In-situ Strain and Deformation Measurements of Inflatable Aeroshell Test Articles

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BACKGROUND & MOTIVATION

➢Hypersonic Inflatable Aerodynamic Decelerators (HIADS)

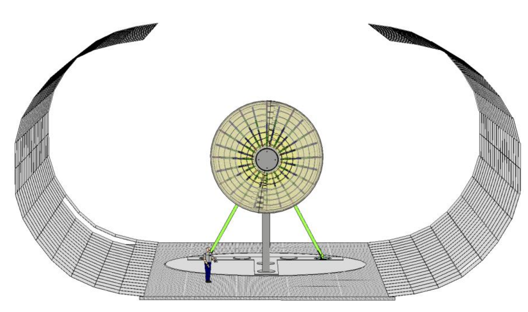
HIADs expand the options for payloads entering planetary bodies with an atmosphere by greatly lowering ballistic coefficient of an entry vehicle. As part of a broad technology maturation plan, wind tunnel testing for large scale HIADs (6 m – 8.5 m) is underway to develop design, analysis, manufacturing, and assembly techniques for inflatable aeroshell structures. New instrumentation concepts are considered for purposes of measuring strain and deformation on the flexible aeroshell. One piece of developmental instrumentation explored, elastomeric strain gauges, is discussed below.

➢Large Scale Wind Tunnel Test Series

National Full-Scale Aerodynamics Complex (NFAC)

✓Primary Objectives

Characterize the HIADs response to changes in dynamic pressure and angle of attack over a range of expected flight conditions.

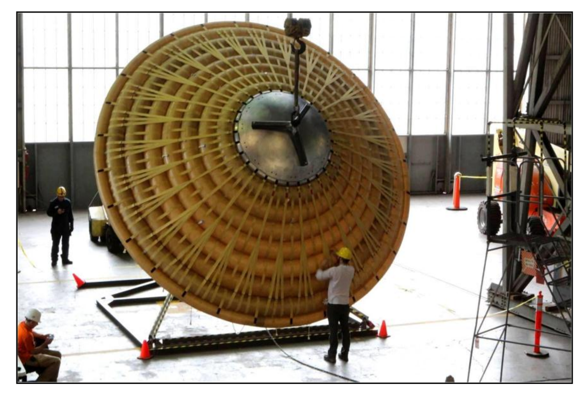


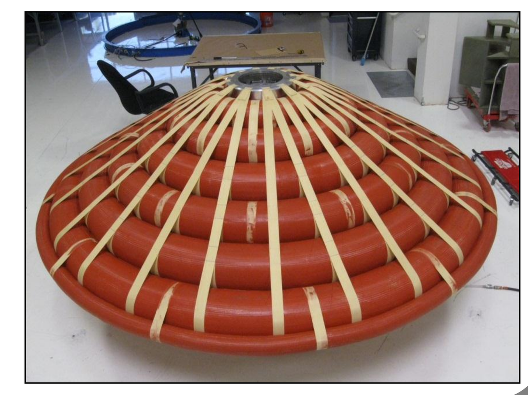
✓Secondary Objectives

Determine effects of variations in internal pressure on the structural stiffness, measure hysteresis of HIAD deformation, and evaluate developmental instrumentation.

➢HIAD Structure Overview

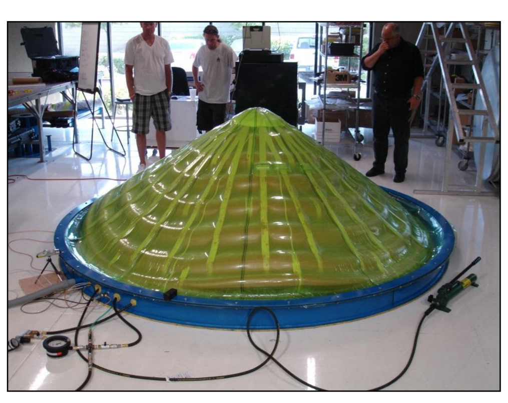
The HIAD structure mainly consists of inflatable tori joined together by structural Kevlar straps that are attached to the center body. Adjacent tori are also joined together. An aerocover is laid and tensioned over the top of the tori and straps, but is not shown below.





DEVELOPMENTAL INSTRUMENTATION

STRAIN IN FLEXIBLE MATERIALS



➢Structural and Toroid Straps

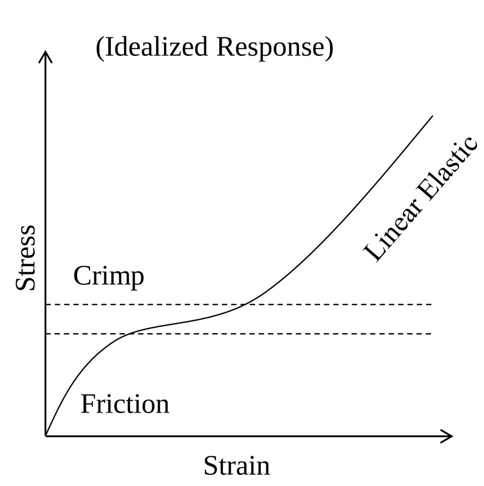
➢Main Straps (1.75", 4000lbf)

➢Toroid Straps (2", 2000lbf)

Inadequate or uneven tension in the Kevlar straps leads to undesirable aeroshell deflections

➢Material Modeling for Inflatable Structures

Fabrics responses differ from traditional solid mechanics. Friction, Crimp Interchange, Slip, and Locking are common terms used to describe fabric behavior. Understanding these different behaviors is important to the developing of an appropriate aeroshell material model.



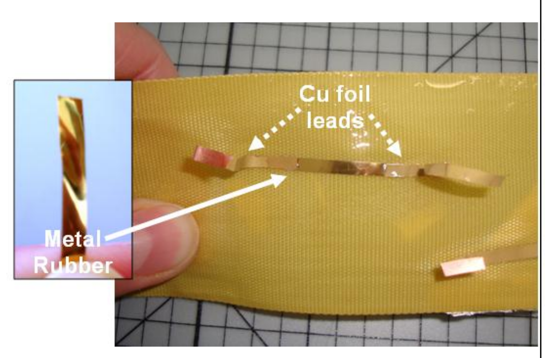
Most inflatable aeroshell models assume a planar orthotropic material

$$\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{Bmatrix} = \begin{bmatrix} 1/E_1 & -\nu_{12}/E_2 & 0\\ -\nu_{21}/E_1 & 1/E_2 & 0\\ 0 & 0 & 1/G_{12}\end{bmatrix}\begin{Bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{Bmatrix}$$

ELASTOMERIC STRAIN GAUGES

➢In situ Strain Measurement

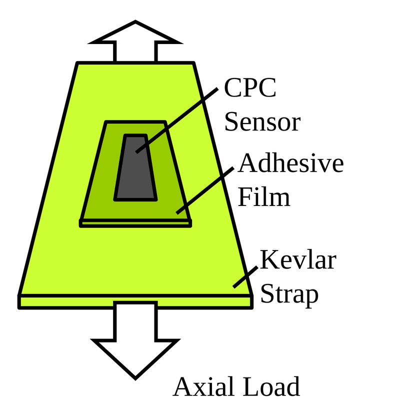
Traditional strain sensors are not compatible with deformations of textile fabrics.



- ✓ Standard foil resistive gauges can measure strain of up to 2.5%
- ✓ Highly flexible structures can experience strains >> 10%

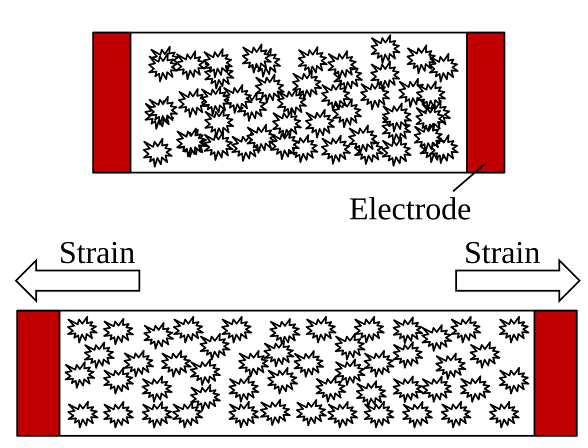
➢Metal Rubber™ by Nanosonic

- ✓ High electrical conductivity of metal
- ✓ Low Modulus of elastomers (~0.1 MPa)



➢Conductive Polymer Composites

Nanocomposite material that consists of electrically conducting nanoparticles and non-conducting polymers. The electrical resistance responds to the applied mechanical strain.



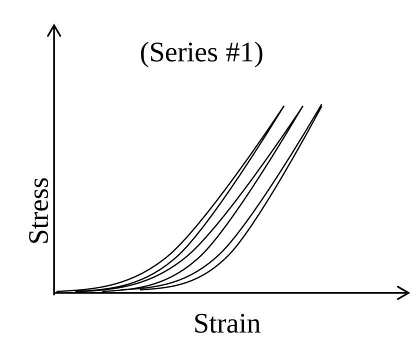
TEST GOALS & OBJECTIVES

- ✓Material Characterization
- ✓Sensor Calibration
- ✓Integration of Sensor onto Fabric
- ✓Effects of Strain Rate on Sensor (Deployment & Entry)
- ✓Effects of Cyclic Loading on Sensor (Hysteresis)
- ✓Effects of Temperature/Humidity on Sensor (Environment)
- ✓Effects of Folding/Packaging on Sensor (Durability)
- ✓Effects of Aging on Sensor (Storage)

➢Tensile Testing for Characterization of MR™ in a Simulated Loading Environment

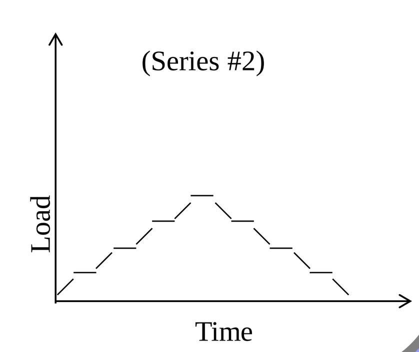
Qualitative Objectives

1. Facilitate understanding of integration issues into future flight test articles



Quantitative Objectives

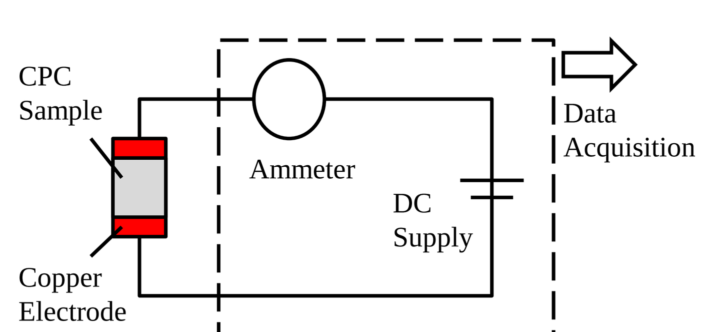
1. Test durability of sensors when subjected to cyclic and extended loading
2. Determine accuracy of sensors when subjected to cyclic and extended loading
3. Determine the influence of the sensors on the material properties of the straps



EXPERIMENTAL SETUP

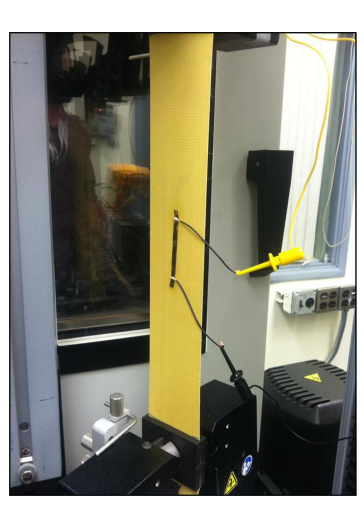
➢Test Conditions for Cyclic and Extended (Ramp) Loading

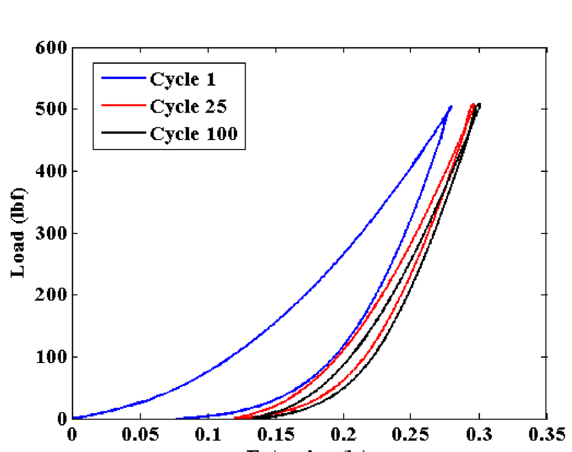
Several ASTM standards were combined to design this test series. For cyclic loading, 5 samples are taken up to a maximum load of 1000 lbf for 100 cycles each. For extended loading, 5 samples are ramped up to a maximum load of 1000 lbf and back down in 7 steps. Each step is held for 10 min. The strap's gauge length is 10".



➢MR™ Strain Sensor Attachment Summary

Wire leads were attached to either end of the MR™ sensors. The sensors were adhered to the central region of the uncoated straps. The sensors had gauge lengths of 1". The adhesive was a specialty urethane system with similar modulus to the sensors and is very durable. The baseline resistance was nominally 50 Ω.





➢Conditioning Structural and Toroid Straps

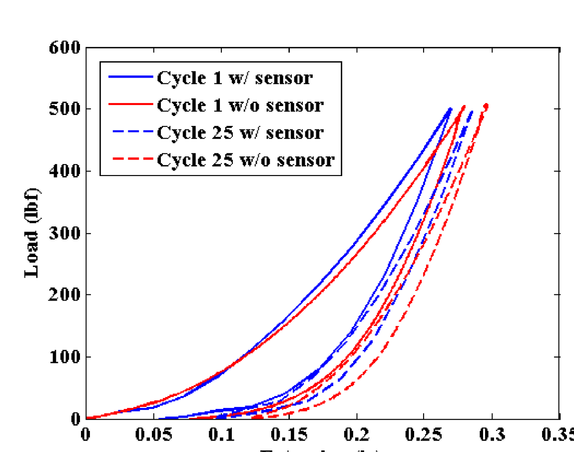
Pristine straps need to be cycled in order remove most of the hysteresis. The straps used on the actual HIAD test model are cycled prior to being applied.

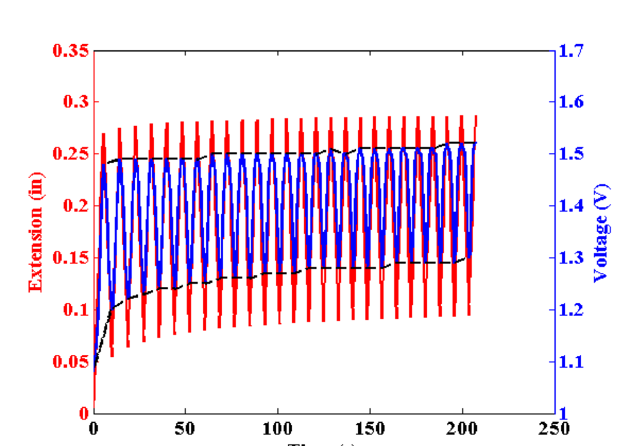
- ✓ First cycle exhibits strong signs of hysteresis
- ✓ Later cycles exhibit less of a bi-linear response
- ✓ ~50% Strain Set

RESULTS & DISCUSSION

CYCLIC LOADING – Load vs. Time (Left), Extension vs. Time (Right)

Integration of the sensor is important for ease of application and to ensure that the sensor is not intrusive on the strap's material properties. It can be seen that sensor has the effect of a small increase in stiffness.

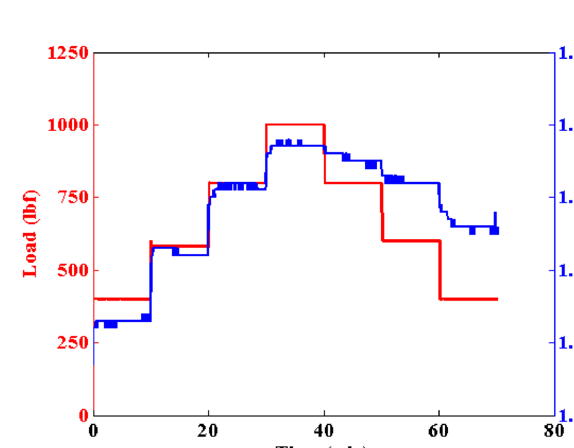


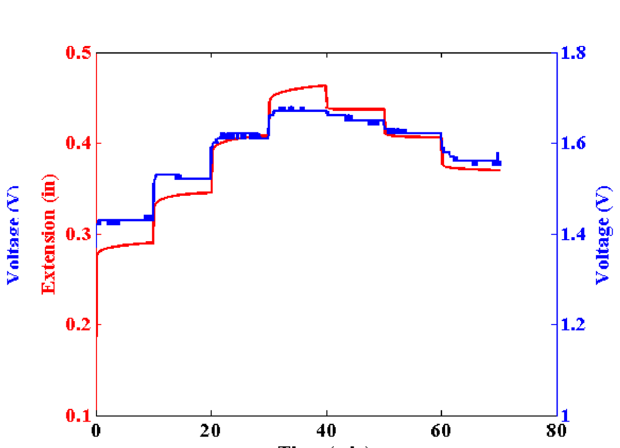


The figure on the right shows the cyclic extension and output voltage plotted vs. time for the 2" straps. Only the first 25 cycles are shown in order to better show the comparison. It can be seen that the output voltage follows extension well. In cases when the extension is not known a priori, the voltage can be converted into extension via a gauge factor. This is particularly useful for flight test articles or test requiring in situ measurements.

RAMP LOADING – Load vs. Time (Left), Extension vs. Time (Right)

The results for the extended loading indicate that the sensors do not perform as well over extended periods of time. The voltage follows the extension much better during the ramp up than the ramp down phase.





CONCLUSION

Obtaining strains and deformations in the flexible test articles used for the NFAC testing is a difficult task. The material properties can be obtained from experimental testing, but the complexity of the structure makes obtaining valuable information difficult. In situ strain measurement techniques for these materials are not ready for use on the NFAC models. In order to move toward this goal, the above developmental strain measurement instrumentation was considered for future testing. An initial feasibility study was conducted to determine whether or not this technology should be considered. A series of uniaxial tension tests were run with the flexible strain sensor applied to the HIAD's structural straps. The types of testing were chosen based on characteristics necessary for inclusion on future test articles. The preliminary results are promising for the strain sensors; showing that they are able to repeatedly measure the strain in the straps over many cycles. The sensors did not perform as well during the extended loading tests. Future work includes working with the company to fix these issues, as well as, create a series of tests to address the remaining tests goals outlined above.

ACKNOWLEDGMENTS

➢David Hash, NASA Ames

➢Tammy Harrison, NASA Ames, EAP

➢Jerry Ridge, NASA Ames

➢Andrea Hill, NanoSonic Inc.

➢Cole Corbin, NASA LaRC

➢Brandon Smith, NASA Ames