



# CM-2 Environmental/Modal Testing of Spacehab Racks

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## Abstract

Combined environmental/modal vibration testing has been implemented at the NASA Glenn Research Center's Structural Dynamics Laboratory. The benefits of combined vibration testing are that it facilitates test article modal characterization and vibration qualification testing.

The Combustion Module-2 (CM-2) is a space experiment that launches on Shuttle mission STS-107 in the SPACEHAB Research Double Module. The CM-2 flight hardware is integrated into a SPACEHAB single and double rack. CM-2 rack level combined vibration testing was recently completed on a shaker table to characterize the structure's modal response and verify the random vibration response. Control accelerometers and limit force gauges, located between the fixture and rack interface, were used to verify the input excitation. Results of the testing were used to verify the loads and environments for flight on the Shuttle.

## INTRODUCTION

The Combustion Module-2 (CM-2) is a combustion science experiment consisting of eight packages that are integrated into SPACEHAB single and double racks (Figure 1). The CM-2 hardware is a reflight of CM-1 hardware, which was designed and environmentally qualified for Spacelab and flew on Shuttle STS-83 (April 4, 1997) and STS-94 (July 1, 1997). The CM-2 design loads and vibration environments for SPACEHAB are higher than CM-1, requiring requalification of the CM-2 hardware for mission assurance.

The NASA Glenn Research Center Structural Dynamics Laboratory (SDL) developed a cost and schedule saving approach to requalifying the CM-2 hardware by subjecting the integrated single and double racks to combined environmental/modal vibration testing. The objective of the rack level baseshake testing was to characterize the random vibration package response at  $\frac{1}{4}$  flight excitation, and scale the response to flight levels. The scaled flight level random vibration response is compared to the previous CM-1 qualification test history. The benefit of the low level test excitation ( $\frac{1}{4}$  flight) is that it reduces the fatigue exposure of the CM-2 commercial, vibration sensitive electronic hardware. The scaled flight level package random vibration response was also used to verify random load factors used for CM-2 package design.

## **BASESHAKE RACK LEVEL TESTING**

Combined environmental/modal rack level testing (References 1 and 2) of the CM-2 single and double racks was completed in the NASA Glenn Research Center SDL using a 35,000 pound-force vertical electrodynamic shaker and a 28,000 pound-force horizontal electrodynamic shaker and 96 channels of digital data acquisition.

The baseshake vibration tests were performed with the integrated rack attached to a rigid fixture, and supported by the shaker with a 72 inch expander head. The double rack test configuration is shown in Figure 2. The L-shaped test fixture supporting the rack weighed 1,360 pounds and was assembled from 6 inch x 6 inch x ½ inch box beams. The fundamental frequency of the bare fixture is 120 Hz. The test configured double rack weighed approximately 1,120 pounds with all five packages integrated in the rack. A significant package mass in this rack is the Experiment Package (EP) weighing 600 pounds. The total weight of the test configuration including double rack, packages and test fixture was 2,480 pounds. Four control accelerometers and five force gauges (three-axis strain gauge type) located at the rack to fixture interface were used for the purpose of test control and limit response (Figure 3). The response accelerometer locations were defined based on pre-test finite element modal analysis of the integrated rack/fixture configuration. 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 at several low level excitations to assess linearity of response. Linearity was reasonable for all three axes tested, providing confidence when scaling the 1/4 flight random vibration levels to flight levels.

Test control was excellent with respect to the 1/4 flight rack test specification (Figure 4). There was an inconsequential exceedance to the test specification from 900-1,600 Hz due to test configuration interaction with the shaker and expander head.

## **ENVIRONMENTAL RANDOM VIBRATION TESTING**

A comparison of the EP Y-axis random vibration test specifications for the CM-1 and CM-2 programs is shown in Figure 5. The package test specification is defined at the interface between the package and the rack mounting post. The 9.5 dB difference in the plateau of the EP random vibration test specifications requires package requalification for CM-2 mission assurance. Typical requalification is performed for each package individually using a rigid fixture. This approach is time intensive, costing the program schedule. The Structural Dynamics Laboratory instituted an integrated rack approach to testing the package hardware, thus saving the program schedule. Rack level testing was completed in one-half of the time of eight individual package tests. The advantage of rack level testing is it provides flight boundary conditions to the package. For individual package level testing, an artificial rigid fixture interface is used at the package interface.

The CM-2 package and rack test specifications were developed by the Boeing Company for SPACEHAB based on a reverberant ground acoustic test of the SPACEHAB Single Module. The acoustic test excitation was based on Shuttle launch acoustics measured in the cargo bay (140 dB overall SPL). The SPACEHAB Module was integrated with flight racks and package mass simulators designed to represent a variety of potential payload configurations. Accelerometer

measurements were made at the rack-to-SPACEHAB Module interface and the rack-to-package interface.

NASA Glenn Research Center performed  $\frac{1}{4}$  flight rack level random vibration baseshake testing using excitation levels and accelerometer locations defined in the SPACEHAB ground acoustic test. The  $\frac{1}{4}$  flight response was scaled to flight levels. A comparison is made between the acoustic and baseshake interface response for the EP (Figure 6). The EP interface vibration response is much less in the baseshake test than in the acoustic test from 350-1,600 Hz.

A comparison is made between acoustic and baseshake test transfer functions calculated for the EP in the Y-axis test configuration (Figure 7). The transfer function is defined as the ratio of the Experiment Package interface response to the rack-to-module interface response. In the frequency range from 40-940 Hz, the baseshake transfer function has a value less than one. The transfer function calculated from the acoustic test is larger than from the baseshake test, except below 40 Hz where the CM-2 integrated rack fundamental frequency dominates. The consequence of baseshake rack level testing is that the inertial effects of the integrated rack with CM-2 flight packages provides mass attenuation, reducing the random vibration input to the EP package.

The benefit of  $\frac{1}{4}$  flight random vibration test is the reduced excitation levels minimized fatigue exposure to vibration sensitive, commercial electronic components mounted inside the CM-2 packages. The  $\frac{1}{4}$  flight excitation package responses were scaled to flight levels and compared to the previous CM-1 qualification test history. The environmental approach used to address mission assurance proved effective, without having to requalify CM-2 flight hardware.

## **MODAL TESTING AND LOADS ANALYSIS**

Modal sinusoidal resonance survey testing of the CM-2 single and double racks was conducted to verify the CM-2 integrated rack finite element models. Pre-test finite element modal analysis was performed to define the rack test accelerometer locations. Post-test model correlation was performed to improve the finite element model prediction of the rack test mode shapes.

The CM-2 single and double rack finite element models are analytically integrated into the SPACEHAB Research Double Module and Shuttle for a coupled loads analysis of the launch configuration. The coupled loads analysis provides a set of transient load factors. The transient load factors are combined with package random vibration load factors to define a set of CM-2 package design load factors.

Preliminary CM-2 design load factors were greater than CM-1 design loads. In order to reduce the CM-2 package design load to avoid any hardware redesign, the CM-2 program requested a design coupled loads analysis to specifically address Z-axis transient loads.

The CM-2 package random vibration load factors were recalculated based on the package interface random vibration response from the rack level testing. The random vibration loads were computed using the package natural frequencies and effective masses determined from a modal analysis of each package with flight boundary conditions. The effective mass is used as a weighting factor in the random vibration load calculation. For each natural frequency, a random vibration load is calculated using the Single Degree Of Freedom (SDOF) Frequency Response, assuming a dynamic magnification  $Q=10$ , and the package interface random vibration response measured from the rack level test. The load for each frequency is multiplied by the corresponding

effective mass factor and then all of these products are summed (root-sum-squared) for each axis, for each package.

Using this methodology, the CM-2 design loads were lowered so that there were no exceedances to CM-1 design loads. This had a large impact on the project, saving the cost of redesign and maintaining the launch schedule.

## **CONCLUSIONS**

The application of combined environmental/modal testing for the CM-2 flight program was a cost effective way to reduce the design load factors and verify the package environments for mission assurance. The advantage of rack level testing is it provides flight boundary conditions to the package. Performing rack level testing instead of individual package level tests saved the program one half the testing time. Furthermore, the ¼ flight rack tests reduced the fatigue exposure to the CM-2 commercial, vibration sensitive electronic hardware. Integrated rack level testing provided the inertial effect of mass attenuation reducing the package interface random vibration response. By reducing the CM-2 package loads and vibration environments, the CM-2 program saved the cost of hardware requalification and redesign.

## **REFERENCES**

1. "Combustion Module-1 (CM-2): SPACEHAB Double Rack with Protoflight Packages Sinusoidal Resonance Survey and ¼ Flight Level Vibration Characterization Test Report," Structural Dynamics Laboratory Test Report SDL-TR 99-34, NASA Glenn Research Center, December 7, 1999.
2. "Combustion Module-1 (CM-2): SPACEHAB Single Rack with Protoflight Packages Sinusoidal Resonance Survey and ¼ Flight Level Vibration Characterization Test Report," Structural Dynamics Laboratory Test Report SDL-TR 99-29, NASA Glenn Research Center, December 30, 1999.



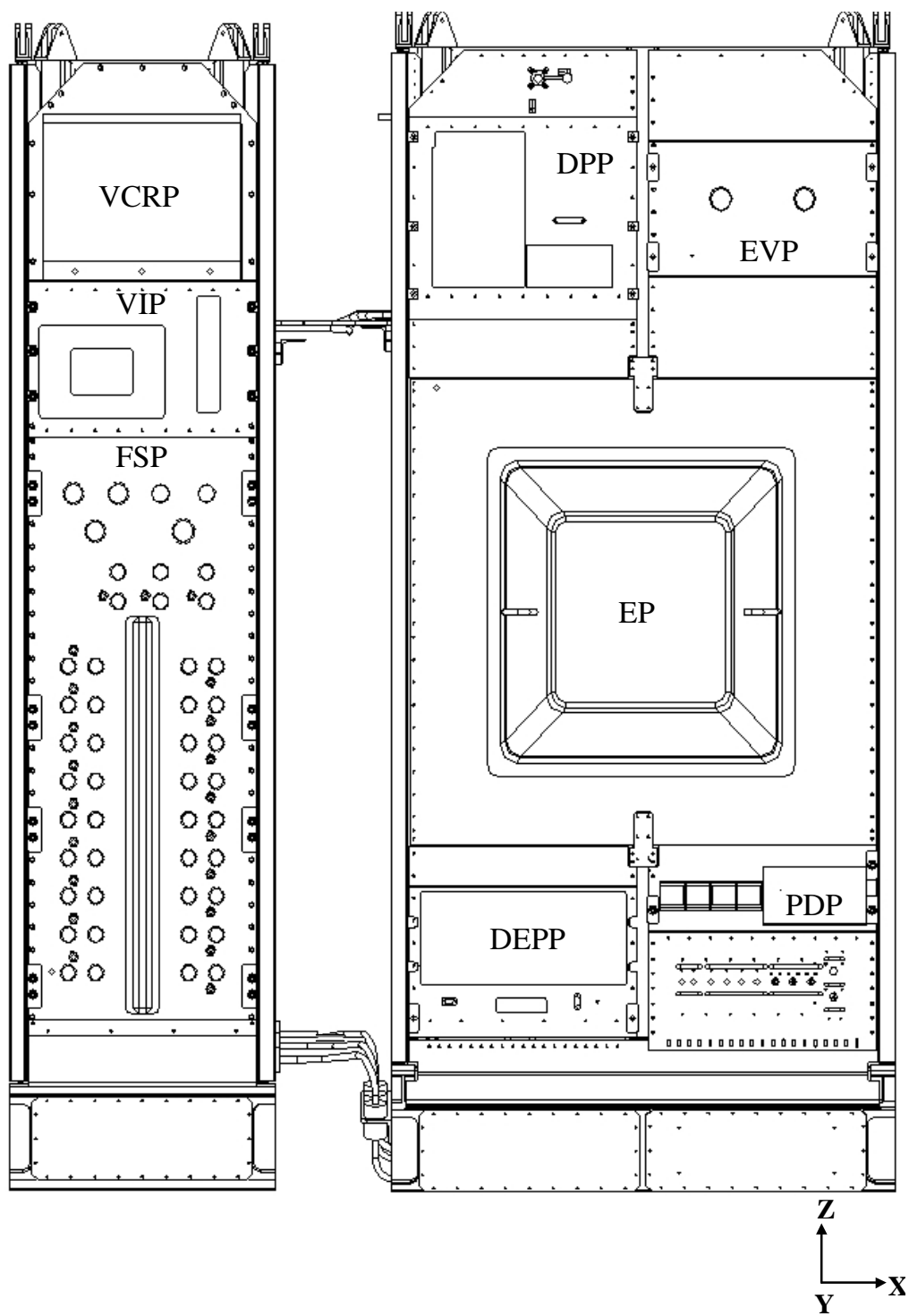


FIGURE 1. CM-2 Single and Double Rack Configuration.

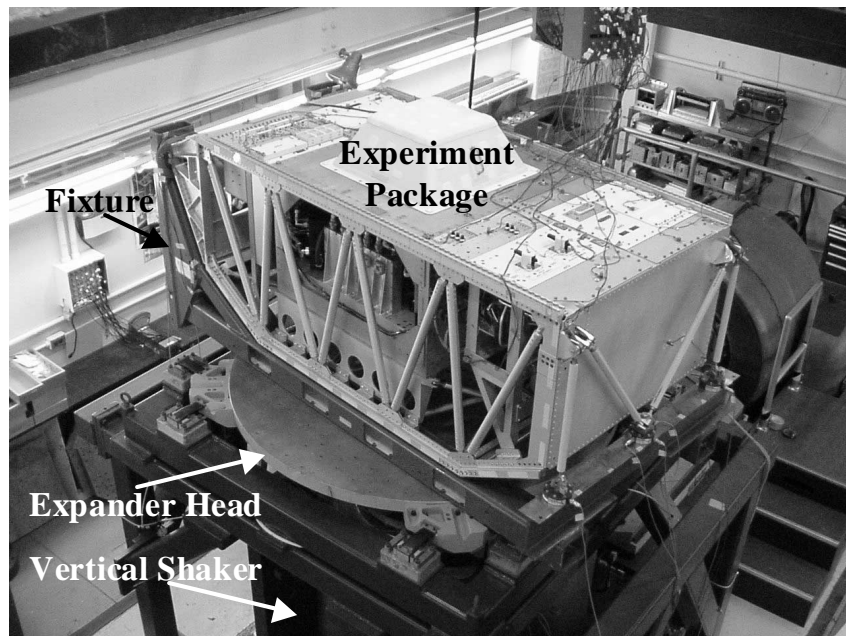


FIGURE 2. CM-2 Double Rack Test Configuration.

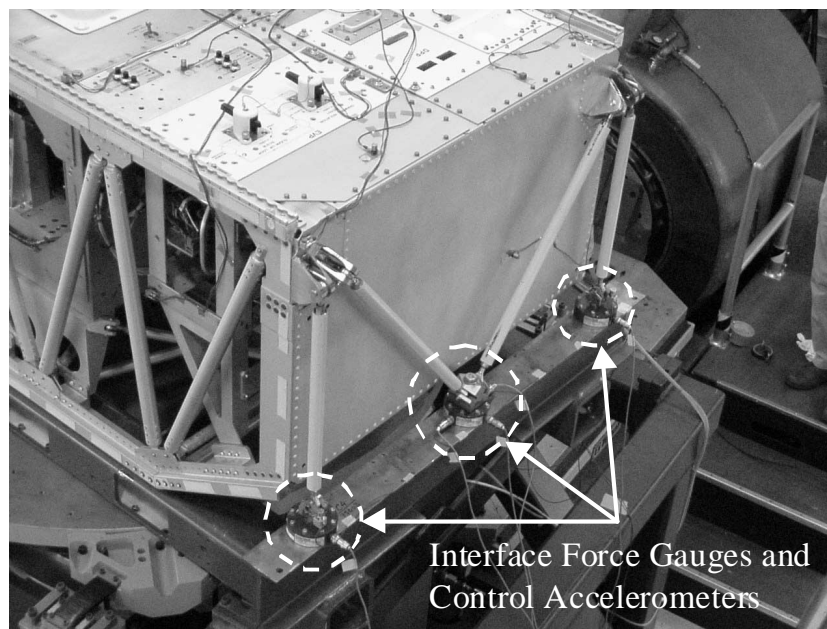


FIGURE 3. Rack-to-Fixture Interface Instrumentation.

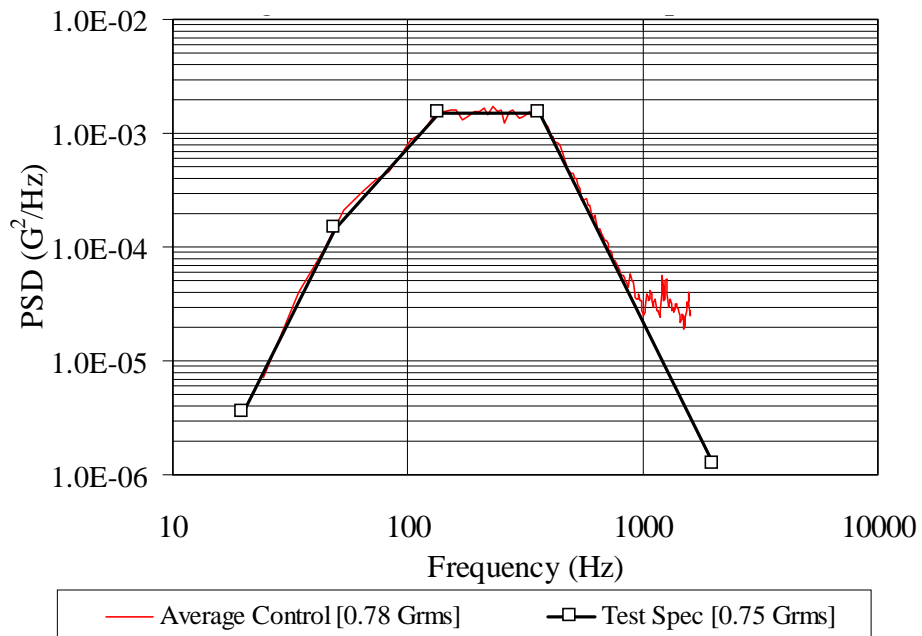


FIGURE 4. CM-2 Double Rack Interface Control  
¼ Flight Random Vibration Test Specification.

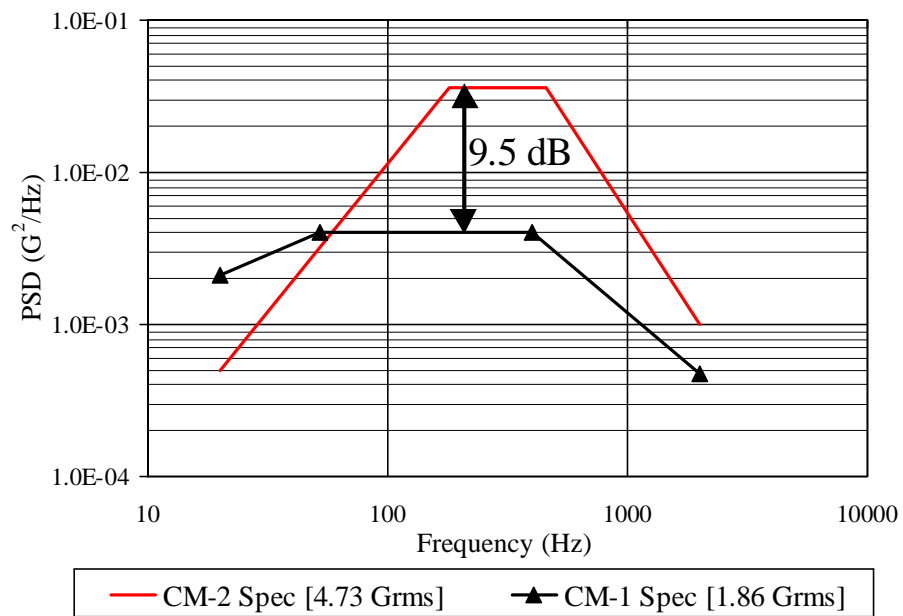


FIGURE 5. CM-1 and CM-2 Experiment Package  
Flight Random Vibration Test Specifications (Y-Axis).

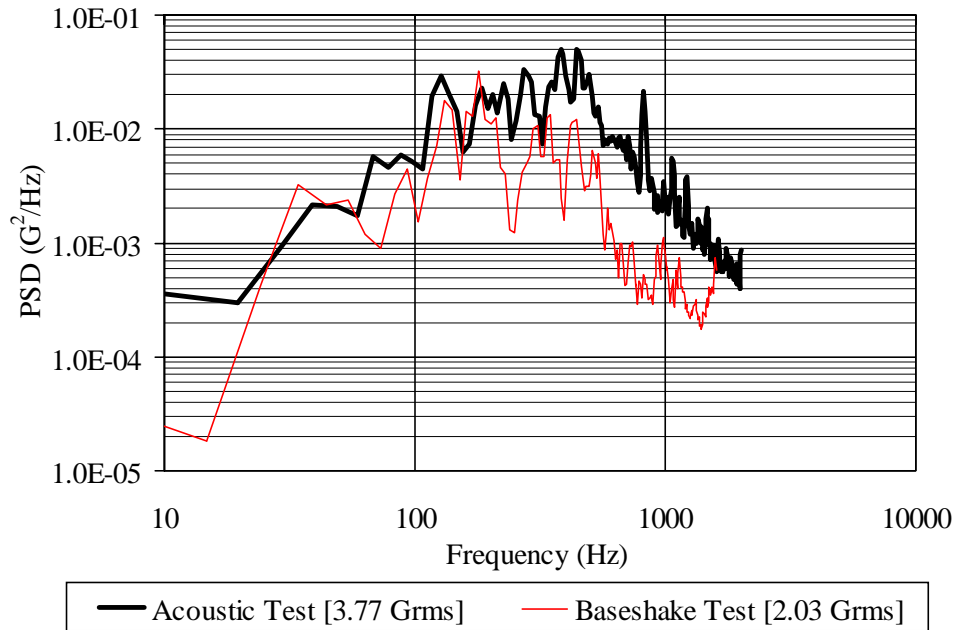


FIGURE 6. Comparison of Acoustic and Baseshake Rack Testing Experiment Package Interface Flight Response (Y-Axis).

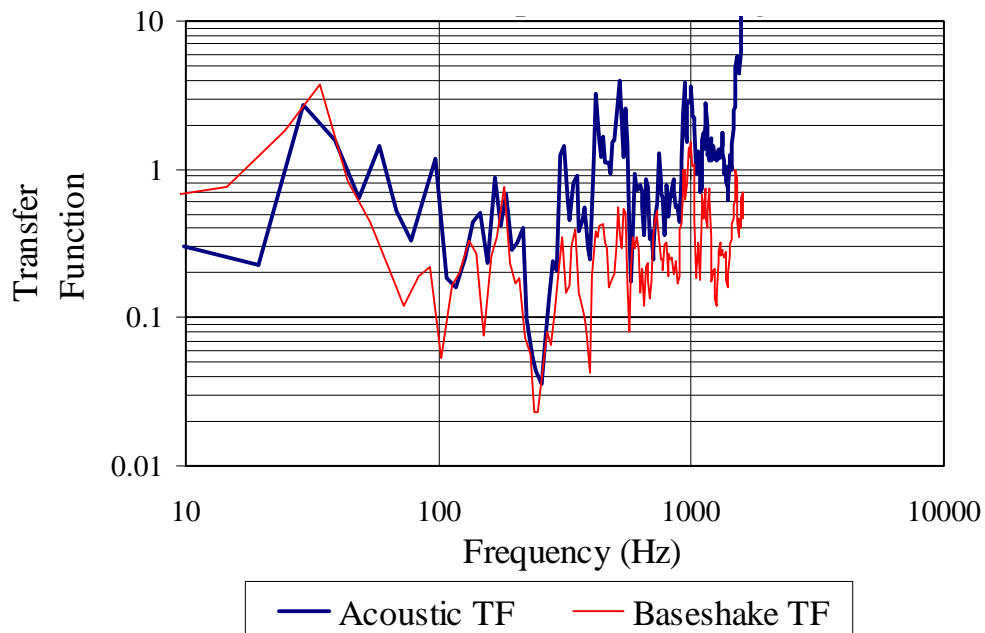


FIGURE 7. Acoustic and Baseshake Transfer Functions for the Experiment Package (Y-Axis).

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