Section 20

ISS Design Analysis Cycle & Environment Predictions

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ZIN Technologies

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Presentation Overview

- Analysis Cycles
  - Design Analysis Cycles, DAC
  - Verification Analysis Cycles, VAC
  - Non Isolated Rack Assessment, NIRA
- Allocations
- Quasi – Steady Environment
  - Methods & Tools
  - Disturbers
  - Results
- Vibratory Environment
  - Methods & Tools
  - Disturbers
  - Results
- Summary

Acronyms

AC : Assembly Complete
ARIS : Active Rack Isolation System
COF : Columbus Orbital Facility
DAC : Design Analysis Cycle
EF : Exposed Facility
ELM : Experiment Logistics Module
GN&C: Guidance, Navigation, and Control
ISPR : International Standard Payload Rack
JEM : Japanese Experiment Module
NIRA : Non Isolated Rack Assessment
PIDS : Prime Item Development Specification
PM : Payload Module
RS : Russian Segment
SSP : Space Station Program
USOS: United States On-orbit Segment
VAC : Verification Analysis Cycle

Design Analysis Cycles

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

- DAC-9 was completed in March 2002.
- DACs capture updated models & disturbance forcing functions.
- System model developed for Assembly-Complete (AC) configuration when micro-g requirements become applicable.
- System model development is an evolutionary process through Design Analysis Cycles (DAC). Current cycle is DAC-9.
- Each cycle reflects the current assembly sequence and the updated component models. Test-verified (VAC quality) models are available for components that have already flown.

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

- Verify that the hardware launched complies with Assembly Complete microgravity requirements.
- Priority tasks necessary for Certification of Flight Readiness.
- Example: ISS Stage 6A Quasi-Steady environment (as measured by MAMS) and SSMRBS was correlated (using actual Solar Flux Data, actual array configuration, and vehicle attitude). Model to environment deviation was only 3-4%.

Microgravity sustaining engineering efforts underway

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

Non – Isolated Rack Assessment (NIRA)

- Uses the DAC model
- Latest Version completed 1999
- Next update June 2003
- Reports μg at rack interfaces on a per element (US LAB, JEM, etc.) basis
- Assumptions/Limitations
  - Station in μg mode
  - Includes payload and crew disturbances
  - Does not include active (ARIS) or passive isolation at the crew interface
- Data used by payload developers
  - More conservative since all payload disturbances are included
  - Developer simulates lab to rack isolation technique based on their specific rack configuration

DAC/NIRA Comparison

DAC

- Vehicle Disturbers /Response
- Does not include Payload Disturbers
- Includes Crew exercise devices
- Includes Active Rack Isolation System (ARIS)
- Used to show vehicle compliance to μg specification requirements

NIRA

- Payload Disturbers (Based on Allocations)
- Does not include rack isolation
- Used to predict μg requirements at rack interfaces
- All other disturbance sources provided through DAC analyses

Allocations

Combined Vibratory Acceleration Requirements

Sub-allocation of System Allowable

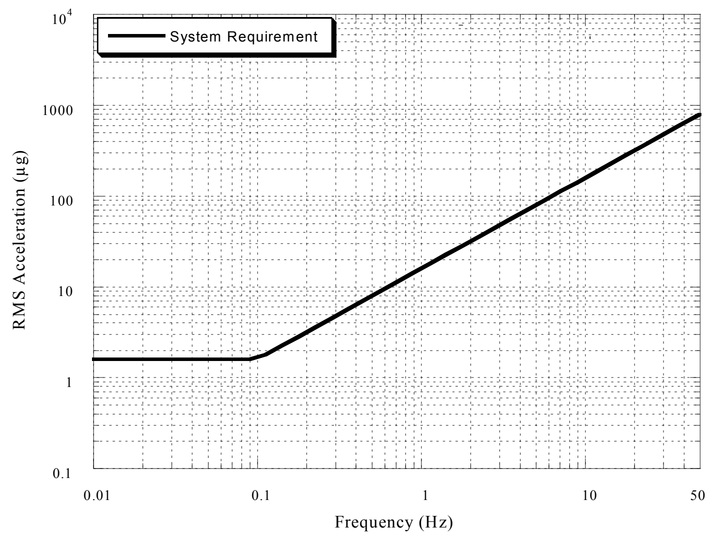
19.5 % to COF Segment.

19.5 % to JEM Segment.

19.5 % to Russian Segment.

Rest to USOS Segment:

Node 3, CRV, Hab, US Lab, CAM, Cupola, X-PM



Individual Transient Acceleration Requirements

- Instantaneous magnitude limit of <u>1000 μg per axis.</u>
- Integrated acceleration limit of <u>10 μg-sec per axis</u> over any 10-sec interval.

Allocations
Rack Locations

ISPR Locations in Station Analysis Coordinate Frame (ft)

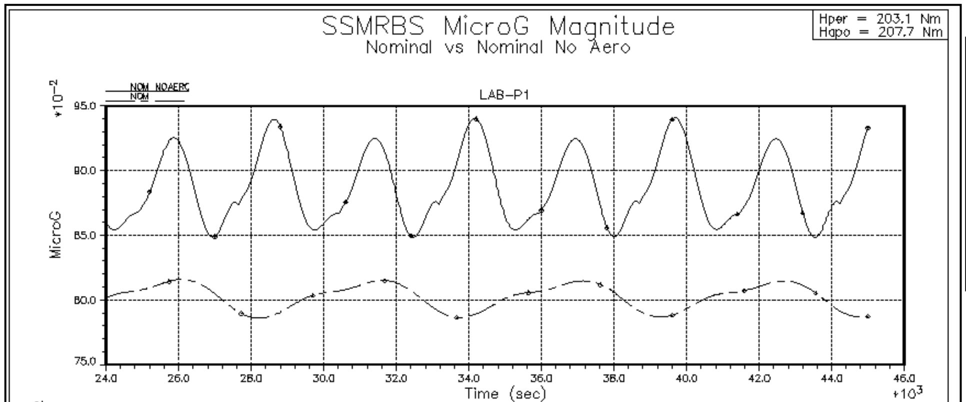
Shaded areas not applicable to μg requirement

ISPR RACK LOCATIONS				OTHER POINT OF INTEREST			
X	Y	Z	Description	X	Y	Z	Description
15.62	0.00	11.16	USL-O1	35.14	0.00	-4.88	CAM MID
12.12	0.00	11.16	USL-O2	35.14	0.00	-11.44	CAM TOP
8.62	0.00	11.16	USL-O3	-17.66	-1.32	14.80	SYSTEM-C
5.12	0.00	11.16	USL-O4	36.08	19.87	11.16	APM-CLG3
1.62	0.00	11.16	USL-O5	36.08	23.42	11.16	APM-CLG4
15.62	4.75	15.91	USL-S1	48.41	-47.16	22.70	JEF1-F1
12.12	4.75	15.91	USL-S2	28.44	-47.16	22.70	JEF2-A1
8.62	4.75	15.91	USL-S3	47.82	-50.77	22.70	JEF3-F2
5.12	4.75	15.91	USL-S4	29.03	-50.77	22.70	JEF4-A2
15.62	-4.75	15.91	USL-P1	47.82	-54.38	22.70	JEF5-F3
12.12	-4.75	15.91	USL-P2	29.03	-54.38	22.70	JEF6-A3
5.12	-4.75	15.91	USL-P4	48.41	-57.99	22.70	JEF7-F4
30.39	-12.31	15.91	JPM1-A1	28.44	-57.99	22.70	JEF8-A4
39.89	-12.31	15.91	JPM2-F1	41.87	-64.44	22.70	JEF9-O1
30.39	-15.81	15.91	JPM3-A2	34.98	-64.44	22.70	JEF10-O2
39.89	-15.81	15.91	JPM4-F2	41.44	-54.38	14.81	JEF11-U1
30.39	-19.31	15.91	JPM5-A3	37.81	-58.45	14.81	JEF12-U2
39.89	-19.31	15.91	JPM6-F3	-3.35	79.54	7.12	S3LO
30.39	-22.81	15.91	JPM7-A4	-3.35	71.00	7.12	S3LI
30.39	-26.31	15.91	JPM8-A5	-3.35	79.54	-7.12	S3UO
39.89	-26.31	15.91	JPM9-F5	-3.35	71.00	-7.12	S3UI
39.89	-29.81	15.91	JPM10-F6	-3.35	-79.54	7.12	P3LO
35.14	12.68	11.16	APM-CLG1	-3.35	-79.54	-7.12	P3UO
35.14	16.22	11.16	APM-CLG2	-54.98	-0.03	13.71	FGB-CG
39.89	12.68	15.91	APM-FWD1	-97.85	-0.03	13.23	SM-CG
39.89	16.22	15.91	APM-FWD2	6.79	-0.16	16.14	USL-CG
39.89	19.87	15.91	APM-FWD3	35.31	-24.92	15.56	JEM-CG
39.89	23.42	15.91	APM-FWD4	35.14	17.83	15.91	APM-CG
30.39	12.68	15.91	APM-AFT1				
30.39	16.22	15.91	APM-AFT2				
30.39	19.87	15.91	APM-AFT3				
30.39	23.42	15.91	APM-AFT4				

Quasi-Steady Analysis Methods & Tools

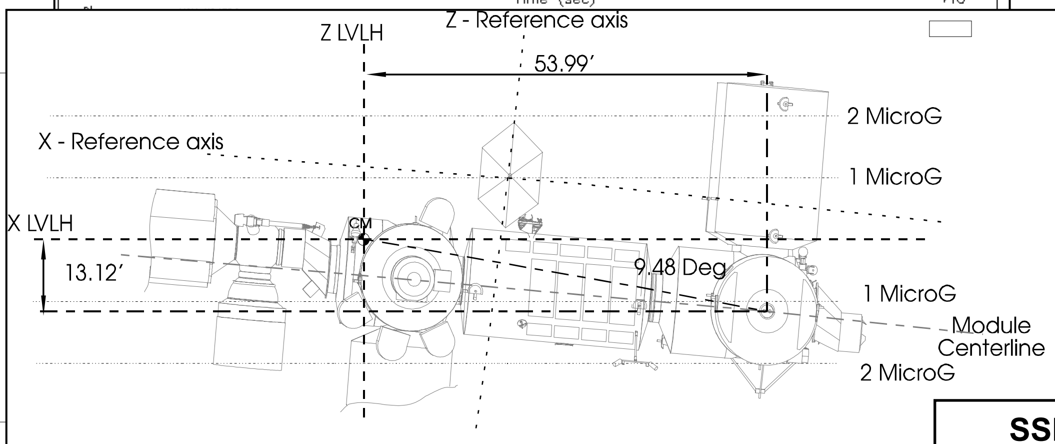
- **Perform integrated analysis to ensure microgravity quasi-steady disturbances will not exceed microgravity quasi-steady acceleration limits for the Assembly Complete International Space Station using the μg control plan inputs.**
- **System Level**
  - **Frequencies < .01 Hz, 1.0 μg Peak and .2 μg perpendicular component**
- **Element level**
  - **Quasi-steady microgravity requirements flow down to the PIDS as an allocation of .02 μg on individual disturbances, excluding the effect of drag and gravity gradient. US LAB and HAB are allocated 0.04 μg each for all combined quasi-steady disturbances**
- **Quasi-Steady Individual Disturbance defined as:**
  - **Quasi-steady disturbance is defined as having 95% of its power below .01 Hz in any 5400 second period**
    - Any step function greater than 200 seconds
    - Any exponential decay with a time constant greater than 200 seconds
    - Other disturbances analyzed for percentage content below .01 Hz
- **Perform studies to compare Orbiter attached, Core complete mass properties, Max and no aero runs**

Quasi-Steady Analysis
Methods & Tools



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

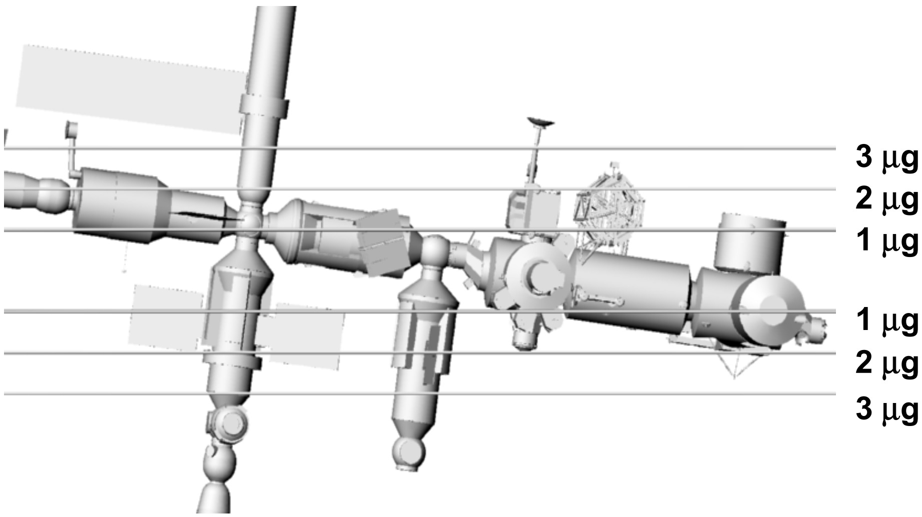
verify_atm_density (density)

Marshall Engineering Thermosphere (MET) Earth Atmospheric Density model

Quasi-Steady Analysis Disturbance Inputs

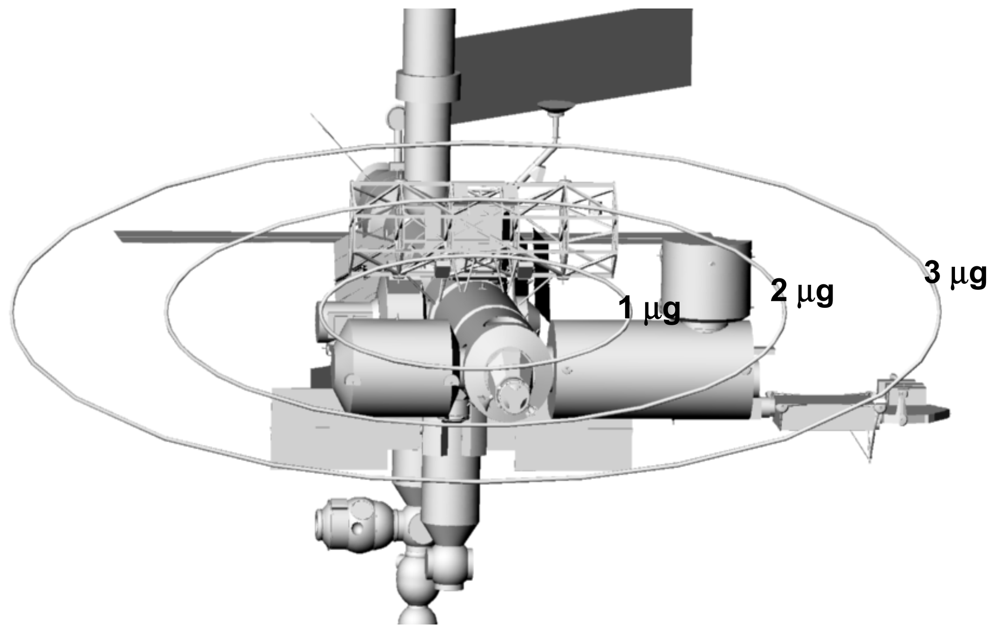
- **Centrifuge startup and shut down**
  - **Spin-up for 120 sec to 236 deg/s, spin for 6.4 hours, spin-down for 120 sec.**
  - **Starts at 17000 sec**
- **TRRJ slew at low betas**
  - **TRRJ 0 beta slew rates - TRRJ Torque Power Spectral Density has 87.7% of its power below .01 Hz.**
  - **Not Applicable**
- **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**

Quasi-Steady Results
DAC 9 – Assembly Complete



Quasi-steady Performance:
- 14 of 32 ISPRs < 1.0 μg
- All satisfy stability criteria

Some elements not shown



Quasi-Steady Results
DAC 9 – Assembly Complete

Location	µG Vector		Unit Vector			Cone Angle
	Magnitude (µG)	⊥ Component (µG)	X	Y	Z	Max angle from unit vector (deg)
CG	0.234	0.038	-0.995	-0.090	0.030	20.885
USL-C1	0.298	0.083	-0.630	-0.500	-0.594	18.659
USL-C2	0.266	0.066	-0.751	-0.529	-0.395	22.312
USL-C3	0.244	0.045	-0.854	-0.518	-0.054	22.811
USL-C4	0.237	0.059	-0.830	-0.411	0.378	23.246
USL-C5	0.245	0.085	-0.672	-0.249	0.698	24.359
USL-S1	0.796	0.107	-0.315	0.096	-0.944	7.781
USL-S2	0.743	0.105	-0.330	0.128	-0.935	8.237
USL-S3	0.691	0.104	-0.348	0.165	-0.923	8.739
USL-S4	0.642	0.102	-0.369	0.208	-0.906	9.291
USL-P1	0.811	0.107	-0.247	-0.401	-0.882	7.632
USL-P2	0.754	0.105	-0.259	-0.412	-0.874	8.124
USL-P4	0.641	0.102	-0.288	-0.439	-0.851	9.320
JPM1-A1	1.187	0.111	-0.159	-0.593	-0.789	5.480
JPM2-F1	1.349	0.114	-0.154	-0.556	-0.817	4.959
JPM3-A2	1.266	0.111	-0.135	-0.669	-0.731	5.143
JPM4-F2	1.422	0.114	-0.134	-0.628	-0.766	4.705
JPM5-A3	1.355	0.111	-0.114	-0.730	-0.674	4.809
JPM6-F3	1.506	0.114	-0.115	-0.688	-0.716	4.449
JPM7-A4	1.453	0.111	-0.094	-0.779	-0.620	4.491
JPM8-A5	1.558	0.112	-0.077	-0.817	-0.571	4.197
JPM9-F5	1.696	0.114	-0.081	-0.779	-0.622	3.963
JPM10-F6	1.801	0.115	-0.067	-0.812	-0.579	3.745
APM-CLG1	0.668	0.112	-0.369	0.498	-0.785	9.613
APM-CLG2	0.759	0.113	-0.344	0.631	-0.695	8.593
APM-FWD1	1.246	0.116	-0.263	0.227	-0.938	5.338
APM-FWD2	1.300	0.116	-0.265	0.330	-0.906	5.144
APM-FWD3	1.369	0.117	-0.265	0.422	-0.867	4.919
APM-FWD4	1.449	0.118	-0.262	0.500	-0.826	4.693
APM-AFT1	1.110	0.113	-0.281	0.299	-0.912	5.869
APM-AFT2	1.174	0.114	-0.280	0.407	-0.869	5.595
APM-AFT3	1.254	0.115	-0.276	0.501	-0.820	5.295
APM-AFT4	1.342	0.117	-0.270	0.576	-0.772	5.005

Location	µG Vector		Unit Vector			Cone Angle
	Magnitude (µG)	⊥ Component (µG)	X	Y	Z	Max angle from unit vector (deg)
CAM-MID	1.518	0.111	0.068	-0.104	0.992	4.281
CAM-TOP	2.306	0.111	0.093	-0.060	0.994	2.794
APM-CLG3	0.875	0.116	-0.318	0.711	-0.627	7.587
APM-CLG4	0.990	0.117	-0.296	0.773	-0.561	6.815
JEF1-F1	2.980	0.121	-0.057	-0.749	-0.660	2.388
JEF2-A1	2.682	0.115	-0.049	-0.795	-0.605	2.511
JEF3-F2	3.074	0.122	-0.049	-0.772	-0.633	2.336
JEF4-A2	2.800	0.116	-0.041	-0.814	-0.579	2.431
JEF5-F3	3.181	0.123	-0.042	-0.793	-0.608	2.286
JEF6-A3	2.914	0.117	-0.034	-0.833	-0.552	2.364
JEF7-F4	3.299	0.125	-0.036	-0.809	-0.586	2.238
JEF8-A4	3.022	0.119	-0.026	-0.850	-0.526	2.306
JEF9-O1	3.412	0.127	-0.022	-0.849	-0.528	2.181
JEF10-O2	3.321	0.124	-0.018	-0.862	-0.506	2.198
JEF11-U1	2.599	0.123	0.005	-0.944	-0.330	2.766
JEF12-U2	2.714	0.124	0.015	-0.957	-0.289	2.663
S3LO	3.268	0.163	-0.125	0.982	0.141	2.877
S3LI	2.931	0.155	-0.125	0.978	0.165	3.072
S3UO	3.950	0.152	-0.042	0.830	0.556	2.272
S3UI	3.683	0.145	-0.034	0.797	0.603	2.324
P3LO	3.374	0.122	0.104	-0.958	0.269	2.078
P3UO	4.202	0.113	0.142	-0.764	0.629	1.546
FGB-CG	1.487	0.121	-0.028	0.851	0.525	4.741
SM-CG	1.651	0.106	0.030	0.265	0.964	3.990
USL-CG	0.664	0.103	-0.326	-0.138	-0.935	9.030
JEM-CG	1.560	0.113	-0.083	-0.795	-0.601	4.246
APM-CG	1.267	0.116	-0.272	0.410	-0.871	5.247

- **Rack count 14 of 32 less than 1 µg**
- **Good stability, all 32 racks below .2 µg**

Quasi-Steady Results
DAC 9 - Assembly Complete, Comparison

14 of 32 racks less than 1 μg magnitude

Configuration	CG			Principle Axis			Mass	Rack count
	X-ft	Y-ft	Z-ft	Y-deg	P-deg	R-deg	lb.	under 1 μg
7/15/94	-24.77	-0.7	13.55	-5.1	-3.31	0.12	836955	18
3/13/95 (DAC1)	-23.49	-2.26	12.67	-8.15	-4.13	-0.23	896110	16
DAC2	-23.41	-3.02	11.71	-6.17	-4.15	0.08	855301	14
DAC3	-23.07	-1.51	12.9	-1.24	-5.53	0.49	893181	11
DAC4	-21.23	-0.96	15.51	-3.34	-8.28	0.27	893045	14
DAC5	-22.08	-1.19	15.82	-4.05	-9.41	0.1	900412	10
DAC6	-19	-1.18	14.7	-3.26	-7.25	0.37	920170	14
DAC7	-16.21	-0.67	14.74	-5.87	-8.15	-0.16	994969	14
DAC8	-15.34	-1.28	14.87	-8.44	-6.13	0.12	1035473	15
DAC9	-17.66	-1.32	14.8	-6.36	-7.04	0.28	1005479	14
DAC9_CORE	-19.35	-0.59	14.93	-12.55	-10.53	-0.59	947788	10
DAC9_CORE_ADJ	-16.27	-0.63	13.76	-8.78	-9.93	0.14	902738	8
DAC9_ORB	-4.24	-1.09	22.03	8.97	9.49	-1.1	1222209	2
DAC9_CORE_ORB	-4.94	-0.49	22.5	15.4	5.96	-0.76	1164518	3
DAC9_CORE_ORB_ADJ	-1.88	-0.51	21.86	32.12	7.19	-3.68	1119471	4

Quasi-Steady Results
DAC 9 - Core Complete

- **US Core Complete**
  - **US less Node 3, CRV, and HAB**
  - **RSA includes reduced SPP, 2-Soyuz, Multi-Purpose Module (MPM), RM1. RM2, No DC2**
- **Using preliminary mass properties developed by Micro-gravity group**
- **Quasi-steady numbers are <u>PRELIMINARY</u>**
- **Mass Properties were developed by:**
  - **Subtracting all RSA elements from core body**
  - **Subtracting N3 and Hab from core body**
  - **Adding back new RSA mass properties to core body (delivered from assy. and manifest group, Nancy Wilks)**
  - **Reduced flat plate area accordingly (1/2 SPP, removed appropriate areas for N3,CRV,HAB)**

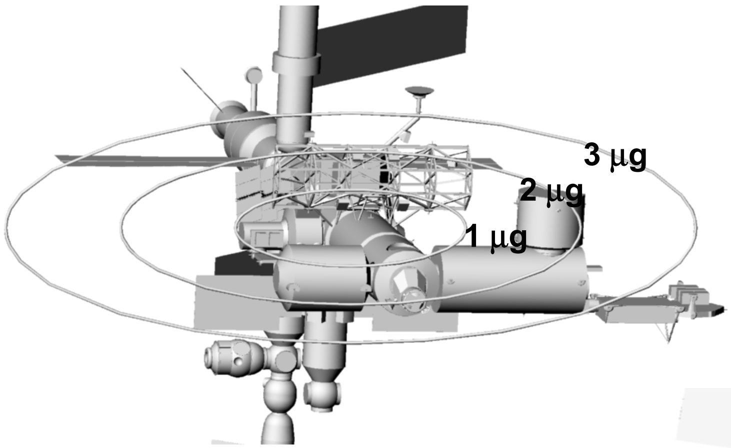
Quasi-Steady Results
DAC 9 - Core Complete

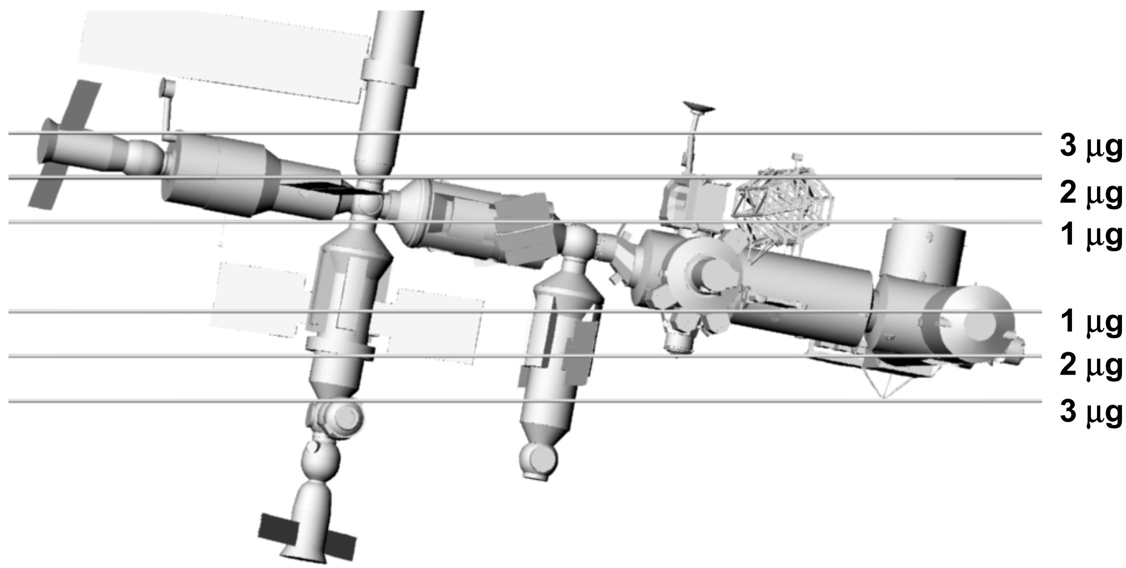
Location	μG Vector Magnitude (μG)	μG Vector ⊥ Component (μG)	Unit Vector X	Unit Vector Y	Unit Vector Z	Cone Angle Max angle from unit vector (deg)
CG	0.228	0.039	-0.983	-0.161	0.087	21.717
USL-C1	0.535	0.104	-0.309	-0.561	-0.768	11.220
USL-C2	0.460	0.101	-0.343	-0.602	-0.721	12.719
USL-C3	0.390	0.096	-0.391	-0.659	-0.643	14.425
USL-C4	0.328	0.090	-0.458	-0.734	-0.502	15.983
USL-C5	0.279	0.079	-0.539	-0.810	-0.230	19.577
USL-S1	1.039	0.108	-0.302	-0.105	-0.948	6.011
USL-S2	0.957	0.107	-0.317	-0.083	-0.945	6.459
USL-S3	0.877	0.106	-0.335	-0.057	-0.941	6.975
USL-S4	0.799	0.104	-0.356	-0.024	-0.934	7.575
USL-P1	1.085	0.107	-0.212	-0.452	-0.866	5.720
USL-P2	1.000	0.106	-0.219	-0.463	-0.859	6.147
USL-P4	0.833	0.104	-0.237	-0.491	-0.838	7.233
JPM1-A1	1.578	0.111	-0.136	-0.582	-0.802	4.105
JPM2-F1	1.814	0.113	-0.136	-0.551	-0.824	3.658
JPM3-A2	1.648	0.110	-0.112	-0.642	-0.759	3.925
JPM4-F2	1.879	0.113	-0.115	-0.606	-0.787	3.529
JPM5-A3	1.727	0.110	-0.089	-0.693	-0.716	3.742
JPM6-F3	1.953	0.113	-0.095	-0.654	-0.750	3.396
JPM7-A4	1.814	0.110	-0.068	-0.736	-0.673	3.563
JPM8-A5	1.907	0.110	-0.049	-0.773	-0.633	3.391
JPM9-F5	2.120	0.113	-0.059	-0.733	-0.677	3.134
JPM10-F6	2.213	0.113	-0.044	-0.765	-0.642	3.011
APM-CLG1	0.973	0.113	-0.340	0.064	-0.938	6.678
APM-CLG2	1.015	0.114	-0.356	0.202	-0.912	6.433
APM-FWD1	1.647	0.116	-0.277	0.002	-0.961	4.057
APM-FWD2	1.671	0.116	-0.291	0.086	-0.953	4.005
APM-FWD3	1.709	0.117	-0.302	0.169	-0.938	3.928
APM-FWD4	1.761	0.118	-0.310	0.244	-0.919	3.836
APM-AFT1	1.424	0.113	-0.299	0.059	-0.952	4.582
APM-AFT2	1.461	0.114	-0.312	0.154	-0.938	4.487
APM-AFT3	1.513	0.115	-0.322	0.245	-0.915	4.361
APM-AFT4	1.575	0.116	-0.328	0.325	-0.887	4.222

Location	μG Vector Magnitude (μG)	μG Vector ⊥ Component (μG)	Unit Vector X	Unit Vector Y	Unit Vector Z	Cone Angle Max angle from unit vector (deg)
CAM-MID	1.155	0.110	0.146	-0.335	0.931	5.503
CAM-TOP	1.909	0.109	0.170	-0.187	0.967	3.321
APM-CLG3	1.094	0.115	-0.361	0.314	-0.878	6.022
APM-CLG4	1.167	0.116	-0.364	0.416	-0.833	5.690
JEF1-F1	3.430	0.119	-0.041	-0.723	-0.690	2.039
JEF2-A1	2.981	0.112	-0.025	-0.774	-0.632	2.211
JEF3-F2	3.510	0.120	-0.031	-0.745	-0.666	2.003
JEF4-A2	3.096	0.113	-0.015	-0.793	-0.609	2.146
JEF5-F3	3.608	0.121	-0.021	-0.765	-0.644	1.967
JEF6-A3	3.201	0.114	-0.005	-0.812	-0.584	2.092
JEF7-F4	3.721	0.122	-0.013	-0.781	-0.624	1.929
JEF8-A4	3.297	0.115	0.005	-0.829	-0.559	2.044
JEF9-O1	3.770	0.122	0.007	-0.823	-0.567	1.904
JEF10-O2	3.628	0.120	0.014	-0.839	-0.544	1.935
JEF11-U1	2.937	0.120	0.045	-0.908	-0.417	2.384
JEF12-U2	3.015	0.120	0.059	-0.926	-0.372	2.323
S3LO	3.111	0.151	-0.212	0.974	0.080	2.812
S3LI	2.771	0.146	-0.212	0.972	0.102	3.032
S3UO	3.683	0.143	-0.088	0.845	0.528	2.289
S3UI	3.419	0.137	-0.074	0.812	0.579	2.366
P3LO	3.420	0.115	0.198	-0.948	0.249	1.926
P3UO	4.224	0.108	0.242	-0.759	0.604	1.464
FGB-CG	1.876	0.116	0.012	0.843	0.538	3.610
SM-CG	2.218	0.105	0.080	0.305	0.949	2.863
USL-CG	0.860	0.105	-0.291	-0.275	-0.916	7.063
JEM-CG	1.951	0.112	-0.059	-0.748	-0.661	3.359
APM-CG	1.582	0.115	-0.306	0.157	-0.939	4.192

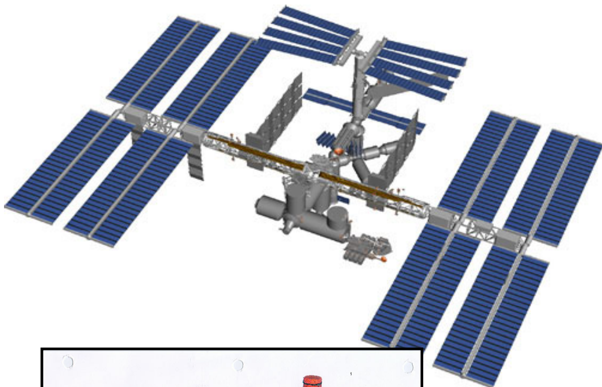
- **10 racks under 1 μg**

Quasi-Steady Results
DAC 9 - Core Complete

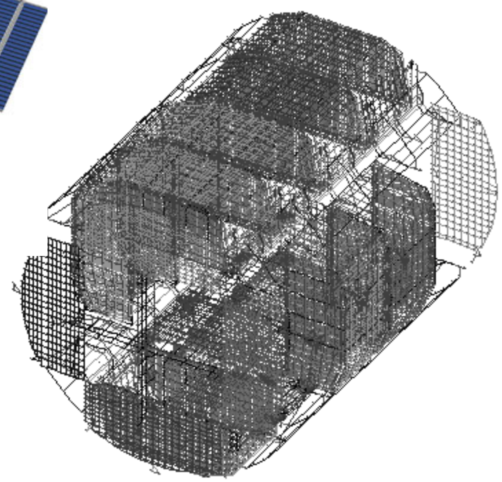


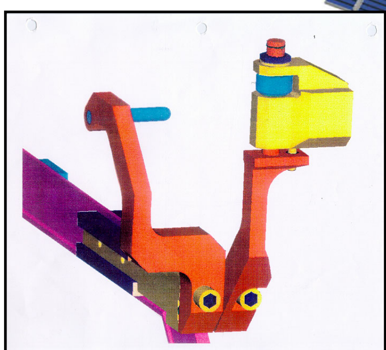


Vibratory Analysis (Structural Dynamic) Methods & Tools



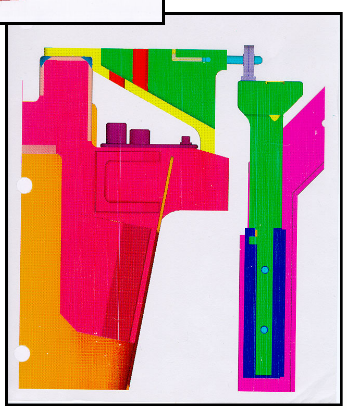
Enhanced COF Model





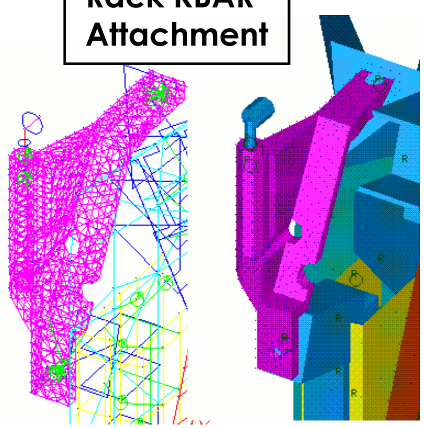
Lower Pivot

Non-isolated Rack I/F

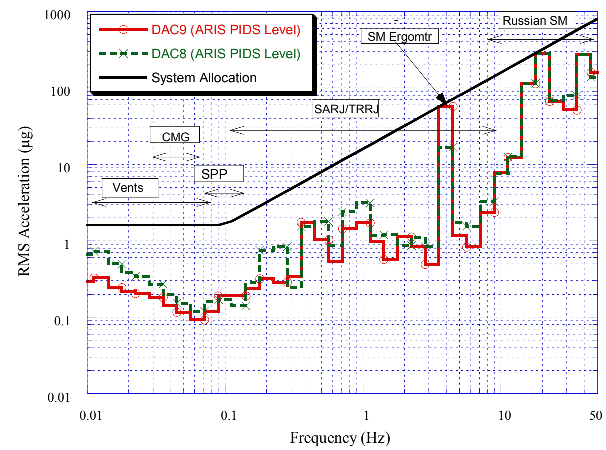


Upper KBAR

Rack KBAR Attachment



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



Vibratory Analysis
Methods and Assumptions

- “Structural dynamic” micro-gravity assessments (0 to 50 Hz.)
- Frequency domain analysis for steady-state disturbances
  - Analysis frequency vector superposition of 2 frequency sets
    - **8457 system modes resonant frequencies**
    - **2000 supplemental frequencies at constant logarithmic spacing.**
- Time domain simulations for transient disturbances
  - Simulations performed with 0.01 second time step to have Nyquist frequency of 50 hz
  - Simulations performed for 100 seconds provide data down to lower frequency limit of 0.01 hz.

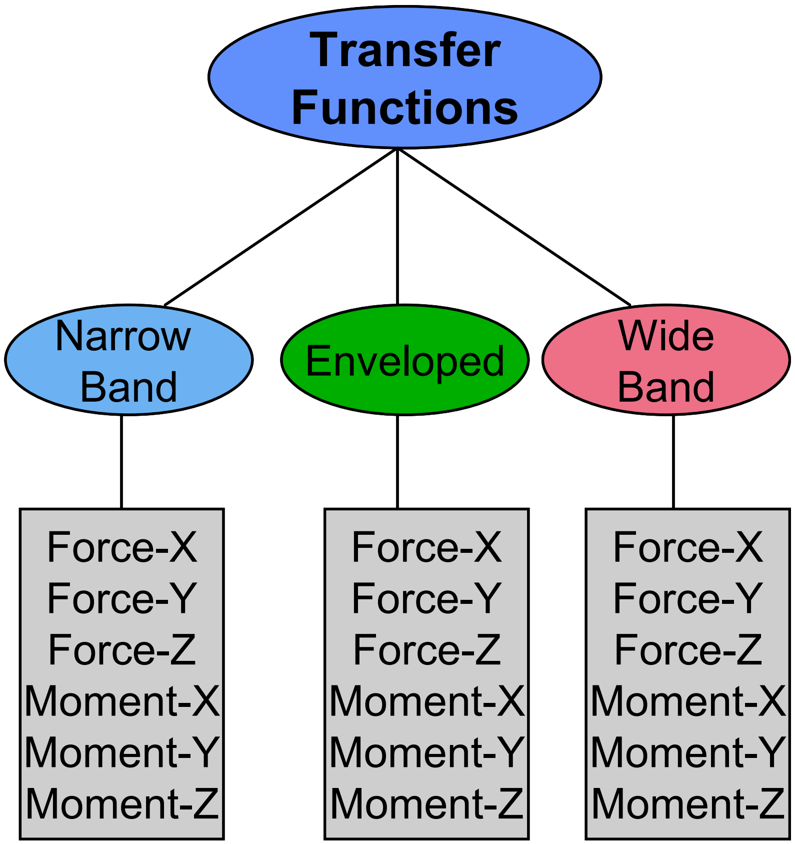
Damping

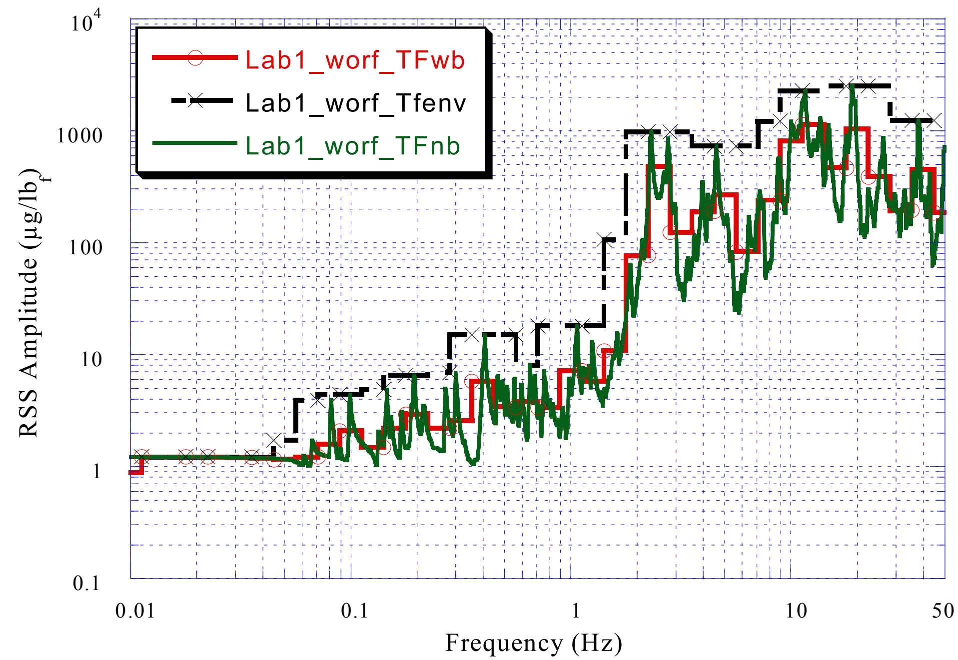
- 0.25% for all modes

Attenuation

- ARIS attenuation applied
  - PIDS level
  - FCA verification level

Vibratory Analysis
Transfer Functions





$$TF_{wb} = \sqrt{\frac{1}{\Delta F}\sum_{\Delta F} H(f)^2 \Delta f_{nb}}$$

where ΔF is an 1/3 octave band

Vibratory Analysis
Finite Element Models

- Component models obtained from various sources - element developers, international partners.
- Models usually obtained through Loads & Dynamics AIT
- Some models obtained directly from source
- Models come in various formats: simple stick-beam representations, detailed bulk data, reduced mass/stiffness matrices.
- CONFIGURATION
  - DAC-8 system model represented Rev.C configuration. This was updated to Rev. F configuration for DAC-9, major differences in Russian segment.
  - Node 4 / Propulsion module not included.

COMPONENT MODELS	SOURCE
US Laboratory Module (US Lab)	Boeing Hsv
Japanese Experiment Module (JEM)	NASDA
ESA Attached Pressurized Module (APM)	ESA
Centrifuge Accommodation Module (CAM)	NASDA/ARC
Node 2 and Node 3	Alenia
Photo-Voltaic Arrays	Boeing CP

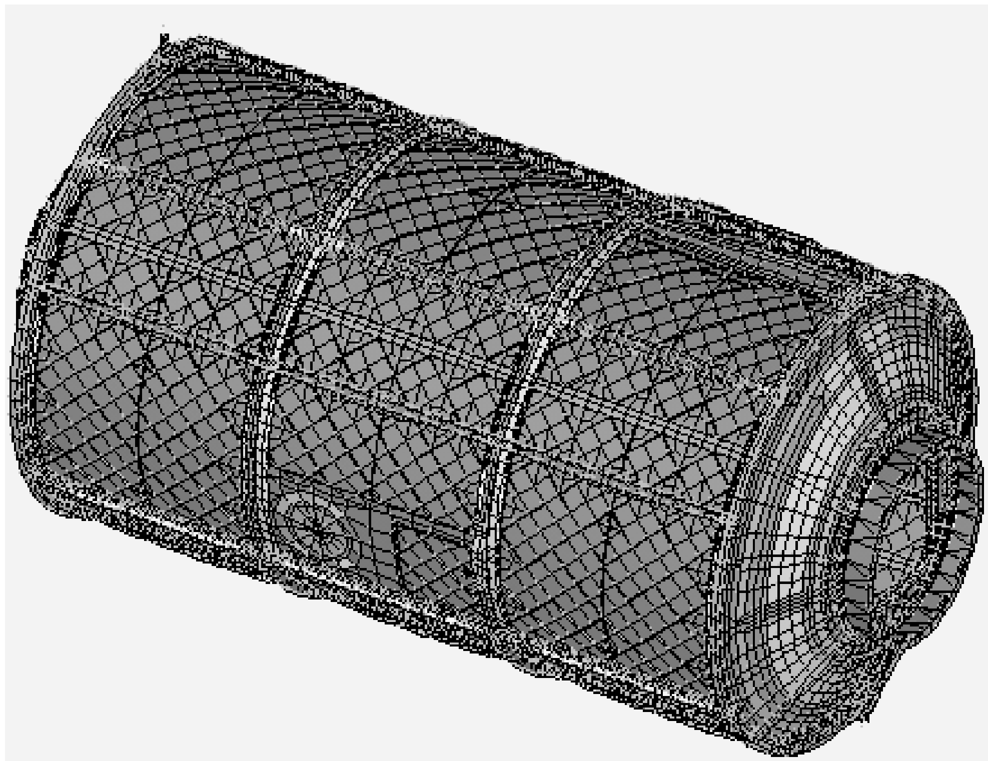
US Lab Finite Element Model (Boeing, HSV)

- US Lab model comprised of 32 Super-elements: Shell, Forward ESS, Aft ESS, 4 Standoffs, LCA, 12 Racks, 12 Isolation Plates
- Includes detailed rack models and attachments - pivot pins, K-bars, knee braces, bayonet fittings. ARIS racks are not included.
- For DAC-9, **unique system rack models were used** rather than a generic rack model used for DAC-8.
- Craig-Bampton reduction performed on all US Lab component models. Modal content to 100 Hz. was retained. Total integrated weight 36325 lb.

Experimental Validation

- Modal Survey Test performed by Boeing, Hsv., “Laboratory Module Dynamic Model Correlation Report,” Encl. to 2-8263-BKC-018-99
- Launch configuration - Common Module with one standoff, one rack, CBM’s, Mass Simulators for PMA.
- Frequency range for Model Correlation, 0 to 50 Hz.
- Deflection data from static testing and transfer function correlation studies to further validate on-orbit model.

Integrated US Lab Model



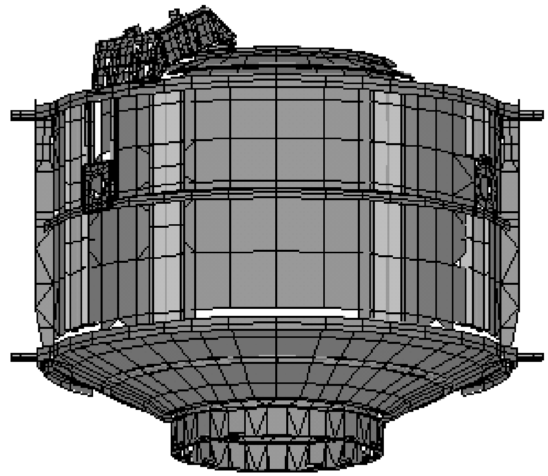
JEM Finite Element Model (NASDA)

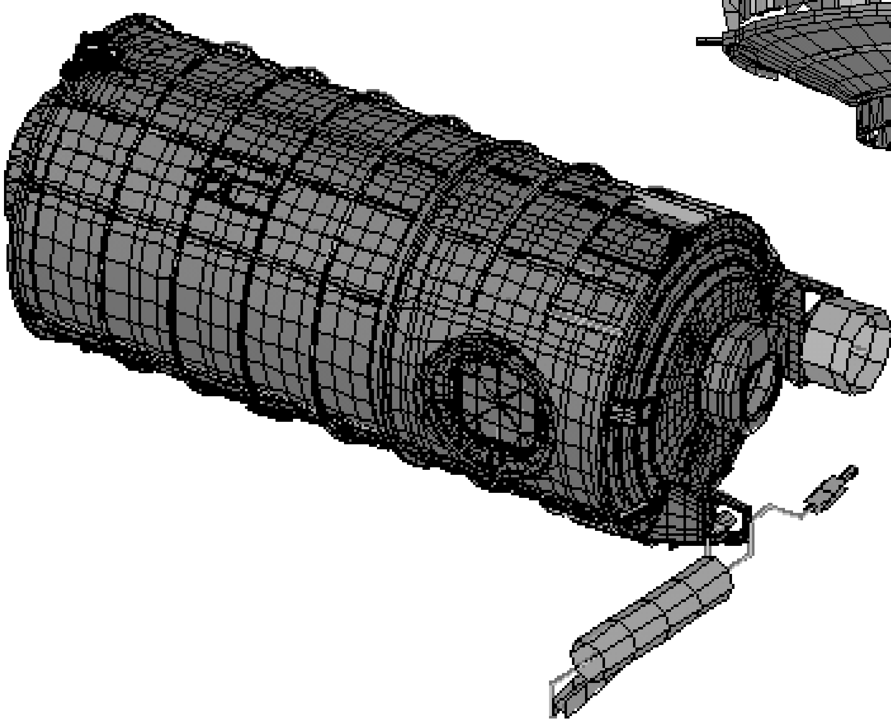
- JEM model comprised of JEM-PM, ELM-PS, EF, and ELM-ES. Only the JEM-PM and ELM-PS were updated from DAC-8 to reflect latest design and structural test results (Rf. NU-98930, 2/3/2000).
- Includes detailed rack models (24 racks in PM, 8 racks in ELM-PS) and updated rack attachment hardware models (K-Bar, pivots).
- Craig-Bampton modal reduction performed on PM, ELM-PS and EF,
  - 942 modes to 100 Hz retained for JEM-PM and ELM-PS
  - 155 modes to 100 Hz retained for JEM-EF and ELM-ES
  - Total integrated weight is 103320 lb

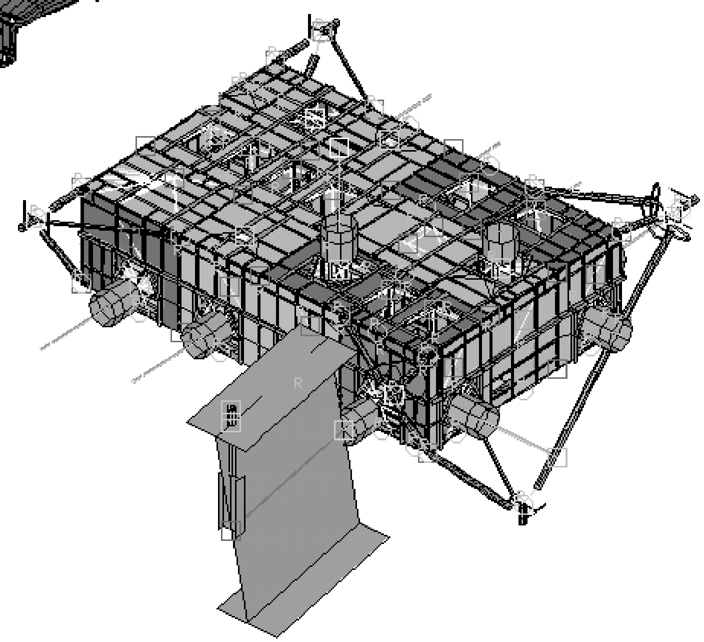
Experimental Validation

- Modal Survey test performed for PM, ELM-PS (launch configuration), and for EF, ELM-ES (launch and on-orbit configuration).
- Frequency range for Model Correlation, PM 25 Hz., EF 32 Hz., ELM-ES 17 Hz.
- Deflection data from static testing and local modal tests used to validate stiffness of equipment support structures and interfaces.

Vibratory Analysis
JEM Component Models

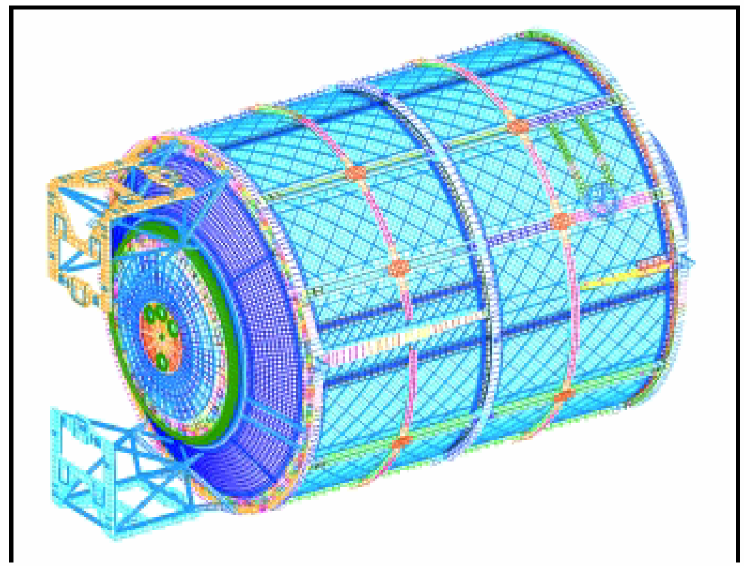




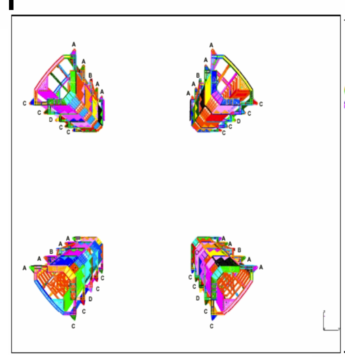


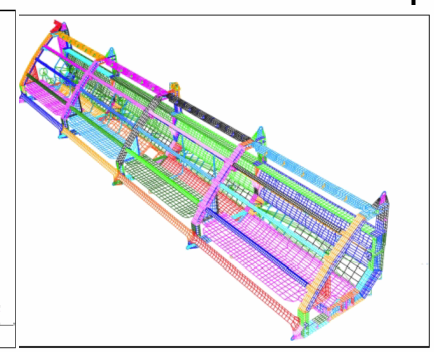
COF Finite Element Model (ESA, Alenia)

- Detailed model of ESA-COF (COL-RP-AI-0202, 3/03/2000) comprising of
  - Primary structure: cylinder,cones, rings and fitting
  - 4 Stand-offs (Craig Bampton reduced format)
  - Hatch (Bulk data)
  - Common Berthing Mechanism (Bulk data)
  - Forward and Port internal structure (Bulk data)
  - External Platform (Bulk data)
  - Racks
    - **13 NASDA racks (CB reduced format)**
    - **3 S/S racks (2 CB reduced format, 1 bulk data)**



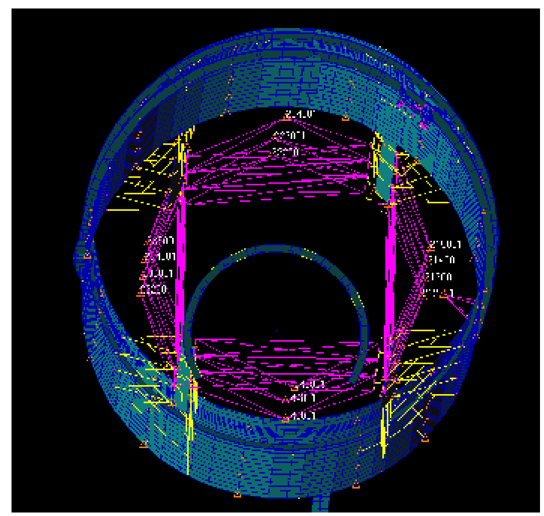
- Model reconfiguration
  - Remove racks F1,F2,A1,A2
    (Assumed location of ARIS racks): 1700 kg.
  - Change rack-to-module connections (OA/2) for racks A3, A4, F3, F4
- Model Reduction
  - Craig-Bampton modal reduction performed on ESA-COF, modal content:1000 modes to 97 Hz.
  - Total integrated weight 42150 lb.





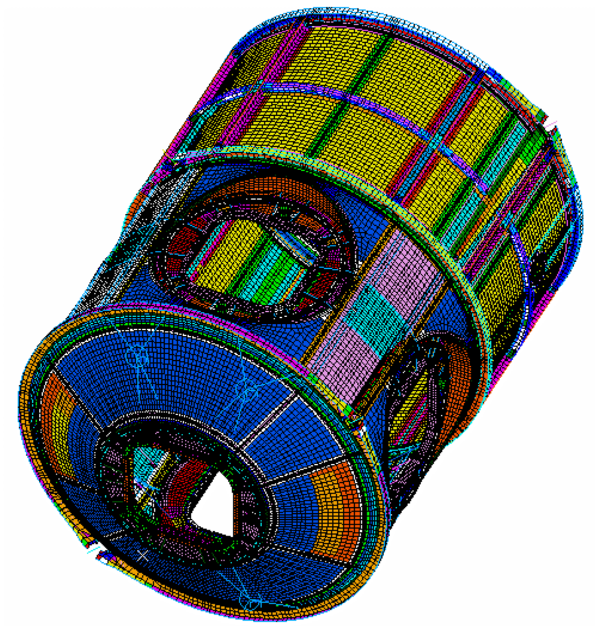
CAM Finite Element Model (NASDA, ARC)

- Detailed model of Centrifuge Accommodation Module including Centrifuge Rotor (Rf. NU-100293, 10/3/2000).
- CAM module generated based on the test-verified JEM-PM model.
- Includes detailed Centrifuge rack model and concentrated mass representation of other rack models.
- Craig-Bampton modal reduction performed on integrated CAM, modal content: 665 modes to 100 Hz .
- Centrifuge spin mode retained
- Total integrated weight 42620 lb.

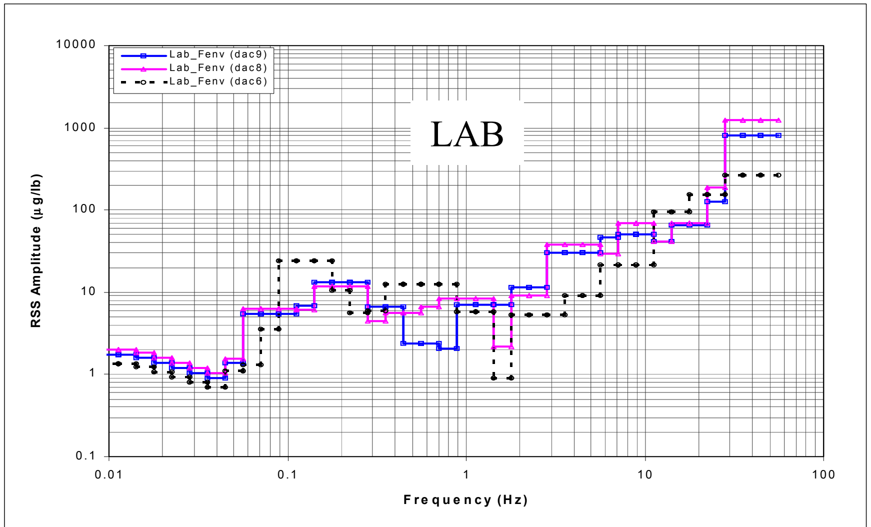


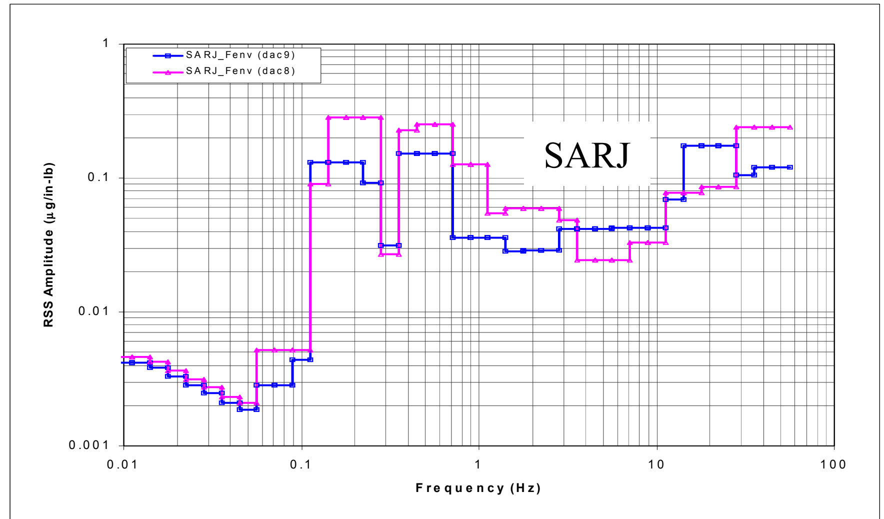
Node 2 Finite Element Model (Alenia, MSFC)

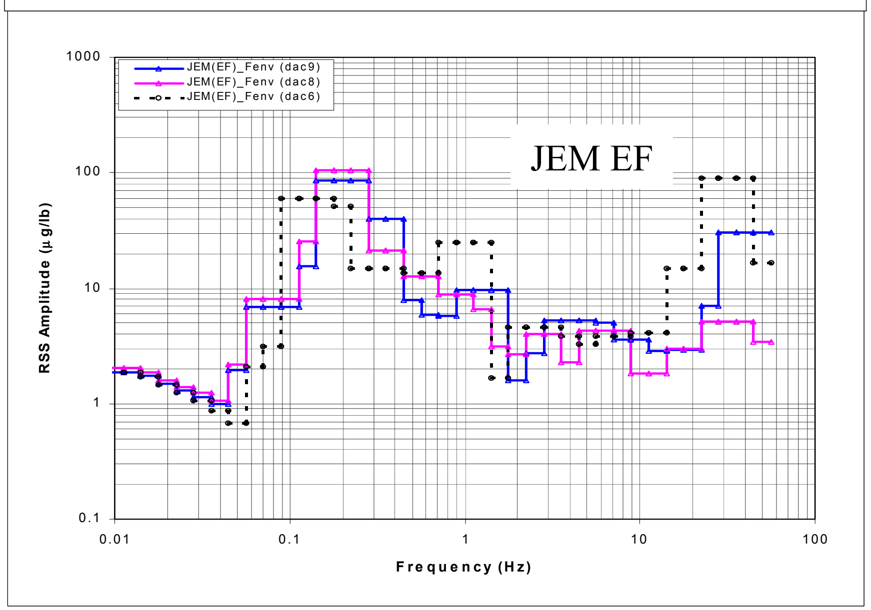
- Detailed model of Node 2 developed by Alenia (Rf. N2-RP-AI-0070, 2/1/2001, N2-RP-AI-0115, 2/23/2001).
- Model includes all primary and secondary structures
  - standoffs, mid-bay & alcove structure, fwd/aft cones, 4 DDCU racks, ISPR
- Identical model used for Node 2 and Node 3
- Model provided by Alenia as Craig-Bampton reduced mass and stiffness matrices.
  - modal content: 301 modes to 57 Hz
  - total weight 34900 lb.

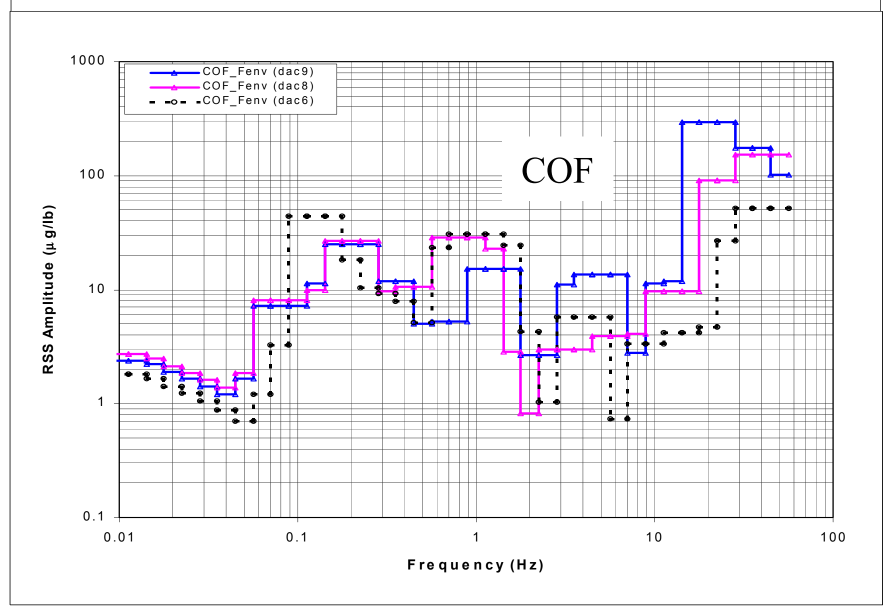


Vibratory Analysis
DAC9 FEM Transfer Functions



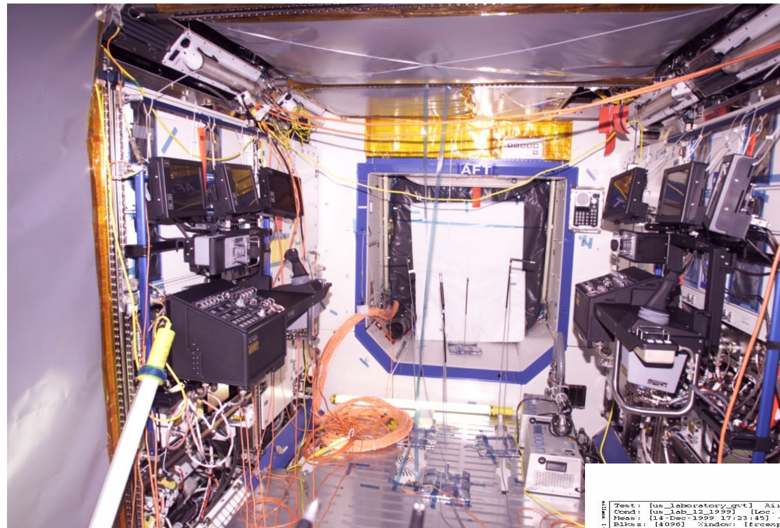




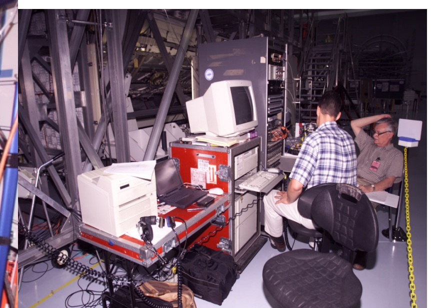


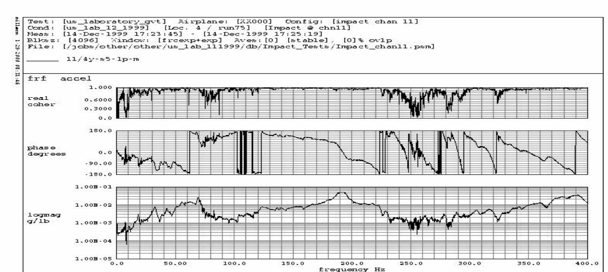
Vibratory Analysis
Disturbance Analysis & Testing

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

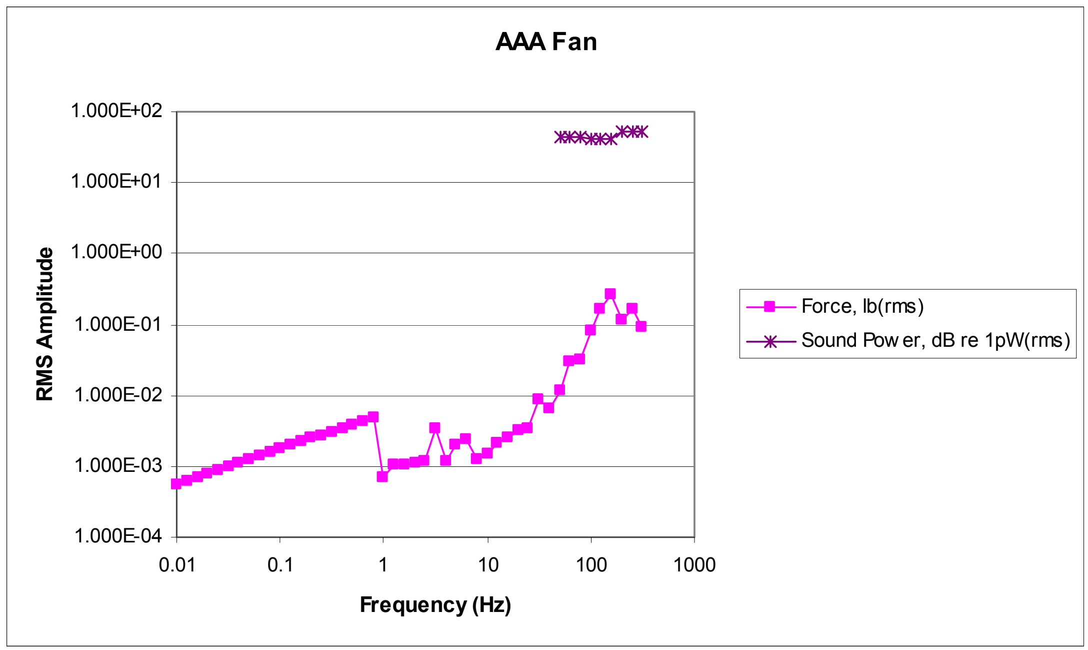
EQUIPMENT			PG/IP	DISTURBANCE COMPONENT ASSURACY (WEIGHTING * RATING)									ACCURACY RATING
TYPE	ITEM	NUMBER		QUASI-STEADY	VIBRATORY								0 </= AR </= 10
					MECHANICAL				ACOUSTICAL				
					NB		WB	TR	NB		WB	TR	
					Fndmtl.	Harmonics			Fndmtl.	Harmonics			
Flight 1A/R - FGB													
	ECLSS 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

Vibratory Analysis
Forcing Functions - Database

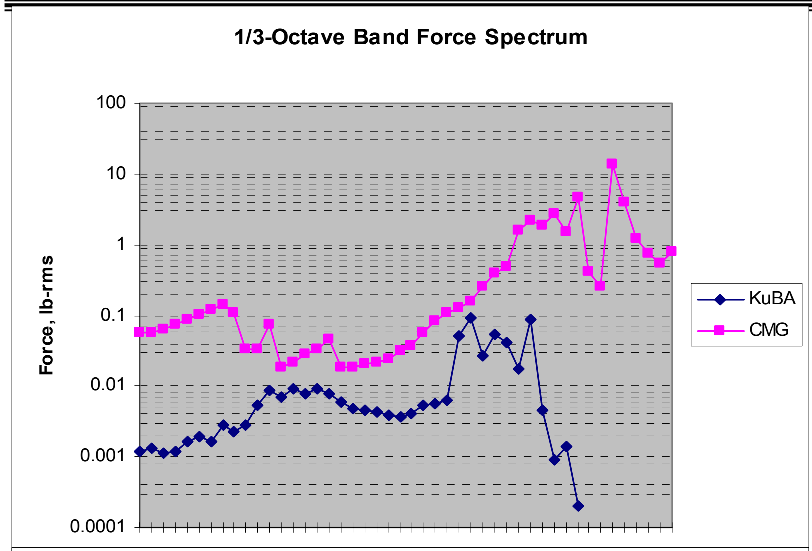
Co. / Agency	BHV			
Item	Fan, AAA (175 W, nominal)			
Location (Number)	Lc1 (1), Lc2 (1), Lc3 (1)			
	Ls1 (1), Ls2 (1), Ls3 (1)			
	Lf3 (1), Lf4 (1), Lf6 (1)			
	Lp1 (1), Lp2 (1), Lp4 (1)			
Duty	0.2 for each fan			
References	144			
Bibliography	1,2,11,17,26,38,50,52,55,56,75			
Comments	Umbalance force 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

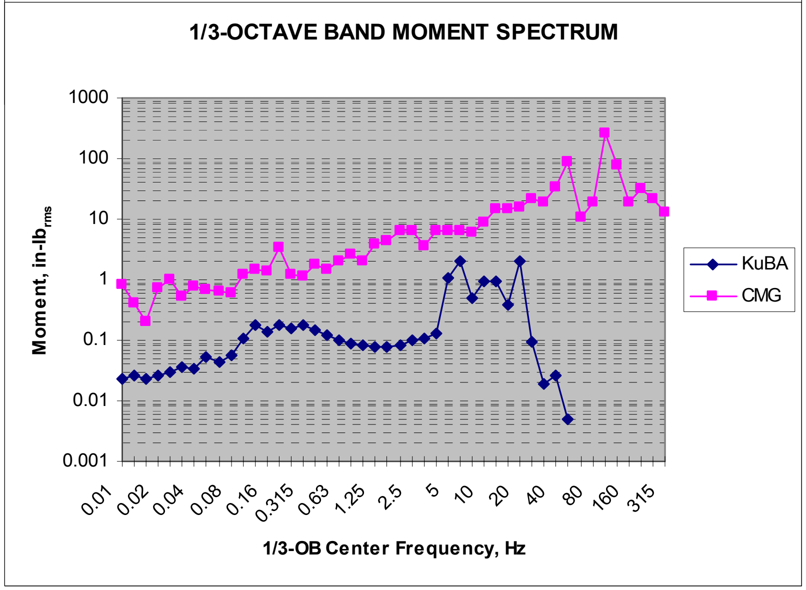
DISTURBANCE DATABASE

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

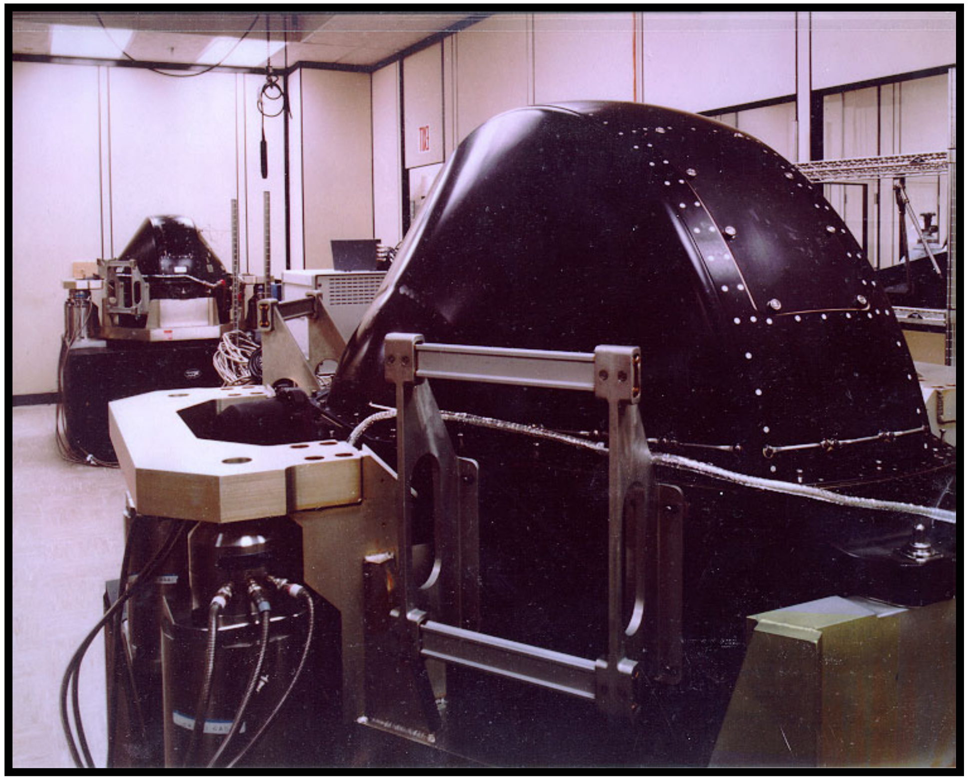


Vibratory Analysis
Forcing Functions - CMG



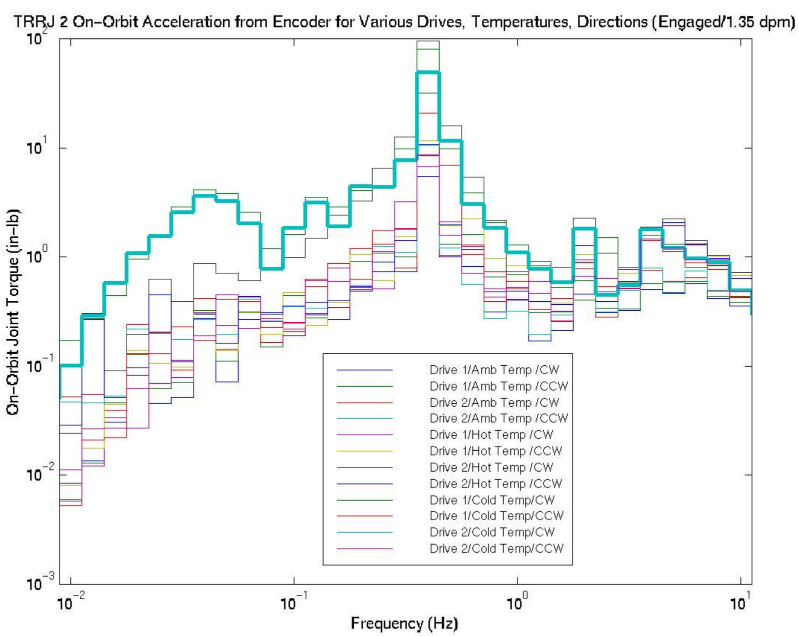


Control Moment Gyros (CMG) For Torque Equilibrium Attitude



Articulate Joints For PV Array Solar Incidence

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



SARJ Drive Motor In Test

SARJ Qual Unit With Trundle Bearings Installed

Treadmill

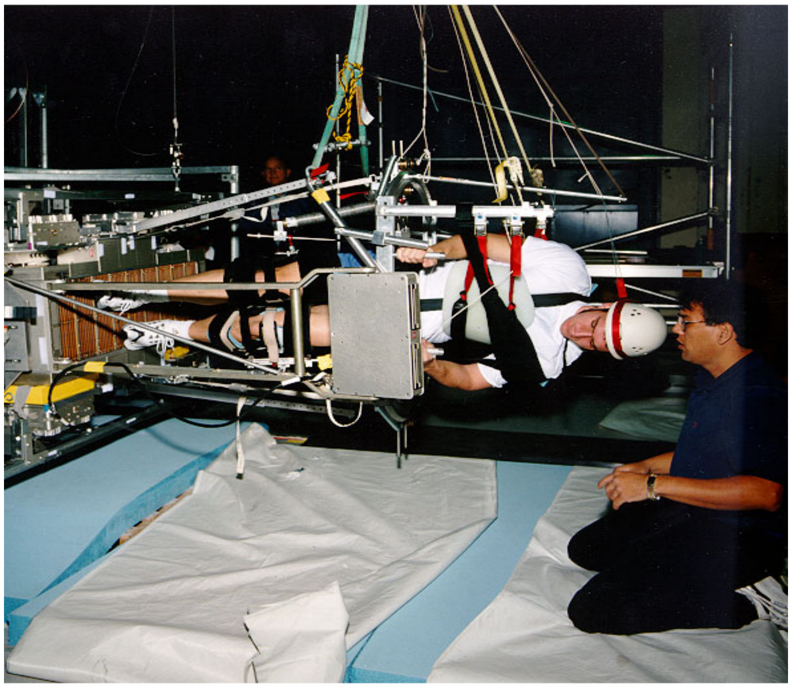
- SM treadmill disturbance definition based on horizontal test measurements for TVIS certification.
- Measurements include source isolation effects
- Force measurements from 3 cases were used as inputs for transient analysis.
  - speed 1.9, 4.2, and 8.1 m/h

Cycle Ergometer

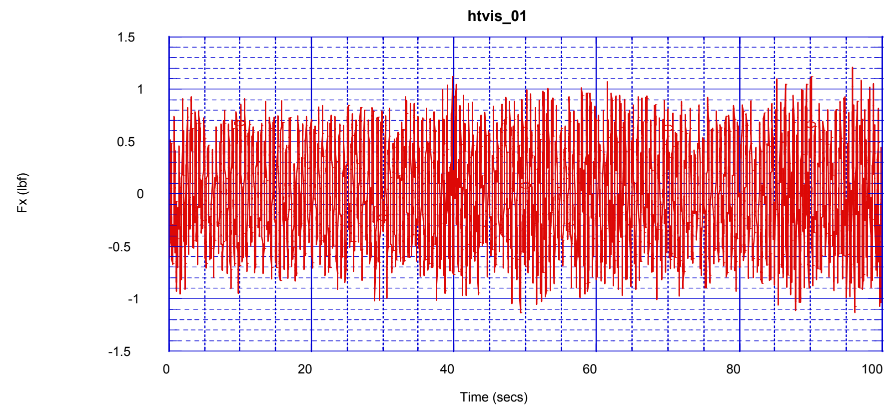
- US Lab ergometer disturbance definition based on test measurements for CEVIS certification.
- Measurements include source isolation effects
- Force measurements from 4 cases were used as inputs for the transient analysis.
  - 190 lb. cycling 60, 75, 90, and 105 rpm
- Ergometer mounted on rack seat-tracks in US Lab. Possible relocation to Node 1.

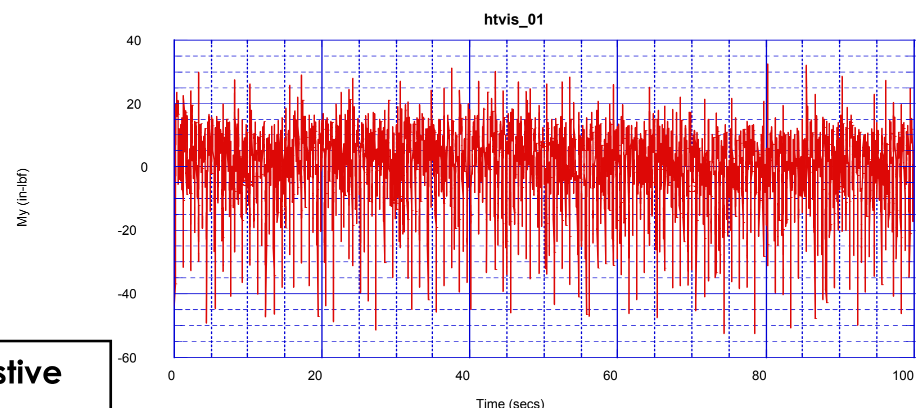
Vibratory Analysis
Forcing Functions - Exercise Devices

TVIS Certification Test



6 DOF Transient Force/Moment For Various Subjects



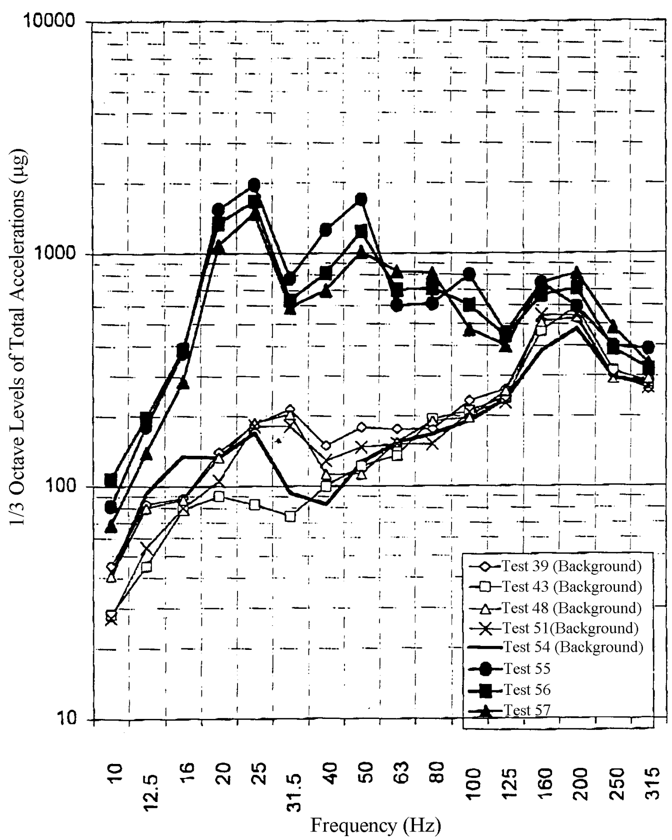


<u>Crew Exercise Equipment:</u> Treadmill, Ergometer, Resistive Exercise Device (Isolated/Non-isolated)

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

Vibratory Analysis
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:

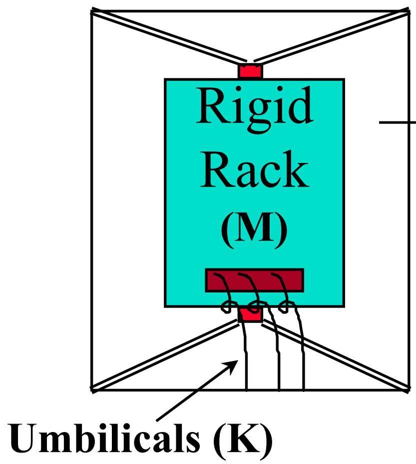
- * one WPA (test data -eq.))
- * one WOO (actuated) (test data -eq.)
- * two WTMO (actuated) (test data - eq.)
- * fluxed ducting (test data - sect.)

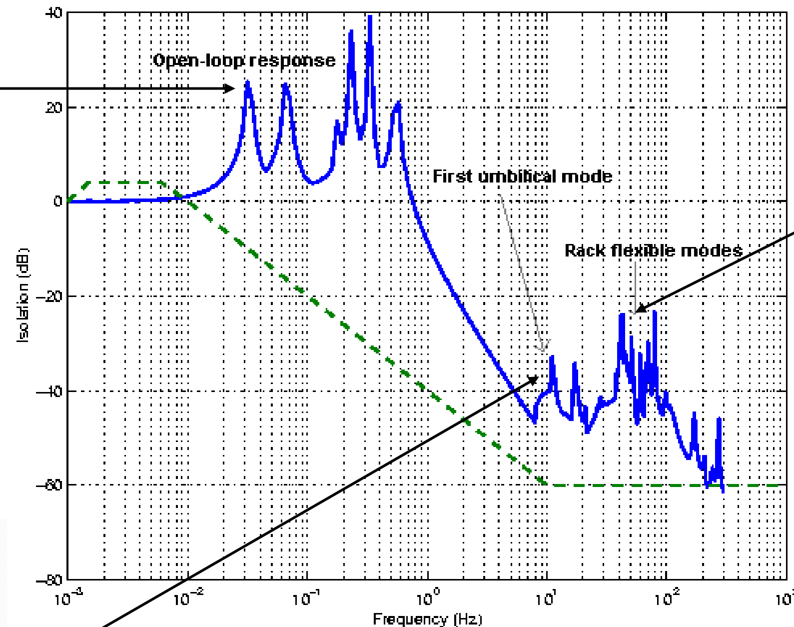
Structural Stick/slip :

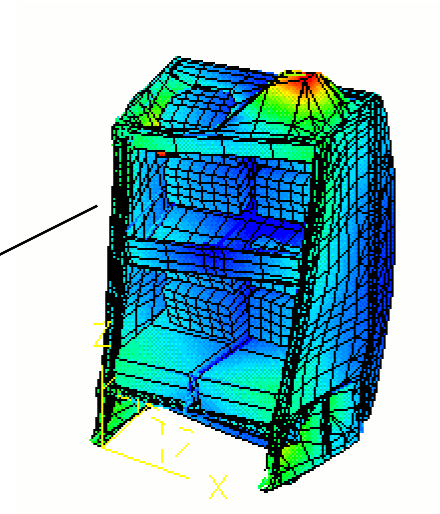
- * Stick/slip at MDPS/bracket interface (analytical evaluation)

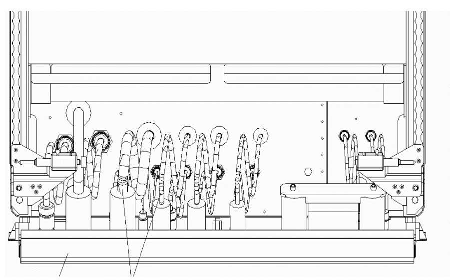
NASDA ICS Antenna Slew & Tracking

Vibratory Analysis
Rack





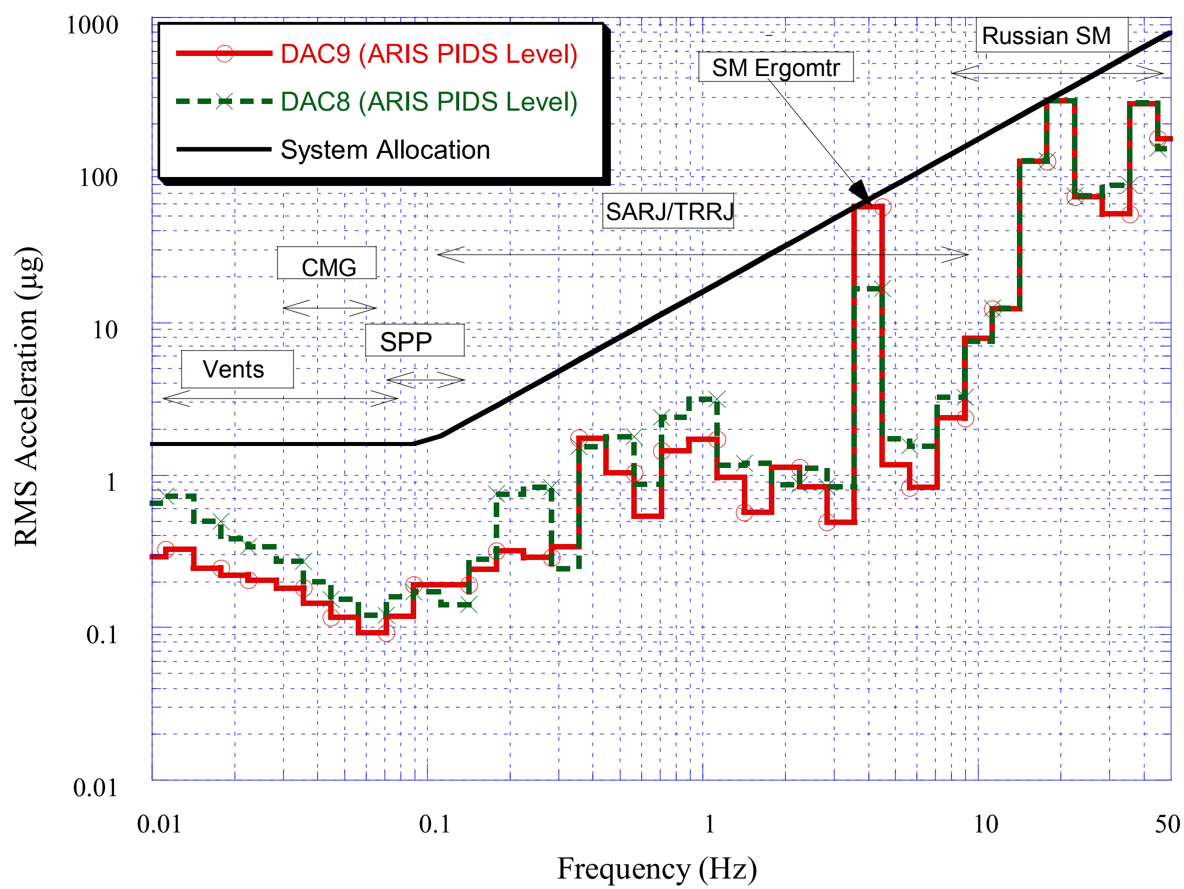




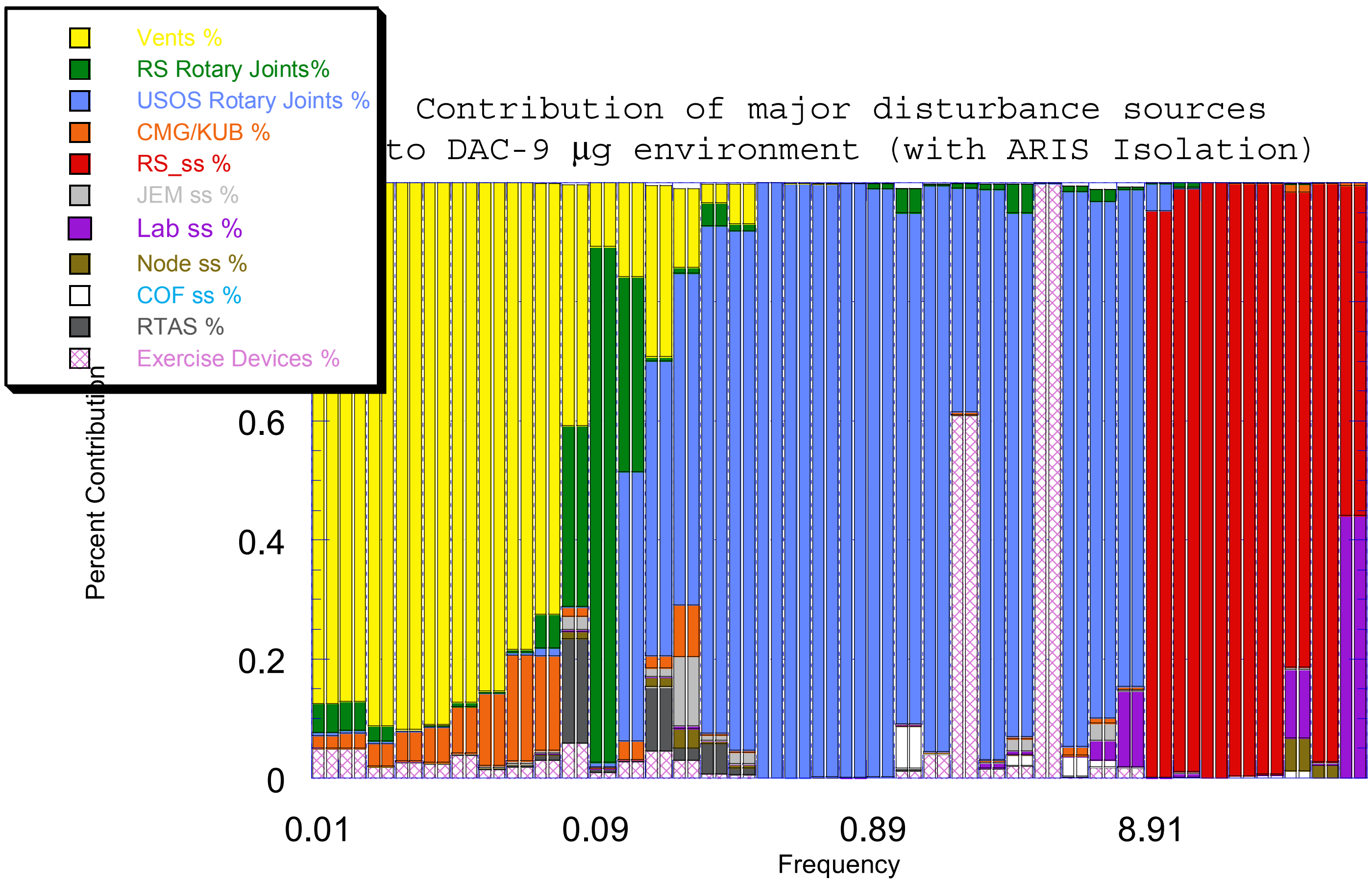
- **Resonances between 0.01-1 Hz are rigid rack-umbilical modes (M-K)**
- **Resonance around 10 Hz is the umbilical loop resonance**
- **Resonances above 26 Hz are due to rack flexible modes being excited by umbilical and pushrod resonances.**

Vibratory Results
DAC 9 - Composite

DAC-9 Microgravity Environment Prediction (with PIDS level ARIS)

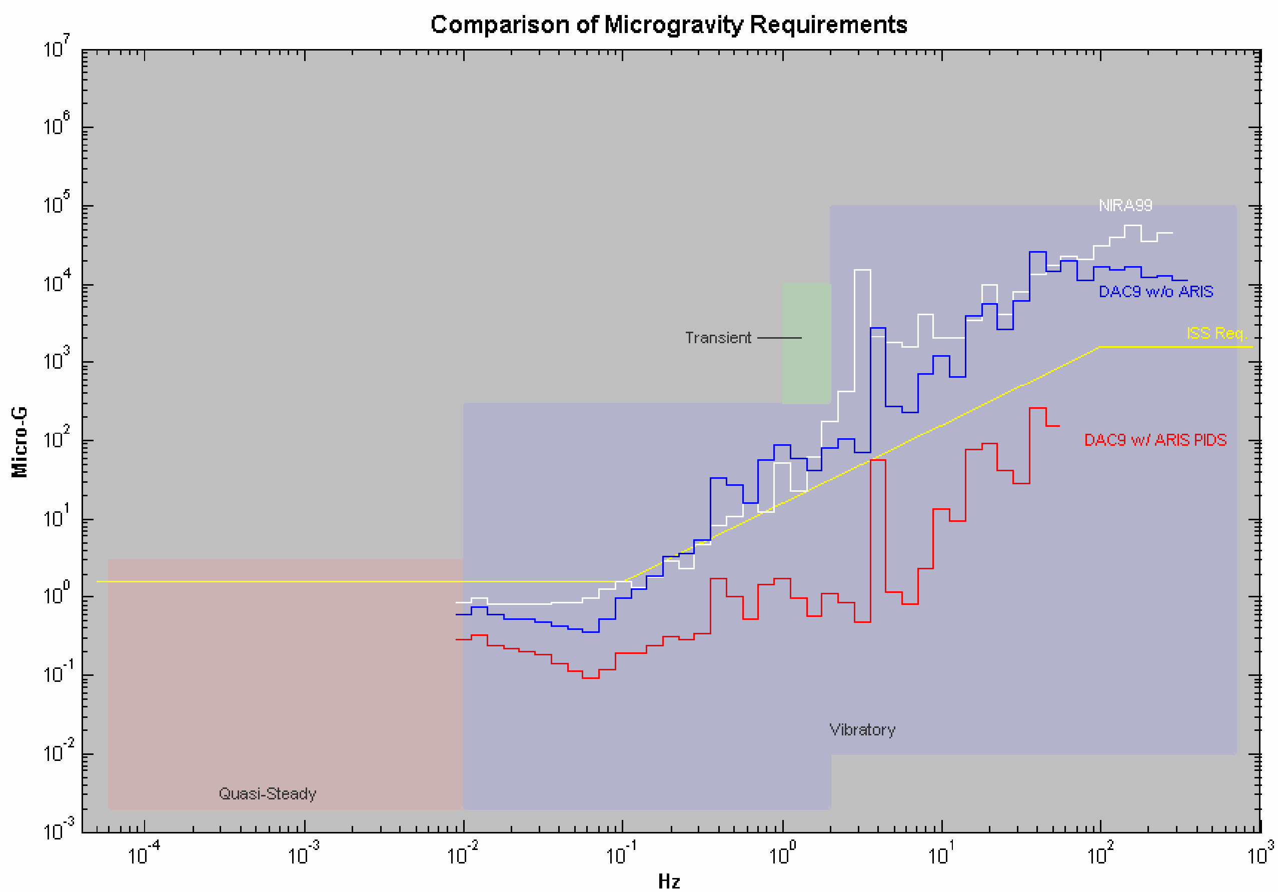


Vibratory Results
DAC 9 – Composite

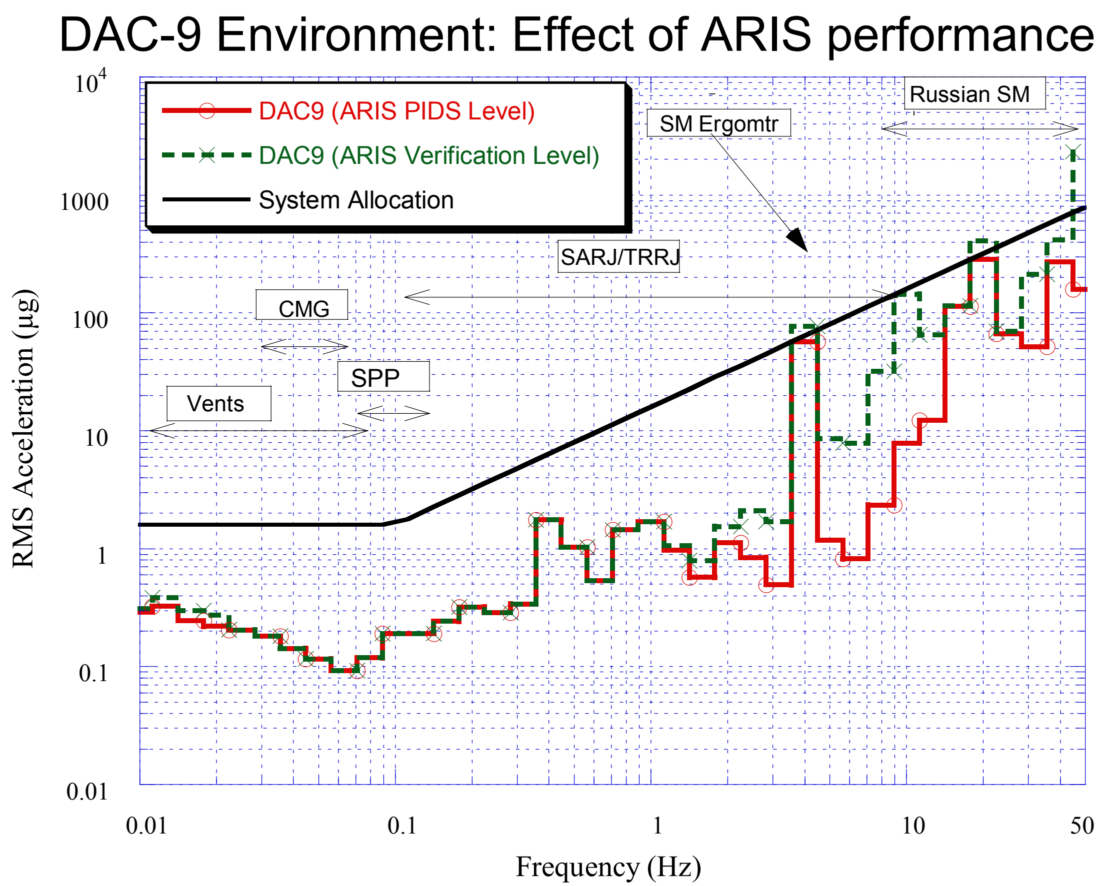


Vibratory Results
DAC 9 – ARIS

Microgravity Environment Performance
(ARIS PIDS)

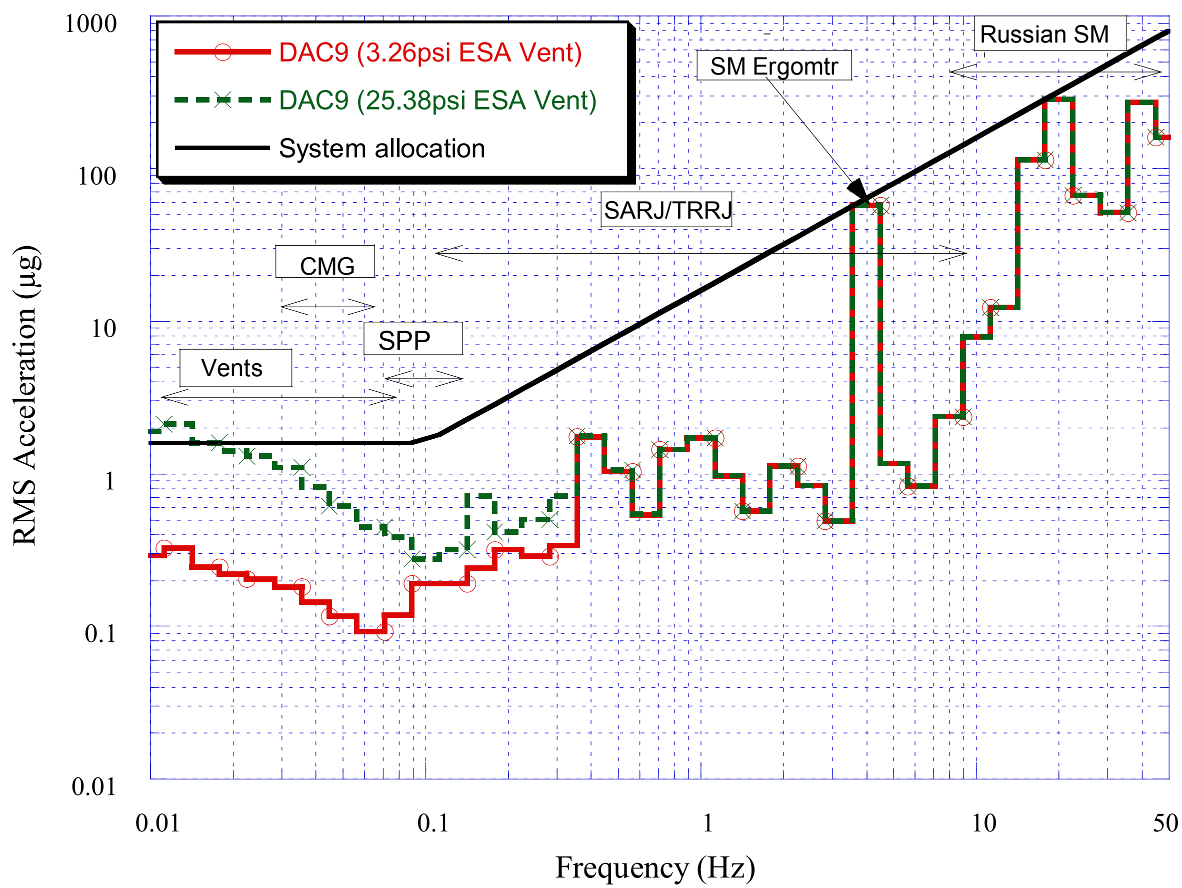


Vibratory Results
DAC 9 - ARIS



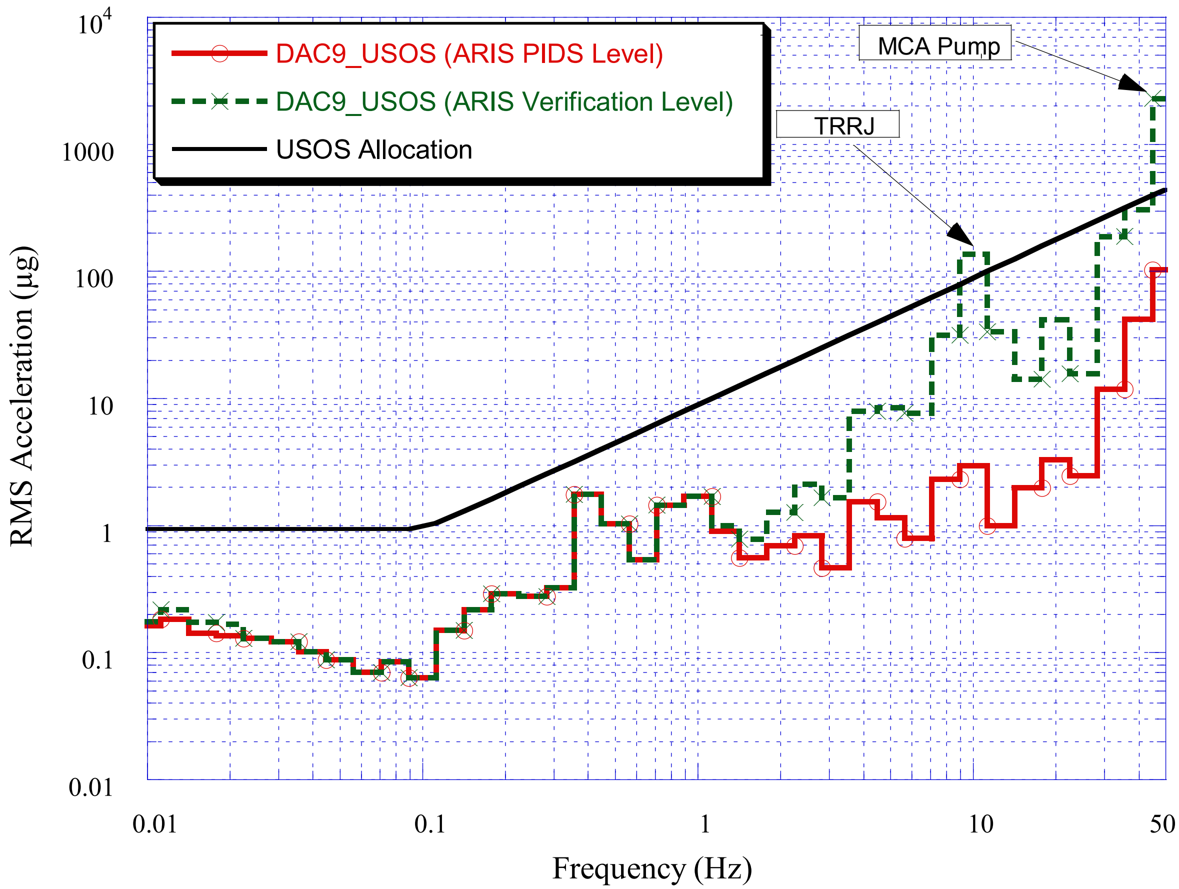
Vibratory Results
DAC 9 – Composite, Venting

DAC-9 Microgravity Environment Prediction (with PIDS level ARIS)
Effect of ESA Vent Disturbance Definition

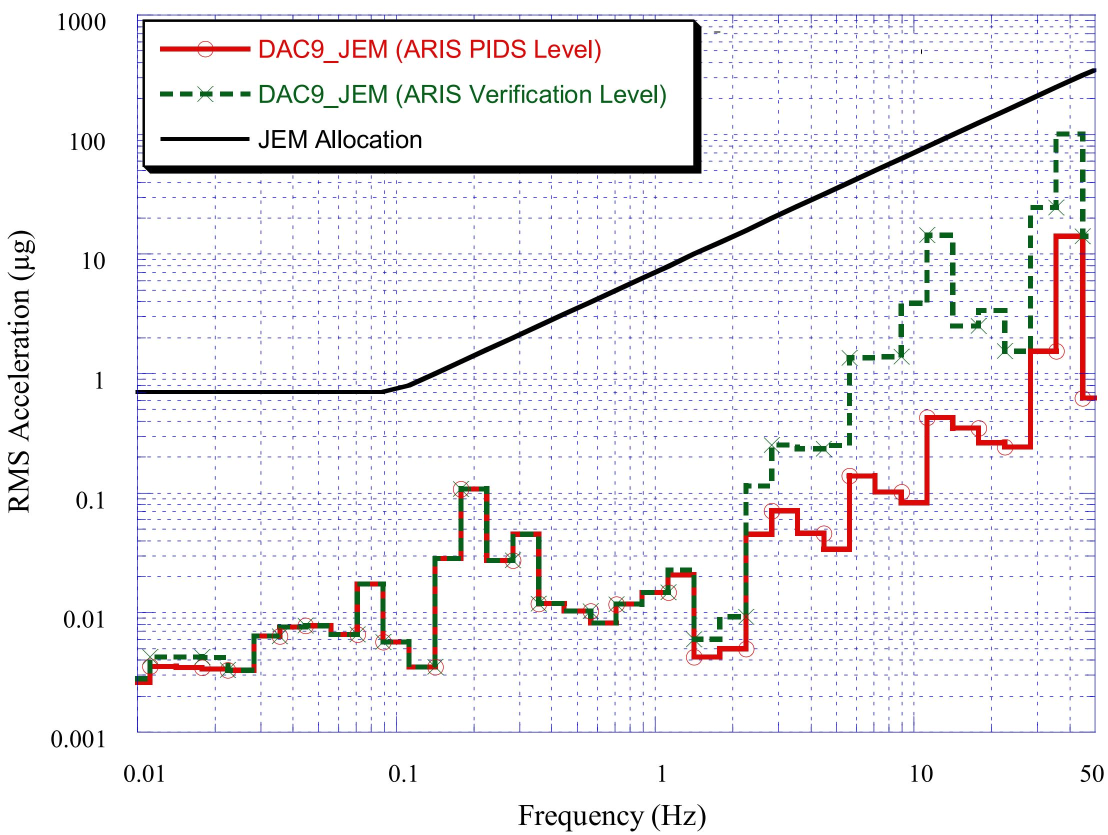


Vibratory Results
DAC 9 – USOS

DAC-9 Environment: USOS Disturbance

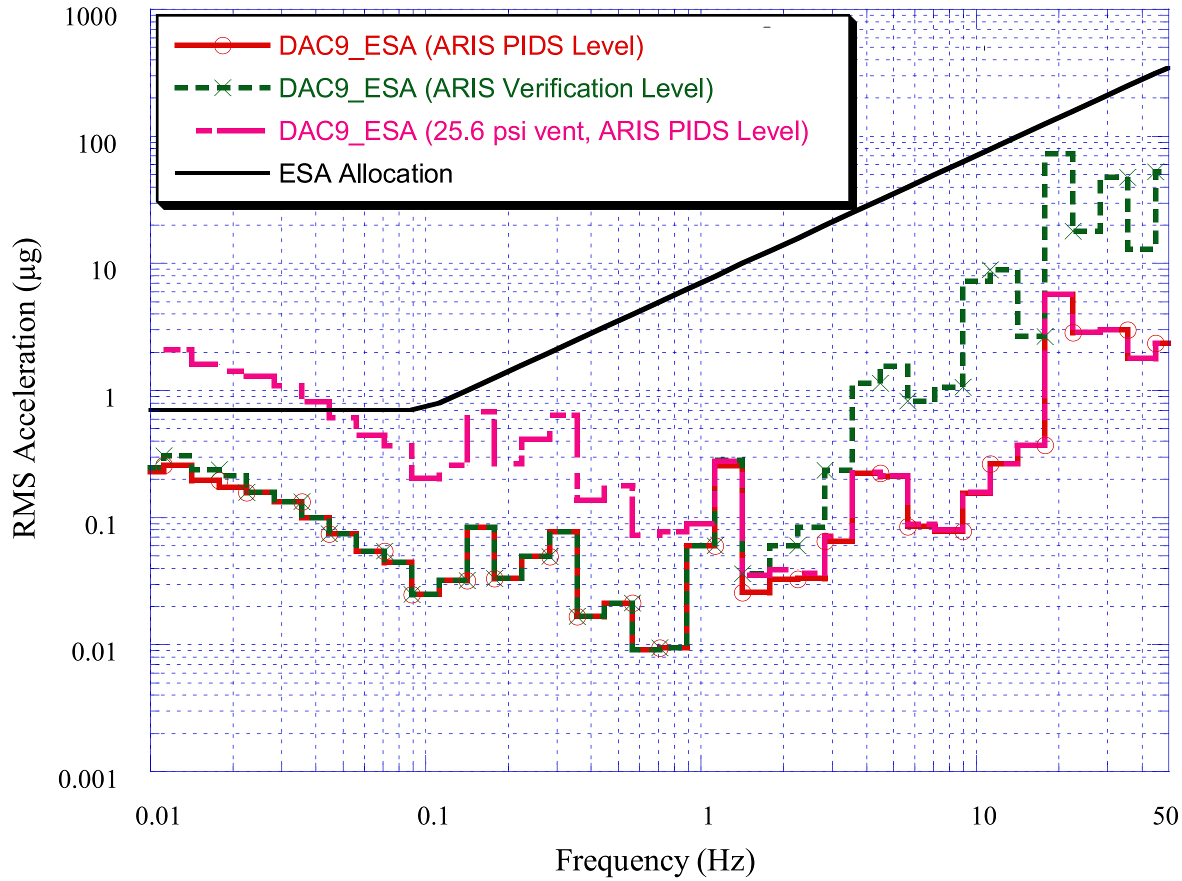


DAC-9 Environment: JEM Disturbance



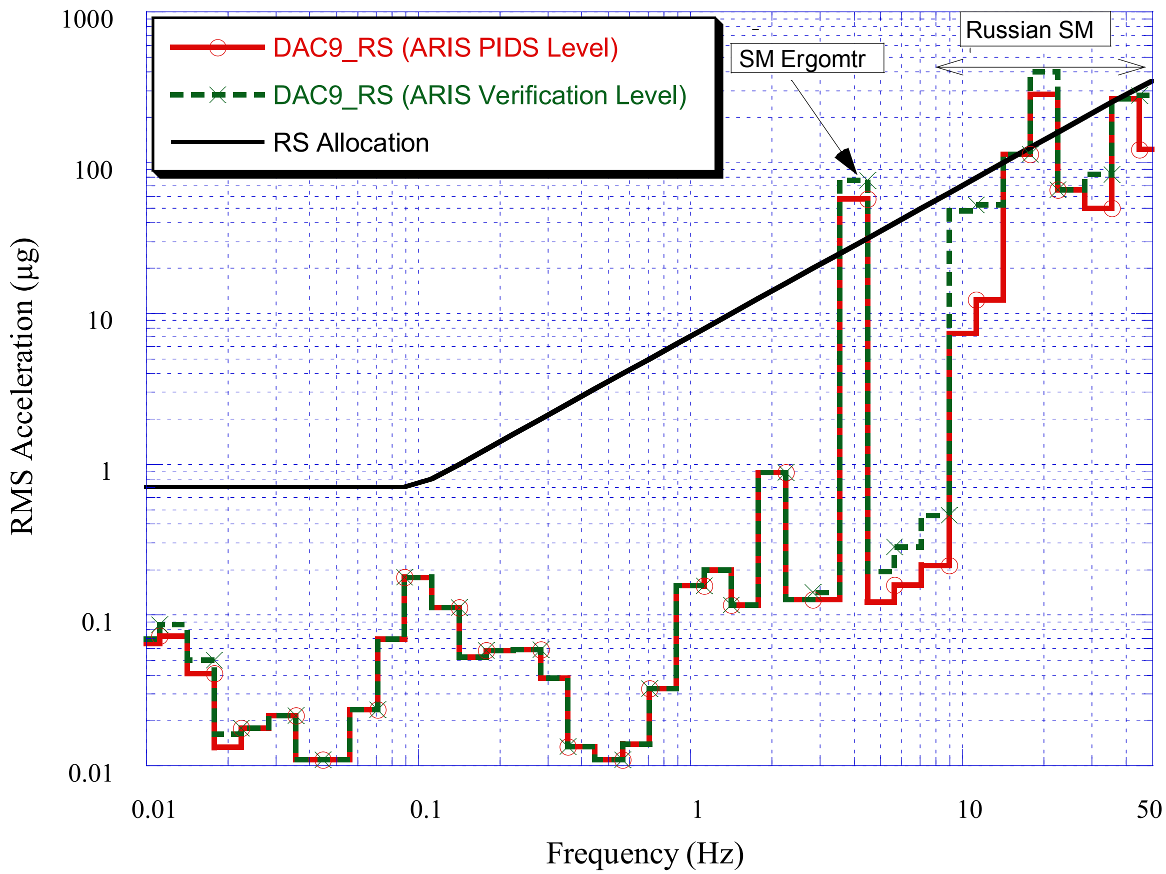
Vibratory Results
DAC 9 – ESA

DAC-9 Environment: ESA Disturbance



Vibratory Results
DAC 9 – RS

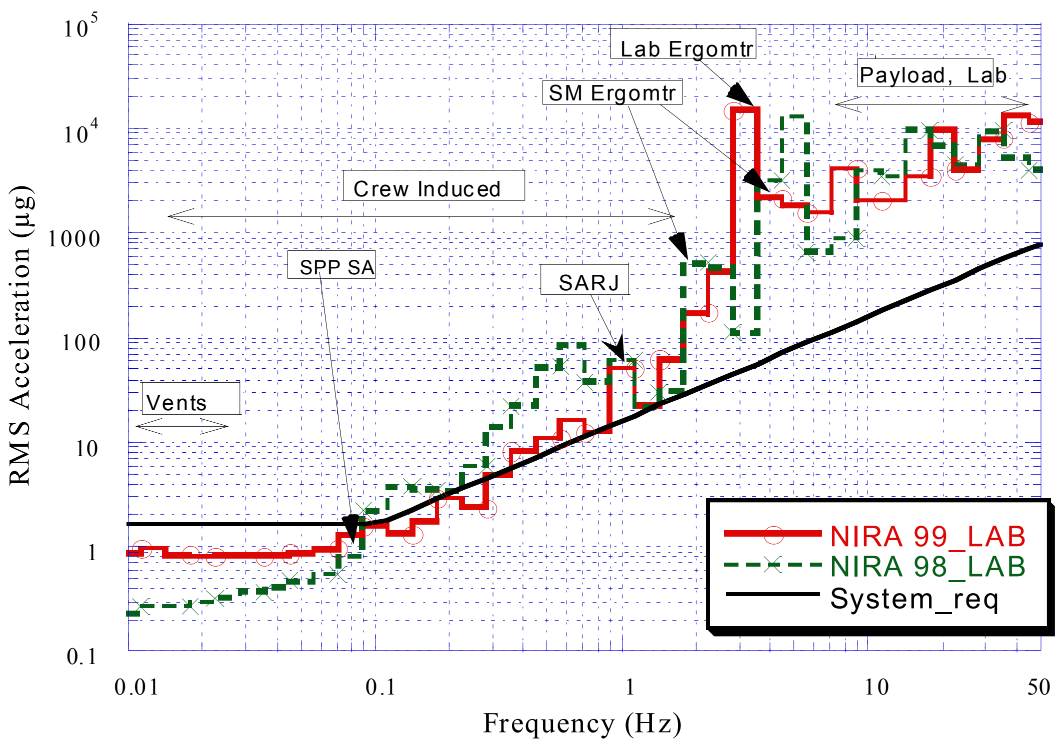
DAC-9 Environment: RS Disturbance



Vibratory Results
NIRA 99 - US Lab

Non-Isolated Rack Assessment Differences From DAC9 Requirement Compliance Results

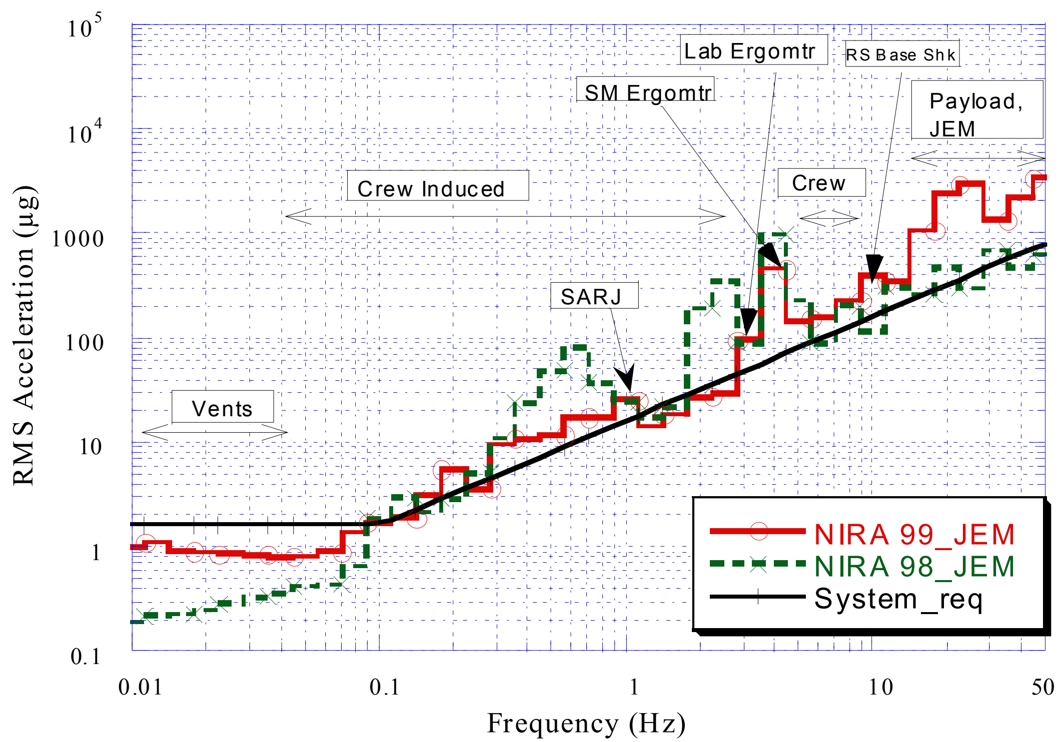
- 1% Damping
- + 2Crew translations & 2console ops
- + Payload disturbances (8 racks in Lab, 3 in COF and 2 in JEM)(21 sources per rack includes AAA fan.)
- @ Non-isolated rack interfaces
- Non-isolated Lab ergometer - subsequently isolated



Vibratory Results
NIRA 99 - JEM-PM

<u>Non-Isolated Rack Assessment Differences From DAC9 Requirement Compliance Results</u>

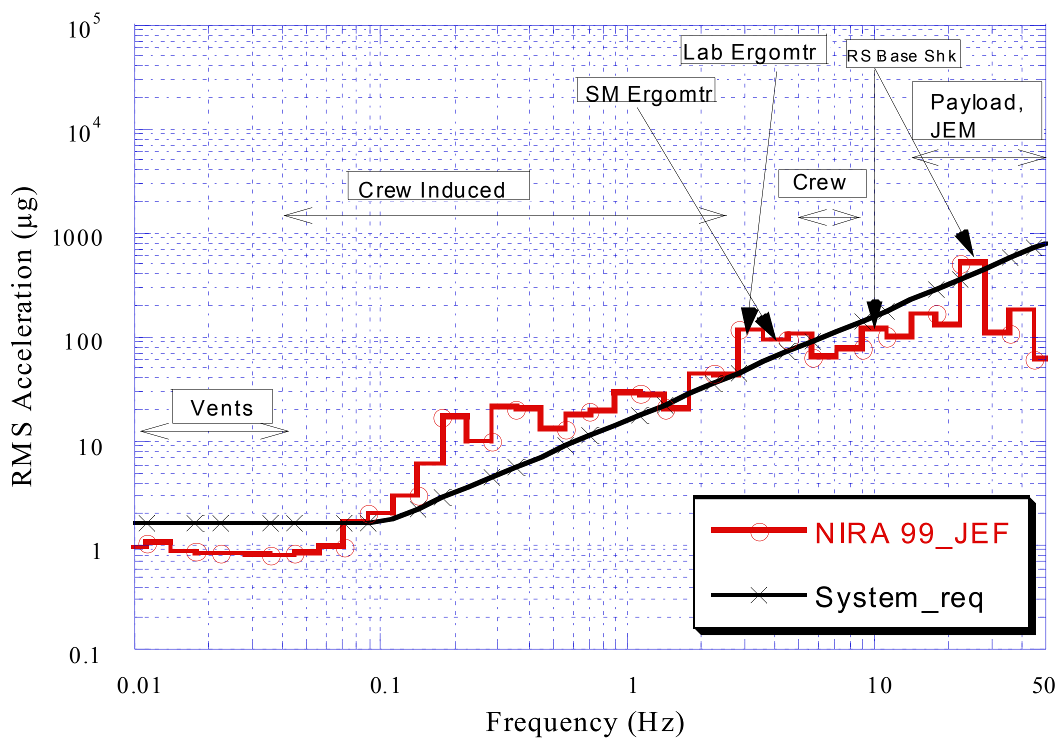
- 1% Damping
- + 2Crew translations & 2console ops
- + Payload disturbances (8 racks in Lab, 3 in COF and 2 in JEM)(21 sources per rack includes AAA fan.)
- @ Non-isolated rack interfaces
- Non-isolated Lab ergometer - subsequently isolated



Vibratory Results
NIRA 99 - JEM-EF

Non-Isolated Rack Assessment Differences From DAC9 Requirement Compliance Results

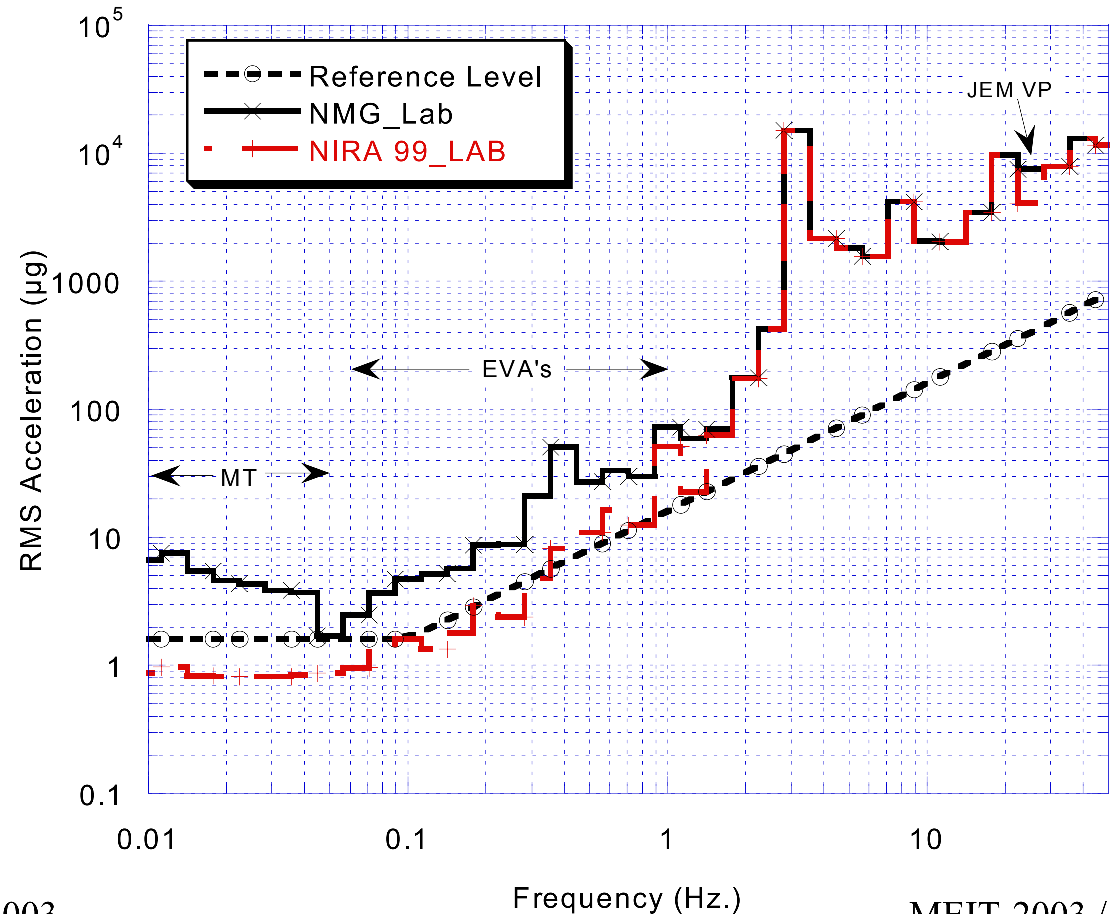
- 1% Damping
- + 2Crew translations & 2console ops
- + Payload disturbances (8 racks in Lab, 3 in COF and 2 in JEM)(21 sources per rack includes AAA fan.)
- @ Non-isolated rack interfaces
- Non-isolated Lab ergometer - subsequently isolated



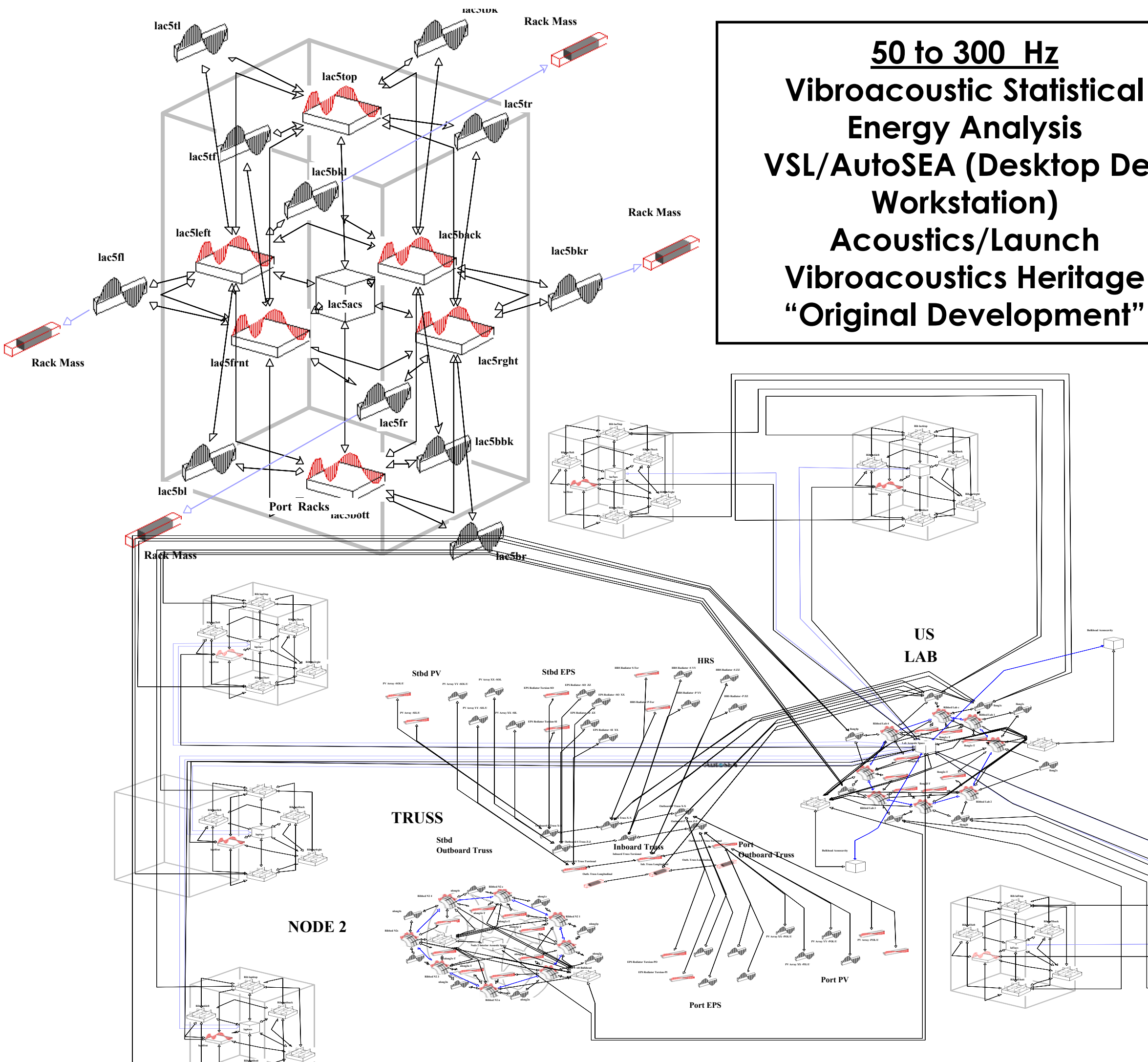
Vibratory Results - NIRA 99
Non-Microgravity Mode (External Ops Case)
U.S. Lab

<u>Non-Microgravity Mode Differences From NIRA-99</u>

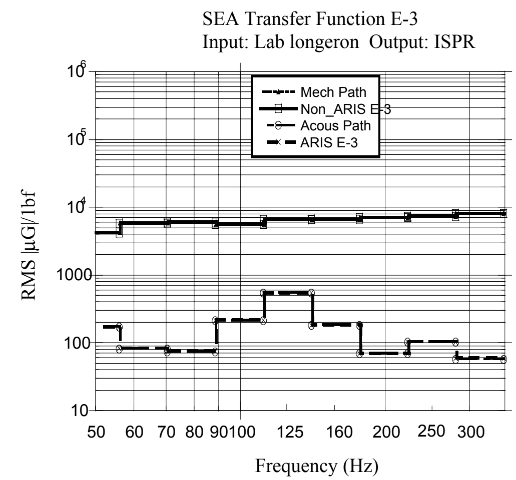
- **Add non-microgravity mode disturbances to NIRA-99**
- **External Operations Case presented includes 2 EVA's, JEM Airlock and Mobile Transporter ops**
- **Other cases examined focused on thruster activity - reboost, CMG de-saturation, attitude hold**
- **Cases still to be examined: docking, berthing,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

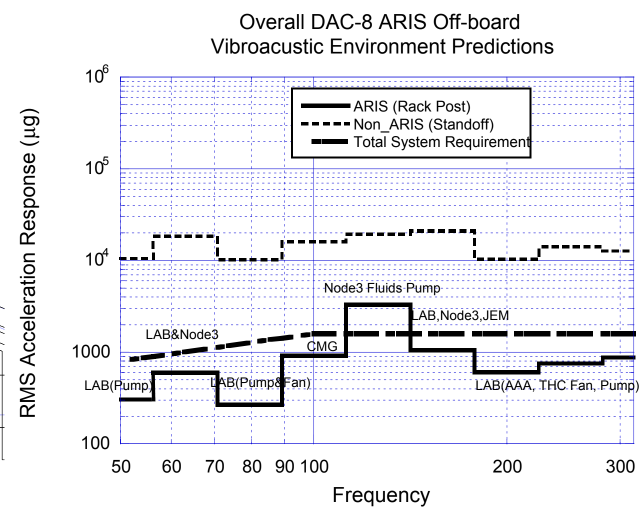


VibroAcoustic Analysis Methods & Tools

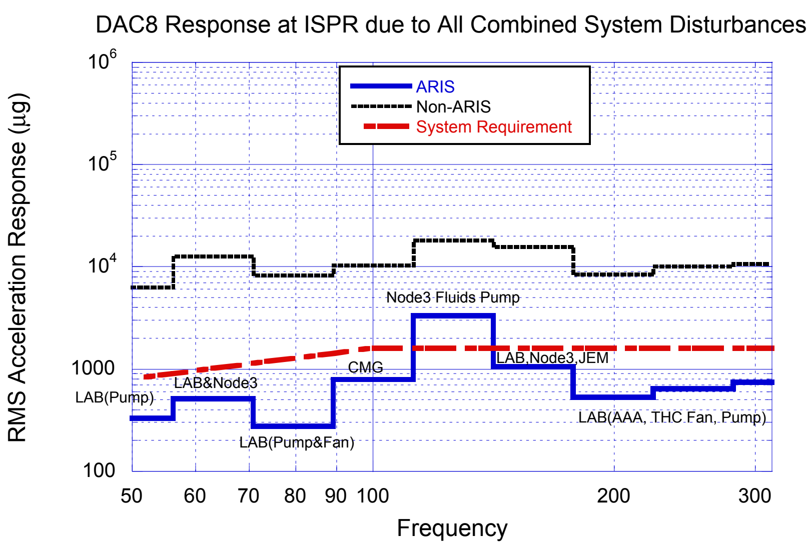


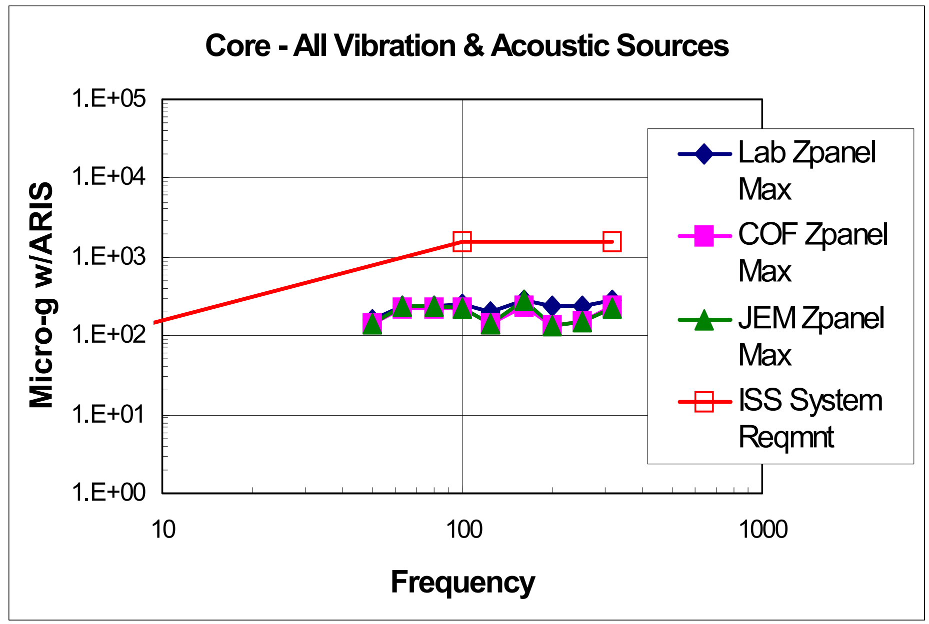
<u>50 to 300 Hz</u>
Vibroacoustic Statistical Energy Analysis
VSL/AutoSEA (Desktop Dell Workstation)
Acoustics/Launch Vibroacoustics Heritage
"Original Development"





Vibroacoustic Results





Summary

- 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

Summary

- DAC-9 quasi steady predictions shows 14 of 32 rack locations meet 1μg requirement.
- DAC-9 vibratory environment prediction is below the overall system allocation with standard ARIS attenuation (i.e.. PIDS requirement + margin). However, with the 25.6 psi exit pressure ESA vent disturbance will cause exceedance at low frequencies.
- When ARIS performance is accounted for there are exceedances due to the SM ergometer, SM a/c compressor and Lab pump harmonics.
  - Exception E–TDS V6A.1.3-06-1 processed for SM Ergometer/ARIS from Flt 6A to UF3. To be resolved by first obtaining on-orbit confirmation of both the acceleration environment and the ARIS isolation performance (ICE experiments), and then by determining the appropriate modifications and by their subsequent implementation.
  - Exception E–TDS V2.1.3-03,04 processed for non-compliance of the SM TCS compressor as identified by RSC-Energia based on the Service Module ground test results.To be resolved through design changes (longer flex hoses, soft rubber mounts), ground test validation and on-orbit installation.
  - Exceedances due to Lab pump harmonics addressed through refined analysis, VAC5A.
- All transients meet integrated 10-second transient requirements except ESA vent
  - 16 microg seconds for 3.26 psi exit pressure case
  - 130 microg seconds for 25.4 psi exit pressure case