Inflatable Habitat Inspection Needs

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In-Space Inspection Workshop
Session 3a-4, January 31, 2017

Overview

- Inflatable Structure Brief History
- Inflatable Module Shell Layers
  - Shell Layer Inspection Needs
- Flight Testing Inspection Needs
- Ground Testing Inspection Needs
- Inspection Hardware Needs

Inflatable Structures Brief History

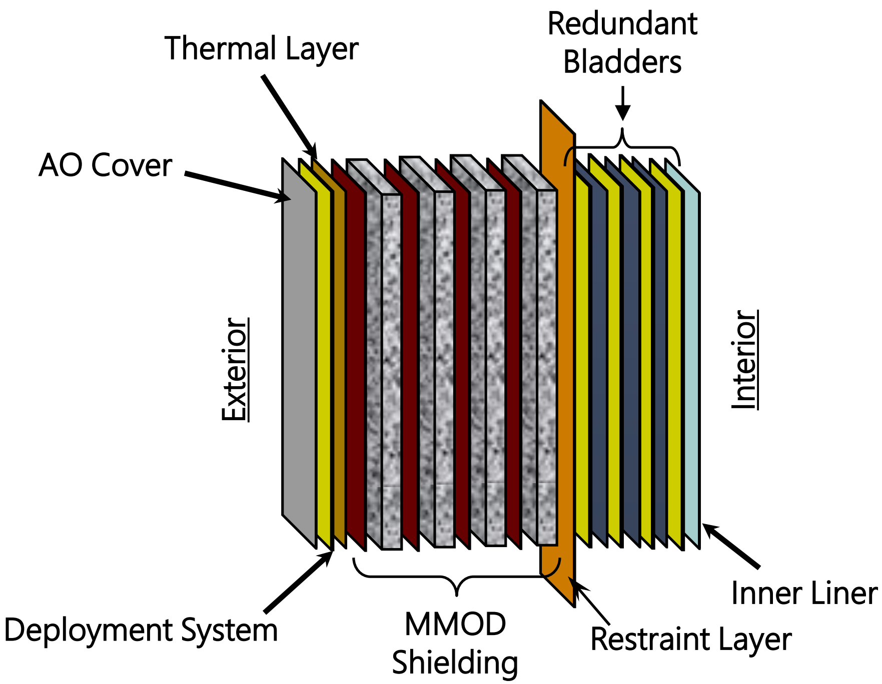
- Inflatable habitats are fabric based pressure vessels, composed of multiple layers of materials
- Fabric layers can be packed tightly for launch and expanded in orbit, providing significant volume savings
- TransHab (1990's)
  - Originally designed for Mars transit
  - 25-ft diameter x 3 stories high
  - 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, currently planned for 2-year mission
  - 10.5-ft diameter x 13-ft long
  - Technology demonstrator on ISS that potential for equipment testing in space
- NextSTEP (2014+)
  - Commercial habitat concepts for cis-lunar and Mars architectures
  - Multiple companies looking at utilizing inflatables as habitats and airlocks

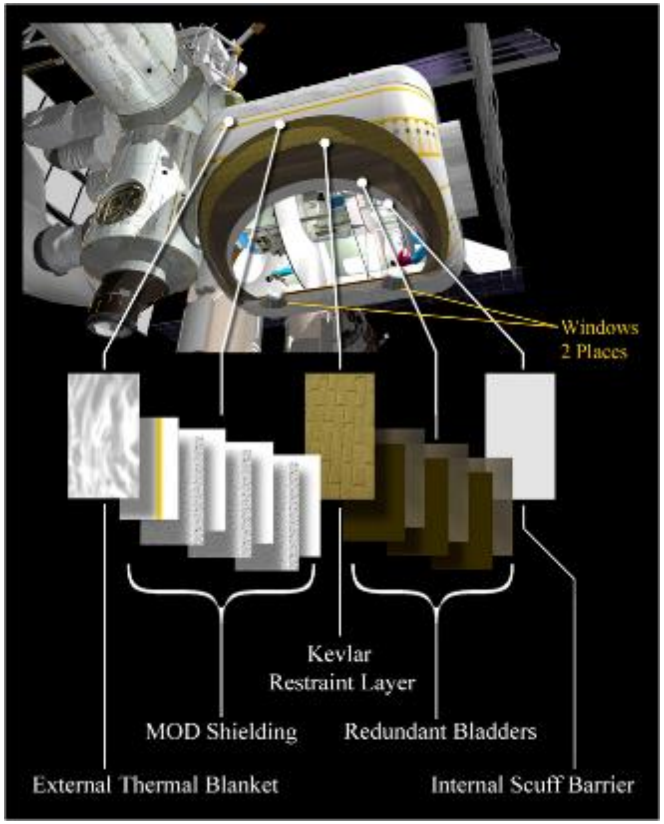
NASA TransHAB Module

Bigelow Genesis Module

Inflatable Module Shell Layers

- Habitat is composed of high strength materials, stacked in a layered configuration for structure, pressure, micro-meteoroid and thermal considerations





TransHAB Layer Configuration

Shell Layers Inspection Needs

Inner Liner

Material Needs

Flame Resistant, puncture resistant. Typical Nomex, Kevlar felt.

Inspection Needs

Detect, identify and locate damage.

Consideration

May have to be removed to perform a through inspection of the bladder.

Bladder

Material Needs

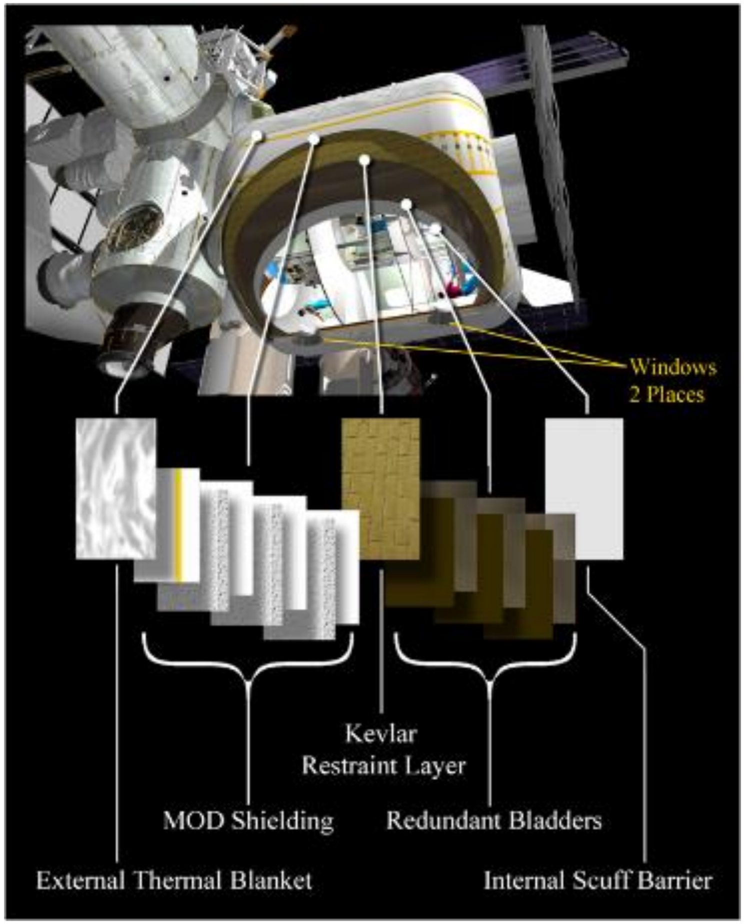
Flexible at low temps, low permeability, single or multi-layered, oversized, able to be manufactured (seam). Typical polymer film.

Inspection Needs

Detect, identify and locate damage.

Consideration

Some low permeable layers may have a metalized layer which may cause inspection challenges. Seeing through metalized layers is beneficial.



TransHAB Layer Configuration

Shell Layers Inspection Needs

Restraint Layer

Material Needs

High strength fabrics that carry the structural pressure load. Typical Vectran or Kevlar.

Inspection Needs

Detect, identify and locate damage in real-time and post-damage. Measure strap load/strain in real-time.

MMOD Layers

Material Needs

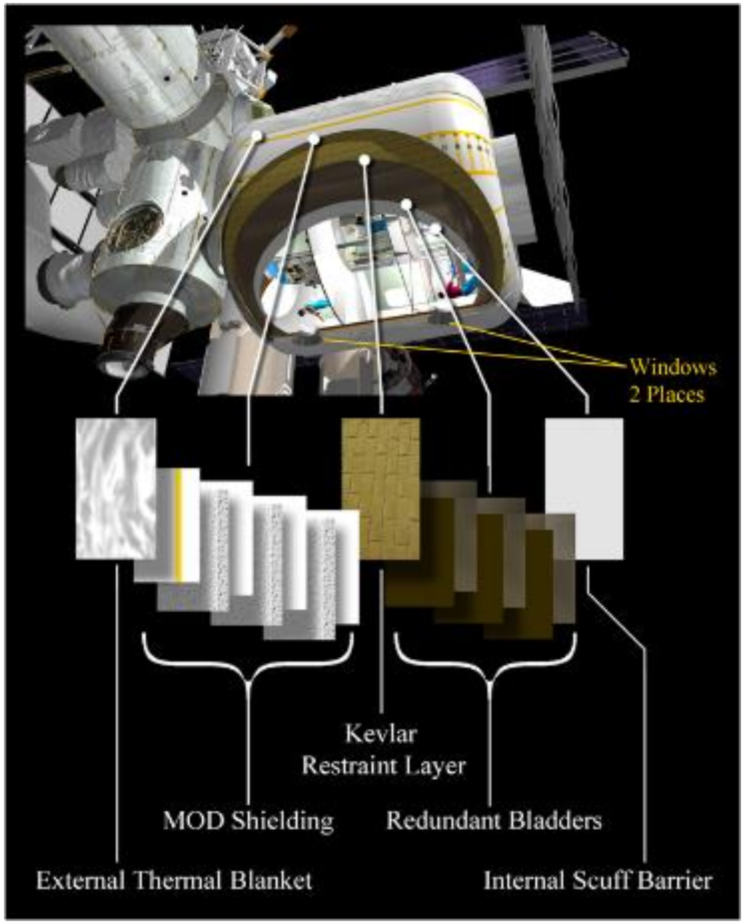
Stacked multiple layers of high strength debris shields. Typical ceramic fabric layers with Kevlar sheets as rear-wall. More efficient with standoff between layers.

Inspection Needs

Detect, identify and locate damage size and depth of damage in real-time and post-impact.

Consideration

May be separated by cored out open cell foam possibly in vacuum packed bags. Orbital debris protection required for LEO drives shield size and mass.



TransHAB Layer Configuration

Shell Layers Inspection Needs

Thermal Layer

Material Needs

Helps minimize large thermal gradients. Typical multiple layers of aluminized Kapton, aluminized Beta Cloth.

Inspection Needs

Detect, identify and locate damage, monitor thermal performance.

Consideration

Seeing through metalized layers is desirable.

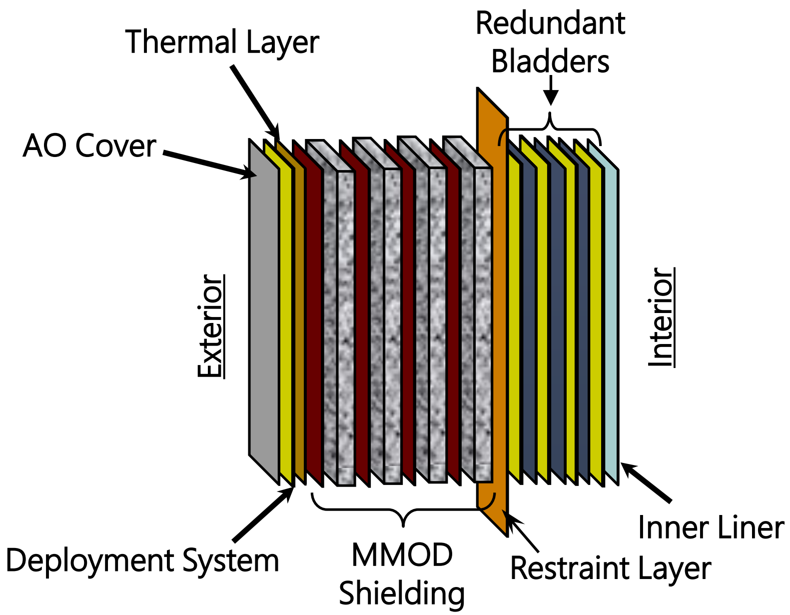
Deployment Layer

Material Needs

Wraps folded layers in stowed configuration, supports launch ascent loads. Typical Kevlar or Nylon webbing or cords.

Inspection Needs

Monitor real-time deployment process. Detect, identify and locate damage.



Atomic Oxygen Layer

Material Needs

Required for low earth orbit (LEO). Typical Beta Cloth.

Inspection Needs

Detect, identify and locate damage.

Flight Testing Inspection Needs

- Prelaunch packaged state
  - 3D metrology scan
- Launch/Ascent
  - External video (Optional: Measure billowing)
- Vehicle extraction
  - External video
- On-orbit before deployment
  - Thermal imaging
- Deployment
  - Measure deployment dynamics
  - Video imaging (internal/external)
  - Position and shape of layers during deployment
- Post-deployment (Validation of initial deployment)
  - Leak detection/location
  - Damage detection/location
  - Thermal imaging

TransHAB Vacuum Deployment Test

Flight Testing Inspection Needs

- On-orbit operations
  - Monitor on-orbit environments
    - Temperature
    - Pressure
    - Radiation
  - Leak detection
    - Acoustic emissions
    - External gas emitting sensors
    - Video
  - Measure strain/load of structural restraint layer
  - Detect impact damage (autonomous and crew supported)
    - Impact detection sensors (EVA/IVA)
    - Damage detection
      - Thermal imaging
      - Penetrating 3-D Imagers
      - Serpentine imaging robots (w/ inner liner removal)
      - External camera inspection (fixed, translating, and free flyers)

BEAM Expansion on ISS

Ground Testing Inspection Needs

- Development Testing - Possible opportunities to include NDE sensors for some tests
- Modal Testing
  - WLE, DIDS, and Acoustic Emission
  - Sensors can be installed internal/external
- Micrometeoroid/Orbital Debris Hypervelocity testing
  - Impact detection (at impact)
  - Impact location methods
- Leak Testing (at operational pressure)
  - Leak detection/location
- Damage Tolerance Testing
  - Impact detection when damage imparted
  - Damage inspection methods

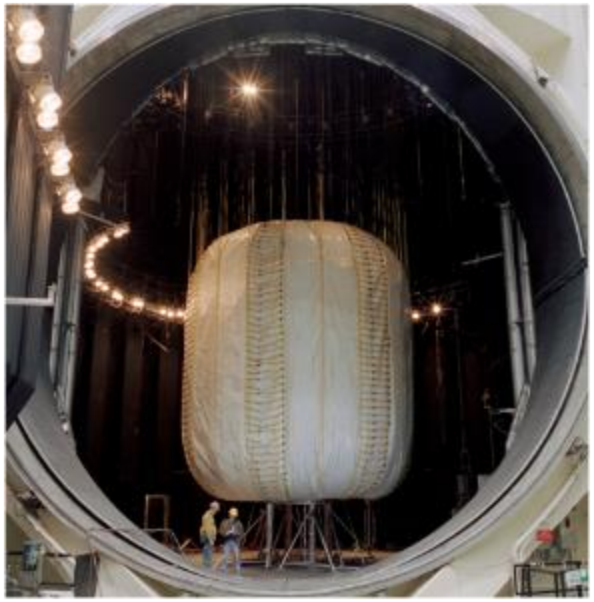
Damage Tolerance Testing

Inflatable Hypervelocity Impact Testing

Ground Testing Inspection Needs

- Burst Testing
  - Fabric strain/load measurement methods
  - Non-invasive measurement methods
- Creep/Burst Testing
  - Long term strain/load measurements
  - Change in properties prior to ultimate burst
- Thermal Vacuum Testing (sub-scale)
  - Thermal imaging in the folded and deployed states
- Thermal Vacuum Testing (full scale)
  - Thermal imaging in the folded and deployed states
- Rapid Depress/Ascent Testing (sub-scale)
  - Imaging in the folded and deployed states

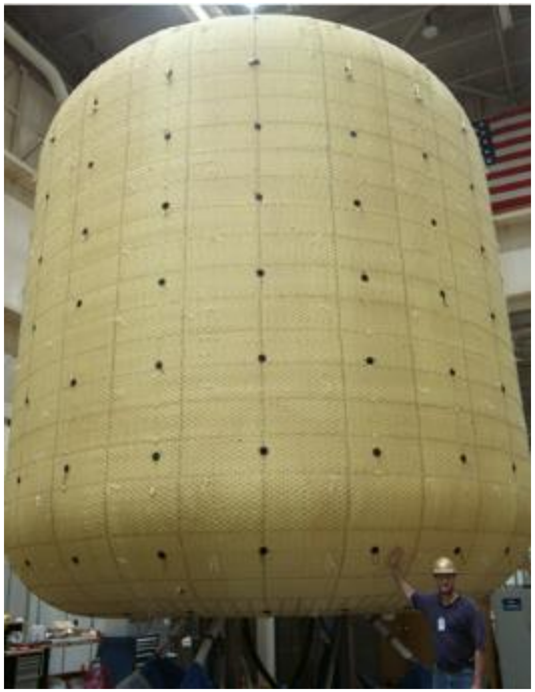
Damage Tolerance Testing



TransHAB Vacuum Deployment Test

Inspection Hardware Needs

- Desired Characteristics
  - Small
  - Lightweight
  - Low-power
  - Accurate
  - Sensitive
  - Inexpensive
  - Durable
  - Ease of use
  - Multi-functional



TransHAB Deployment Testing

Inflatable Modal Testing

- Potential solutions?
  - Contact us!
  - We have upcoming ground test opportunities and can work with you to develop flight hardware

Questions?

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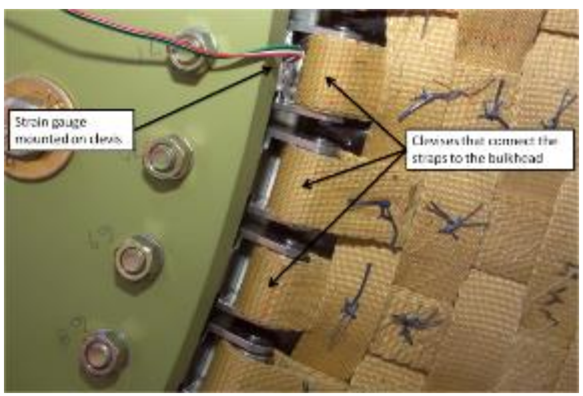
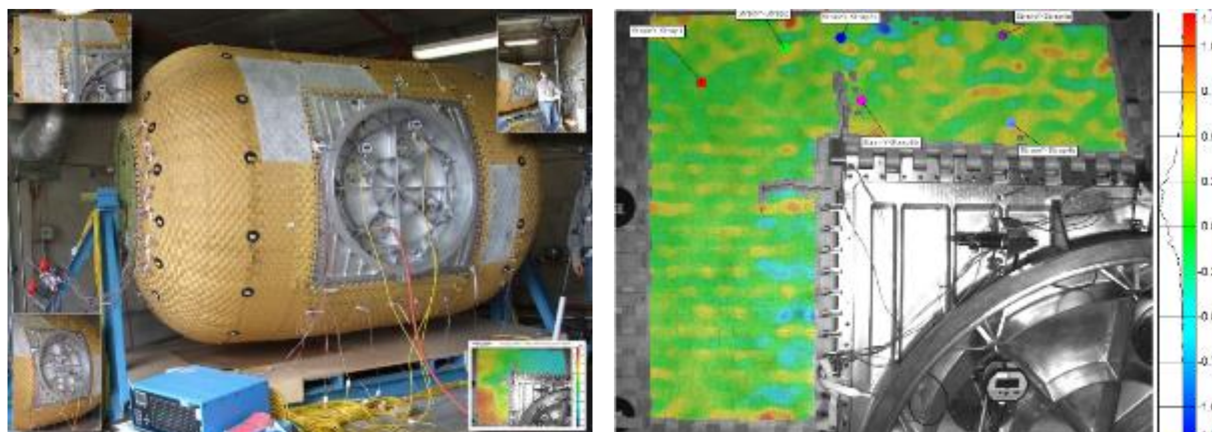
BACK UP

Inflatable Habitat Strain Measurements

- Current strain monitoring techniques for inflatable structures utilize optical measurement systems on fabrics and traditional foil strain gauges on metallic components
- Photogrammetry/digital image correlation (DIC) uses a dual camera system and speckle pattern to measure the strain on the fabric restraint layer
- DIC system is very accurate and provides good results, but is limited to a small surface area
- DIC system only works for ground tests when the restraint layer is visible, it does not work in space environment with MMOD and thermal layers



Close-up View of Restraint Strap and Bulkhead Interface with Clevis Strain Gauge



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