GROUND VIBRATION TEST OF A COMMERCIAL AIRCRAFT

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ABSTRACT

Test organizations are facing increasing challenges for improving test efficiency to reduce test costs and meet schedule requirements. This paper addresses the ground vibration testing of a commercial aircraft in Long Beach, California. Both sine and random testing were performed on the entire aircraft, as well as specific critical components. The coordination of the test teams, parallel setup procedures, optimized test sequences, new data systems, and customized data acquisition and processing procedures have greatly improved test efficiency. Discussions on test setup, instrumentation, test methodologies, and test results are presented in this paper.

INTRODUCTION

The 717-200 is the smallest twinjet in The Boeing Company commercial aircraft family. It was designed specifically for the growing 100-seat very short-haul market. Powered by the new BMW Rolls-Royce BR715 engine, the 717-200 is designed to be the most efficient, most reliable, quietest, and have the lowest emission of any airplane of its class. This airplane represents the combined efforts of a global team of supplier-partners in North America, Europe, and Asia.

The objective of the ground vibration test (GVT) was to measure the vibration modal data necessary to substantiate the flutter analysis, in compliance with the structural requirements for Federal Aviation Administration (FAA) Certification.

The 717 GVT was conducted in April 1998 at the Boeing facility in Long Beach. A series of 61 test runs were performed to measure modal frequencies, damping and mode shapes for vibration modes considered significant from the standpoint of flutter. Sinusoidal sweeps, sinusoidal dwells, random, and impact excitation procedures were used in these tests. A total of 89 modes for the overall aircraft, control surfaces, and components were determined [1].

The aircraft was tested in the zero-fuel condition. Two BMW Rolls-Royce engines were installed. During the test, both engines were rotated to prevent possible damage to engine bearings caused by vibration.

The test aircraft was supported by bungee cords at the nose landing gear (Figure 1) and by deflated tires at the main landing gears. The main landing gears rested on blocks, with the inboard tires as the sole contact points. Tires were deflated to minimize stiffness.

The 717 GVT was scheduled for 10 days, including setup and tear down. This schedule was based on the actual test time of the Boeing MD-90 GVT [2]. During that test, the test schedule had been reduced from 21 days to 10 days. The test schedule begins when the test group receives custody of the aircraft and terminates when the aircraft is returned to its pretest condition. It is essential to complete the test within the given time frame so that the first flight of the test aircraft is not delayed.

In order to improve efficiency, the test team examined every aspect of testing from test plan, test procedures, and instrumentation, to data collection and analysis. As a result of this effort, the test was completed 4 days ahead of schedule, reducing the test time by 60%. This paper addresses the test methods and the factors that contributed to its success.

INSTRUMENTATION AND SETUP

This test benefited significantly from the MD-90 GVT experience [2]. Major test setup was 80% complete while the aircraft was still in Manufacturing's custody. This included cable setup, accelerometer installation, and end-to-end check. This eliminated not only the setup time but also the costly troubleshooting time for bad cables or transducers. During the test, Avionics, Flight Control and Flight Test Instrumentation groups also gained access to the aircraft for preparing the auto-pilot and spoiler tests on a noninterfering basis. Close coordination between the various groups was essential for minimizing the schedule delay.

A full-scale aircraft GVT performed at Long Beach typically requires up to 400 accelerometers. Based on the pretest analysis results, an effort was made to decrease the number of accelerometers to 298. The smaller set of accelerometers significantly reduced instrumentation setup time. Of the 298 accelerometers, 36 were reference accelerometers used for sine sweep test and for mode tuning. They were distributed at prominent locations throughout the aircraft mainly at the extremities (such as wing tips, etc). The reference accelerometers were bridge-type accelerometers that

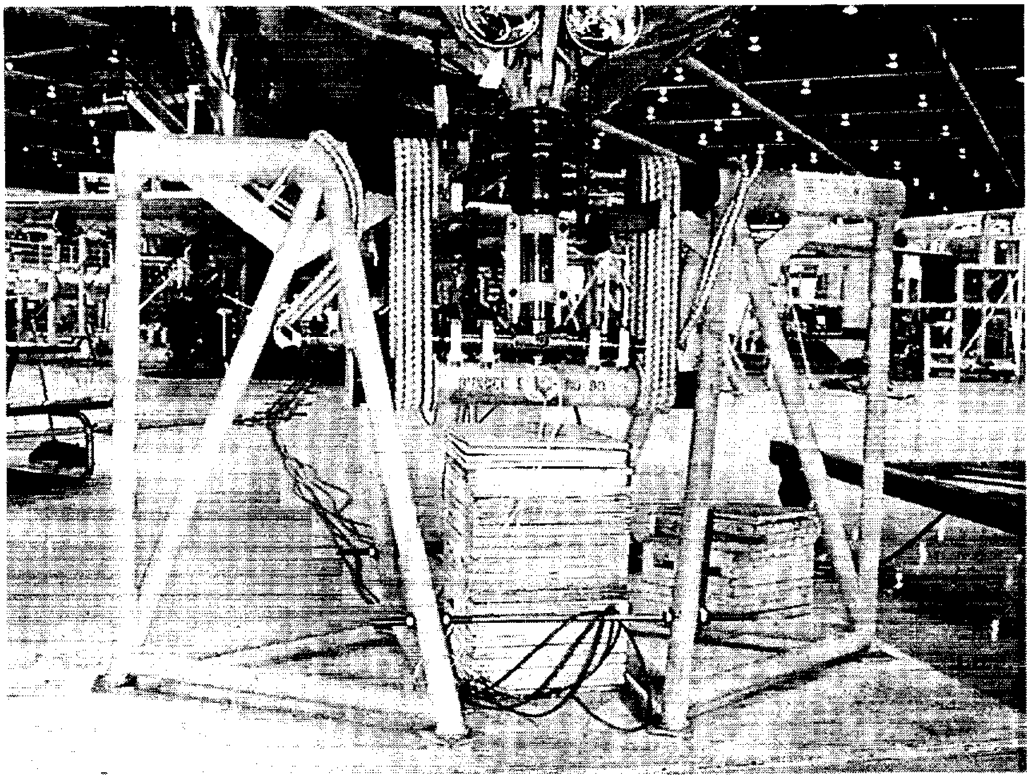

Figure 1. Nose landing gear support.

can measure signal down to 0 Hz. The remaining 262 accelerometers were ICP-type modal accelerometers used to measure the mode shapes. All instrumentation cables, including accelerometer cables, fan-out adapters, junction boxes, 100-feet computer cables, and patch panels, were thoroughly inspected and appropriately integrated before testing. A systematic cable layout plan, including channel end-to-end test procedures, was developed to reduce test setup time.

Two Hewlett-Packard (HP) VXI data systems, each equipped with 16-bit E1432A digitizers, were used for the test. A data system diagram is shown in Figure 2. The primary system, HP1, had a 144-channel acquisition capability. And the other, HP2, equipped with 48 channels of digitizers on loan from another Boeing division. This enabled the HP1 to complete data collection from 268 accelerometers and six force channels in two rather than three acquisition passes for each random or sine dwell test run. It also allowed the HP2 to acquire data from all 36 reference channels simultaneously for the sine dwell and sine sweep tests.

TEST METHODOLOGIES

Traditionally, an aircraft GVT includes three types of tests: Sine sweep, sine dwell and multiple-reference random [3] tests. The test began with a pretest sine dwell test that was used to confirm instrumentation function, accelerometer locations, and orientations. Following this, a sine sweep test identified the global aircraft modes for the subsequent sine dwell tests. Structure linearity was verified by applying various force levels to the structure during the sine sweep test. Based on the linearity results, the appropriate force levels for sine dwell and random tests were determined.

The multiple-reference random test was used as the primary modal test method for the 717 GVT. A six-reference (shaker) burst random test was conducted early in the test to obtain most of the aircraft global modes.

Additional sine dwell tests were conducted after the random test to verify the critical modes. Sine dwell tests were accomplished by using the traditional manual mode tuning technique in conjunction with the computer-generated, multichannel amplitude-phase-scatter (APS) technique [2]. The APS software continuously displayed the real and imaginary components of the frequency response functions (FRF) at the dwelling frequency as dots in the complex plane. When a mode was manually tuned in, the dots were lined up near vertical and HP1 was then used to collect mode shape data from all the force and response channels.

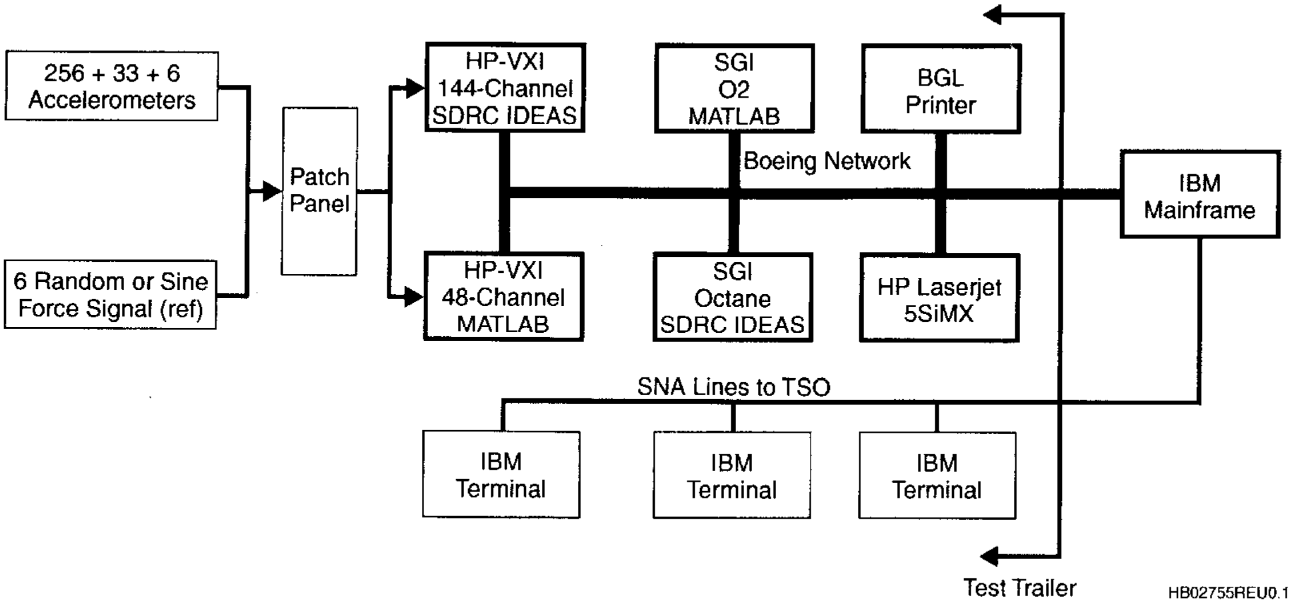

Figure 2. 717 GVT system and data flow diagram.

DATA ANALYSIS AND VALIDATION

Preliminary data validation was conducted using the HP1. This included reciprocity checks for the FRFs and multiple coherence function checks. The reciprocity check was used to verify structural linearity. A typical reciprocity plot is shown in Figure 3. The multiple coherence function was used to check the correlation between one response and all the reference channels. Figure 4 shows a typical multiple coherence function.

Data acquisition and analysis operations were conducted in parallel to reduce test time. Data analysis was carried out using two Silicon Graphics, Inc., (SGI) computers. One SGI computer was dedicated to parameter estimation while the second computer performed modal correlation, mode shape animation and generated plots. For parameter estimation, the multivariate mode indicator function (MMIF) [4] was used to show overall modes from the multiple reference accelerometer FRFs. Examples of a burst random FRF and an MMIF are shown in Figures 5 and 6, respectively. The final parameter estimation results were obtained using the Polyreference method. An example of a mode shape plot is shown in Figure 7. A total of 89 modes were measured for the overall aircraft, control surfaces, and components. After the mode shapes were measured, they were transmitted through the Ethernet to the Flutter Analysis group for further processing. This included the modal orthogonality check and mode shape validation.

CONCLUSION

The 717 GVT was highly successful in both data quality and test efficiency. The principal test setup was performed concurrently with manufacturing activities to minimize the overall test time. The careful planning and installation of the accelerometers and cables, and the system end-to-end check, eliminated troubleshooting time. An optimized test sequence, including sine dwell, sine sweep, multiple-reference random and impact tests, was performed to improve overall test efficiency. Conducting random tests early on further reduced the number of sine dwell runs. The APS sine-dwell technique considerably improved the mode tuning efficiency. Using multiple computers also allowed efficient parallel data collection and analysis operations. Lastly, this test benefited from the technical interchange and personnel cooperation between the various Boeing divisions. These factors contributed to the success of this test.

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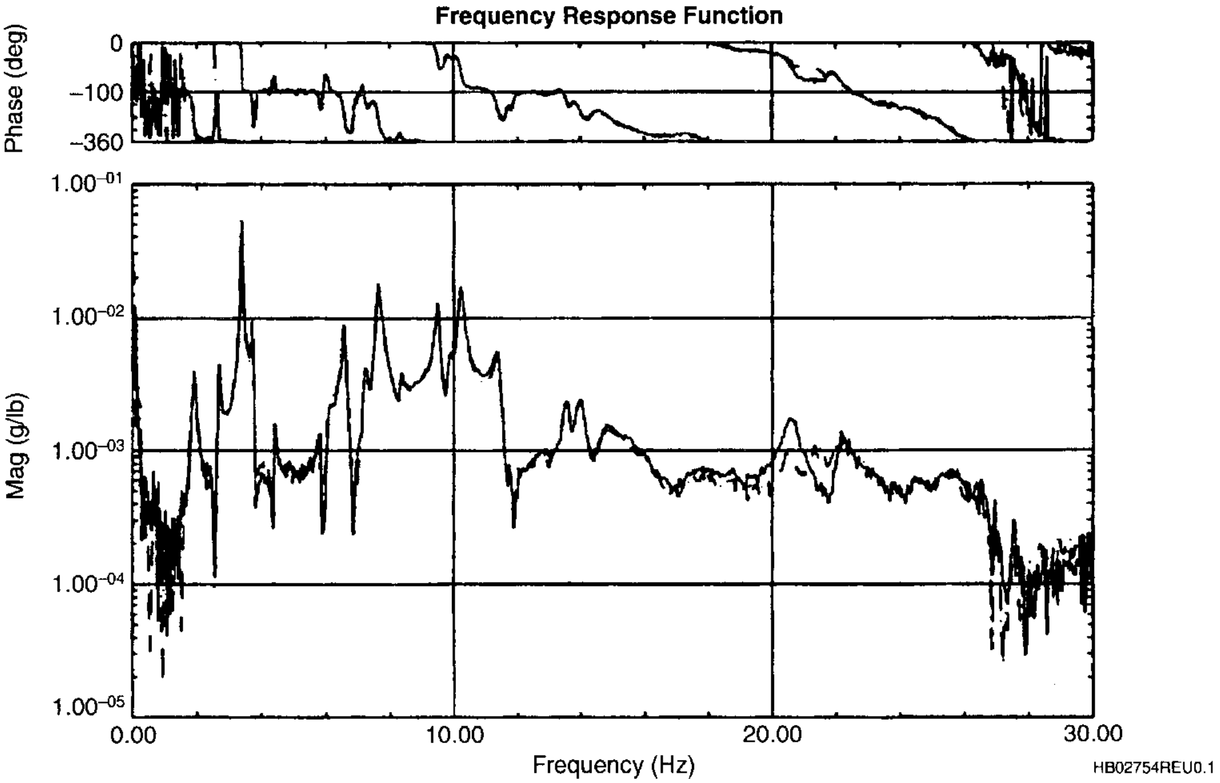

Figure 3. Typical reciprocity plot.

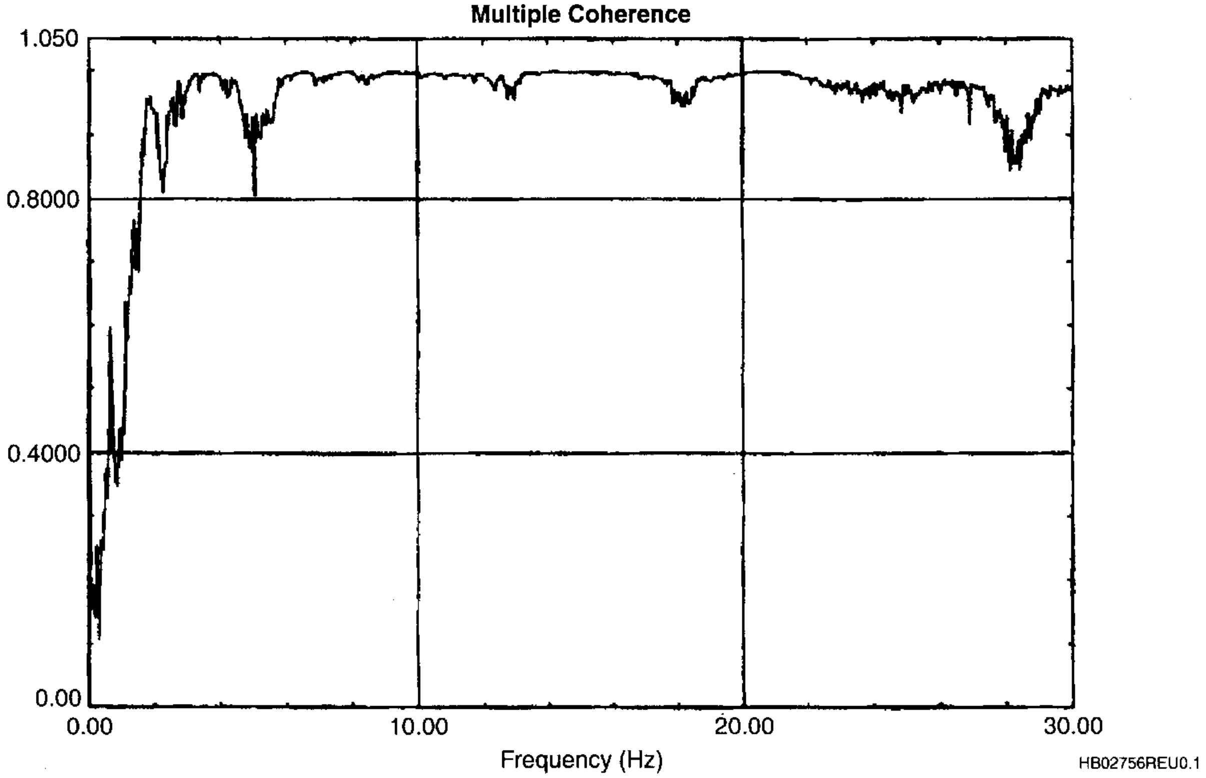

Figure 4. Typical multiple coherence plot.

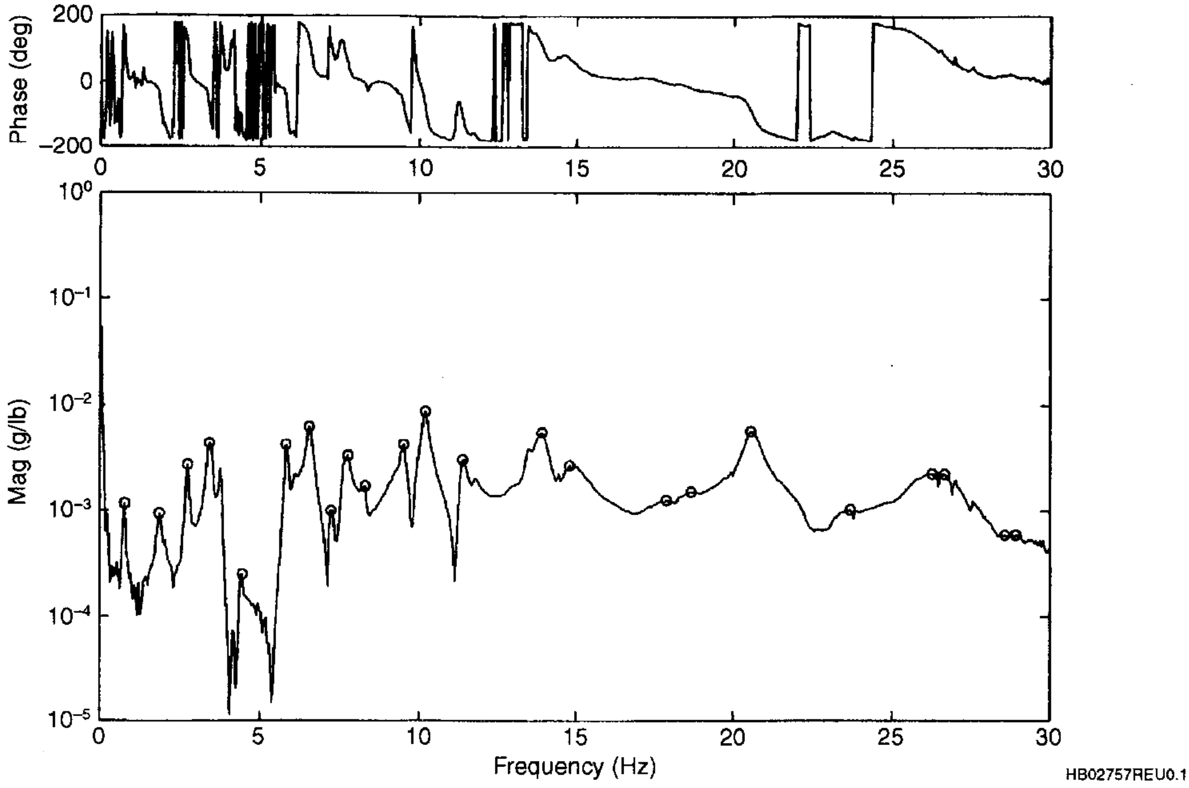

Figure 5. Typical burst random FRF plot.

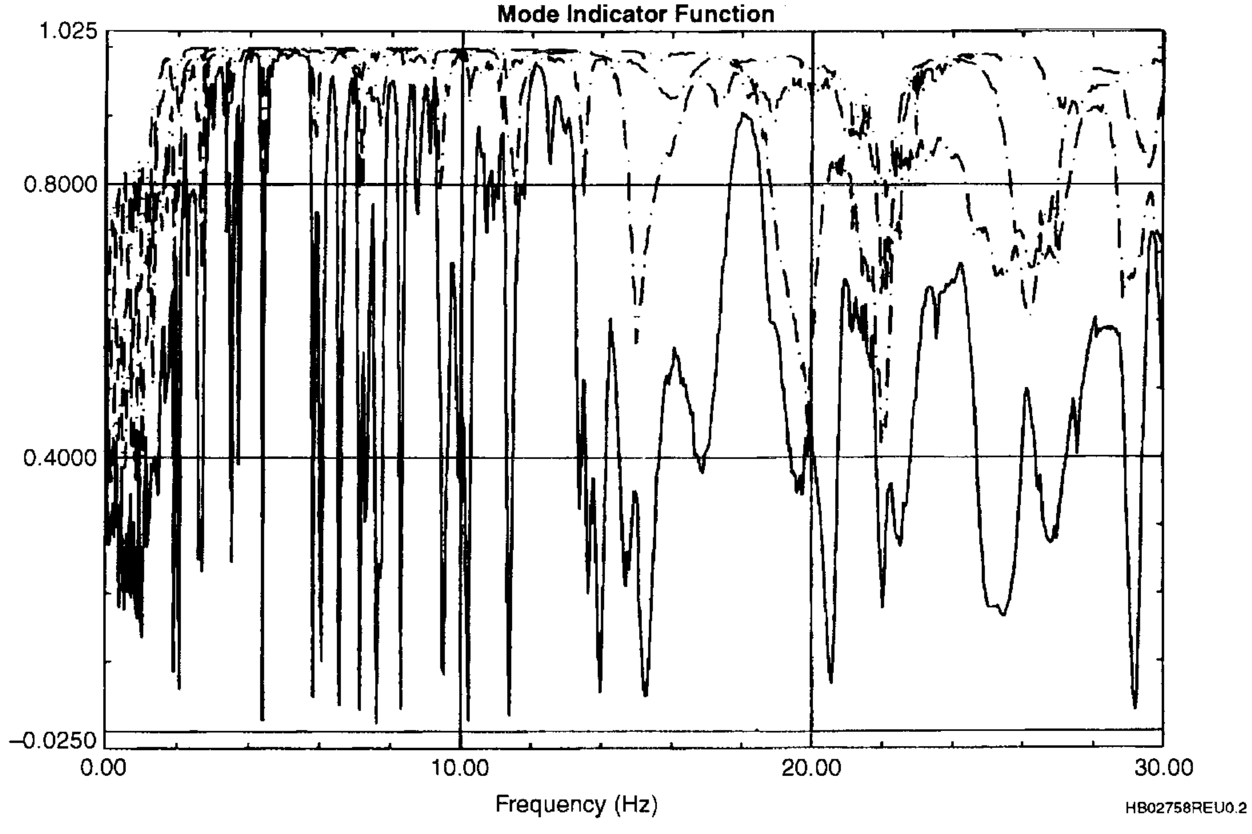

Figure 6. Typical multivariate mode indicator function plot.

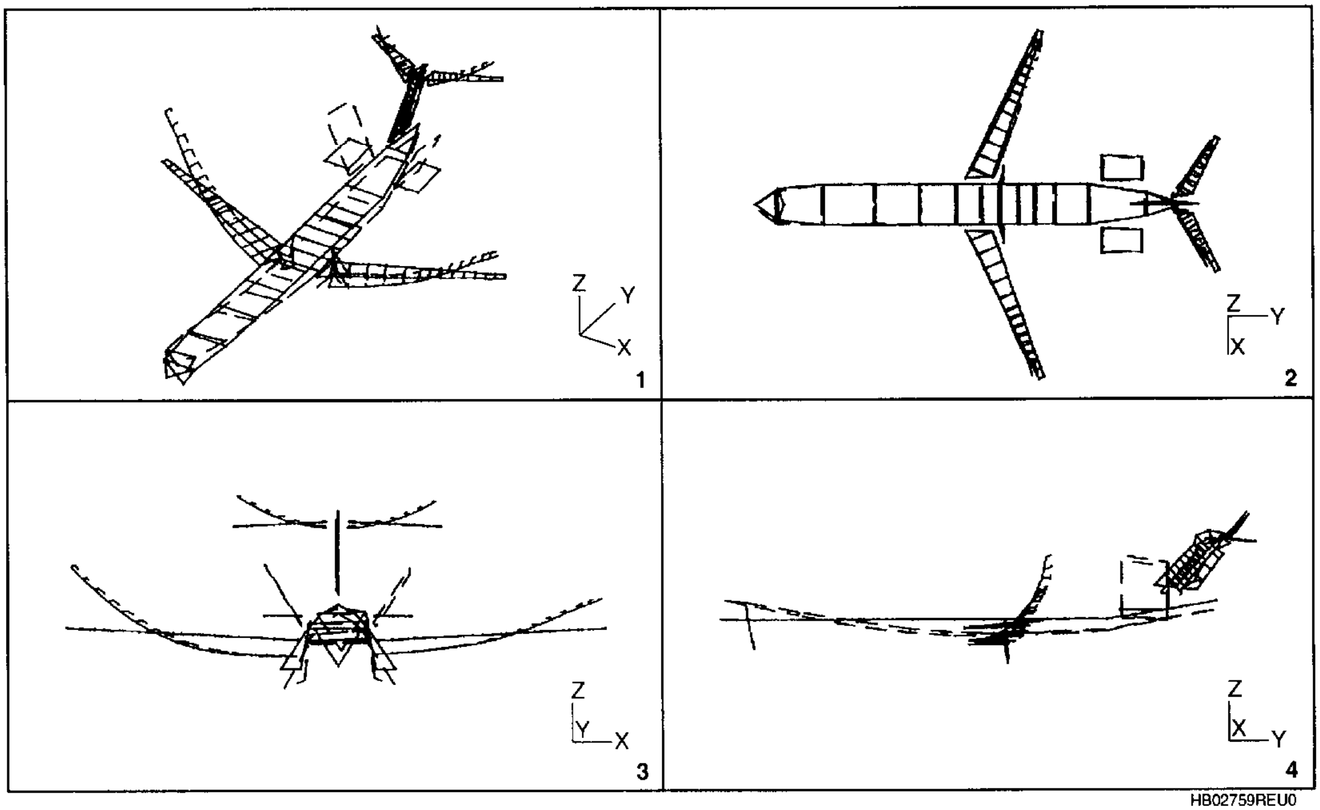

Figure 7. Typical mode shape plot.