ISS Design Analysis Cycle 8 Environment Predictions

Microgravity Environment Interpretation Tutorial
NASA Glenn Research Center
March 6-8, 2001

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Presentation Overview

- Design Analysis Cycle
- Analysis Methods
- Active Rack Isolation System
- Disturbance Forcing Functions
- Quasi-steady Accelerations
- Vibratory Accelerations

Design Analysis Cycle (DAC) 8

DACs may be viewed as PDR/CDR level analyses or "special" case studies.

- **DAC8 was completed in winter 1999.**
- **DAC9 is in process with results expected summer of 2001.**
- **DACs capture updated models & disturbance forcing functions.**

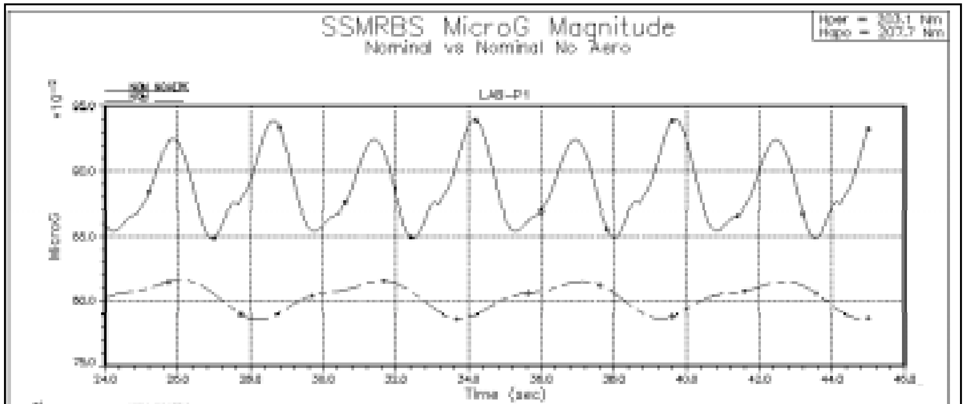
Verification Analysis Cycles (VACs) are in process and are conducted on a flight by flight basis.

- **Verify that the hardware launched complies with Assembly Complete microgravity requirements.**
- **Priority tasks necessary for Certification of Flight Readiness.**

Microgravity sustaining engineering efforts underway.

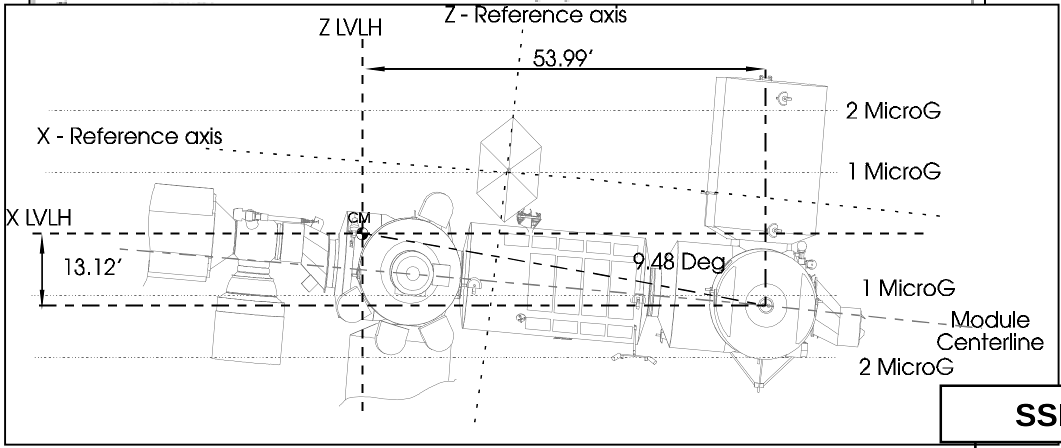
- **Use of on-orbit measurements for issue resolution, uncertainty reduction, analytical model correlation.**
- **Support anomaly resolution and operations.**

Methods & Tools
Quasi-Steady Analysis



Below 0.01 Hz

- Orbital Mechanic Multi-Rigid Body Closed Loop Attitude Control Analysis
- Space Station Multi Rigid Body Simulation (NASA SPARC)
- SSMRBS used for GN&C Software Verification



$$\vec{a} = -\mu\left(\frac{\vec{r}_p}{r_p^3} - \frac{\vec{r}_g}{r_g^3}\right) - \vec{\omega}\times\left(\vec{\omega}\times\vec{r}_{p/g}\right) - \dot{\vec{\omega}}\times\vec{r}_{p/g} + \vec{a}_D$$

Gravity Gradient | Centripetal | Tangential | Aerodynamic Drag

SSMRBS Environment Data Validation

verify_gfield (gravity)

ADA Advanced Simulation Development System (ASDS) Gravitational Potential (GOTPOT) model

verify_bfield (magnetic)

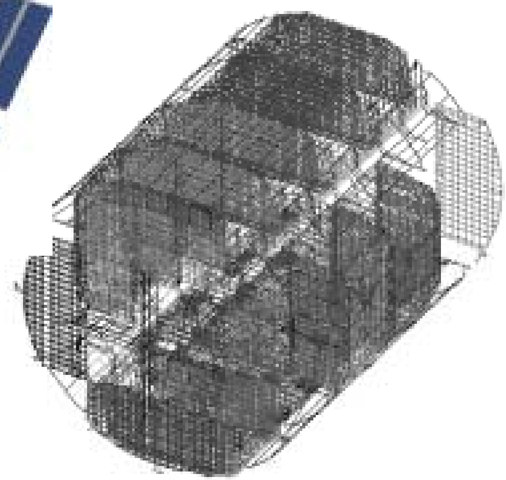
Goddard Space Flight Center International Geophysical Reference Field (IGRF) Earth Magnetic model

verify_atm_density (density)

Marshall Engineering Thermosphere (MET) Earth Atmospheric Density model

Methods & Tools
Structural Dynamic Analysis

Enhanced COF Model

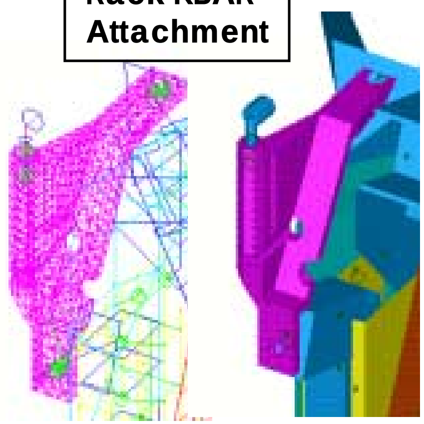


Lower Pivot

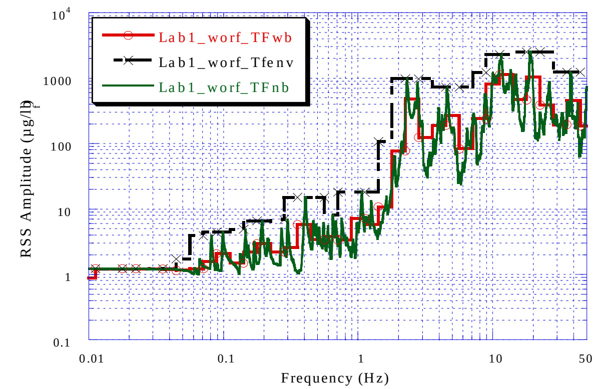
Non-isolated Rack I/F

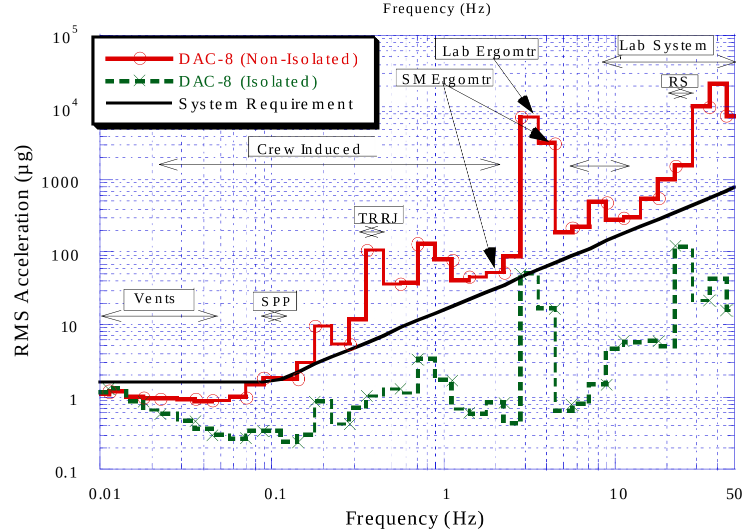
Upper KBAR

Rack KBAR Attachment

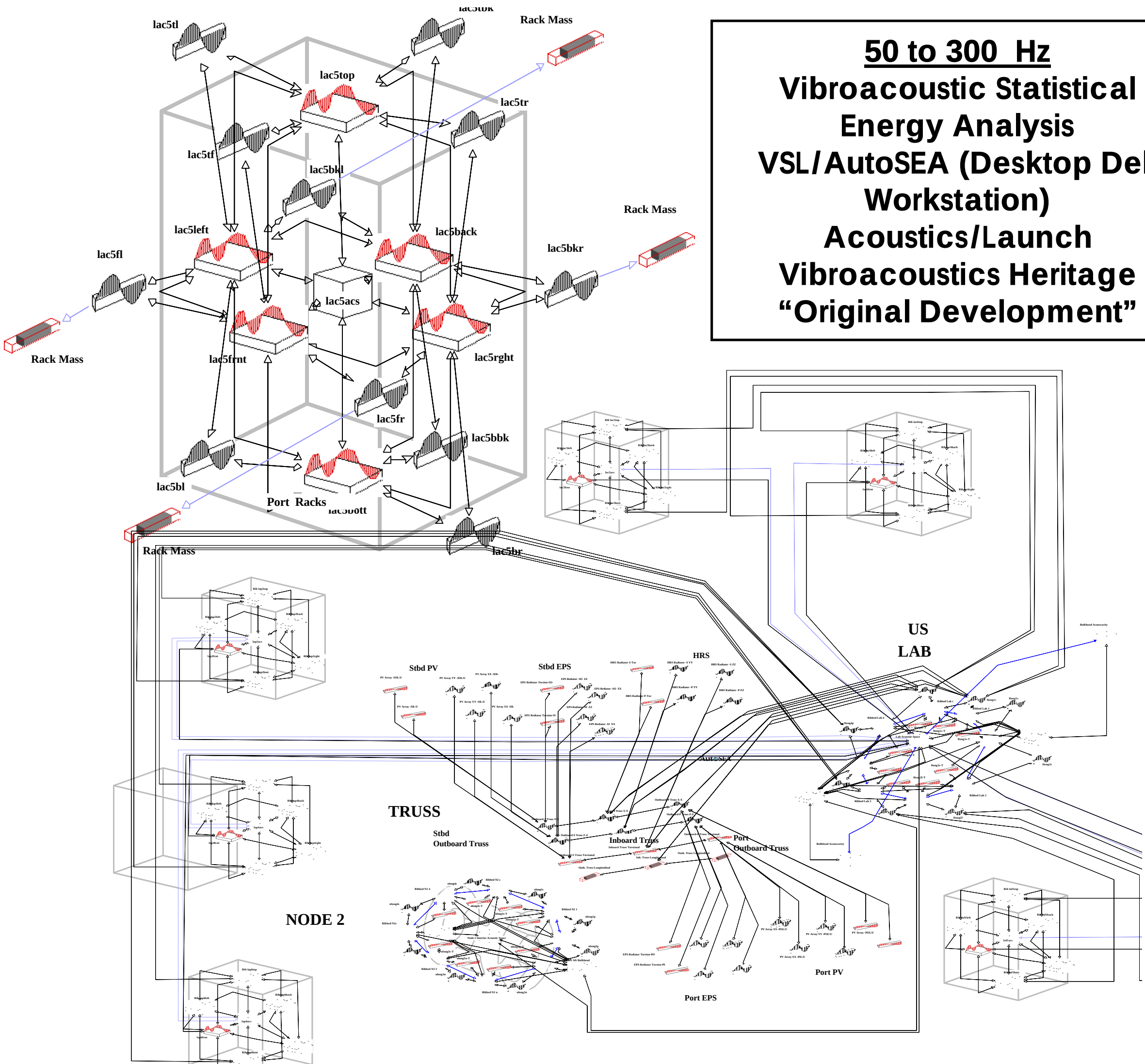


<u>0.01 to 50 Hz</u>
Structural Dynamic Finite Element Analysis
MSC/NASTRAN (NASA CRAY)
"Enhanced" Loads & Dynamics Models

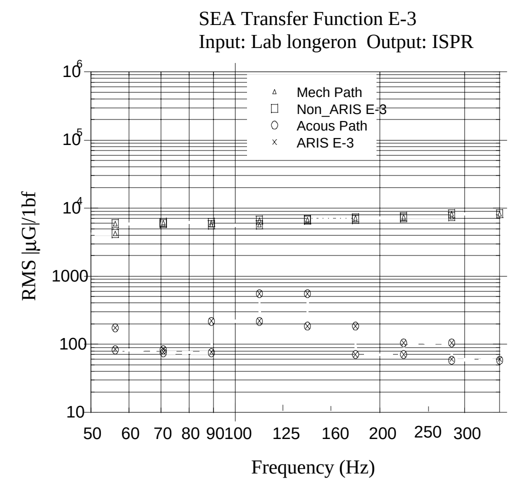


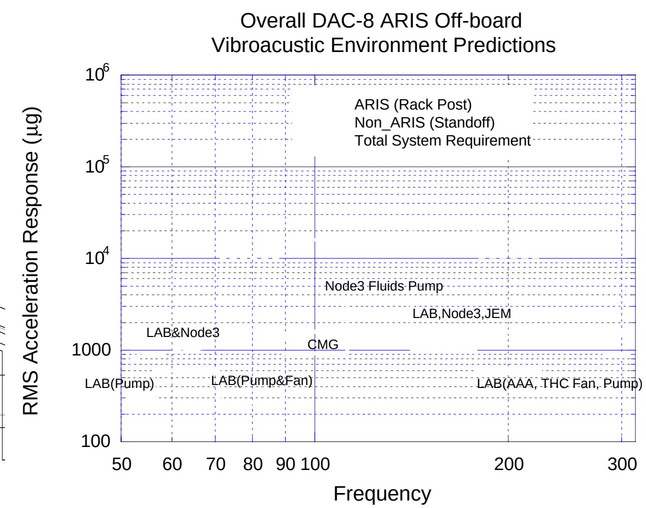


Methods & Tools
VibroAcoustic Analysis

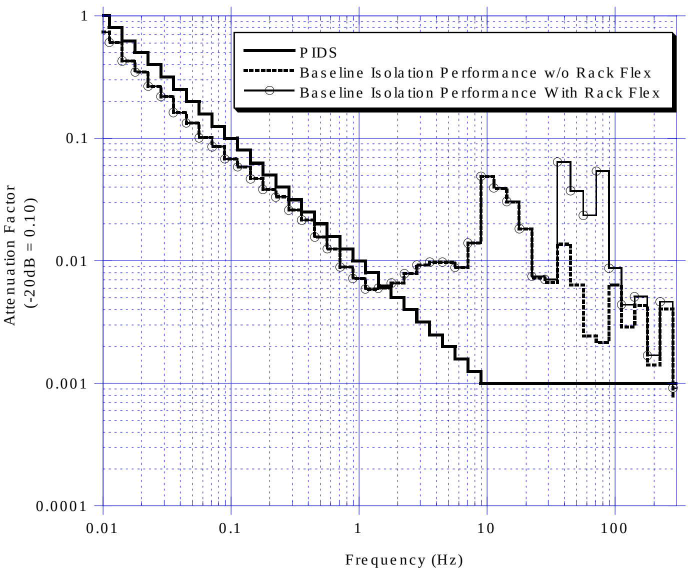


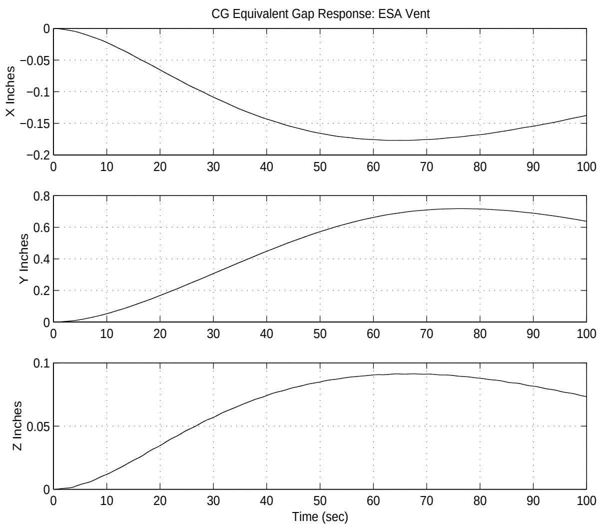
<u>50 to 300 Hz</u>
Vibroacoustic Statistical Energy Analysis
VSL/AutoSEA (Desktop Dell Workstation)
Acoustics/Launch Vibroacoustics Heritage
"Original Development"



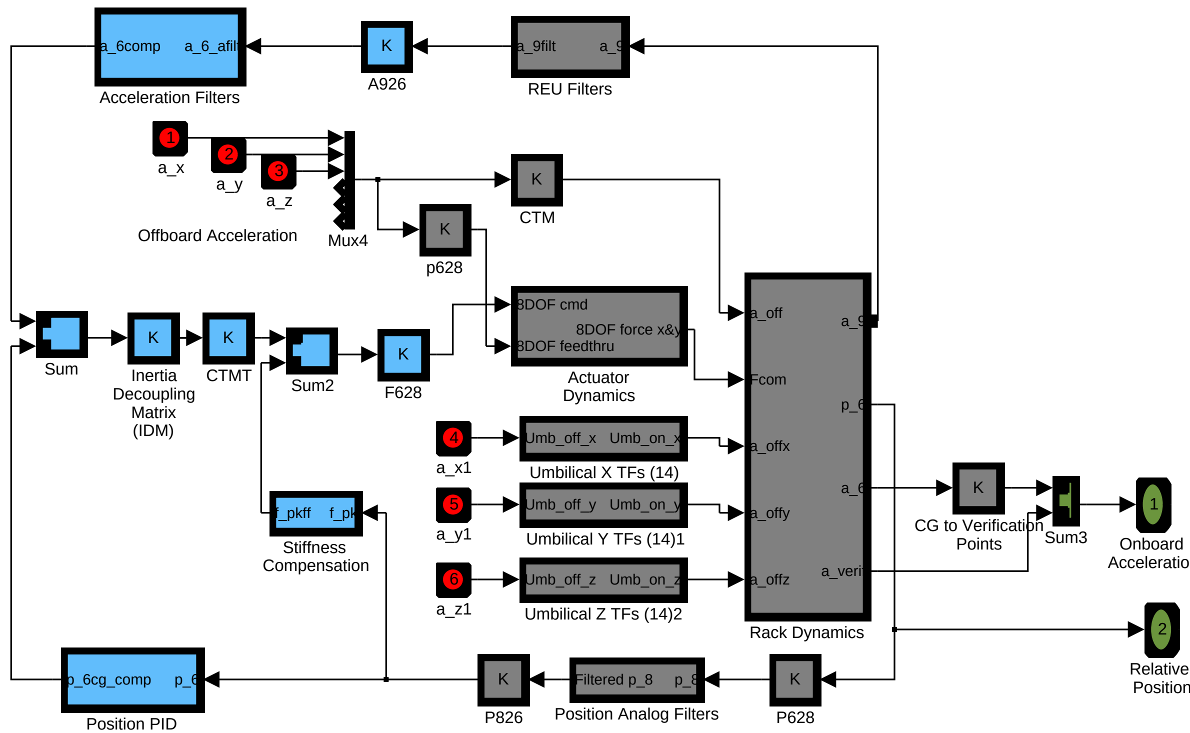


Methods & Tools
Controls Analysis





Active Rack Isolation System
Control System Analysis
Matlab/Simulink (NASASparc)



Methods & Tools
Disturbance Analysis & Testing

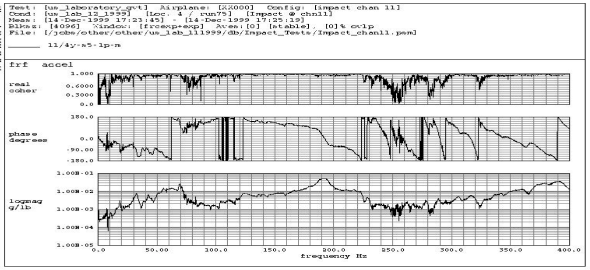
NODE TEST

LAB TEST

EQUIPMENT							
TYPE	ITEM	DAC5 VMDB	RSA ORU LOGISTICS	KhSC EN-10-01, P2	PRIME DDB	COMMENTS	ASSESSED
SOLAR ARRAY	DRIVE	1	2	2	2		
FAN	THC	2	11	8	8	VIB ONLY	X
	DUST COLLECTOR			2	2	VIB ONLY	X
	CONTROL SYSTEM			1	1	NQ	N/A
	CONTIN. FILTER			1	1	NQ	N/A
	TCS			2	2	1-VIB, 1-NQ	1-X, 1-N/A
	COMFORT	1	3	3	3	LOW POWER	N/A
	FIRE HAZARD			10	10	LOW POWER	N/A
	BANK OF FANS	1					
	LIFE SUPPORT	1	4				
PUMP	TCS	2		2	2	VIB ONLY	X
HEAT EXCH.	TCS - GAS/LIQUID	2		4	4	KHSC INSIG.	
VALVE	TCS RETURN	1		2	2	KHSC INSIG.	
	TCS REGULATOR	1		1	1	KHSC INSIG.	
	LIFE SUP-PRESS	1		1	1	KHSC INSIG.	
	LIFE SUP-PRESS REDUCTION	1		1	1	KHSC INSIG.	
	LIFE SUP-EQUAL	1		1	1	KHSC INSIG.	
	LIFE SUP-CNTRL	2		1	1	KHSC INSIG.	
TV	CAMERA	1		3 EXT-NQ	3 EXT-NQ	EXT & NQ	N/A
PHONE	LOUDSPEAKER	3	4	3	3	CONTINGINCY	N/A
TOTAL		22	24	45	45		

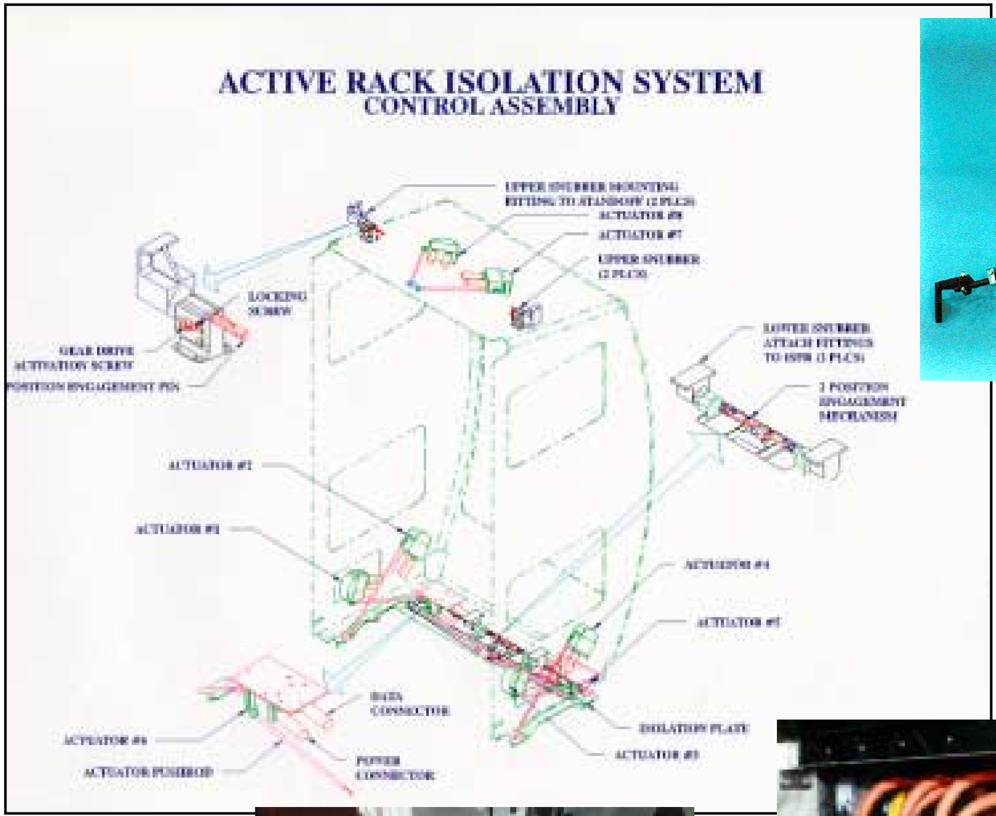
Capture &

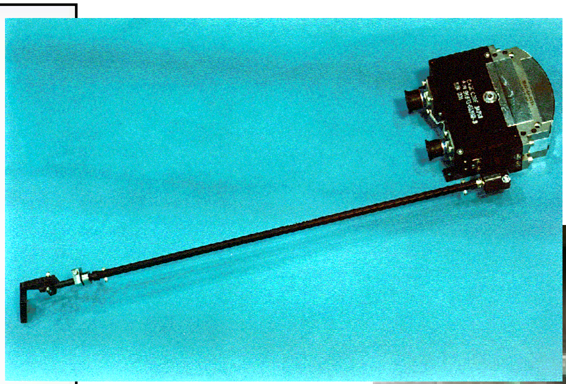
Adequacy



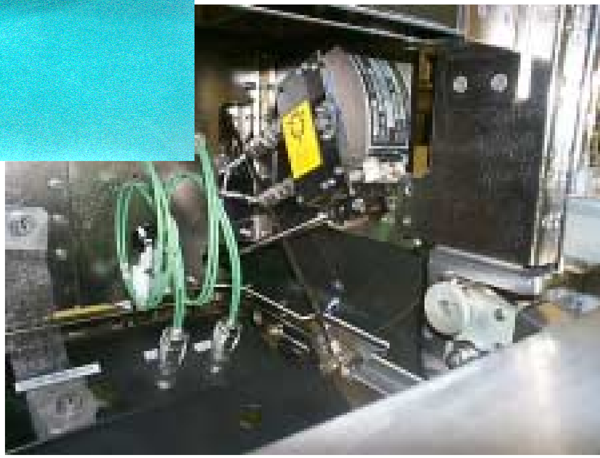
EQUIPMENT		NUMBER	PG/IP	DISTURBANCE COMPONENT ASSURACY (WEIGHTING * RATING)									ACCURACY RATING
TYPE	ITEM			QUASI-STEADY	VIBRATORY								0 </= AR </= 10
					MECHANICAL				ACOUSTICAL				
					NB		WB	TR	NB		WB	TR	
					Fndmtl.	Harmonics			Fndmtl.	Harmonics			
Flight 1A/R - FGB													
	ECLSS Fans	12	RS		8*8	4*8	2*0				1*0		6.4
	TCS Pumps	2	RS		8*6	4*6	2*0				1*0		4.8

ARIS

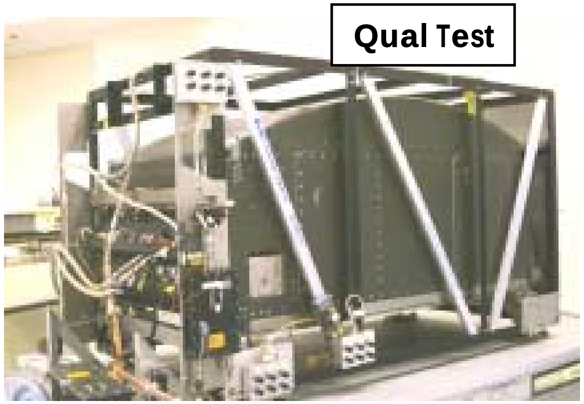




Actuator



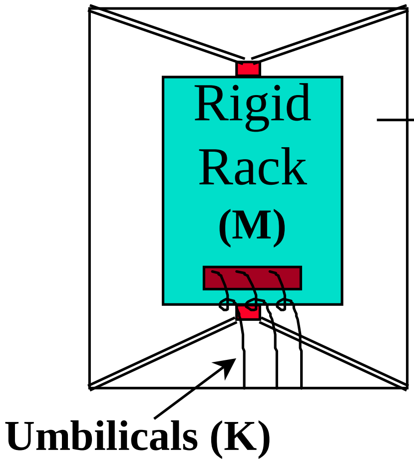
Qual Test

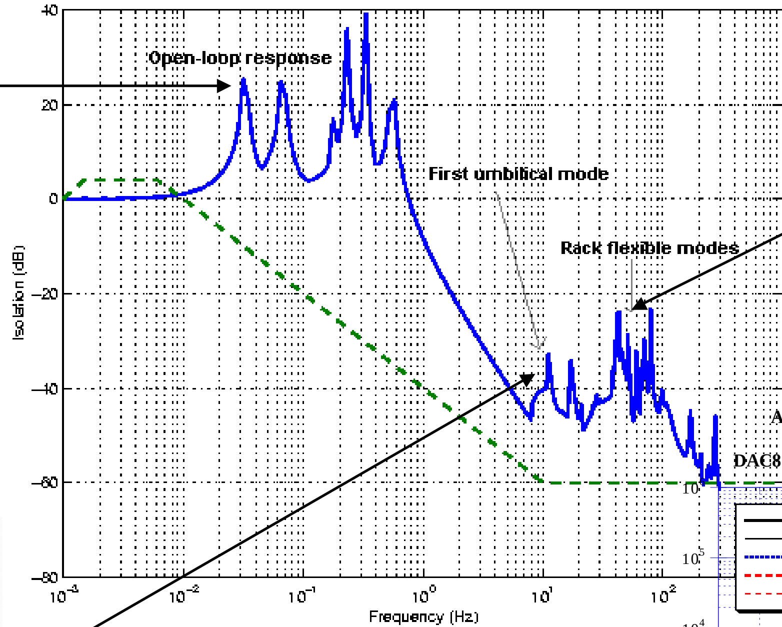


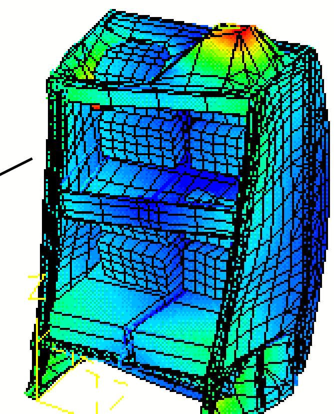
Snubber

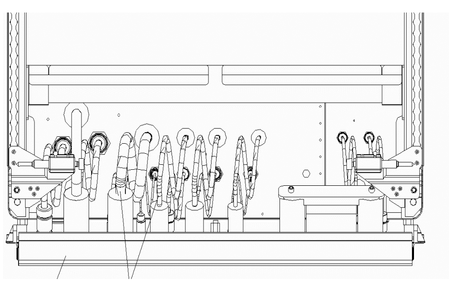
Umbilicals

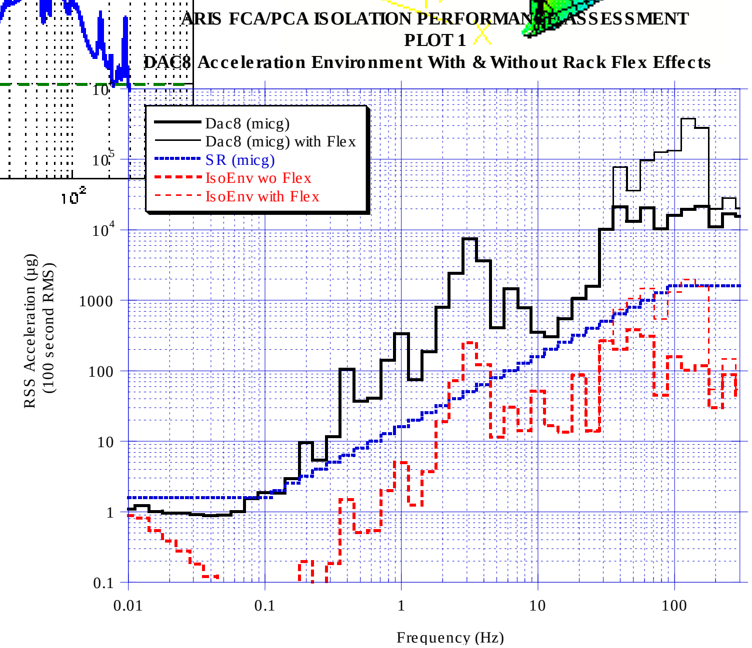
ARIS





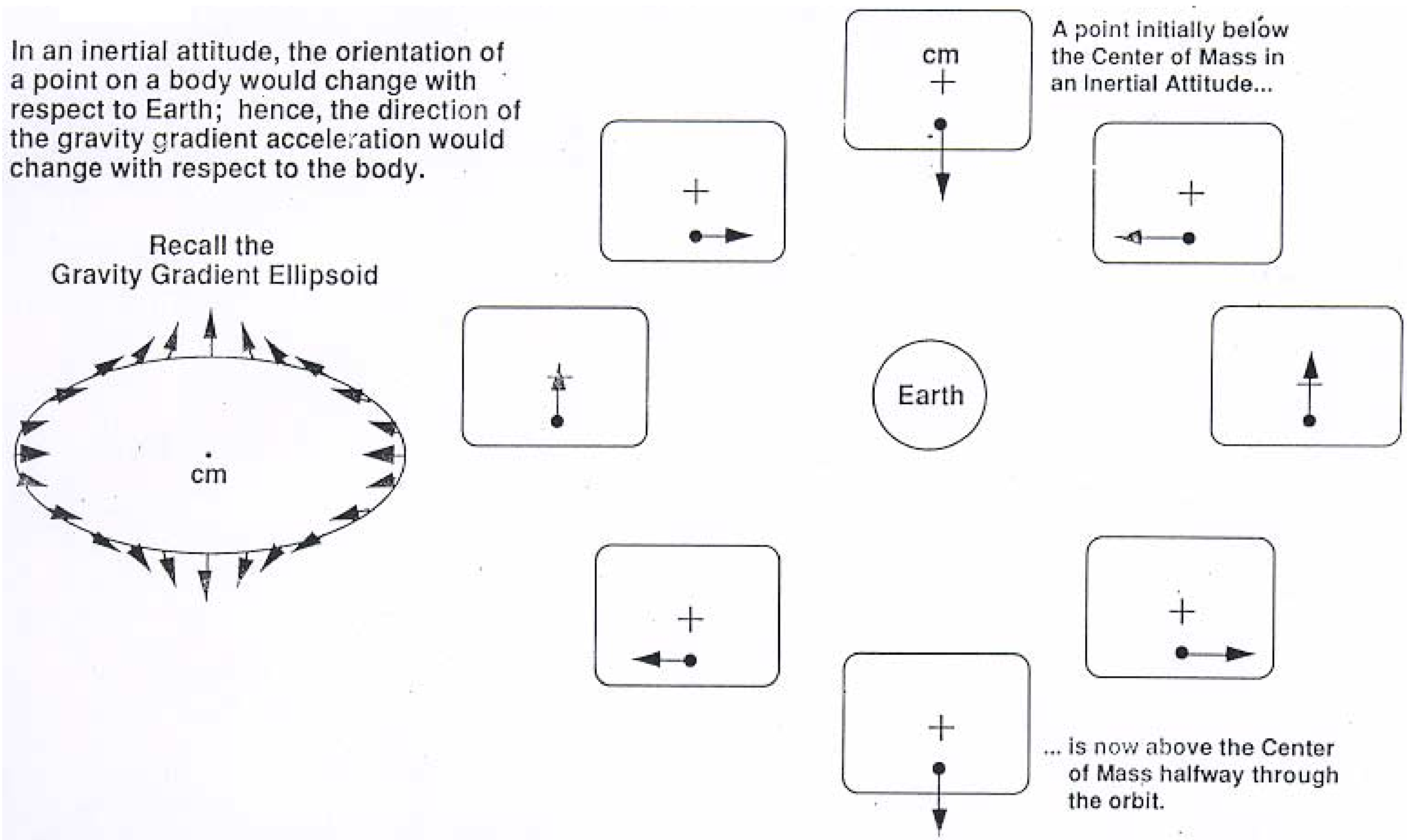




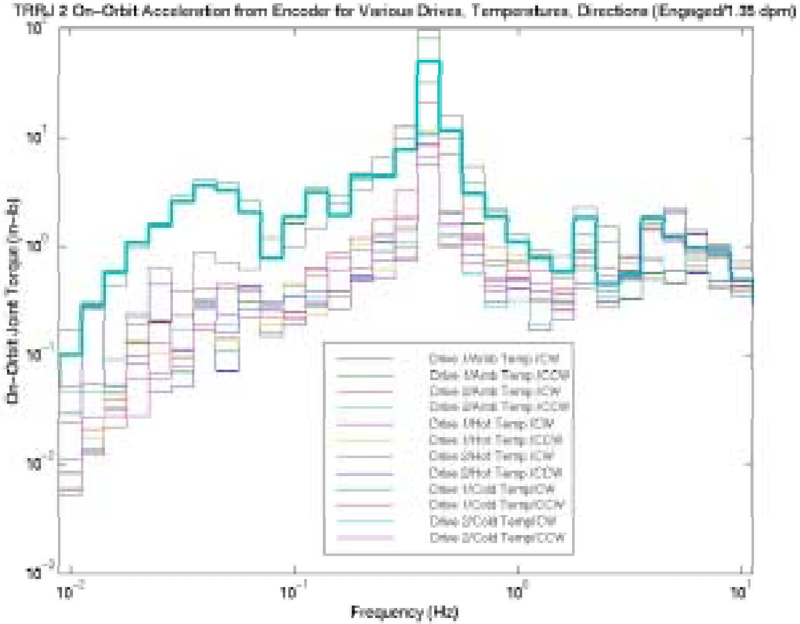


- Resonances between 0.01-1 Hz are rigid rack-umbilical modes (M-K)
- Resonance around 10 Hz is the umbilical loop resonance
- Resonances above 26 Hz are due to rack flexible modes being excited by umbilical and pushrod resonances.

Forcing Functions
Quasi-steady Stability - Once Per Orbit Rotation



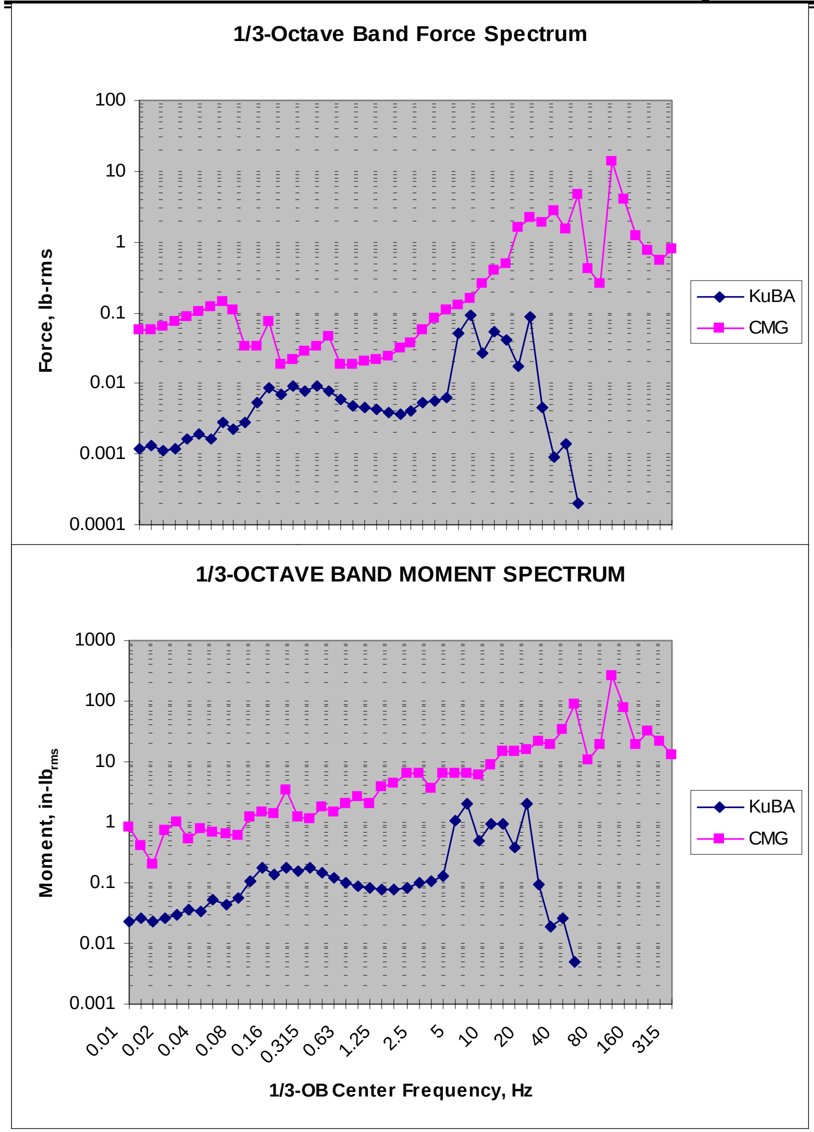
<u>Solar and Radiator Rotary Joints:</u> Torque Ripple, Bearing Friction, Gear Train Meshing Friction, Position/Resolver Error

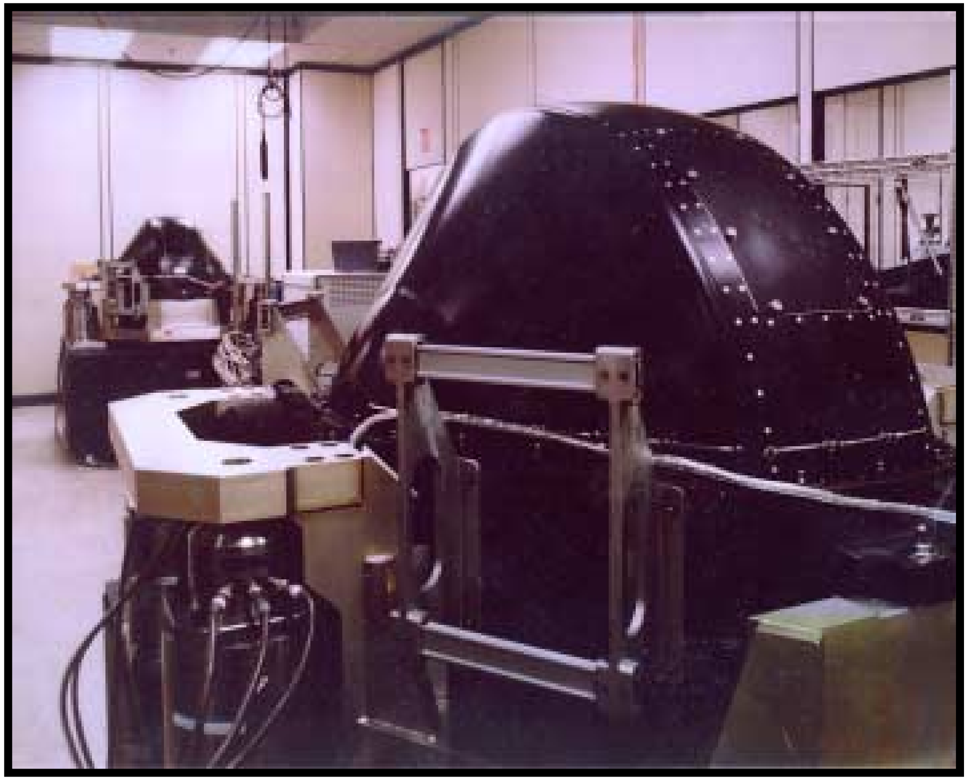


SARJ Drive Motor In Test

SARJ Qual Unit With Trundle Bearings Installed

Forcing Functions
Control Moment Gyros For Torque Equilibrium Attitude



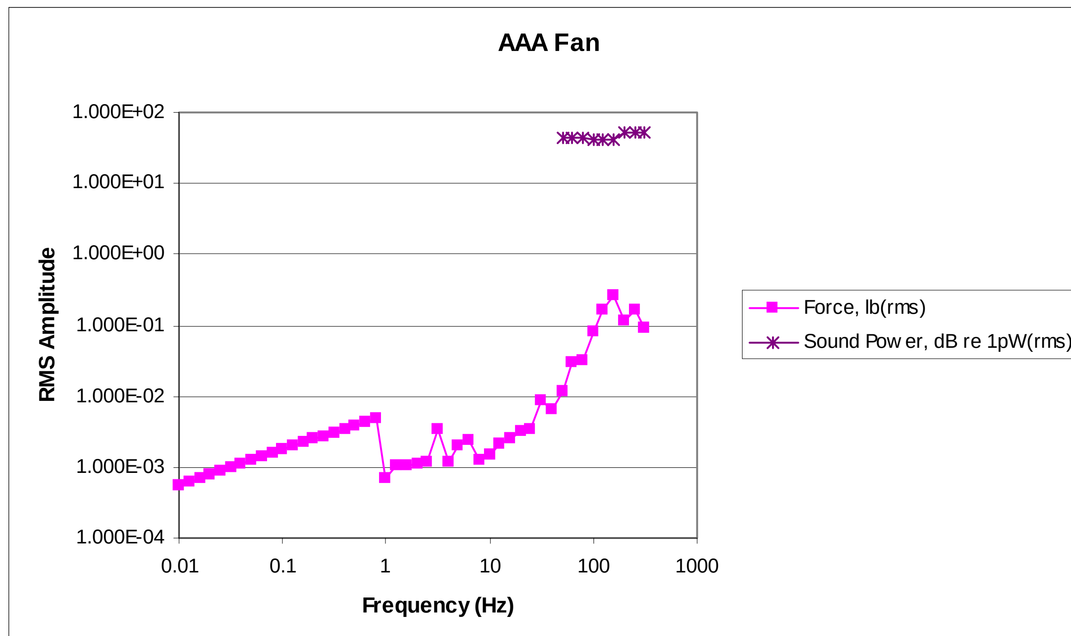


Forcing Functions

Co. / Agency	BHV			
Item	Fan, AAA (175 W, nominal)			
Location (Number)	Lc1 (1), Lc2 (1), Lc3 (1)			
	Ls1 (1), Ls2 (1), Ls3 (1)			
	Lf3 (1), Lf4 (1), Lf6 (1)			
	Lp1 (1), Lp2 (1), Lp4 (1)			
Duty	0.2 for each fan			
References	144			
Bibliography	1,2,11,17,26,38,50,52,55,56,75			
Comments	Umbalance force is assumed to be 0.115			
1/3-OB Ctr Freq, Hz	Time, s	Force, lb(rms)	Moment, in-lb(rms)	Sound Pow er, dB re 1pW(rms)
0.01		5.520E-04		
0.0125		6.175E-04		
0.016		6.960E-04		
0.02		7.810E-04		
0.025		8.730E-04		
0.0315		9.820E-04		
0.04		1.100E-03		
0.05		1.235E-03		
0.063		1.390E-03		
0.08		1.560E-03		
0.1		1.750E-03		
0.125		1.950E-03		
0.16		2.200E-03		
0.2		2.470E-03		
0.25		2.760E-03		
0.315		3.100E-03		
0.4		3.490E-03		
0.5		3.910E-03		
0.63		4.380E-03		
0.8		4.940E-03		
1		6.995E-04		
1.25		1.033E-03		
1.6		1.033E-03		
2		1.113E-03		
2.5		1.212E-03		
3.15		3.497E-03		
4		1.194E-03		
5		2.034E-03		
6.3		2.373E-03		
8		1.288E-03		
10		1.525E-03		
12.5		2.159E-03		
16		2.498E-03		
20		3.200E-03		
25		3.321E-03		
31.5		8.471E-03		
40		6.464E-03		
50		1.197E-02		4.450E+01
63		2.921E-02		4.450E+01
80		3.200E-02		4.450E+01
100		8.052E-02		4.120E+01
125		1.643E-01		4.120E+01
160		2.564E-01		4.120E+01
200		1.155E-01		5.200E+01
250		1.633E-01		5.200E+01
315		9.077E-02		5.200E+01

DISTURBANCE DATABASE

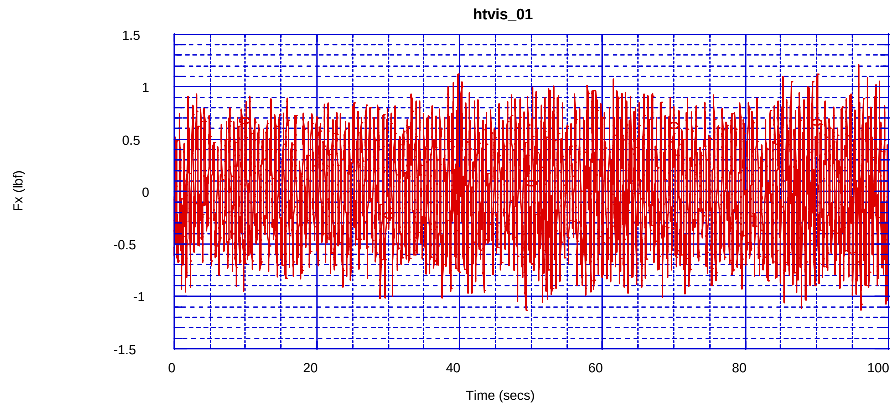
<u>Pressurized Module Disturbances:</u> Fans, Pumps, Valves, Coldplates, Ducts (Mechanical and Acoustic)

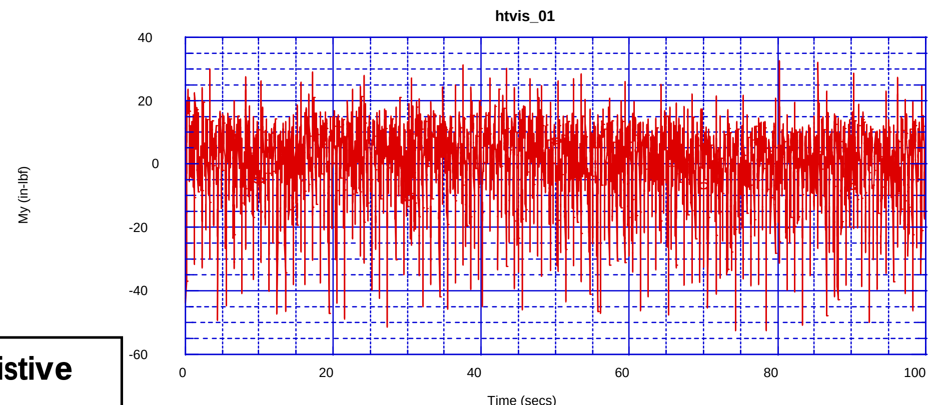


Forcing Functions

TVIS Certification Test

6 DOF Transient Force/Moment For Various Subjects





<u>Crew Exercise Equipment:</u> Treadmill, Ergometer, Resistive Exercise Device (Isolated/Non-isolated)

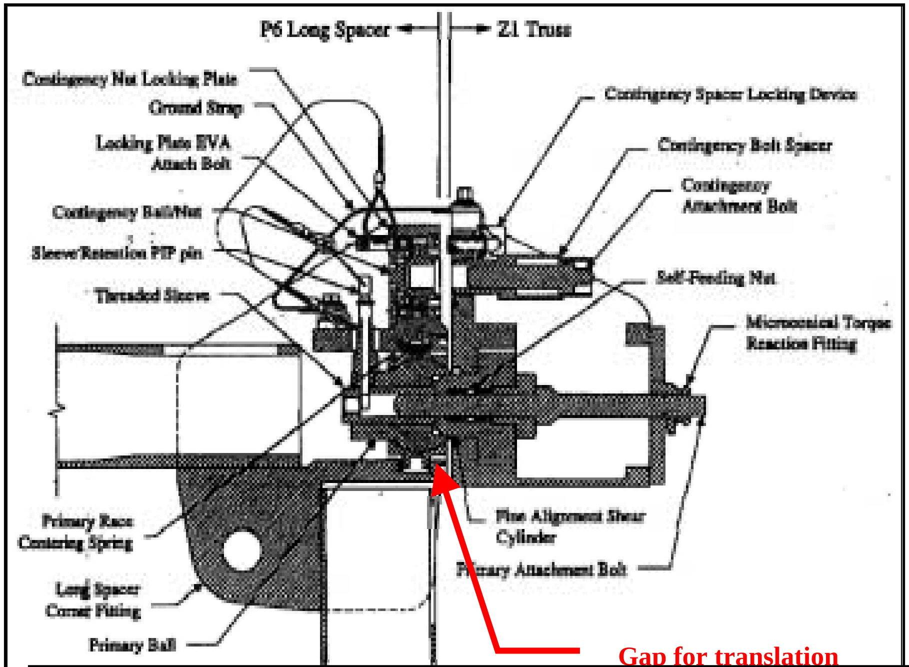
<u>InterVehicular Activity:</u> Translation, Station Keeping, Console Operations, ... Scheduled Maintenance.

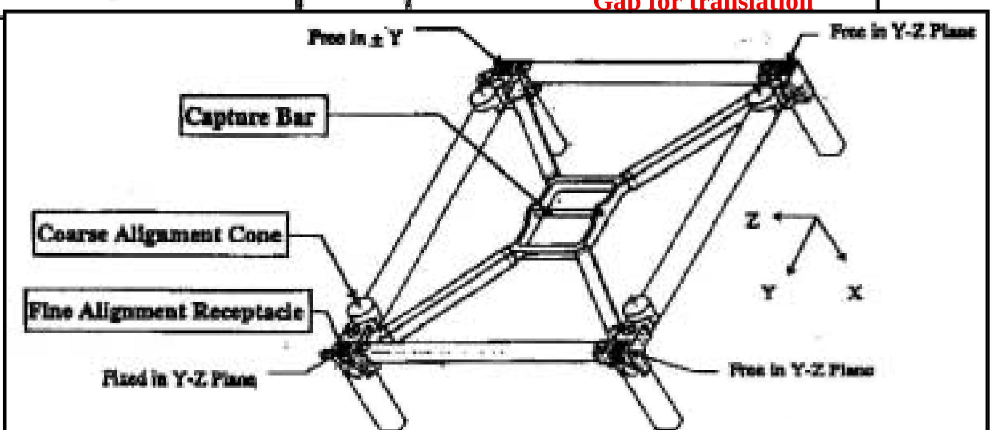
Forcing Functions

Thermal Induced Vibration

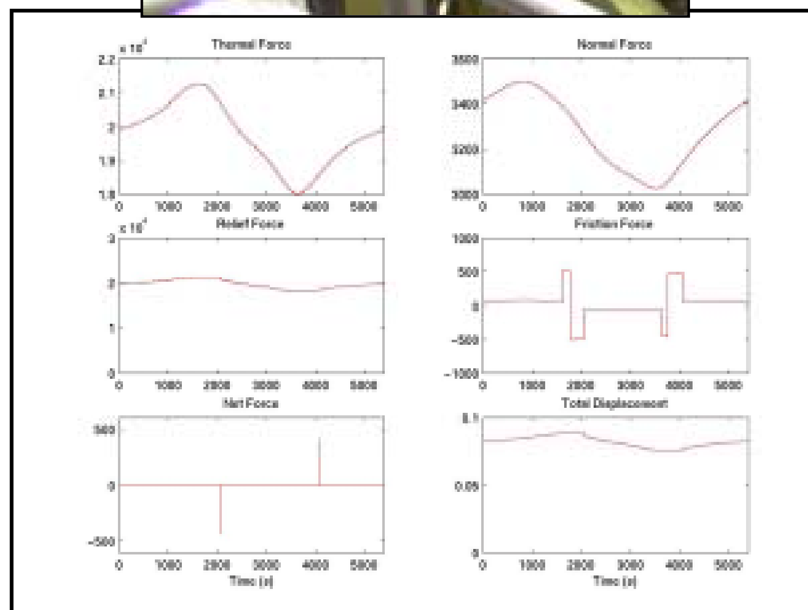
HARDWARE ITEM	STATIC FRICTION RELEASE (STICK-SLIP)	THERMAL STEP & MODAL DEFLECTION	SLOWLY VARYING DEFORMATION (~ORBITAL RATE)	THERMAL BUCKLING (OIL CANNING)
SHORT SPACER/ LONG SPACER INTERFACE	SIGNIFICANT • Rocketdyne Truss Attachment System (RTAS) forcing function developed by BHB (Refs. 10, 11, & 12). • BHOU assessment indicates that RTAS stick/slip is a Microgravity Critical Item (MGCIL) (Refs. 4). • Disturbance adequacy rating of 7 meets verification criteria.	NOT APPLICABLE TO INTERFACE	NOT APPLICABLE TO INTERFACE	NOT APPLICABLE TO INTERFACE
LONG SPACERS	NONE • No sliding joints other than at interface with short spacer – see short spacer/long spacer interface (Ref. 6).	NONE • No vibration modes below 30 Hz (Ref. 6).	NOT APPLICABLE • Item by itself is very stiff. Only when integrated with other elements (including non-PG2) will item experience low frequency motion (Ref. 17).	NONE • Constructed of hollow, extruded aluminum tubes with 3/16 inch minimum thickness. There are no thin plates or long slender members(Ref. 6).
IEAs	NONE • No sliding joints other than at interface with EPS radiator (Ref. 6) – see IEA/EPS radiator interface.	NONE • No vibration modes below 30 Hz (Ref. 6). • An IEA with full sun exposure could see a heat-up rate of 4 degrees F per hour. The rate is slow due to the mass of the structure (Ref. 20).	NOT APPLICABLE • Item by itself is very stiff. Only when integrated with other elements (including non-PG2) will item experience low frequency motion (Ref. 17).	NONE • Free thermal expansion with no thin plates or long slender members (Ref. 6)
EPS RADIATORS	NONE • No sliding joints other than at interface with EPS radiator (Ref. 6) – see IEA/EPS radiator interface.	NEGLIGIBLE • Fundamental vibration mode at 0.23 Hz is too high to be affected by slow temperature variations (Ref. 6). • Other than the PV Arrays, most items have a long thermal time constant, e.g. 15 minutes for the radiators (Ref. 15). • Each radiator weighs about 1600 lbs, compared to 2400 lbs for the PV Array, and about half of it is a concentrated load at the base. The radiator is about a quarter of the size of the PV Array. The forces and moments generated at the base of the radiator will be much smaller than that generated at the base of the PV Array which are negligible (Ref. 17).	NEGLIGIBLE • Each radiator weighs about 1600 lbs, compared to 2400 lbs for the PV Array, and about half of it is a concentrated load at the base. The radiator is about a quarter of the size of the PV Array. The forces and moments generated at the base of the radiator will be much smaller than that generated at the base of the PV Array which are negligible (Ref. 17).	NONE • The radiators are freely expanding structures (Refs. 6 & 17).

Forcing Functions

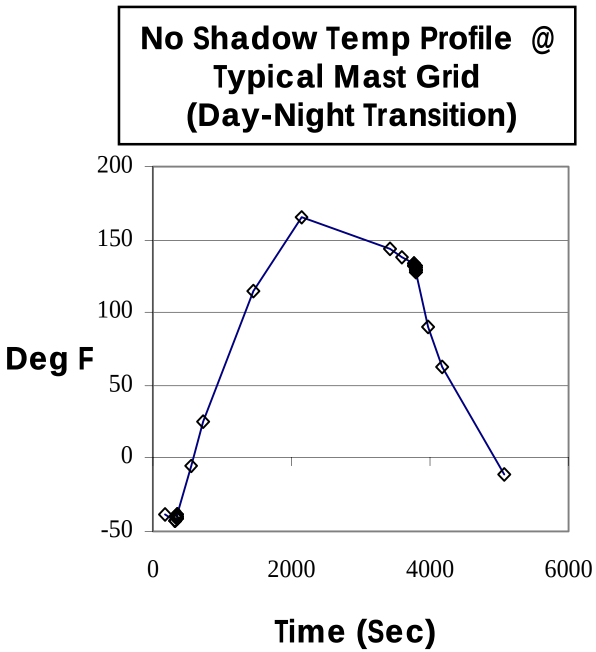


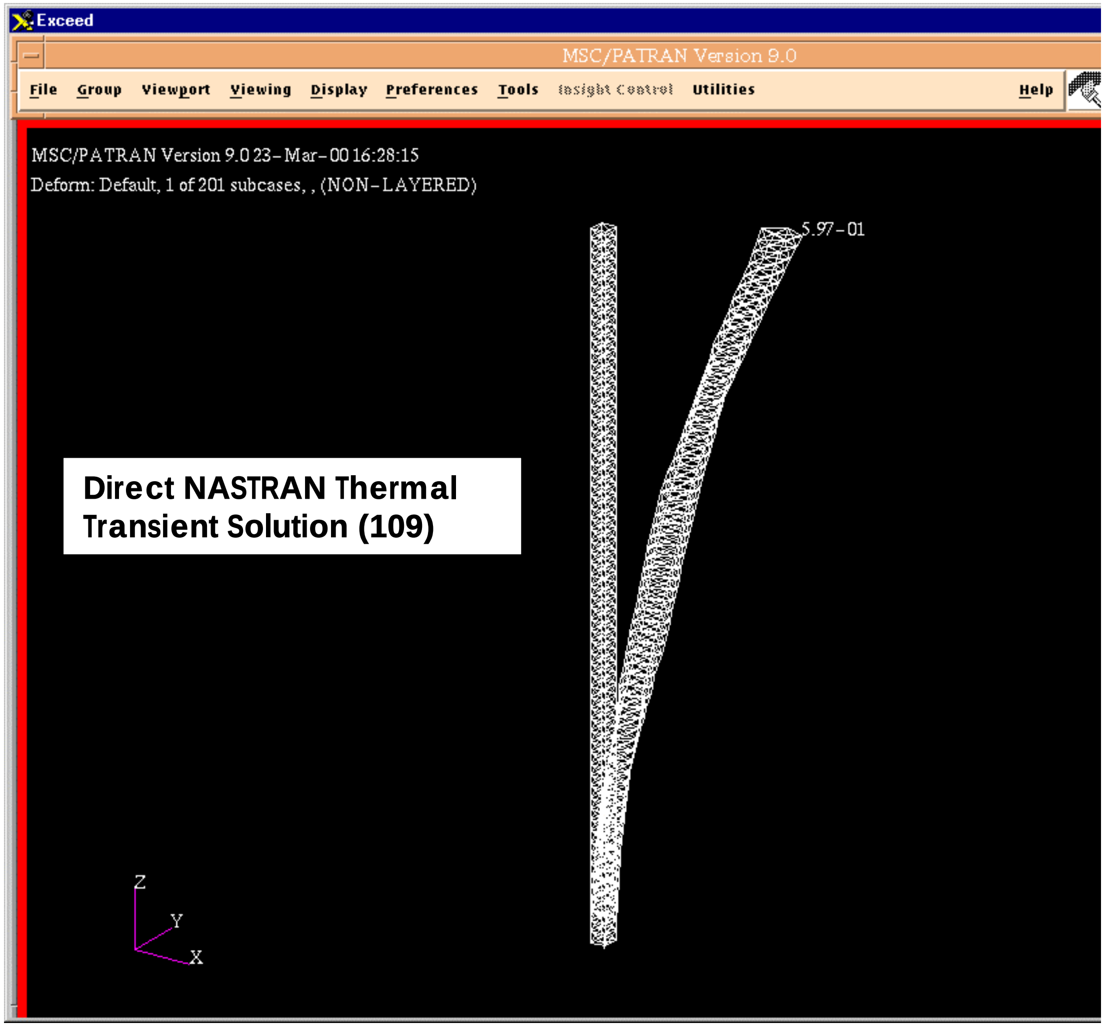


RTAS Stick-Slip



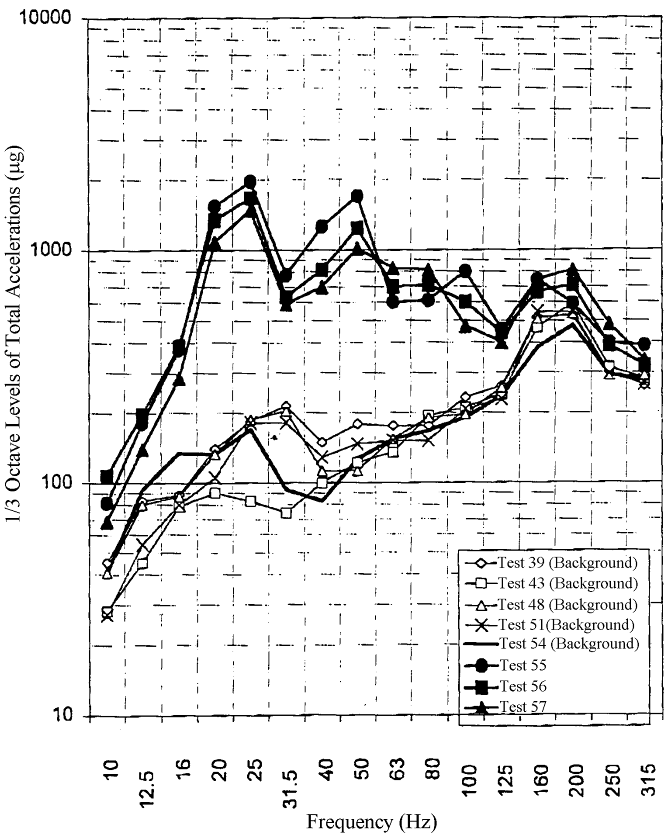
Forcing Functions





Forcing Functions

RS Service Module Element Ground Test



ESA Columbus Module Component Ground Test

ECLSS : -

* one Cabin fan assy (CFA EM5) (test data eq. &sect.)
* one Cabin fan assy as IMV Supply fan (test data eq. & sect.)
* one Cabin fan Assy as IMV Return Fan (test data - eq. &sect.)
* two Condensate Water Separator Assies (CWSA EM) (test data - eq. & sect.)
* one Condensate Heat Exchanger/Thermal Control valve (CHX/TCV) (testdata - eq. & sect.)
* TWO WASTE GAS Line shut Off Valve (LSOV) (test data -eq.)
* One WLSV EM (test data - eq.)
* Two PPO2 (test data -eq.)
* Airbox (Test data-Section)

TCS:

* one WPA (test data -eq.))
* one WOO (actuated) (test data -eq.)
* two WTMO (actuated) (test data - eq.)
* fluxed ducting (test data - sect.)

Structural Stick/slip :

* Stick/slip at MDPS/bracket interface (analytical evaluation)

NASDA ICS Antenna Slew & Tracking

ISS Traffic Model

- **The traffic plan includes a complete traffic event schedule and a projected resupply/return loading by cargo category starting with first element launch through end of life.**
- **The integrated traffic plan is also used to support design analysis, unique transportation system studies, off-nominal operations planning, and to assess the viability of long-term planning inputs from International Partners.**

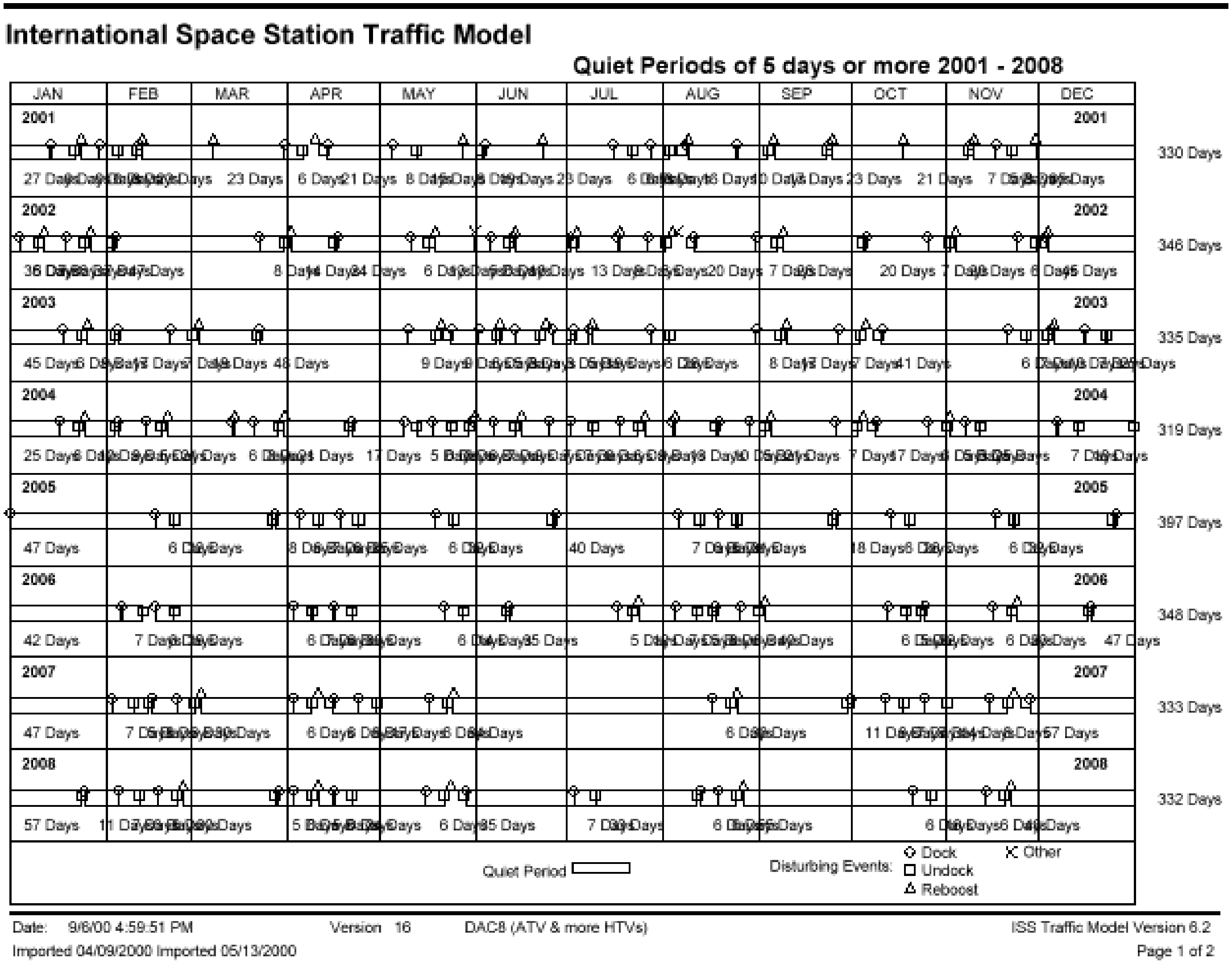
What are the major disturbers to ISS micro-g

- Docking events
- Undocking events
- Reboosts
- EVAs

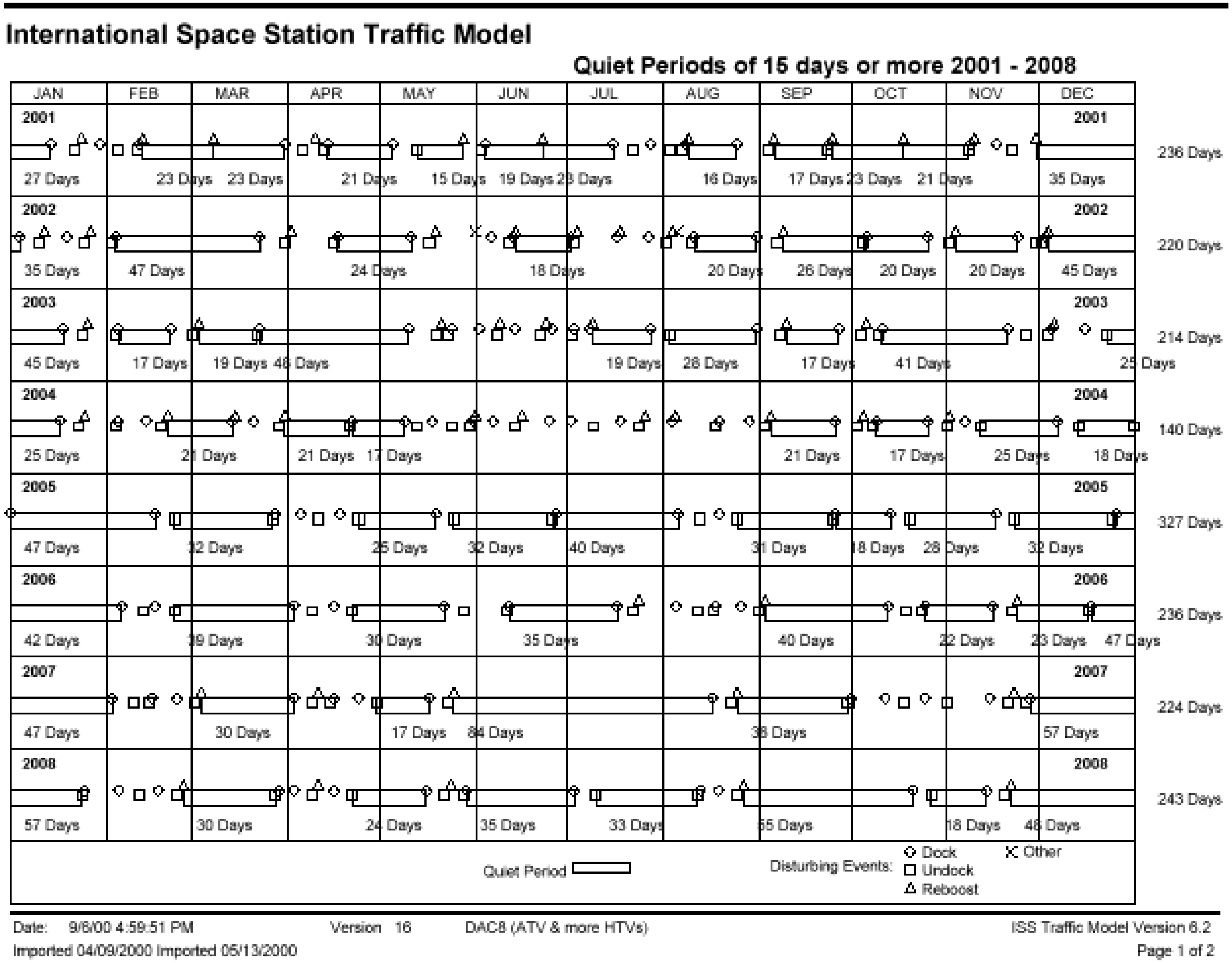
Threats to micro-gravity periods

- Debris Avoidance Maneuvers
- Deferred or contingency EVAs
- Launch schedule changes

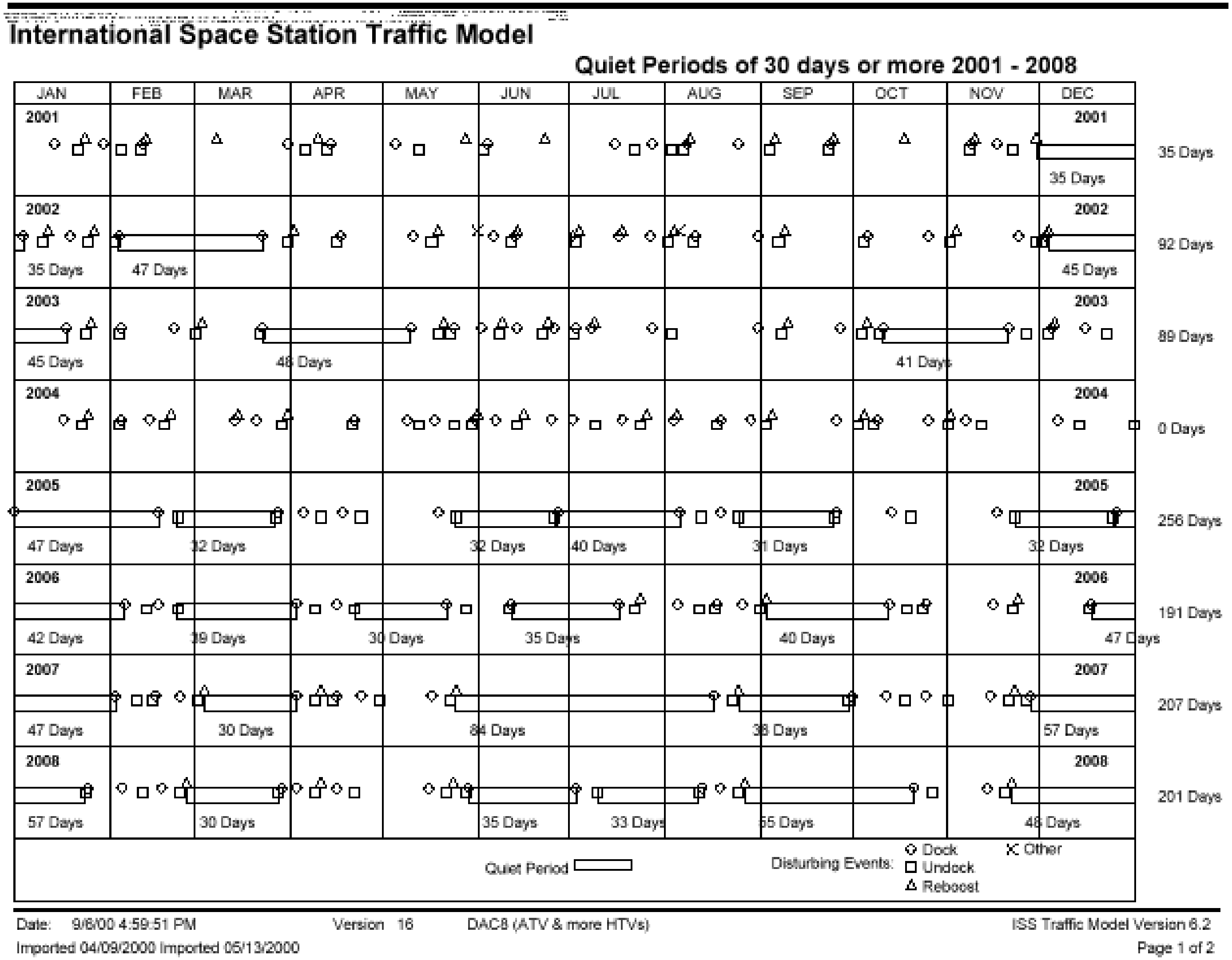
DAC8 Assembly >5 Day Periods



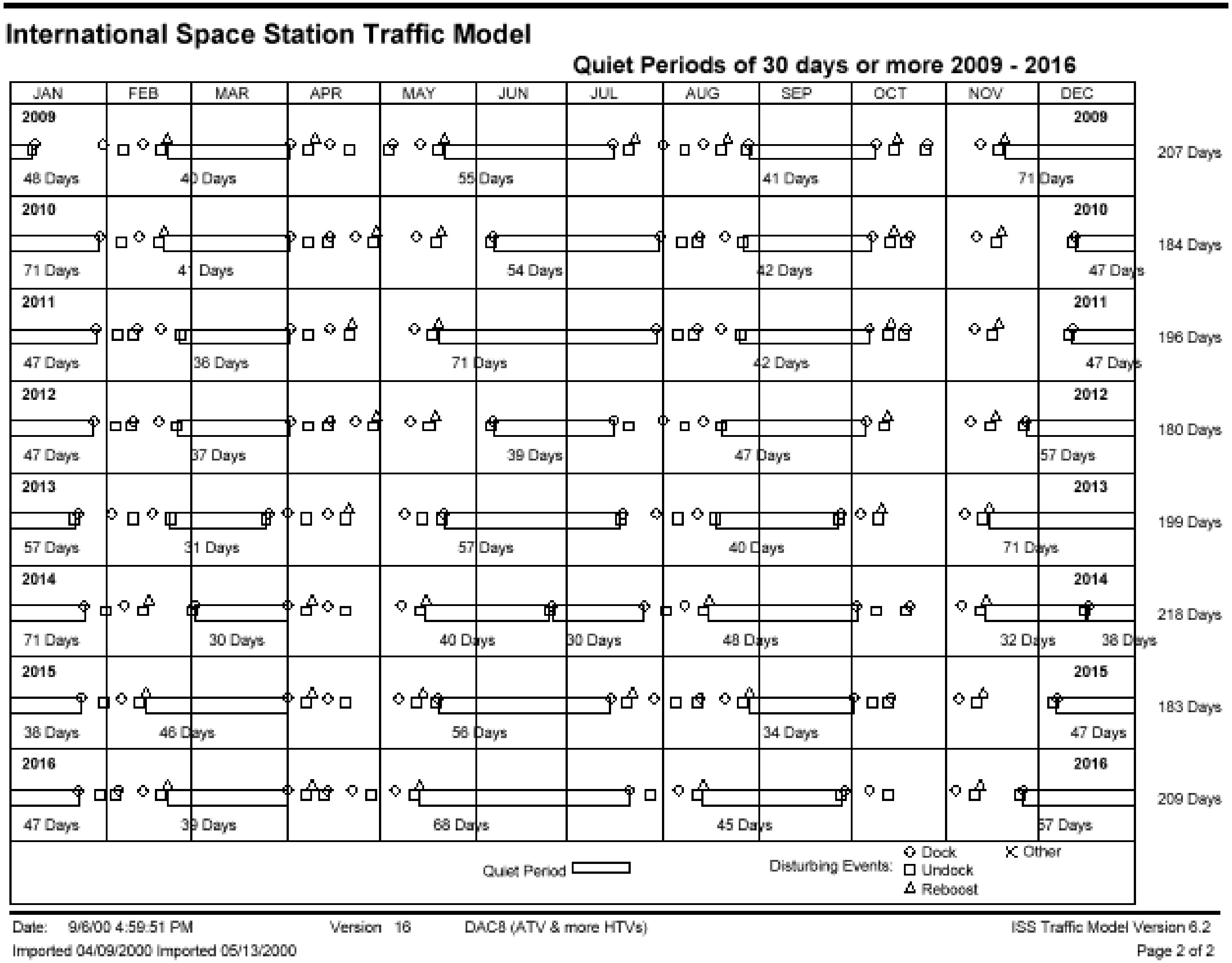
DAC8 Assembly >15 Day Periods



DAC8 Assembly >30 Day Periods



DAC8 Assembly Complete >30 Day Periods

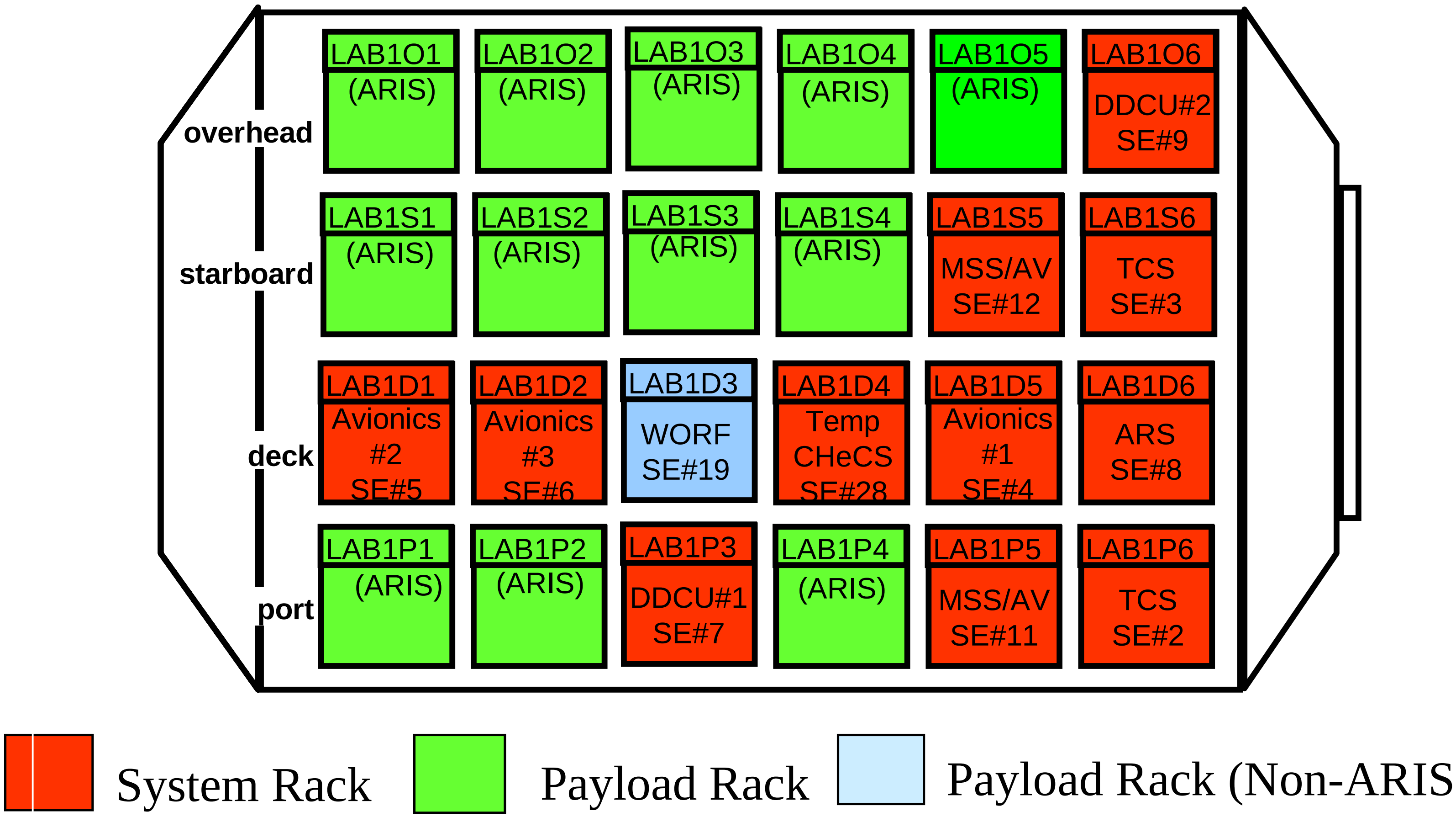


Conclusion

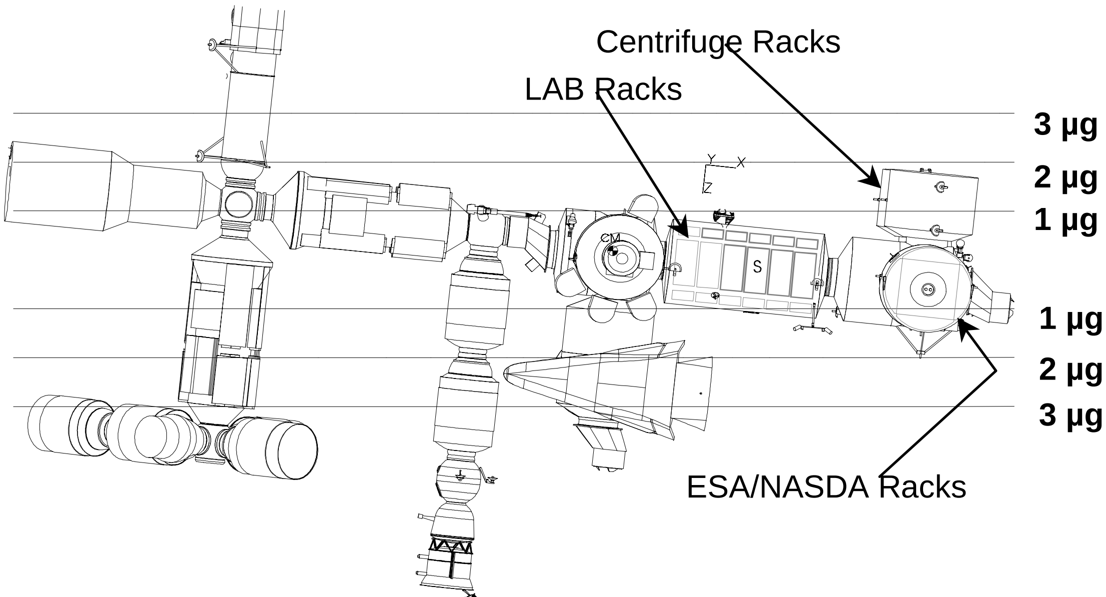
- **Currently there is no requirement to meet the micro-gravity period requirement during assembly**

- **Based on analysis the micro-gravity requirement can be satisfied during the assembly complete period**

Rack Topology at Assembly Complete (Analysis Configuration)

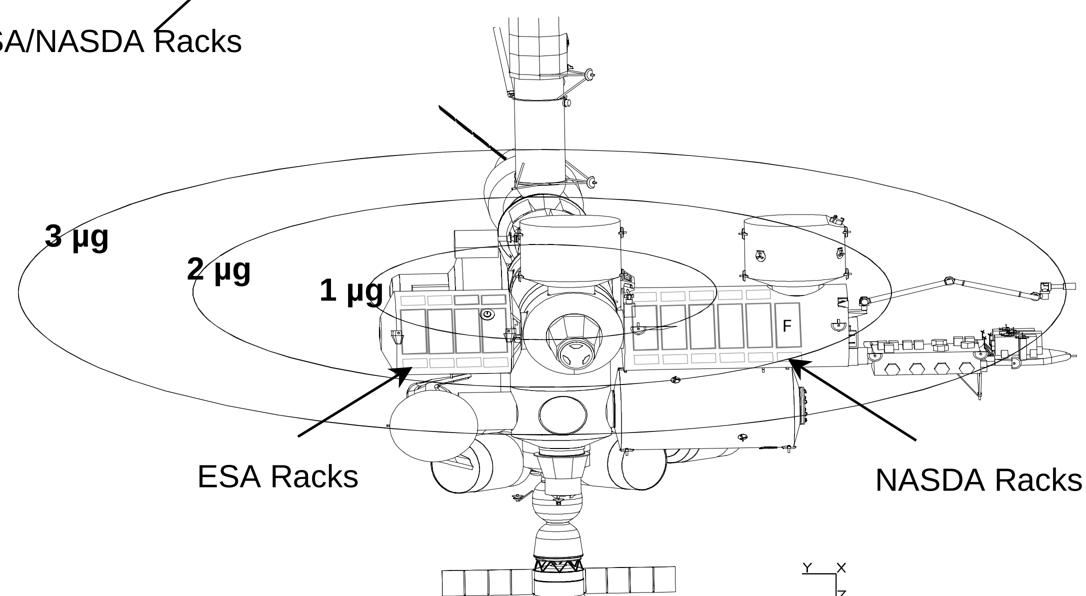


DAC8 Quasi-Steady Performance



<u>Quasi-steady Performance</u>:
- **15 of 32 ISPRs < 1.0 µg**
- **16 of 32 ISPRs < 1.2 µg**
- **All satisfy stability criteria**

<u>Flight Attitude</u>:
- **Pitch -6.97 degrees**
- **Yaw -8.07 degrees**
- **Roll 1.16 degrees**



DAC8 Quasi-Steady Performance

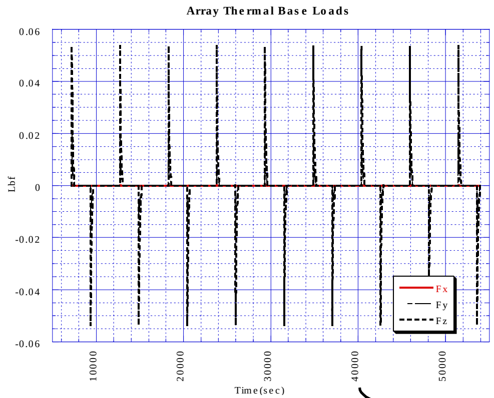
15 of 32 racks less than 1 μg magnitude & 0.2 μg perpendicular component.

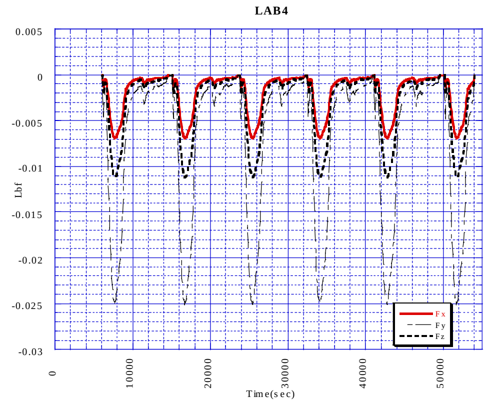
Location	Rack Position in ISS Frame			μG Vector		Unit Vector				Cone Angle	
	X (ft)	Y (ft)	Z (ft)	Magnitude (μG)	⊥ Component (μG)	X	Y	Z	Max angle from unit vector (deg)	⊥ Component @ max angle (μG)	Magnitude at max angle (μG)
CG	-15.34	-1.28	14.87	0.210	0.038	-0.994	-0.107	0.013	20.660	0.025	0.065
USL-C1	15.55	0.00	11.26	0.245	0.064	-0.624	-0.773	-0.119	24.100	0.054	0.122
USL-C2	12.05	0.00	11.26	0.232	0.063	-0.665	-0.722	0.191	26.258	0.050	0.101
USL-C3	8.55	0.00	11.26	0.230	0.070	-0.635	-0.584	0.506	26.070	0.051	0.104
USL-C4	5.05	0.00	11.26	0.243	0.078	-0.546	-0.406	0.733	23.624	0.056	0.129
USL-C5	1.55	0.00	11.26	0.266	0.084	-0.446	-0.247	0.860	20.229	0.062	0.168
USL-S1	15.55	4.84	16.11	0.689	0.087	-0.321	0.068	-0.945	7.346	0.087	0.672
USL-S2	12.05	4.84	16.11	0.645	0.086	-0.340	0.108	-0.934	7.765	0.086	0.628
USL-S3	8.55	4.84	16.11	0.602	0.084	-0.362	0.154	-0.919	8.219	0.084	0.584
USL-S4	5.05	4.84	16.11	0.560	0.083	-0.386	0.207	-0.899	8.793	0.076	0.488
USL-P1	15.55	-4.84	16.11	0.722	0.088	-0.217	-0.488	-0.845	7.082	0.088	0.707
USL-P2	12.05	-4.84	16.11	0.671	0.087	-0.230	-0.497	-0.837	7.551	0.087	0.656
USL-P4	5.00	-4.84	16.11	0.570	0.085	-0.264	-0.519	-0.813	8.725	0.084	0.546
JPM1-A1	29.66	-10.82	15.92	1.035	0.091	-0.126	-0.652	-0.748	5.190	0.091	1.006
JPM2-F1	40.00	-10.82	15.92	1.193	0.093	-0.118	-0.617	-0.778	4.618	0.093	1.156
JPM3-A2	29.66	-14.32	15.92	1.121	0.092	-0.097	-0.726	-0.680	4.810	0.092	1.089
JPM4-F2	40.00	-14.32	15.92	1.274	0.094	-0.094	-0.688	-0.720	4.339	0.094	1.234
JPM5-A3	29.66	-17.82	15.92	1.217	0.092	-0.072	-0.783	-0.617	4.450	0.092	1.182
JPM6-F3	40.00	-17.82	15.92	1.364	0.094	-0.072	-0.744	-0.664	4.068	0.094	1.321
JPM7-A4	29.66	-21.32	15.92	1.320	0.093	-0.050	-0.827	-0.561	4.122	0.093	1.283
JPM8-A5	29.66	-24.82	15.92	1.429	0.093	-0.032	-0.860	-0.510	3.831	0.093	1.392
JPM9-F5	40.00	-24.82	15.92	1.566	0.095	-0.036	-0.825	-0.564	3.585	0.095	1.520
JPM10-F6	40.00	-28.32	15.92	1.675	0.096	-0.021	-0.854	-0.521	3.384	0.096	1.627
APM-CLG1	34.84	14.39	10.74	0.517	0.089	-0.435	0.684	-0.586	9.998	0.089	0.505
APM-CLG2	34.84	18.33	10.74	0.640	0.093	-0.379	0.794	-0.475	8.422	0.093	0.629
APM-FWD1	40.00	14.39	15.91	1.078	0.094	-0.272	0.266	-0.925	5.027	0.094	1.067
APM-FWD2	40.00	18.33	15.91	1.146	0.095	-0.277	0.390	-0.878	4.781	0.095	1.135
APM-FWD3	40.00	22.26	15.91	1.229	0.096	-0.277	0.493	-0.825	4.521	0.096	1.219
APM-FWD4	40.00	26.19	15.91	1.326	0.098	-0.274	0.576	-0.771	4.267	0.098	1.316
APM-AFT1	29.67	14.39	15.91	0.963	0.092	-0.297	0.366	-0.882	5.528	0.092	0.951
APM-AFT2	29.67	18.33	15.91	1.045	0.094	-0.295	0.491	-0.820	5.173	0.094	1.033
APM-AFT3	29.67	22.26	15.91	1.142	0.095	-0.290	0.587	-0.756	4.824	0.095	1.131
APM-AFT4	29.67	26.19	15.91	1.251	0.098	-0.282	0.661	-0.695	4.504	0.098	1.242
CAM-MID	36.08	0.00	4.17	0.608	0.091	-0.045	-0.410	0.911	8.877	0.091	0.581
CAM-TOP	36.08	0.00	0.00	1.077	0.092	0.033	-0.216	0.976	5.019	0.092	1.042

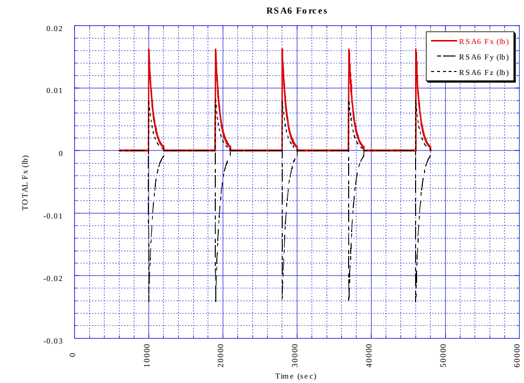
DAC8 Quasi-steady Individual Disturbance Inputs

- **Centrifuge startup and shut down**
  - **Spin-up for 120 sec to 236 deg/s, spin for 6.4 hours, spin-down for 120 sec.**
  - **Starts at 17000 sec**
- **TRRJ slew at low betas**
  - **TRRJ 0 beta slew rates - TRRJ Torque Power Spectral Density has 87.7% of its power below .01 Hz.**
  - **Not Applicable**
- **Solar Thermal base loads**
  - **Exponential decay for 210 seconds every 2160 seconds (night), 3360 (day), forces combined for eight arrays**
  - **Lighting dependent , continuous**
- **LAB4 Vent**
  - **Force profile, duration of 8700 seconds**
  - **Starts at 6000 seconds**
- **RSA6 Vent**
  - **Exponential decay of 600 seconds every 9000 seconds**
  - **Starts at 10000 seconds**
- **Treadmill Gyro Start-up**
  - **+.23 ft-lbs. for 10minutes, 0 ft-lbs. for 60 minutes, -.23 ft-lbs. for 10 minutes, repeated every 30 minutes.**
  - **Starts at 6000 seconds**

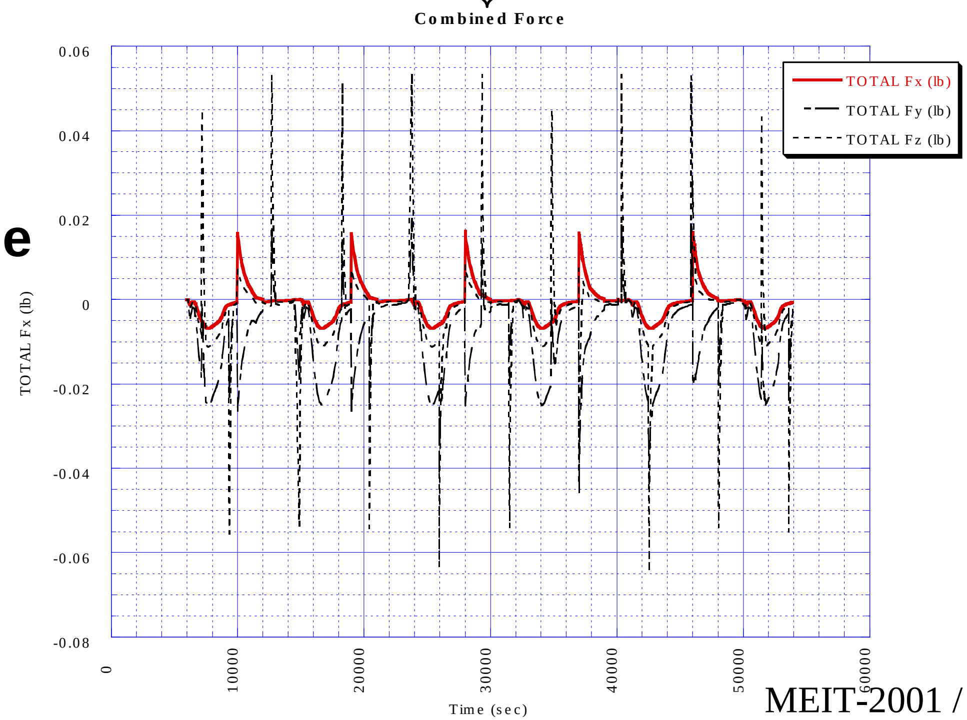
DAC8 Quasi-steady Individual Disturbance Inputs



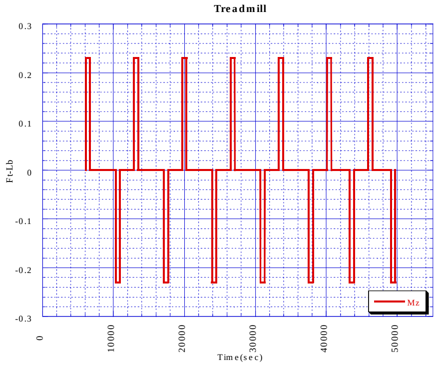


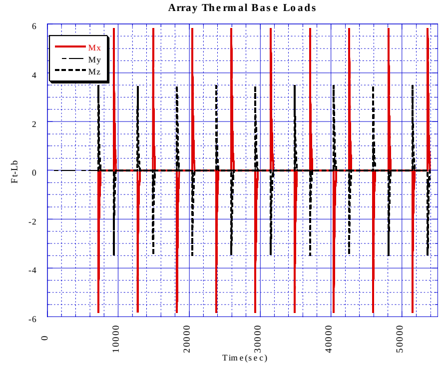


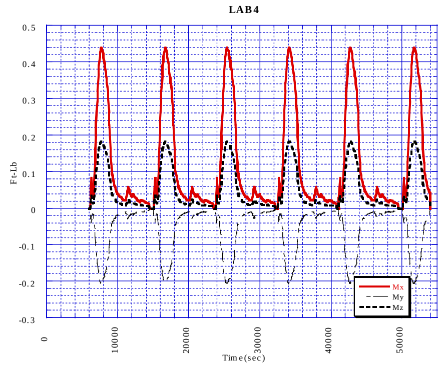
Force files combined into one file

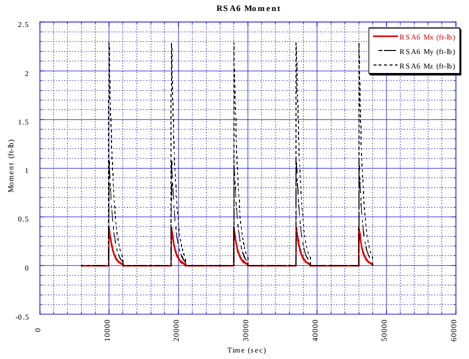


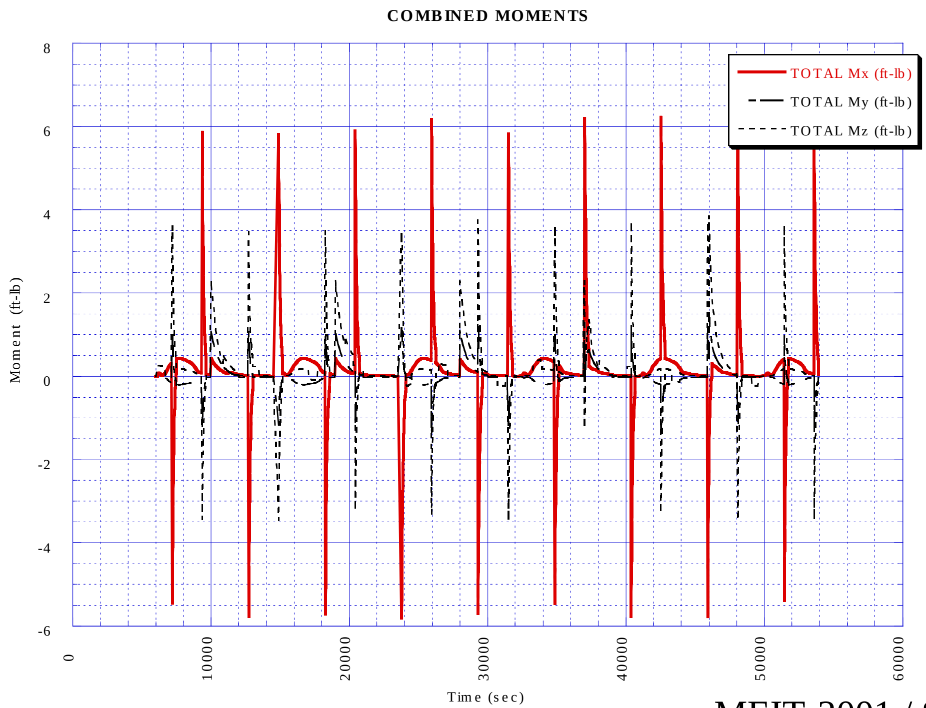
DAC8 Quasi-steady Individual Disturbance Inputs











Moments combined into one file

DAC8 Quasi-Steady Performance With Individual Disturbances Delta Comparison

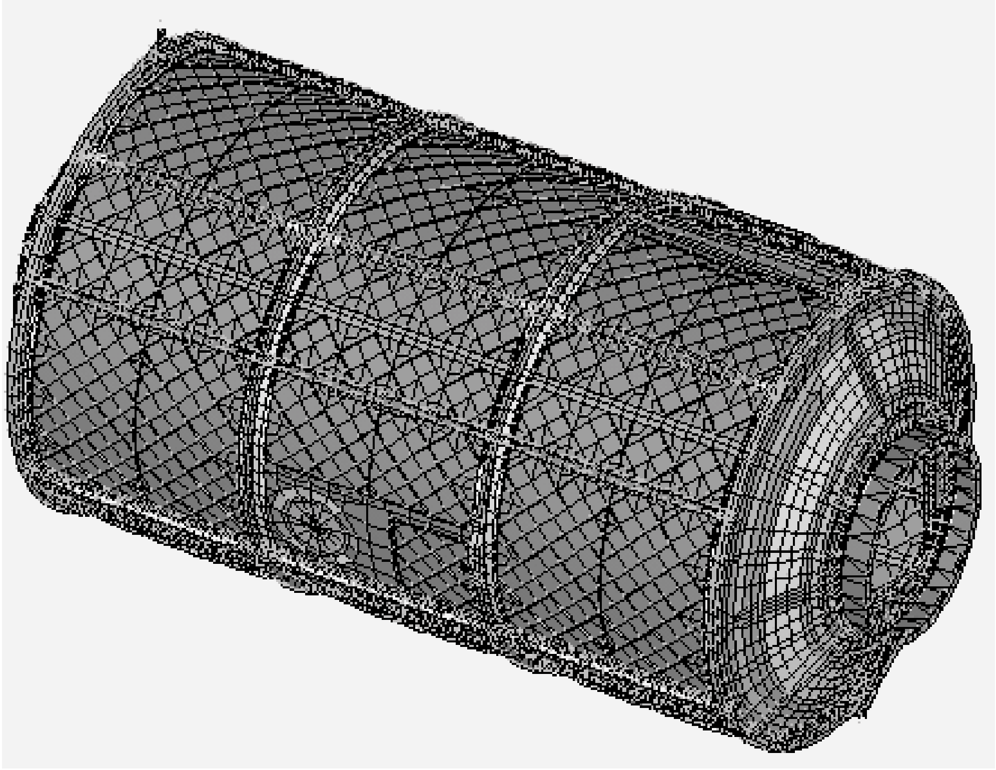
14 versus 15 of 32 racks under 1 μg magnitude and .2 μg perpendicular component (APM AFT1 to 1.068 & 0.22)

Location	Magnitude Disturbance (μG)	Magnitude Nominal (μG)	Magnitude Delta Dist-Nom (μG)	Mag % Difference	⊥ Component Disturbance (μG)	⊥ Component Nominal (μG)	⊥ Component Delta Dist-Nom (μG)	⊥ Component % Difference
CG	0.211	0.210	0.001	0%	0.080	0.046	0.203	74%
USL-C1	0.293	0.245	0.048	20%	0.158	0.064	0.094	147%
USL-C2	0.269	0.232	0.037	16%	0.150	0.063	0.087	138%
USL-C3	0.258	0.230	0.028	12%	0.140	0.070	0.070	100%
USL-C4	0.259	0.243	0.016	7%	0.128	0.078	0.050	64%
USL-C5	0.293	0.266	0.027	10%	0.116	0.084	0.032	38%
USL-S1	0.711	0.689	0.022	3%	0.170	0.087	0.083	95%
USL-S2	0.668	0.645	0.023	4%	0.156	0.086	0.070	81%
USL-S3	0.625	0.602	0.023	4%	0.142	0.084	0.058	69%
USL-S4	0.584	0.560	0.024	4%	0.128	0.083	0.045	54%
USL-P1	0.791	0.722	0.069	10%	0.139	0.088	0.051	58%
USL-P2	0.735	0.671	0.064	10%	0.127	0.087	0.040	46%
USL-P4	0.623	0.570	0.053	9%	0.105	0.085	0.020	24%
JPM1-A1	1.132	1.035	0.097	9%	0.150	0.091	0.059	65%
JPM2-F1	1.293	1.193	0.100	8%	0.188	0.093	0.095	102%
JPM3-A2	1.225	1.121	0.104	9%	0.153	0.092	0.061	66%
JPM4-F2	1.383	1.274	0.109	9%	0.172	0.094	0.078	83%
JPM5-A3	1.327	1.217	0.110	9%	0.157	0.092	0.065	71%
JPM6-F3	1.480	1.364	0.116	9%	0.174	0.094	0.080	85%
JPM7-A4	1.435	1.320	0.115	9%	0.162	0.093	0.069	74%
JPM8-A5	1.547	1.429	0.118	8%	0.168	0.093	0.075	81%
JPM9-F5	1.691	1.566	0.125	8%	0.183	0.095	0.088	93%
JPM10-F6	1.804	1.675	0.129	8%	0.189	0.096	0.093	97%
APM-CLG1	0.710	0.517	0.193	37%	0.151	0.089	0.062	70%
APM-CLG2	0.856	0.640	0.216	34%	0.133	0.093	0.040	43%
APM-FWD1	1.184	1.078	0.106	10%	0.268	0.094	0.174	185%
APM-FWD2	1.283	1.146	0.137	12%	0.259	0.095	0.164	173%
APM-FWD3	1.393	1.229	0.164	13%	0.249	0.096	0.153	159%
APM-FWD4	1.513	1.326	0.187	14%	0.242	0.098	0.144	147%
APM-AFT1	1.068	0.963	0.105	11%	0.219	0.092	0.127	138%
APM-AFT2	1.176	1.045	0.131	13%	0.211	0.094	0.117	124%
APM-AFT3	1.296	1.142	0.154	13%	0.206	0.095	0.111	117%
APM-AFT4	1.423	1.251	0.172	14%	0.206	0.098	0.108	110%
CAM-MID	0.650	0.608	0.042	7%	0.238	0.091	0.147	162%
CAM-TOP	1.100	1.077	0.023	2%	0.252	0.092	0.160	174%

US Lab Model Frequencies

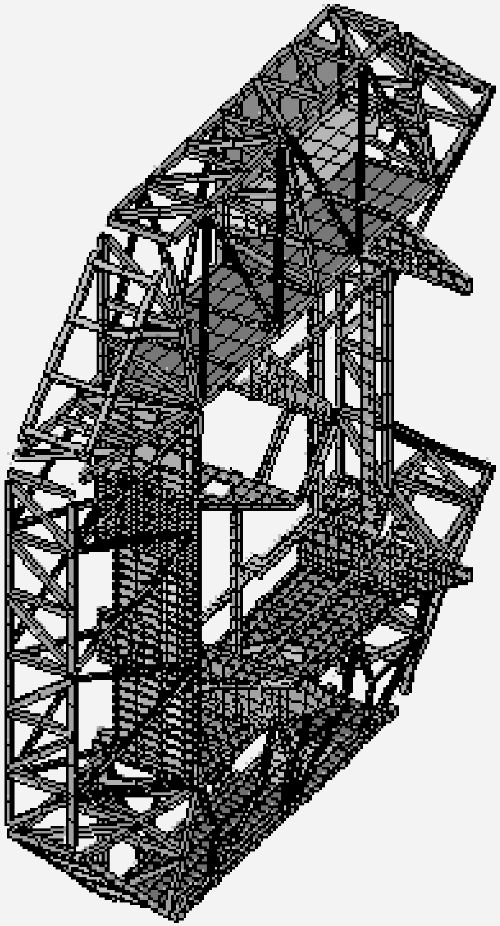
9.29E-04	Rigid Body Mode
1.60E-03	Rigid Body Mode
2.06E-03	Rigid Body Mode
2.33E-03	Rigid Body Mode
2.69E-03	Rigid Body Mode
3.93E-03	Rigid Body Mode
2.39E+00	
2.83E+00	
2.89E+00	
2.99E+00	
3.04E+00	
3.08E+00	
3.12E+00	
3.29E+00	
3.39E+00	
3.62E+00	
3.75E+00	
4.04E+00	

Integrated US Lab Model

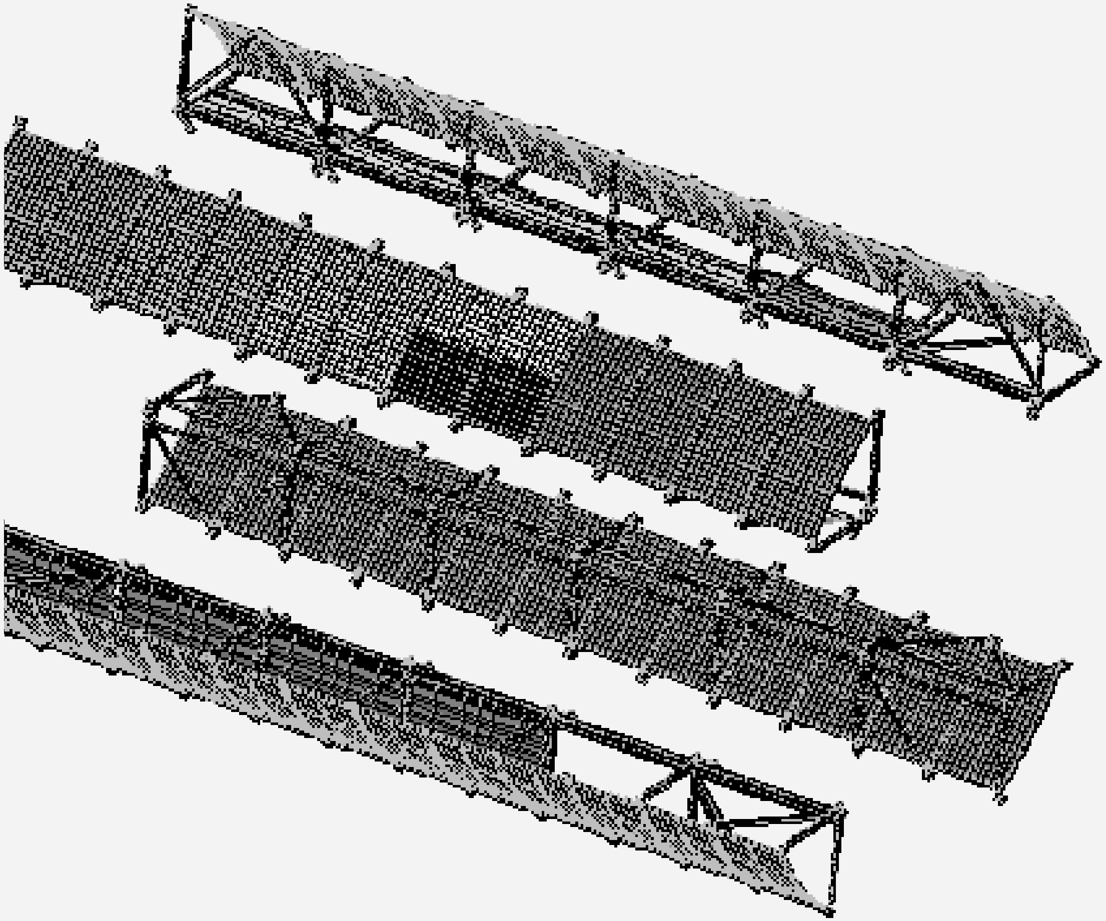


DAC8 Finite Element Model

Aft ESS

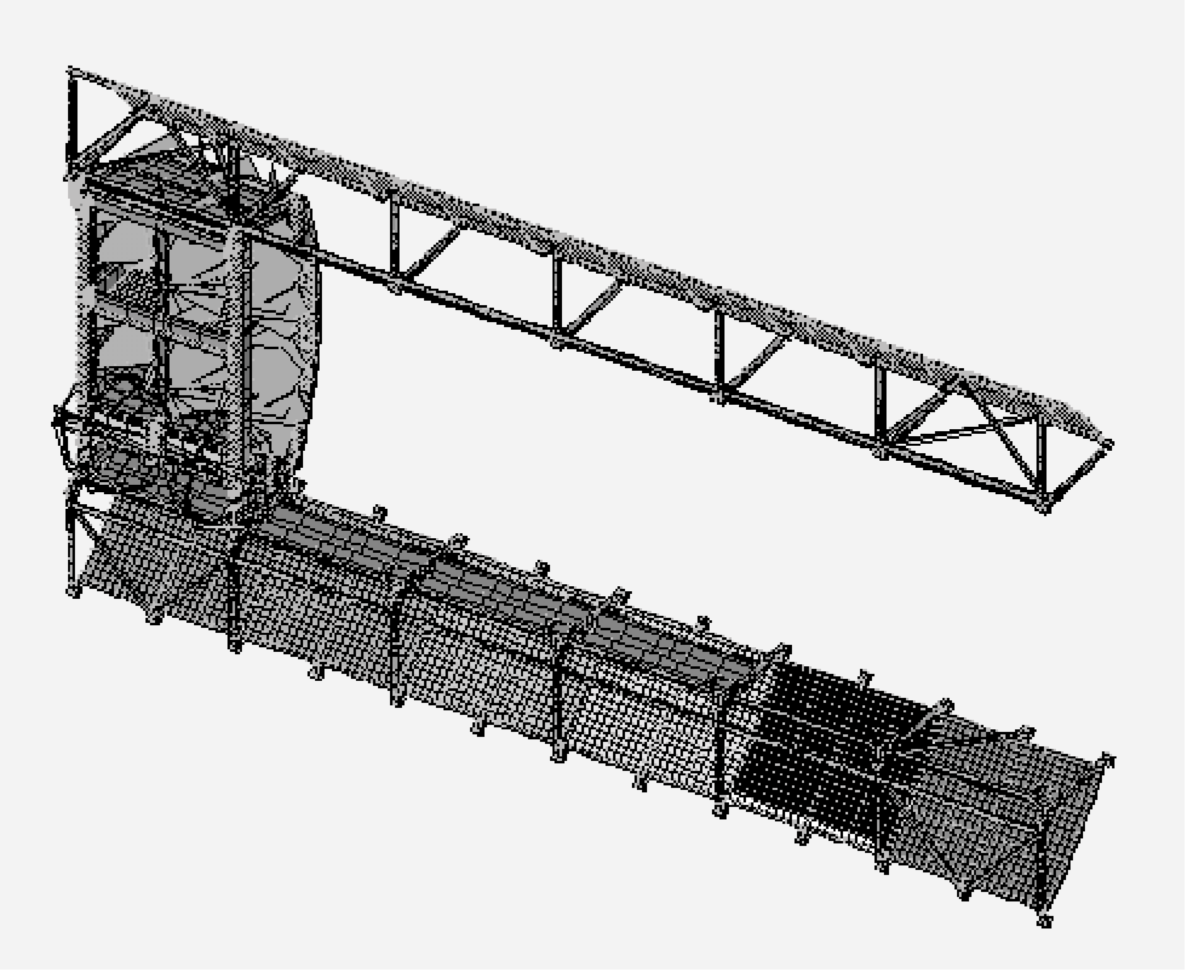


Standoffs



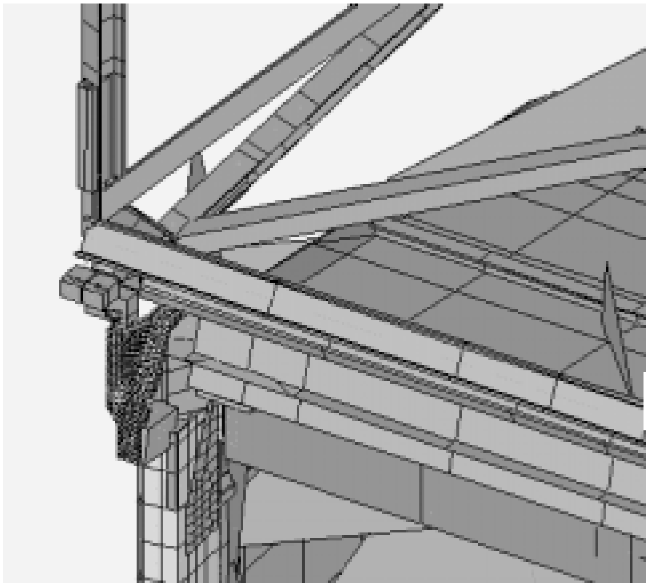
DAC8 Finite Element Model

Rack Integrated with Standoffs

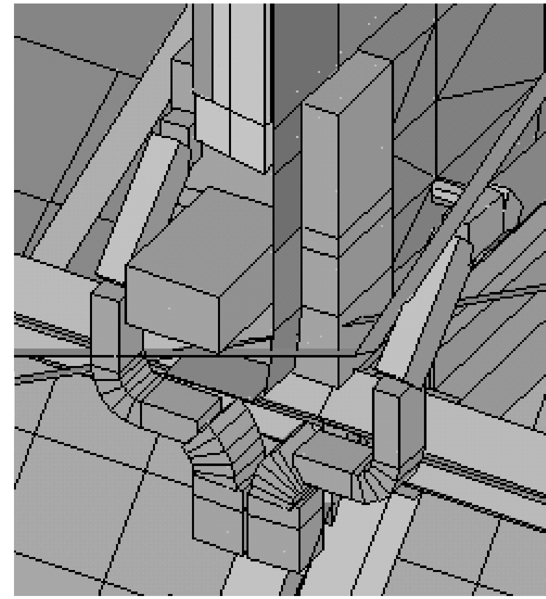


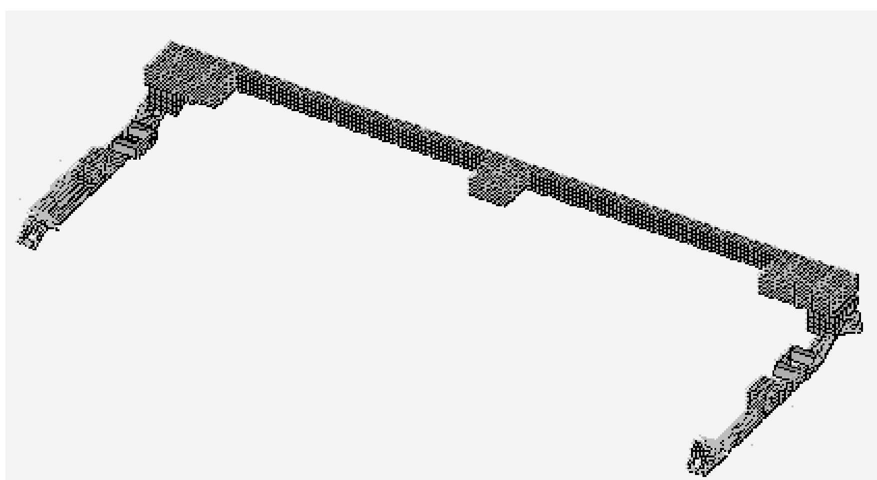
DAC8 Finite Element Model

K-Bar



Pivot Pins

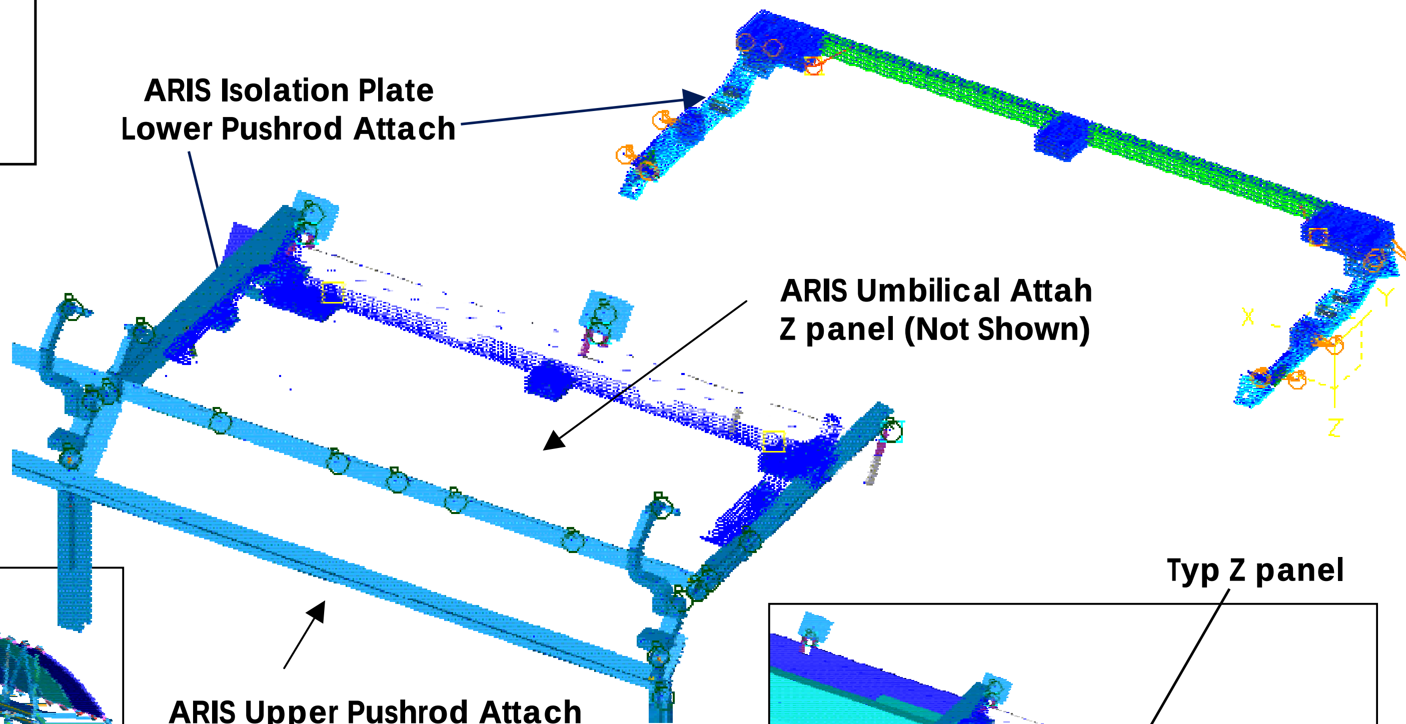




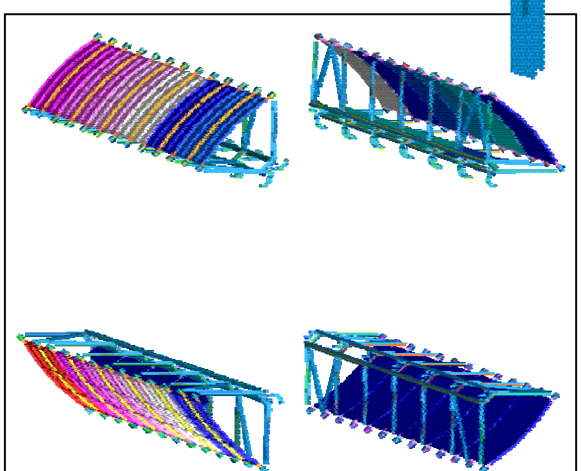
Isolation Plate

Requirement Applicability

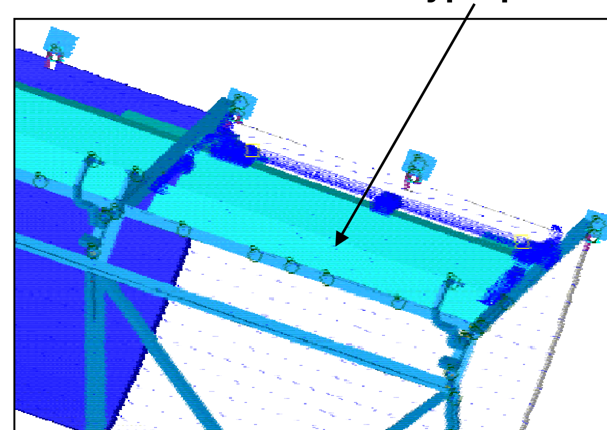
@ 50% Of ISPRs In APM/JEM/LAB Vibratory @ Rack To Module Interface



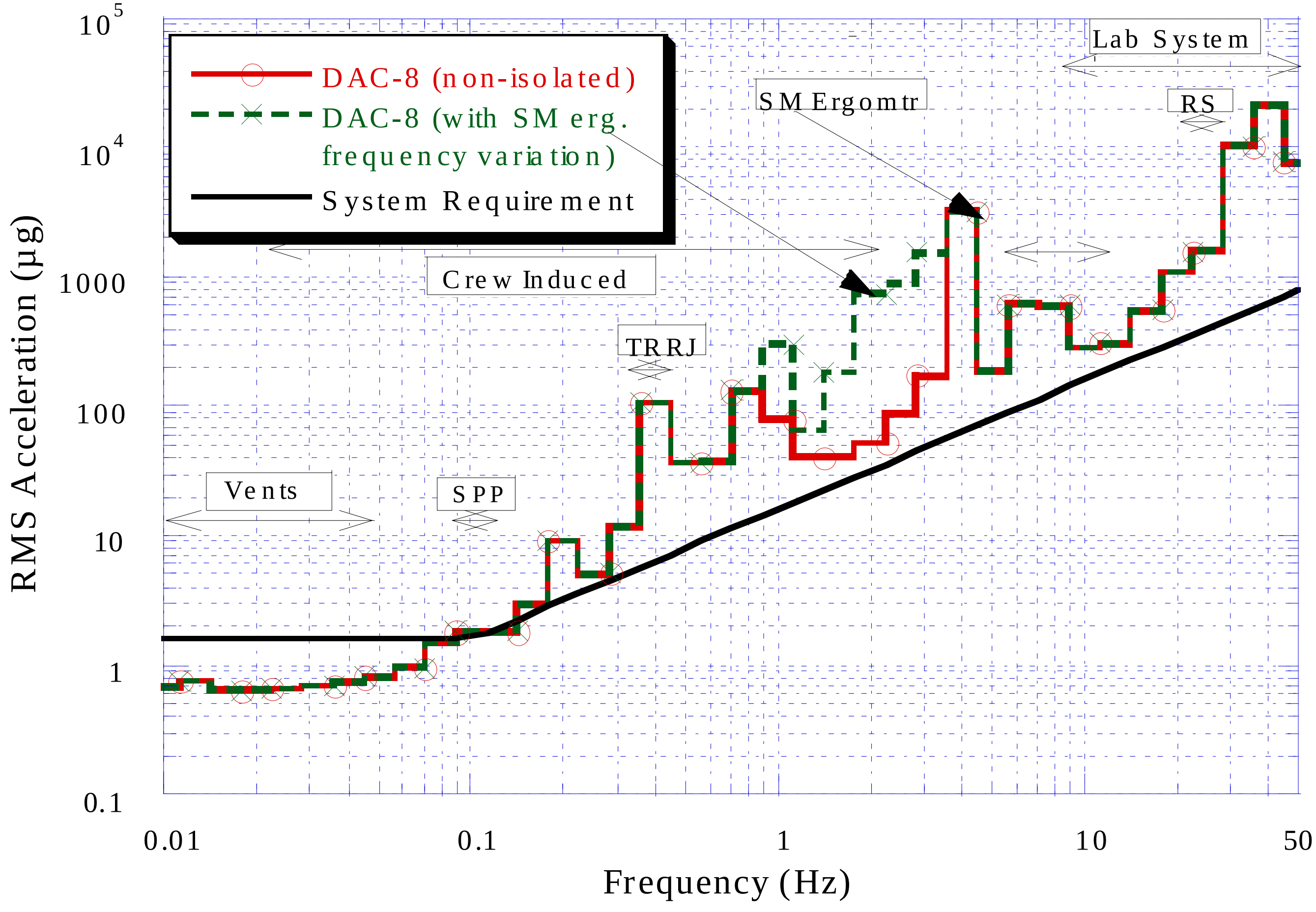
Lab Standoffs



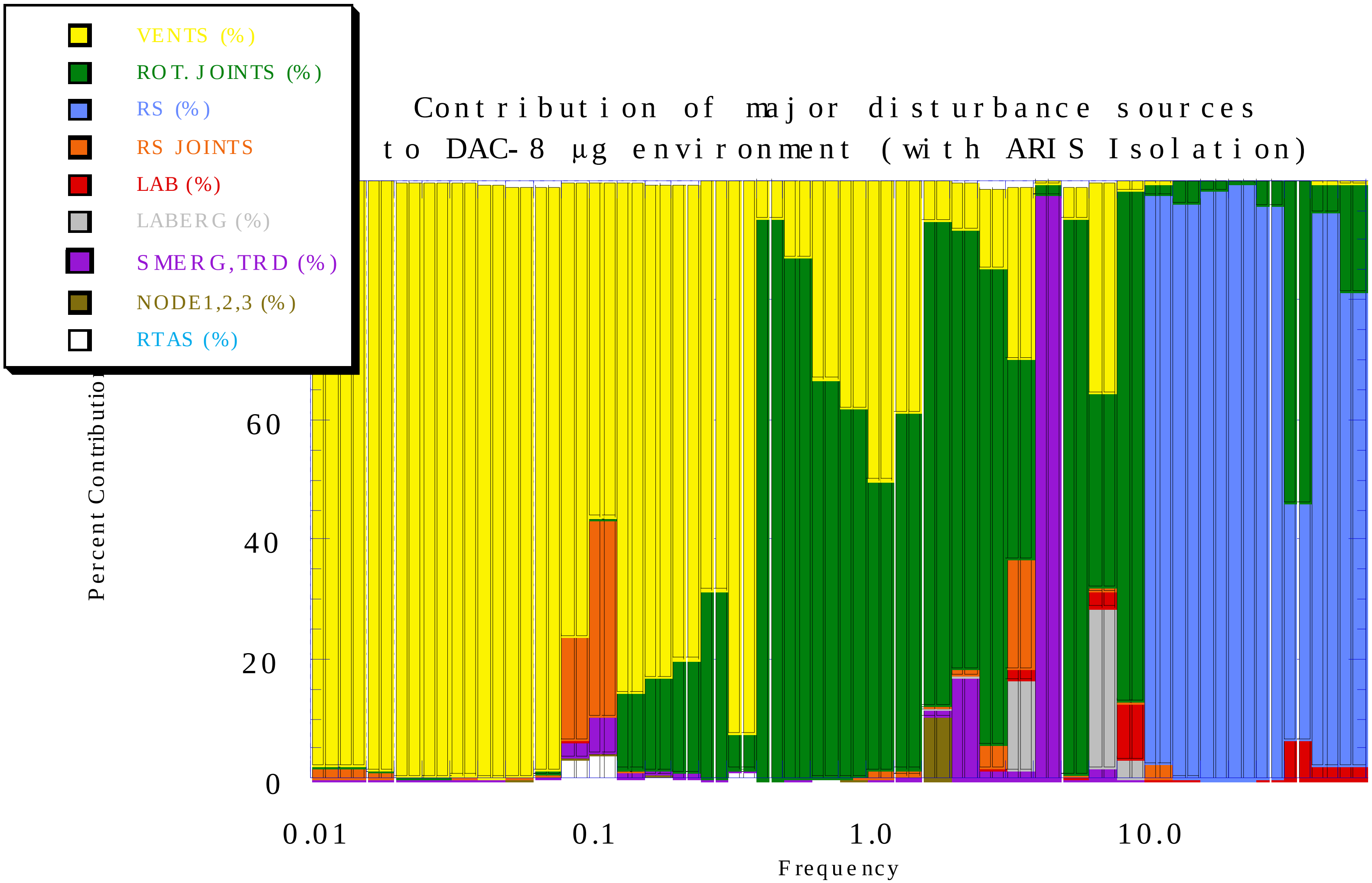
Typ Z panel



DAC8 Non-Isolated Performance
Structural Dynamic Frequency Range



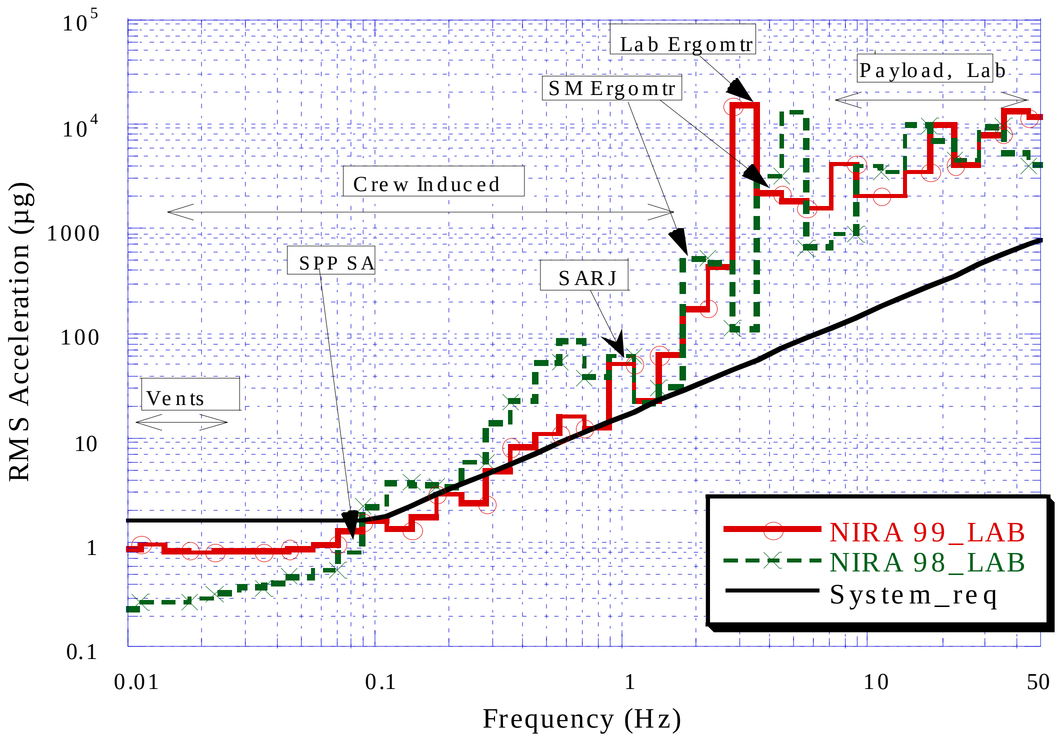
DAC8 Performance
Structural Dynamic Frequency Range



NIRA 99 - US Lab
Structural Dynamic Frequency Range

Non-Isolated Rack Assessment Differences From DAC8 Requirement Compliance Results

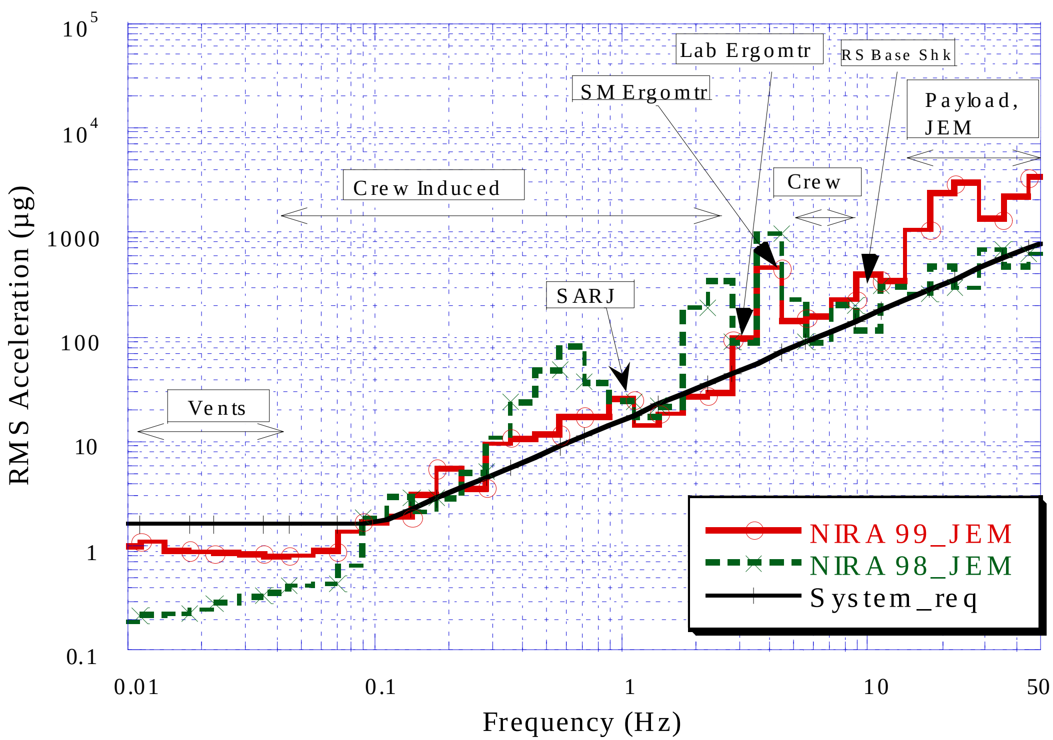
- **1% Damping**
- **+ 2Crew translations & 2console ops**
- **+ Payload disturbances (8 racks in Lab, 3 in COF and 2 in JEM)(21 sources per rack includes AAA fan.)**
- **@ Non-isolated rack interfaces**
- **Non-isolated Lab ergometer - subsequently isolated (see DAC8)**



NIRA 99 - JEM-PM
Structural Dynamic Frequency Range

Non-Isolated Rack Assessment Differences From DAC8 Requirement Compliance Results

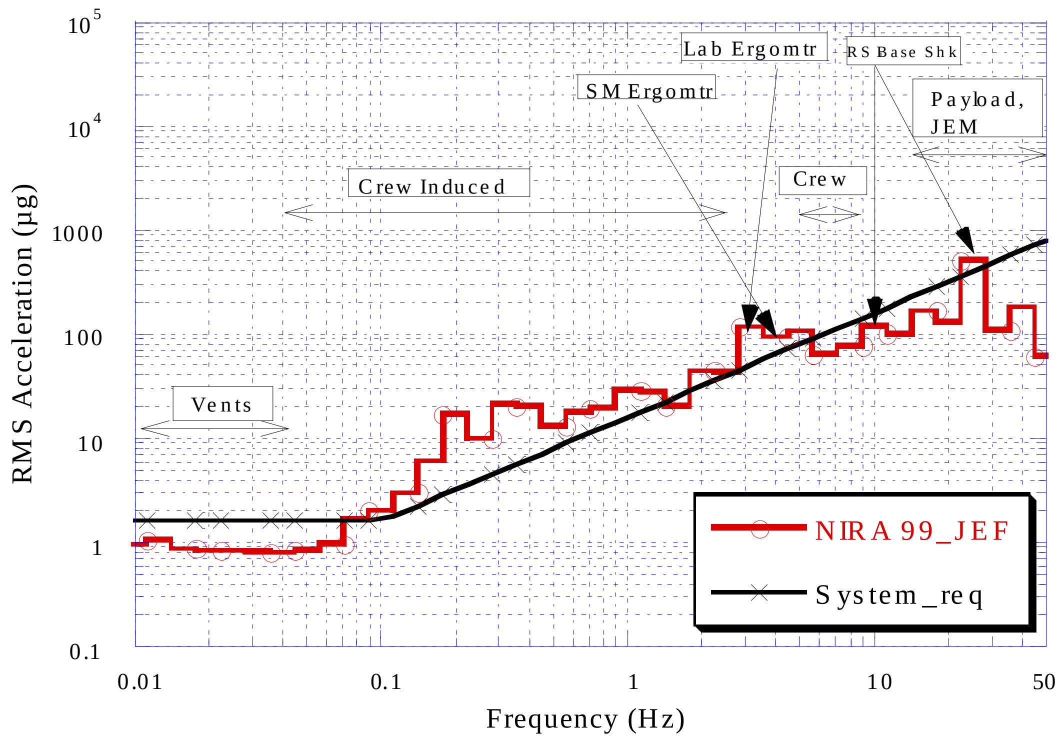
- 1% Damping
- + 2Crew translations & 2console ops
- + Payload disturbances (8 racks in Lab, 3 in COF and 2 in JEM)(21 sources per rack includes AAA fan.)
- @ Non-isolated rack interfaces
- Non-isolated Lab ergometer - subsequently isolated (see DAC8)



NIRA 99 - JEM-EF
Structural Dynamic Frequency Range

Non-Isolated Rack Assessment Differences From DAC8 Requirement Compliance Results

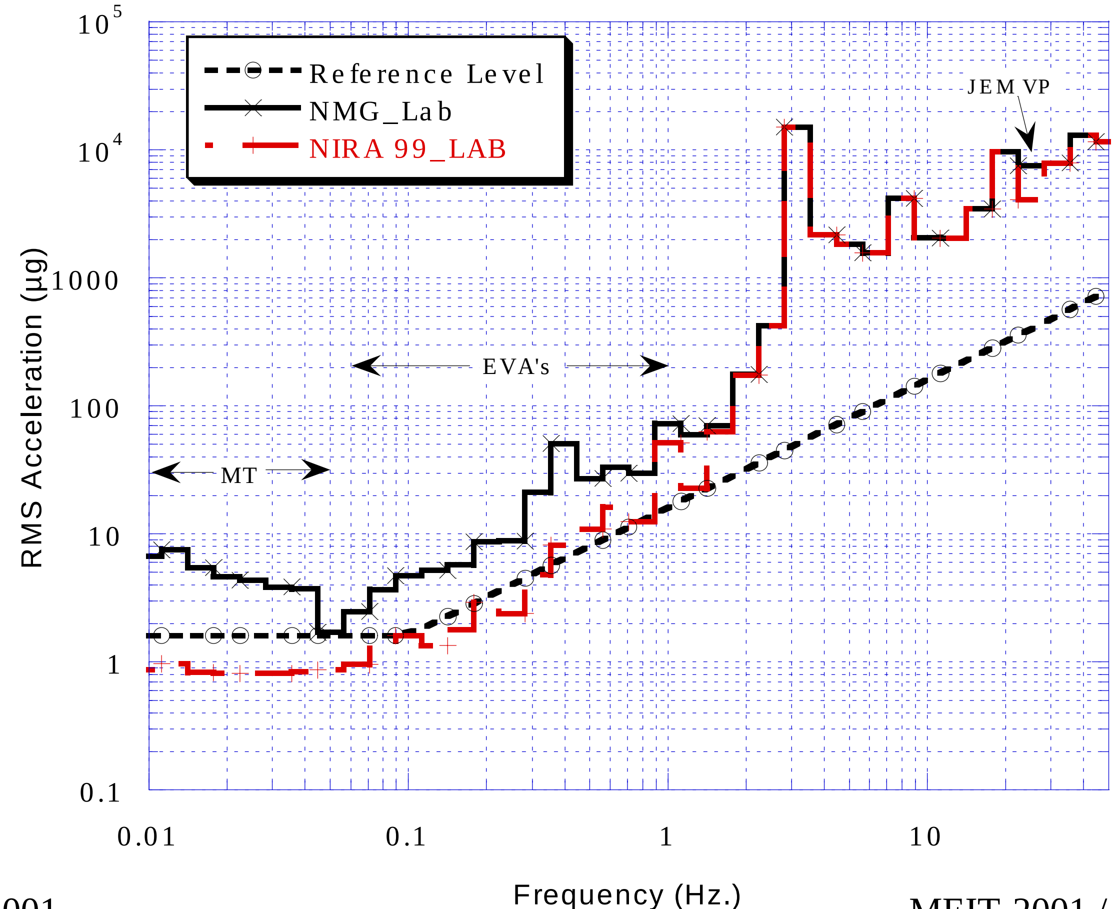
- **1% Damping**
- **+ 2Crew translations & 2console ops**
- **+ Payload disturbances (8 racks in Lab, 3 in COF and 2 in JEM)(21 sources per rack includes AAA fan.)**
- **@ Non-isolated rack interfaces**
- **Non-isolated Lab ergometer - subsequently isolated (see DAC8)**



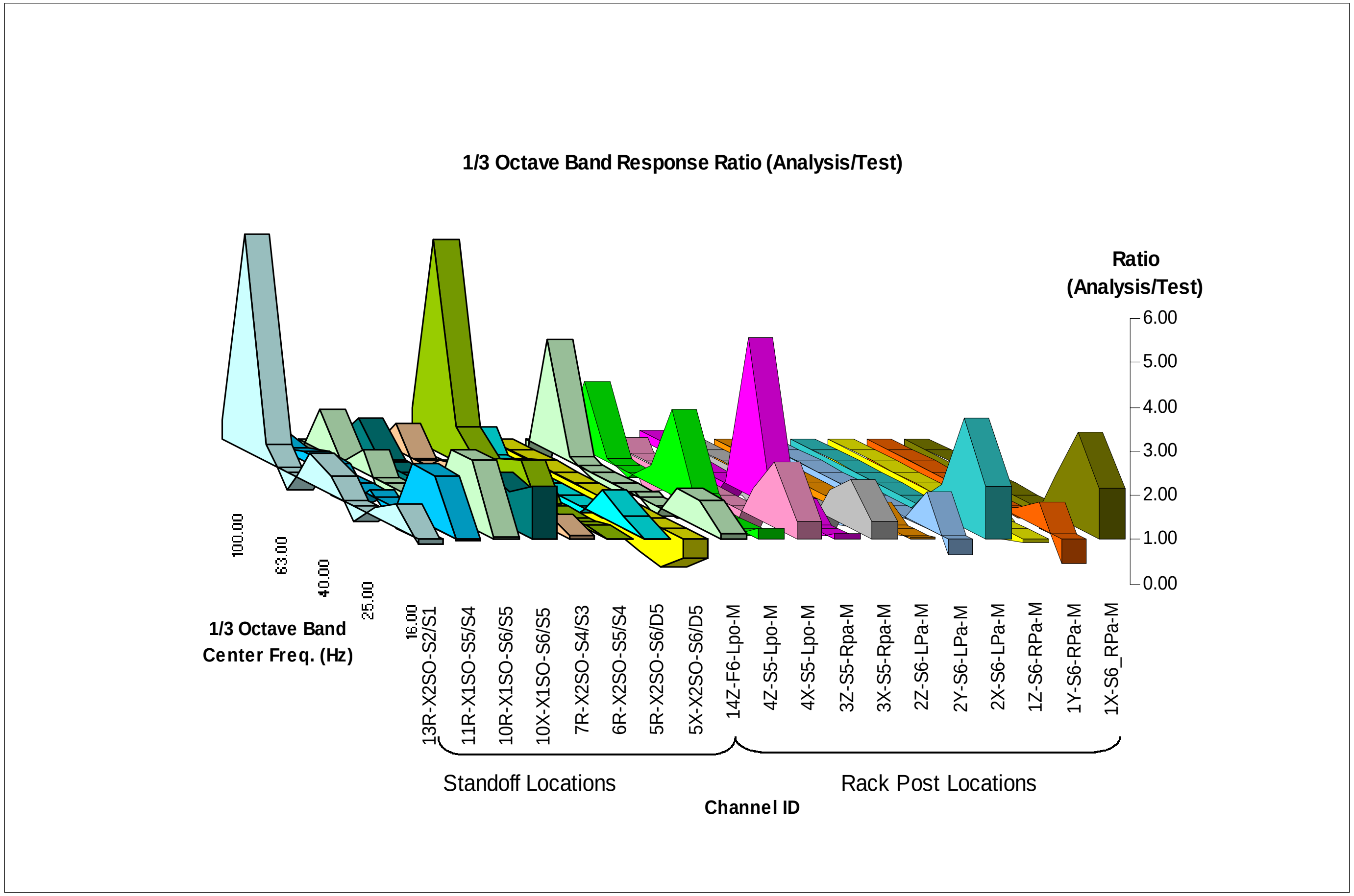
Non-Microgravity Mode (External Ops Case) - U.S. Lab Structural Dynamic Frequency Range

Non-Microgravity Mode Differences From NIRA-99

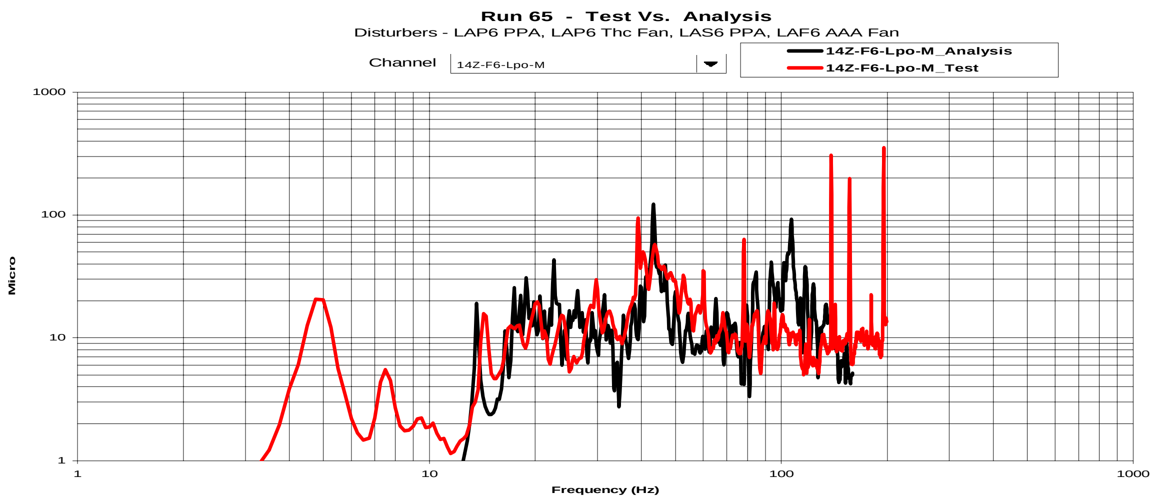
- **Add non-microgravity mode disturbances to NIRA-99**
- **External Operations Case presented includes 2 EVA's, JEM Airlock and Mobile Transporter ops**
- **Other cases examined focused on thruster activity - reboost, CMG de-saturation, attitude hold**
- **Cases still to be examined: docking, berthing, rack rotation, et cetera**

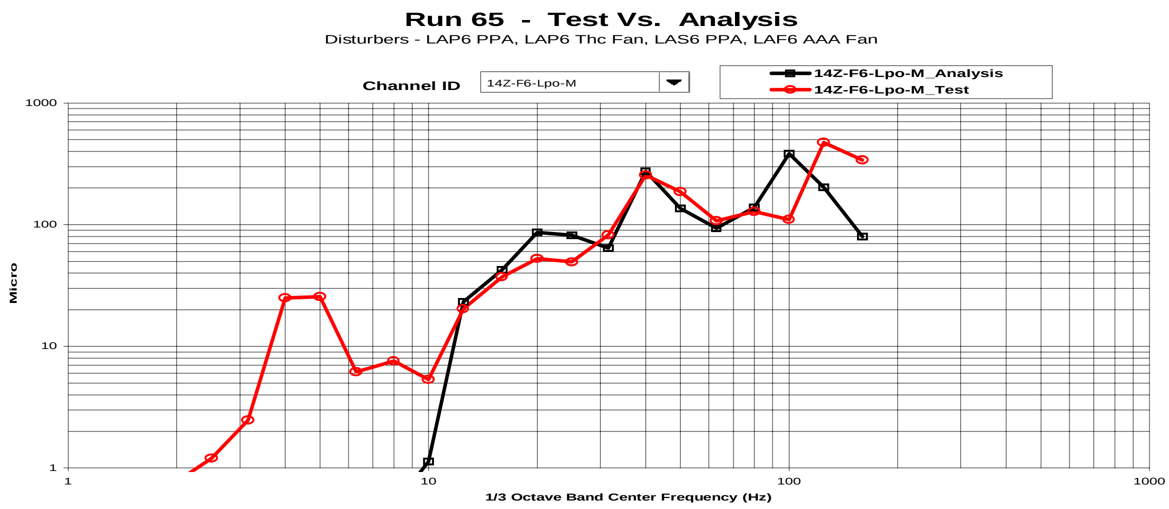


U.S. Lab Ground Test To Analysis Comparison With Ground Test Finite Element Model

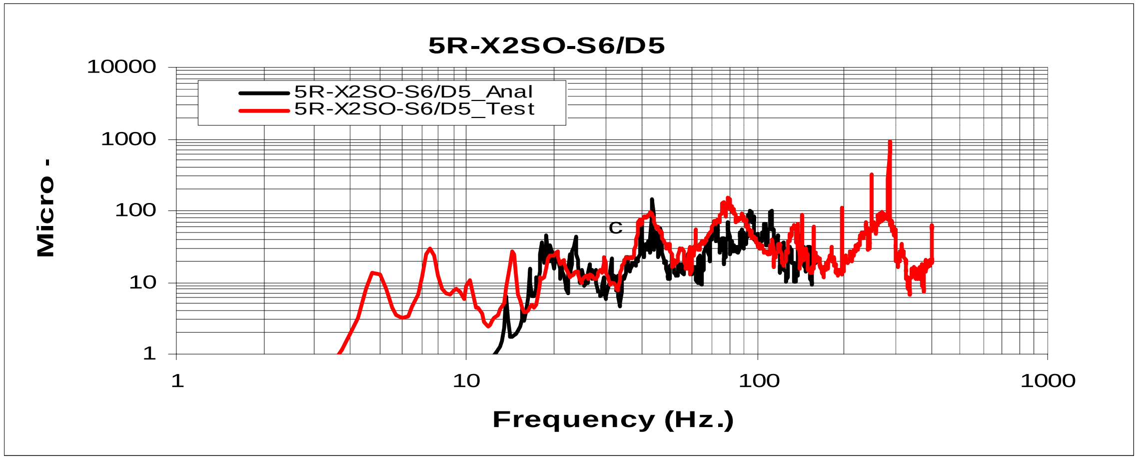


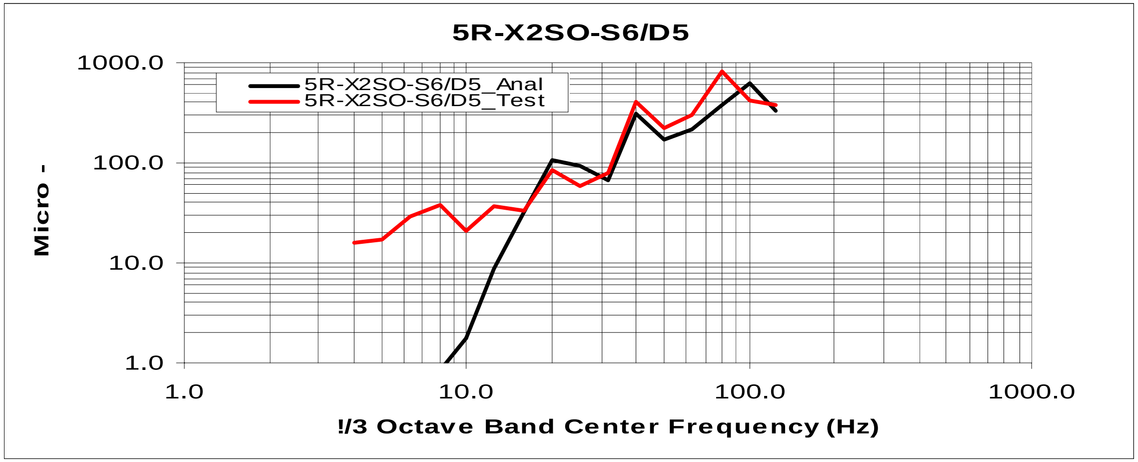
U.S. Lab Ground Test To Analysis Comparison
Rack F6 Response



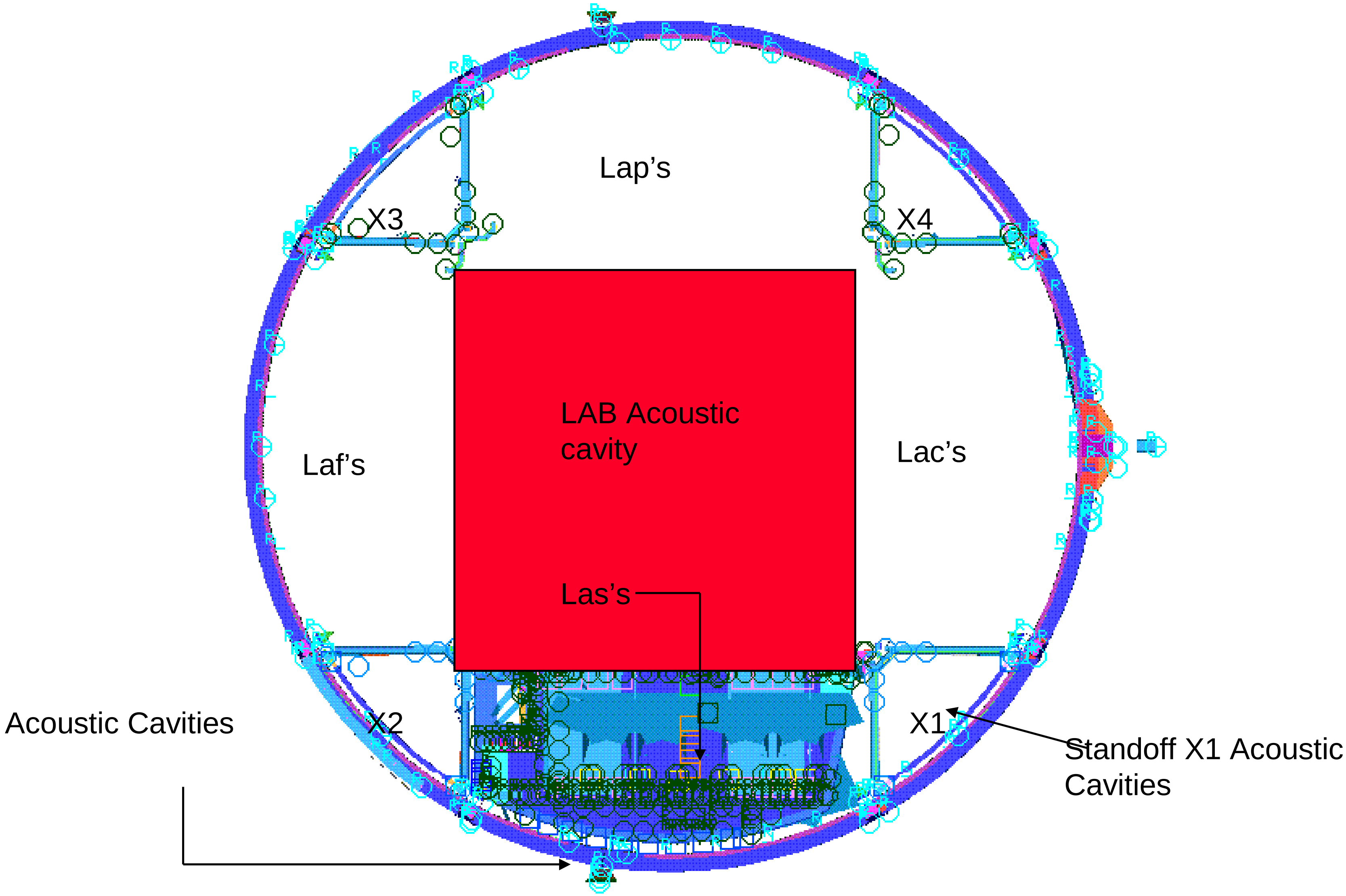


U.S. Lab Ground Test To Analysis Comparison
Standoff S6/S5 Response

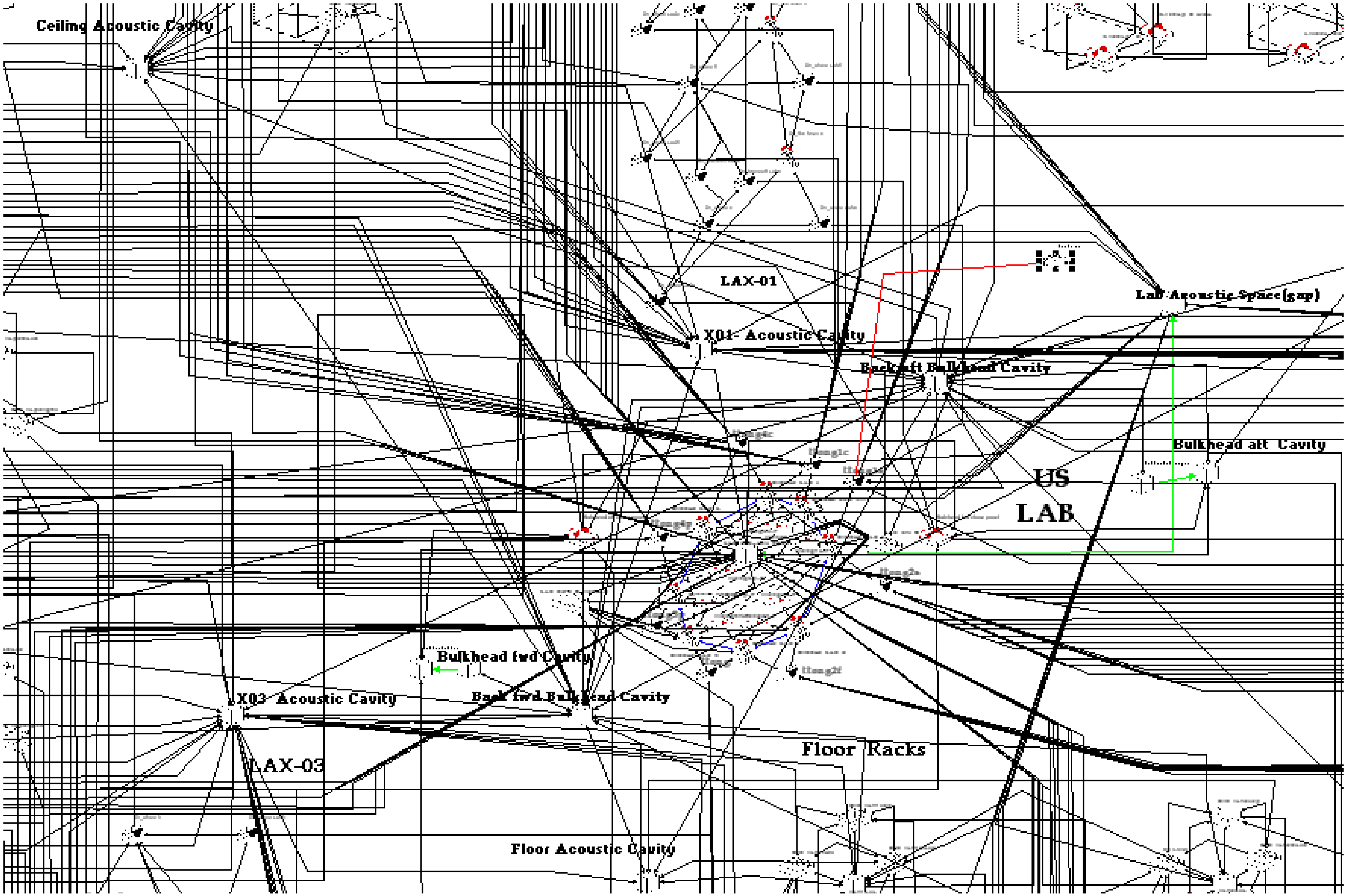




DAC8 Statistical Energy Analysis Model

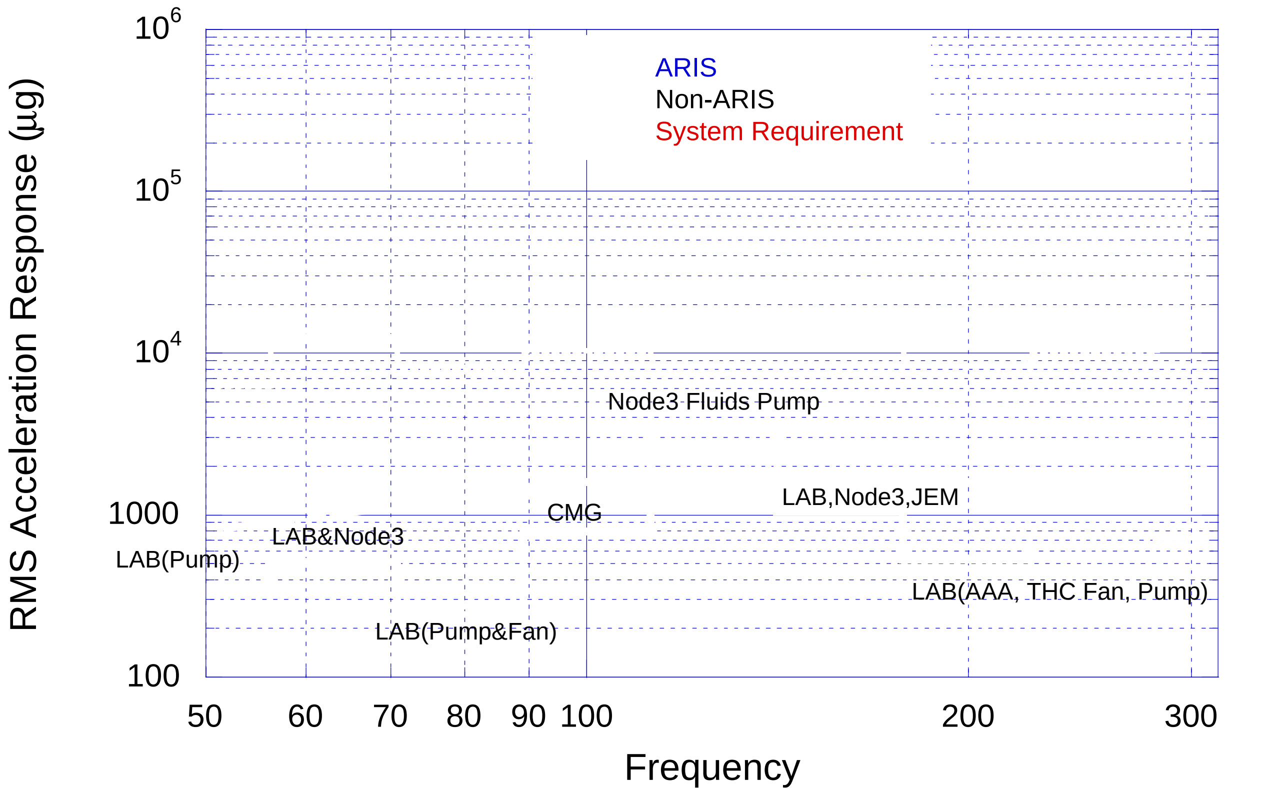


DAC8 Statistical Energy Analysis Model

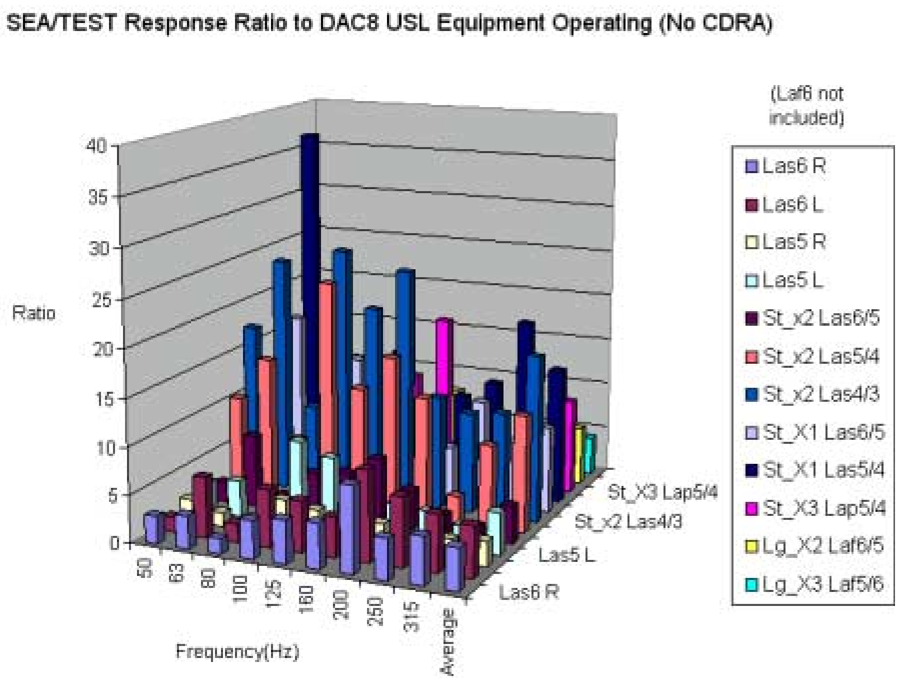


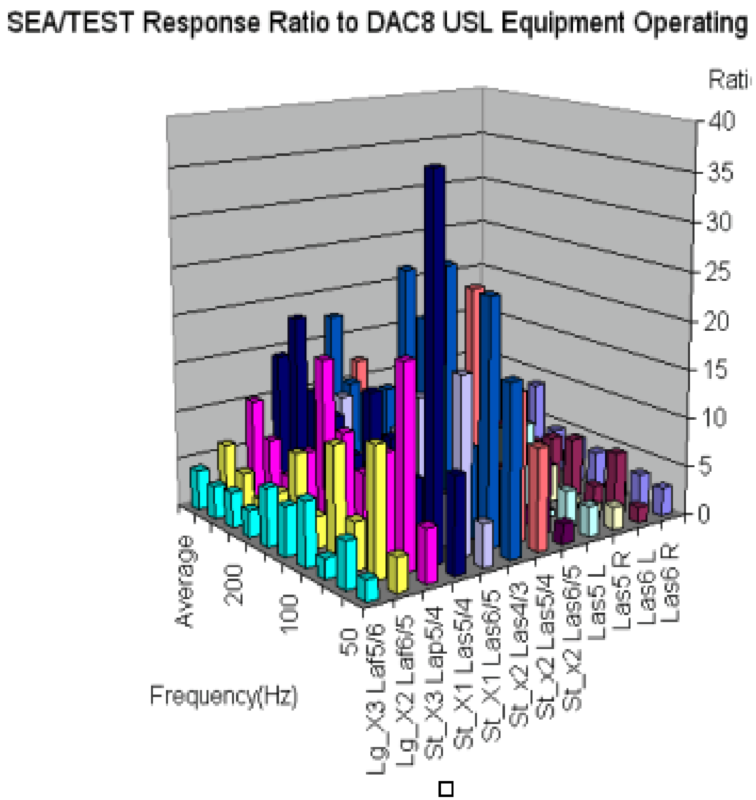
DAC8 Performance
Vibroacoustic Frequency Range

DAC8 Response at ISPR due to All Combined System Disturbances

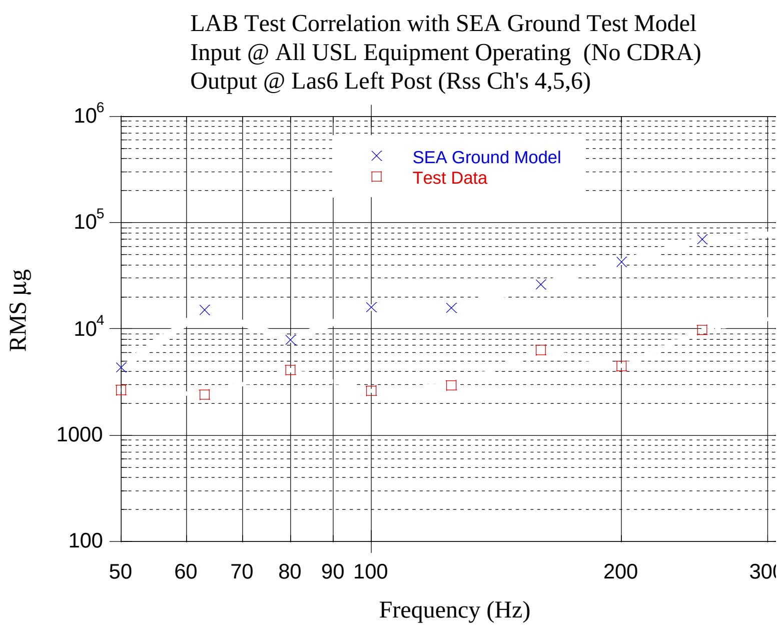


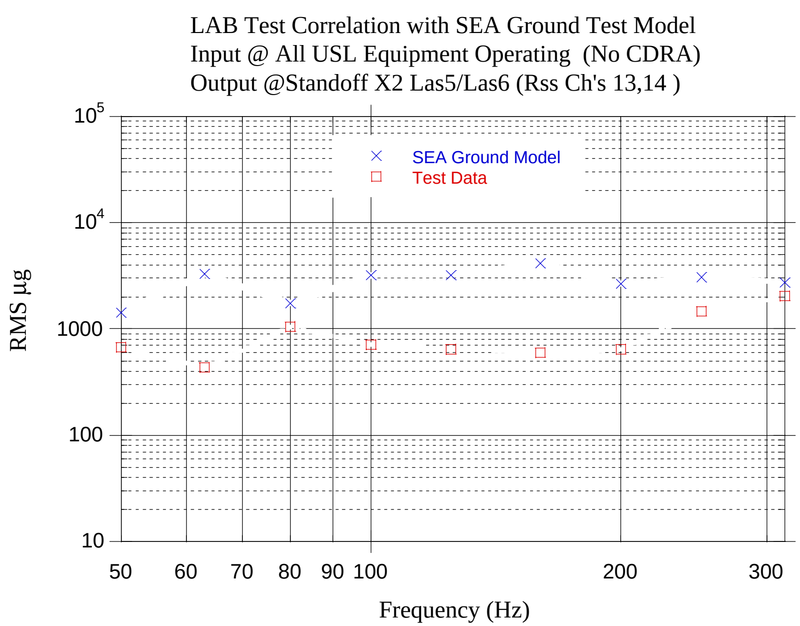
U.S. Lab Ground Test To Analysis Comparison With Ground Test Statistical Energy Model

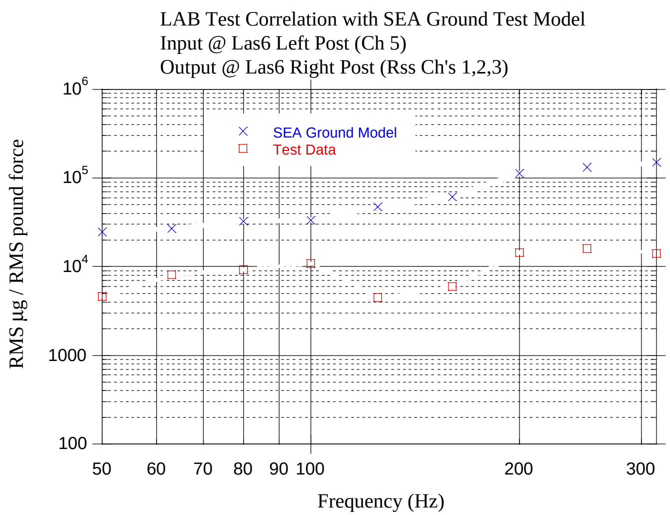




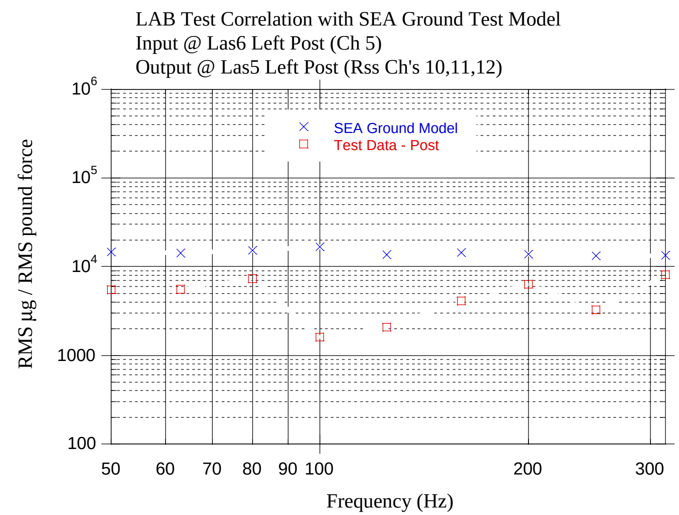
U.S. Lab Ground Test To Analysis Comparison
Rack and Standoff Response



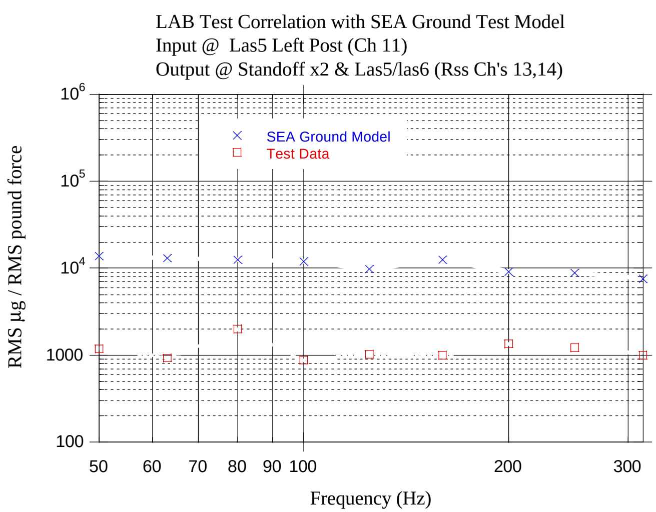




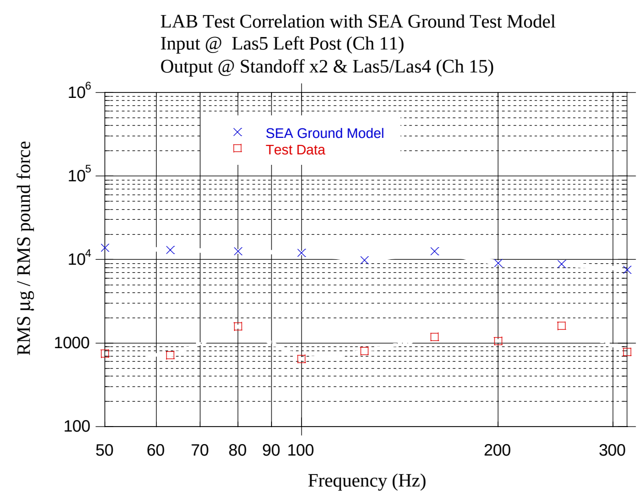
LAB Test Correlation with SEA Ground Test Model
Input @ Las6 Left Post (Ch 5)
Output @ Las6 Right Post (Rss Ch's 1,2,3)
SEA Ground Model
Test Data
RMS µg / RMS pound force
Frequency (Hz)



LAB Test Correlation with SEA Ground Test Model
Input @ Las6 Left Post (Ch 5)
Output @ Las5 Left Post (Rss Ch's 10,11,12)
SEA Ground Model
Test Data - Post
RMS µg / RMS pound force
Frequency (Hz)

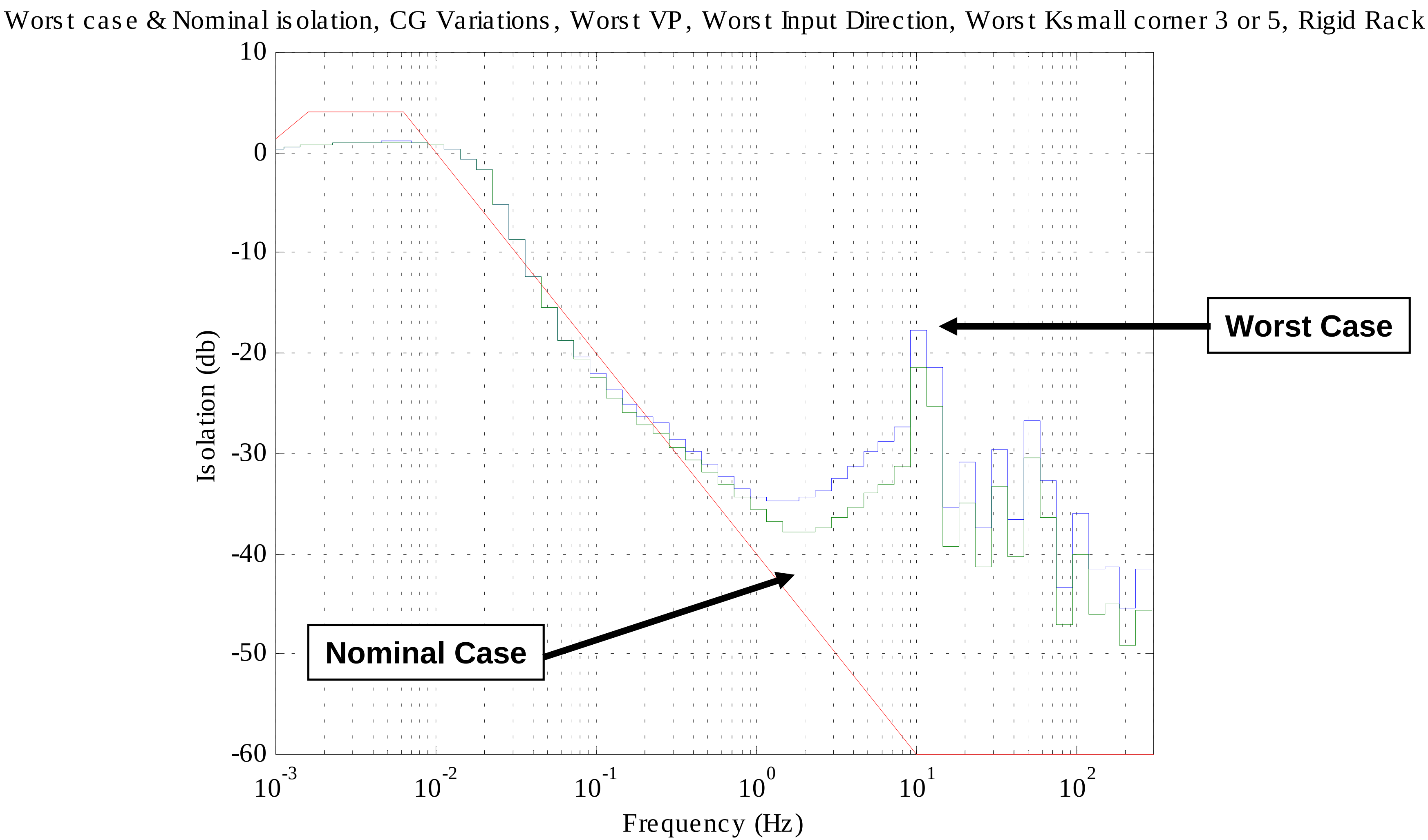


LAB Test Correlation with SEA Ground Test Model
Input @ Las5 Left Post (Ch 11)
Output @ Standoff x2 & Las5/las6 (Rss Ch's 13,14)
SEA Ground Model
Test Data
RMS µg / RMS pound force
Frequency (Hz)

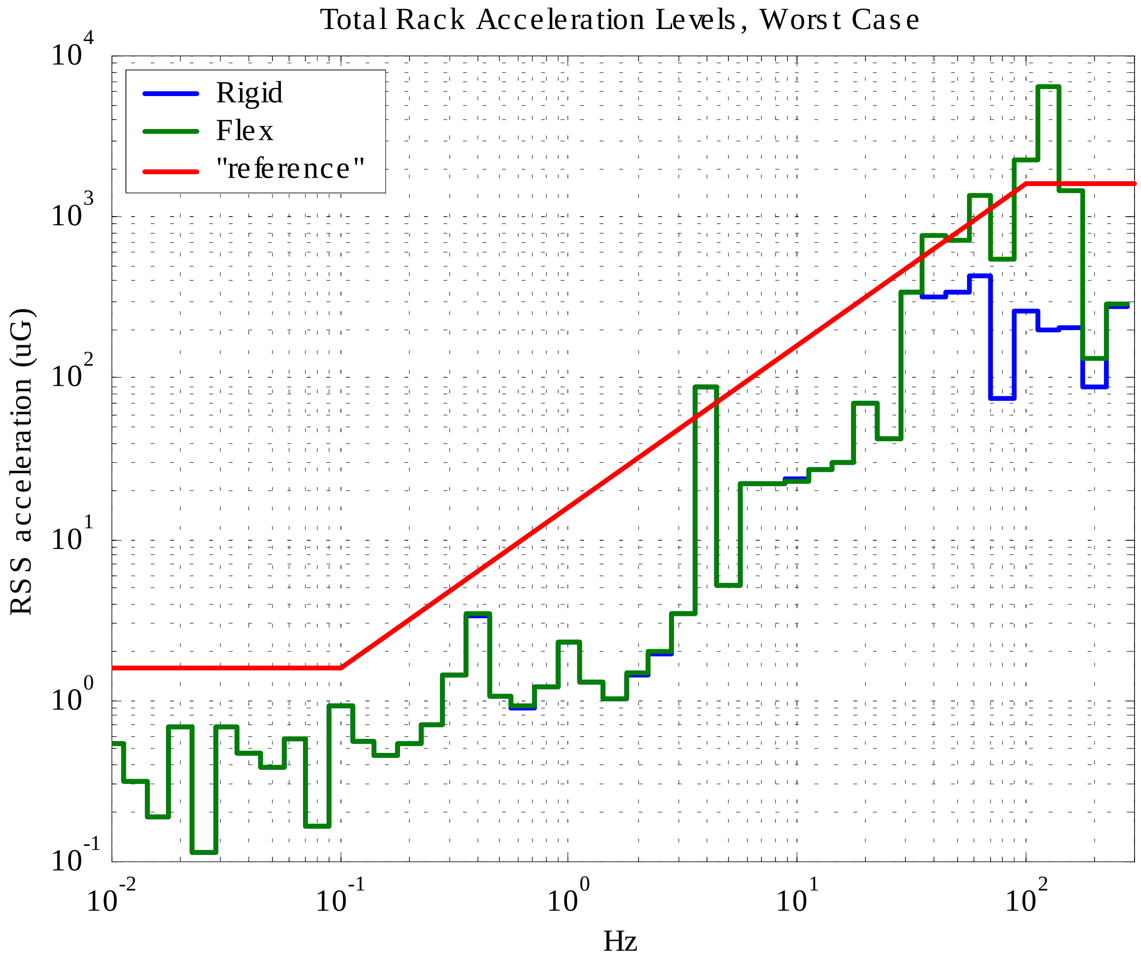


LAB Test Correlation with SEA Ground Test Model
Input @ Las5 Left Post (Ch 11)
Output @ Standoff x2 & Las5/Las4 (Ch 15)
SEA Ground Model
Test Data
RMS µg / RMS pound force
Frequency (Hz)

ARIS Isolation Performance



Total Isolated Rack Acceleration Levels (ARIS Verification Conditions)



The ISS vehicle has been designed to provide researchers a viable microgravity environment established jointly with the science community.

- **Features:**
  - **Laboratories located near the vehicle center of mass**
  - **Articulating photovoltaic and radiator appendages to enable once per orbit vehicle rotation**
  - **Non-propulsive attitude control**
  - **Source isolated exercise equipment**
  - **Receiver isolation systems**
  - **Microgravity Mode operations**

- **Design Convergence:**
  - **Requirements**
  - **Control Plan**
  - **Key Ground Tests**
    - Control Moment Gyros
    - Rotating Joints
    - Node1
    - Service Module
    - Lab
    - COF sub-systems
  - **Verification**

Summary (continued)

Initial payload microgravity requirements have been approved for the non-isolated, pressurized payloads.

Key threats & planned/recommended countermeasures:

- **ARIS isolation performance - "Shake down" experiment on flight 6A - "ARIS ICE".**
- **Service Module air conditioner compressor non-compliance - Approved ground test and on-orbit installation of vibration mounts and extended fluid flex lines.**
- **Service Module ergometer non-compliance with verified ARIS performance. - Pursue early measurements to confirm predictions and resolve if necessary.**
- **U.S. Lab ergometer non-compliance due to rack to pivot pin impact. - - Pursue early measurements to confirm predictions and resolve if necessary.**
- **Payload disturbances, payload rack structural dynamics. - Work requirement definition and verification process.**

Sustaining Engineering Underway:

- **Use early on-orbit measurement data to establish confidence in analytical models**
- **Support operations**
- **Perform anomaly resolution**
- **Insure Assembly Complete compliance**

Acronyms

CoFR : Certification of Flight Readiness
COF : Columbus Orbital Facility
GN&C: Guidance, Navigation, and Control
IRD : Interface Requirements Document
JEM : Japanese Experiment Module
PD : Payload Developer
PIA : Payload Integration Agreement
PEI : Payload Engineering Integration
POIC : Payload Operations Integration Center
RS : Russian Segment
SSP : Space Station Program
USOS: United States On-orbit Segment