Section 12
Microgravity Control Integration Process & Disturbance Predictions for ISS Rack Payloads

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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 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 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

ATCU Housing

Fan Filter

Wire Rope Isolators
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 Process Summary

- **Boeing Ground & On-orbit Test Data Archive and Documentation**
- **Boeing NASTRAN Model Archive and Documentation**
- **Facility Test Data**
- **NASTRAN Subsystem Models**
- **Validated Matlab Subsystem Models**
- **Model Validation and Detailed Verification Analysis for EXPRESS**
- **ARIS Simulink Archive of Model Blocks and Documentation**
- **Model Assemblies and Documentation**
- **Matlab Parameter Selection m-files and Documentation**
- **Verification Objective Analysis Approach**
- **Model and Parameter Case Selection to Meet Each Verification Objective**
- **Design Case**
- **Design Parameters**
- **ARIS Controller Design**

- Blue: Boeing Product
- Tan: Facility Product
- Green & Yellow: TBD Product
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

Internal CIR Structural Components

Boeing ARIS ISPR FEM

Combustion Chamber Center Line with Lumped Masses Defined

Note: FCF Common Doors Removed to show Internal CIR Structural Components

<table>
<thead>
<tr>
<th>CIR Mass Properties Nominal Configuration</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>1039 Kg (2290 Lbs)</td>
</tr>
<tr>
<td>Center of Gravity Based on Rack Datum</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>18.30 in.</td>
</tr>
<tr>
<td>Y</td>
<td>-11.72 in.</td>
</tr>
<tr>
<td>Z</td>
<td>39.89 in.</td>
</tr>
<tr>
<td>Principal Moments of Inertia at CG</td>
<td></td>
</tr>
<tr>
<td>$I_{xx}$</td>
<td>1,032,910 Lbs-in²</td>
</tr>
<tr>
<td>$I_{yy}$</td>
<td>1,179,055 Lbs-in²</td>
</tr>
<tr>
<td>$I_{zz}$</td>
<td>509,470 Lbs-in²</td>
</tr>
</tbody>
</table>
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**
Microgravity Control Integration Process & Disturbance Predictions for ISS Rack Payloads

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)
- Common IPSU (2) (IPP)
- FOMA Control Unit (FCU)
- PI Avionics
- Electrical Power Control Unit (EPCU)
- Laptop Computer

- Rack Closure Door
- SAMS RTS
- Active Rack Isolation Subsystem (ARIS)

- 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

- Combustion Chamber
- Optics Bench Slides
- Optics Bench
- 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

<table>
<thead>
<tr>
<th>Normal Modes Analysis</th>
<th>No Modal Tests Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 – 6 Rigid Body Modes</td>
<td></td>
</tr>
<tr>
<td>Mode 7 – 486 Hz</td>
<td></td>
</tr>
</tbody>
</table>

Fan Data:
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

<table>
<thead>
<tr>
<th>Weight</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.256 lbs</td>
<td></td>
</tr>
<tr>
<td>0.002 lbs</td>
<td></td>
</tr>
</tbody>
</table>

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

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MEL Test Configuration #2

<table>
<thead>
<tr>
<th>Normal Modes Analysis</th>
<th>Modal Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 – 6 Rigid Body Modes</td>
<td>26.7 Hz</td>
</tr>
<tr>
<td>Mode 7 – 26.7 Hz Plate Mode</td>
<td>68.9 Hz</td>
</tr>
<tr>
<td>Mode 8 – 75.0 Hz Plate Mode</td>
<td>165.8 Hz</td>
</tr>
<tr>
<td>Mode 9 – 177.3 Hz Plate Mode</td>
<td>246.3 Hz</td>
</tr>
<tr>
<td>Mode 10 – 232.6 Hz Plate Mode</td>
<td></td>
</tr>
</tbody>
</table>

FEM Information

- 4020 Nodes
- 2416 Solid Elements
- 232 Shell Elements
- 3 Lumped Masses
- 36 MPC’s

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 – 6 Rigid Body Modes</td>
<td>6 Rigid Body Modes</td>
</tr>
<tr>
<td>Mode 7 – 25.6 Hz Plate Mode</td>
<td>25.6 Hz</td>
</tr>
<tr>
<td>Mode 8 – 72.8 Hz Plate Mode</td>
<td>72.8 Hz</td>
</tr>
<tr>
<td>Mode 9 – 171.8 Hz Plate Mode</td>
<td>171.8 Hz</td>
</tr>
<tr>
<td>Mode 10 – 225.8 Hz Plate Mode</td>
<td>225.8 Hz</td>
</tr>
</tbody>
</table>

Modal Tests

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
**Microgravity Control Integration Process & Disturbance Predictions for ISS Rack Payloads**

**MEL Test Configuration #4**

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

**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

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**Tutorial**

**Figure 4**

[Diagram showing MEL Test Configuration #4 with labels for MEL Test Platform, Hollow Cone, Circular Plate, Lord Isolators, MEL Fixture Plate, 12”x12”x1” Mount Plate, Horizontal Isolated Plate, Unbalanced Fan (Lumped Mass).]
MEL Fan / Plate Simulink Model
MEL Test Vs. Modeling Approach

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MEL Test Vs. Modeling Error Analysis
Verification & Validation

- **Analytical Verifications**
  - Rack NASRAN 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)
Microgravity Control Integration Process & Disturbance Predictions for ISS Rack Payloads

CIR-Isolation CG Response to Onboard Loads (ATCU-rss) [v3.0]
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

EXPRESS Rack #1

EXPRESS Rack #2

MAMS

SAMS RTS Drawer #1

SAMS RTS Drawer #2

EE-F02

EE-F03

EE-F04

ISPR Utility Panels

ISPR Light Tray Lip

Shaker Controller

Shaker

ARIS-ICE POP

EE-F05

EE-F06

PCS Test Section

PCS Avionics Section

SAMS ICU

SE-F05

SE-F06

SE-F04

SE-F03
Microgravity Control Integration Process & Disturbance Predictions for ISS Rack Payloads

ARIS-ICE Data

Offboard Structure

ARIS “Idle”

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ARIS “Idle”

ARIS “Active”

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