Section 17
Survey of Microgravity Vibration Isolation Systems

Dr. Mark Whorton

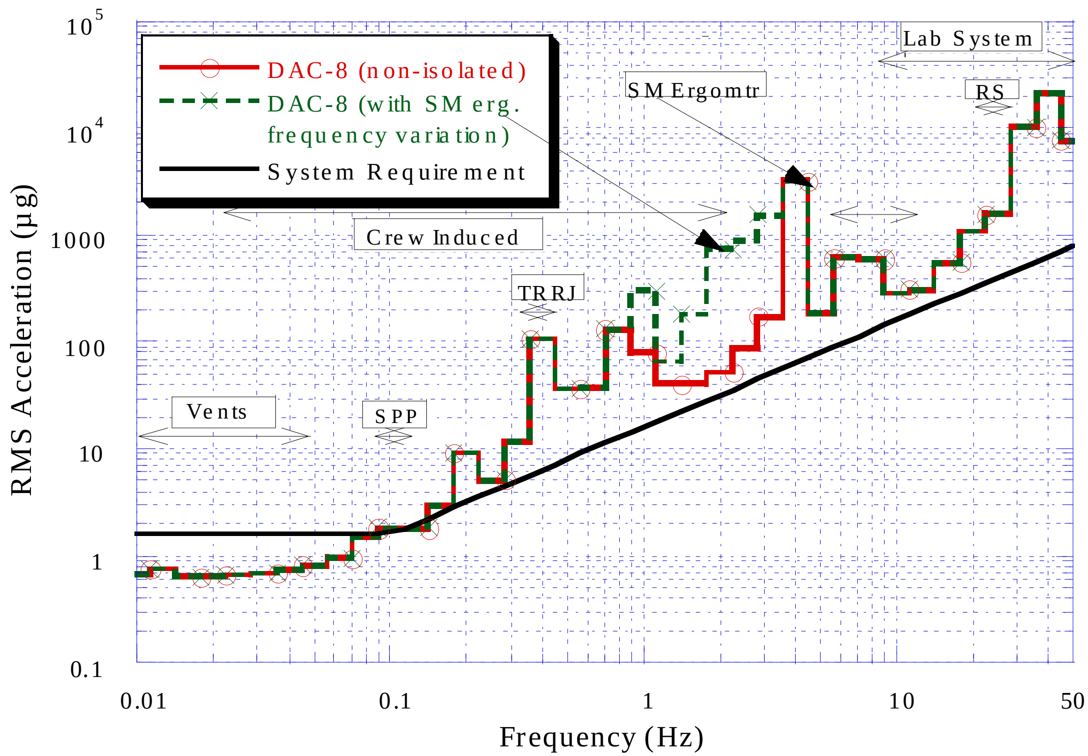
Principal Investigator for g-LIMIT

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

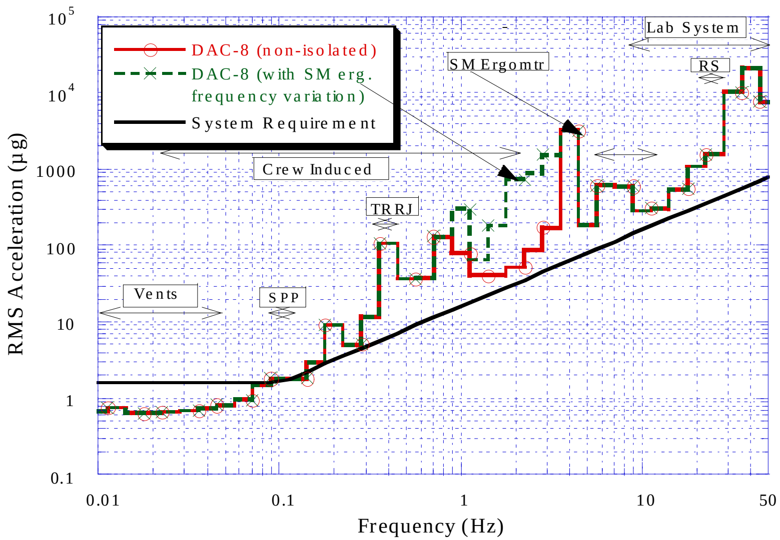


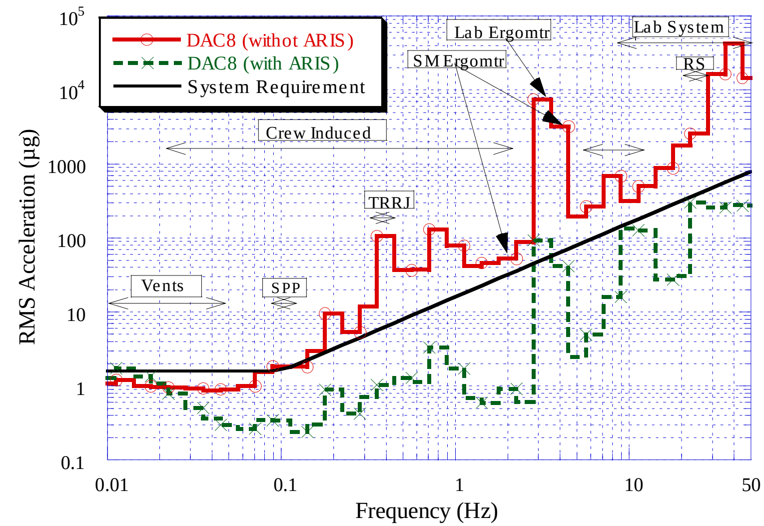
SSP-MG99-074A March 30, 2000

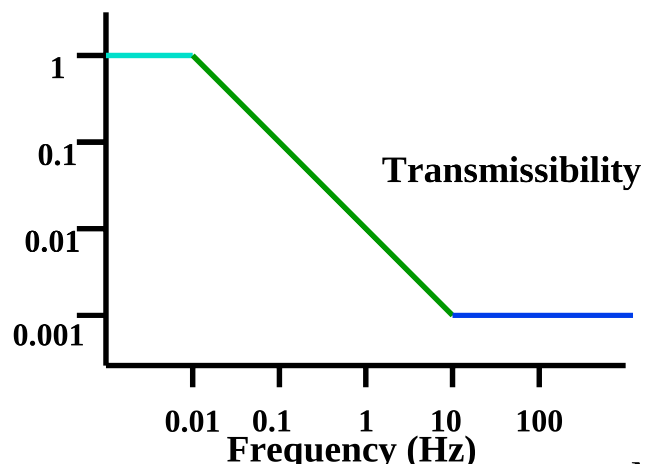
The acceleration environment is expected to significantly exceed acceptable levels

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

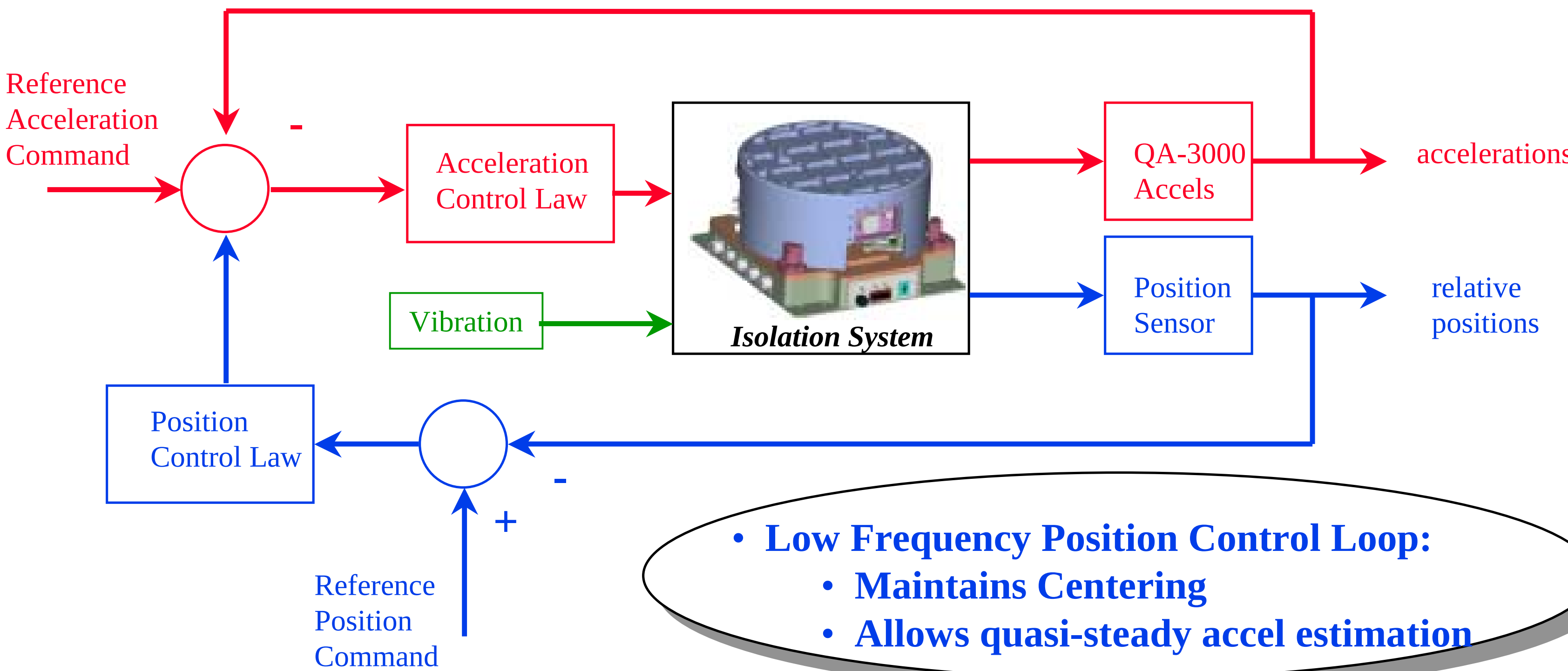
Why is Vibration Isolation Necessary for ISS?







- **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)

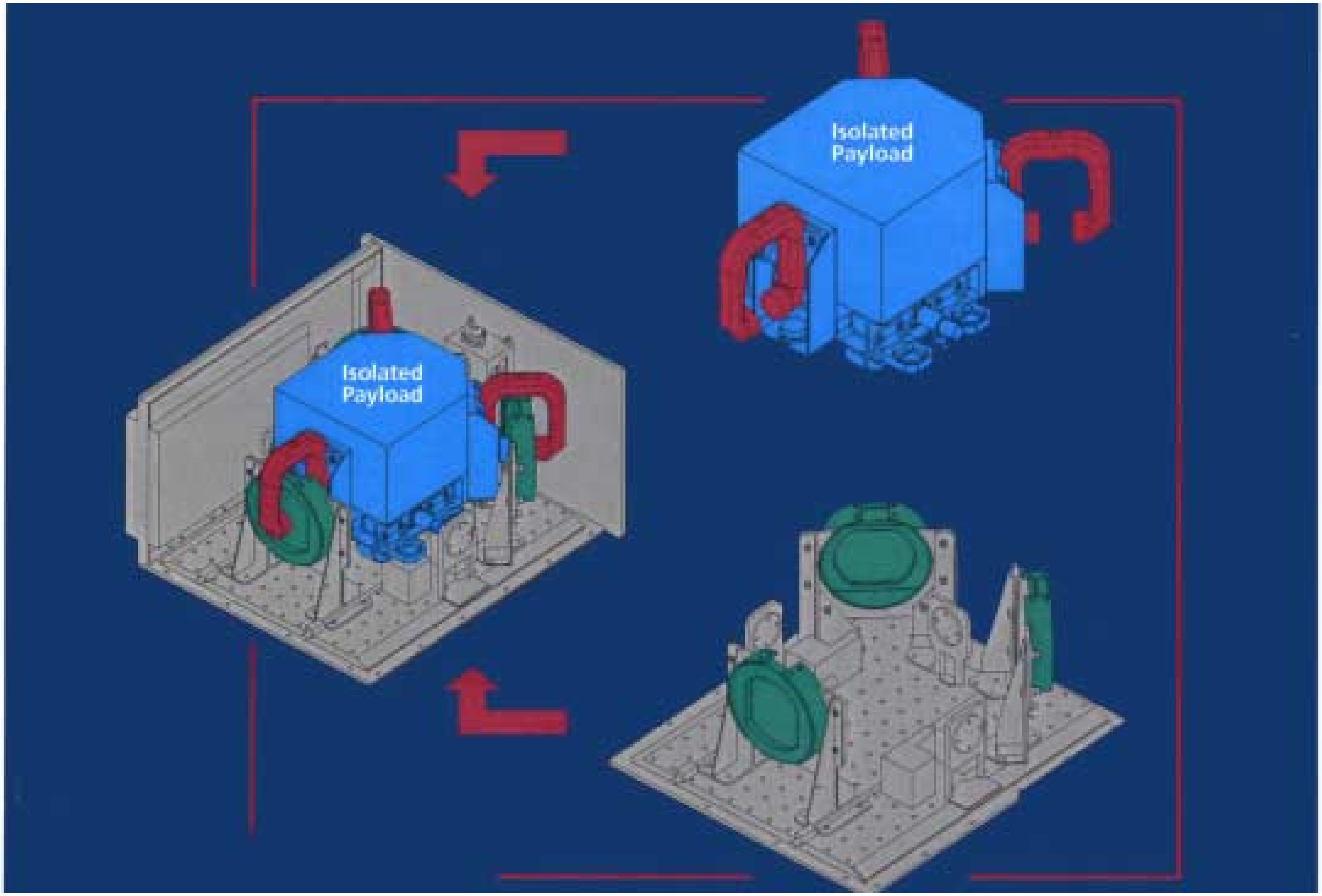
Introduction

- 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

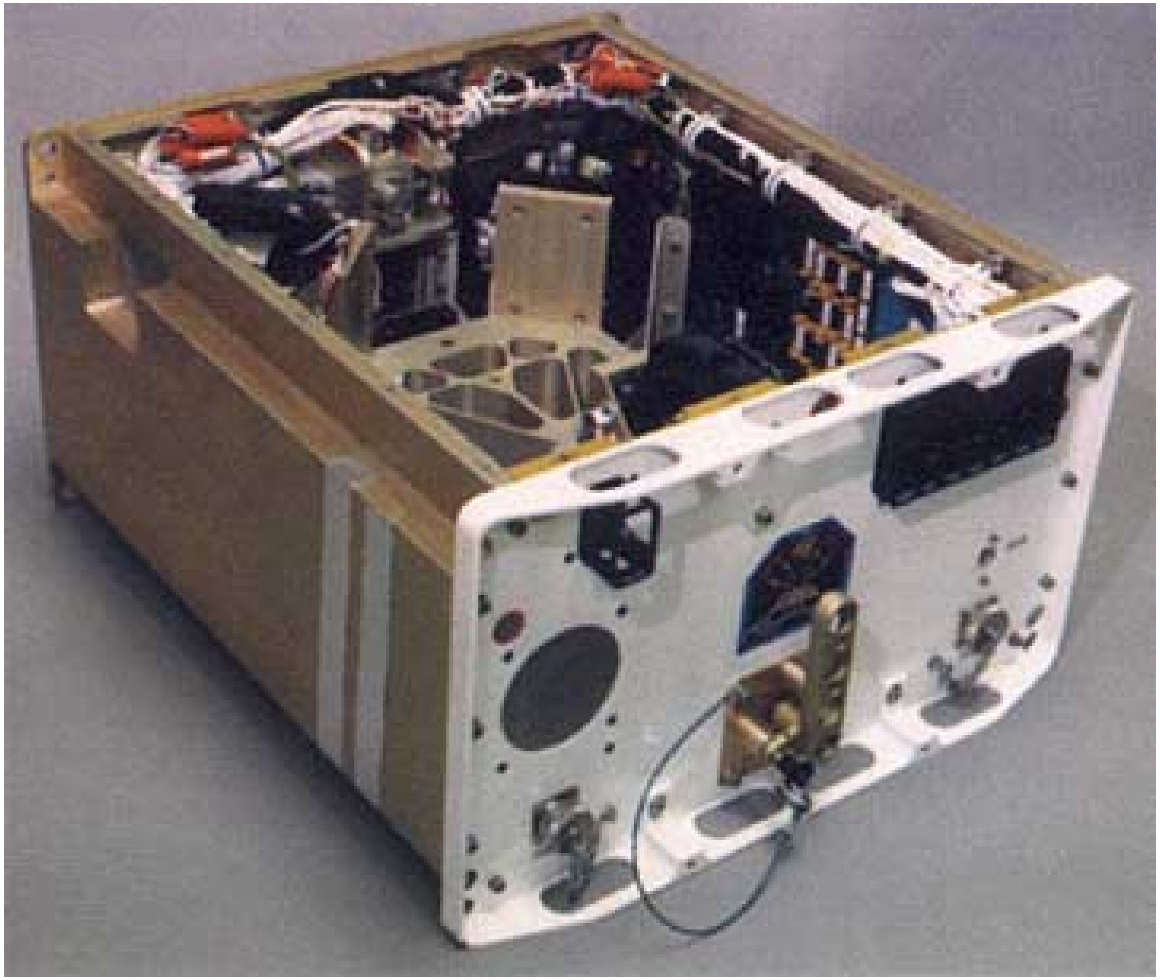
The STABLE Vibration Isolation System

- 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

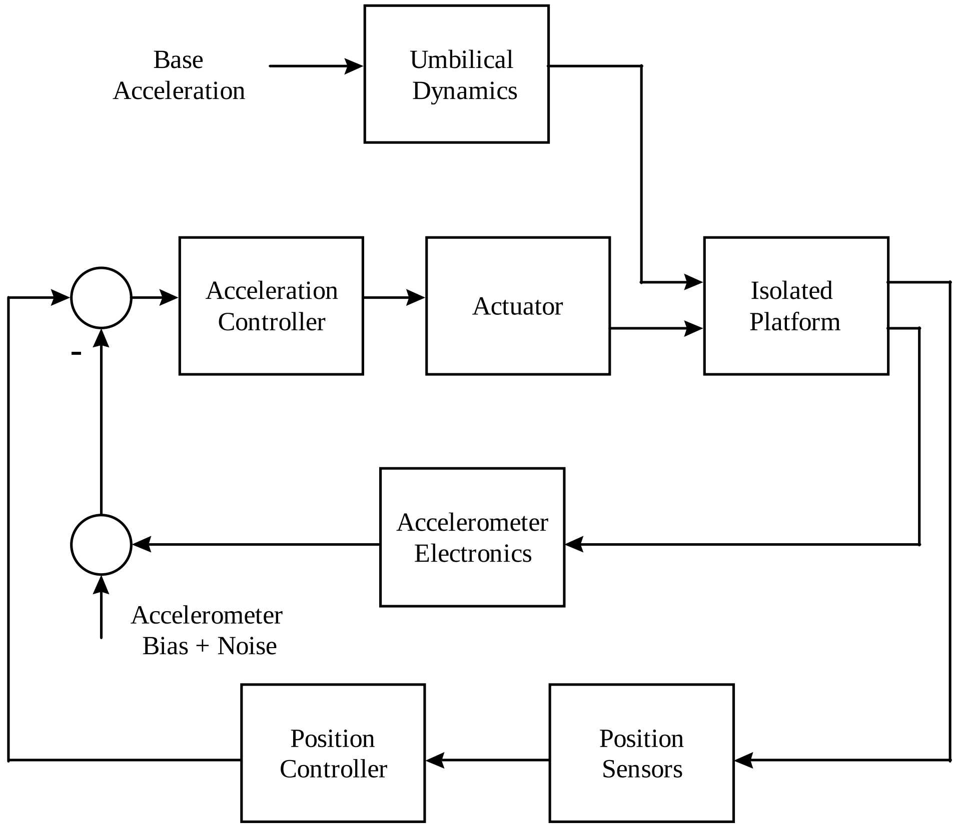


STABLE Flight Unit

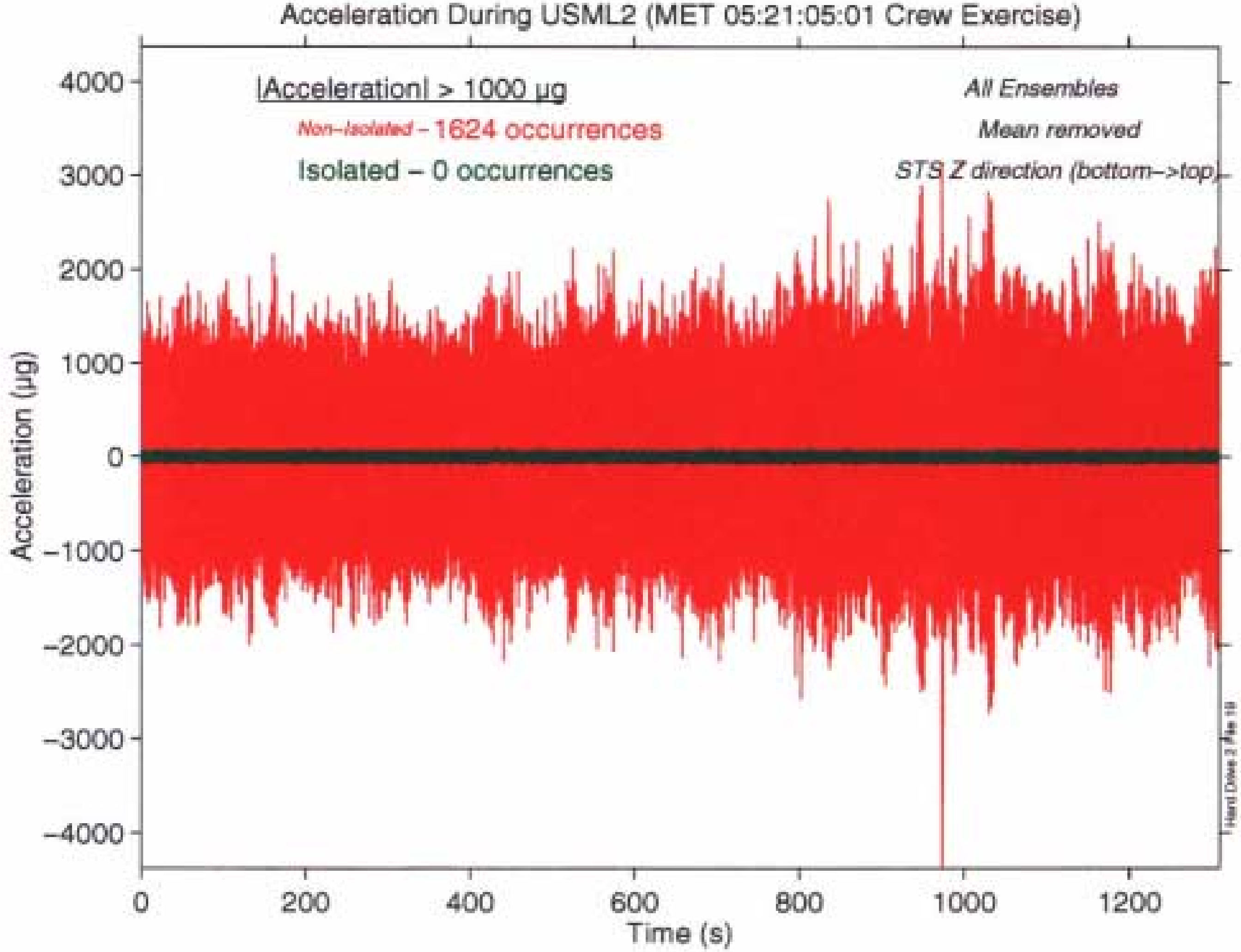


Payload Specialist Dr. Fred Leslie operating STABLE

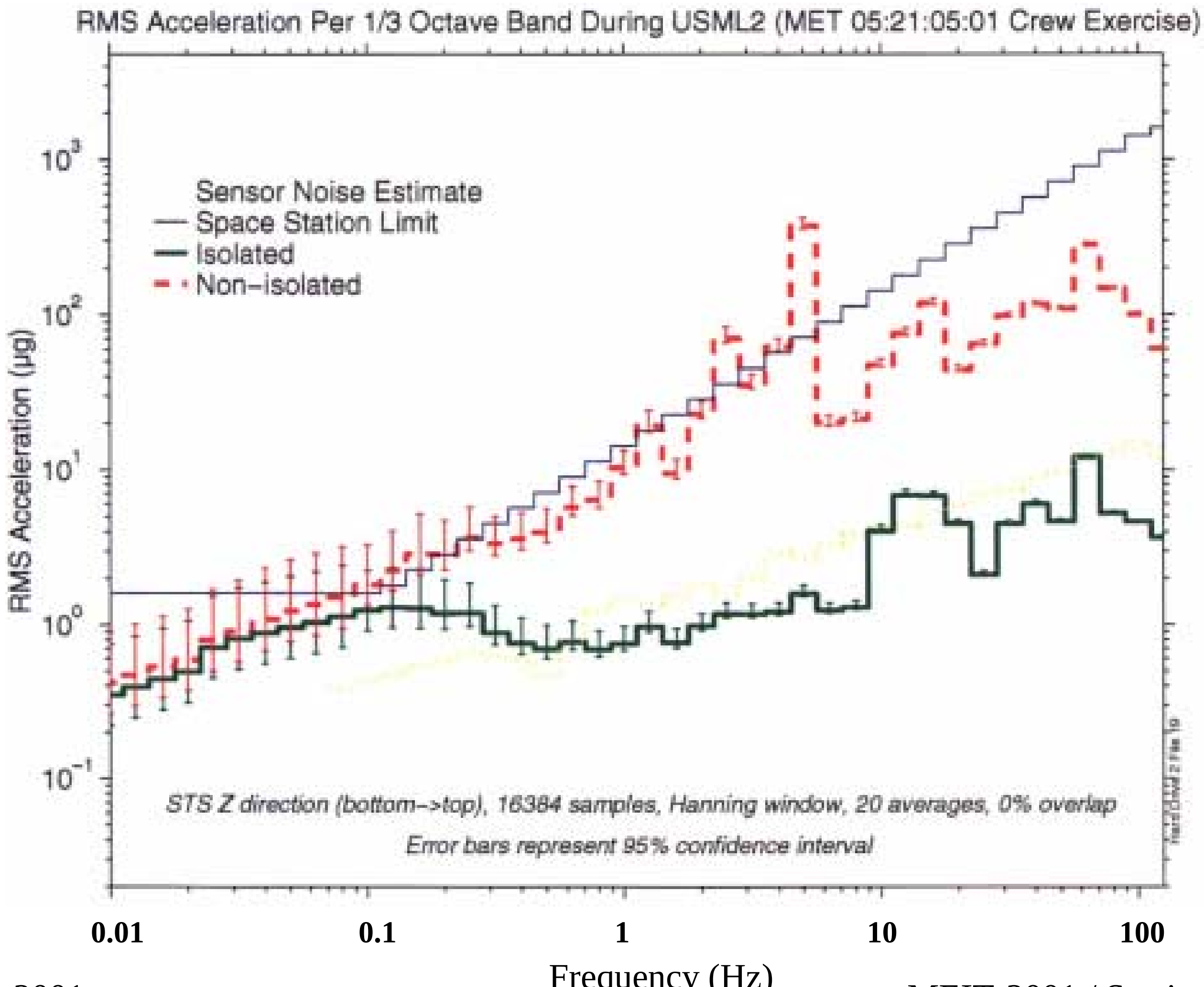
STABLE Control System Block Diagram



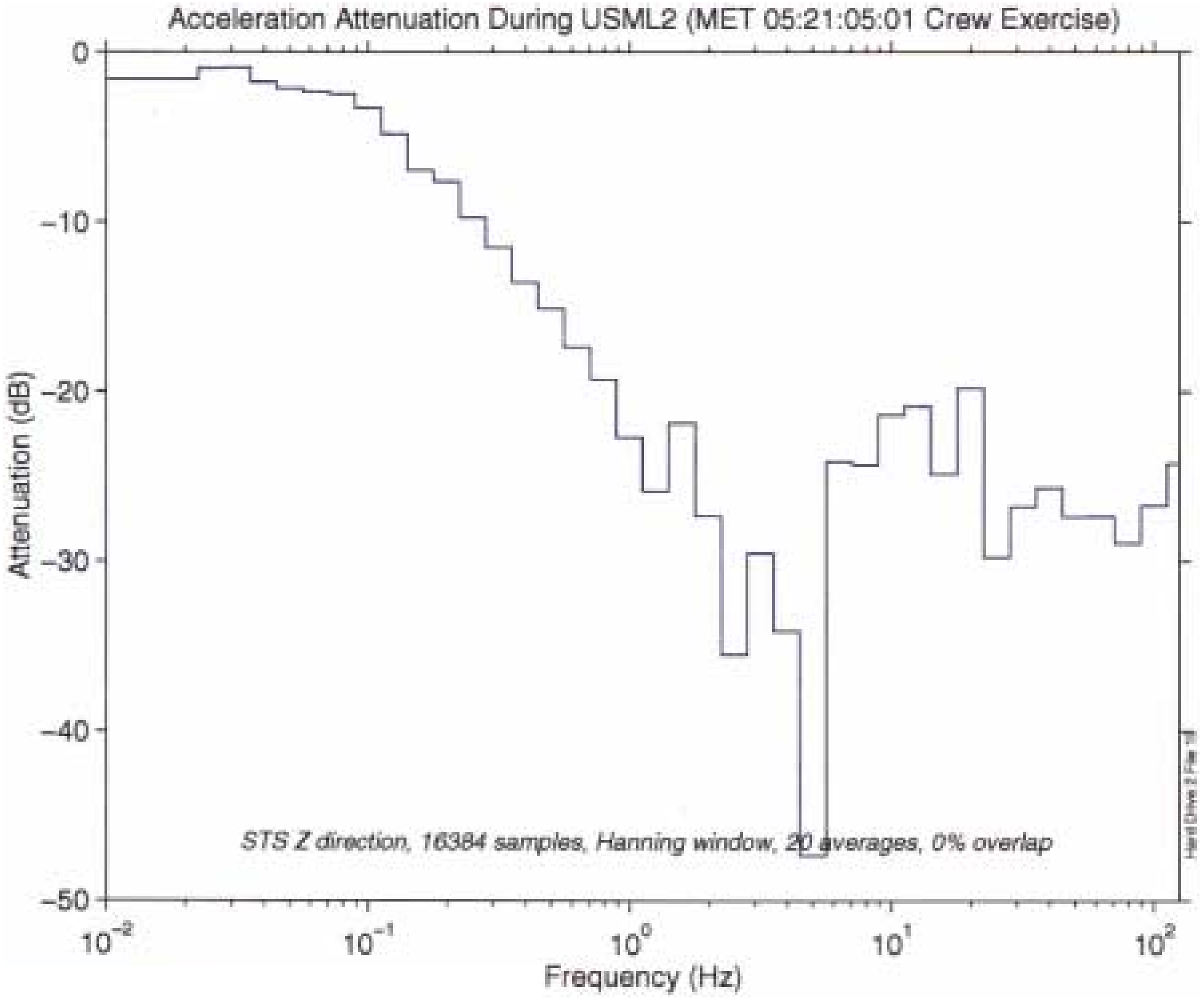
STABLE: Typical Active Isolation Time Response



STABLE: Typical Active Isolation Frequency Response



STABLE: Typical Active Isolation Attenuation



MIM Background

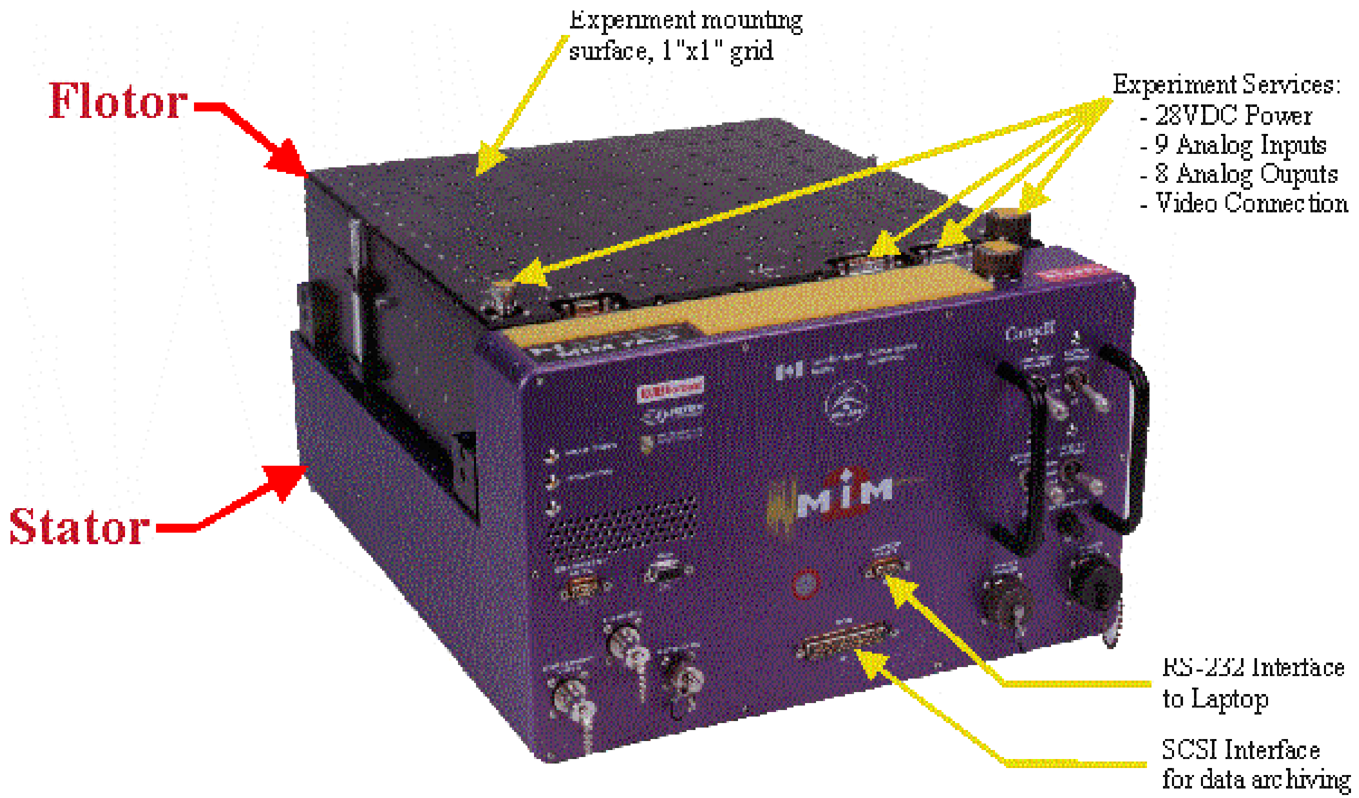
- **The Microgravity Vibration Isolation Mount (MIM) has been developed over the past 10 years by CSA under the direction of Bjarni Tryggvason**
- **2 MIM versions have been produced to date:**
  - **First version of MIM is known as MIM-1:**
    - In operation for two years onboard Russian Mir space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

MIM Background

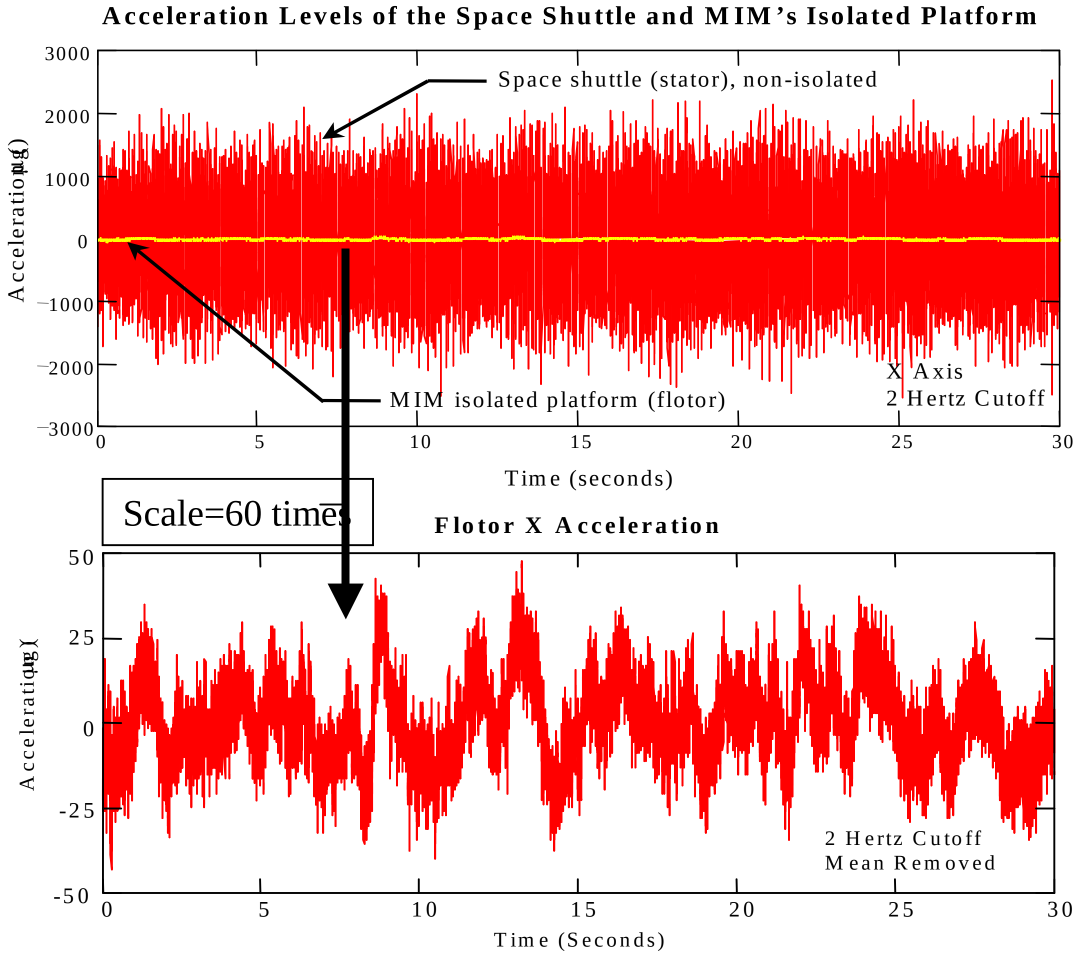
- **Second version of MIM is known as MIM-2:**
  - Flown onboard the Space Shuttle during mission STS-85 with Canadian Astronaut Bjarni Tryggvason;
  - MIM-2 acquired a total of 100 hours of operations.

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

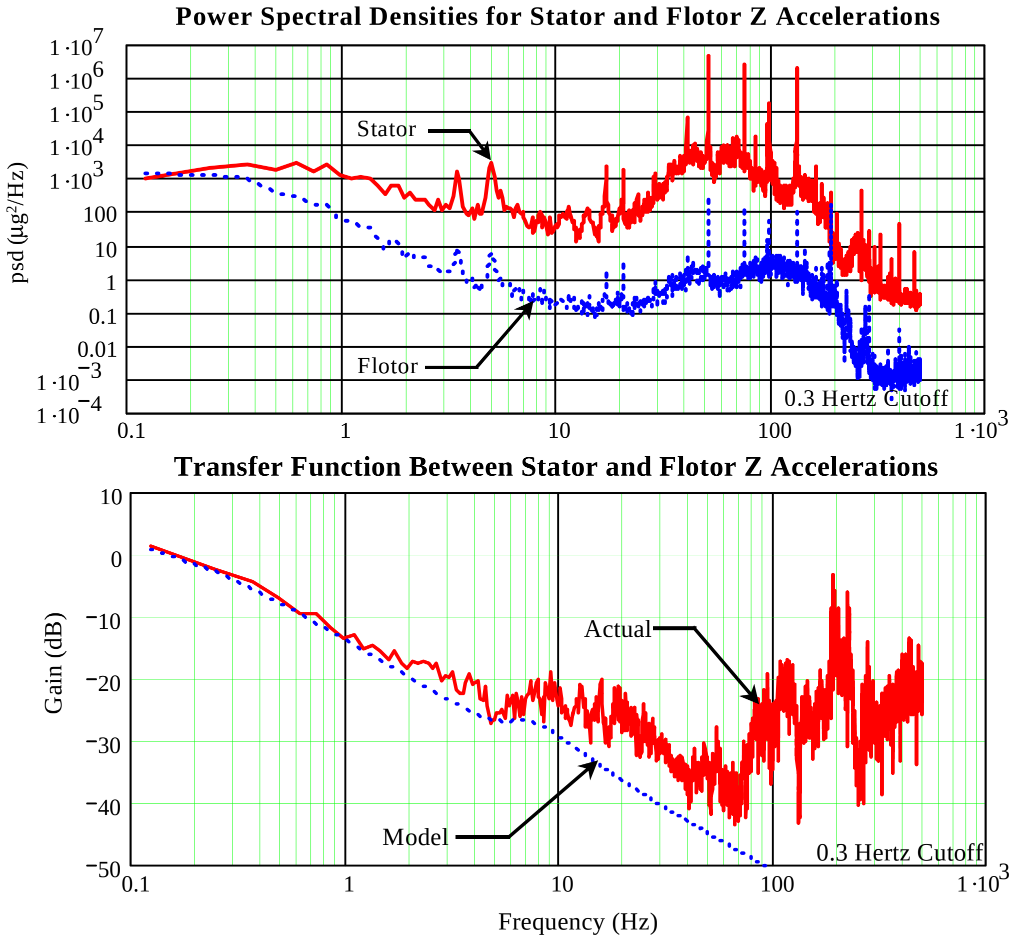


MIM-2 Summary for STS-85



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

MIM-2 Summary for STS-85

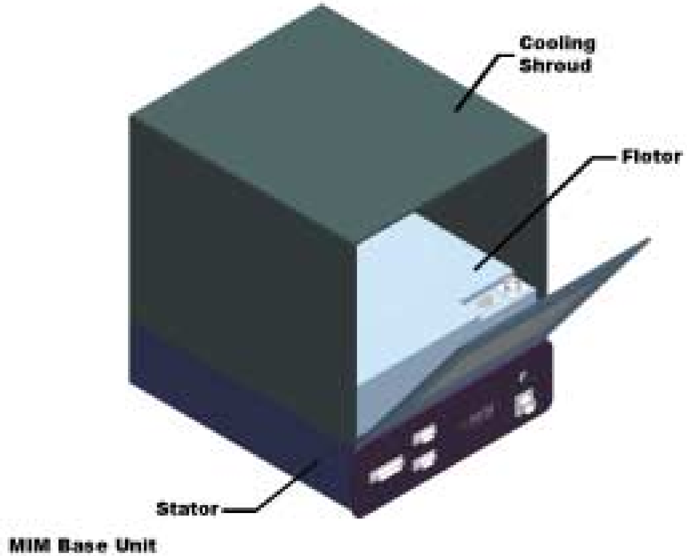


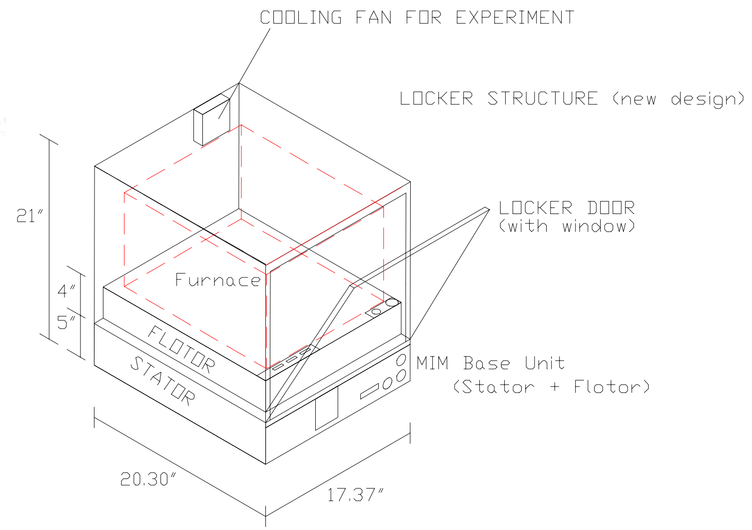
Data filtered by a 100 Hz low-pass filter and sampled at 1000 samples per second

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

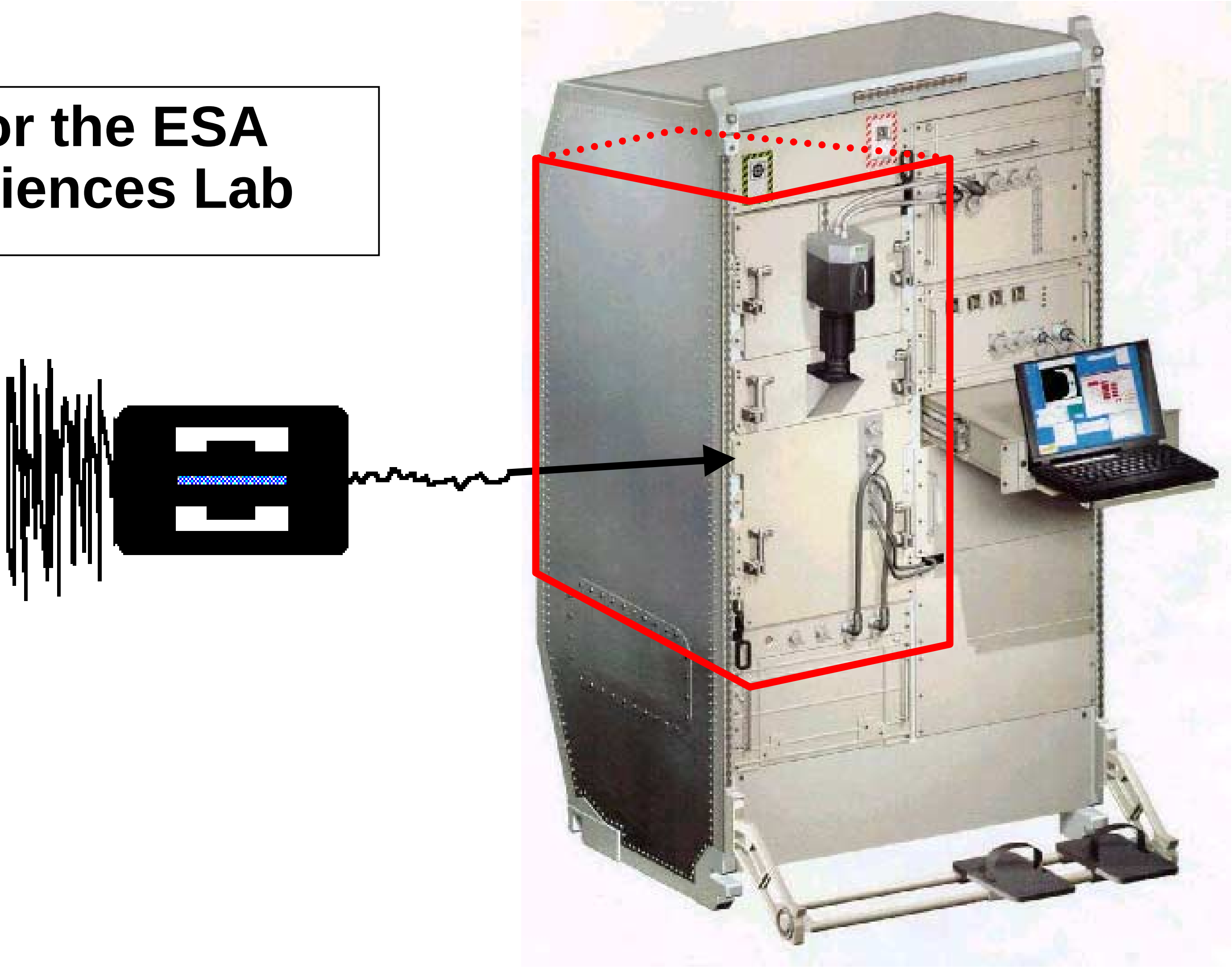
MIM Base Unit Description





- Comprised of Stator, Double Flotor and Flotor Enclosure
- Key support facility for science payloads
- Designed to support small payloads in an EXPRESS rack
- Housed in a double mid-deck locker

MVIS for the ESA Fluid Sciences Lab



The Active Rack Isolation System (ARIS)

- Rack-level Isolation System
- Developed by Boeing
- Flown on RME 1313 / MIR Spacehab STS-79, August 1996
- ISS baseline solution for acceleration system specification
- Scheduled for Isolation Characterization Experiment, ISS flight 6A

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.

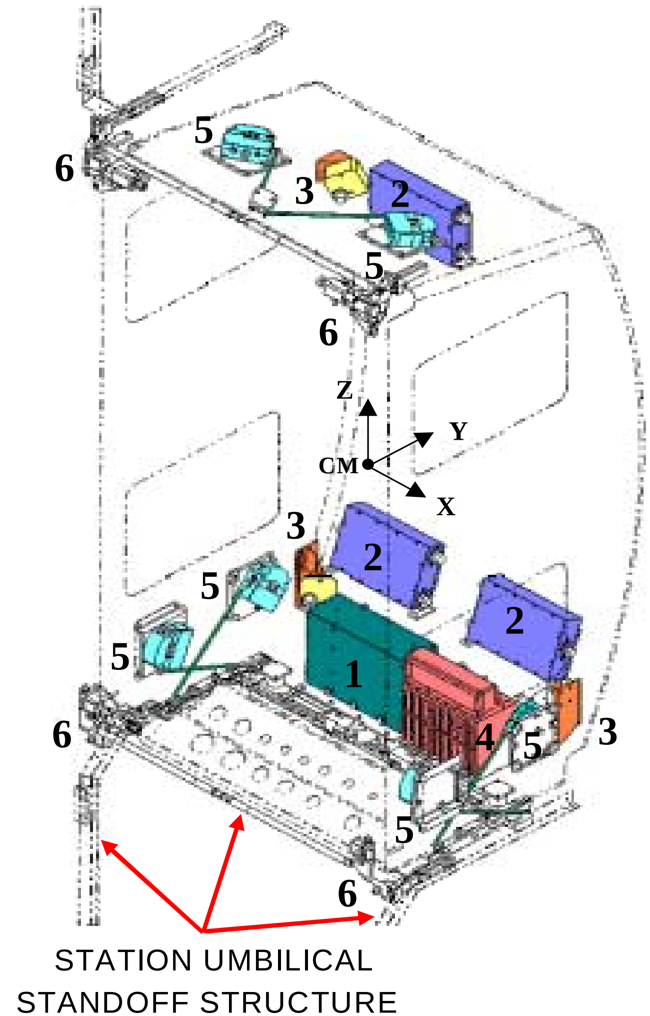
3 Accelerometer Heads : Built small to fit in rack corners. 2 Tri-axial (Bottom), 1 Bi-axial (Top)

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

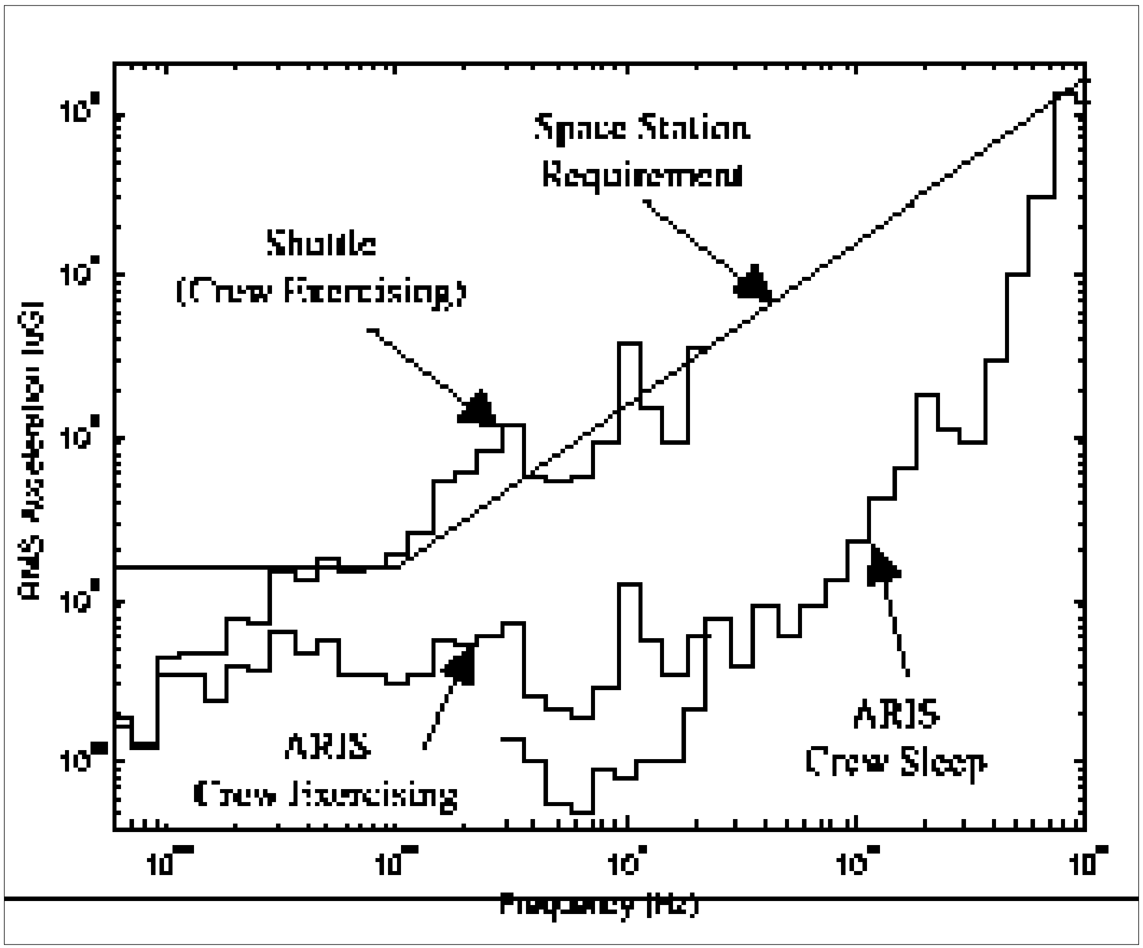
5 8 Actuators : Voice coil rotary actuator used to reduce profile and power consumption.

5 8 Position Sensors : Integrated with actuators.

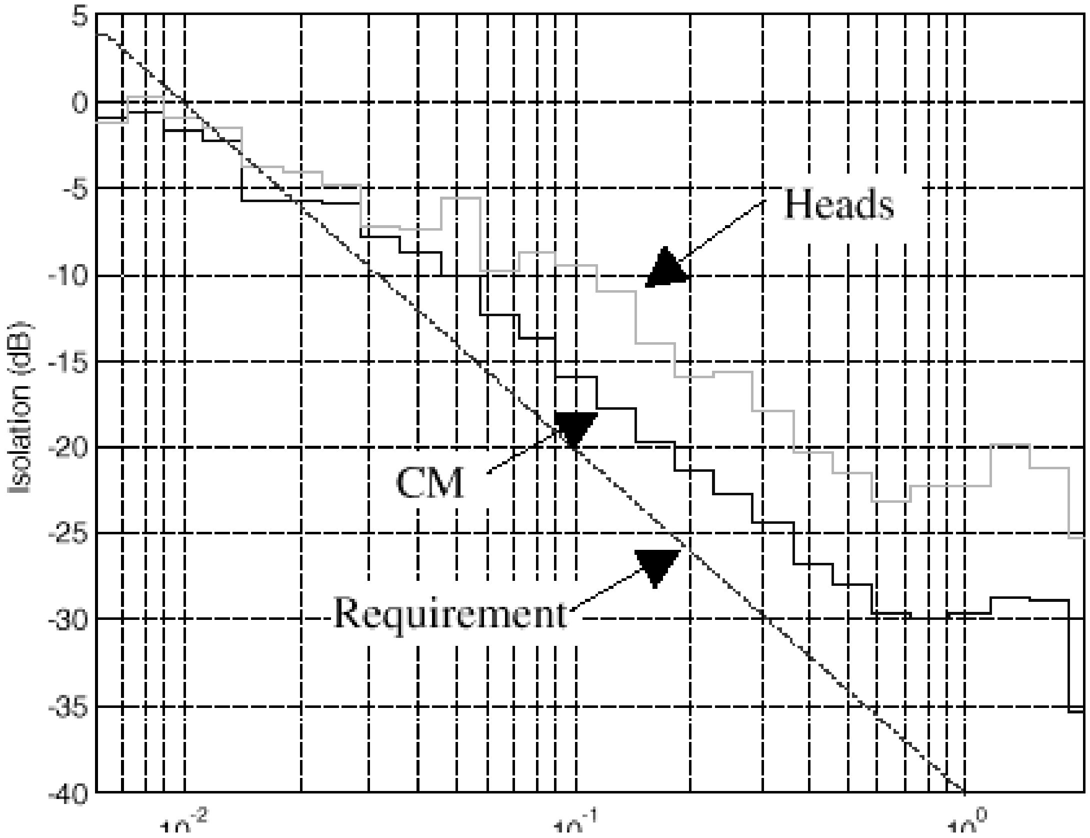
6 Hard stop Bumpers



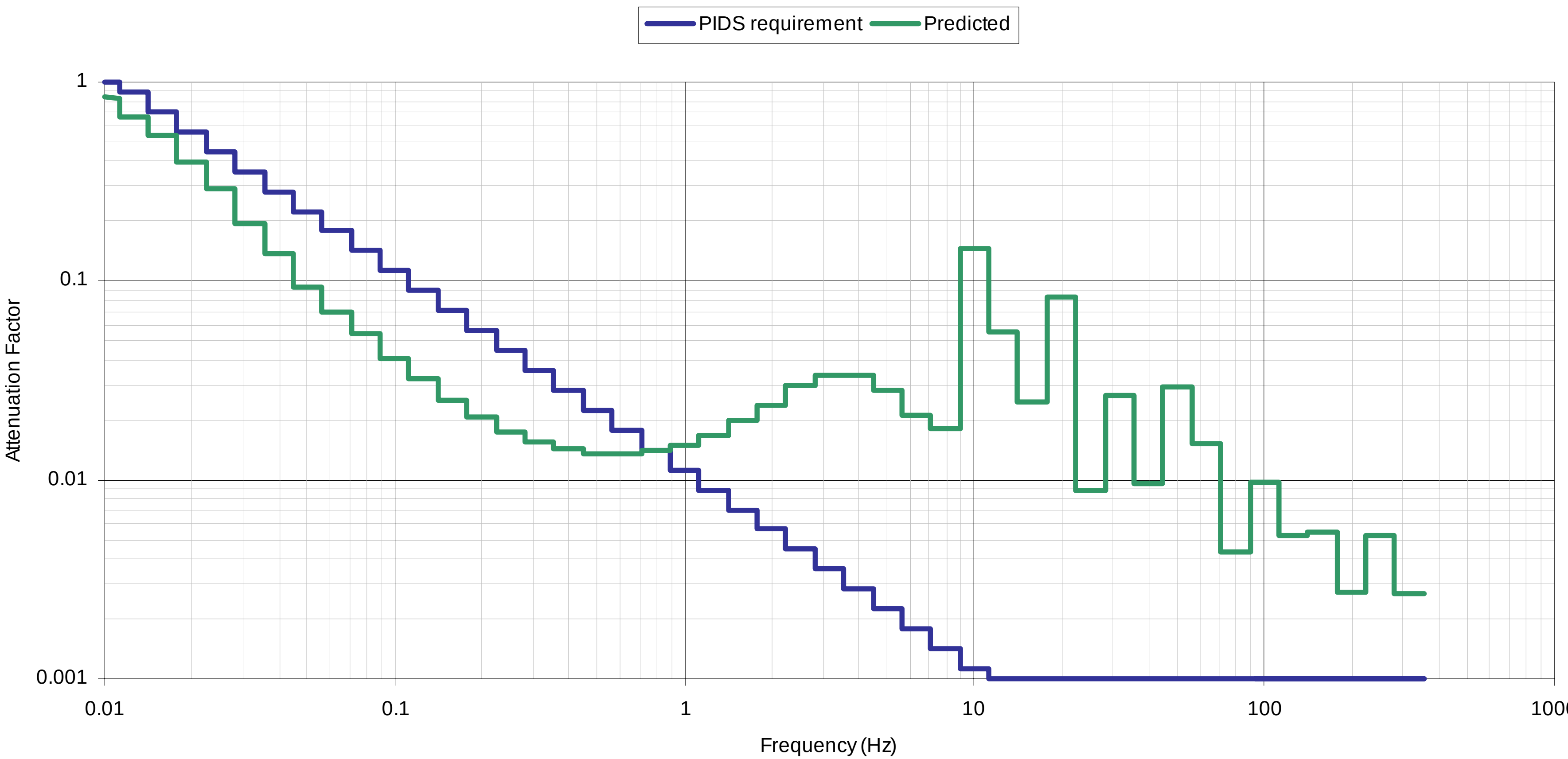
ARIS RME 1/3-Octave Band Acceleration Measurements



ARIS RME Isolation Performance

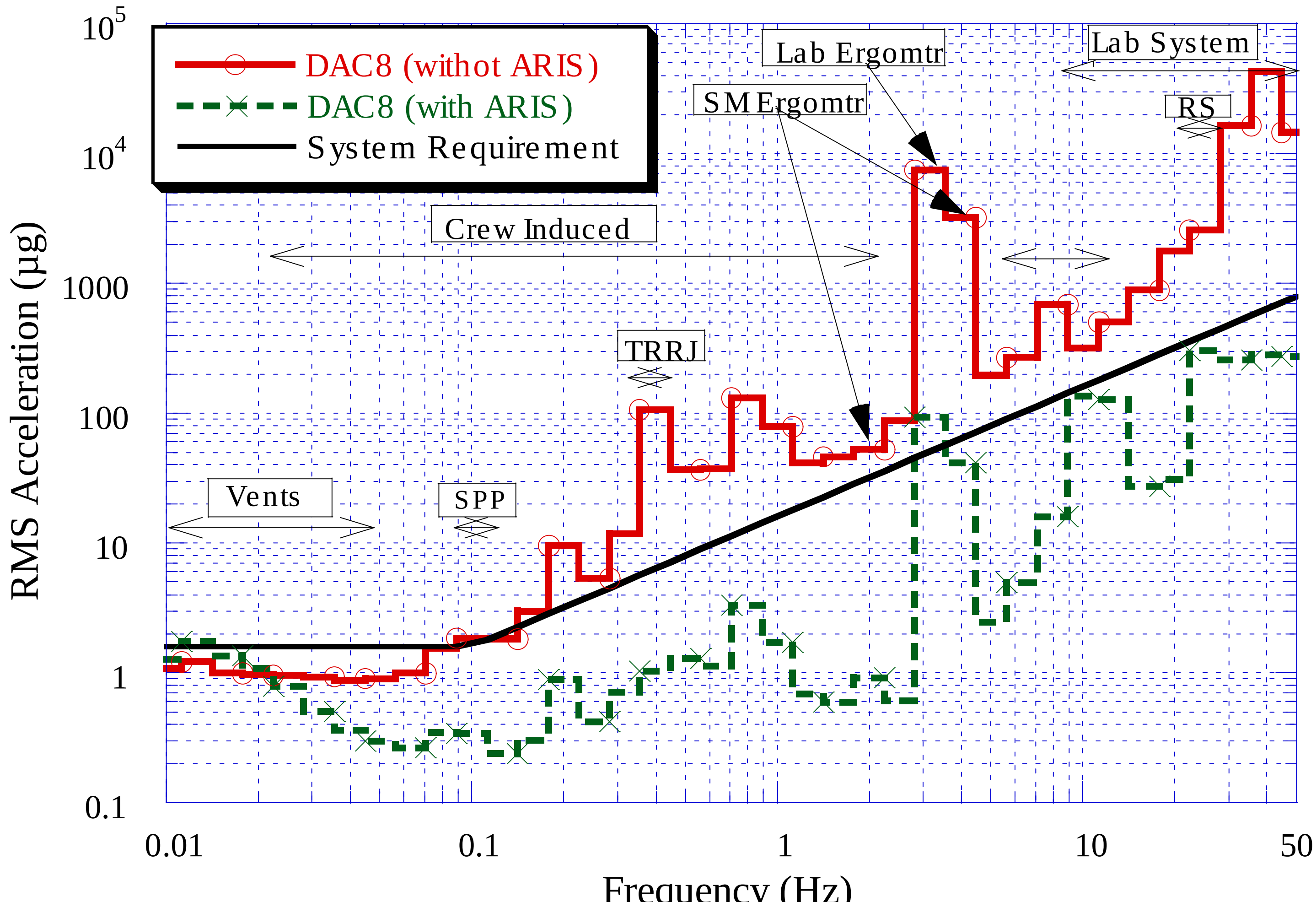


ARIS Isolation Performance: Requirement and Current Prediction (1/00)



Current ARIS isolation prediction without anti-bump invoked

Acceleration Environment with 1/00 ARIS Isolation Prediction



ARIS Forward Work Plan

<u>Focal Points:</u>

- 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 (MSG)

- **Small Volume / Low Power**
- **Standard MSG interfaces**
- **Permits multiple experiment operation**
- **Allows crew contact with MSG during ops**
- **Accomodates larger payloads**
- **Modular/reconfigurable design**
- **Scheduled for launch: UF2, Feb. 2002**
- **In-house development by NASA/MSFC**

g-LIMIT System Assembly

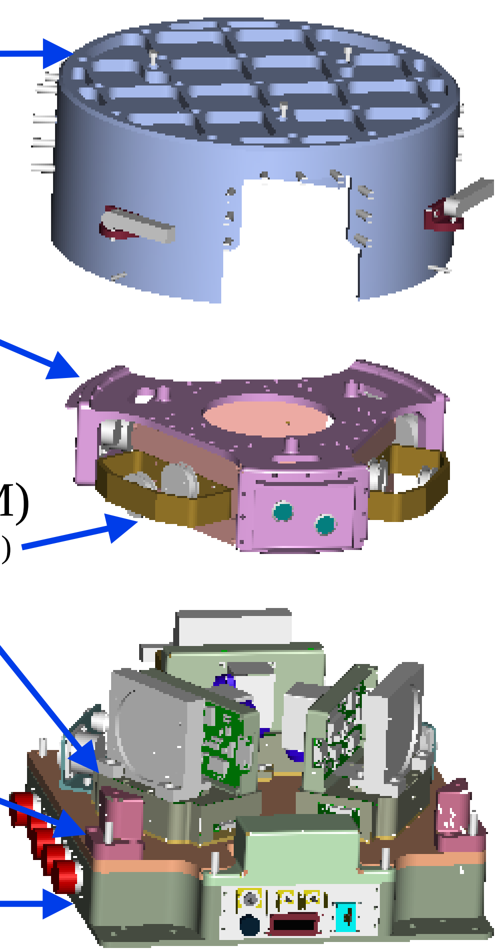
Payload Mounting Structure (PMS)

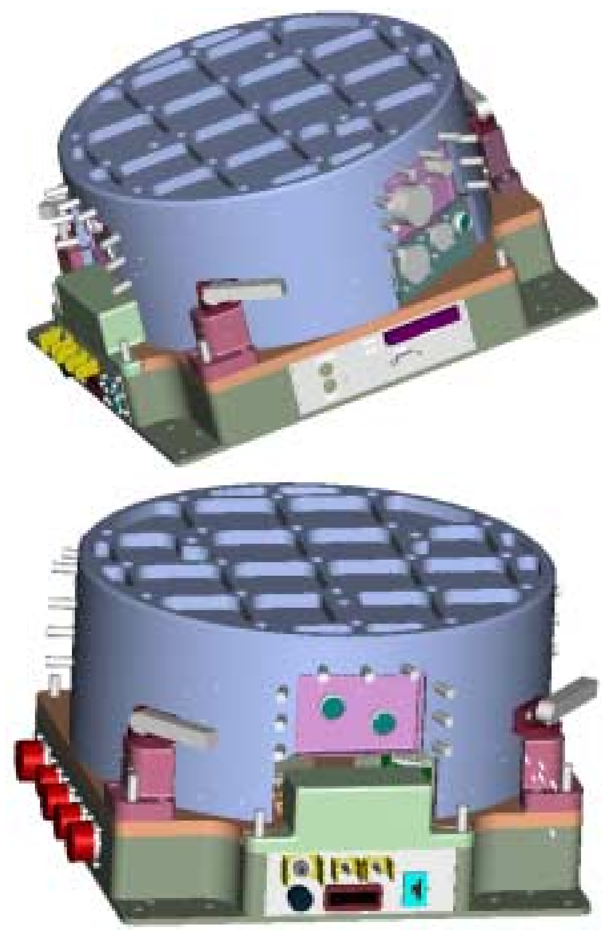
Umbilical Interface Plate (UIP)

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

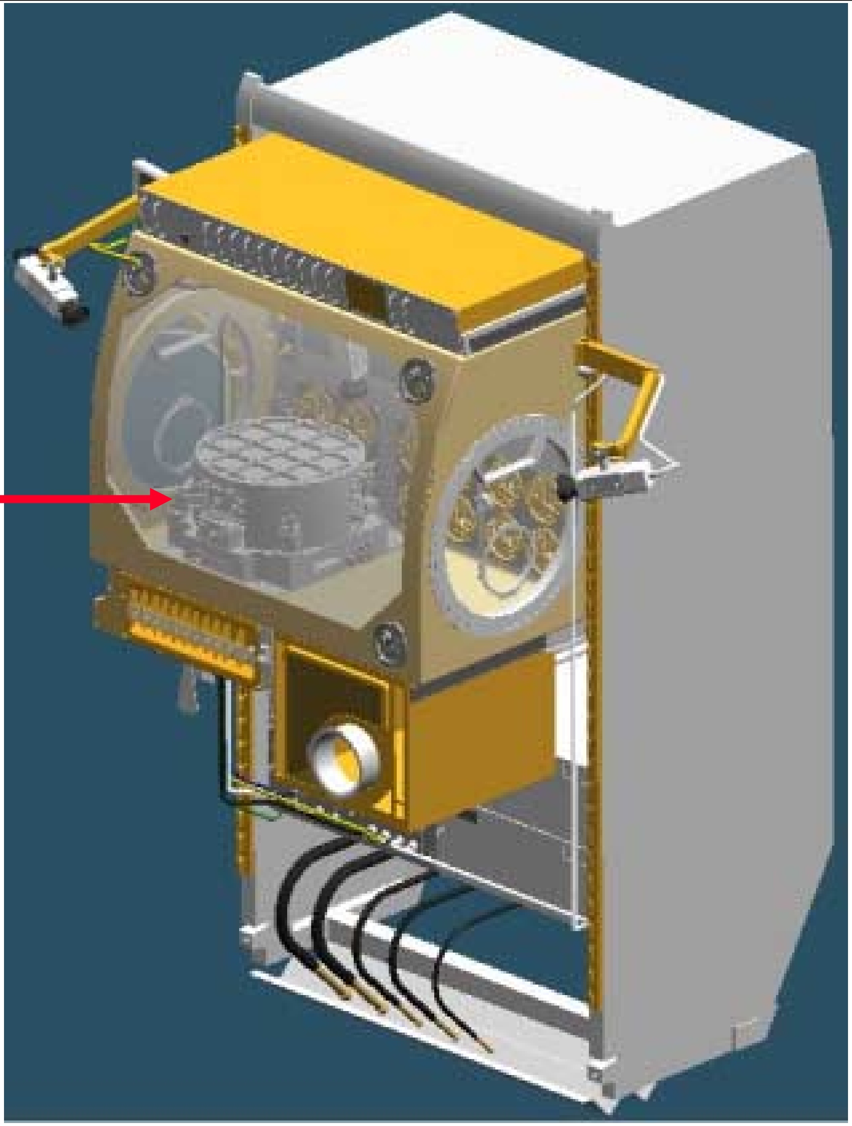
Bumpers (3)

Power & Information Processor (PIP)



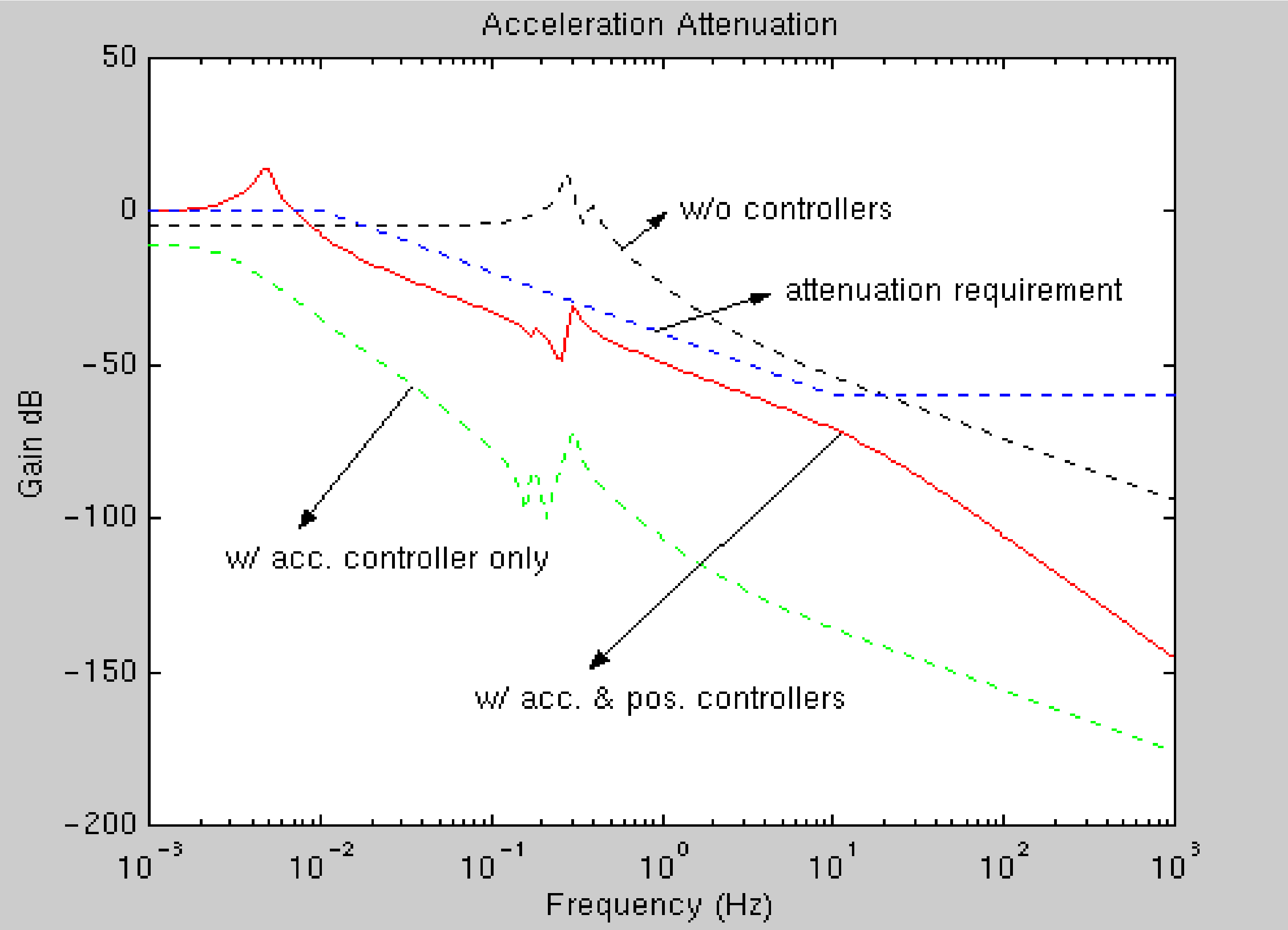


g-LIMIT Trainer in MSG

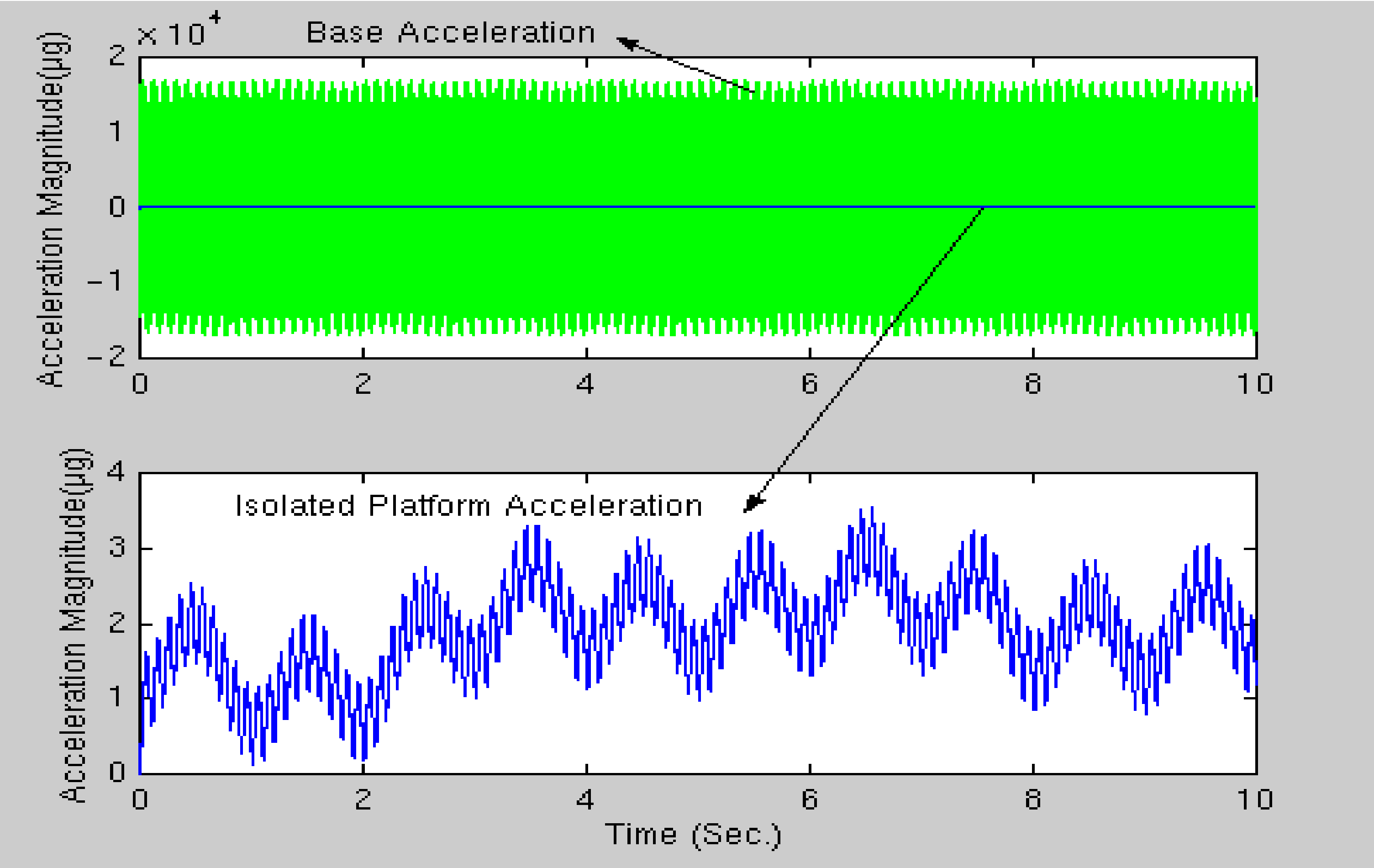


g-LIMIT Trainer in MSG

g-LIMIT 6DOF, Baseline PID Controllers (X-axis)



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



Base acceleration = 1.6 sin(0.01 hz*t)+16 sin(0.1 hz*t)+160 sin(1 hz*t)+1600 sin(10 hz*t)+16000 sin(100 hz*t)

Availability of Flight Systems:

STABLE:

- **No plans to fly on ISS, but available**

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 Performance Flight Characterization of an International Space Station Active Rack Isolation Prototype System," Proceedings of The 16th IEEE Instrumentation and Measurement Technology Conference (IMTC/99), Venice, Italy, May 24-26, 1999.
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.