INSTRUMENTATION FOR THE CHARACTERIZATION OF INFLATABLE STRUCTURES

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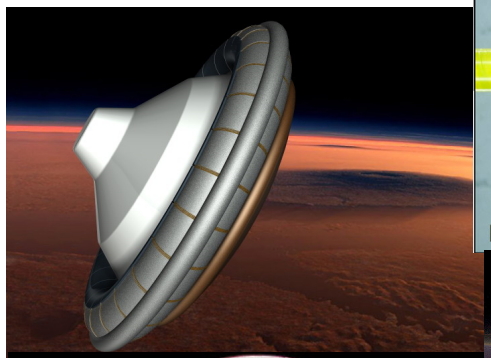
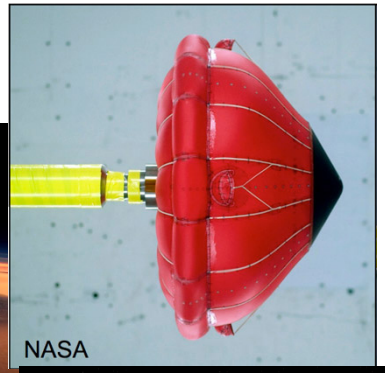
Outline

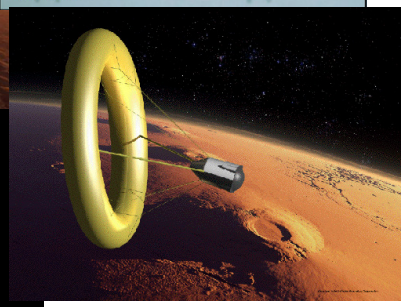
1. The Development of Inflatable Structure Technologies
2. Material and Structural Testing
3. HIAD Testing in the NFAC 40’ x 80’ Wind Tunnel
4. HIAD Wind Tunnel Models
5. Global and Local Deformation Measurements
6. Strap Load Measurements
7. Surface Pressures
8. Data Acquisition

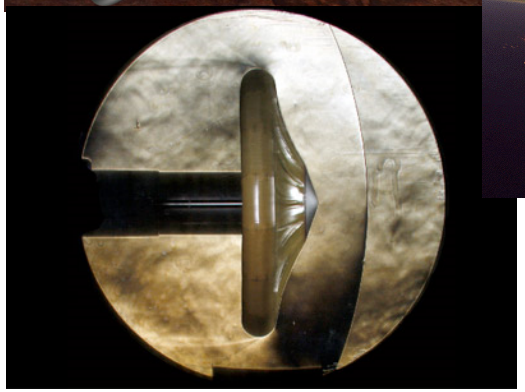
Development of Inflatable Structures

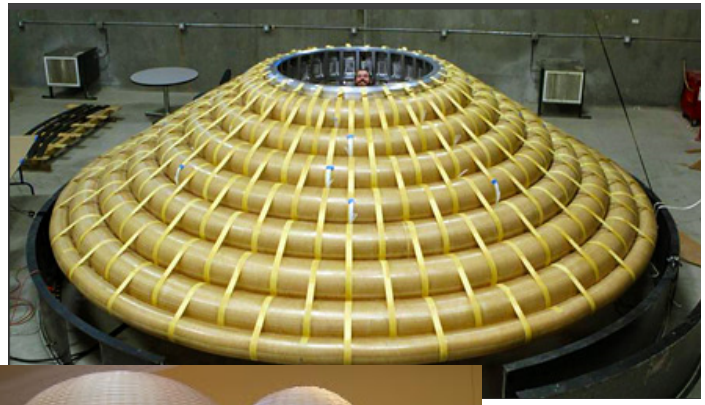
- **Decelerators**
  - HIADs, SIADs, Ballutes, etc
- **Habitats**
  - Orbit, Moon, Mars, etc











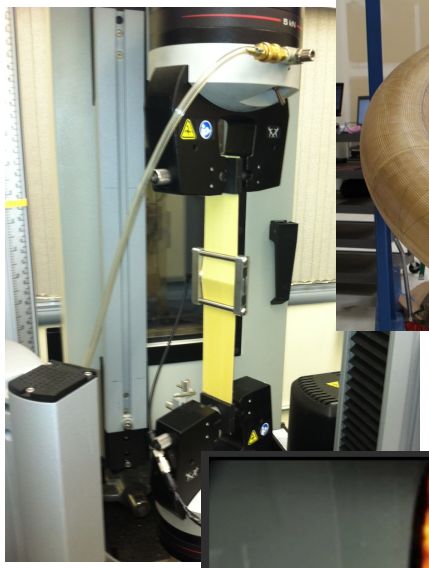
The capabilities of new materials have enabled the development of many of these concepts

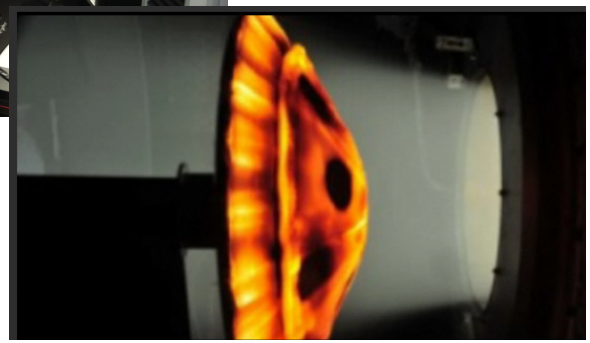
Images Courtesy NASA and Lockheed Martin

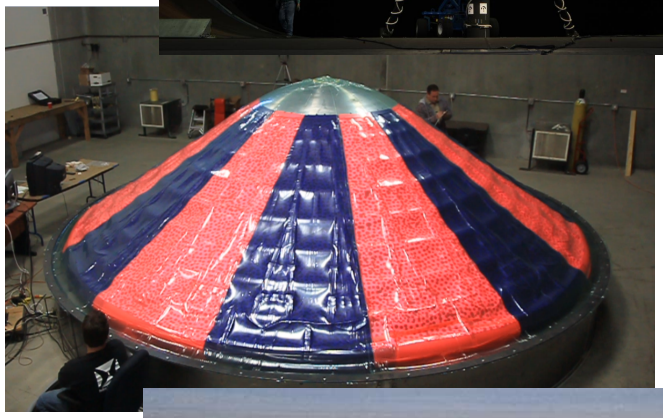
Material and Structural Testing

Component Level and System Level Testing

- Load Tests
- Modal Tests
- Degradation Tests
- Temperature and Vacuum Tests
- Inflation and Leakage Tests



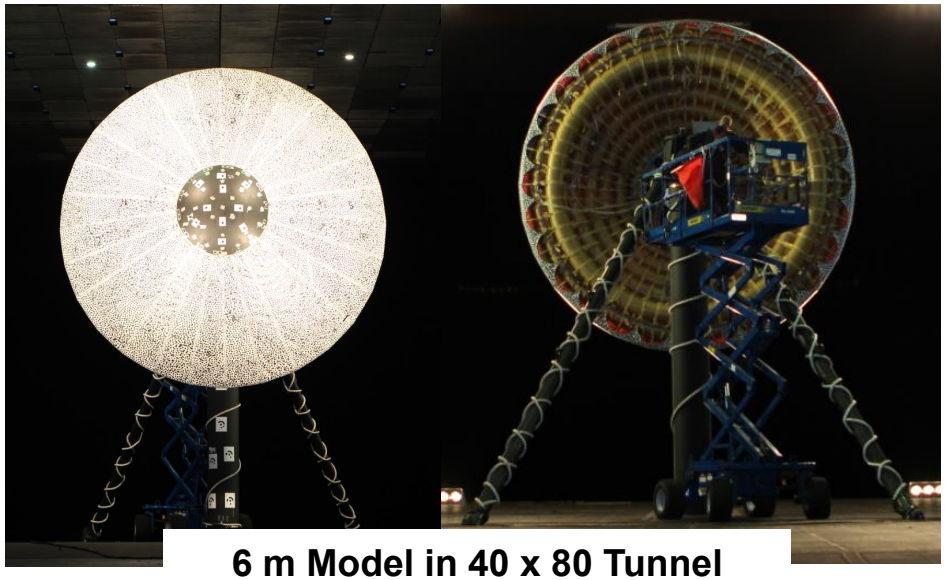




Images Courtesy NASA and HDT / Airborne

HIAD NFAC 40’ x 80’ Wind Tunnel Testing

- **Ground Testing of inflatable structures:**
  - **Wind Tunnel Testing**
  - Static Load Tests
  - Modal Tests
  - Inflation and Leakage Tests
  - Stowage and Deployment
  - Environmental testing (thermal, vacuum)

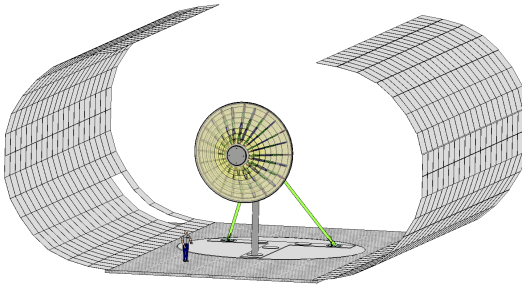


6 m Model in 40 x 80 Tunnel

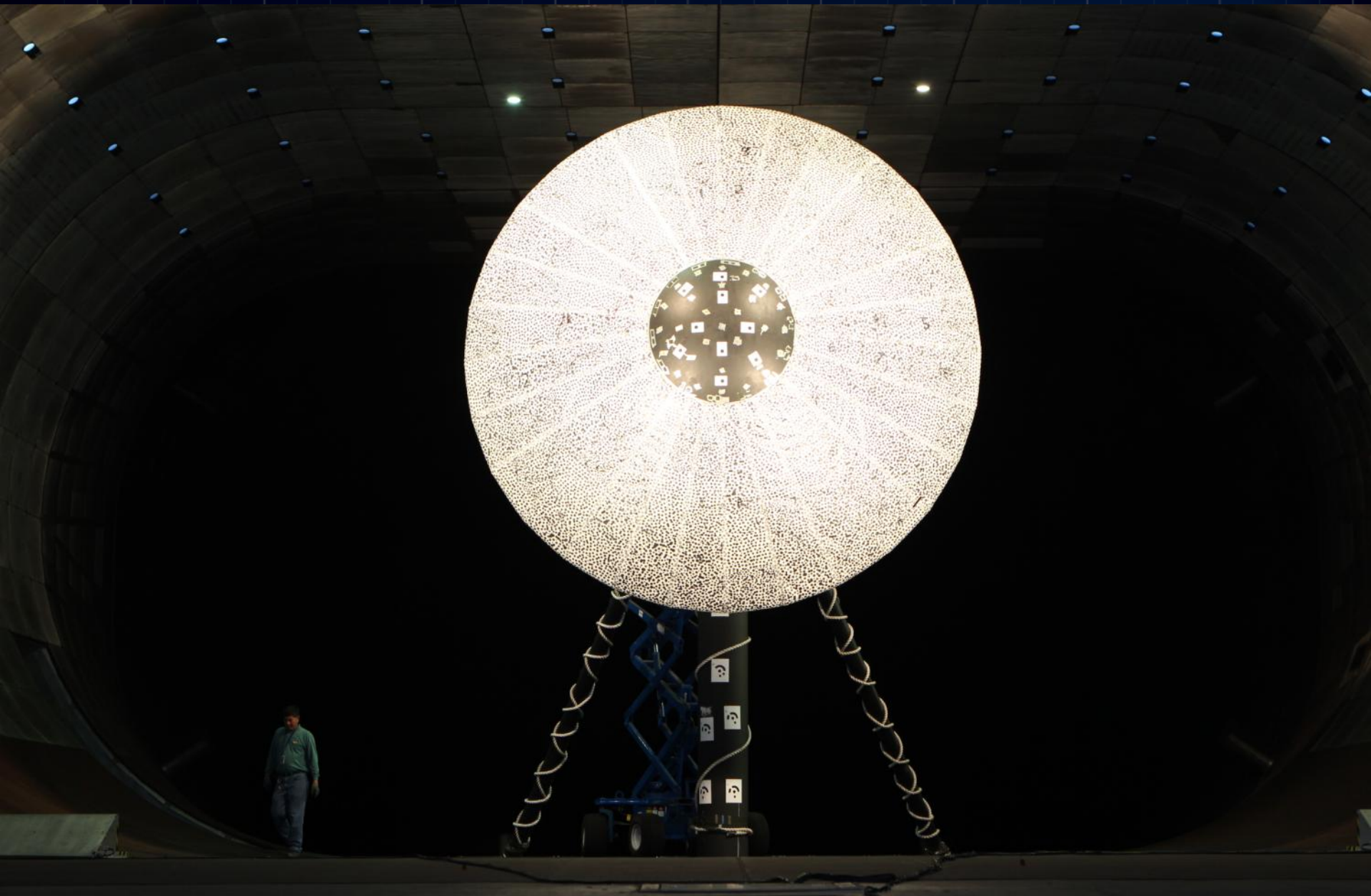
- **Primary objective for 3 m and 6 m test articles:**
  - Characterize inflatable structure stiffness and shape change due to aerodynamic loads (dynamic pressure, angle of attack) and inflation pressure
  - Obtain test data for model development and correlation

  Secondary: Develop Instrumentation

- **Test measurements include:**
  - Global and Local Deformation
  - Surface Pressures
  - Tunnel Pressure
  - Strap Loads
  - Inflation Pressure
  - Dynamic Displacement and Oscillations



6 m Test Article in the 40’ x 80’ Wind Tunnel



6 m Test Article in the 40’ x 80’ Wind Tunnel

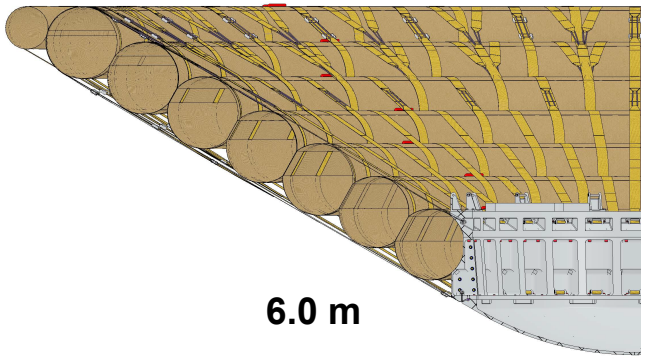
Ground Test Campaign HIAD Models

6.0 m Test Article

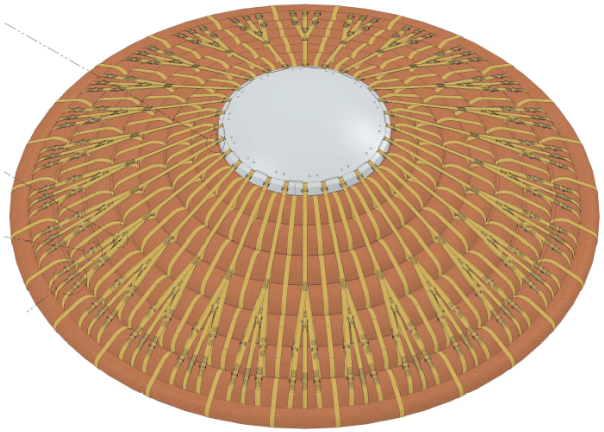
- Stacked torus design
- Utilizes and aerocover (aerodynamic surface)
- Tested in two different configurations (both using an aerocover); with and without an additional stiffening torus

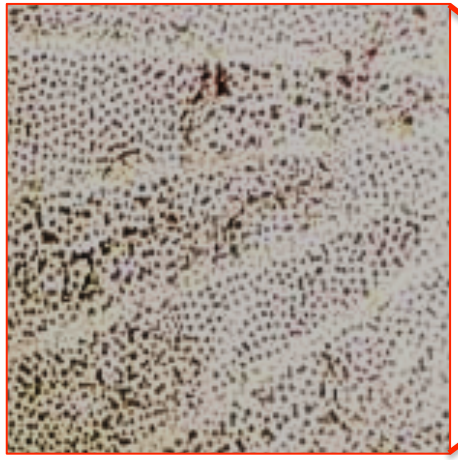
3.0 m Test Article

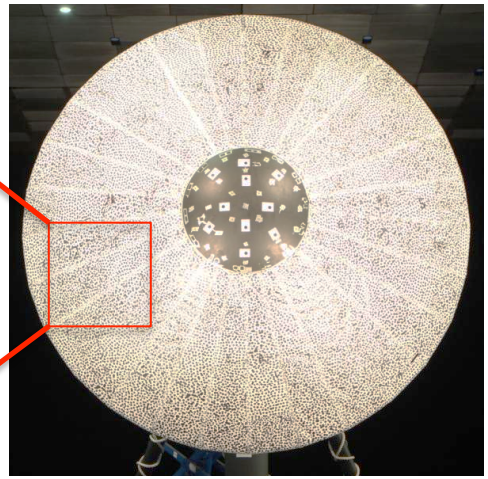
- Constructed with flight materials to demonstrate design and expected performance of similar flight testing and wind tunnel tests
- Tested in two different configurations; first with a thermal protection system and second with an aerocover



6.0 m

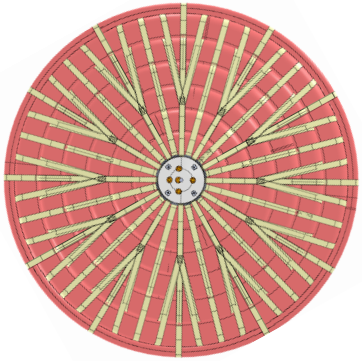






6.0 m Aerocover

Aerocover Speckled for Photogrammetry

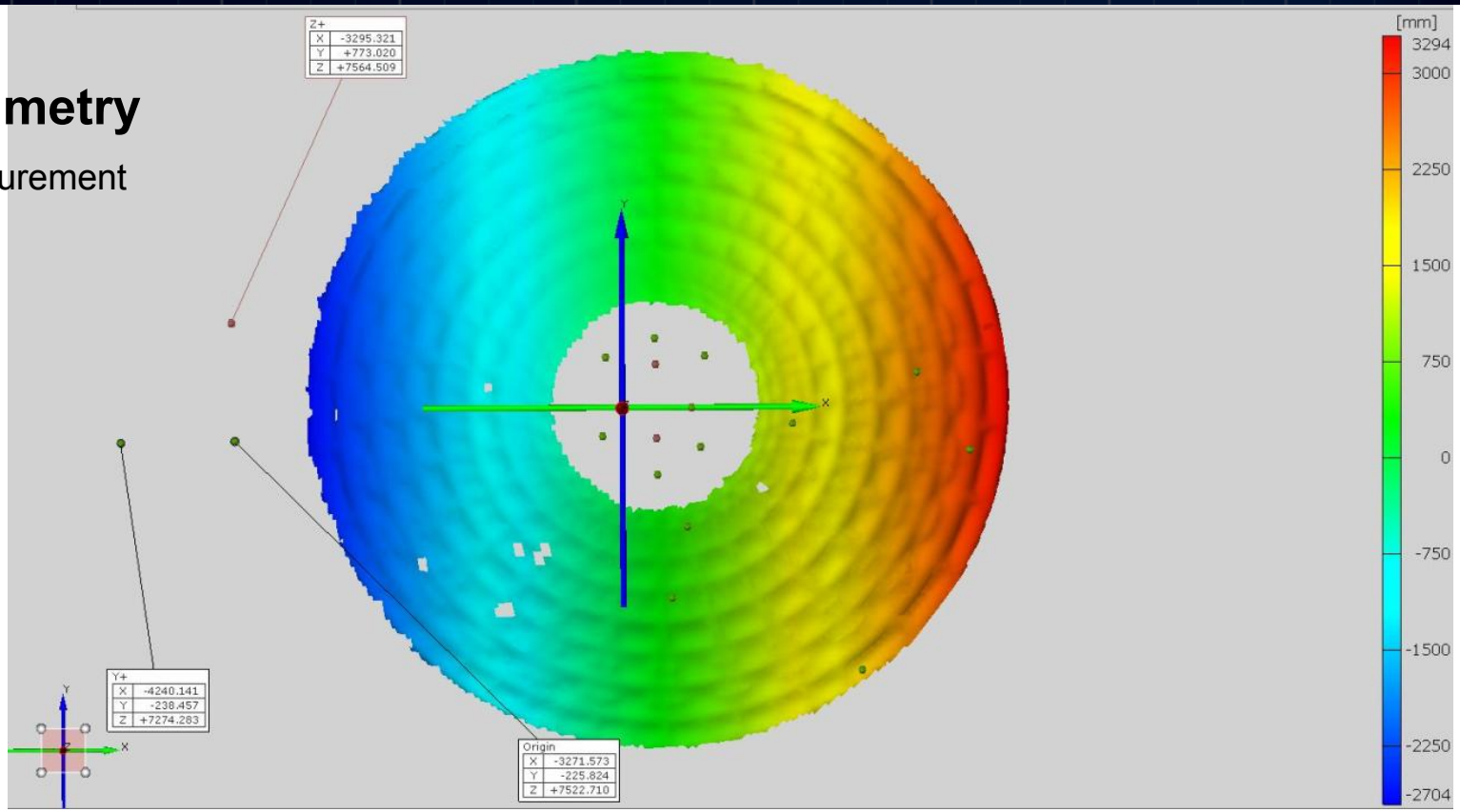


3.0 m

Global and Local Deformation

Photogrammetry

Primary Measurement



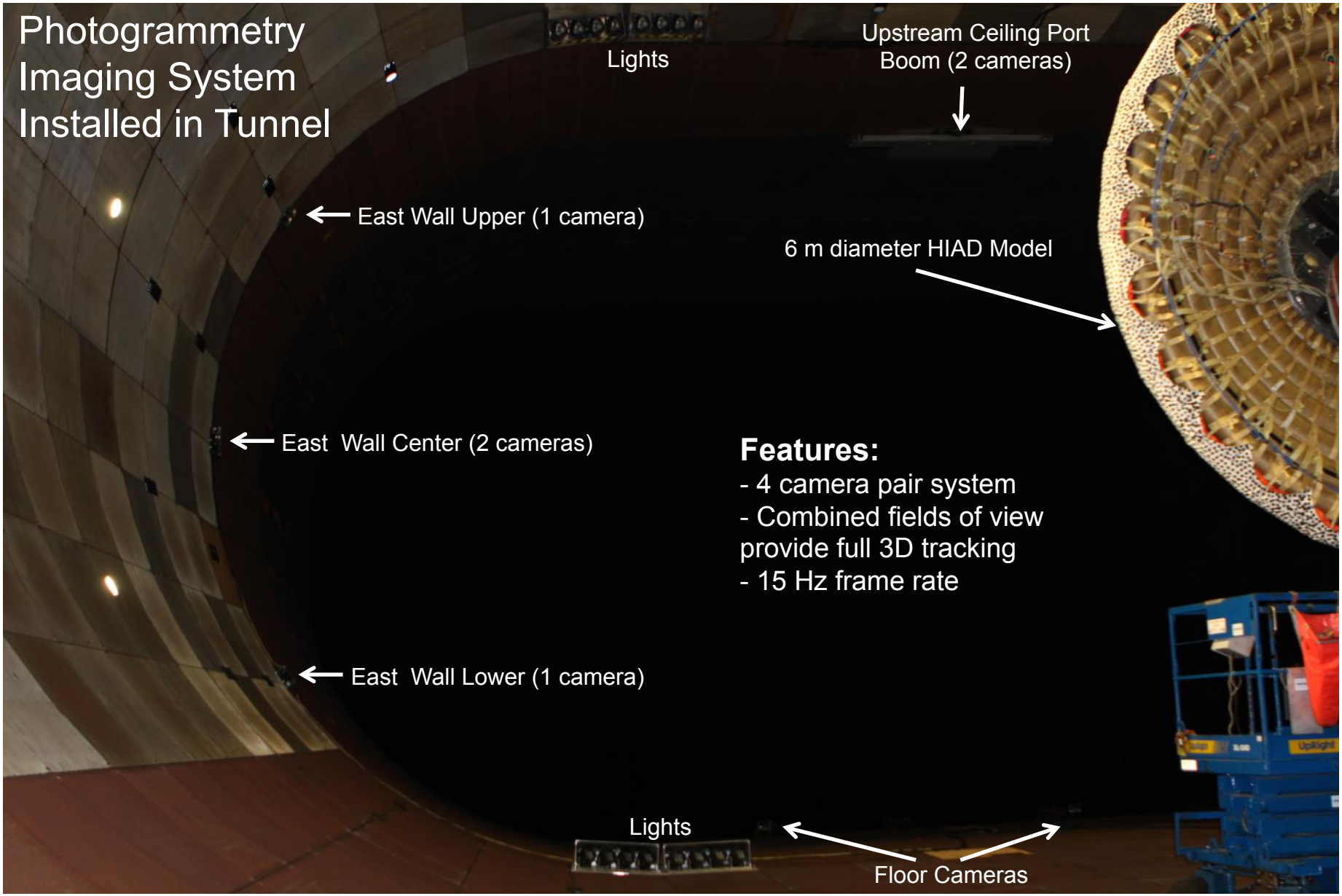
Requirements:

- Measure full 3 & 6 m HIAD model deformation at full range of tunnel conditions angle of attack
- Angle of Attack: -10 to +25 deg

Approach:

- Utilize 4 camera pair imaging system with randomly patterned aerocover on the forebody surface
- 32- 750 W theater lamps to illuminate front surface
- In tunnel calibration utilizing large calibration cross

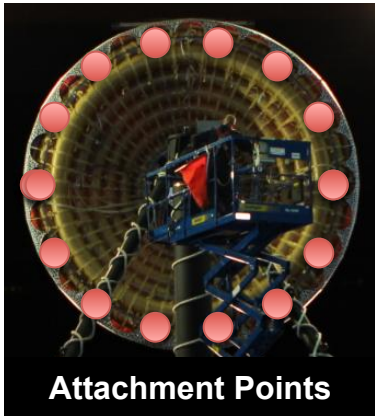
Global and Local Deformation

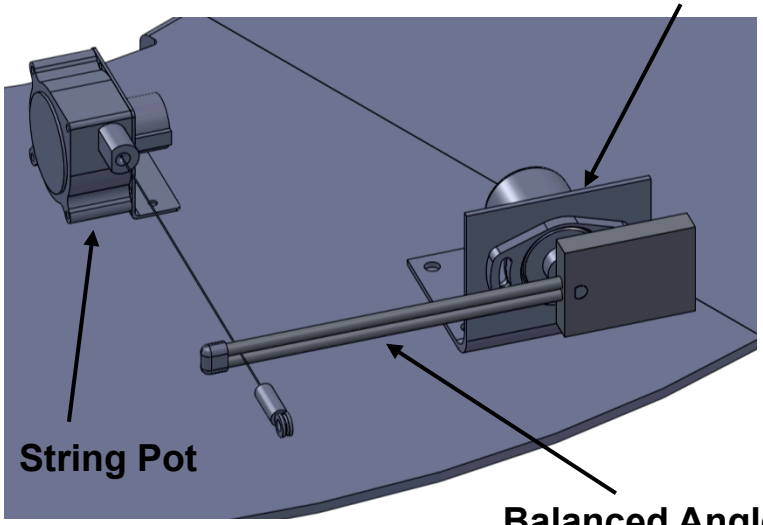


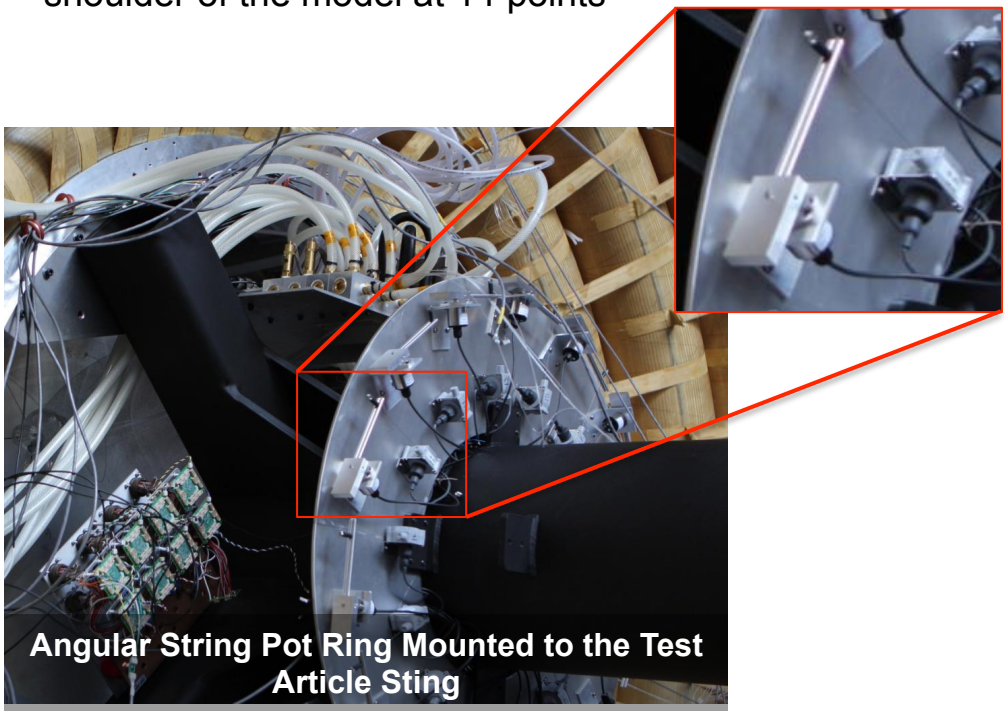
Global and Local Deformation

Angular String Potentiometer

- Accurately tracks movement in a 2D field
- String pot will be teamed with an angular transducer to measure the angle at which the string pot line is deployed
- Balanced angle tracking bar mimics the angle of the string pot line
- The String Pot lines are anchored to the shoulder of the model at 14 points





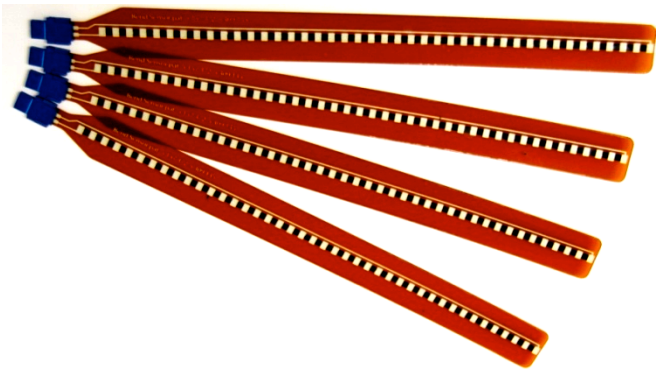


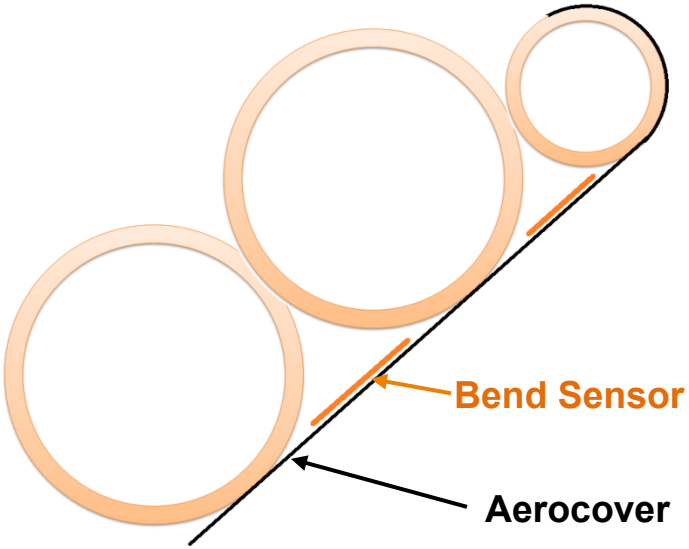
Estimate of Deformation at a High Angle of Attack, Low Inflation Pressure

Global and Local Deformation

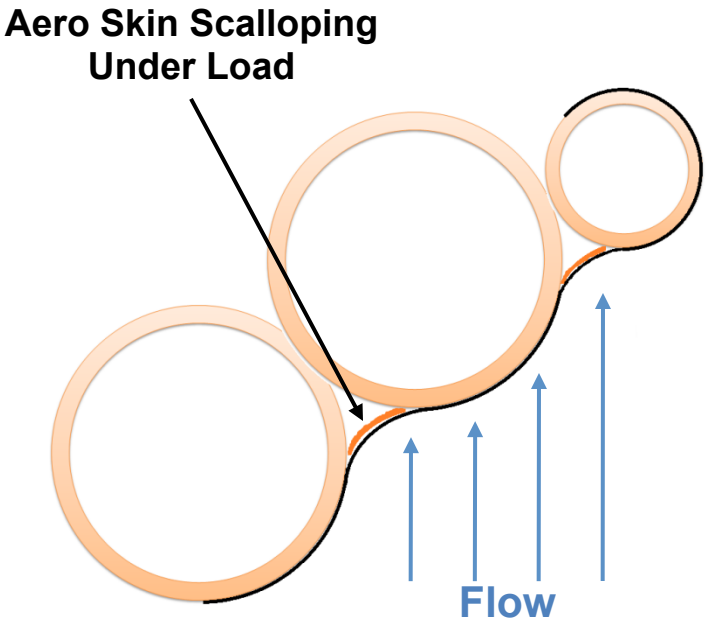
Bend Sensors

- Bend sensors provide a resistive response to bending (strain) of the sensor's membrane.
- An array of bend sensors will be placed on the aerocover between different tori in an effort to determine the magnitude of the scalloping.
- Local deformation or scalloping can give an indication of the localized heating seen within a TPS



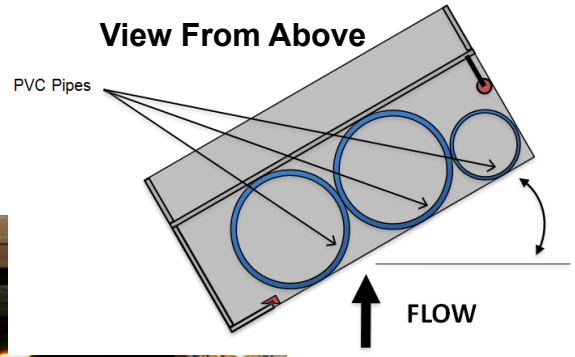


Aeroshell Section – Under No Aero Load



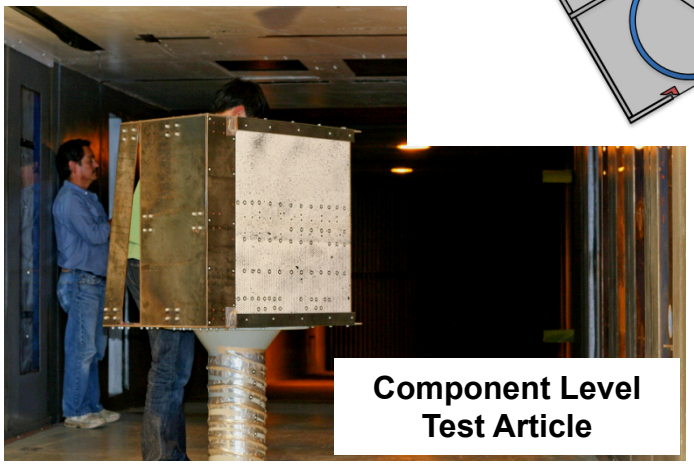
Aeroshell Section – Under High Aero Load

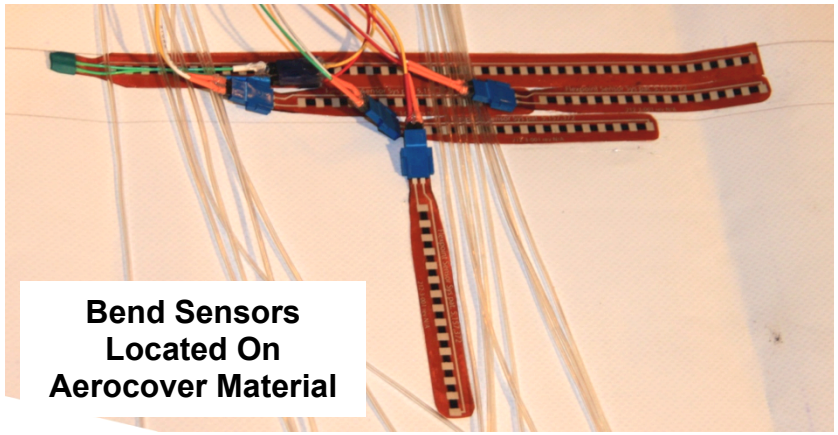
Local Deformation

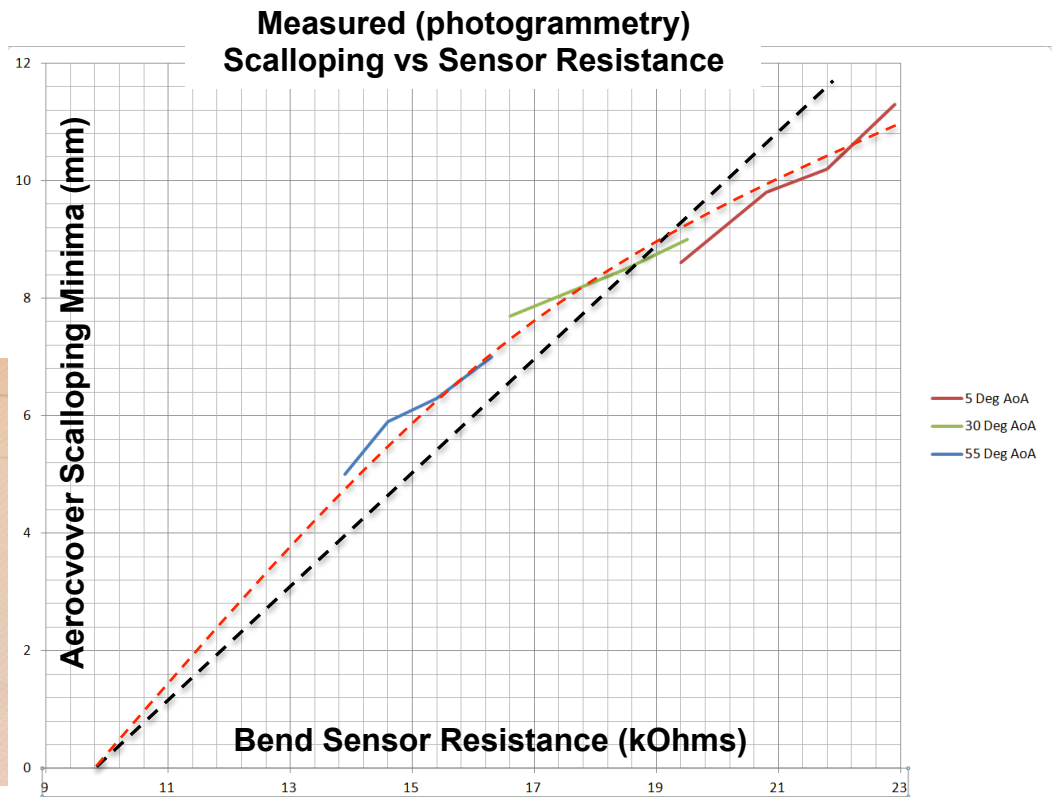


Component Level Testing at the NASA ARC 7' x 10' Wind Tunnel

Sensor Response compared to Photogrammetry results gave confidence in moving forward with the sensor



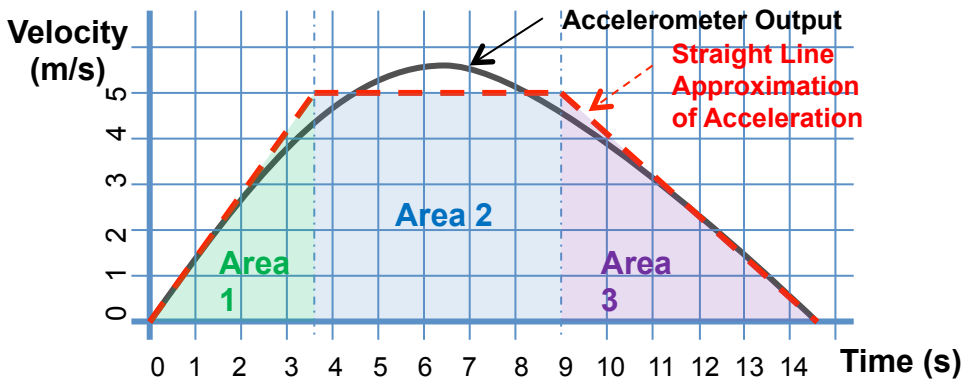




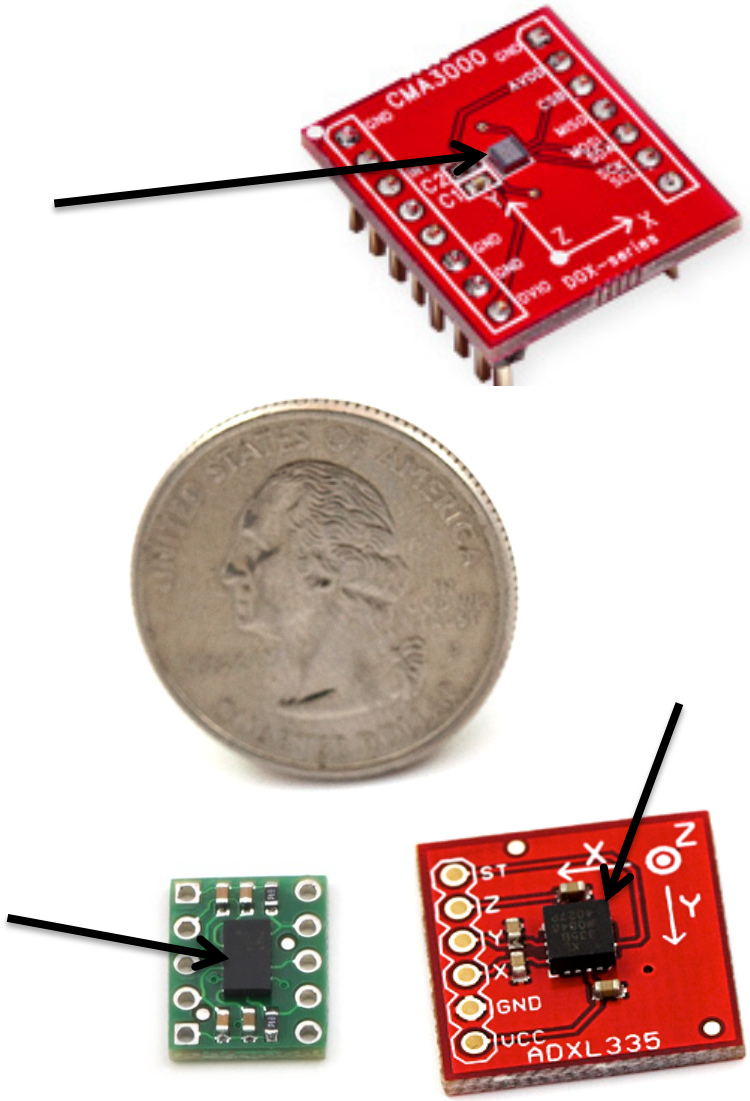
Dynamic Displacement

3-Axis MEMS Accelerometers

-Co-Located with the sting potentiometer anchors at multiple location across the HIAD shoulder as a proof of concept to use accelerometers as dynamic deformation sensors
- Investigating max g's half peak to peak, how accelerometers react in relation too each other, and rough estimates of point tracking



Displacement Calculations Given Accelerations (Hard to Implement Due to Sensor Accuracy and Drift)

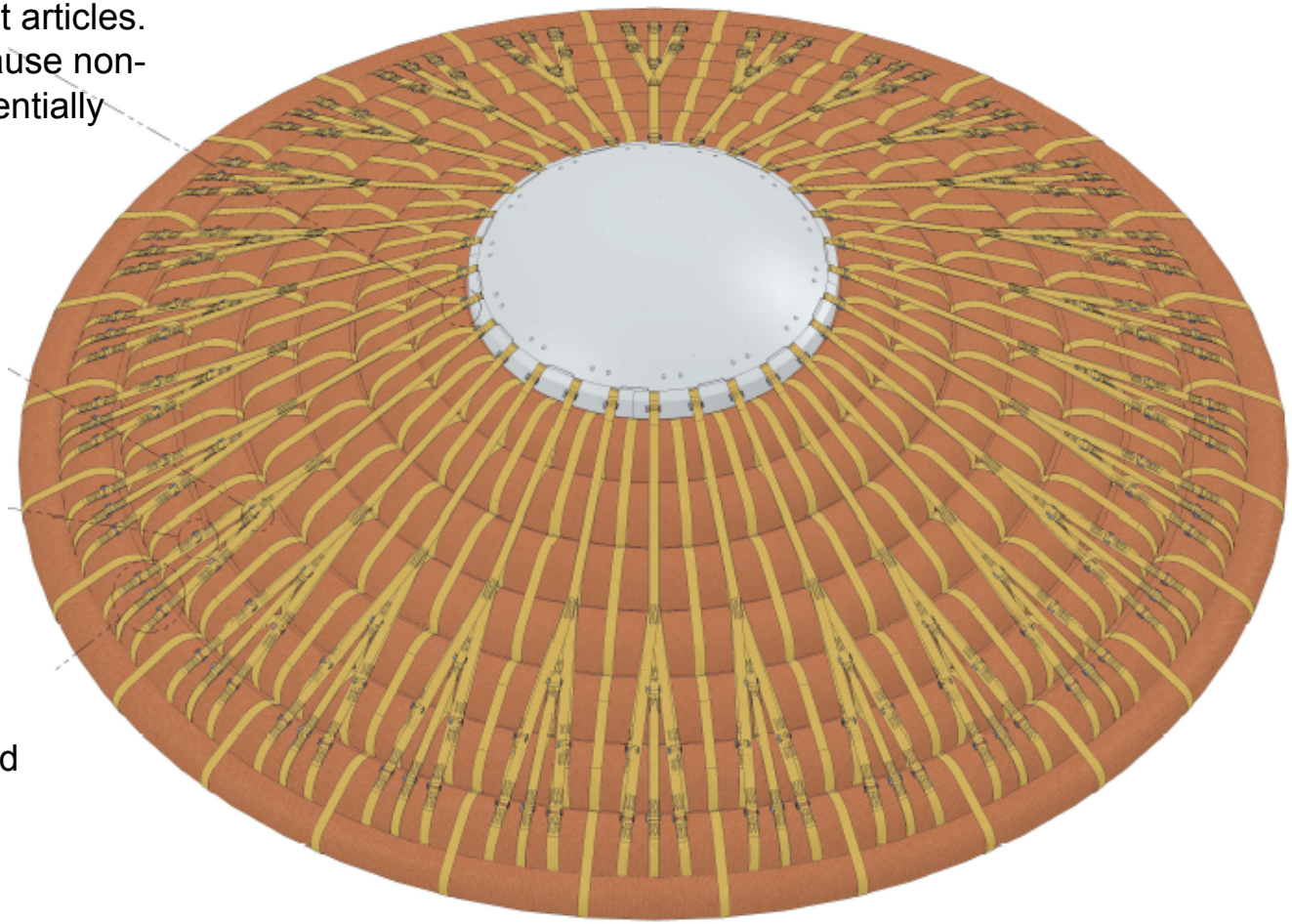


±3g, 6g and 11g available

Strap Load Measurements

The complexity of the structural strapping arrangement and small variations in fabrication make it difficult to model the load paths within the HIAD test articles. Off nominal strap loads can cause non-uniform displacement and potentially damage the tori.

- **Pairing Straps**
- **Radial Straps**

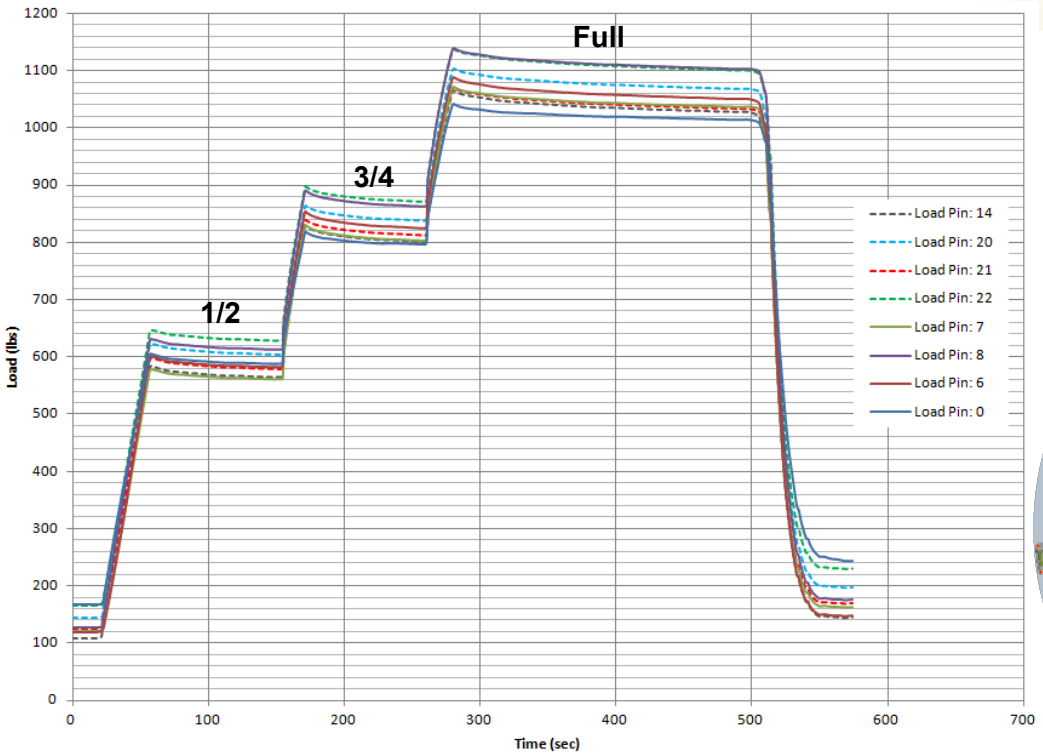


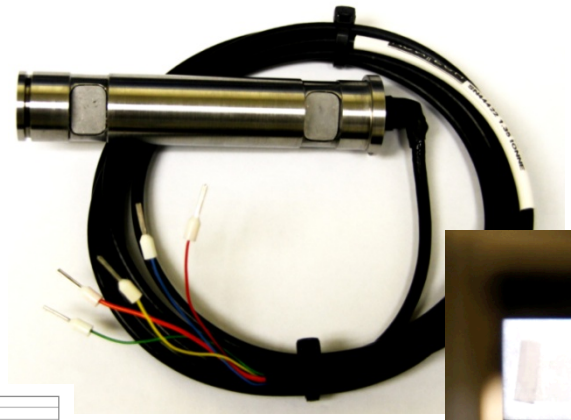
In response to this problem multiple measurement techniques have been explored and implemented during the HIAD wind tunnel testing.

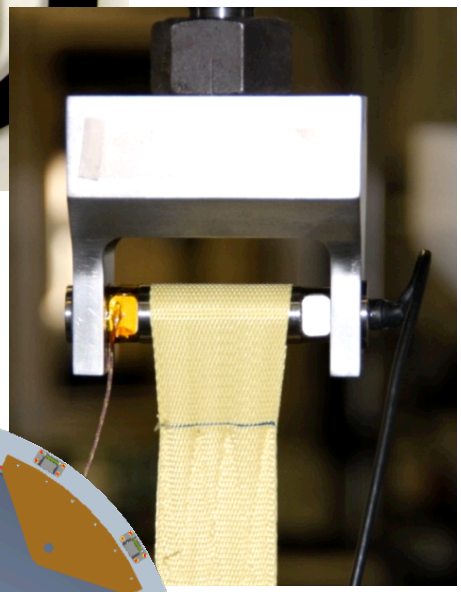
Strap Load Measurements

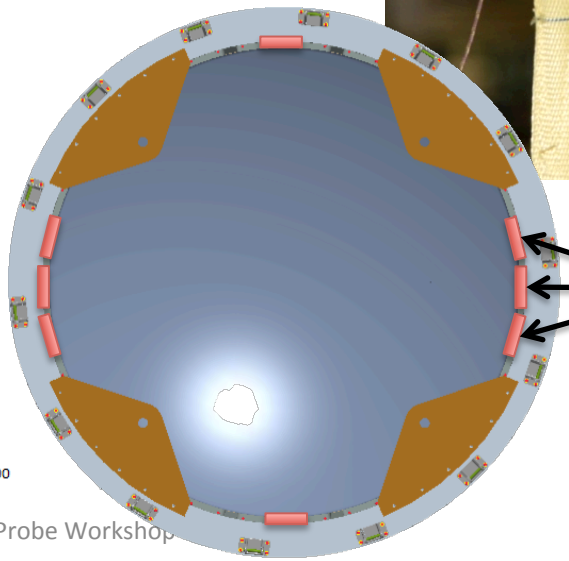
Loadcell Pins

- Loadcell pins provide a measurement in the crucial regions where the inflatable's straps are tied into the rigid centerbody of the HIAD





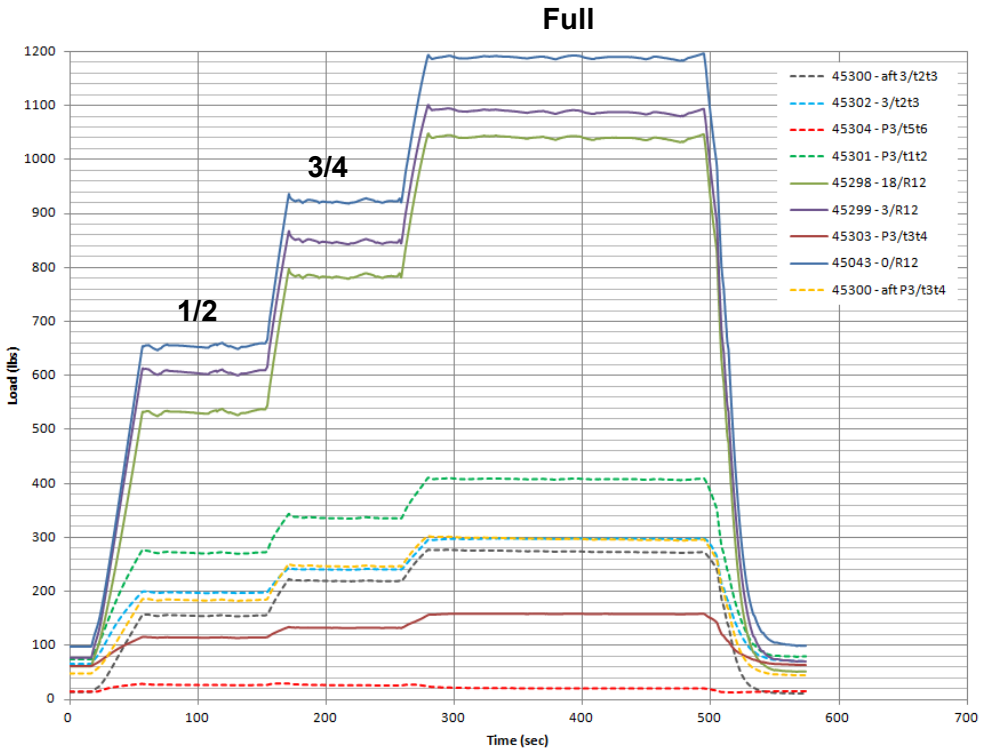


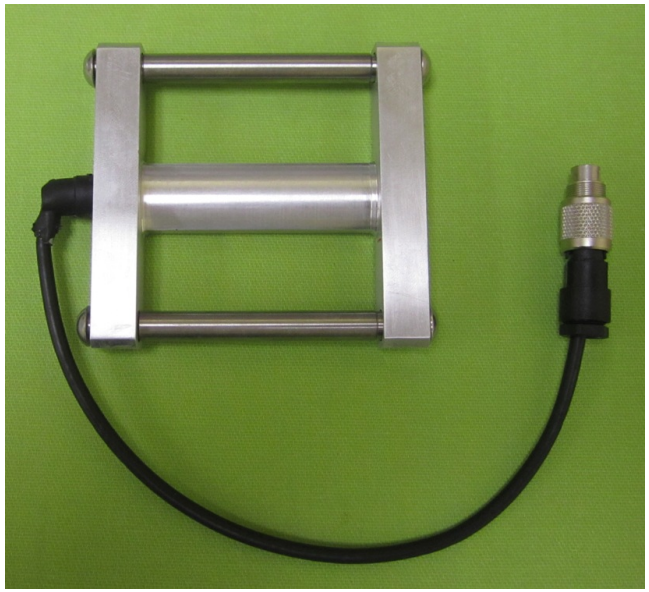


Strap Load Measurements

Strap Tension Loadcells

- Calibrated to give a reliable response to tension seen the strap webbing. Helping to determine load paths created by different strapping arrangements and the tolerances in the inflatable model fabrication

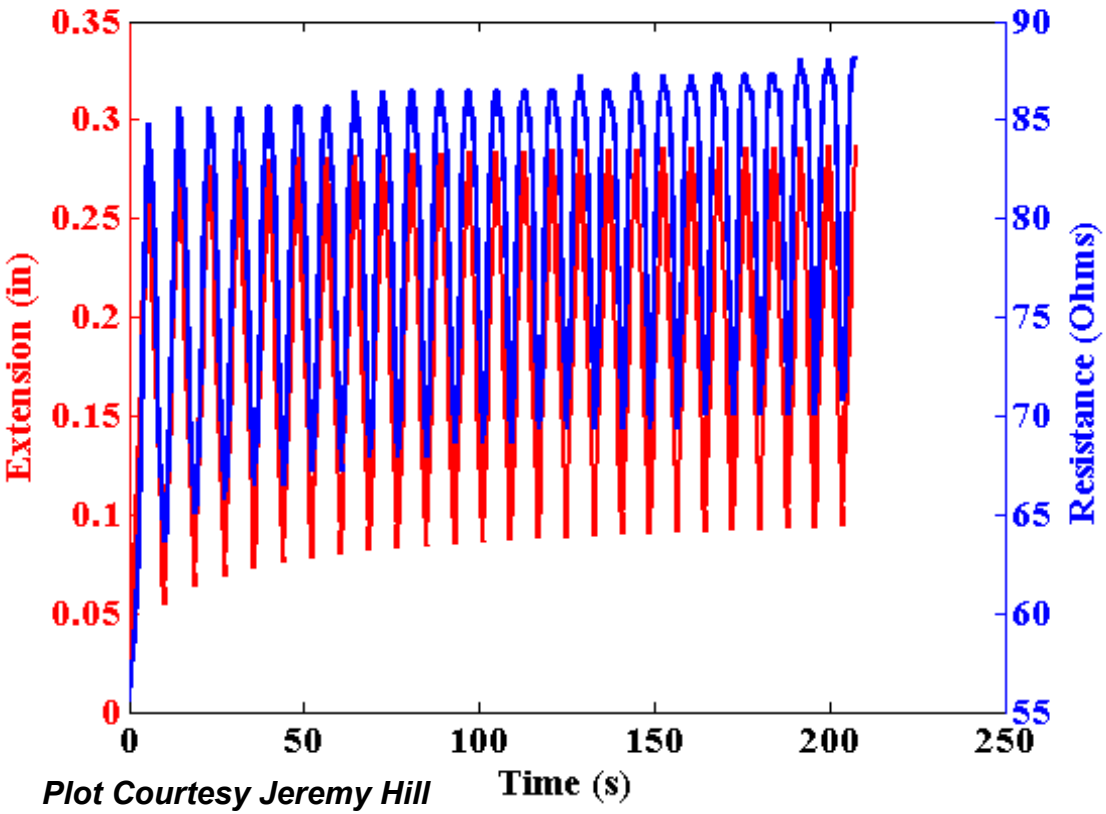




Strap Load Measurements

Metal Rubber Strain Gages

- High Elasticity (Capture Strains up to ~50%)
- Low Profile Sensor
- Low TRL
- Co-located on Wind Tunnel Models With Strap Tension Gages



Plot Courtesy Jeremy Hill

Load Frame Testing of Sensor

Surface Pressure Measurements

Challenging to Obtain Pressure Measurements on Flexible Substrates

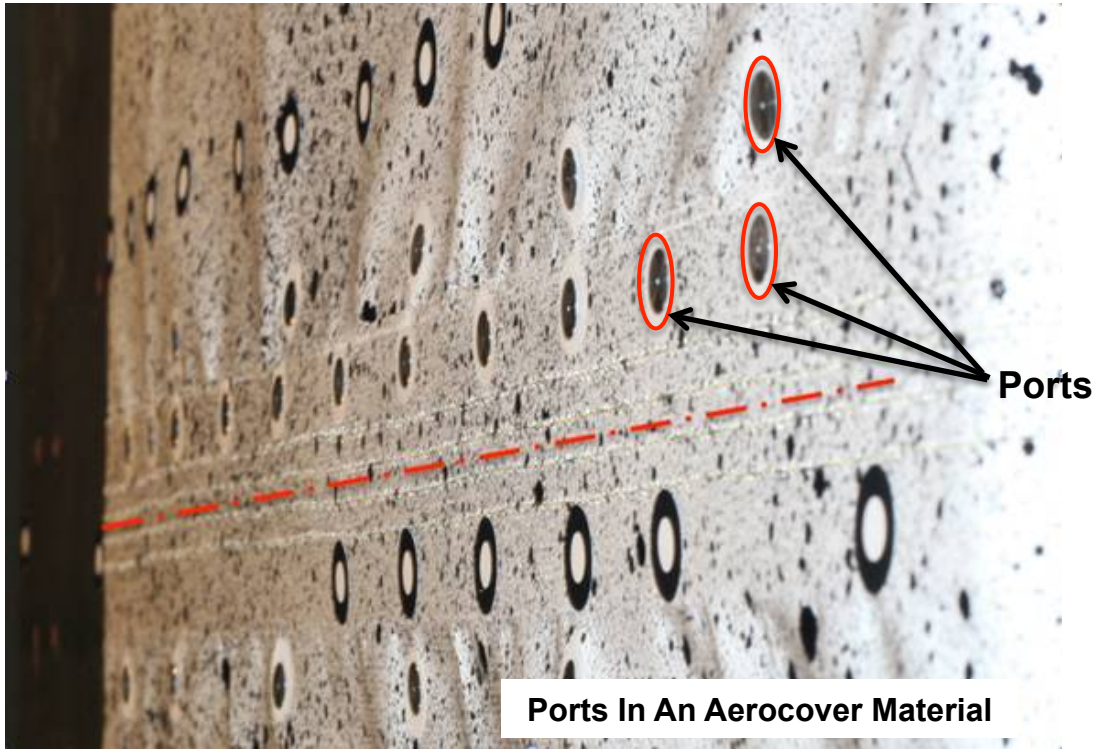
Machined Pressure Ports:

- Made from stainless steel with a 0.020” port hole, and 0.040” OD tubing.
- A brass washer is also machined to provide a backing to the pressure port.
- The tubing mates with a 0.04” pressure tubing.

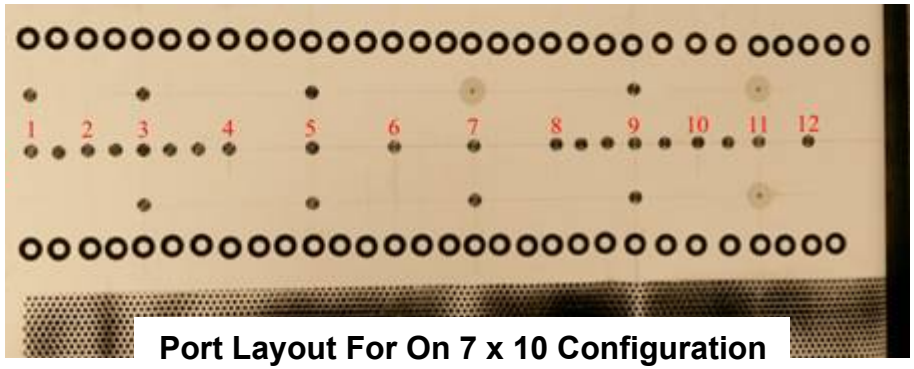
Top View

Disassembled View

Backside View



Ports In An Aerocover Material

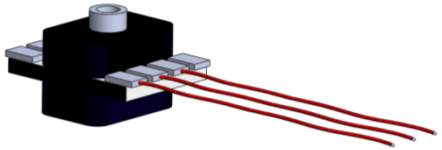


Port Layout For On 7 x 10 Configuration

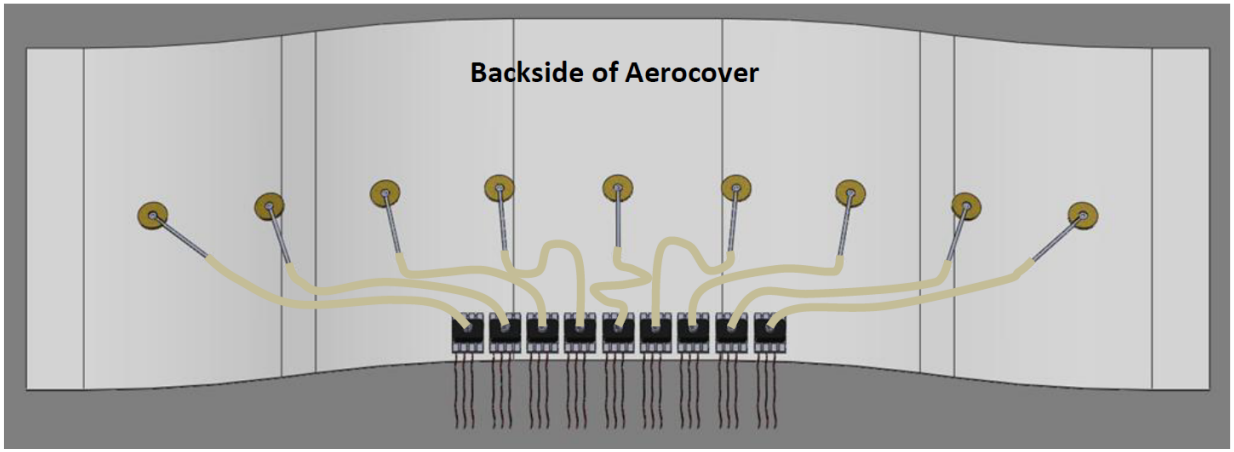
Surface Pressure Measurements

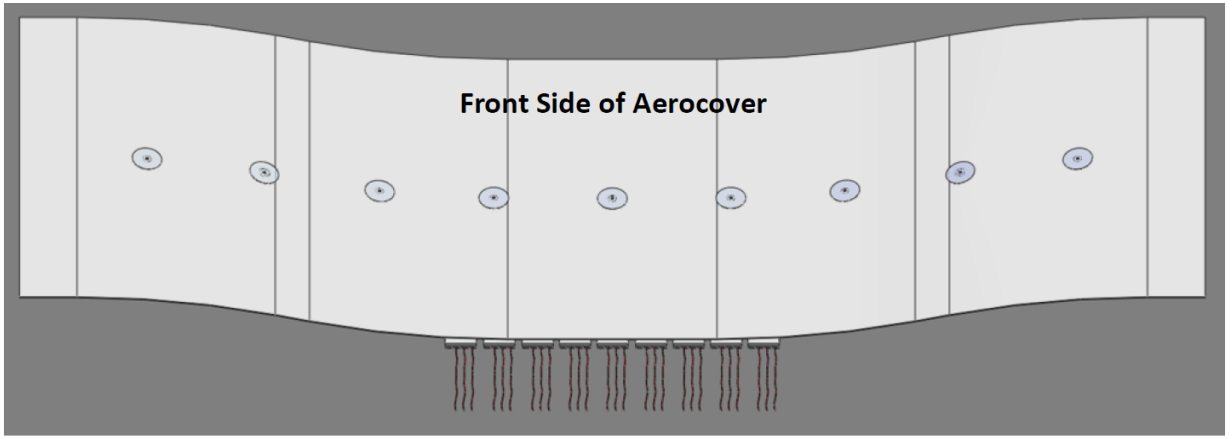
High Frequency Pressure Measurements

- Ports will be placed between two adjacent tori to get high frequency measurements along a scalloped region.



MEMS Pressure Transducer

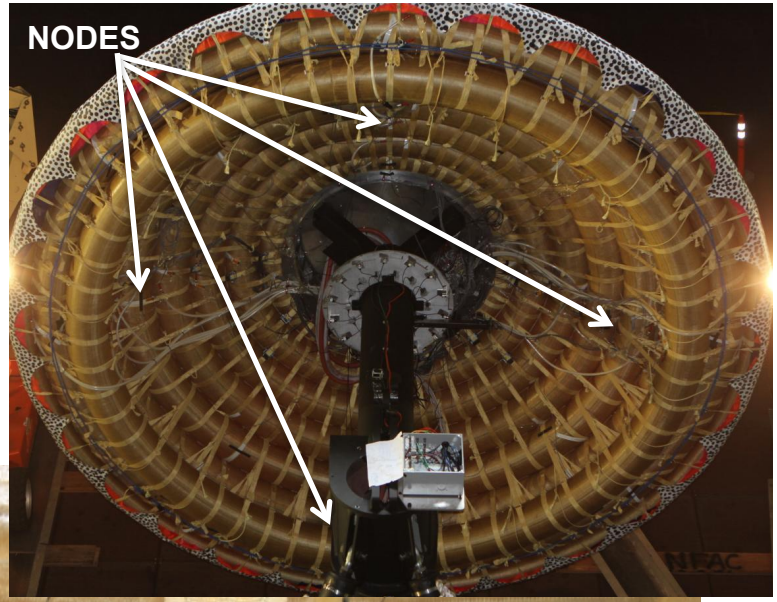


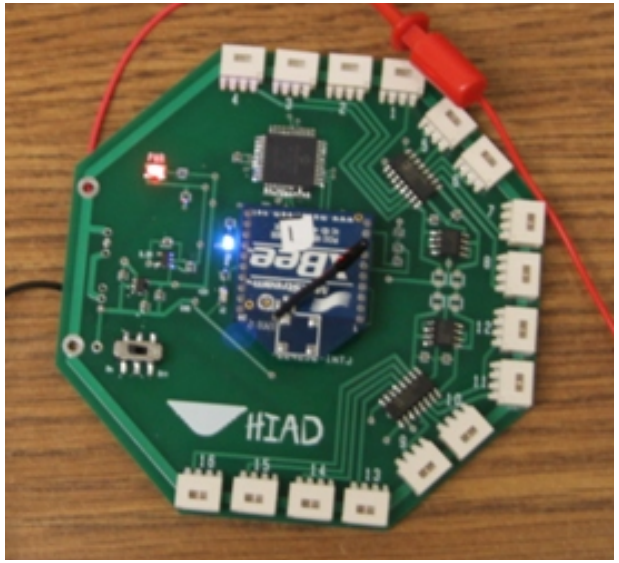


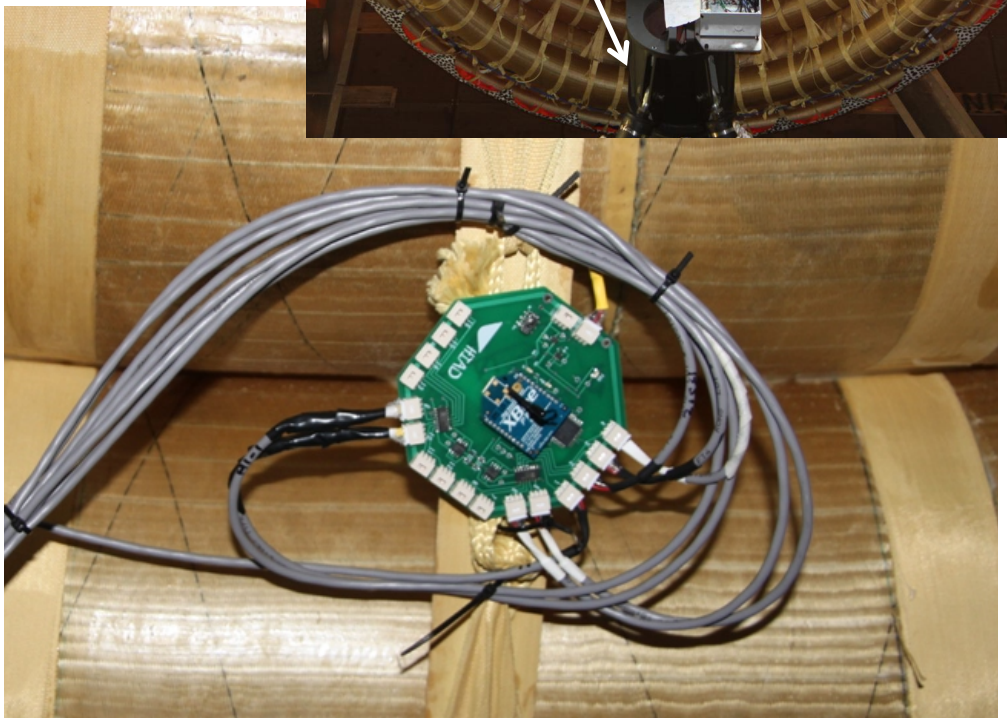
Custom Wireless Data Acquisition

Wireless Data System for HIAD Testing

- Four custom wireless nodes (up to 16 channels each) will condition the response from the bend sensor arrays, metal rubber strain gages, and thermistors
- Each wireless node will transmit to a solitary base station located in the NFAC T-frame (under the base of the tunnel floor







Instrumentation Overview

Instrumentation (~400 Measurements)

MEASUREMENT	INSTRUMENTATION	PURPOSE	# OF SENSORS	PRIORITY
Model Static Deformation	Photogrammetry	Flexible Structure Characterization	4 Camera Pairs	Primary
Dynamic Loading / Strap Loads	Strap Tension Gages	Safety Monitoring / Model Validation	21	Primary
Model Forces & Moments	NFAC Balance	Safety Monitoring / Aero Measurements	Balance System	Primary
Inflation Pressure	Pressure Transducers	Variable Inflation Feedback	9	Primary
Nosecone Pressure	Pressure Scanner	Model / AoA Validation	13	Primary
Aeroshell Pressure	Pressure Scanner	CFD Model Validation	105	Primary
Tunnel Wall Pressure	Pressure Scanner	CFD Anchoring	150+	Primary
Structural Strap Loads	Load Pins	Model Validation	8	Primary
Model Surveillance	HD Video	Model Surveillance	4	Primary
Aeroshell Dynamic / Static Deformation	Angular Transducer	Flexible Structure Characterization	14	Secondary
Aeroshell Dynamic / Static Deformation	String Potentiometer	Flexible Structure Characterization	14	Secondary
Aeroshell High Frequency Pressure	MEMS Pressure Sensors	Proof of Concept / High Freq Content	10	Secondary
Dynamic Response	Accelerometers	Deflection Monitoring	8	Secondary
Aero Cover Deflection	Bend Sensors	Flexible Structure Characterization	14	Secondary
Structural Strap Strain	Elastomeric Strain Gages	Model Validation / Tech Maturation	10	Secondary
Temperature	Thermistors	Characterize Sensor Thermal Environment	6	Secondary
Focused Video Inspection	HD Video (GoPro)	Detailed Surveillance	3	Secondary

Acknowledgements

NASA LaRC
Neil Cheatwood
Anthony Calomino
Steve Hughes
Keith Johnson
Sean Hancock
John Van Norman

Everyone at the NFAC

NASA ARC
Alan Cassell
Jeff Brown
Bill Quach

HDT/Airborne
Brian Gilles
David Jurewicz
Paul Anderson
Glenn Brown