Validation of Base-Driven Modal Survey Capability

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DDF Proposal - Overview

- **Purpose: To prove feasibility of Base-Driven Modal Survey as alternate technique to Fixed-Base Modal Survey for extracting modal parameters**

- **Approach:**
  1. Perform standard modal survey/correlation on representative test article
  2. Perform base-driven modal survey on same test article
  3. Compare results/develop guidelines

- **Rationale:**
  - Correlated finite element models required to accurately predict flight loads
  - Base-driven modal survey is a cost-effective means for extracting modal data necessary to correlate finite element models
  - Currently fixed-base modal survey is only accepted way of extracting modal parameters (frequency, mode shapes, damping)
  - Data does not exist to prove viability of base-driven modal survey

Base-Driven vs Fixed-Base Modal

- **Need for Model Correlation**
  - Improved flight loads predictions ➔ More efficient structures/mechanical systems
  - Requirement for test verified models for Verification Coupled Loads Analysis
- **Current Approach – Dedicated Fixed-Base Modal Survey Test**
  - 1-2 weeks test effort (15 – 20 $K)
  - Dedicated modal test facility
  - Design/fab/analysis of mass mockups
  - Pre-test analysis to ensure that test config = flight config

MODAL SURVEY TEST FACILITY

- **Base-Driven Modal Survey Approach**
  - Testing performed as part of standard vibration testing (sine/random)
  - Modal extraction performed on shaker table – dedicated test facility not required
  - Hardware tested in flight configuration, at flight input levels
- **Applicabililty**
  - Component/subsystems with few modes to be correlated
  - Observatory level testing

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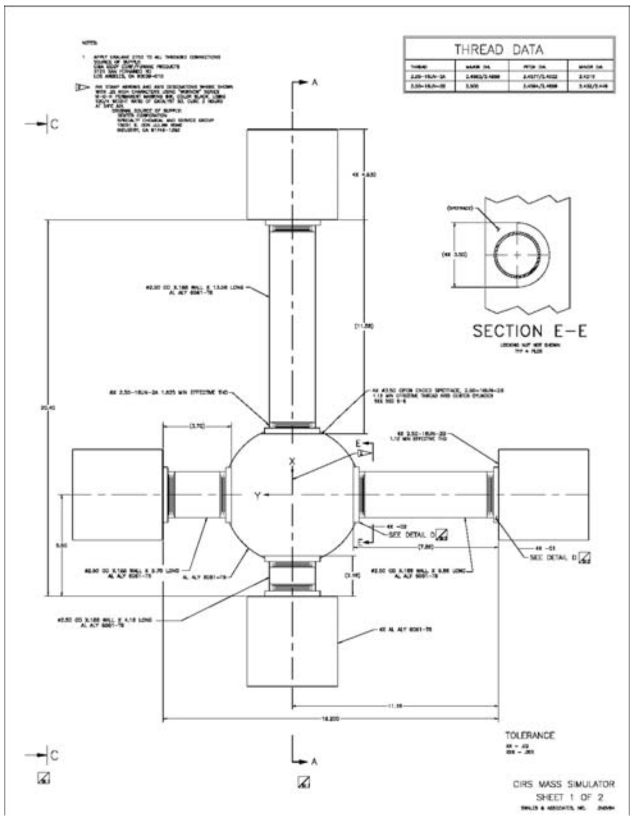
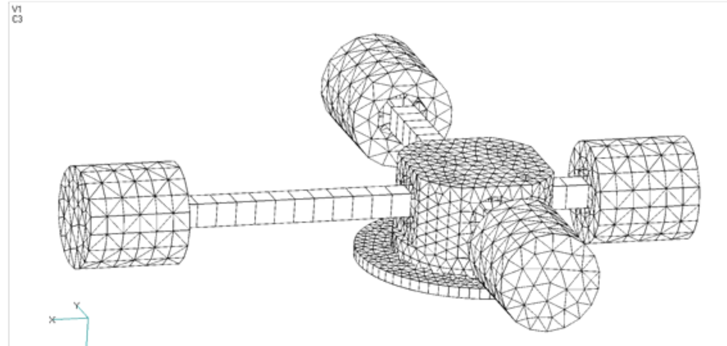
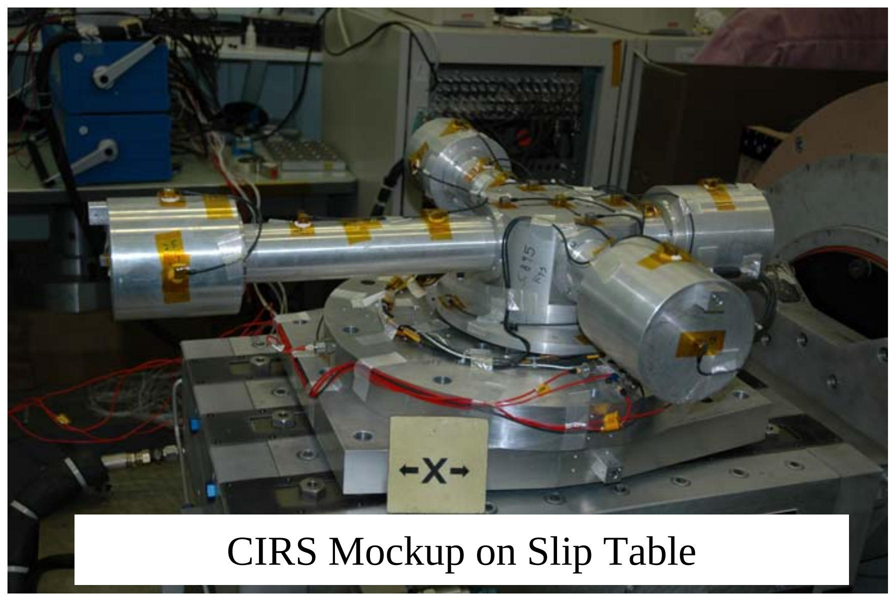
DDF Test Article

- **Cassini Infared Spectrometer (CIRS) Mass Mockup**
- **Weight: 57 lbs**
- **Dimensions: 30” x 30” x 6”**




NASTRAN Finite Element Model



CIRS Mockup on Slip Table

Test Instrumentation

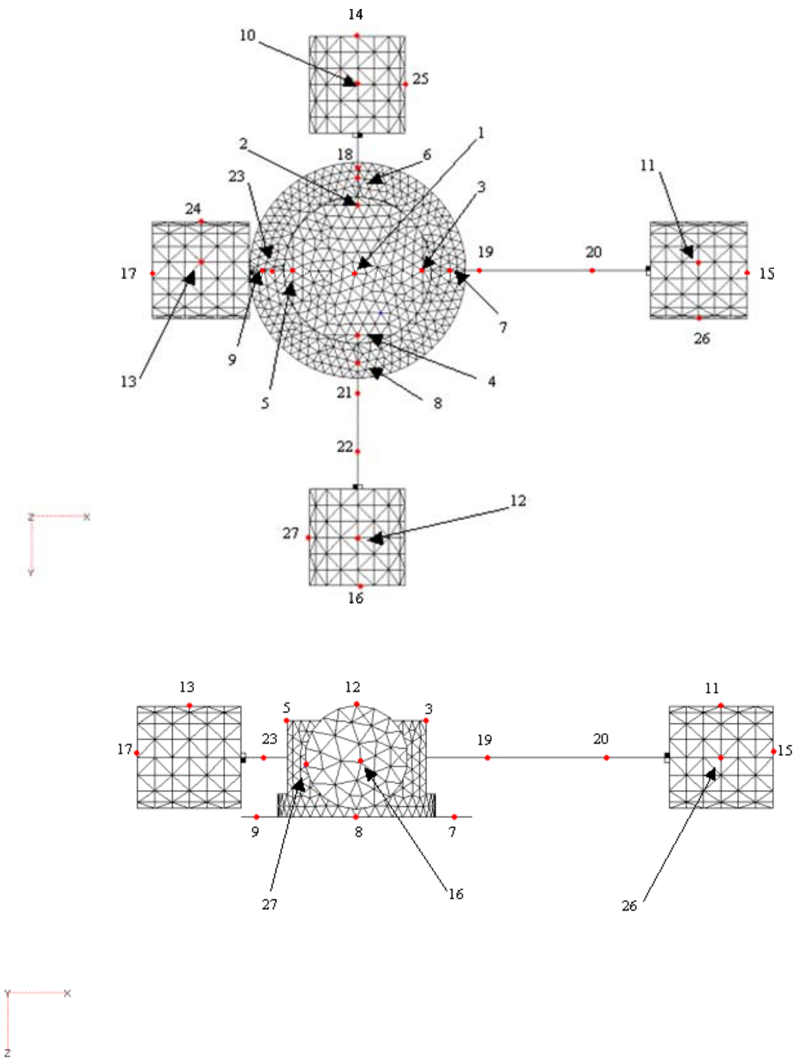


Table 1. Accelerometer Grid ID's, Coordinates and Descriptions

Acc No	Grid ID	X Coord*	Y Coord*	Z Coord*	Description
1	1687	1.183	2.181	-4.6	Centered on top of hub
2	1567	0	-3.317	-4.6	On top of hub at the outer edge in the -y dir
3	2138	3.317	0	-4.6	On top of hub at the outer edge in the +x dir
4	1587	0	3.317	-4.6	On top of hub at the outer edge in the +y dir
5	2246	-3.317	0	-4.6	On top of hub at the outer edge in the -x dir
6	2970	0	-4.75	0	On base flange along 9.5in diam circle (bolt hole location circle) in the -y dir
7	2951	4.75	0	0	On base flange along 9.5in diam circle (bolt hole location circle) in the +x dir
8	3015	0	4.75	0	On base flange along 9.5in diam circle (bolt hole location circle) in the +y dir
9	2981	-4.75	0	0	On base flange along 9.5in diam circle (bolt hole location circle) in the -x dir
10	823	0	-9.482	-5.315	Centered on top of cylindrical mass in the -y dir
11	201	17.362	-0.428	-5.278	Centered on top of cylindrical mass in the +x dir
12	555	0	13.641	-5.315	Centered on top of cylindrical mass in the +y dir
13	324	-7.962	-0.428	-5.278	Centered on top of cylindrical mass in the -x dir
14	919	-0.0037	-11.947	-2.840	Centered on outer face of cylindrical mass in the -y dir
15	101	19.827	0.1517	-3.145	Centered on outer face of cylindrical mass in the +x dir
16	637	0.225	16.107	-2.607	Centered on outer face of cylindrical mass in the +y dir
17	371	-10.427	0.243	-3.075	Centered on outer face of cylindrical mass in the -x dir
18	2767	0	-5.166	-2.85	Midway along the arm (tube) in the -y dir
19	2755	6.212	0	-2.85	Symmetrically spaced 1/3 the length of the arm in the +x dir
20	2761	12.001	0	-2.85	Symmetrically spaced 2/3 the length of the arm in the +x dir
21	2746	0	6.264	-2.85	Symmetrically spaced 1/3 the length of the arm in the -y dir
22	2749	0	9.212	-2.85	Symmetrically spaced 2/3 the length of the arm in the -y dir
23	2771	-4.407	0	-2.85	Midway along the arm (tube) in the -x dir
24	286	-7.96162	-2.465	-2.85	Centered on the side of cylindrical mass in the -x dir
25	1011	2.42755	-9.48162	-2.42196	Centered on the side of cylindrical mass in the -y dir
26	32	17.3616	-2.465	-2.85	Centered on the side of cylindrical mass in the +x dir
27	744	2.42755	13.6416	-2.42196	Centered on the side of cylindrical mass in the +y dir

Note: the origin is located at the center of the bottom of the hub where it interfaces with the base flange

Test vs Analysis Comparison

- **The finite element model is considered test correlated if for significant modes (>10% modal effective mass) the following requirements are met:**
  - Analytical frequencies are within 5% of the measured test frequencies
  - Cross-orthogonality between the test mode shapes and the analytical predicted mode shapes show >0.90 on the diagonal and <0.10 on the off-diagonal

- **Cross-Orthogonality is defined as**

$$\left[\mathrm{X\text{-}Orth}\right] = \left\{\phi_{AA}\right\}^T \left[M_{AA}\right]\left\{\phi_{Test}\right\}$$

where

ϕ_{AA} = Analytical Modeshapes (Nresp x Modes)

$\left[\mathrm{M}_{\mathrm{AA}}\right]$ = Analytical Mass Matrix (Nresp x Nresp)

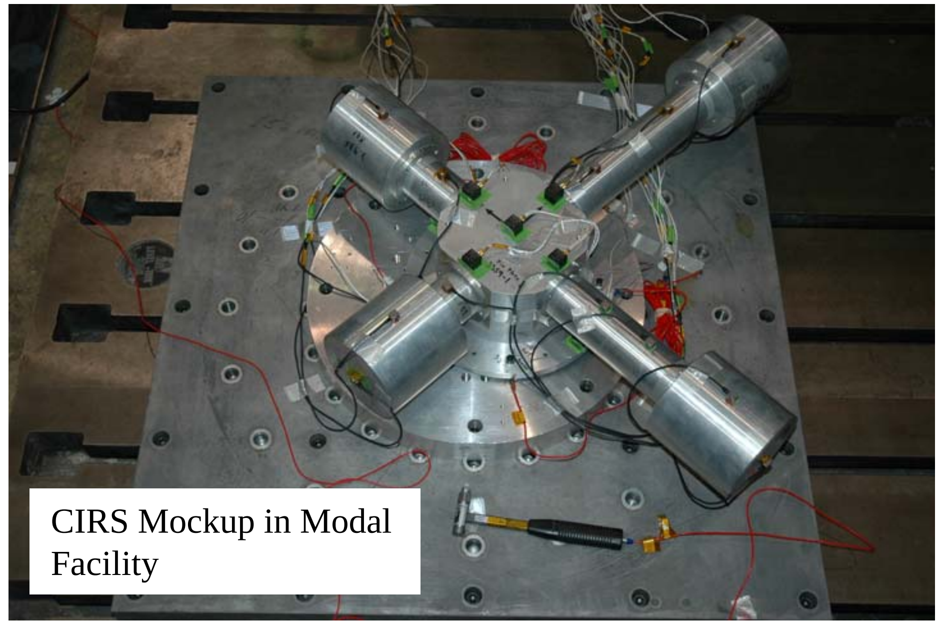
ϕ_{Test} = Modeshapes extracted from Test (Nresp x Modes)

$\left[\mathrm{X\text{-}Orth}\right]$ = Cross - orthogonality Matrix (Modes x Modes)

Correlated CIRS FEM Using Traditional Modal Survey

Frequency Comparison

Modal Survey (Hz)	Analysis (Hz)	% Diff
84.87	84.88	0.004
90.33	90.35	0.030
121.17	120.62	0.451
132.89	131.46	1.072
211.61	210.37	0.589
226.18	225.63	0.246
288.96	287.16	0.623
335.75	334.03	0.513



CIRS Mockup in Modal Facility

Cross-Orthogonality

		CIRS FEM							
	Freq(Hz)	84.88	90.35	120.62	131.46	210.37	225.63	287.16	334.03
Modal Survey	84.87	-0.99	-0.020	0.022	-0.023	0.007	0.025	-0.032	0.003
	90.33	-0.058	-0.996	0.022	0.046	0.004	0.024	-0.002	0.019
	121.17	0.018	0.028	0.984	0.060	0.122	-0.023	0.004	0.030
	132.89	0.031	-0.049	-0.031	-0.995	-0.008	0.032	0.002	0.026
	211.61	0.002	0.013	0.115	-0.001	-0.965	0.214	0.063	0.097
	226.18	-0.024	-0.021	-0.002	-0.021	-0.157	-0.955	-0.094	0.105
	288.96	-0.043	0.003	-0.014	0.017	0.029	-0.117	0.848	-0.040
	335.75	-0.003	0.002	0.059	-0.015	-0.097	-0.039	0.051	-0.785

Vibration Test Runs

Table 1. Swept Sine Vibration Runs (Each Axis)

Frequency (Hz)	Input Level (g)	Sweep Rate (oct/min)
50 – 1000	0.10	4.0, 2.0, 1.0
50 – 1000	0.25	4.0
50 – 1000	0.50	4.0*
50 – 200	0.10	1.0 Hz/sec

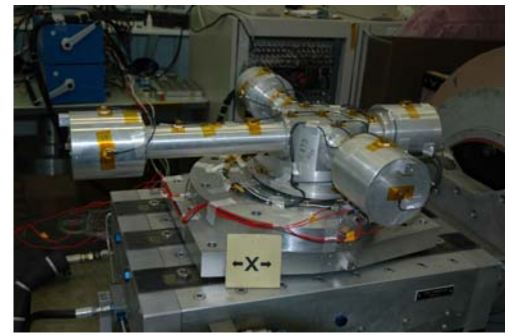
***Run shall be performed twice using 1 and 2 control channels respectively**

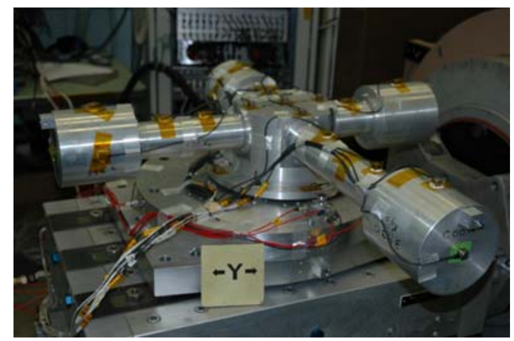
Table 3. Random Vibration Runs (Each Axis)

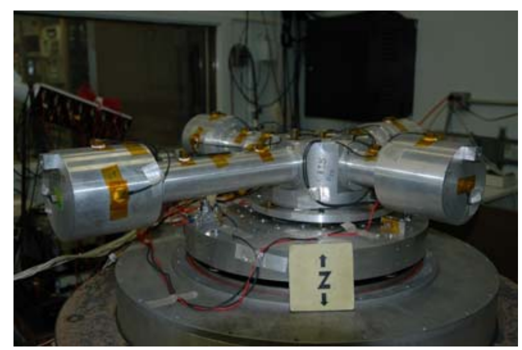
Frequency (Hz)	Input Level (g2/Hz)	Duration (Sec)
50 – 1000	0.001	120
50 – 1000	0.01	120
50 – 1000	0.04	120*

***Run shall be performed twice using 1 and 2 control channels respectively**

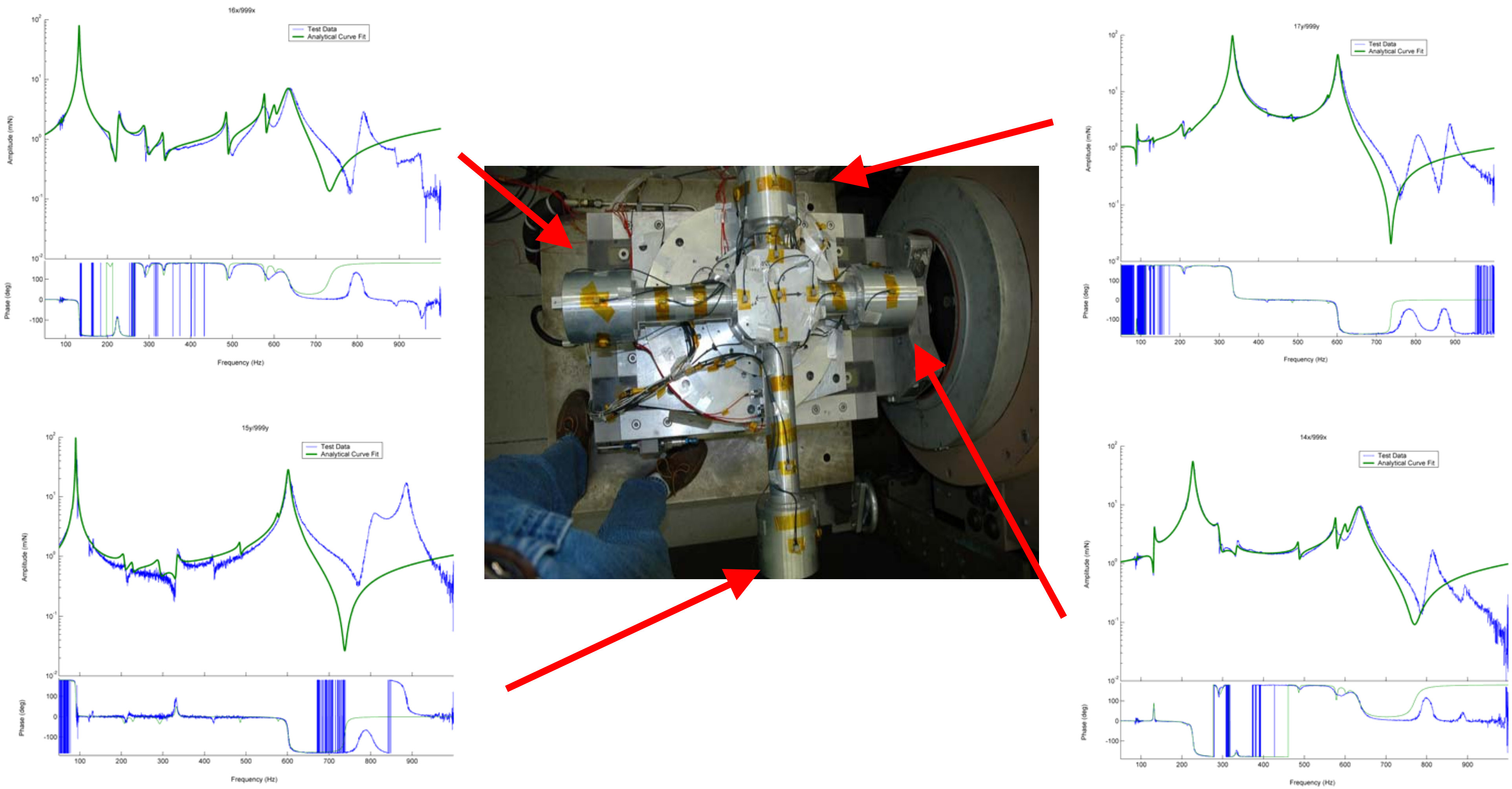
Total Vibration Test Runs = 30 (10 per Axis)







Modal Extraction Using Vibration Data



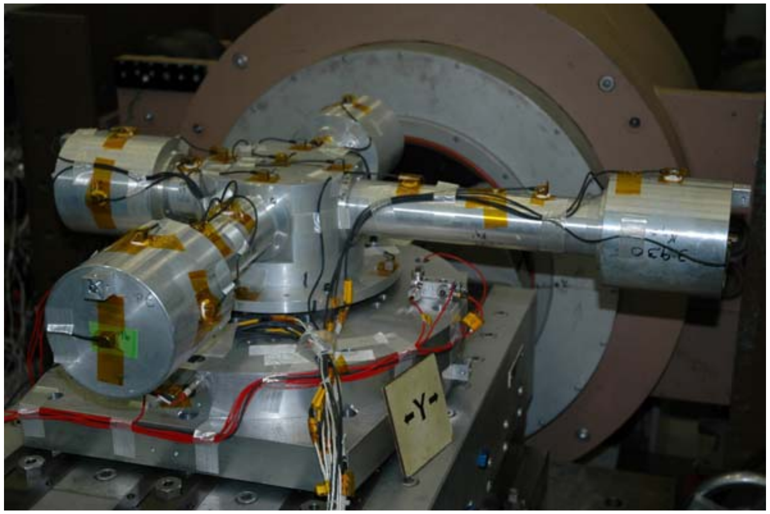
Cross-Orthogonality Results for 0.1g Sweep @ 4oct/min

		Vibration Test Data						
	Freq (Hz)	81.38	90.19	132.34	206.25	226.95	290.41	333.74
Correlated FEM	84.88	0.840	-0.024	-0.029	-0.025	-0.03192	0.008	0.000
	90.35	0.323	1.002	0.050	-0.011	-0.028	0.048	0.012
	120.62	-0.101	-0.024	0.049	-0.041	0.018	0.079	0.027
	131.46	-0.049	0.051	-1.012	-0.009	-0.033	0.037	0.025
	210.37	-0.013	-0.009	-0.004	0.957	-0.156	-0.031	0.075
	225.63	0.058	0.024	-0.024	0.222	1.006	-0.109	0.074
	287.16	0.045	0.000	0.016	-0.050	0.102	-0.928	-0.045
	334.03	-0.045	0.002	-0.017	-0.037	0.036	-0.139	-0.664

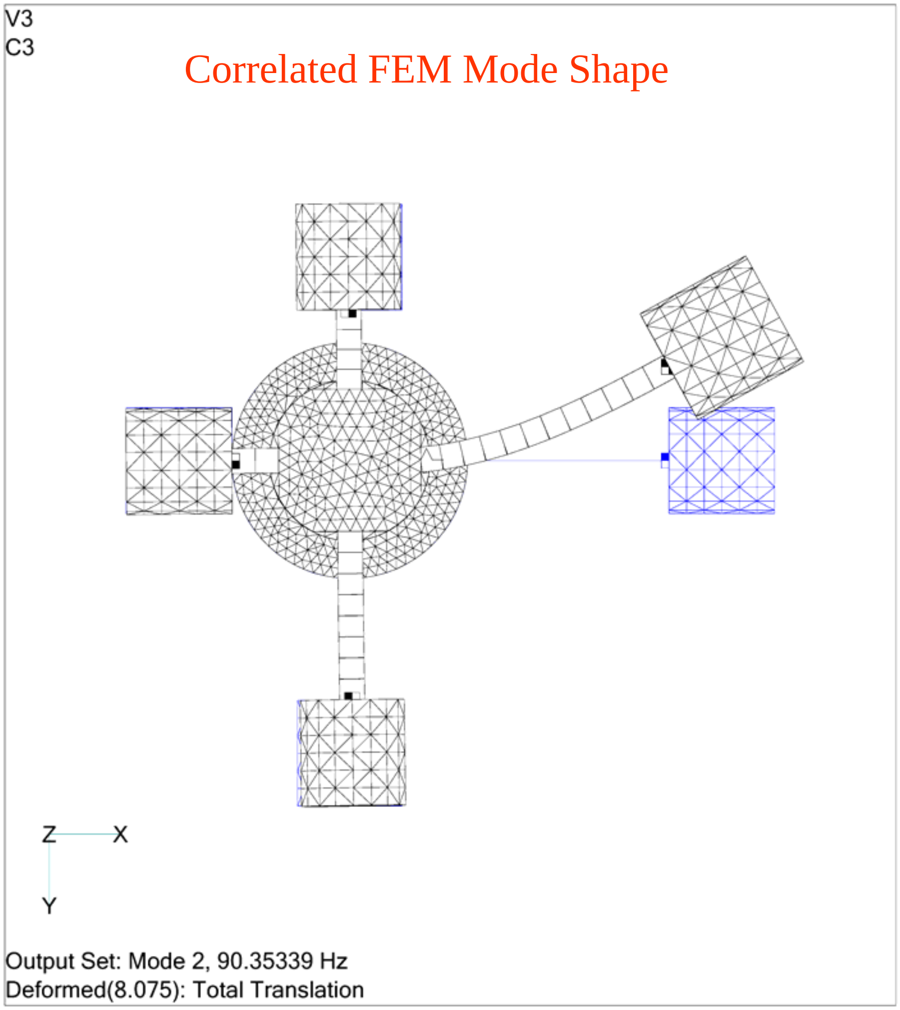
Frequency Comparison

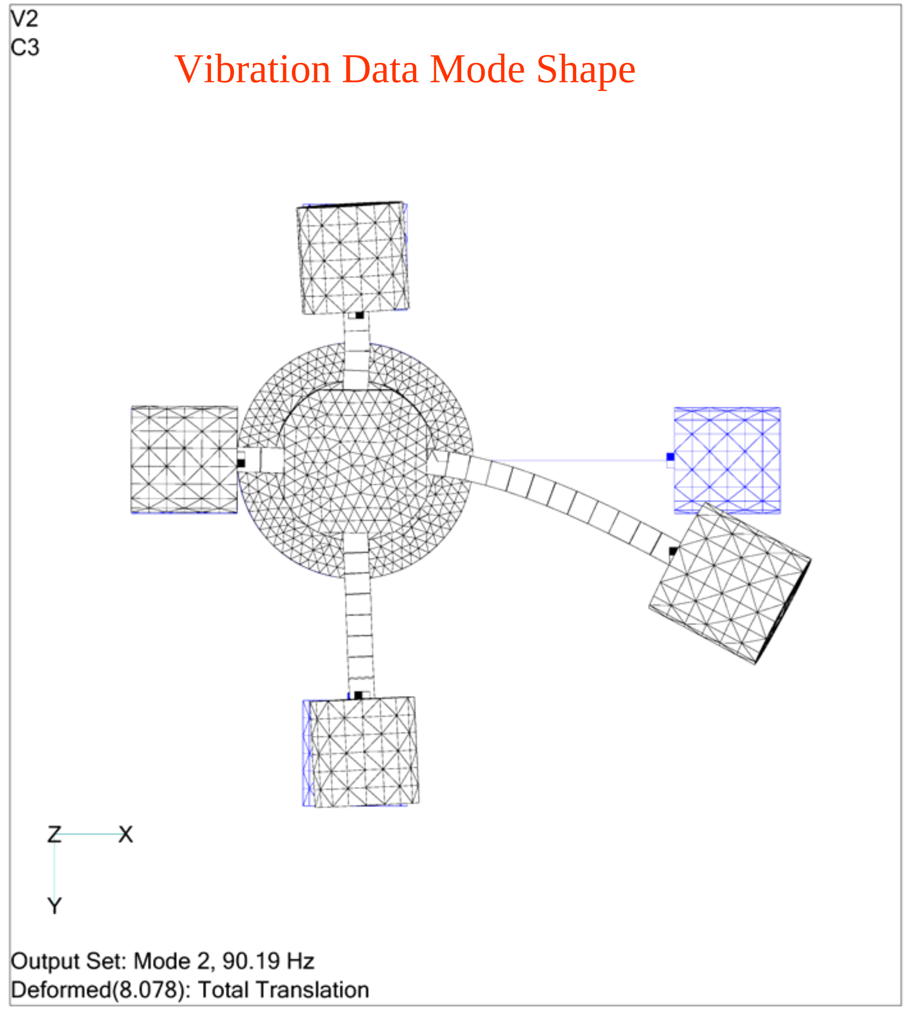
Correlated FEM (Hz)	Sine Sweep (Hz)	%Diff
84.88	81.38	4.1%
90.35	90.19	0.2%
120.62	---	----
131.46	132.34	-0.7%
210.37	206.25	2.0%
225.63	226.95	-0.6%
287.16	290.41	-1.1%
334.03	333.74	0.1%

Mode not identified due to rocking of shaker head (See Page 12)



Comparison of Vibration Data with Correlated FEM





Issues/Problems

- **Only able to correlate first 8 modes of CIRS mockup using standard modal survey techniques because of limitations with test setup**
  - Difficulty exciting rotational modes
  - Insufficient time to troubleshoot problems.
- **Rocking of shaker head during thrust axis vibration test resulted in poor quality data for the Z-axis vibration test**
  - Need to examine other data sets to see if rocking is consistent across input types and levels
  - Need to examine alternate means of processing data to improve quality
- **Schedule constraints in getting access to modal facility and shaker facility limited time available to process data**
  - All vibration runs complete and data archived
  - Only 0.1g sweep @ 4 oct/min has been processed to date

Summary/Conclusion

- **FEM model of the CIRS mockup created**
- **CIRS mockup FEM correlated using standard Fixed-Base modal survey techniques**
- **Entire Suite of planned vibration tests have been completed**
- **Test data from the 0.1g @ 4oct/min test run has been processed and modal parameters successfully extracted**
- **Excellent correlation for lateral (X & Y) modes. Poor correlation for thrust (Z)**
- **Two issues uncovered that must be explored further**
  - Higher order modes not well correlated using either fixed-base or base-driven data
  - Thrust axis (Z) rocking during vibration resulted in poor quality data
- **Additional Work Planned (Under Internal AETD Funding)**
  - Process all acquired test runs to determine how different vibration parameters effect quality of data
  - Review vertical axis data across different runs to see if rocking behavior is consistent
  - Process data using different input references to see if quality of data can be improved
- **<u>DDF Investigation showed feasibility of using base-driven vibration data to extract modal parameters.</u>**