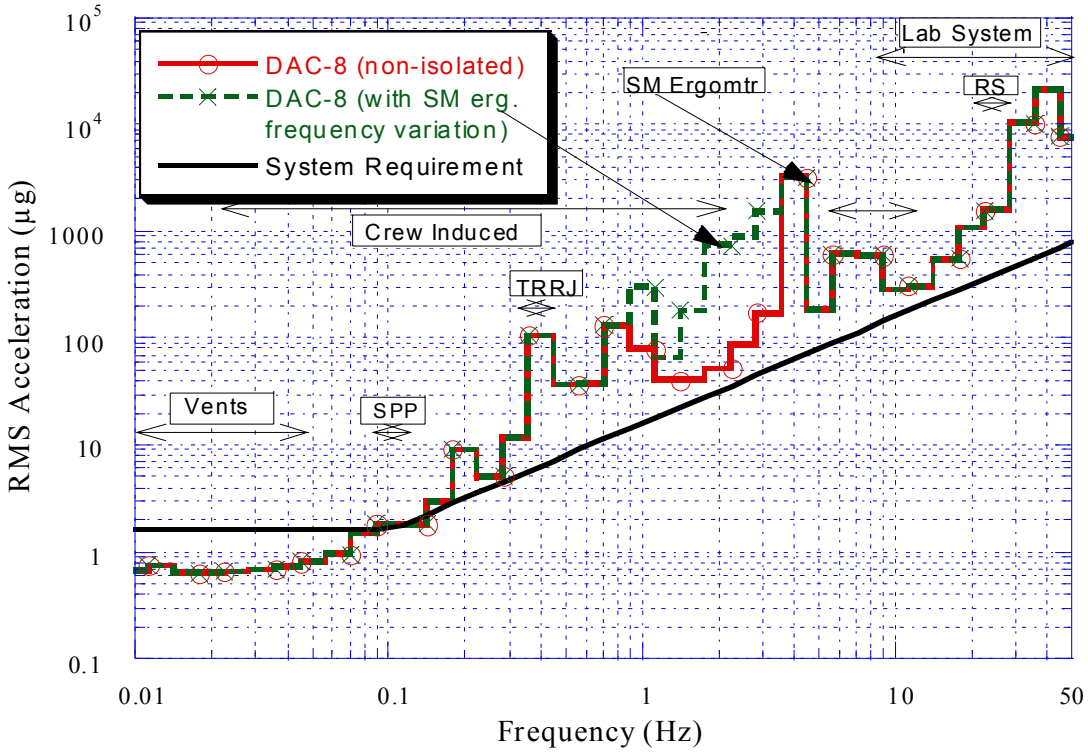
Section 15:
Survey of Microgravity Vibration Isolation Systems

Dr. Mark Whorton
Principal Investigator for g-LIMIT
NASA Marshall Space Flight Center

Outline:

- **Review of Vibration Isolation Technology**
- **Survey of Flight Systems**
- **Future Trends**
- **Flight System Availability on ISS**

The ISS will provide a world-class research facility for microgravity science

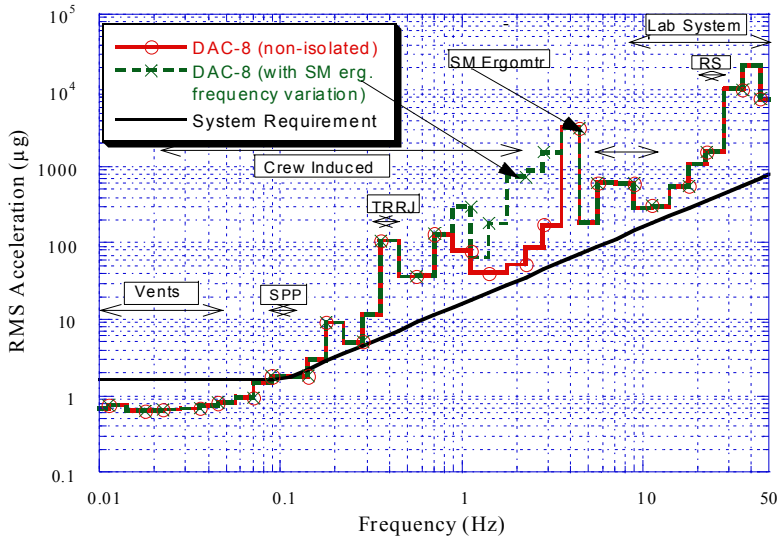


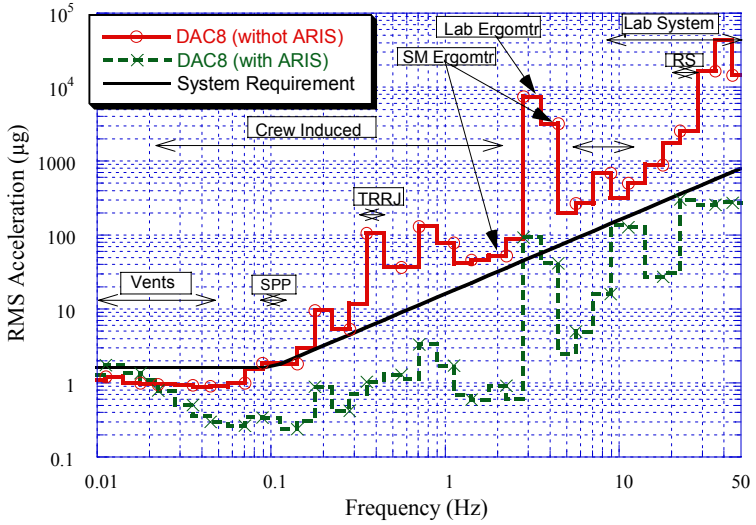
SSP-MG99-074A March 30, 2000

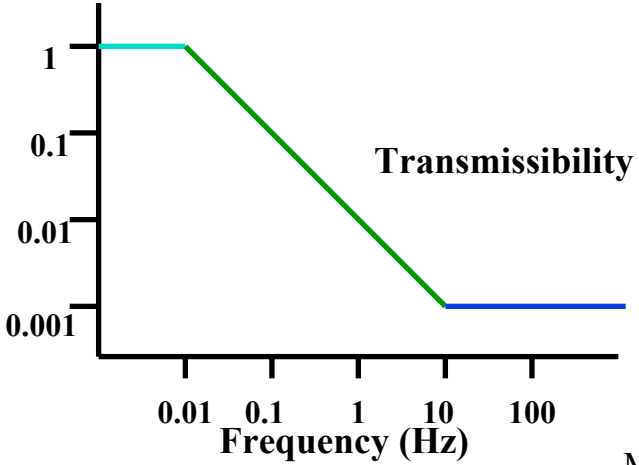
The acceleration environment is expected to significantly exceed acceptable levels

Microgravity vibration isolation systems are required to provide an environment conducive to world-class science research

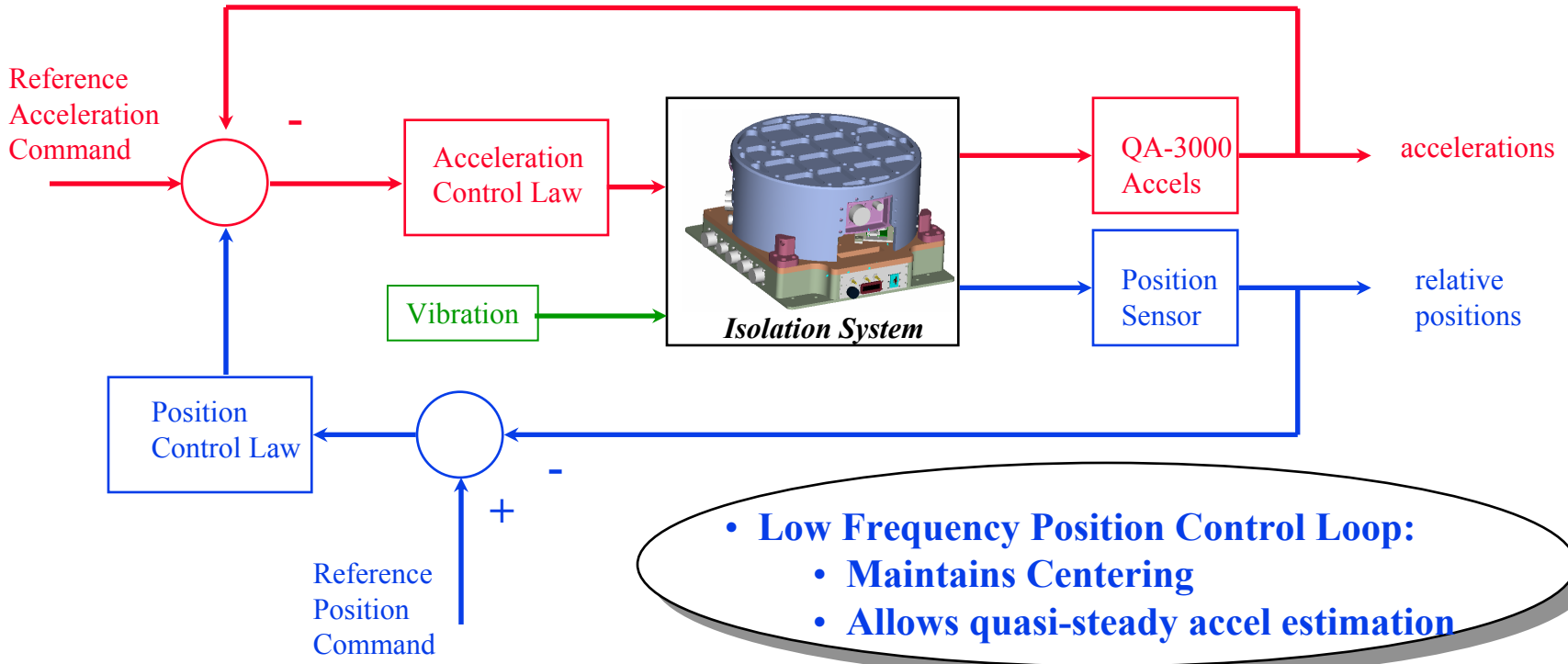
Why is Vibration Isolation Necessary for ISS?







- **High Frequency Acceleration Control Loop:**
  - **Cancels Inertial Motion of the Platform**
  - **Allows "Good Vibrations"**



- **Low Frequency Position Control Loop:**
  - **Maintains Centering**
  - **Allows quasi-steady accel estimation**

Comparison of Approaches

Type	Advantages	Disadvantages
Passive	•Low Cost •Low Maintenance •Reliable •No Power	•Isolate only higher freq (> 1-10 Hz) •Typically requires large volume •Cannot mitigate payload induced vibrations •Resonance vs attenuation trade
Active Rack Level (ARIS)	•Low freq attenuation •Least power & volume (mult. payloads/single unit) •standard user interface	•Cannot mitigate payload induced vibrations •requires payloads to be "good neighbors" •highly sensitive to crew contact •Potential high maintenance
Active Sub-Rack Level (g-LIMIT, STABLE, MIM)	•Low freq attenuation •Mitigates payload induced vibration •can be optimized for individual user	•More power & volume than rack-level (single payload/single unit)

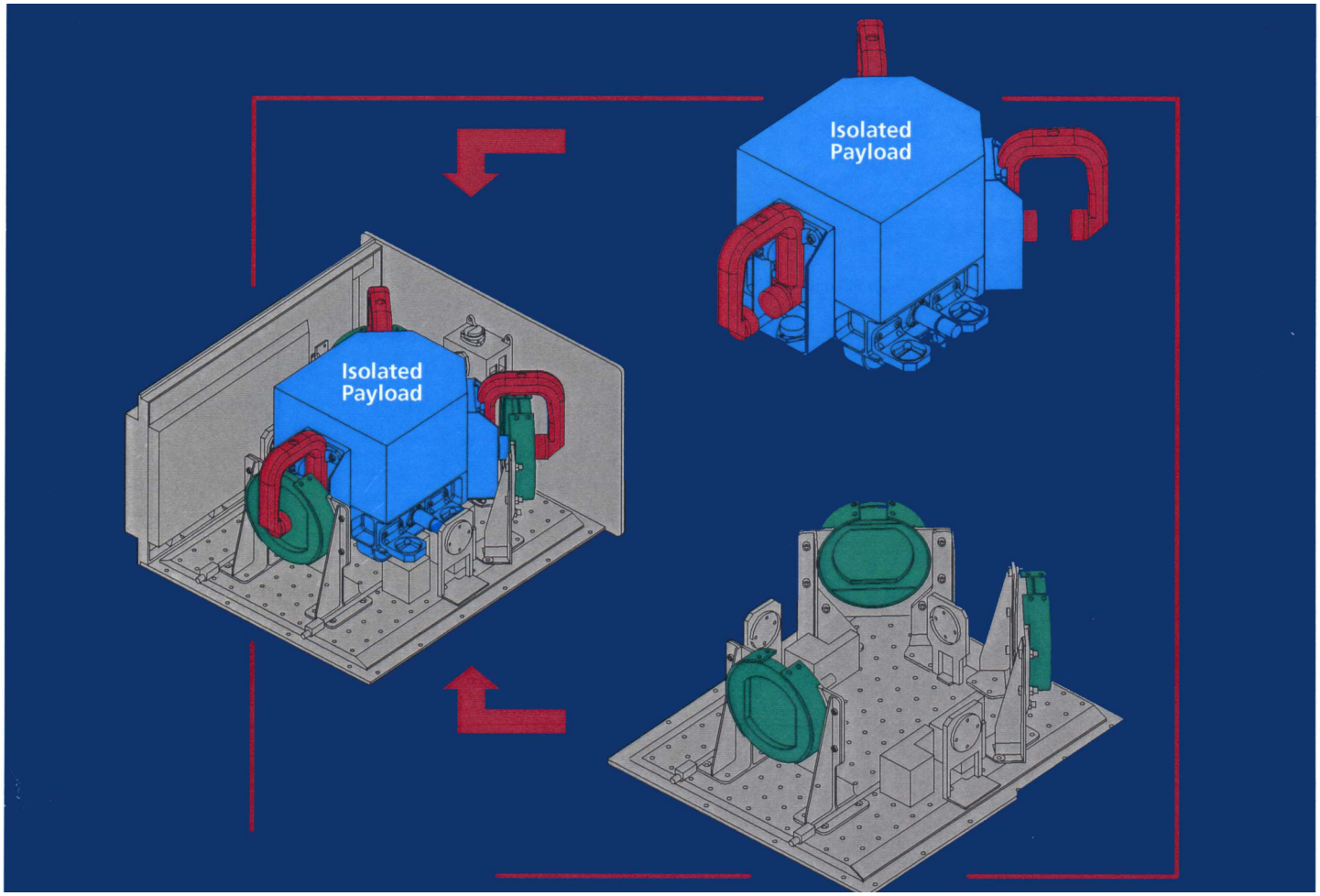
Introduction

- To date, three microgravity vibration isolation systems have been flight tested in orbit:
  - STABLE (Suppression of Transient Accelerations By LEvitation)
  - ARIS (Active Rack Isolation System)
  - MIM (Microgravity Vibration Isolation Mount)
- Each system will be surveyed using data provided by each investigation team

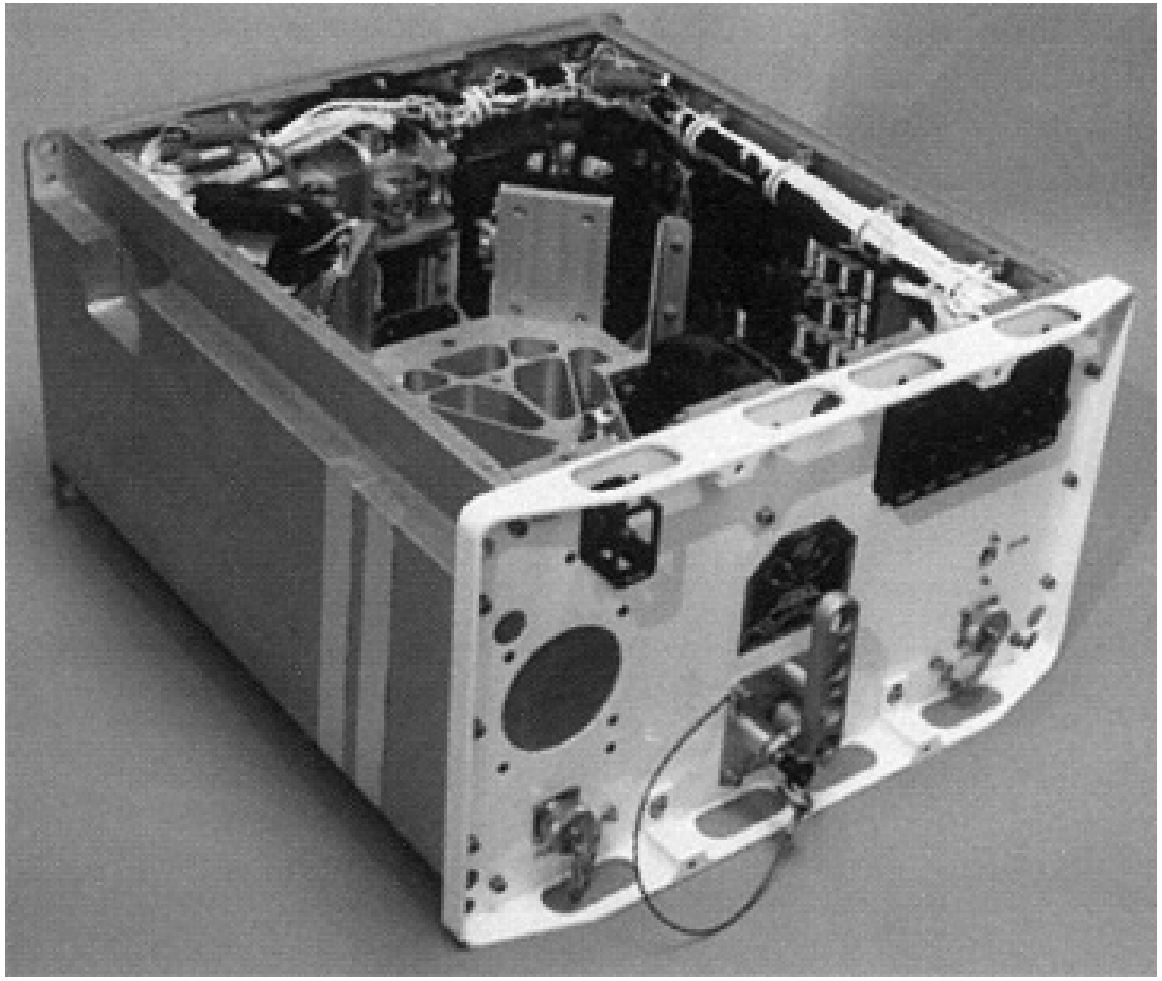
The STABLE Vibration Isolation System

- Payload-level Isolation System
- Developed jointly by NASA MSFC and Boeing (formerly MDAC)
- Flown on STS-73/USML-02, October 1995
- A Faster/Better/Cheaper approach
  - 4.5 months from ATP to delivery
  - Utilized COTS components
  - Necessitated robust control design
  - Supported a fluid physics experiment

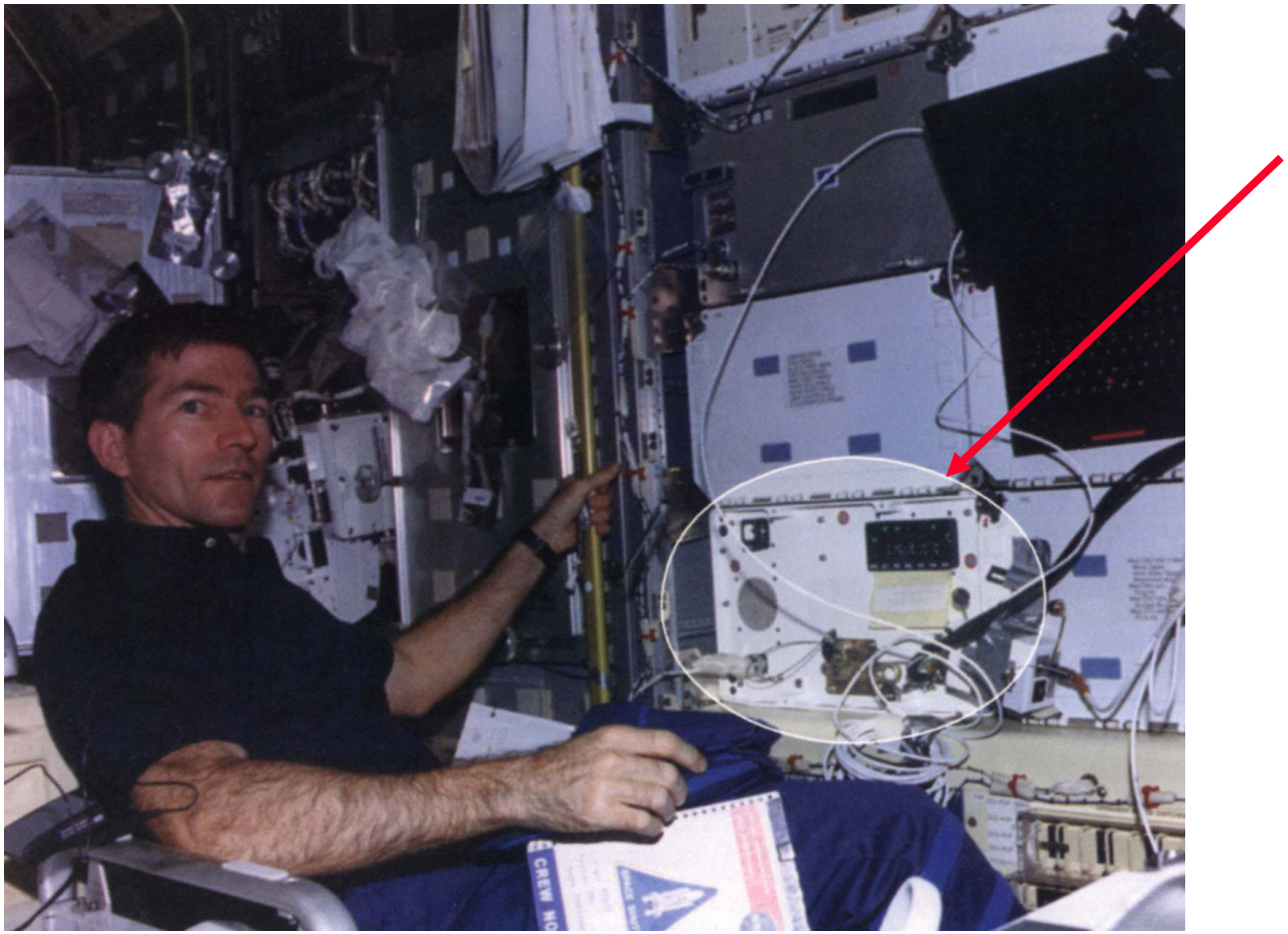
Integration of Payload into STABLE Locker



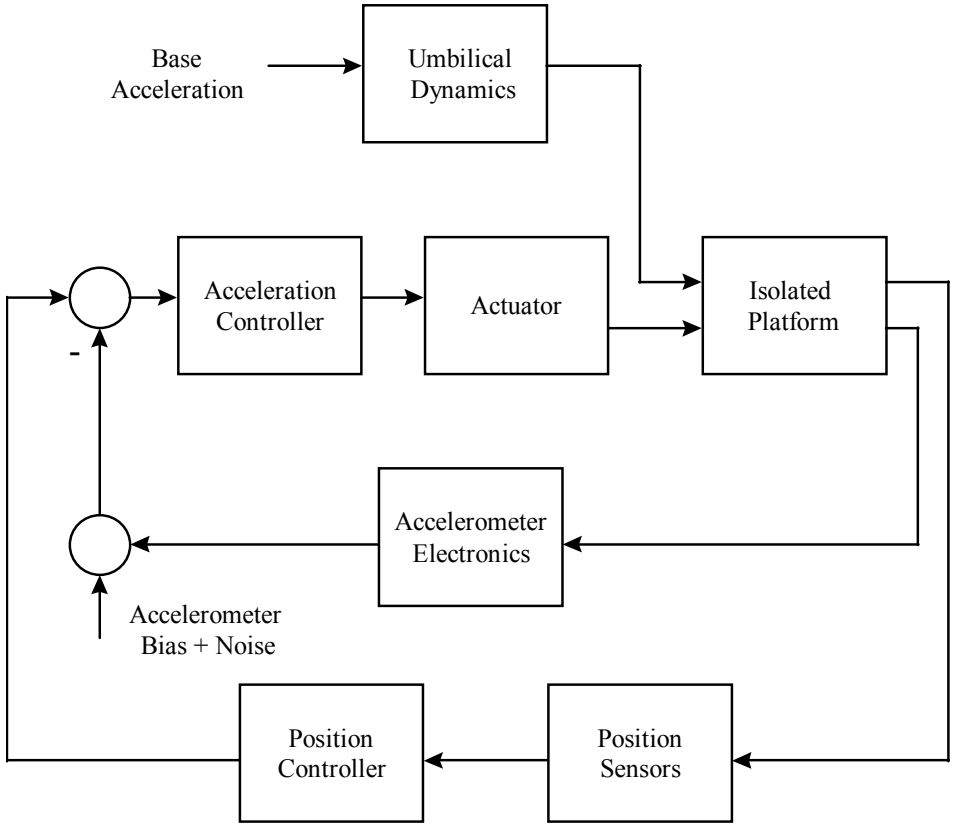
STABLE Flight Unit



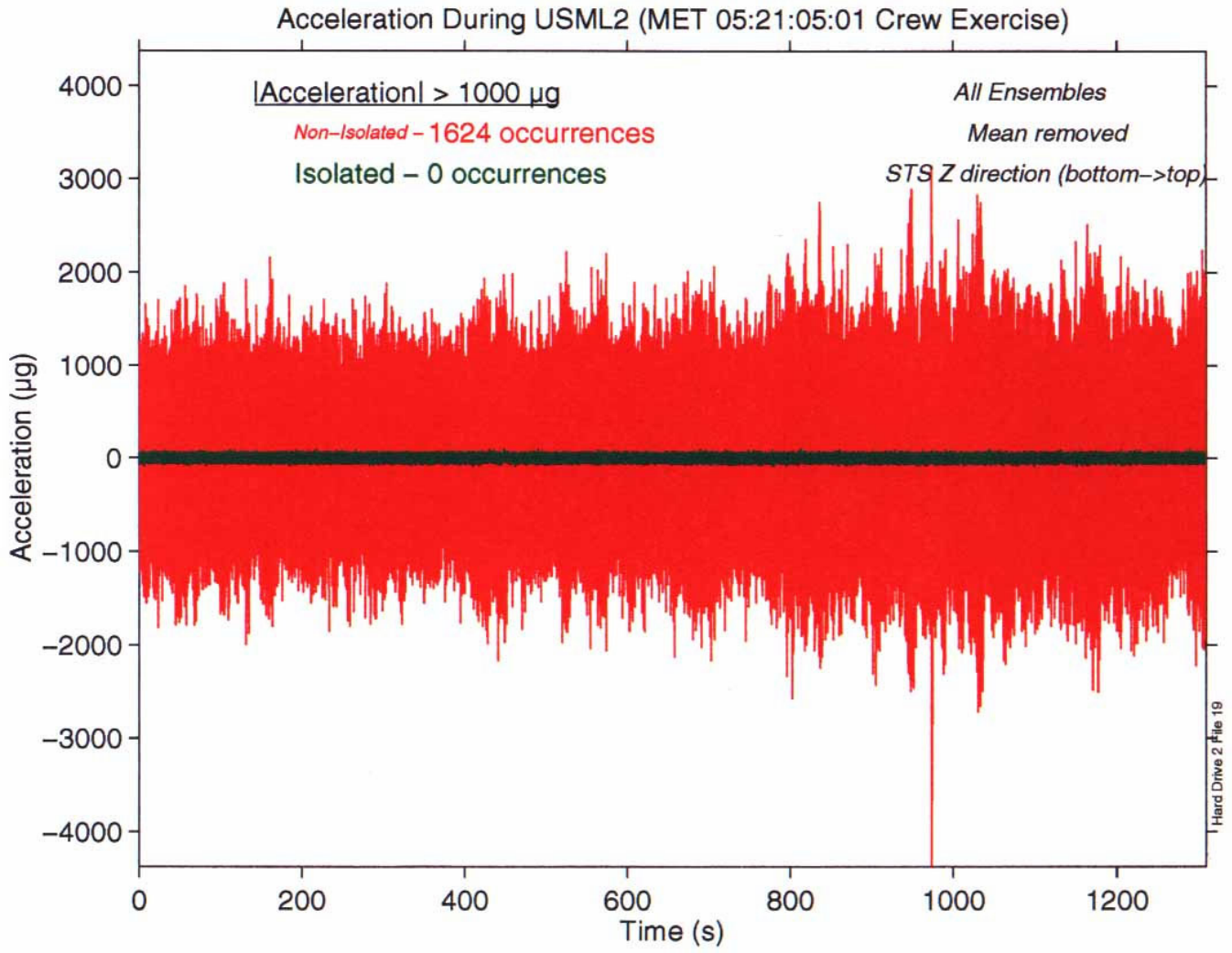
Payload Specialist Dr. Fred Leslie operating STABLE



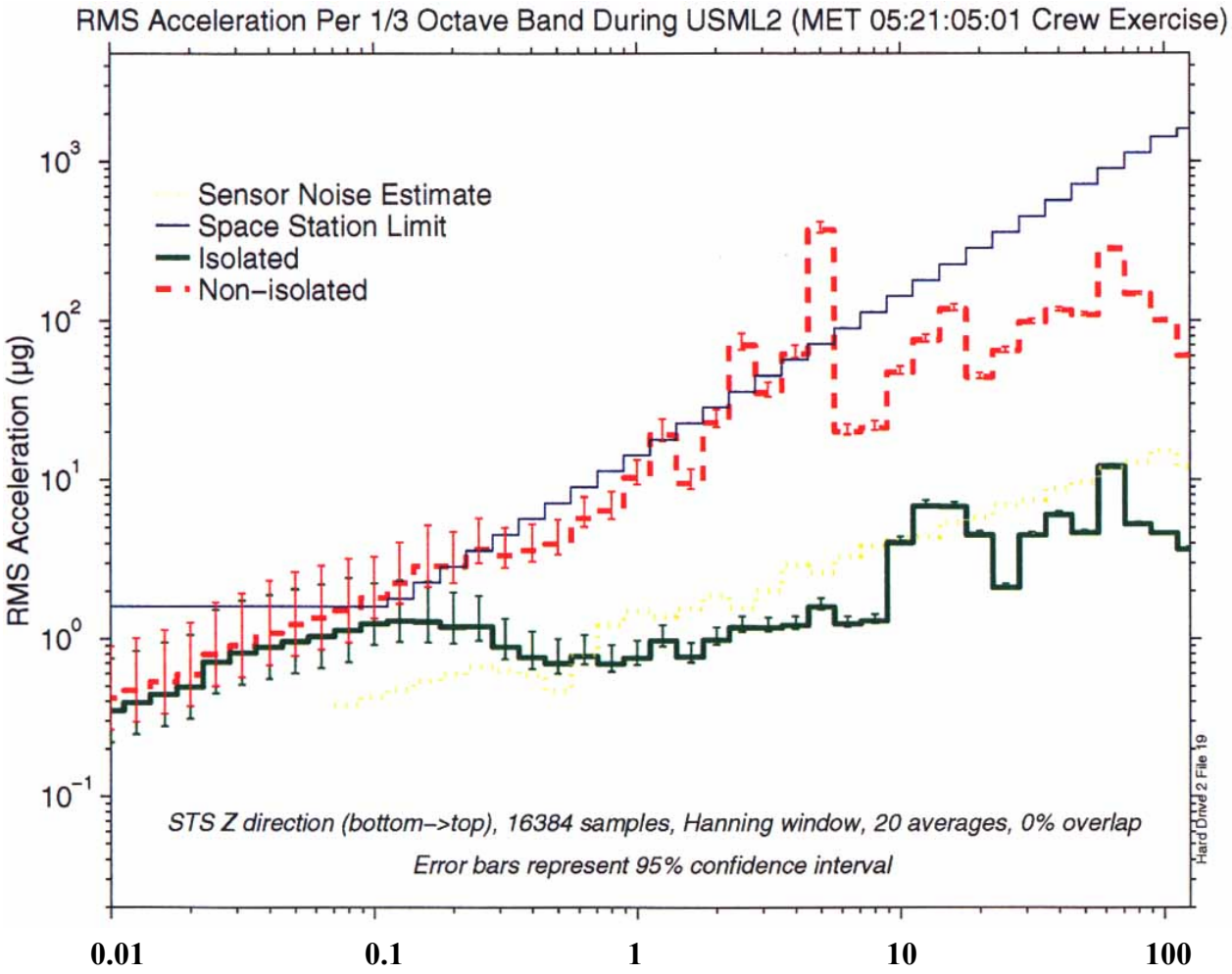
STABLE Control System Block Diagram



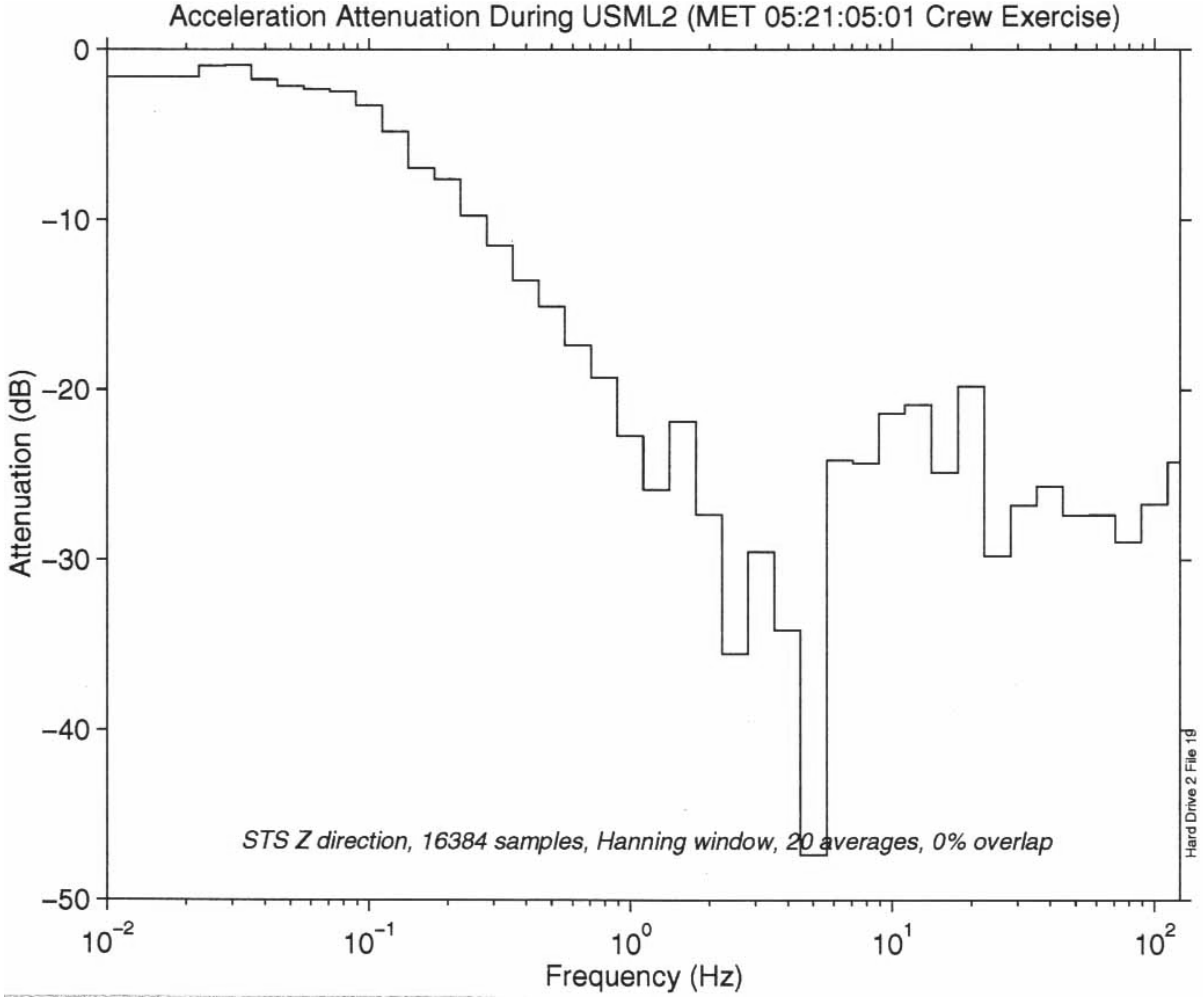
STABLE: Typical Active Isolation Time Response



STABLE: Typical Active Isolation Frequency Response

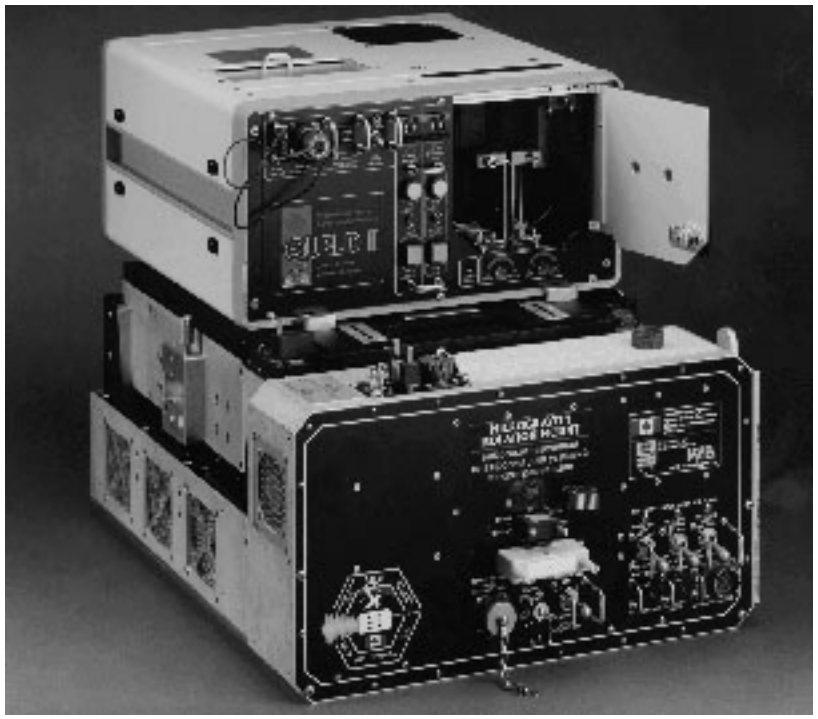


STABLE: Typical Active Isolation Attenuation



MIM Background

- **The Microgravity Vibration Isolation Mount (MIM) has been developed over the past 10 years by CSA under the direction of Bjarni Tryggvason**
- **2 MIM versions have been produced to date:**
  - **First version of MIM is known as MIM-1:**
    - In operation for two years onboard Russian Mir space station since May 1996;
    - accumulating over 3000 hours.

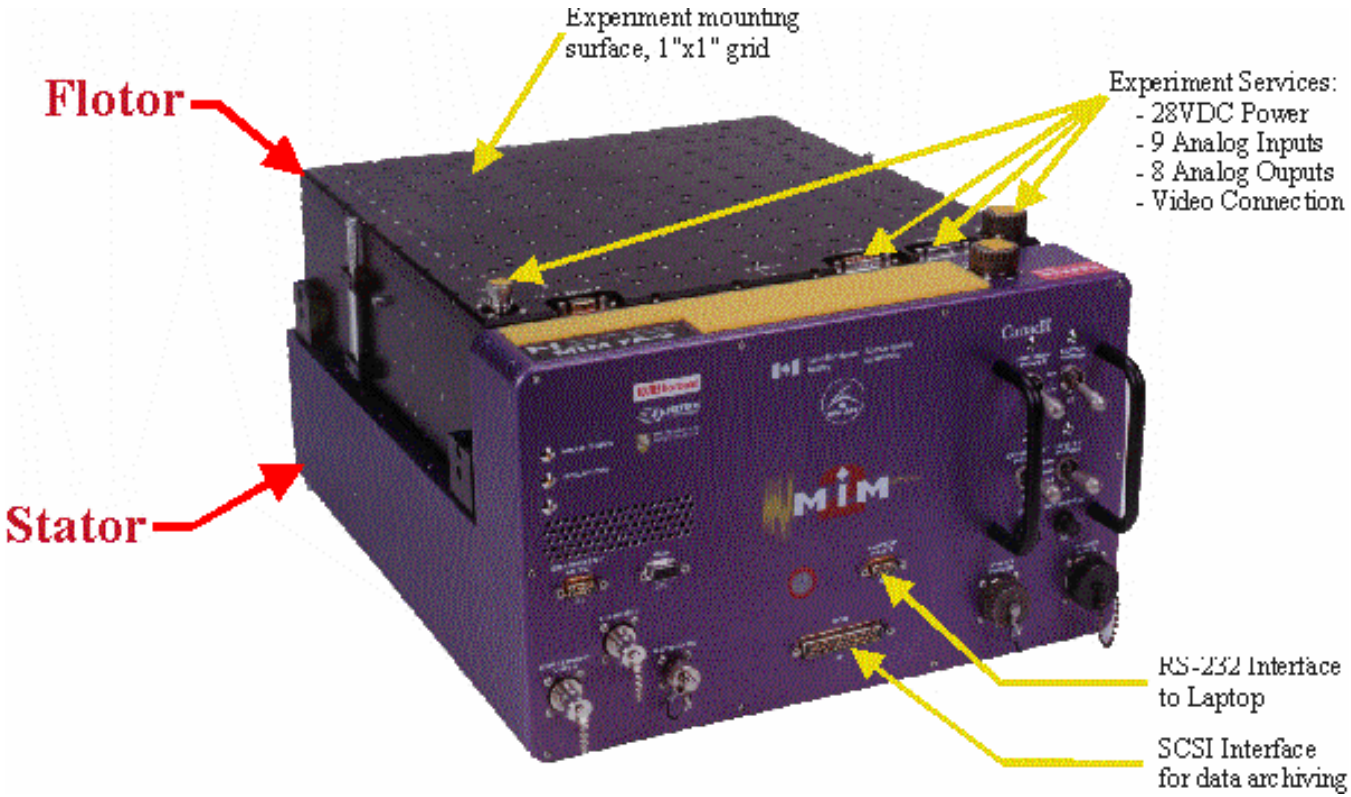


MIM Background

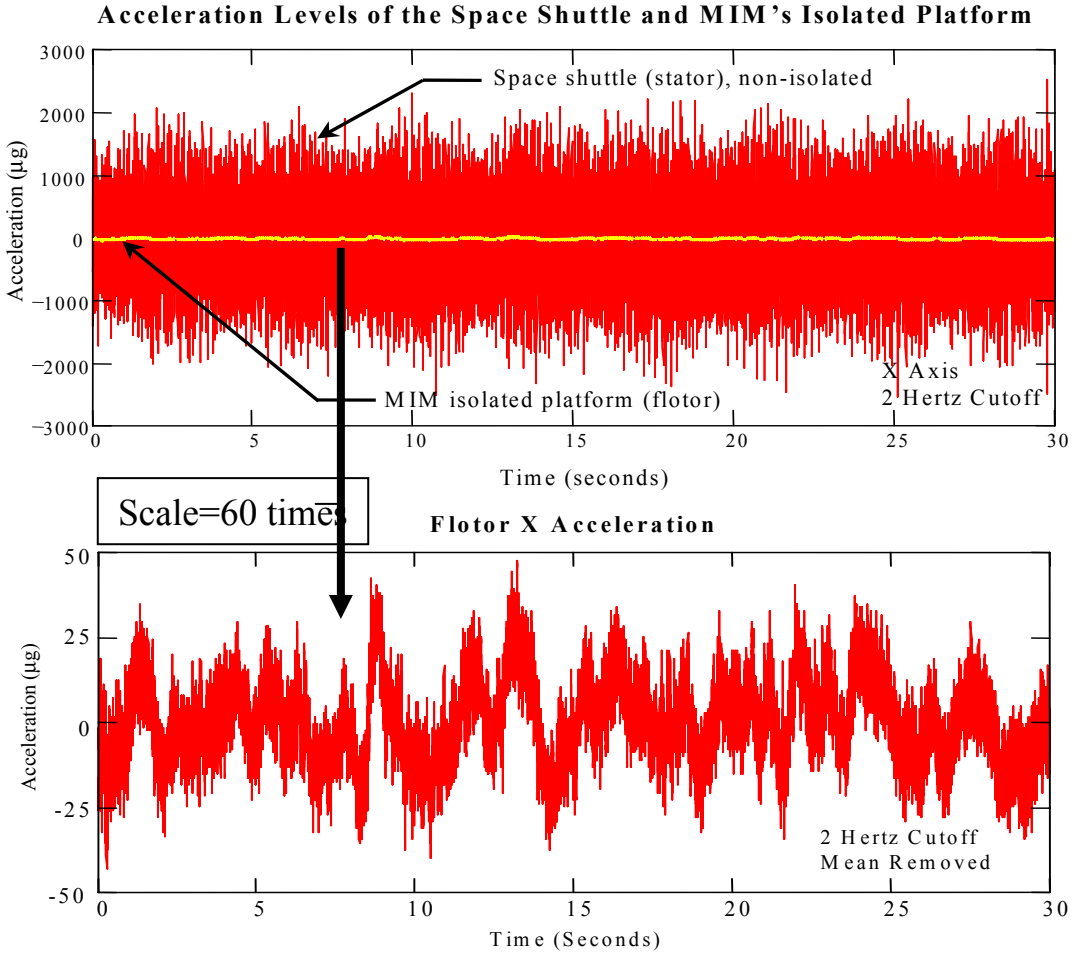
- **Second version of MIM is known as MIM-2:**
  - Flown onboard the Space Shuttle during mission STS-85 with Canadian Astronaut Bjarni Tryggvason;
  - MIM-2 acquired a total of 100 hours of operations.

MIM-2 Description:

- 8 wide gap Lorentz force actuators(magnets on flotor & coils on stator);
- 3 light emitting diodes imaged on 3 position sensitive devices (PSD);
- 6 accelerometers for monitoring stator & flotor acceleration

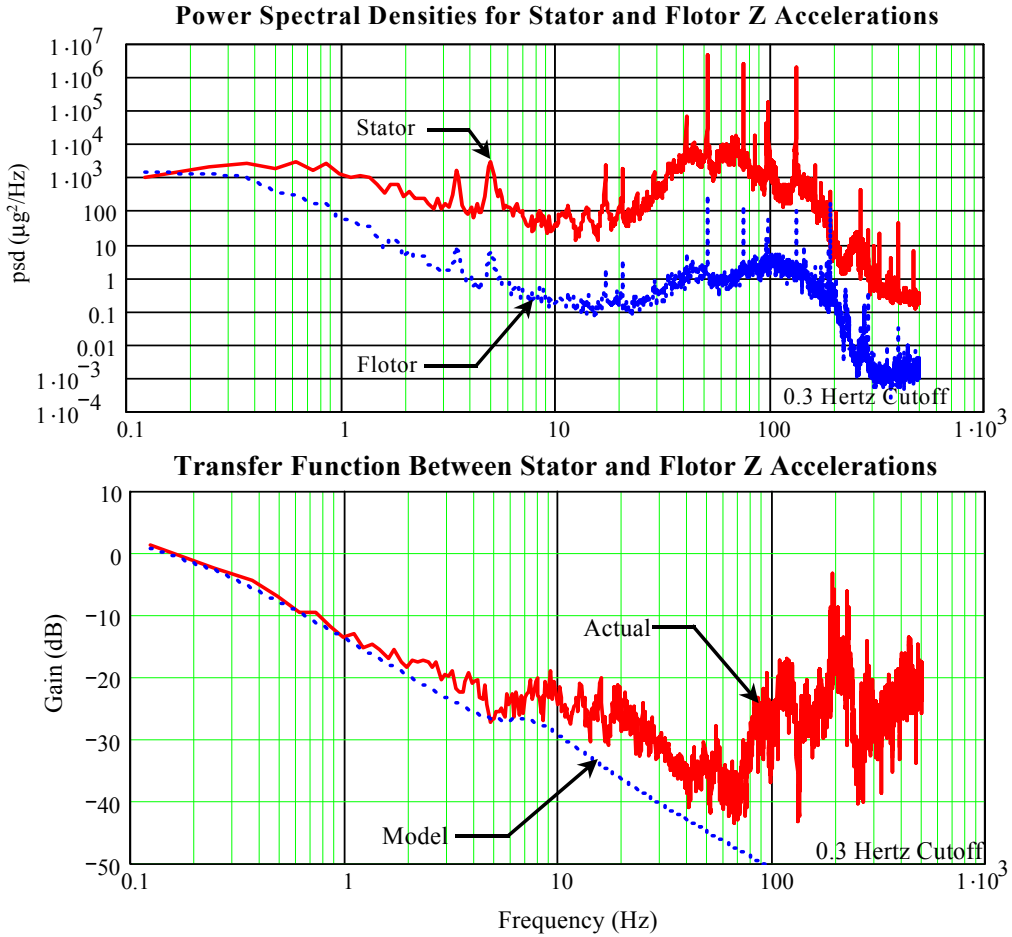


MIM-2 Summary for STS-85



Data filtered by a 100 Hz low-pass filter and sampled at 1000 samples per second

MIM-2 Summary for STS-85



Data filtered by a 100 Hz low-pass filter and sampled at 1000 samples per second

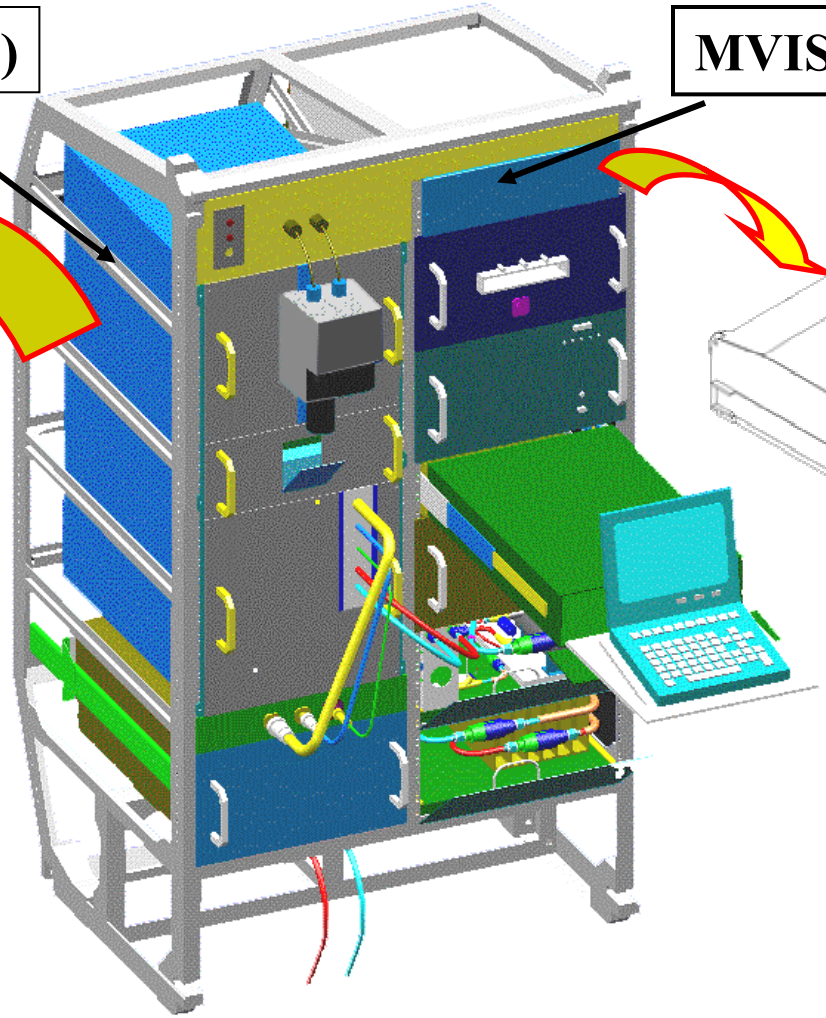
MIM-2 summary for STS-85

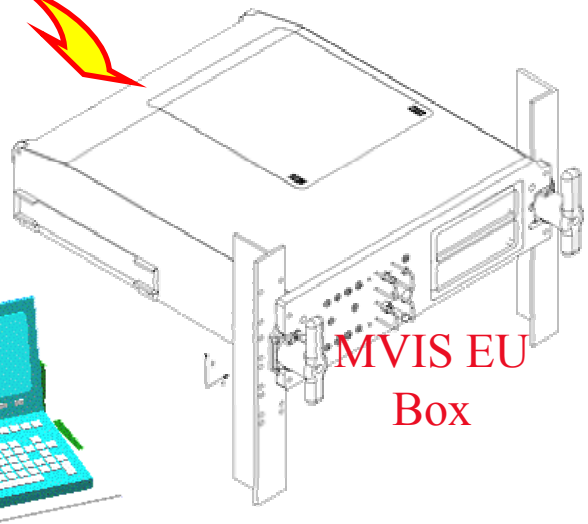
- MIM has shown the capability to isolate down to 0.3 Hertz with that limit related to the PSD case material

- Models indicate that with current umbilical and replacement of PSDs, isolation cutoff frequencies of approximately 0.04 Hertz can be achieved
  - To reach 0.01 Hertz, improvements to the umbilical are required

Fluid Core Element (FCE)

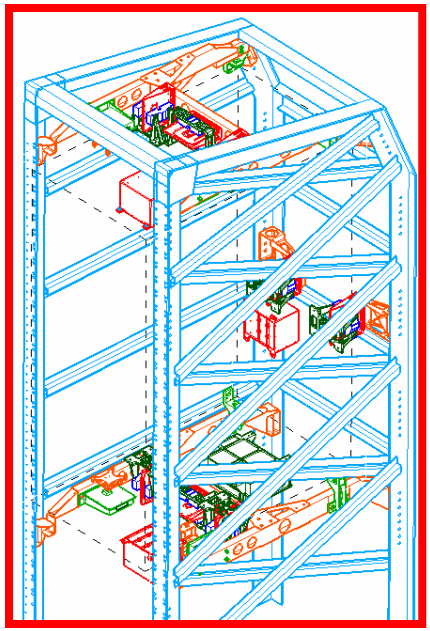
MVIS Electronic Unit

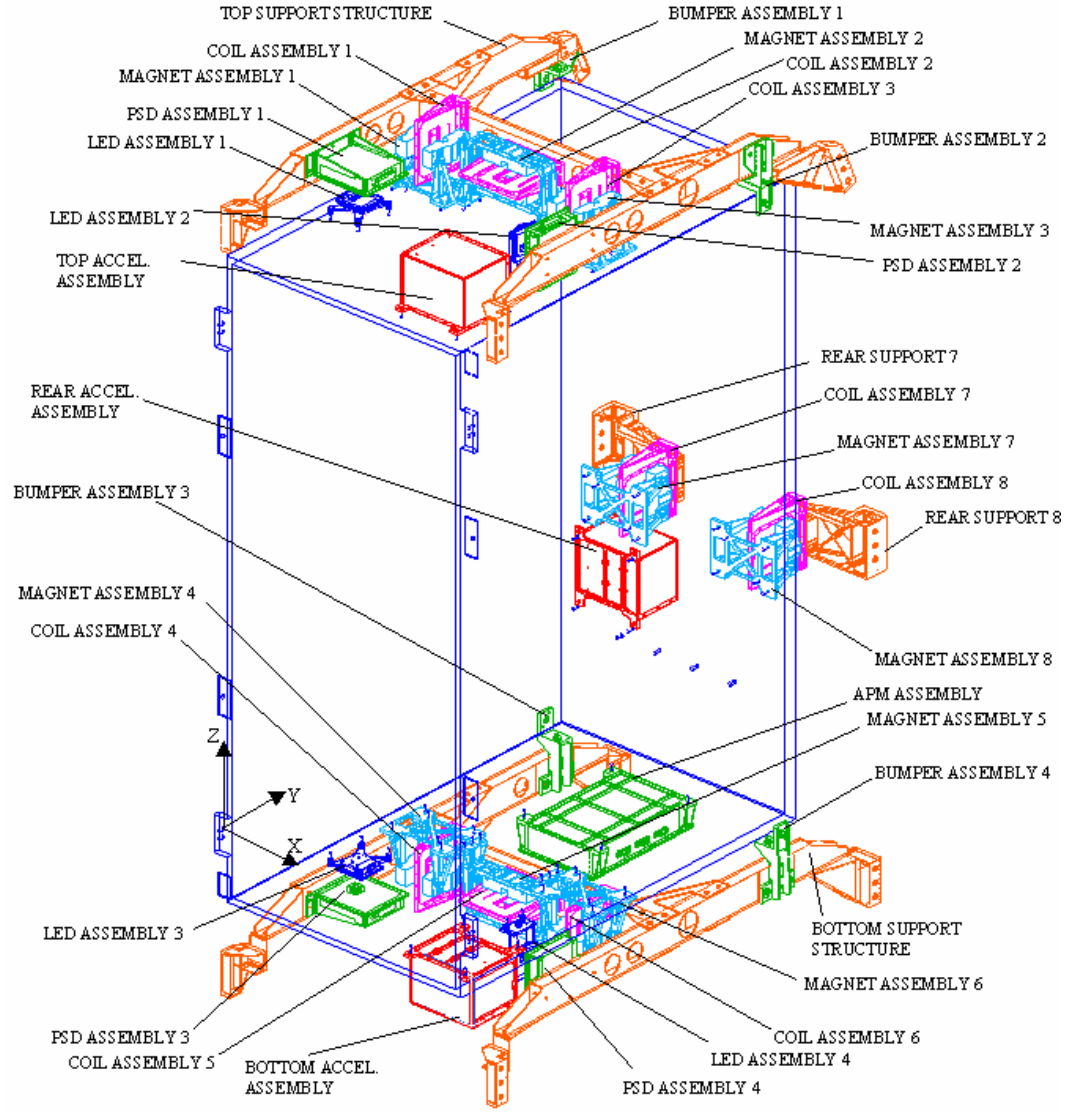




MVIS EU Box

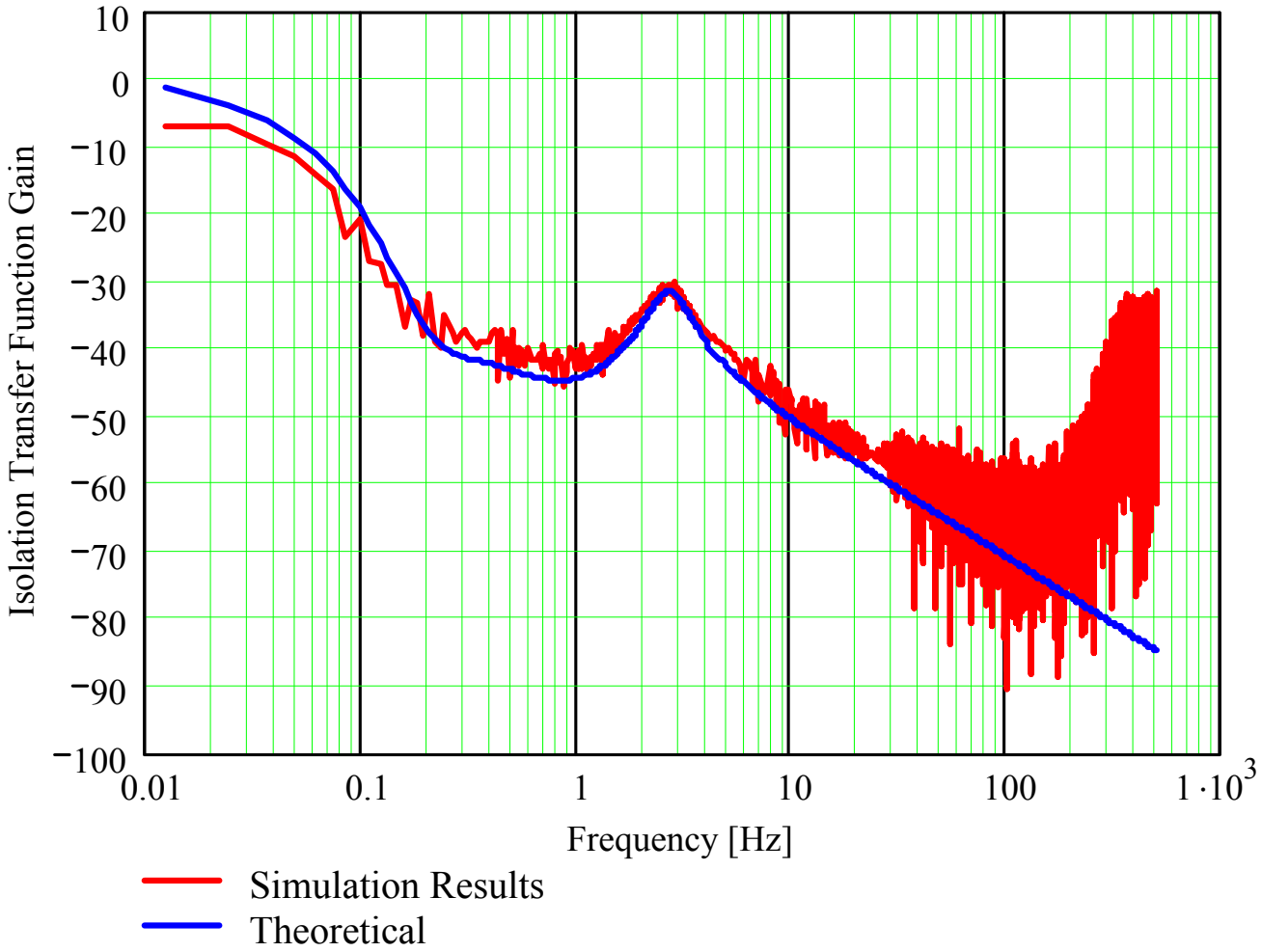
FCE / ISPR Mounted Items



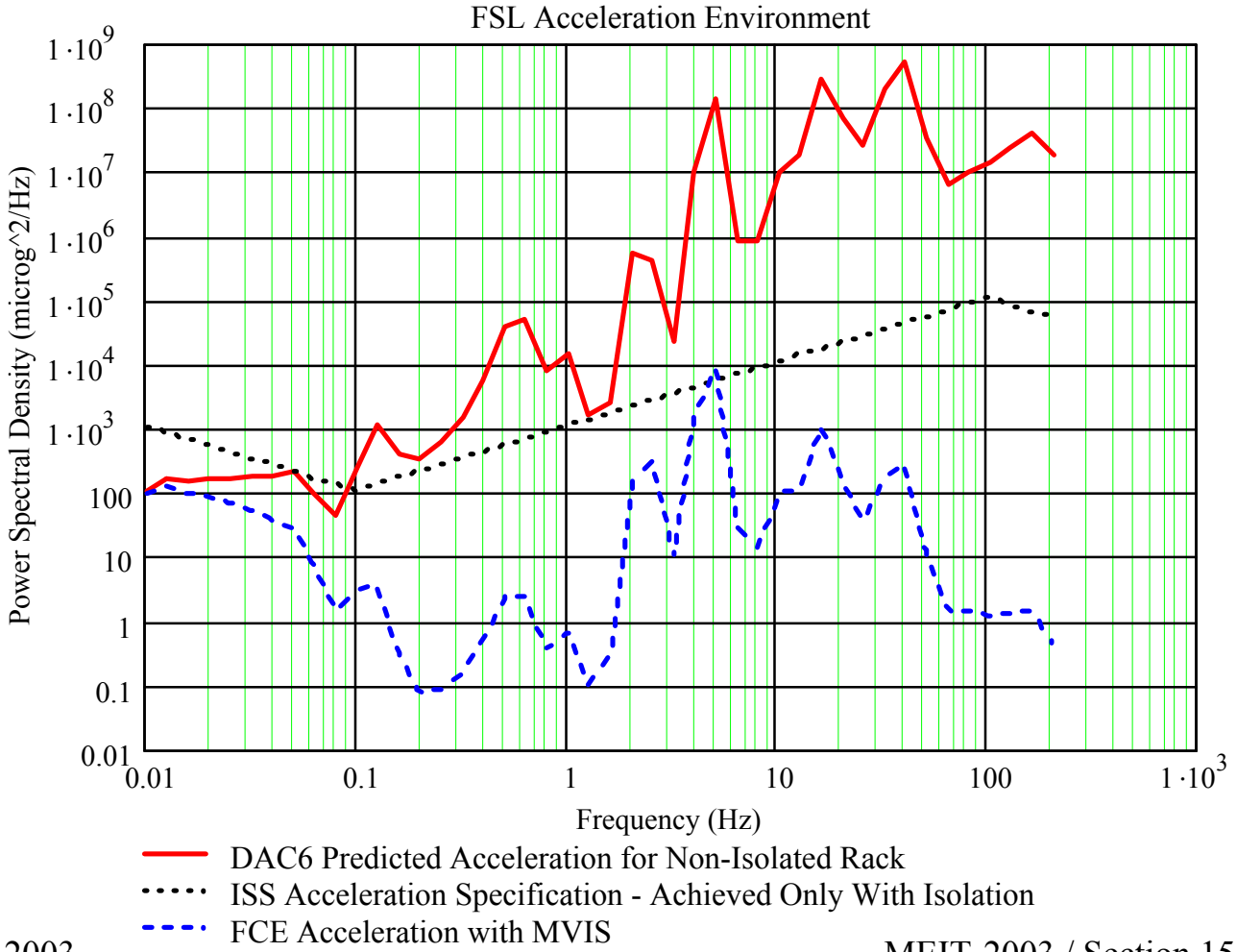


MVIS Hardware

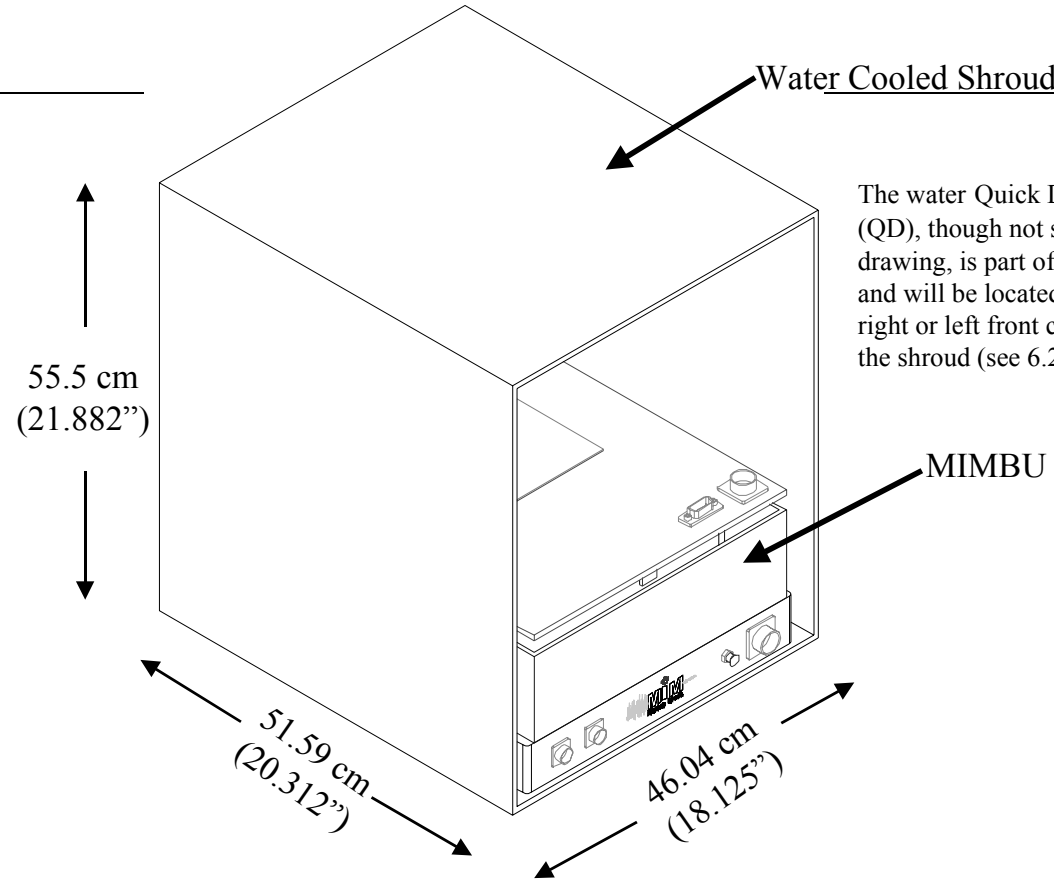
Predicted Isolation Transfer Function



Isolation Performance Predicted for MVIS

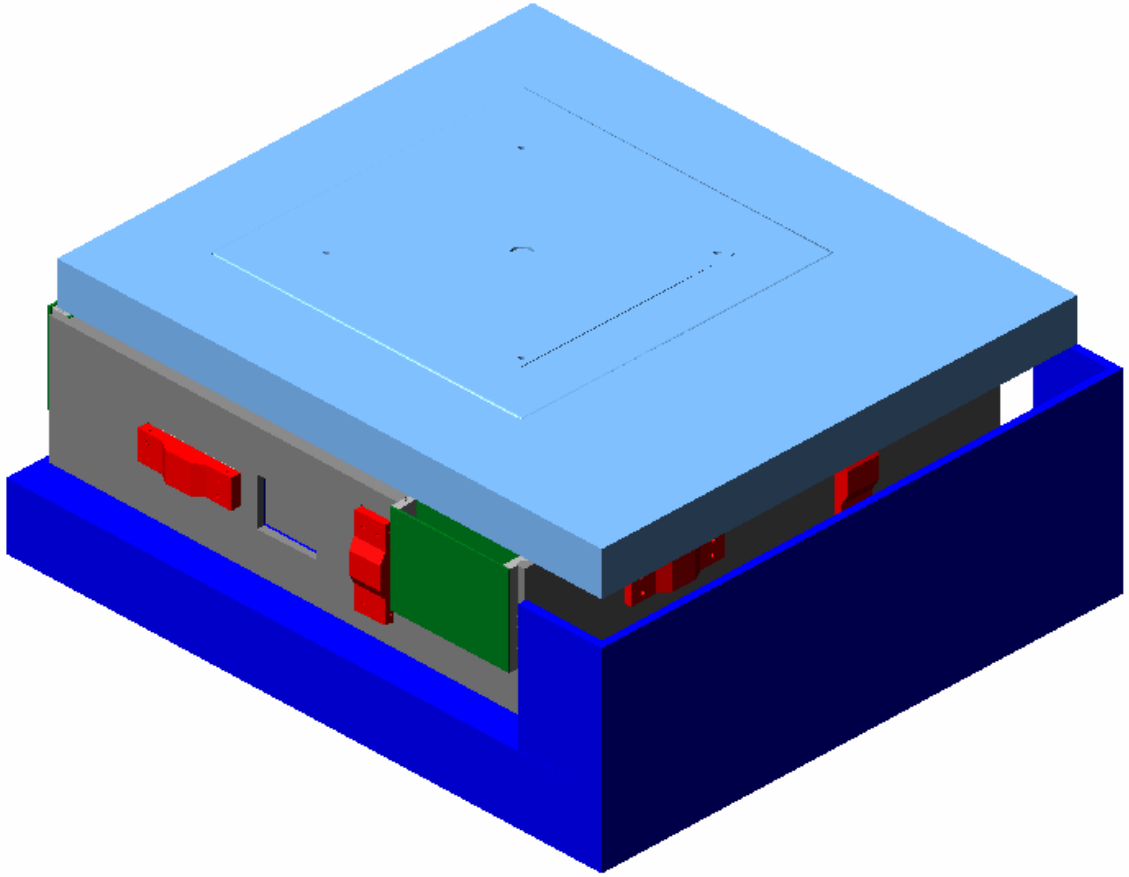


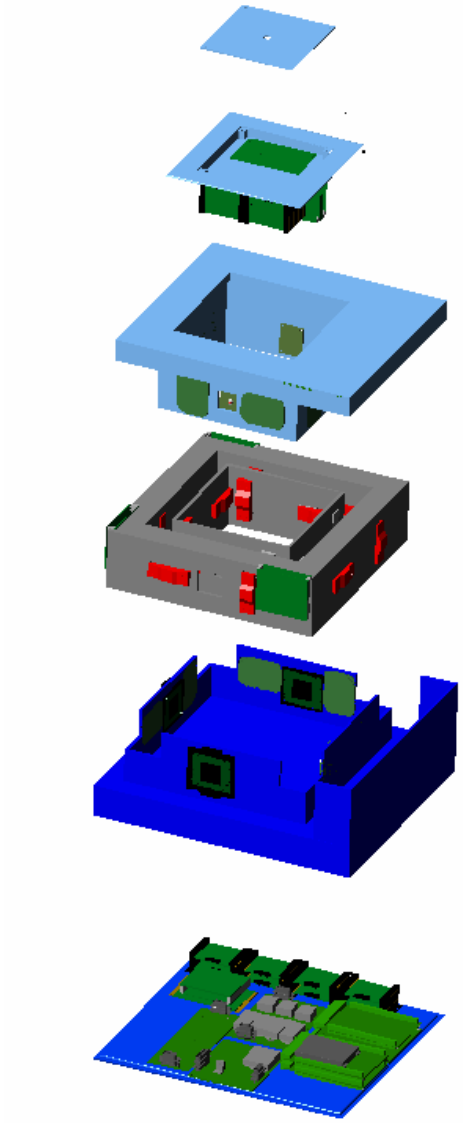
MIM Base Unit Configuration



The water Quick Disconnect (QD), though not shown on this drawing, is part of the shroud and will be located at the lower right or left front corner of the shroud (see 6.2.3.5).

MIM Base Unit: Two Stage Isolation to Allow Investigation of G-Jitter Effects





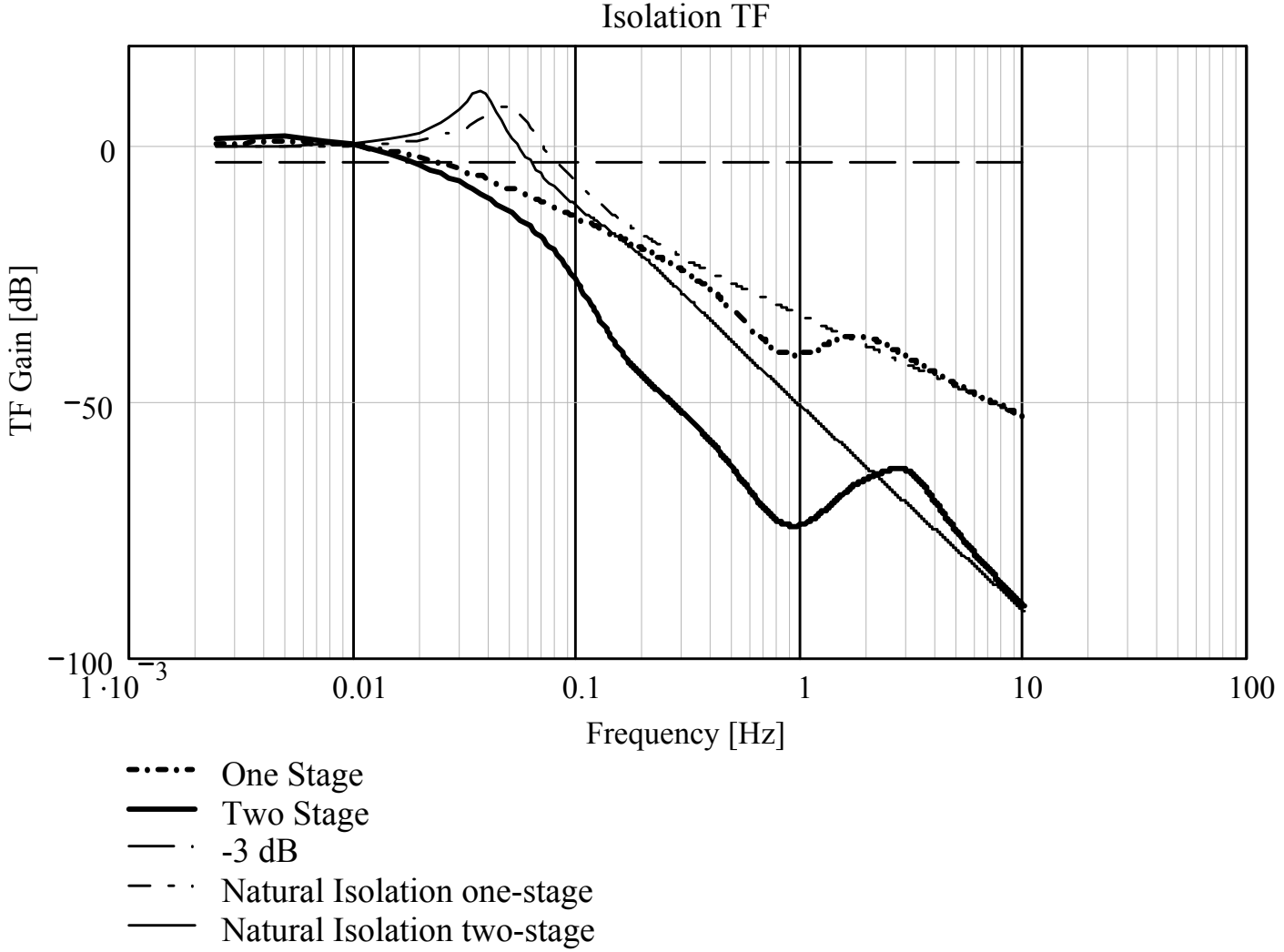
MIM Base Unit

Top Flotor

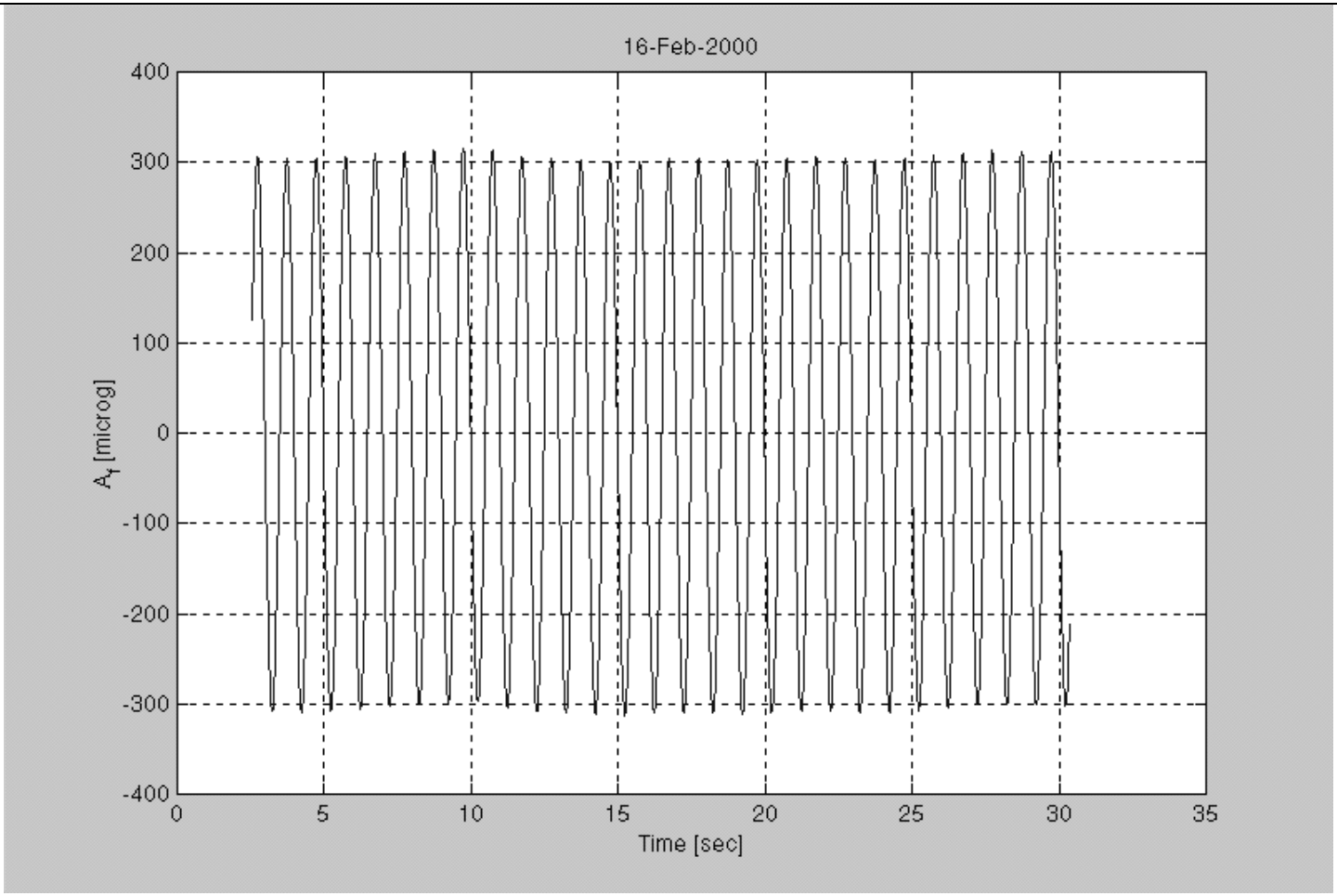
Intermediate Flotor

Base

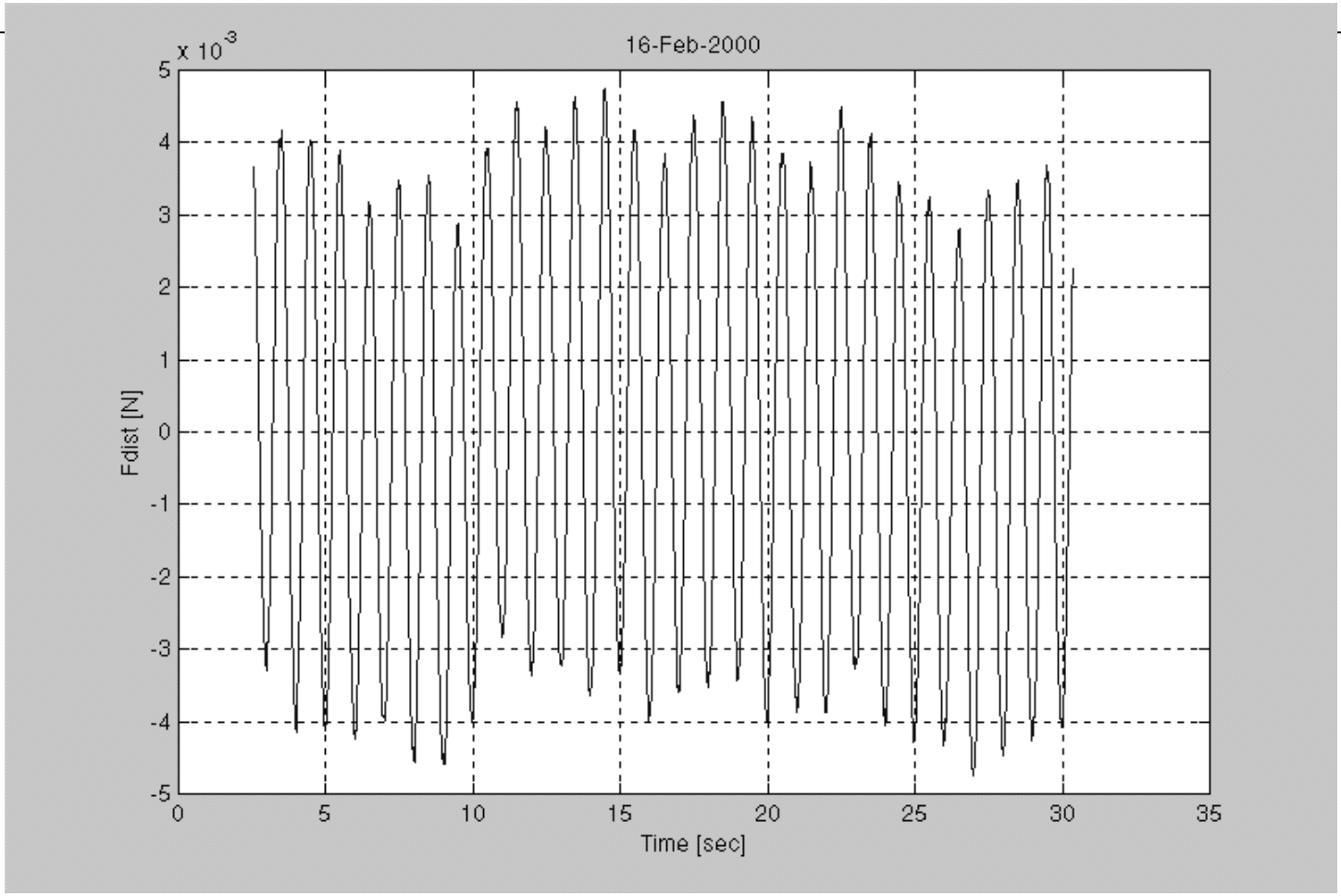
MIM Base Unit Isolation Performance



MIM Base Unit:Driven Accelerations on Top Flotor



Reaction Force to ISS in Driven Mode Operation



Schedule

MVIS is currently being manufactured

- **FCE mounted component were delivery to ESA in early November for vibration testing**
- **Flight harness will be delivered to ESA in December**
- **Remaining flight hardware to be delivered to ESA by mid 2003**

MIMBU configuration is complete

- **Work is on hold until MVIS is completed**
- **Launch is expected in 2005**

The Active Rack Isolation System (ARIS)

- Rack-level Isolation System
- Developed by Boeing
- Flown on RME 1313 / MIR Spacehab STS-79, August 1996
- Over 1700 test runs for Isolation Characterization Experiment completed since June 2001
- Planned Utilization:
  - EXPRESS Racks
  - Fluid Combustion Facility
  - Materials Science Research Facility

Boeing Active Rack Isolation System (ARIS)

1 Dual Processor : Decoupling implemented in controller allows freedom to place actuators and sensors. Payloads have extensive command, data acquisition, and control options.

2 3 Sensor Electronic Units : Programmable analog filters & gains & 16 bit analog-to-digital converters.

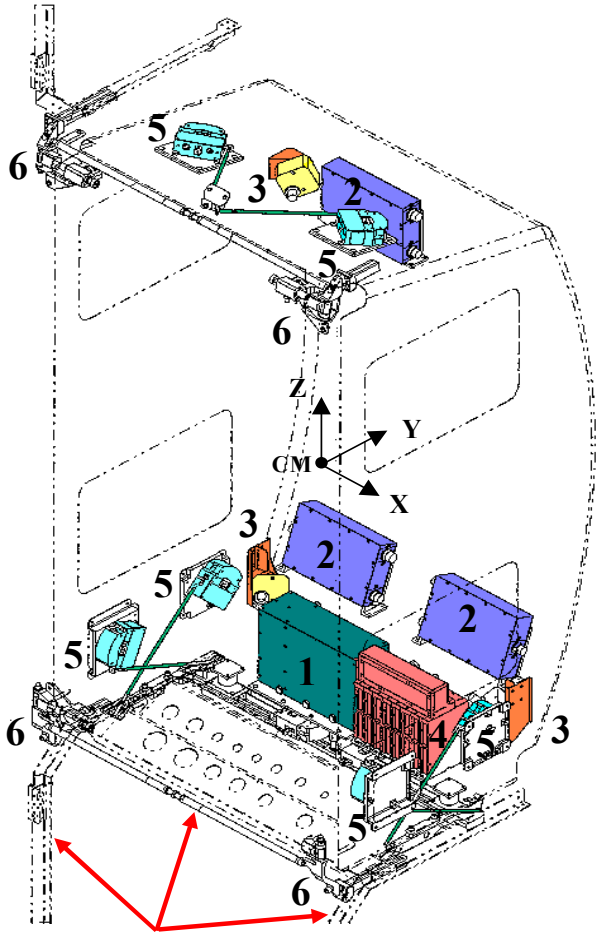
3 Accelerometer Heads : Built small to fit in rack corners. 2 Tri-axial (Bottom), 1 Bi-axial (Top)

4 8 Actuator Drivers : Pulse width modulation used to reduce power consumption

5 8 Actuators : Voice coil rotary actuator used to reduce profile and power consumption.

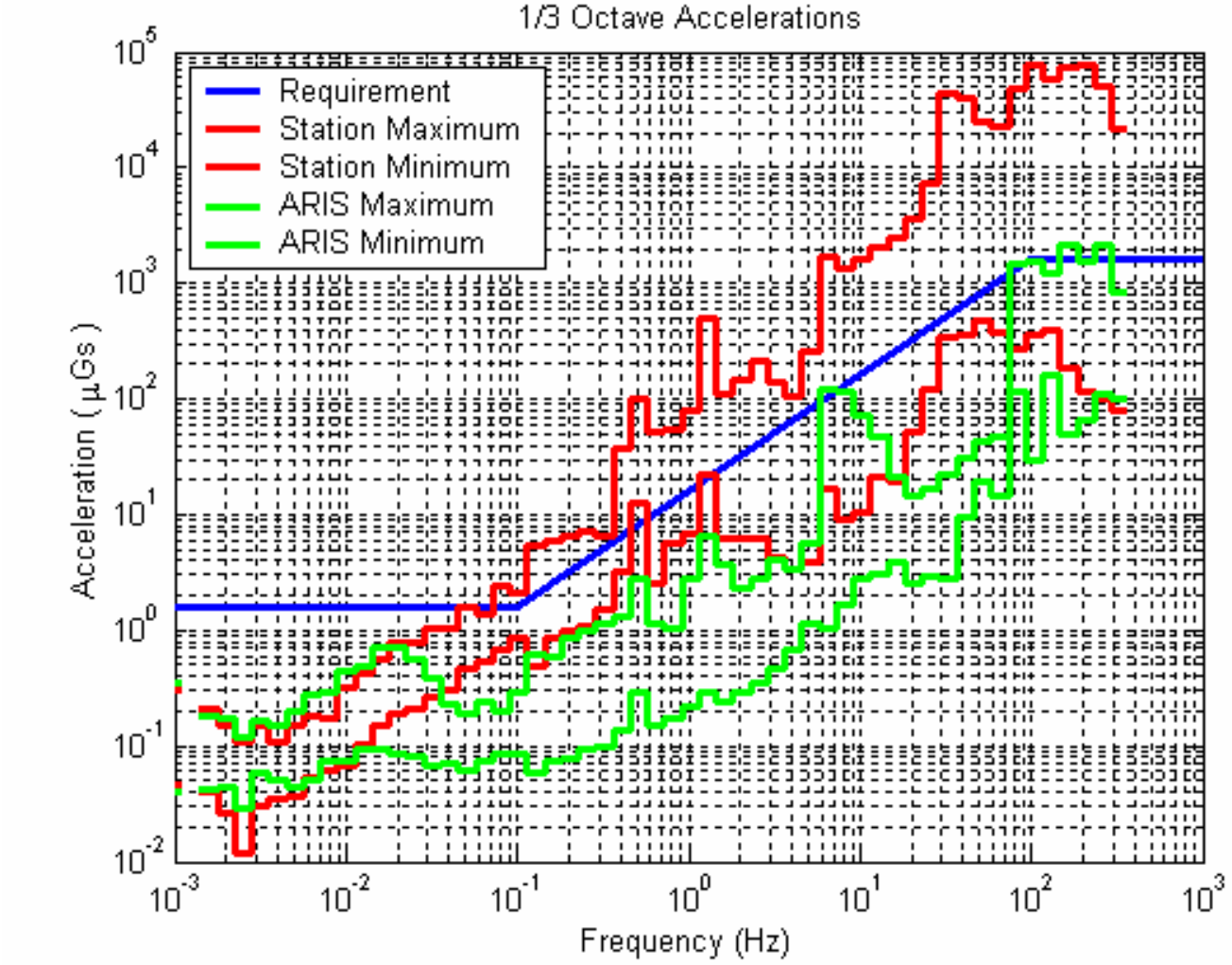
5 8 Position Sensors : Integrated with actuators.

6 Hard stop Bumpers

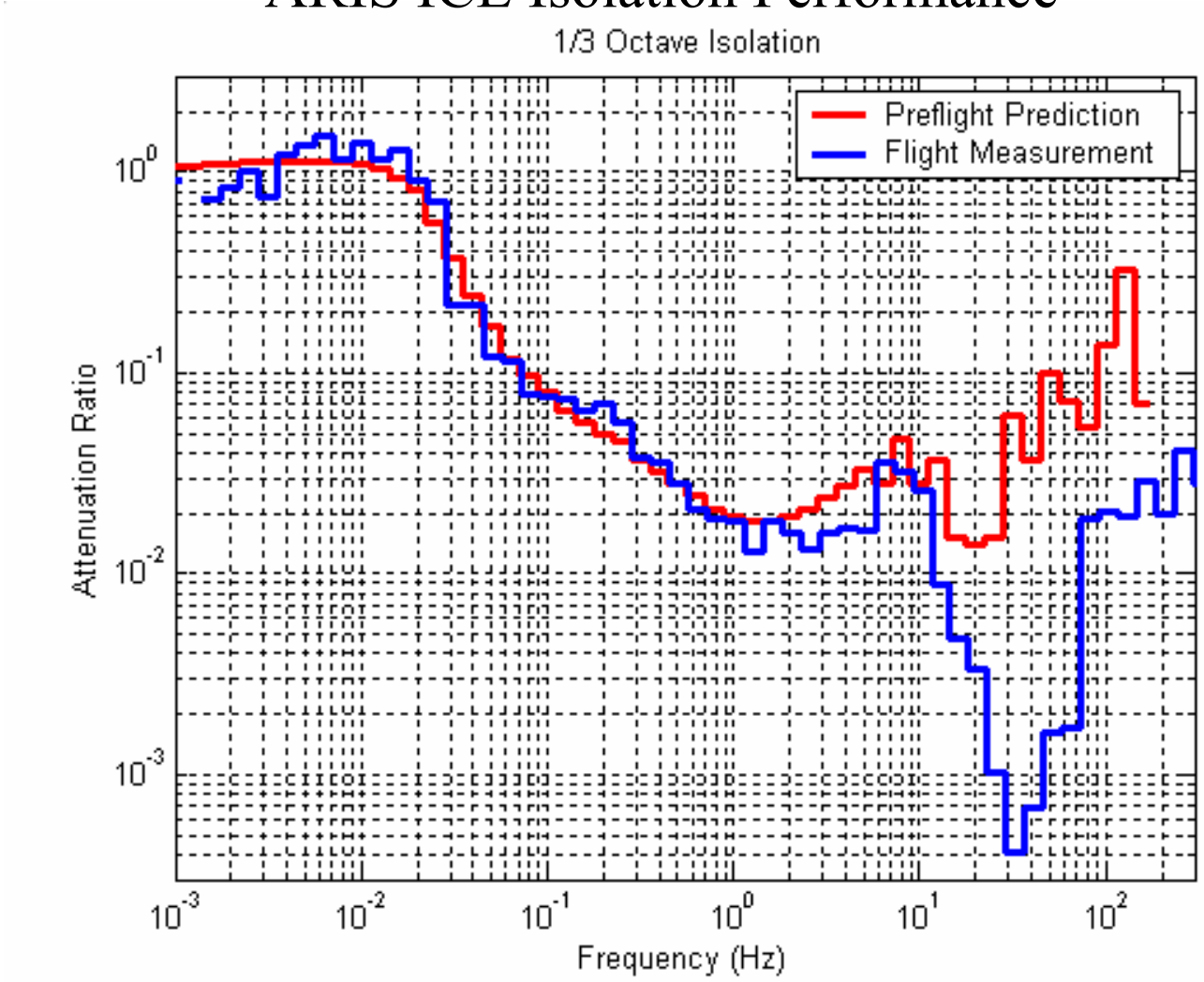


STATION UMBILICAL
STANDOFF STRUCTURE

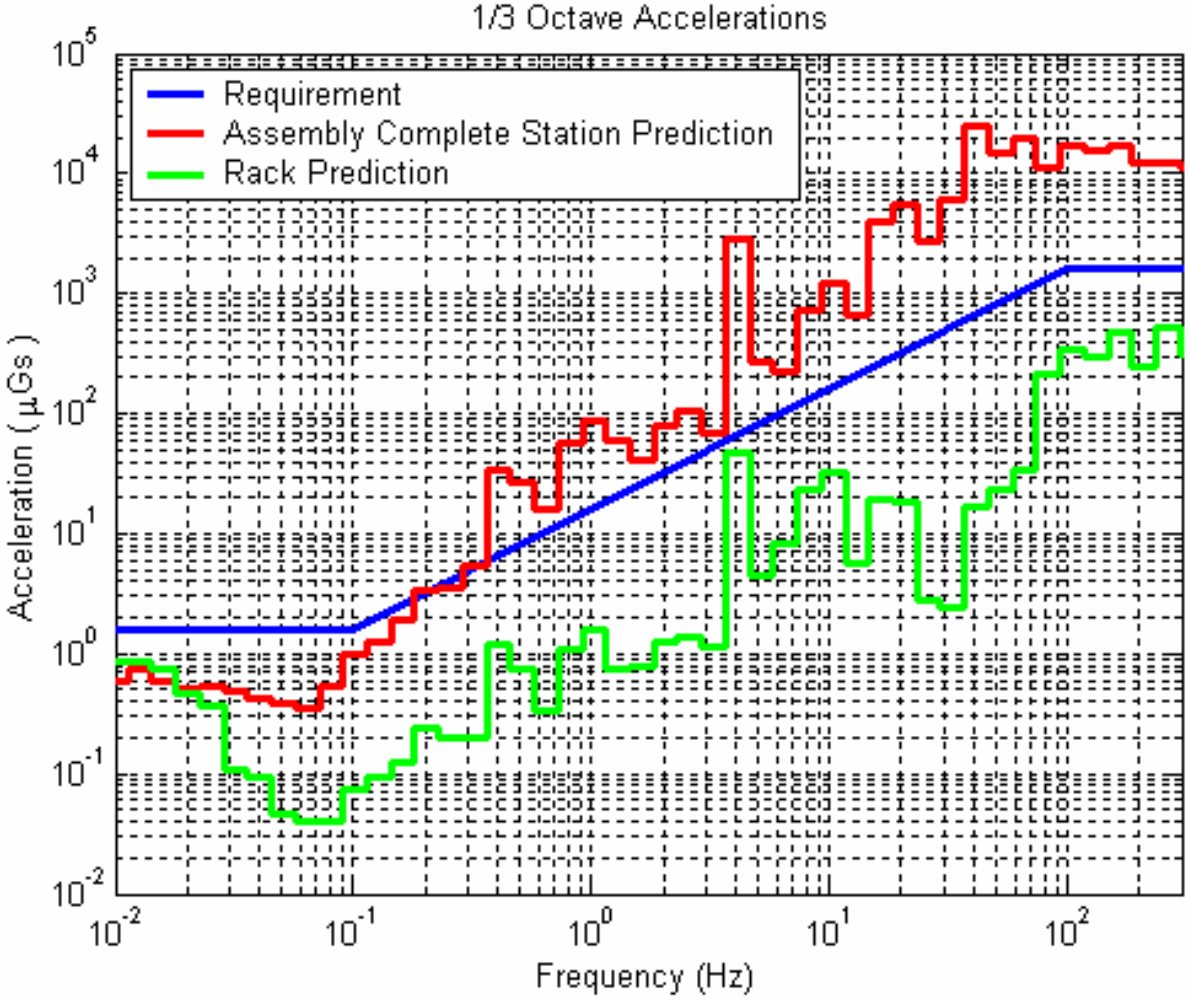
ARIS ICE 1/3-Octave Band Acceleration Measurements



ARIS ICE Isolation Performance



ARIS EXPRESS Predicted Performance at Assembly Complete



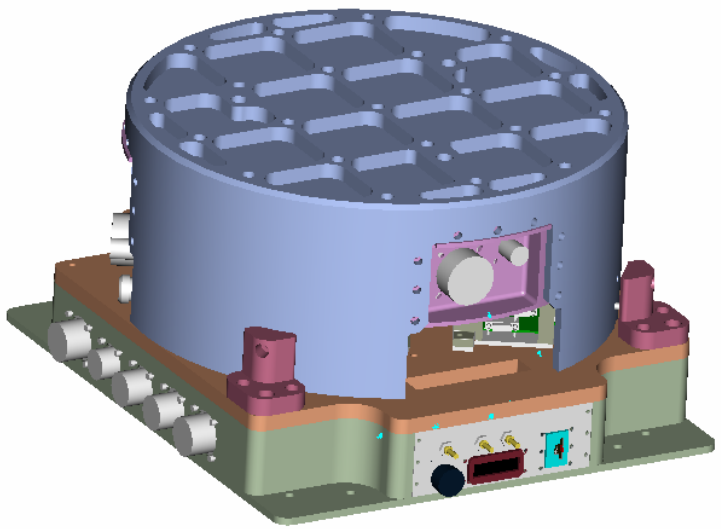
ARIS Utilization

Focal Points:

- Remove conservatism in models
- Increase control bandwidth
- Improve umbilical design
- Investigate z-panel dynamics
- Investigate rack stiffness and damping enhancements
- Payload scheduled control design

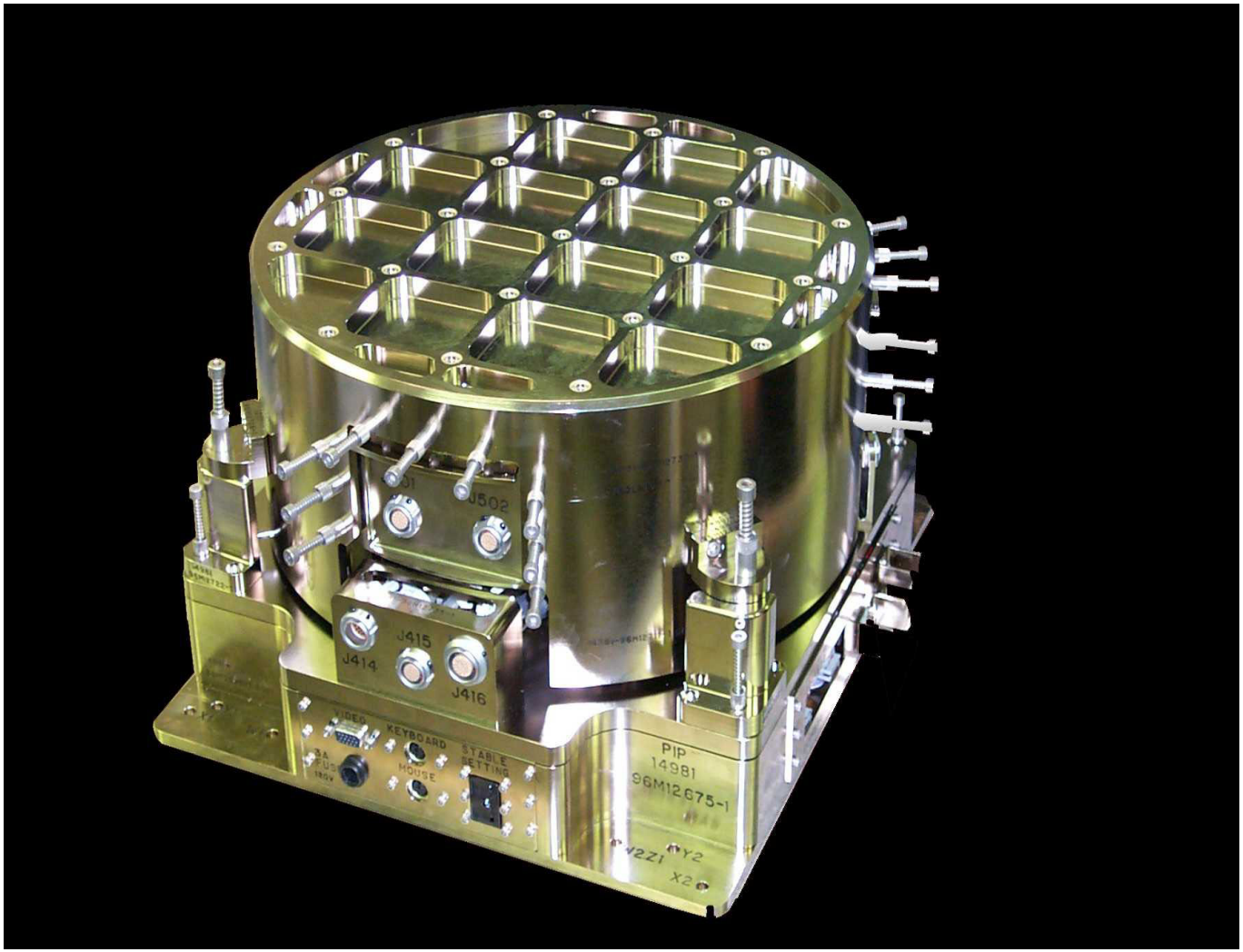
g-LIMIT

A Vibration Isolation System for the Microgravity Science Glovebox



- Designed & built in-house by MSFC
- Characterized as a MSG Glovebox Investigation
- Manifested for launch:
  - ULF1 Mission; 3/1/03
- Characterization testing:
  - Increment 7
- Payload support operations after characterization

g-LIMIT Flight Unit



Dimensions:
~ 14” x 16” footprint
~ 10” tall

g-LIMIT System Assembly

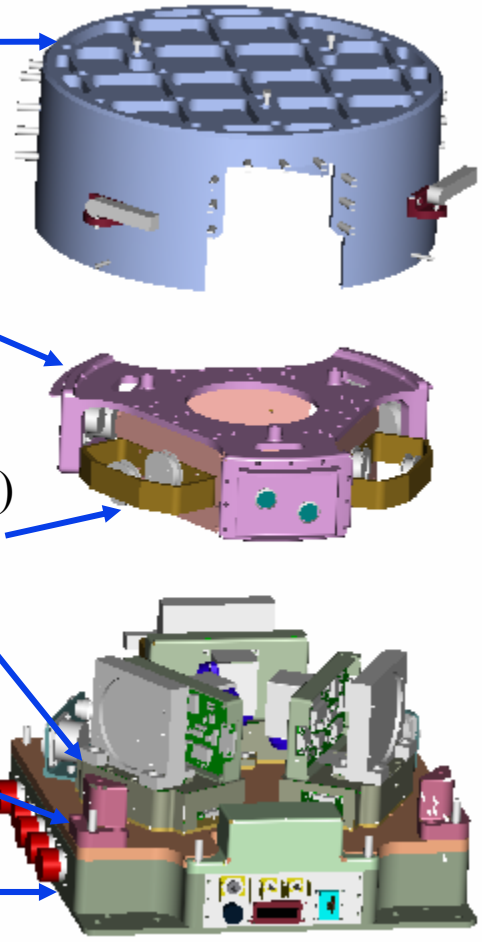
Payload Mounting Structure (PMS)

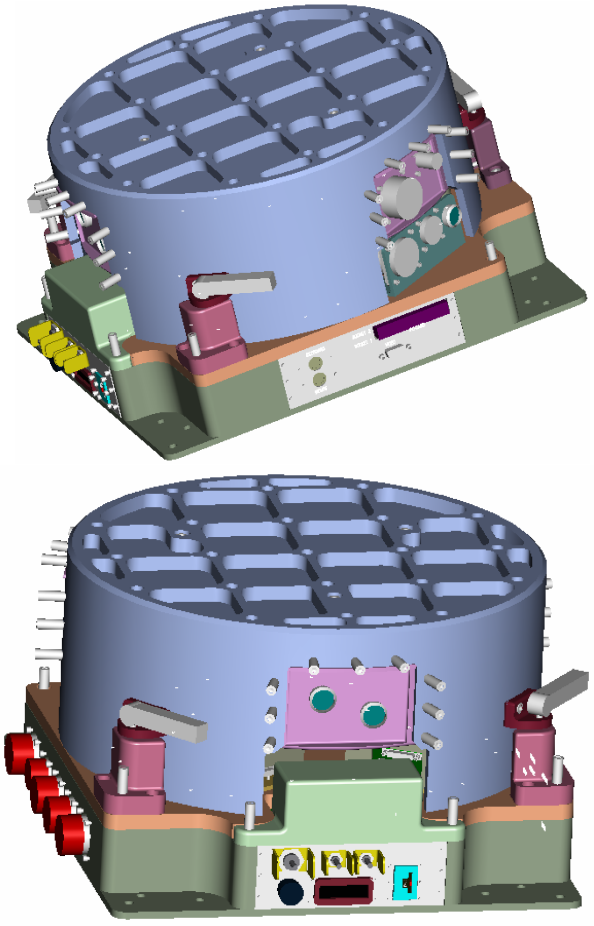
Umbilical Interface Plate (UIP)

Isolator Module (IM)
- Platform subsystem (TASC*)
- Base subsystem (Base)
- 3 units

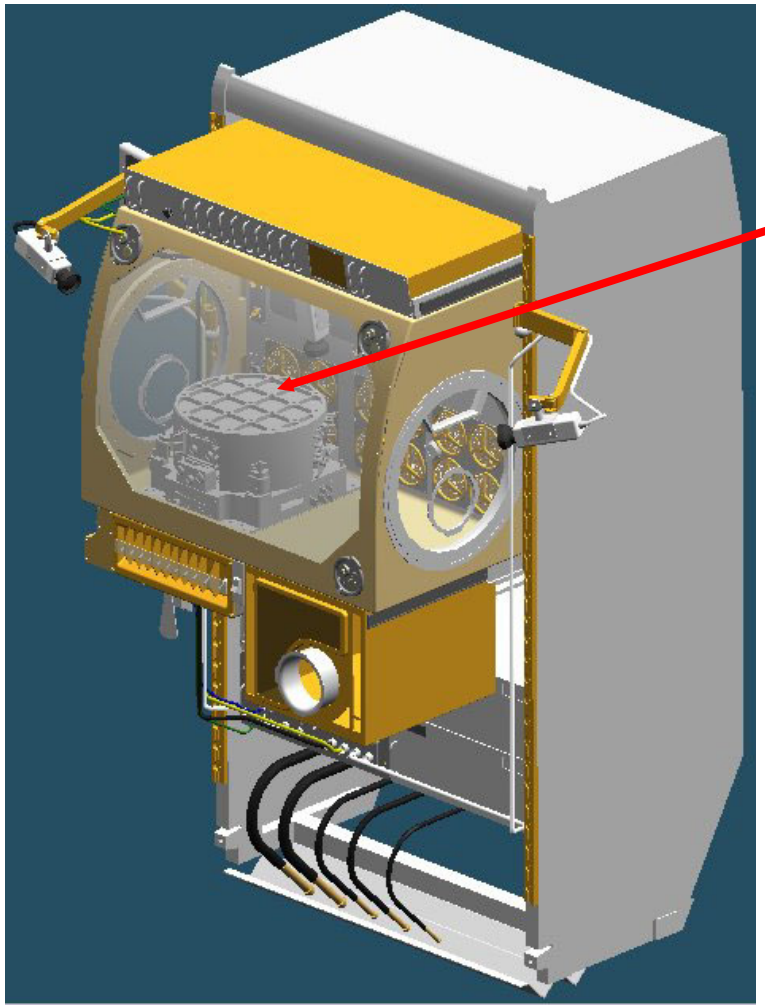
Bumpers (3)

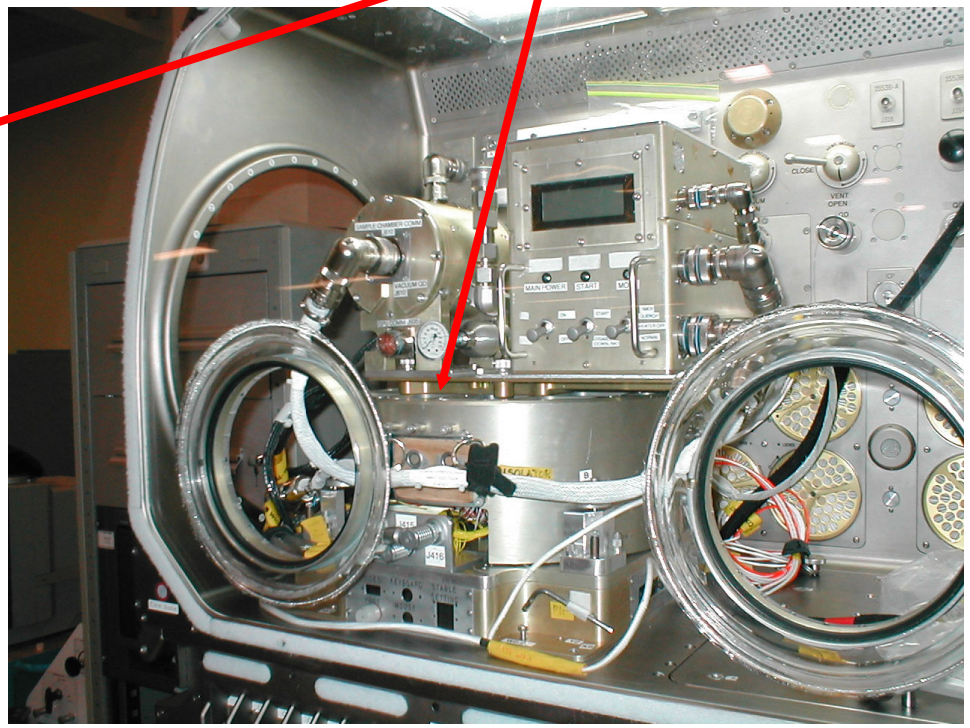
Power & Information Processor (PIP)



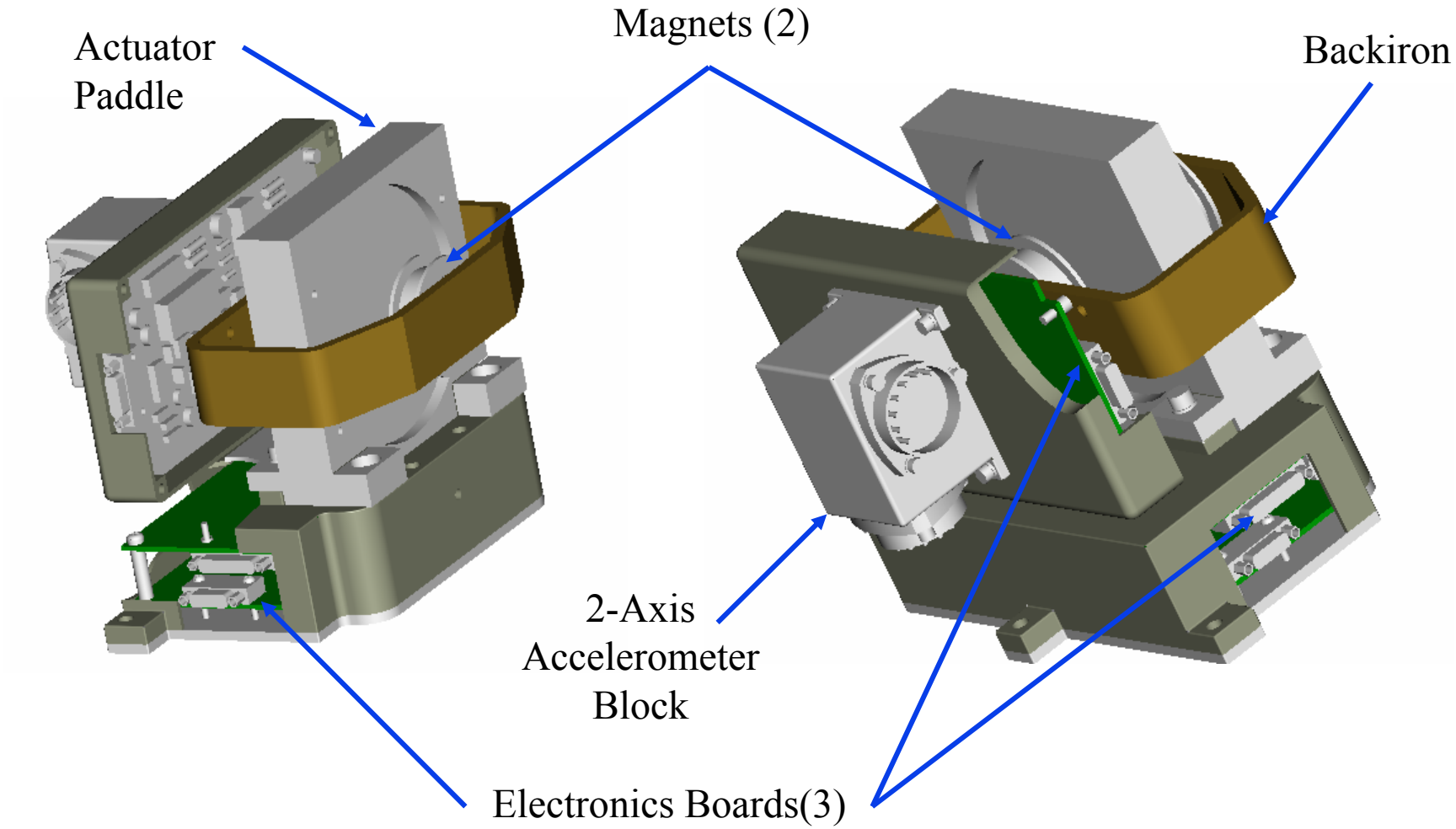


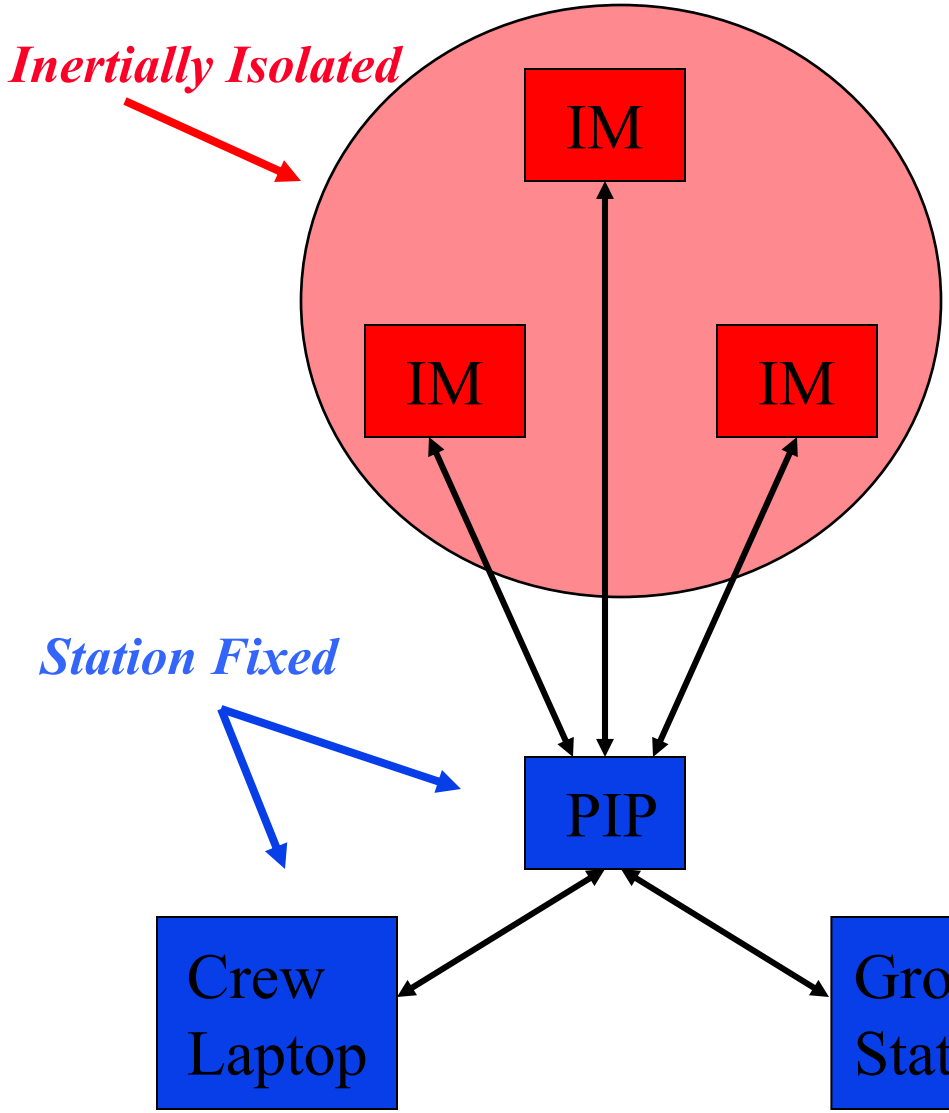
g-LIMIT in MSG





Isolation Module (IM)





Isolator Module (IM):

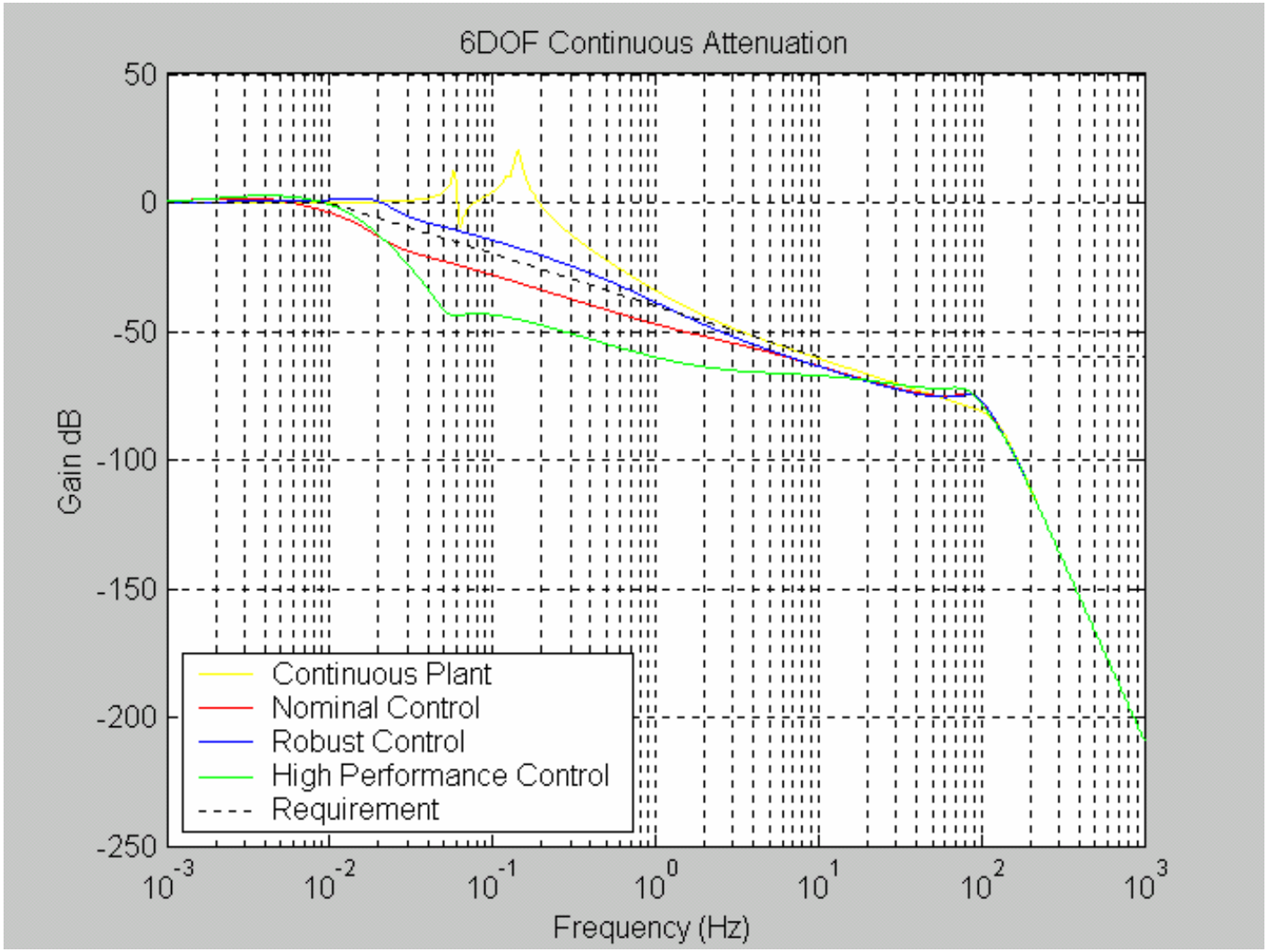
2 Accels

2 Posn Sensors

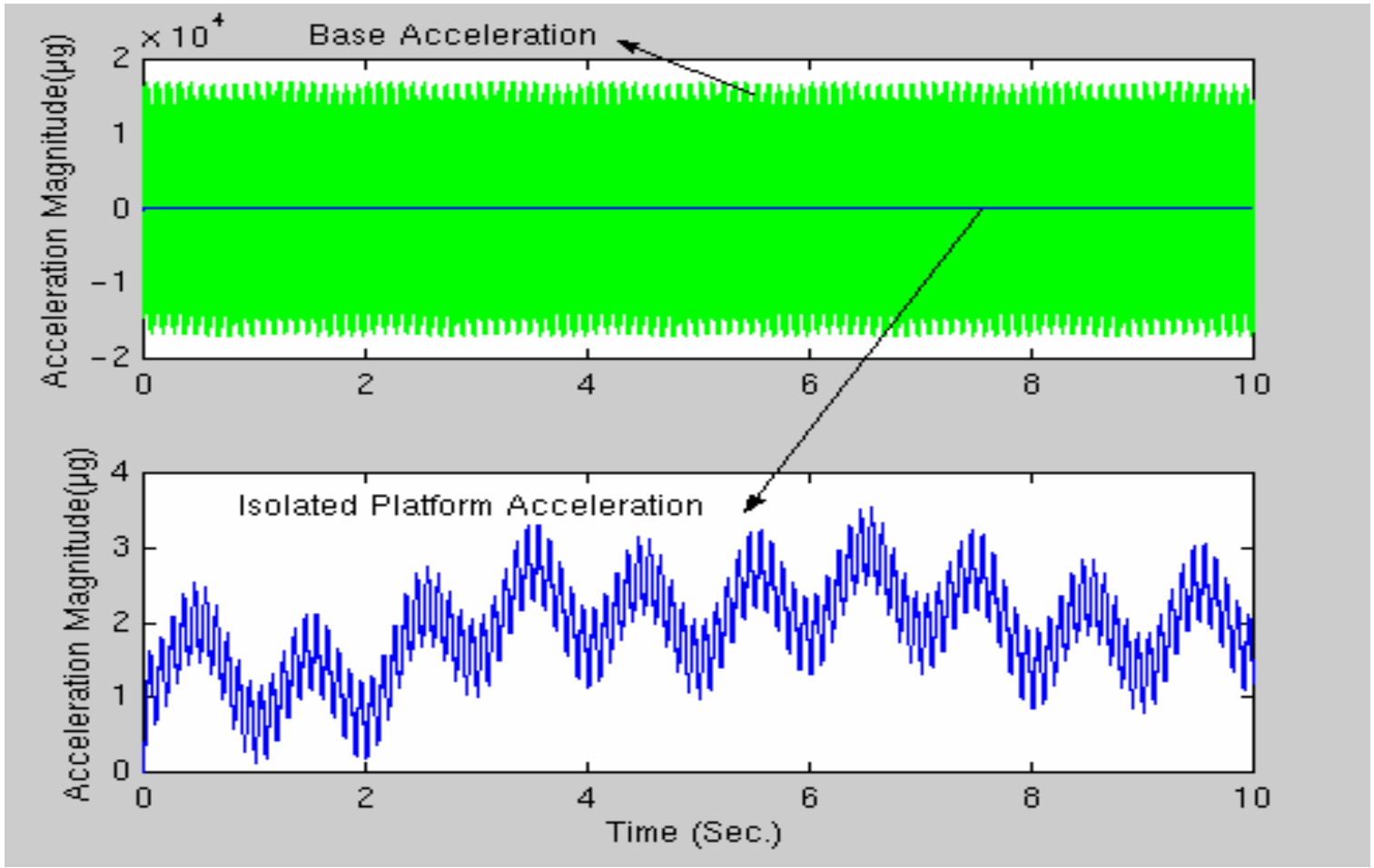
2 Actuators

Power & Information Processor (PIP):

- **266 MHz Pentium II**
- **PC104 Architecture**
- **1 GB Data Storage**
- **2 PCMCIA Slots**
- **2 RS 232 slots**
- **2 RS 422 slots**
- **Video/Keyboard/Mouse**
- **Ethernet**


6DOF Continuous Attenuation
Gain dB
Frequency (Hz)
50
0
-50
-100
-150
-200
-250
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
Continuous Plant
Nominal Control
Robust Control
High Performance Control
Requirement

g-LIMIT 6DOF, Acceleration Time Response (X-axis)



Controllers Technologies to be Tested using g-LIMIT

- **Baseline classical controllers (Jackson, Kim, Whorton)**
- **Fixed Order H_2 / μ designs (Whorton)**
- **H_∞ designs (Whorton)**
- **H_2 designs (Hampton, Calhoun, Whorton)**
- **Interval Model Controller (Tantaris, Keel)**
- **Student classical designs**
- **Adaptive controllers (pending software update)**

Summary of Flight Systems Availability:

STABLE:

- **No current plans to fly on ISS**

MIM-2, et.al.:

- **Use on ISS coordinated through CSA**

ARIS:

- **10 units currently to be delivered to ISS**
  - **Express, FCF, MSRF**

g-LIMIT:

- **Employed in MSG**
- **Flight Unit, Spare, & Derivatives applicable elsewhere**

Further Reading:

1. Grodsinsky C. and Whorton, M., "Survey of Active Vibration Isolation Systems for Microgravity Applications," *Journal of Spacecraft and Rockets*, Vol. 37, No. 5, Sept. – Oct. 2000.
2. Bushnell, G. S., and Becraft, M. D., "Microgravity Flight Characterization of an International Space Station Active Rack Isolation System," AIAA Paper # TBD, Presented at the 2002 World Space Congress...
3. Nurre, G. S., Whorton, M. S., Kim, Y., Edberg, D. L., and Boucher, R., "Performance Assessment of the STABLE Microgravity Vibration Isolation Flight Demonstration," submitted for publication to *Journal of Spacecraft and Rockets*.
4. Tryggvason, B. V., Stewart, B. Y., DeCarufel, J., and Vezina, L., "Acceleration Levels and Operation of the Microgravity Vibration Isolation Mount (MIM) on the Shuttle and Mir Space Station", AIAA Paper No. AIAA-99-0578, presented at the 37th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, January 11-14, 1999.
5. Jackson, Kim, Whorton, "Design and Analysis of the g-LIMIT Baseline Vibration Isolation Control System," AIAA Paper No. 2002-5019, Presented at the 2002 AIAA Guidance, Navigation, and Control Conference, Monterey, CA, August 5-8, 2002.