Lessons Learned from CM-2 Modal Testing and Analysis

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The Combustion Module-2 (CM-2) is a space experiment that was launched on shuttle mission STS-107 in the SPACEHAB Double Research Module. The CM-2 flight hardware is installed in SPACEHAB single and double racks. The CM-2 flight hardware was vibration tested in the launch configuration to characterise the structure's modal response. Cross-orthogonality between test and analysis mode shapes was used to assess model correlation. Lessons learned for pre-test planning and model validation are discussed.

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1. INTRODUCTION

The Combustion Module-2 (CM-2) is a combustion science experiment consisting of eight packages installed in SPACEHAB single and double racks. CM-2 was flown on the shuttle mission STS-107 (January 16, 2003) in the SPACEHAB Double Research Module. The CM-2 hardware is a retest of CM-1 hardware, which was originally designed and qualified environmentally for Spacelab for shuttle missions STS-83 (April 4, 1997) and STS-94 (July 1, 1997).

Modal testing and model correlation analysis was conducted on the modified double rack flight hardware (centre post removed) for the purpose of finite element model validation. Verified rack models are analytically installed into the SPACEHAB Double Research Module for an integrated shuttle coupled loads analysis.

2. TEST AND ANALYSIS OBJECTIVES

The objective of the CM-2 modal testing is to characterise the primary modes in each axis for the test configuration. The objective of the CM-2 model correlation is to establish correspondence between test and analysis primary mode shapes. The cross-orthogonality correlation goal is greater than 0.9 for diagonal terms, and less than 0.1 for off-diagonal terms of the matrix. The fundamental frequency correlation goal in each axis is ±5 percent, and ±10 percent for higher order frequencies.

Base shake modal testing was implemented using 35,000 pound force vertical and 28,000 pound force horizontal electrodynamic shakers and 96 channels of digital data acquisition at the NASA Glenn Research Center's Structural Dynamics Laboratory. This approach was innovative in that it combined environmental and modal testing.[1]

The test configuration incorporates a rigid fixture attached to the double rack, and is supported by the shaker with a 72 inch expander head. The double rack test configuration is shown in Fig. 1. The double rack has dimensions: 80 inches height, 41 inch width and 29 inch depth. The L-shaped fixture weighs 1,360 pounds and is constructed from $6\times6\times1/2$ inch box beams. The empty fixture fundamental frequencies were found to be 120 Hz (Z-axis), 142 Hz (Y-axis), and 158 Hz (X-axis). The test-configured double rack weighed 2,480 pounds including the double rack, five packages and the test fixture. Four control accelerometers and five load cells (three-axis strain gauge type) located at the rack to fixture interface were used for test control and limit response (Fig. 2). Rack test excitation included sinusoidal (excitation level: 1/8, 1/4, 1/2, g's-peak, frequency range: 5-400 Hz) and random vibration (excitation level: 1/4 flight excitation with an overall of 0.75 Grms, frequency range: 20-2,000 Hz). Sinusoidal testing was conducted with several low level excitations to assess linearity of the structure. The rack structure responded as a strain softening system. Control of the random vibration excitation was within test tolerances. Frequency response functions (FRFs) were computed based on the $H_2 = G_{yy}/G_{xy}$ method (emphasising resonant response) using a reference triaxial accelerometer mounted on the shaker table. Due to laboratory constraints (data acquisition and accelerometer availability), 82 response accelerometers were used for modal testing.

Pre-test modal analysis was performed using a three-tiered approach to define accelerometer locations: 1) kinetic energy, 2) systematised Guyan reduction,[2] and 3) engineering judgement. The kinetic energy method was the primary method used to identify accelerometer locations. Systematised Guyan reduction and engineering judgement methods were also used to supplement the kinetic energy method, particularly when identified instrumentation locations were inaccessible or closely spaced.

The criterion for selection of target modes is based on effective modal mass (> 10%). Pre-test target modes of the test configuration were 31.4 Hz (X-axis), 36.1 Hz (Y-axis), 52.1 Hz and 53.4 Hz (Z-axis). The two closely spaced Z-axis modes could not be differentiated due to spatial under sampling using the 82 channel response accelerometer set. The lesson learned from this is to perform modal assurance criterion and cross-orthogonality checks between the high fidelity finite element model (197,994 degrees of freedom) and the