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DYNAMIC TEST RESULTS FOR THE CASES GROUND EXPERIMENT

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INTRODUCTION

The Controls, Astrophysics, and Structures Experiment in Space (CASES) Ground Test Facility (GTF) has been developed at Marshall Space Flight Center (MSFC) to provide a facility for the investigation of Controls/Structures Interaction (CSI) phenomena, to support ground testing of a potential shuttle-based CASES flight experiment, and to perform limited boom deployment and retraction dynamics studies. The primary objectives of the ground experiment are to investigate CSI on a test article representative of a Large Space Structure (LSS); provide a platform for Guest Investigators (GI's) to conduct CSI studies; to test and evaluate LSS control methodologies, system identification (ID) techniques, failure mode analysis; and to compare ground test predictions and flight results.

The proposed CASES flight experiment consists of a 32 meter deployable/retractable boom at the end of which is an occulting plate. The control objective of the experiment is to maintain alignment of the tip plate (occulter) with a detector located at the base of the boom in the orbiter bay. The tip plate is pointed towards a star, the sun, or the galactic center to collect high-energy X-rays emitted by these sources. The tip plate, boom, and detector comprise a Fourier telescope. The occulting holes in the tip plate are approximately one millimeter in diameter making the alignment requirements quite stringent. Control authority is provided by bidirectional linear thrusters located at the boom tip and Angular Momentum Exchange Devices (AMED's) located at mid-boom and at the tip. The experiment embodies a number of CSI control problems including vibration suppression, pointing a long flexible structure, and disturbance rejection. The CASES GTF is representative of the proposed flight experiment with identical control objectives.

CASES GTF OVERVIEW

The CASES GTF provides a mechanism for testing many aspects of a flight experiment, such as vibration suppression, boom deployment and retraction, sensor and actuator performance, real-time computer software and hardware evaluation, electronics, power, optical measurement systems, and interfaces. Some aspects of the testing are affected by the earth's gravity and air damping. The dynamics of the boom and tip plate are modified by gravity, and sensor biases due to gravity and the earth's rotation must be eliminated through software. In addition, gravity precludes pointing experiments on the ground, and deployment and retraction is not possible with the tip plate attached. However, there are a number of ideas under investigation to overcome these problems and devise a scheme to perform pointing experiments and to perform limited deployment and retraction experiments. Such deployment and retraction experiments have been conducted on the boom without the tip plate in place.

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The CASES GTF is located at MSFC in Building 4619 in the Load Test Annex (LTA) high bay area. A schematic of the facility is shown in Figure 1. The test article is suspended vertically from a platform at the 132 foot level. The disturbance system provides two translational Degrees Of Freedom (DOF). Disturbances representative of those which would be experienced on orbit may be imparted on the structure. A simulated Mission Peculiar Experiment Support Structure (MPESS) is the interface between the disturbance system and the test article to simulate a flight experiment interface between the Shuttle, MPESS, and the payload. The CASES test article consists of a 32 meter boom which supports a simulated occulting plate at the boom tip, and a simulated detector plate attached to the MPESS. As in the proposed flight experiment, control authority is provided by AMED's and two bidirectional linear thrusters.

The primary test article is the 32 meter Solar Array Flight Experiment-I (SAFE-I) boom which was modified for the CASES facility. The boom has 135 bays, weighs about 25 pounds, and retracts into a canister of length 1.83 meters. The boom has a triangular cross section with 25.4 centimeter sides. The longitudinal members (longerons) are continuous elements composed of a fiberglass composite. The boom canister is mounted to a simulated MPESS, which emulates interface between the Shuttle and the experiment. It has four horizontal bays, each measuring 0.7x0.7x0.6 meters, is 2.44 meters high, 2.13 meters wide, and is composed of aluminum elements. The mass of the structure is approximately 488 kilograms. The MPESS is connected to the tripod via a pipe which is 1.52 meters long and 40.6 centimeters in diameter, a 2.5 centimeters thick aluminum interface plate, and several additional interface plates which act as bending and torsional stiffeners. The tip plate, which simulates an occulting plate, is connected to the boom tip. The tip plate has four simulated masks, is about 2x2 meters excluding the boom/plate interface device, and has a mass of about 32 kilograms.

Two Unholtz-Dickie Model 6 shakers provide translational disturbances to a tripod supported on air bearings to which the simulated MPESS is attached. Each shaker provides 4448 newtons peak force with a ±7.6 centimeter stroke and a 1000 Hz bandwidth. A Linear Motion System (LMS) interfaces each shaker with the tripod to allow for low-friction motion in two directions simultaneously. The tripod floats on an air bearing system which consists of an annular air bearing surface and three air pads. The ring, which has an outside diameter of 4.6 meters and an inside diameter of 2.7 meters, provides a large, flat surface on which the air bearings float. The three pressurized air pads provide for "frictionless" translation. At a given operating pressure and load, each air pad operates like a spring. The load and pressure can be adjusted to achieve a desired air pad stiffness. The air gap is monitored via an optical and capacitance system.

The control actuation system consists of two single-axis AMEDs at a mid-length position on the boom, three single-axis AMEDs at the boom tip, and two single-axis bidirectional linear thrusters at the boom tip. The AMEDs are used for vibration suppression at a mid-point and at the tip of the boom. Each AMED package consists of two motors attached to reaction wheels, two 2-axis gyros and the associated gyro electronics. The tip AMED package is augmented with a third motor and reaction wheel. The two orthogonal thrusters will be used primarily for pointing the boom in the flight experiment, but will be used for vibration suppression in the ground experiment. The linear thrusters have a force capability of ±9 newtons at up to 10 Hz. Each thruster weighs approximately four pounds.

The measurement system consists of angular velocity and acceleration sensors at the base, boom angular velocity sensors in the mid-length and tip AMED packages, tip acceleration sensors, and an optical Tip Displacement Sensor (TDS). Each PCB accelerometer weighs one pound, has a resolution of 0.0001g with a range of ±2 g, and has a bandwidth of 800 Hz. Each gyro weighs 150 grams, has a bandwidth of approximately 100 Hz, and a threshold rate of 0.01 degrees/hour. Auxiliary measurements include reaction wheel speed, AMED motor current, and fault indicators. The auxiliary measurements are available for health and safety monitoring. A Boom Motion Tracker records boom mode shapes for post processing.

The CASES computer system provides real-time control with 64 sensor inputs, 64 actuator outputs, and a 100th order controller at rates up to 250 Hz. Lower order controllers may be executed at higher rates. The computer system, developed by AP Labs, consists of a host computer and a separate real-time system. The host provides the user interface, performs the run-time plotting and storage, and provides applications for pre-processing (program development, debugging, and control design) and post-processing. The host is a Sun workstation on the VME bus running UNIX. Included in the host is a Sun SPARC 1e processor, 600 MB of hard disk space, 20 MB of memory, and a color graphics display. The real-time system performs input, scaling, control processing, and output functions. The real-time system is a VME bus based computer running AP Labs real-time IOS (Input/Output Subsystem) and includes a 68020 supervisory processor, 3 Sky Warrior II array processors, four 16-channel 12-bit A/D cards, eight 8-channel 12-bit D/A cards, and 8 MB global memory. Analog signal processing is performed via filtering, multiplexing, and demultiplexing systems located on the boom and in the control room.

MODAL TESTING OF THE CASES GTF

A modal survey of the CASES GTF was completed on January 24, 1992.[1] PCB Structcel 330A Accelerometers were mounted triaxially at 148 points on the facility for a total of 444 accelerometers. Accelerometer triads were located at 98 points along the boom, 7 points on the suspension tripod, 24 points on the simulated MPESS, and 19 points on the tip plate. The primary frequency range used in recording the response of the 148 triads was 0 to 64 Hz with data recorded for a reduced set of points over the ranges of 0 to 128 Hz and 0 to 256 Hz.

Three different excitation methods were used to excite the structure during the tests. The primary excitation source was the pair of Unholtz-Dickie Model 6 shakers driven with an HP 3565 front end that provided a random signal filtered from 0.5 to 55.0 Hz. Use of the shakers provided an *in situ* test scenario. Force levels of 138 newtons RMS and 156 newtons RMS were applied to the test structure via the shakers. Because the shakers failed to excite some of the lower frequency bending and torsional modes, particularly those below 2 Hz, additional excitation methods were used. To excite the torsional modes, a random input was applied at the tip plate using an APS Model 113 shaker driven by the HP3565. The frequency range used in recording the responses resulting from the forces applied at the tip was 0 to 64 Hz. Responses from all 148 locations were recorded. All force inputs applied by the shaker systems were measured using PCB Model 208A03 force transducers. The third excitation source used in the modal testing was the manual application of an impulse load. The impulse was required to excite the lowest frequency bending modes. Because this force could not be accurately measured, decaying acceleration sinusoids were observed on an oscilloscope for frequency identification. Mode shapes for the first bending modes and first torsion mode were visually observed. The frequencies of the first bending modes are on the order of 0.1 Hz.

Data acquisition and signal processing were accomplished using an HP9000/370SRX work station with an HP 3565 multiple channel front end system. Leuven Measurement System (LMS) F-monitor software was used to acquire transducer outputs, calculate frequency response functions (FRF's), and to store the FRF's on tape. Software developed by the University of Cincinnati was used to calculate the modal parameters, mode shapes, modal frequency, and modal damping, by means of a curve fitting algorithm applied to the FRF's. A Multiple Degree of Freedom (MDOF) curve fitting technique was used on the data because of the high modal density within a narrow frequency range and the lightly damped modes. Verification of the measured modes was accomplished using the Complex Mode Indicator Function (CMIF) and the Modal Assurance Criteria (MAC). The power spectrum from each load cell was monitored in real time and recorded using an HP 3562A Dynamic Signal Analyzer.

MODAL TEST RESULTS

Table I summarizes the results of the modal testing on the CASES GTF. The modal frequency and damping for the first 37 modes are listed in the table. Note that values of damping for the first 5 modes are not given because these low frequency modes were obtained via manual impulse and observation as described in the previous section. All 35 modes listed in the chart are below 32 Hz in frequency. The highest damping value is approximately 6.3 percent. Five modes are observed to be below 1.0 Hz in frequency. Characteristic LSS behavior is notable in the closely spaced clusters of modes, particularly in those frequencies below 10 Hz, making for a challenging controller design problem. Mode shapes for the modes listed in Table I have been plotted and are available in reference 1. The majority of the mode shapes, corresponding frequencies and damping values were identified by the FRF's obtained from the inputs to the base of the mast. The modes above 32 Hz (not shown in chart) were found using the CMIF, as were the five torsional modes between 3.12 Hz and 17.5 Hz. FRF's have been generated for all the sensor locations used in the test procedure. Shown in Figures 2 through 5 are typical FRF's taken from sensors located on the base, at mid-boom, and at the tip, respectively. The modal data collected will be further analyzed and used to tune the CASES finite element model which will then be incorporated into the facility simulation.

REFERENCE

1. Anderson, J. B., T. C. Driskill, P. Jefferson, and J. O. Lassiter, Controls, Astrophysics, and Structures Experiment in Space (CASES) Mast Modal Survey Test Report, NASA MSFC Technical Report number LSS(CASES)-DEV-ED92-001, Dynamics Test Branch, Structural Test Division, Structures and Dynamics Laboratory, NASA Marshall Space Flight Center, February 21, 1992.

Mode Number	Frequency	Damping (%)	Mode Type
1	0.112	-	Bending
2	0.120	-	Bending
3	0.210	-	Torsion
4	0.520	-	Bending
5	0.530	-	Bending
6	1.391	4.811	Bending
7	1.868	3.075	Bending
8	2.802	4.339	Bending
9	2.995	3.463	Bending
10	3.133	4.562	Torsion
11	4.215	6.323	Bending
12	4.598	3.787	Bending
13	4.974	2.241	Bending
14	6.027	1.438	Bending
15	6.565	3.730	Bending
16	6.703	1.881	Torsion
17	8.182	1.333	Bending
18	9.864	2.288	Bending
19	10.864	1.931	Torsion
20	12.312	3.125	Bending
21	14.537	1.381	Bending
22	15.243	1.396	Bending
23	15.855	0.609	Bending
24	16.816	3.671	Torsion
25	18.035	0.927	Bending
26	19.856	3.643	Bending
27	20.878	3.375	Bending
28	22.044	1.198	Bending
29	23.085	1.760	Bending
30	24.211	0.823	Bending
31	25.827	0.804	Bending
32	26.029	1.252	Bending
33	28.365	0.733	Torsion
34	29.764	1.988	Bending
35	31.650	1.325	Bending

Table I. Modal Frequencies, Damping, and Type for CASES GTF.

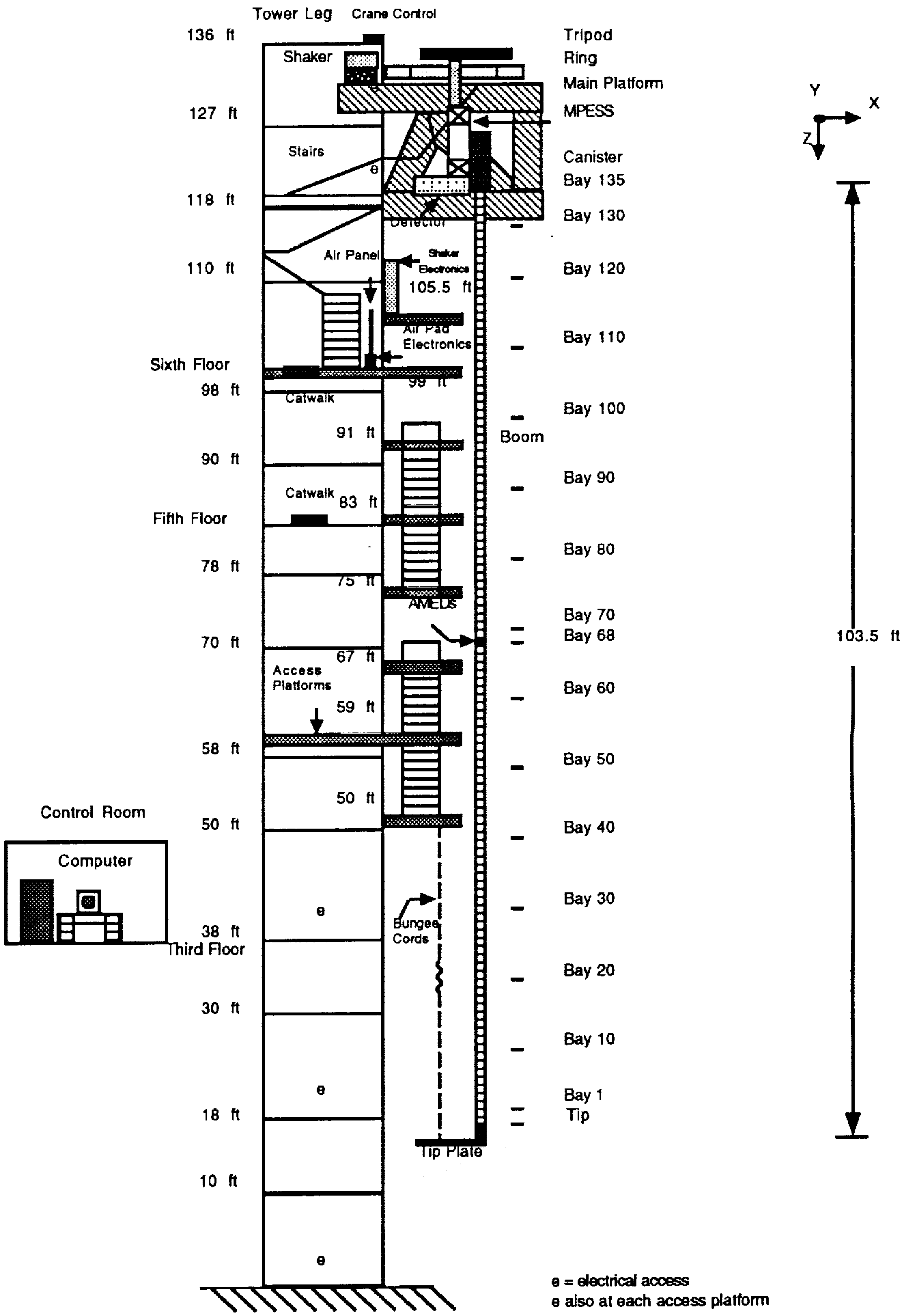

Figure 1. CASES GTF Schematic

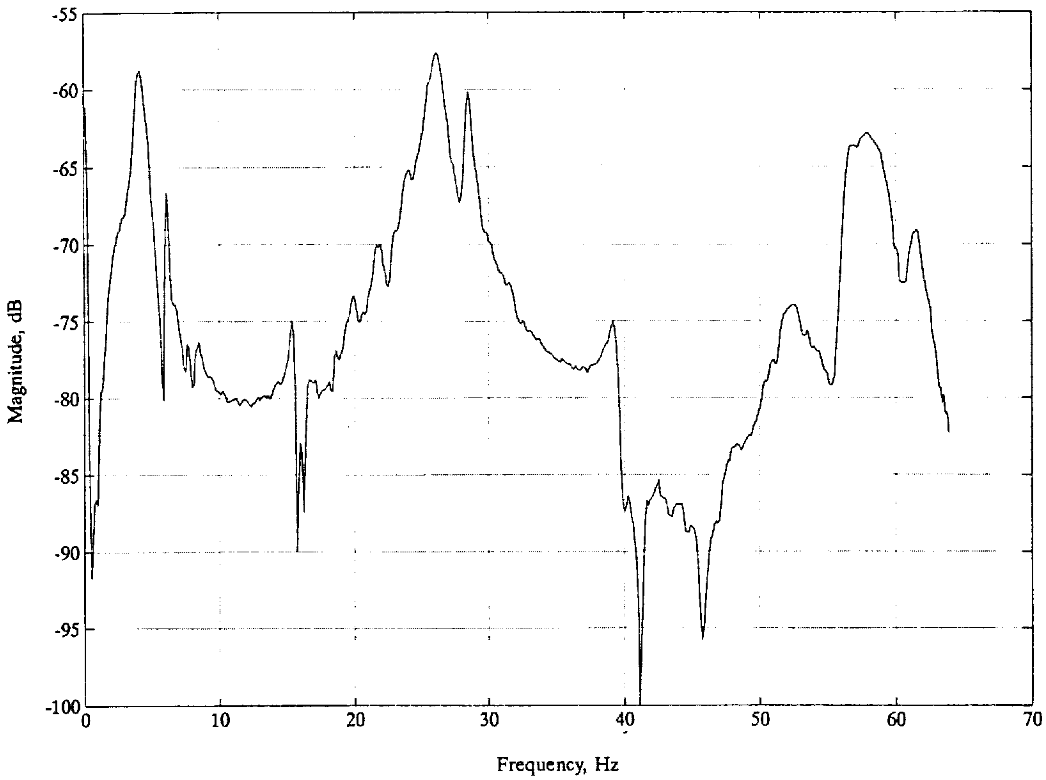

Figure 2. Base FRF, (X - Axis)

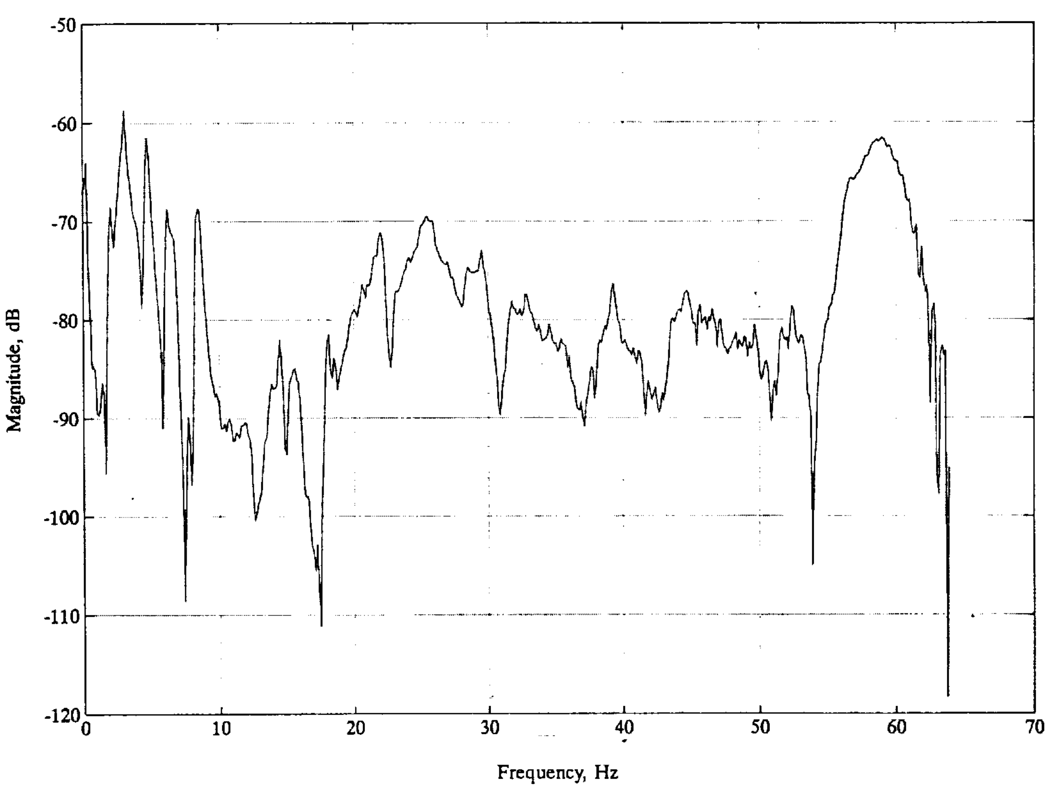

Figure 3. Mid-Boom FRF, (X - Axis)

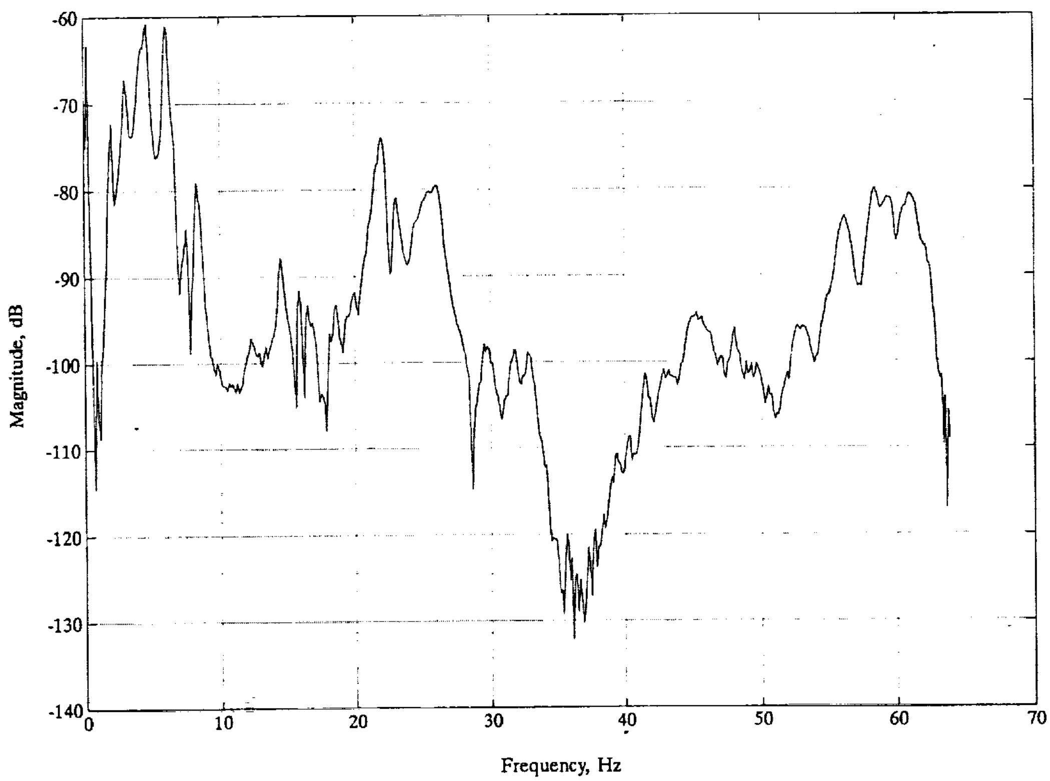

Figure 4. Boom Tip FRF, (X - Axis)

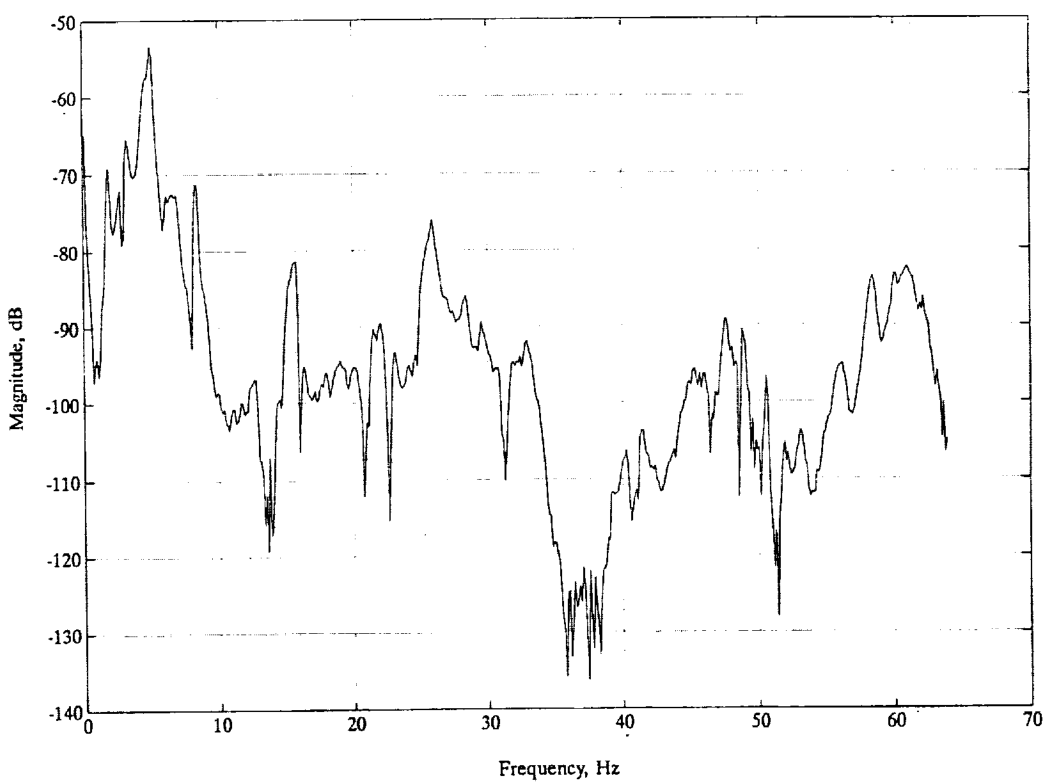

Figure 5. Boom Tip FRF, (Y - Axis)