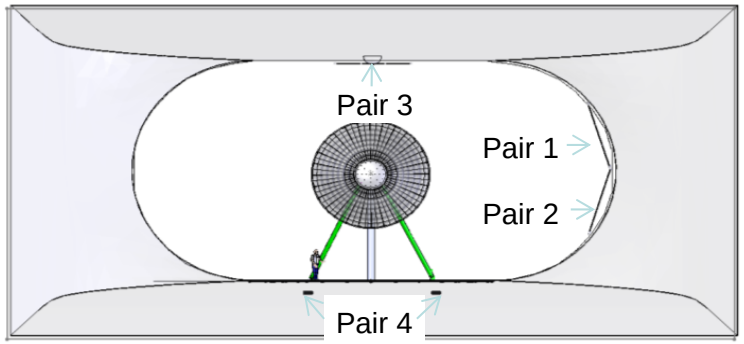
# Photogrammetry System

**Top View**




**Side View**



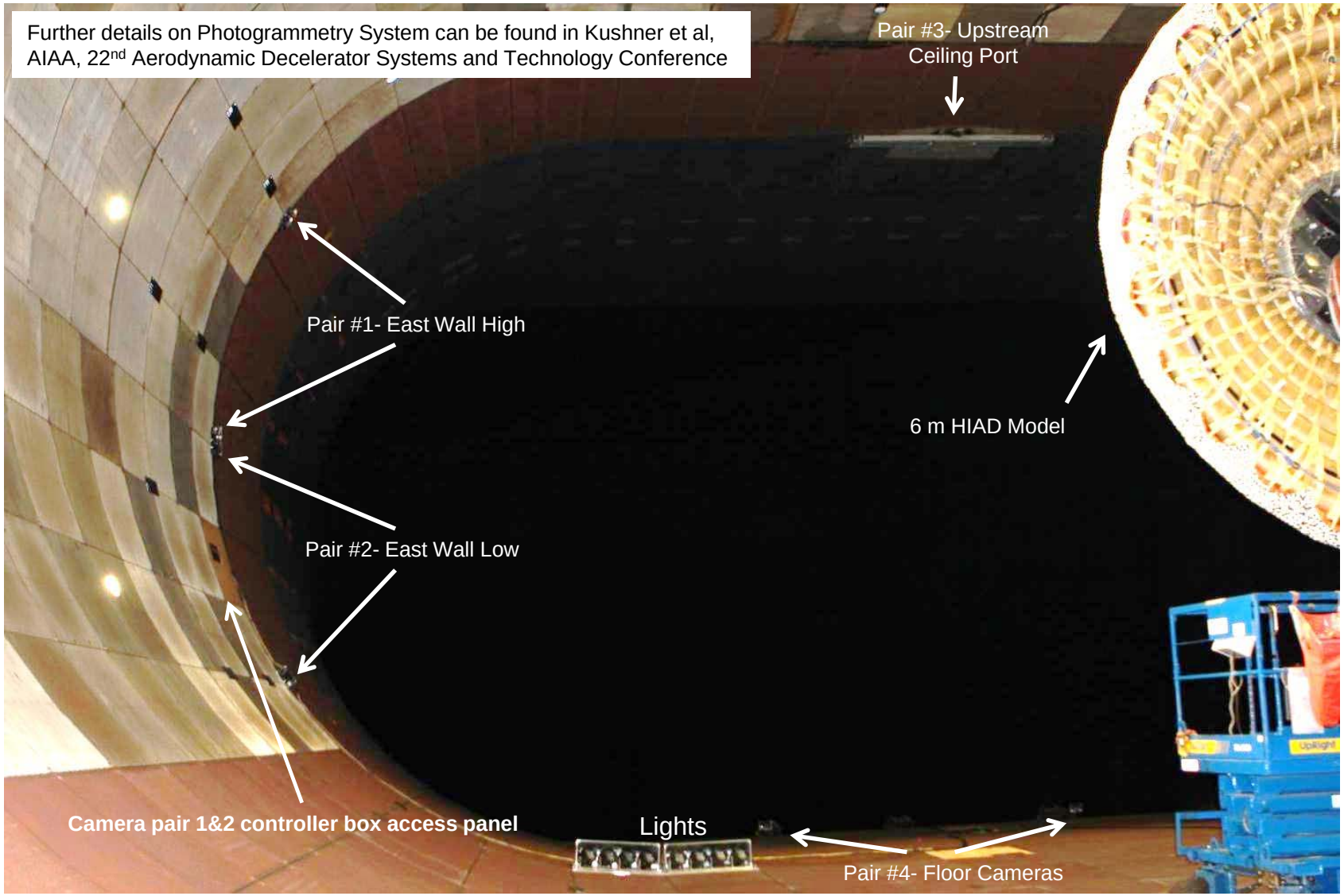




**Front View**

| Pair | Location | Distance | Model Coverage |
|---|---|---|---|
| 1 | East High | 45-47 | 6m at -15 deg or higher |
| 2 | East Low | 45-47 | 6m at -15 deg or higher |
| 3 | Ceiling Dome | 46 | Upper portion of HIAD for most solutions |
| 4 | Mic Stands | 53 | Solutions used in all data |

**Summary Table**

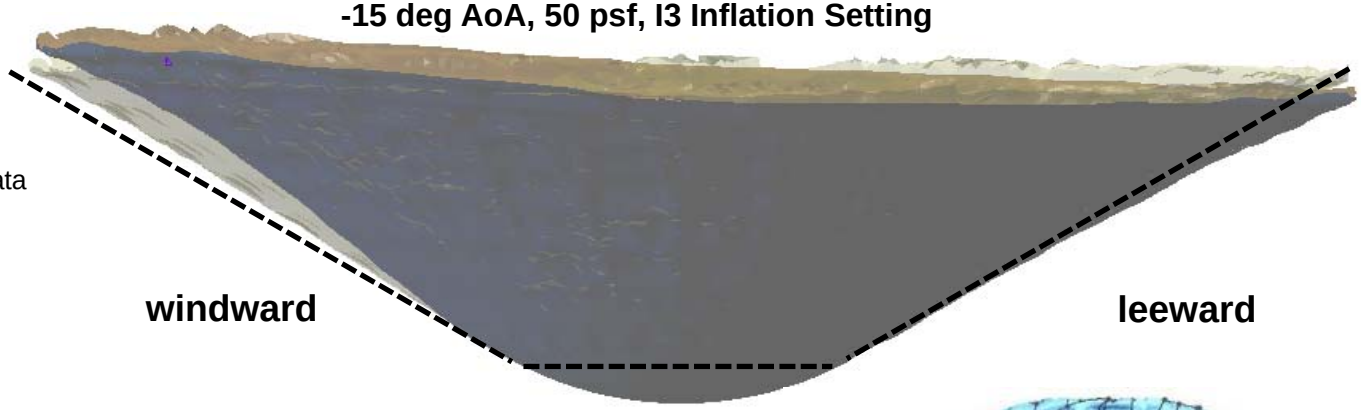
# Photogrammetry System



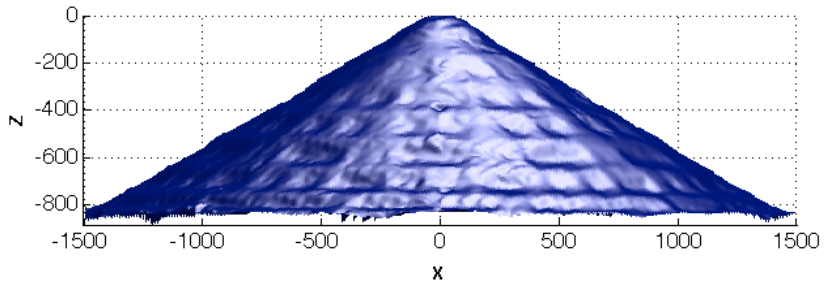
# Photogrammetry Data

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

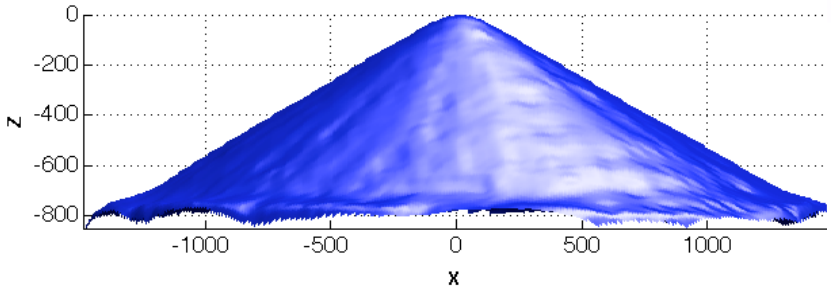
**Overlay of Baseline (Dark Grey) on Tri-Torus**
**-15 deg AoA, 50 psf, I3 Inflation Setting**

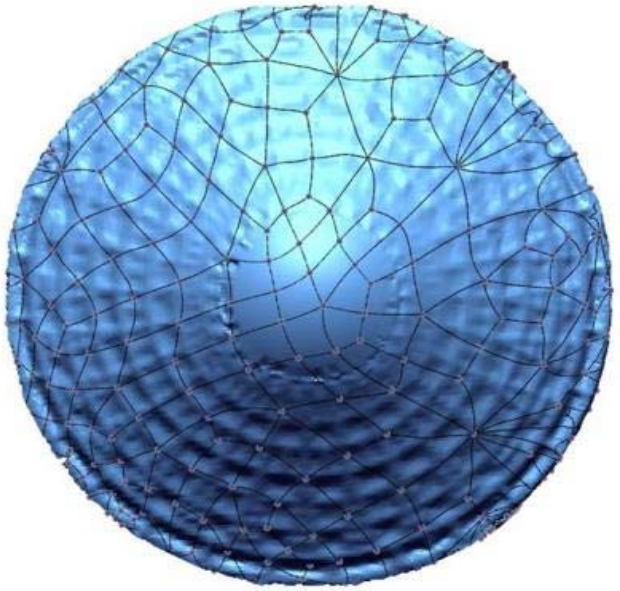



3 m Aerocover



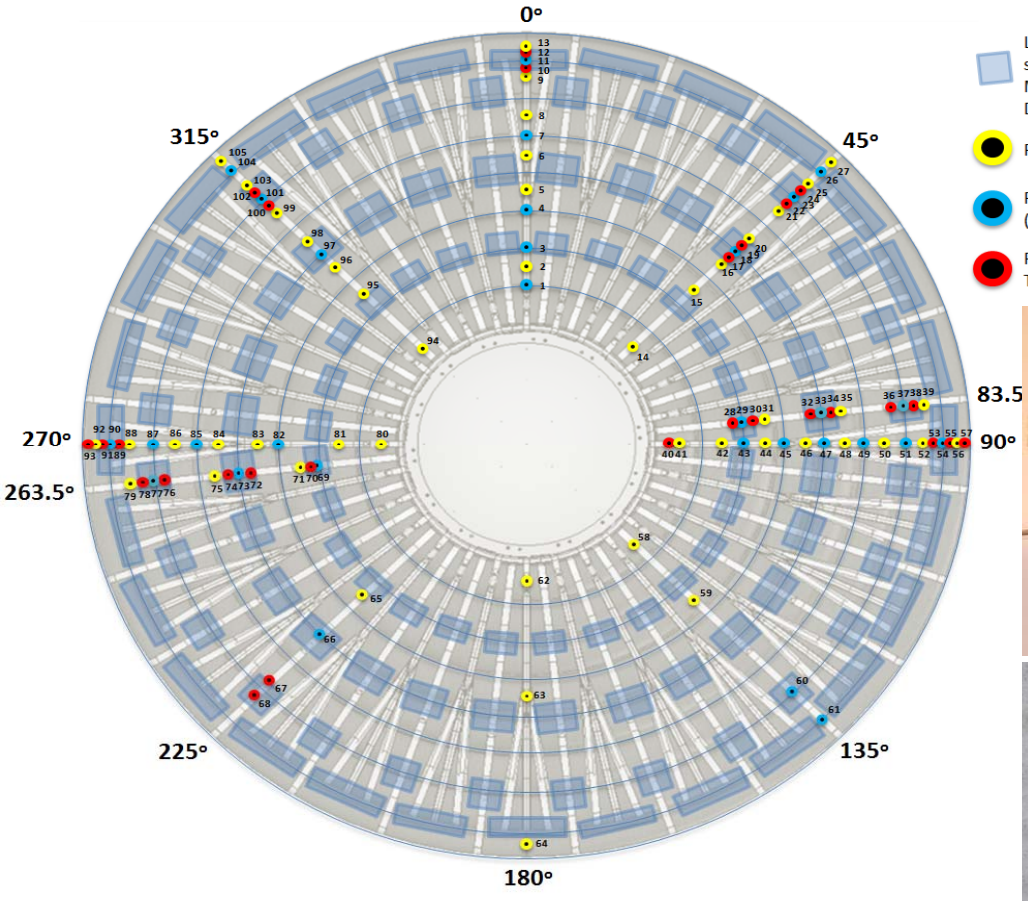

3 m w/ TPS



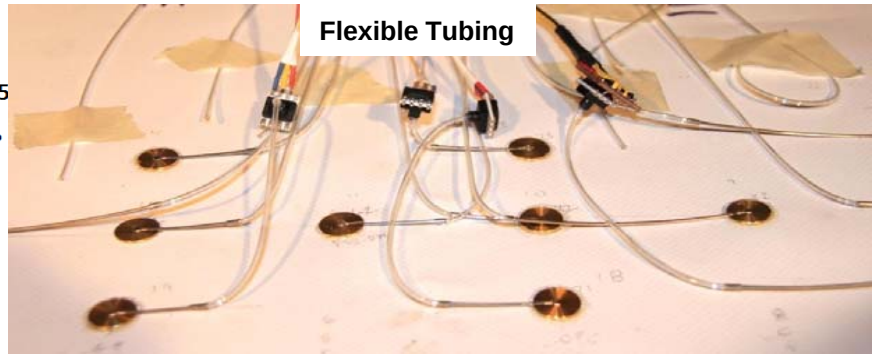



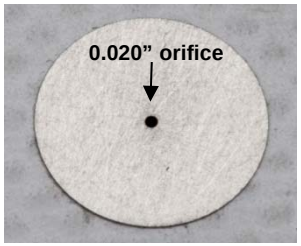
**Deflected surface data ready for CFD grid generation**

# Test Article Surface Pressures

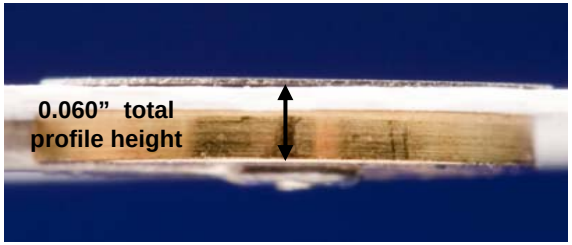



**105 Embedded Pressure Taps**




**Tap Orifice**



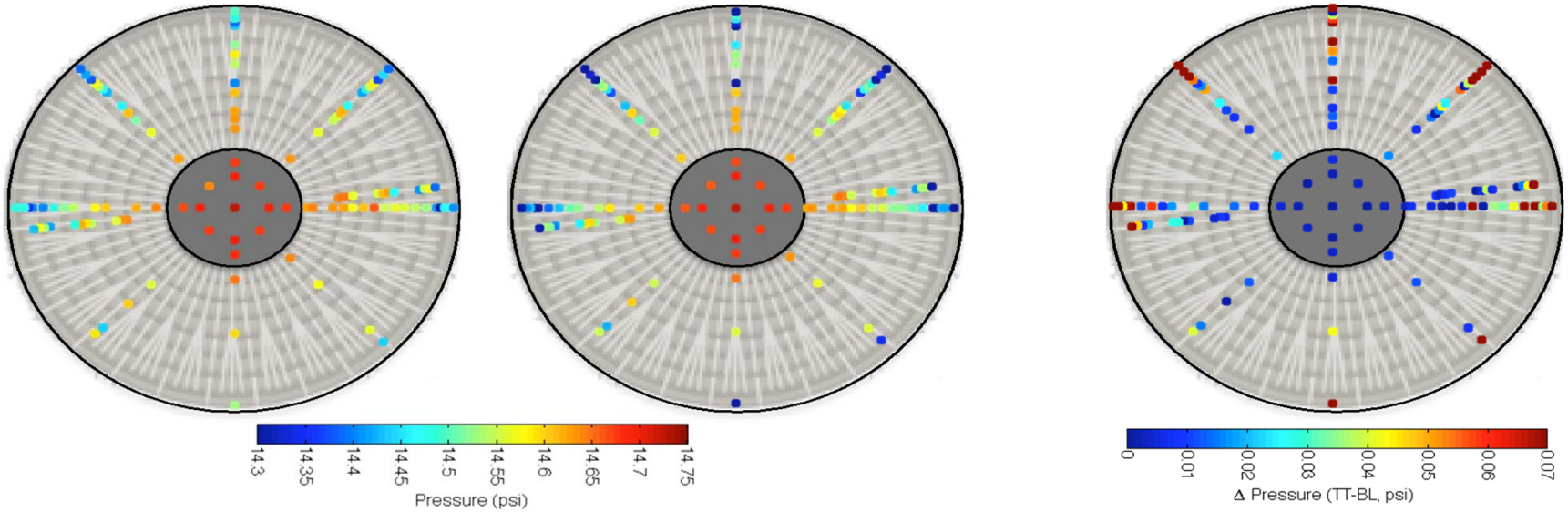

**Low Profile Design**

# Surface Pressure Data

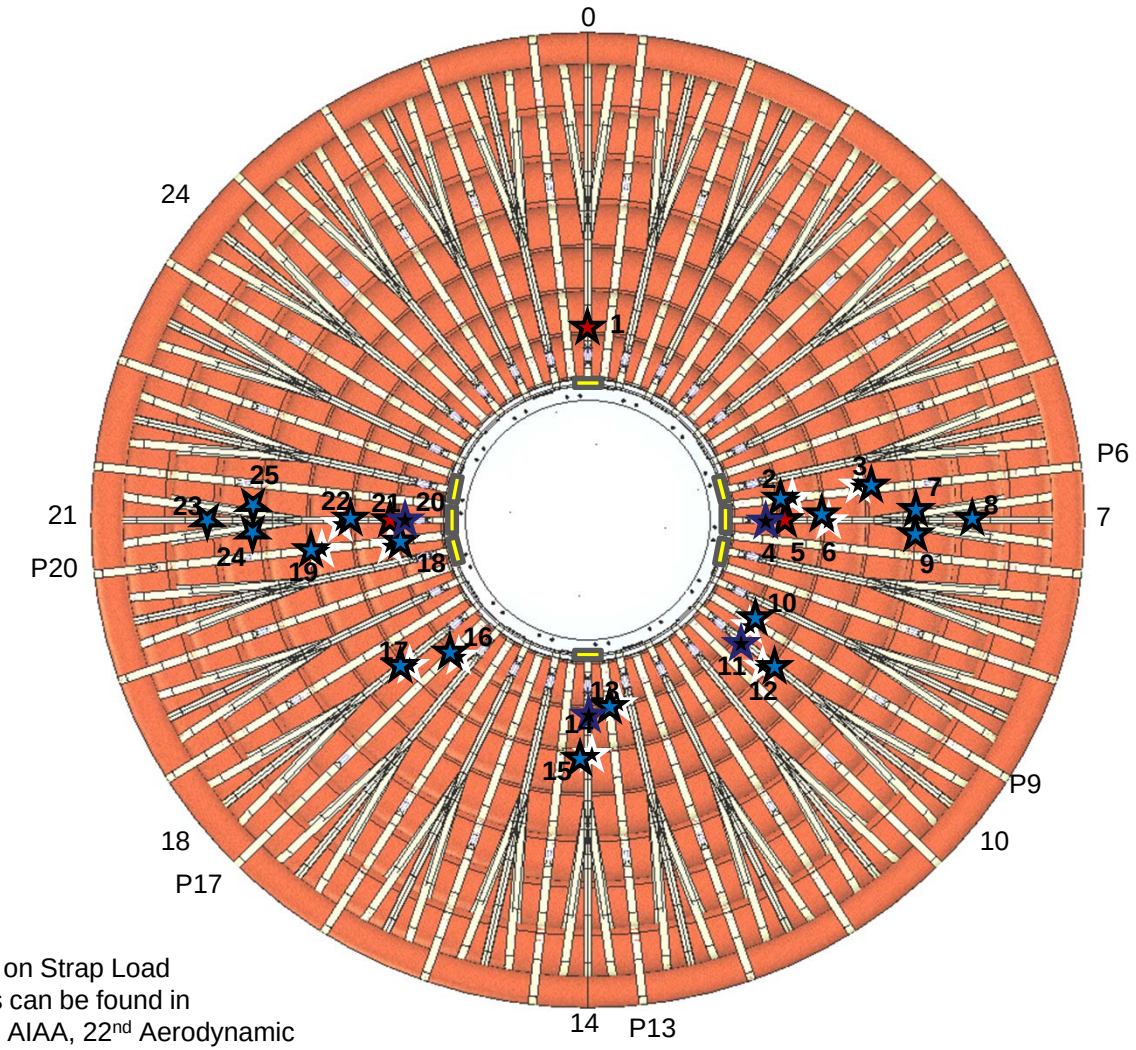
Tri-Torus: i2, 50psf, 0º

Baseline i2, 50psf, 0º

Tri-Torus - Baseline

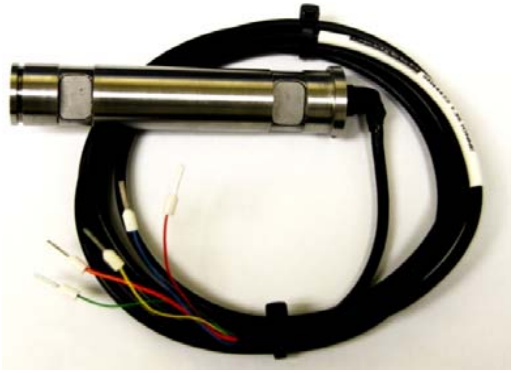


# Load Pins & Load Cells



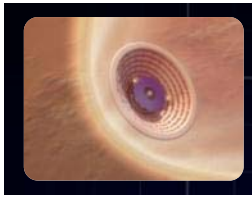

Load Cell Distribution Map

Load Pins- Yellow Bars



Strap Load Cells- Stars

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



# Summary

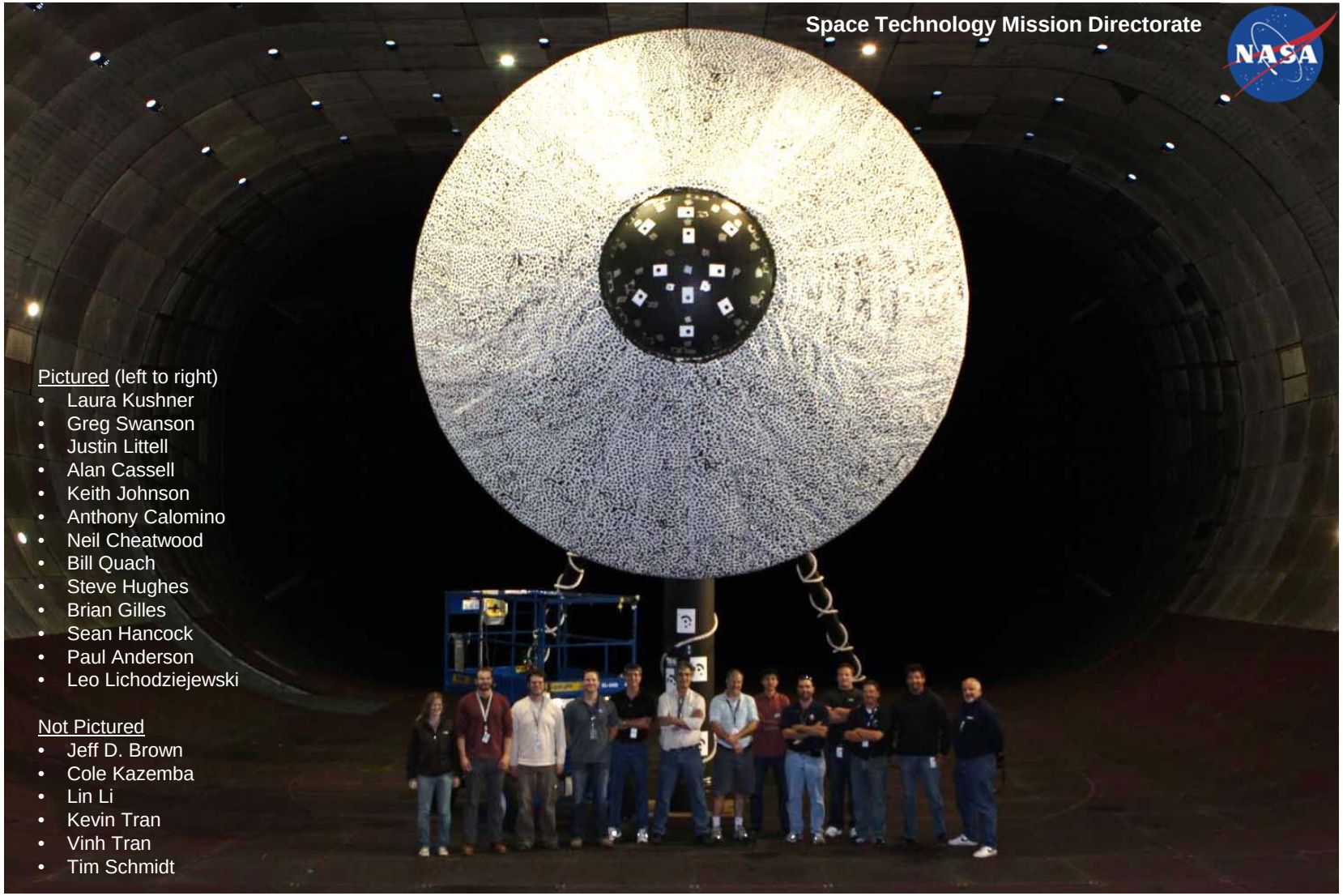
## Results Overview

**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

| Model Configuration | # Test Points | Primary Data Products | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Photogrammetry | Strap Load Cells | Strap Load Pins | Surface Pressures | Wall Pressures | Aero Forces & Moments | Inflation Pressures |
| **6 m Tri-Torus** | 151 | Full Model Coverage | 21 | 8 | 118 | 138 | Yes | Yes |
| **6 m Baseline** | 106 | Full Model Coverage | 21 | 8 | 118 | 138 | Yes | Yes |
| **3 m** | 94 | Full Model Coverage | 21 | N/A | 118 | 138 | Yes | Yes |
| **3 m w/ TPS** | 28 | Full Model Coverage | 21 | N/A | 5 | 138 | Yes | Yes |

# Acknowledgements- Core Test Team



# Acknowledgements- Test Team Photo

# Questions?