Instrumentation Needs of Inflatable Space Structures

Doug Litteken
NASA Johnson Space Center
douglas.litteken@nasa.gov

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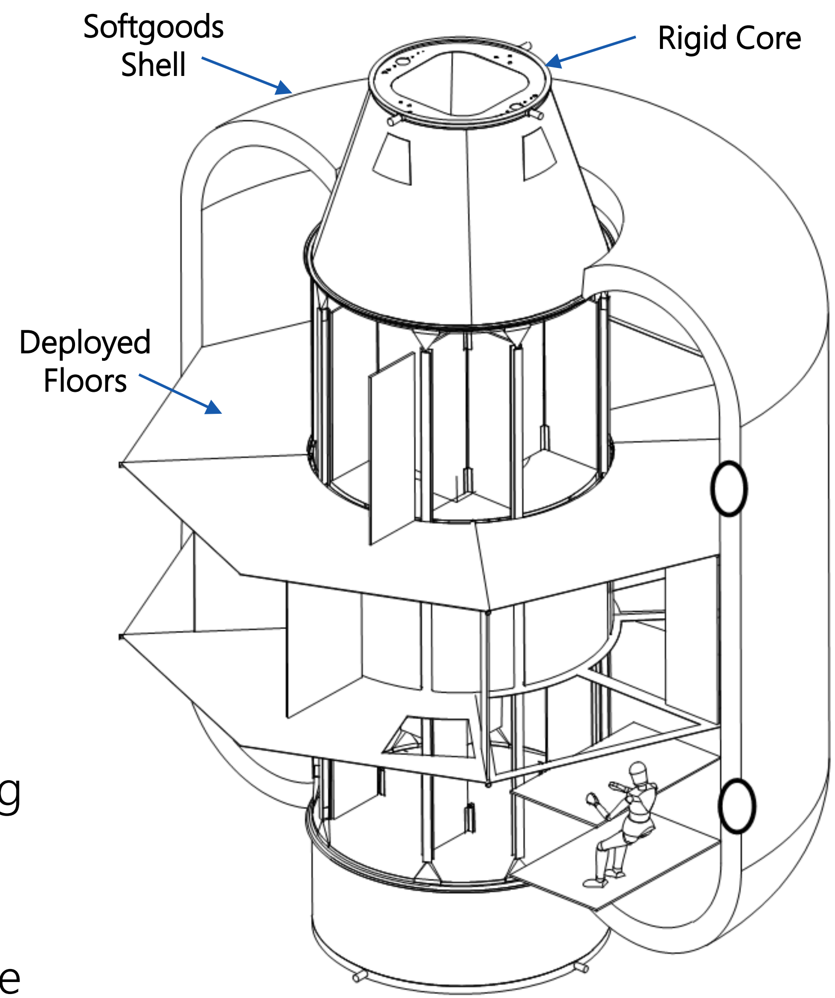
What is an inflatable structure?

Inflatable Module Design

- Inflatable habitats are fabric based pressure vessels, composed of multiple materials stacked in a layered configuration for structure, pressure, micro-meteoroid and thermal considerations
- Fabric layers can be packed tightly for launch and expanded in orbit, providing significant volume savings
- Typically contains a rigid 'core' with softgoods shell pressure wall surrounding
- Internal components are installed on the ground inside the core and secondary structure is deployed and outfitted by the crew after inflation of the module



NASA TransHab Module

Inflatable Structures History

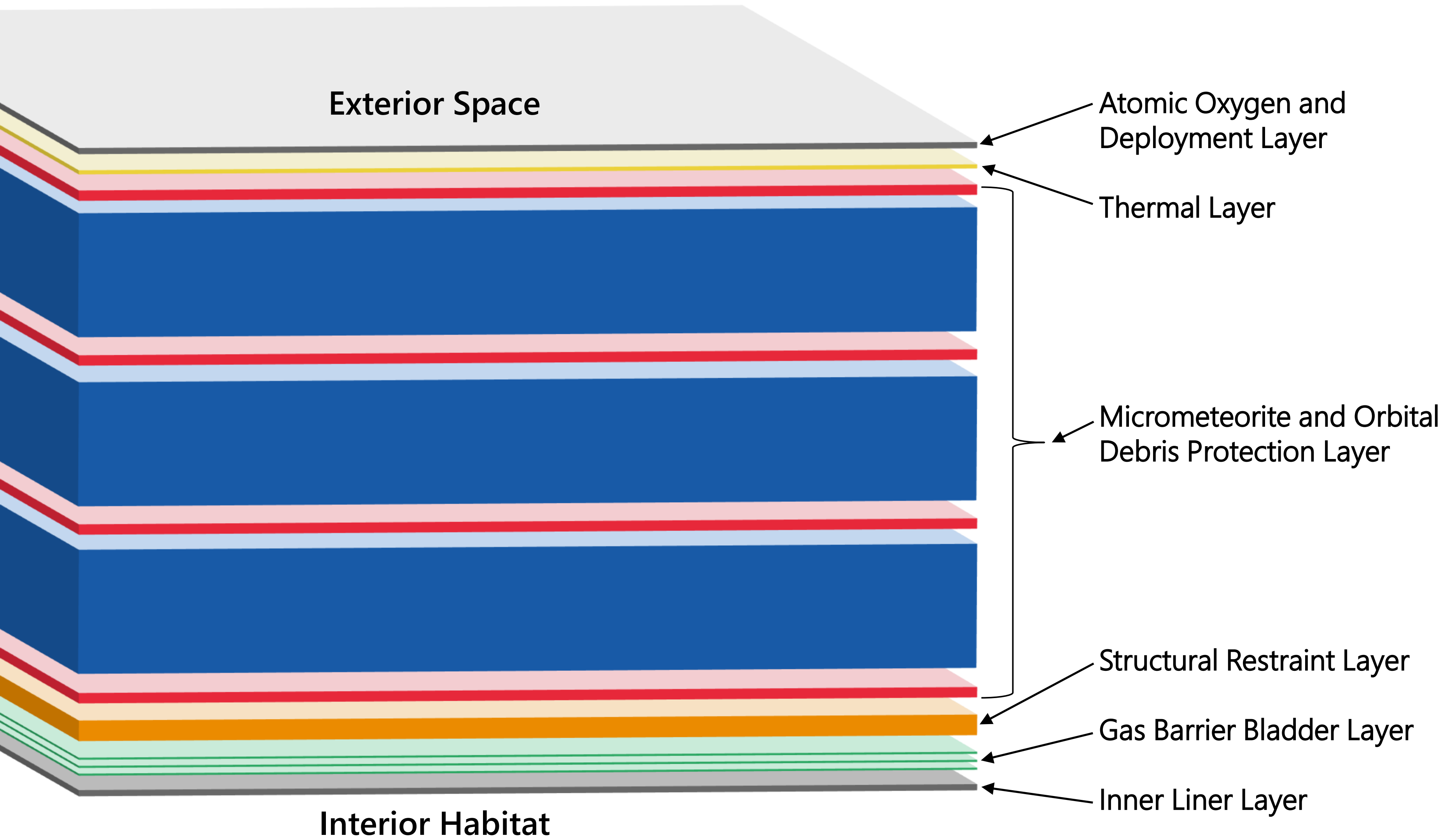
- **TransHab (1990's)**
  - Originally designed for Mars transit
  - 25-ft diameter x 3 stories high
  - Morphed into ISS Design
- **Bigelow Aerospace (1999+)**
  - Launched two sub-scale modules (Genesis I, 2006) and (Genesis II, 2007)
  - BEAM launched on SpaceX-8 berthed to ISS in April and inflated in May 2016, continuously operated and occupied by crew ever since
  - 10.5-ft diameter x 13-ft long
  - Technology demonstrator on ISS with potential for equipment testing in space
- **NextSTEP (2014+)**
  - Commercial habitat concepts for cis-lunar architectures
  - Multiple companies looking at utilizing inflatables as habitats and airlocks
  - Concepts being developed into Gateway habitat module

NASA TransHAB Module

Bigelow BEAM on ISS

How are inflatables made?

Inflatable Module Shell Layers



What are the structural health monitoring needs of an inflatable?

Inflatable SHM Needs

- Structural health monitoring (SHM) needs of an inflatable are not much different than that of a metallic module
  – Impact detection
  – Leak detection
  – Thermal control
  – Radiation monitoring
  – Structural strength
- How does a *softgoods* pressure wall change these measurements?
  – Can fabrics protect against hyper-velocity impacts?
  – Are polymers more susceptible to leaks?
  – Is there enough insulation to maintain internal temperature?
  – Does the shell provide any radiation protection?
  – How are loads being carried through the structure?

Inflatable Module Shell Layers

Atomic Oxygen and Deployment Layer

- **Material:** Required for low Earth orbit, typically Beta Cloth. Used to cinch the shell layers for launch.
- **Sensor Needs:** Detect, identify and locate damage. Monitor deployment shape.

Thermal Layer

- **Material:** Helps minimize large thermal gradients. Typically multiple layers of aluminized Kapton, aluminized Beta Cloth.
- **Sensor Needs:** Detect, identify and locate damage, monitor thermal performance.

MMOD Layer

- **Material:** Stacked layers of high strength debris shields. Typically ceramic fabric layers with Kevlar sheets as rear wall with foam stand-off between layers.
- **Sensor Needs:** Detect, identify and locate damage size and depth of damage in real-time and post-impact.

Instrumentation focus of outer layers is impact detection and damage assessment

Inflatable Module Shell Layers

Exterior Space

Interior Habitat

Structural Restraint Layer

- **Material:** High strength fabrics that carry the structural pressure load. Typically Vectran or Kevlar.
- **Sensor Needs:** Detect, identify and locate damage in real-time and post-impact. Measure strap load/strain in real-time over long periods of time.

Bladder Layer

- **Material:** Flexible at low temps, low permeability, single or multi-layered, oversized, able to be manufactured (seam). Typically polymer or metallized film.
- **Sensor Needs:** Detect, identify and locate damage, monitor thermal performance, monitor condensation or humidity levels to prevent microbial growth.

Inner Liner Layer

- **Material:** Flame Resistant, puncture resistant. Typically Nomex, Kevlar felt.
- **Sensor Needs:** Detect, identify and locate damage.

Instrumentation focus of inner layers is structural performance and thermal control

What about the BEAM module?

Are there any sensors on BEAM?

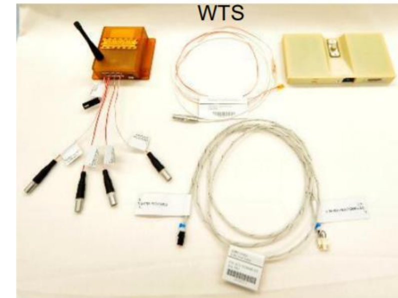
BEAM Installation Video

BEAM Installation Video, from NASA Johnson YouTube Channel:
https://www.youtube.com/watch?v=VopaBsuwikk

BEAM Sensor System Overview

- Distributed Impact Detection System (DIDS)
  - Detects structural impacts using piezoelectric accelerometers on inner surface
- Deployment Dynamics Sensors (DDS)
  - Records acceleration loads during inflation using accelerometers on bulkheads
- Wireless Temperature Sensors (WTS)
  - Monitors temperature of inner surface using thermocouples
- Radiation Environment Monitor (REM)
  - Monitors radiation environment internal to BEAM structure
- Radiation Area Monitor (RAM)
  - Passive radiation monitoring badges

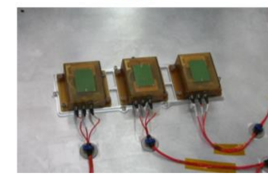
Data and images provided by G. Valle and N. Wells:
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180006494.pdf

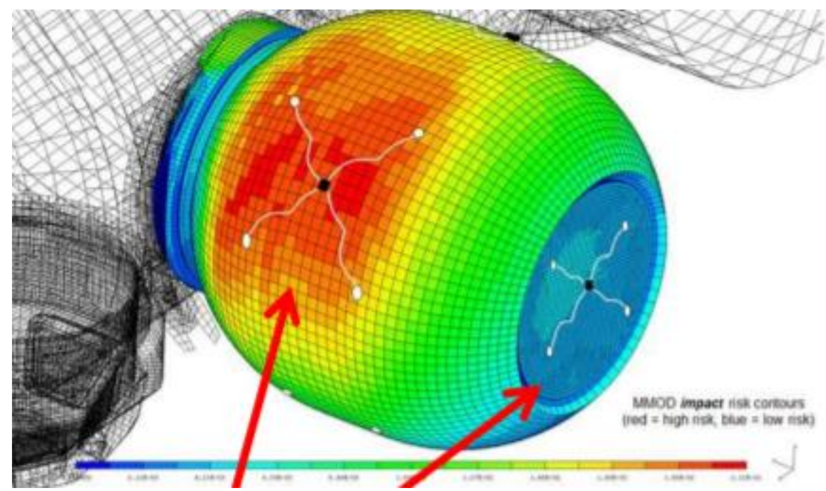


REM

RAM

DDS





Example of Impact Detection Reading

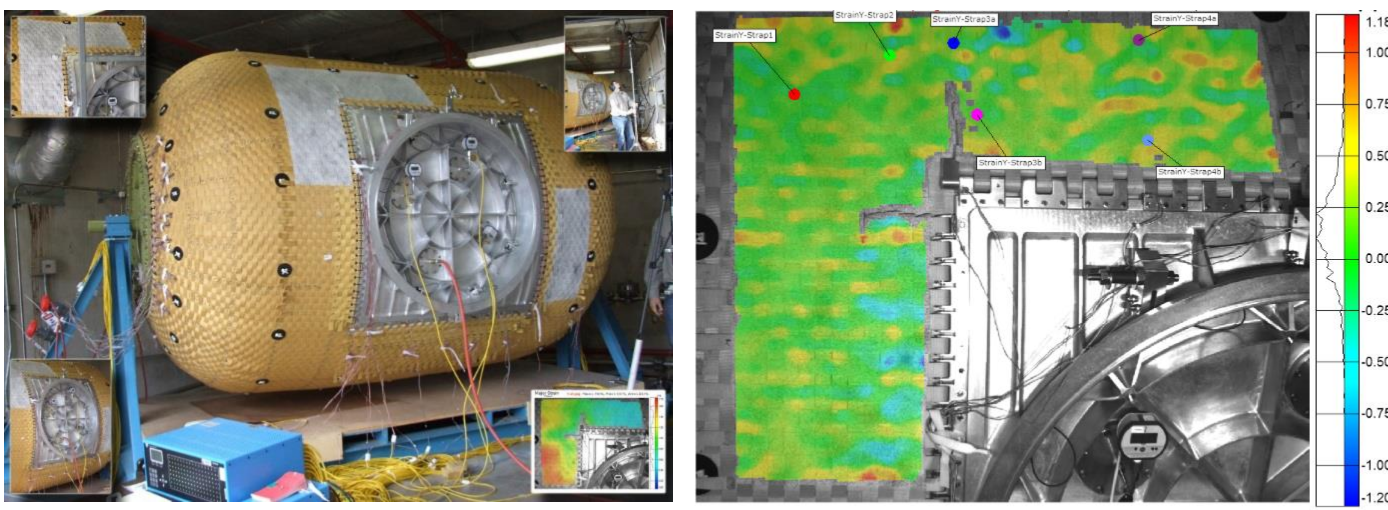
What about the structural restraint layer?

Structural Restraint Layer

- NASA's inflatable modules are made from Kevlar and Vectran materials due to their high strength-to-weight ratio
- These materials are not isotropic and do not behave regularly like metals
- Both materials have a known creep problem, where they fail prematurely after being loaded for extended periods of time
- A lack of manufacturing standards in the industry and poor understanding of the stress state of these materials creates a wide range of material properties for analysis
- This leads NASA to require an inflatable to be designed to a factor of safety of 4, which creates an inefficient and over-conservative design
- **Better strain monitoring techniques will help in evaluating the performance of these materials and monitoring them during flight**

SHM of Restraint Layer

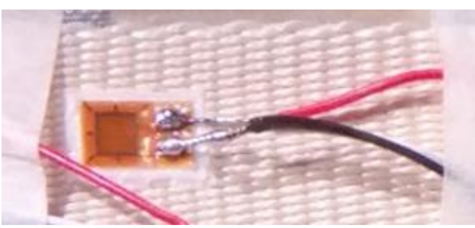
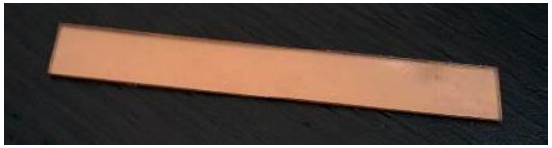
- Current ground testing strain monitoring for fabrics uses optical measurement systems
- Photogrammetry/digital image correlation (DIC) uses a dual camera system and speckle pattern to measure the strain on the fabric layer
- DIC provides very accurate and reliable results, but can only be used o ground testing when the outer layers are removed



Photogrammetry Setup (Left) and Results (Right) from Pressurization Test Showing Strain in Straps
(D. Litteken et al, 2012, AIAA Structures)

SHM of Restraint Layer

- Other systems (non-optical) have been evaluated for strain measurement, with varying results
- Most devices are resistance or capacitive based stretch sensors that can be integrated into the restraint layer (as shown below)
- Fiber optic systems have also been evaluated with promising results

High Elongation Foil Strain Gage	**Conductive Paint/RTV**	**Conductive Thread Coverstitch**
		
Conductive Polymer Cord	**NanoSonic Metal Rubber**	**StretchSense Fabric Sensor**
		

(D. Litteken et al, 2017, AIAA Structures)

Collecting the data and evaluating it in real time is the biggest hurdle

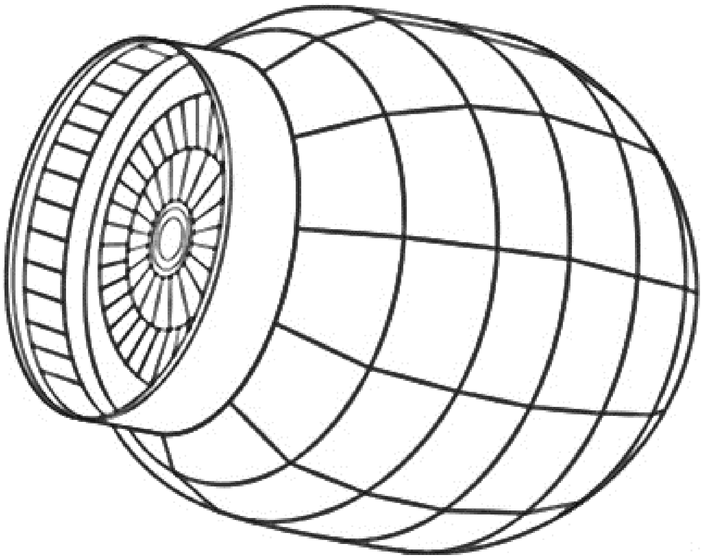
The “Smart” Inflatable

Impact Detection
- Triangulate impact location
- Measure size and depth of impact damage
- Notify crew of potential damage for repair

Leak Detection and Prevention
- Triangulate leak location
- Measure size and leak rate
- Notify crew of pressure leak
- Utilize self-healing materials to prevent leaks

Temperature & Humidity Monitor
- Monitor temperature and humidity levels of bladder layer
- Notify crew if cleaning is required

What would it look like if we had it all?



Radiation Monitor
- Monitor radiation levels inside habitat at various locations
- Warn crew of impending solar storm/increased activity

Structural Monitoring
- Measure load in the restraint layer
- Capture changes in load over time
- Identify and locate any highly loaded straps or stress concentrations
- Warn crew of potential pending failures

Acceleration Monitoring
- Measure movement of structural bulkheads and softgoods layers
- Monitor layers during deployment
- Measure acceleration loads from docking or operation loading
- Warn crew of potential pending failures

We need your help to make this a reality!

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