Section 12

Microgravity Control Integration Process &

Disturbance Predictions for ISS Rack Payloads

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ZIN Technologies

Presentation Agenda

- Overview
- Isolation Approaches
- Microgravity Control Requirements
- Analytical Tools Available
- Process Flow
- Modeling Requirements
- Disturbance Prediction & Measurement
- Pre-Launch Testing
- Verification & Validation
- Potential On-Orbit Testing
- Contact List

Overview

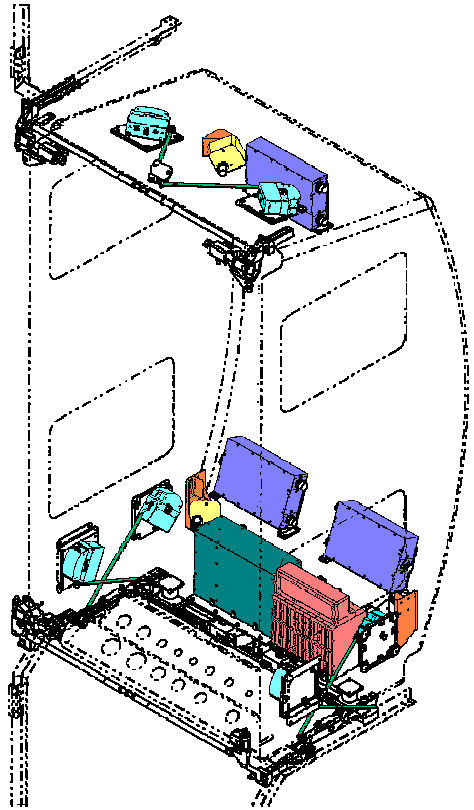
- Protect Science for 30 Day Microgravity Periods
- Vibration Isolation Approaches (ARIS, PaRIS, other)
- Microgravity Requirements for Science Locations
- NEED FOR A CLEAR COMMON APPROACH
- Identify Payload Disturbers (Offboard & Onboard)
- Basis for Payload Microgravity Allocations
- Microgravity Requirement Verifications
- Fluids & Combustion Facility Assessment
- ARIS-ICE Work for EXPRESS Rack No. 2

Isolation Approaches

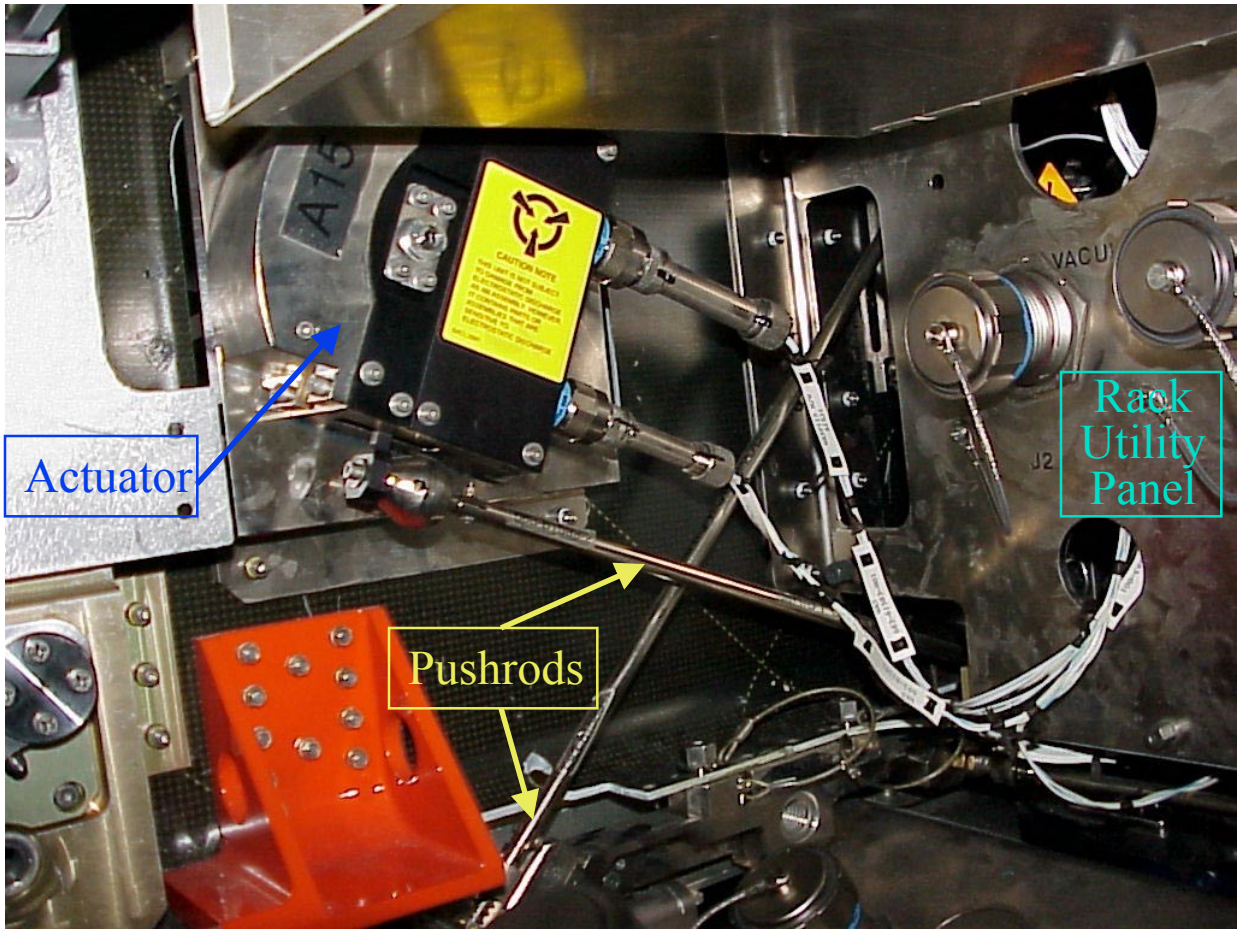
- **Active Rack Isolation System (ARIS)**
  - Active Rack Isolation Bandwidth ~ 0.01 to 2 Hz (Configuration Dependent)
  - Passive Rack Isolation Bandwidth ~ 2 Hz & Up (Configuration Dependent)
  - Connected to ISS by 8 Pushrods and 13 to 14 Umbilicals (Updated Set)
  - Use of Isolation Plate Attached 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 No. 2 in U.S. Lab Module
  - Scheduled for 6 ISPR's (4 EXPRESS Racks, FIR, & MSRR)
  - Programmable Controller
  - ARIS Hold Command Keeps Rack in Centered Position

ARIS Overview - Design

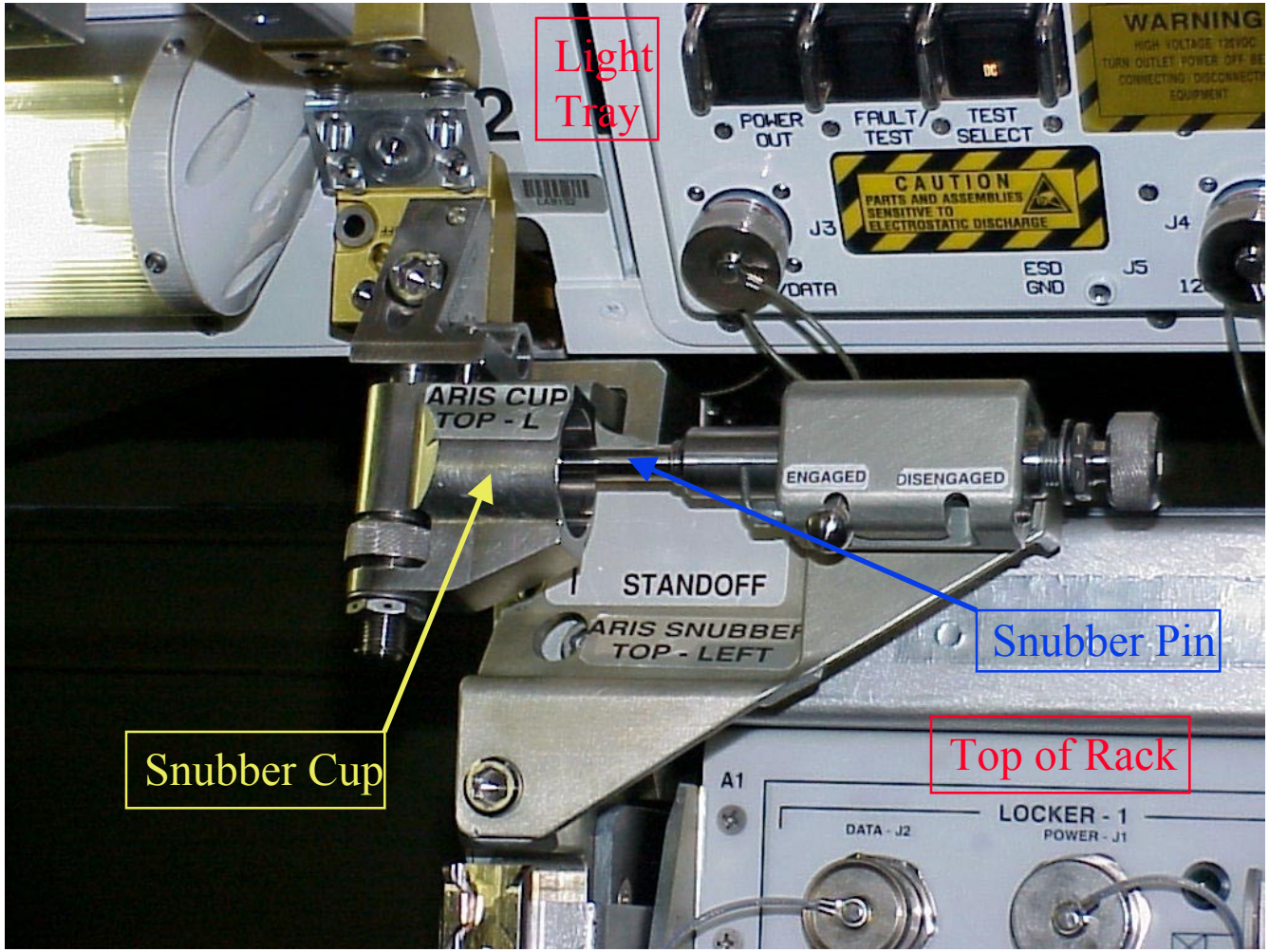
- ARIS Controller (Control & input/output): Decoupling implemented in controller allows freedom to place actuators and sensors. Payloads have extensive command, data acquisition, and control options.
- 3 Remote Electronic Units : Programmable analog filters & gains & 16 bit analog-to-digital converters.
- 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.



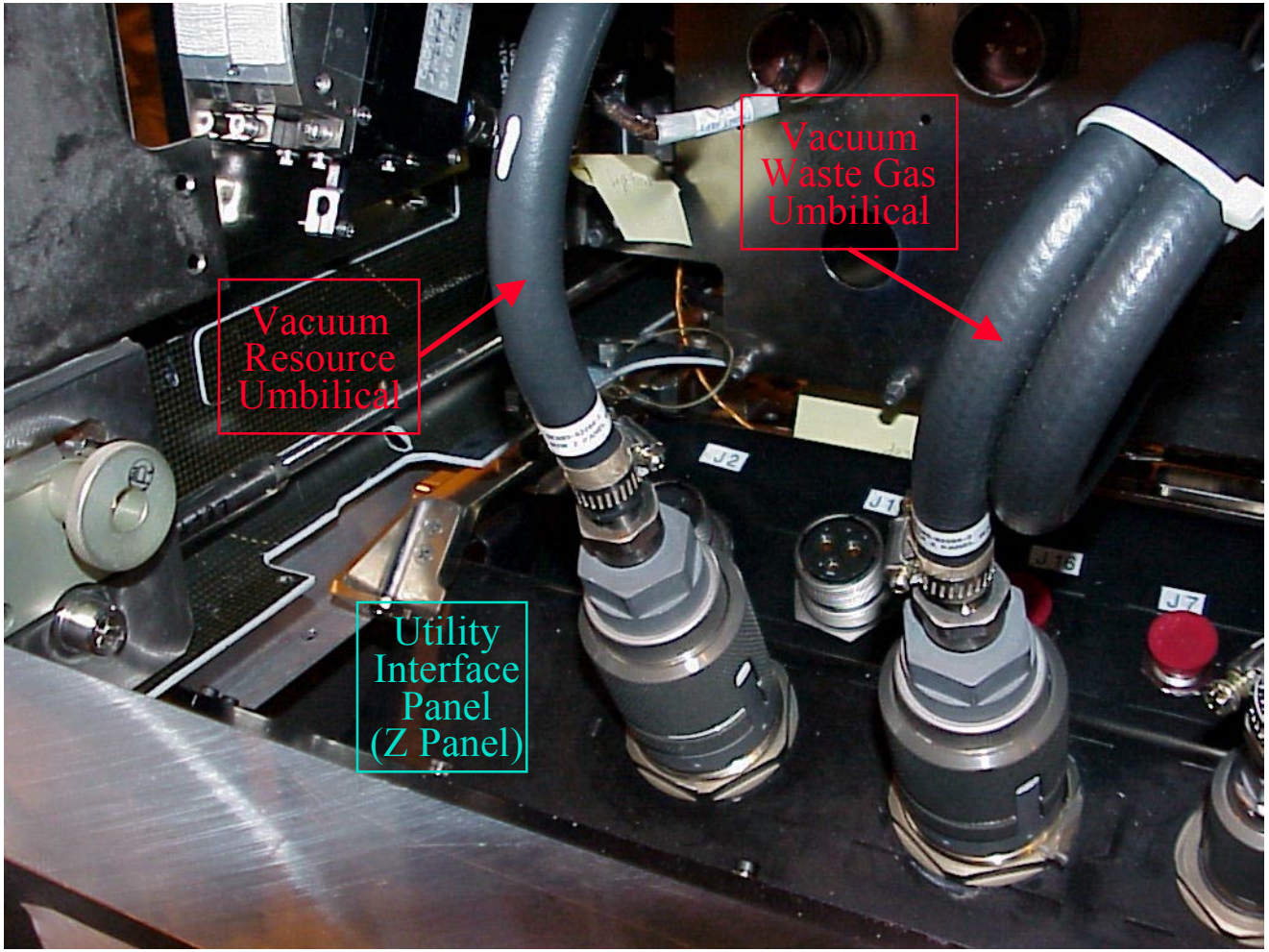
ARIS Actuator & Pushrods



ARIS Snubber & Cup



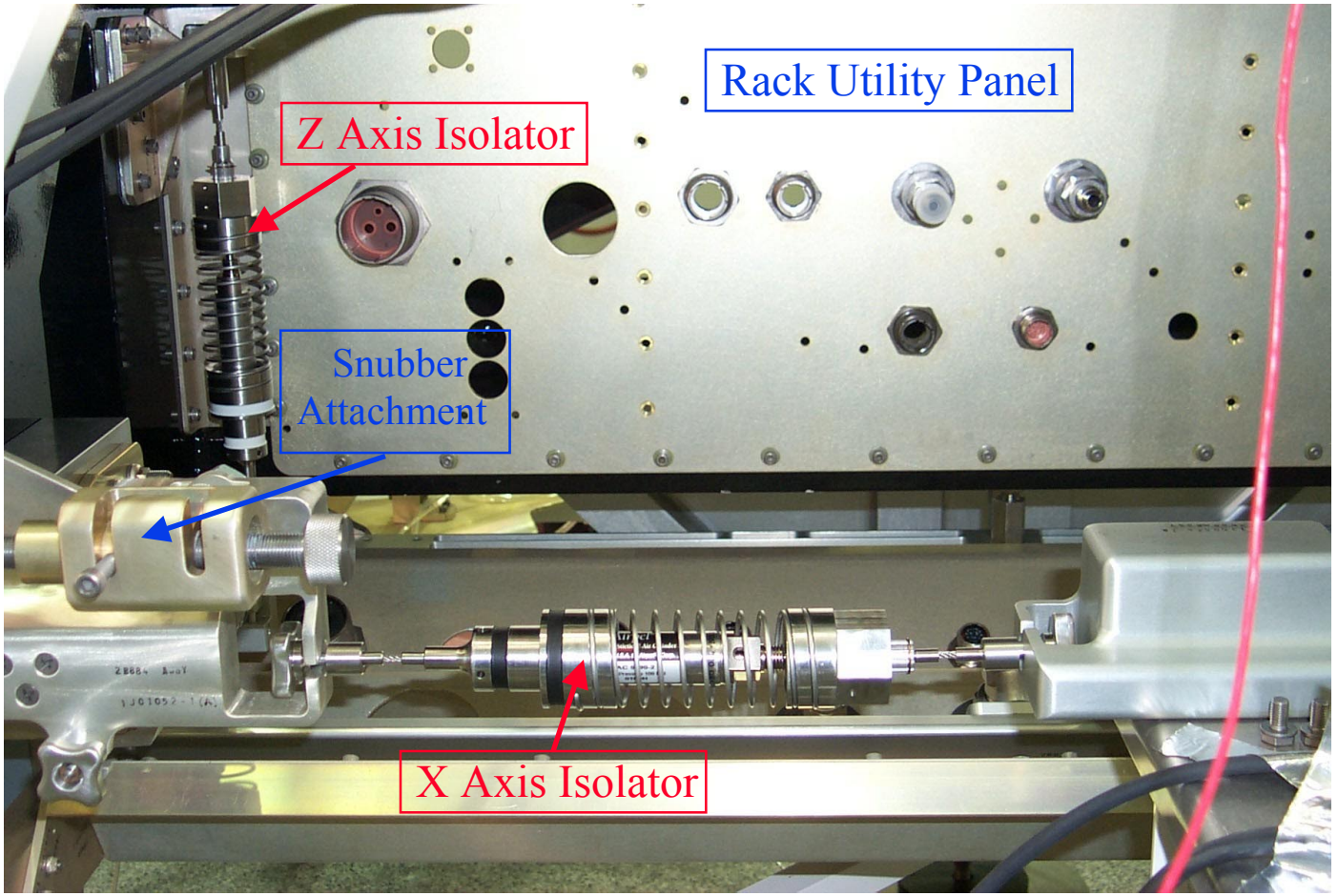
Vacuum Umbilicals on Z Panel



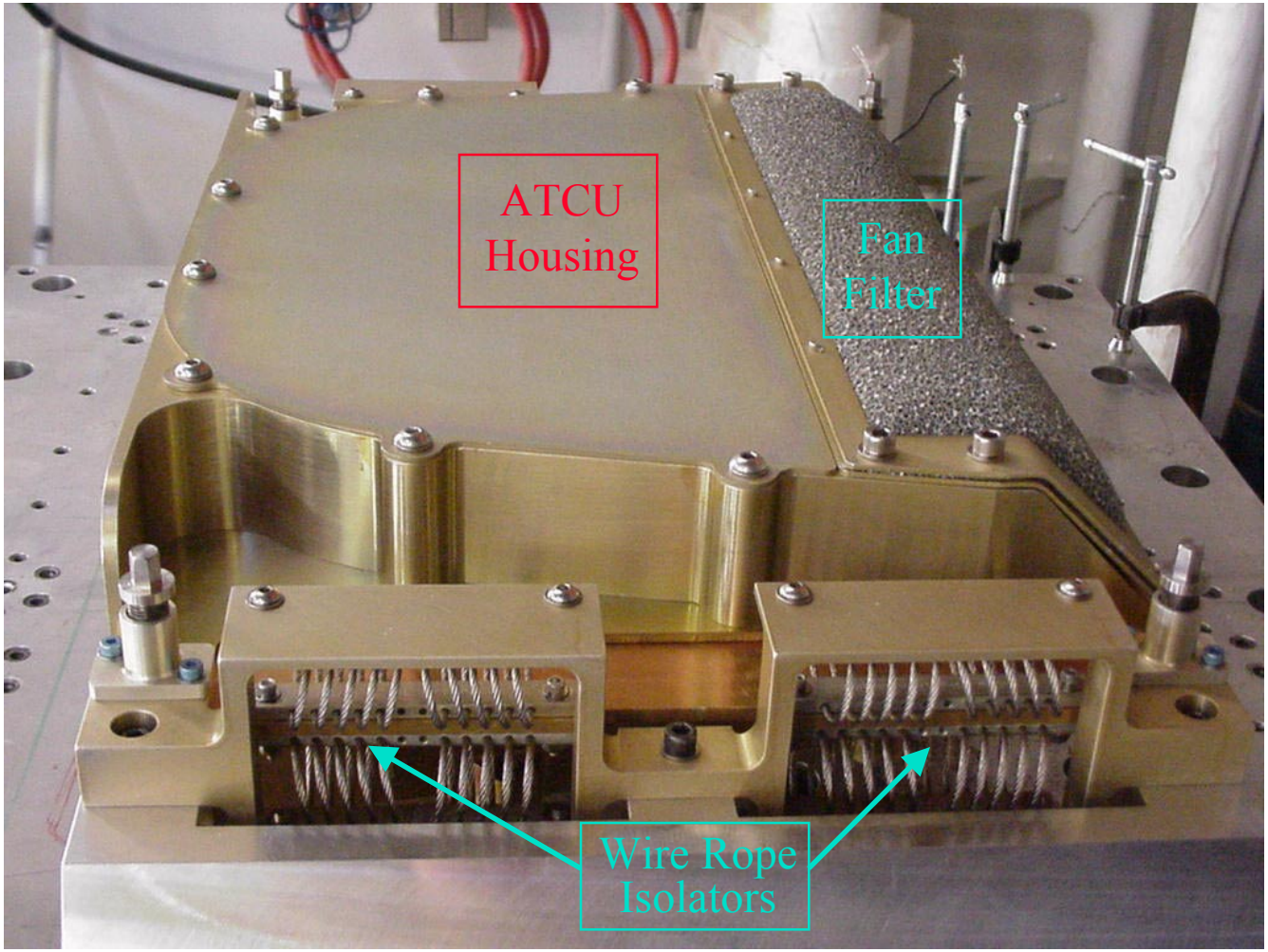
Isolation Approaches

- **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 and 13 to 14 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 2 ISPR's (HHR & 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 and 13 to 14 Umbilicals
- **Local Disturber Isolation**
  - ATCU Example – Wire Rope Isolators & Isolation Grommets

PaRIS X & Z Axis Isolators



FCF Air Thermal Control Unit



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
  - Based on 19 Active Racks
  - Payload Rack Microgravity Requirements in 57000-NA-0110H (PIRN 0110H)
    - Quasi-Steady Requirements
    - Vibratory Requirements (Acceleration & Force Methods)
    - Transient Requirements
  - ARIS Requirements (ARIS PIRN)
    - Document Pending Approval
    - Onboard to Offboard Vibration
    - Rigid Body Analysis (All Free-Free ARIS Rack Modes > 17 Hz)
    - FEM Analysis Method (Some ARIS Rack Modes < 17 Hz)

Microgravity Control Requirements

- **Payload Requirements (Continued)**
  - ARIS Requirements (ARIS PIRN) (Continued)
    - ARIS Sensor Saturation
    - Rack Sway Space Limits
  - Generic Microgravity Control Plan (SSP57010 Appendix E Draft)
    - Document Pending Approval
    - ARIS Rack Allocations
    - Microgravity Disturbance Verification Approaches
  - 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
  - Science Requirements Documentation

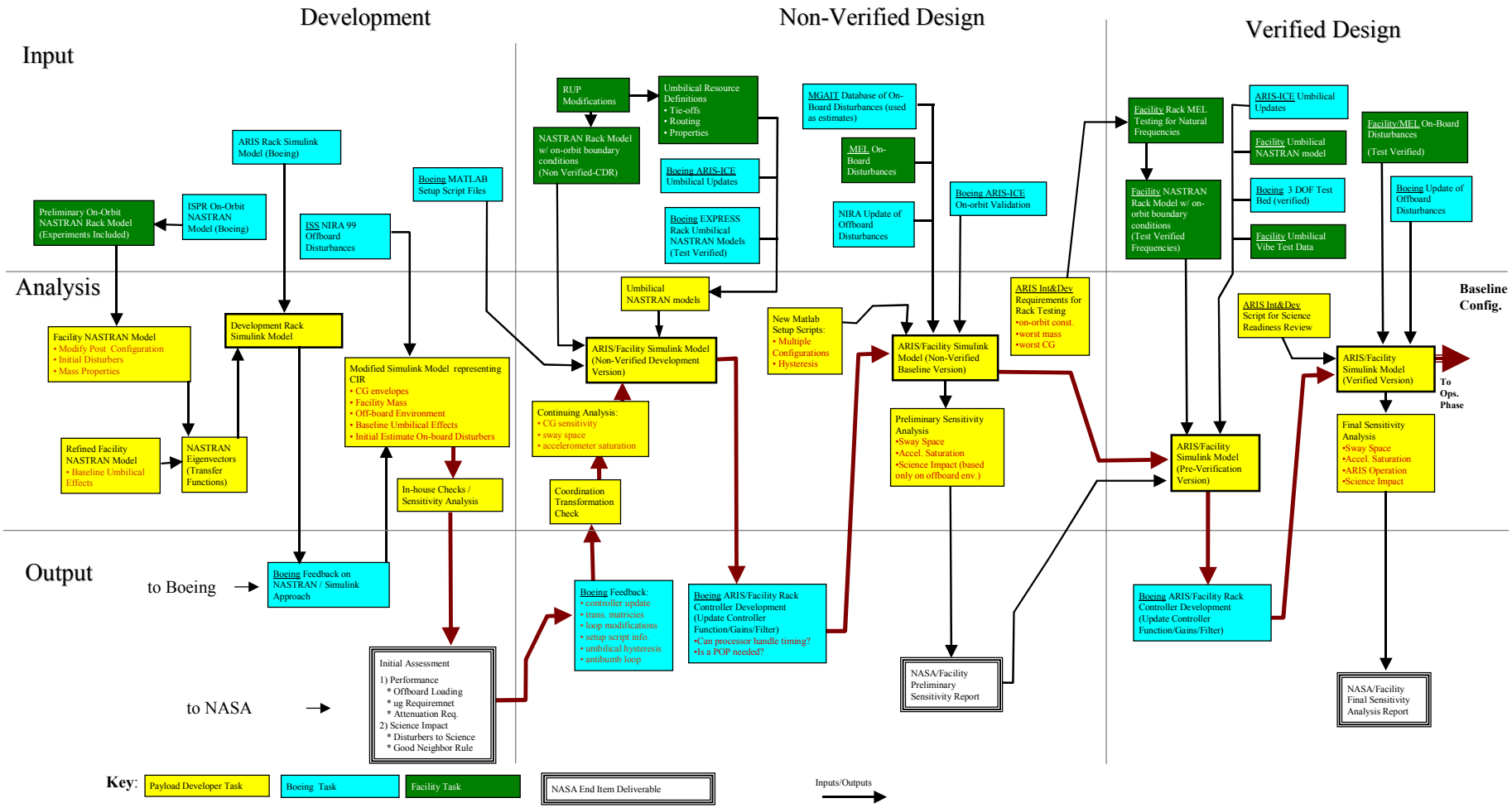
Analytical Tools Available

- NASTRAN for Rack, Umbilical, & Payload Modeling
- AutoSEA Modeling for Based on Density of Modes (At Least 3 Modes Needed Within Bandwidth)
- MATLAB Simulink for ARIS & PaRIS Response & ARIS Controller Tuning

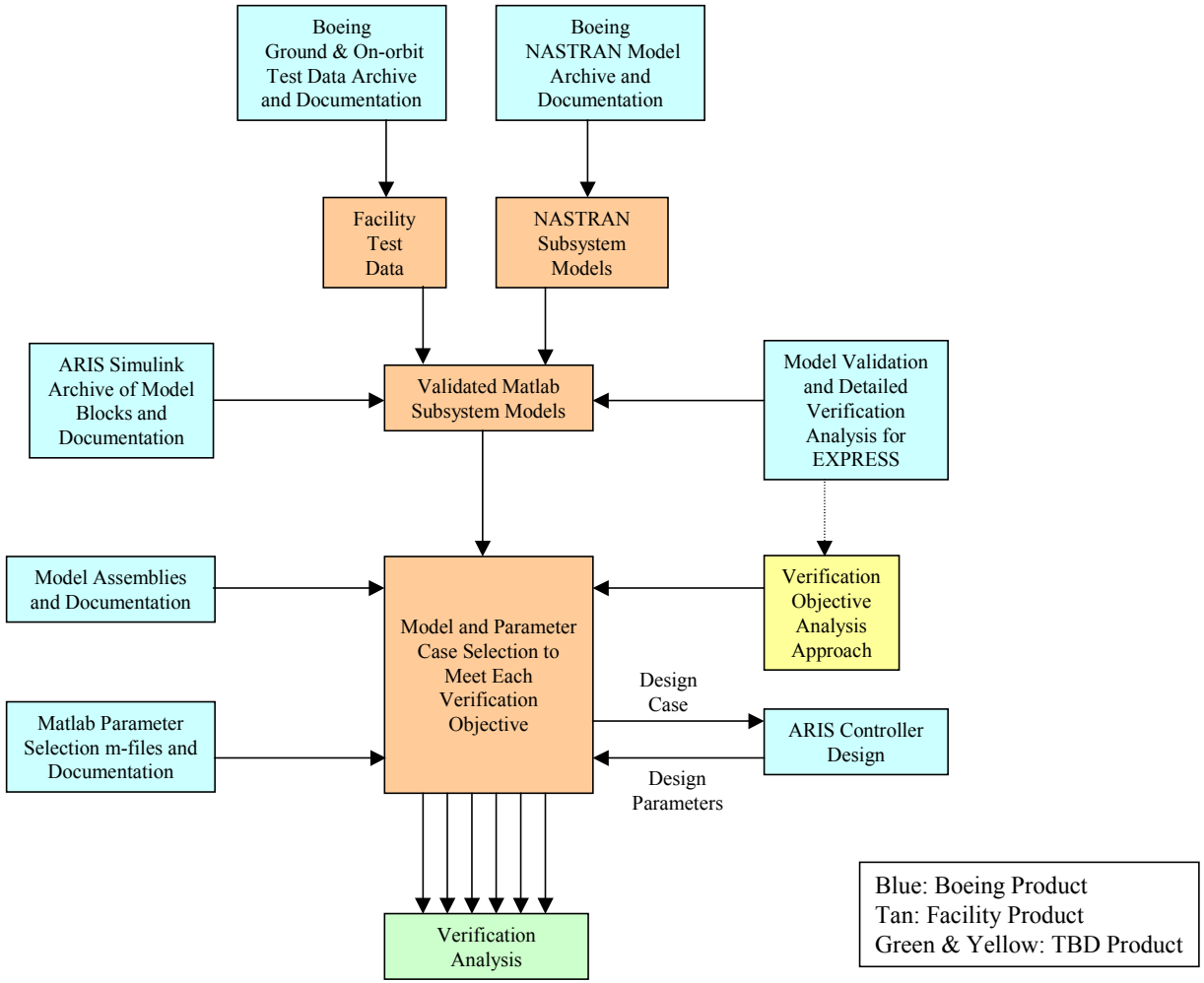
Process Flow

- **ISS Program Responsibilities**
  - On-Orbit ISPR NASTRAN Model (with or w/o ARIS or PaRIS)
  - Umbilical NASTRAN Models
  - Umbilical Stiffness Data (Stiffness Matrices)
- **ARIS Responsibilities (if ARIS rack)**
  - Ground & On-Orbit Test Data
  - Simulink Model of ARIS 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

ARIS Integration Analytical Process Flow (February 5, 2002)

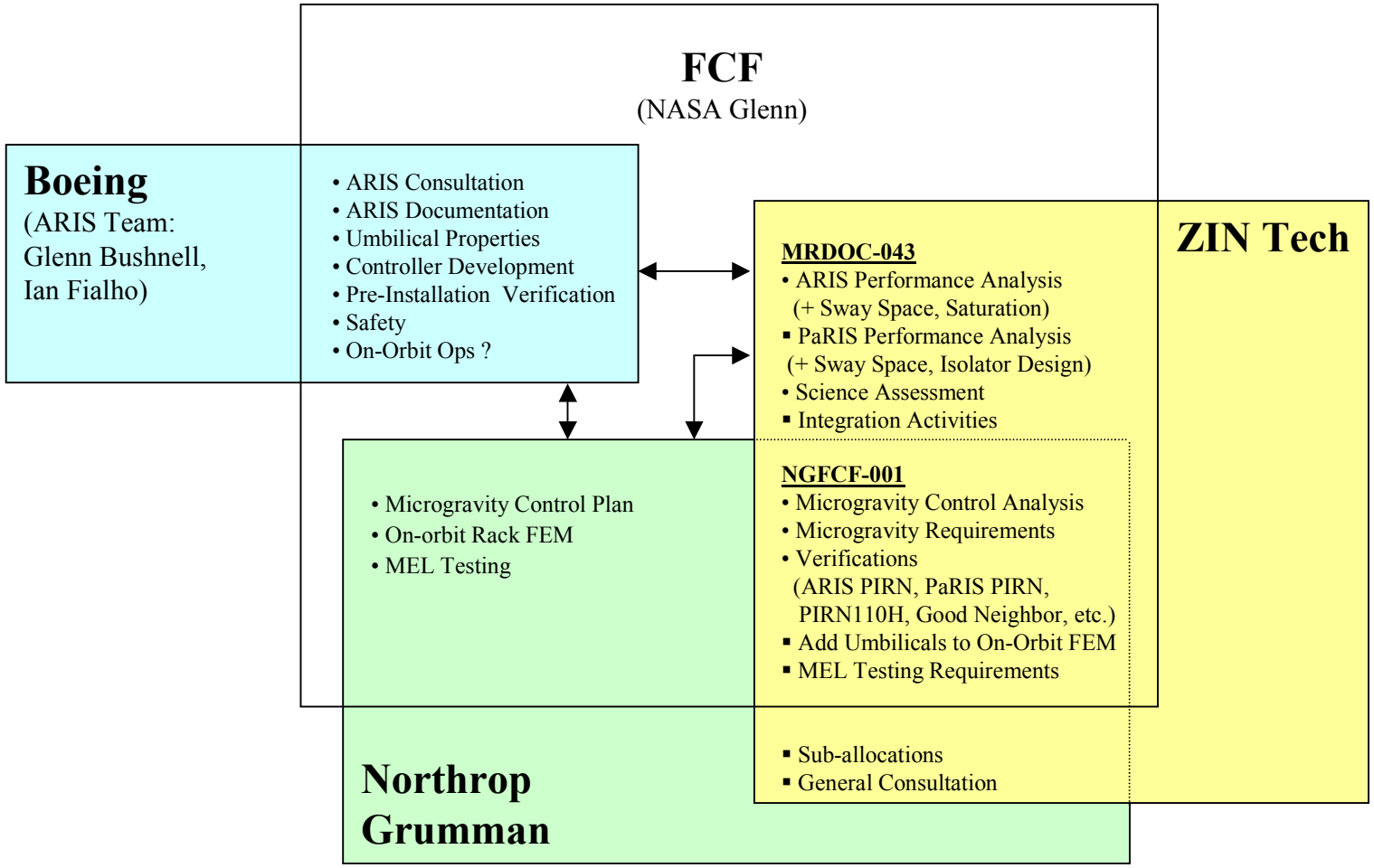


ARIS Process Summary



ZIN FCF Microgravity Support Overview (Version 0.2, February 11, 2002)

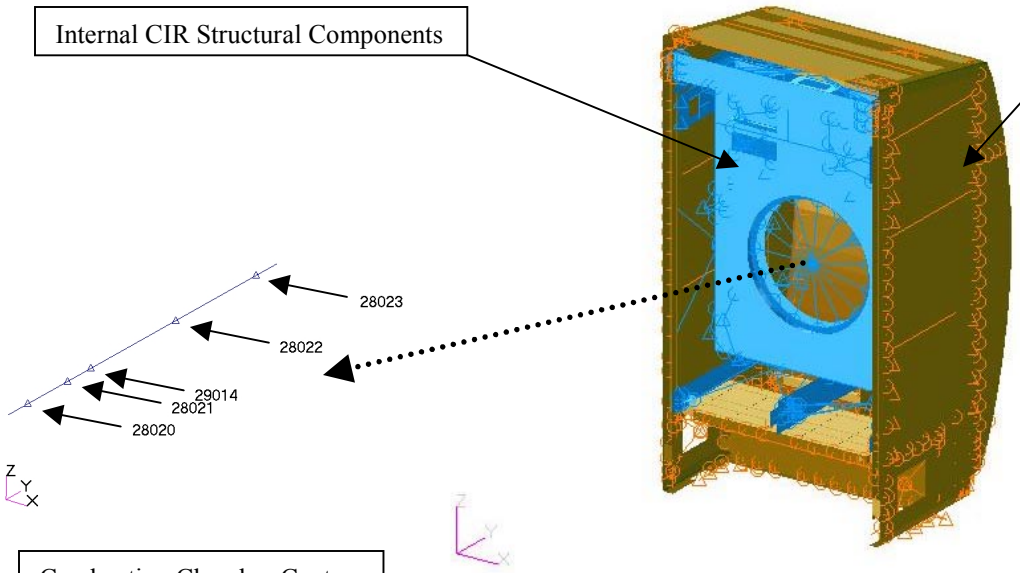
Note: please disregard scale



Modeling Requirements

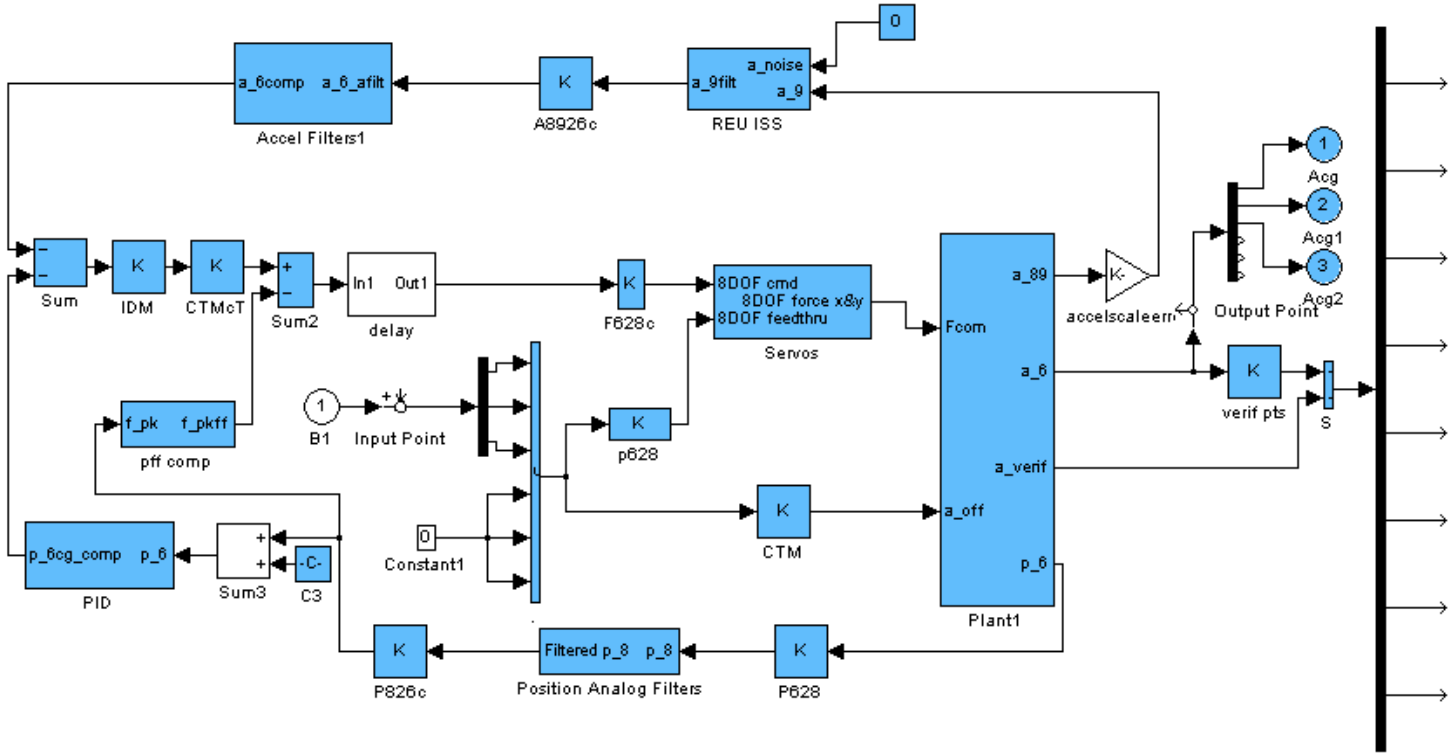
- **ISS Supplied On-Orbit Model of Adjacent ARIS Rack Interface**
- **ISS On-Orbit ISPR NASTRAN Model**
  - ARIS or PaRIS On-Orbit Components Added
- **Facility Rack On-Orbit NASTRAN Model**
  - Refinement in Disturber Locations
  - Refinement in Science Locations
- **Umbilical NASTRAN Models**
  - Tuned Based on Ground or On-Orbit Testing
- **Facility Rack Simulink Model**
  - Rigid Body Mode Loop
  - Flexible Rack Loop
  - Umbilical Loop
  - Tunable Controller

CIR On-Orbit NASTRAN Model



CIR Mass Properties Nominal Configuration	Value
Weight	1039 Kg (2290 Lbs)
Center of Gravity Based on Rack Datum	
X	18.30 in.
Y	-11.72 in.
Z	39.89 in.
Principal Moments of Inertia at CG	
I_{xx}	1,032,910 Lbs-in^2
I_{yy}	1,179,055 Lbs- in^2
I_{zz}	509,470 Lbs- in^2

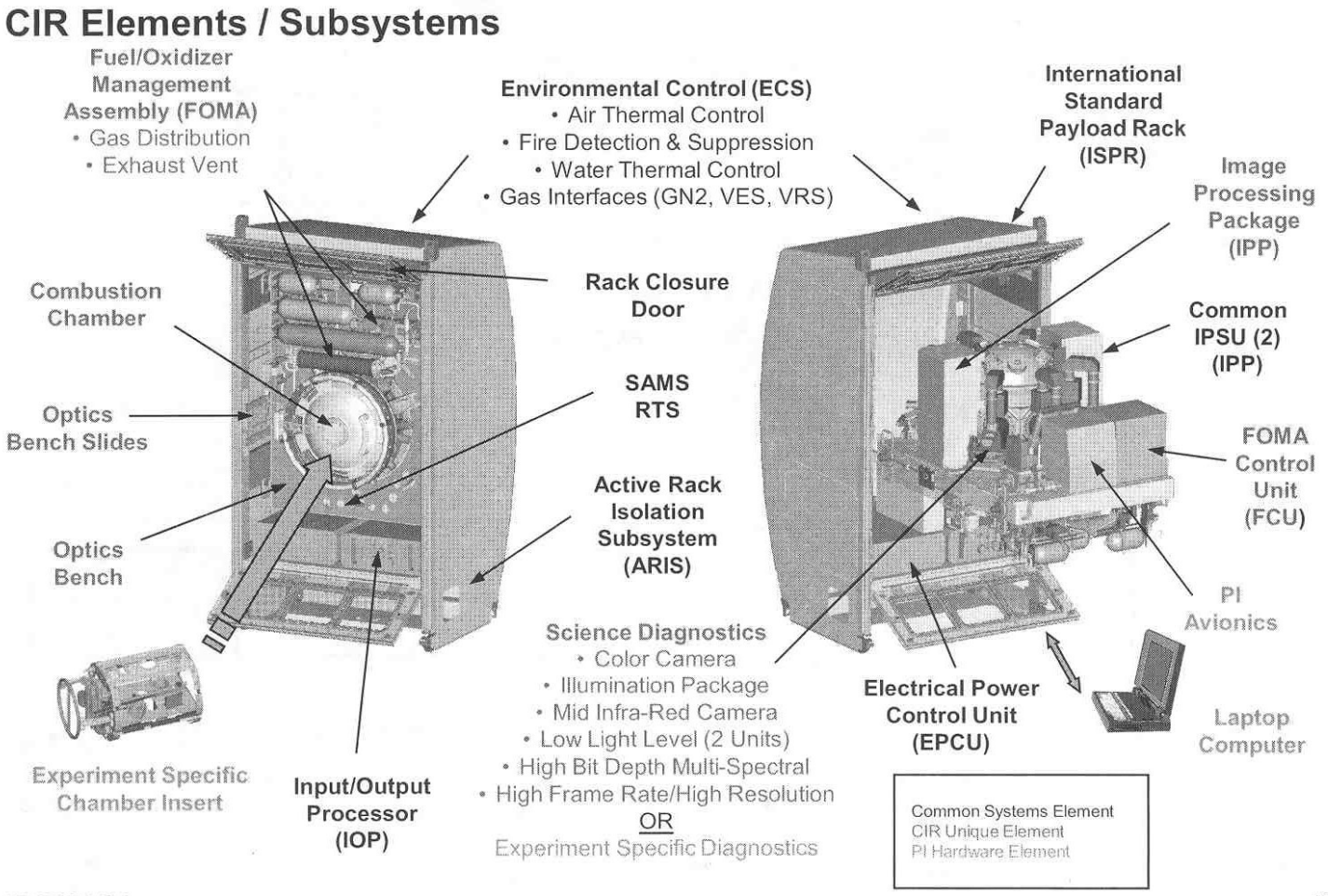
CIR Simulink Model



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 MGAIT 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 Approaches**
  - Suspend Disturbers by Cabling in Microgravity Emissions Lab (MEL)
  - Test Integrated Rack Disturbers on Ground
  - Suspend Entire Integrated Rack by Cabling & Activate Disturbers (Probable Size Limitations)
- **Microgravity Allocations of Disturbers - TBD**


CIR Elements / Subsystems
Fuel/Oxidizer Management Assembly (FOMA)
• Gas Distribution
• Exhaust Vent
Environmental Control (ECS)
• Air Thermal Control
• Fire Detection & Suppression
• Water Thermal Control
• Gas Interfaces (GN2, VES, VRS)
International Standard Payload Rack (ISPR)
Image Processing Package (IPP)
Combustion Chamber
Rack Closure Door
Common IPSU (2) (IPP)
SAMS RTS
Optics Bench Slides
FOMA Control Unit (FCU)
Active Rack Isolation Subsystem (ARIS)
Optics Bench
PI Avionics
Science Diagnostics
• Color Camera
• Illumination Package
• Mid Infra-Red Camera
• Low Light Level (2 Units)
• High Bit Depth Multi-Spectral
• High Frame Rate/High Resolution
OR
Experiment Specific Diagnostics
Electrical Power Control Unit (EPCU)
Laptop Computer
Experiment Specific Chamber Insert
Input/Output Processor (IOP)
Common Systems Element
CIR Unique Element
PI Hardware Element

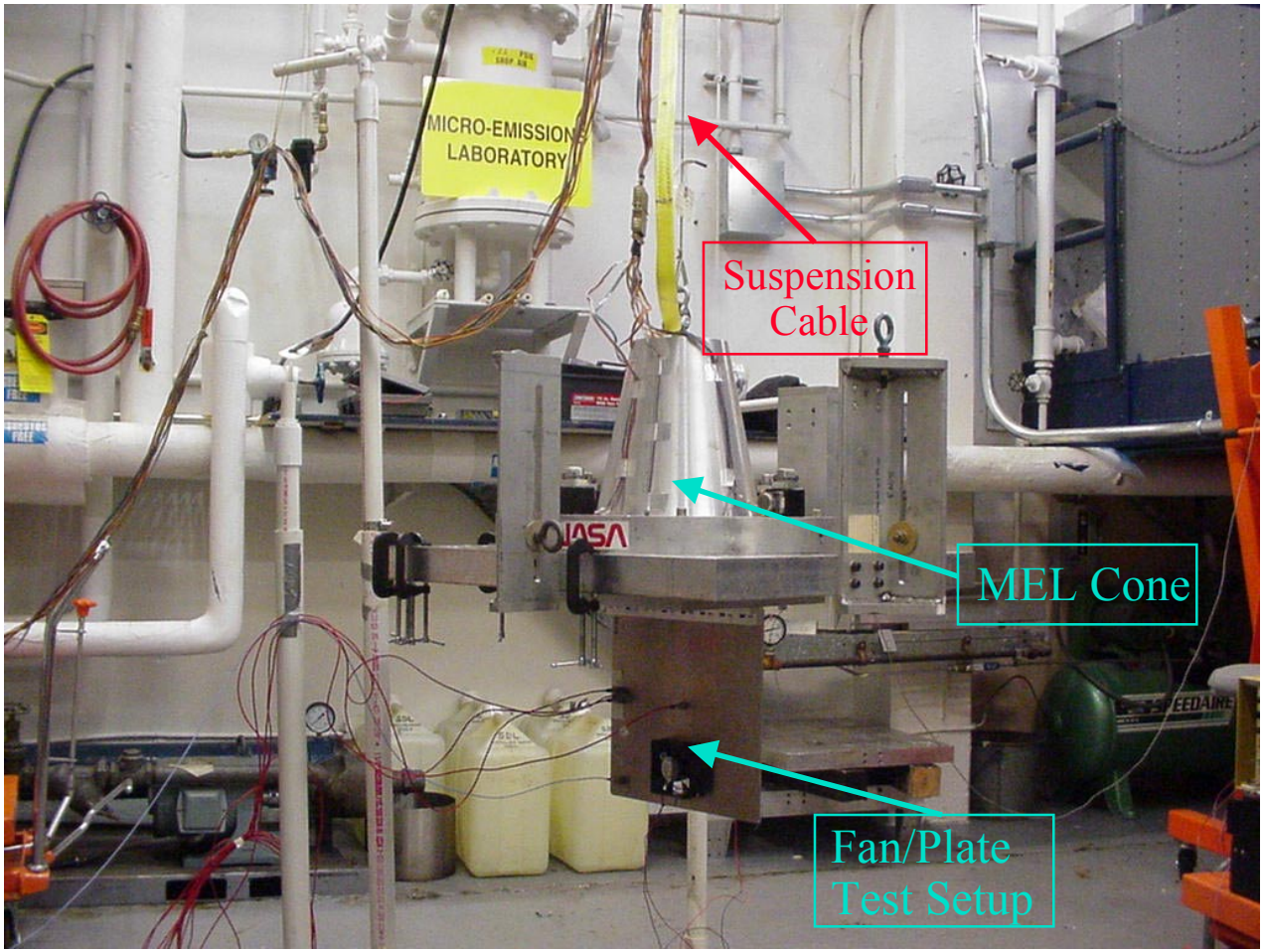
Pre-Launch Testing

- 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 Umbilicals at PaRIS 3 DOF Test Bed

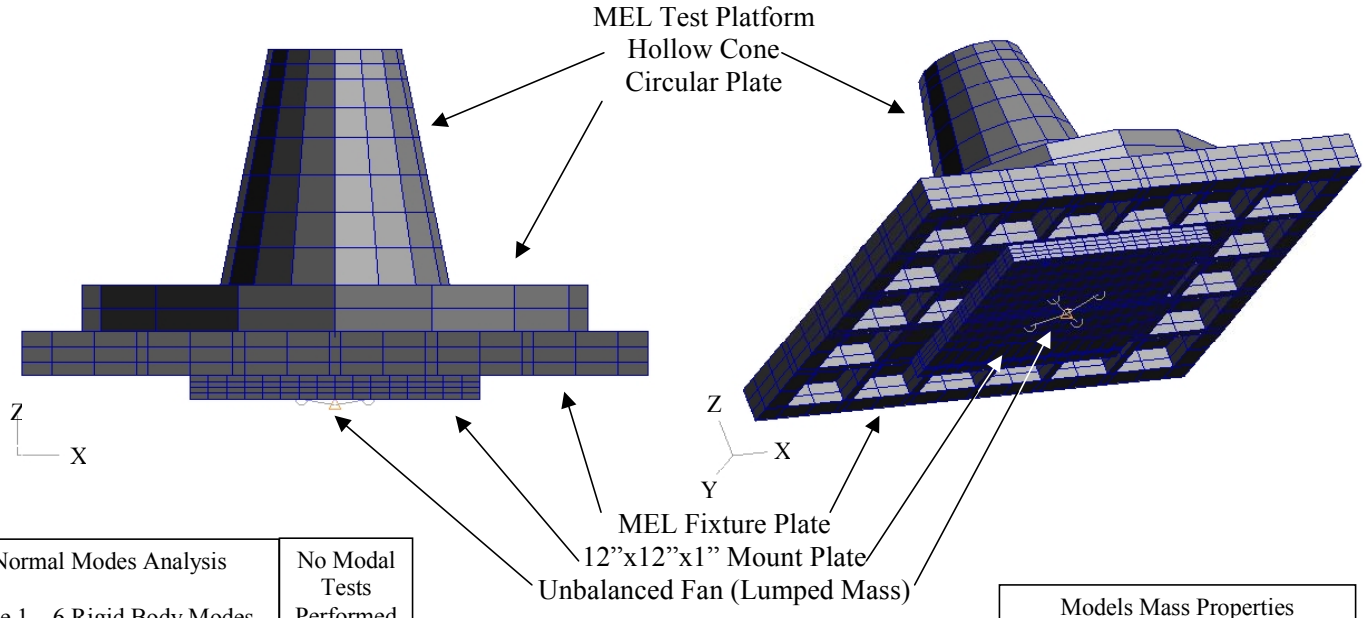
MEL Modeling & Comparison

- **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
  - Total Suspension Capacity of 750 lb.
  - Located at NASA GRC
- **Defines Forces & Moments at the Test Unit C.G.**
- **MEL Comparison of Test Results & Modeling**
  - Setup Fan / Plate Test & Associated NASTRAN Model
  - 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



MEL Test Configuration #1



Normal Modes Analysis	No Modal Tests Performed
Mode 1 – 6 Rigid Body Modes Mode 7 – 486 Hz	

Fan Data:	Weight
Comair/Rotron Fan 7 Blades at 3" diameter Model No. FE24H3 Serial No. 031165 3000 RPM @ 24 Vdc Unbalanced Load: Washer glued to one blade	0.256 lbs 0.002 lbs

FEM Information

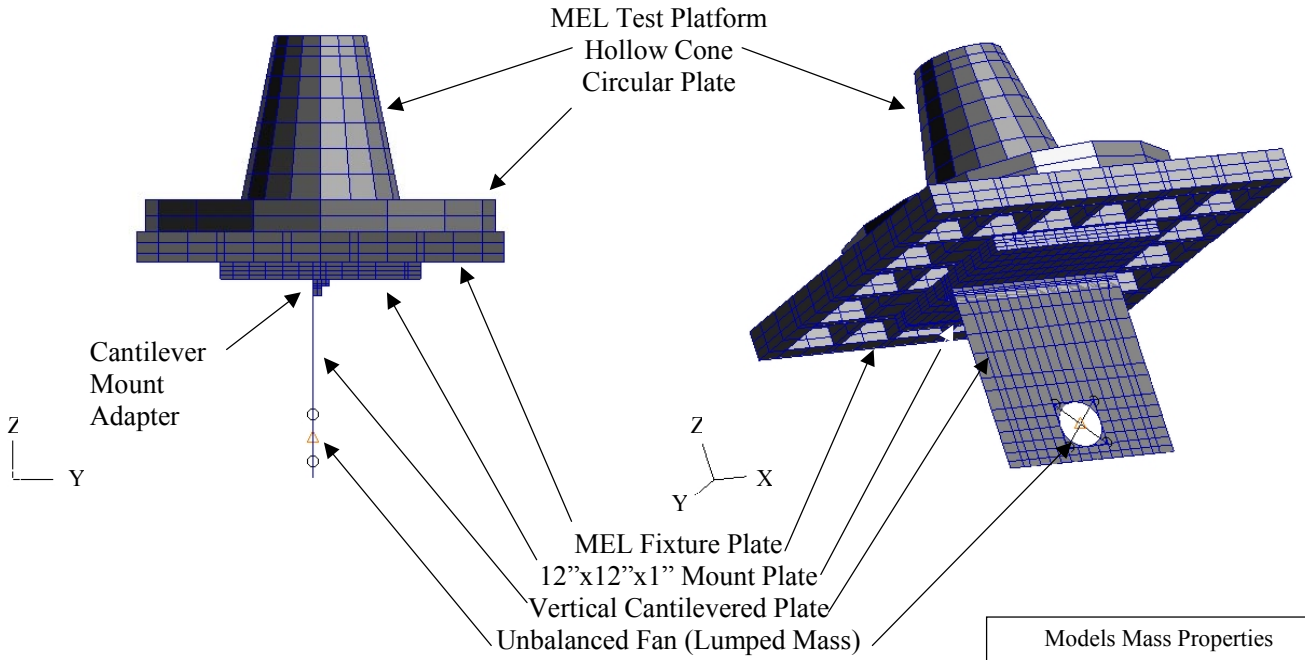
3486 Nodes
2224 Solid Elements
3 Lumped Masses
36 MPC's

Models Mass Properties

Weight = 215.8 Lbs
CG: x=0.0 y=0.0 z=+1.065"
Mass Moments of Inertia @ CG
Ixx = 9196 lbs-in^2
Iyy = 11275 lbs-in^2
Izz = 16716 lbs-in^2

Figure 1

MEL Test Configuration #2



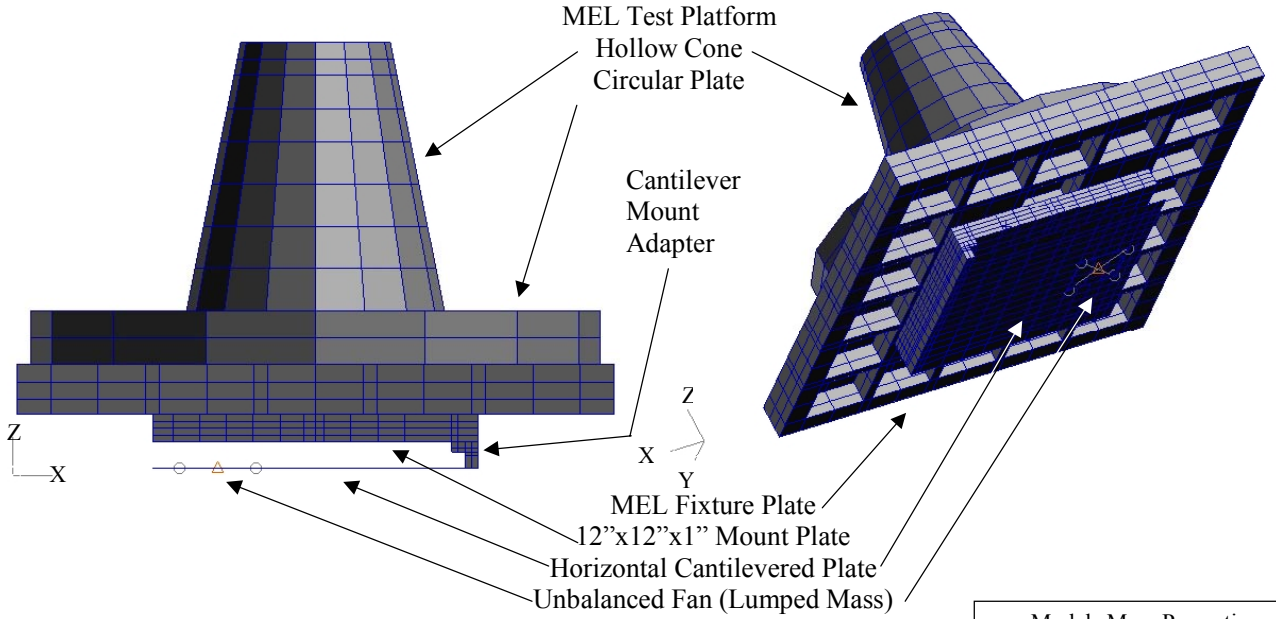
Normal Modes Analysis	Modal Tests
Mode 1 – 6 Rigid Body Modes	
Mode 7 – 26.7 Hz Plate Mode	26.7 Hz
Mode 8 – 75.0 Hz Plate Mode	68.9 Hz
Mode 9 – 177.3 Hz Plate Mode	165.8 Hz
Mode 10 – 232.6 Hz Plate Mode	246.3 Hz

FEM Information
4020 Nodes
2416 Solid Elements
232 Shell Elements
3 Lumped Masses
36 MPC's

Models Mass Properties
Weight = 219.6 Lbs
CG: x=0.0 y=0.0 z=+0.965"
Mass Moments of Inertia @ CG
Ixx = 9819 lbs-in^2
Iyy = 11472 lbs-in^2
Izz = 16223 lbs-in^2

Figure 2

MEL Test Configuration #3



Normal Modes Analysis	Modal Tests
Mode 1 – 6 Rigid Body Modes	
Mode 7 – 25.6 Hz Plate Mode	25.6 Hz
Mode 8 – 72.8 Hz Plate Mode	65.4 Hz
Mode 9 – 171.8 Hz Plate Mode	165.6 Hz
Mode 10 – 225.8 Hz Plate Mode	235.4 Hz

FEM Information

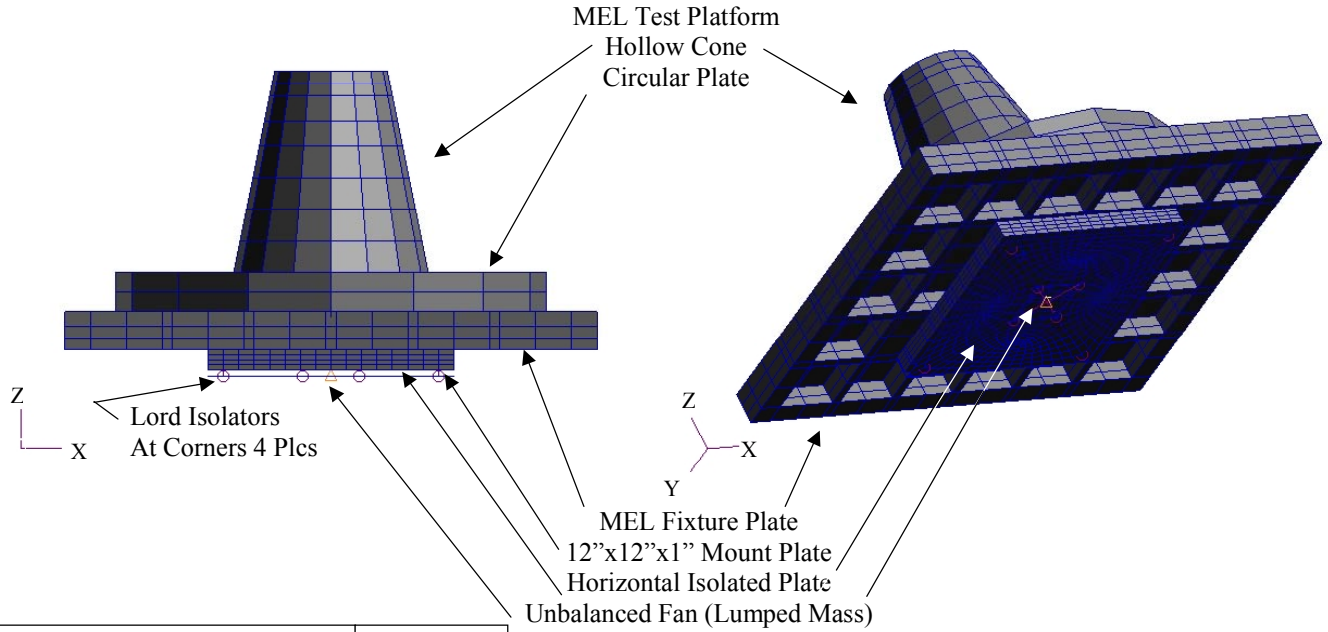
4006 Nodes
2416 Solid Elements
232 Shell Elements
3 Lumped Masses
36 MPC’s

Models Mass Properties

Weight = 217.7 Lbs
CG: x=0.0 y=0.0 z=+0.980”
Mass Moments of Inertia @ CG
Ixx = 9276 lbs-in^2
Iyy = 11373 lbs-in^2
Izz = 16083 lbs-in^2

Figure 3

MEL Test Configuration #4



Normal Modes Analysis	Modal Tests
Mode 1 – 6 Rigid Body Modes	
Mode 7,8 – 25.7 Hz Isolator Mode	25.7 Hz
Mode 9 – 26.7 Hz Isolator Mode	26.8 Hz
Mode 10 – 40.7 Hz Isolator Mode	No Data
Mode 11,12 – 43.8 Hz Isolator Mode	45.2 Hz
Mode 13 – 133.7 Hz Plate Mode	123.6 Hz
Mode 14 – 146.4 Hz Plate Mode	157.3 Hz
Mode 15 – 175.6 Hz Plate Mode	No Data
Mode 16, 17 – 232.3 Hz Plate Modes	276 Hz

FEM Information

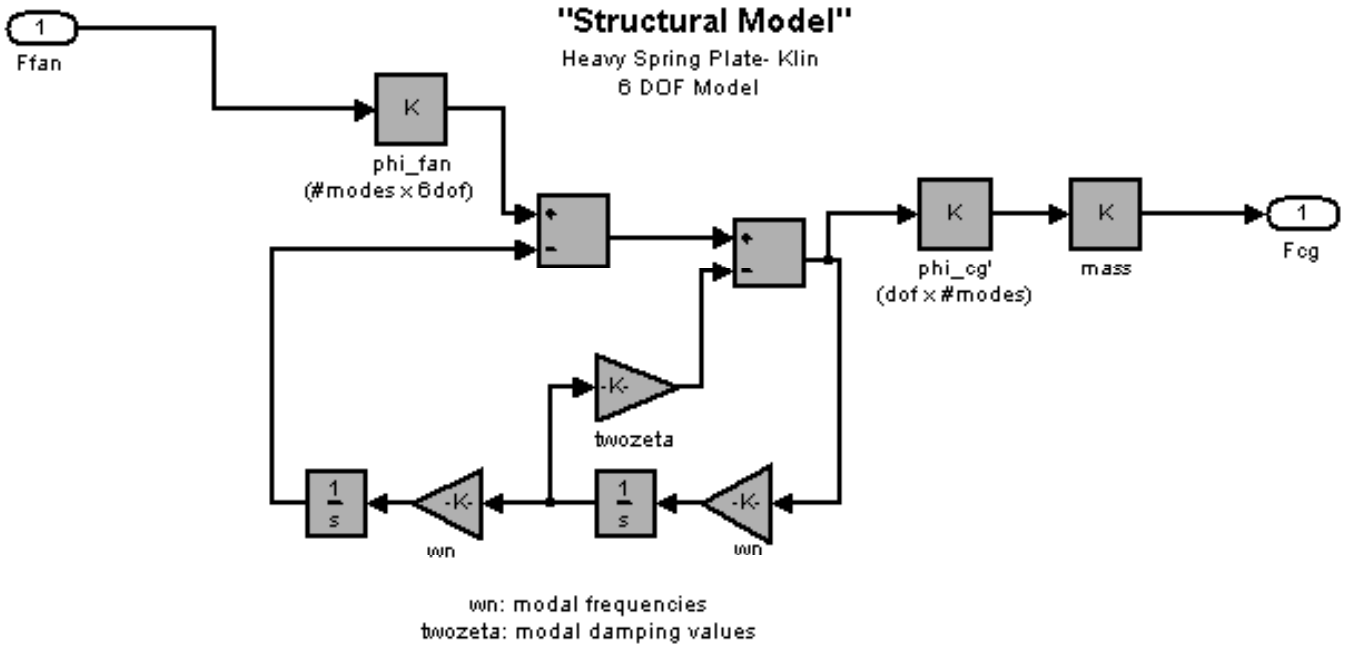
4226 Nodes
2224 Solid Elements 568 Shell Elements
3 Lumped Masses 40 MPC's
12 Spring Elements (3 Springs X,Y, Z/Isolator)

Models Mass Properties

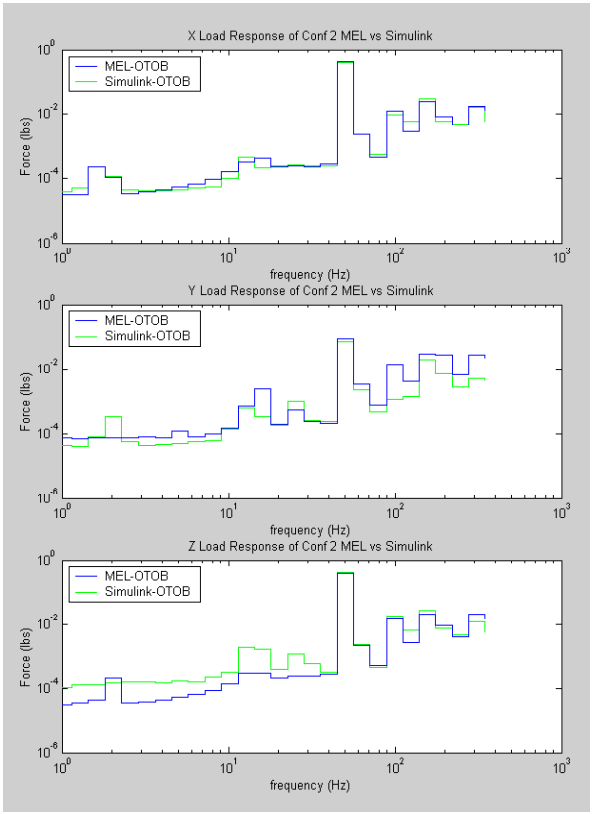
Weight = 217.1 Lbs
CG: x=0.0 y=0.0 z=+1.0"
Mass Moments of Inertia @ CG
Ixx = 9429 lbs-in^2
Iyy = 11341 lbs-in^2
Izz = 16073 lbs-in^2

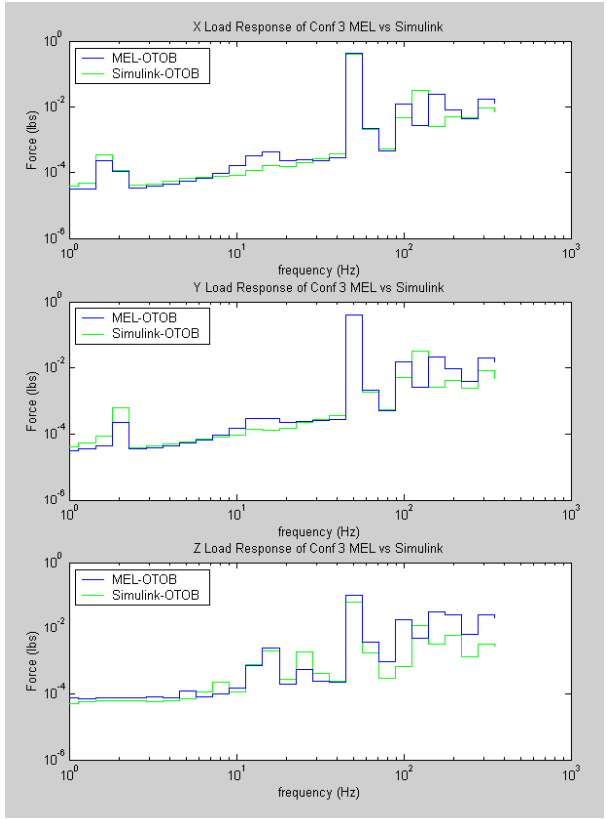
Figure 4

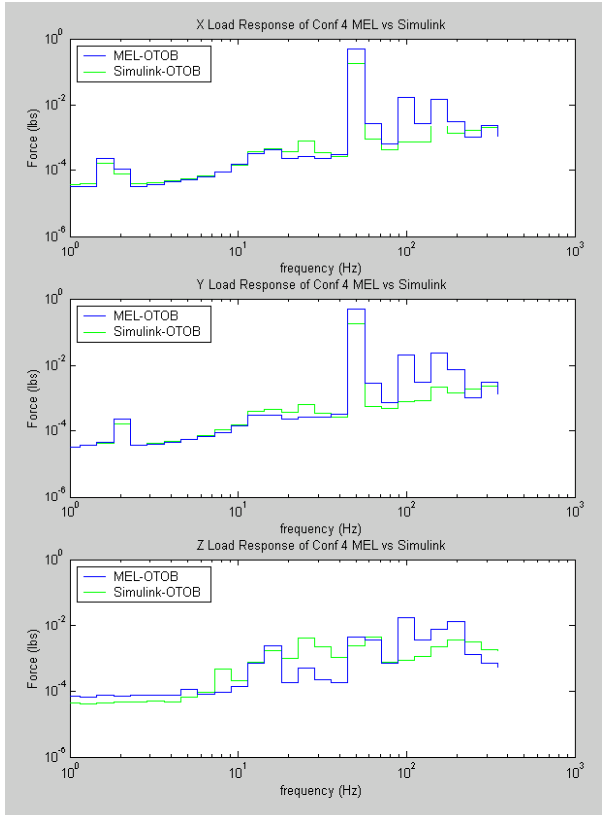
MEL Fan / Plate Simulink Model



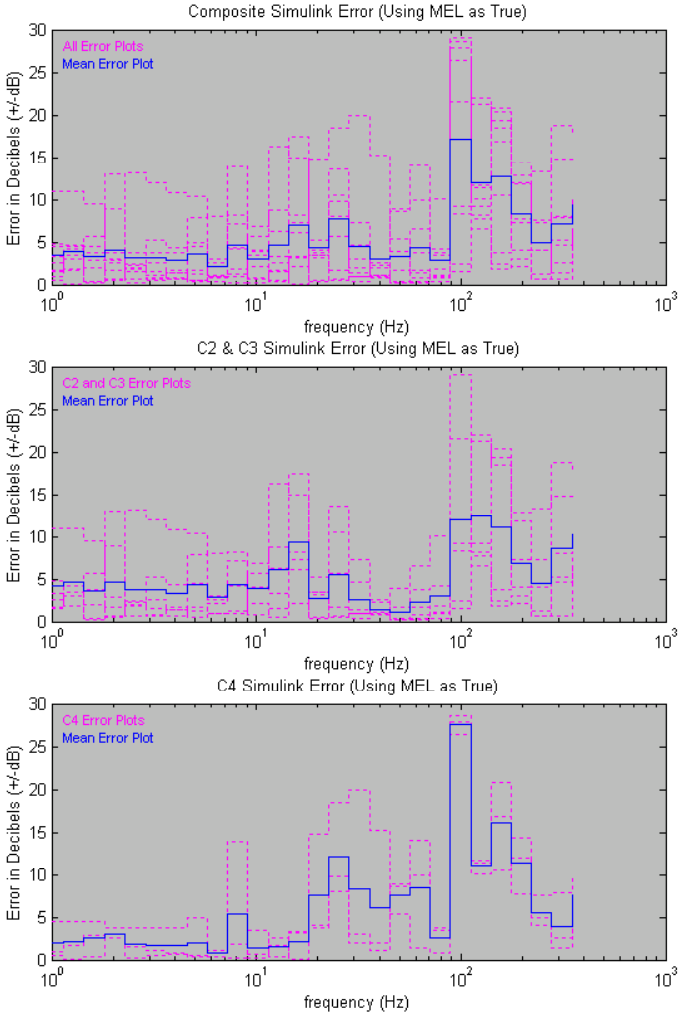
MEL Test Vs. Modeling Approach







MEL Test Vs. Modeling Error Analysis



Verification & Validation

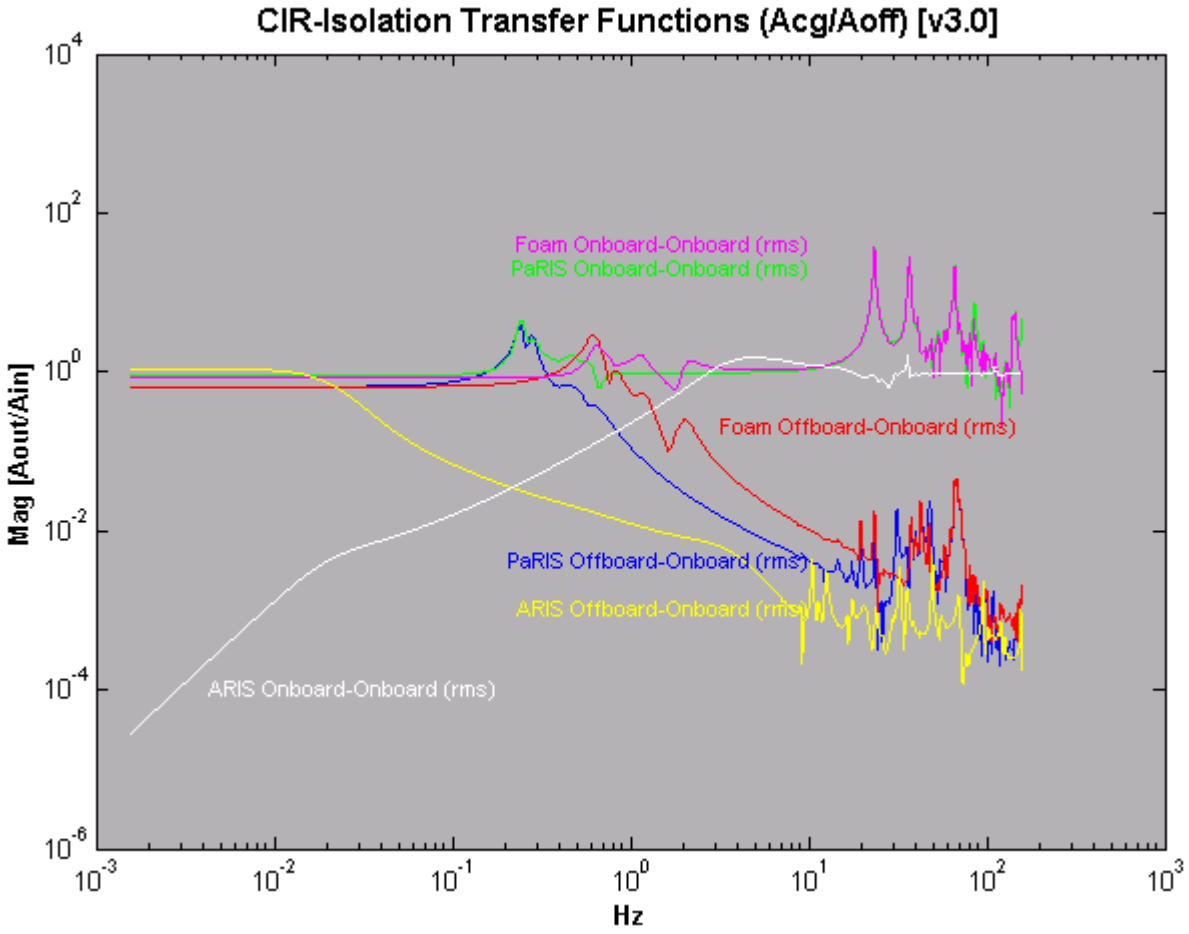
- **Analytical Verifications**
  - Rack NASTRAN Models
  - MATLAB Simulink Models
- **ARIS Performance – Sway Space & Sensor Saturation Are Based On:**
  - Payload Unique Stiffness & Damping of Umbilical Set
  - Payload Unique Mass & Center of Mass Position
  - Payload Unique Disturbance & Rack Dynamic Response
  - Payload Experiment Configuration
- **Maximize Use of Test Results in Updated Analytical Models**
  - Comparison With ISS Microgravity Requirements
  - Comparison With Science Requirements

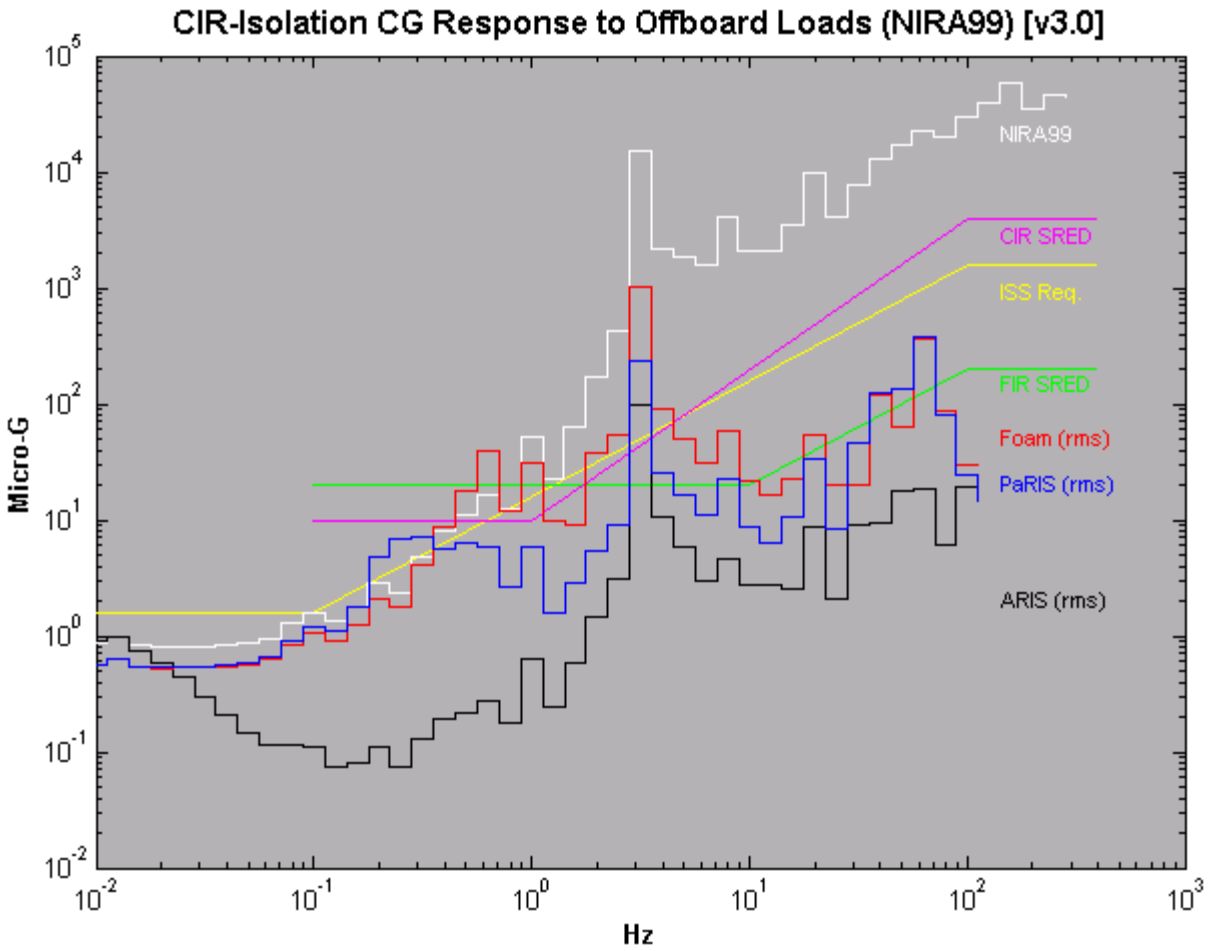
FCF Microgravity Assessment

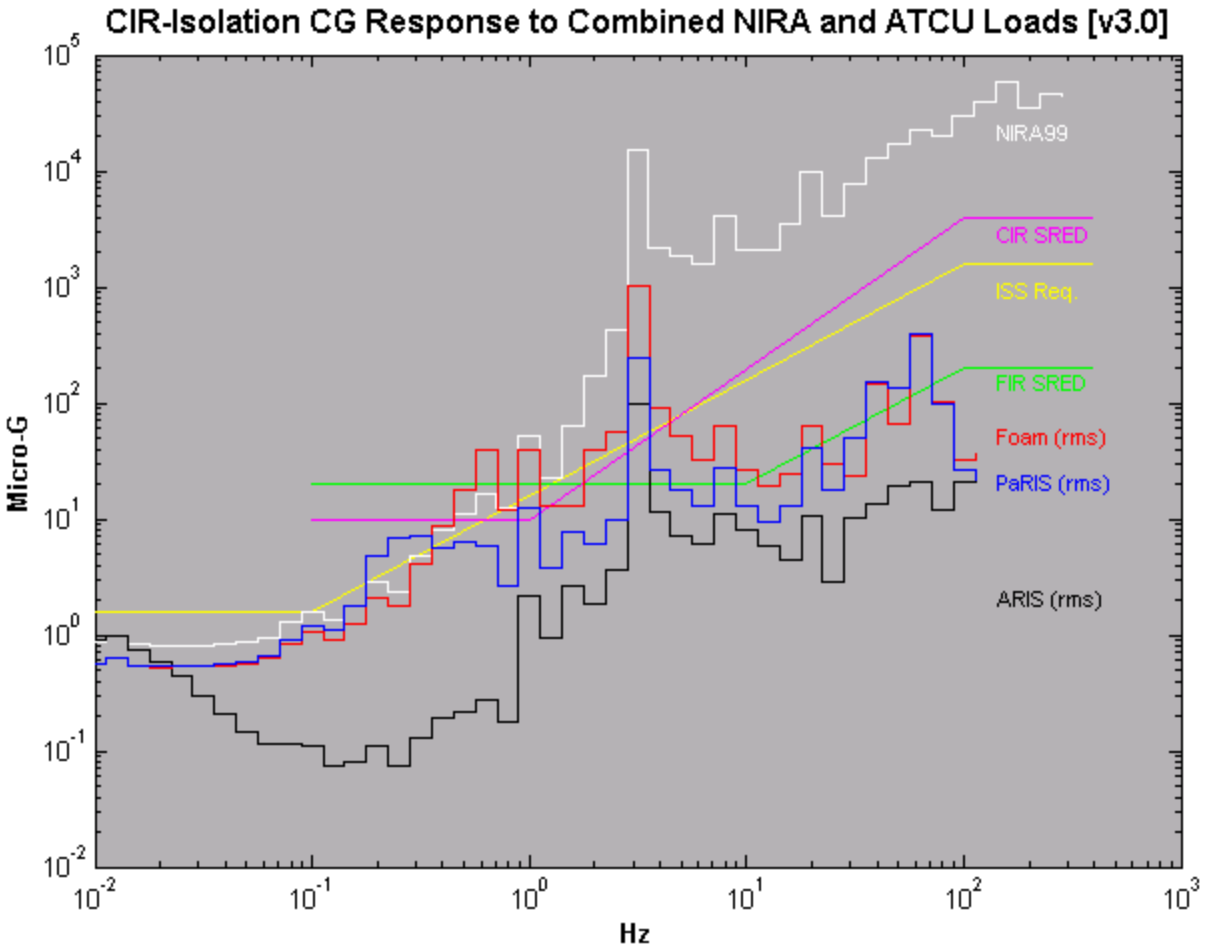
- Predicted Offboard Loading (NIRA99 data from US Lab)
- Single Onboard Loading (ATCU fan disturbance data)
- Combined Effects of Both Single Onboard and Predicted Offboard
- Added Vacuum Resource Umbilical to EXPRESS ARIS Umbilicals
- Performance at CG and Verification Points
- Onboard to Offboard Impact
- Comparison to CIR & FIR Science Requirements Envelopes (SREDs)

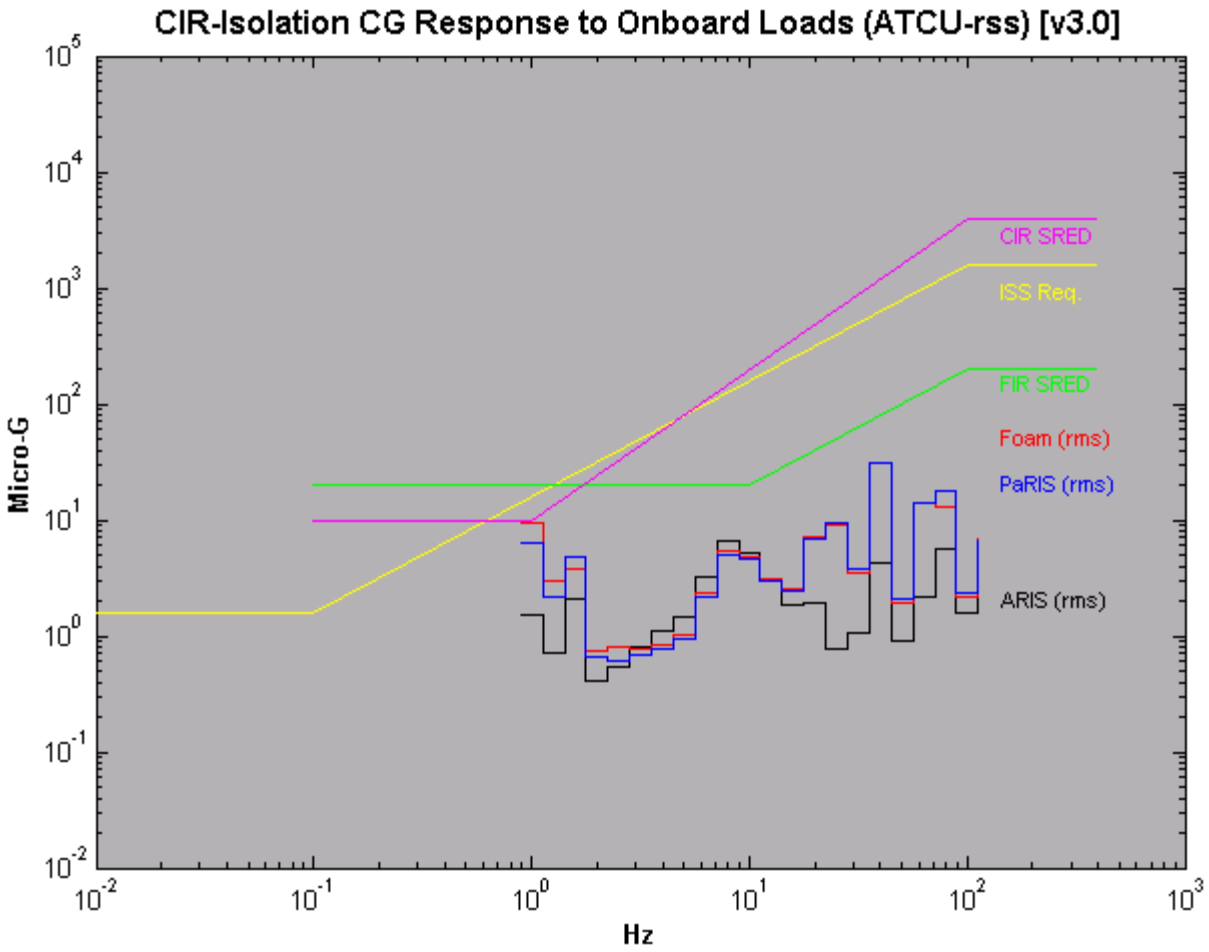
CIR Analysis Observations

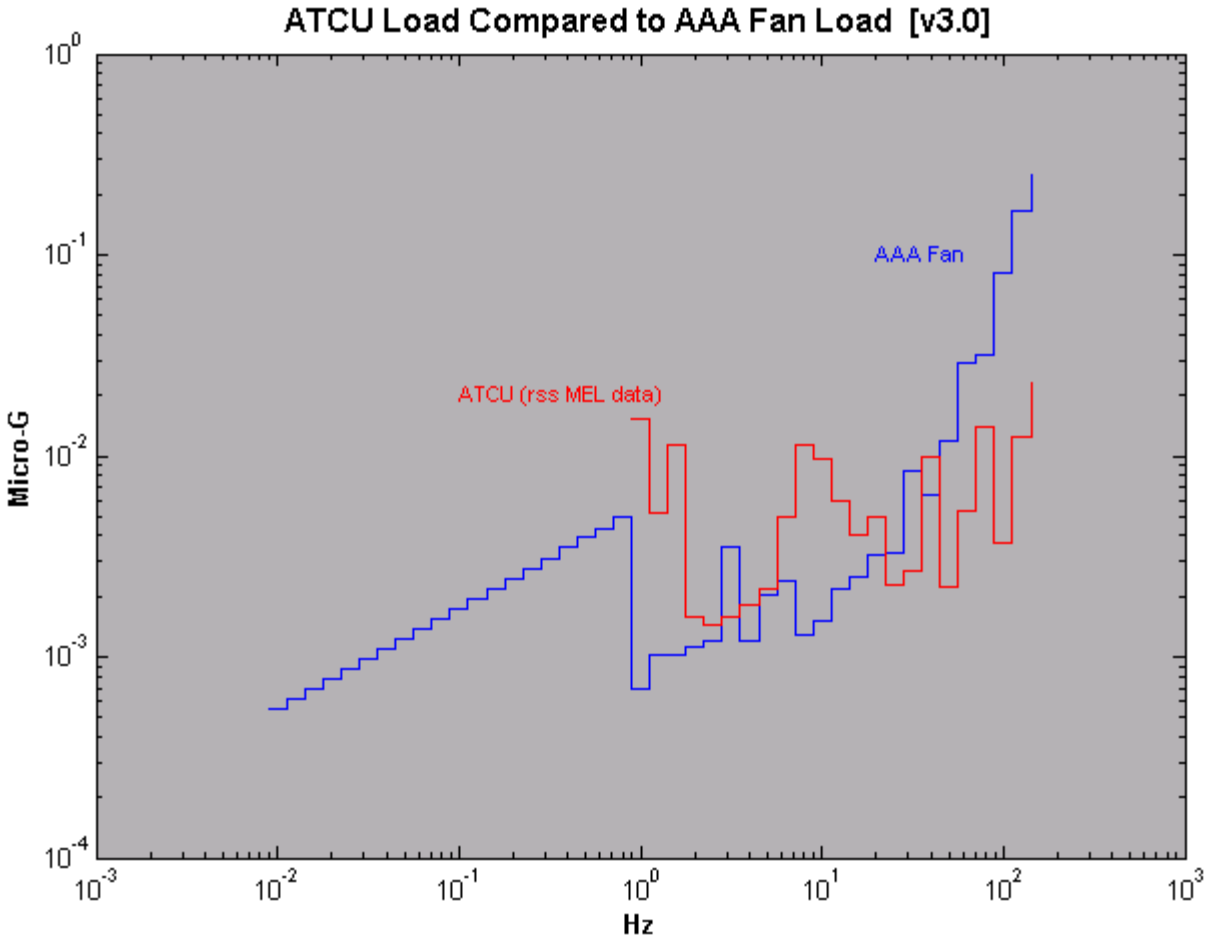
- Analysis Performed with Untuned ARIS Controller
- Higher Level of Risk Without Active Isolation
- ARIS Provides Two Orders of Magnitude Margin From 0.01 to 1.0 Hz
- Passive Isolation Provides Little or No Margin From 0.1 to 1.0 Hz
- Disturbances Near Umbilical Modes Exceed Requirements
- PaRIS Is Not Effective Until Levels Above 0.5 Hz
- Comparison of ATCU and AAA Fan Disturbances (page 41)


CIR-Isolation Transfer Functions (Acg/Aoff) [v3.0]
Mag [Aout/Ain]
Hz
Foam Onboard-Onboard (rms)
PaRIS Onboard-Onboard (rms)
Foam Offboard-Onboard (rms)
PaRIS Offboard-Onboard (rms)
ARIS Offboard-Onboard (rms)
ARIS Onboard-Onboard (rms)


CIR-Isolation CG Response to Offboard Loads (NIRA99) [v3.0]
Micro-G
Hz
NIRA99
CIR SRED
ISS Req.
FIR SRED
Foam (rms)
PaRIS (rms)
ARIS (rms)


CIR-Isolation CG Response to Combined NIRA and ATCU Loads [v3.0]
Micro-G
Hz
NIRA99
CIR SRED
ISS Req.
FIR SRED
Foam (rms)
PaRIS (rms)
ARIS (rms)


CIR-Isolation CG Response to Onboard Loads (ATCU-rss) [v3.0]
Micro-G
Hz
CIR SRED
ISS Req.
FIR SRED
Foam (rms)
PaRIS (rms)
ARIS (rms)


ATCU Load Compared to AAA Fan Load [v3.0]
Micro-G
Hz
AAA Fan
ATCU (rss MEL data)
10^0
10^-1
10^-2
10^-3
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3

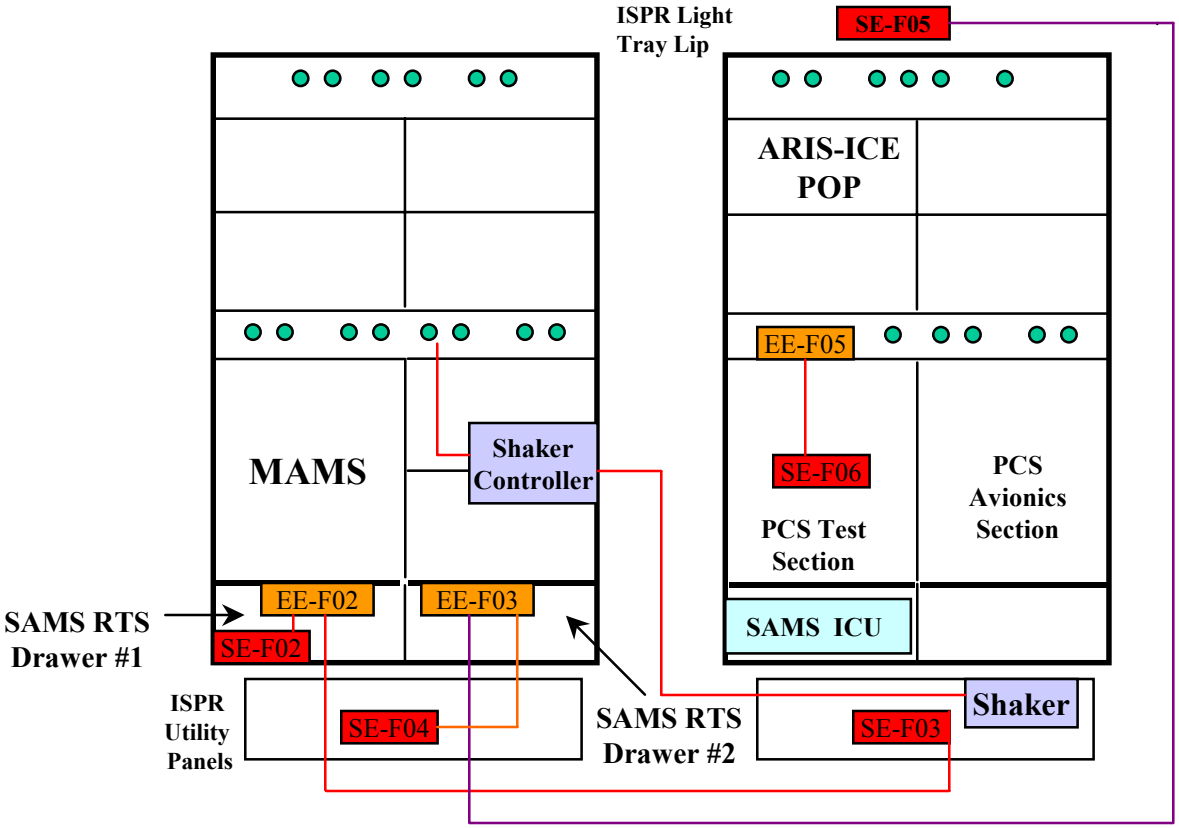
Potential On-Orbit Testing

- Characterize Facility Racks On-Orbit
- ARIS-ICE Rack Ping Test
- ARIS-ICE 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

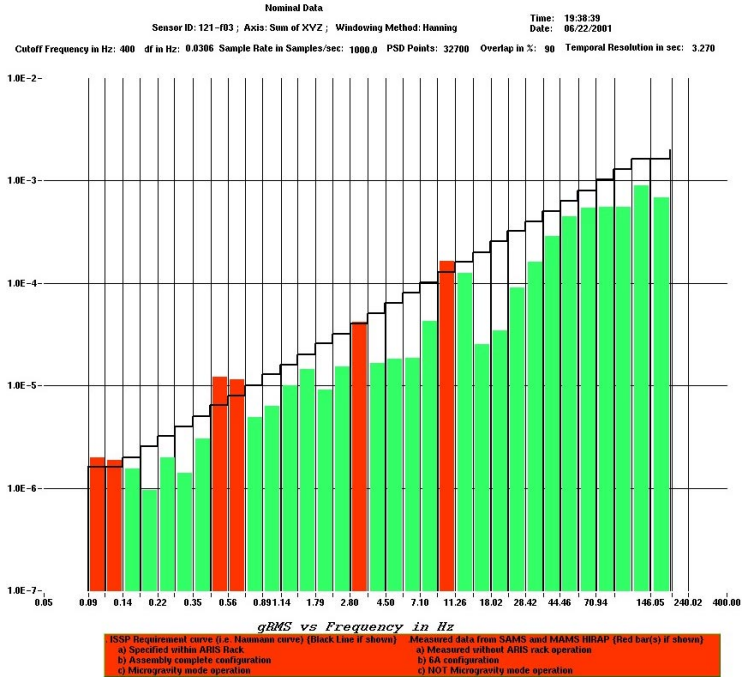
Evaluation of ARIS Performance Based on SAMS

- Five SAMS SE's Utilized
  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

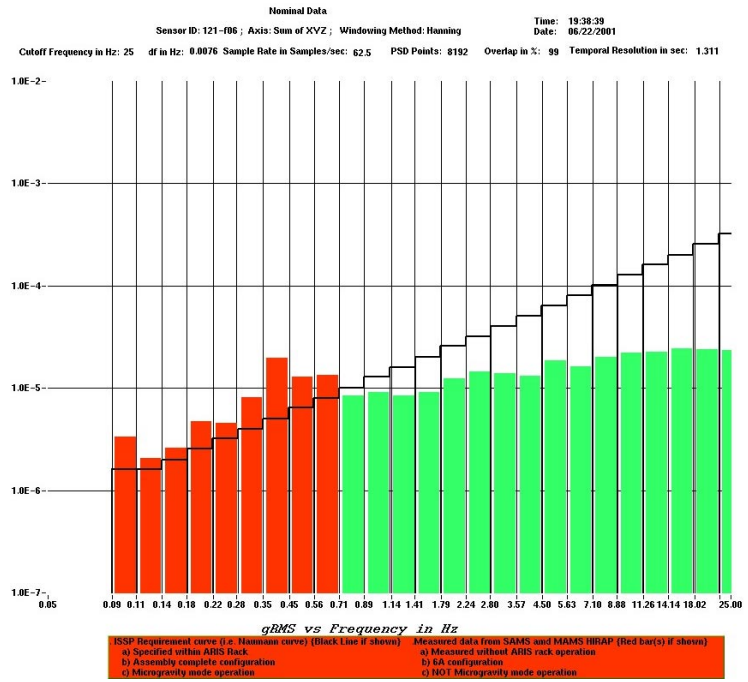
Location of SAMS Sensors for ISS Increment 2



ARIS-ICE Data

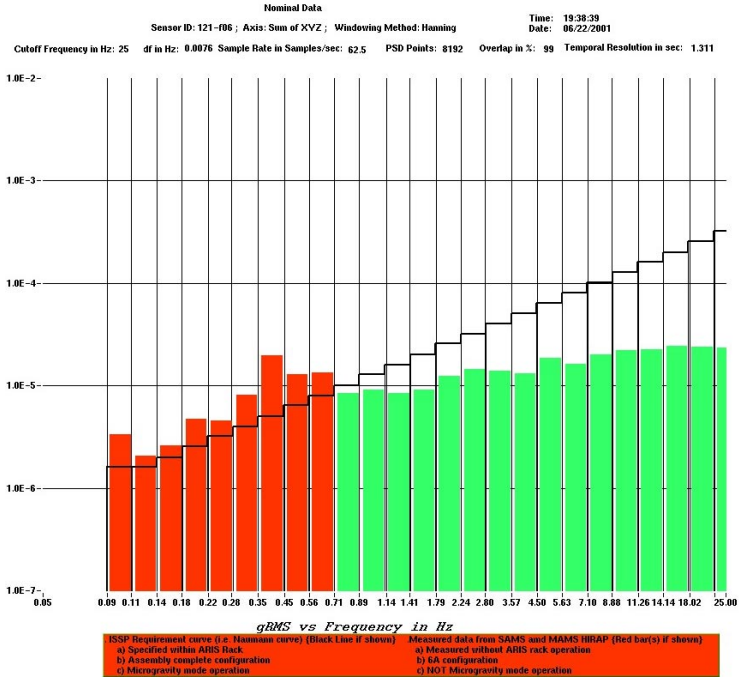


Offboard Structure

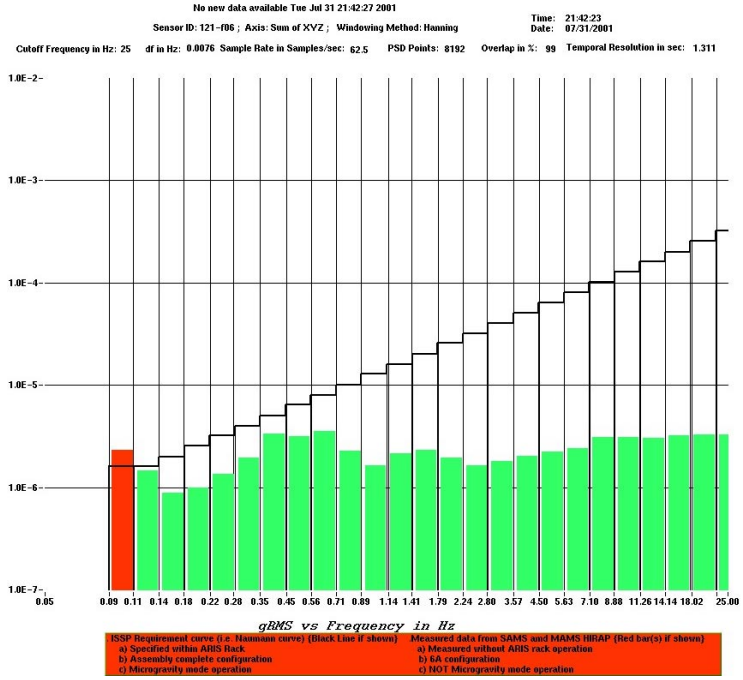


ARIS “Idle”

ARIS-ICE Data



ARIS "Idle"



ARIS "Active"

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