Title:

Validation of Base-Driven Modal Survey Capability

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Initiation Year:

FY 2004

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$12,000

Actual or Expected Expenditure of FY 2004 Funding:

$12,000

Status of Investigation at End of FY 2004:

Transition to Applied Engineering and Technology Directorate (AETD) internal funding

Expected Completion Date:

June 2005

Purpose of Investigation:

The purpose of this investigation is to show the viability of extracting modal parameters, which include frequency, mode shape, and damping, from data measured during base-driven vibration testing. During this type of vibration test, the test article is vibrated at its mounting interface or base. Modal parameters describe the physical attributes of the structure and this information is required to create test-validated math models that can accurately predict launch loads. Typically it is necessary to perform a modal survey test at a dedicated test facility to make sure that the base of the test article does not move. The ability to extract modal parameters from base-driven vibration test data without the need for a separate modal survey test can result in significant cost and schedule savings to flight programs.

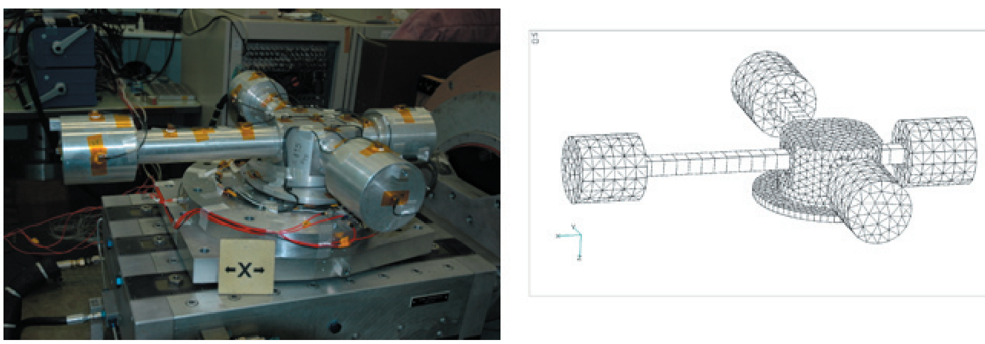
This investigation is important because it provides the necessary test bed for attempting to prove the viability of modal survey techniques. The theoretical basis for extracting modal parameters from vibration test data is fairly straightforward. What has been missing is sufficient test data to understand the limitations of the method and to determine the test parameters necessary to extract good-quality modal information. This data-gathering activity did not happen in the past because Goddard flight projects wanted to avoid the additional cost and schedule impacts associated with proving base-driven modal extraction techniques if they have already committed to performing a traditional modal survey. Conversely, flight projects have not been willing to risk using base-driven vibration testing as the sole means of extracting modal parameters if the method has not been proven. This investigation makes it possible to gather the data necessary to compare modal results derived from base-driven vibration testing with traditional fixed-base modal survey data for a single test article. These data then can be used to validate base-driven modal survey techniques for use with future flight hardware.

FY 2004 Accomplishments:

This investigation has accomplished a number of its goals, but has not fully completed all of the planned activities. The investigation was structured to provide a comparison between modal parameters extracted from a traditional fixed-based modal survey with those extracted using base-driven excitation techniques.

The test article used for this investigation is the mockup of the Cassini Infrared Spectrometer (CIRS) instrument. A detailed finite element model (FEM) of the CIRS mockup was developed based on engineering drawings. This FEM and the test article are shown in Figure 1. Using this model, a study was done to determine the accelerometer set necessary to capture accurately significant modes of the mockup. During the test, 150 channels were used, including 69 response accelerometers on the test article. Additional analysis was performed to understand the effect of the force gauges on boundary conditions and to determine a set of safe input levels for performing vibration testing. A traditional fixed-base modal survey was performed using the Goddard Space Flight Center's modal facility in Bldg 10. The mockup FEM was then correlated using the fixed-base modal data to meet standard cross-orthogonality criteria of >.9 on the diagonal and < .1 on the off-diagonal. Because of limitations with the test setup and availability of the modal facility, it was only possible to get good-quality modal data to correlate the first eight modes of the CIRS mockup. These modes represent the two-cantilevered modes of each arm in the vertical and lateral directions.

Figure 1.



The CIRS mockup was also subjected to the full set of planned vibration tests in the Goddard vibration facility. The test suite included swept sine testing with varying input levels and sweep rates, along with random vibration testing at varying input levels. A total of 36 different runs in all three axes (i.e., 12 runs/axis) were performed as part of this investigation. For each test run, we measured the input acceleration level, interface force, and acceleration response on the test article.

The final goal of the investigation, which is the extraction of modal parameters from the vibration data and comparison with the correlated FEM, has not been fully accomplished. Because of schedule constraints with the vibration facility, the vibration testing was not completed until late November. Therefore, there has not been sufficient time to process all of the acquired test data for inclusion in this report. To date, only the data from the 0.1g sine sweep with a sweep rate of 4 oct/min has been processed. An example of the data processing showing the curve fit to the measured X-axis interface force sum is shown in Figure 2, "Example of curve fit technique used to

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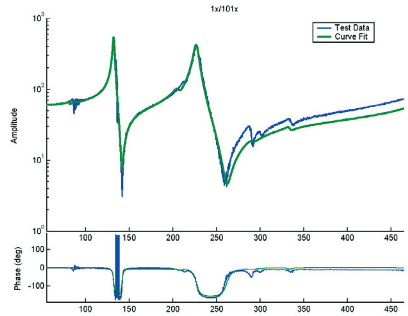

extract modal parameters from vibration data. X-axis force sum (lb/g) for 0.1g sweep @ 4 oct/min is shown." The data from the lateral axis (X and Y) vibration tests showed excellent agreement with the correlated FEM. However, the vertical axis (Z) data, with the test article mounted to the head-expander, showed poor agreement. Preliminary review of these data indicates that the poor data quality is related to the ability of the shaker to control moment. A comparison of input acceleration levels at different locations on the shaker head showed that the input was not uniform due to rocking of the shaker armature. An example of the cross-orthogonality between the correlated FEM and the shapes extracted from the 0.1g sweep data is shown in Figure 3.

Figure 3.

		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

Planned Future Work:

Processing of the 0.1g sweep data has shown that it is possible to extract modal parameters from base-driven test data and meet the criteria for FEM correlation. Future work will include the processing of the remainder of the test runs to determine the effect that different test parameters have on the quality of the extracted modal data. Based on these results a set of guidelines will be developed for the use of base-driven modal extraction techniques.

As was noted, there were problems with extracting modal parameters using data from the vertical axis shake. This discrepancy will be investigated further to determine if this behavior is consistent across the different test runs. Also, different approaches will be investigated to improve the quality of the modal prediction in the vertical direction by processing the data using different input accelerometers and using force data from the individual force gauges.

Summary:

The purpose of this investigation is to show the viability of extracting modal parameters from base-driven vibration test data. This investigation is innovative in that this approach relies on the use of force gauges, which have only recently become common in vibration testing. However, no flight program has taken advantage of this capability because sufficient data do not exist to show that a base-driven modal survey can provide the same level of accuracy as traditional fixed-base modal survey testing. This investigation provides the test bed necessary to validate the base-driven modal extraction technique and identify the approach's capabilities and limitations so that engineers can write guidelines for future use. The payoff to this work will be sufficient understanding of the capabilities of base-driven modal survey so that it can be used as part of a vibration test program without the need for a dedicated modal survey test.

The success criteria for this investigation included the creation of a correlated math model of the CIRS mass mockup using standard fixed-base modal test techniques. As part of this investigation, a number of vibration tests were to be performed using this test article. The vibration testing was to consist of different input types, input levels, and test durations. Modal data would be extracted from each test run to examine how different test parameters would affect the quality of the extracted modal data. Finally, guidelines would be developed for using base-driven modal survey techniques for future flight hardware. As a result of this investigation, a correlated math model of the CIRS mockup was developed and all planned vibration testing was completed. However, it was not possible to process the entire set of acquired test data and formulate guidelines for future use within the funding period. This work will continue under internal AETD funding.

The primary risk factors for this investigation are the unknowns inherent in modal and vibration testing. These unknowns relate to having sufficient access to the test facilities, the ability to obtain measurements of sufficient quality, and limitations in the test configuration. The techniques necessary to perform modal extraction from base-driven test data have been demonstrated using analytically derived data. The key to this investigation was to determine how the process is affected by the realities of acquiring and working with actual test data. For example, the modal survey test setup was not able to accurately capture all the modes of the test article. However, there was not sufficient time in the schedule to investigate and correct this limitation. The modal data extracted from vibration testing in the vertical direction was of poor quality because of limitations with the vibration control system. Finally, schedule constraints in getting access to the modal and vibration facilities prevented all of the test runs from being processed within the funding period.