Section 18
Survey of Microgravity Vibration Isolation Systems

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Outline:

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

- COTS – commercial off-the-shelf
- MVIS – Microgravity Vibration Isolation System
- ISPR – International Standard Payload Rack
- MSG – Microgravity Science Glovebox
- DOF – Degree of Freedom
The ISS will provide a world-class research facility for microgravity science

![Graph showing RMS acceleration vs frequency for different systems and induced frequencies.]

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?

![Graph showing transmissibility and RMS acceleration vs. frequency for different scenarios.]

- DAC-8 (non-isolated)
- DAC-8 (with SM erg.
  frequency variation)
- System Requirement

RMS Acceleration (µg)

- SM Ergomtr
- Crew Induced
- Lab System
- Vent
- SPP
- TRRJ

Transmissibility

- DAC8 (without ARIS)
- DAC8 (with ARIS)

RMS Acceleration (µg)

- SM Ergomtr
- Lab System
- Lab Ergomtr
- Crew Induced
• 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
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## Comparison of Approaches

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Passive</td>
<td>• Low Cost</td>
<td>• Isolate only higher freq ( &gt; 1-10 Hz)</td>
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<tr>
<td></td>
<td>• Low Maintenance</td>
<td>• Typically requires large volume</td>
</tr>
<tr>
<td></td>
<td>• Reliable</td>
<td>• Cannot mitigate payload induced vibrations</td>
</tr>
<tr>
<td></td>
<td>• No Power</td>
<td>• Resonance vs attenuation trade</td>
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<tr>
<td>Active Rack Level</td>
<td>• Low freq attenuation via large mass</td>
<td>• Cannot mitigate payload induced vibrations</td>
</tr>
<tr>
<td>(ARIS)</td>
<td>• Least power &amp; volume (multi. payloads/single unit)</td>
<td>• Requires payloads to be “good neighbors”</td>
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<tr>
<td></td>
<td>• Standard user interface</td>
<td>• Highly sensitive to crew contact</td>
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<tr>
<td></td>
<td></td>
<td>• Potential high maintenance</td>
</tr>
<tr>
<td>Active Sub-Rack Level</td>
<td>• Low freq attenuation via high gain feedback</td>
<td>• More power &amp; volume than rack-level (single payload/single unit)</td>
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<tr>
<td>(g-LIMIT, STABLE, MIM)</td>
<td>• Mitigates payload induced vibration</td>
<td></td>
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<td></td>
<td>• Can be optimized for individual user</td>
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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

- **Base Acceleration**
- **Umbilical Dynamics**
- **Acceleration Controller**
- **Actuator**
- **Isolated Platform**
- **Accelerometer Electronics**
- **Position Controller**
- **Position Sensors**
STABLE: Typical Active Isolation Time Response

Acceleration During USML2 (MET 05:21:05:01 Crew Exercise)

\[ \text{Acceleration} \] > 1000 \( \mu \)g

- Non-isolated: 1624 occurrences
- Isolated: 0 occurrences

STS Z direction (bottom→top)

All Ensembles
Mean removed
STABLE: Typical Active Isolation Frequency Response

RMS Acceleration Per 1/3 Octave Band During USML2 (MET 05:21:05:01 Crew Exercise)

Sensor Noise Estimate
Space Station Limit
Isolated
Non-isolated

STS Z direction (bottom→top), 16384 samples, Hanning window, 20 averages, 0% overlap
Error bars represent 95% confidence interval

Frequency (Hz)
STABLE: Typical Active Isolation Attenuation

Acceleration Attenuation During USML2 (MET 05:21:05:01 Crew Exercise)

STS Z direction, 16384 samples, Hanning window, 20 averages, 0% overlap
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

Acceleration Levels of the Space Shuttle and MIM’s Isolated Platform

- Space shuttle (stator), non-isolated
- MIM isolated platform (flotor)

X Axis 2 Hertz Cutoff

Data filtered by a 100 Hz low-pass filter and sampled at 1000 samples per second
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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.
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Fluid Core Element (FCE)  |  MVIS Electronic Unit

FCE / ISPR
Mounted Items

MVIS: Microgravity Vibration Isolation System

March 2-4, 2004
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MVIS Hardware
Predicted Isolation Transfer Function

- Simulation Results
- Theoretical
Isolation Performance Predicted for MVIS

![Graph showing power spectral density vs frequency for FSL Acceleration Environment.](image)

- **Red line**: DAC6 Predicted Acceleration for Non-Isolated Rack
- **Dotted line**: ISS Acceleration Specification - Achieved Only With Isolation
- **Blue dashed line**: FCE Acceleration with 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
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MIM Base Unit

Top Flotor

Intermediate Flotor

Base
MIM Base Unit Isolation Performance

Isolation TF

- One Stage
- Two Stage
- -3 dB
- Natural Isolation one-stage
- Natural Isolation two-stage

TF Gain [dB]

Frequency [Hz]
MIM Base Unit: Driven Accelerations on Top Floator
Reaction Force to ISS in Driven Mode Operation
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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
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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.


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.


6. **Hard stop Bumpers**

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STATION UMBILICAL STANDOFF STRUCTURE
ARIS-ICE Express Configuration
ARIS ICE 1/3-Octave Band Acceleration Measurements
ARIS ICE Isolation Performance

![ARIS ICE Isolation Performance Graph](image-url)
ARIS EXPRESS Predicted Performance at Assembly Complete
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**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: LF1 Mission
- 15 Days Characterization testing
- Payload support operations after characterization
g-LIMIT Flight Unit

Dimensions:
~ 14” x 16” footprint
~ 10” tall
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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
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Isolation Module (IM)

- Actuator Paddle
- Magnets (2)
- Backiron
- 2-Axis Accelerometer Block
- Electronics Boards (3)
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
g-LIMIT 6DOF, Acceleration Time Response (X-axis)
Controllers Technologies to be Tested using g-LIMIT

- Baseline classical controllers (Jackson, Kim, Whorton)
- Fixed Order $H_2 / \mu$ designs (Whorton)
- $H_\infty$ 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:
• In operation on ISS

g-LIMIT:
• To be utilized in MSG
Further Reading:


