Bigelow Expandable Activity Module (BEAM) ISS Distributed Impact Detection System (DIDS)

Technology Demonstration, Utilization, and Potential Future Applications

Nathan Wells

BEAM GFE Instrumentation Lead

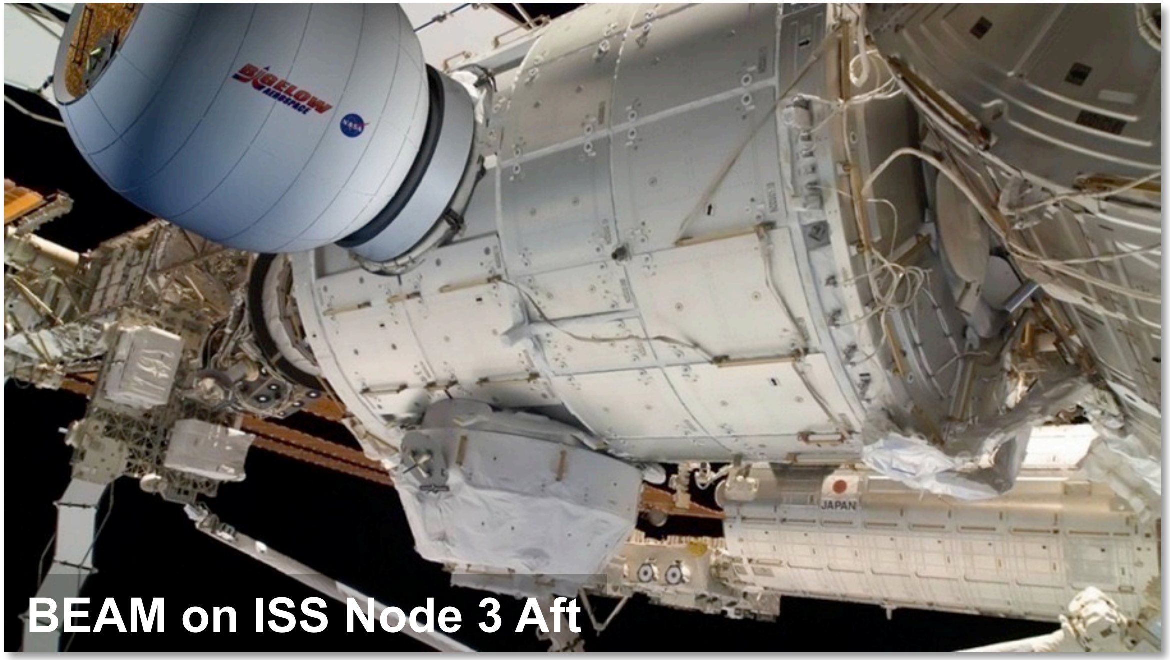
S&I TDT Webinar

Aug. 15th, 2023

Agenda

1. **Project Objectives and Overview**
   - Bigelow Expandable Activity Module (BEAM)
2. **DIDS Utilization and Performance**
3. **Future Plans & Summary**
4. **Team Acknowledgements**

BEAM Project Objectives

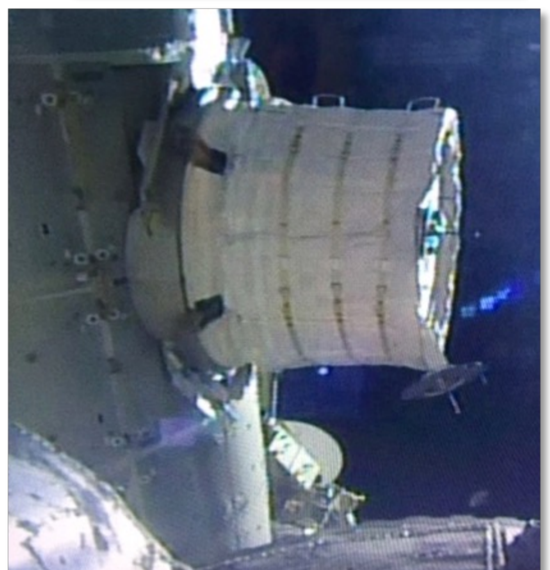


- Demonstrate a commercial expandable habitat module on ISS in partnership with Bigelow Aerospace (BA)
- Increase human-rated inflatable structure Technology Readiness Level (TRL) to 9
- Address key elements of NASA's Space Technology Roadmaps to prepare for future deep space and surface habitat missions
- Exploit experience from NASA's TransHab design and BA's Genesis I & II pathfinder flights

BEAM animation by NASA/JSC on YouTube
https://youtu.be/VopaBsuwikk

BEAM launched, berthed, and deployed on ISS

- BEAM launched on SpX-8 (April 8, 2016), Dragon/BEAM arrived Node 2 (April 10^{th}), SSRMS extracted BEAM from Dragon Trunk on Node 2 Nadir, moved it to Node 3, and berthed it on Node 3 Aft port (April 15-16 2016), and fully pressurized on May 28, 2016.



BEAM Overview

- BEAM was initially intended as technology demonstration project for a 2yr operational period.

- To help NASA characterize the performance of the BEAM module, sensor systems were installed to help monitor the effectiveness of thermal insulation properties, Micro-Meteoroid/Orbital Debris shielding protection layers and radiation shielding properties.

- In 2017, the BEAM was prepared to accommodate up to 3,402 lbs of stowage mass and consequently all wireless sensors systems were converted to hard-wired systems to help with potentially RF interference issues.

- In 2019, the BEAM module life was re-evaluated and certified until 2028 and is currently used to accommodate long-term storage items on ISS where the hatch into Node 3 is remained closed for the majority of operations.

BEAM stowage bags

BEAM stowage items

BEAM expanded configuration

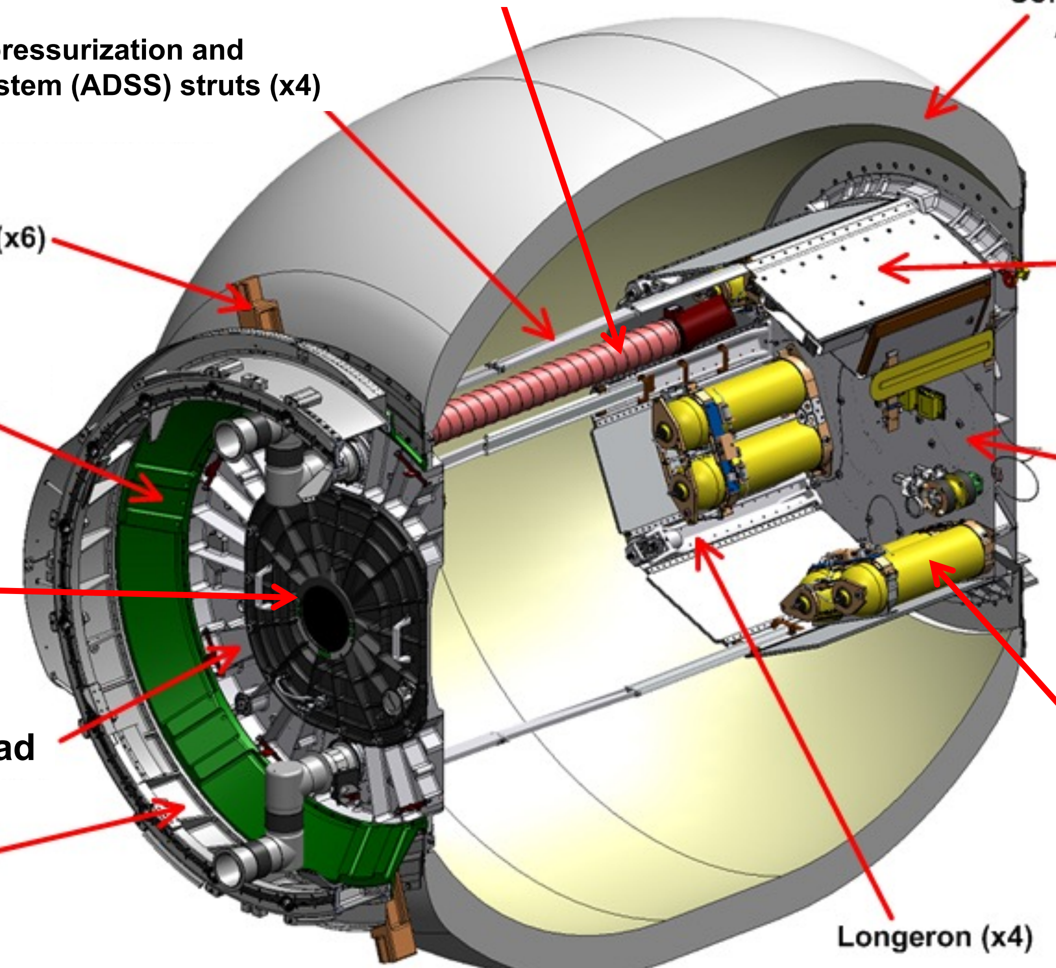


Illustration of pre-stowage configuration

BEAM Sensor System Overview

Sensor	Parameter	Deployment	Data Retrieval	Current Status
Distributed Impact Detection System (DIDS)	Detects structural impacts to BEAM	Installed pre-launch: •4 transducers on the bulkheads Installed on orbit: •12 transducers on the soft goods •sensor boxes	Via coaxial cable to Space Station Computer (SSC) in Node 3 (closed hatch)	Active
Deployment Dynamics Sensors (DDS)	Records acceleration loads during inflation stage	3 DDS units and triaxial accelerometers are installed prelaunch	USB to SSC (BEAM ingress)	No longer active (only used during deployment and modal testing)
Wireless Temperature Sensors (WTS)	Monitors temperature of BEAM surface (IVA)	4 WTS units Installed on-orbit (qty 4 RTD channels each)	Via coaxial cable SSC in Node 3 (closed hatch)	Not active – communication issue after 4 yrs of operation.
Radiation Environment Monitor (REM)	Monitors radiation environment internal to the BEAM structure	2 REM Installed on-orbit	USB to SSC in Node 3 (closed hatch)	Active
Radiation Area Monitor (RAM)	Passive radiation monitoring badges	6 RAMs Installed on-orbit	Replaced and returned to ground every Soyuz vehicle cycle	No longer active after

BEAM Sensor System Overview

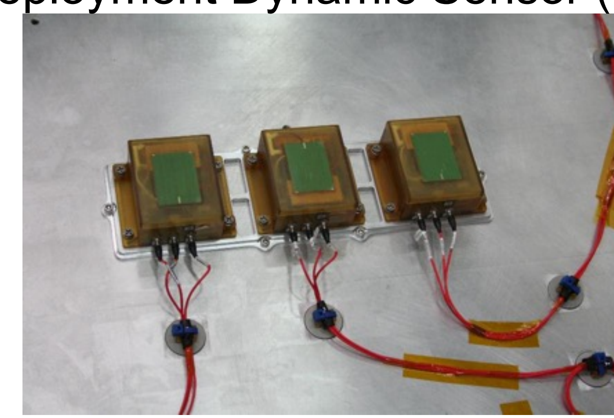
Distributed Impact Detection System (DIDS)

Wireless Temperature System (WTS)

Radiation Environment Monitor (REM)

Radiation Area Monitor (RAM)

Deployment Dynamic Sensor (DDS)



Distributed Impact Detection System Overview

Purpose: Used as a technology demonstration for Micro Meteoroid/Orbital Debris (MM/OD) Impact detection system of an inflatable structure and BEAM module shielding layer performance.

Deployment: Qty 4 Accel Transducer cables installed pre-launch to Aft Bulkhead and remaining kitted hardware installed on-orbit. Used 2221F Endevco Piezoelectric Charge Output Uniaxial Accelerometers.

Operations: Each DIDS data recorder remains in a low power listening mode until a trigger is recorded above a set g threshold value and records a 270 ms of 30 KHz sampled data window to internal memory for each of its independent 4 channels. New trigger status is downlinked daily and raw trigger can be downlinked on an as needed basis.

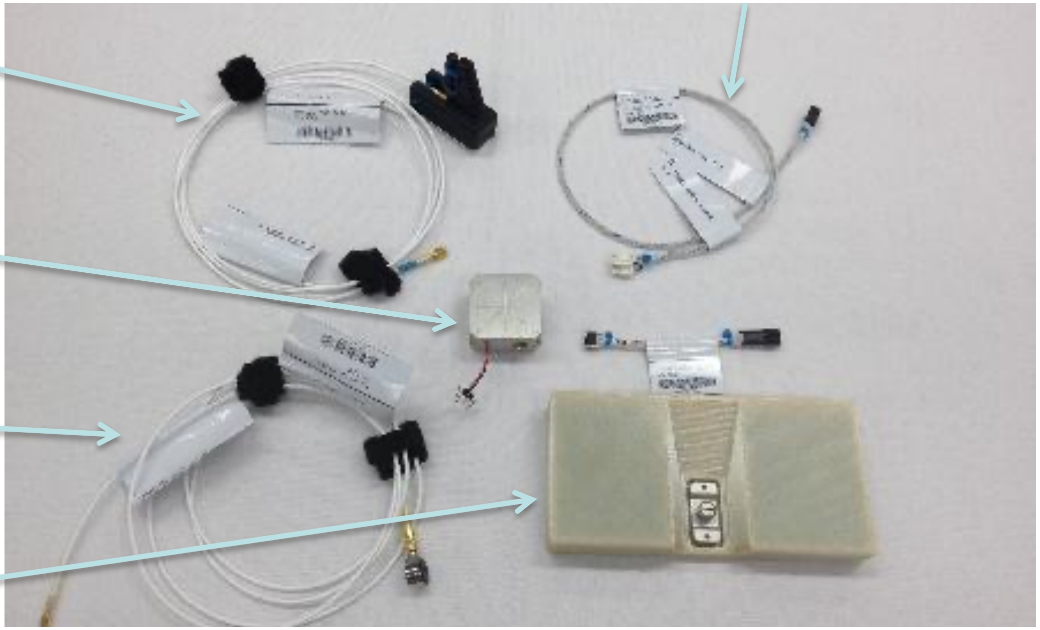
Qty 1 Battery Pack Cable

Qty 1 Antenna Mount

Qty 1 Accelerometer Data Recorder

Qty 4 Accel Transducer Cable

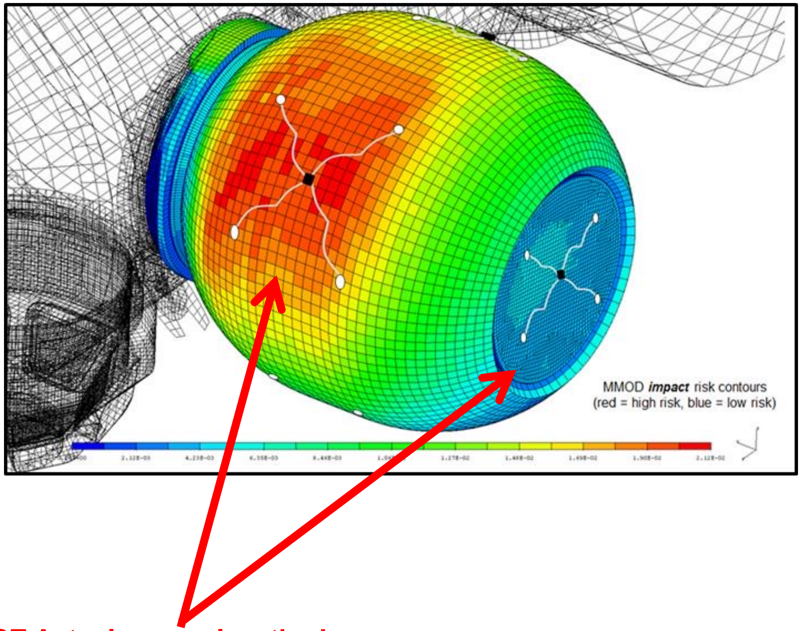
Qty 1 Extended Life Battery Pack



Impact Detection Kit Contents

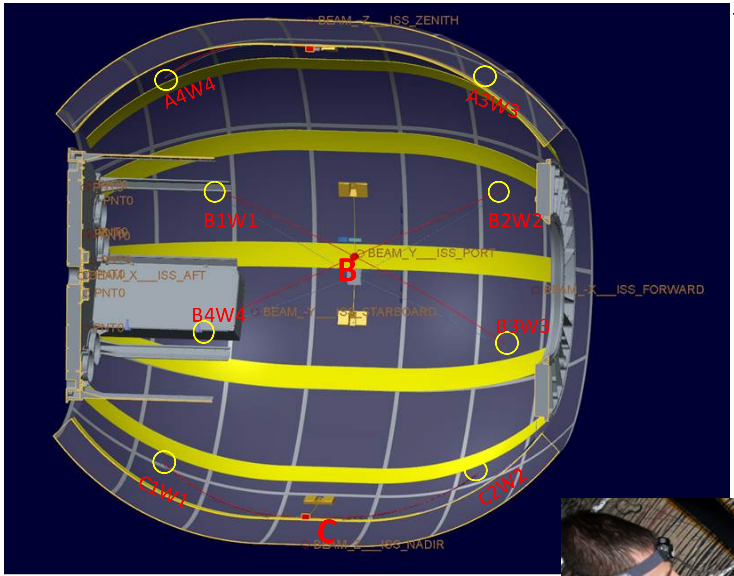
Distributed Impact Detection System Overview

- Detects MM/OD and IVA Events
- Uses 3 VDC custom designed external Battery Pack, operational life of 4 years prior to battery pack replacement under normal conditions.
- Can store 9999 events on an internal SD memory card
- 12 DIDS piezoelectric accelerometers were adhered to air barrier via pre-applied double-sided transfer tape and Kapton tape by crew
- 4 DIDS accelerometers hard-mounted to Aft Bulkhead structure



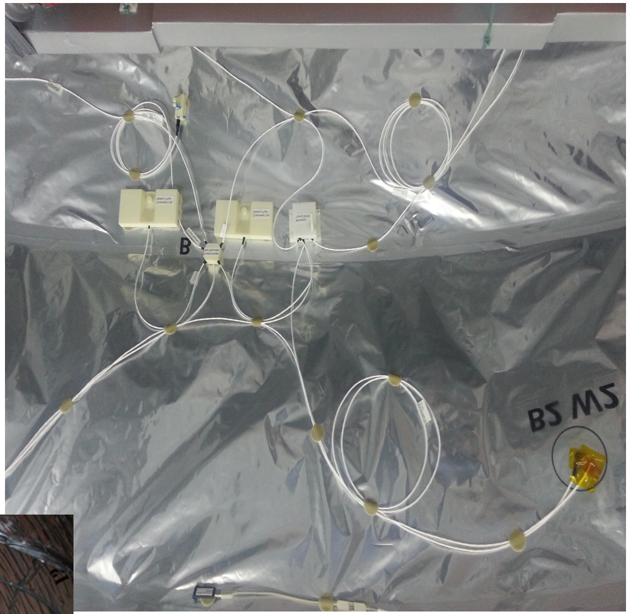
NOTE: NOT Actual sensor location!
DIDS Sensors locations are for illustration purpose only.
DIDS Sensors are Internal to Structure.

DIDS Sensor Labeling and On-Orbit Installation



BEAM Sensor 3D Model View

- BEAM air barrier had been pre-marked for DIDS/WTS sensor installation locations.
  - Sensor locations were configured to ensure maximum internal coverage and to monitor pre-flight identified high-risk MM/OD impact probability locations.



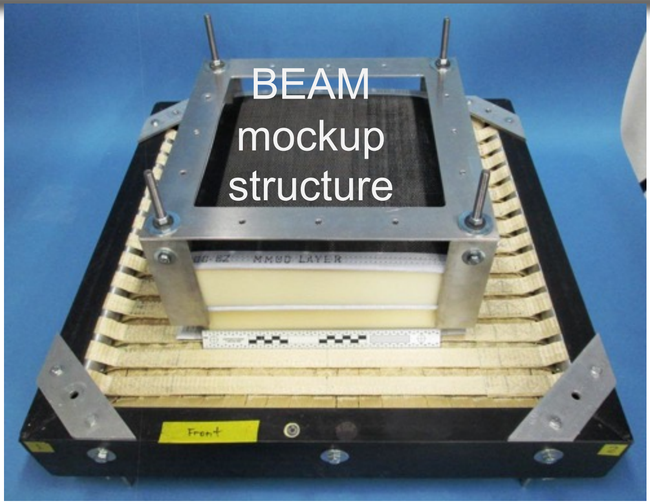
BEAM Mock-up View

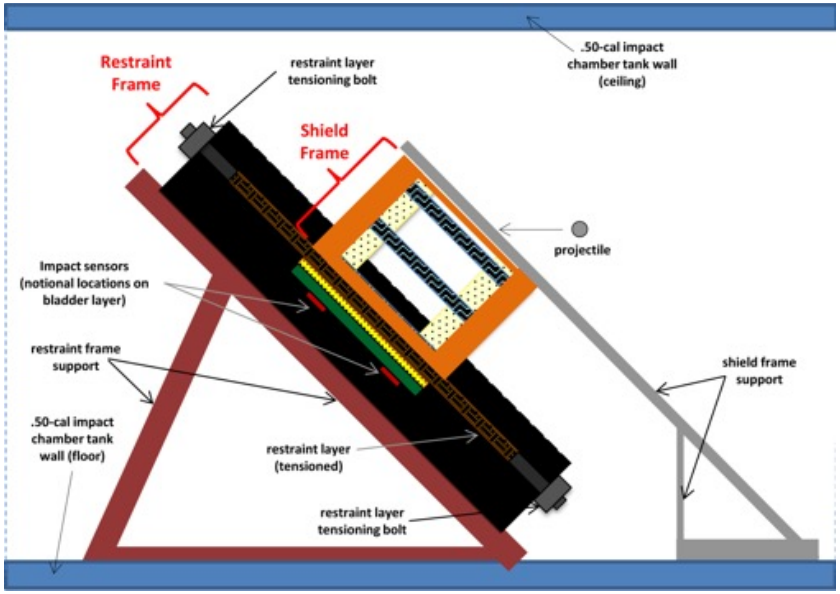
Note: Cables attached to inner air barrier with 1 3/8” dia Velcro dots

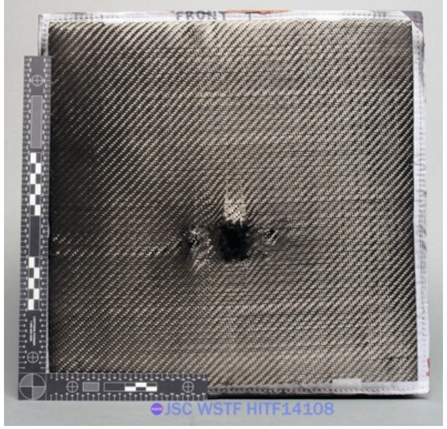
BEAM view with sensors installed on air barrier prior to stowage configuration

Hypervelocity Impact DIDS Ground Testing

- Performed 8 hypervelocity impacts on a model mockup of the BEAM structure. (See photo)
- Impactor energies ranged from ~100J up to 7800J. Multiple angles of impact (30-45^{o}), speeds (3.1 – 7.1 Km/s), impactor sizes (0.15 – 5.97 mm), and material types (glass, Al, SS).
- Instrumented with two DIDS systems for a total of eight accelerometer channels.
  - The restraint layer acted like a unified plate.
  - Performed tap tests to measure velocities in restraint layer.
  - Estimated the signal's diffraction and attenuation effects with distance.

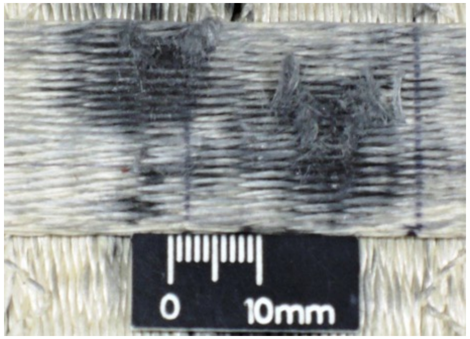






Front face sheet damage

Example of Ballistic Limit Failure



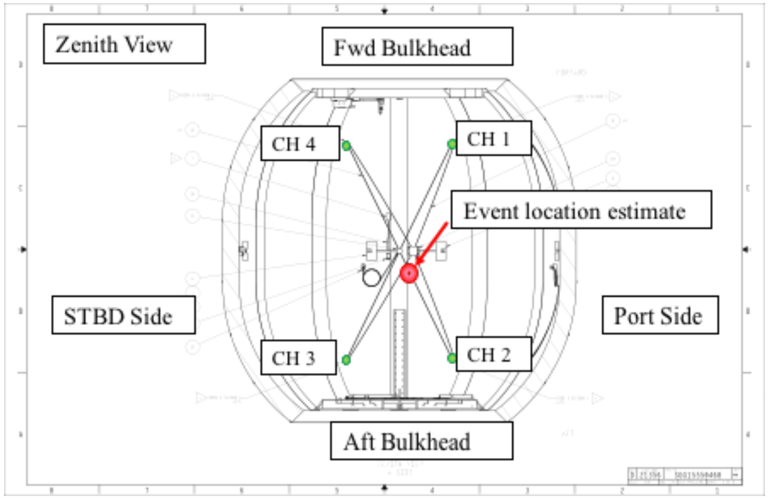
Close up of restraint layer damage

BEAM Impact Detection Performance Overview

- Initial DIDS operations required engineering to tweak the trigger threshold parameters to ensure DIDS accelerometers would not falsely trigger due to low level ISS background noise being injected into the module structure.
  - Crew activity induced loads to structure have been routinely recorded during previous crew ingresses in the module
- DIDS operations had to be adjusted initially to disable an internal amplifier which had been left active and was causing increased power consumption.
- During BEAM preparation of stowage items, the Aft bulkhead DIDS unit became damaged while removing other equipment and had to be replaced with a spare.

BEAM Impact Detection Performance Overview

- On GMT 059 (2/28/17) first likely external impact to BEAM was recorded by all three DIDS units monitoring the internal air barrier surfaces. Recorded signals ranged between 1 - 3 g's acceleration
  - Signal contained high frequency content
  - Triangulated to have impacted on Zenith side (between Channel 2 & 3)
  - Estimated impact amplitude on restraint layer is ~260 g's based on hypervelocity ground test derived models and data suggests the impact would not have penetrated all the way to the restraint layer

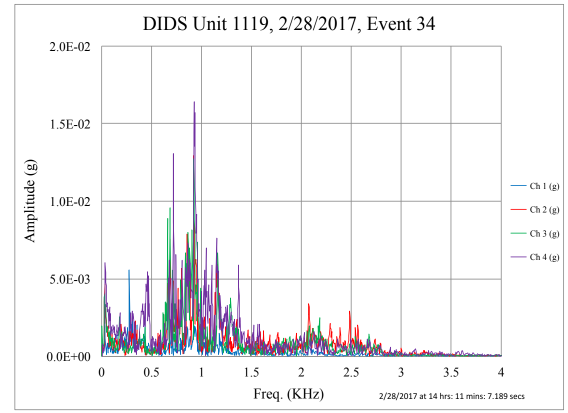


Estimated epicenter location of GMT059 impact

  - Pictures of estimated impact location were requested via the ISS External High Definition Camera (EHDC) P1LOOB, however the camera gave very little Zenith surface viewpoint

BEAM Impact Detection Performance Overview

Zenith DIDS Time History (all 4 channels)



Zenith DIDS Frequency Response

BEAM Future Plans & Summary

Future Plans

- BEAM was originally planned for a 2 yr operational mission to demonstrate and advance the technology with infrequent human ingresses.
  - Continue to utilize BEAM as a stowage module
  - Continue to characterize the MM/OD shielding properties of the BEAM module using DIDS.

Summary

- Overall BEAM has been performing beyond expectations!
- BEAM has advanced human rated expandable modules to TRL 9.
- The DIDS system has been operating 24/7 for a total of 8 years without any major issues.
  - Potential alternate DIDS application being evaluated as a small atmospheric leak detection system for future NASA applications.

Team Acknowledgements

- The author of this presentation would like to provide a special thanks to the entire BEAM project team, Bigelow Aerospace and Invocon Inc. as well as specific individuals below:

  - BEAM Project Manager – Doug Litteken
  - DIDS Sustaining Engineers – Bob Hunkins and Issa Zaid
  - MM/OD Monitoring Performance – Dr. Eric Madaras, Michael Grygier and Katie Duffy-Deno
  - Invocon (DIDS hardware OEM) – Aaron Trott, Eric
  - Thermal Performance – John Iovine, Dr. William Walker, and Zaida Hernandez
  - Radiation Sensor System & Performance – Dr. Dan Fry and the entire Space Radiation Analysis Group (SRAG)

BEAM Ops Team during deployment

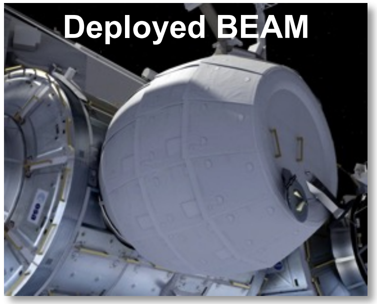
Backup

Why Expandables? (1/2)

1. **Lower launch/ascent volume** relative to metallic modules
   - Pro: Reduced size, drag and mass of the launch vehicle (or fairing), or more cargo inside the same fairing
   - Con: Increased complexity for deployment and internal outfitting

BEAM	Packed	Inflated	Inflated/Packed Ratio
Mass (w/ PCBM & FSE)	~1400 kg (~3K lb)		1.0
Volume	**3.6 m^3**	**16 m^3**	**4.4**
Length (w/ FRGF)	2.16 m	4.01 m	1.9
Diameter	2.36 m	3.23 m	1.4
Pressure	0	14.7 psi	-

Key benefit of inflatables: launch small, then get big in space or on the surface of the moon or Mars

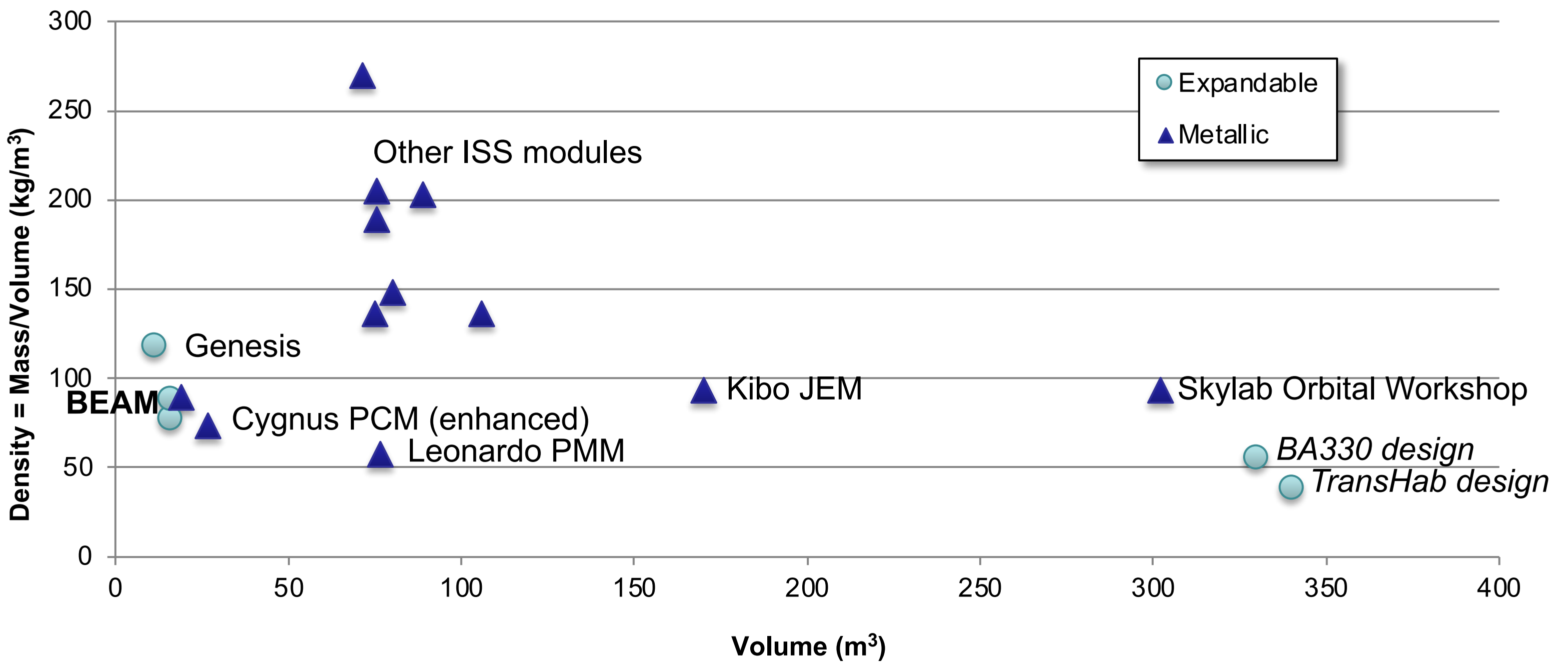


Why Expandables? (2/2)

2. Less mass for the same volume as metallic modules? Maybe.

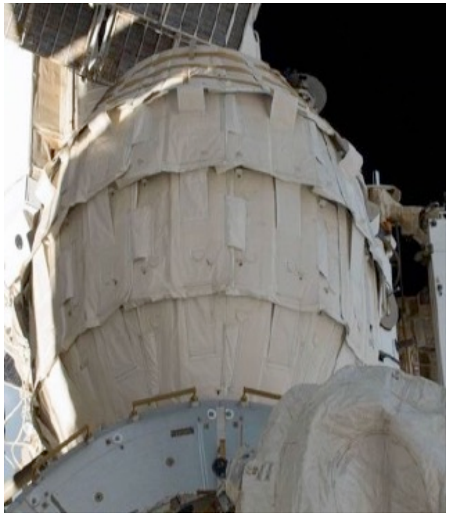
- Depends upon mission and design requirements, outfitting, materials, size, etc.
- Current expandable module experience only at low volumes, not mass-optimized
- Small, mass-optimized metallic modules can be less dense than robust BEAM tech demo
- Large expandable module designs *potentially* offer lower density due to much greater specific strength of fabrics vs. metal alloys, though this must be proven in flight
- More experience with expandable modules may reduce mass due to reduced factor of safety (e.g., ISS requires FoS = 4.0 for fabric structures, 2.0 for aluminum)

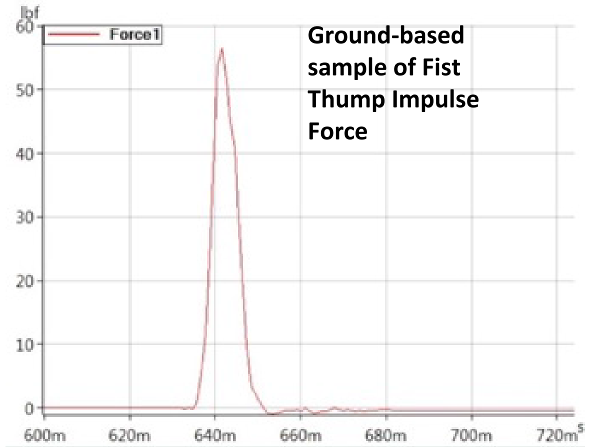
Quick-Look Module Density Comparison

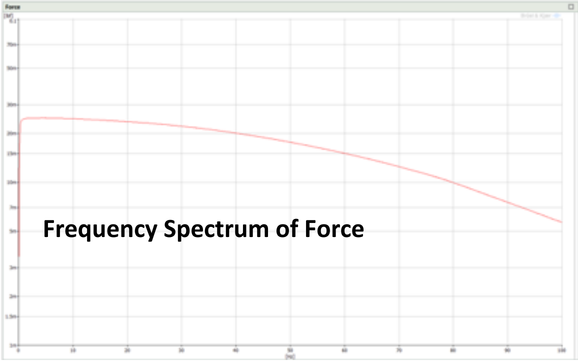


Modal Test

- Compare structural modal frequencies of the BEAM on ISS to those measured during BEAM ground testing in 1-G (w and w/o MMOD)
  - Measured w/ Internal Wireless Instrumentation System (IWIS) (primary), DIDS, and DDS
  - Targets 1-3 and 8 (BEAM shell); targets 4-7 aft bulkhead. Adjust computer structural models as necessary to better represent BEAM in micro-G on ISS.
  - 5 impulses at each target x 2 series
  - 3 accelerometer axes x 8 targets x 2 series = 48 total spectra.
  - Multiple ground and on-orbit modal frequencies were correlated based upon accelerometer response, knowledge of the mode shape from ground tests, and impulse excitation location and direction.
  - There is greater confidence in lower frequency modes.







Modal Test- Preliminary Results and Forward Work

- **Preliminary Results**
  - Large frequency differences between the on-orbit and ground-based tests for the first three modes: the first lateral bending modes are 10 – 14% higher and the first torsion mode is 28% higher on-orbit than in ground tests. Possible reasons for these differences include the following:
    - MMOD layer interaction with the BEAM restraint layer/wall is different on-orbit than under 1-G ground test conditions. Performing ground tests with and without MMOD was valuable for showing this.
    - The spaceflight article and the ground test article have different masses. The first two mode frequencies are higher than in ground-based tests, even without MMOD installed.
    - The ISS interface with BEAM is different from the ground-based test.
- **Forward work**
  - Compare modal frequencies of the ISS-attached BEAM loads model to on-orbit test frequencies.
  - Investigate modelling techniques for attaching MMOD layers
  - Investigate mass differences and perform an operational modal analysis (OMA)
  - Perform a similar analysis on the DDS, DIDS, and Camera Microphone data.

MM/OD Impact Detection System Overview

- A pre-flight MM/OD impact detection system feasibility assessment involved performing a variety of tests to ensure the sensor system could be installed onto the softgoods material and detect an impact response.

•Tests included:
- •Instrumented tap testing of Damage Tolerant Test (DTT) inflatable for screening sensor attachment method and standalone data acquisition testing
- •Pull-testing of sensor attachment method to softgoods material
- •Wiring/DAQ hardware attachment mechanism inside of module
- •Hypervelocity Impact Testing with representative coupon of softgoods material w/MM/OD shielding
- •RF communications testing inside of the module

NASA provided inflatable module for initial sensor system feasibility assessment which was <u>NOT</u> part of the BEAM project.

MM/OD Impact Detection System Overview

Hypervelocity Impact (HVI) Testing Accomplishments

- Demonstrated that the system recorded signal matched accurately with a calibrated data acquisition system at White Sands Test Facility (WSTF).
- Verified that adhesive attachment method for accelerometers to smooth surfaces (Bladder) survives HVI impacts.
- Velocity behavior of the restraint layer was determined (Anisotropic effects and speed of sound measured).
- Most of these HVI tests did not reach the restraint layer, and instead were captured by the shielding layers. Since the shielding system was resting on the restraint layer in these tests, the momentum from those impacts did transfer into the restraint layer via the foam coupling.

Education and Public Outreach

- **BEAM full-size mockup in B.9 at JSC (publicly visible on the Space Center Houston Red Tour)**
- **NASA Twitter & Facebook posts, Facebook Live, Reddit AMA**
- **TV, radio and print media interviews and articles**
  - NASA TV Space Station Live interview
  - Aerospace Daily & Defense Report
  - The Economist article, “Pump it up, Scotty”, described BEAM as “bouncy castles in space”
  - 60 Minutes aired segment with Robert Bigelow and Bigelow Aerospace
- **Online articles**
  - Bigelow Aerospace BEAM page: http://bigelowaerospace.com/beam/
  - NASA Feature: http://www.nasa.gov/mission_pages/station/news/beam_feature.html
  - NASA Landing Page: http://cms.nasa.gov/content/bigelow-expandable-activity-module
  - NASA Announcement: http://www.nasa.gov/home/hqnews/2013/jan/HQ_13-024_Bigelow_ISS_Module.html
  - Space News: http://spacenews.com/bigelow-module-ready-to-fly-to-space-station/
  - American Airlines magazine: http://magazines.aa.com/content/beam-me

BEAM installation animation by JSC/IGOAL on YouTube
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