Bigelow Expandable Activity Module (BEAM) Monitoring Systems

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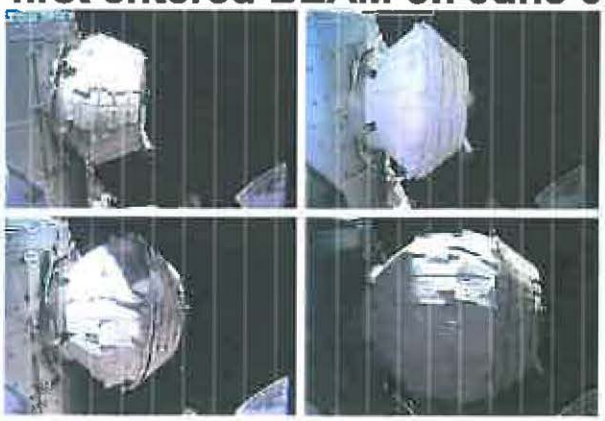
Agenda

- BEAM Project Overview
- BEAM Sensor System Overview
- Current State of BEAM Sensor Systems
- Future Plans & Summary
- Q&A

BEAM Project Overview

- **What is Bigelow Expandable Activity Module (BEAM)?**
- **https://youtu.be/VopaBsuwikk**
- **The Bigelow Expandable Activity Module (BEAM) is an expandable habitat technology demonstration on ISS.**
  - **Increase human-rated inflatable structure Technology Readiness Level (TRL) to level 9.**
- **NASA managed ISS payload project in partnership with Bigelow Aerospace.**
- **Launched to ISS on Space X 8 (April 8th, 2016).**
- **Fully expanded on May 28th, 2016.**
- **Jeff Williams/Exp. 48 Commander first entered BEAM on June 6th, 2016.**

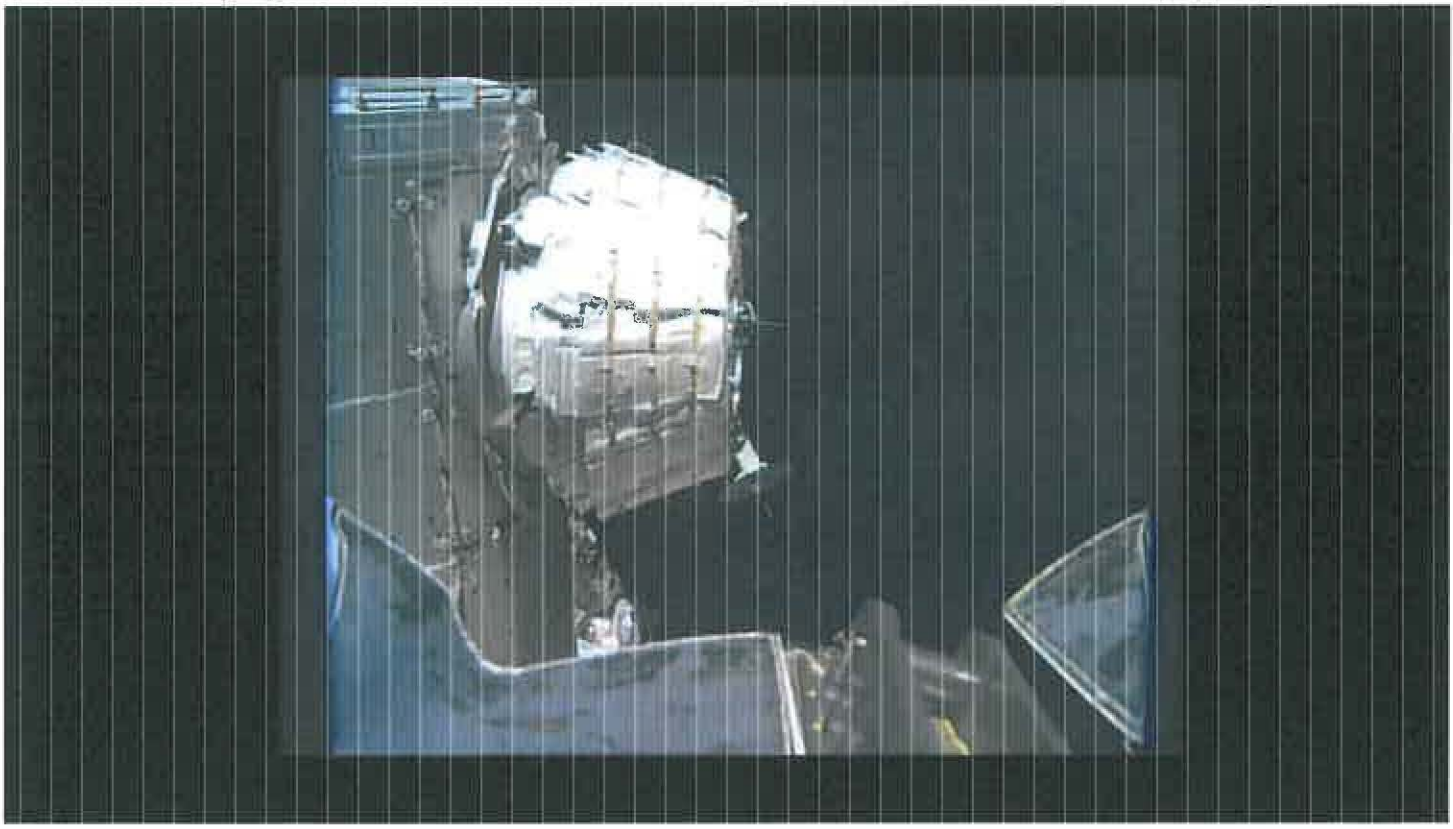
Artist rendition of BEAM attached to Node 3 Aft



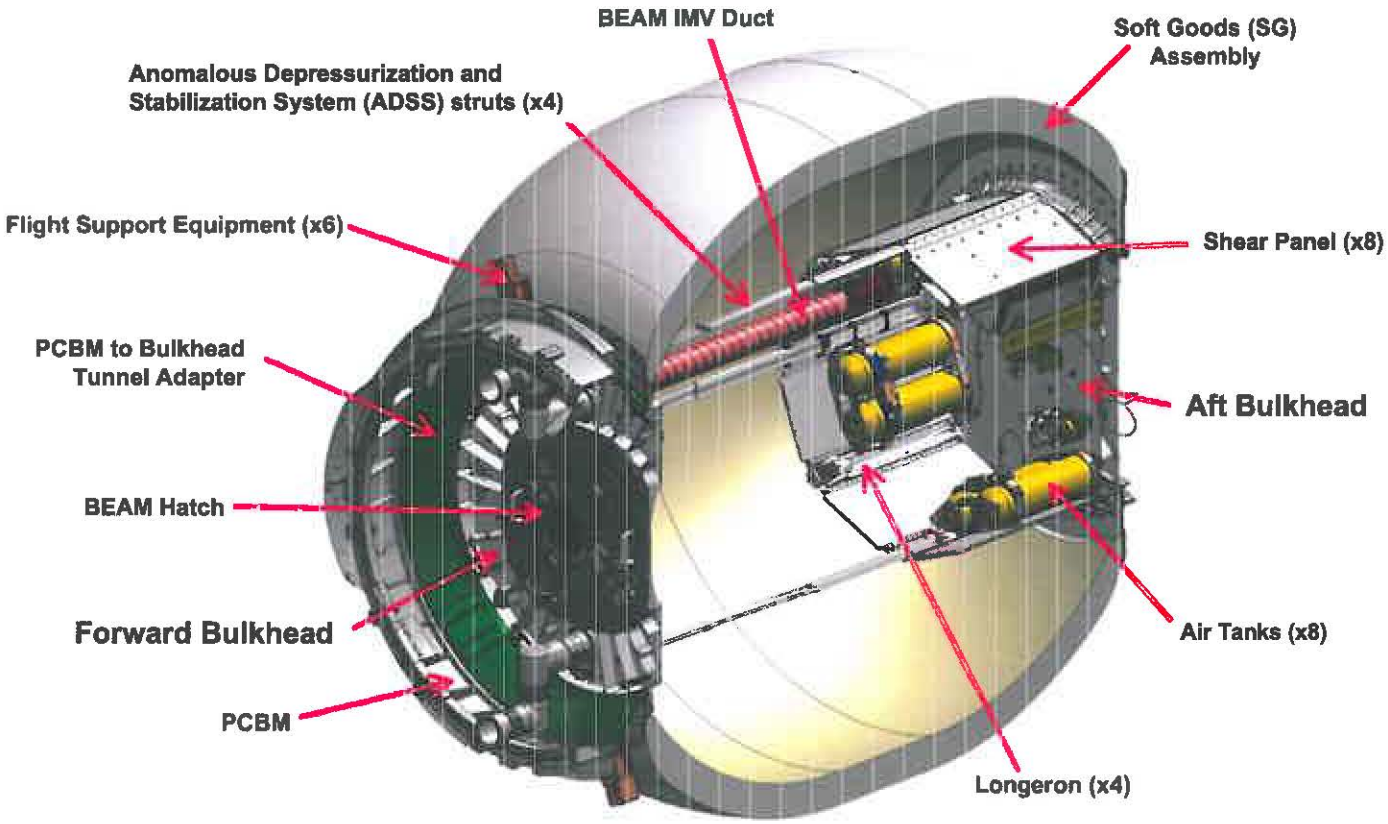
Timeline pictures of BEAM expansion

BEAM Project Overview

7 hours of deployment in 25 seconds with a sample of audio including RSS popping…



BEAM Project Overview



BEAM Project Overview

- First use of inflatable module in ISS or any manned space program.

- Inflatable structures provide more useable volume per launch mass vs. traditional rigid modules.
  - BEAM was compressed 4 times its expansion volume in the Space X Dragon trunk.
- NASA desires engineering data on Bigelow module deployment and on-orbit operation:

  - deployment dynamics (NASA PI – M. Grygier)
  - thermal performance (NASA PI – J. Iovine/W. Walker)
  - debris impact monitoring (NASA PI – Dr. E. Madaras)
  - radiation monitoring (NASA PI – DR. D. Fry)

- Flight-heritage sensor systems will be adapted to collect this data requires new interfacing hardware (cables, etc.) and longer-life battery power and data acquisition system modifications

Project 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 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 NOT part of the BEAM project.

Hypervelocity Impact (HVI) Testing Accomplishments

- Demonstrated that the system recorded signal matched accurately with a calibrated data acquisition system at 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.

BEAM Sensor System Overview

Sensor	Parameter	Deployment	Data Retrieval	Previous Use
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	RF to SSC (closed hatch)	ISS Ultrasonic Background Noise Test SDTO
Deployment Dynamics Sensors (DDS)	Records acceleration loads during inflation stage	3 DDS units and triaxial accelerometers are installed prelaunch	USB to SSC (BEAM ingress)	Shuttle Wing Leading Edge accelerometers and Crew Seat DTO
Wireless Temperature Sensors (WTS)	Monitors temperature of BEAM surface (IVA)	4 WTS units installed on-orbit (qty 4 RTD channels each)	RF to SSC (closed hatch)	Shuttle Wireless Strain Gauge Instrumentation System
Radiation Environment Monitor (REM)	Monitors radiation environment internal to the BEAM structure	2 REM Installed on-orbit	USB to SSC (closed hatch)	REM SDTO
Radiation Area Monitor (RAM)	Passive radiation monitoring badges	6 RAMs Installed on-orbit	Replaced and returned to ground every Soyuz vehicle cycle	

BEAM Sensor System Overview

DIDS

WTS

REM

RAM

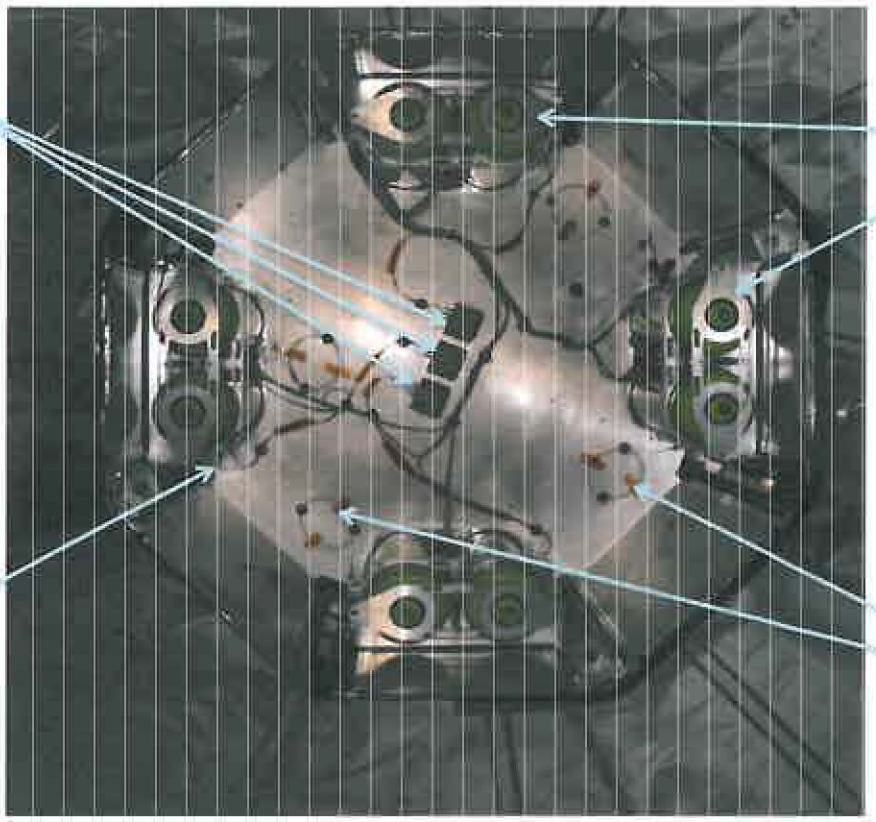
DDS

Deployment Dynamic Sensor (DDS)

Purpose: Used as a technology demonstration for characterizing the BEAM Module deployment dynamics with accelerometers on the Aft bulkhead surface.

Deployment: Hardware pre-installed prior to launch on Aft bulkhead.

Qty 3 Deployment Dynamic Sensor (DDS) units



Qty 8 Air Inflation Tanks

Qty 3 triaxial accelerometers

Qty 4 single axis accels with cables for DIDS

Distributed Impact Detection System (DIDS)

Purpose: Used as a technology demonstration for Micro Meteoroid/Orbital Debris (MM/OD) Impact detection system of an inflatable structure for BEAM Module during the 2 yr operational phase.

Deployment: Qty 4 Accel Transducer cables installed pre-launch to Aft Bulkhead and remaining kitted hardware installed on-orbit

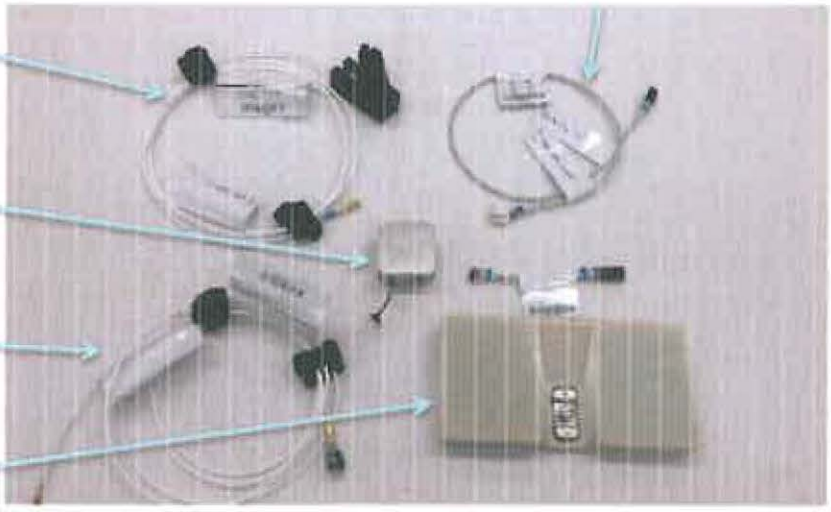
Qty 1 Battery Pack Cable

Qty 1 Antenna Mount

Qty 1 Accelerometer Data Recorder

Qty 4 Accel Transducer Cable

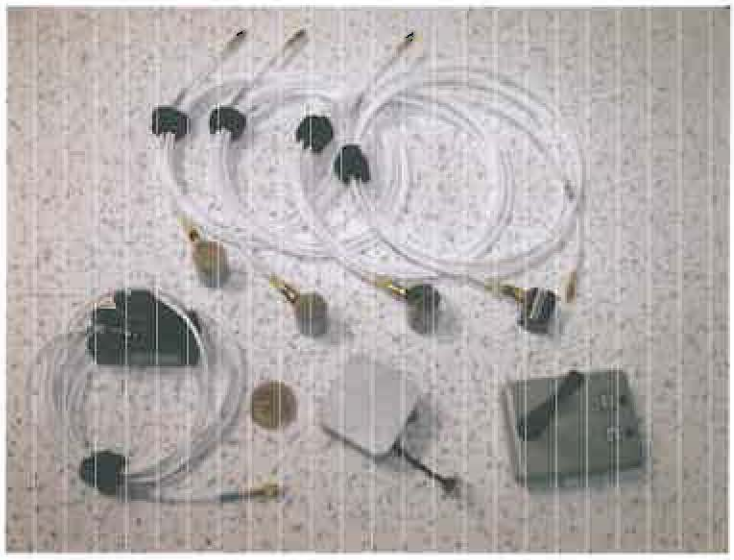
Qty 1 Extended Life Battery Pack



Impact Detection Kit Contents

BEAM Distributed Impact Detection System (DIDS)

- Small, low power, battery operated, autonomous, wireless system used to detect structural impacts.
  - Low power, quiescent mode until triggered by "event"
  - Detects MMOD and IVA Events
  - Uses 3 VDC L91 Battery Pack, expected operational life of 2 years.
  - Can store 9999 events on an internal memory card



Wireless Temperature Sensor (WTS)

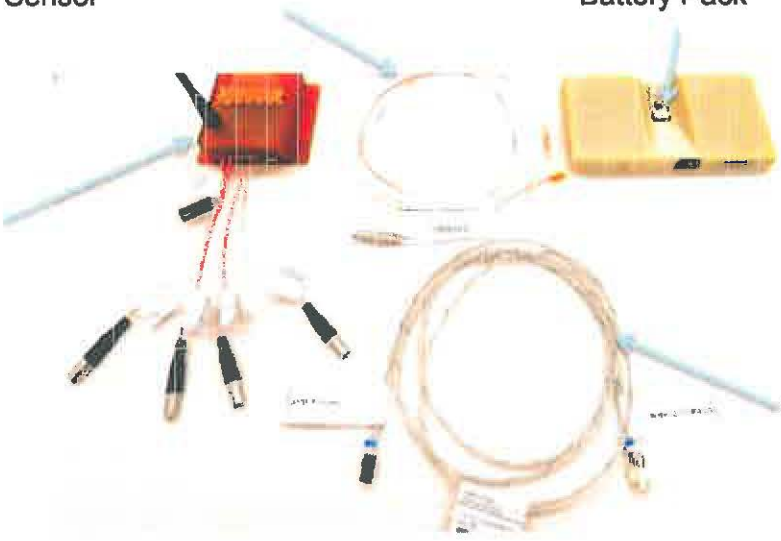
Purpose: Used as a technology demonstration for characterizing the BEAM Module internal temperature environment during the 2 yr operational phase.

Deployment: Qty 4 Wireless Temp System Kits installed on-orbit

Qty 4 Resistive Temp Device Sensor

Qty 1 Extended Life Battery Pack

Qty 1 Wireless Temp Sensor

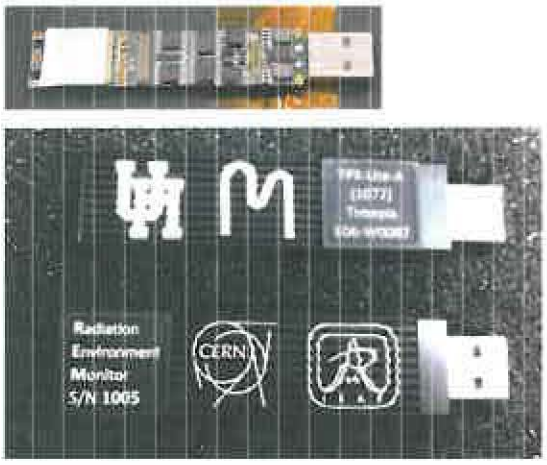


Qty 1 Battery Pack Cable

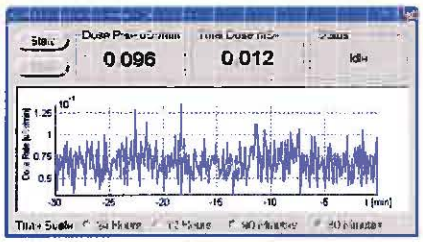
Wireless Temp Sys Kit Contents

Radiation Sensors

- **Passive and active sensors will be deployed**
- **Couples small radiation sensor with advanced electronics**
- **Memory dump via USB available**
- **Provides spectral information (energy deposition as function of particle type and energy) and radiation dose**
- **Active detectors will connect to SSC via USB interface**
- **Minimum 1 month of cumulative data required for active measurements**
- **Passives will come back to ground during nominal ISS Soyuz return cycle**

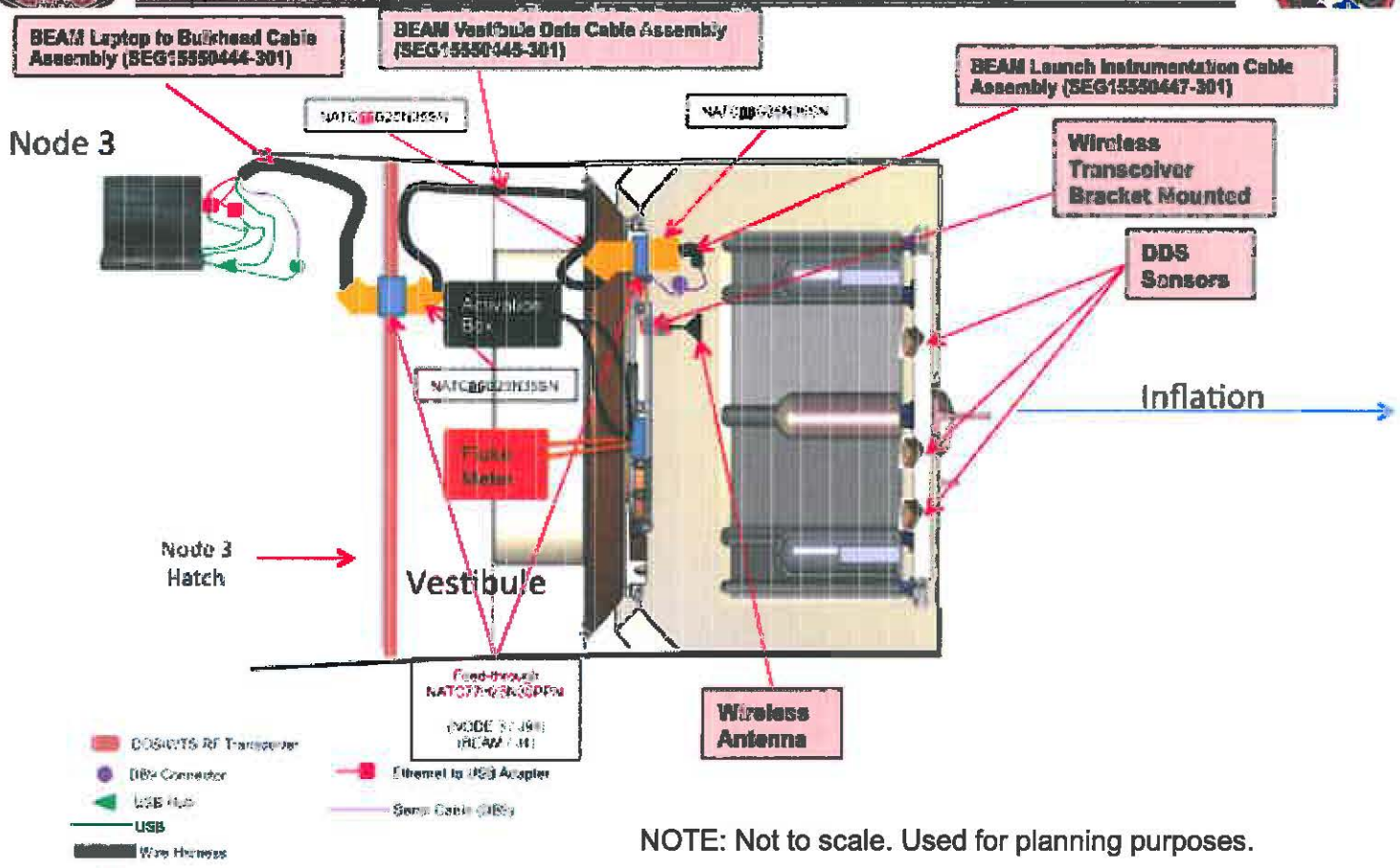


Active Instrumentation (REM)



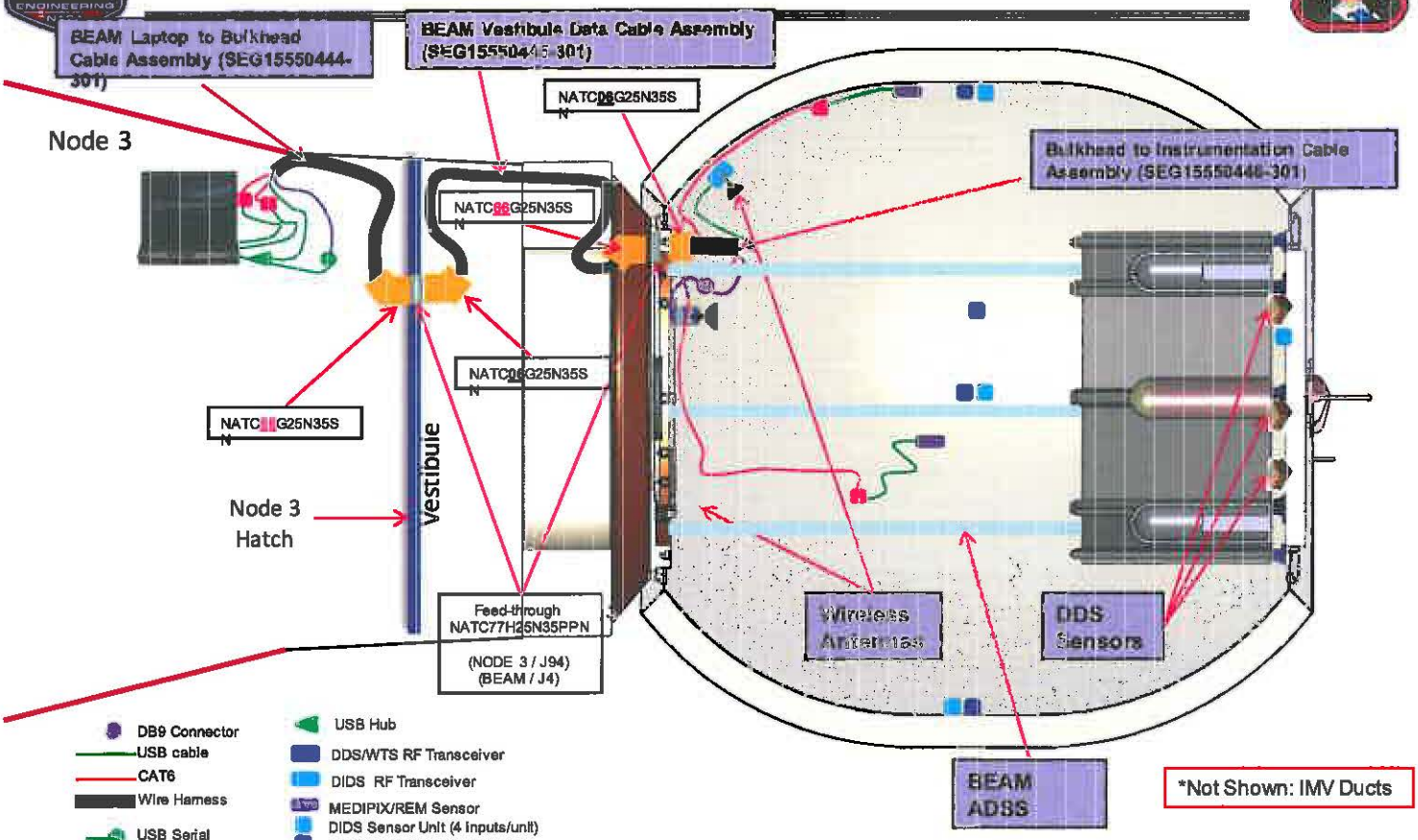
Passive Instrumentation (RAM)

BEAM Instrumentation (DDS) Pre-Inflation



NOTE: Not to scale. Used for planning purposes.

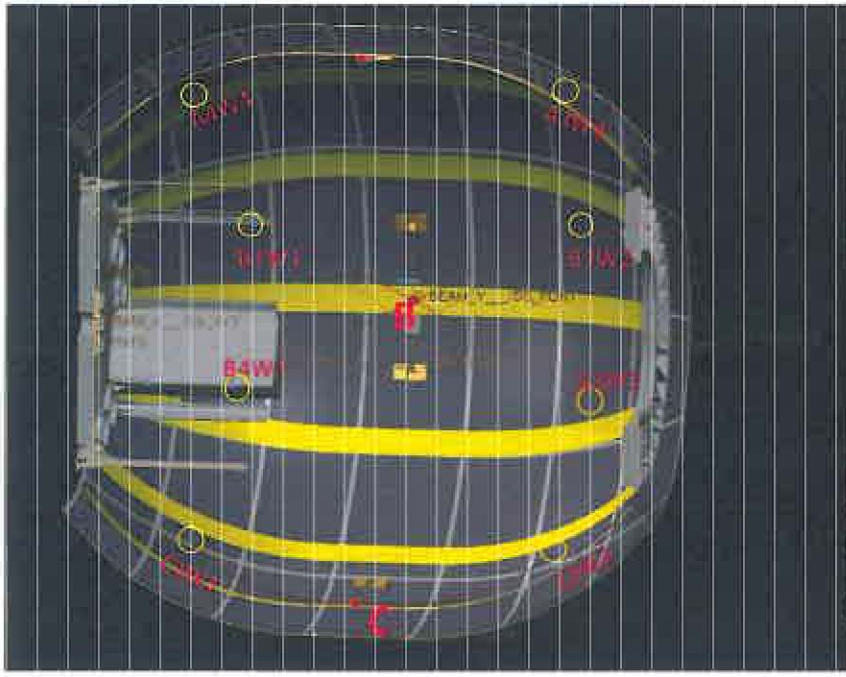
BEAM Instrumentation (DIDS, WTS & REM) Post-Inflation



*Not Shown: IMV Ducts

NOTE: Not to scale. Used for planning purposes.

Sensor Labeling/ On-Orbit Installation



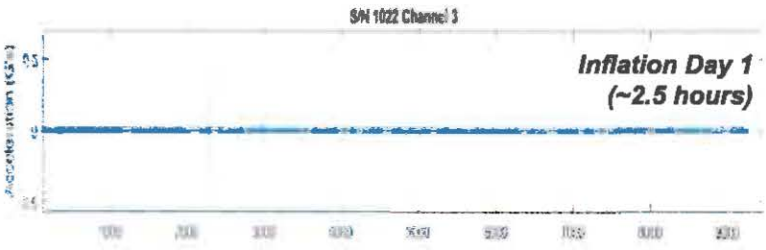
BEAM Sensor 3D Model View

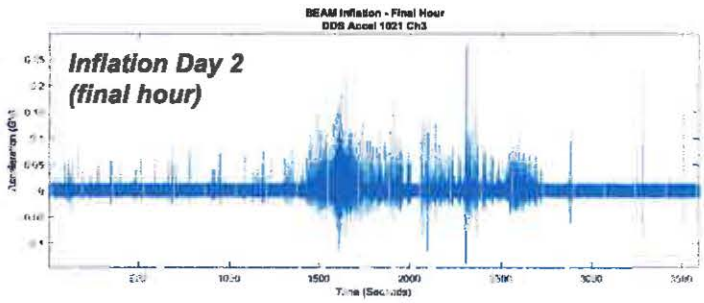
BEAM Mock-up View

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

Initial sensor results

- The DDS successfully recorded 10 hrs of accelerometer data during the BEAM deployment.
  - Thousands of impulses were measured from the Rip-Stitch Strap (RSS) stitches popping.
  - Max 0.5g peak during initial inflation attempt and max 0.3g during the final inflation.
  - No indication of ADSS struts binding or high transient loads on ISS.





- DDS will be used for future Modal testing inside of BEAM.

Initial sensor results

- Initial WTS system results
  - WTS system has been working without anomalies since installation
  - BEAM is warmer than predicted (no condensation observed)
  - Packed soft goods resisted heat leak more than expected
  - Thermal and CFD models are being updated with actual data

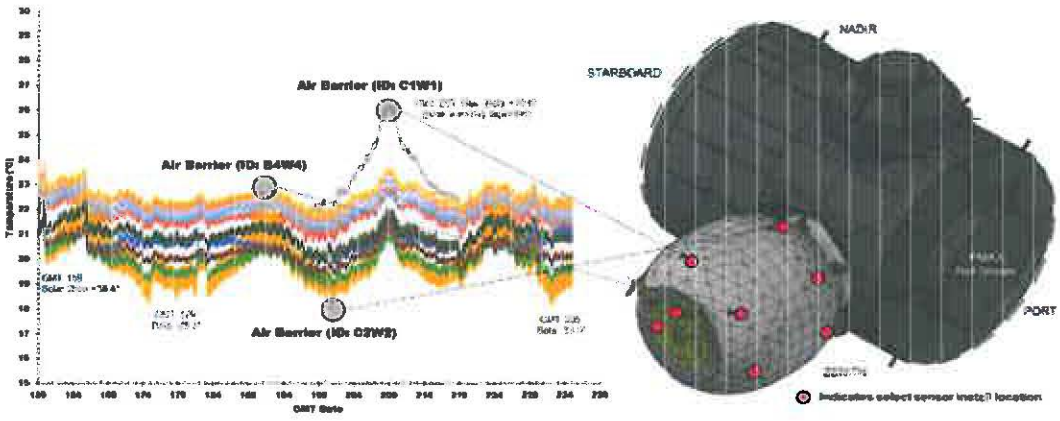
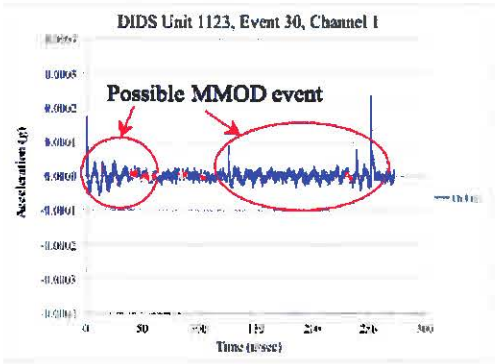


Figure 1. BEAM TEMPERATURE DATA: 06/07/2016 – 08/22/2016

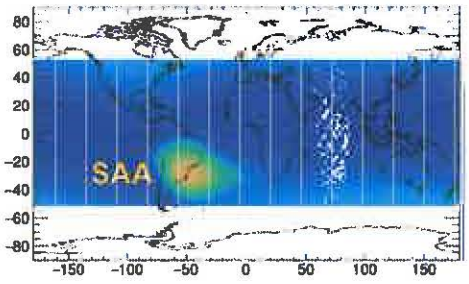
Initial sensor results

- Impacts (DIDS) system results
  - DIDS RF communication problems began in late June and communication ceased for three units by August. Cause has been attributed to premature battery depletion due to an inadvertent high gain amplifier setting being enabled.
  - Bonus: Power depletion data helps characterize DIDS end of life behavior
  - DIDS have been nominal since battery pack replacement in ingress #4 on Sep. 5th.
  - One sensor recorded a small event on June 18: small MM/OD impact and/or sensor loosening from shell
  - DIDS continues to monitor for MM/OD and and will be used to support future modal testing.



Initial sensor results

- Radiation (REM) initial results
  - System has been operating without issues since installation (although GUI needs to be relaunched on a weekly basis due to scheduled laptop reboots.
  - Galactic Cosmic Ray (GCR) dose rate similar to other ISS modules
  - As expected, REMs measured higher trapped field dose rate—e.g., in South Atlantic Anomaly (SAA)—inside BEAM than in other ISS modules due to thinner shell and lack of equipment racks in BEAM technology demonstrator
  - BEAM tech demo data will be used to assess shielding requirements for expandable habitat modules configured for human exploration missions



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.
  - ISS management is evaluating options for using BEAM as a long-term hardware stowage module which would require extending the two year life and reconfiguration of the wireless instrumentation communication & additional batteries.

Summary

- BEAM will help advance the human rated expandable module to TRL 9 and in the future should be considered as a solution for volume/mass savings in future planetary and space exploration applications.
- Use BEAM sensor data and lessons learned to fold into new habitat design
  - Embed sensors into softgoods material during fabrication process that would not risk damage to the module during compression/expansion phases.

Q & A