Section 18:

Microgravity Control & Disturbance Predictions for ISS Payloads

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Presentation Agenda

- **Overview**
- **Isolation Approaches**
- **Microgravity Control Requirements**
- **Analytical Tools Available**
- **Process Flow**
- **Modeling Requirements**
- **Disturbance Prediction & Testing**
- **Disturbance Allocations**
- **Verification & Validation**
- **On-Orbit Testing**
- **Contact List**

Overview

- **Protect Science for 30 Day Microgravity Periods**
- **Vibration Isolation Approaches (ARIS, PaRIS, other)**
- **Microgravity Requirements for Science Locations**
- **Need for a Clear Common Approach**
- **Identify Payload Disturbers (Offboard & Onboard)**
- **Basis for Payload Microgravity Allocations**
- **Microgravity Requirement Verifications**
- **Fluids & Combustion Facility Assessment**
- **EXPPCS Disturbances (Operational Scenario Example)**
- **ARIS Operations for EXPRESS Rack No. 2**

Acronyms

- ARIS – Active Rack Isolation System
- CIR – Combustion Integrated Rack
- EXPPCS – EXPeriment Physics of Colloids in Space
- EXPRESS – EXpediate the PRocessing of Experiments to Space Station
- FCF – Fluids Combustion Facility
- FIR – Fluids Integrated Rack
- HHR – Habitat Holding Rack
- ICE – ISS Characterization Experiment
- MAMS – Microgravity Acceleration Measurement System
- MEL – Microgravity Emissions Laboratory
- MSRR – Material Science Resource Rack
- NIRA – Non-Isolated Rack Assessment
- PaRIS – Passive Rack Isolation System
- RTS – Remote Triaxial System
- SAMS – Space Acceleration Measurement System
- SE – Sensor Enclosure
- SM – Service Module
- SRED – Science Requirement Envelope Document

Isolation Approaches

- **Active Rack Isolation System (ARIS)**

    - Active Rack Isolation Bandwidth ~ 0.01 to 2 Hz (Configuration Dependent)

    - Passive Rack Isolation Bandwidth ~ 2 Hz & Up (Configuration Dependent)

    - Connected to ISS by 8 Pushrods and Configuration Dependent Umbilicals

    - Use of Isolation Plate Attached to US Lab Structure

    - Use of 6 Snubbers & Snubber Cups

    - Alignment Guides Used to Lock Down Rack

    - Actuates Rack by Responding to Sensed Position and Accelerations

    - Currently Working in EXPRESS Rack Nos. 2 & 3 in U.S. Lab Module

    - Scheduled for 7 ISPR's (4 EXPRESS Racks, FIR, MSRR, & TBD)

    - Programmable Controller Tied in to On-Orbit Processor

   - ARIS Modes – Initialize, Idle, Active, Rest, Hold, Secure, Passive, Nogo

ARIS Operational Modes

- **Initialize – Enters this stage when power is applied to the rack**
- **Idle – No control of rack position; rack can bounce off hard stops; health status of ARIS provided**
- **Active – ARIS senses and compensates acceleration; rack position is monitored & limited to prevent contact with mechanical stops**
- **Rest – Rack moved to center position; actuator forces remain constant; rack can move due to station motion**
- **Hold – Rack is centered by position feedback during station maneuvers**
- **Secure – Rack is held secure by alignment guides in the snubber cups**
- **Passive – Rack is held by foam inserts in the snubber cups**
- **Nogo – Transitions to this state when system errors are detected; like idle mode with no actuator commands**

ARIS Overview - Design

ARIS Controller (Control & input/output): Decoupling implemented in controller allows freedom to place actuators and sensors. Payloads have extensive command, data acquisition, and control options.

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

3 Tri-axial Accelerometer Heads : Built small to fit in rack corners

1 Actuator Driver : Pulse width modulation used to reduce power consumption

8 Actuators : Voice coil rotary actuator used to reduce profile and power consumption.
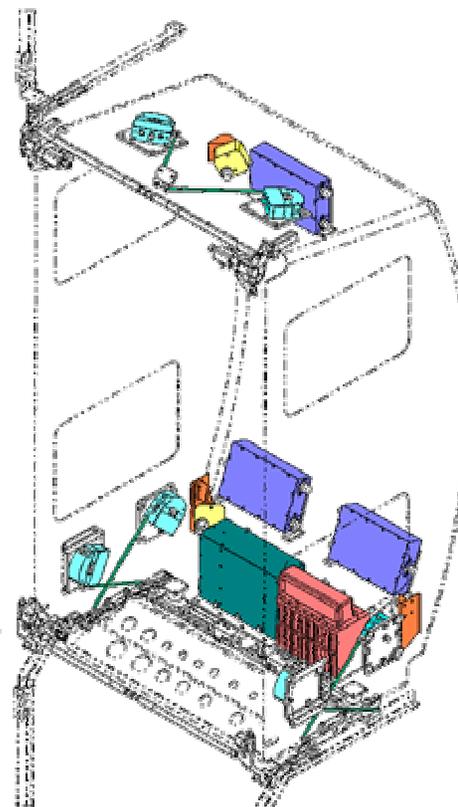
# ARIS Actuator & Pushrods
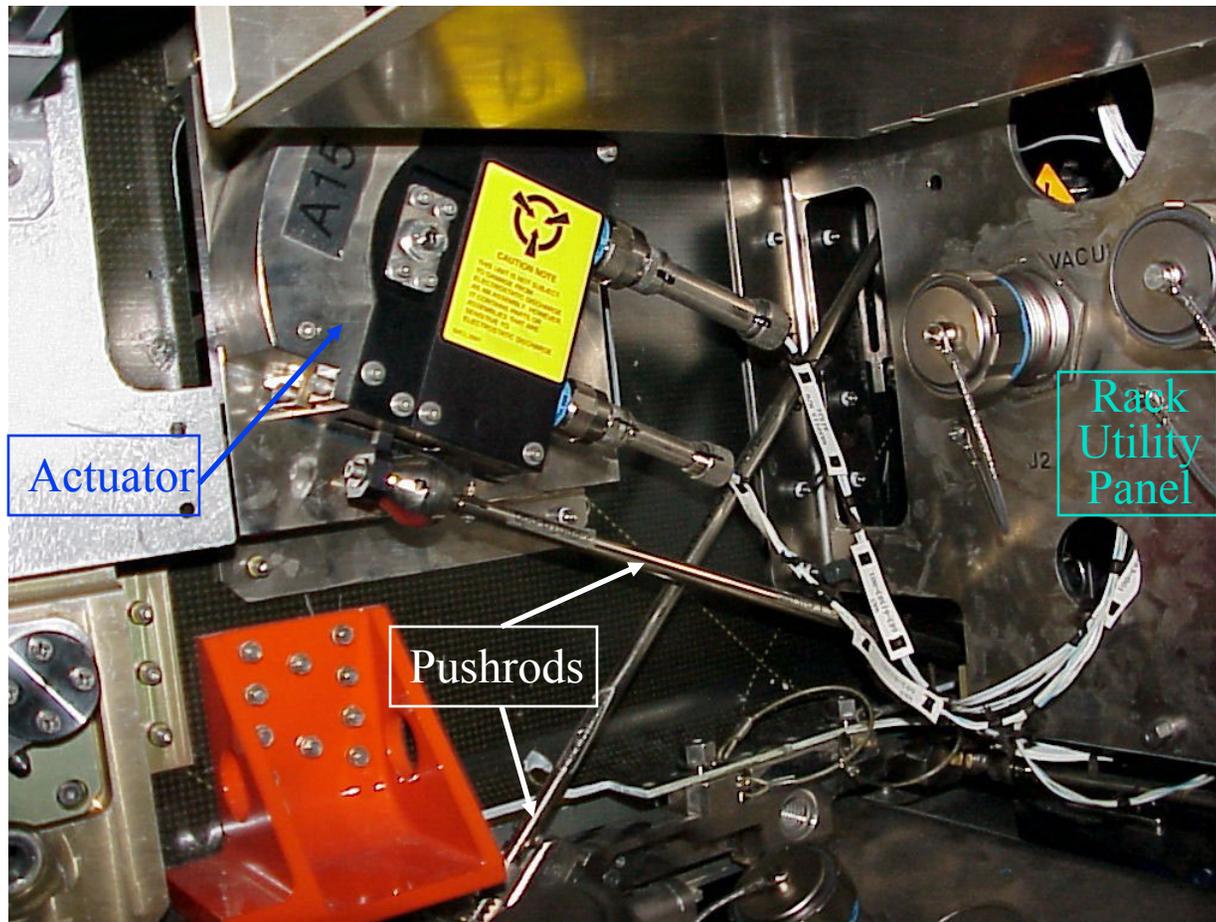
ARIS Snubber & Cup
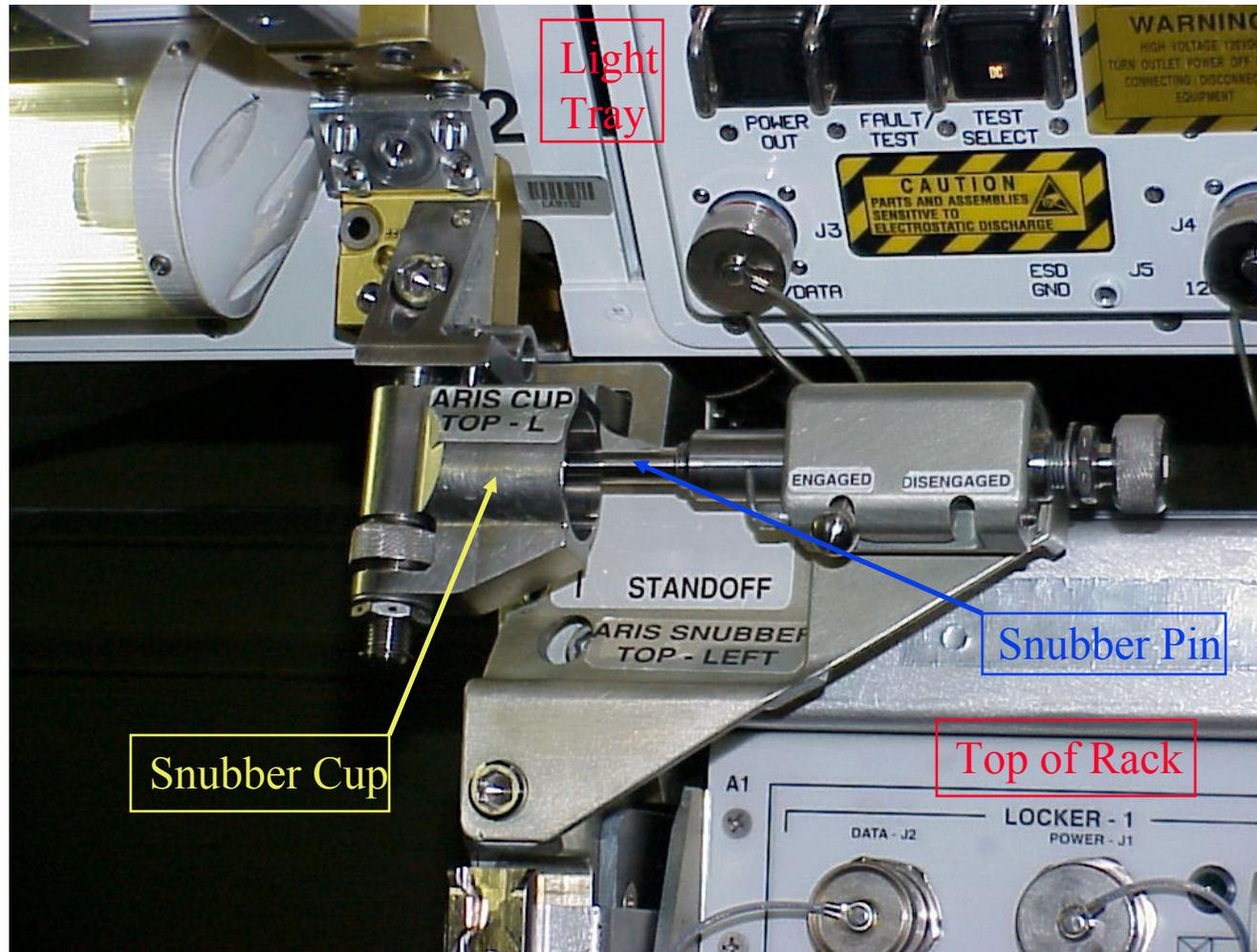
ARIS Umbilical Set for EXPRESS Rack No. 2 to US Lab Z Panel

Vacuum Umbilicals on Z Panel

Vacuum Resource Umbilical

Vacuum Waste Gas Umbilical

Utility Interface Panel (Z Panel)
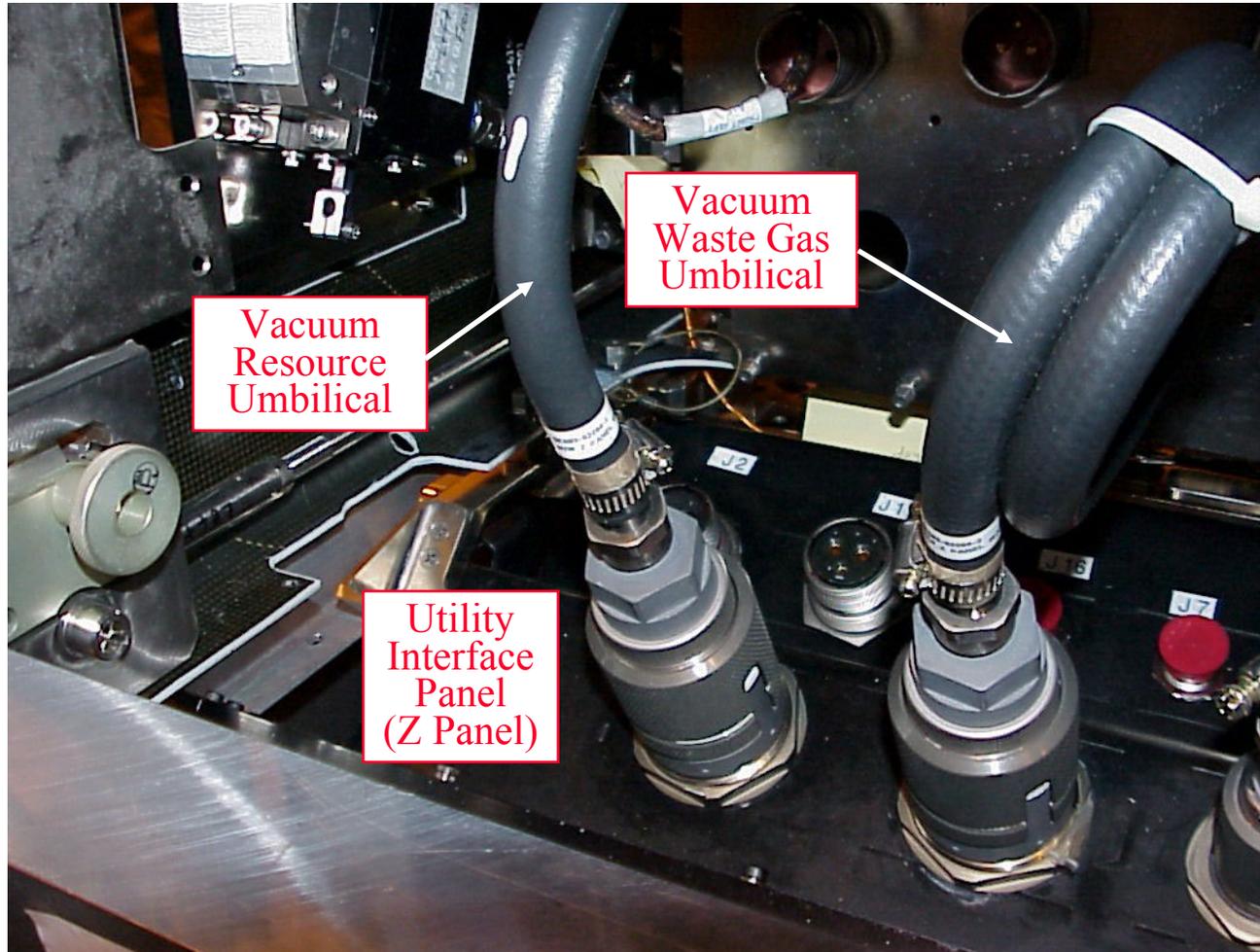
Isolation Approaches

- **Passive Rack Isolation System (PaRIS)**
  - Utilizes Some Existing ARIS Hardware
  - Passive Rack Isolation Bandwidth ~ 0.5 Hz & Up (Configuration Dependent)
  - Connected to ISS by 8 Spring/Damper Isolators & Configuration Dependent Umbilicals
  - Use of Isolation Plate Attached to US Lab Structure
  - Use of 6 Snubbers & Snubber Cups
  - Alignment Guides Used to Lock Down Rack
  - Scheduled for 3 ISPR's (two for HHR & one for CIR)
  - Pre-Launch Tunable Directional Dependent Stiffness & Damping
- **Foam Inserts in ARIS Snubber Cups**
  - Foam Damping Material Placed in Front 4 Snubber Cups
  - Passive Rack Isolation Bandwidth ~ 1.0 Hz & Up (Configuration Dependent)
  - Connected to ISS by Snubber Isolation Material & Configuration Dependent Umbilicals
  - Utilized On-Orbit in US Lab Module for EXPRESS Rack No. 2
- **On-Orbit Protection (Microgravity Rack Barrier)**
- **Local Disturber Isolation at Source (Grommets or Damping Material)**

PaRIS X & Z Axes Isolators
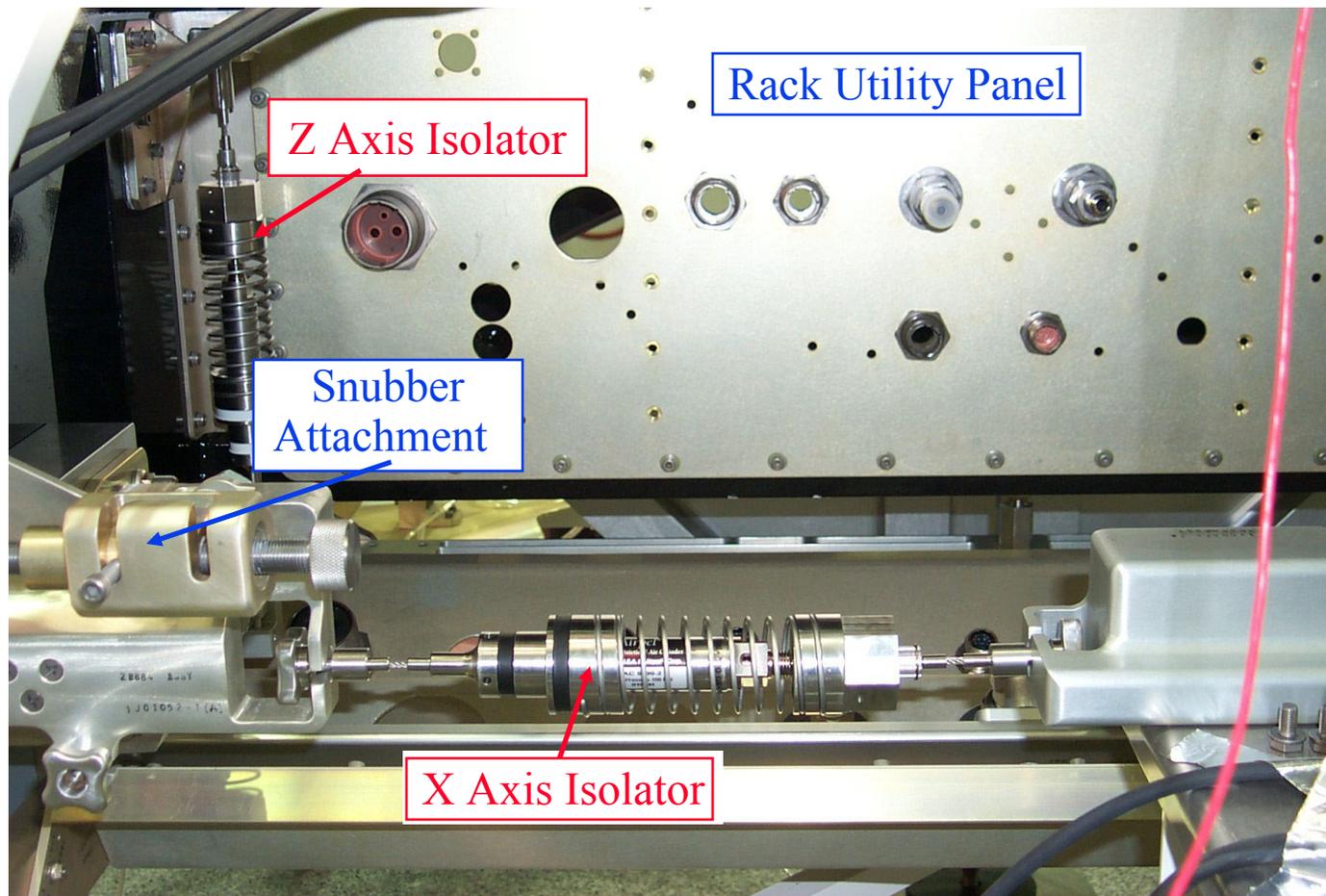
Microgravity Rack Barrier

- EXPRESS Rack No. 2 in US Lab Module

- Used for Microgravity Racks

- Attached to Rack during Initial Set-up

- Protects Payloads from Crew Induced Loads
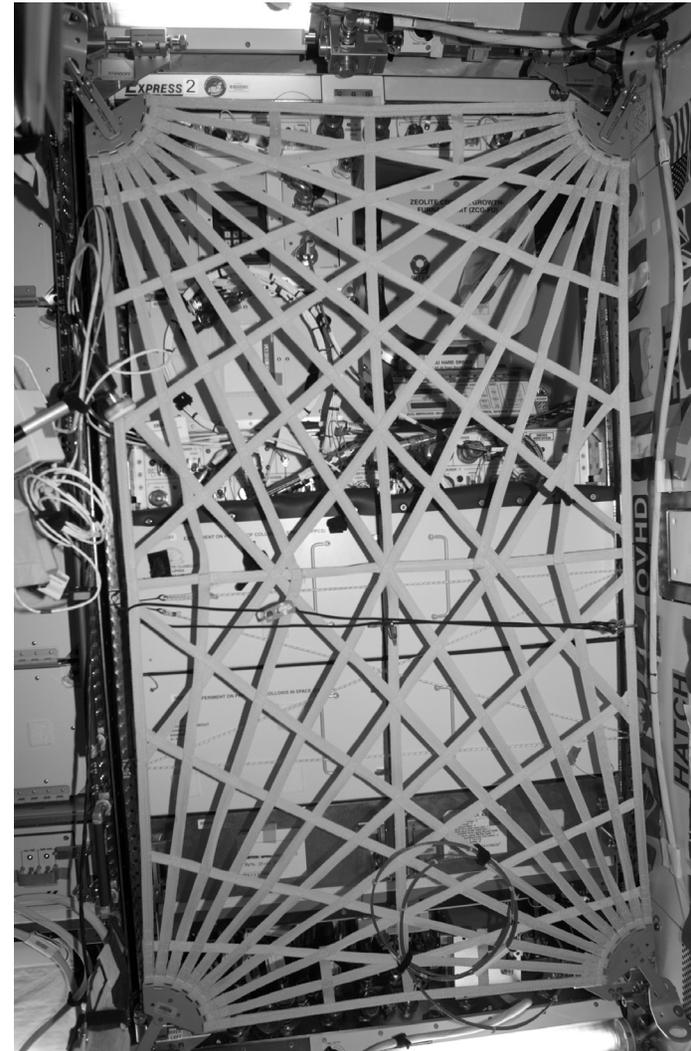
Microgravity Control Requirements

- **Payload Requirements**

  - Based on Being a Good Neighbor (Limit Payload Disturbances on Environment of Other Payloads During ISS Microgravity Modes)

  - Disturbance Force Limits at Rack Attachment Brackets or Isolation System Connections to ISS

  - Payload Rack Microgravity Requirements in 57000-NA-0110H (PIRN 0110H)

    - Quasi-Steady Requirements (10 lb-sec impulse limit for any 10 to 500 sec. period)

    - Vibratory Requirements (acceleration & force methods)

    - Transient Requirements (10 lb-sec limit for any 10 sec. period & 1000 lb peak limit)

  - Generic Microgravity Control Plan (SSP 57916)

    - Appendix Pending Approval

    - ARIS Sensor Saturation

    - Rack Sway Space Limits

    - ARIS Rack Allocations

    - Microgravity Disturbance Verification Approaches

Microgravity Control Requirements

- **Payload Requirements (Continued)**

  - PaRIS Requirements Not Currently Developed

    - PIRN 0110H Should Be Met at Rack Interface

    - Sway Space Limits Needed

- **Project (Facility Rack) Requirements**

  - Based on Acceptable Microgravity Level at Science Location

  - Specific Science Microgravity Requirements

  - For FCF: Science Envelope Requirements Document (SRED)

Analytical Tools Available

- **NASTRAN for Rack, Umbilicals, Isolators, & Payload Modeling**

- **AutoSEA Modeling Based on Density of Modes (Used for frequency greater than 50 Hz with at least 3 modes needed within each bandwidth)**

- **MATLAB Simulink for ARIS & PaRIS Response & ARIS Controller Tuning**

Process Flow

- **ISS Program Responsibilities**
  - On-Orbit ISPR NASTRAN Model (with or w/o ARIS or PaRIS)
  - Reduced US Lab NASTRAN & SEA Models
  - ISS Offboard Rack Vibration Environment (NIRA)

- **Isolation System Responsibilities**
  - Umbilical & Isolator Stiffness & Damping for Analytical Models
  - Simulink Model of ARIS / PaRIS System and Generic Rack & Umbilicals
 - Tune ARIS Controller for Payload Rack

- **Payload Developer Responsibilities**
  - Identify & Assess Rack Disturbers
  - Facility On-Orbit NASTRAN Model with Disturber & Science Locations
  - Facility Simulink Model with Transfer Functions for Key Interfaces
  - Modify Model for Different On-Orbit Configurations
 - Complete Microgravity Verifications

Process Summary

Microgravity Control Integration Analytical Process Flow

Development **Non-Verified Design** **Verified Design**

Input

| ISPR / Support Hardware Models | ISS Model Updates From Testing | ISS Model Validation From Testing |

Critical Design Review

Baseline Configuration Achieved

Analysis

| Create Facility Dynamic Models | Preliminary Microgravity Dynamic Models | Final Microgravity Dynamic Models |

To Operations Phase

Deliverables

| Microgravity Control Plan | Preliminary Microgravity Control Report | Final Microgravity Control Report |

Launch - 24 Months

Launch - 20 Months

Launch – 7.5 Months

Key: | Payload Developer Task | ISS Program Task | ISS Program Deliverable |

Inputs/Outputs

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On-Orbit NASTRAN Model

Facility Rack Simulink Model
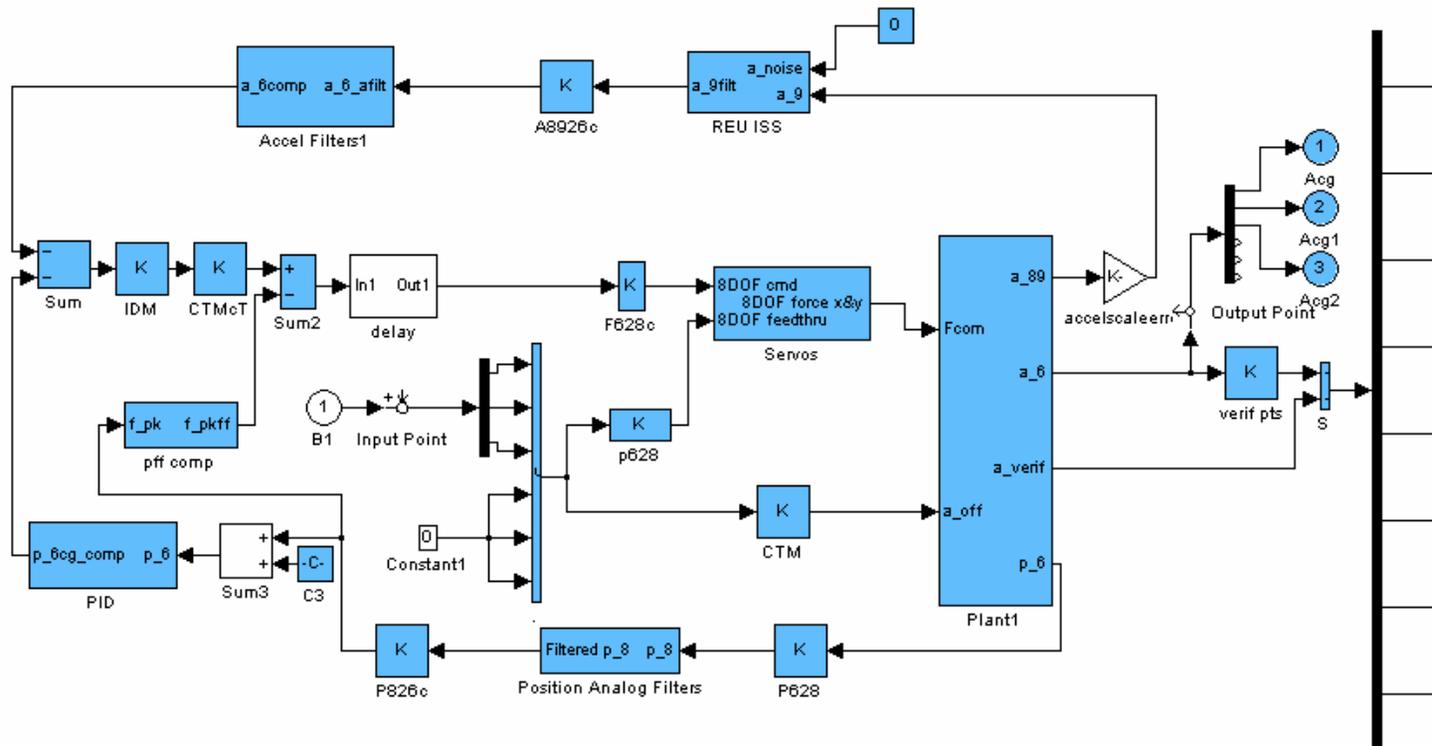
Model does not yet include anti-bump or hysteresis effects.
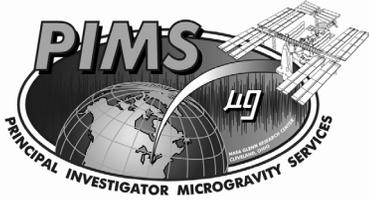
Disturbance Prediction & Measurement

- **Write Facility Microgravity Control Plan**

  - Identify Potential Disturbers
  - Facility Microgravity Critical Items List
  - Explain Disturbance Testing Approach

- **Disturbance Prediction**

  - Utilize MIPT Disturber Data Base for Initial Onboard Disturbers
  - Non-Isolated Rack Assessment (NIRA) Predictions for Offboard Environment at Assembly Complete
  - Utilize SAMS Offboard Rack Acceleration Data for Pre-Assembly Complete Phases
  - Input into Facility Rack Predictive Model

- **Disturbance Measurement Pre-Launch**

  - Utilize 3 Degree of Freedom Air Table
  - Pendulous Measurements of Disturbers by Cabling in Microgravity Emissions Lab (MEL)
  - Suspend Entire Integrated Rack by Cabling & Activate Disturbers

- **Microgravity Allocations of Disturbers**

  - Compare Microgravity Levels with Margin Available
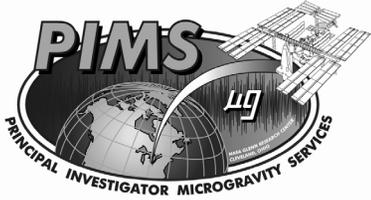
Pre-Launch Testing

- **Disturber Testing in Microgravity Emissions Lab (MEL)**

- **Umbilical Stiffness Testing (ARIS Air Slide Mass Test Device)**

- **Rack Characterization Tests (Modal and Modal Damping)**

- **Rack Mass Model with Umbilicals at ARIS 3 DOF Test Bed**

- **Rack Mass Model with Isolators & Umbilicals at PaRIS 3 DOF Test Bed**

# NASA GRC MEL Modeling & Comparison

- **6 DOF Inertial Measurement System**

  - 98 lb. Mushroom Cone

  - 33 foot Suspension Cable

  - Zero Rate Spring Mechanism and Pneumatic Suspension System (0.3 Hz)

  - 10 QA-700 Servo Control Accelerometers

- **Defines Forces & Moments at the Test Unit C.G.**

- **MEL Comparison of Test Results & Modeling**

  - Setup Fan / Plate Test & Associated NASTRAN Model for 4 Configurations

  - Showed Damping Key to Accurate Model Predictions (Assumed 2%)

  - Preliminary ARIS-ICE Data Is Indicating Some Modal Damping in the 4% to 5% Range

MEL Setup for Fan Test
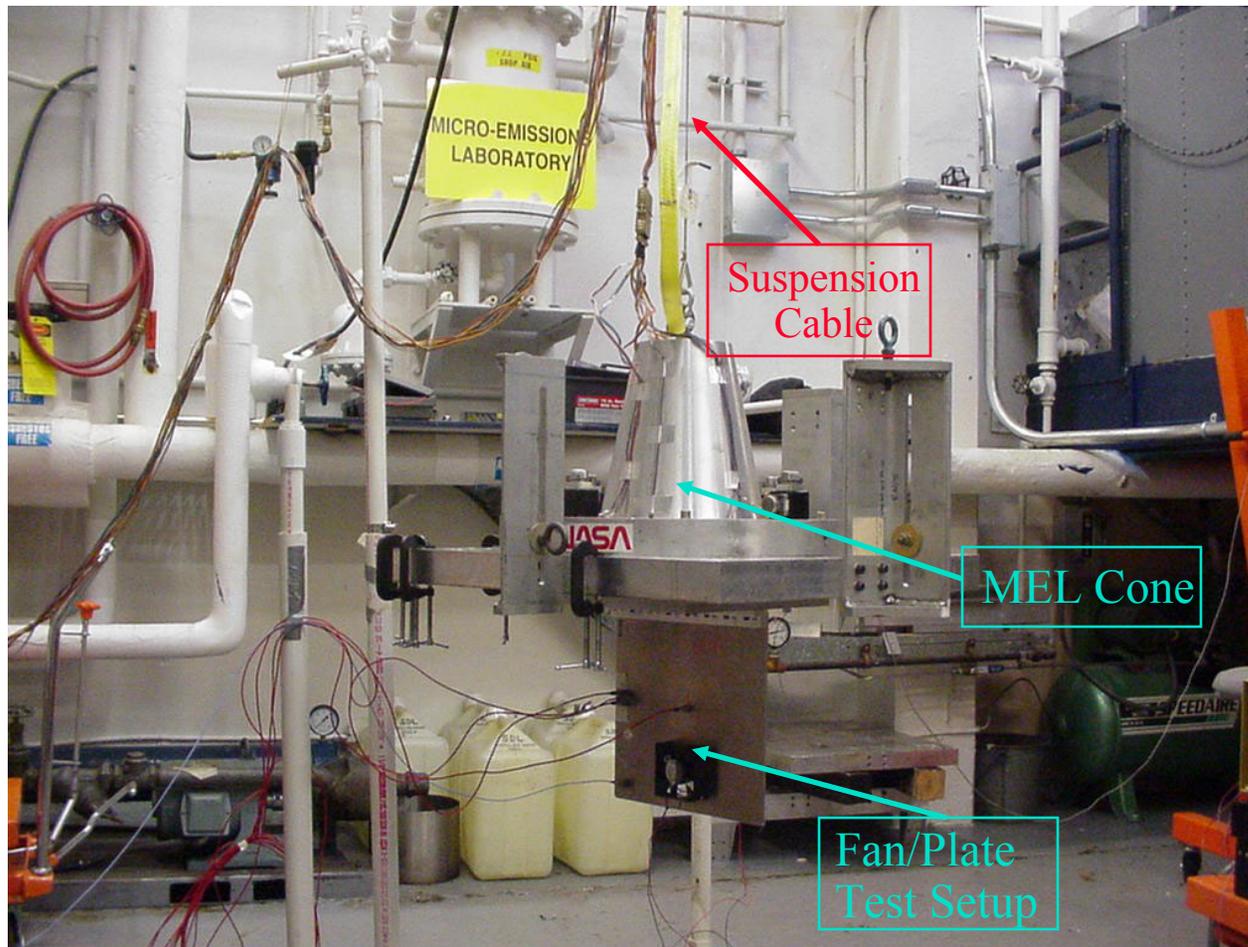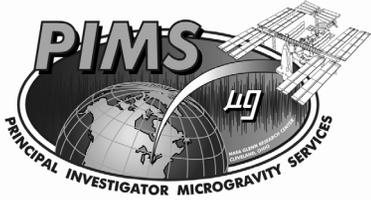
EXPeriment Physics of Colloids in Space (EXPPCS) MEL Testing

- **EXPPCS Tested in the MEL Prelaunch**

- **Data from 1 to 300 Hz Obtained**

- **Forces at Experiment to Rack Interface**

- **Compared with EXPRESS Rack Allocations**

- **MEL Background Noise Check Performed**

- **Ten EXPPCS Operational Scenarios Run**

- **Three Vibratory Exceedances Found**

EXPPCS MEL Testing

Simulated Middeck Locker/Adapter Plate

Suspended MEL Cone

Test Section (TS) Double Middeck Locker Configuration

Avionics Section (AS) Double Middeck Locker Configuration

EXPPCS MEL Operational Testing

- **Op#1 – Avionics Fans & Hard Drives (startup)**

- **Op#2 – Avionics Fans Steady State, Hard Drive Startup**

- **Op#3 – Mixer Startup, Sedimentation Mix**

- **Op#4 – Mixer Steady State, Sedimentation Mix**

- **Op#5 – Mix / Melt Cycling (6°/sec for several hours)**

- **Op#6 – Rheology**

- **Op#7 – Carousel Rotation (2°/sec for 180°)**

- **Op#8 – Fiber Cell (0.10^o motion every 5 sec)**

- **Op#9 – Avionics Fan Steady State**

- **Op#10 – Avionics Fan Power Up**

EXPPCS Interface Forces to EXPRESS Rack (ARIS)
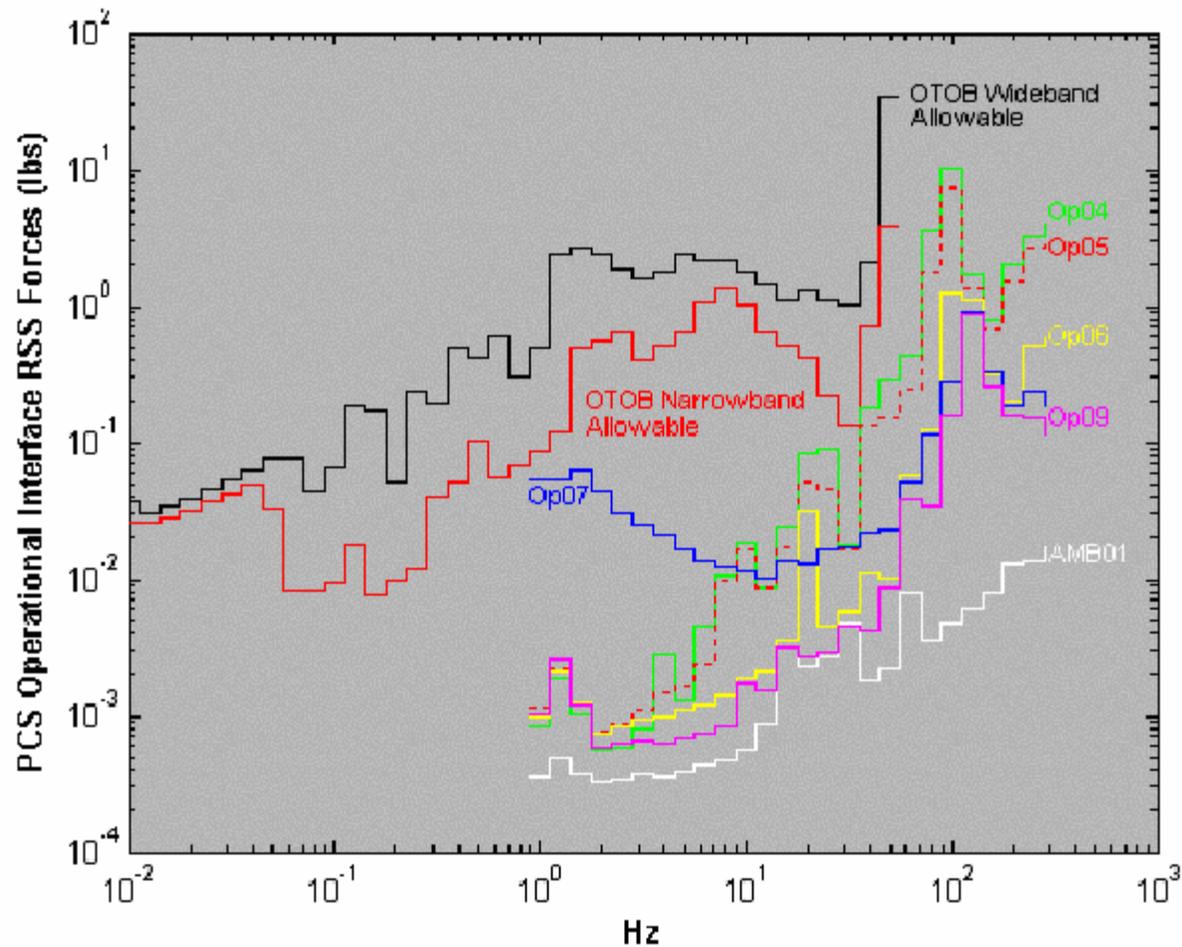
EXPPCS Interface Forces to EXPRESS Rack (Non –ARIS)
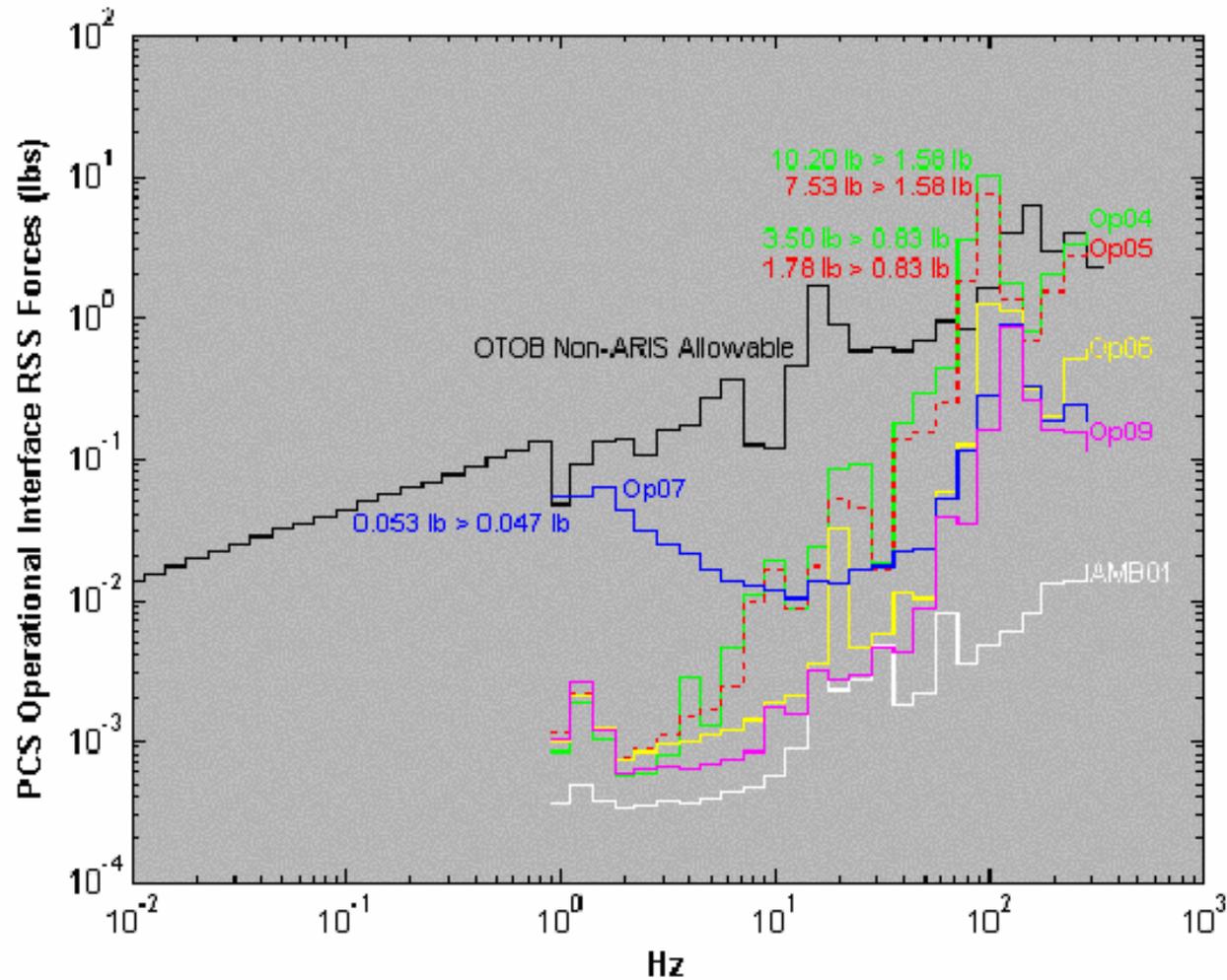
Verification & Validation

- **Analytical Verifications**

  - Rack NASTRAN Models

  - MATLAB Simulink Models

- **ARIS Performance – Sway Space & Sensor Saturation Are Based On:**

  - Payload Unique Stiffness & Damping of Umbilical Set

  - Payload Unique Mass & Center of Mass Position

  - Payload Unique Disturbance & Rack Dynamic Response

  - Payload Experiment Configuration

- **Maximize Use of Test Results in Updated Analytical Models**

  - Comparison With ISS Microgravity Requirements

 - Comparison With Science Requirements (SRED)
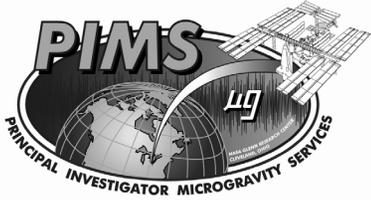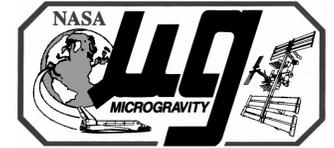
FCF Microgravity Assessment Example

- Predicted Offboard Loading (NIRA99 data from US Lab)

- Onboard Loadings Based on MEL Testing Used

- Combined MEL Test Data (Onboard) and NIRA (Predicted Offboard)

- Added Vacuum Resource Umbilical to EXPRESS ARIS Umbilicals

- Performance at Experiment Location and Verification Points

- Onboard to Offboard Impact

- Comparison to CIR & FIR Science Requirements Envelopes (SREDs)

- Development of CIR & FIR Experiment Microgravity Allocations

CIR-PARIS Science Insert Interface Response to Onboard and Offboard Loads [v6.0]
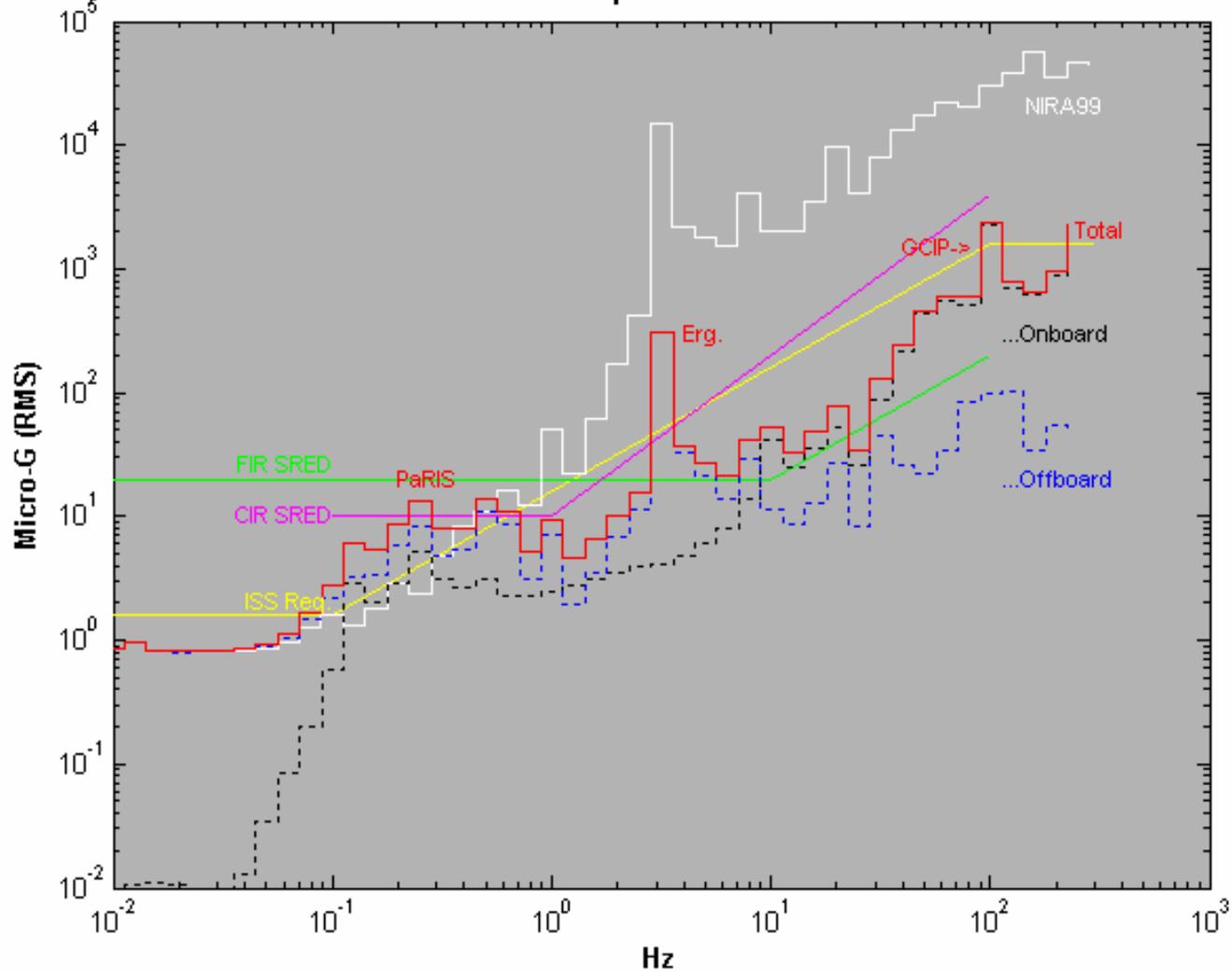
CIR-PARIS MDCA Science Response to Onboard and Offboard Loads [v6.0]
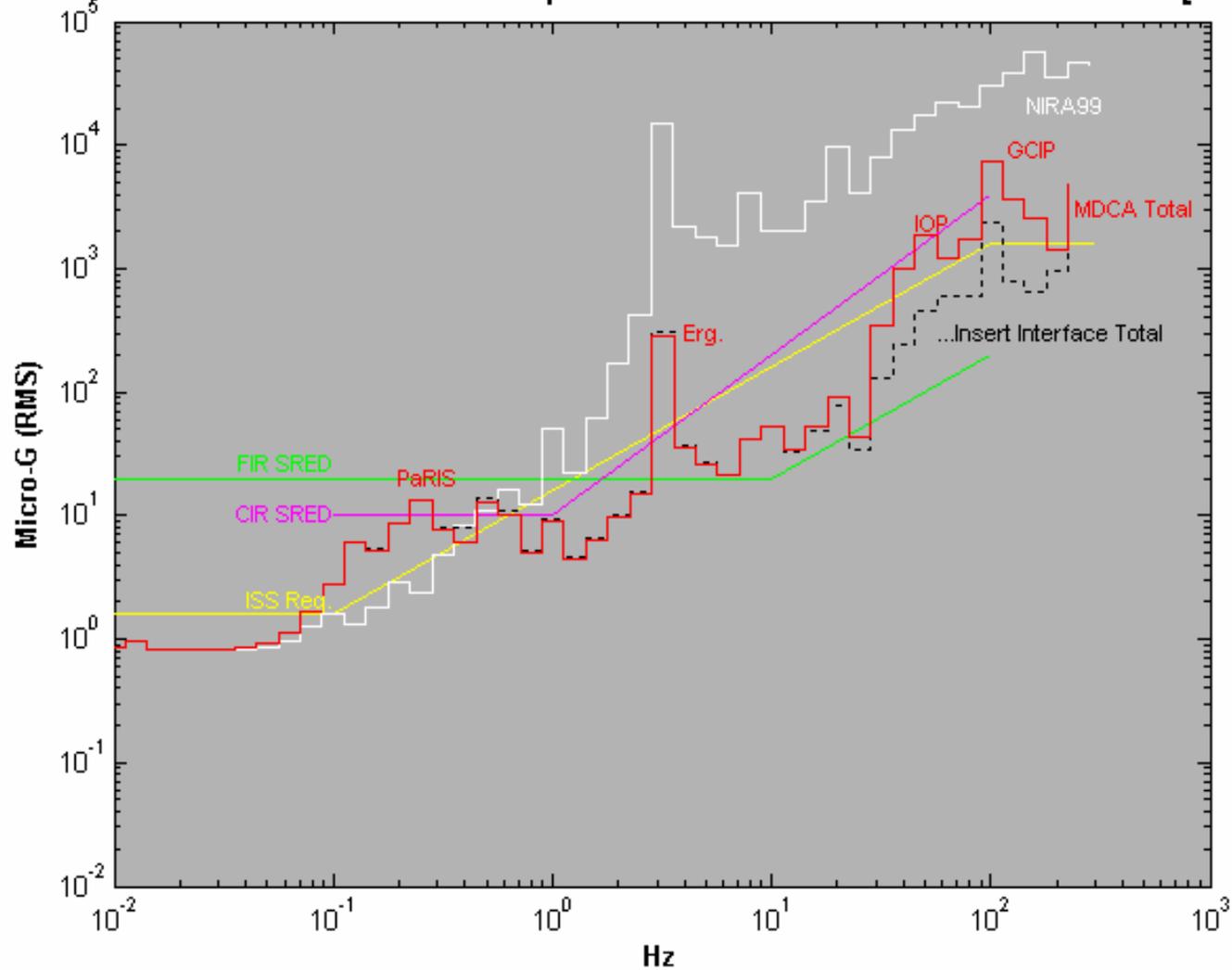
Preliminary CIR Science Allocations

• **CIR generic levels at science package interface (red)**

  • **Does not include science package contributions**

  • **Maximum integrated levels are estimated for an ideal generic science package (dotted blue)**

• **Below 4 Hz the generic level has a slight increase above 0.1 Hz**

• **Above 4 Hz, the generic levels are used <u>plus</u> 6 dB to provide margin for science package loads and dynamics**

Predicted CIR Maximum Microgravity Levels [v6.0]

FIR-ARIS Science Response to Onboard and Offboard Loads [v6.0]
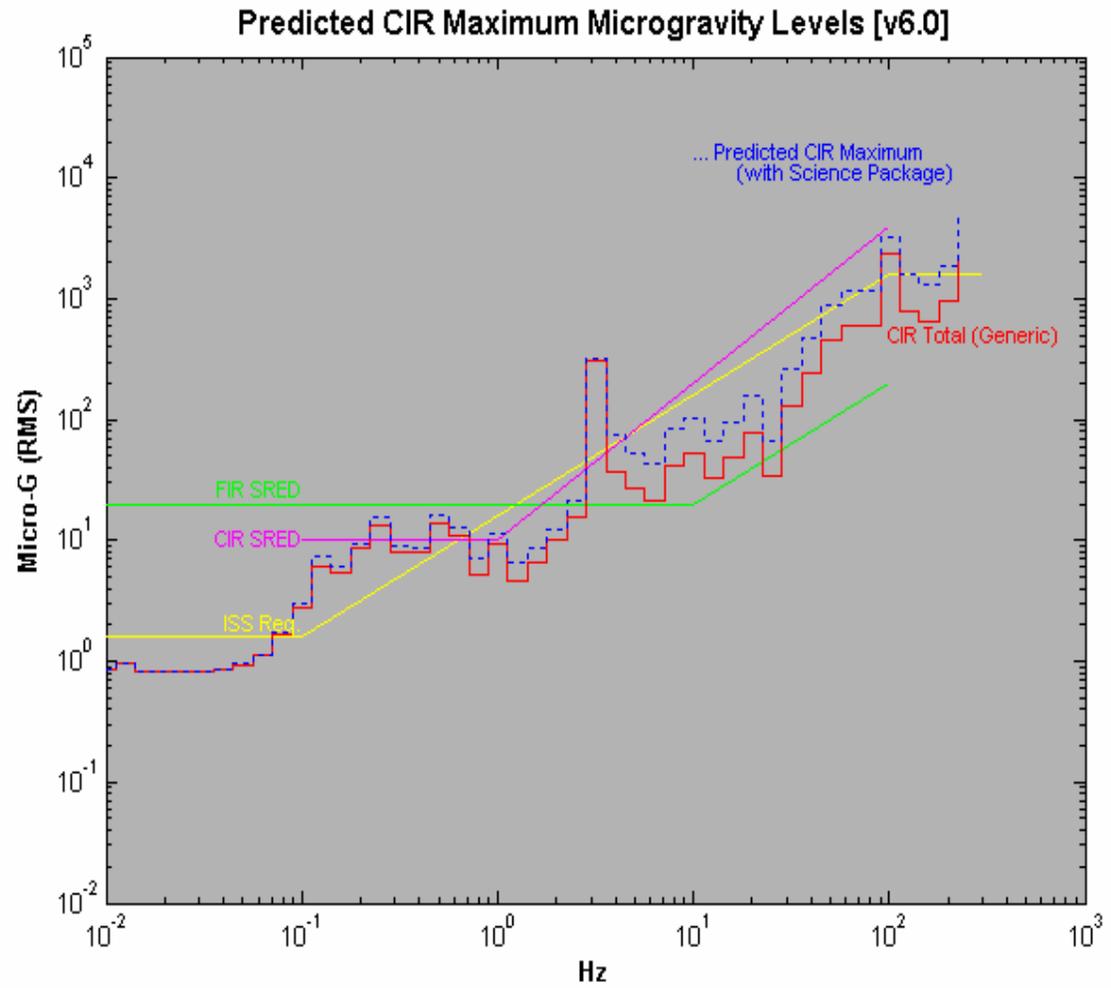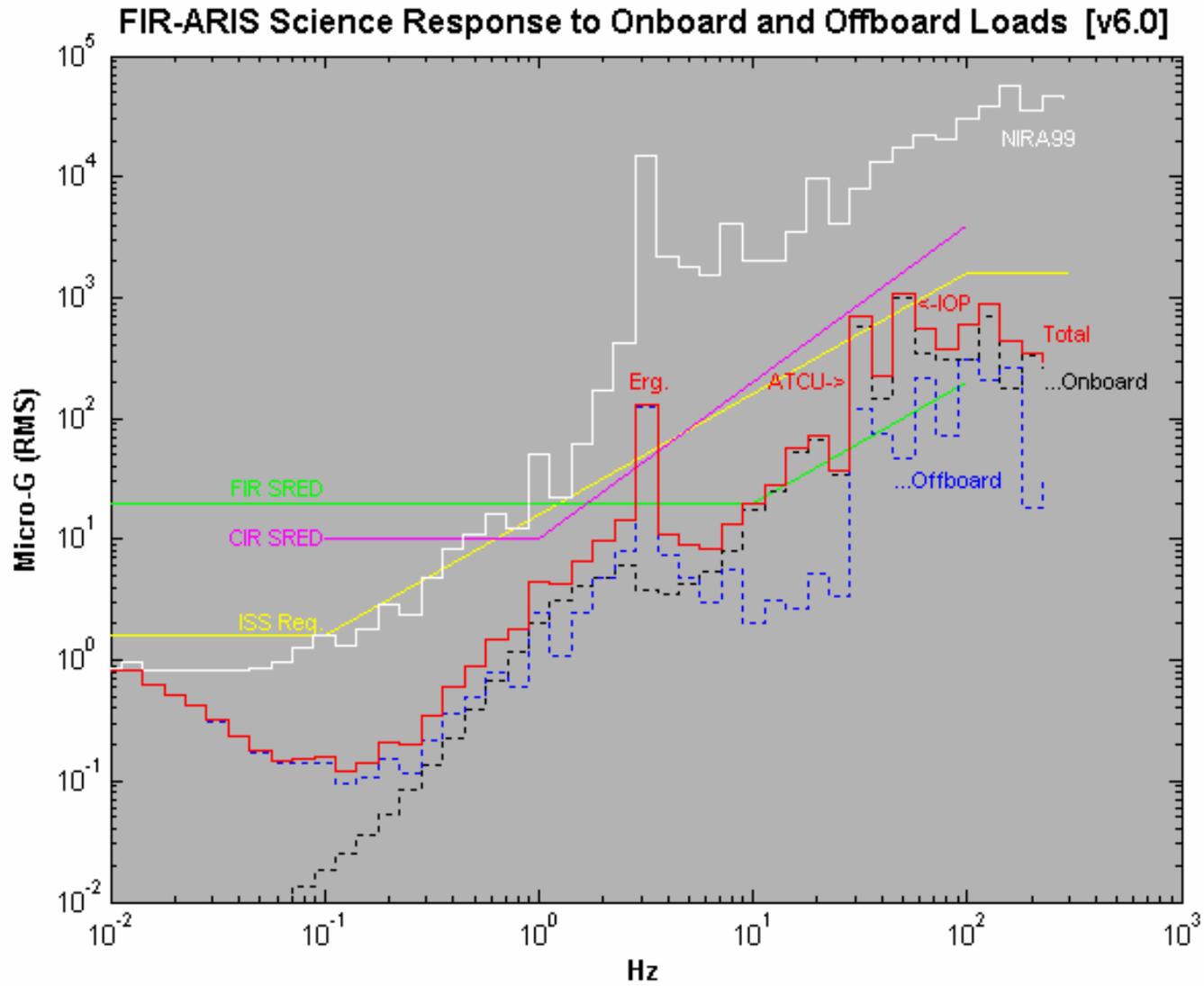
Preliminary FIR Science Allocations

- **FIR generic levels at science package interface (red)**

  - **Exceeds FIR SRED (green)**

  - **Does not include science package contributions**

  - **Maximum integrated levels are estimated for an ideal generic science package (dotted blue)**

  - **Below 4 Hz the generic level has a slight increase above 0.1 Hz**

- **Above 4 Hz, the generic levels are used plus 6 dB to provide margin for science package loads and dynamics**


Predicted FIR Maximum Microgravity Levels [v6.0]

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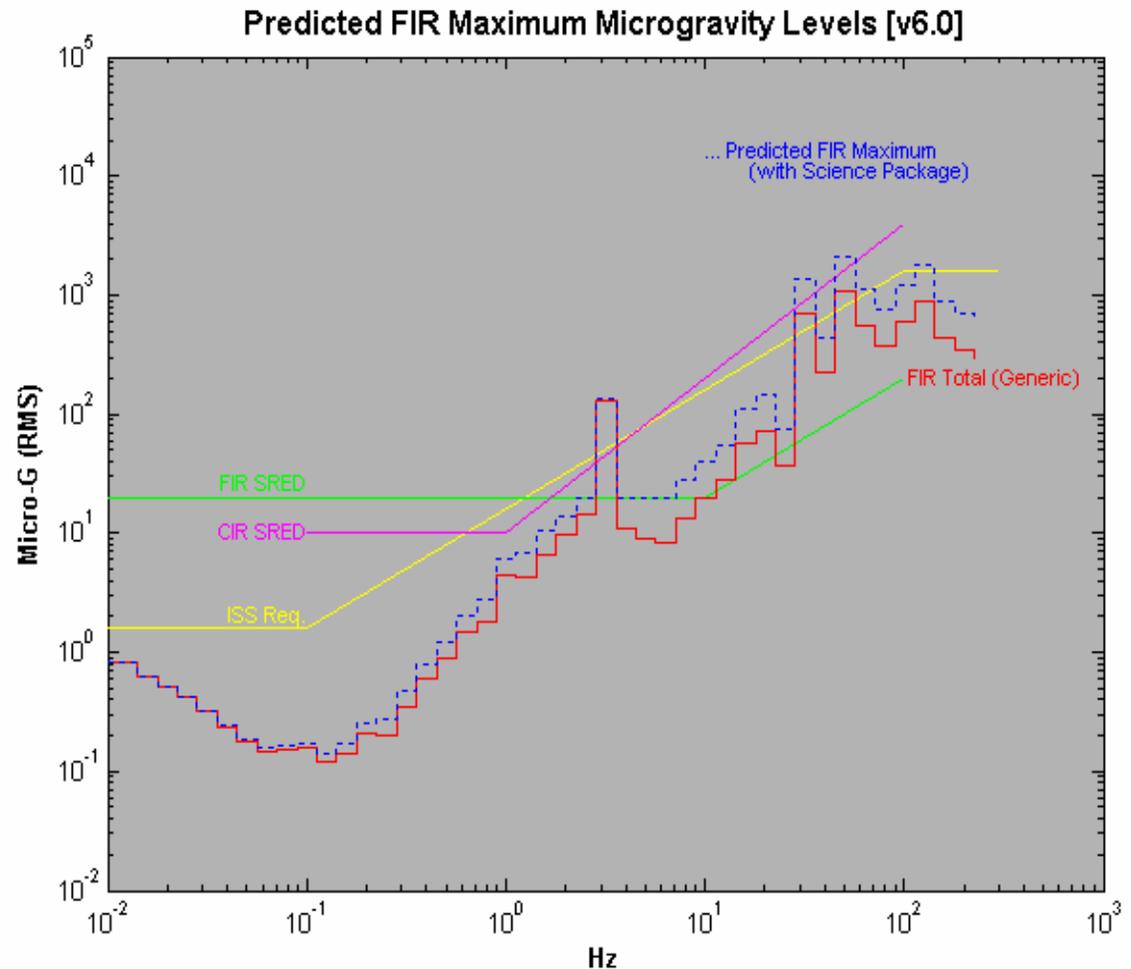
FIR-Hardmount Force Limit Check for PIRN110H [v6.0]
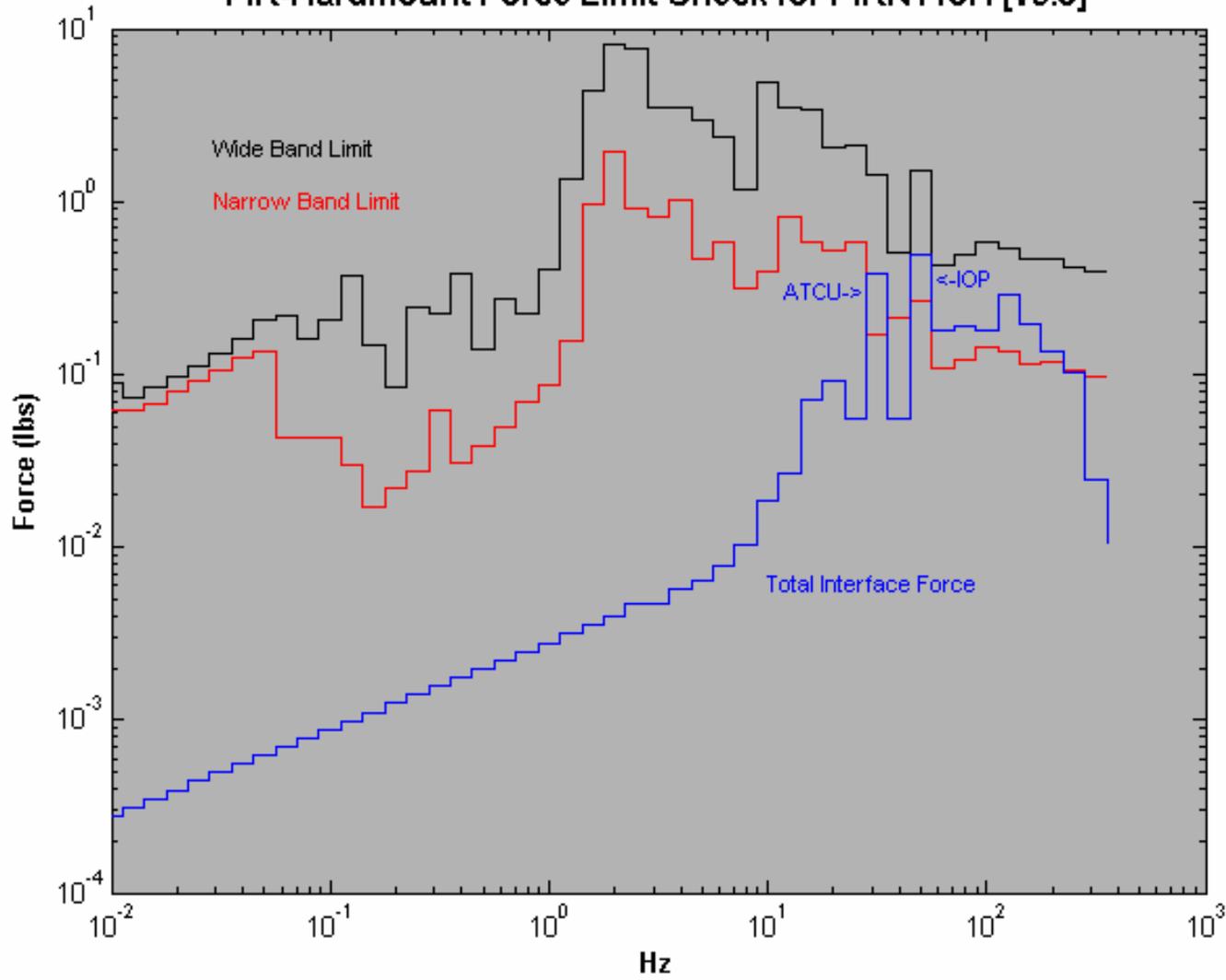
FIR-ARIS Onboard Force Limit Check for PIRN110H [v6.0]

FIR-ARIS Snubber Pin Relative Sway Response [v4.0]
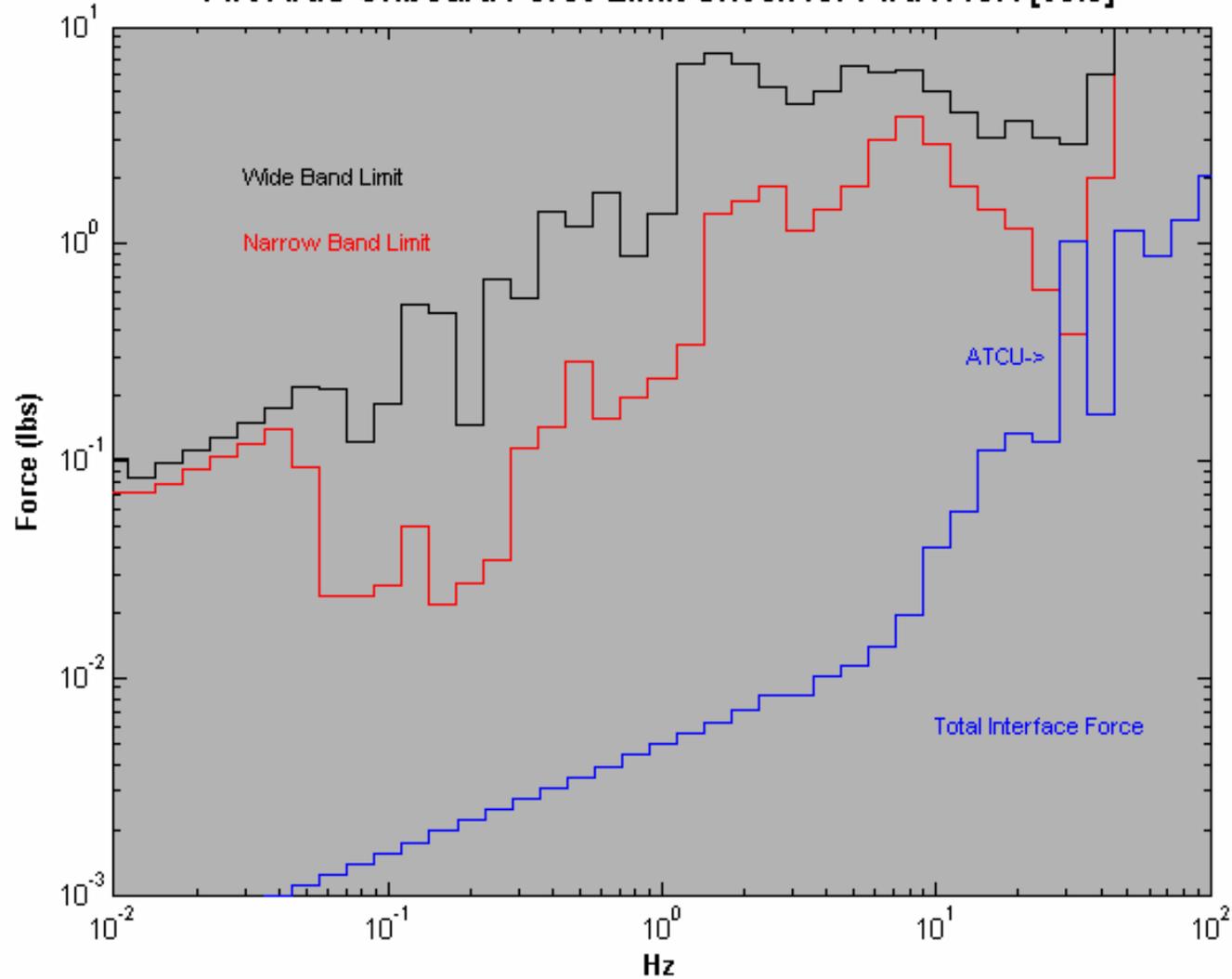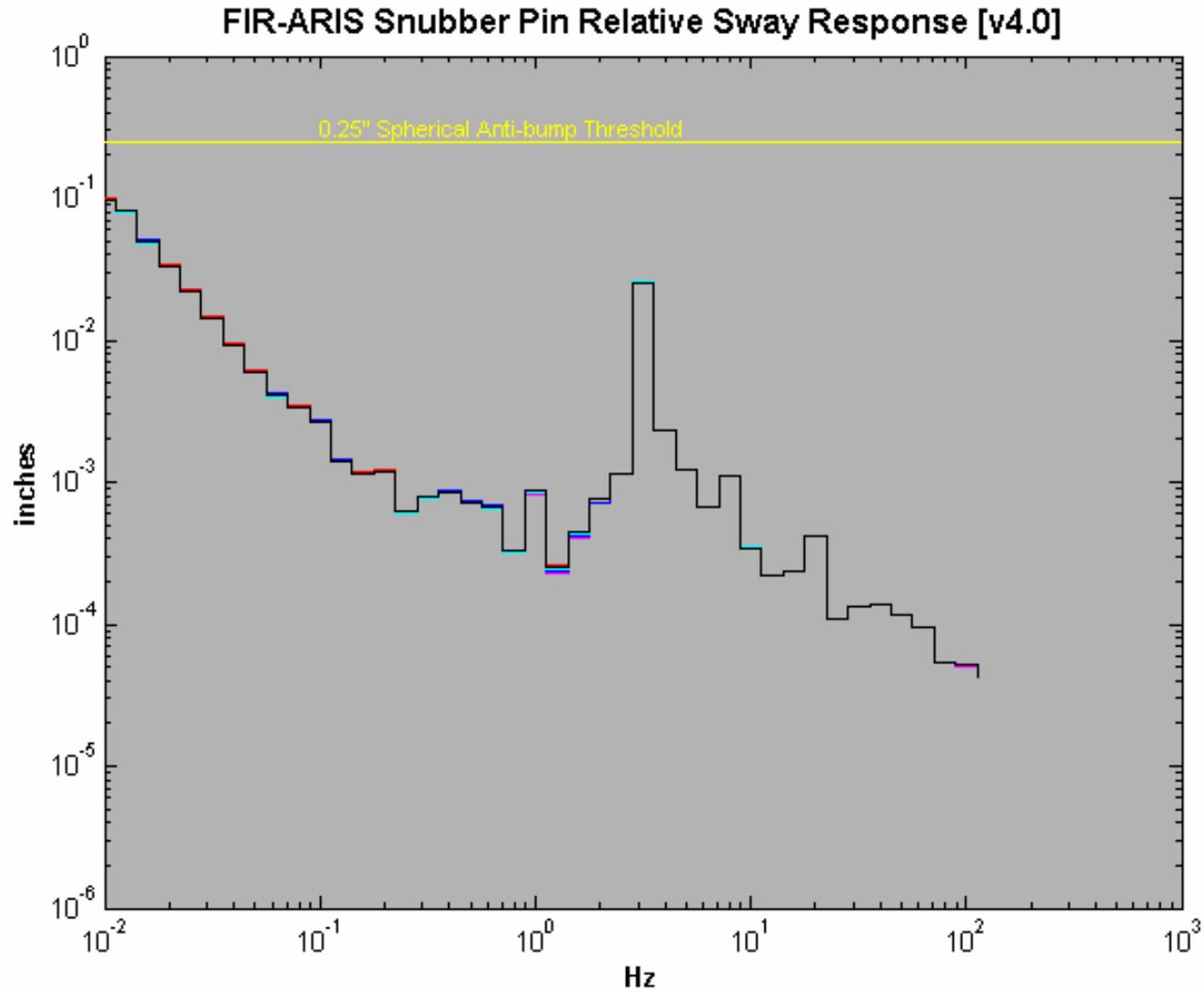
Potential ISS On-Orbit Testing

- **Characterize Facility Racks On-Orbit**

- **Stiffness Characterization for Umbilicals**

- **Sway Space Check for ARIS & PaRIS Racks**

- **Need for SAMS Heads Onboard & Offboard Rack to Calculate Transfer Functions**

- **Update Models Based on Actual On-Orbit Data**

- **Utilize Models for Payload Configuration Change Predictions**

- **Predict Microgravity Levels at Science Experiments by Using Models**
  - SAMS & MAMS Locations Specified with Measured Data Input into Model
  - Science Locations Modeled for Obtaining Data Based on Actual Measurements

Evaluation of ARIS Performance Based on SAMS

- Five SAMS SE's Utilized for ARIS-ICE Assessment
    1. **SE-F02 in RTS Drawer #1 in EXPRESS Rack #1 (Non-ARIS).**
    2. **SE-F03 on US Lab Z-Panel below EXPRESS Rack #2.**
    3. **SE-F04 on US Lab Z-Panel below EXPRESS Rack #1.**
    4. **SE-F05 on US Lab Light Tray above EXPRESS Rack #2.**
    5. **SE-F06 on EXPPCS located in EXPRESS Rack #2 (ARIS).**

- Compare Microgravity Levels of Onboard Rack with Offboard Rack Locations

- Compare ARIS Rack with Non-ARIS Rack Microgravity Levels

- Compare Predicted Behavior with Actual Measured Behavior

Location of SAMS Sensors during ISS Increment 2

ISPR Light
Tray Lip

SE-F05

ARIS-ICE
POP

EE-F05

SE-F06

PCS
Avionics
Section

PCS Test
Section

SAMS ICU

MAMS

Shaker
Controller

SAMS RTS
Drawer #1

EE-F02

SE-F02

EE-F03

ISPR
Utility
Panels

SE-F04

SAMS RTS
Drawer #2

Shaker

SE-F03

EXPRESS Rack #1   EXPRESS Rack #2

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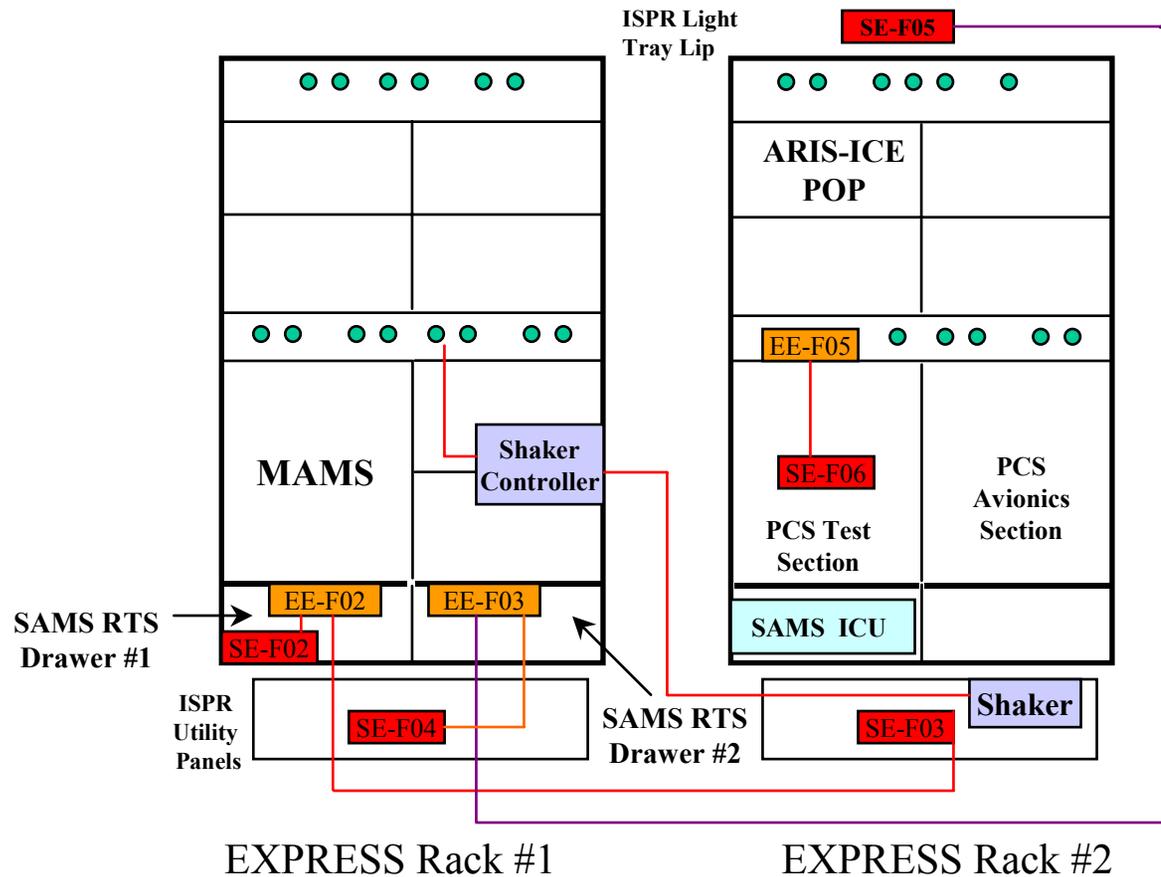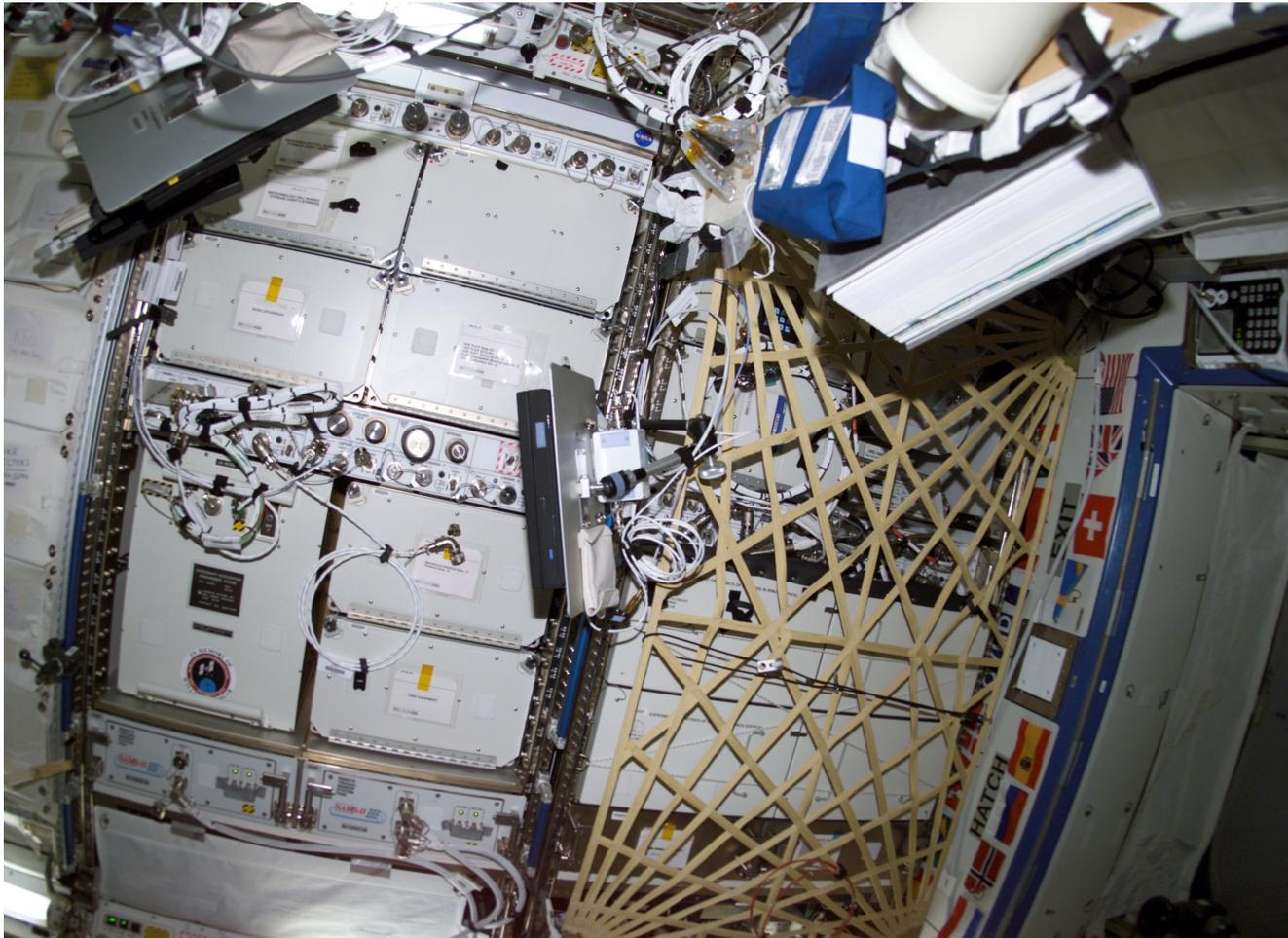
EXPRESS Racks Nos. 1 & 2 Onboard US Lab Module

Microgravity Environment Hardware for EXPRESS Racks 1 & 2

SAMS SE-F05

MAMS Hardware

SAMS RTS Drawer No. 1

SAMS SE-F02 Inside

SAMS RTS Drawer No. 2
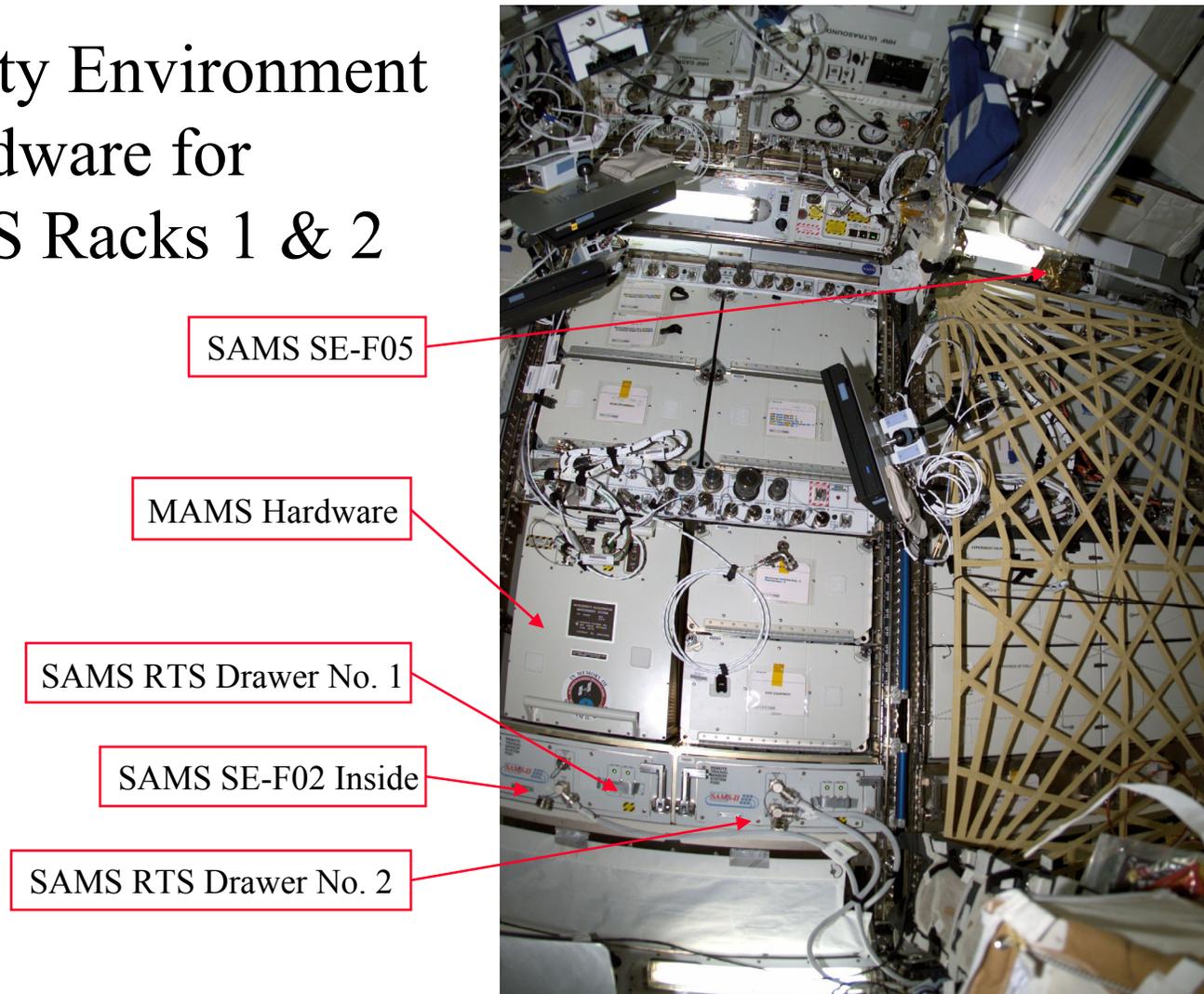
EXPRESS Rack No. 2
Rack Utility Panel (RUP)
with Umbilicals &
SAMS SE-F03

SAMS SE-F03
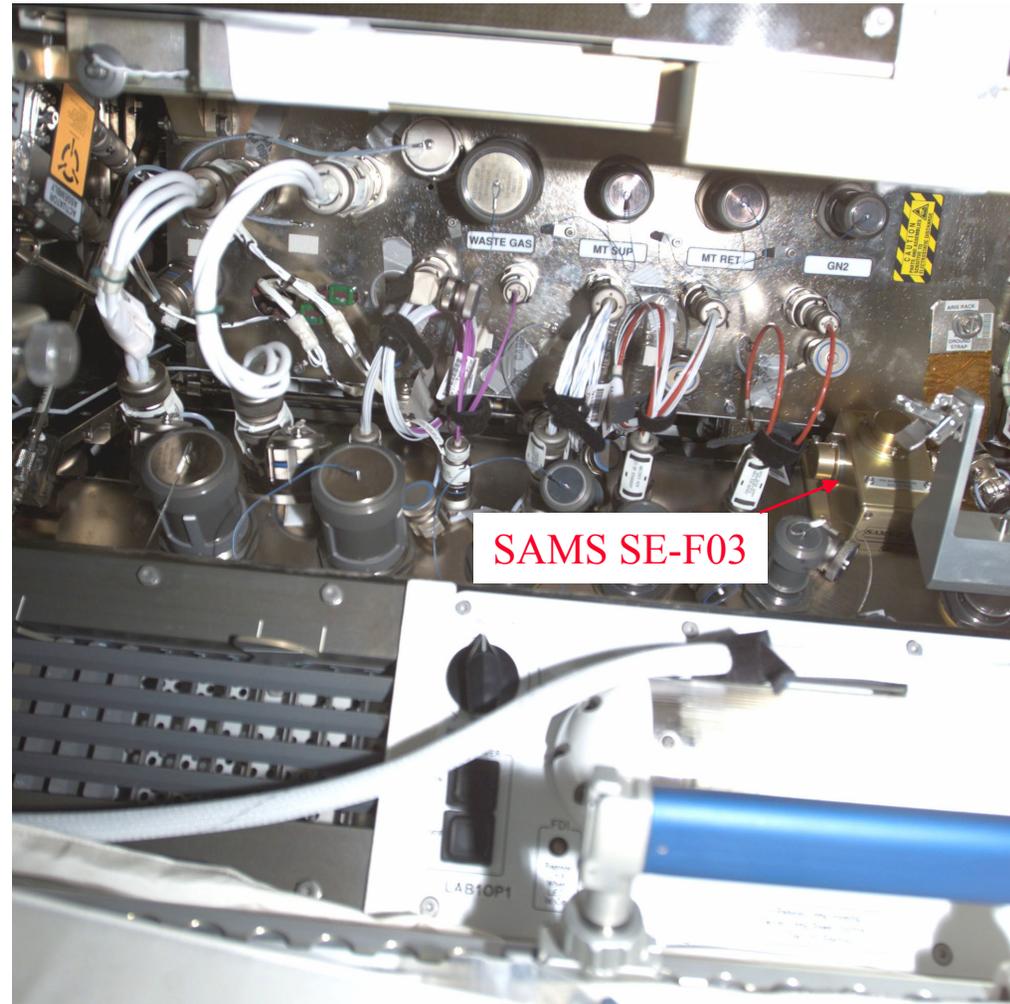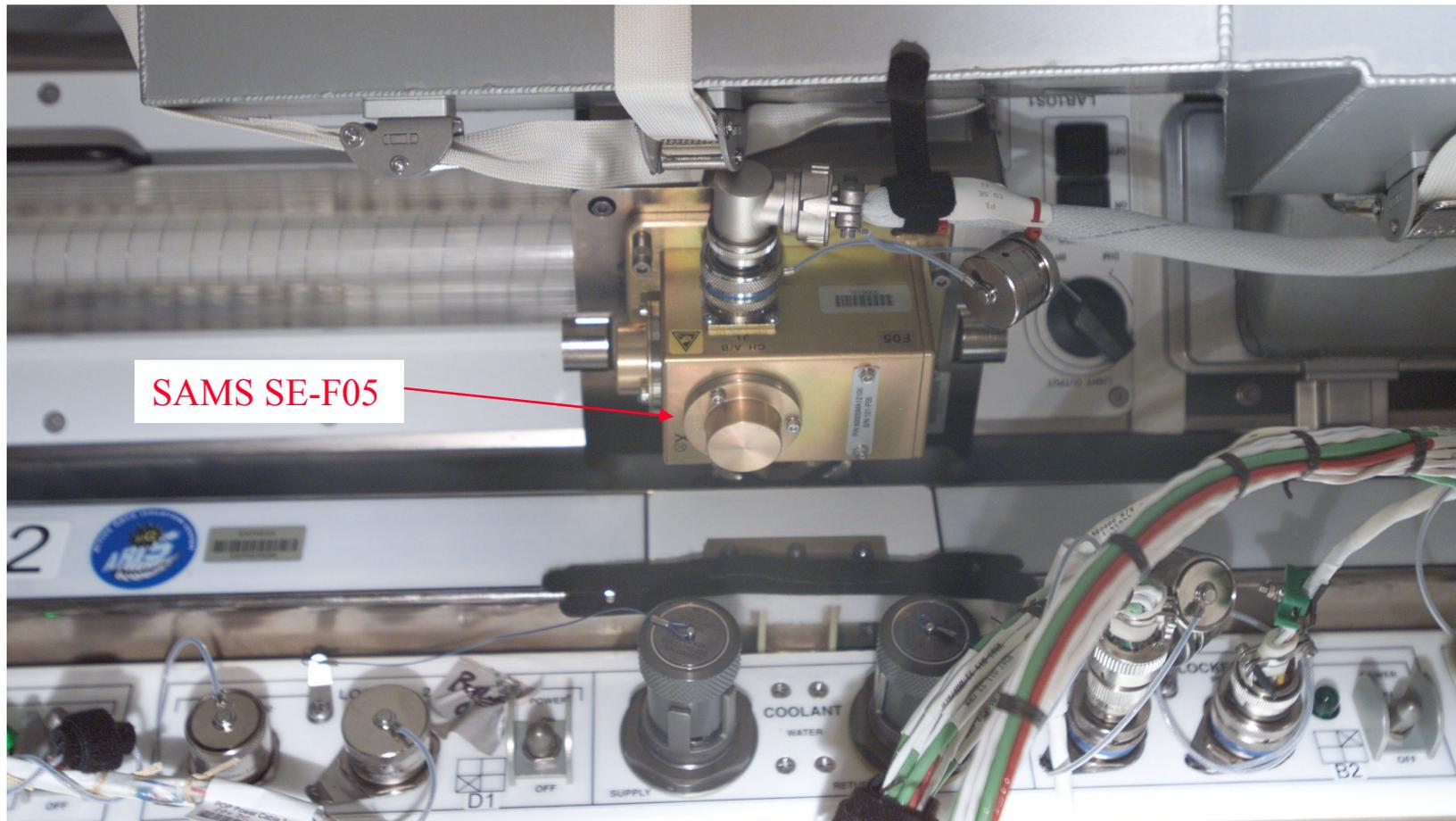
SAMS SE-F05

SAMS SE-F05 Above EXPRESS Rack No. 2

SAMS SE-F06 Mounted on EXPPCS Test Section of EXPRESS Rack No. 2

SAMS SE-F06

ARIS Active – EXPRESS Rack No. 1 (SE-F02)

sams2, 121f02 at LAB1O2, ER1, Drawer 1:[128.73 −23.53 144.15]
62.5 sa/sec (25.00 Hz)
Δf = 0.008 Hz, Nfft = 7501
Mode: 100sec

ARIS Activity
Start GMT 03−Aug−2001,18:25:00.000
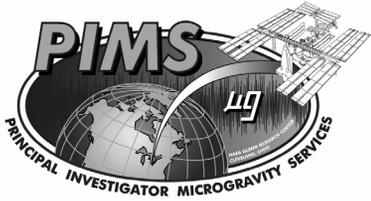
Increment: 2, Flight: 7A
Sum
Hanning, k = 1
Span = 120.00 sec.

ARIS Active – Z Panel Offboard ER 2 (SE-F03)

sams2, 121f03 at LAB1O1, ER2, Lower Z Panel:[191.54 −40.54 135.25]
1000.0 sa/sec (400.00 Hz)
Δf = 0.008 Hz, Nfft = 120000
Mode: 100sec

Increment: 2, Flight: 7A
Sum
Hanning, k = 1
Span = 120.00 sec.

Aris Activity
Start GMT 03−Aug−2001,18:25:00.001

One-Third Octave Bands (Hz)
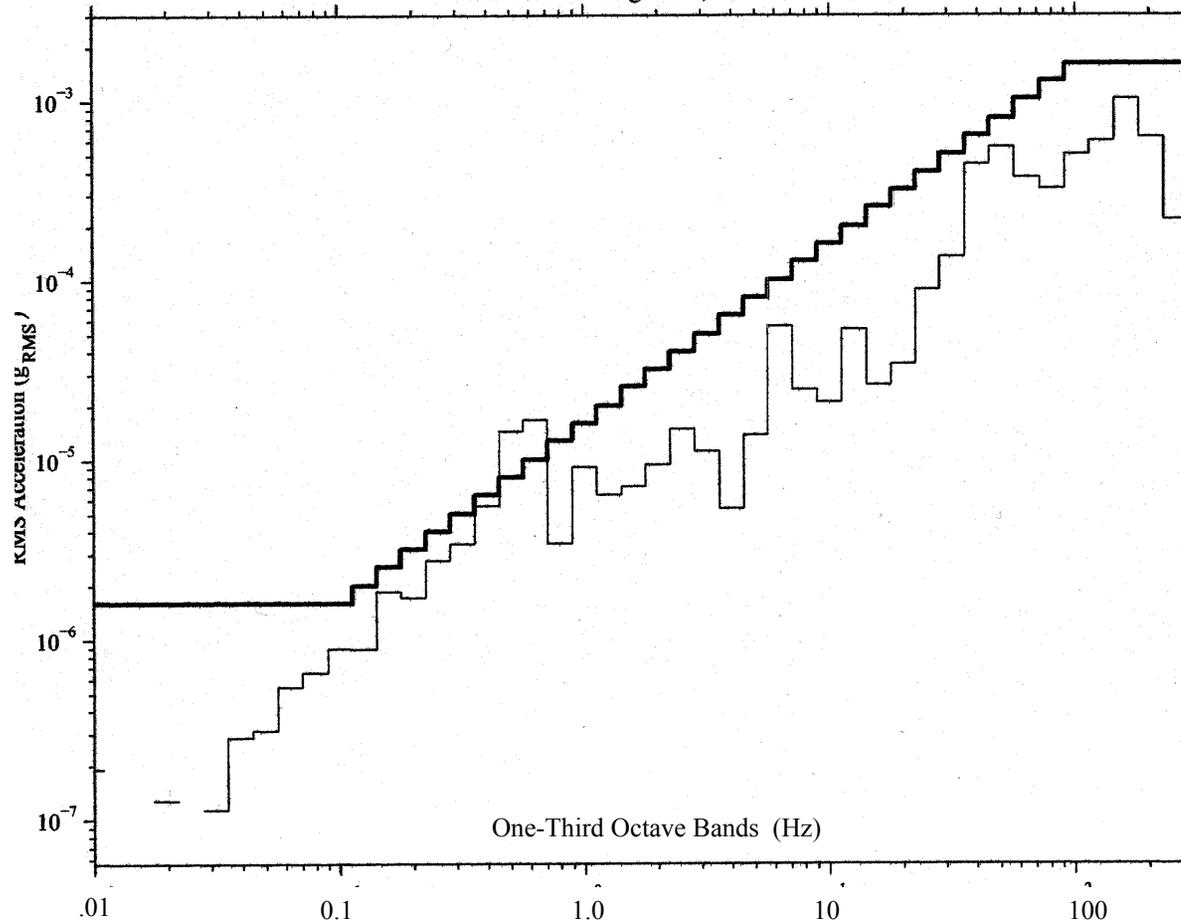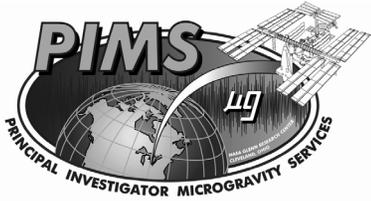
RMS Acceleration (g RMS)

ARIS Active – EXPRESS Rack No. 2 (SE-F06)

sams2, 121f06 at LAB1O1, ER2, PCS Test Section:[179.90 −6.44 145.55]
1000.0 sa/sec (400.00 Hz)
Δf = 0.008 Hz, Nfft = 120001
Mode: 100sec

sams2_accel, LAB1O1, ER2, PCS Test Section, 400.0 Hz (1000.0 s/sec)
Start GMT 03−Aug−2001,18:25:00.000
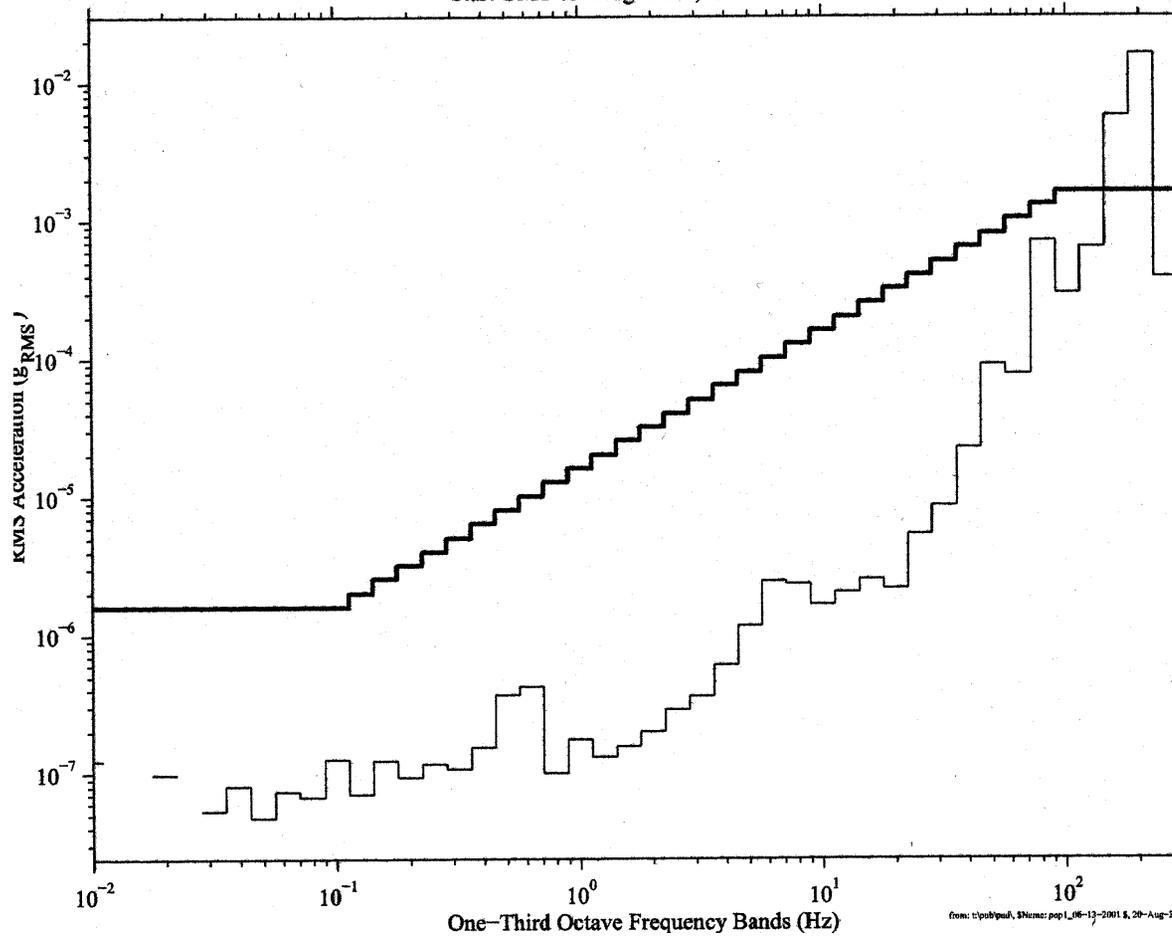
Increment: 2, Flight: 7A
Sum
Hanning, k = 1
Span = 120.00 sec.

from: t:\pub\paul, $Name: pap1_06−13−2001 $, 20−Aug−2001,18:26:02.610
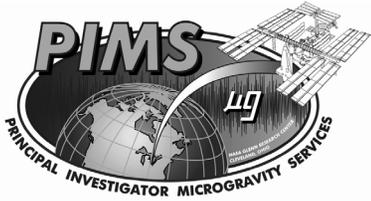
ARIS Idle – EXPRESS Rack No. 1 (SE-F02)

sams2, 121f02 at LAB1O2, ER1, Drawer 1:[128.73 −23.53 144.15]
250.0 sa/sec (100.00 Hz)
Δf = 0.008 Hz, Nfft = 29999
Mode: 100sec

ARIS Activity
Start GMT 14−Aug−2001,17:12:00.004

Increment: 2, Flight: 7A
Sum
Hanning, k = 1
Span = 119.99 sec.
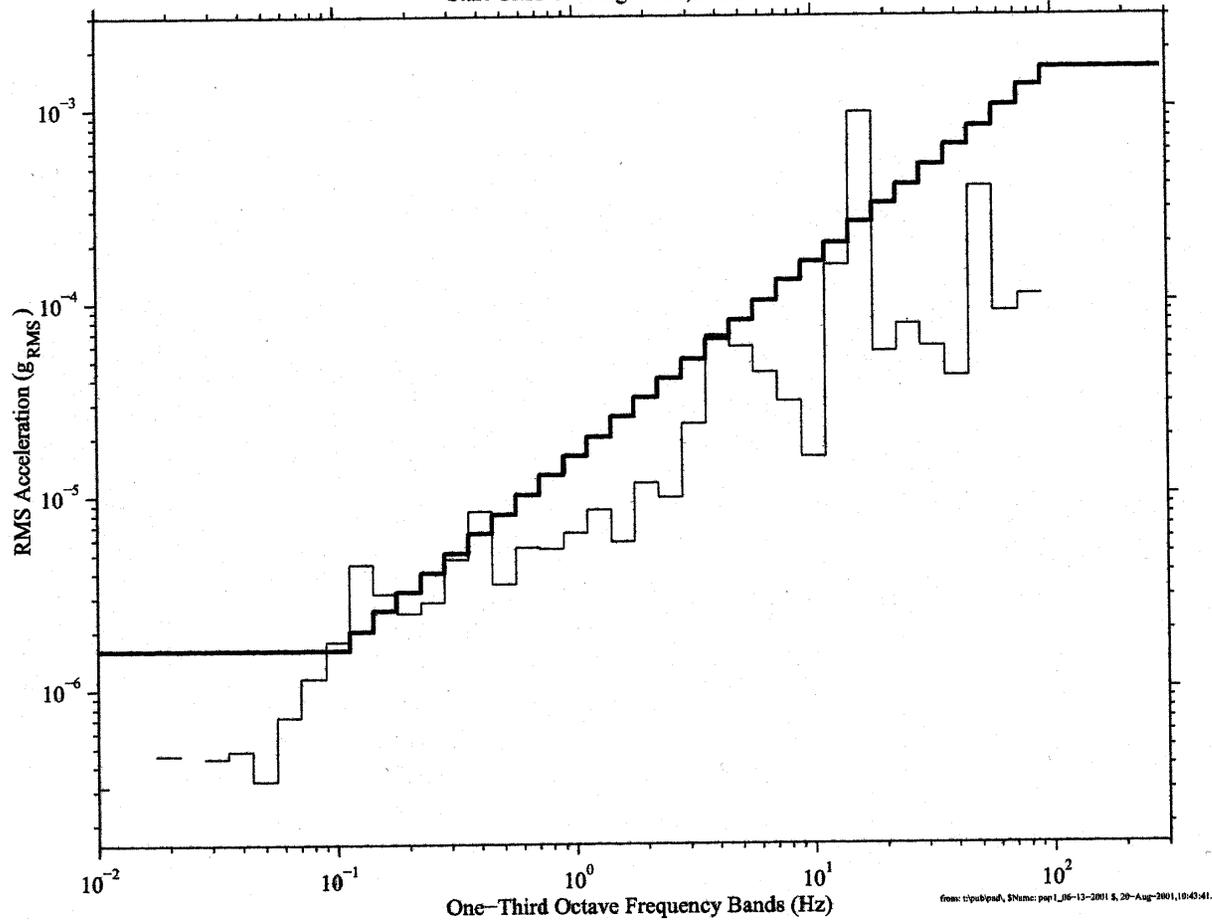
RMS Acceleration (g_RMS)

One−Third Octave Frequency Bands (Hz)

from: t:\pub\pad\, $Name: pop1_06−13−2001 $, 20−Aug−2001,10:43:41.2
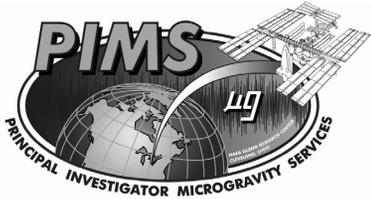
ARIS Idle – Z Panel Offboard ER 2 (SE-F03)

sams2, 121f03 at LAB1O1, ER2, Lower Z Panel:[191.54 −40.54 135.25]
500.0 sa/sec (200.00 Hz)
Δf = 0.008 Hz, Nfft = 60236
Mode: 100sec

ARIS Activity
Start GMT 14−Aug−2001,17:12:00.001

Increment: 2, Flight: 7A
Sum
Hanning, k = 1
Span = 120.00 sec.

One-Third Octave Bands (Hz)
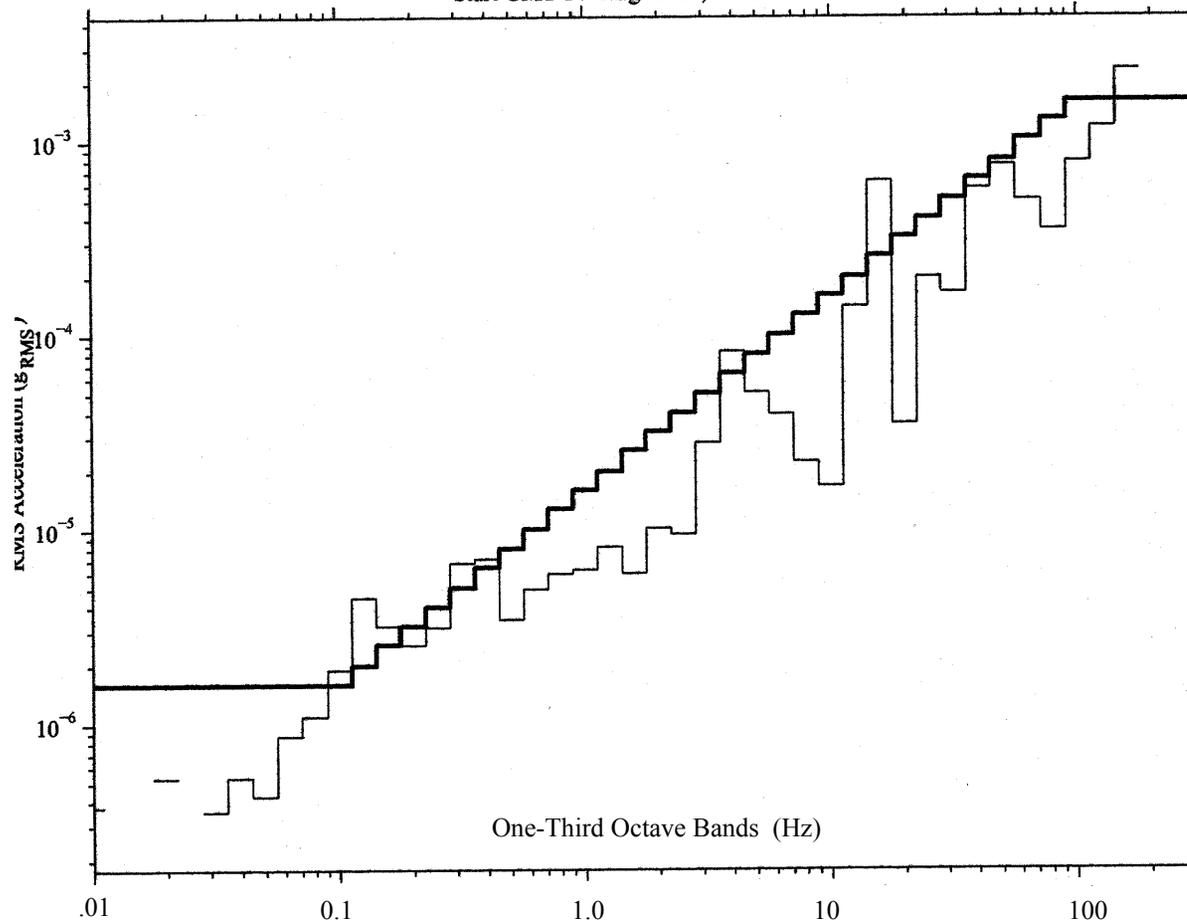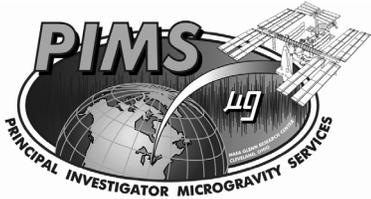
ARIS Idle – EXPRESS Rack No. 2 (SE-F06)

sams2, 121f06 at LAB1O1, ER2, PCS Test Section:[179.90 −6.44 145.55]
500.0 sa/sec (200.00 Hz)
Δf = 0.008 Hz, Nfft = 60000
Mode: 100sec

Increment: 2, Flight: 7A
Sum
Hanning, k = 1
Span = 120.00 sec.

ARIS Activity
Start GMT 14−Aug−2001,17:12:00.002

One−Third Octave Frequency Bands (Hz)

On-Orbit Measured ISS Acceleration Levels

1/3 Octave Accelerations

Legend:
- ISS Requirement
- Station Maximum
- Station Minimum
- ARIS Maximum
- ARIS Minimum

SM Ergometer
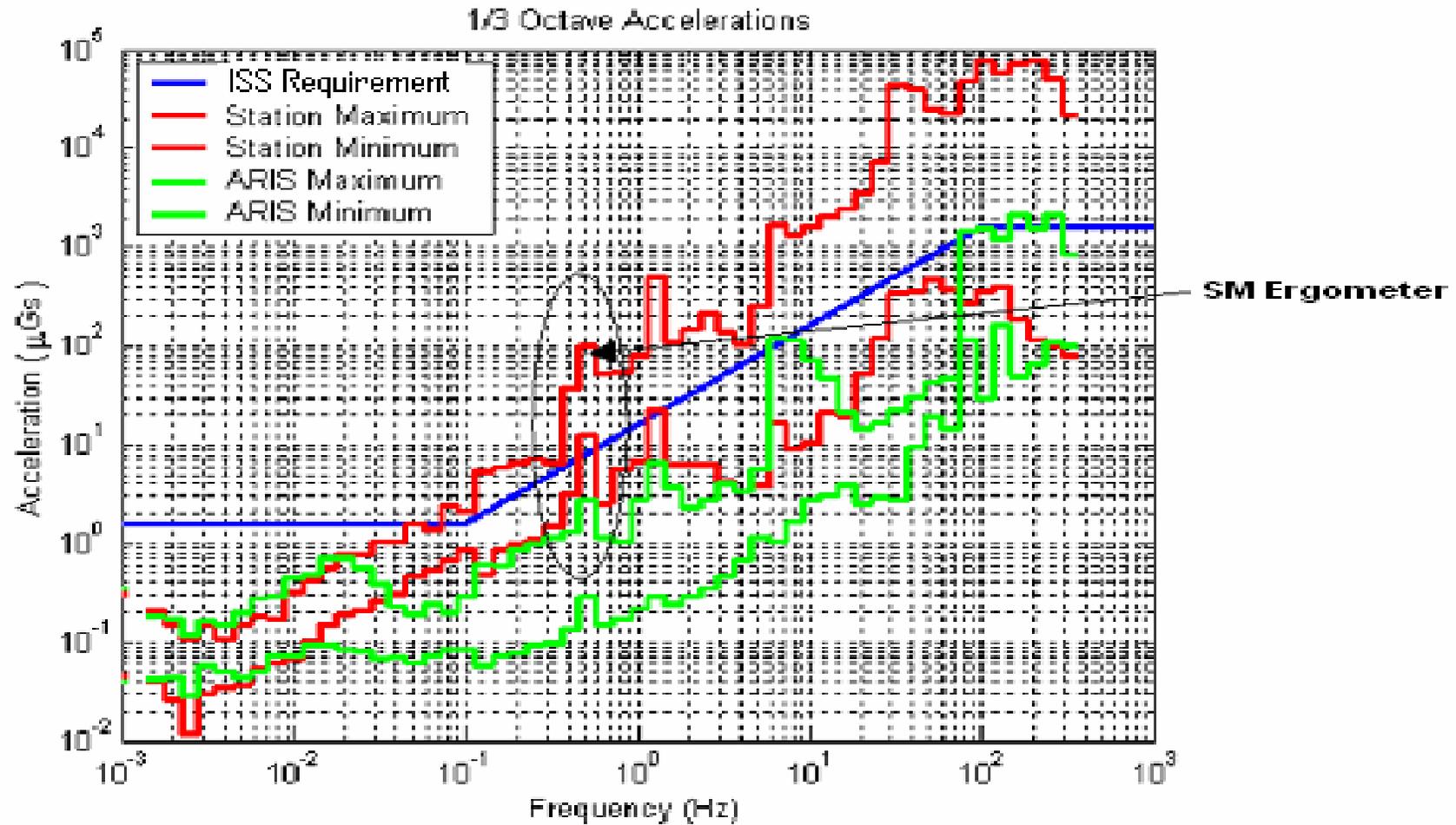
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