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Langley's CSI Evolutionary Model: Phase 0

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Introduction

Improvements in space science data quality will require pointing systems which can provide accurate, reliable, and robust pointing performance in the presence of uncertainty. One of the key ingredients of these pointing systems is the interaction of closed-loop controllers and the flexible body dynamics of space platforms and platform appendages. A focused research activity has been initiated to develop combined controls and structures technology to enhance the design of space science pointing systems.

The focused technology, referred to as Controls-Structures Interaction (CSI), consists of three complimentary stages: design, ground testing, and flight validation. At the NASA Langley Research Center, a CSI ground test program has developed a generic testbed for line-of-sight (LOS) pointing enhancement using CSI technology. The CSI evolutionary model (CEM) testbed can be used to monitor LOS pointing performance during a wide variety of disturbances. As CSI theoretical and hardware developments are made, their implementation can be verified by using the CEM.

This paper documents the phase 0 version of the CEM. First a description of the testbed capabilities and major subsystems is given. Next a NASTRAN [1] finite element model for the structure and state space models for the structure, actuators and sensor filters are presented. Subsequently, the testbed dynamic characteristics and preliminary experimental data are described. Model data given in the appendices serves to document the analysis and simulation models used at the Langley Research Center in support of the phase 0 CEM testbed.

Testbed Description

The CEM has been designed to possess dynamic properties typical of spacecraft platforms proposed for remote sensing and communications. As such, unwanted interaction between sensor pointing control systems and the flexible body dynamics of the platform can be qualitatively assessed. The schematic of Fig. 1 shows the phase 0 structural platform consists of a long truss-bus and several appendages with varying degrees of flexibility. A low powered laser is mounted to the vertical tower such that the beam reflects upon a mirrored surface mounted on the reflector. The beam reflection is measured by a photo-diode array attached directly above the reflector. This laser-reflector-detector system enables the global LOS pointing to be

measured. Note that the reflection of the beam from one part of the platform to another is typical of science platforms which use offset-fed antennas for communications.

Figure 2 shows the structural model used in the CSI testbed. The following sections describe the structure and three other major parts of the phase 0 testbed: Instrumentation, LOS pointing system, and the excitation, control and data acquisition computer systems. Performance specifications are based on LaRC experience and not necessarily indicative of manufacturers stated performance or the performance to be expected in different applications. All units are in the in-lb-sec system unless otherwise indicated. While much detail is given in this section, the reader is urged to read the modeling section of this paper to derive the needed information to construct models of the testbed.

Structure

The Phase 0 structure consists of a three-dimensional truss constructed from 10 inch cubical bays. As shown in Fig. 3, the testbed has a 62 bay long bus, four 10 bay horizontal appendages, an 11 bay vertical laser tower, and a four bay vertical reflector tower. Thus, there is a total of 117 ten inch cubical bays. In addition, there is a 192 inch diameter reflector on one end of the truss-bus. The entire structure is cable suspended to permit "rigid" body and flexible body dynamics. The following paragraphs describe the truss, struts, reflector, and suspension system.

Truss---The truss is made from aluminum tubes and node balls using high-strength steel threaded rods to connect the tubes to the node balls. As seen in the close-up view of Fig. 4, there are only two strut sizes. The battens and longerons have a 10 inch node ball center-to-center length, whereas the diagonals have a 14.142 inch center-to-center length. Figure 4 also shows the dominant lacing pattern used in the truss. The dominant pattern has either six or seven struts intersecting at a given node ball. The exception to this lacing pattern is in the four horizontal appendages which have either five or eight struts intersecting at the node balls.

Struts---A typical truss strut, shown in Fig. 5, consists of a homogeneous section of 6061-T6 aluminum tube with a joint at each end. The tube is 5/8" in diameter with a wall thickness of 0.058 inches. The joint is a combined mechanical/bonded system. The joint is made using a tapered plug, which is bonded into a tapered section of the tube, and a threaded steel rod, which is used to affix the strut to the node ball. The threaded rod is bonded to a stud on one end (with Locktite), inserted through the plug and then secured from slipping out of the plug with a nut on

the opposite end. The tapered plug is then bonded to the tube with a Hysol adhesive (EA 934A) and cured at 150° F for 1.5 hours. Each strut was subsequently proof loaded in tension to 2600 lbs of static load to verify the bond integrity.

The length of the strut is set using the jig shown in Fig. 6. Three nuts are placed on the ends of the two exposed threaded rods. The inner nut, towards the tube, is torqued to 50 in-lbs to preload the plug assembly to 1600 lbs. This level of preload was determined to provide a linear, low-hysterectic behavior of the joint over the expected load range. The length is then set by finger tightening the outer most nuts against the inside of the jig. The length is fixed using the jam (middle) nuts which are torqued in excess of 50 in-lbs against the outer most nuts. The gauge length for the battens and longerons was 8.388 inches and the gauge length for the diagonals was 12.530 inches. This procedure provided a dimensional tolerance of ± 0.050 inches in the assembled truss as measured from node ball center to center.

Strut mass and stiffness properties are given in Table 1 for each type of strut. It is noted these are effective properties based on individual strut and subassembly tests.

Reflector --- In addition to the truss, the structural subsystem contains a reflector structure to simulate large appendages which may be found on space platforms. The reflector is a 16 foot diameter ribbed structure with a mirrored surface which reflects the laser light beam in the optical path of the LOS pointing subsystem. The reflector has 8 ribs evenly spaced to support a composite panel upon which the mirrored surface is bonded.

Figure 7 shows a three-view schematic of the reflector. The reflector is rotated at an angle of 39.1 degrees relative to the horizontal plane such that the optical path from the laser to the reflector is directed vertically from the reflector to the detector scoring system. A 1/32" steel cable, pretensioned to 11.7 lbs., connects the ends of each rib to form a dish shape in the reflector. Aluminium angle bar, 1.5 inches on each side by 1/4" thick, is used to tilt the reflector relative to the four bays of reflector truss as shown in Fig. 8.

For some analyses, the reflector can be modeled as a rigid body with an inertia matrix about the reflector center of gravity (CG). In the FEM's global coordinates, shown in Figs. 7 and 9, the reflector CG is located at $x=612.77$, $y=0$, $z=58.861$ with a total weight of 93.17 lbs. (Note the origin of the coordinate system is located in the center of the main truss at the end opposite of the reflector.) The reflector inertia matrix about this CG is

$$M = \begin{bmatrix} 2.4138e-1 & 0 & 0 & 0 & 1.4208e+1 & 0 \\ 0 & 2.4138e-1 & 0 & -1.4208e+1 & 0 & 1.4791e+2 \\ 0 & 0 & 2.4138e-1 & 0 & -1.4791e+2 & 0 \\ 0 & -1.4208e+1 & 0 & 1.0628e+3 & 0 & -8.7825e+3 \\ 1.4208e+1 & 0 & -1.4791e+2 & 0 & 9.1638e+4 & 0 \\ 0 & 1.4791e+2 & 0 & -8.7816e+3 & 0 & 8.0896e+4 \end{bmatrix} \begin{matrix} xx \\ yy \\ zz \\ rx \\ ry \\ rz \end{matrix}$$

The reflector properties, and static test results are given in Ref. [2]. In addition, the reflector is further described in the Finite Element Model section of this report.

Suspension--- The suspension system for the CEM attaches to two primary support points in the ceiling of the test facility. These points are located at a FEM global z coordinate of 803.5 inches. Figure 9 shows a schematic of the major parts of the suspension. As can be seen, the two primary suspension cables are yoked such that four points on the CEM are connected to the suspension system.

Two linear extension springs are attached near the ceiling suspension points to reduce the effects of the suspension system on the CEM flexible-body dynamics. These springs each have a stiffness coefficient of 25 lbs/in. All suspension cables are 7X9 1/8" steel braided cables. The suspension system also includes two pulleys and a winch which is used to raise and lower the CEM. The winches are used infrequently, usually to lower the model onto fixed supports to facilitate hardware changes.

The main design consideration for the suspension system was to reduce the effect of the suspension on the first flexible vertical bending mode (mode 8). Hence, the four horizontal trusses are located near node lines for this mode. Four CEM connection points were needed to maintain a reasonable level of prestress in the truss due to gravity. The suspension system produces a maximum strut preload of 838 lbs as indicated by the load distribution shown in Fig. 10.

Instrumentation

Currently, several different types of actuators and sensors are available for use with the CEM testbed for both control and system identification. Table 2 gives a complete listing of the

coordinate location, FEM node location, and type of sensor and actuator that are placed on the CEM.

Accelerometers --- Two types of linear accelerometers are available on the CEM; 18 servo and 195 piezo-film accelerometers. The servo accelerometers are provided for low-frequency acceleration measurements. They are generally used as input to control algorithms and low-frequency system identification algorithms. The piezo-film accelerometers are provided for use with the system identification algorithms at frequencies above 1 Hz.

The servo accelerometers are Sundstrand model QA-900 accelerometers. The 18 accelerometers, shown in Fig. 11, are located at 6 bays (3 at each bay). The servo accelerometer orientation is coincident with the global x, y, and z directions. Nominal accelerometer characteristics are given in Table 3. Eight of the servo accelerometers are collocated with the air thrusters, and they are generally input to the control algorithms. The location and direction for these control accelerometers are shown in Fig. 12. The collocation is obtained by mounting the thrusters on the outside face of the truss and the accelerometers on the opposite side of the thruster plate. The mounting is shown in Fig. 13. It should be noted that the z direction accelerometer is mounted on the plate with the y direction thruster and vice-versa. Similar relations exist between the x and y direction accelerometers and thrusters.

The piezo-film accelerometers are PCB model 330A Structcel accelerometers. These accelerometers are combined with a model 433A signal conditioner to produce the nominal characteristics given in Table 4. The accelerometers are mounted in a tri-axial configuration. The tri-axial accelerometer mounting locations are schematically shown in Fig. 14. Twenty five tri-axial accelerometers are located on the reflector; two tri-axial accelerometers are located on the suspension system, and the remaining 38 tri-axial accelerometers are distributed throughout the truss. The mounting configuration is intended to provide adequate spatial resolutions for the vibration modes of interest.

Rate Sensors --- Eight Watson model 30 rate sensors measure the truss angular rates. The locations for these sensors are shown in Fig. 11. The manufacture's nominal characteristics are given in Table 5. Experience to date has shown these sensors to be noisy and sensitive to linear acceleration. Hence, these transducers have not been used for control or system ID.

Strain Gages --- Twelve longerons are instrumented with strain gages to measure axial strain in the strut. The locations of these struts are shown in Fig. 15. The gages are 350 ohm

foil gages with a gage factor of 2.115. These sensors are used for load verification and as inputs to safety algorithms.

Air Thrusters --- There are 16 air thrusters operating in pairs at 8 locations, shown in Fig. 12. The thrusters, shown in Fig. 16, are linear, bi-directional devices designed and built by Boeing Aerospace [3]. They are operated in pairs to insure pure translational forces when mounted on opposite sides of a truss bay. Each thruster will produce a peak force of 2.2 lbs. The thruster's dynamics are described in the modeling section of this paper.

Shakers --- Up to eight long-stroke electrodynamic shakers are available to apply excitations at most points on the structure. The shakers are APS Dynamics model 113 shakers. These shakers feature a one pound armature sliding on air bearings with a six inch stroke. The shakers can be operated in either voltage or current-feedback mode. Load cells between the armature and truss measure the input force. Nominal characteristics, for the shaker with a fixed boundary condition are given in Table 6.

LOS Pointing Scoring --- To measure the pointing performance of the testbed, a laser motion optical detector (LaMOD) [4] was designed and fabricated by Control Dynamics Company of Huntsville Alabama. The LaMOD uses a 5 milliwatt Helium-Neon Uniphase 105-1 laser and a microprocessor scanned photo-diode array to detect linear beam position over a 40 inch by 40 inch area. The detector is shown in Fig. 17. The microprocessor output is 3 analog signals. An analog 5 volt TTL signal indicates the beam is present in the detection area with sufficient intensity. The low intensity of the laser beam in the CEM application requires that almost all lights inside the laboratory be extinguished (background lux level 0.02) to achieve sufficient laser beam to background intensities. The remaining two signals give an analog signal proportional to the beam displacement from the origin in two perpendicular axes. The beam position is given in rectangular x and y coordinates by

$$X = 2.23 V_x \quad , \quad Y = 2.23 V_y \quad (1)$$

where V_x and V_y are the analog output voltages (after DC bias removal) and $X=0$ and $Y=0$ are the coordinates of the detector center.

The LaMOD resolution is limited by the number of photo diodes and the algorithm used for estimating the beam location. Photo-diodes are placed on 1 inch centers and a row and column scanning is performed to compute beam location. In lieu of fabrication tolerances, an 8 bit A/D

converter, and static measurement data, it is believed the resolution of the LaMOD system is 0.3 inches over the detector area.

The LaMOD was designed to achieve at least a 50 Hz update rate of the V_x and V_y voltages. This results in a Nyquist frequency bandwidth of 25 Hz. Although limited dynamic calibrations have been performed on the LaMOD, it is believed a bandwidth of at least 25 Hz is present in the system.

The angular resolution of LaMOD application on the CEM is dependent on the distance from the reflector to the detector. The detector is mounted vertically above the reflector at a distance of 708 inches relative to the inertial coordinate system located at the center of the main truss.. This results in a pointing resolution of

$$\delta\phi = \tan^{-1} \left(\frac{0.3}{708} \right) = 425 \mu \text{ radians}$$

Later versions of the CEM include improving the resolution of the LOS pointing detection system to 15 μ radians (~ 3 arcsec).

Control Trailer and Computers

The last subsystem of the CEM testbed involves the computer based control and data acquisition systems. Currently, all signals to and from the sensors and actuators are analog. The signal conditioning, data acquisition, and control are performed in a control room located next to the testbed. The following paragraphs describe the signal flow paths, data acquisition equipment, and control hardware.

Signal Flow Path -- The signal flow schematic is shown in Fig. 18. Most sensor signals pass through a junction located outside the control room. This junction provides access to and from the control room. Space has been provided, in the junction box, for expanding existing sensors and the addition of different types of sensors. From the junction box the signals are routed to their respective signal conditioner and passed on to a patch panel. The patch panel allows the sensor signals to be routed to data acquisition systems, control systems, recorders, and/or trouble-shooting equipment.

Actuator commands take a slightly different path. The commands are generated in either the signal generator, data acquisition system, or control system. The command signals are routed

through a safety system before being sent to the testbed. The safety system provides manual as well as automatic (limit checking) shut down capability. From the safety system the thruster command signals are passed directly to the thruster signal conditioners located on the CEM. For configuration convince, the shaker command signals are routed through the junction box.

Data Acquisition -- There are two primary data acquisition systems located in the control room. These systems are schematically shown in Fig. 19. The Zonic System 7000 is a commercial general purpose data acquisition/signal processing system primarily used for system identification. This system provides 48 channels of simultaneous data acquisition and two channels of excitation. The system can take either time domain or frequency domain data. The time domain data can be throughput to a 350 Mbyte throughput disk. Throughput rates depend on the number of channels acquired, the ensemble blocksize and the type of background calculations being performed in the signal processor. The maximum nominal throughput rate is 1.25 KHz for 48 channels using a maximum blocksize of 2048. Both frequency and time domain data can be saved in ASCII or SDRC's ADF formats to transfer to other applications.

The CAMAC (Computer Automated Measurement and Control) based system is primarily used for closed-loop control data acquisition. The system provides the analog-to-digital/digital-to-analog interface to several computing platforms which are discussed in the following section. The CAMAC system is composed of modules which are mounted in a 'crate'. These modules interface an external process to an internal bus called a dataway. Modules are available to provide analog input and output, communication interfaces, and computer interfaces. Currently, up to 36 analog inputs and 30 analog outputs can be supported. The real-time rates are computer dependent which are discussed in the following section.

Control Systems and Software -- Two systems are available for performing real-time control. One is based on a Digital Equipment Corp. VAX computer; the other is based on Control Data Corp. CYBER 175 computer. Both computers interface to the sensors/actuators through the CAMAC system described above.

The CYBER 175 computer is located in Building 1268A at LaRC. The system is part of the ARTS (Advanced Real-Time Simulation) system at LaRC [5,6]. This computer communicates with the CAMAC crate via a fiber-optic ring-network. The data link provides a 50 Mbit/second transfer rate between the CAMAC and the computer. The minimum real-time frame rate achievable on the system is 5 msec/frame (200 Hz), with 1.4 msec of this time available for control law

computations. Figure 20 shows the operations that occur during each frame and the compute time available for other frame rates.

The VAX is the primary control computer and is located in the control room. The computer, a VAXstation 3200, communicates with the CAMAC crate via a parallel interface. The system generally operates using a VMS operating system; however, for time critical problems, the system can be configured using a real-time operating system called VAXELN. Figure 21 presents the speed of this system in terms of controller size. The controller is a linear time-invariant controller using 8 inputs and 8 outputs. Data from 8 inputs and 11 outputs can be acquired for 100 seconds at a sampling rate of 200 Hz. using the VAX system.

The software for performing control is similar for both systems. Both system's software is written in FORTRAN, and based around generic control law (GCL) subroutines. The GCL subroutines were developed to support the Control-Structure Interaction program at Langley and are partially documented in [6]. These routines perform linear time-invariant control computations of the form

$$\begin{aligned}\dot{x} &= A x + B y, \\ u &= C x + D y\end{aligned}$$

where x is the controller state, y is the measured input signal to the controller and u is the control force. For digital implementation, the above equations are discretized as

$$\begin{aligned}x(k+1) &= \Phi x(k) + \Gamma y(k), \\ u(k) &= C x(k) + D y(k)\end{aligned}$$

where Φ and Γ are given by

$$\begin{aligned}\Phi &= e^{Ah} \\ \Gamma &= \int_0^h e^{As} B \, ds\end{aligned}$$

A source code listing for the VAX 3200 is given in Appendix 1.

The VAX 3200 implementation has been modified to allow use of higher computational frame rates by using the MATLAB M-file in Appendix 2 to perform an eigenvector transformation on the controller system matrices. This transformation results in a tri-diagonal A matrix. The real-time code takes advantage of a tri-diagonal A matrix to reduce computational delay in updating the controller state equation. A further check for non-zero D matrix is performed to allow a speed increase in the calculation of the controller output equation. Figure 21 shows the

size of an 8 input and 8 output controller that can be implemented in this fashion given a desired sample rate in Hz.

A sample controller data file is shown in Appendix 3 . The first 17 lines in the initialization file are used to set various test parameters. These include test time, sample rate, excitation and control times, excitation options, controller size data, scale factors, and options or digital filtering of actuator commands and sensor input, and an option to calculate sensor root-mean-square (RMS) values.

Excitation command options include sinusoids, random noise, pulses, and user defined excitation. The controller data file variable Xmode selects the type of excitation to be used. For Xmode = 1, the next two lines select the sine frequency (in Hz) and amplitude (in volts) of the each thruster pair. If Xmode = 2, the next line determines the number of iterations for each actuator that the random sequence is held constant. If Xmode = 3, the next line determines the length of the pulse to the actuator by the number of iterations (ie, 10 iterations at .5 sec sample rate means a pulse length of 5 sec). If Xmode = 4, the user will be prompted for the name of a data file that contains the thruster commands.

A general digital filtering capability is provided for excitation commands, control commands, and sensor outputs. When one of these options are selected, the user is prompted for a file name that contains the numerator and denominator coefficients of the filter (maximum order = 8).

After program initialization, the test begins by taking 1000 samples of the sensor data and calculating the sensor bias. When bias taking is complete, the test is run using the data file parameters. If thruster commands or sensor outputs exceed a limit, the test is stopped and a message is displayed to tell the operator whether it was a sensor or actuator trip. The operator may terminate a test at any time by typing CTRL-C at the keyboard. At completion of a test, the operator is prompted for a file name to which the actuator command and un-biased sensor data is written. The data file is saved as a MATLAB binary file to simplify data reduction.

Analytical and Experimental Model Characterization

Models of the CEM have been developed for simulation, controller design and dynamic analyses. The NASTRAN finite element program has been used to analyze the static and dynamic behavior of

the CEM. State space models for the actuator dynamics and sensor filters have been constructed using empirical techniques. These models are discussed in the following paragraphs.

Finite Element Structure Model and Test Correlation

The finite element model used to analyze the CEM has been refined based on test data. Although the model does not predict the CEM dynamics exactly, it is felt this is a reasonable model to use for control synthesis and simulation. The modes below 5 Hz are predicted quite well, whereas the modes above 5 Hz have varying levels of discrepancy between the test and analysis data. The FEM will be presented first followed by Bode diagrams of the analysis and test data for the 64 transfer functions which represent the eight thruster inputs and the eight collocated accelerometers.

The FEM, shown in Fig. 22, has 640 grid points with 3840 degrees of freedom. There are 1627 bar, 22 rod, 116 triangular plate, 3 quadrilateral plate and 38 spring elements in the model. Concentrated masses are modeled using CONM2 elements. Table 7 is a summary of grid points on the CEM with a descriptive indication of the location. Fig. 23 shows the location of some grid points on the CEM. The type of element, element identification number, of elements, property identification and location of the elements is described in Table 8. Table 9 gives the physical and material properties based on the property identification numbers. (The subscript "EFF" refers to the effective property used in the finite element modeling approach. Table 10 lists the mass properties of the CEM used in the FEM. The measured and predicted weight of the CEM differs by less than 2 percent.

The above data has been used to construct NASTRAN data decks for analysis. Appendix 4 gives the NASTRAN input for the static analysis including differential stiffness [7] due to the gravity preload in the CEM. This input deck runs under version 65 of MSC NASTRAN. A second runstream, given in Appendix 5, is used to compute the vibrational modes and frequencies of the CEM using the mass and stiffness matrices from the database created from executing the deck in Appendix 4. Note this data base includes the suspension cable effects.

The FEM frequencies for the CEM and associated mode shapes are given in Figs. 24-109 for all modes below 50 Hz. Table 11 also gives a list of predicted frequencies and some corresponding test data. It is noted that to construct a state space model of the CEM using modal coordinates, the mode shape coefficients at the actuator and sensor locations are required. For the eight collocated thrusters and accelerometers (located at nodes 492, 489, 501, 498, 503, 502,

494, 493), the mode shape coefficients are given in Table 12 for a subset consisting of 40 modes below 50 Hz. These data have been used to construct linear state space models for control design. For example, a nine mode state space model of the structure is given in Appendix 6 based on 8 force inputs at the thruster locations and 8 collocated acceleration outputs. Note the damping for this model was based on test data.

Damping in the CEM has been found to be nonlinear with amplitude. This is not surprising since rubber hoses are used to transmit compressed air to the thrusters. At nominal excitation levels the damping values used in the simulation model are given in Table 11. With the FEM frequencies and mode shapes and the test damping values, test and analysis Bode plots of the frequency response from 0 to 10 Hz is shown in Figs. 110-173. The test data were obtained using random excitation from 0 to 10 Hz, averaging 50 responses with a frequency resolution of 0.024 Hz. It has been found that increased frequency resolution result in somewhat higher peaks at the resonant frequencies. The analytical Bode plots also include the thruster dynamics which are described in the following section.

Thruster Dynamics Model

The thrusters were bench tested using the apparatus shown in Fig. 174. Four strain gaged load cells measure the output force as the input voltage to each thruster was swept from 0 to 50 Hz. Typical frequency response functions for the thrusters are shown in Fig. 175. The analysis model, also shown in Fig. 175, is a first order differential equation representation of the thruster dynamics. The model, which agrees well with the measured amplitude and phase of the thruster has the form

$$f(s) = \frac{\alpha}{s + \beta} v(s)$$

where f is the thruster force in lbs., v is the input voltage in volts, s is the Laplace variable, α is the gain, and β is the pole. Table 13 lists the constants for each thruster.

At the CEM LOS pointing control bandwidth, 10 Hz, the thrusters produce about 3 dB of amplitude attenuation and 12 degrees of phase lag. For many applications, the thruster dynamics can be ignored in the controller design. This has permitted the study of some novel dissipative controllers using only acceleration feedback [8].

Sensor Filter Dynamics Models

For controls experiments, the data are processed through A/D hardware in a CAMAC crate. This crate provides the ability to analog filter using third order Bessel filters. The available cutoff frequencies are 10, 20, 50, and 100 Hz. The transfer function models for these filters are:

$$10 \text{ Hz.} \quad V_o(s) = \frac{8.5265e-14(s^2 + 256.00s + 8.2683e18)}{(s+83.284)(s^2 + 132.45s + 8483.4)} V_i(s)$$

$$20 \text{ Hz.} \quad V_o(s) = \frac{4.5475e-13(s^2 + 416.00s + 2.4275e19)}{(s+208.23)(s^2 + 331.11s + 53012)} V_i(s)$$

$$50 \text{ Hz.} \quad V_o(s) = \frac{-2.2737e-13(s^2 + 2048.0s - 3.8842e20)}{(s+416.46)(s^2 + 662.24s + 212060)} V_i(s)$$

$$100 \text{ Hz.} \quad V_o(s) = \frac{-2.7285e-12(s^2 + 938.67s - 2.5895e20)}{(s+832.84)(s^2 + 1324.5s + 848340)} V_i(s)$$

where V_o and V_i are the output and input voltages, respectively. Bode plots for each of these filters are shown in Fig. 176.

LOS Pointing Algorithm

The LOS pointing accuracy of the CEM testbed is predicted using the simulation models above to compute the translations and rotations of the laser location and the reflector center. Once these translations and rotations are known, coordinate transformations [9] are used to determine the x and y coordinates of the LOS pointing deviations from nominal pointing. A MATLAB .m file is included in Appendix 7 to permit the calculation of LOS pointing error. The calculation assumes modal coordinate time histories have been computed previously. Appendix 8 also contains a table of translational and rotation modal coefficients of the laser and reflector, respectively. For linearized LOS analysis, the linear transformation from modal coordinate to x and y LOS

pointing coordinates (i.e. the C matrix for LOS output) is given in Appendix 9. Figures 177-192 show the LOS BODE magnitude plots and experimental data using the linearized LOS model.

Active Control Example

To demonstrate the CEM testbed and to indicate the fidelity of the models, closed-loop control of the CEM is presented in this section. The disturbance and open-loop response is described first, followed by controller data and closed-loop response. Subsequently, simulated LOS pointing for the closed loop is correlated with test data.

Open-Loop Excitation

Four pairs of thrusters are used for excitation. Thruster 3 is sinusoidally commanded at 1.9 Hz with an amplitude of 5 volts peak, thruster 4 at 1.7 Hz with 2.25 volts peak and thrusters 6 and 7 are each commanded at 0.145 Hz at 5 volts and 1.25 volts, respectively. Data was acquired at 250 Hz.

Figure 193 shows the open-loop response. The measured accelerations are larger than those predicted by the simulation. It is believed non-linear damping is present in the system which may account for amplitude differences between measured and predicted accelerations. The figure also shows the same excitation voltage is applied in the test and analysis.

Closed-Loop Control

An LQG controller was designed for the first nine modes to improve LOS pointing of the CEM. Because the LQG controller tended to destabilize modes in the 6 to 8 Hz frequency range, a low authority non-model based controller was designed to add damping in the 6 to 8 Hz modes. The two controllers were then combined to form the controller given in Appendix 3. Note that Appendix 3 shows the format of input data to excite and control the CEM testbed. The A, B, C and D controller matrices are stored column by column after some initial script file data.

Figures 194 and 195 shows the closed-loop response and control commands, respectively, after disturbing the testbed as described previously. Closed-loop control is initiated at $t=10$ seconds. The simulated accelerations correlate well in frequency, however the rate of decay is somewhat different. Moreover, the thruster commands while qualitatively similar, differ in amplitude

and sometimes phase. These results are representative indications of the predictive accuracy of the models described herein.

LOS Pointing Scoring

To assess the performance of the above controller, the experimental LOS pointing response is shown in terms of time histories in Fig. 196. Figure 197 shows the simulation time histories computed using the LOS model of Appendix 7. The amplitudes are larger in the experiment than those predicted by simulation. Figure 198 shows the LOS pointing during the excitation and control portions of the experiment as projected from the laser and reflected on the LaMOD detector. Experimental LOS error is somewhat larger than predicted.

Figure 199 shows the simulated and measured LOS pointing and average control power. Although the data are qualitatively similar, there is need for further model refinement to more accurately predict the LOS pointing magnitude.

Nonlinearities

The lack of agreement between the experimental and analytical amplitudes of vibration is attributed to linear model error and partially to damping nonlinearities exhibited by the CEM testbed. In particular, the damping appears to increase with vibration amplitude, perhaps due to the rubber air hoses attached to the thrusters. Figures 200-207 show the driving point frequency response functions from 0 to 2 Hz, at the thruster locations, as the amplitude of the random disturbance is decreased. As can be seen, the response peaks generally increase with decreasing amplitude which indicates the presence of nonlinearities.

Summary

The CEM testbed is designed to develop and verify software and hardware implementations of CSI systems. The phase 0 version of the testbed has been documented in this report to enable investigators to model and develop new technology for realistic CSI systems. Preliminary test data show the CEM testbed is amenable to active control of both flexible and "rigid" body dynamics.

This document has described the testbed, the models developed for control design and for simulation of dynamic behavior, and some preliminary test data. Correlation between test and analysis models is reasonable, however, there remains room for improvement particularly at frequencies above 5 Hz.

Future evolution of the CEM testbed will involve, integrated structure and controller design, active truss struts for actuation and two-axis gimbals for simulation of arc-sec. pointing systems required for advanced science missions. The CEM should be operational in one of its evolved states for the next several years.

References

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9. Lim, K. B. and Horta, L. G., "A Line-Of-Sight Performance Criterion For Controller Design Of A Proposed Laboratory Model," Presented at the AIAA Dynamics Specialist Conference, AIAA paper no. 90-1226, Long Beach, CA, April, 1990.

Table 1. Strut mass and stiffness properties

Size (stiffness) properties				
Member	length	od/id	tube area	effective area
Longeron	10"	0.625/0.509	0.10331	0.12316
Batten	10"	0.625/0.509	0.10331	0.12316
Diagonal	14.142"	0.625/0.509	0.10331	0.11660

Strut Modulus of Elasticity = 10.e+06 psi

Weight properties			
Member	Endfitting (each)	Tube Effective Density	Total Weight w/o ball
Longeron	0.07 lbs	0.845 lb/in ³	0.24407 lbs
Batten	0.07 lbs	0.845 lb/in ³	0.24407 lbs
Diagonal	0.07 lbs	0.860 lb/in ³	0.28181 lbs

Ball Weight = 0.1962 lbs

Table 2. Actuator and sensor locations

Thrusters					
No.	X	Y	Z	Direction	Grid No.
1	5.000	5.000	0.000	Y	492
2	5.000	0.000	5.000	Z	489
3	325.000	5.000	0.000	Y	501
4	325.000	0.000	5.000	Z	498
5	620.000	0.000	40.000	X	503
6	615.000	5.000	40.000	Y	502
7	160.000	0.000	100.000	X	494
8	155.000	5.000	100.000	Y	493

Servo Accelerometers					
No.	X	Y	Z	Direction	Grid No.
1	5.000	0.000	5.000	Z	489
2	0.000	-5.000	5.000	X	2
3	5.000	5.000	0.000	Y	492
4	160.000	-5.000	5.000	Y	66
5	160.000	-5.000	5.000	Z	66
6	160.000	-5.000	5.000	X	66
7	160.000	0.000	100.000	X	494
8	160.000	-5.000	105.000	Z	307
9	155.000	5.000	100.000	Y	493
10	325.000	5.000	0.000	Y	501
11	320.000	-5.000	5.000	X	130
12	325.000	0.000	5.000	Z	498
13	620.000	-5.000	5.000	Z	250
14	620.000	-5.000	5.000	Y	250
15	620.000	-5.000	5.000	X	250
16	615.000	5.000	40.000	Y	502
17	620.000	-5.000	35.000	Z	263
18	620.000	0.000	40.000	X	503

Table 2. Actuator and sensor locations (Continued)
PCB Structcel Accelerometers

No.	X	Y	Z	Direction	Grid No.
1	0.000	5.000	-5.000	X	4
2	0.000	5.000	-5.000	Y	4
3	0.000	5.000	-5.000	Z	4
4	0.000	-5.000	-5.000	X	3
5	0.000	-5.000	-5.000	Y	3
6	0.000	-5.000	-5.000	Z	3
7	60.000	5.000	-5.000	X	28
8	60.000	5.000	-5.000	Y	28
9	60.000	5.000	-5.000	Z	28
10	60.000	-5.000	-5.000	X	27
11	60.000	-5.000	-5.000	Y	27
12	60.000	-5.000	-5.000	Z	27
13	120.000	5.000	-5.000	X	52
14	120.000	5.000	-5.000	Y	52
15	120.000	5.000	-5.000	Z	52
16	120.000	-5.000	-5.000	X	51
17	120.000	-5.000	-5.000	Y	51
18	120.000	-5.000	-5.000	Z	51
19	120.000	55.000	-5.000	X	348
20	120.000	55.000	-5.000	Y	348
21	120.000	55.000	-5.000	Z	348
22	120.000	-55.000	-5.000	X	352
23	120.000	-55.000	-5.000	Y	352
24	120.000	-55.000	-5.000	Z	352
25	120.000	105.000	-5.000	X	388
26	120.000	105.000	-5.000	Y	388
27	120.000	105.000	-5.000	Z	388
28	120.000	-105.000	-5.000	X	392
29	120.000	-105.000	-5.000	Y	392
30	120.000	-105.000	-5.000	Z	392
31	160.000	5.000	-5.000	X	68
32	160.000	5.000	-5.000	Y	68
33	160.000	5.000	-5.000	Z	68
34	160.000	-5.000	-5.000	X	67
35	160.000	-5.000	-5.000	Y	67
36	160.000	-5.000	-5.000	Z	67
37	160.000	5.000	55.000	X	288
38	160.000	5.000	55.000	Y	288
39	160.000	5.000	55.000	Z	288
40	160.000	-5.000	55.000	X	287
41	160.000	-5.000	55.000	Y	287
42	160.000	-5.000	55.000	Z	287
43	160.000	5.000	105.000	X	308
44	160.000	5.000	105.000	Y	308
45	160.000	5.000	105.000	Z	308
46	160.000	-5.000	105.000	X	307
47	160.000	-5.000	105.000	Y	307
48	160.000	-5.000	105.000	Z	307
49	220.000	5.000	-5.000	X	92
50	220.000	5.000	-5.000	Y	92

Table 2. Actuator and sensor locations (Continued)

No.	X	Y	Z	Direction	Grid No.
51	220.000	5.000	-5.000	Z	92
52	220.000	-5.000	-5.000	X	91
53	220.000	-5.000	-5.000	Y	91
54	220.000	-5.000	-5.000	Z	91
55	270.000	5.000	-5.000	X	112
56	270.000	5.000	-5.000	Y	112
57	270.000	5.000	-5.000	Z	112
58	270.000	-5.000	-5.000	X	111
59	270.000	-5.000	-5.000	Y	111
60	270.000	-5.000	-5.000	Z	111
61	320.000	5.000	-5.000	X	132
62	320.000	5.000	-5.000	Y	132
63	320.000	5.000	-5.000	Z	132
64	320.000	-5.000	-5.000	X	131
65	320.000	-5.000	-5.000	Y	131
66	320.000	-5.000	-5.000	Z	131
67	380.000	5.000	-5.000	X	156
68	380.000	5.000	-5.000	Y	156
69	380.000	5.000	-5.000	Z	156
70	380.000	-5.000	-5.000	X	155
71	380.000	-5.000	-5.000	Y	155
72	380.000	-5.000	-5.000	Z	155
73	440.000	5.000	-5.000	X	180
74	440.000	5.000	-5.000	Y	180
75	440.000	5.000	-5.000	Z	180
76	440.000	-5.000	-5.000	X	179
77	440.000	-5.000	-5.000	Y	179
78	440.000	-5.000	-5.000	Z	179
79	500.000	5.000	-5.000	X	204
80	500.000	5.000	-5.000	Y	204
81	500.000	5.000	-5.000	Z	204
82	500.000	-5.000	-5.000	X	203
83	500.000	-5.000	-5.000	Y	203
84	500.000	-5.000	-5.000	Z	203
85	560.000	5.000	-5.000	X	228
86	560.000	5.000	-5.000	Y	228
87	560.000	5.000	-5.000	Z	228
88	560.000	-5.000	-5.000	X	227
89	560.000	-5.000	-5.000	Y	227
90	560.000	-5.000	-5.000	Z	227
91	560.000	55.000	-5.000	X	431
92	560.000	55.000	-5.000	Y	431
93	560.000	55.000	-5.000	Z	431
94	560.000	-55.000	-5.000	X	435
95	560.000	-55.000	-5.000	Y	435
96	560.000	-55.000	-5.000	Z	435
97	560.000	105.000	-5.000	X	471
98	560.000	105.000	-5.000	Y	471
99	560.000	105.000	-5.000	Z	471
100	560.000	-105.000	-5.000	X	475

Table 2. Actuator and sensor locations (Continued)

No.	X	Y	Z	Direction	Grid No.
101	560.000	-105.000	-5.000	Y	475
102	560.000	-105.000	-5.000	Z	475
103	620.000	5.000	-5.000	X	252
104	620.000	5.000	-5.000	Y	252
105	620.000	5.000	-5.000	Z	252
106	620.000	-5.000	-5.000	X	251
107	620.000	-5.000	-5.000	Y	251
108	620.000	-5.000	-5.000	Z	251
109	125.000	0.000	178.750	X	396
110	125.000	0.000	178.750	Y	396
111	125.000	0.000	178.750	Z	396
112	555.000	0.000	178.750	X	480
113	555.000	0.000	178.750	Y	480
114	555.000	0.000	178.750	Z	480
115	620.000	5.000	35.000	X	264
116	620.000	5.000	35.000	Y	264
117	620.000	5.000	35.000	Z	264
118	620.000	-5.000	35.000	X	263
119	620.000	-5.000	35.000	Y	263
120	620.000	-5.000	35.000	Z	263
121	536.025	35.458	17.605	X	2040
122	536.025	35.458	17.605	Y	2040
123	536.025	35.458	17.605	Z	2040
124	557.893	26.884	23.497	X	2042
125	557.893	26.884	23.497	Y	2042
126	557.893	26.884	23.497	Z	2042
127	588.167	13.681	36.762	X	2045
128	588.167	13.681	36.762	Y	2045
129	588.167	13.681	36.762	Z	2045
130	536.025	-35.458	17.605	X	2053
131	536.025	-35.458	17.605	Y	2053
132	536.025	-35.458	17.605	Z	2053
133	557.893	-26.884	23.497	X	2055
134	557.893	-26.884	23.497	Y	2055
135	557.893	-26.884	23.497	Z	2055
136	588.167	-13.681	36.762	X	2058
137	588.167	-13.681	36.762	Y	2058
138	588.167	-13.681	36.762	Z	2058
139	574.988	-85.603	49.170	X	2066
140	574.988	-85.603	49.170	Y	2066
141	574.988	-85.603	49.170	Z	2066
142	587.434	-64.903	47.429	X	2068
143	587.434	-64.903	47.429	Y	2068
144	587.434	-64.903	47.429	Z	2068
145	603.201	-33.029	48.941	X	2071
146	603.201	-33.029	48.941	Y	2071
147	603.201	-33.029	48.941	Z	2071
148	630.091	-85.603	93.811	X	2079
149	630.091	-85.603	93.811	Y	2079
150	630.091	-85.603	93.811	Z	2079

Table 2. Actuator and sensor locations (Continued)

No.	X	Y	Z	Direction	Grid No.
151	629.212	-64.903	81.274	X	2081
152	629.212	-64.903	81.274	Y	2081
153	629.212	-64.903	81.274	Z	2081
154	624.461	-33.029	66.165	X	2084
155	624.461	-33.029	66.165	Y	2084
156	624.461	-33.029	66.165	Z	2084
157	669.055	-35.458	125.376	X	2092
158	669.055	-35.458	125.376	Y	2092
159	669.055	-35.458	125.376	Z	2092
160	658.753	-26.884	105.207	X	2094
161	658.753	-26.884	105.207	Y	2094
162	658.753	-26.884	105.207	Z	2094
163	639.495	-13.681	78.344	X	2097
164	639.495	-13.681	78.344	Y	2097
165	639.495	-13.681	78.344	Z	2097
166	669.055	35.458	125.376	X	2001
167	669.055	35.458	125.376	Y	2001
168	669.055	35.458	125.376	Z	2001
169	658.753	26.884	105.207	X	2003
170	658.753	26.884	105.207	Y	2003
171	658.753	26.884	105.207	Z	2003
172	639.495	13.681	78.344	X	2006
173	639.495	13.681	78.344	Y	2006
174	639.495	13.681	78.344	Z	2006
175	630.091	85.603	93.811	X	2014
176	630.091	85.603	93.811	Y	2014
177	630.091	85.603	93.811	Z	2014
178	629.212	64.903	81.274	X	2016
179	629.212	64.903	81.274	Y	2016
180	629.212	64.903	81.274	Z	2016
181	624.461	33.029	66.165	X	2019
182	624.461	33.029	66.165	Y	2019
183	624.461	33.029	66.165	Z	2019
184	574.988	85.603	49.170	X	2027
185	574.988	85.603	49.170	Y	2027
186	574.988	85.603	49.170	Z	2027
187	587.434	64.903	47.429	X	2029
188	587.434	64.903	47.429	Y	2029
189	587.434	64.903	47.429	Z	2029
190	603.201	33.029	48.941	X	2032
191	603.201	33.029	48.941	Y	2032
192	603.201	33.029	48.941	Z	2032
193	613.466	0.000	58.004	X	2106
194	613.466	0.000	58.004	Y	2106
195	613.466	0.000	58.004	Z	2106

Table 2. Actuator and sensor locations (Continued)

Angular Rate Sensors

No.	X	Y	Z	Direction	Grid No.
1	140.000	-5.000	-5.000	Y	59
2	140.000	-5.000	5.000	Z	58
3	140.000	-5.000	-5.000	X	59
4	540.000	-5.000	5.000	Z	218
5	540.000	-5.000	-5.000	X	219
6	540.000	-5.000	-5.000	Y	219
7	610.000	-5.000	35.000	X	262
8	610.000	5.000	35.000	Y	261

Strain Gauges

No.	X	Y	Z	Direction	Element No.
1	120.000	10.000	5.000	Y	1007
2	120.000	10.000	-5.000	Y	1010
3	130.000	10.000	5.000	Y	1008
4	130.000	10.000	-5.000	Y	1009
5	325.000	-5.000	-5.000	X	131
6	325.000	5.000	-5.000	X	132
7	325.000	-5.000	5.000	X	130
8	325.000	5.000	5.000	X	129
9	550.000	10.000	5.000	Y	1267
10	550.000	10.000	-5.000	Y	1270
11	560.000	10.000	5.000	Y	1268
12	560.000	10.000	-5.000	Y	1269

Center of Laser Detector

No.	X	Y	Z
1	615.000	0.000	708.000

Table 3 Nominal Servo Accelerometer Characteristics

Model	QA-900
Linear Range	+/- 30 g
Sensitivity	5 V/g
Threshold	< 5 μ g
Frequency Response	+/- 0.1% 0-10 Hz +/- 5% 10-300 Hz
Resonant Frequency	> 500 Hz
Damping Ratio	0.3-0.8
Axis Alignment	+/- 2.0 mrad

Table 4 Nominal StructCell Accelerometer Characteristics

Model	330A
Range	+/- 10 g
Sensitivity	1 V/g
Resolution	0.001 g
Frequency Response	+/- 5% 1-1000 Hz <5 Deg Phase Shift 1-500 Hz
Resonant Frequency	3000 Hz
Transverse Sensitivity	< 2%

Table 5 Nominal Rate Sensor Characteristics

Model	ARS-C121-1AX	ARS-C131-1AX
Sensitivity	+/- 3 Deg/s/V	+/- 10 Deg/s/V
Frequency Response	+/- 5% 0-20 Hz +/- 5 Deg 0-10 Hz	+/- 5% 0-20 Hz +/- 5 Deg 0-10 Hz

Table 6 Nominal Shaker Characteristics

Frequency Range	0- 200 Hz
Force Rating	14 lb 0-0.1 Hz 20 lb 0.1-20 Hz
Maximum Stroke	6.25 in p-p
Armature Weight	1.0 lb

Table 7. Summary of FEM grid numbers

Truss Coordinate Information						
Grids	No.	Location	X	Y	Z	
1 252	252	main truss	0,620	+5,-5	+5,-5	
253 268	16	reflector truss	610,620	+5,-5	15,45	
269 312	44	tower truss	150,160	+5,-5	15,115	
313 394	82	forward suspension truss	120,130	+105,-105	+5,-5	
395 396	2	front cable	125	0	803.5,178	
397 478	82	back suspension truss	550,560	+105,-105	+5,-5	
479 480	2	back cable	555	0	803.5,178	
481 482	2	cable spring ends	125,555	0	777	
485 488	4	reflector support bracket	610,620	+5,-5	52.1,60.2	
489 492	4	forward thruster	5	-5,5	-5,5	
493 496	4	tower thruster	150,160	-5,5	100	
497 497	1	laser	155	0	115	
498 501	4	middle thruster	325	-5,5	0	
502 505	4	reflector truss thruster	610,620	-5,5	40	
1001 1008	8	plot scaling grids	-80,700	-390,390	0,780	

Reflector,Cylindrical Coord.

Grids	No.	Location	R, in.	Theta, dgr.	Z, in.
2001 2013	13	rib 1	92.6, 4.6	22.5	19.8,0
2014 2026	13	rib 2	92.6, 4.6	67.5	19.8,0
2027 2039	13	rib 3	92.6, 4.6	112.5	19.8,0
2040 2052	13	rib 4	92.6, 4.6	157.5	19.8,0
2053 2065	13	rib 5	92.6, 4.6	202.5	19.8,0
2066 2078	13	rib 6	92.6, 4.6	247.5	19.8,0
2079 2091	13	rib 7	92.6, 4.6	292.5	19.8,0
2092 2104	13	rib 8	92.6, 4.6	337.5	19.8,0
2106 2106	1	plate center	0, 0	0	2.4375
2107 2114	8	base plate	7.4, 8.1	0,322.1	0
2115 2122	8	sensor plate	7.4, 8.1	0,322.1	2.4375
2123 2130	8	added grid to each rib	64.2	22.5, 337.5	8.569

truss grids = 511
reflector grids = 129
total grids = 640

Table 8. Summary of FEM element numbers

Truss Element Information				
Element	EID's	No.	PID	Location
CBAR	1 248	248	1	main truss, longerons
CBAR	249 500	252	2	main truss, battens
CBAR	501 563	63	3	main truss, batten diagonals
CBAR	564 687	124	3	main truss, top,bottom diagonals
CBAR	688 811	124	13	main truss side diagonals
CBAR	812 855	44	12	tower truss, longerons
CBAR	856 899	44	2	tower truss, battens
CBAR	900 910	11	3	tower truss, batten diagonals
CBAR	911 932	22	13	tower truss, front,back diagonals
CBAR	933 954	22	3	tower truss, side diagonals
CBAR	955 970	16	12	rfl truss, longerons
CBAR	971 986	16	2	rfl truss, battens
CBAR	987 990	4	3	rfl truss, batten diagonals
CBAR	991 998	8	13	rfl truss, side diagonals
CBAR	999 1006	8	3	rfl truss, front,back diagonals
CBAR	1007 1046	40	2	front suspension truss, longeron, +Y
CBAR	1047 1086	40	2	front suspension truss, longeron, -Y
CBAR	1087 1126	40	1	front suspension truss, battens, +Y
CBAR	1127 1166	40	1	front suspension truss, battens, -Y
CBAR	1167 1176	10	3	front suspension truss, batten diag, +Y
CBAR	1177 1186	10	3	front suspension truss, batten diag, -Y
CBAR	1187 1206	20	3	front suspension truss, frt,bck diag, +Y
CBAR	1207 1226	20	3	front suspension truss, frt,bck diag, -Y
CBAR	1227 1246	20	3	front suspension truss, top,btm diag, +Y
CBAR	1247 1266	20	3	front suspension truss, top,btm diag, -Y
CBAR	1267 1306	40	2	back suspension truss, longeron, +Y
CBAR	1307 1346	40	2	back suspension truss, longeron, -Y
CBAR	1347 1386	40	1	back suspension truss, battens, +Y
CBAR	1387 1426	40	1	back suspension truss, battens, -Y
CBAR	1437 1446	10	3	back suspension truss, batten diag, -Y
CBAR	1447 1466	20	3	back suspension truss, frt,bck diag, +Y
CBAR	1467 1486	20	3	back suspension truss, frt,bck diag, -Y
CBAR	1487 1506	20	3	back suspension truss, top,btm diag, +Y
CBAR	1507 1526	20	3	back suspension truss, top,btm diag, -Y

Table 8. Summary of FEM element numbers (Continued)

Suspension and Thruster Elements				
Element	EID's	No.	PID	Location
CRCD	1527 1529	3	14	front suspension cable
CRCD	1530 1532	3	14	back suspension cable
CELAS2	2201 2202	2		cable springs at top
CBAR	1535 1536	2	11	front suspension cable brace, +Y
CBAR	1537 1538	2	11	front suspension cable brace, -Y
CBAR	1539 1540	2	11	back suspension cable brace, +Y
CBAR	1541 1542	2	11	back suspension cable brace, -Y
CQUAD4	1600 1600	1	40	small reflector plate
CTRIA3	1601 1616	16	15	front thruster
CELAS2	2241 2243	3		springs for front thruster air tubing
CTRIA3	1621 1636	16	15	tower thruster
CELAS2	2250 2252	3		springs for tower thruster air tubing
CTRIA3	1641 1656	16	15	mid thruster
CELAS2	2244 2246	3		springs for middle thruster air tubing
CTRIA3	1661 1676	16	15	rfl truss thruster
CELAS2	2247 2249	3		springs for rfl thruster air tubing
CTRIA3	1681 1684	4	15	laser plate
CQUAD4	1691 1692	2	15	controller board plates

Elements Removed From Truss

Element	EID's	No.	PID	Location
CBAR	526 526	-1	3	batten diagonal in way of controller plate
CBAR	542 542	-1	3	batten diagonal in way of controller plate
CBAR	564 564	-1	3	top,bottom diagonals in way of thruster plate
CBAR	565 565	-1	3	top,bottom diagonals in way of thruster plate
CBAR	628 628	-1	3	top,bottom diagonals in way of thruster plate
CBAR	629 629	-1	3	top,bottom diagonals in way of thruster plate
CBAR	688 688	-1	13	side diagonal in way of thruster plate
CBAR	689 689	-1	13	side diagonal in way of thruster plate
CBAR	752 752	-1	13	side diagonal in way of thruster plate
CBAR	753 753	-1	13	side diagonal in way of thruster plate
CBAR	910 910	-1	3	tower batten diagonal in way of laser plate
CBAR	929 929	-1	13	tower front,back diagonal in way of thruster plate
CBAR	930 930	-1	13	tower front,back diagonal in way of thruster plate
CBAR	951 951	-1	3	tower side diagonal in way of thruster plate
CBAR	952 952	-1	3	tower side diagonal in way of thruster plate
CBAR	997 997	-1	13	rfl truss, side diagonal in way of thruster
CBAR	998 998	-1	13	rfl truss, side diagonal in way of thruster
CBAR	1005 1005	-1	3	rfl truss, front,back diagonals in way of thruster
CBAR	1006 1006	-1	3	rfl truss, front,back diagonals in way of thruster

Table 8. Summary of FEM element numbers (Continued)





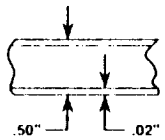
Reflector Elements				
Element	EID's	No.	PID	Location
CBAR	2001 2008	8	16	reflector rib tip
CBAR	2009 2016	8	17	reflector rib
CBAR	2017 2024	8	18	reflector rib
CBAR	2025 2032	8	19	reflector rib
CBAR	2033 2040	8	20	reflector rib
CBAR	2041 2072	32	21	reflector rib
CBAR	2073 2088	16	23	bolts connecting ribs to center plate
CROD	2089 2096	8	24	connectors between ribs and sensor plate
CBAR	2097 2100	4	22	reflector rib tension cables
CTRIA3	2109 2132	24	26	reflector base plate
CTRIA3	2133 2156	24	25	reflector sensor plate
CBAR	2157 2160	4	27	reflector support, longeron
CBAR	2161 2166	6	28	reflector support, diagonal
CBAR	2167 2168	2	29	reflector support, batten
CBAR	2169 2176	8	19	reflector rib, added
CELAS2	2211 2234		24	spring attaching base plate to structure

Lumped Mass Elements				
Element	EID's	No.	Location	
CONM2	3001 3472	472	lumped mass for joints in truss	
CONM2	3501 3630	130	lumped mass, miscellaneous	
CONM2	3701 3896	196	lumped mass, miscellaneous	

Total Elements

CBAR	1627
CROD	22
CTRIA3	116
CQUAD4	3
CELAS2	38
CONM2	798

Table 9. FEM Physical Section Properties

PID	Dimension	Sections	Element	Property of sections	Material Property
1, 2, 12	O.D.=.625" I.D.=.509"		CBAR Longeron & Batten struts	$A_{eff} = 1.337E-1$ $I_{eff} = 1.264E-3$ $J_{eff} = 2.528E-3$	$E = 1.0E7$ $\nu = .333$ $\rho_{eff} = 4.64E-4$
3, 13	O.D.=.625" I.D.=.509"		CBAR Diagonal struts	$A_{eff} = 1.24E-1$ $I_{eff} = 1.495E-3$ $J_{eff} = 2.99E-3$	$E = 1.0E7$ $\nu = .333$ $\rho_{eff} = 4.14E-4$
11	2" X 2" X 3/8"		CBAR Cable to truss connection	$A = 1.36$ $I = 4.8E-1$ $J = 7.0E-2$	$E = 3.0E7$ $\nu = .3$ $\rho_{eff} = 9.24E-4$
14	O.D.=.125"		CPROD Suspension cable	$A = 2.2E-3$ $J = 5.2E-5$	$E = 3.0E7$ $\nu = .3$ $\rho_{eff} = 2.846E-3$
15	O.D.=.125"		CTRIA3 Thruster plates CQUAD4 Laser and thruster controller plates	$t_{eff} = .3024in$	$E = 1.0E7$ $\nu = .333$ $\rho = 0$

where,

- A is the cross sectional area in units of in^2 ,
 - I is the bending moment of inertia in units of in^4 ,
 - J is the torsional moment of inertia in units of in^4 ,
 - E is the Young's modulus in units of lb/in^2 ,
 - G is the shear modulus in units of lb/in^2 ,
 - ν is Poisson's ratio,
 - α is the thermal coefficient of expansion in units of $in/in/^\circ F$
- and ρ is the mass density in units of $lb-s/in^2$.

Table 9. FEM Physical Section Properties (Continued)

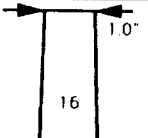
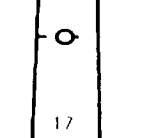
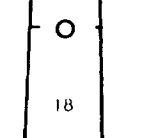
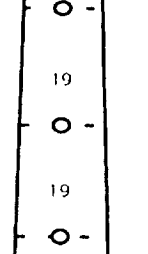
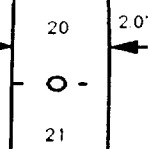
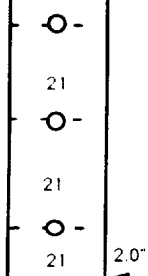
PID	Dimension	Sections	Element	Property of sections	Material Property
16	Width = 1.16"		CBAR Reflector Rib, t=0.25"	A = 2.9E-1 I ₁ = 1.51E-3 I ₂ = 3.252E-2 J = 5.22E-3	E = 1.0E7 G=0.375E7
17	Width = 1.35"			A = 3.375E-1 I ₁ = 1.758E-3 I ₂ = 5.126E-2 J = 6.21E-3	ρ=2.539E-4 α _{eff} =1.458E-8
18	Width = 1.536"			A = 3.84E-1 I ₁ = 2.0E-3 I ₂ = 7.55E-2 J = 7.18E-3	TREF = 0. °F
19	Width = 1.35"			A = 4.3E-1 I ₁ = 2.24E-3 I ₂ = 1.06E-1 J = 8.14E-3	
20	Width = 1.91"			A = 4.775E-1 I ₁ = 2.407E-3 I ₂ = 1.4516E-1 J = 9.1276E-3	
21	Width = 2.0"			A = 5.0E-1 I ₁ = 2.604E-3 I ₂ = 1.6667E-1 J = 1.0417E-2	

Table 9. FEM Physical Section Properties (Continued)




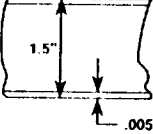
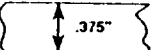
PID	Dimension	Sections	Element	Property of sections	Material Property
22	$D_o=0.03125''$		CRD Reflector Rib Tension Cable	$A=7.67E-4$ $J=0$	$E=3.0E7$ $G=1.154E7$ $\rho_{eff}=4.59E-4$ $\alpha_{eff}=-2.535E-6$
23	$D_o=0.25''$		CBAR Rib to Plate connection bolts	$A=4.909E-2$ $I=1.92E-4$ $J=3.84E-4$	$E=3.0E7$ $G=1.154E7$ $\rho_{eff}=4.59E-4$ $\alpha_{eff}=-2.535E-6$
24	$D_o=0.19''$		CRD Rib to plate connection rods	$A=2.835E-2$ $J=1.28E-4$	$E=3.0E7$ $G=1.154E7$ $\rho=7.33E-4$
25	$t=1.5''$		CTRIA3 Honeycomb reflector panel	$t_{eff}=0.40807$	$E=0.65E7$ $G=2.5E7$ $\rho=5.12E-4$
26	$t=0.375''$		CTRIA3 Reflector plate rib connector	$t=0.375''$	$E=1.0E7$ $G=0.375E7$ $\rho=3.375E-4$

Table 9. FEM Physical Section Properties (Continued)


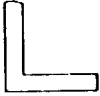


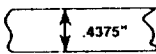
PID	Dimension	Sections	Element	Property of sections	Material Property
27	$D_o=0.25"$		CBAR Reflector support truss longeron	$A=4.418E-1$ $I=1.55E-2$ $J=3.10E-2$	$E=1.0E7$ $G=3.75E6$ $\rho=2.54E-4$
28	$1" X 1" X$ $3/16"$		CBAR Reflector support truss diagonal	$A=3.39E-1$ $I=3.0E-2$ $J=4.39E-3$	$E=1.0E7$ $G=3.75E6$ $\rho=2.54E-4$
29	$1" X 1 1/4" X$ $1/4"$		CBAR Reflector support truss to rib plate connector	$A=5.0E-1$ $I_1=3.97E-2$ $I_2=7.10E-2$ $J=1.1067E-1$	$E=1.0E7$ $G=3.75E6$ $\rho=2.54E-4$
30	$D_o=0.375"$		CBAR Honeycomb panel to truss connectors	$A=6.627E-2$ $I=9.77E-4$ $J=1.942E-3$	$E=3.0E7$ $G=1.154E7$ $\rho=7.33E-4$
40	$t=0.4375"$		CQUAD4 Concentrated mass	$t_{eff}=0.51237"$	$E=3.0E7$ $G=1.154E7$ $\rho=7.33E-4$

Table 10. CEM measured and FEM calculated mass

	Location	Weight (lbs)	
FE Model Experimental	Main Truss	204.09	739.41 753.82
	Tower	35.09	
	Reflector Tower and Support	26.64	
	Forward Suspension Truss	76.04	
	Rear Suspension Truss	76.04	
	Reflector	93.7	
	Thrusters, Sensors, Cableing	129.51	
	Lumped Masses at Joints	92.9	
	Suspension Cables	6.89	
		total weight (lbs)	

Table 11. CEM analytical mode frequencies and test damping

Mode No	Test Frequency	Test Damping	Analysis Frequency	Analysis Damping
1*	0.145	5.7	0.147	5.7
2*	0.149	7.5	0.149	7.5
3*	0.148	7.5	0.155	7.5
4*	0.718	1.5	0.730	0.7
5*	0.740	1.2	0.748	0.7
6*	0.900	0.6	0.874	0.2
7*	1.500	0.4	1.474	0.2
8*	1.710	0.7	1.738	0.3
9*	1.900	0.5	1.883	0.3
10			2.301	0.1
11			2.535	0.1
12*	2.570	2.1	2.839	0.1
13			3.419	0.1
14			3.486	0.1
15			3.587	0.1
16*	4.040	0.4	4.015	0.1
17*	4.300	0.9	4.032	0.1
18			4.206	0.1
19*			4.392	0.1
20			5.029	0.1
21			5.034	0.1
22*	5.330	0.7	5.501	0.1
	5.920	1.1		
23*	6.140	0.3	6.180	0.1
24*			6.231	0.1
25*	6.650	0.3	6.471	0.1
26*			6.670	0.1
	6.790	0.2		
27*	7.240	0.6	7.372	0.1
28*	8.260	0.3	8.293	0.1
29*	9.110	0.2	8.409	0.1
30*			8.456	0.1
31*			8.824	0.1
32*			8.926	0.1
33*			8.966	0.1
34			9.235	0.1
35			9.527	0.1
36			9.901	0.1
37*			12.486	0.1
38			13.615	0.1
39			14.315	0.1
40			14.718	0.1
41			15.886	0.1
42*			16.853	0.1
43*			16.993	0.1

* Modes used in 40 mode reduced CEM model

Table 11. CEM analytical mode frequencies and test damping (Continued)

Mode No	Test Frequency	Test Damping	Analysis Frequency	Analysis Damping
44			18.486	0.1
45			19.192	0.1
46			21.190	0.1
47*			21.938	0.1
48			22.213	0.1
49*			23.437	0.1
50			24.550	0.1
51*			24.914	0.1
52			24.975	0.1
53*			25.629	0.1
54*			26.205	0.1
55			26.283	0.1
56			26.565	0.1
57			27.188	0.1
58			27.656	0.1
59			28.649	0.1
60			28.952	0.1
61			29.146	0.1
62			29.701	0.1
63			29.881	0.1
64*			30.437	0.1
65*			30.567	0.1
66			30.843	0.1
67			31.064	0.1
68			31.339	0.1
69			31.533	0.1
70			31.630	0.1
71*			32.361	0.1
72*			33.380	0.1
73			36.883	0.1
74			37.075	0.1
75			38.180	0.1
76			38.428	0.1
77			38.982	0.1
78			38.991	0.1
79			39.443	0.1
80*			40.707	0.1
81			42.757	0.1
82			43.059	0.1
83*			43.882	0.1
84*			45.762	0.1
85			49.139	0.1
86			50.013	0.1

* Modes used in 40 mode reduced CEM model

Table 12. Thruster and servo accelerometer modal coefficients

Mode No	Location 1	Location 2	Location 3	Location 4
1	-9.0412e-02	-1.7503e-03	-2.2032e-03	8.6983e-04
2	-7.2842e-01	2.1216e-04	-7.4012e-01	1.9792e-04
3	1.1157e+00	-2.6799e-04	6.2103e-02	9.7330e-05
4	-2.3142e-04	-1.1076e+00	-1.5399e-04	-3.9490e-02
5	5.9439e-05	-7.5943e-01	1.9928e-04	-7.4550e-01
6	-6.8777e-02	2.3805e-03	-2.5082e-01	2.0583e-03
7	-9.0841e-01	-9.2293e-04	4.7562e-01	4.0256e-03
8	2.9426e-02	1.2695e+00	-2.6966e-02	-1.0421e+00
9	9.4147e-01	-4.7622e-02	-9.0573e-01	4.2744e-02
12	-2.9829e-03	-3.5789e-01	-1.2875e-03	2.5253e-01
16	-2.0542e-01	-7.2812e-02	-9.5226e-03	7.2871e-03
17	-8.3452e-01	-1.7241e-02	-4.2512e-02	-2.1983e-02
19	8.3909e-02	-1.0430e+00	-4.9171e-03	-6.5816e-02
22	3.0662e-01	-4.5815e-02	4.1271e-01	-1.2829e-02
23	1.5476e-02	-5.8067e-01	-3.6281e-02	-3.9609e-01
24	1.1892e-01	-3.9154e-02	3.6029e-01	-9.2921e-02
25	-2.0457e-02	3.3652e-01	1.9963e-01	2.5025e-02
26	-6.8681e-02	1.0751e+00	-1.2244e-01	-1.4175e-01
27	5.4524e-03	5.4087e-01	1.5533e-01	1.0847e+00
28	-2.0571e-01	2.7394e-02	-9.8462e-01	1.0100e-01
29	-1.1149e-01	6.3311e-03	-7.1186e-01	2.8220e-02
30	3.4329e-02	-4.1892e-02	1.9465e-01	-1.6186e-01
31	-6.4452e-02	-3.5680e-03	9.7786e-02	4.5018e-03
32	-4.3883e-03	4.5883e-02	-2.8610e-02	1.5823e-01
33	-1.5396e+00	-1.0585e-01	-1.7445e-01	-6.0191e-03
37	-1.0503e-02	1.9177e-01	3.6153e-02	6.2227e-01
42	1.7533e-01	1.5125e-01	1.1805e-01	7.5504e-01
43	2.2531e-01	-5.2262e-02	3.7900e-01	-3.5013e-01
47	1.3199e-03	-3.4522e-03	-1.5758e-03	9.5214e-04
49	3.0570e-03	-3.4311e-03	-7.0737e-03	1.9318e-03
51	-3.4096e-02	3.4850e-01	1.0691e-01	-2.9999e-01
53	1.2067e-01	1.0355e-01	-4.4828e-01	-1.3341e-01
54	-1.1949e-01	-6.2880e-02	4.7319e-01	9.6404e-02
64	6.5017e-02	-5.7865e-02	-3.6726e-01	1.0309e-02
65	-1.1117e-01	-5.1386e-03	5.1169e-01	2.7814e-02
71	-2.9288e-02	6.0046e-01	1.3286e-01	-8.0246e-01
72	1.9919e-01	5.8708e-02	-9.3338e-01	-9.2279e-02
80	1.5017e-02	-3.8527e-01	-5.6050e-03	-8.4986e-01
83	-3.2678e-01	4.7441e-02	-2.8168e-01	6.4626e-02
84	-3.8462e-01	-1.3331e-02	-4.8115e-02	-1.1624e-02

Table 12. Thruster and servo accelerometer modal coefficients (Continued)

Mode No	Location 5	Location 6	Location 7	Location 8
1	7.2204e-01	7.6707e-02	7.2043e-01	-4.6856e-02
2	2.8522e-03	-7.0804e-01	2.8556e-03	-6.2905e-01
3	5.9780e-02	-8.8555e-01	5.9586e-02	5.9095e-01
4	-8.7477e-02	2.3484e-04	-2.7368e-01	1.0451e-03
5	-3.0950e-03	-3.4298e-04	3.9825e-03	-1.1842e-03
6	8.2306e-04	3.0302e-01	5.0834e-04	1.3185e+00
7	9.0757e-04	-4.3450e-01	-7.0441e-03	1.1182e+00
8	-3.8239e-01	1.0193e-02	9.5012e-01	1.6953e-02
9	1.2593e-02	3.8921e-01	-2.2581e-02	3.1281e-01
12	-3.8650e-02	-3.3579e-03	-2.0767e-01	3.3597e-03
16	-5.5209e-02	6.7861e-02	-4.1550e-02	1.1263e-01
17	-2.8225e-03	2.8268e-01	-5.3852e-02	4.5806e-01
19	-4.8285e-01	-3.5314e-02	-4.0749e-01	-4.2931e-02
22	6.0601e-03	-8.9994e-02	1.0370e-02	-5.1029e-01
23	-1.8812e-01	-3.4468e-02	1.6912e-01	8.8657e-02
24	2.3797e-02	3.5179e-01	-1.0616e-01	-1.1353e+00
25	-1.8725e-02	-2.1458e-01	-5.2492e-01	-1.2112e+00
26	6.5808e-02	3.4202e-02	-2.2117e+00	3.0859e-01
27	-6.6816e-01	2.2399e-02	5.2024e-01	5.3702e-02
28	-4.6903e-02	4.6728e-02	1.0856e-01	-3.1874e-01
29	-4.7380e-03	-1.0191e-02	5.1792e-02	-2.1000e-01
30	1.9335e-01	-6.6732e-03	-1.2411e-01	5.8518e-02
31	-3.8561e-03	1.5868e-01	3.3501e-03	1.2275e-02
32	-1.4115e-01	-7.7935e-03	9.5157e-02	-8.3770e-03
33	-1.5392e-03	-1.2358e-03	1.1115e-01	-2.4079e-01
37	4.0364e-01	5.9594e-03	3.7390e-01	1.3817e-02
42	-2.2316e-02	2.6324e-02	1.0209e-01	-7.8110e-03
43	6.4287e-03	8.5969e-02	-1.8401e-02	5.4507e-03
47	3.6821e-01	1.8231e-03	6.5610e-03	-6.5663e-04
49	4.8247e-01	-1.6727e-02	6.9708e-03	-1.0732e-03
51	-4.5675e-02	1.0841e-01	2.2423e-01	3.2255e-03
53	-1.8855e-02	-5.7184e-01	8.2317e-02	-5.2186e-02
54	1.0975e-02	3.2085e-01	-5.5956e-02	5.6431e-02
64	3.7594e-02	1.9550e-02	-2.2988e-02	1.2715e-01
65	4.5700e-04	-8.7799e-02	-2.3207e-02	3.7736e-02
71	7.7251e-02	-2.5799e-02	2.5758e-01	2.8133e-02
72	9.2327e-03	4.7463e-01	6.0564e-02	-9.0209e-02
80	3.6026e-02	2.0056e-02	3.7920e-02	9.1418e-03
83	6.5023e-02	1.6615e-01	-1.3645e-01	3.6218e-01
84	-3.8520e-02	5.8296e-02	1.4253e-01	2.7091e-01

Table 13 Measured thruster pole locations

Thruster	Pole, β	Gain, α
1	294.2442	61.5479
2	276.5990	56.0096
3	314.9927	63.5114
4	290.7927	58.2428
5	257.7488	50.7751
6	254.9671	51.1002
8	238.8258	47.2000
9	292.1215	59.0687
10	250.1545	50.6047
11	239.5841	48.5256
12	274.9924	55.9548
13	236.8847	48.2049
14	289.7807	58.0001
15	318.8278	64.6344
16	315.8110	61.3357

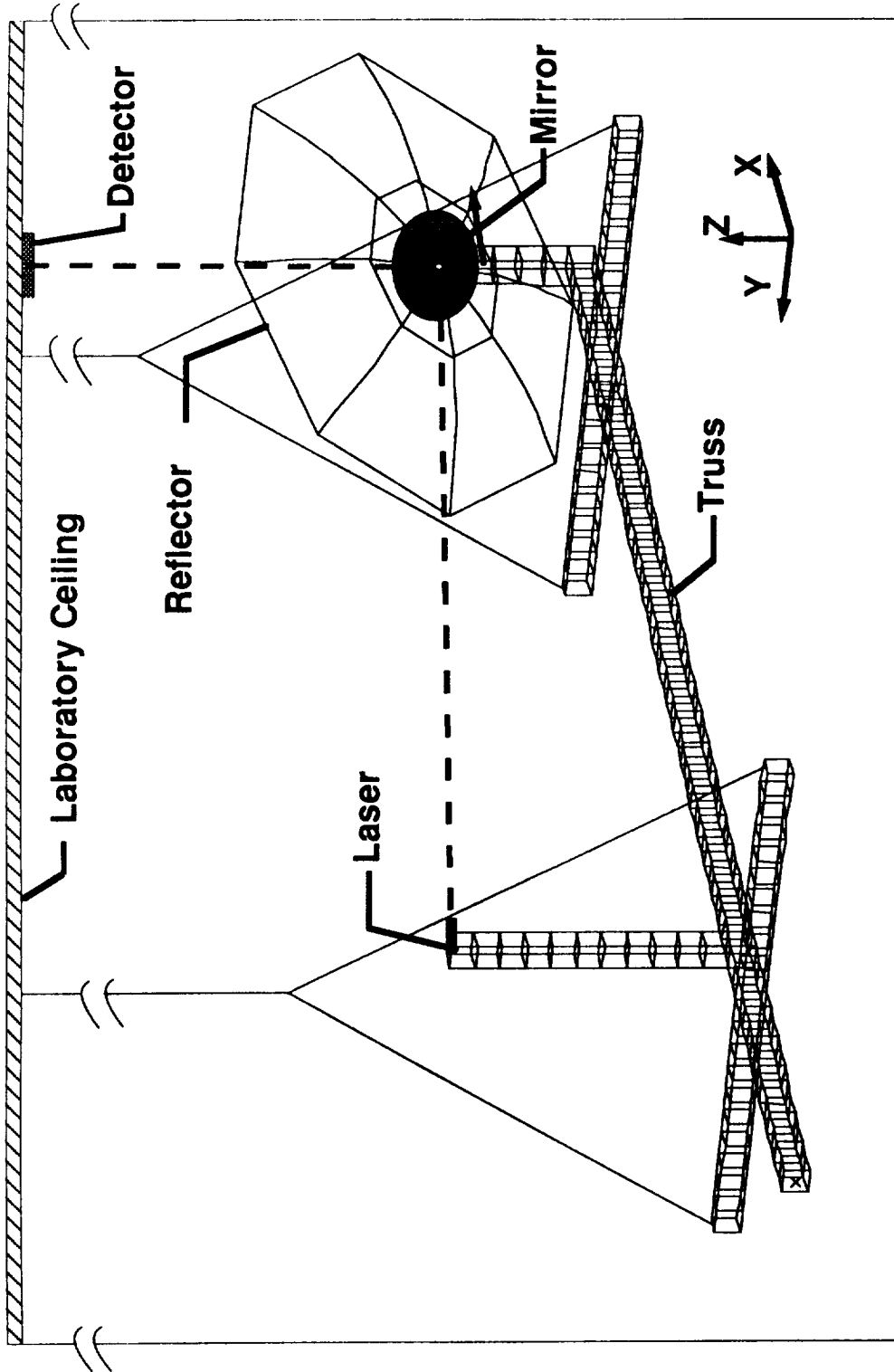


Figure 1. Schematic of CEM testbed

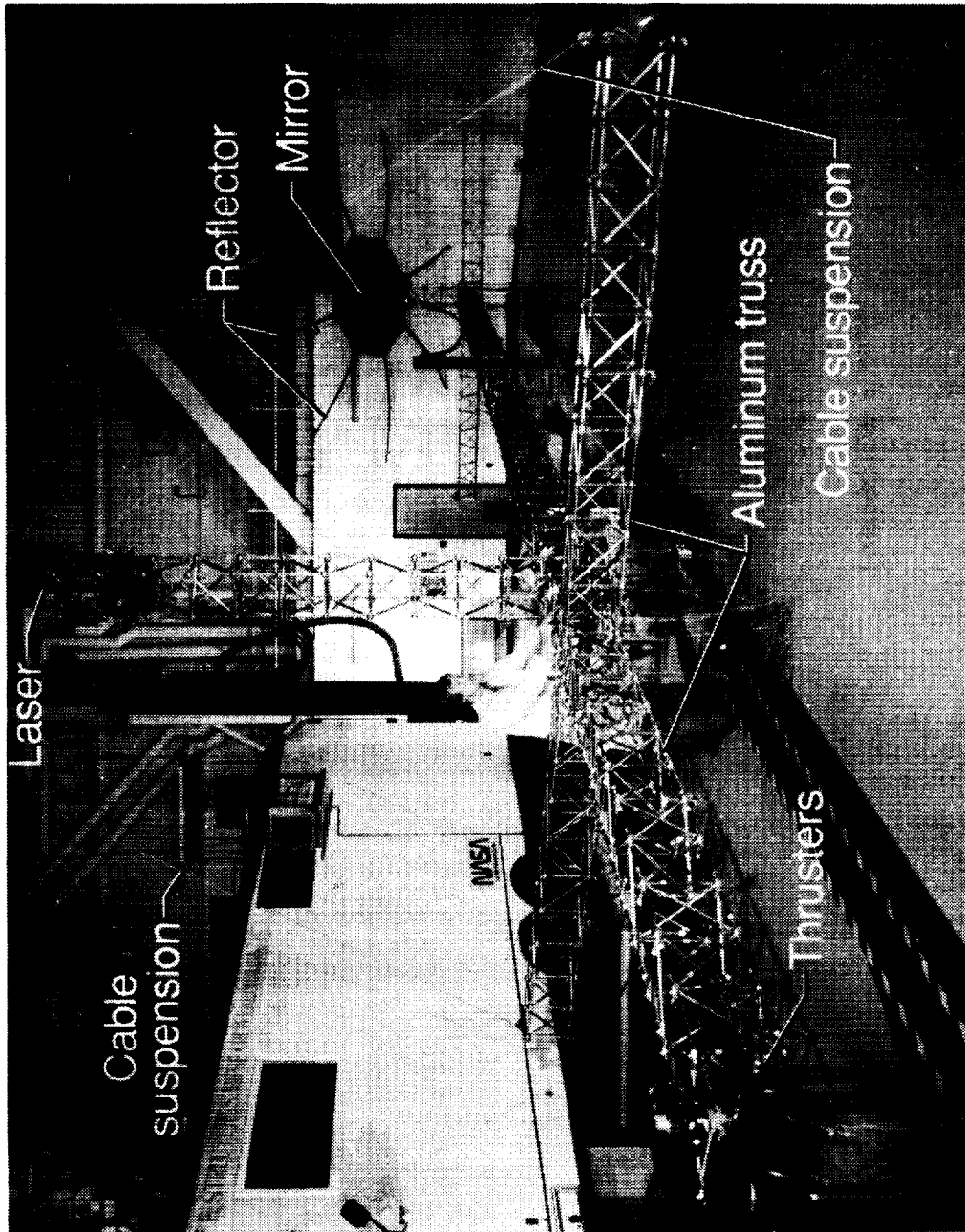


Figure 2. Photograph of the CEM testbed

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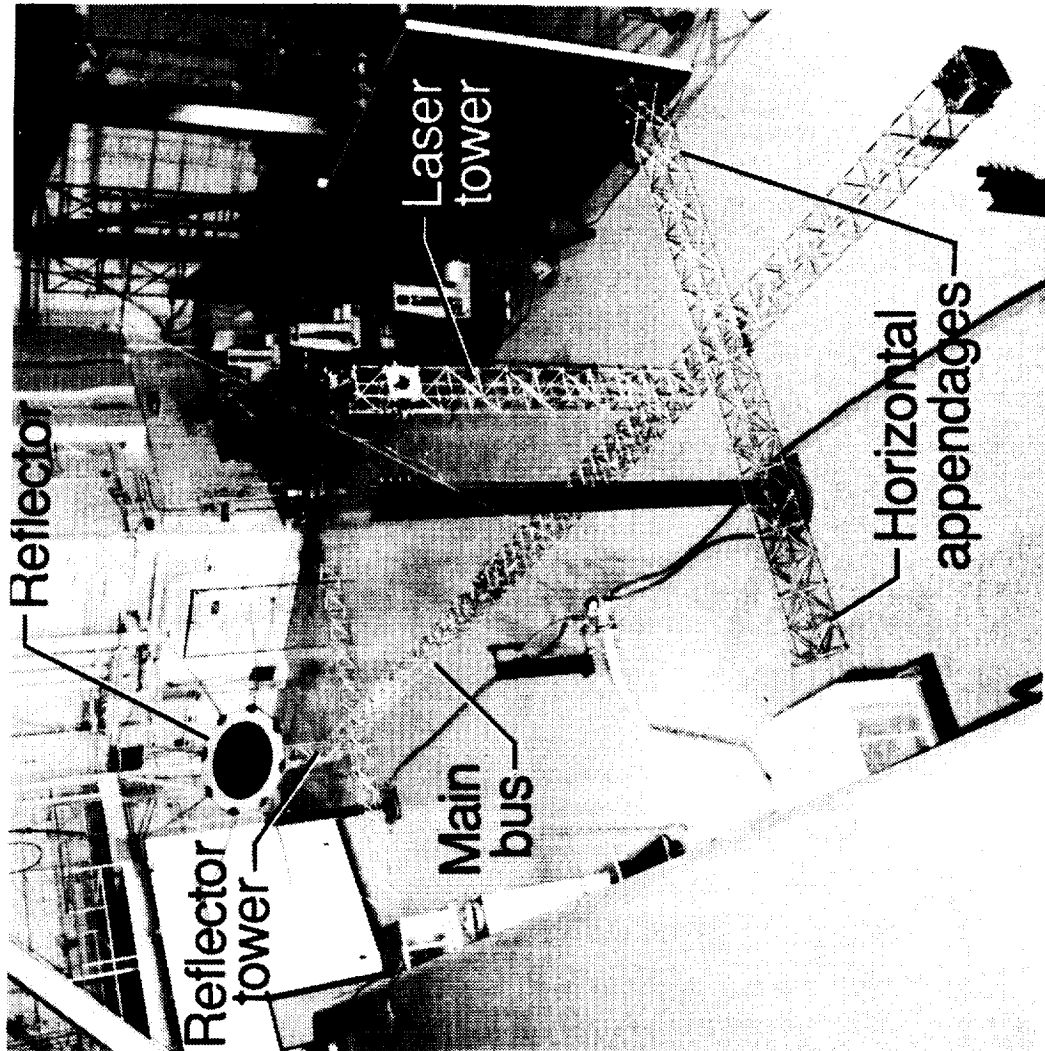


Figure 3. CEM truss and appendages

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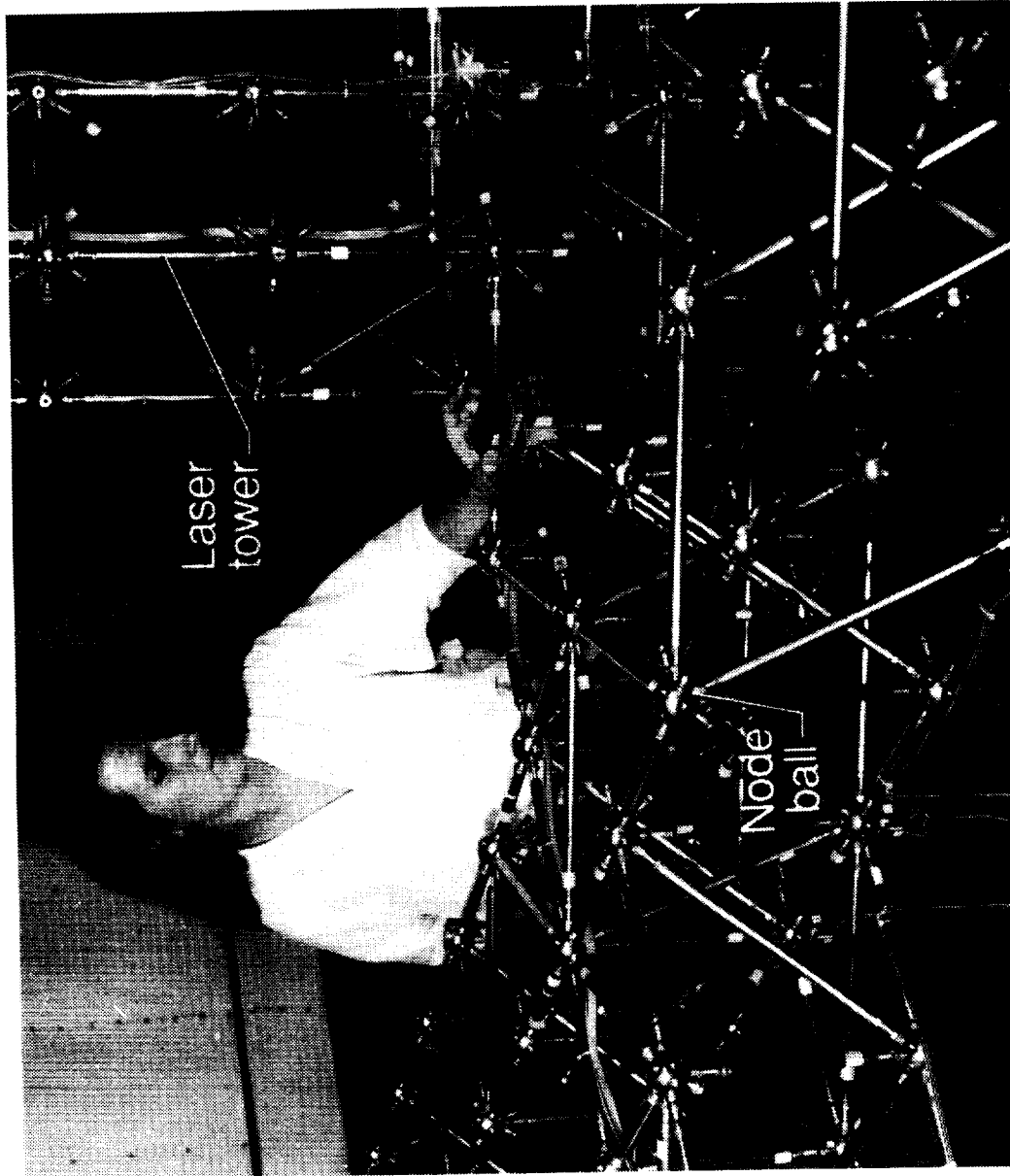


Figure 4. Truss lacing configuration

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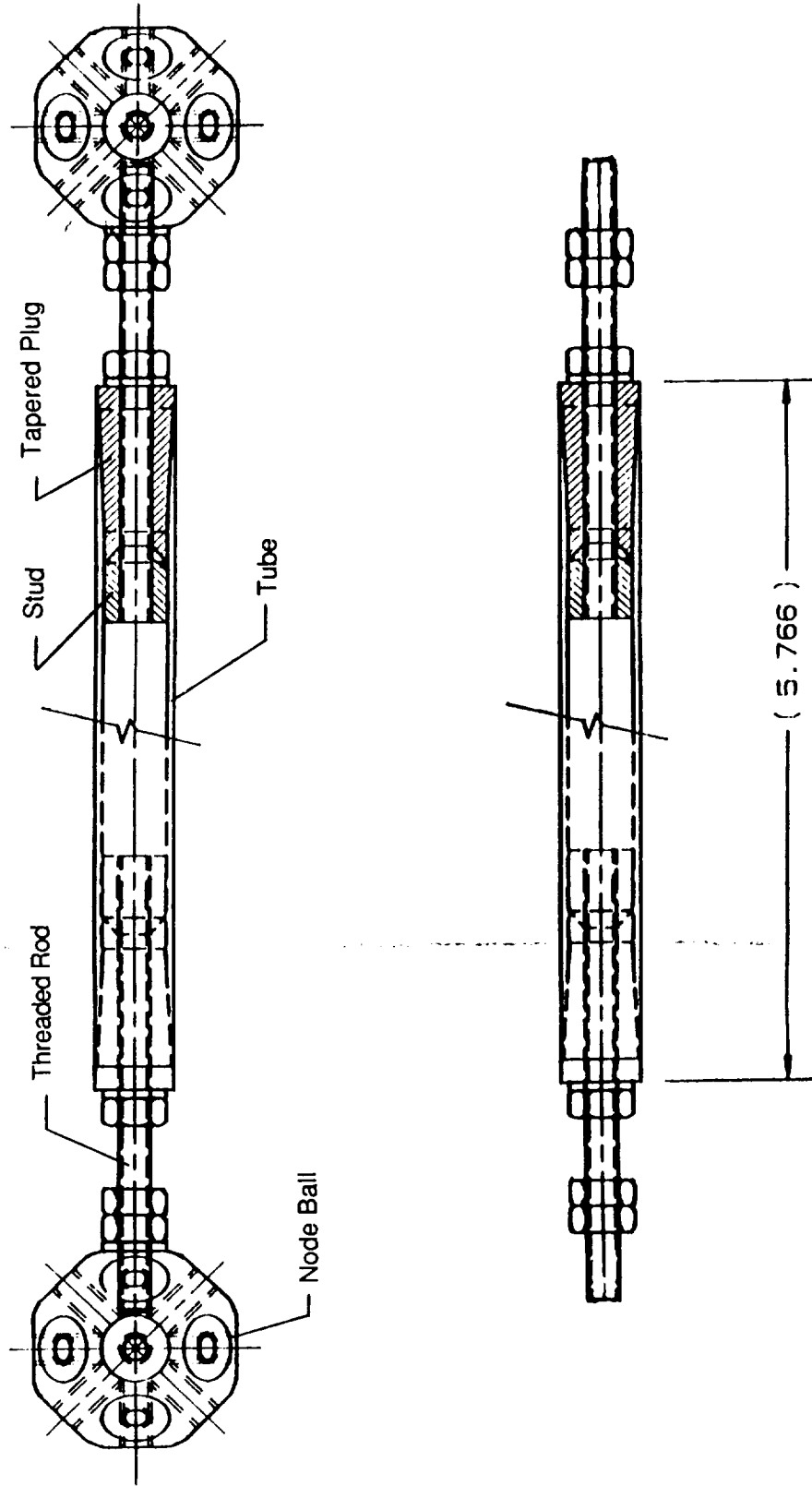


Figure 5. Schematic of truss strut

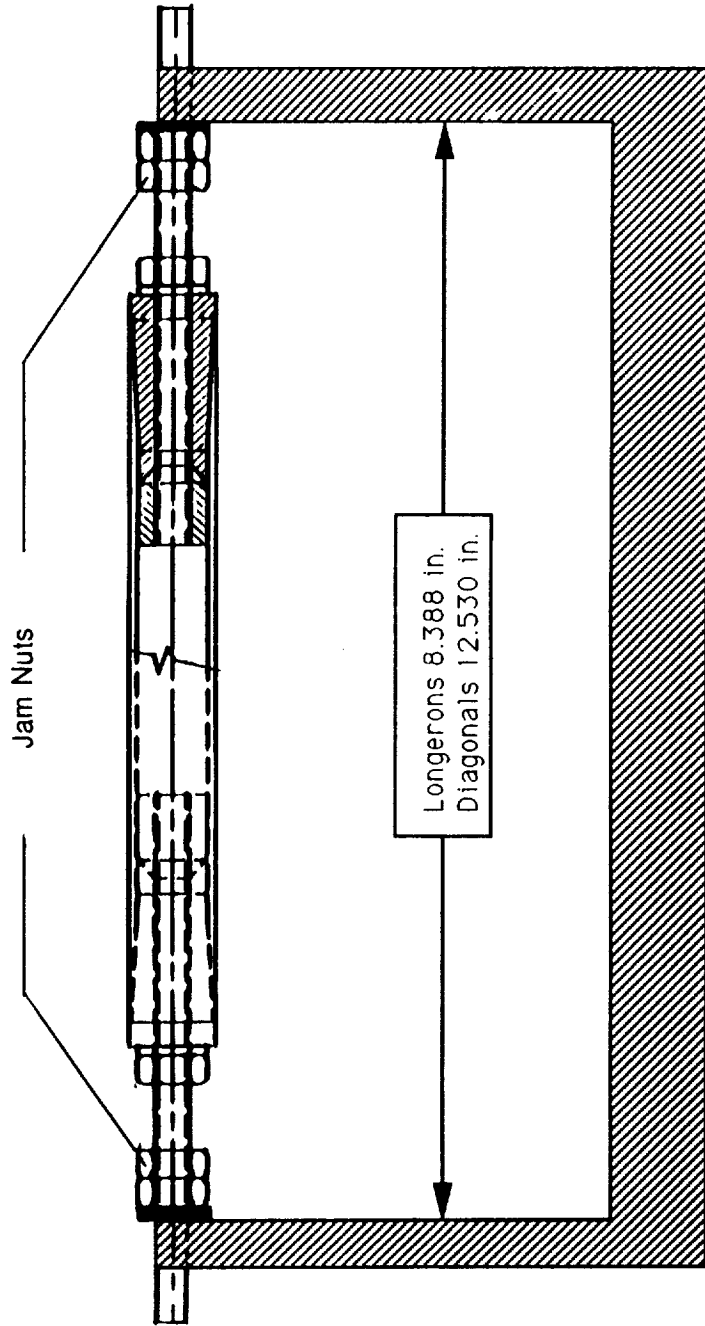


Figure 6. Truss strut length setting jig

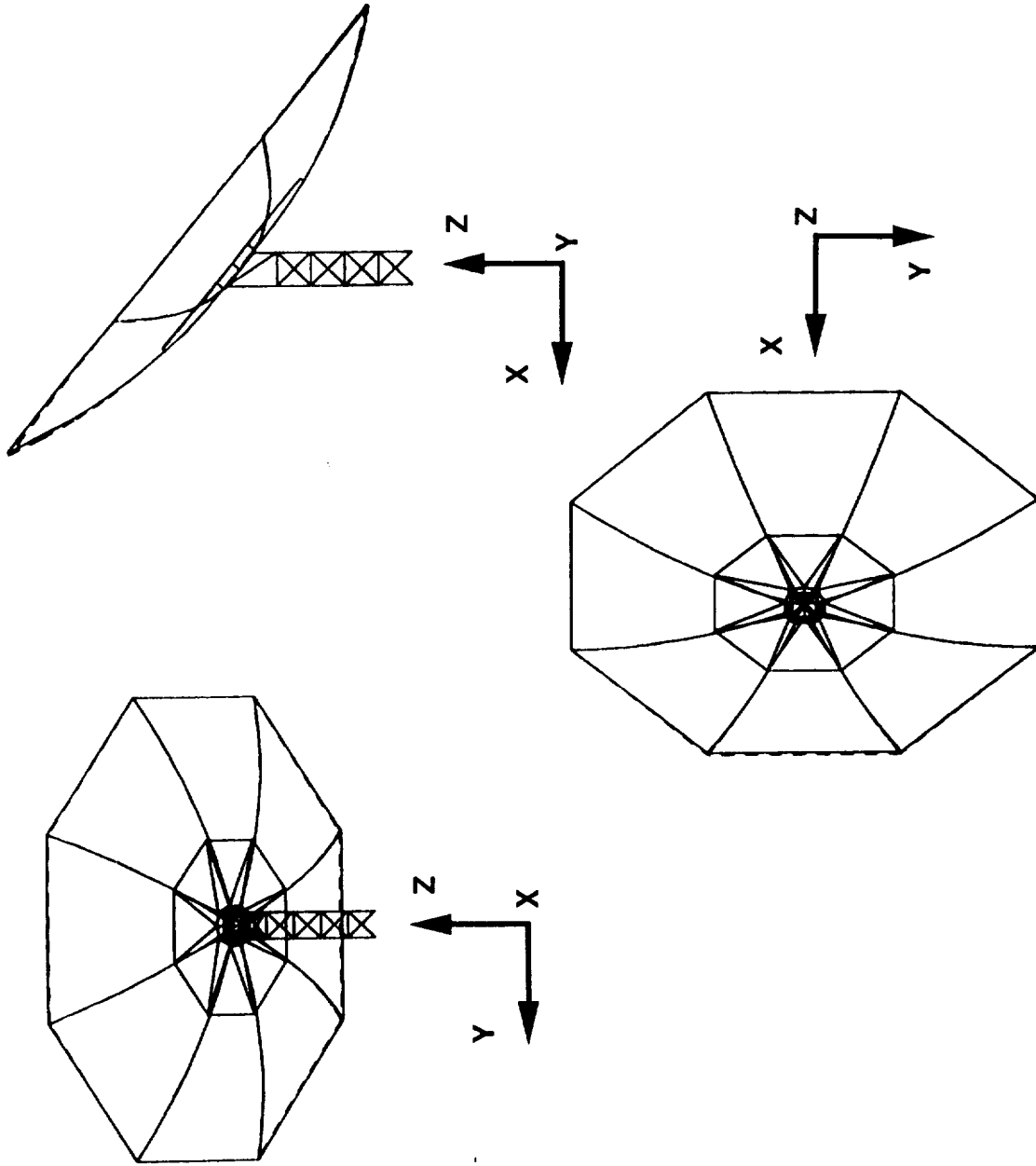


Figure 7. Three-view schematic of reflector

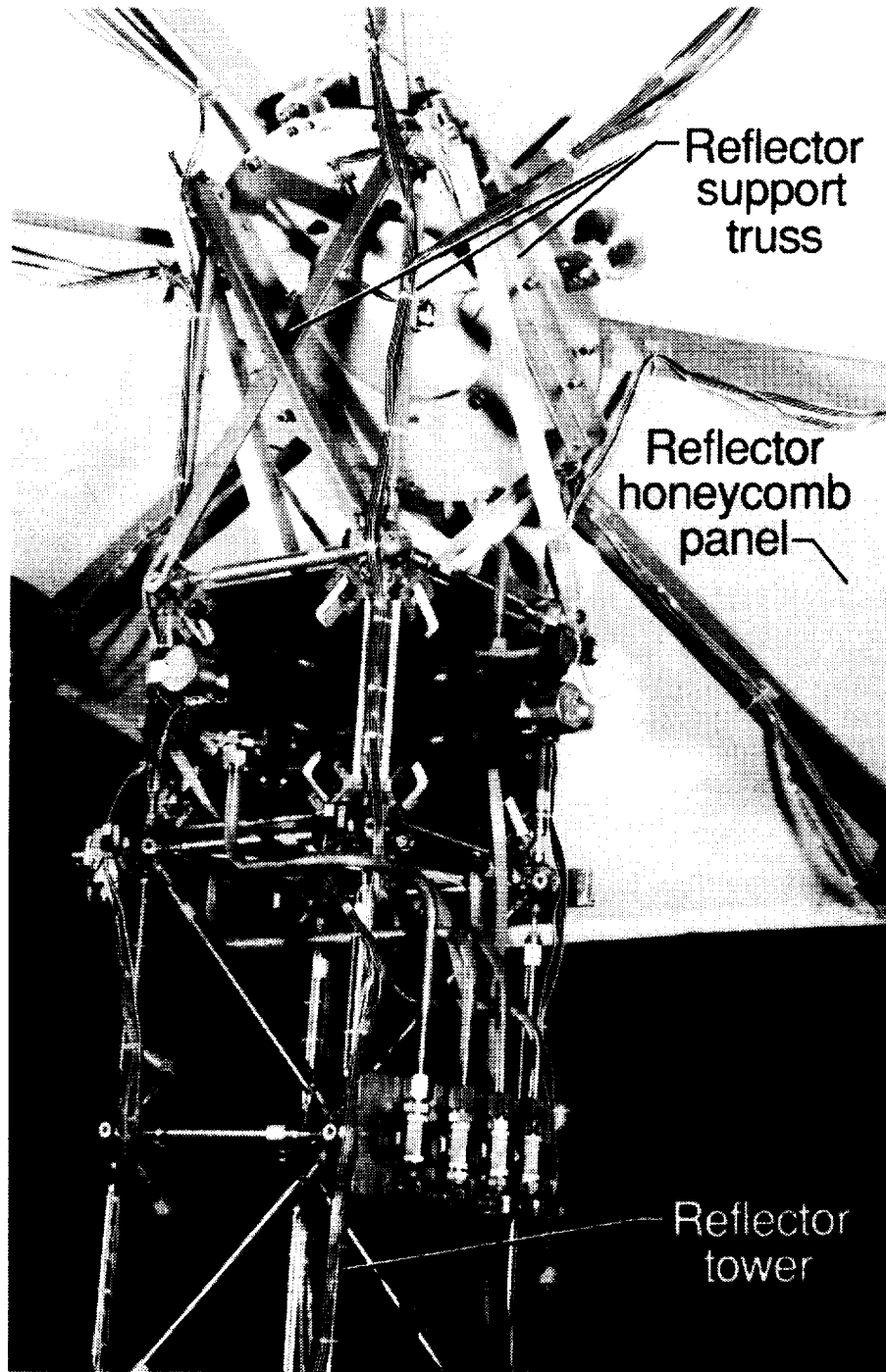


Figure 8. Reflector support truss

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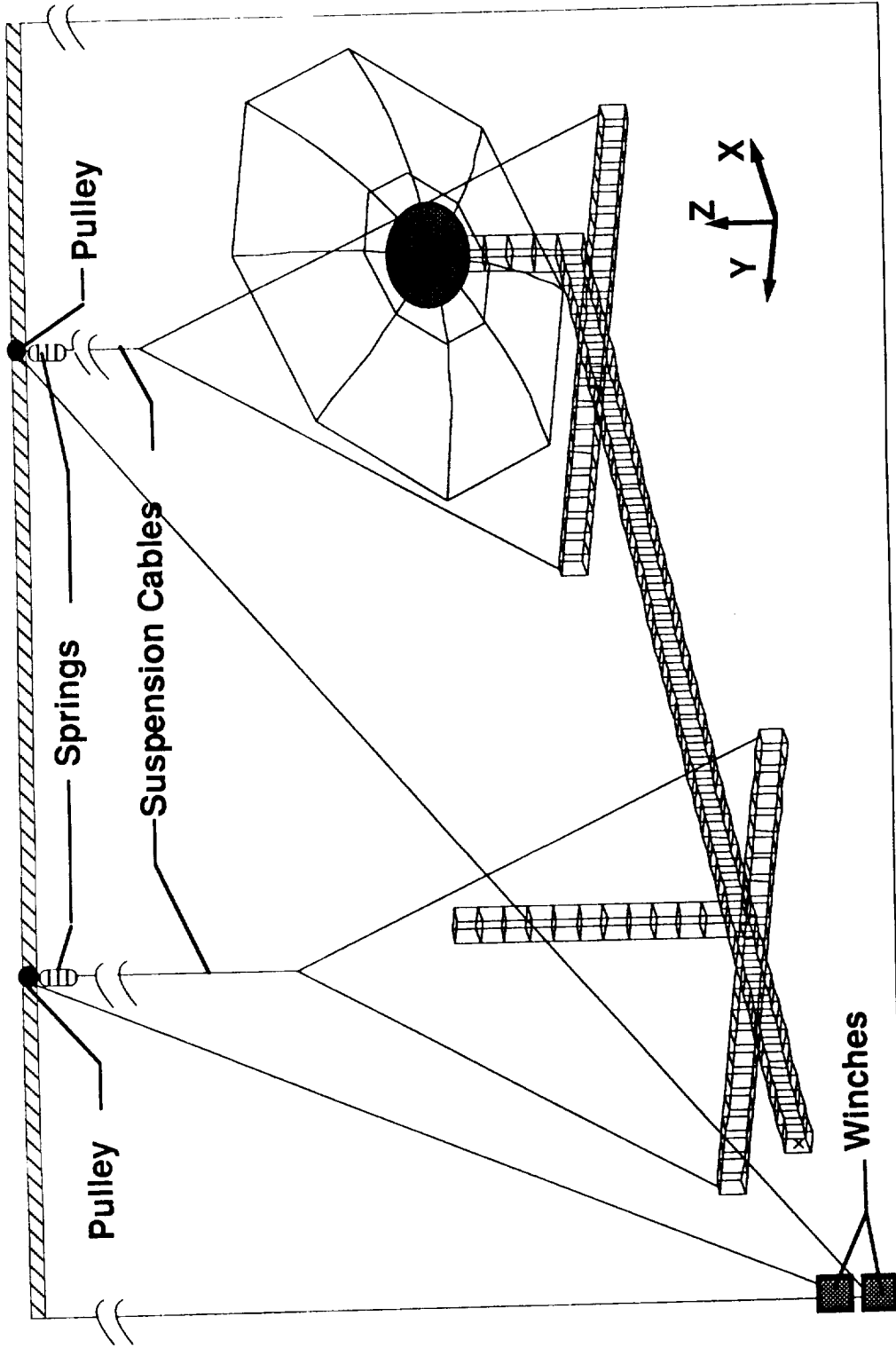


Figure 9. Schematic of CEM suspension

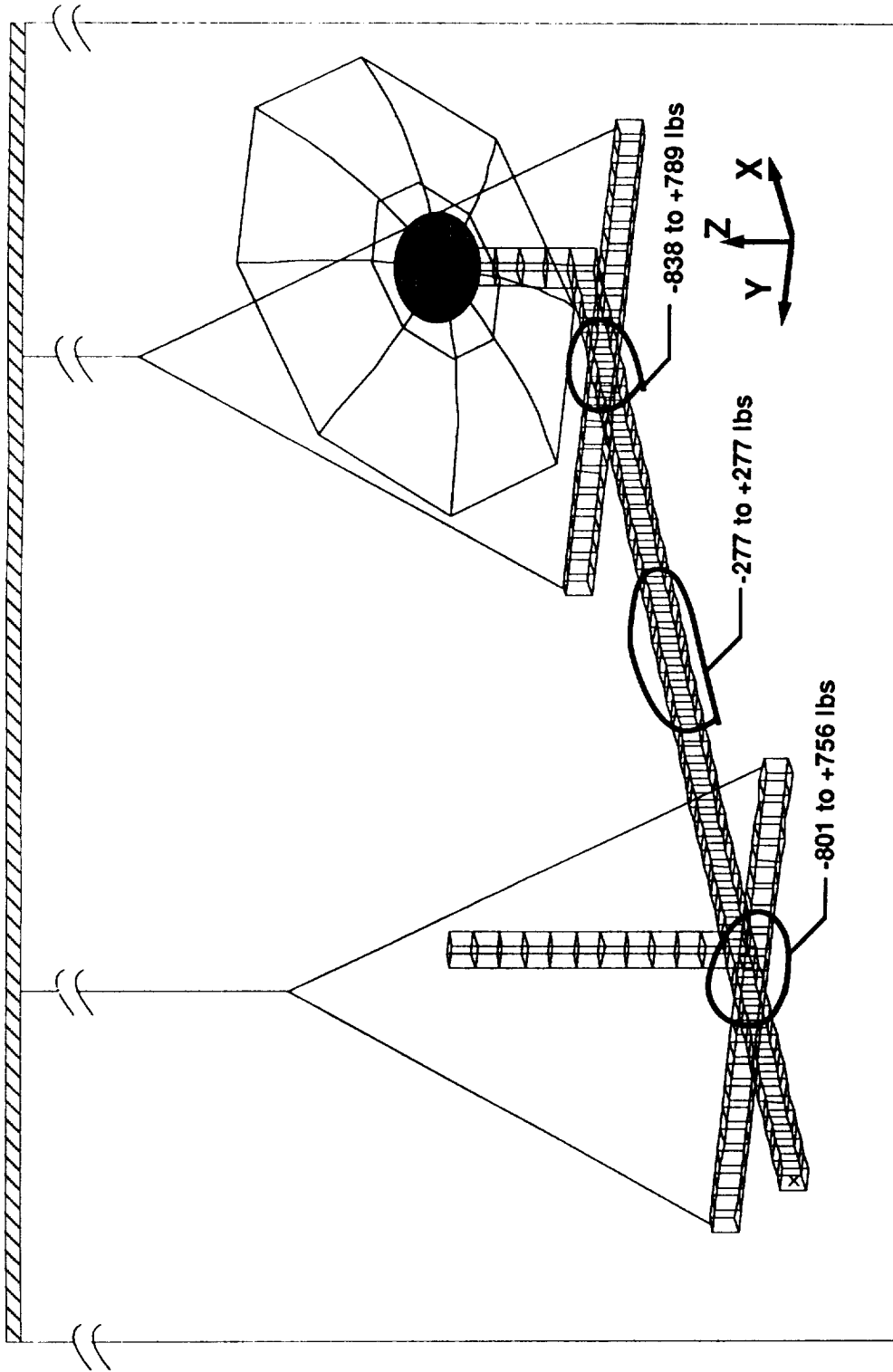


Figure 10. Gravity induced loads in CEM

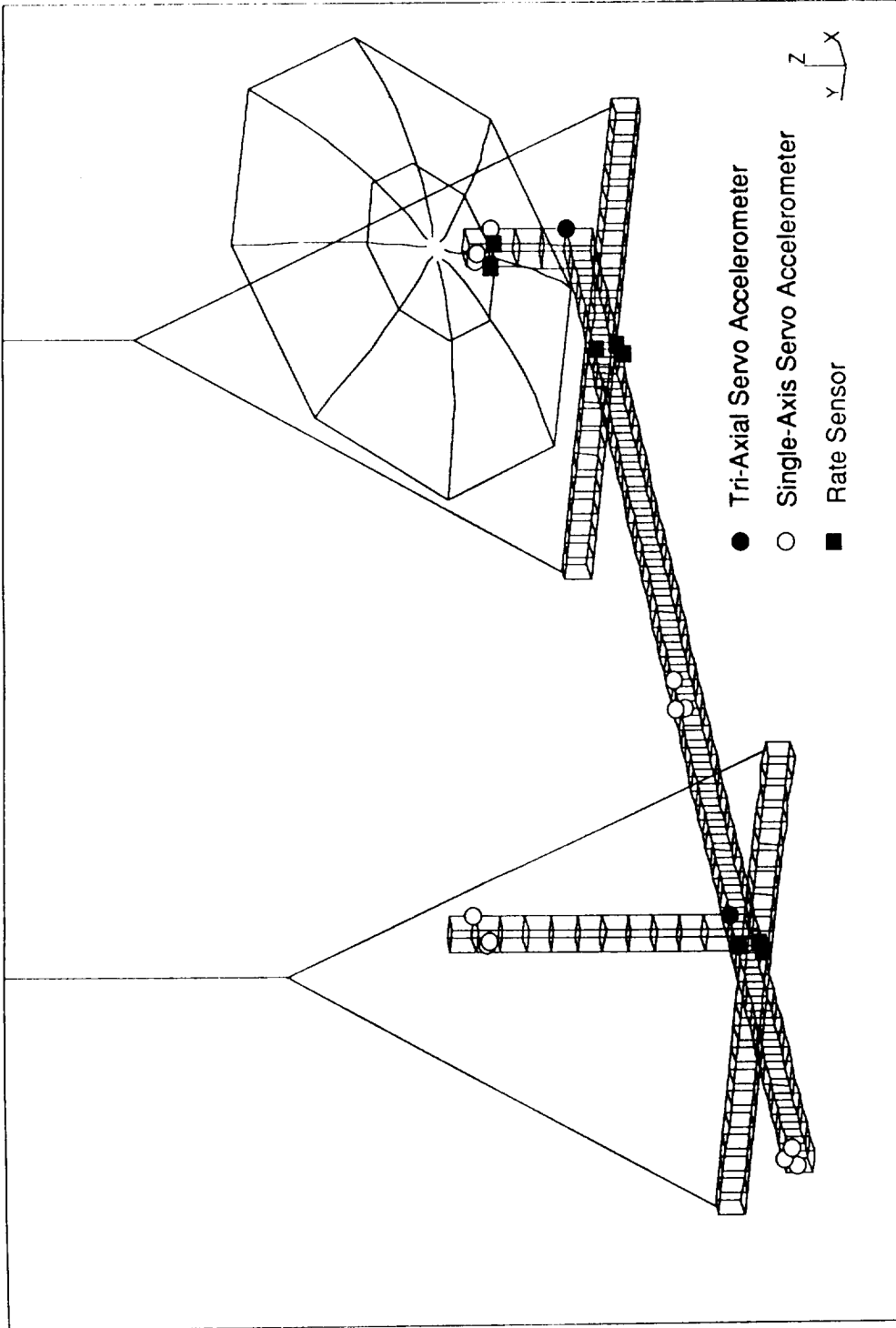


Figure 11. Servo Accelerometer and angular rate sensor locations

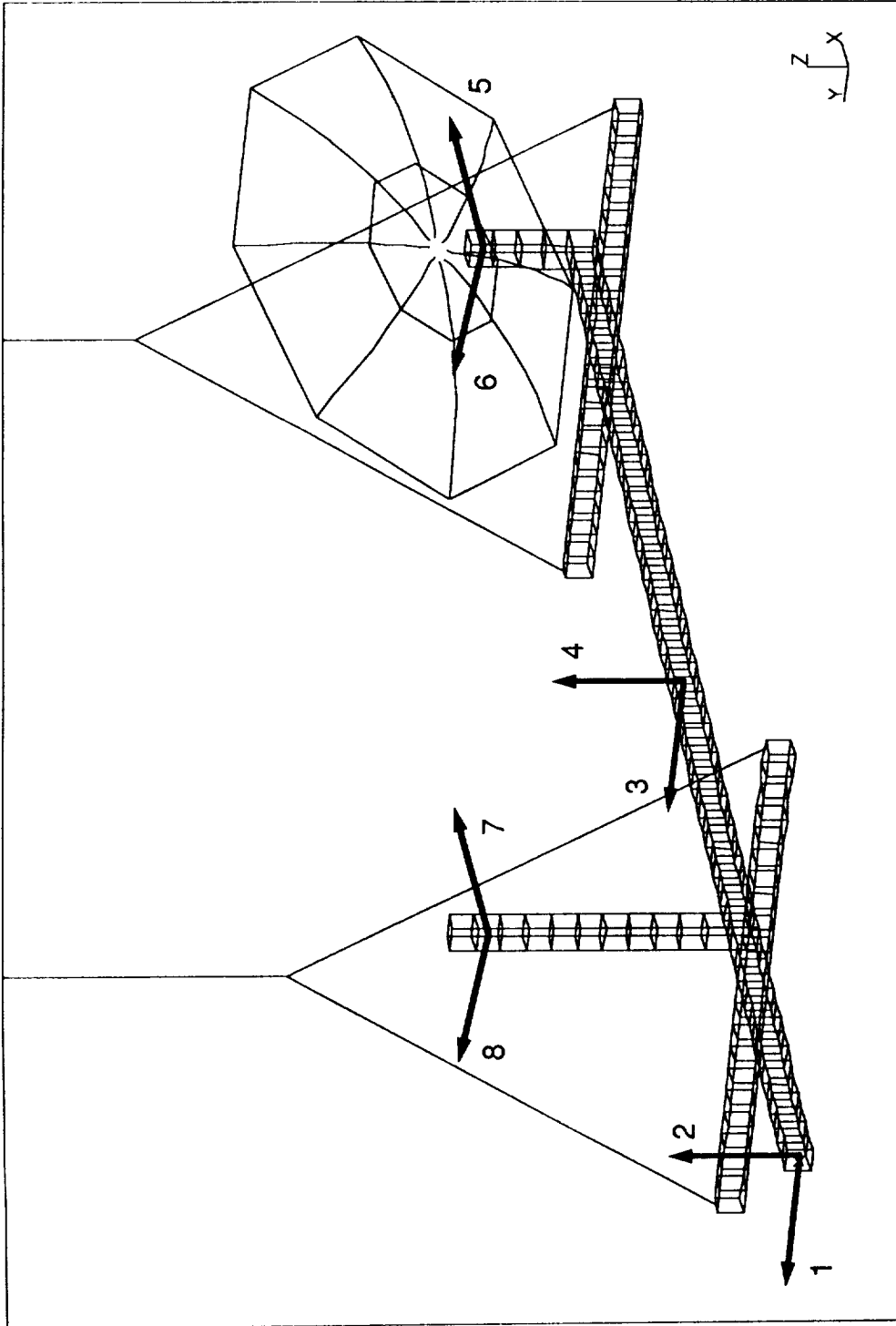


Figure 12. Thruster and collocated servo accelerometer locations

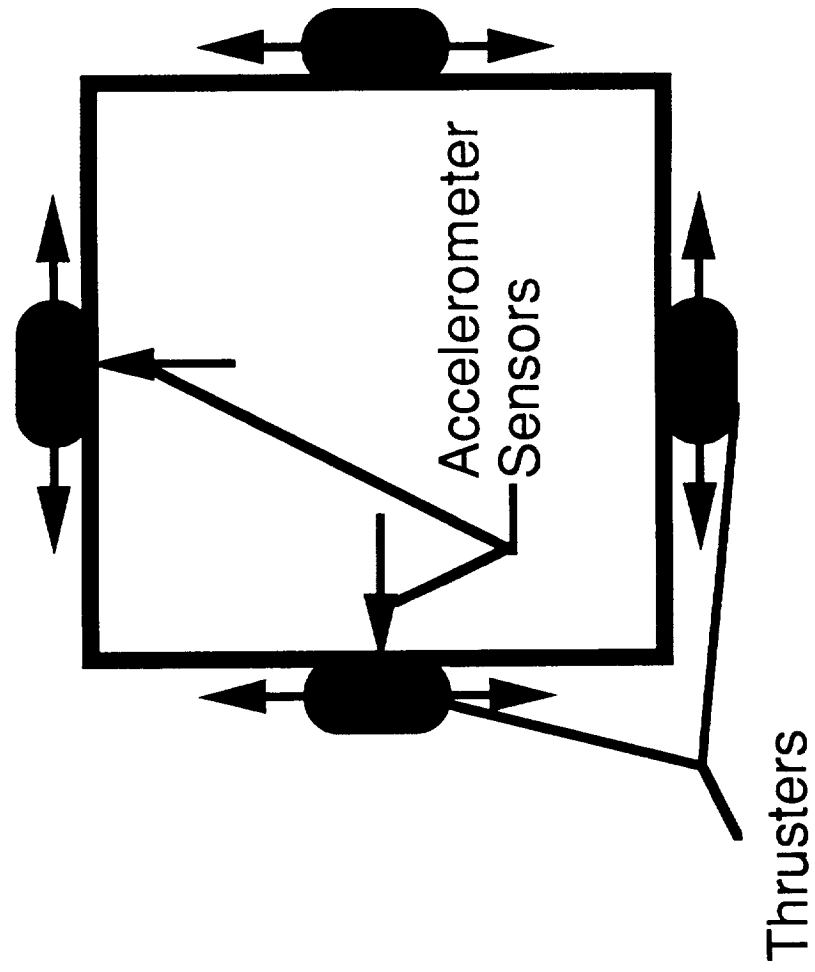


Figure 13. Accelerometer and thruster mounting schematic

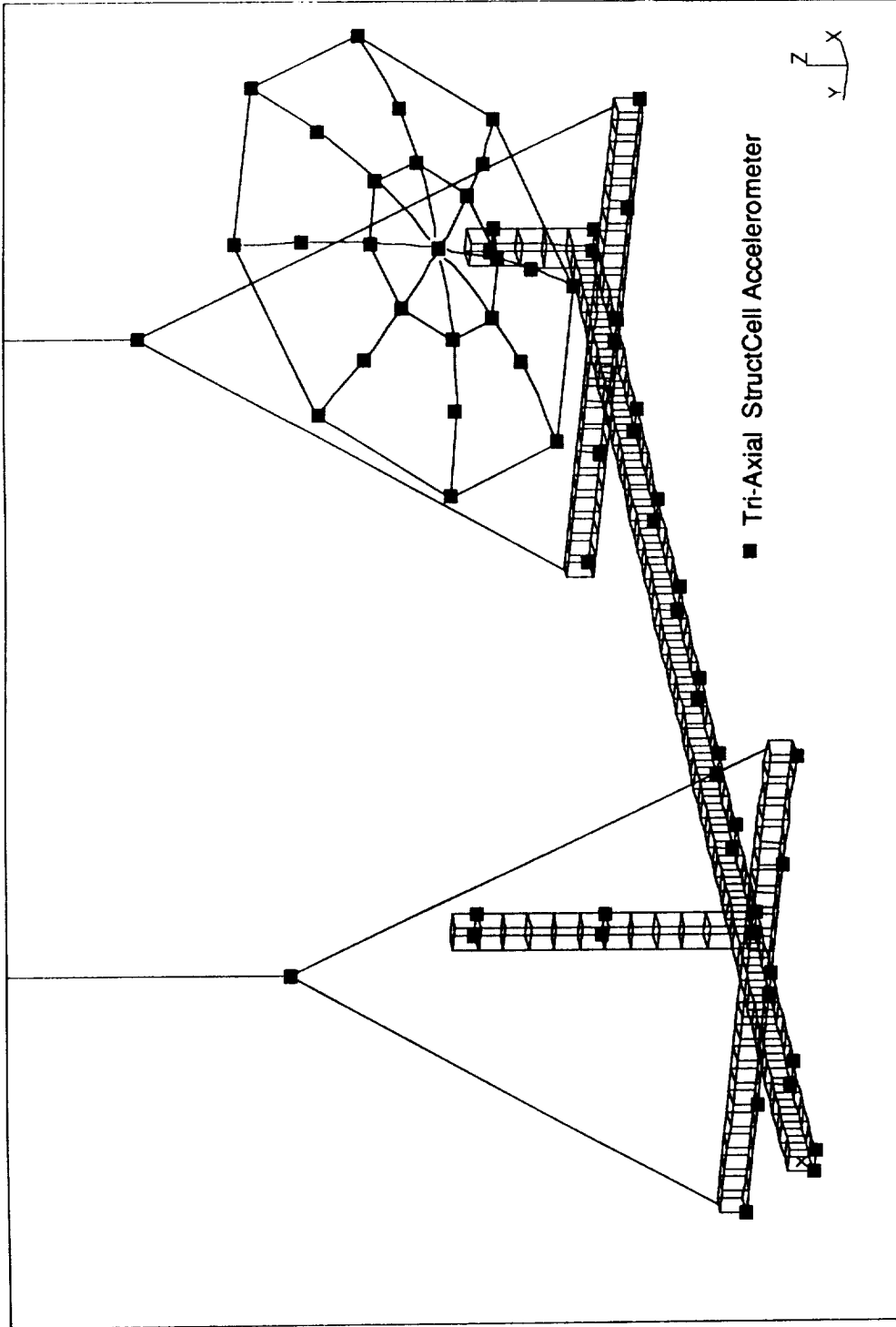


Figure 14. Structcell accelerometer locations

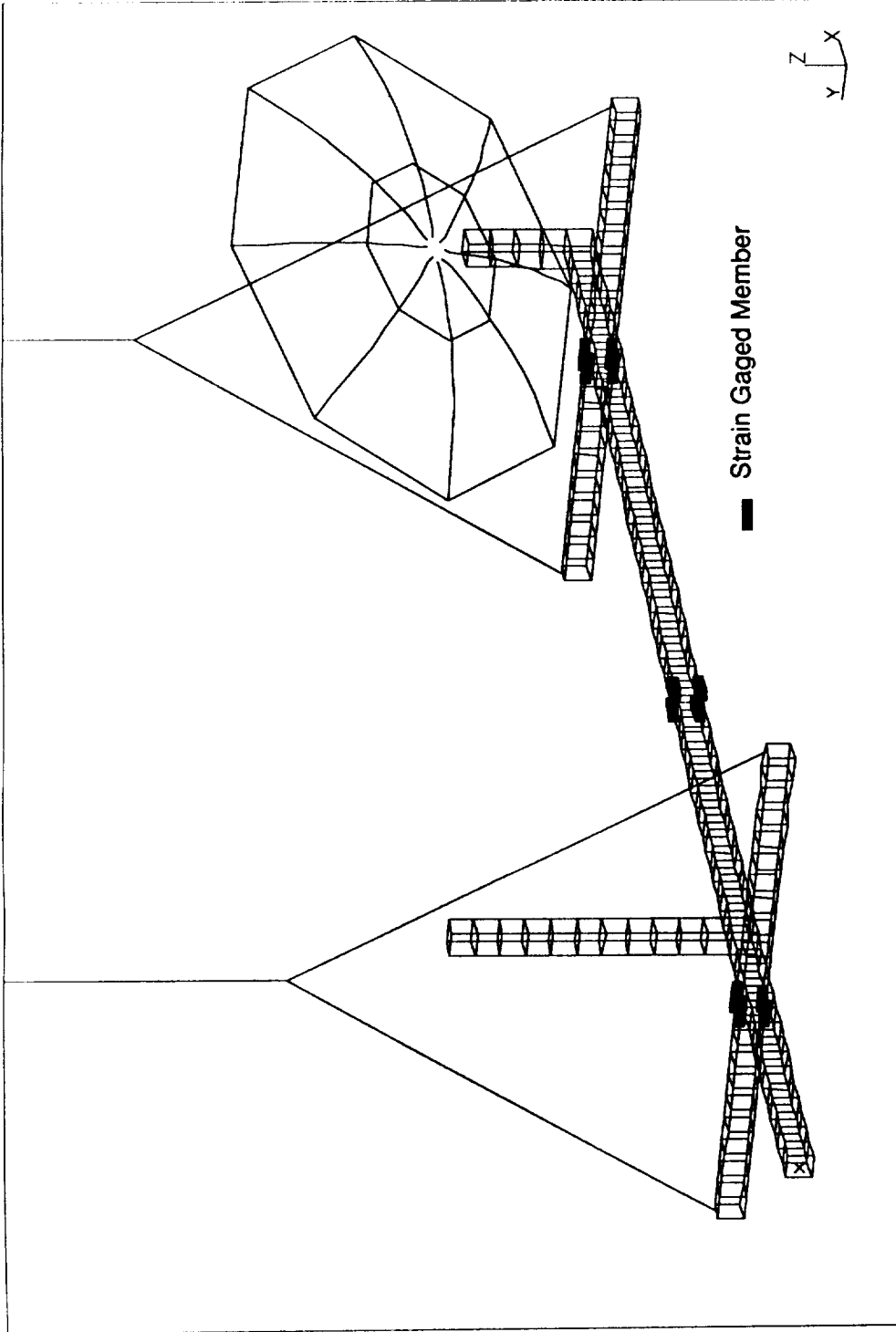


Figure 15. Strain gaged member locations

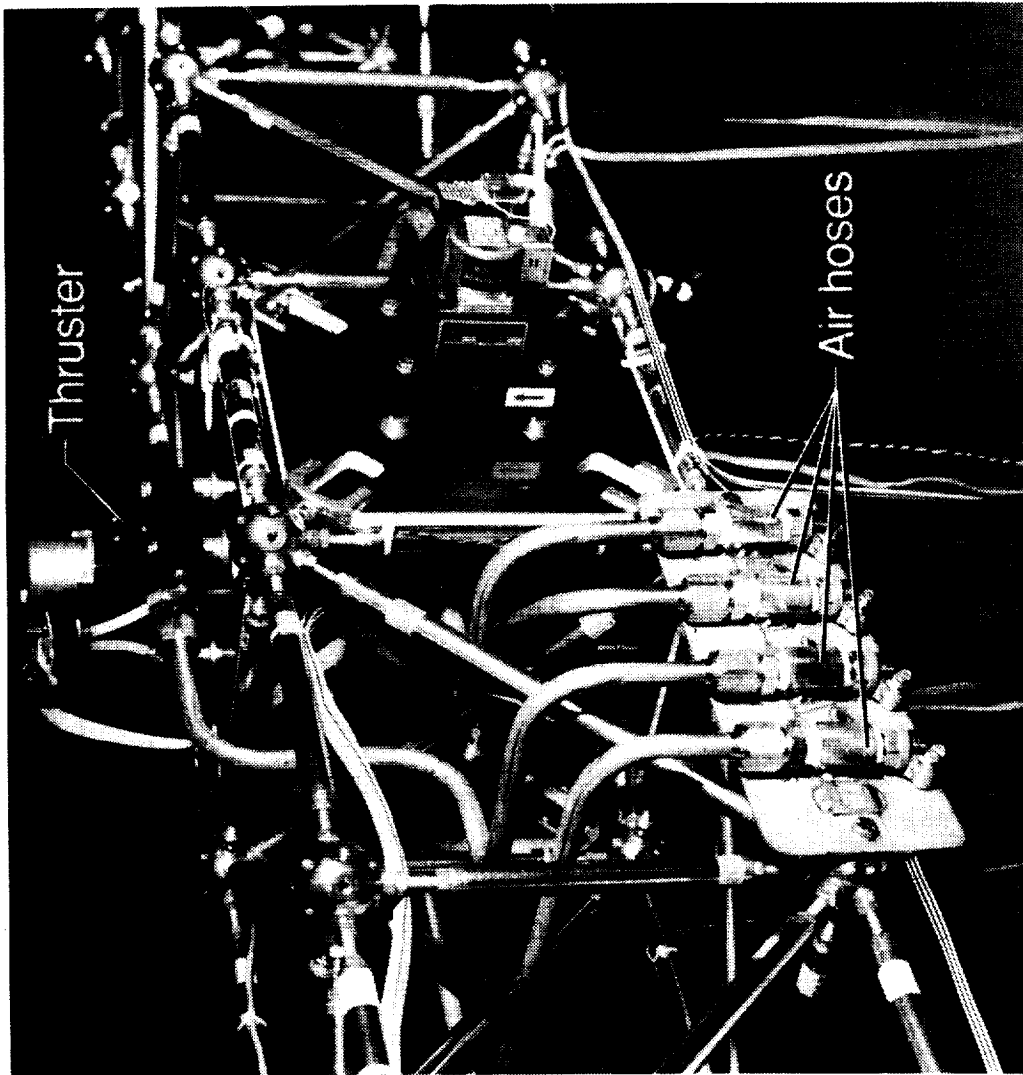


Figure 16. Photograph of thruster mounting

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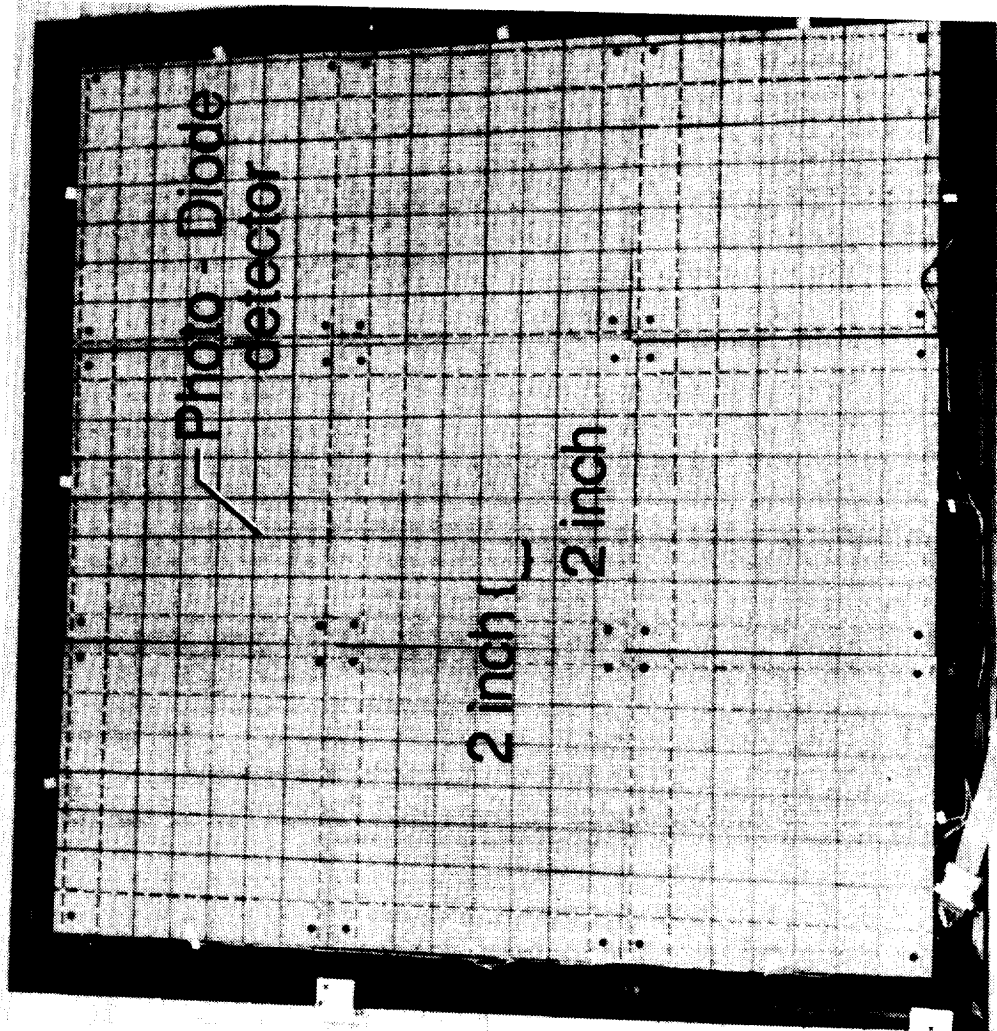


Figure 17. LOS scoring detector

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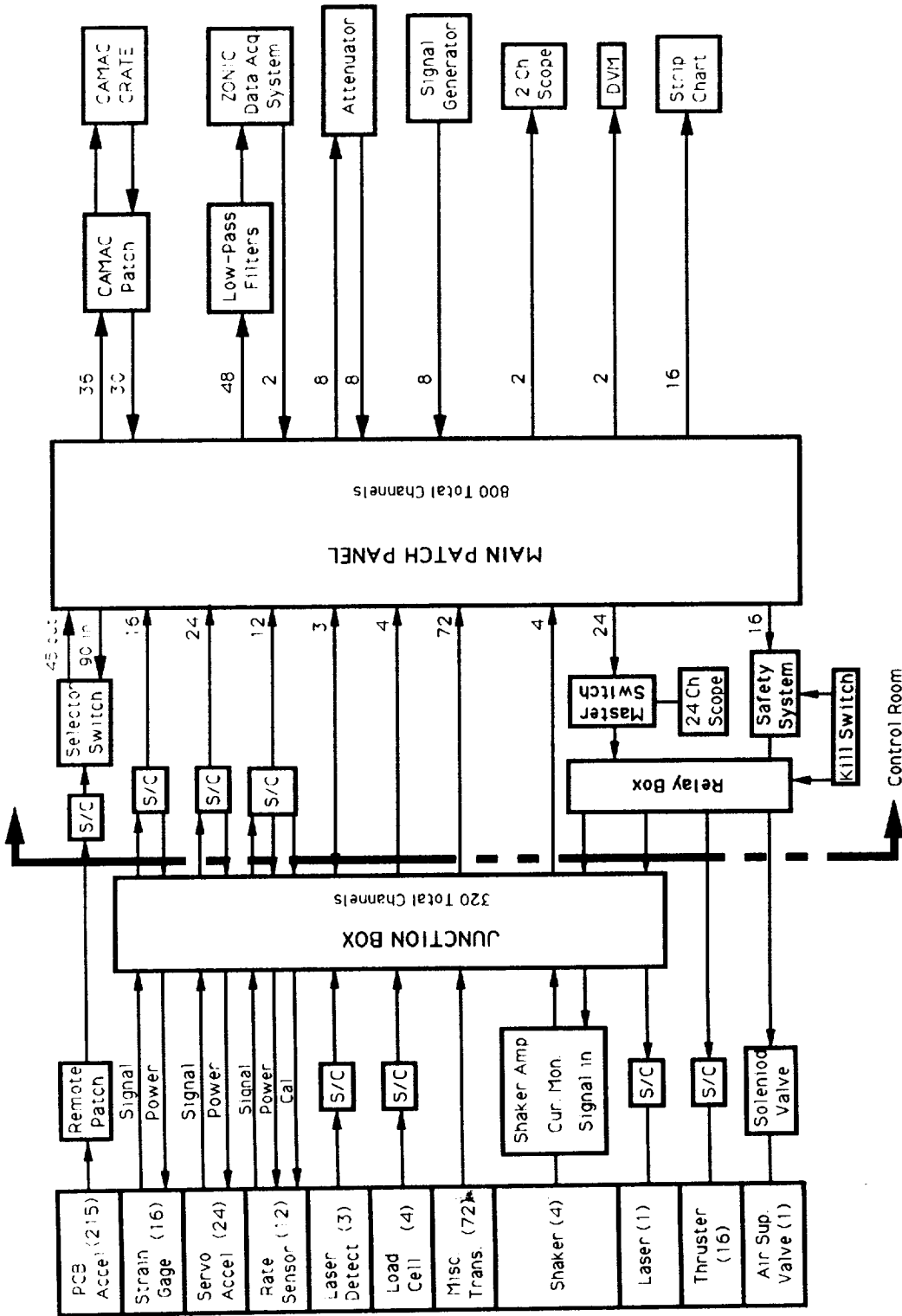


Figure 18. Instrumentation signal flow schematic

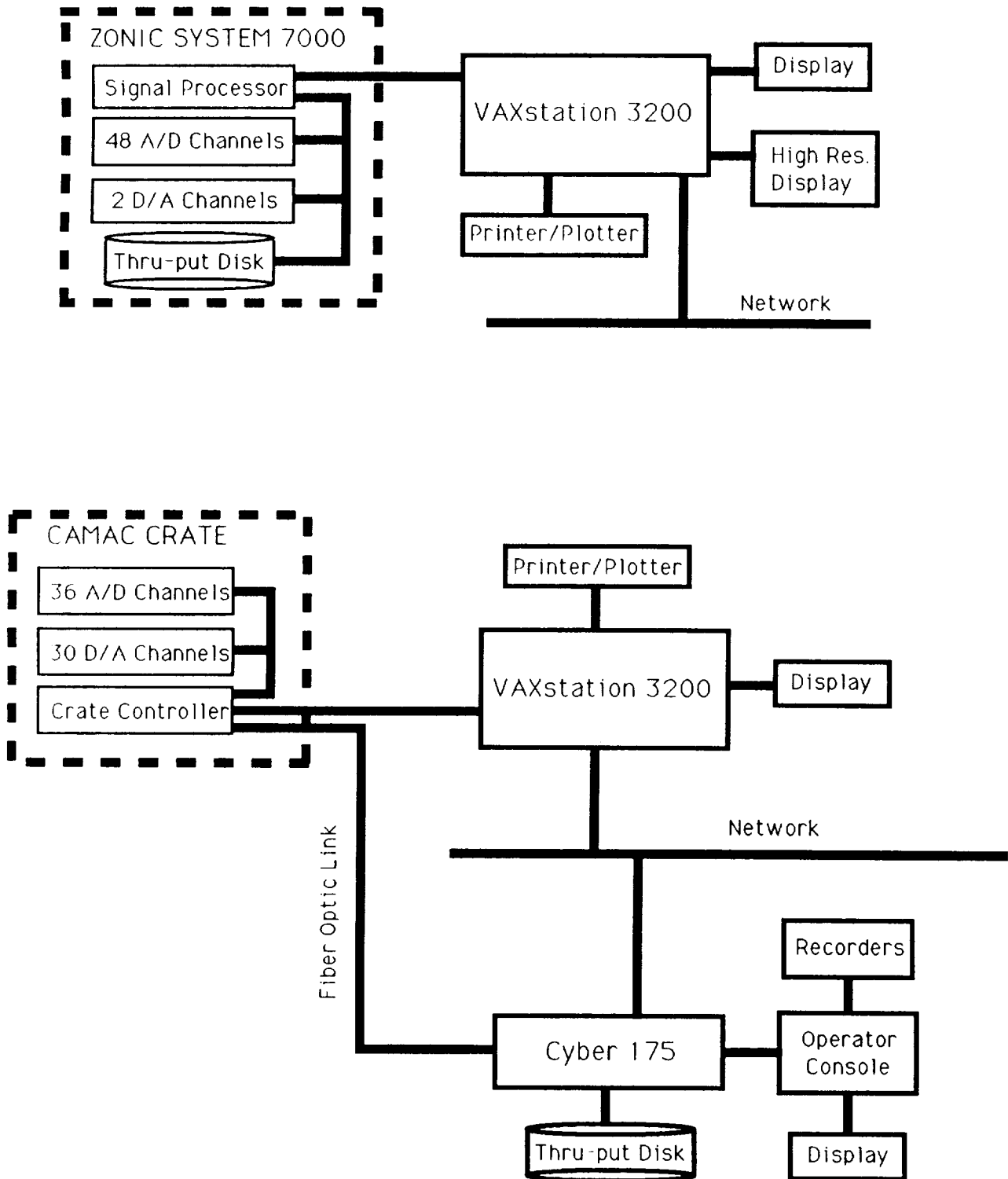


Figure 19. Data acquisition systems

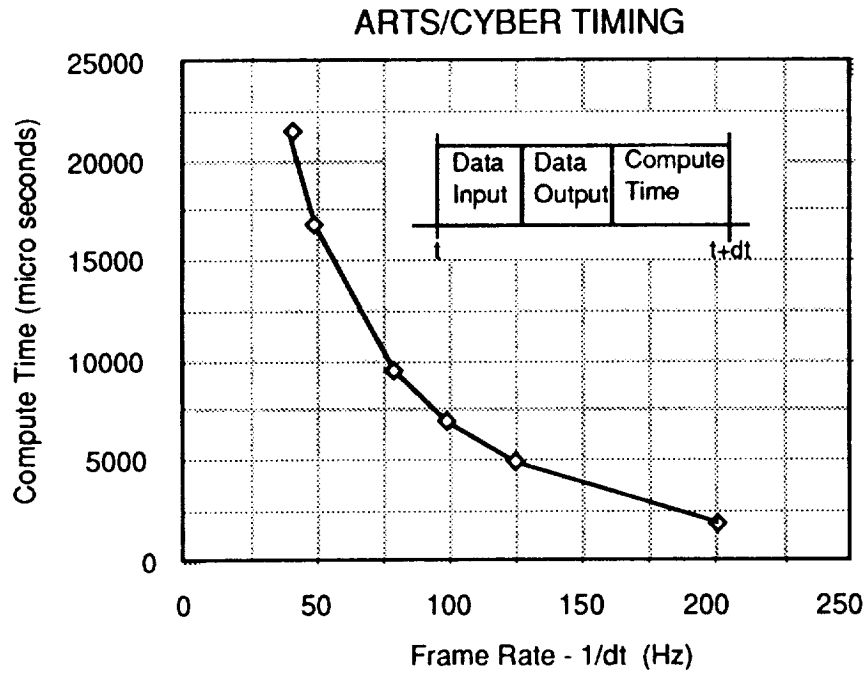


Figure 20. Cyber 175 real-time compute speed

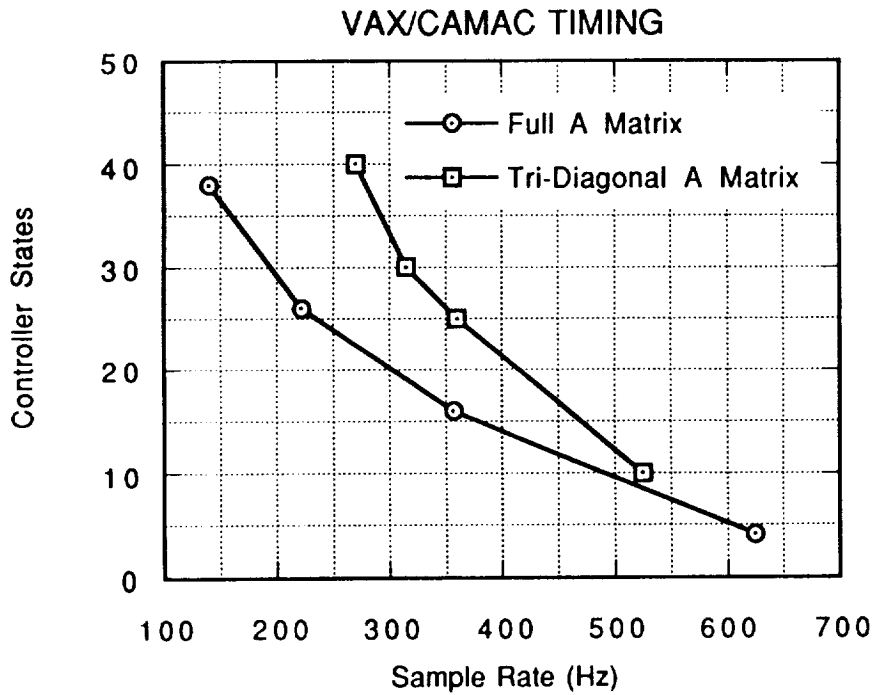


Figure 21. VAX 3200 real-time controller update rate with 8 inputs and 8 outputs

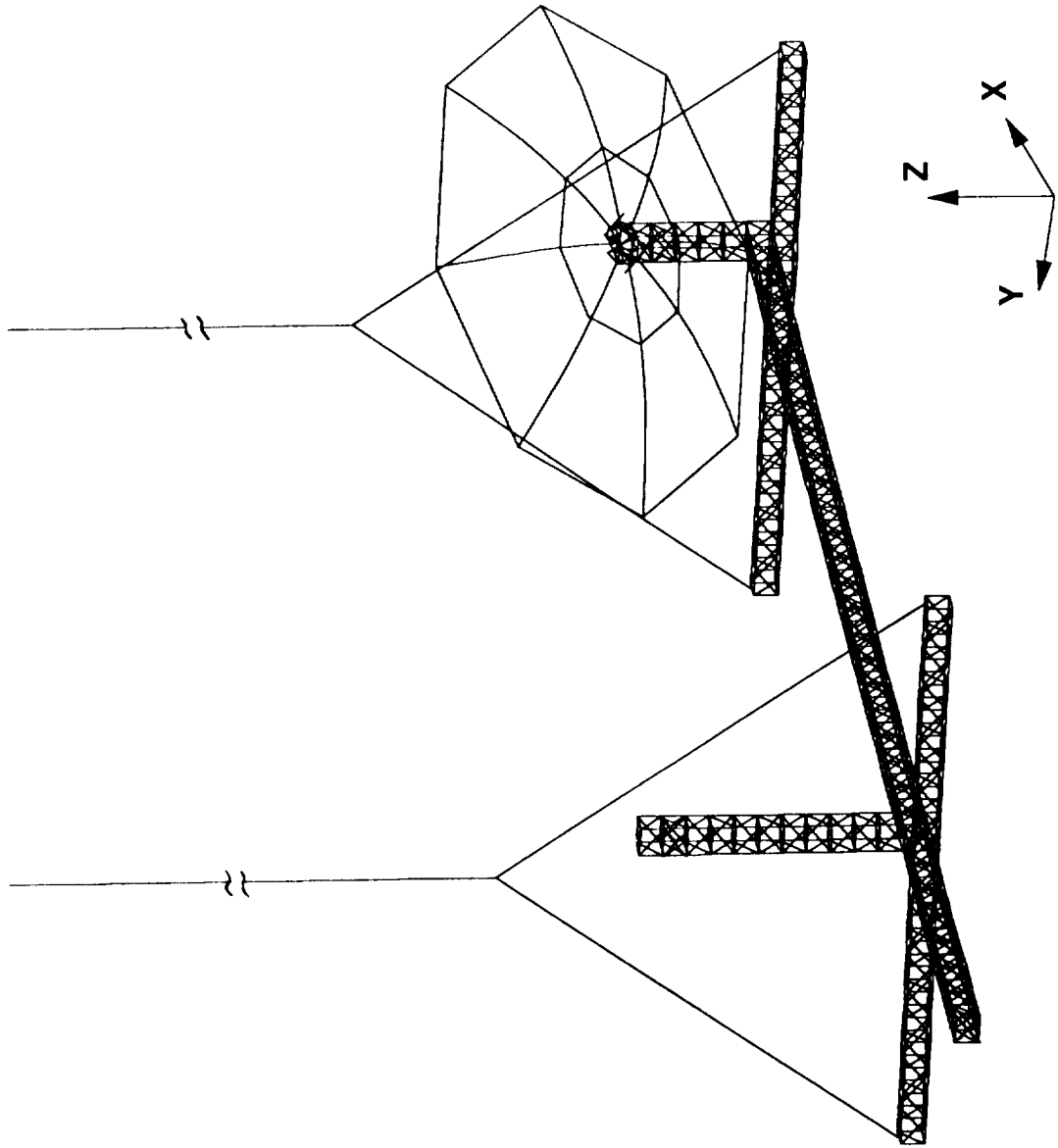


Figure 22. Finite Element model of CEM tested

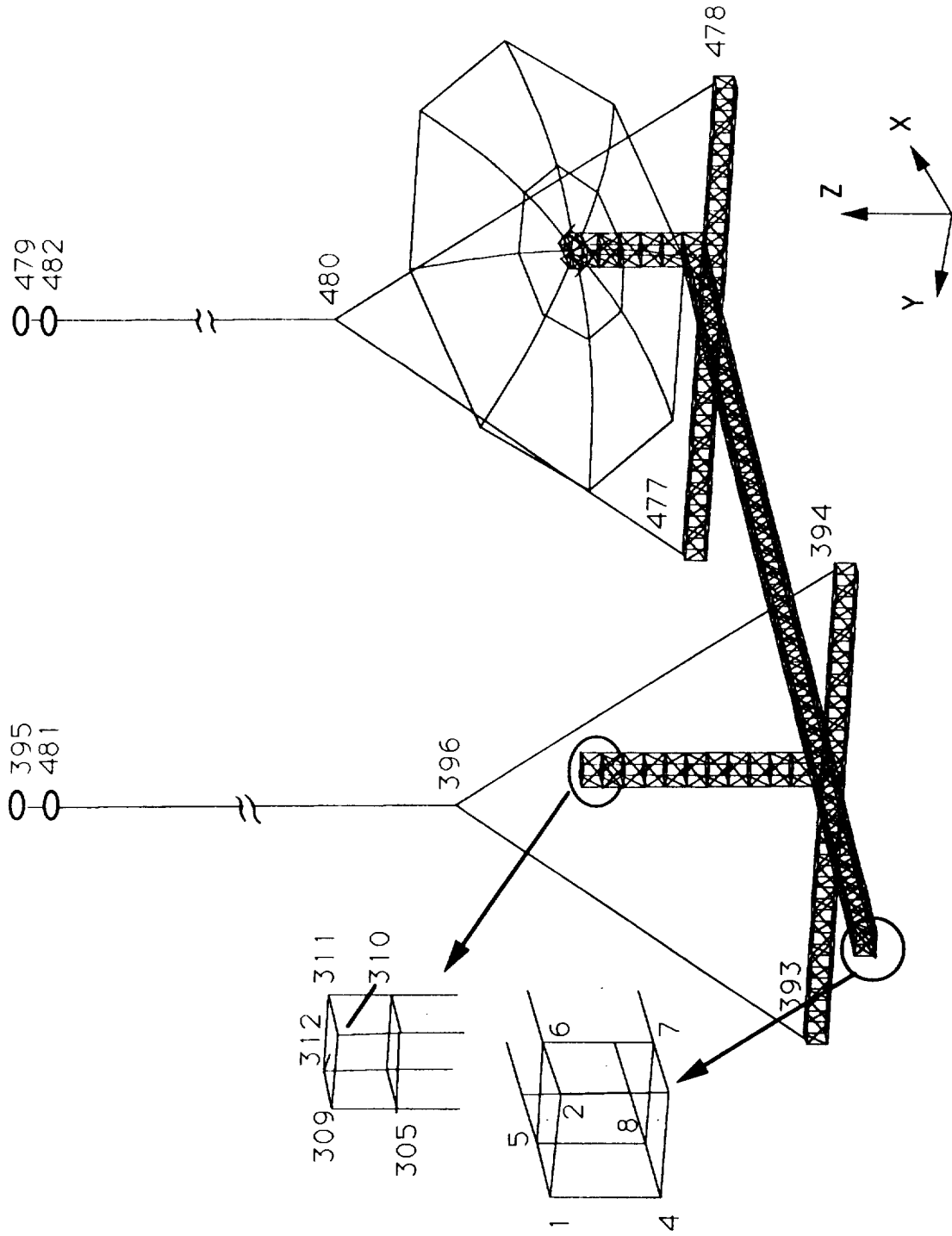
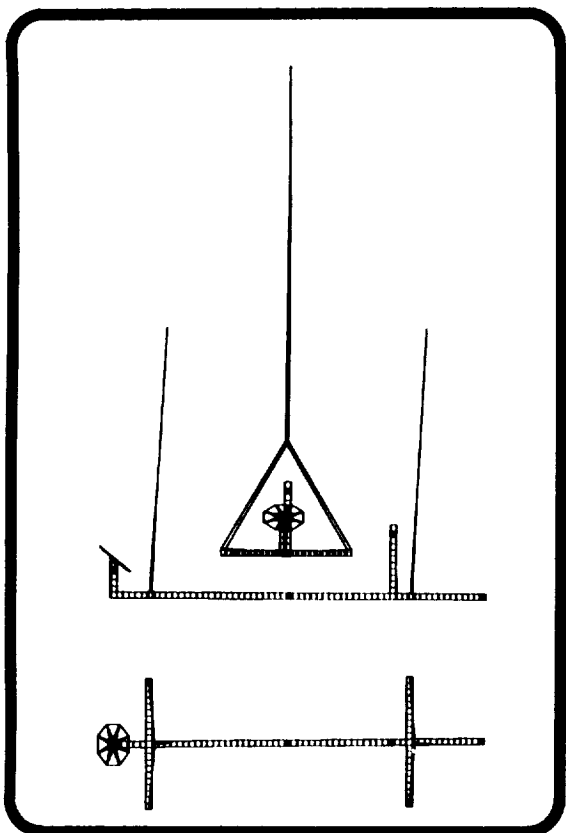
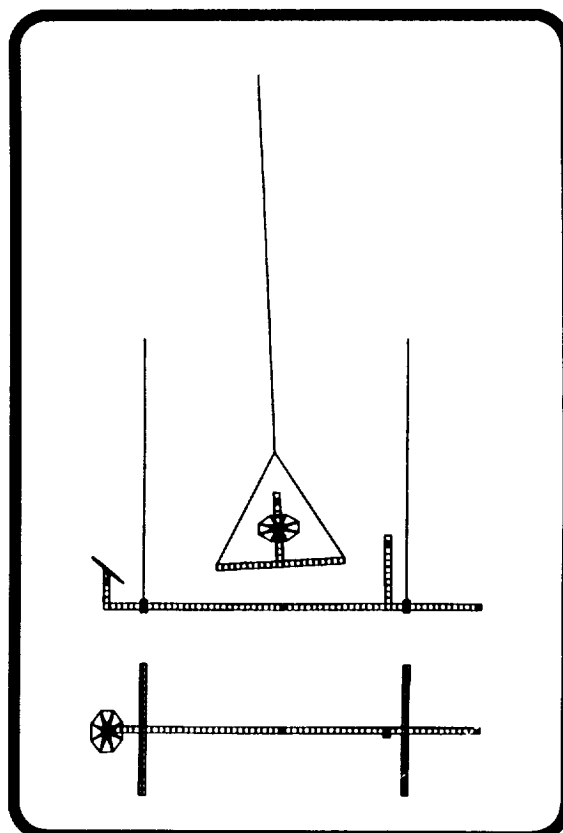
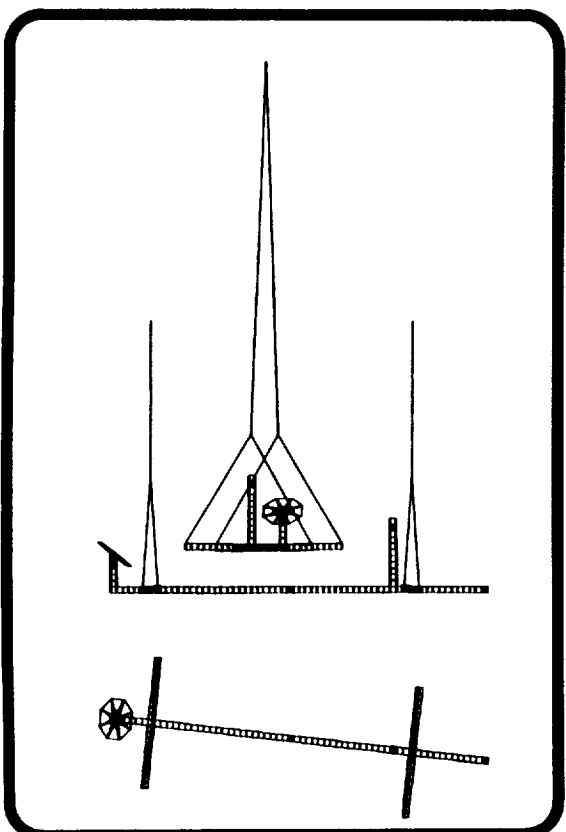
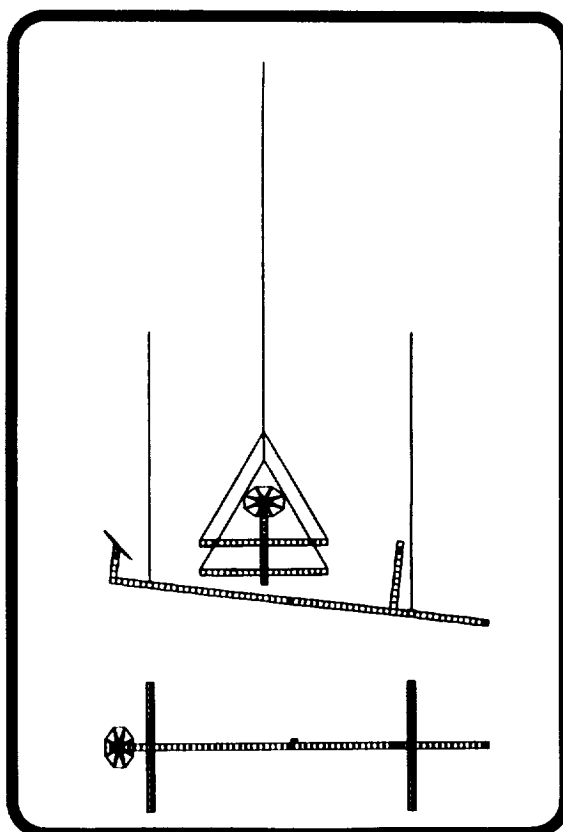


Figure 23. Typical grid point numbering of the finite element model

Figure 24. Mode 1, $f=0.14711$ HzFigure 25. Mode 2, $f=0.14906$ HzFigure 26. Mode 3, $f=0.15521$ HzFigure 27. Mode 4, $f=0.73008$ Hz

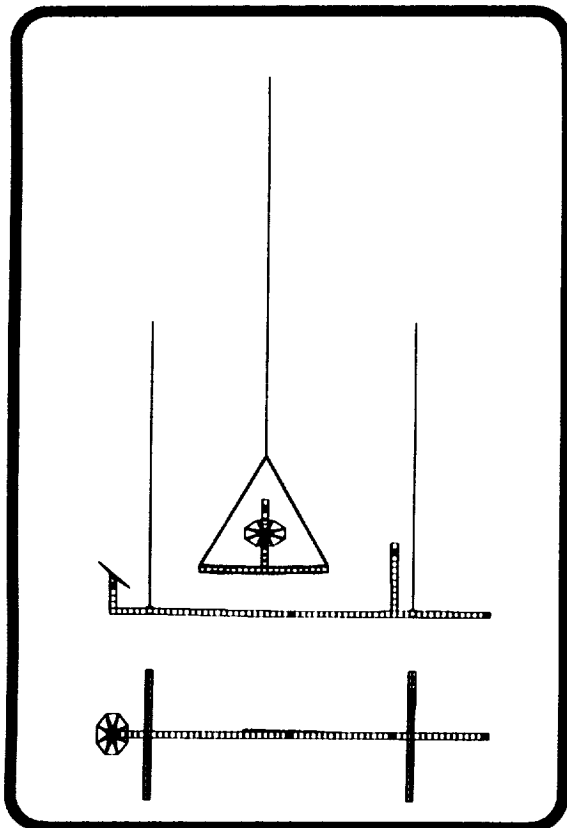


Figure 28. Mode 5, $f=0.74781$ Hz

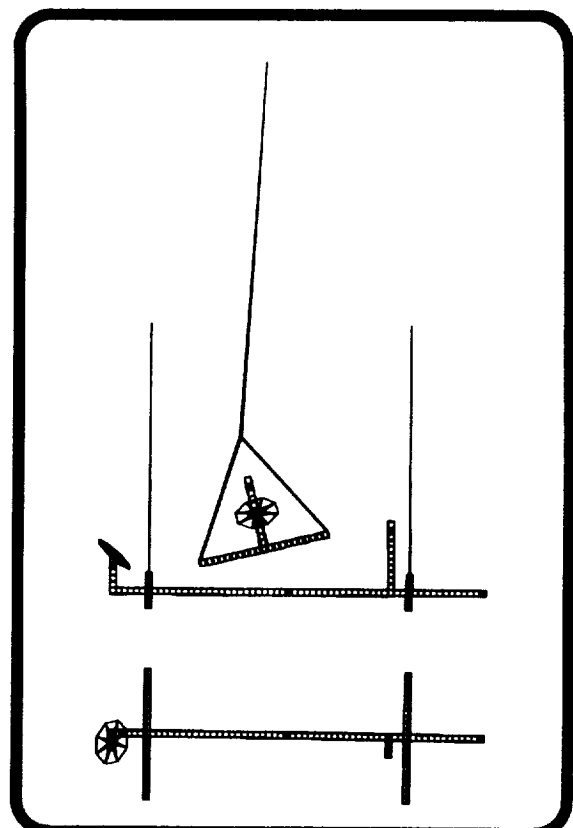


Figure 29. Mode 6, $f=0.87398$ Hz

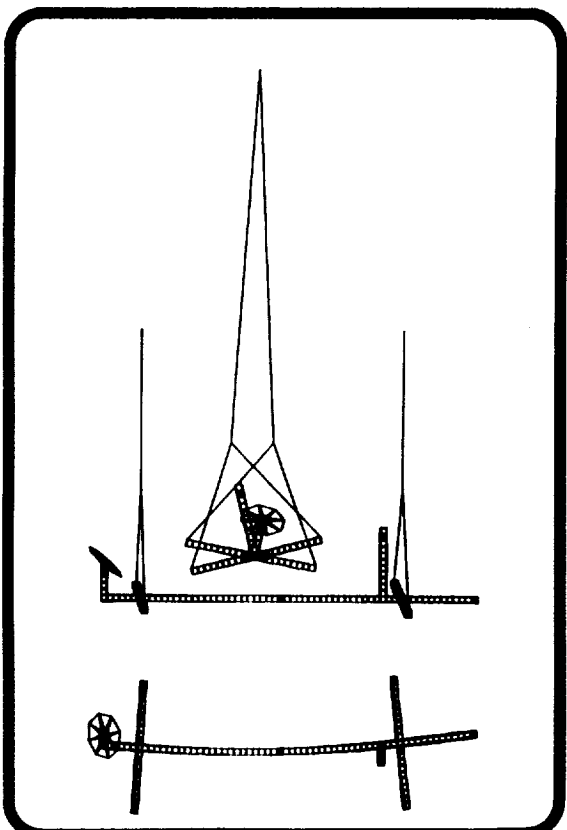


Figure 30. Mode 7, $f=1.4735$ Hz

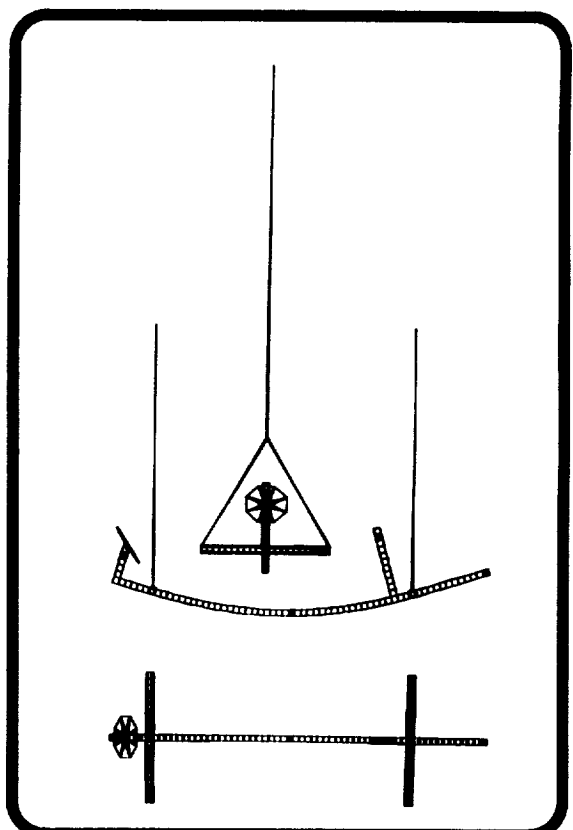


Figure 31. Mode 8, $f=1.7382$ Hz

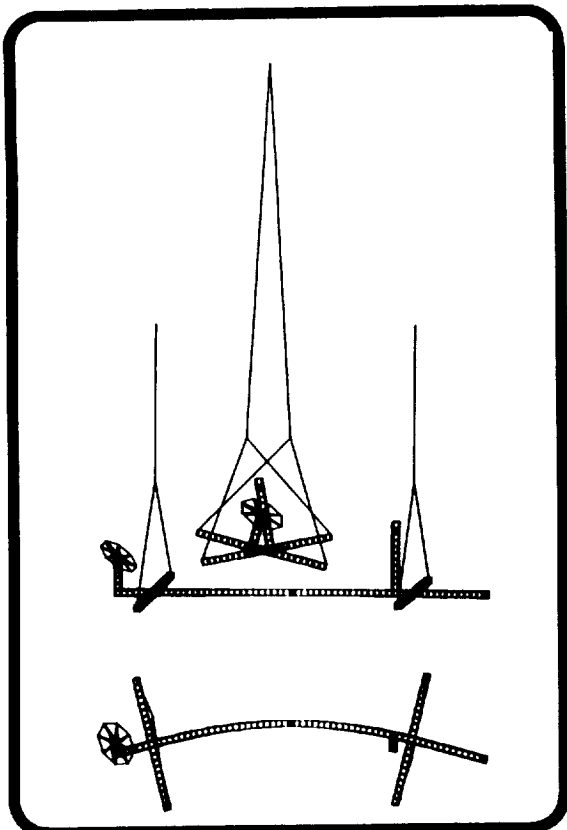


Figure 32. Mode 9, $f=1.8830$ Hz

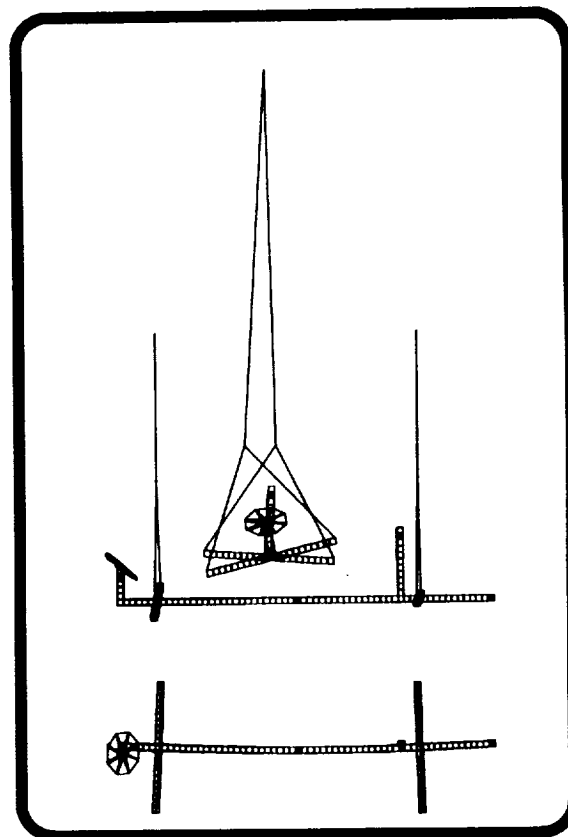


Figure 33. Mode 10, $f=2.3013$ Hz

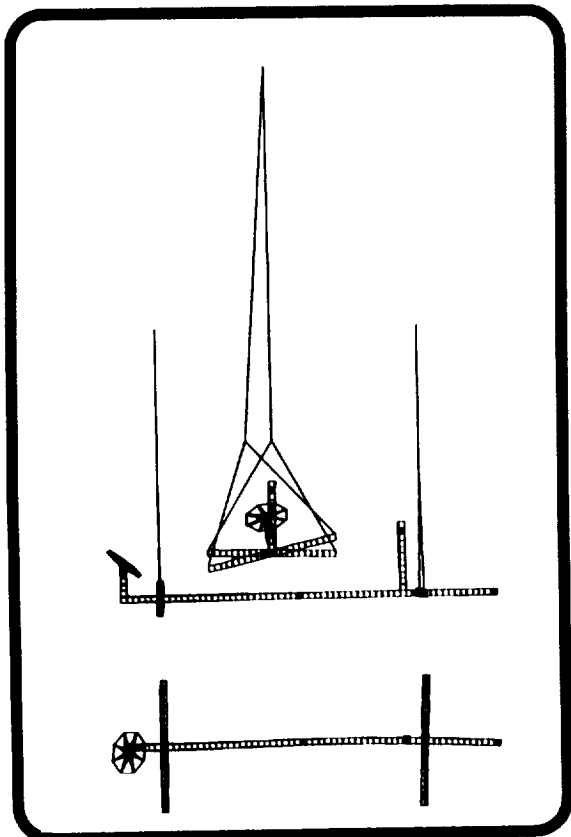


Figure 34. Mode 11, $f=2.5348$ Hz

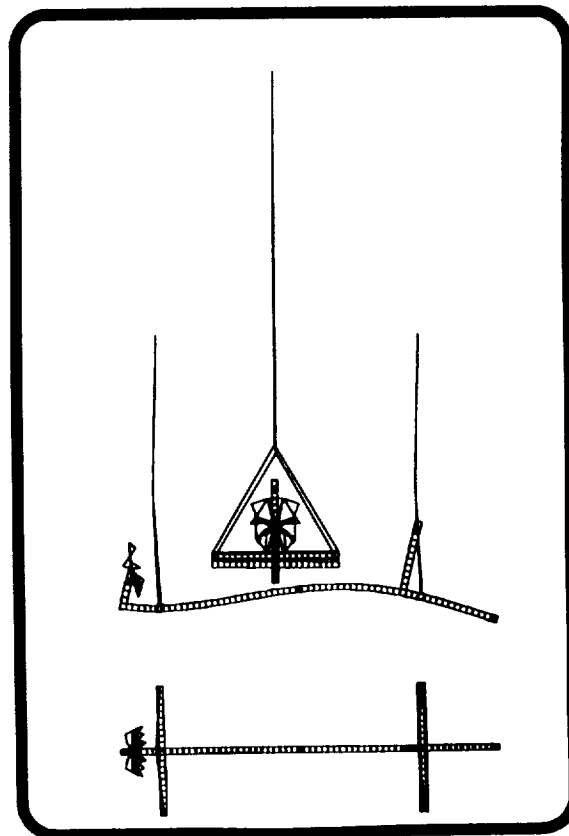


Figure 35. Mode 12, $f=2.8385$ Hz

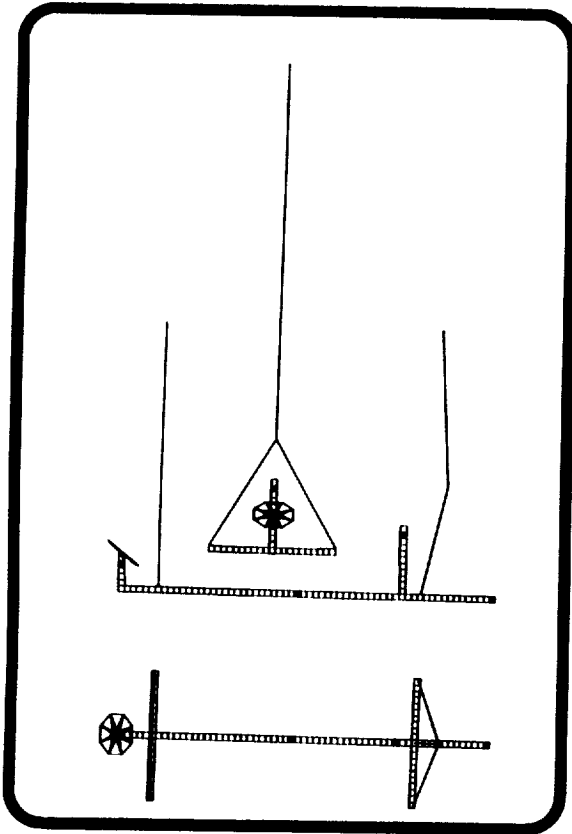


Figure 36. Mode 13, $f=3.4194$ Hz

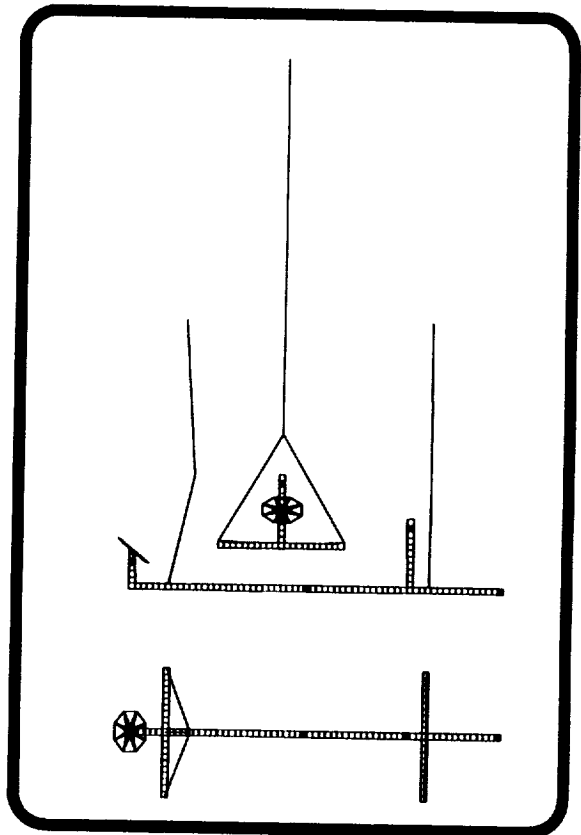


Figure 37. Mode 14, $f=3.4863$ Hz

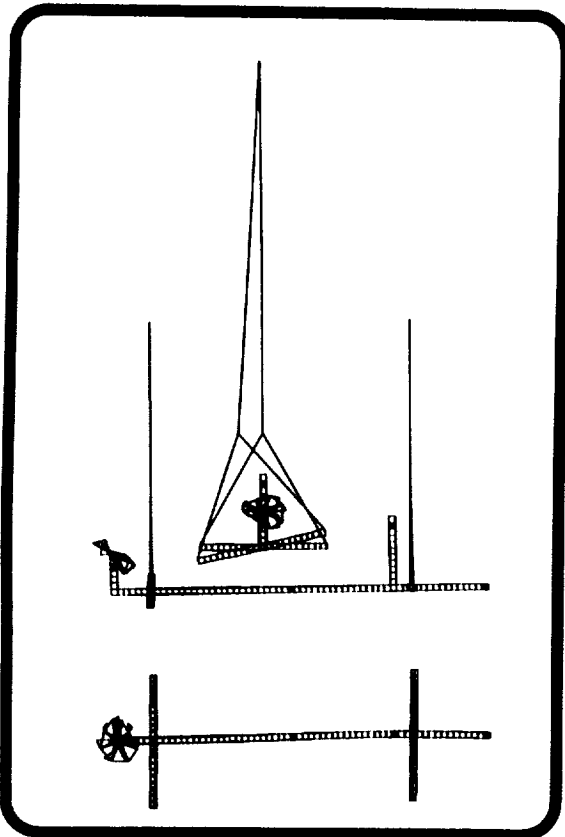


Figure 38. Mode 15, $f=3.5874$ Hz

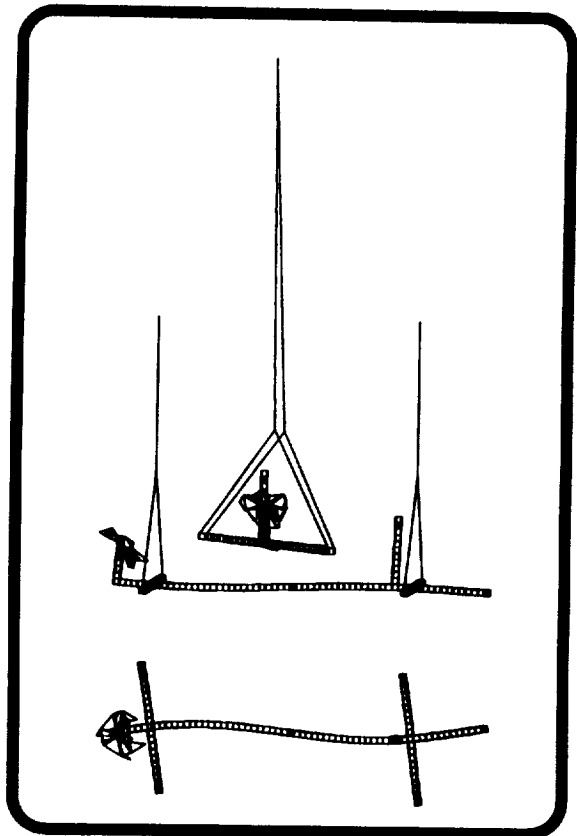
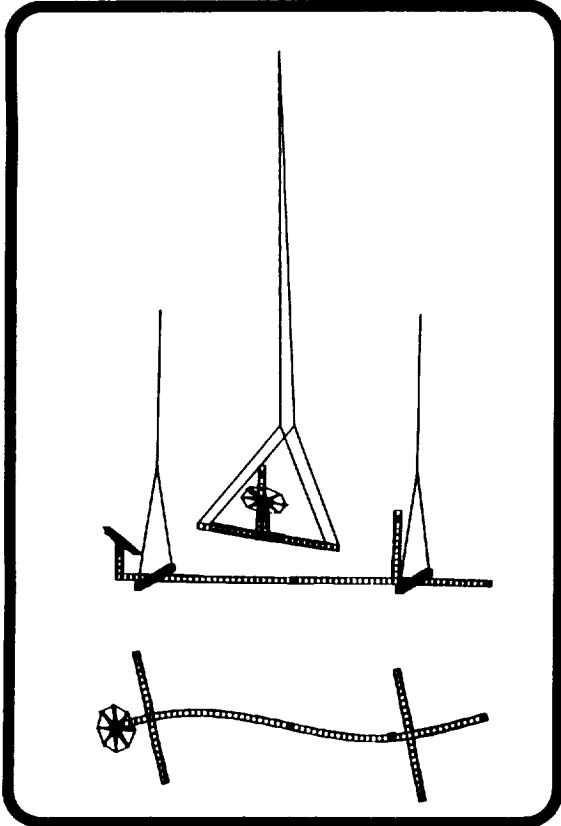
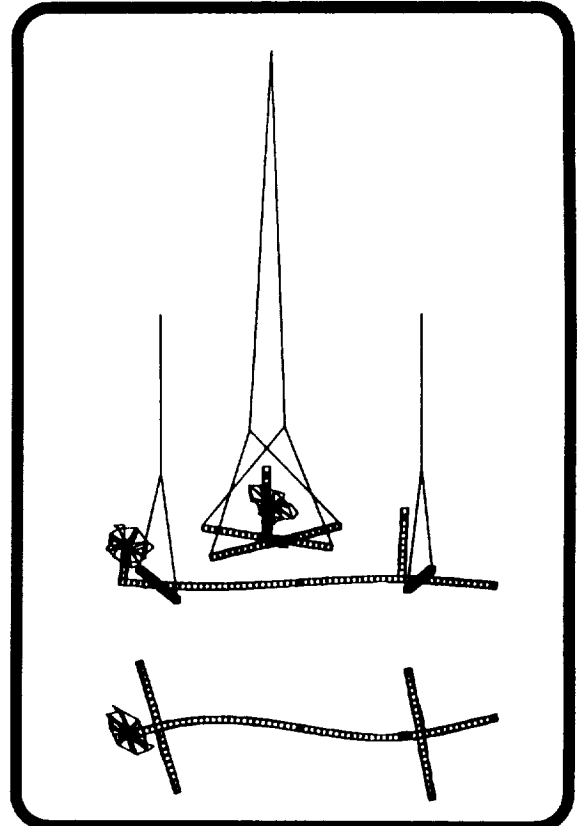
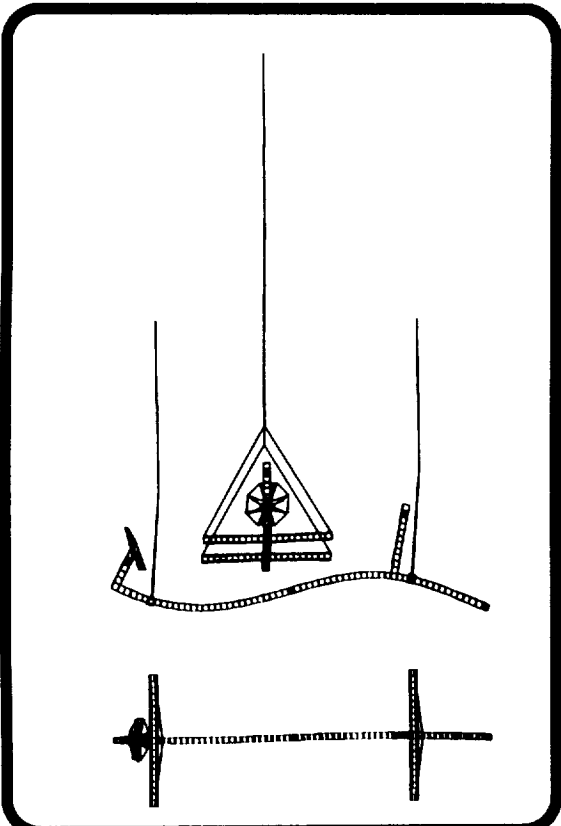
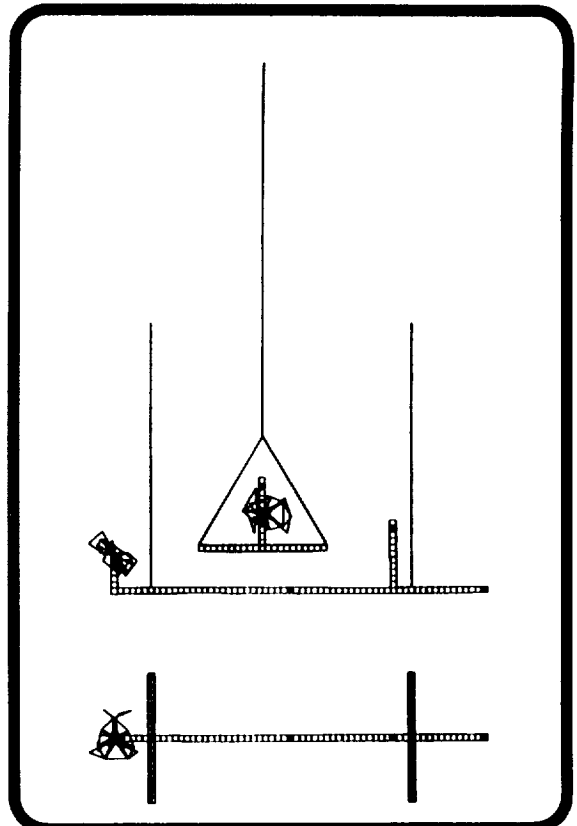


Figure 39. Mode 16, $f=4.0146$ Hz

Figure 40. Mode 17, $f=4.0322$ HzFigure 41. Mode 18, $f=4.2057$ HzFigure 41. Mode 19, $f=4.3918$ HzFigure 42. Mode 20, $f=5.0294$ Hz

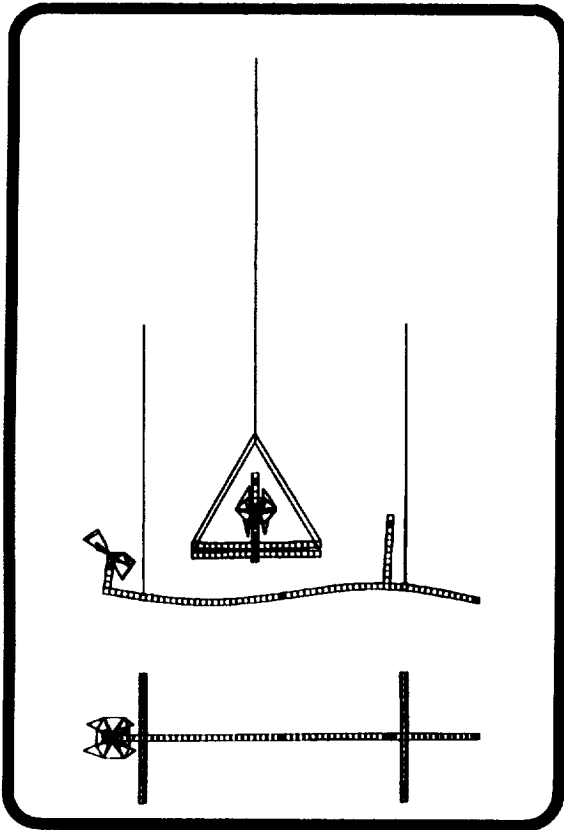


Figure 44. Mode 21, $f=5.0339$ Hz

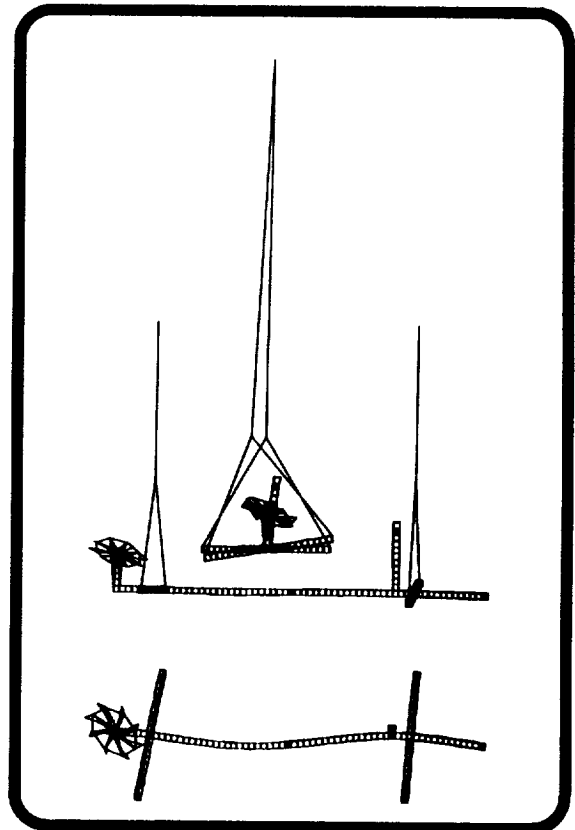


Figure 45. Mode 22, $f=5.5013$ Hz

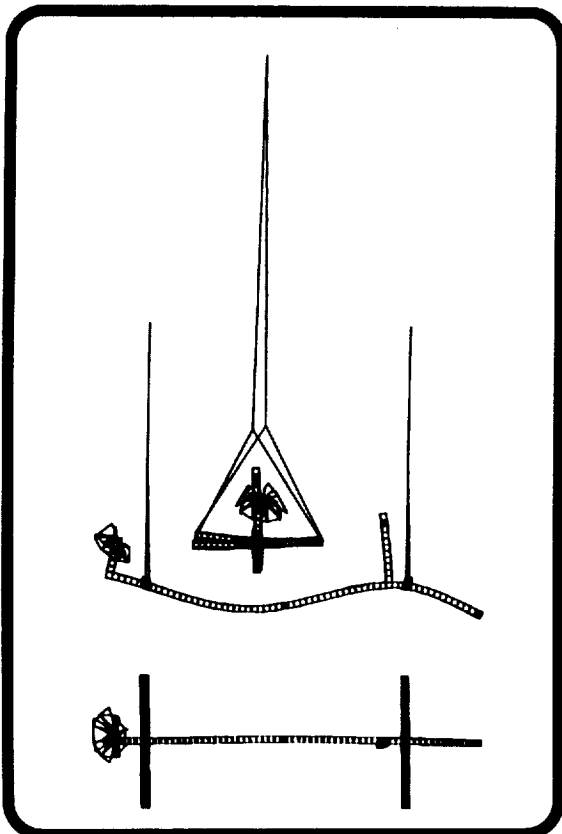


Figure 46. Mode 23, $f=6.1795$ Hz

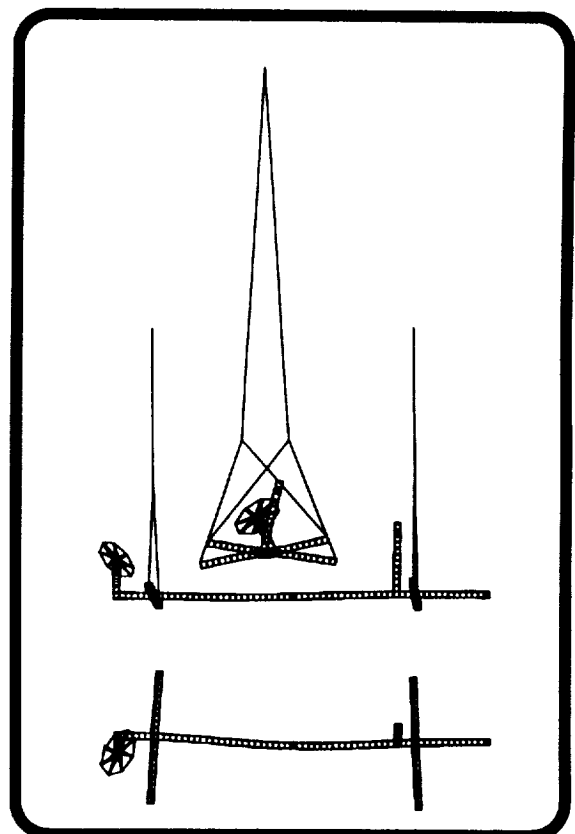


Figure 47. Mode 24, $f=6.2308$ Hz

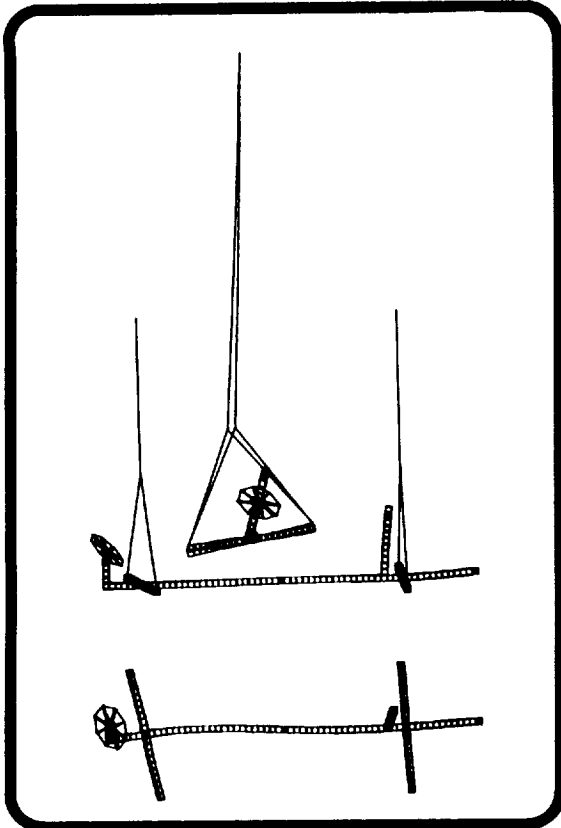


Figure 48. Mode 25, $f=6.4709$ Hz

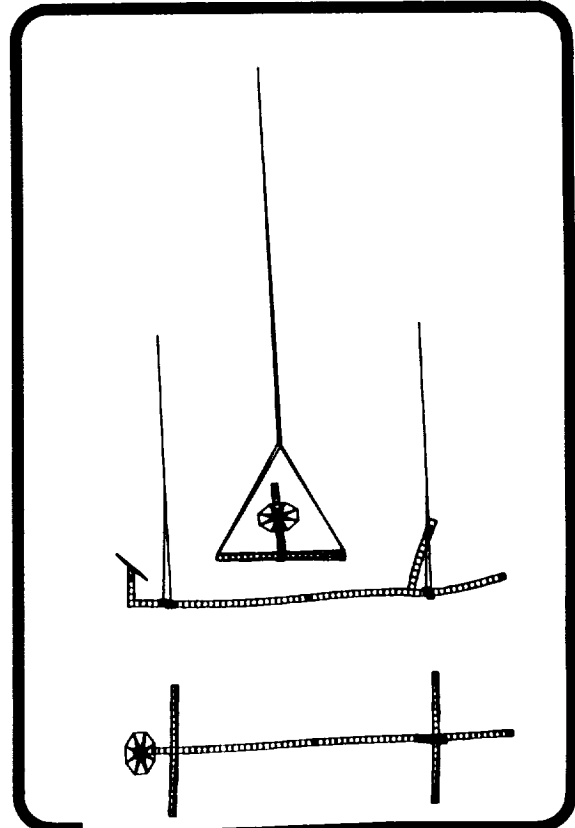


Figure 49. Mode 26, $f=6.6699$ Hz

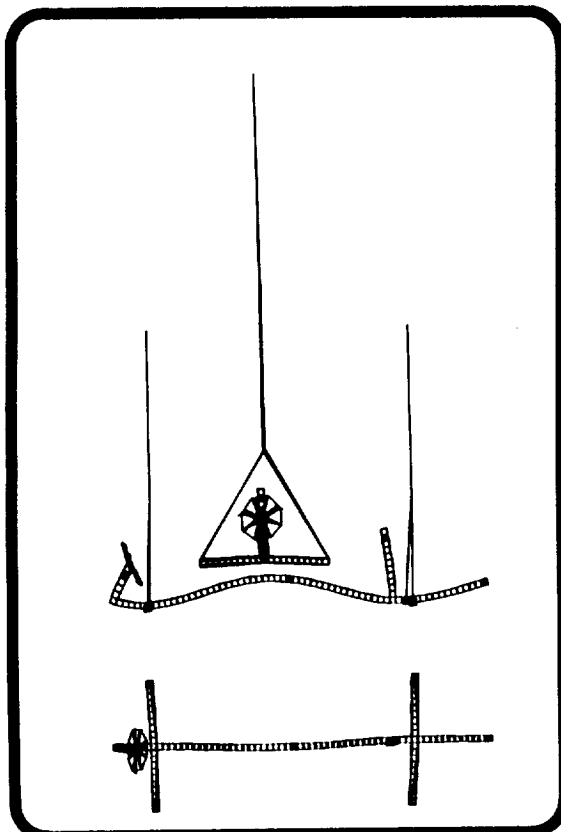


Figure 50. Mode 27, $f=7.3723$ Hz

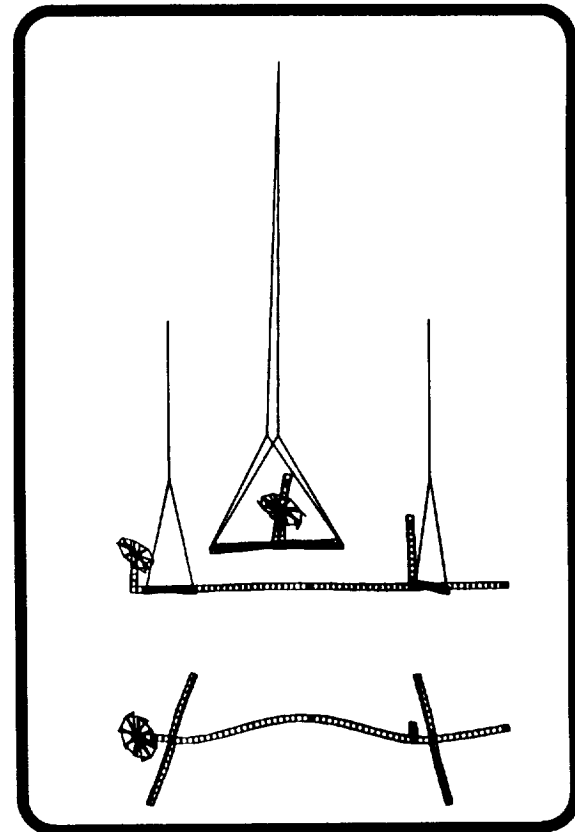


Figure 51. Mode 28, $f=8.2933$ Hz

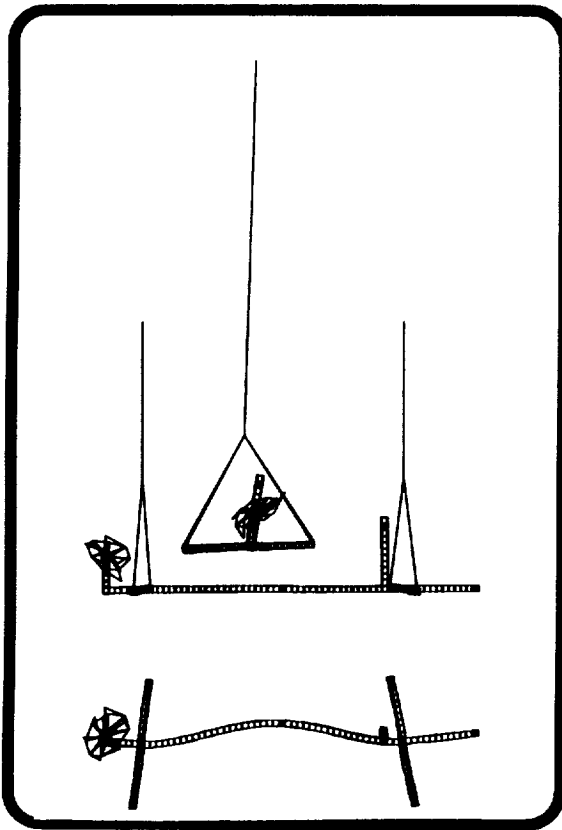


Figure 52. Mode 29, $f=8.4094$ Hz

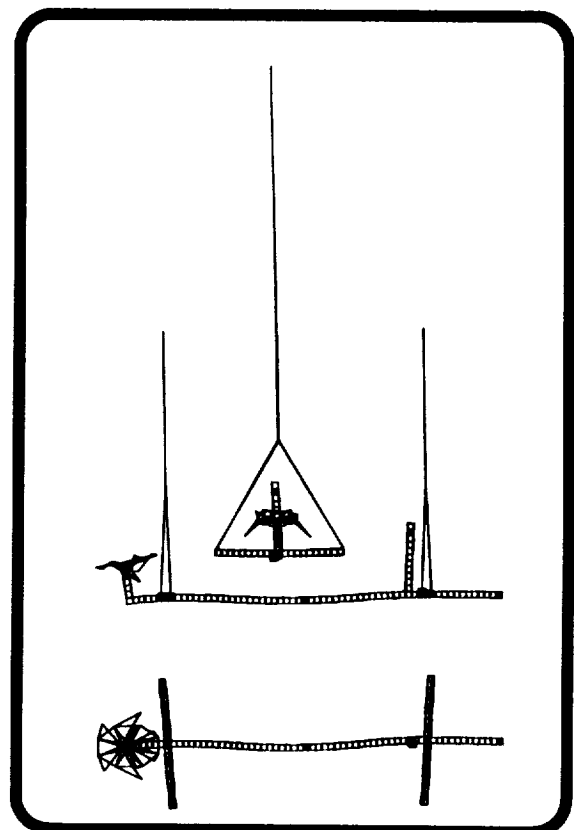


Figure 53. Mode 30, $f=8.4562$ Hz

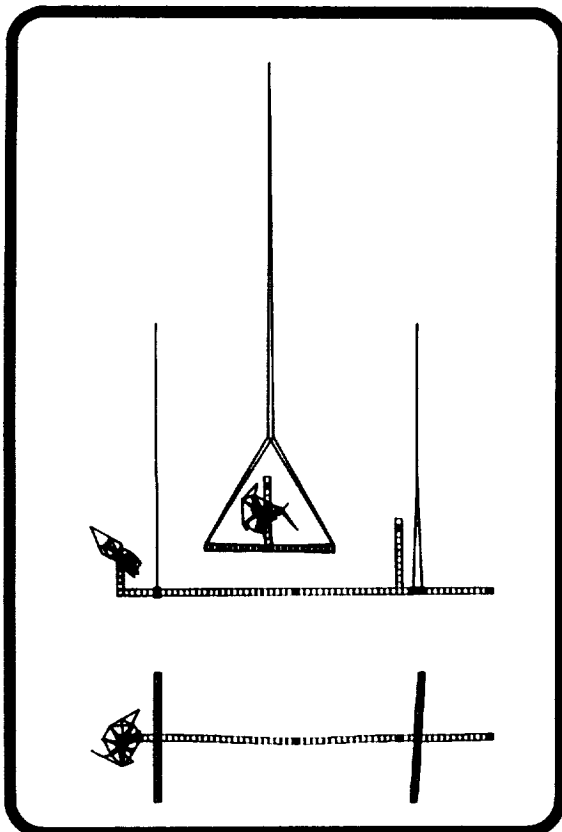


Figure 54. Mode 31, $f=8.8237$ Hz

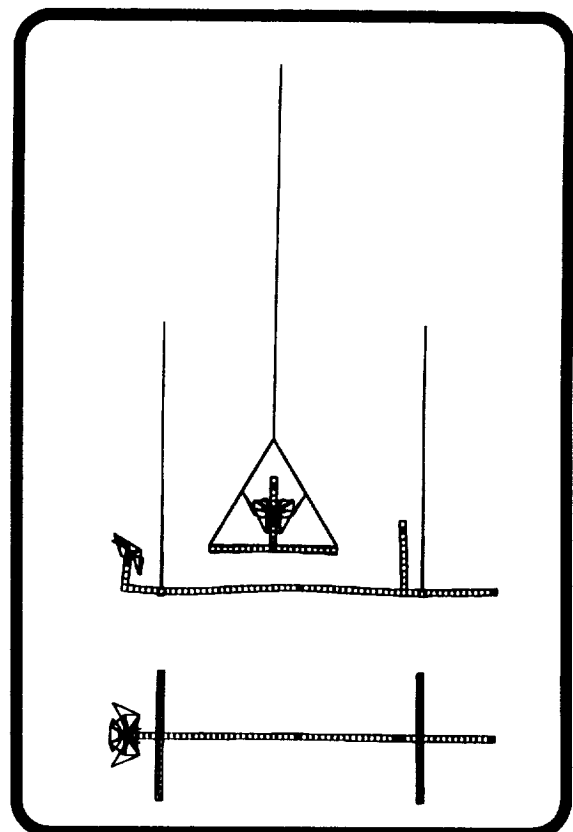


Figure 55. Mode 32, $f=8.9264$ Hz

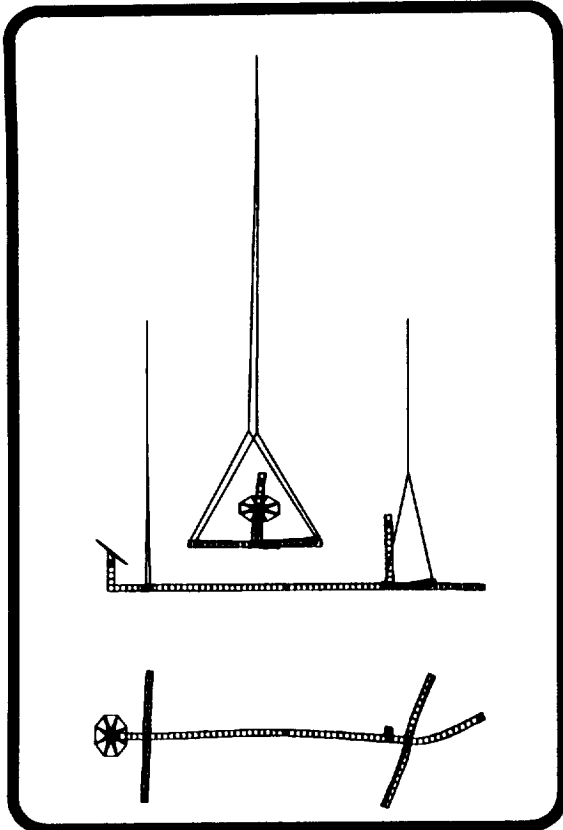


Figure 56. Mode 33, $f=8.9664$ Hz

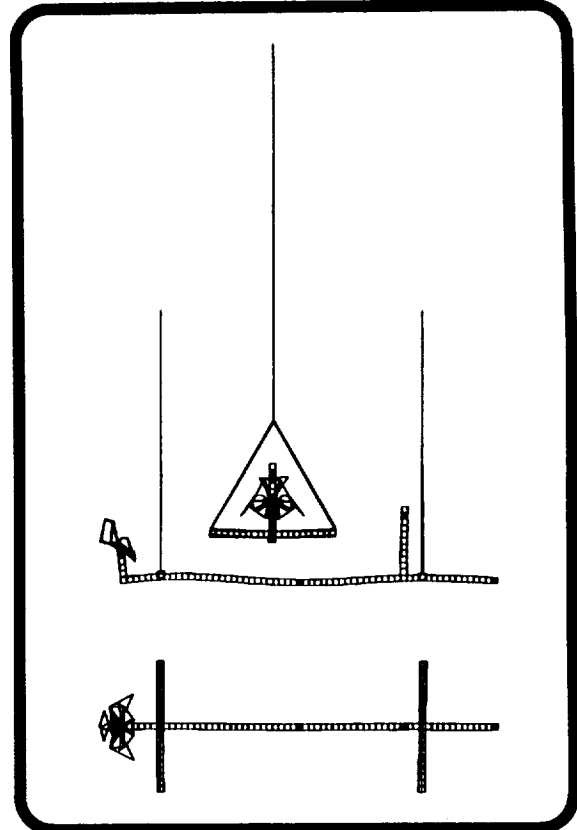


Figure 57. Mode 34, $f=9.2348$ Hz

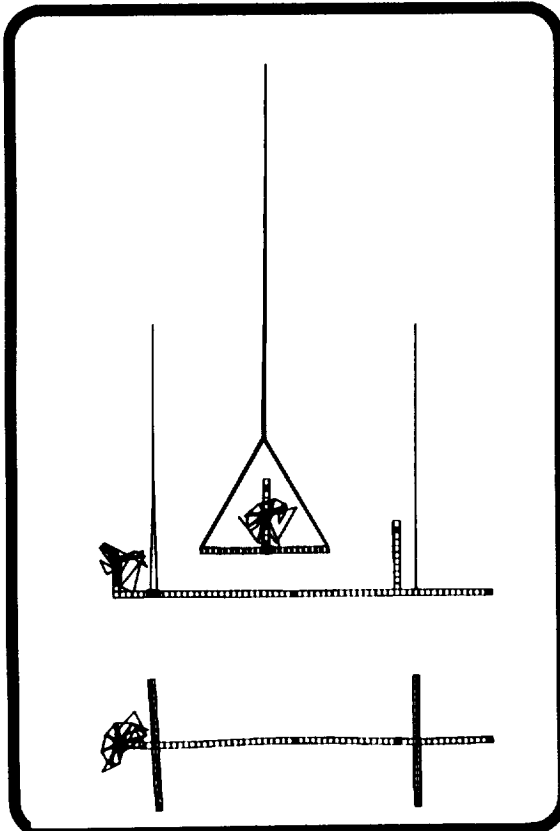


Figure 58. Mode 35, $f=9.5271$ Hz

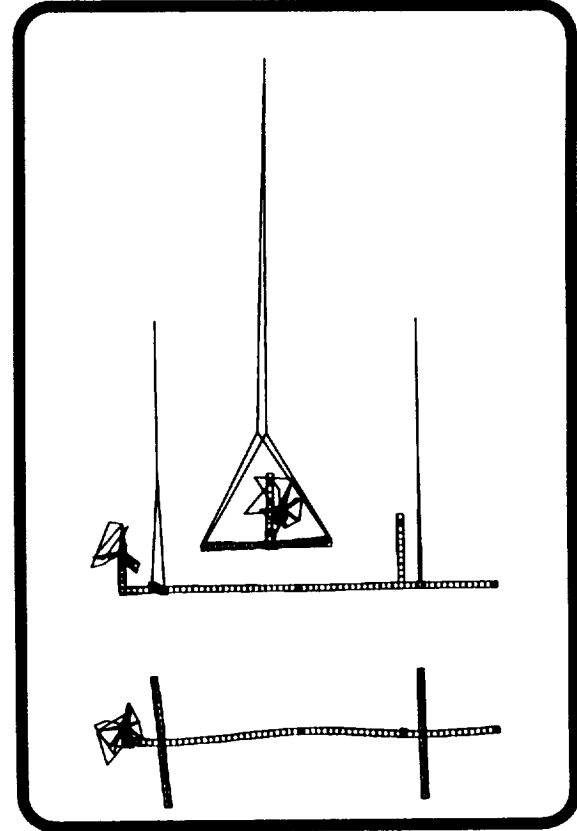
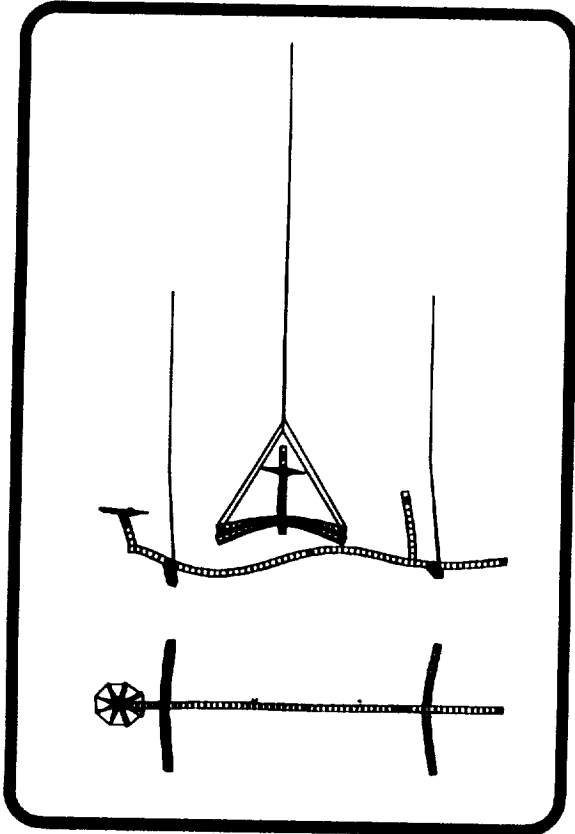
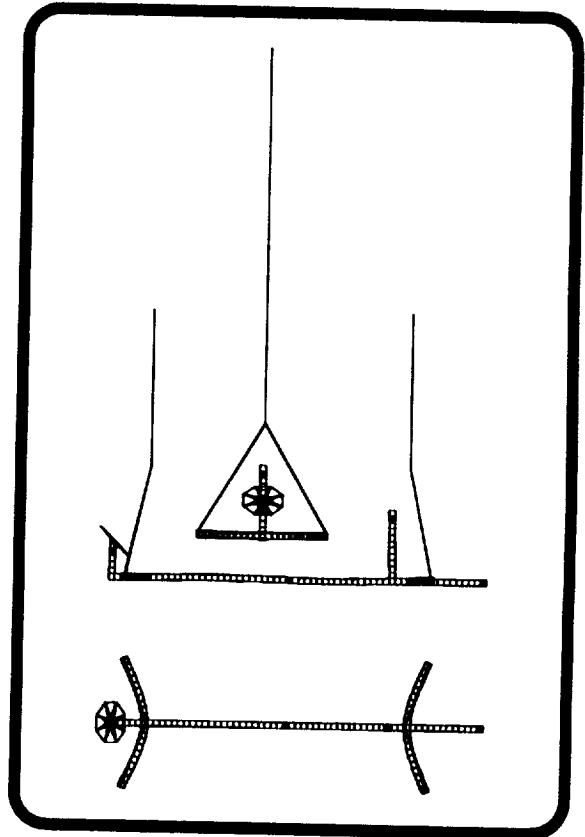
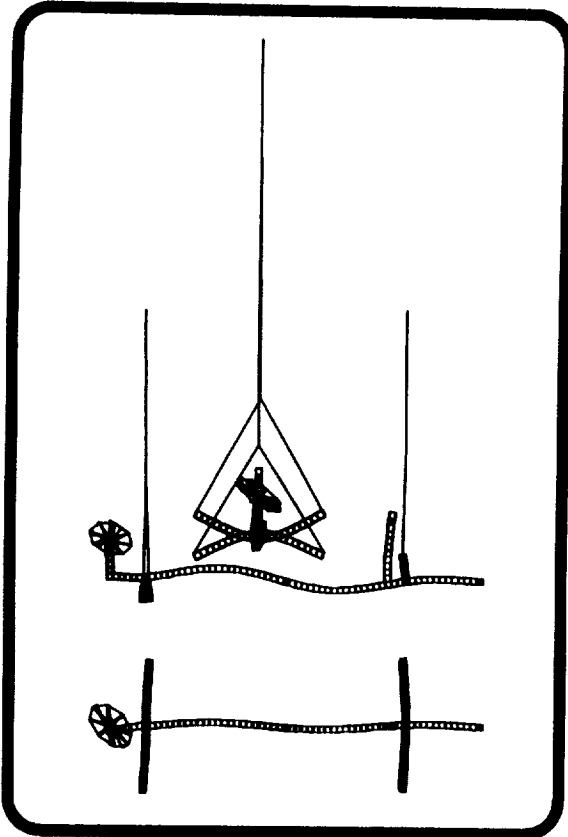
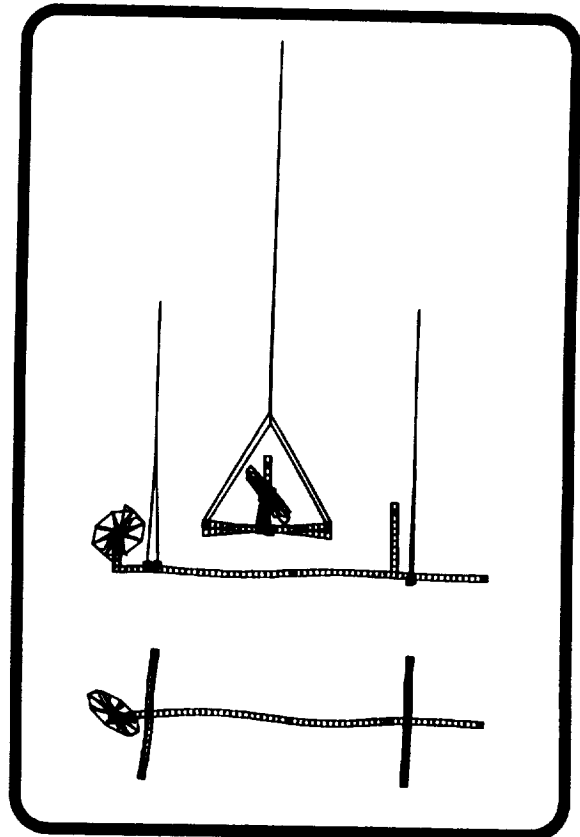


Figure 59. Mode 36, $f=9.9011$ Hz

Figure 60. Mode 37, $f=12.486$ HzFigure 61. Mode 38, $f=13.615$ HzFigure 62. Mode 39, $f=14.315$ HzFigure 63. Mode 40, $f=14.718$ Hz

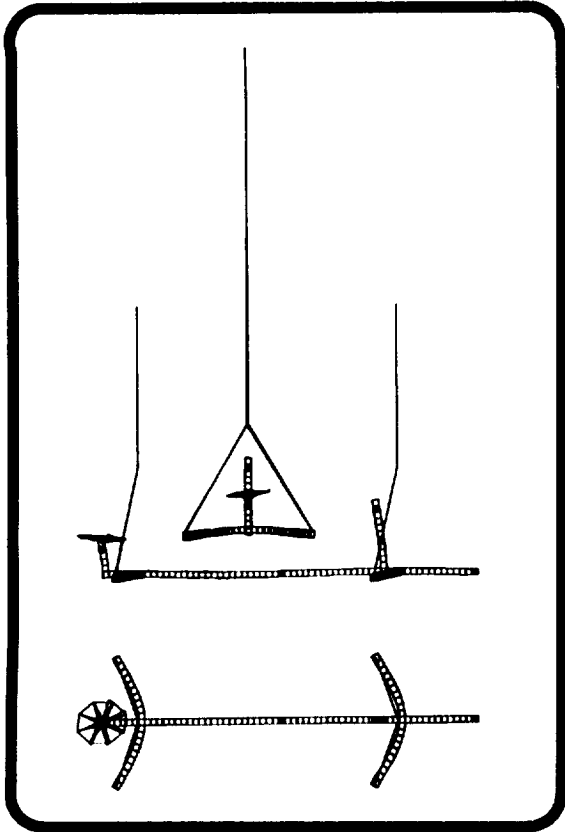


Figure 64. Mode 41, $f=15.886$ Hz

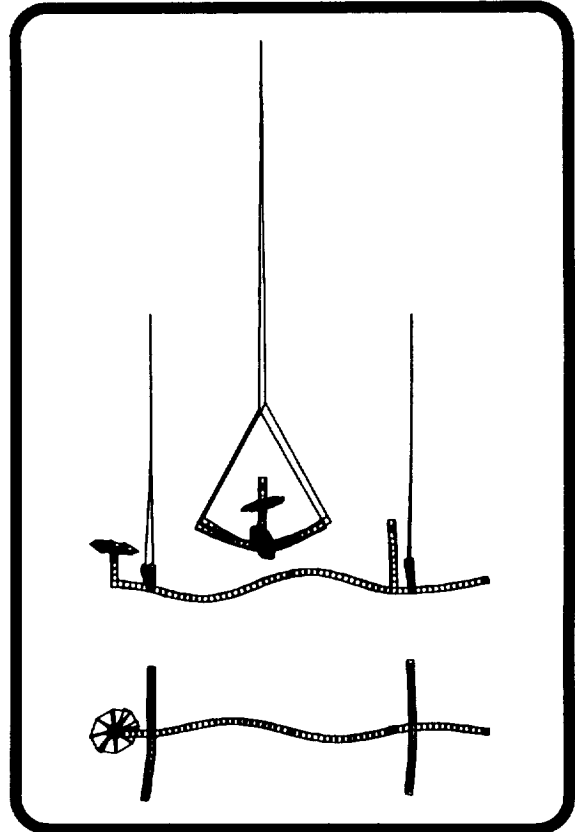


Figure 65. Mode 42, $f=16.853$ Hz

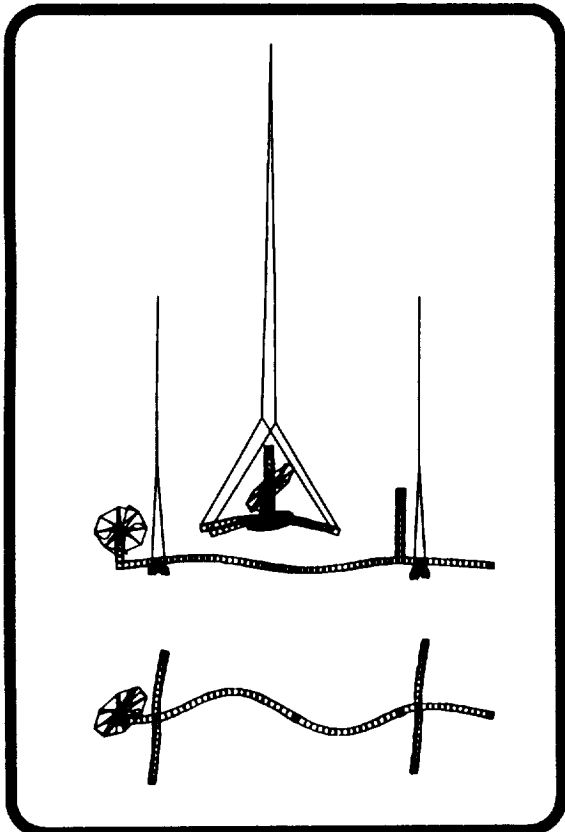


Figure 66. Mode 43, $f=16.993$ Hz

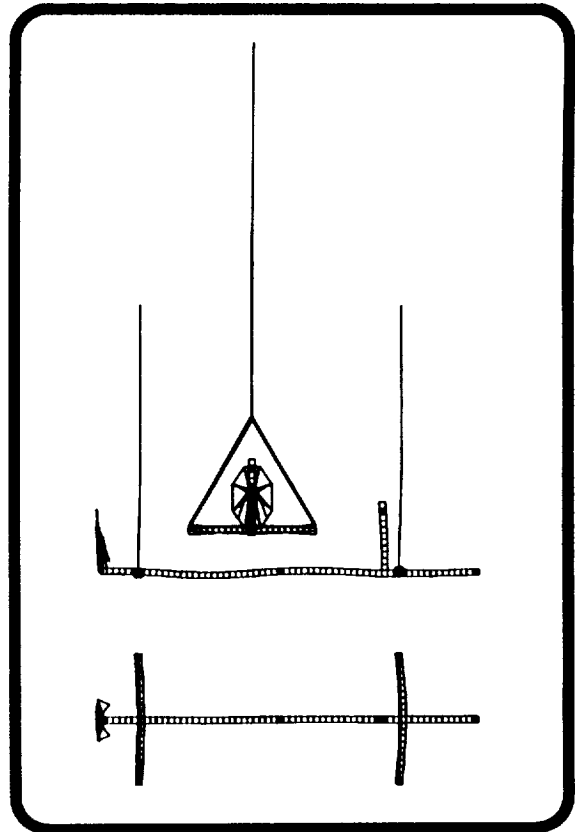


Figure 67. Mode 44, $f=18.486$ Hz

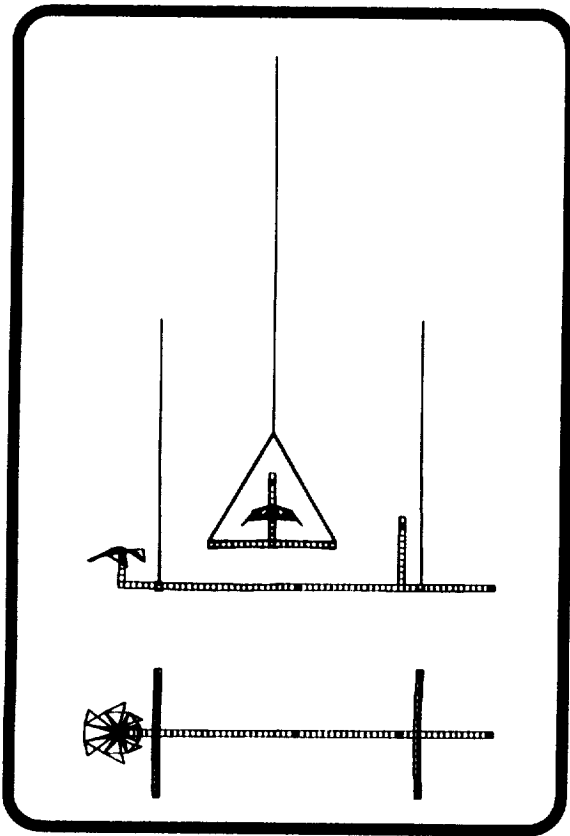


Figure 68. Mode 45, $f=19.193$ Hz

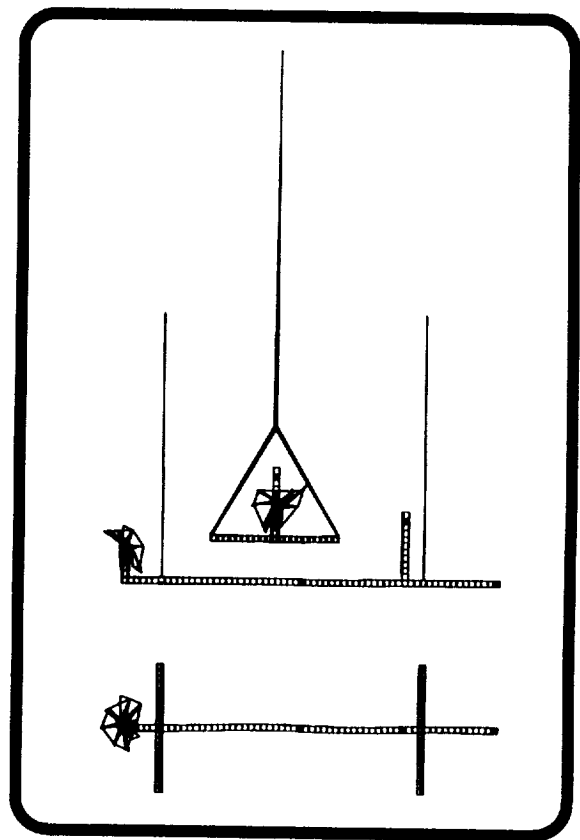


Figure 69. Mode 46, $f=21.190$ Hz

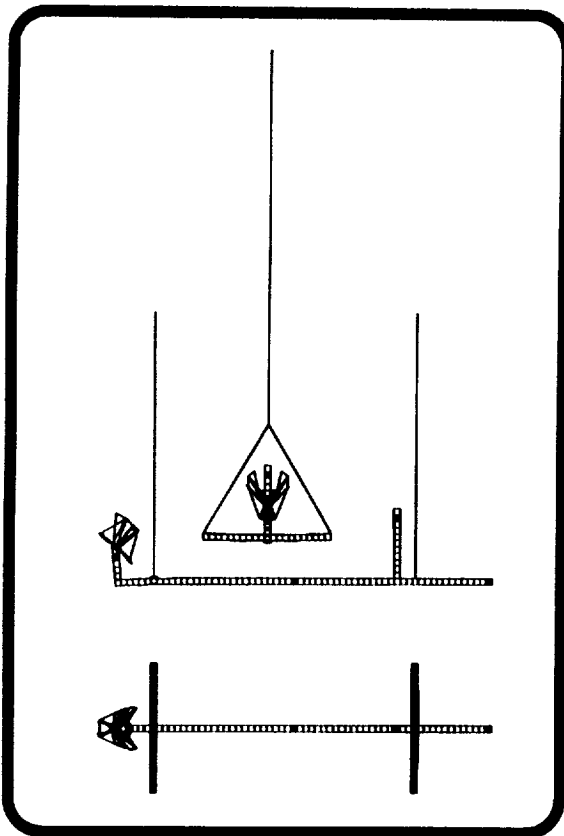


Figure 70. Mode 47, $f=21.938$ Hz

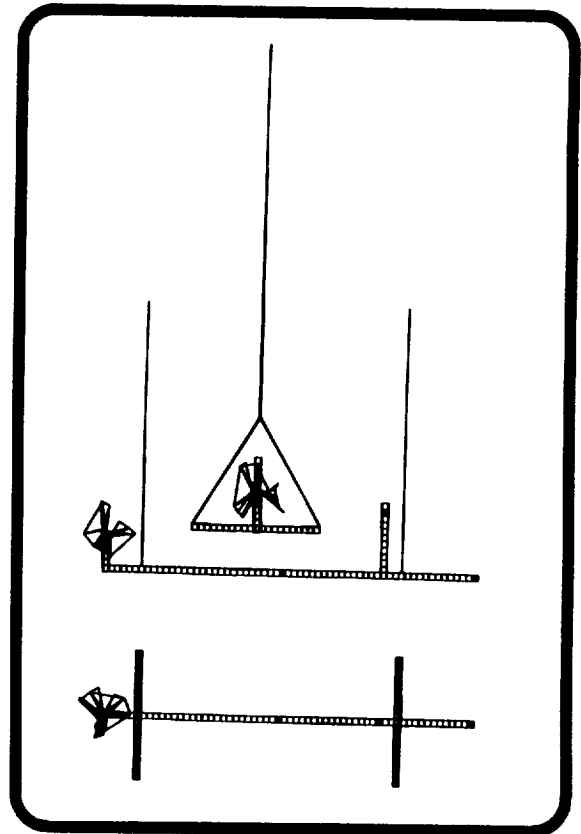


Figure 71. Mode 48, $f=22.213$ Hz

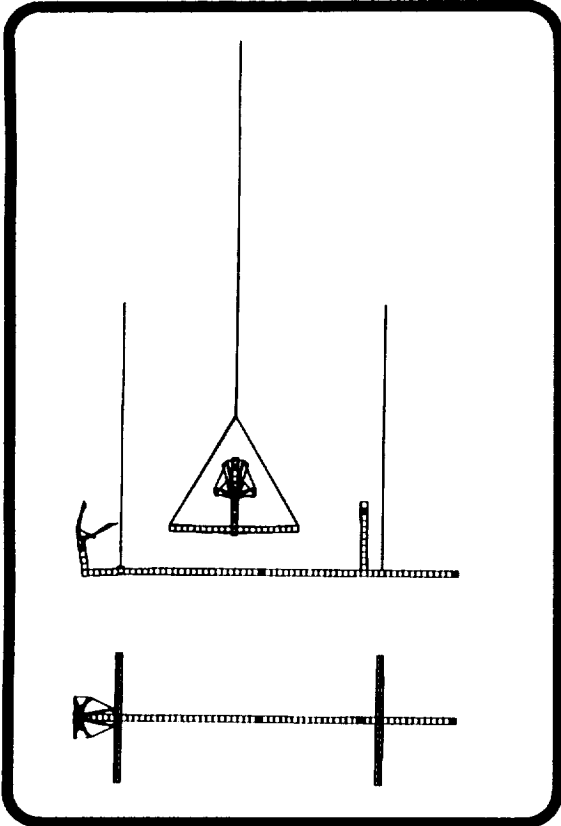


Figure 72. Mode 49, $f=23.437$ Hz

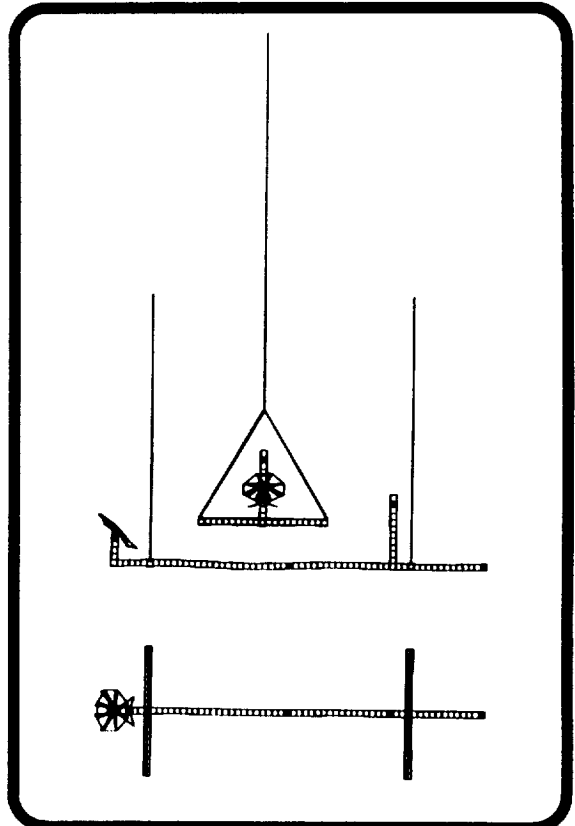


Figure 73. Mode 50, $f=24.550$ Hz

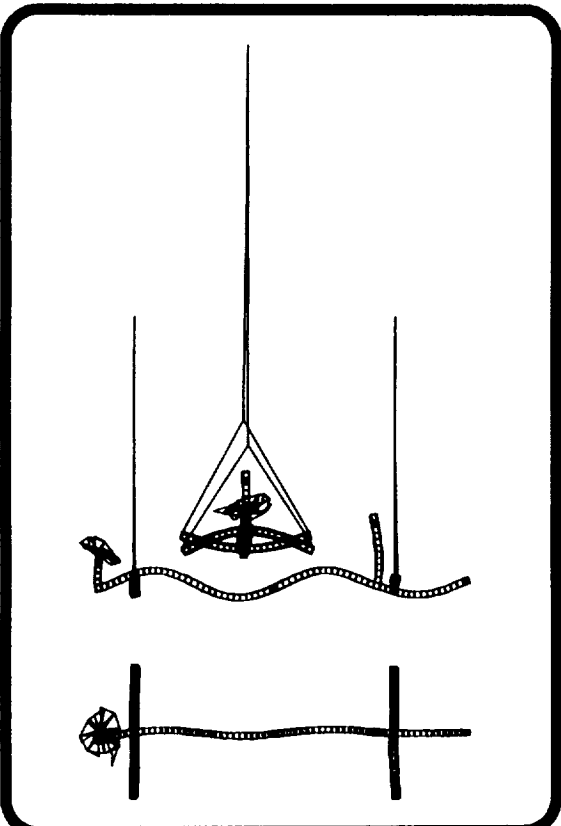


Figure 74. Mode 51, $f= 24.914$ Hz

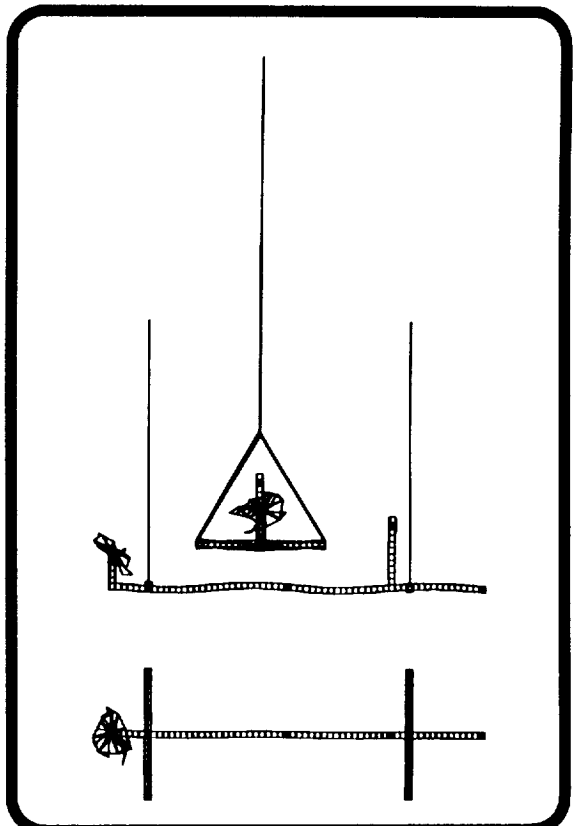
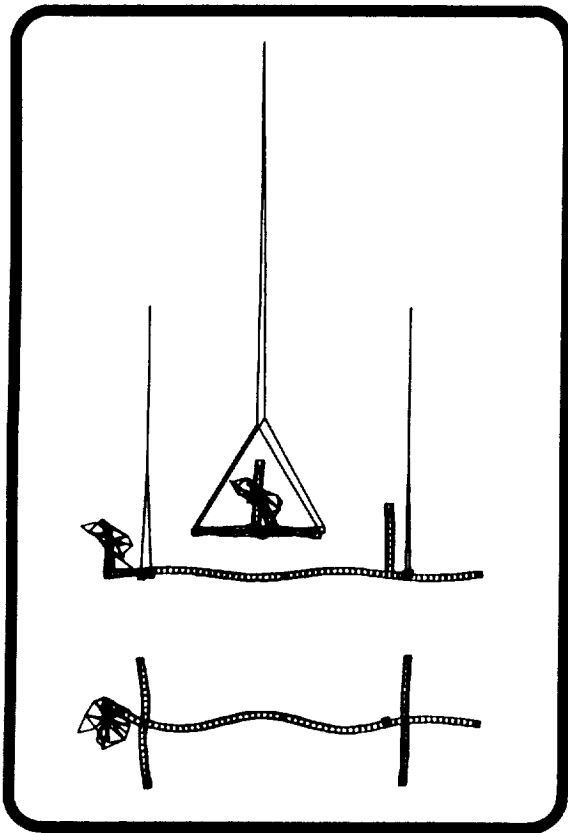
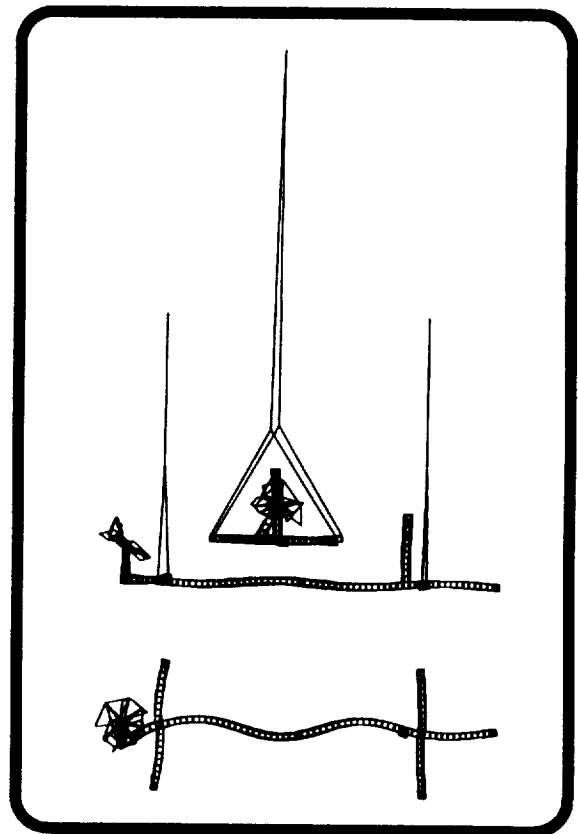
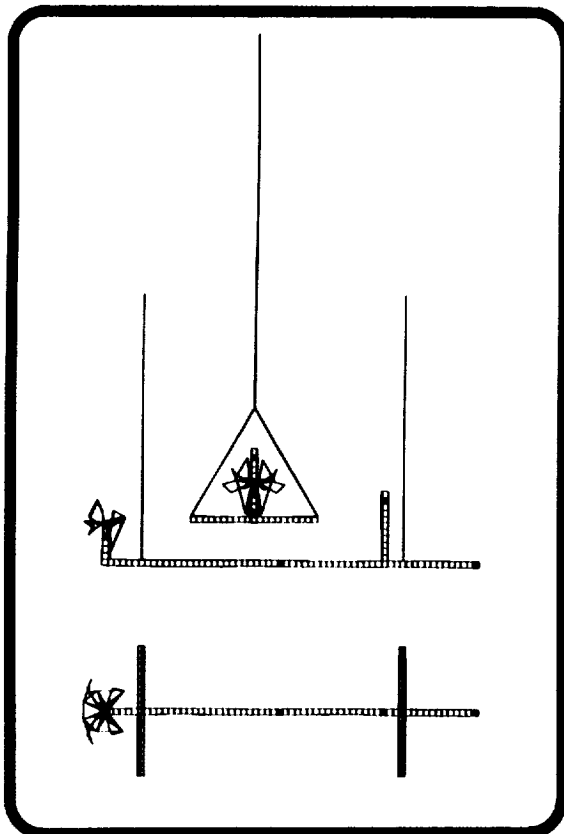
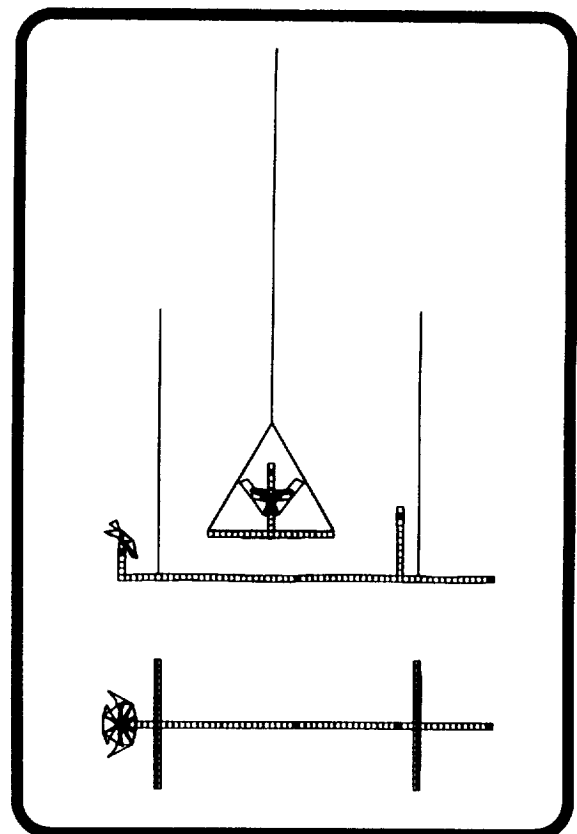


Figure 75. Mode 52, $f= 24.974$ Hz

Figure 76. Mode 53, $f=25.629$ HzFigure 77. Mode 54, $f=26.204$ HzFigure 78. Mode 55, $f=26.283$ HzFigure 79. Mode 56, $f=26.565$ Hz

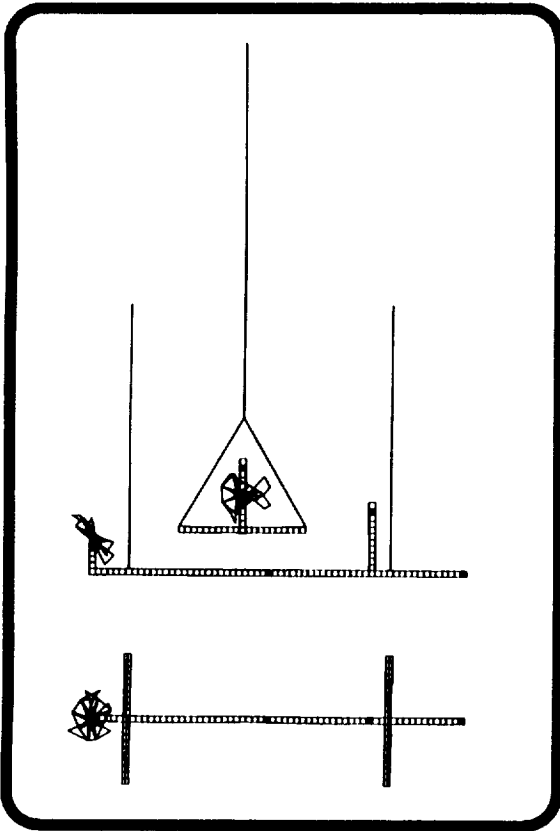


Figure 80. Mode 57, $f=27.188$ Hz

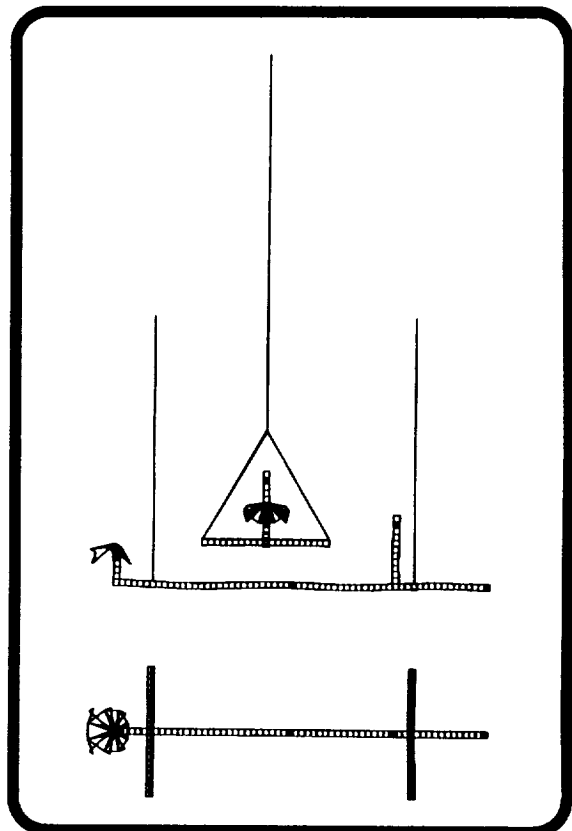


Figure 81. Mode 58, $f=27.656$ Hz

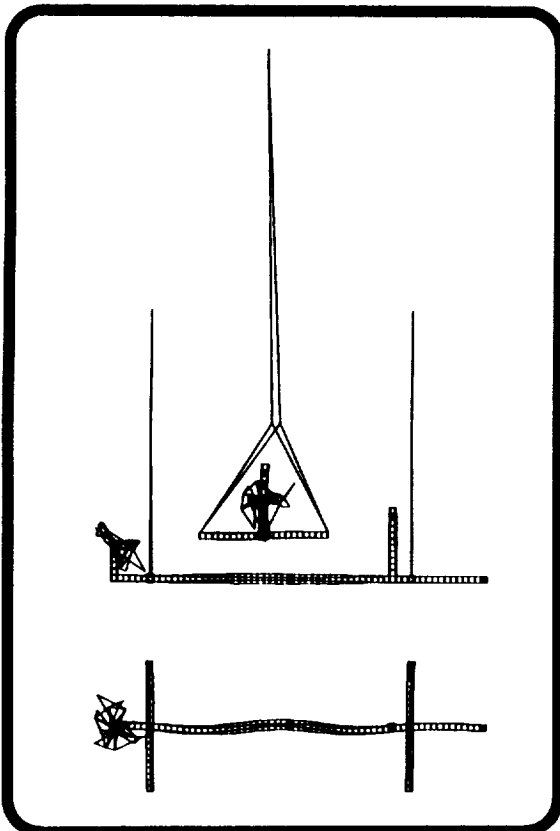


Figure 82. Mode 59, $f=28.649$ Hz

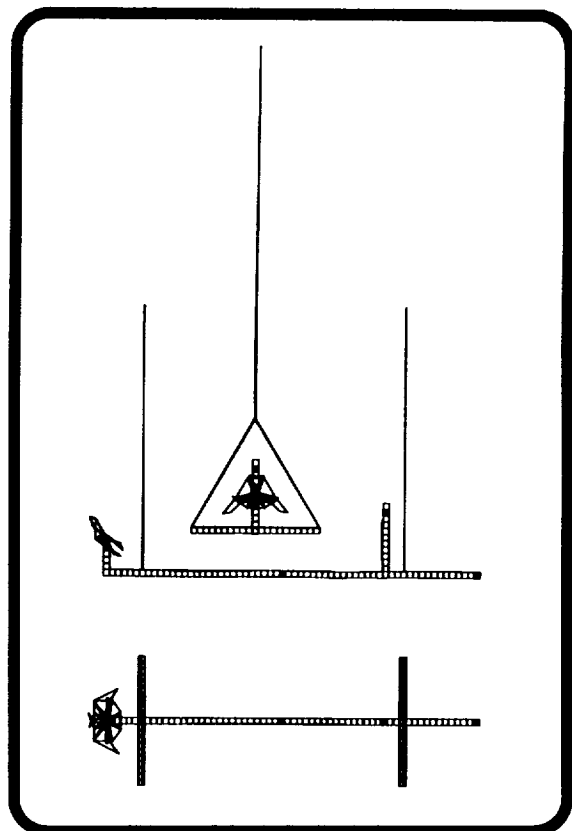


Figure 83. Mode 60, $f=28.952$ Hz

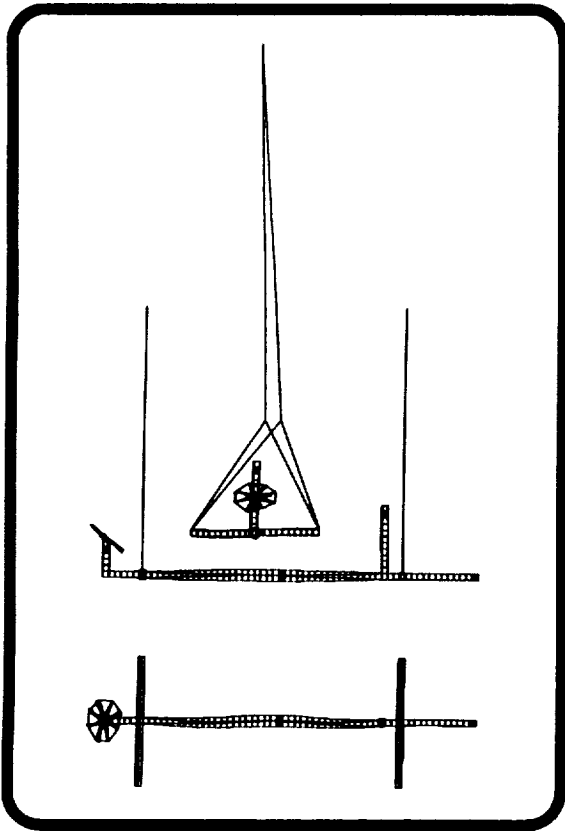


Figure 84. Mode 61, $f=29.146$ Hz

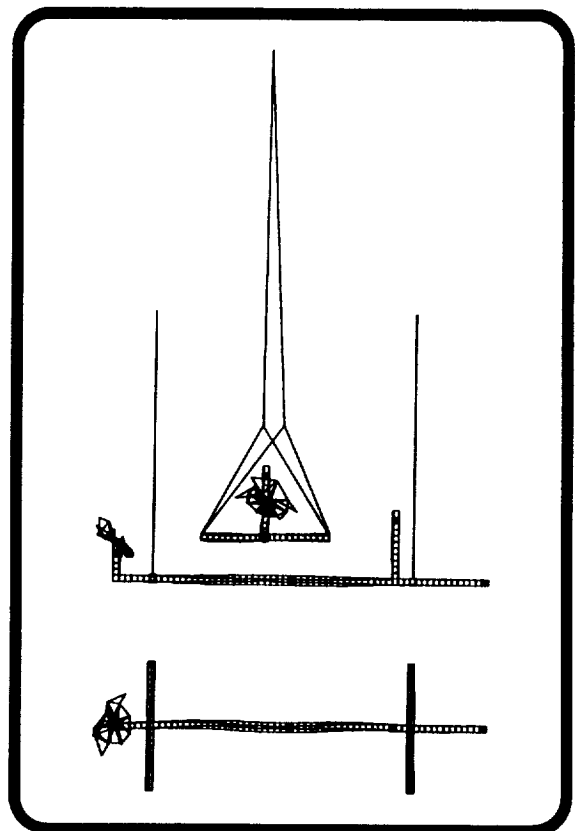


Figure 85. Mode 62, $f=29.701$ Hz

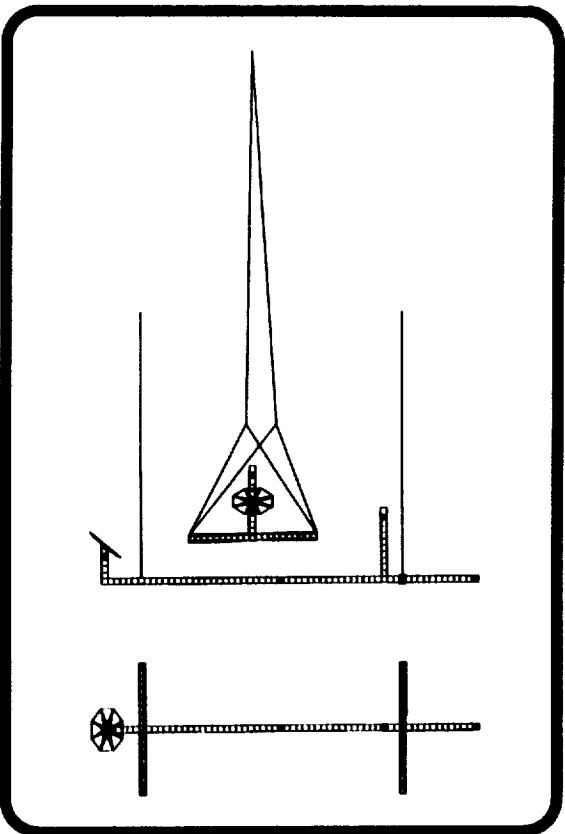


Figure 86. Mode 63, $f=29.881$ Hz

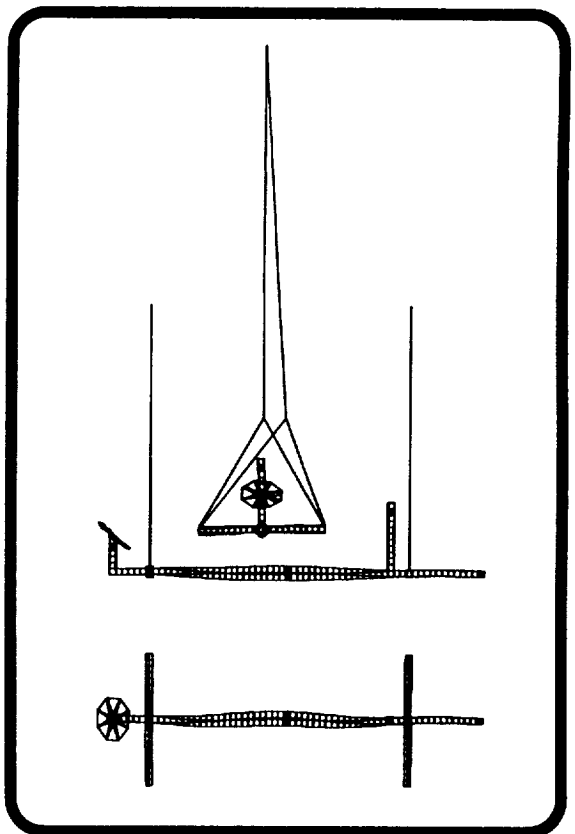
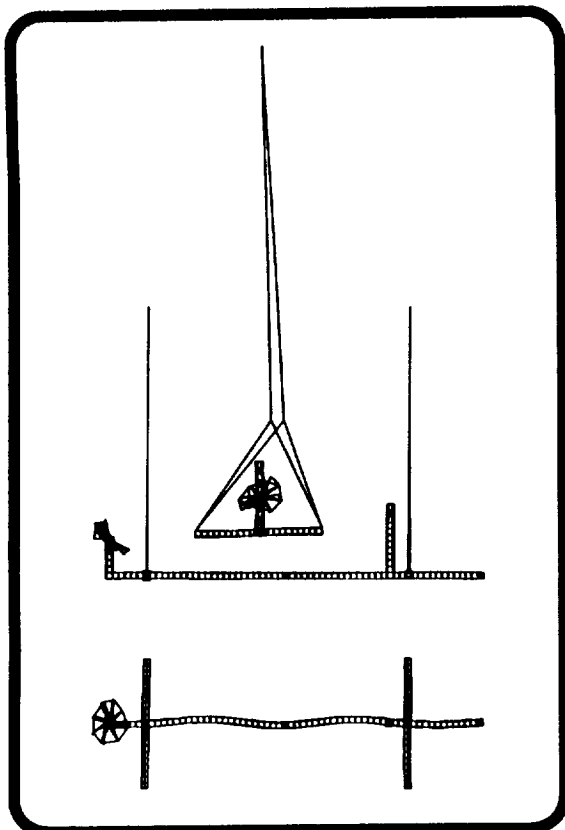
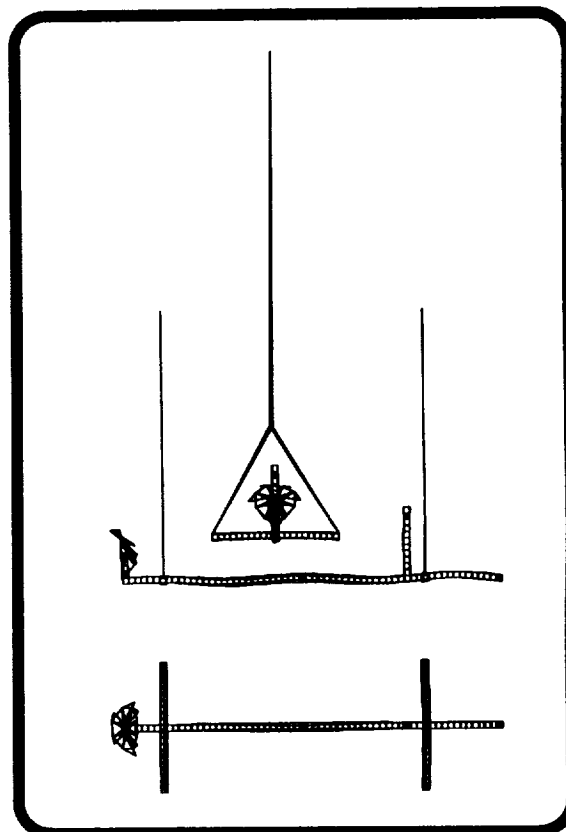
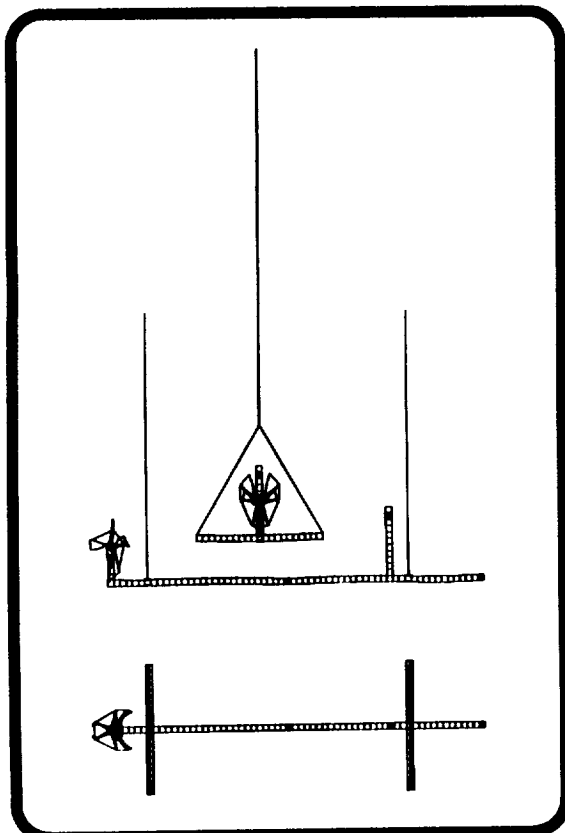
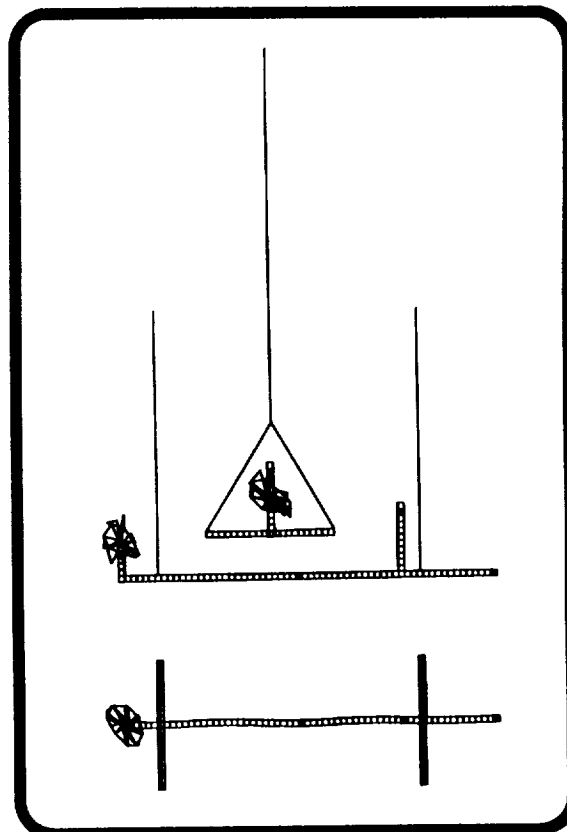


Figure 87. Mode 64, $f=30.437$ Hz

Figure 88. Mode 65, $f=30.567$ HzFigure 89. Mode 66, $f=30.842$ HzFigure 90. Mode 67, $f=31.064$ HzFigure 91. Mode 68, $f=31.339$ Hz

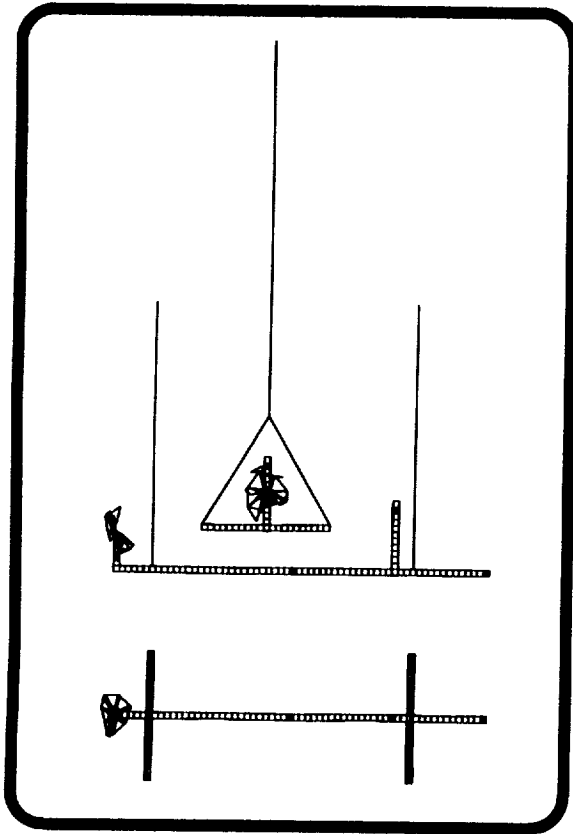


Figure 92. Mode 69, $f=31.533$ Hz

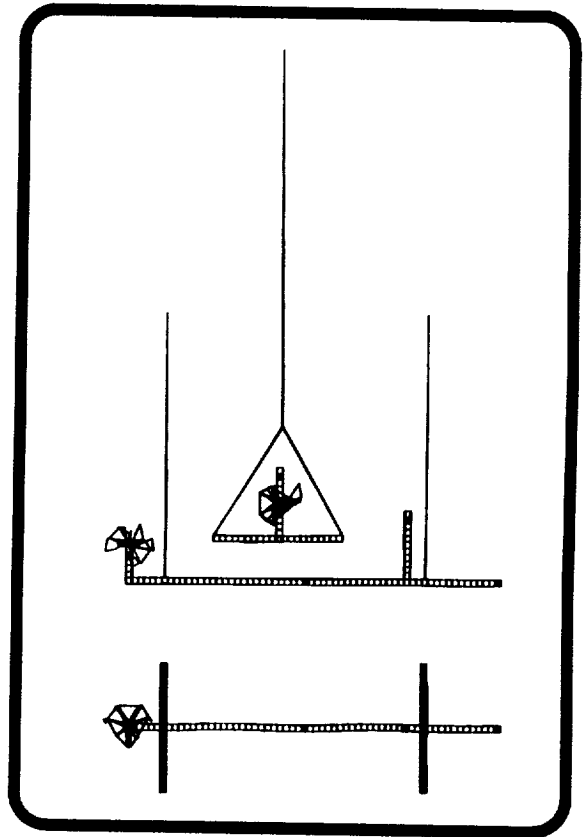


Figure 93. Mode 70, $f=31.630$ Hz

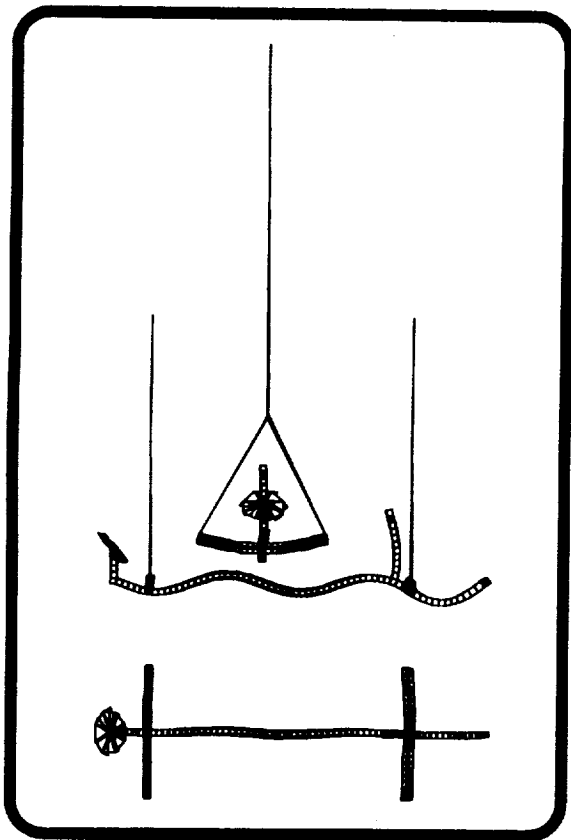


Figure 94. Mode 71, $f=32.361$ Hz

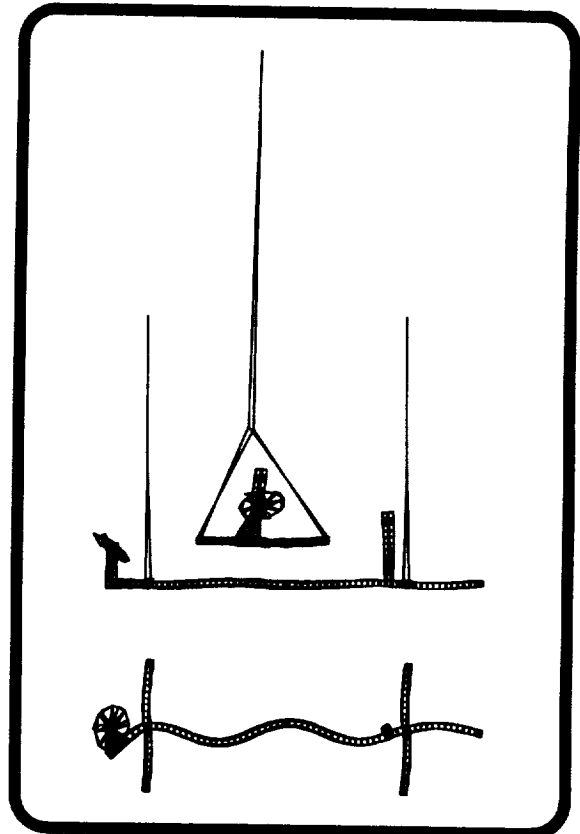


Figure 95. Mode 72, $f=33.380$ Hz

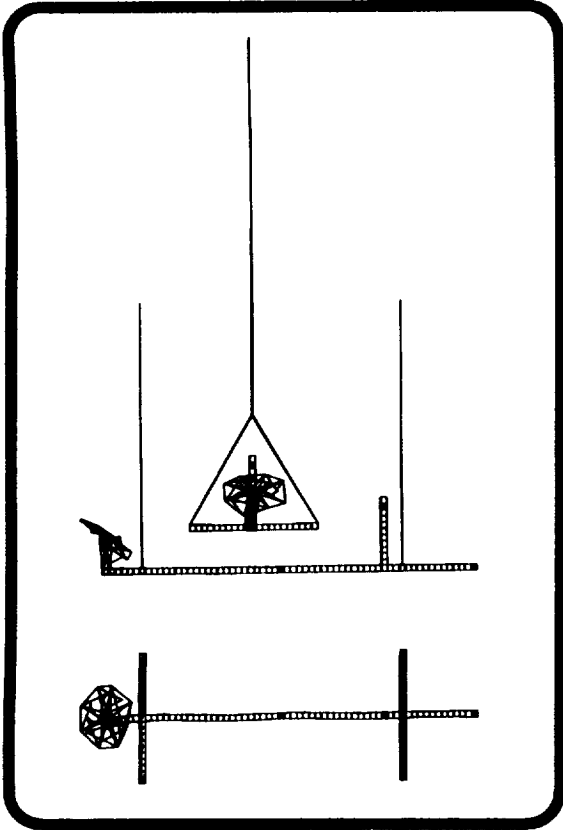


Figure 96. Mode 73, $f=36.882$ Hz

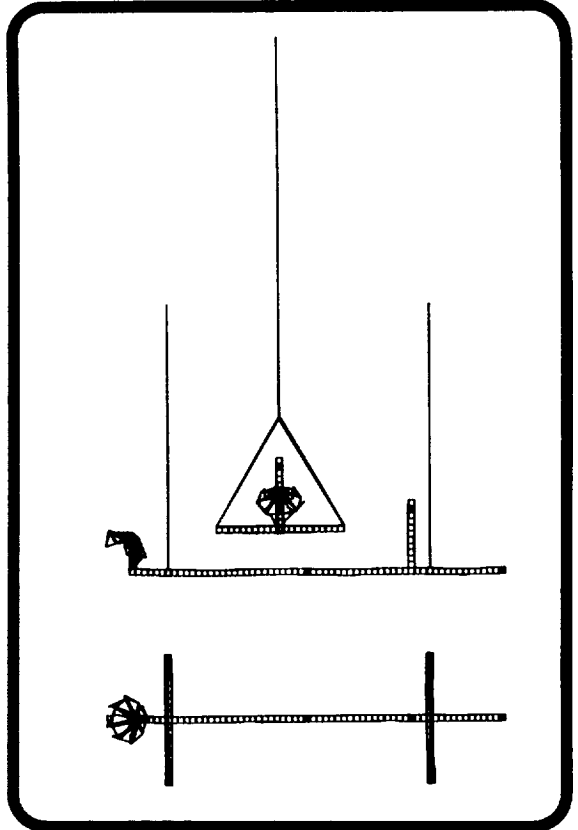


Figure 97. Mode 74, $f=37.075$ Hz

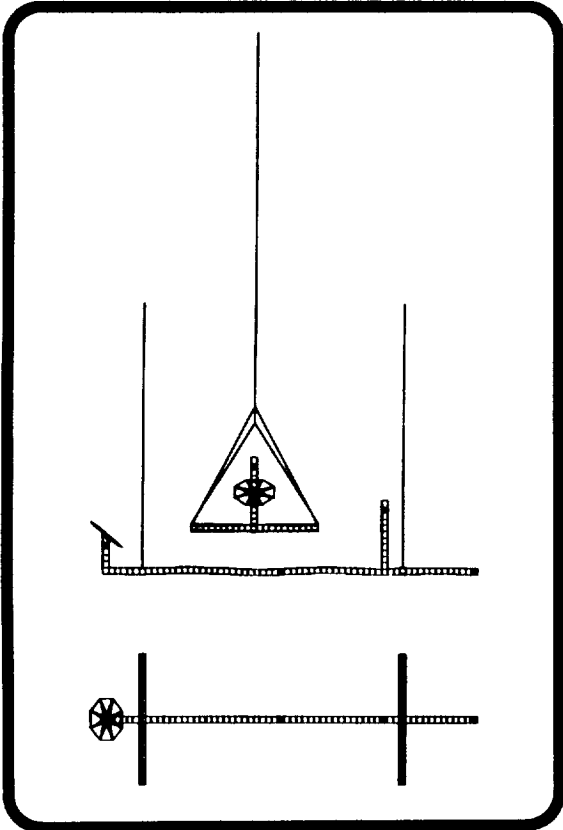


Figure 98. Mode 75, $f=38.180$ Hz

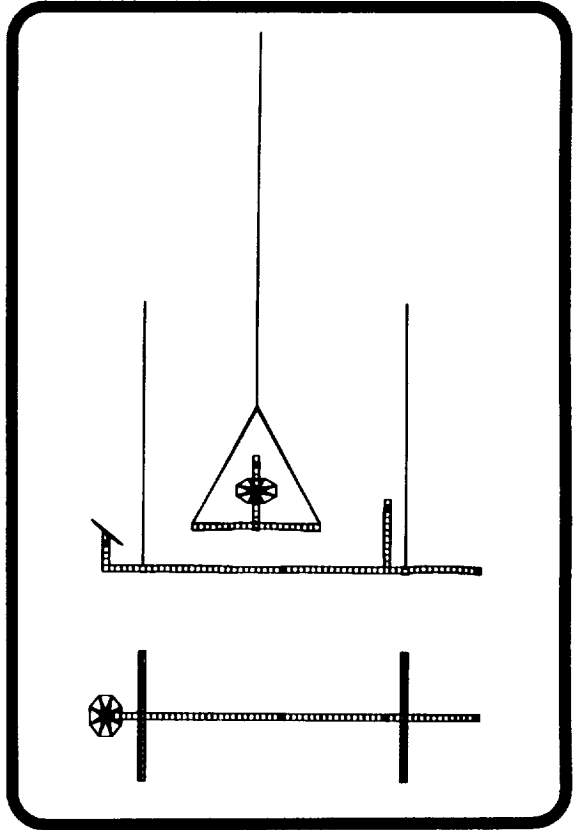


Figure 99. Mode 76, $f=38.428$ Hz

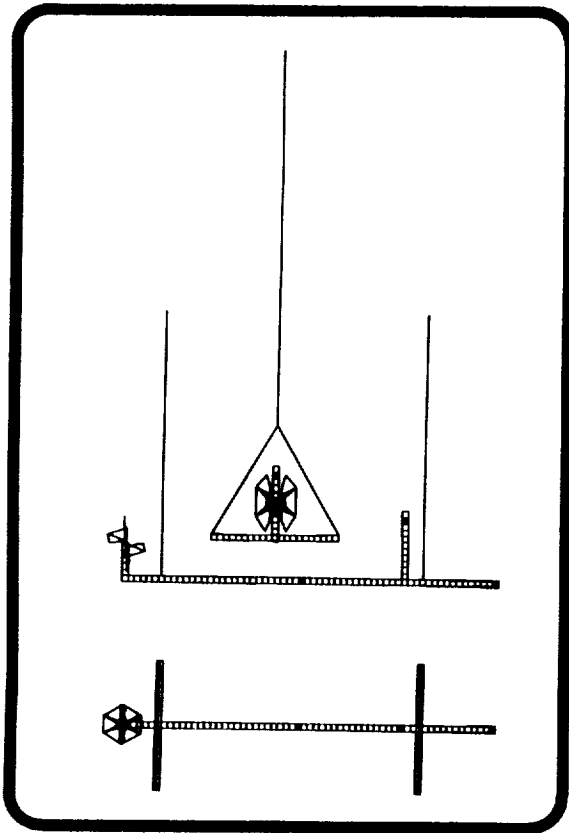


Figure 100. Mode 77, $f= 38.982$ Hz

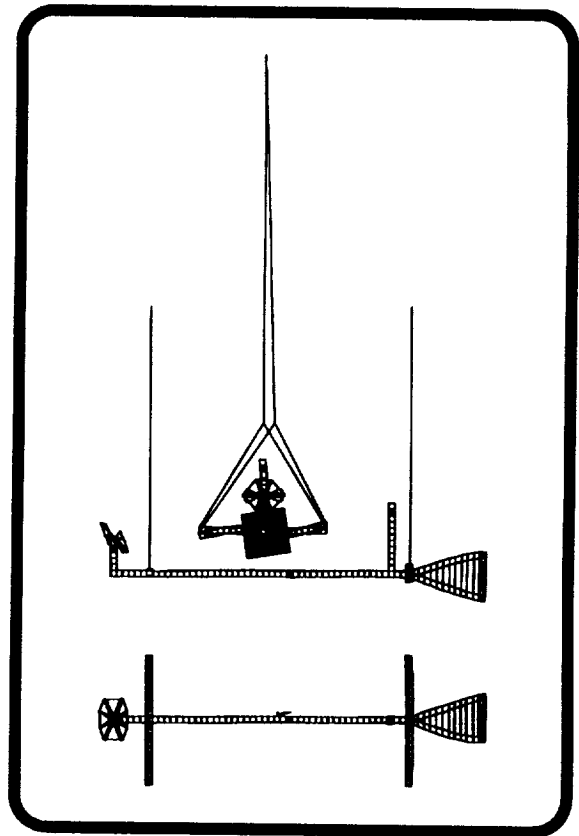


Figure 101. Mode 78, $f=38.992$ Hz

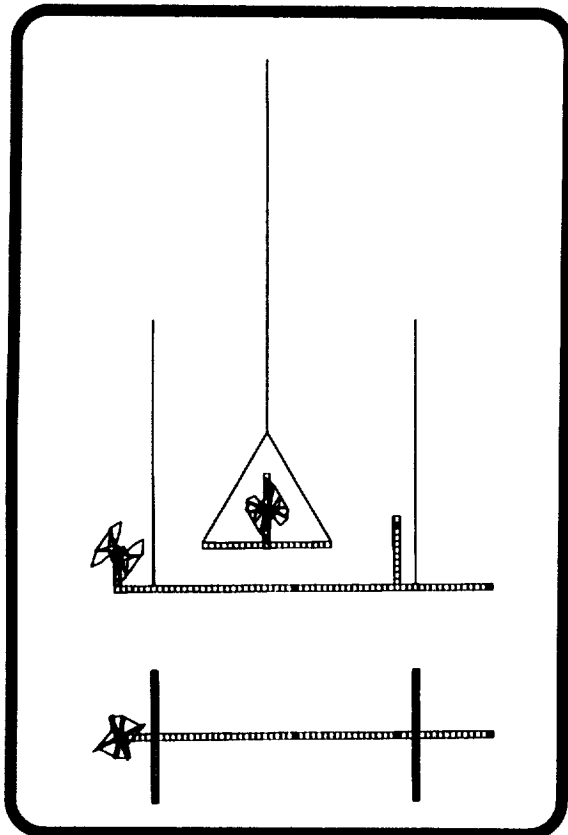


Figure 102. Mode 79, $f=39.443$ Hz

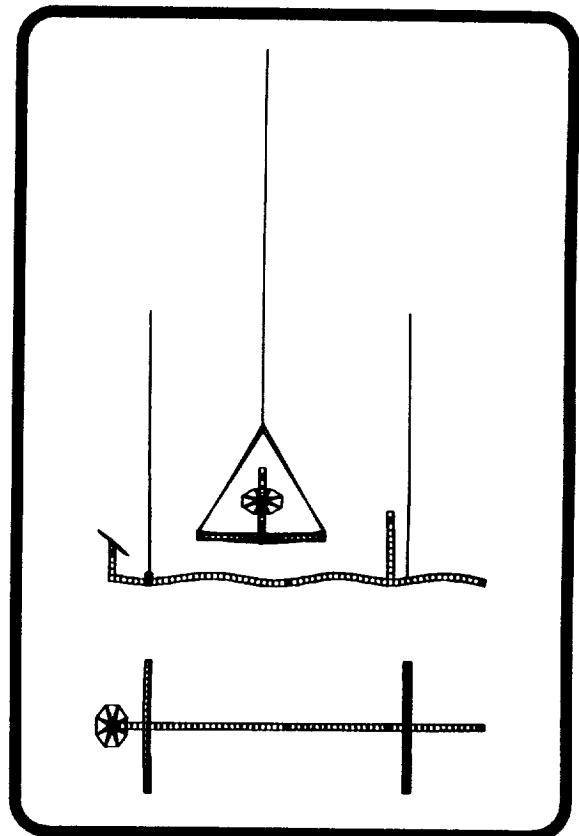
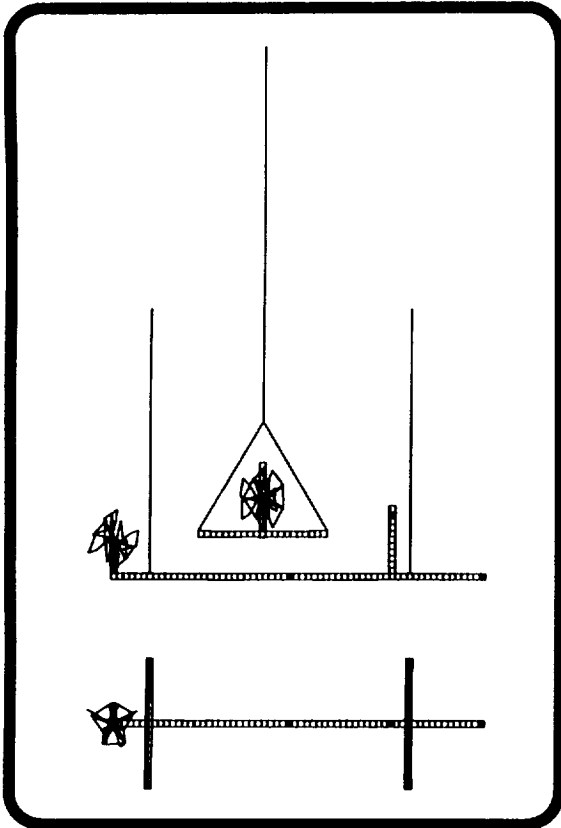
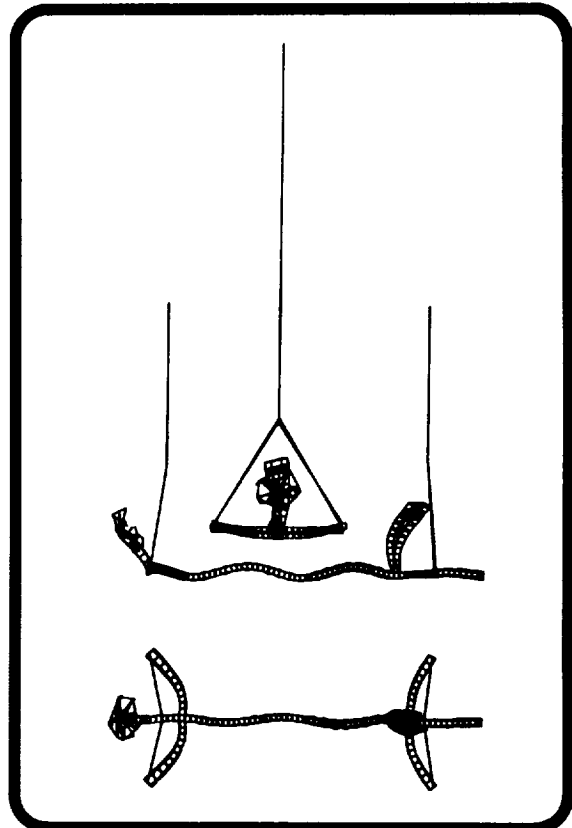
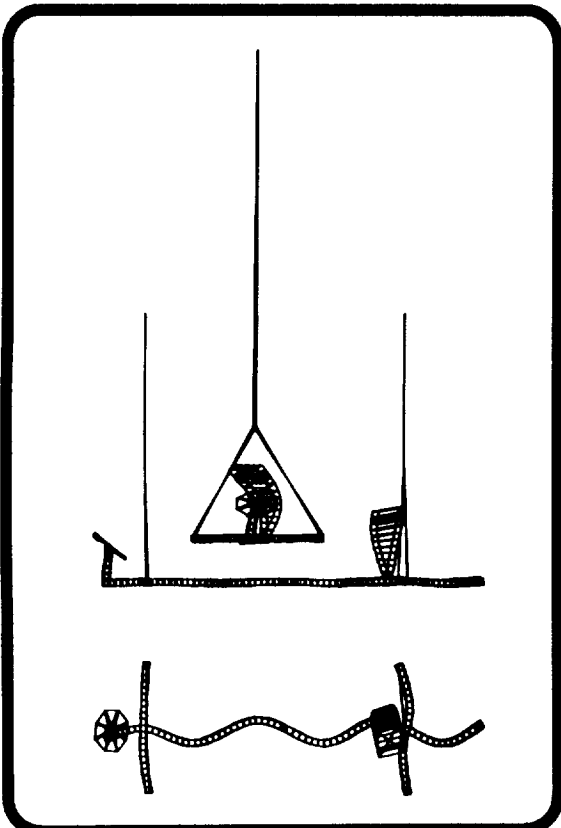
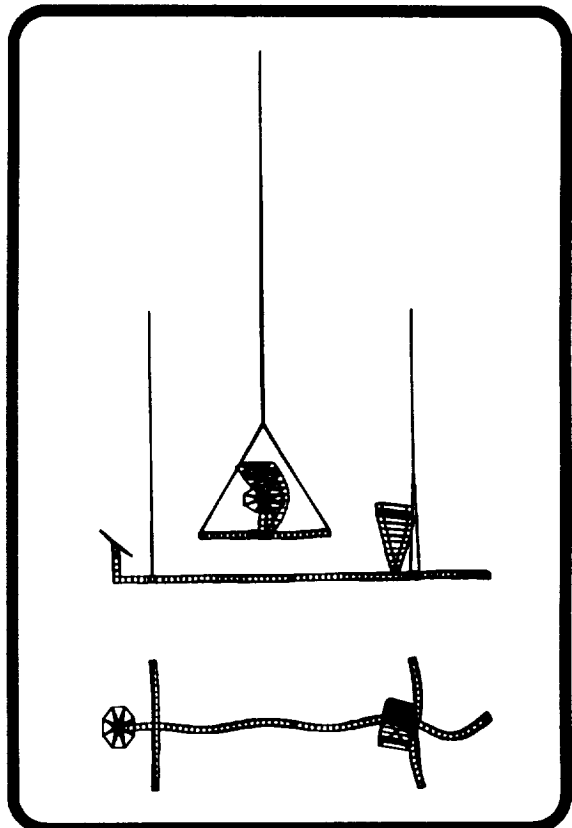
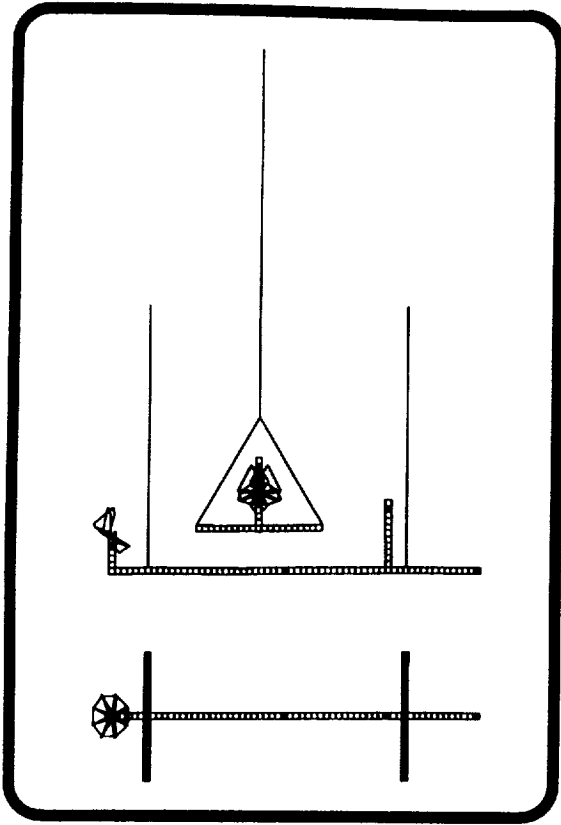
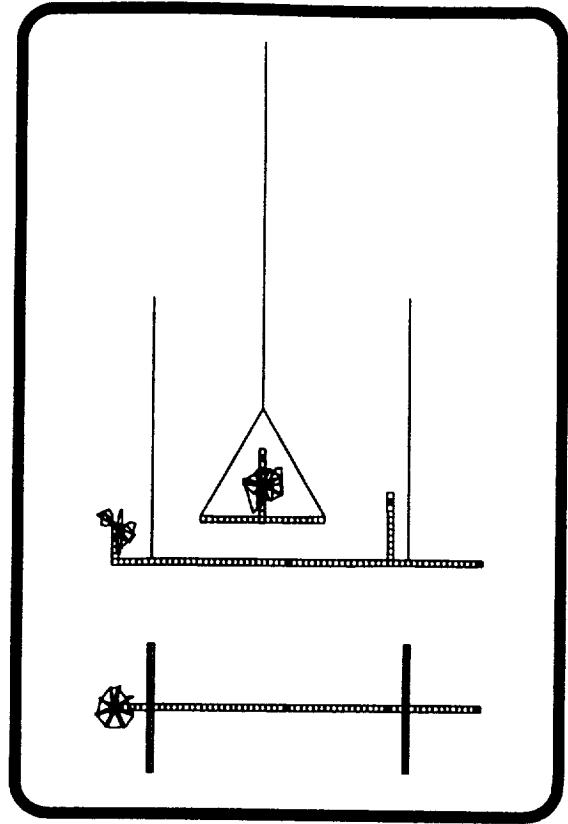


Figure 103. Mode 80, $f=40.706$ Hz

Figure 104. Mode 81, $f=42.757$ HzFigure 105. Mode 82, $f=43.059$ HzFigure 106. Mode 83, $f=43.883$ HzFigure 107. Mode 84, $f=45.763$ Hz

Figure 108. Mode 85, $f=49.139$ HzFigure 109. Mode 86, $f=50.013$ Hz

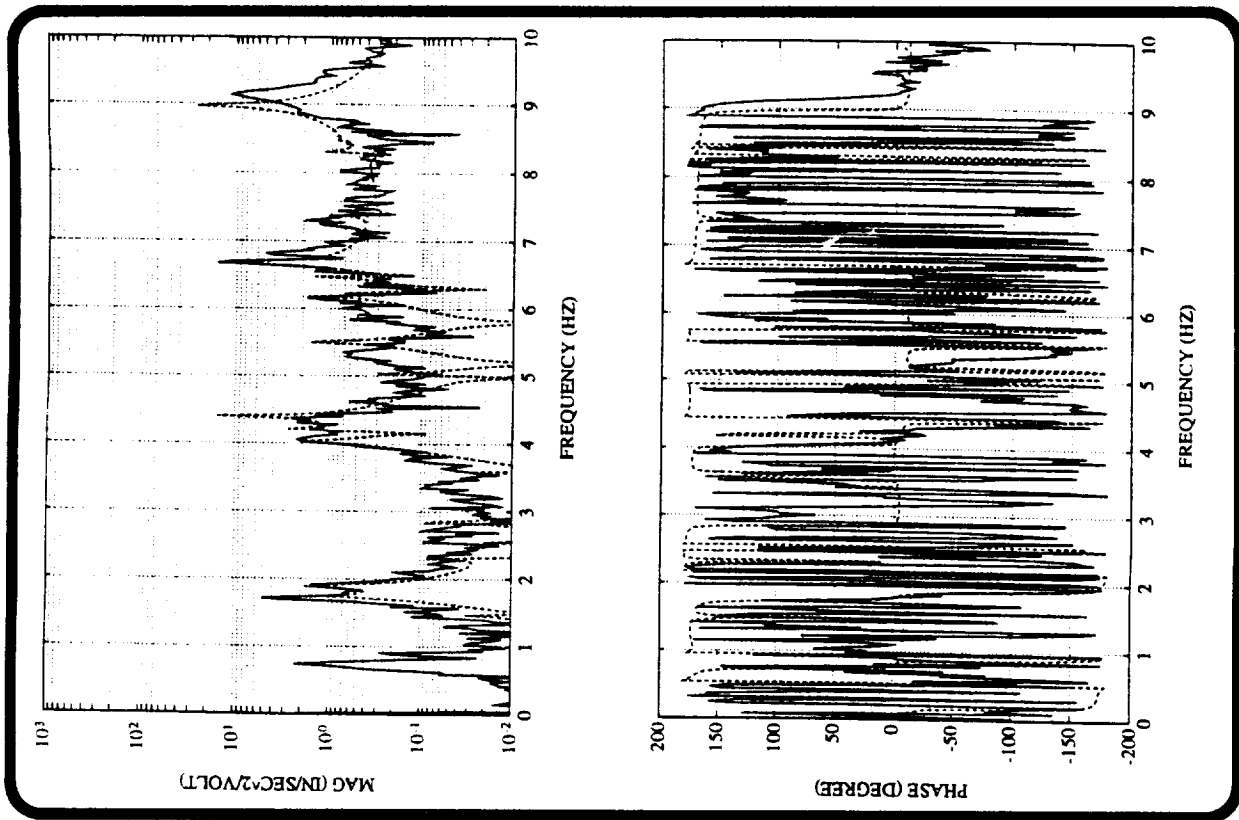


Figure 111. Bode diagram for Accelerometer 2 / Thruster 1

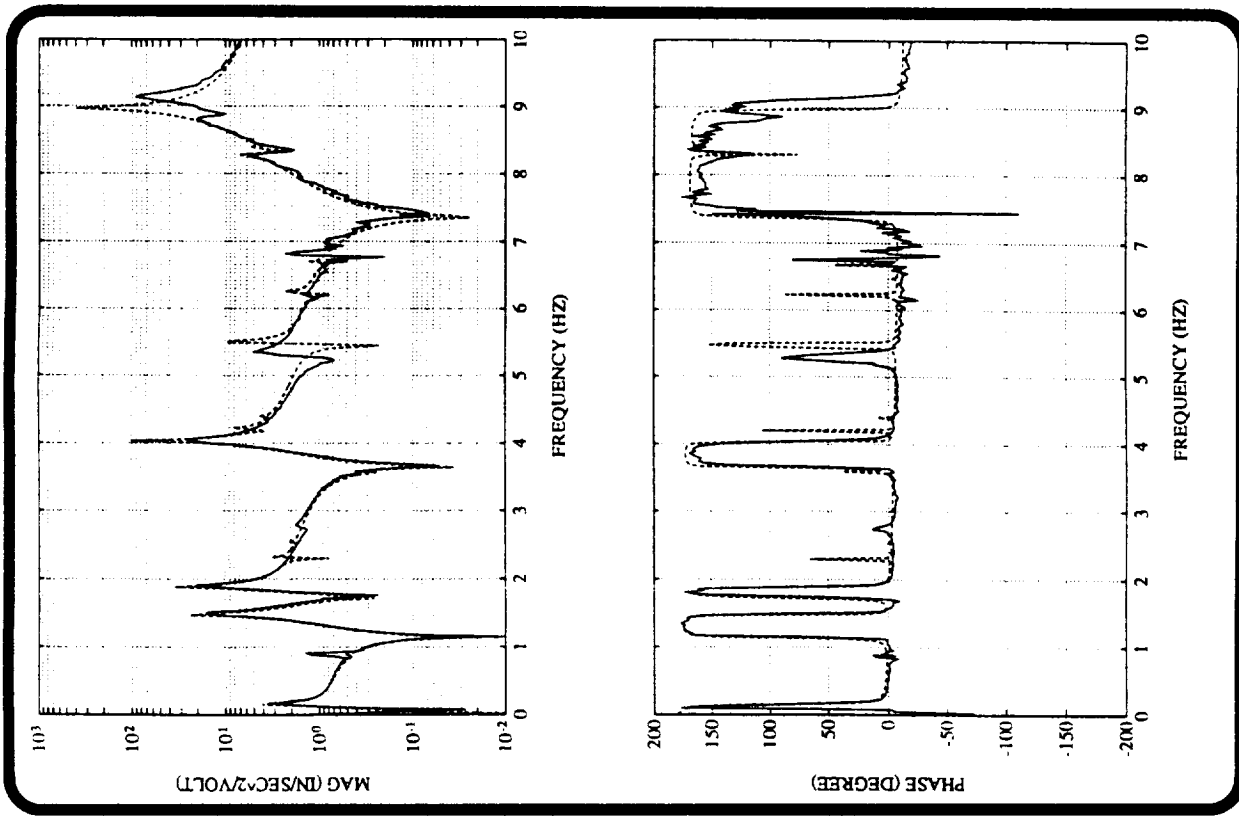


Figure 110. Bode diagram for Accelerometer 1 / Thruster 1

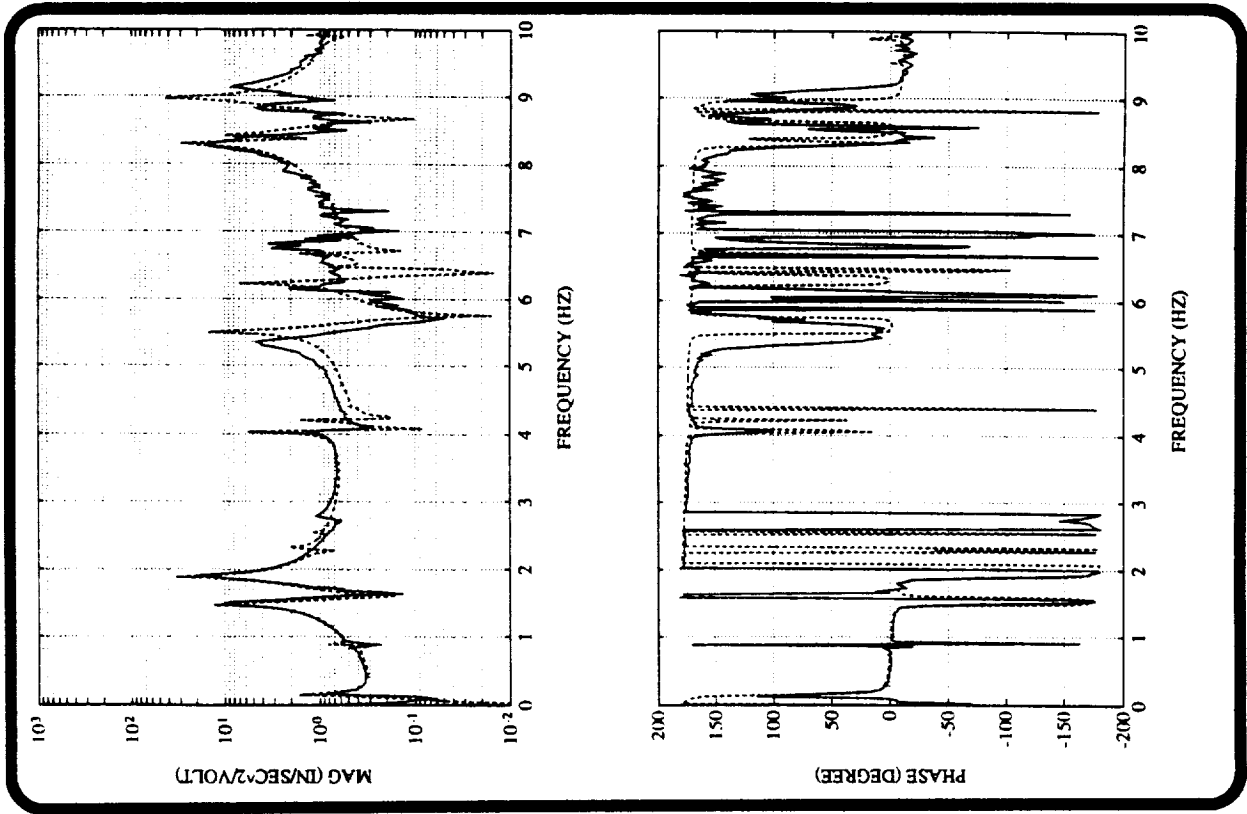


Figure 112. Bode diagram for Accelerometer 3 / Thruster 1

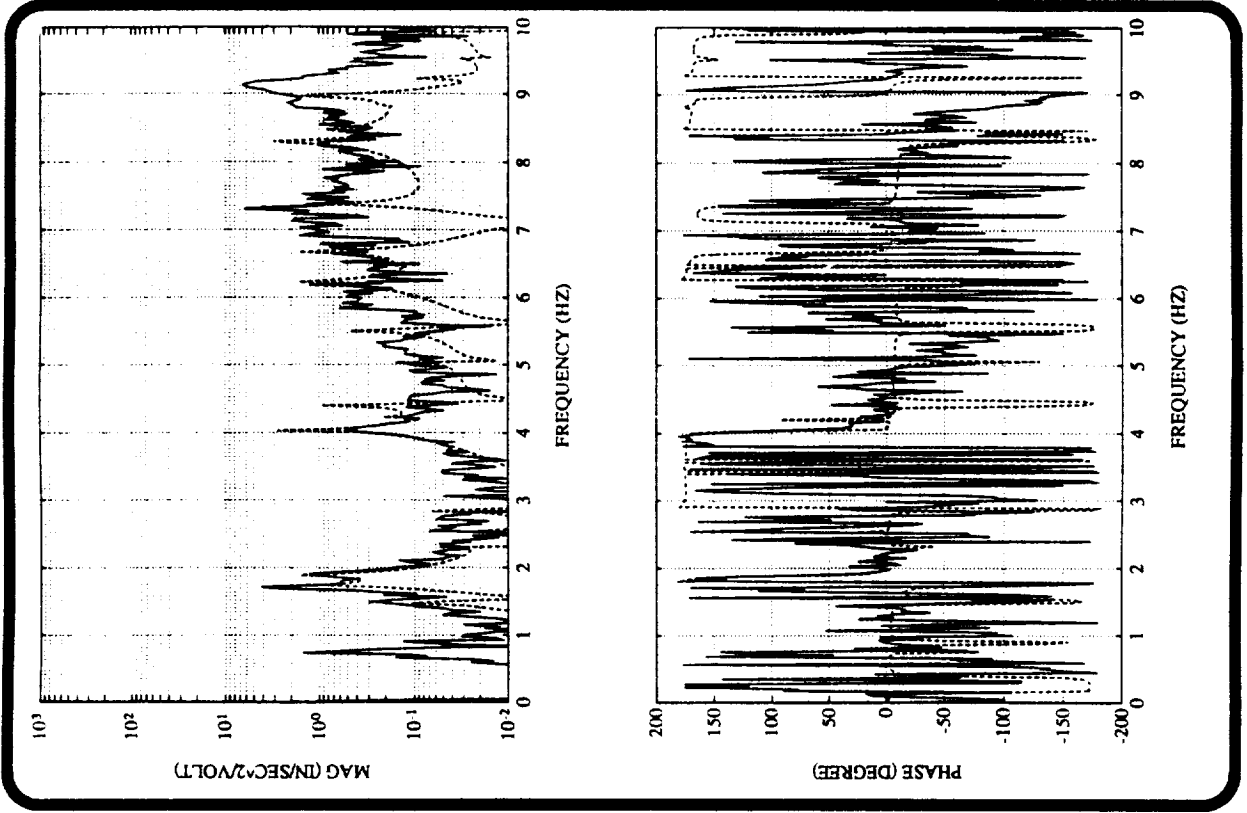


Figure 113. Bode diagram for Accelerometer 4 / Thruster 1

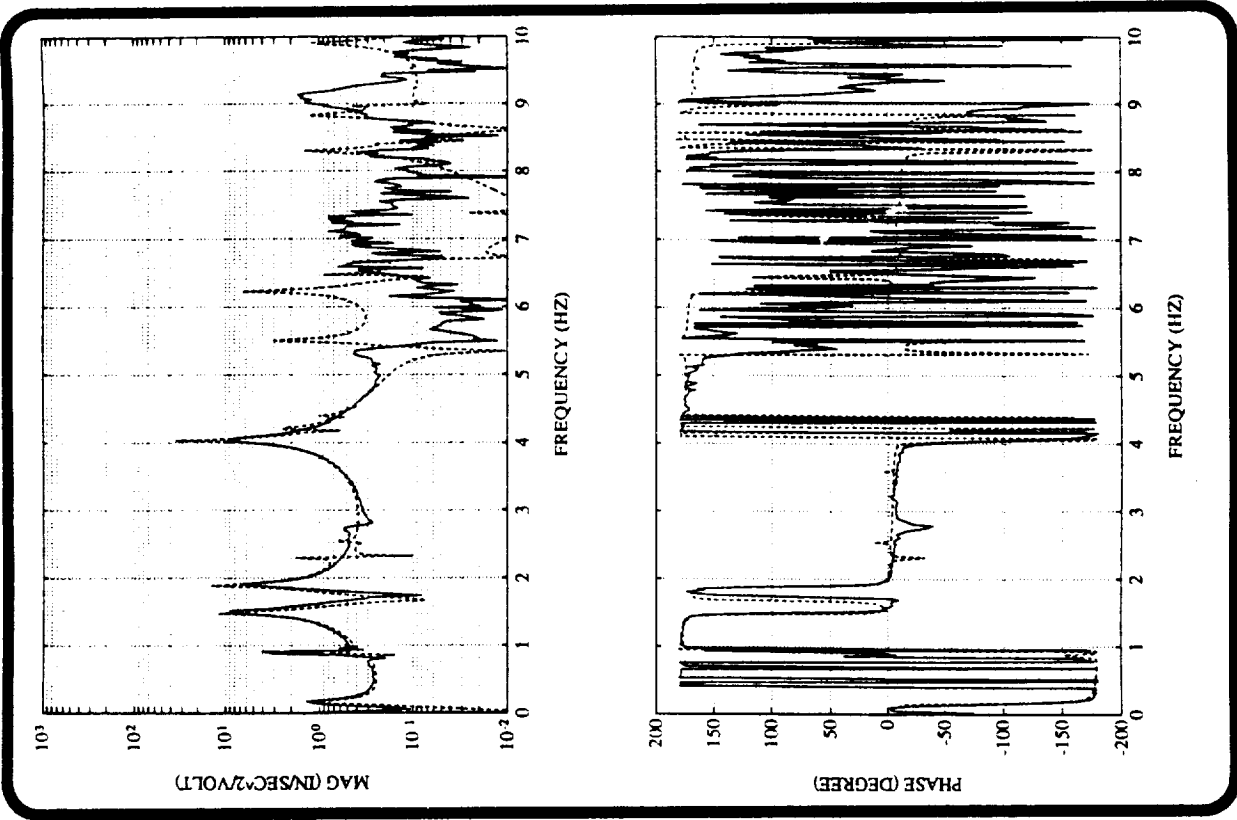


Figure 115. Bode diagram for Accelerometer 6 / Thruster 1

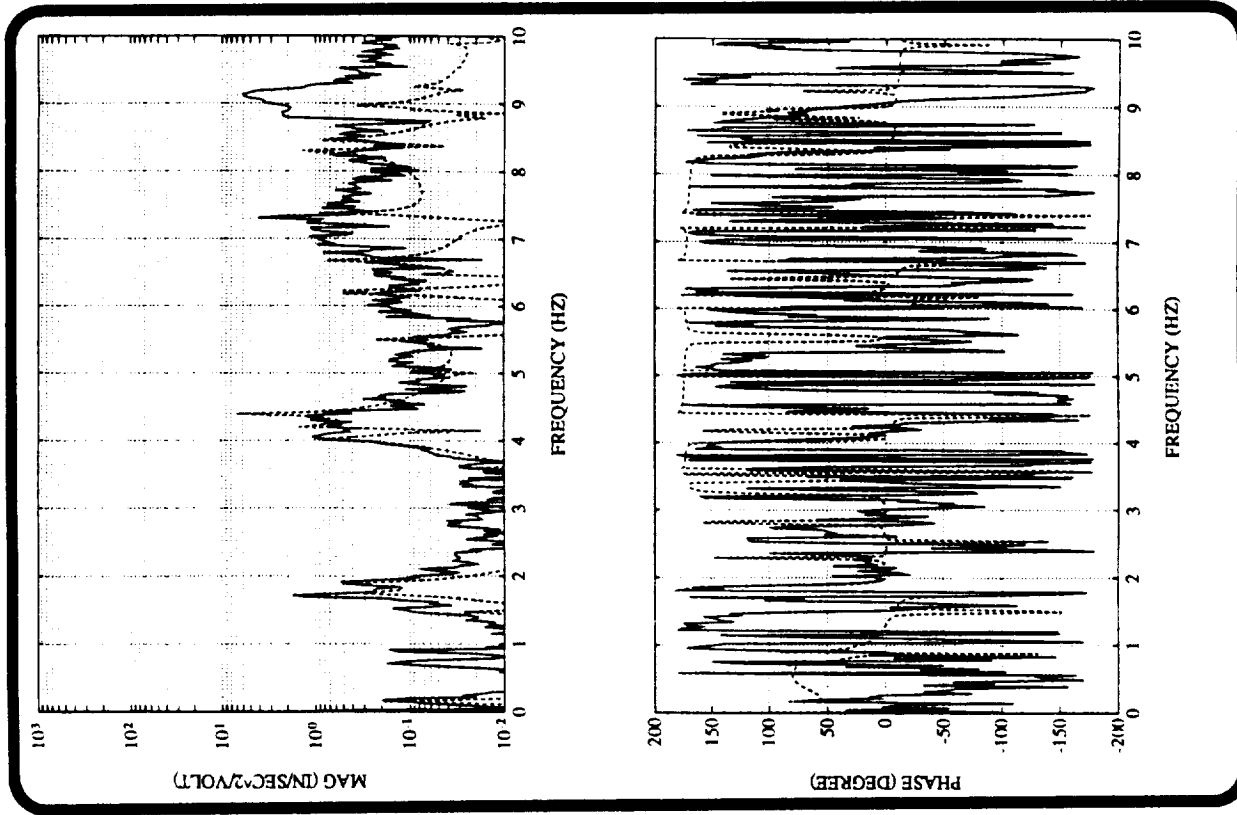


Figure 114. Bode diagram for Accelerometer 5 / Thruster 1

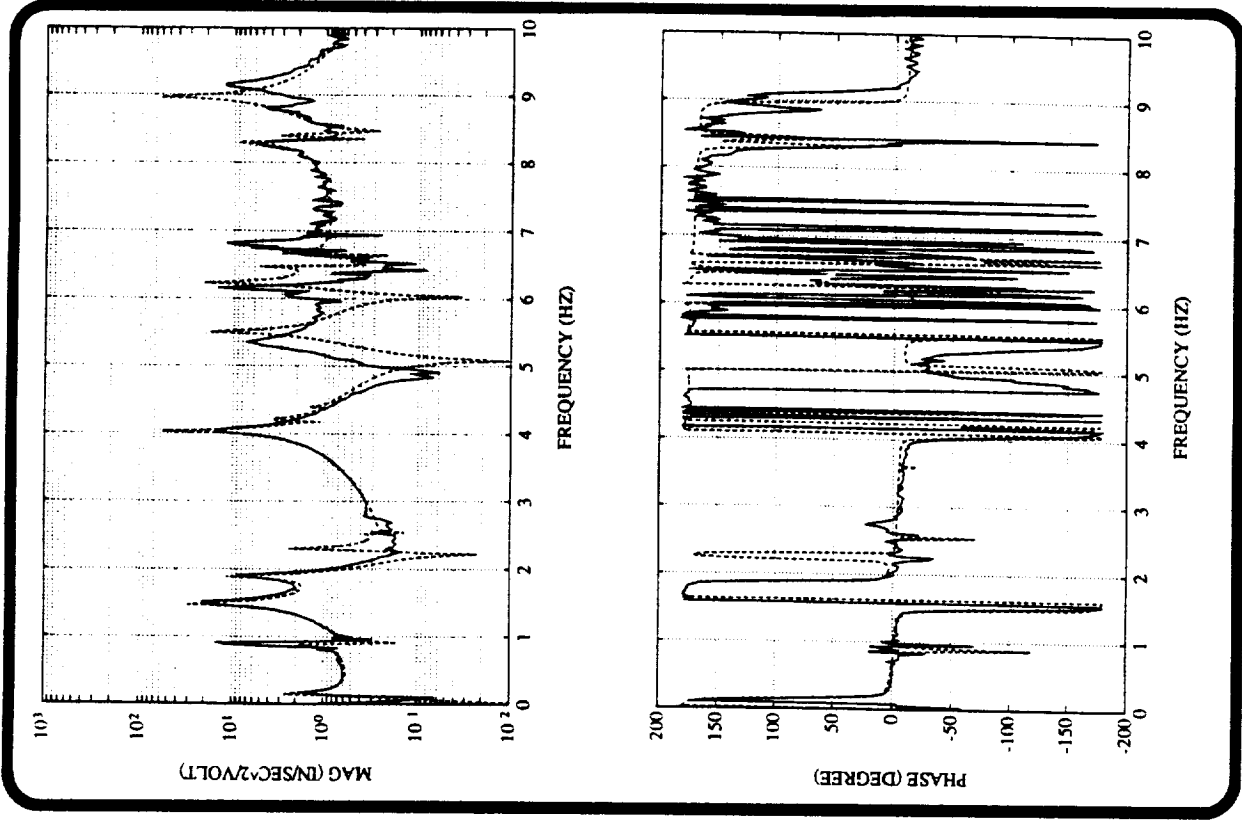


Figure 117. Bode diagram for Accelerometer 8 / Thruster 1

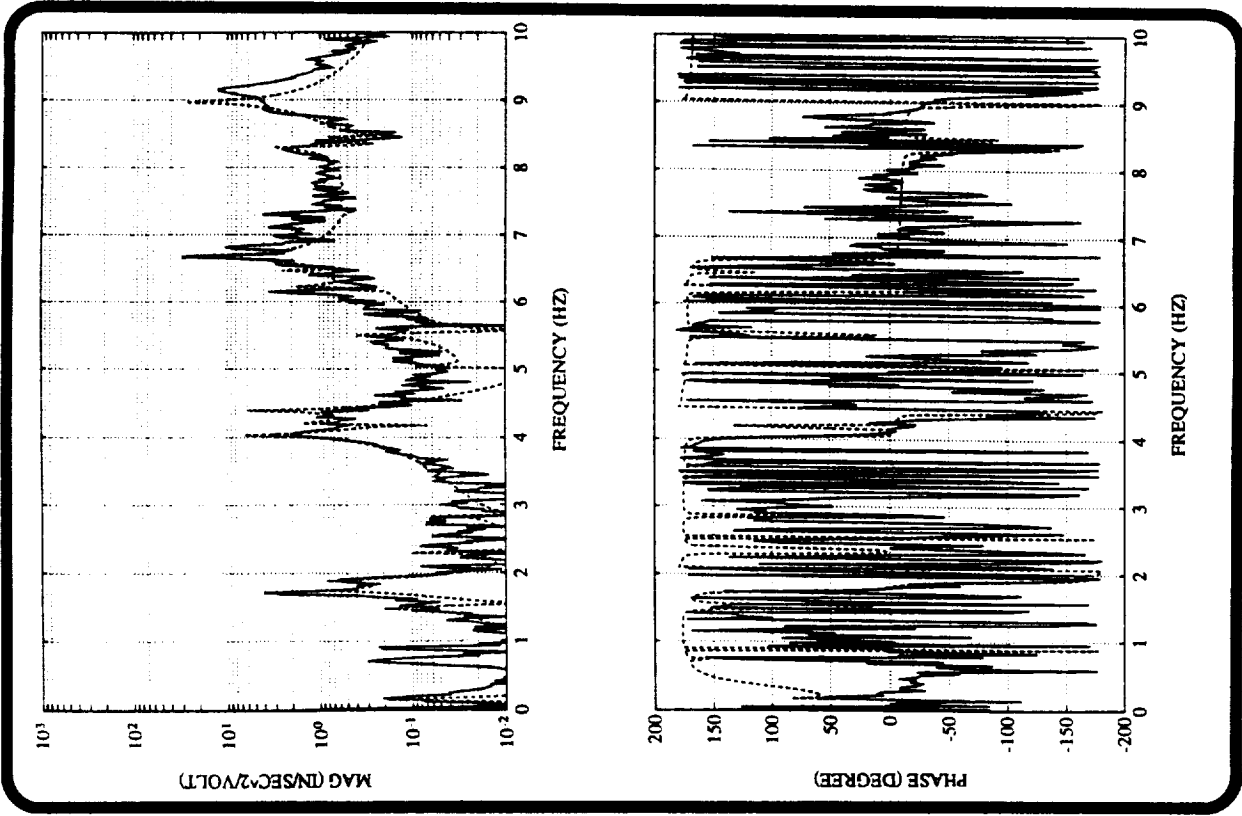


Figure 116. Bode diagram for Accelerometer 7 / Thruster 1

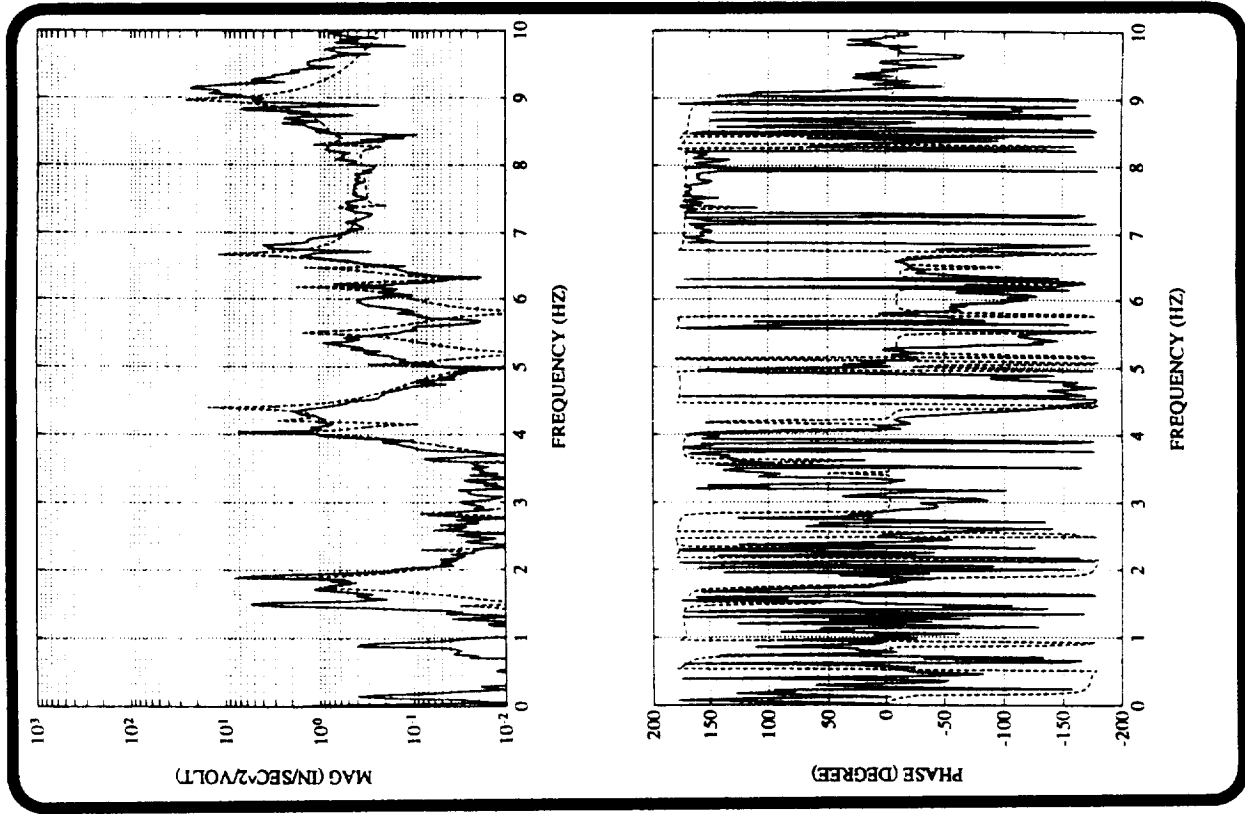


Figure 118. Bode diagram for Accelerometer 1 / Thruster 2

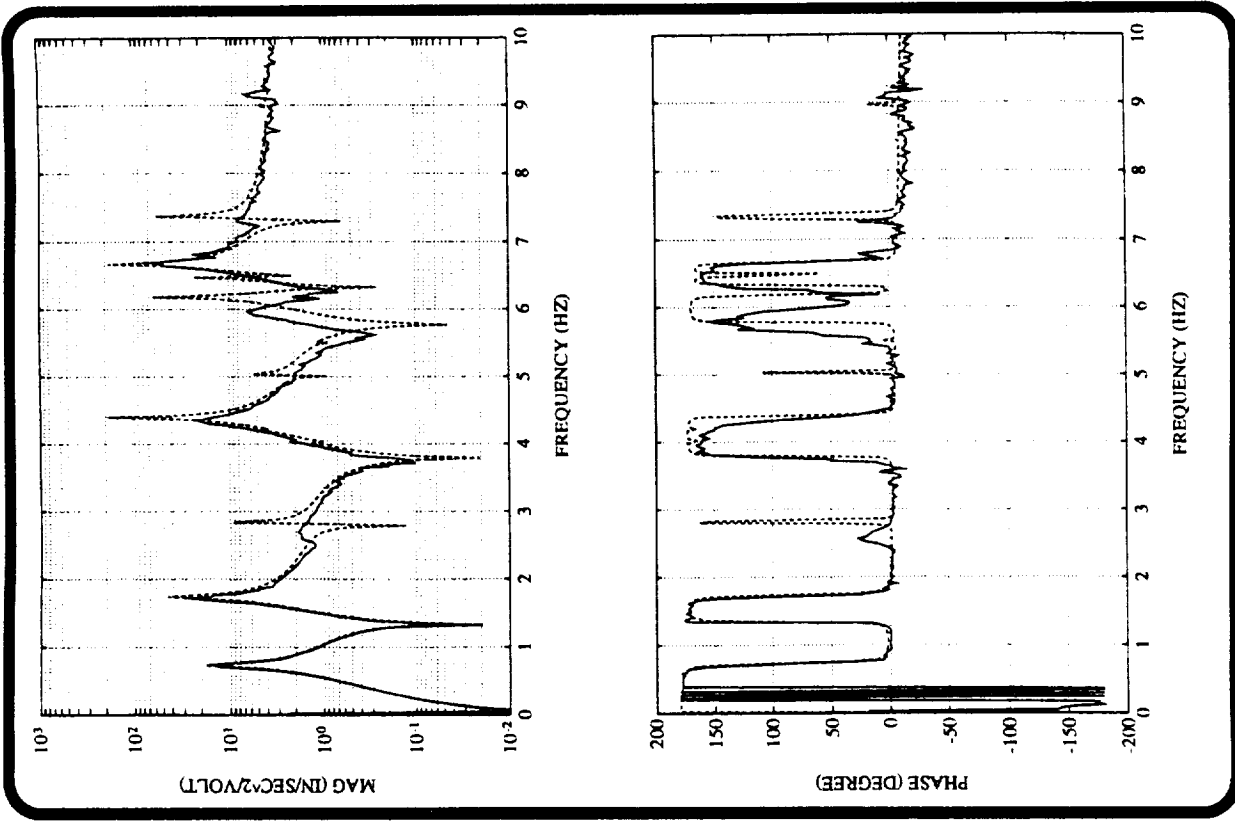


Figure 119. Bode diagram for Accelerometer 2 / Thruster 2

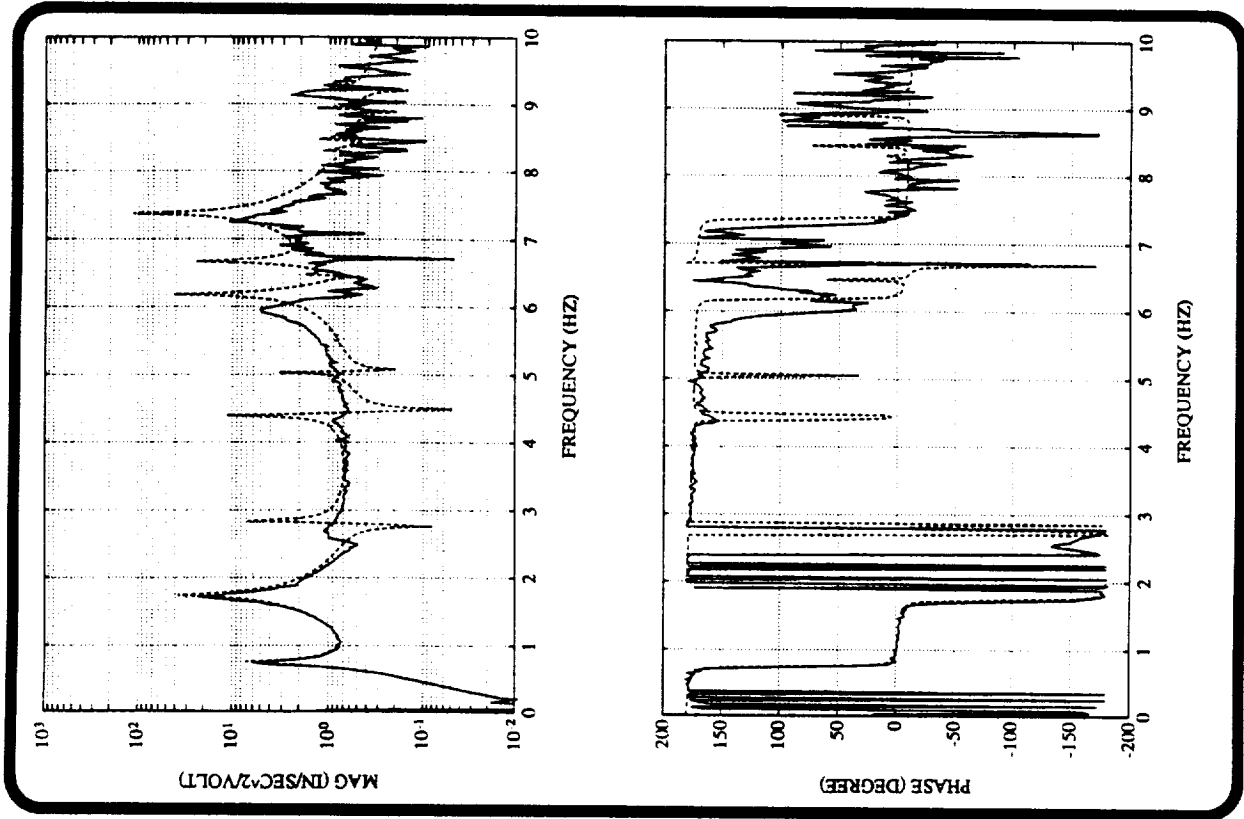


Figure 121. Bode diagram for Accelerometer 4 / Thruster 2

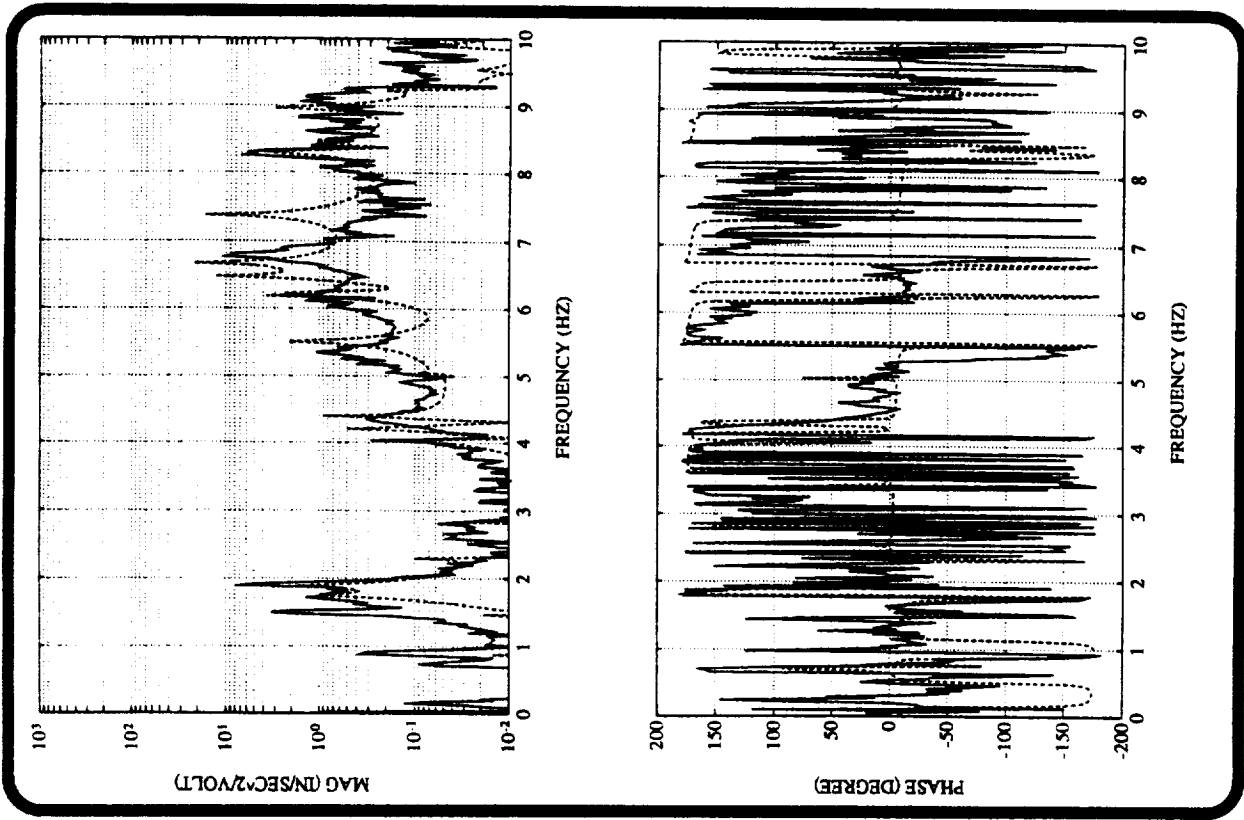


Figure 120. Bode diagram for Accelerometer 3 / Thruster 2

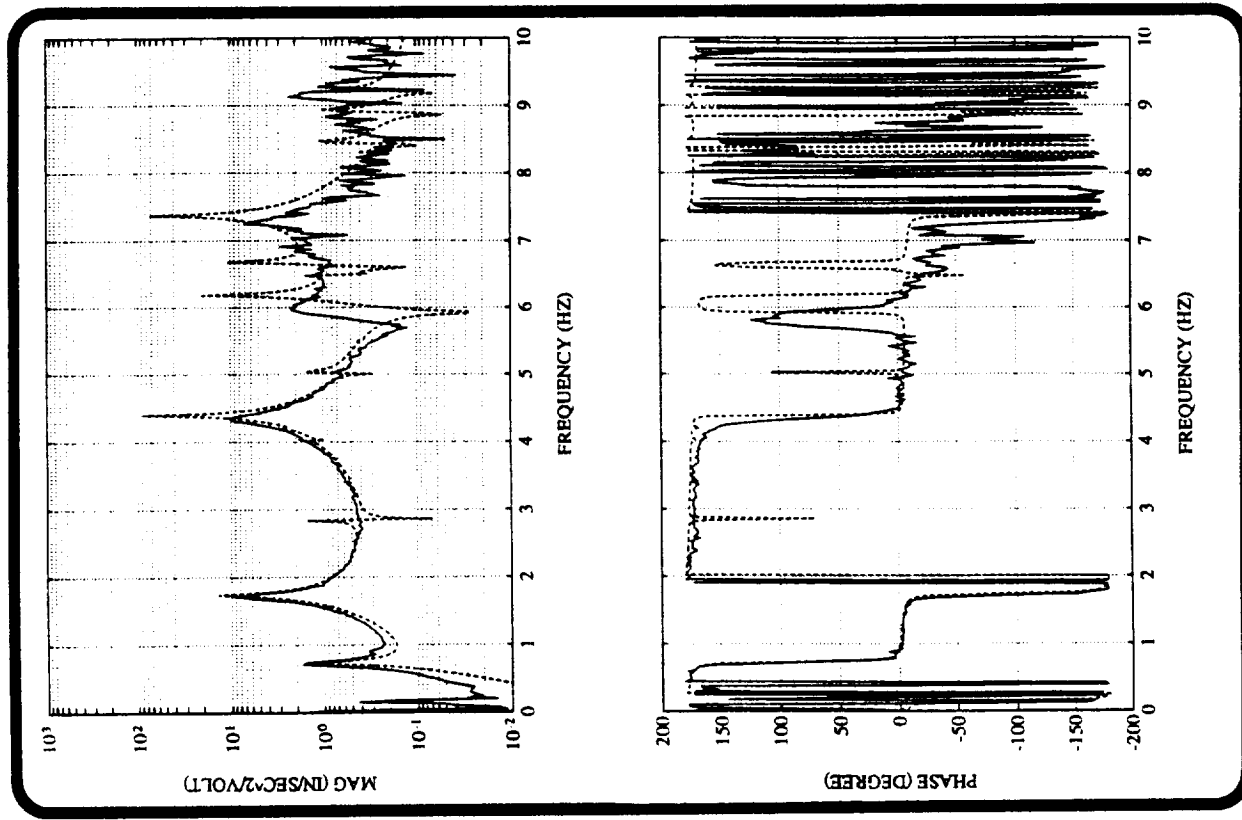


Figure 123. Bode diagram for Accelerometer 6 / Thruster 2

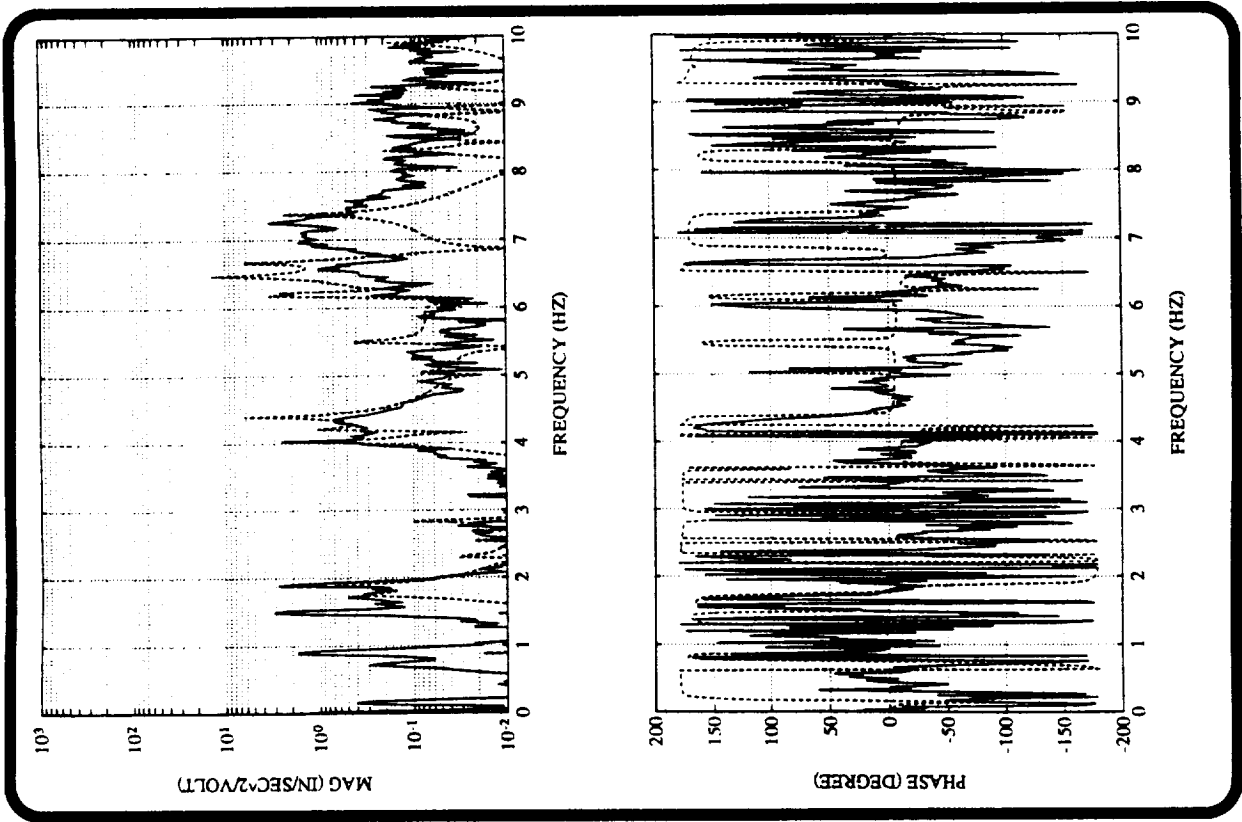


Figure 122. Bode diagram for Accelerometer 5 / Thruster 2

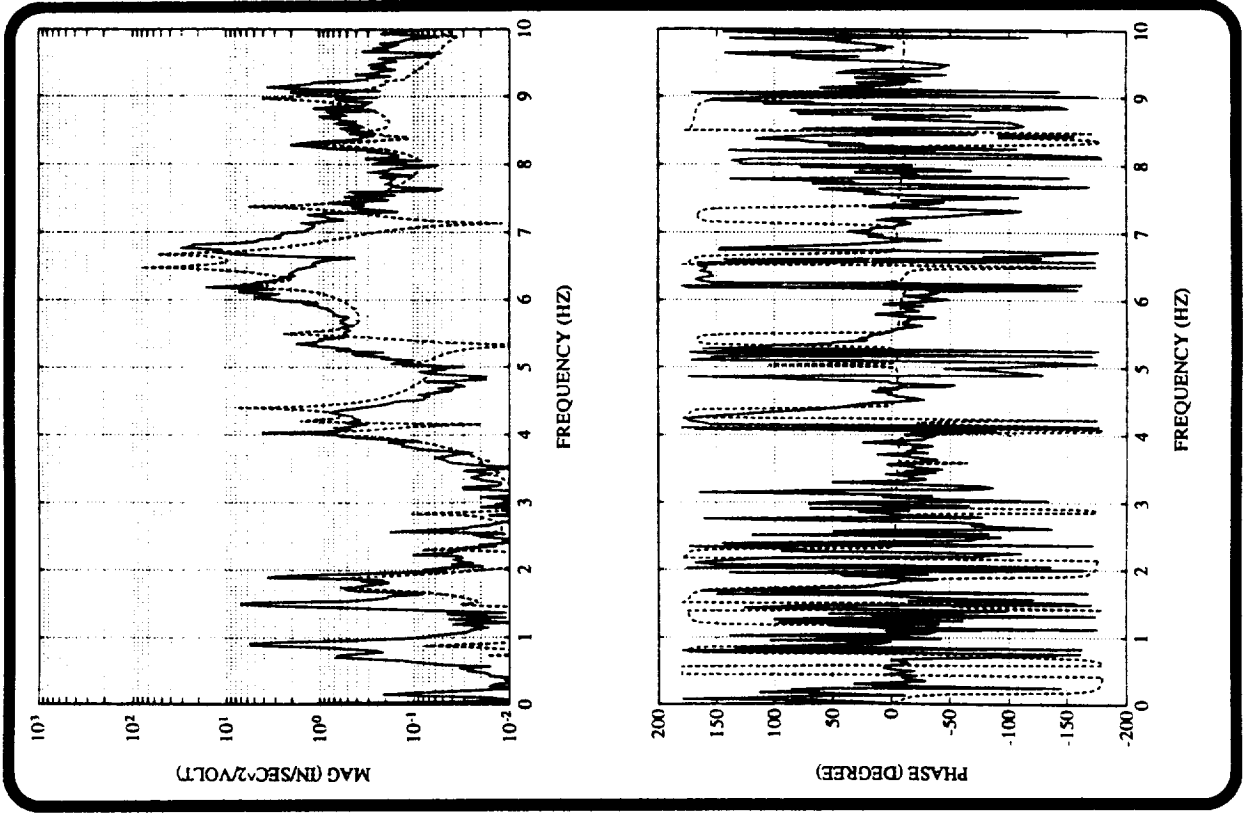


Figure 125. Bode diagram for Accelerometer 8 / Thruster 2

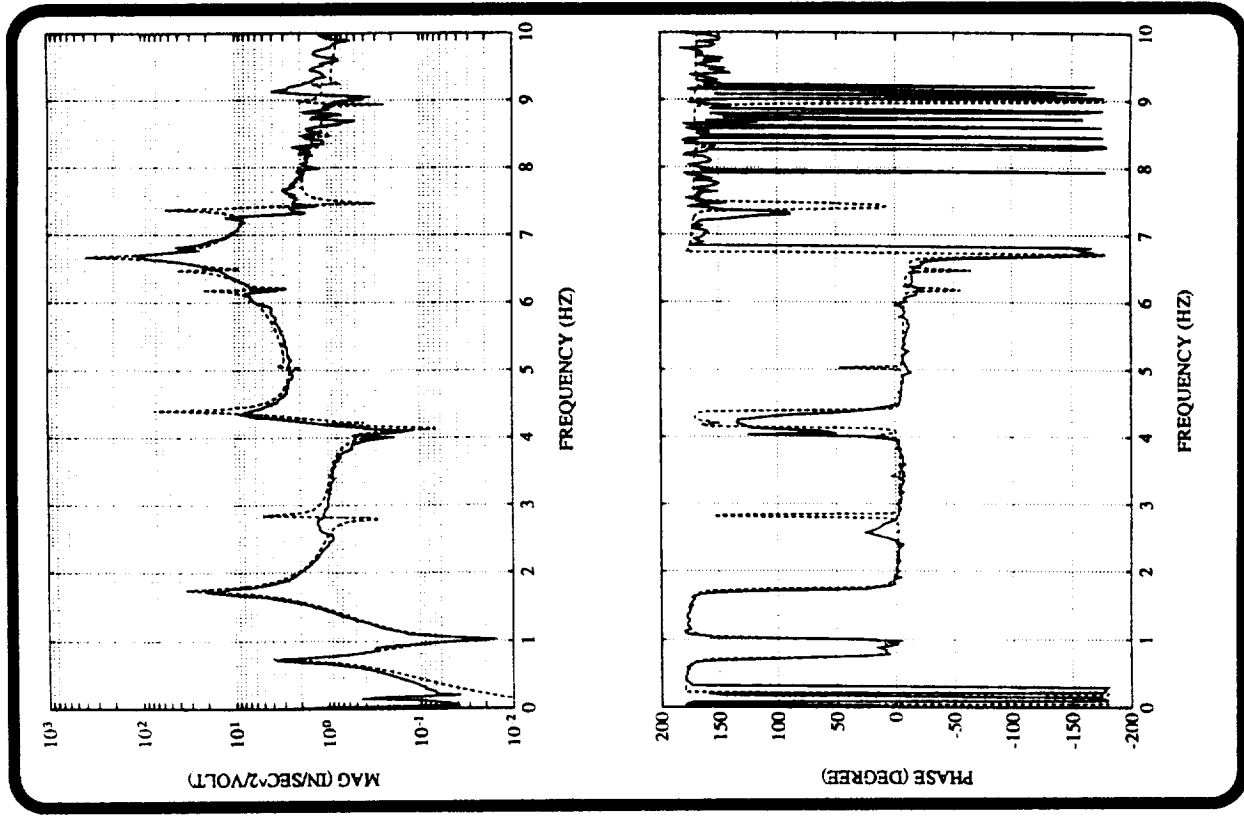


Figure 124. Bode diagram for Accelerometer 7 / Thruster 2

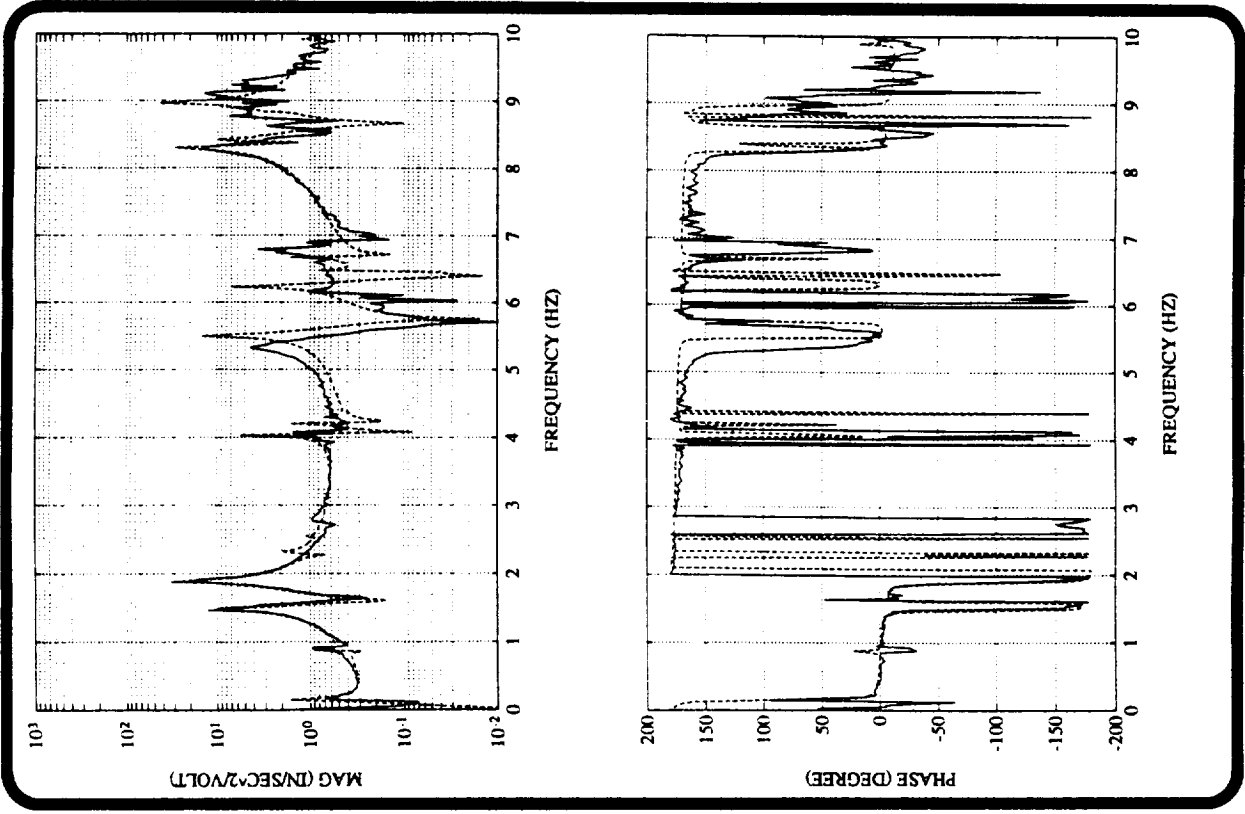


Figure 126. Bode diagram for Accelerometer 1 / Thruster 3

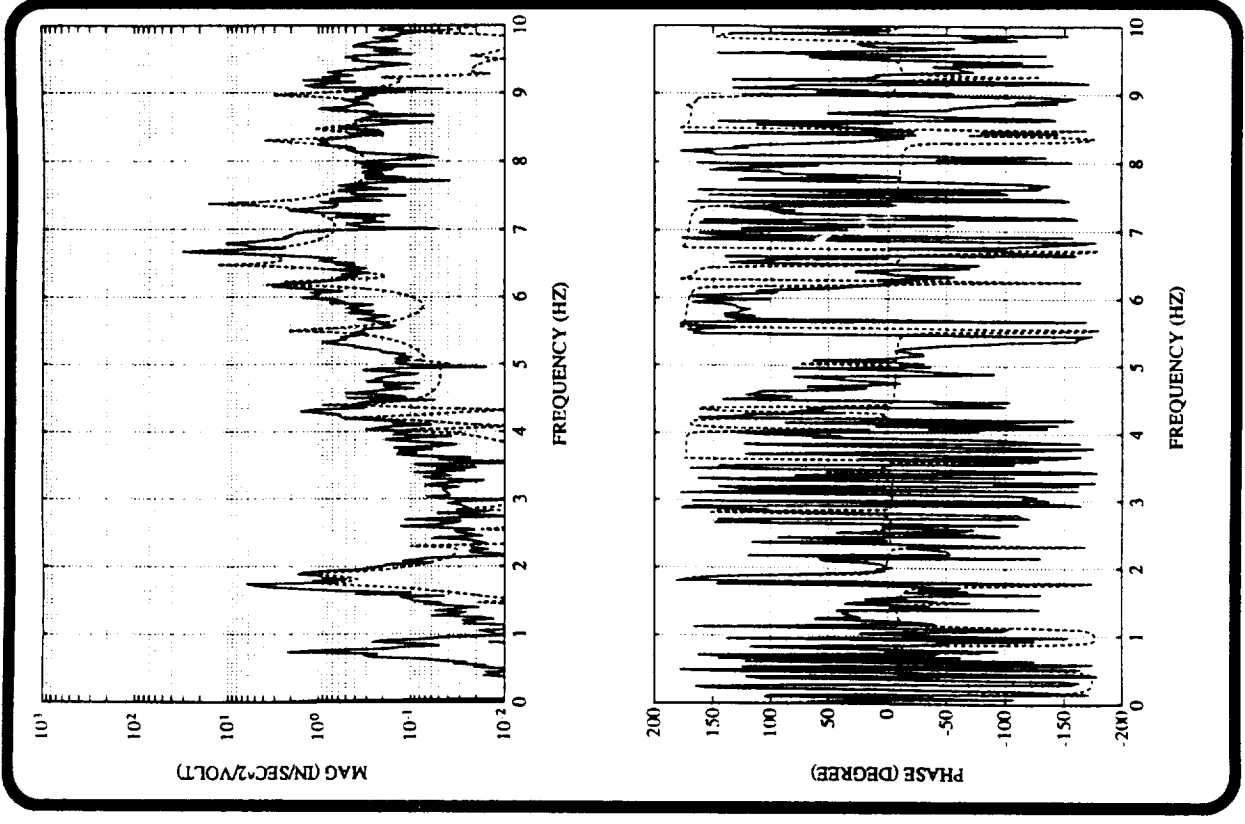


Figure 127. Bode diagram for Accelerometer 2 / Thruster 3

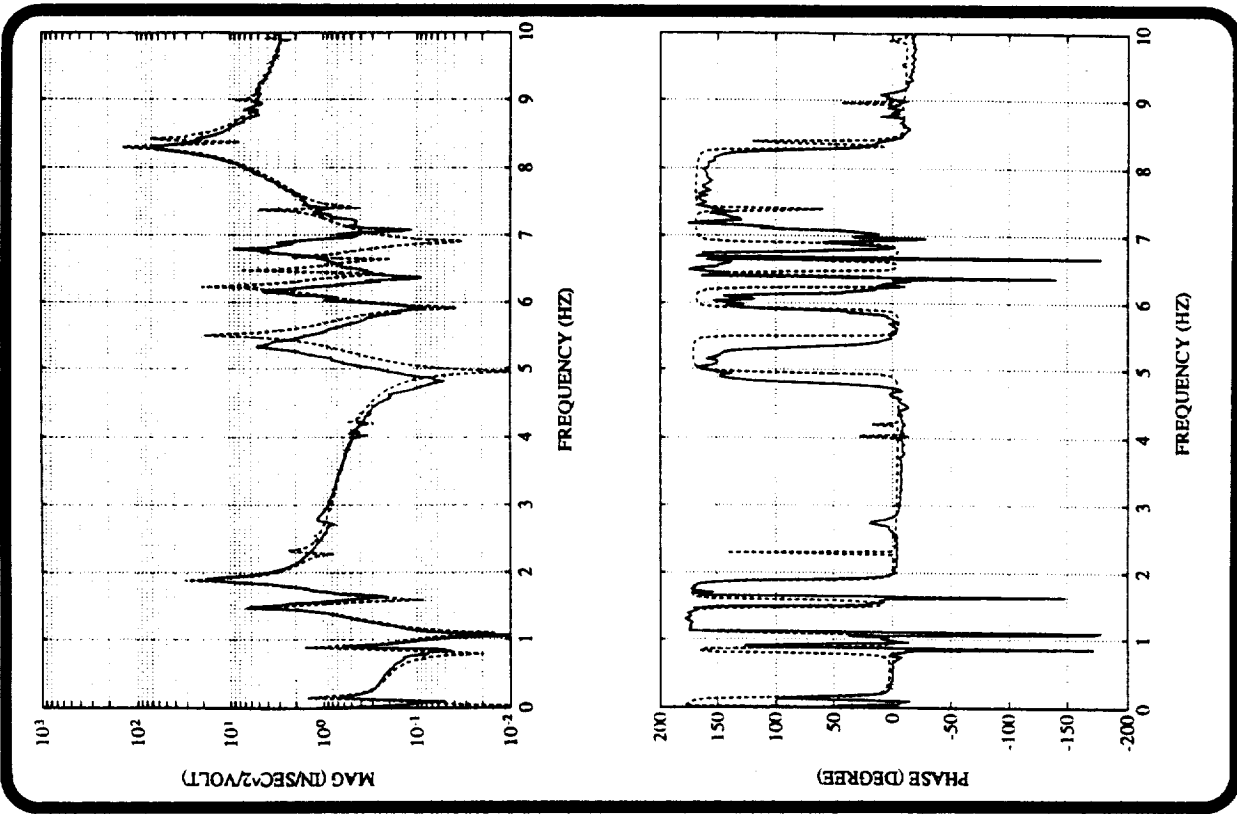


Figure 128. Bode diagram for Accelerometer 3 / Thruster 3

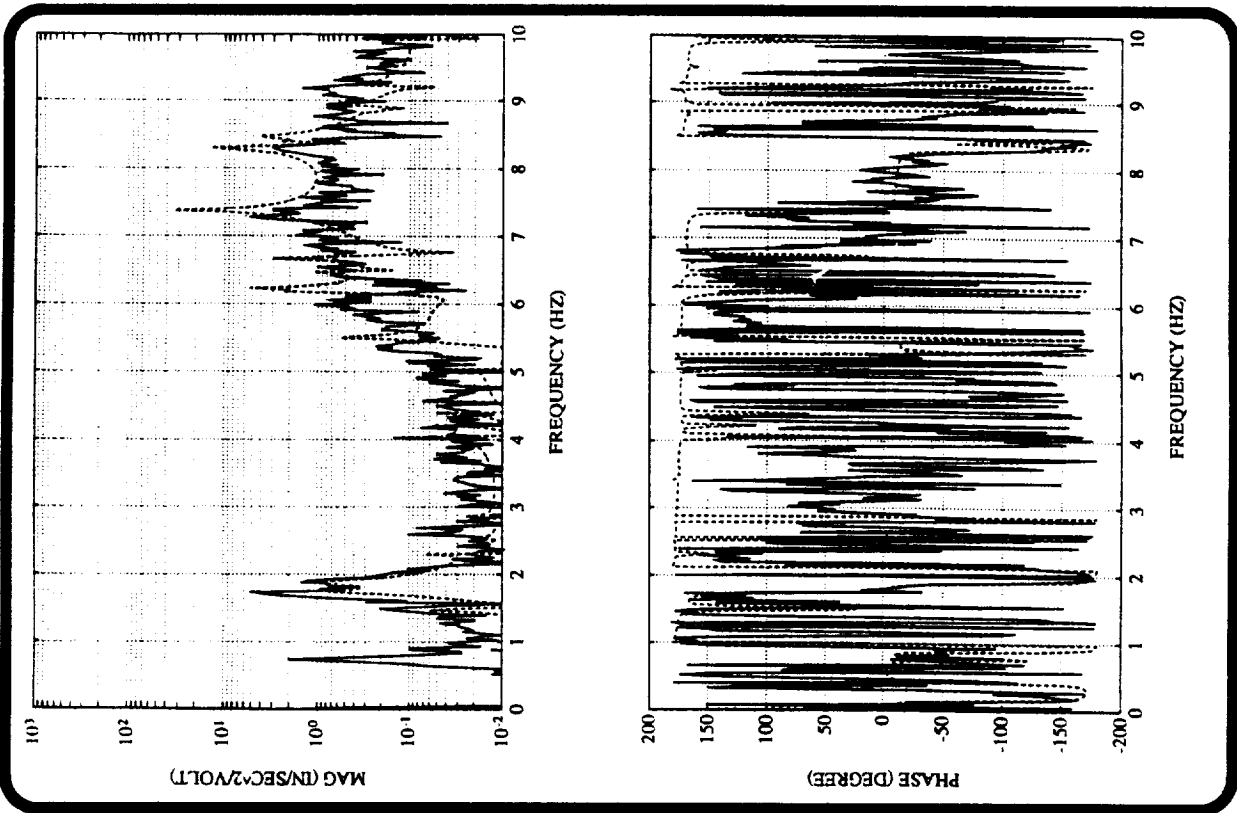


Figure 129. Bode diagram for Accelerometer 4 / Thruster 3

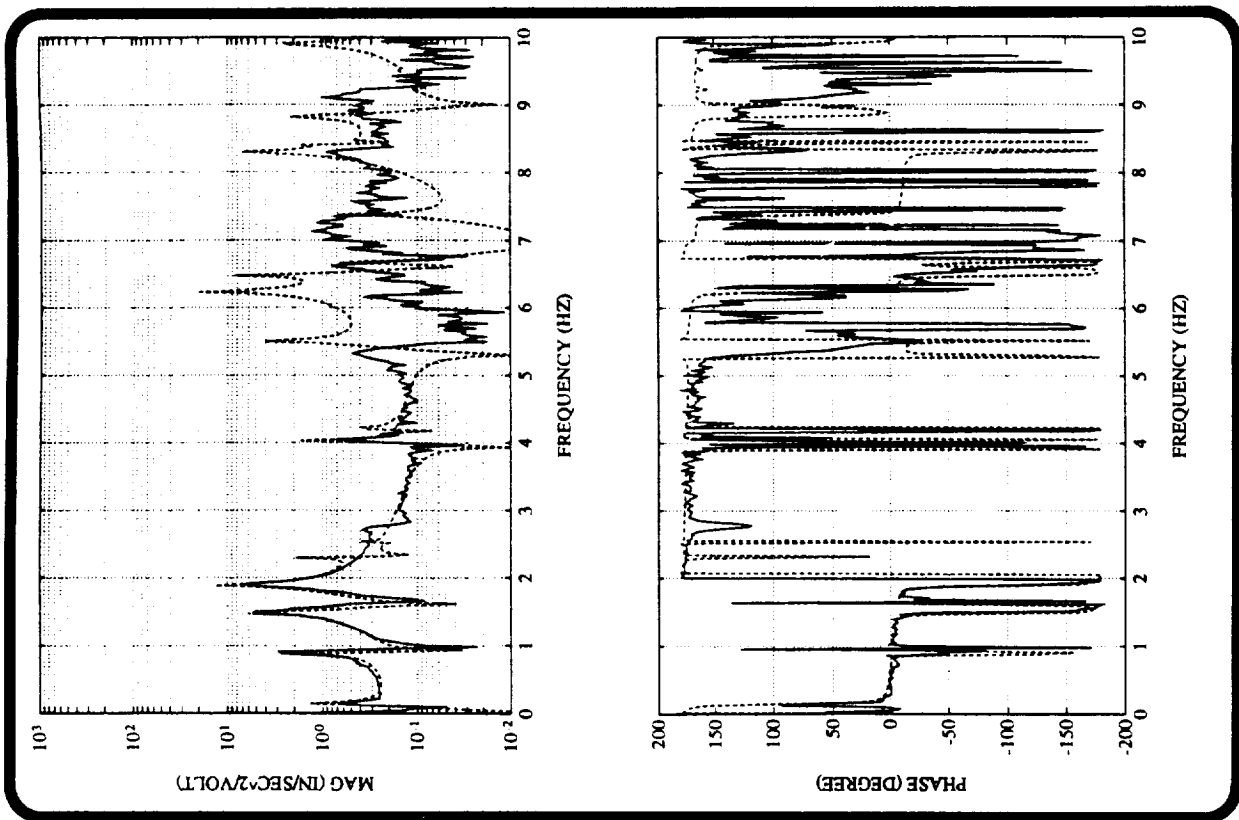


Figure 131. Bode diagram for Accelerometer 6 / Thruster 3

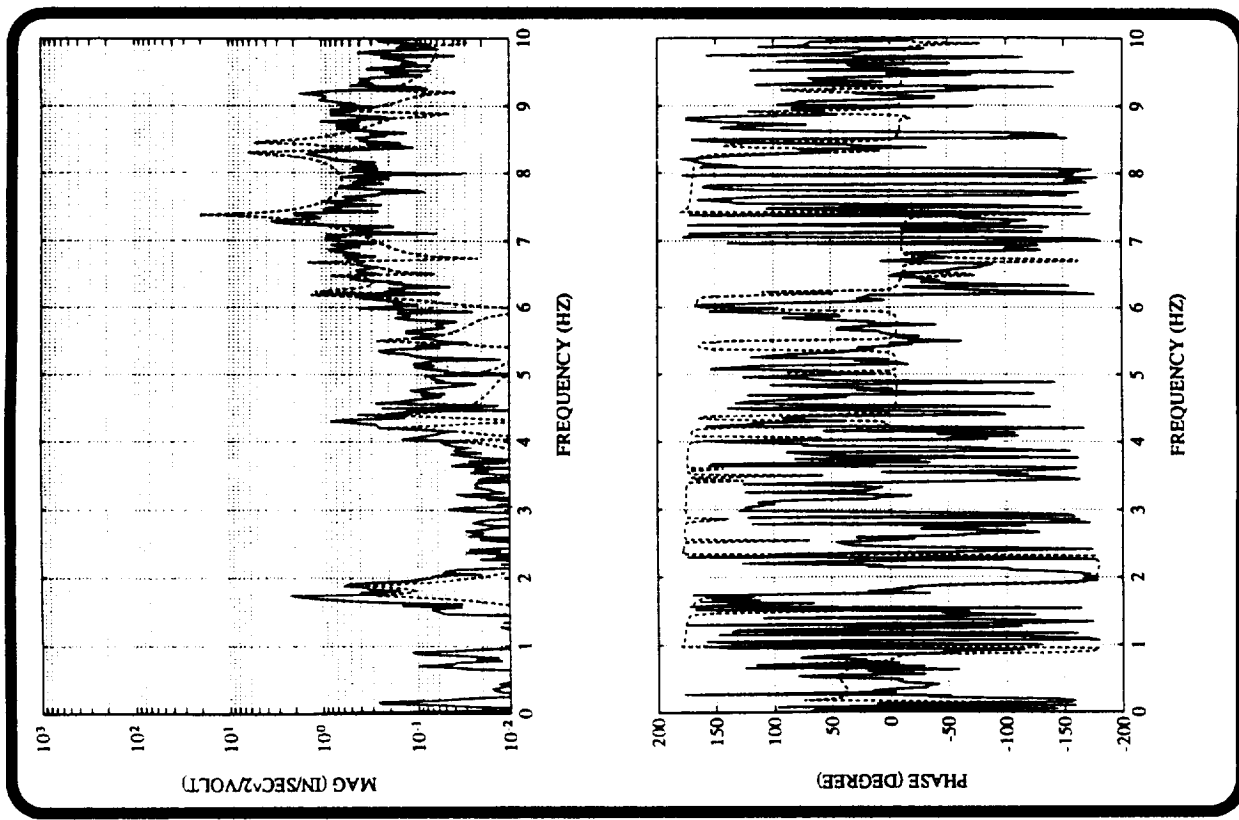


Figure 130. Bode diagram for Accelerometer 5 / Thruster 3

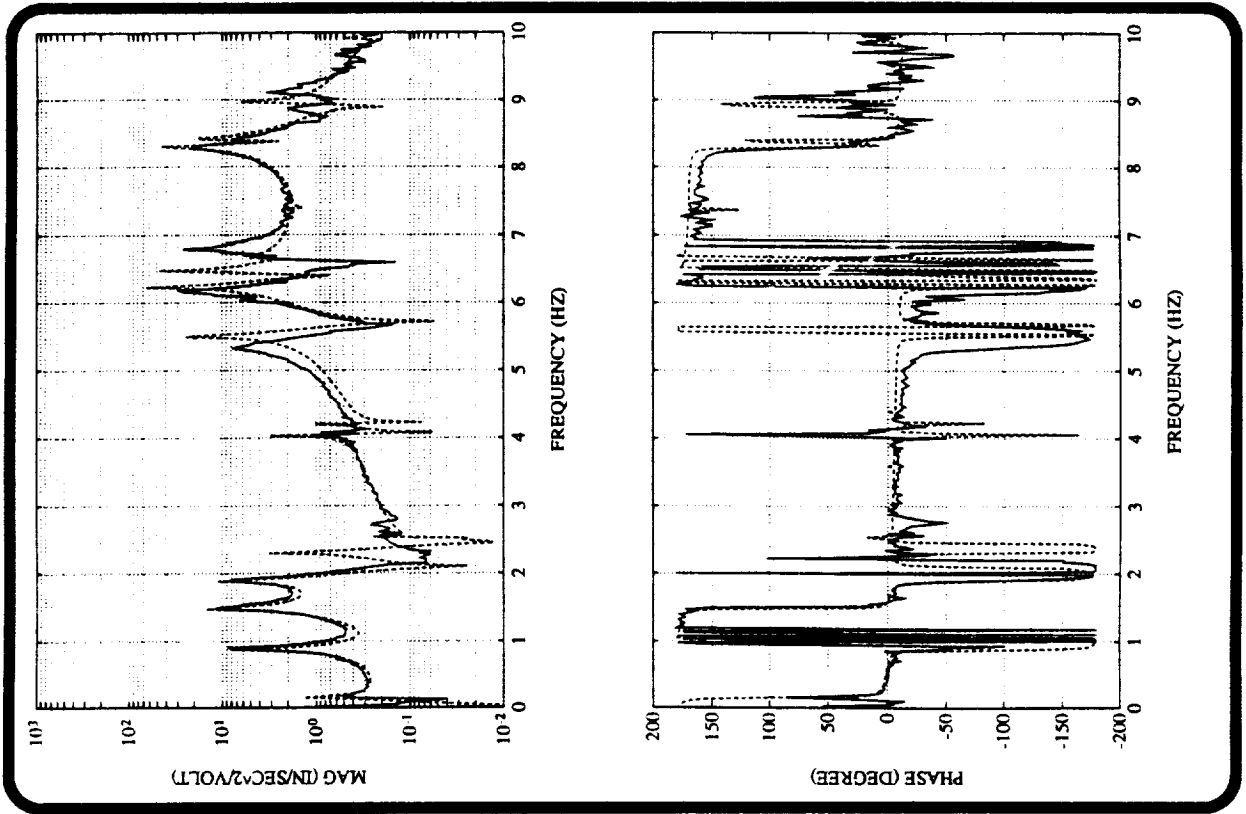


Figure 133. Bode diagram for Accelerometer 8 / Thruster 3

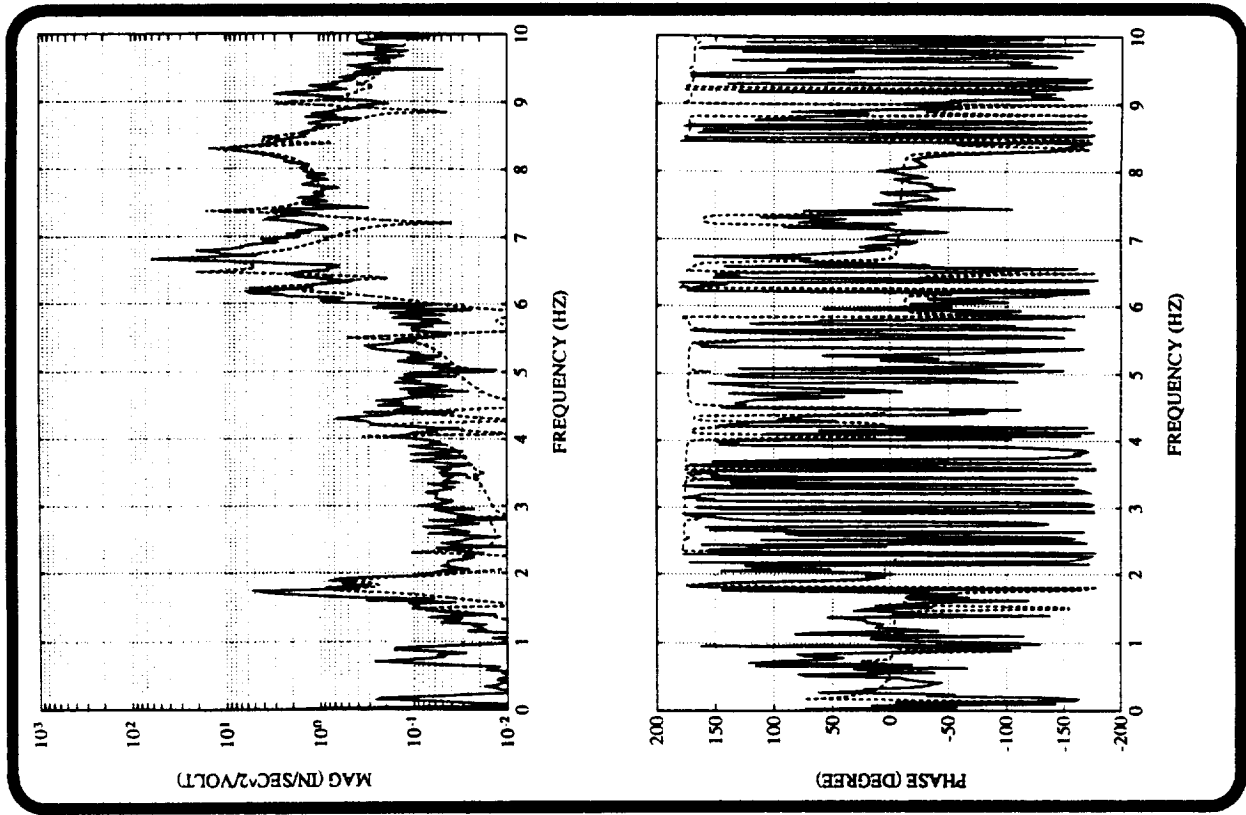


Figure 132. Bode diagram for Accelerometer 7 / Thruster 3

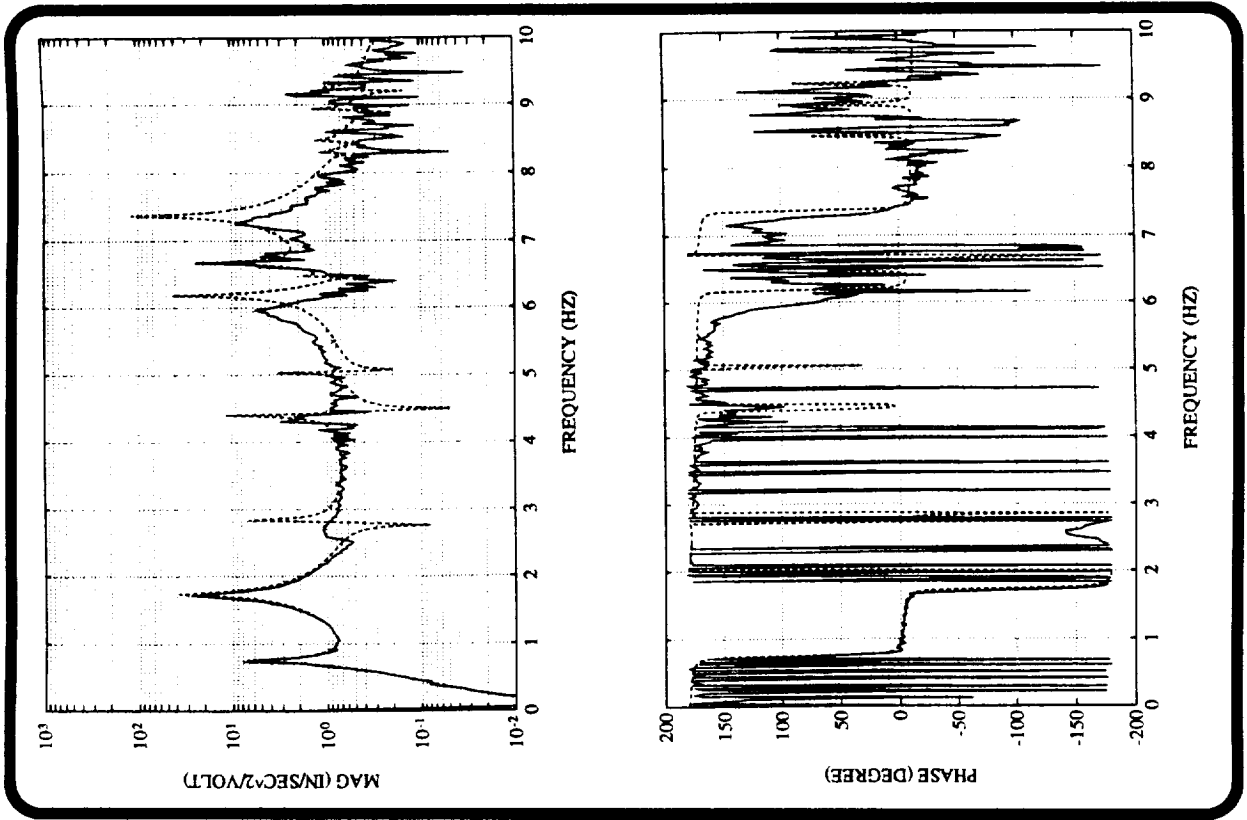


Figure 135. Bode diagram for Accelerometer 2 / Thruster 4

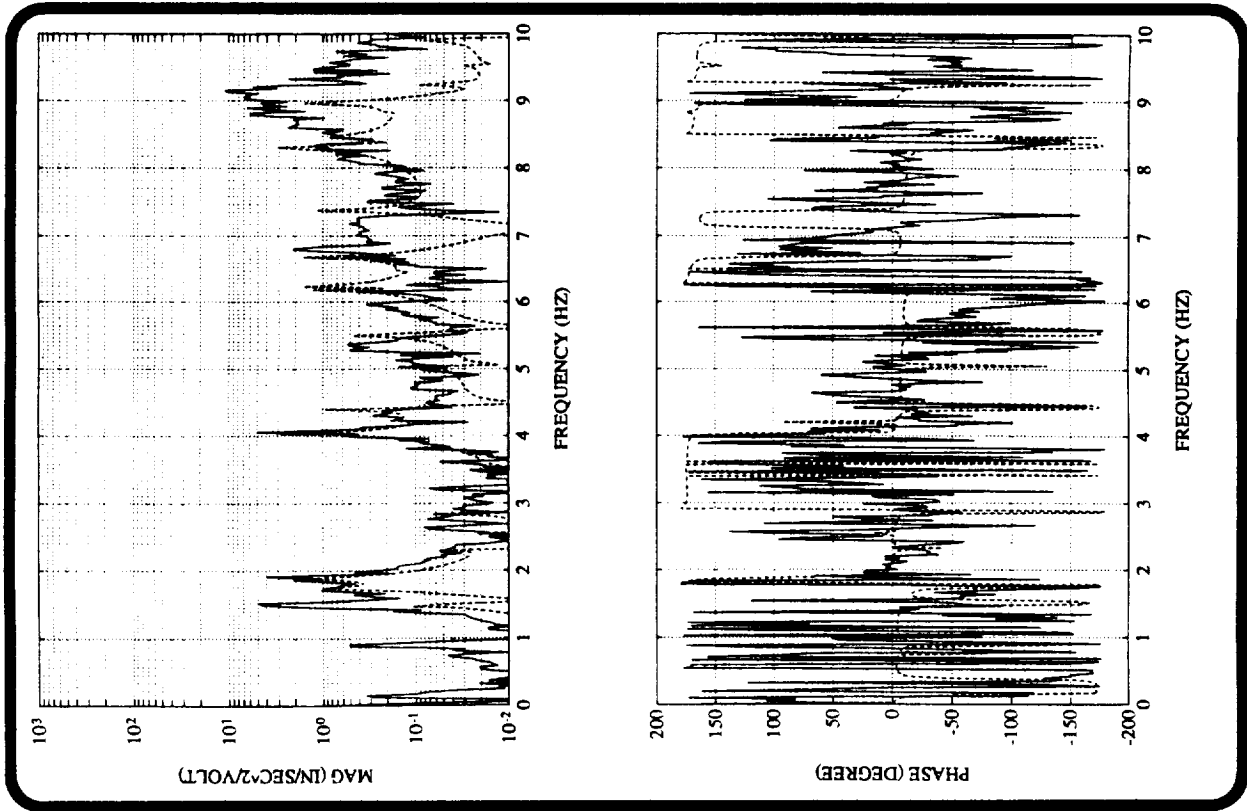


Figure 134. Bode diagram for Accelerometer 1 / Thruster 4

C-2

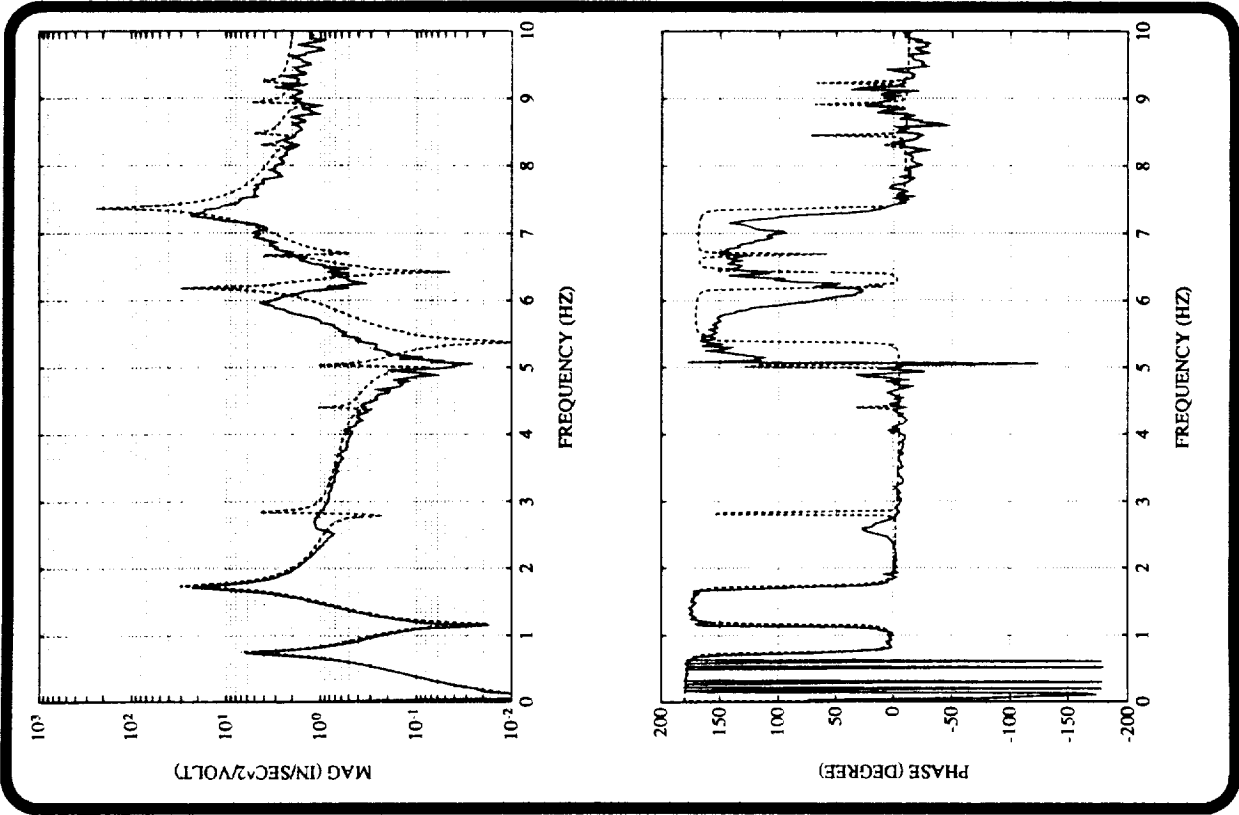


Figure 137. Bode diagram for Accelerometer 4 / Thruster 4

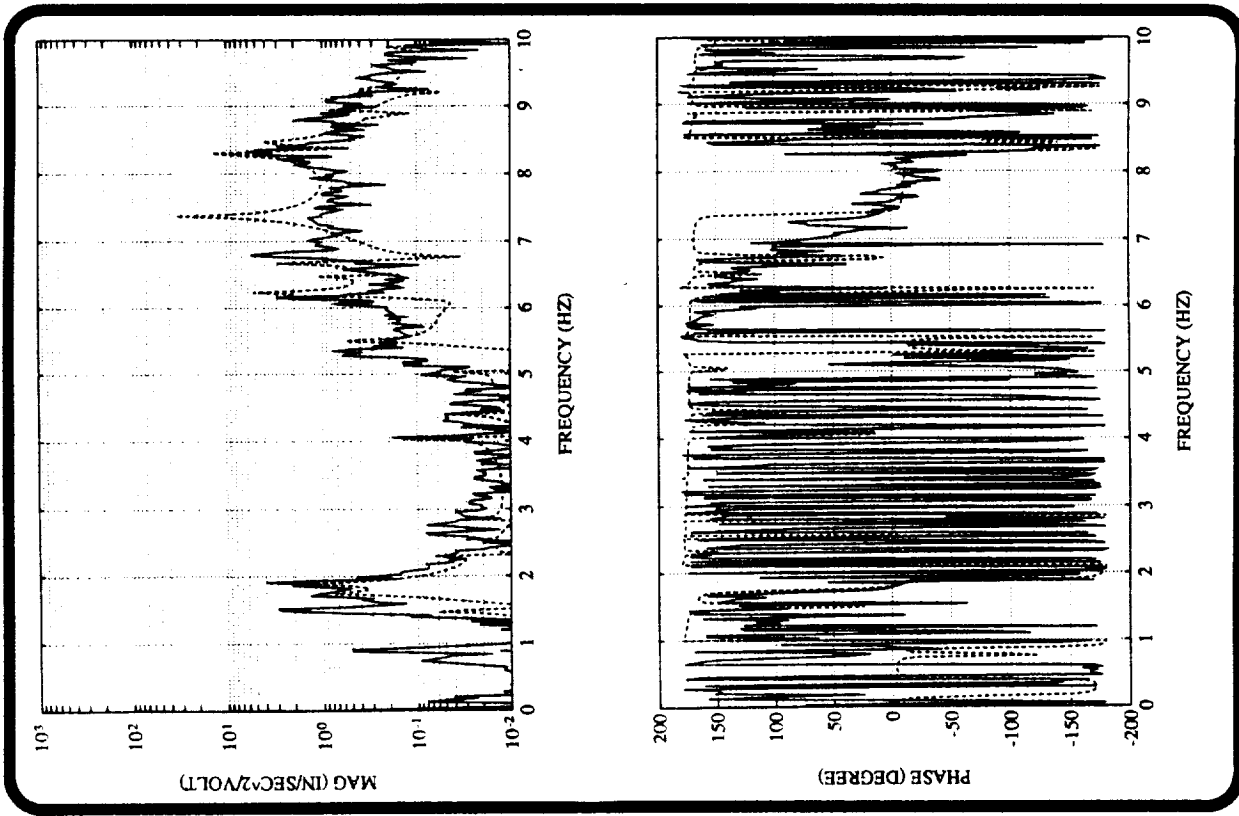


Figure 136. Bode diagram for Accelerometer 3 / Thruster 4

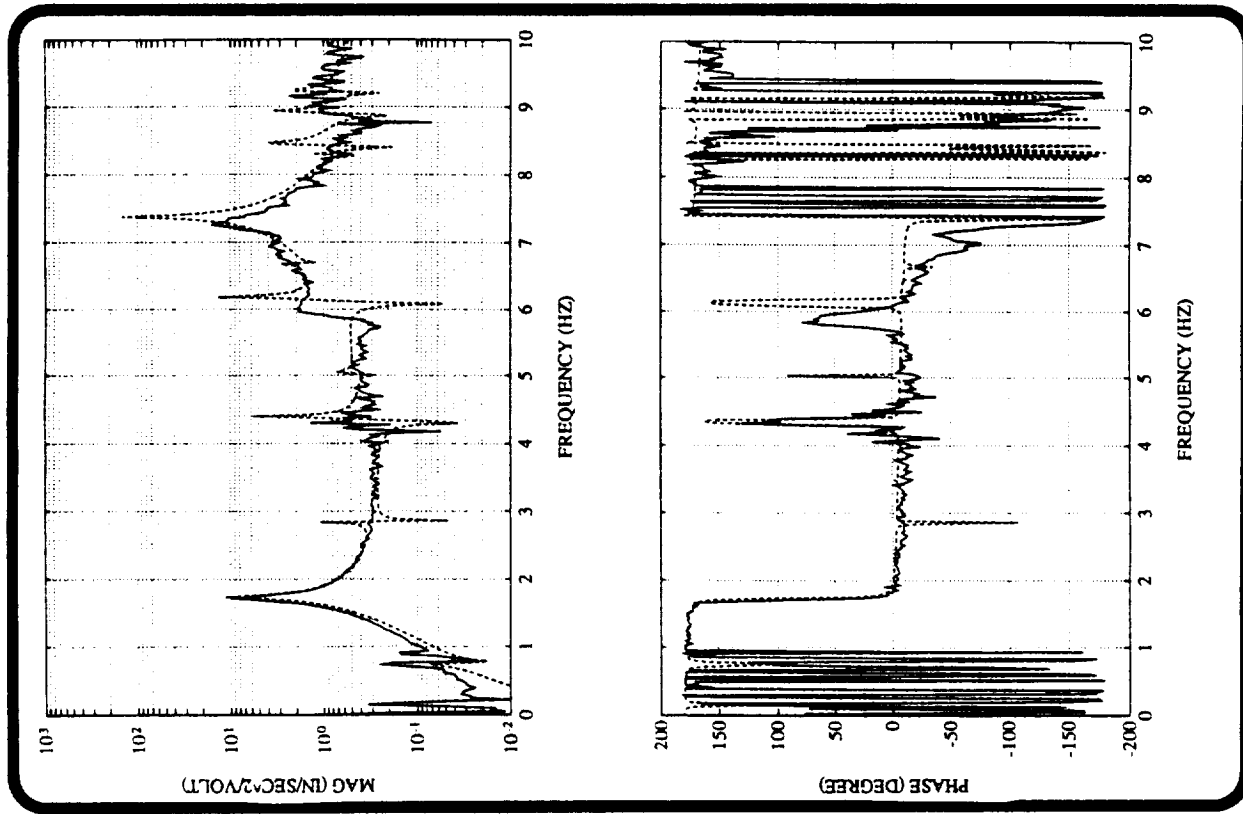


Figure 138. Bode diagram for Accelerometer 5 / Thruster 4

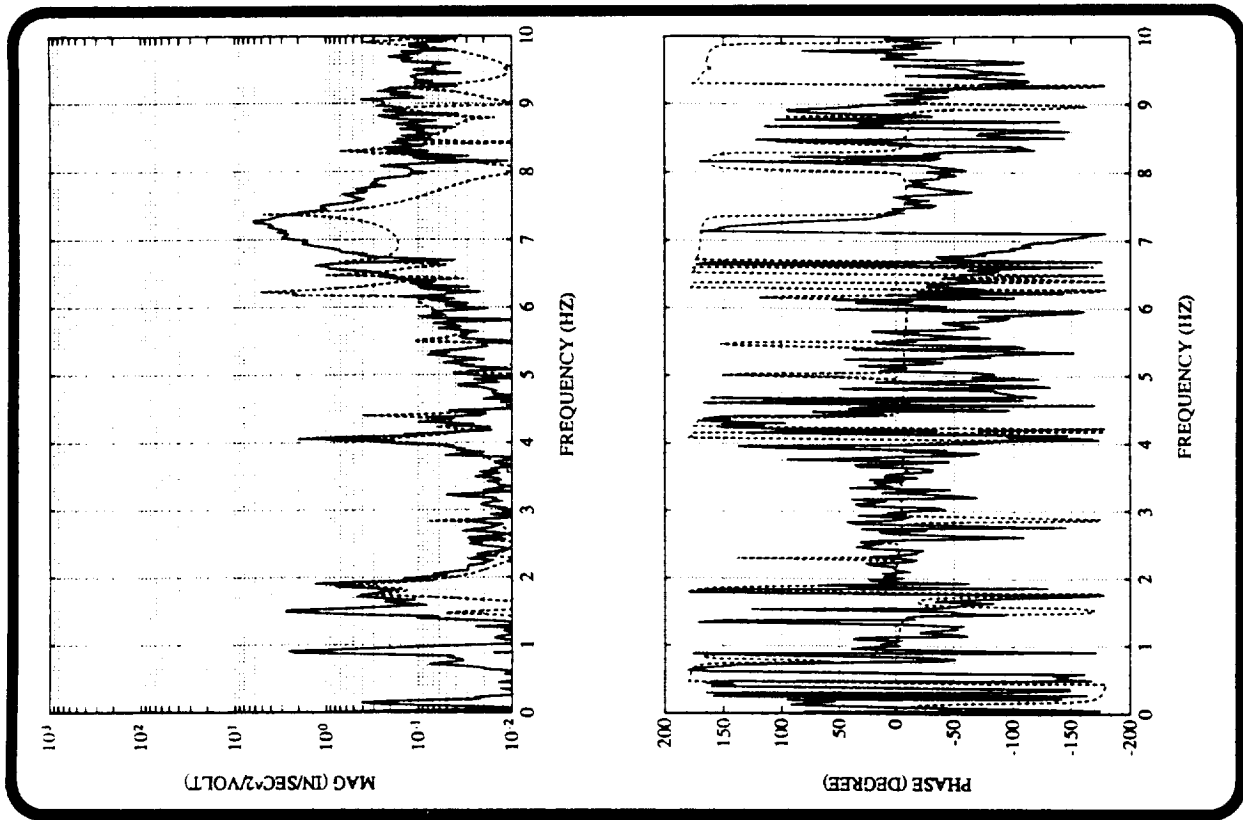


Figure 139. Bode diagram for Accelerometer 6 / Thruster 4

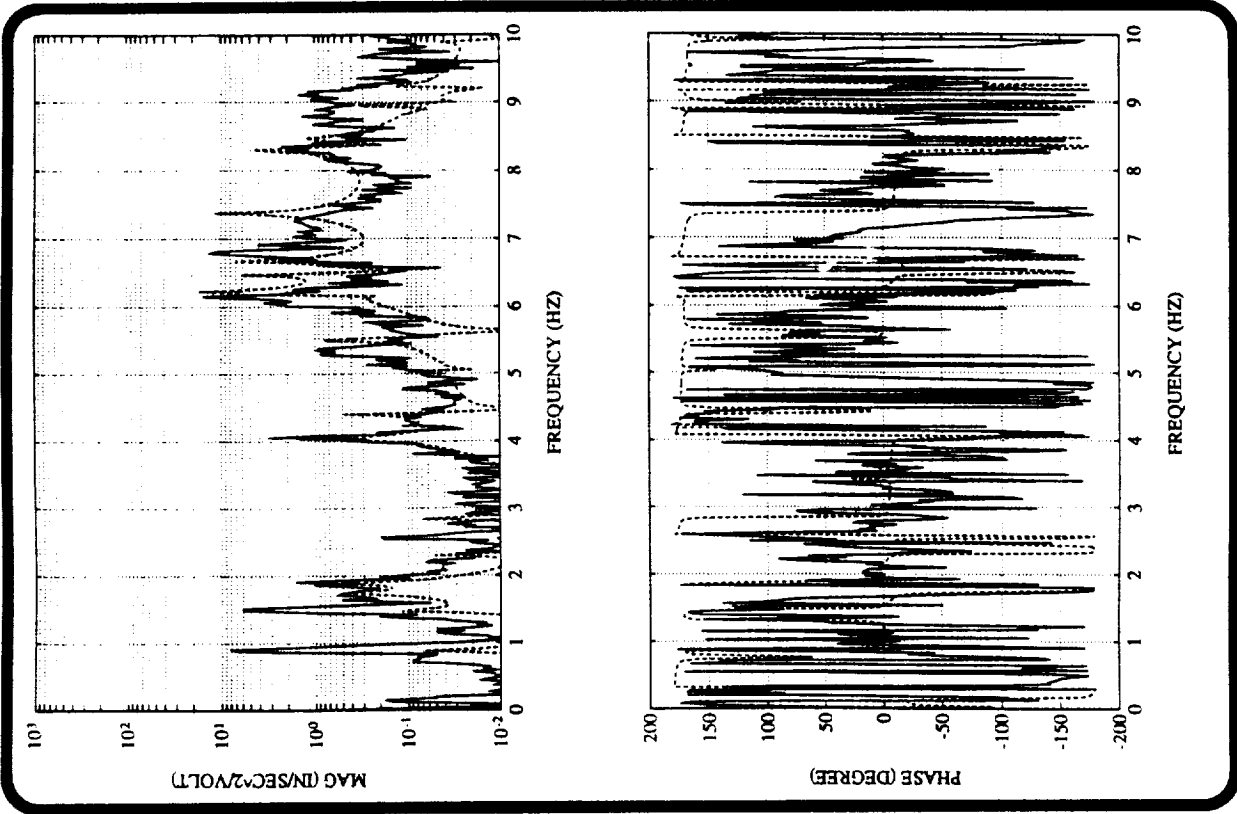


Figure 141. Bode diagram for Accelerometer 8 / Thruster 4

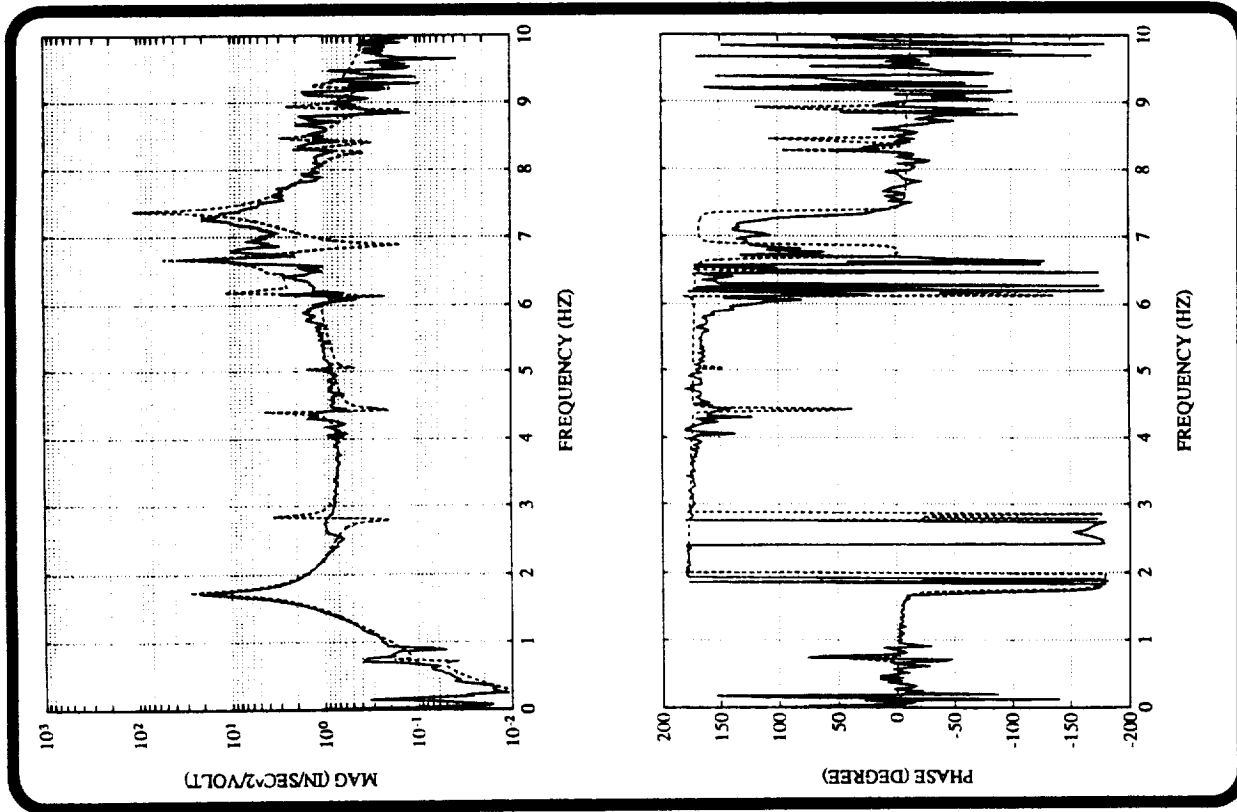


Figure 140. Bode diagram for Accelerometer 7 / Thruster 4

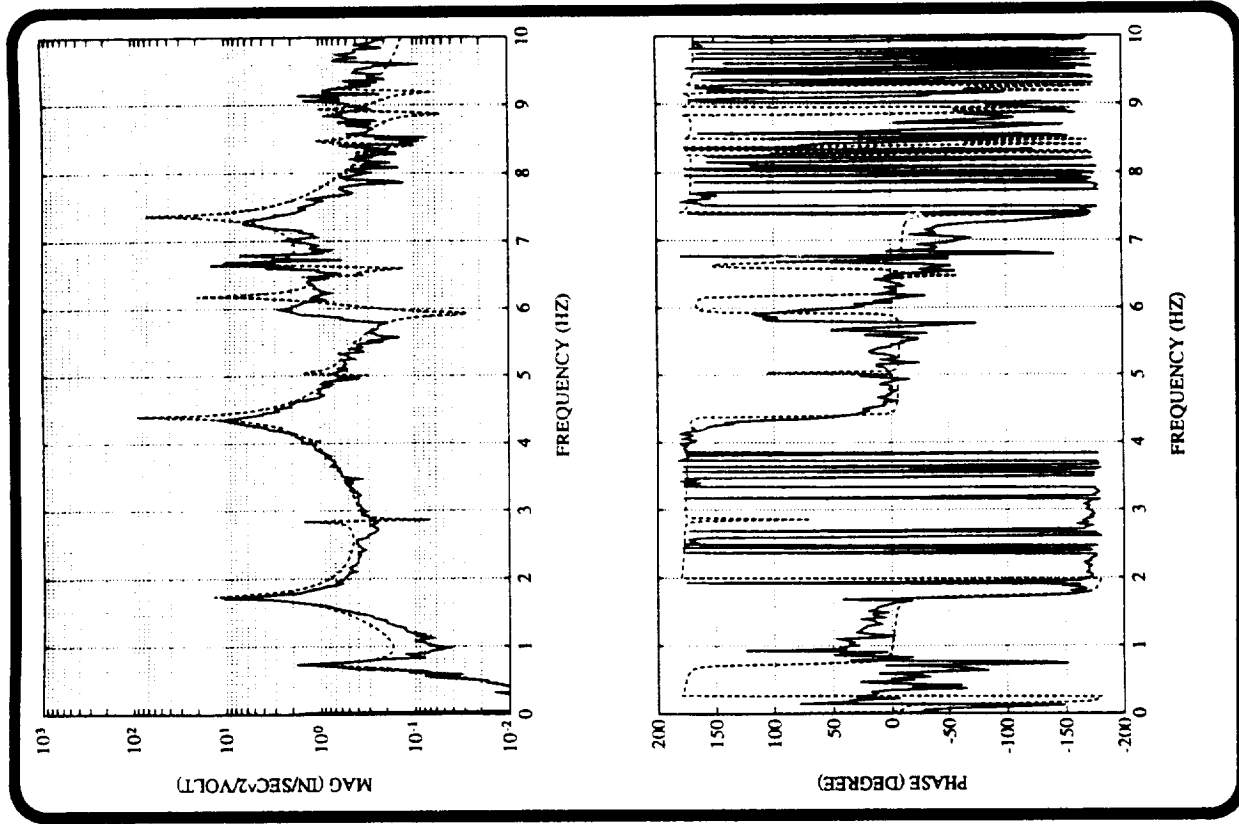


Figure 143. Bode diagram for Accelerometer 2 / Thruster 5

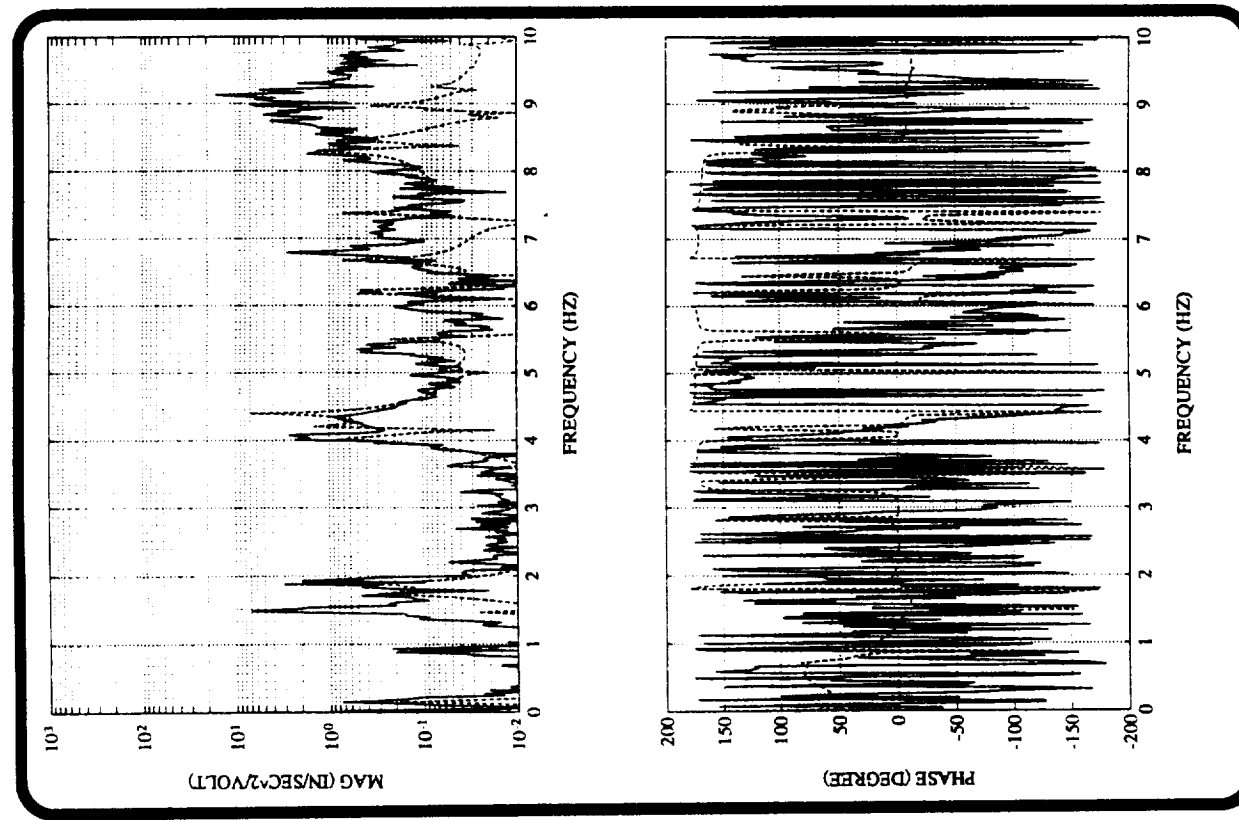


Figure 142. Bode diagram for Accelerometer 1 / Thruster 5

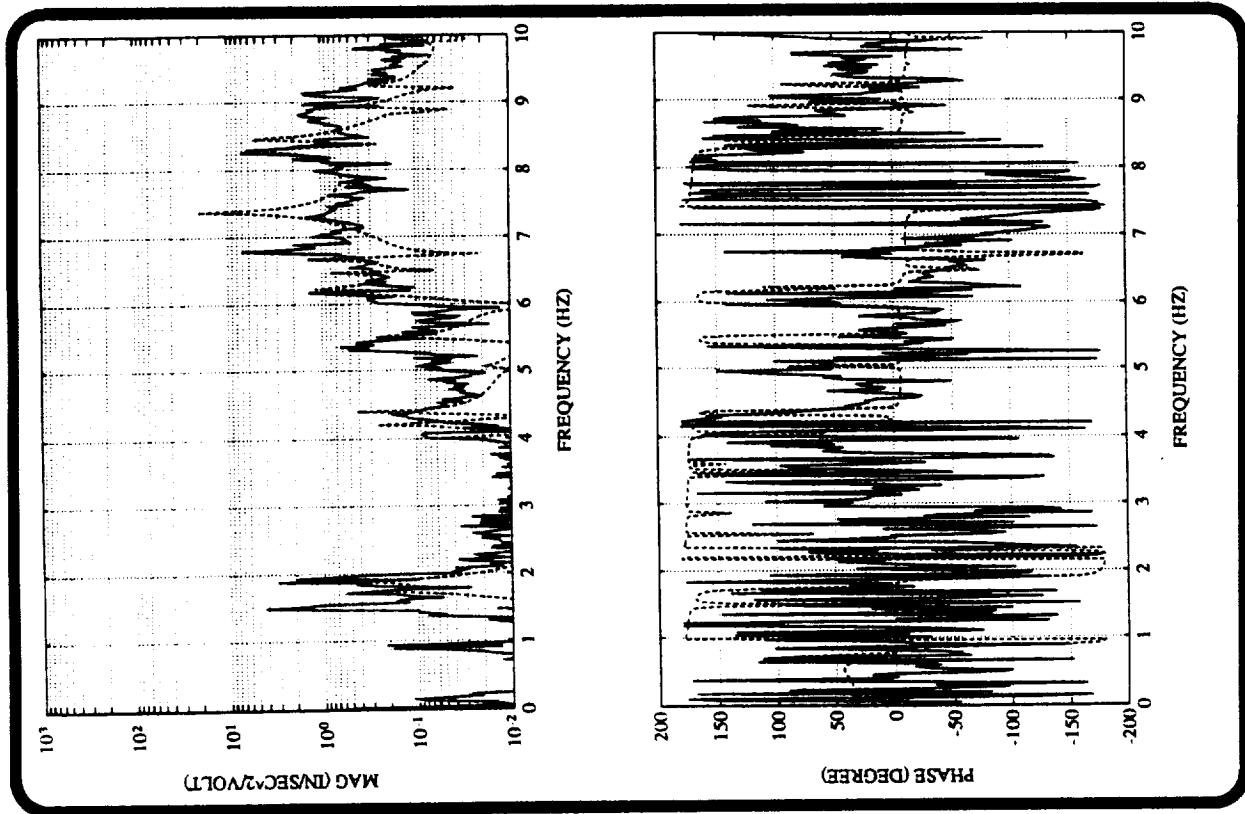


Figure 144. Bode diagram for Accelerometer 3 / Thruster 5

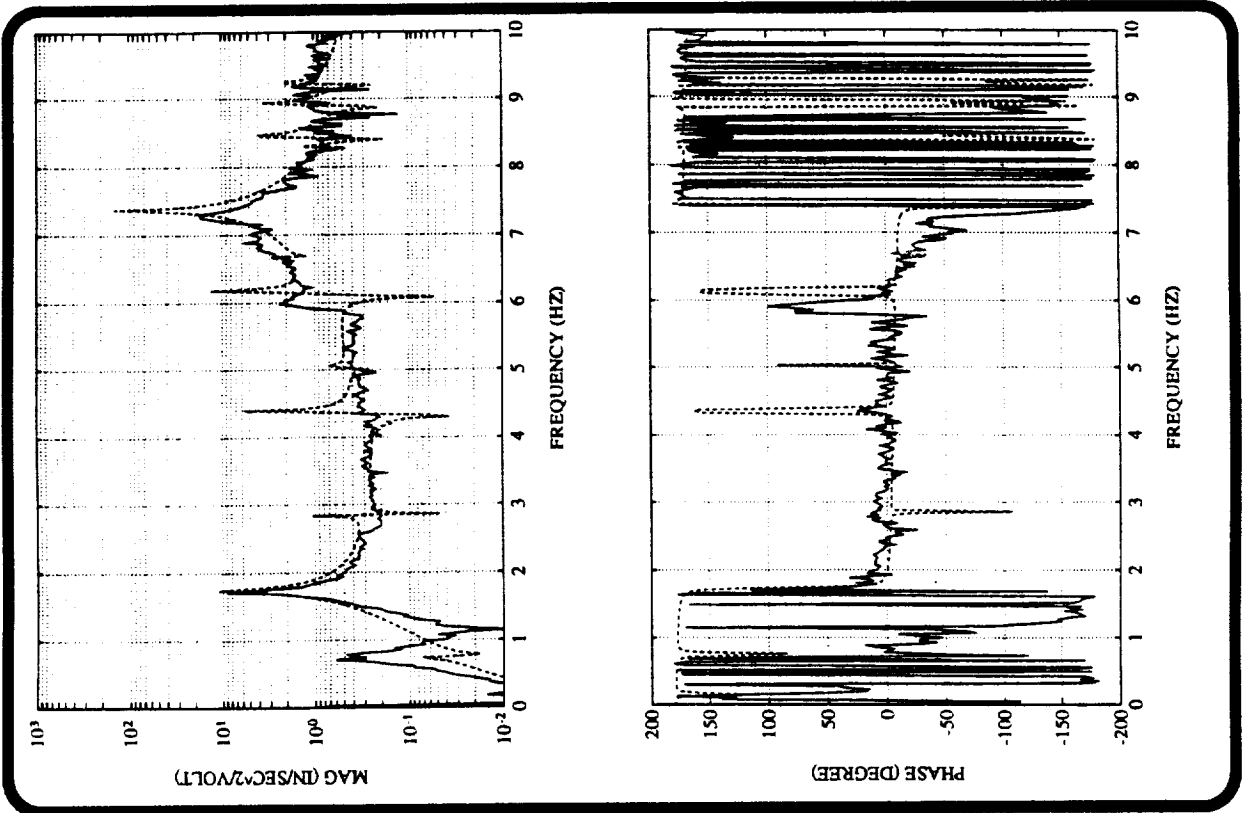


Figure 145. Bode diagram for Accelerometer 4 / Thruster 5

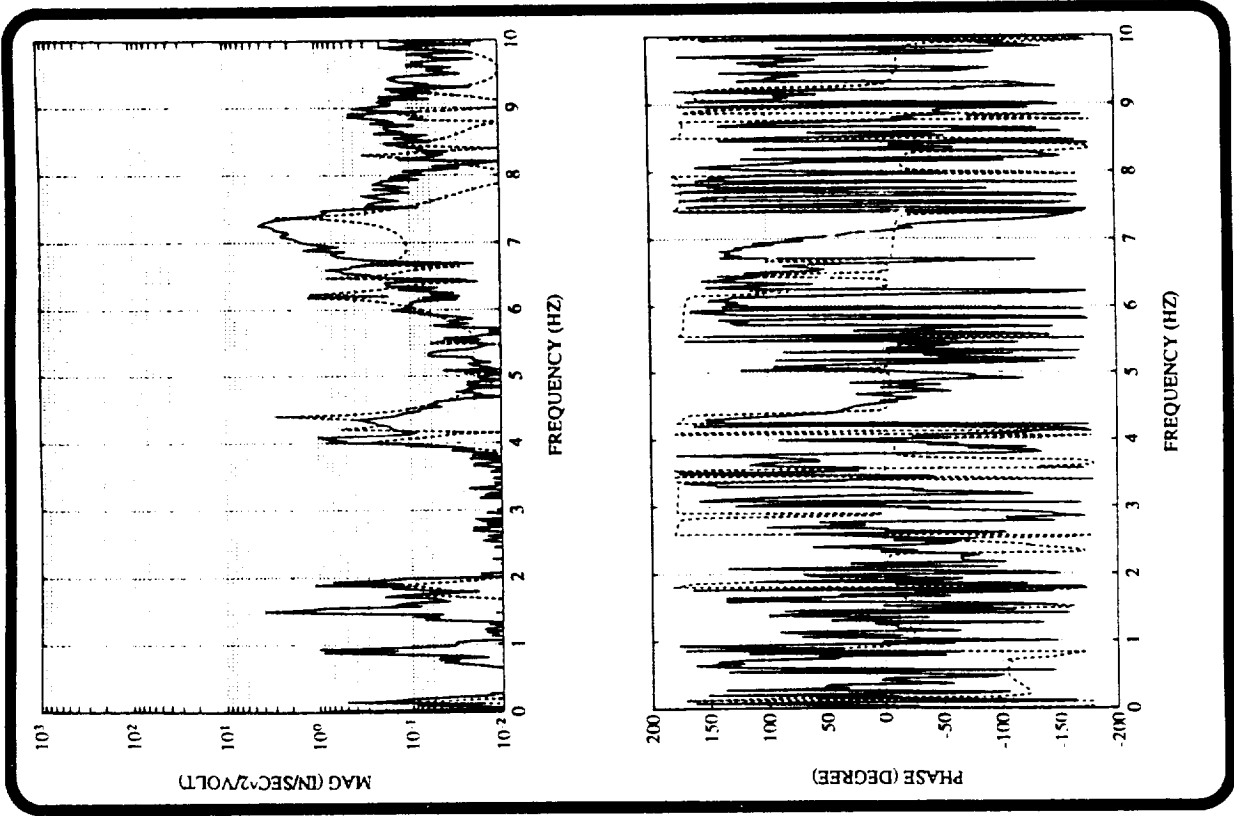


Figure 147. Bode diagram for Accelerometer 6 / Thruster 5

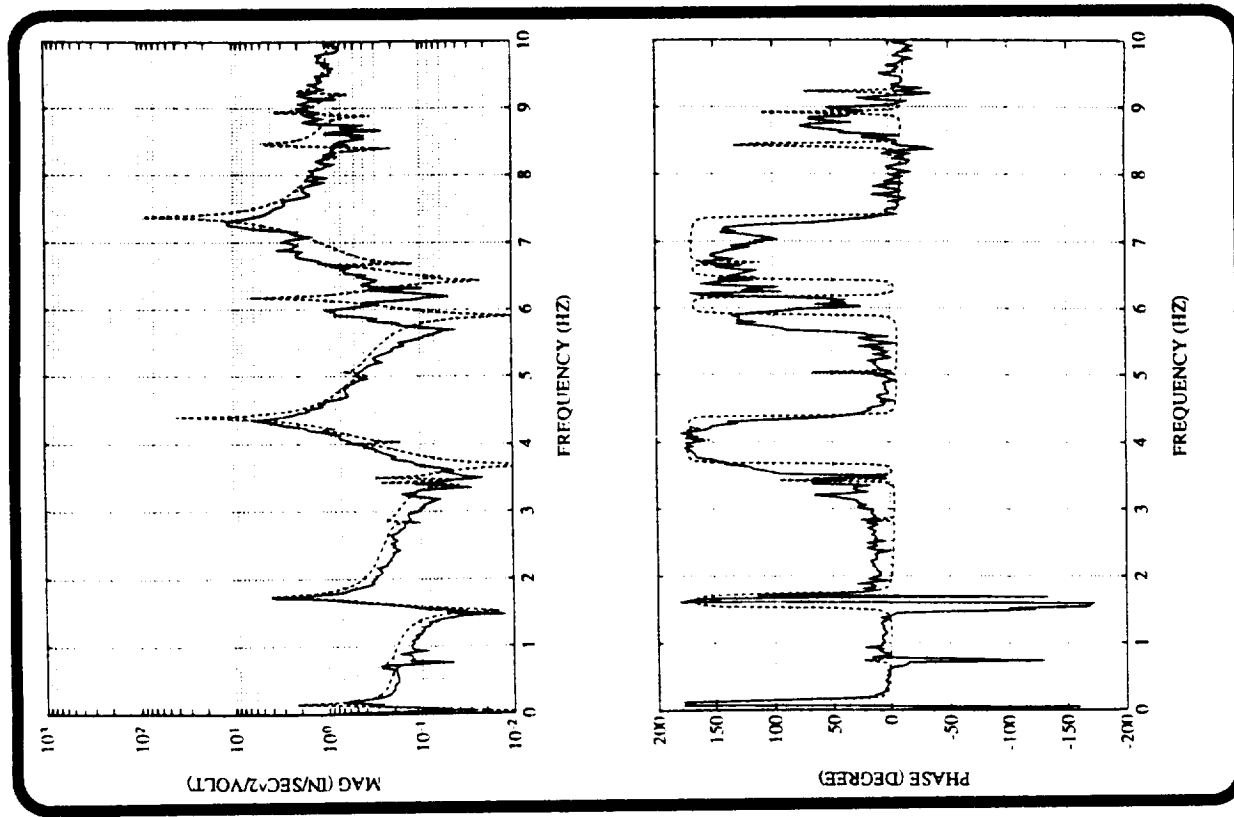


Figure 146. Bode diagram for Accelerometer 5 / Thruster 5

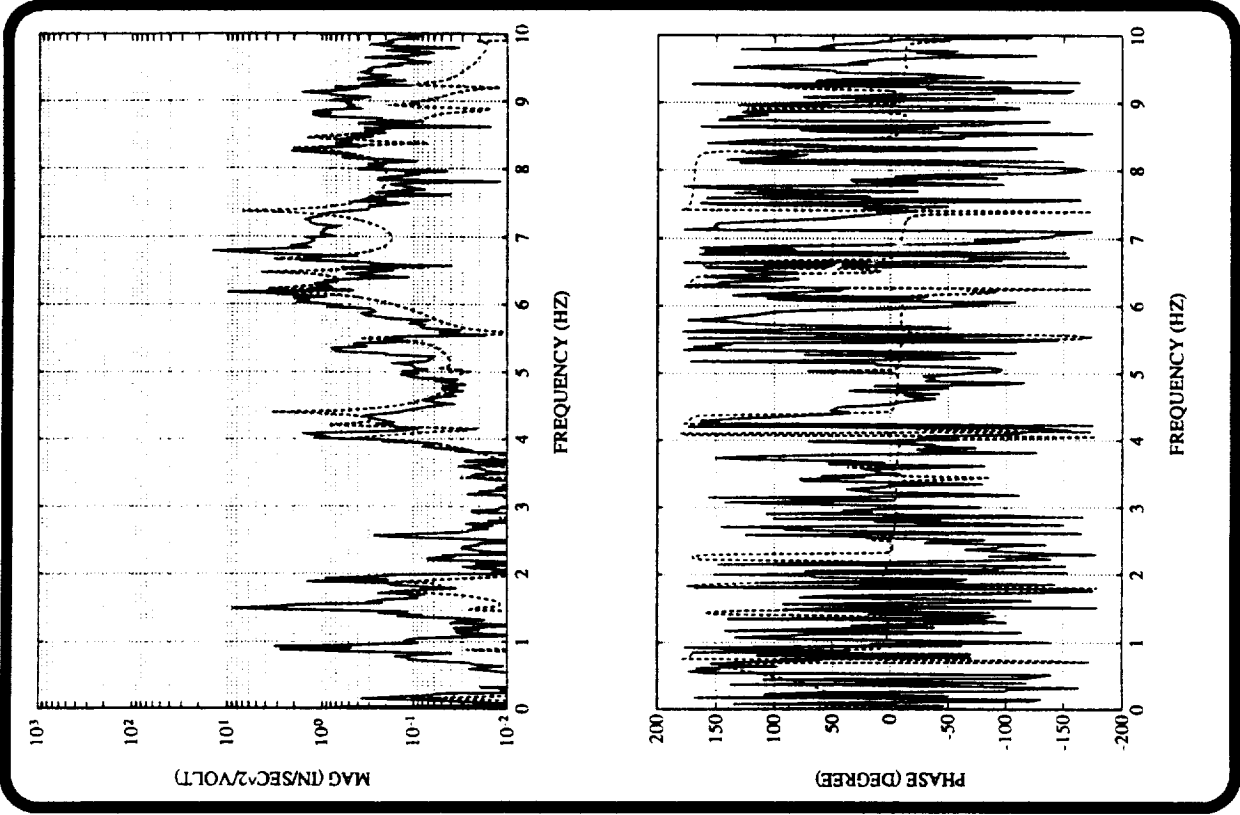


Figure 149. Bode diagram for Accelerometer 8 / Thruster 5

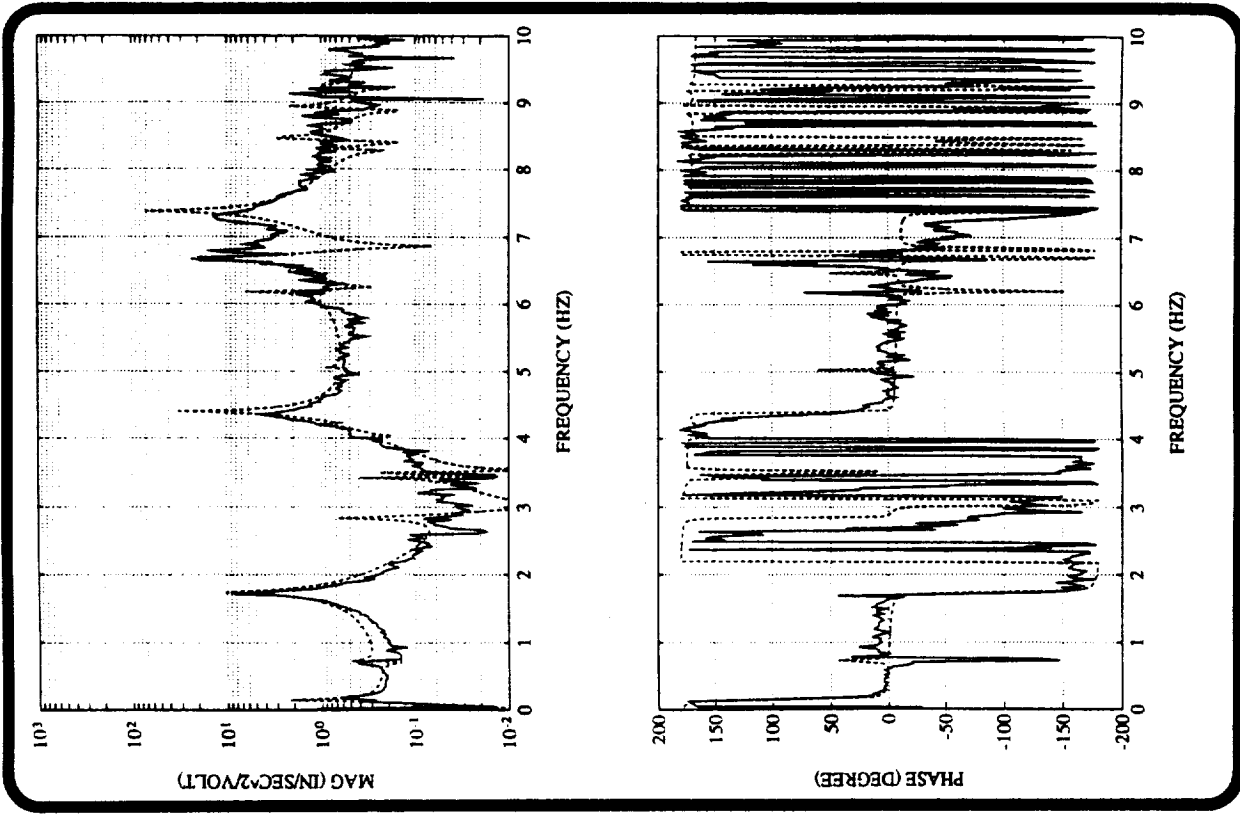


Figure 148. Bode diagram for Accelerometer 7 / Thruster 5

Figure 151. Bode diagram for Accelerometer 2 / Thruster 6

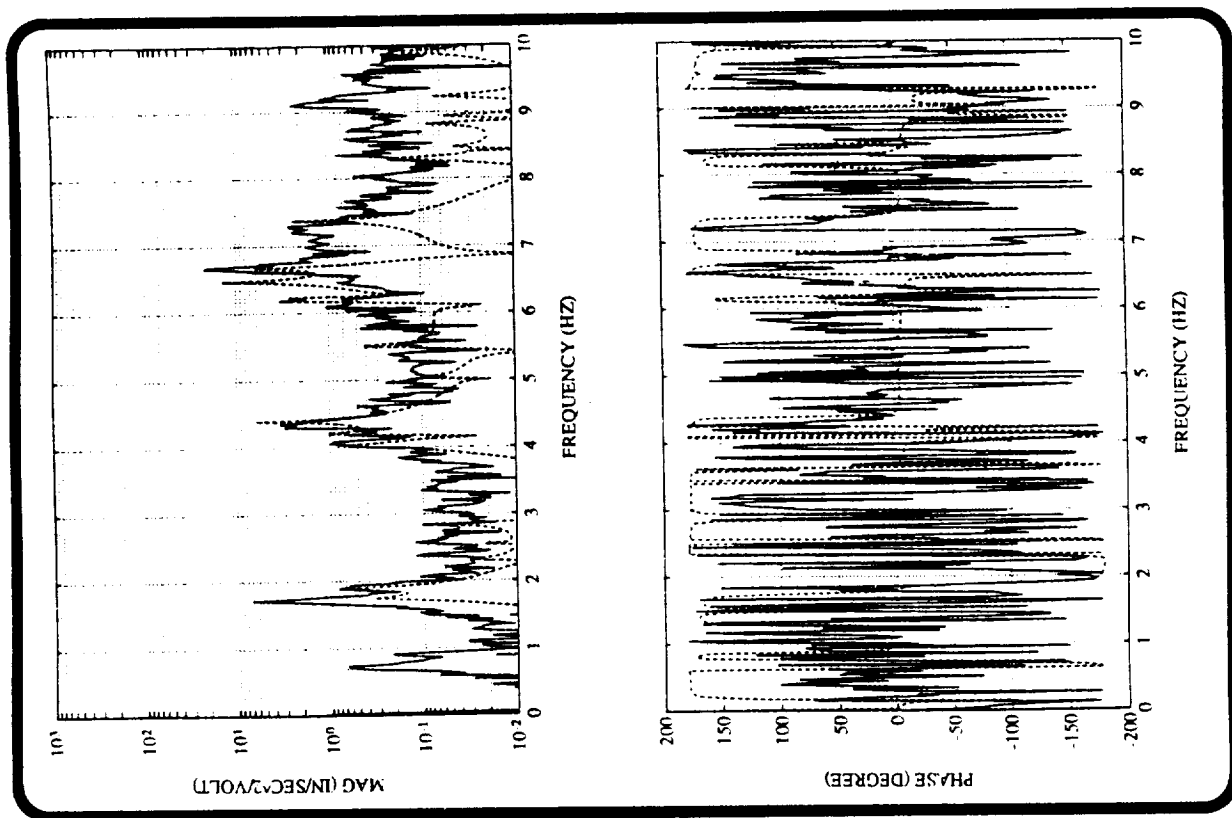
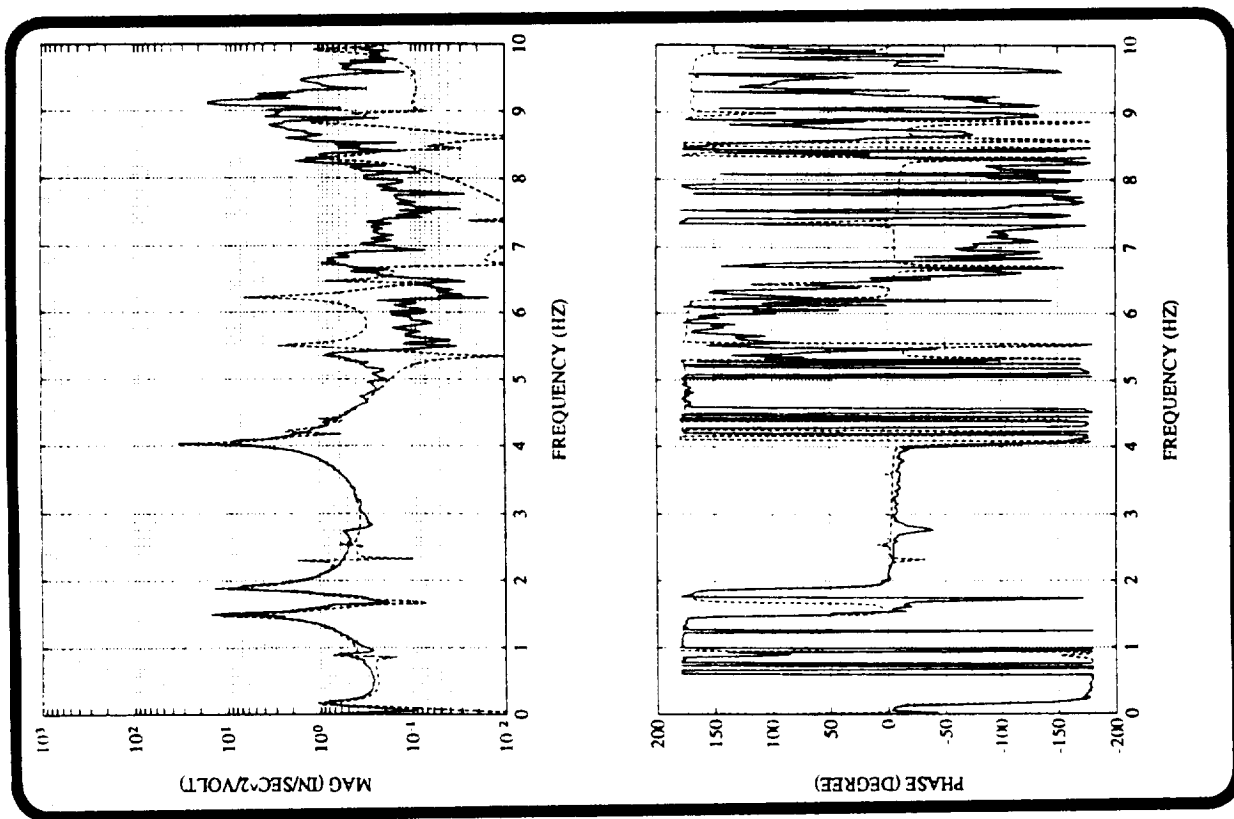


Figure 150. Bode diagram for Accelerometer 1 / Thruster 6



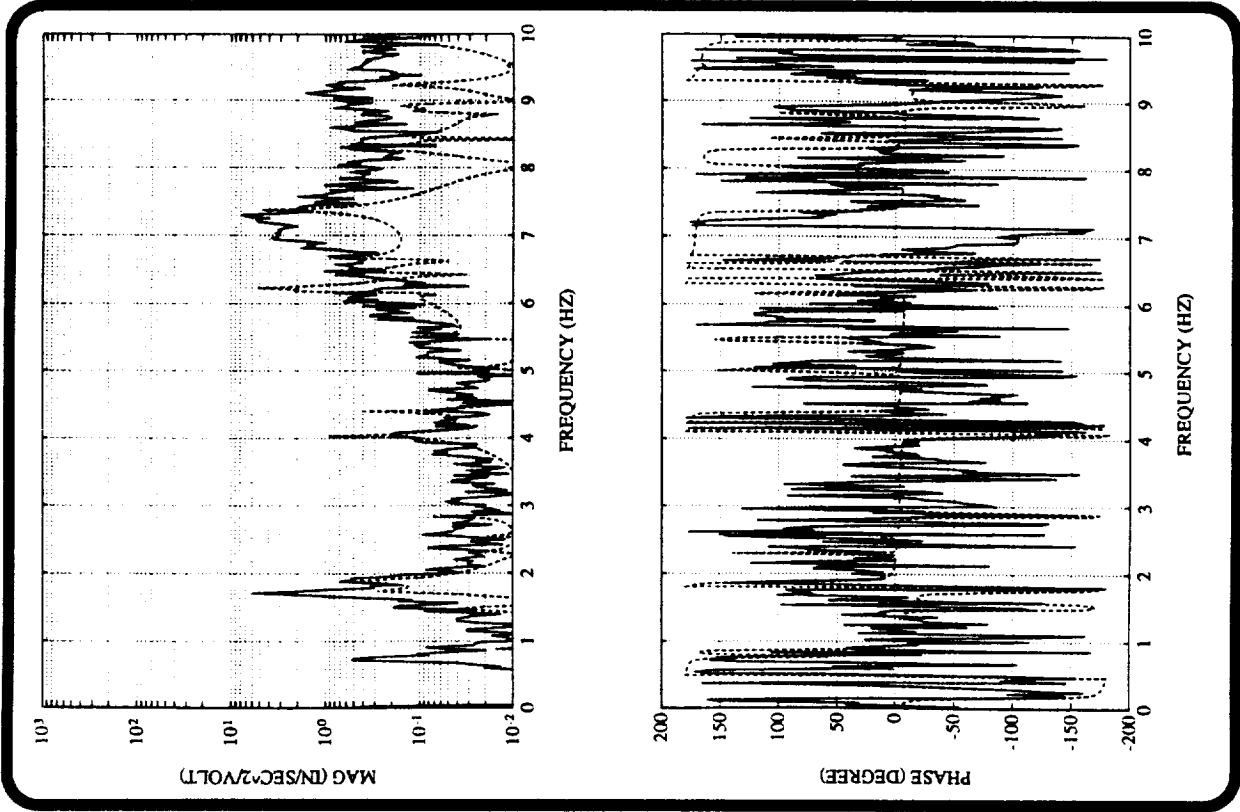


Figure 153. Bode diagram for Accelerometer 4 / Thruster 6

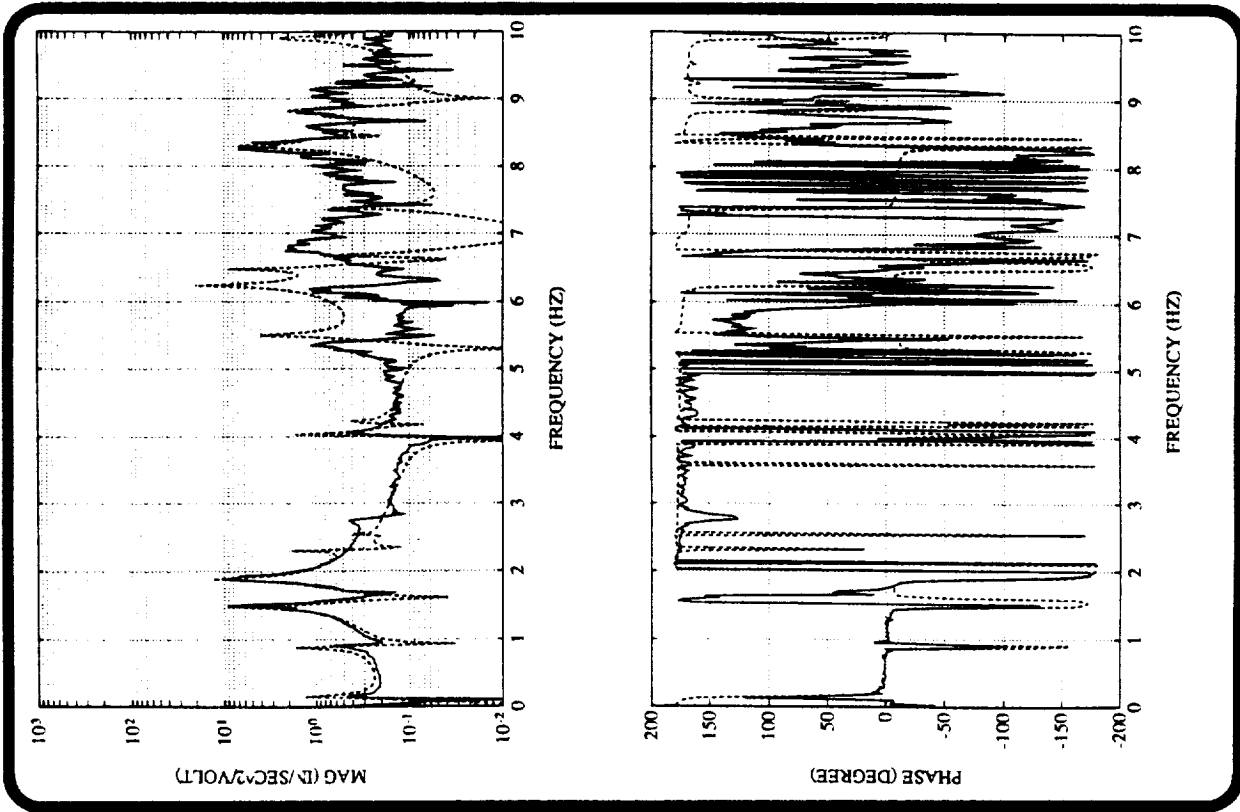


Figure 152. Bode diagram for Accelerometer 3 / Thruster 6

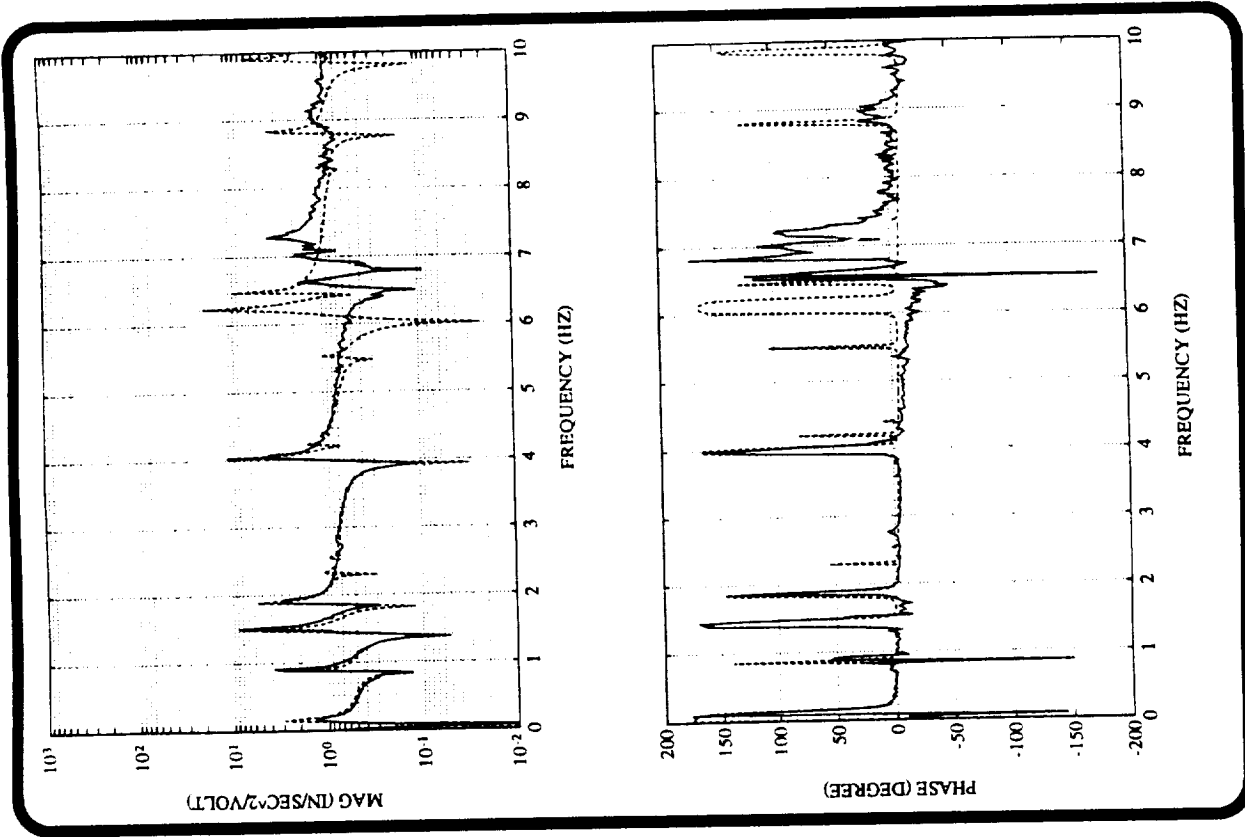


Figure 155. Bode diagram for Accelerometer 6 / Thruster 6

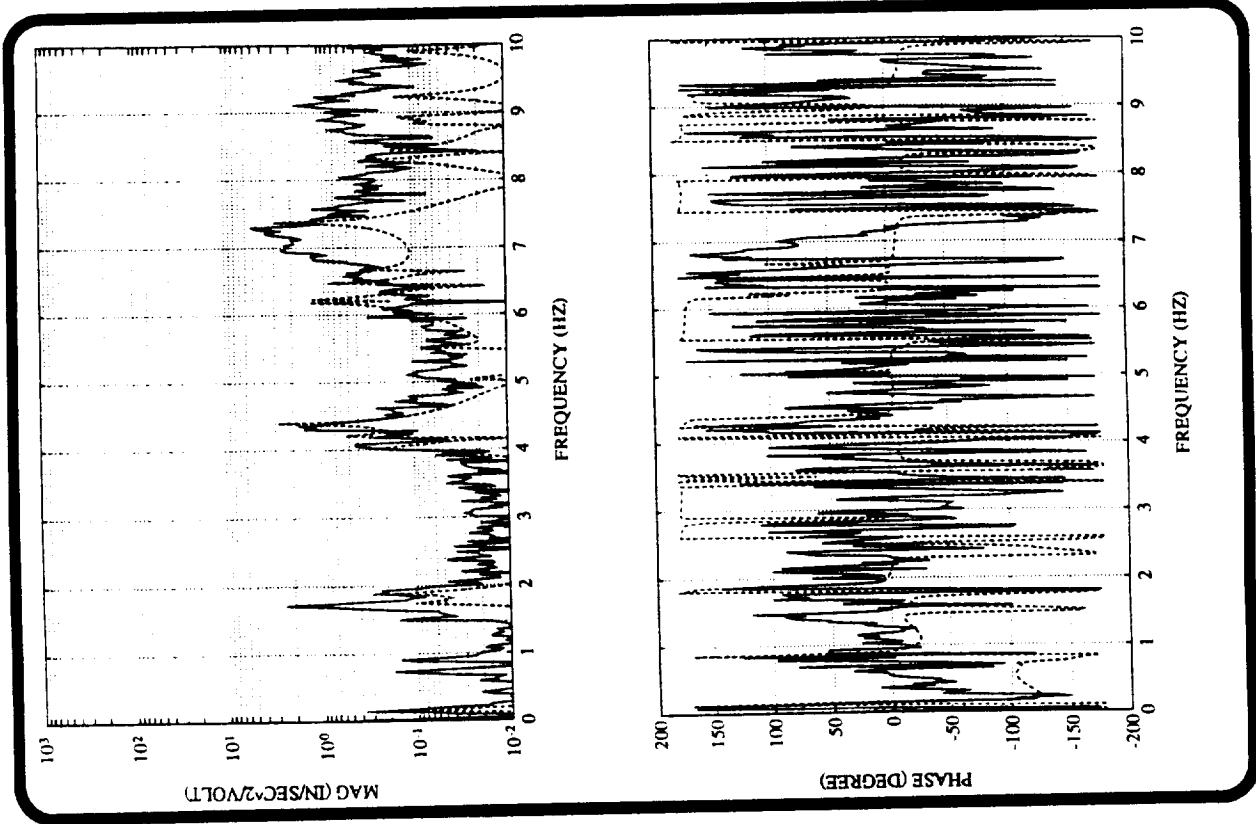


Figure 154. Bode diagram for Accelerometer 5 / Thruster 6

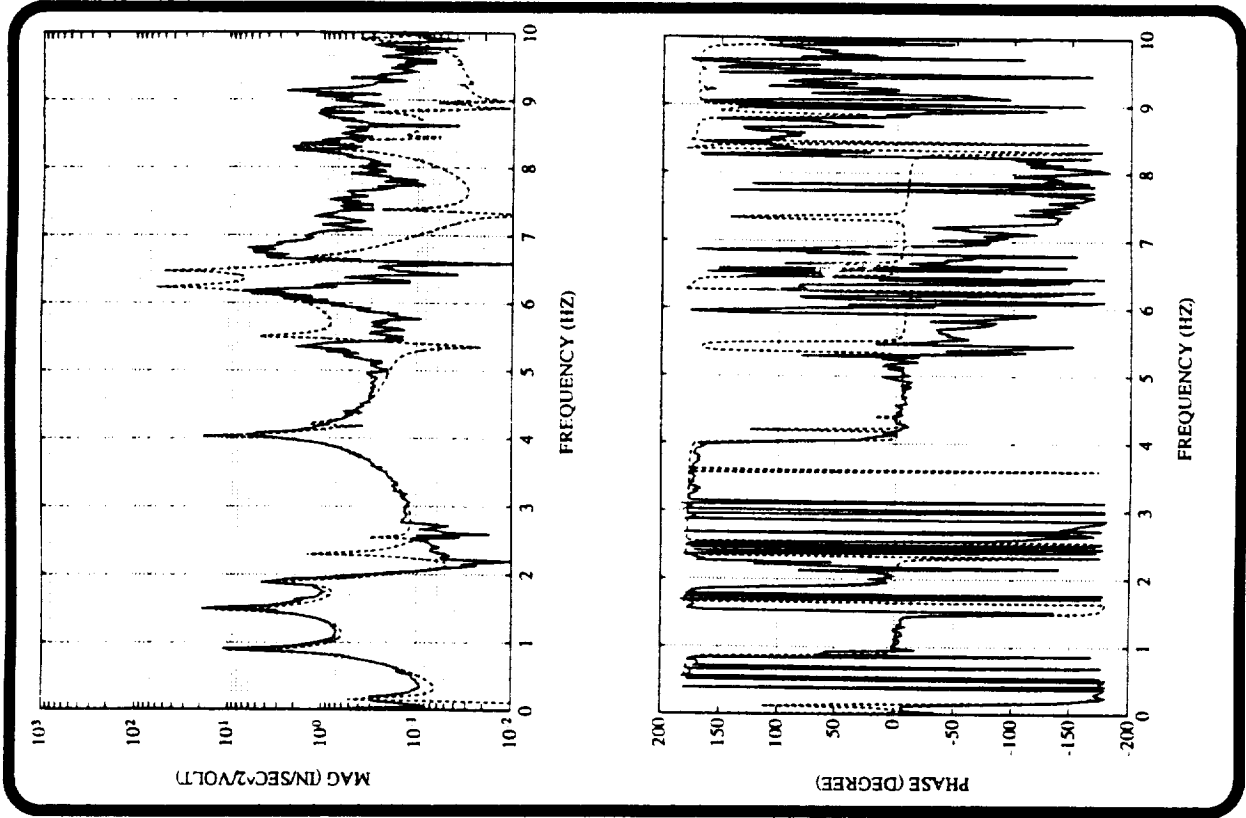


Figure 157. Bode diagram for Accelerometer 8 / Thruster 6

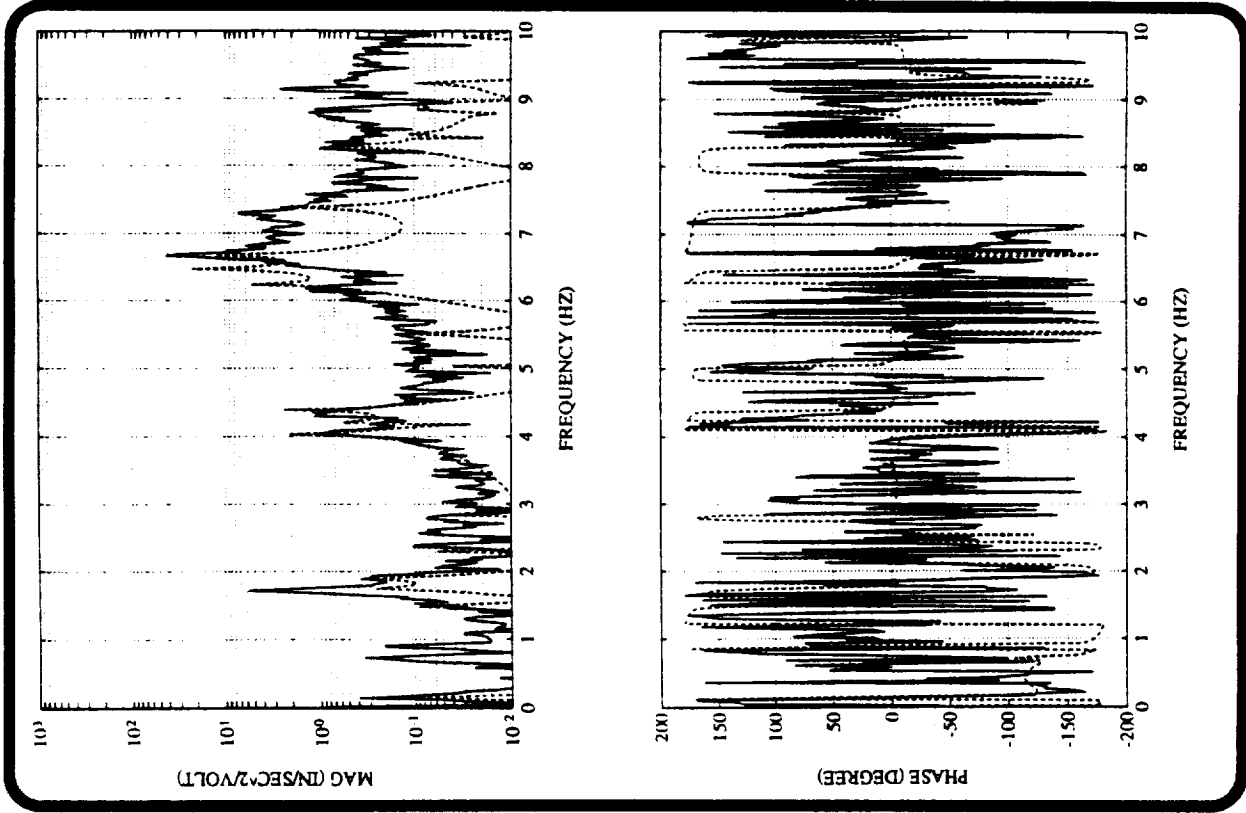


Figure 156. Bode diagram for Accelerometer 7 / Thruster 6

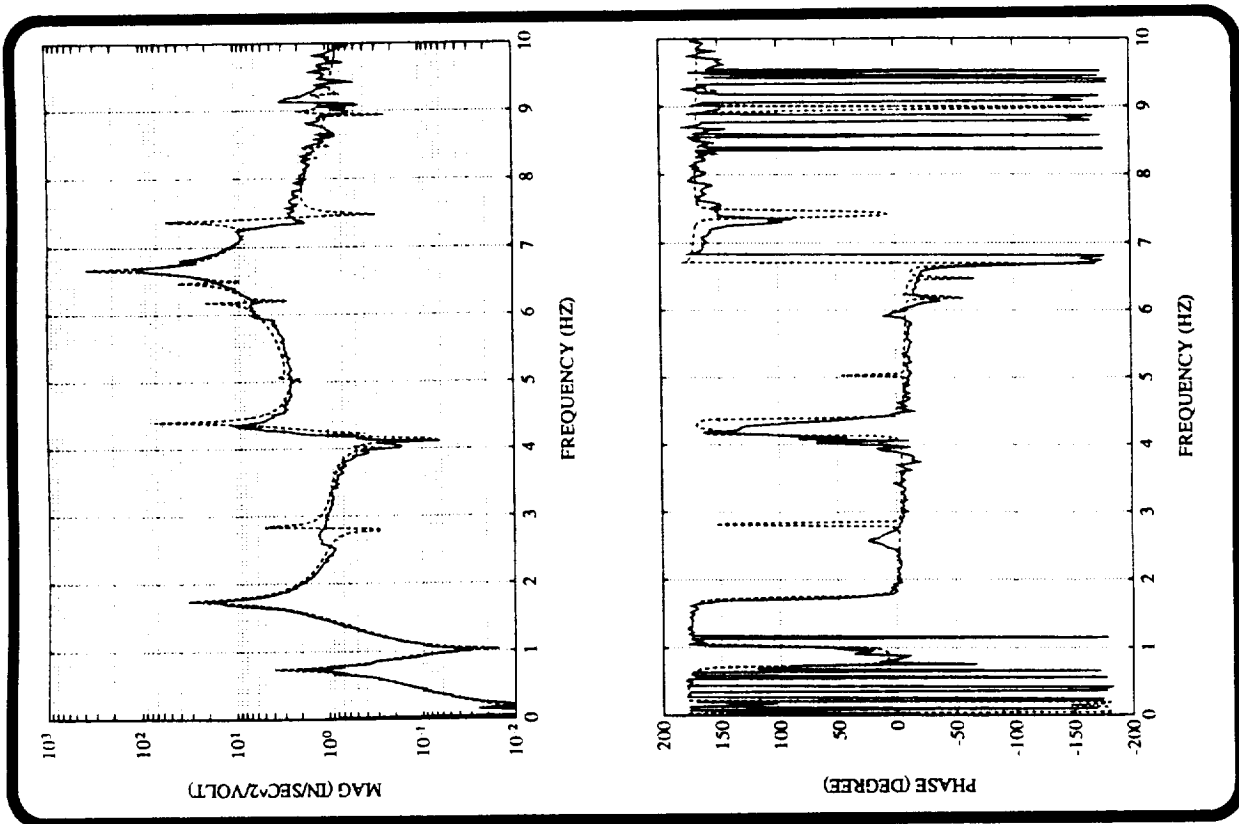


Figure 159. Bode diagram for Accelerometer 2 / Thruster 7

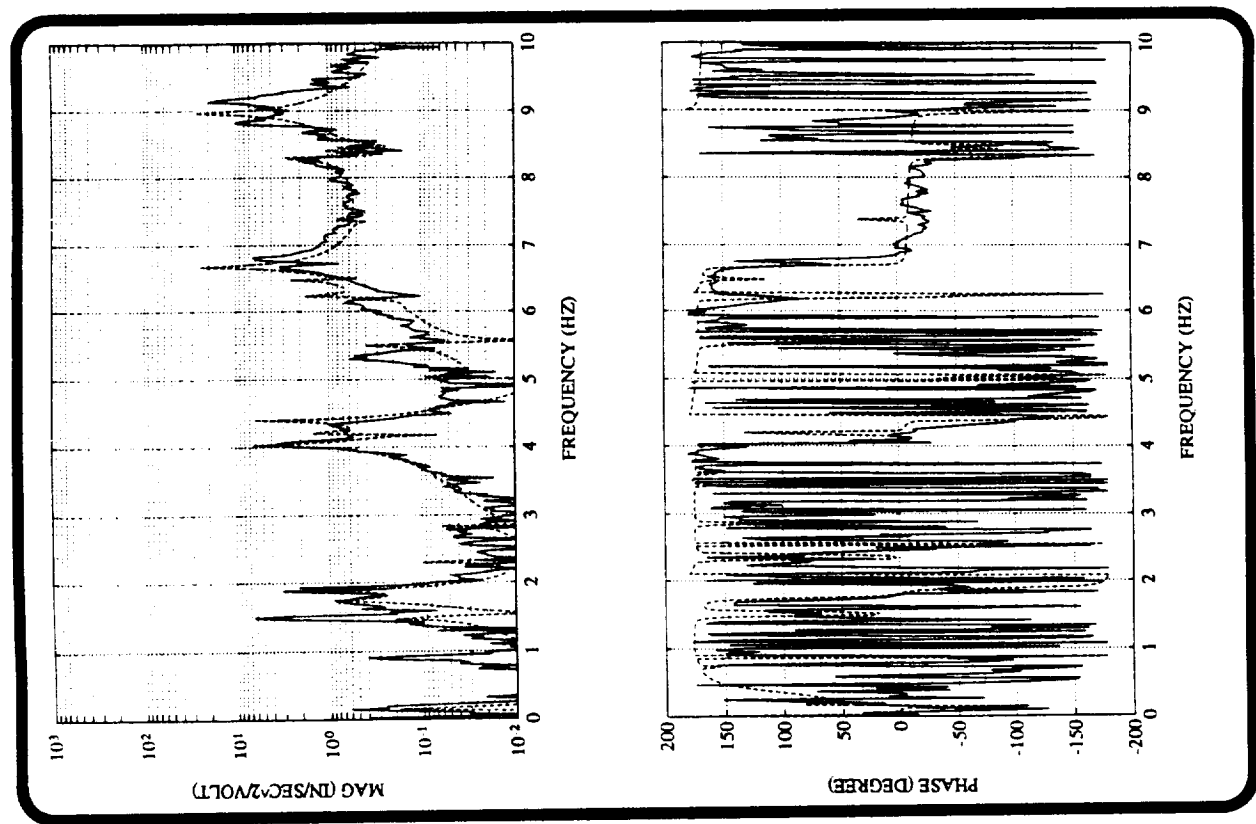


Figure 158. Bode diagram for Accelerometer 1 / Thruster 7

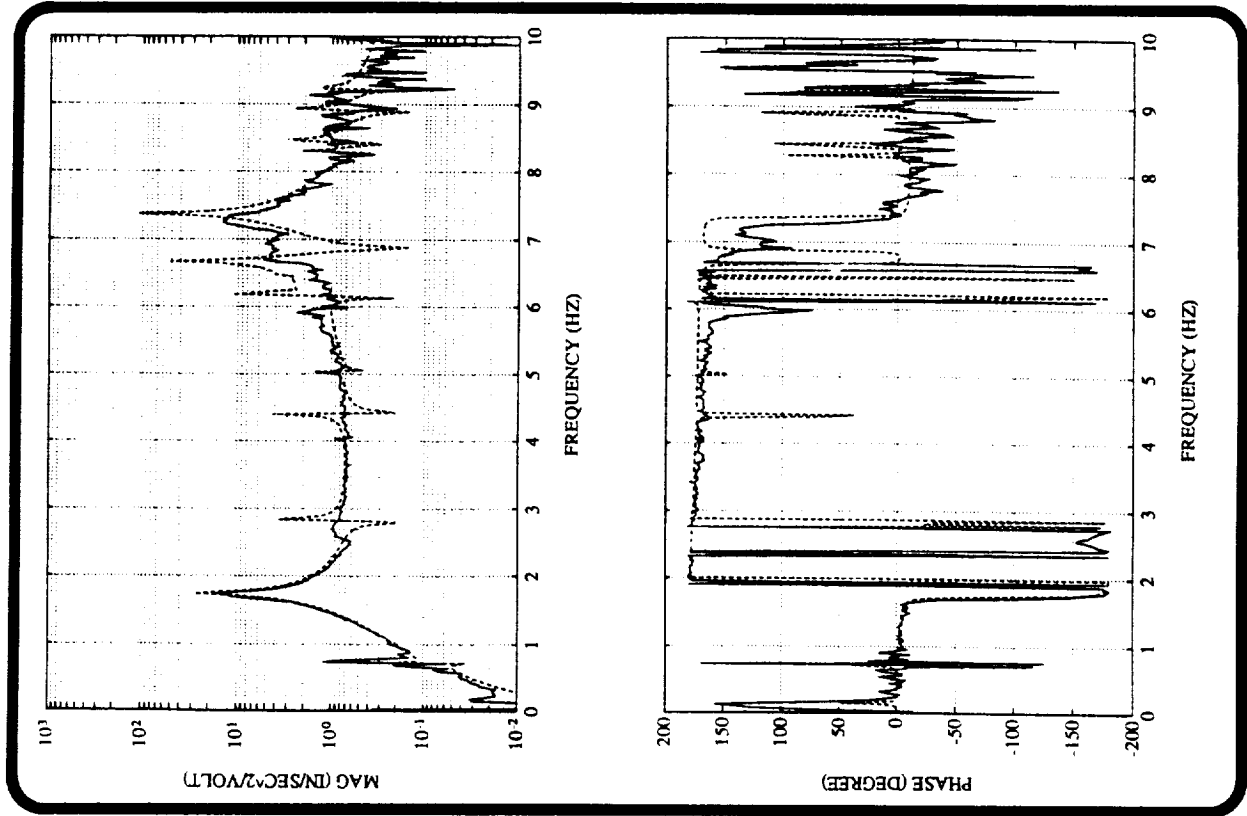


Figure 161. Bode diagram for Accelerometer 4 / Thruster 7

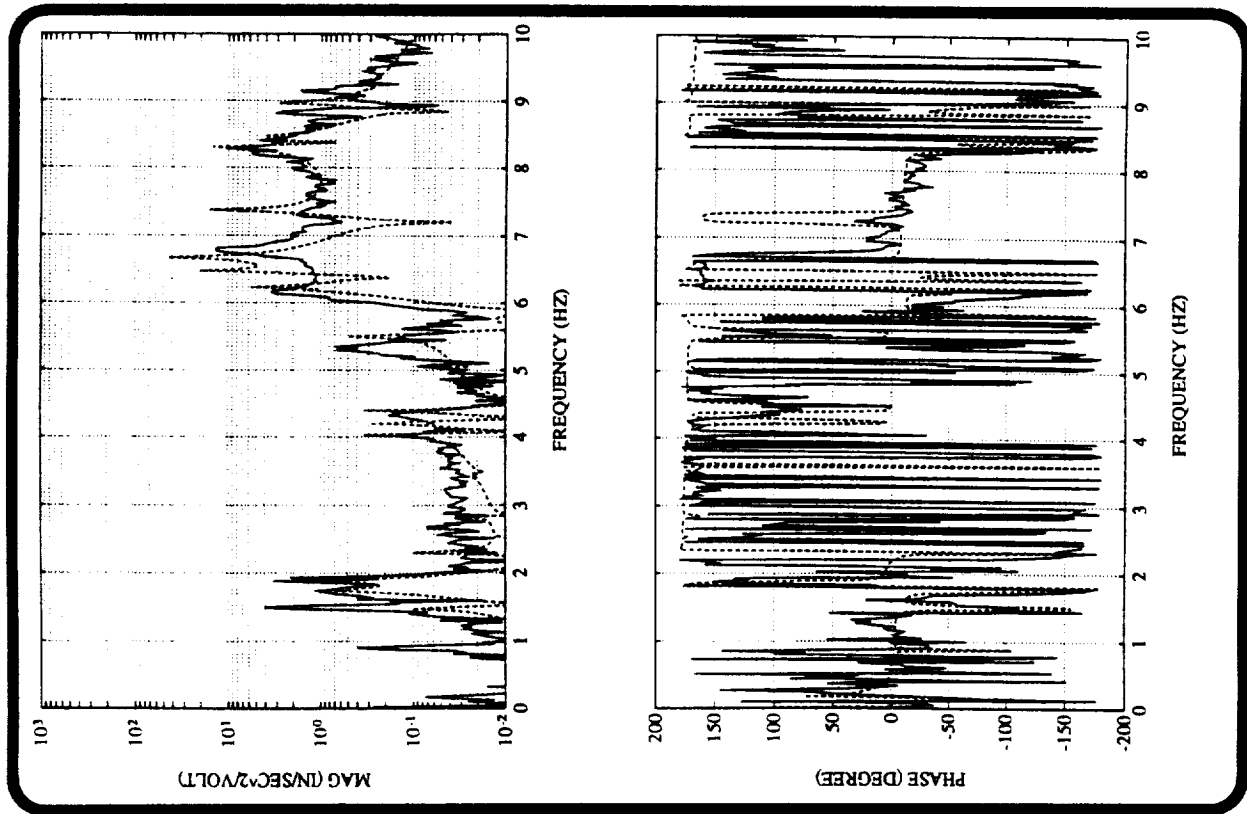


Figure 160. Bode diagram for Accelerometer 3 / Thruster 7

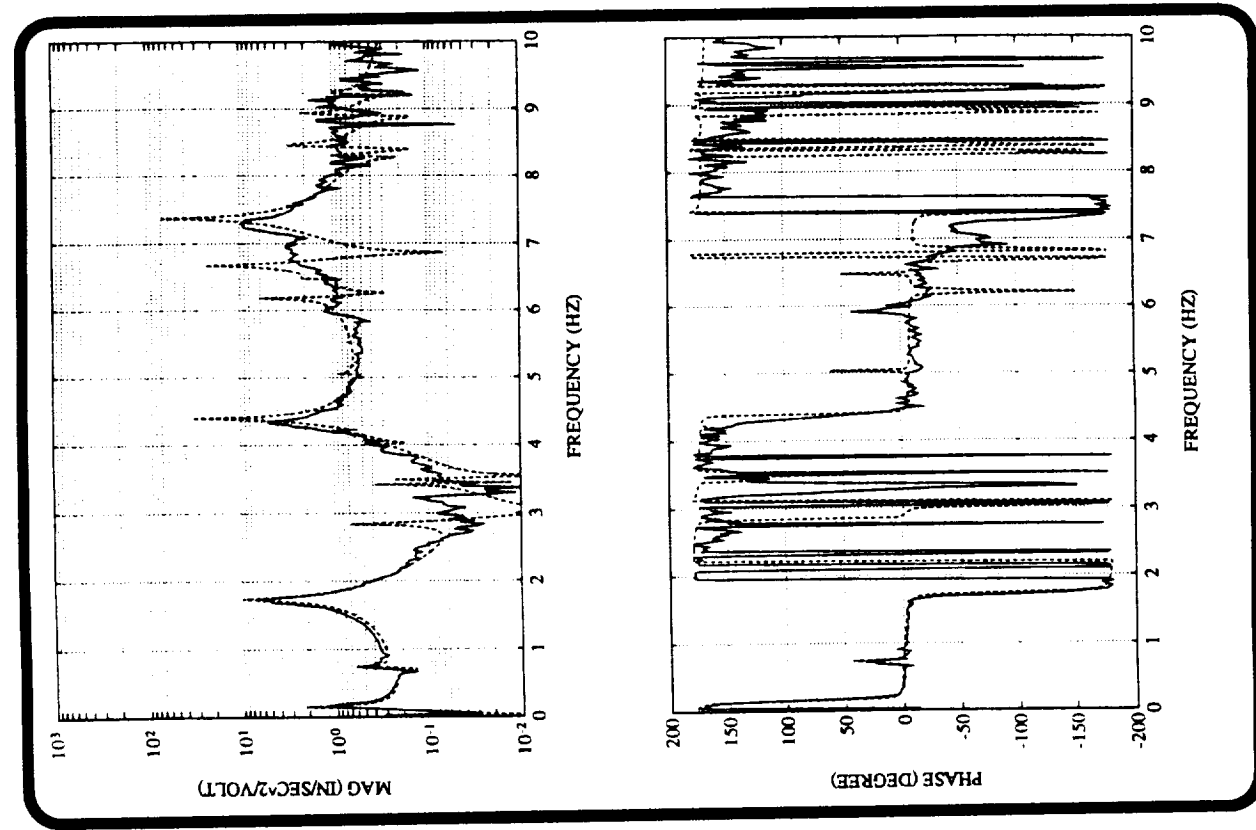


Figure 162. Bode diagram for Accelerometer 5 / Thruster 7

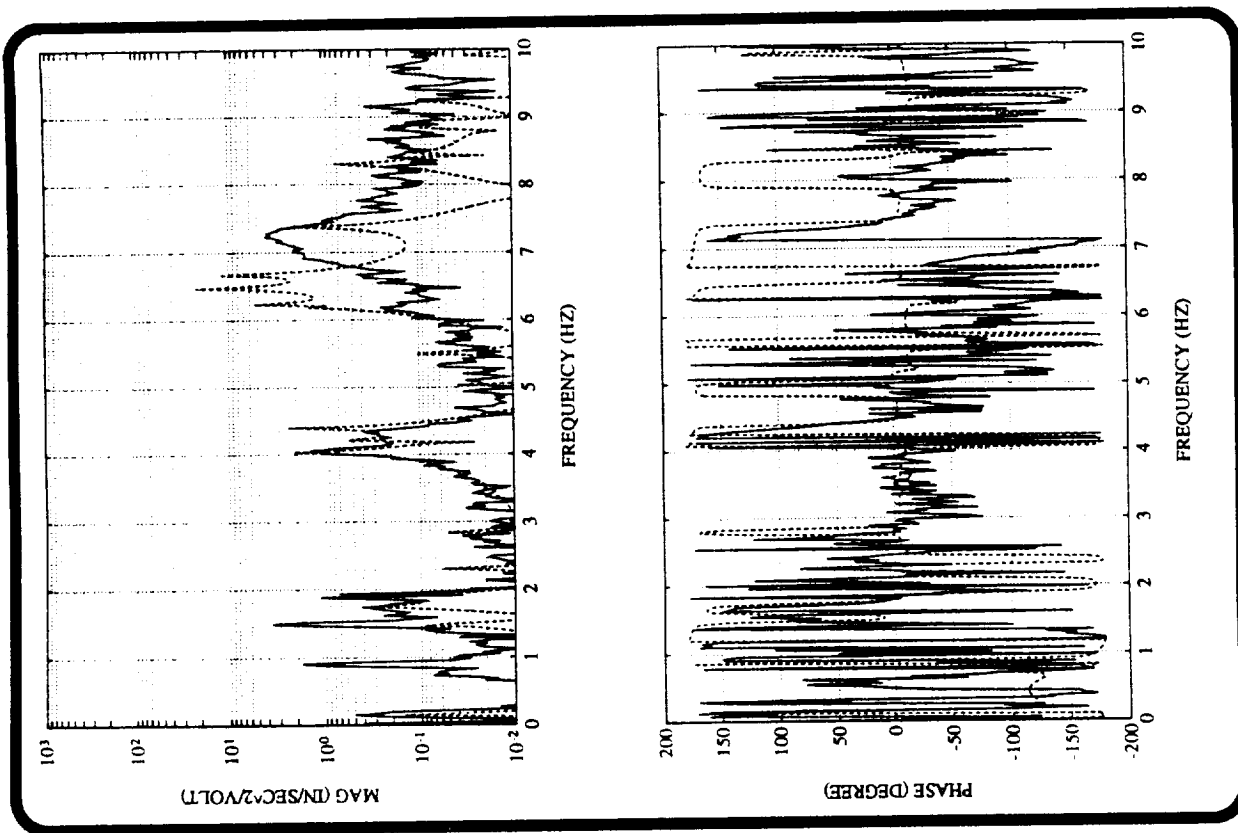


Figure 163. Bode diagram for Accelerometer 6 / Thruster 7

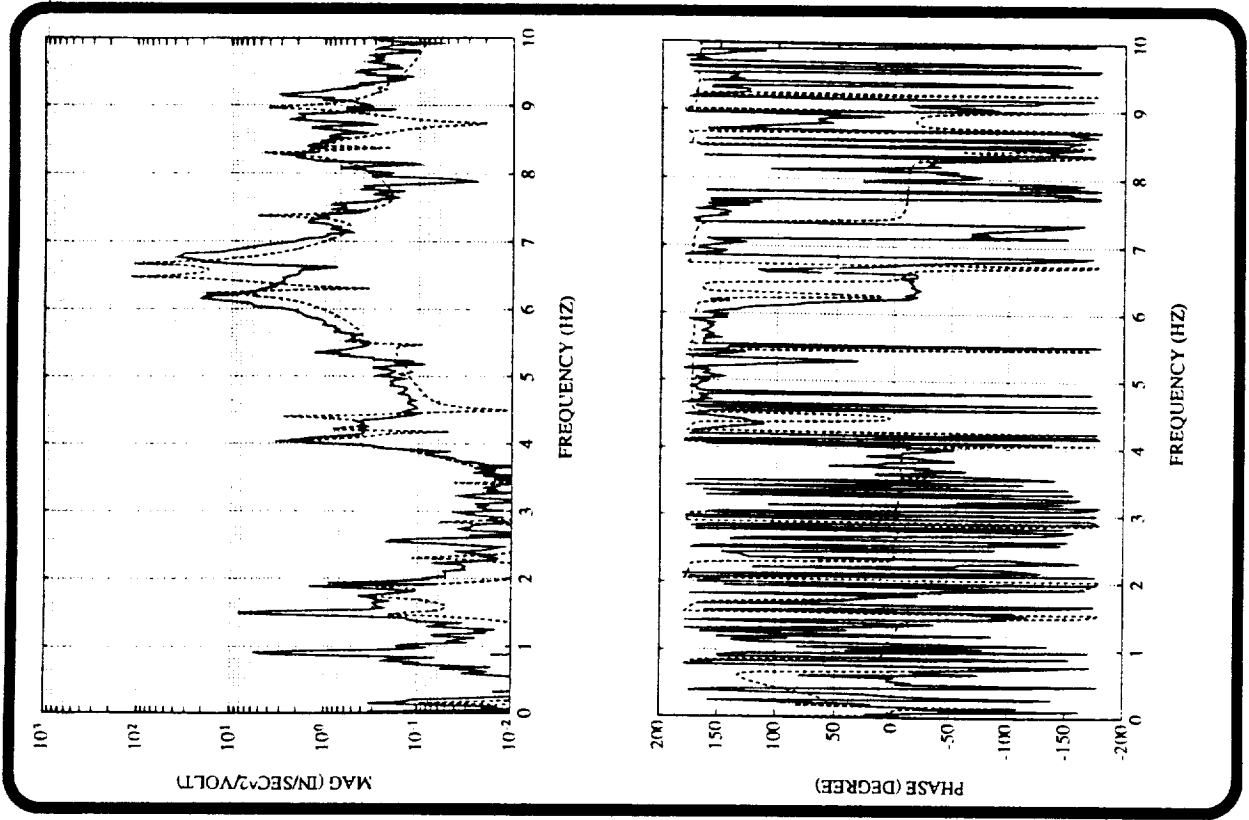


Figure 165. Bode diagram for Accelerometer 8 / Thruster 7

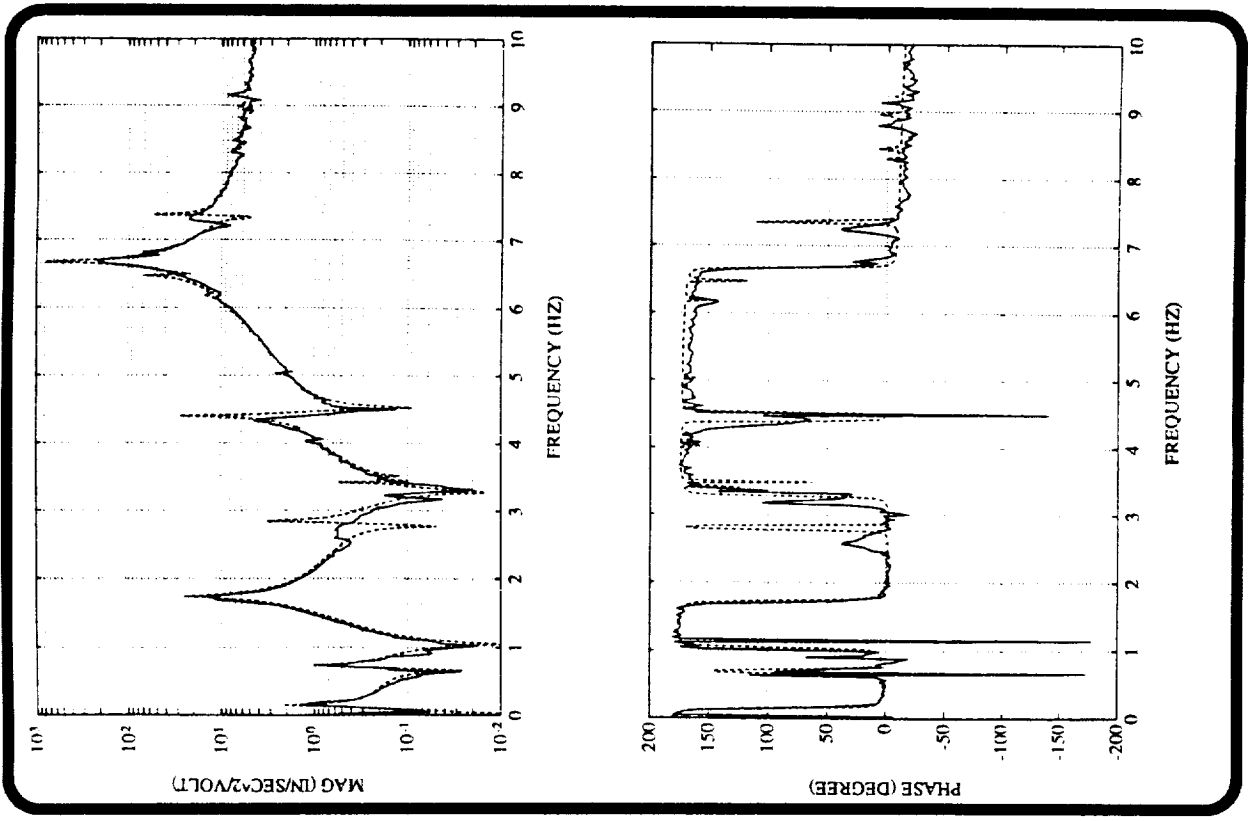


Figure 164. Bode diagram for Accelerometer 7 / Thruster 7

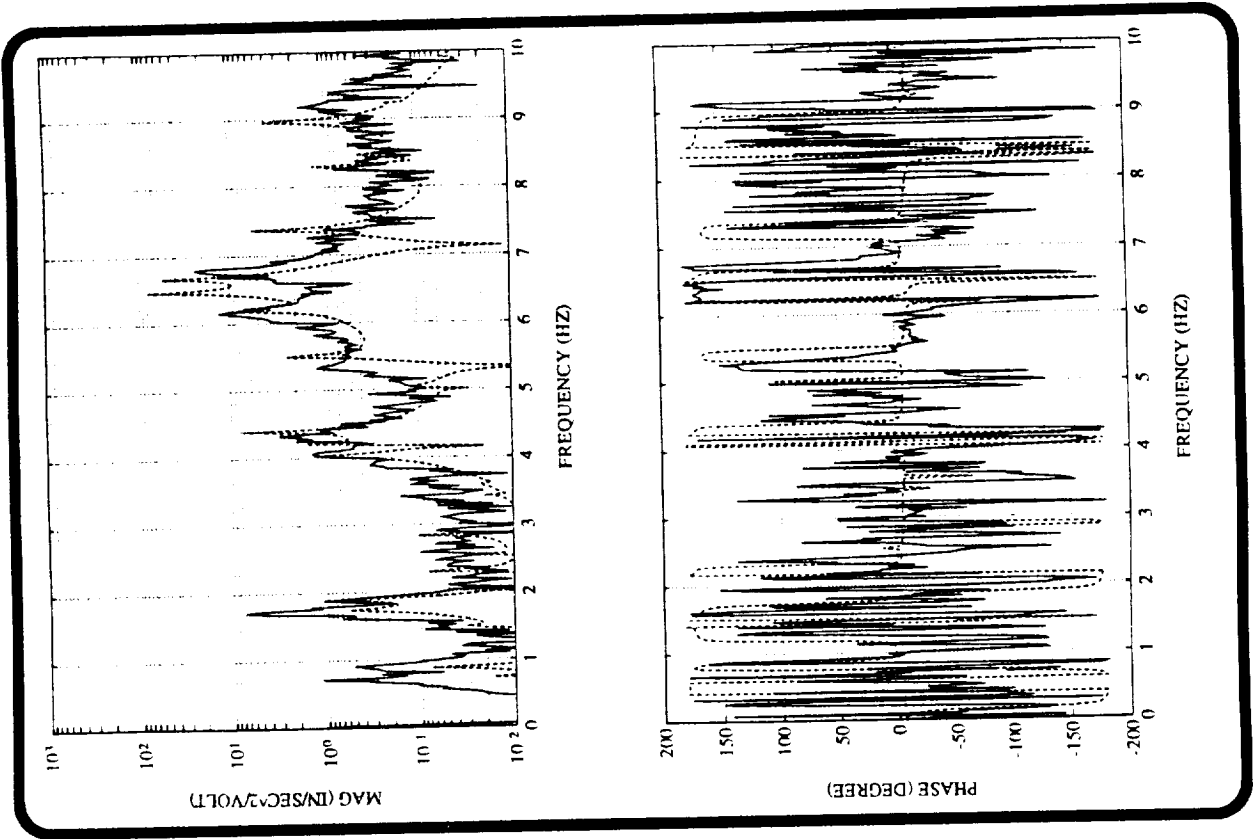


Figure 167. Bode diagram for Accelerometer 2 / Thruster 8

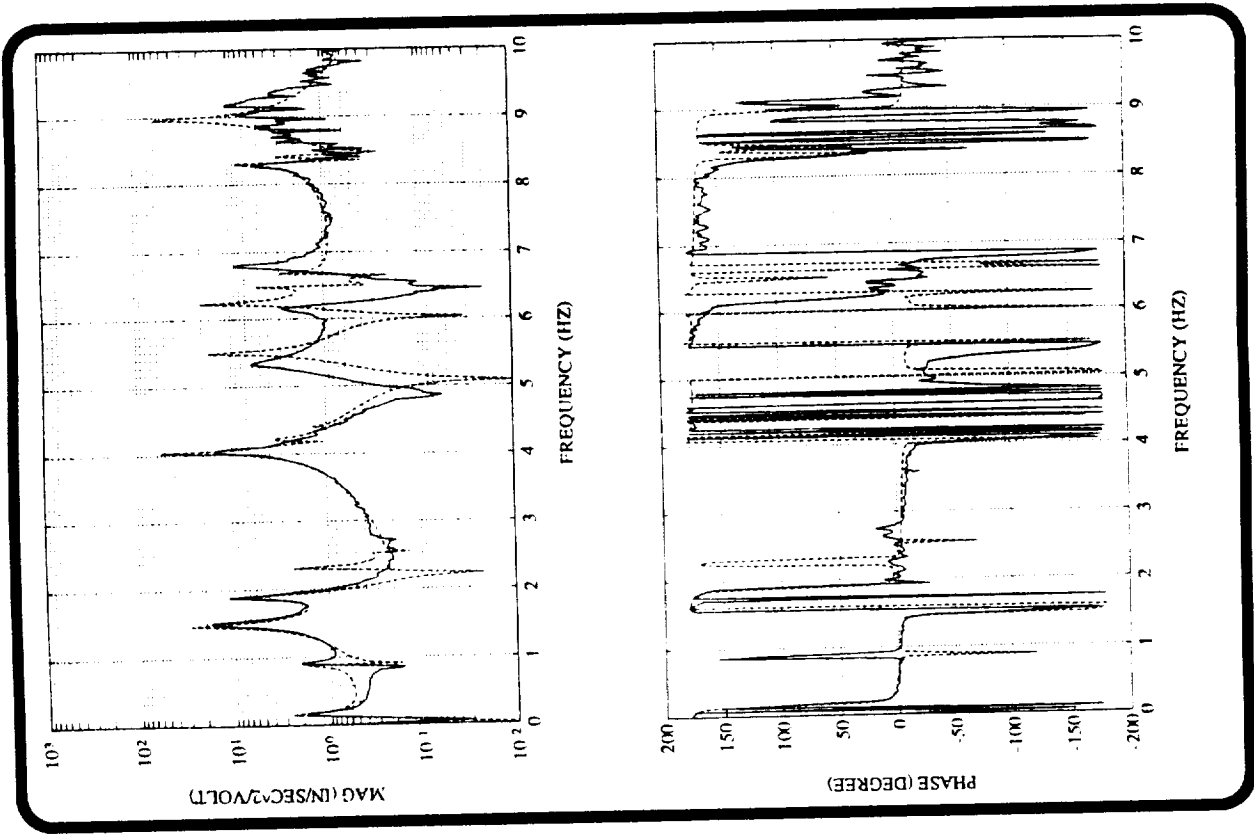


Figure 166. Bode diagram for Accelerometer 1 / Thruster 8

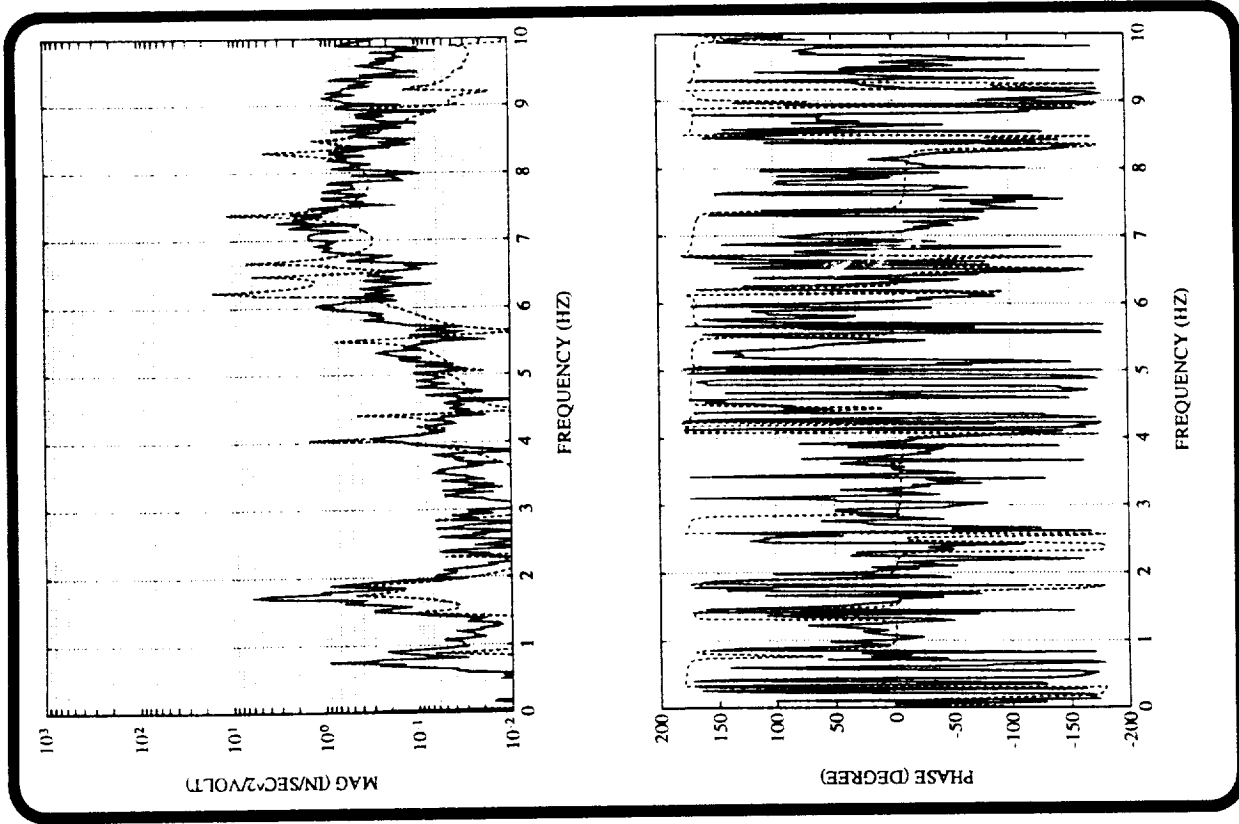


Figure 169. Bode diagram for Accelerometer 4 / Thruster 8

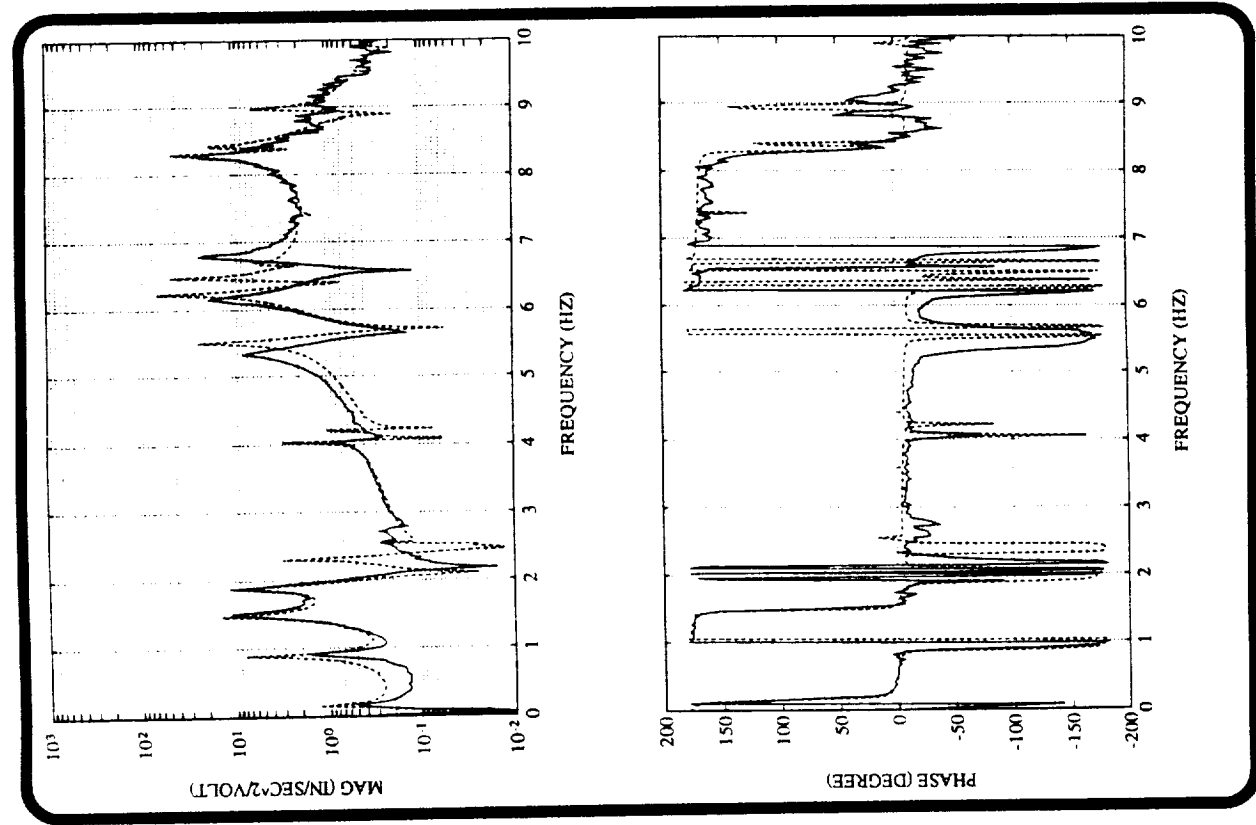


Figure 168. Bode diagram for Accelerometer 3 / Thruster 8

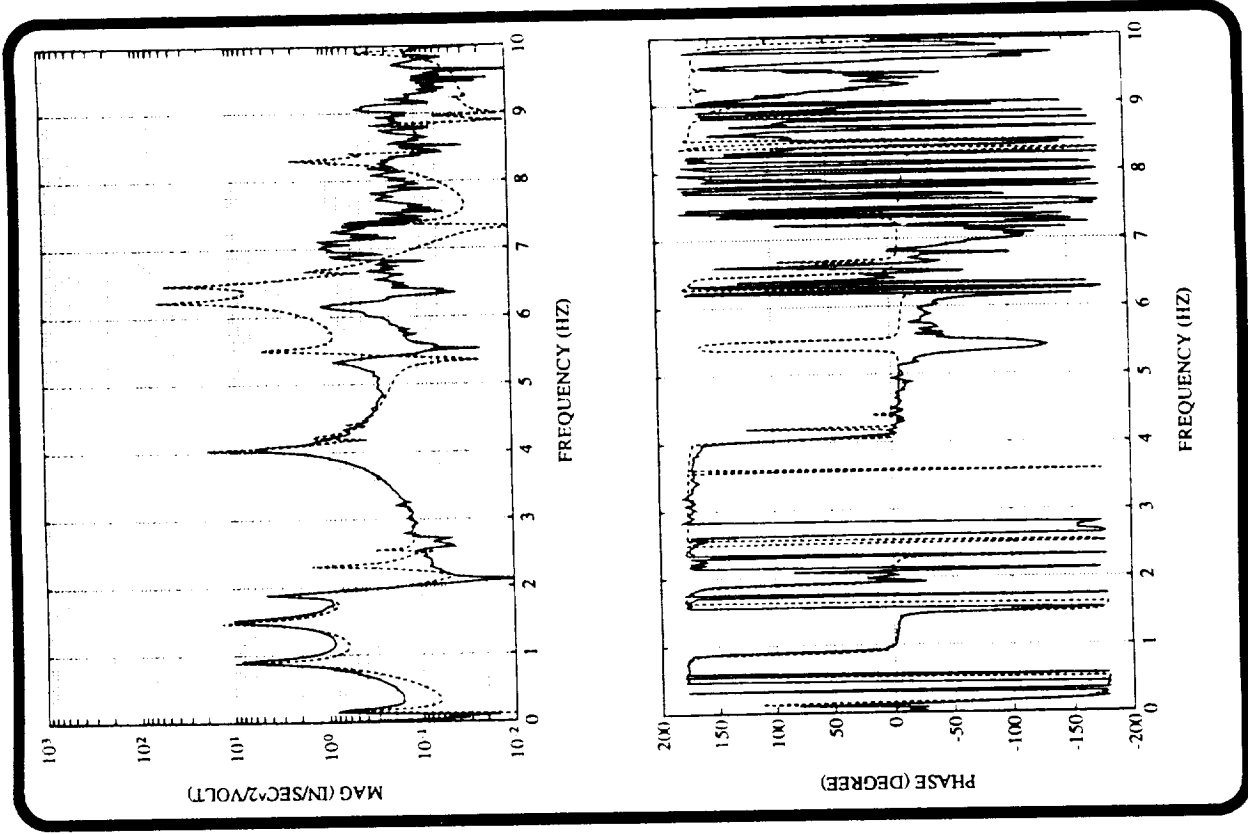


Figure 171. Bode diagram for Accelerometer 6 / Thruster 8

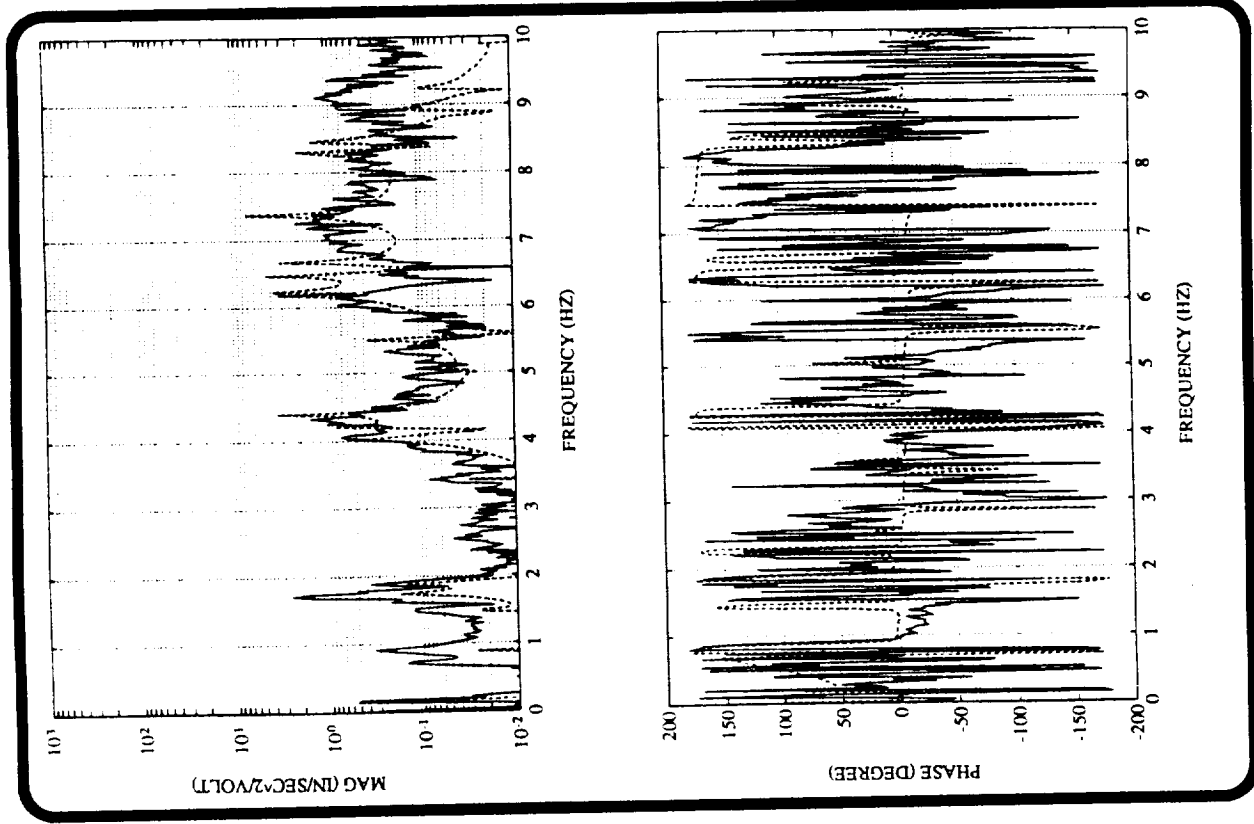


Figure 170. Bode diagram for Accelerometer 5 / Thruster 8

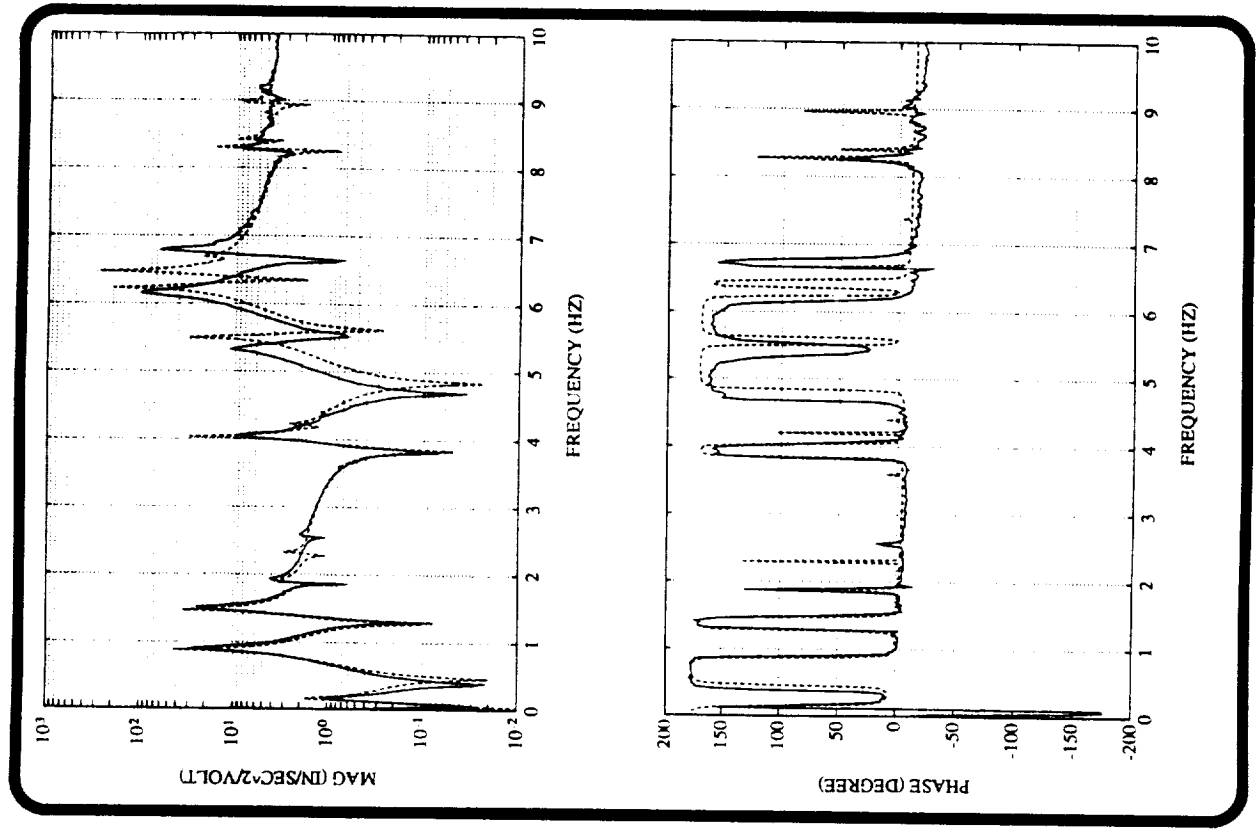


Figure 173. Bode diagram for Accelerometer 8 / Thruster 8

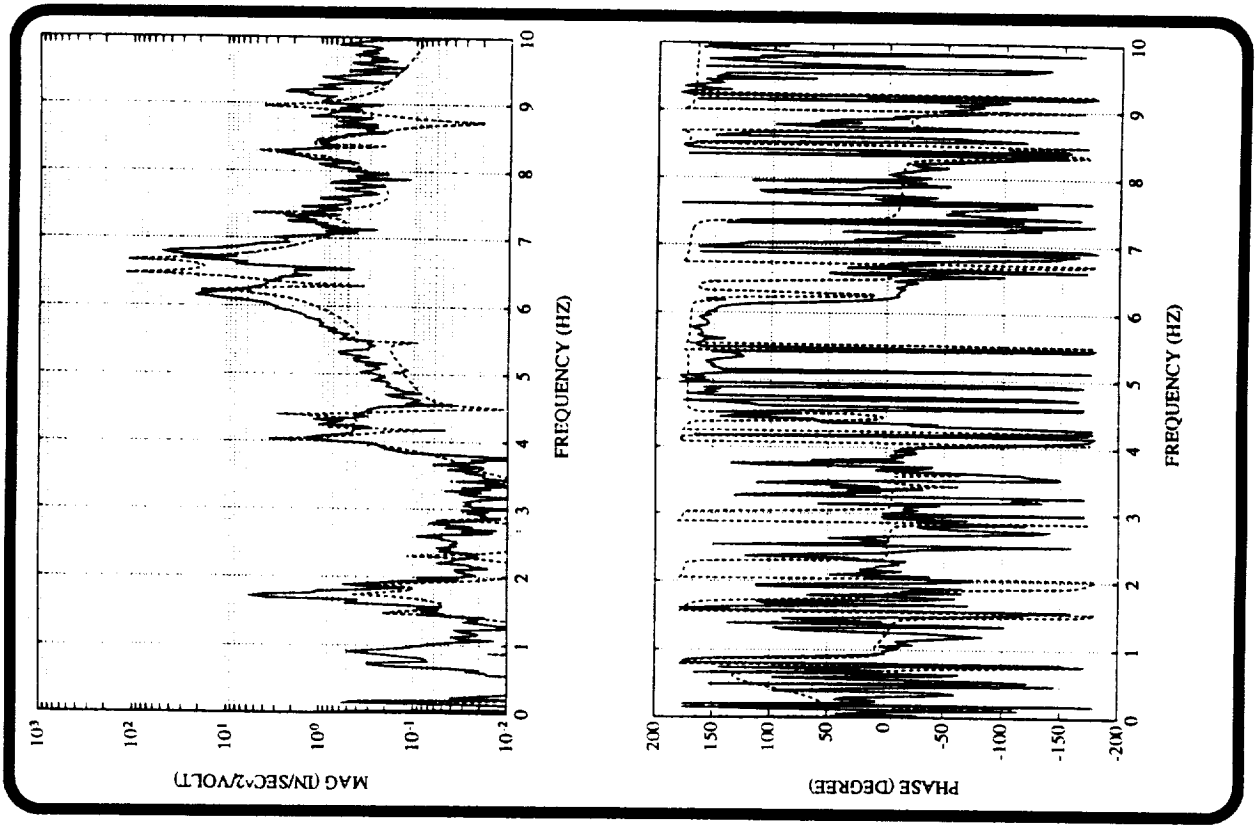


Figure 172. Bode diagram for Accelerometer 7 / Thruster 8

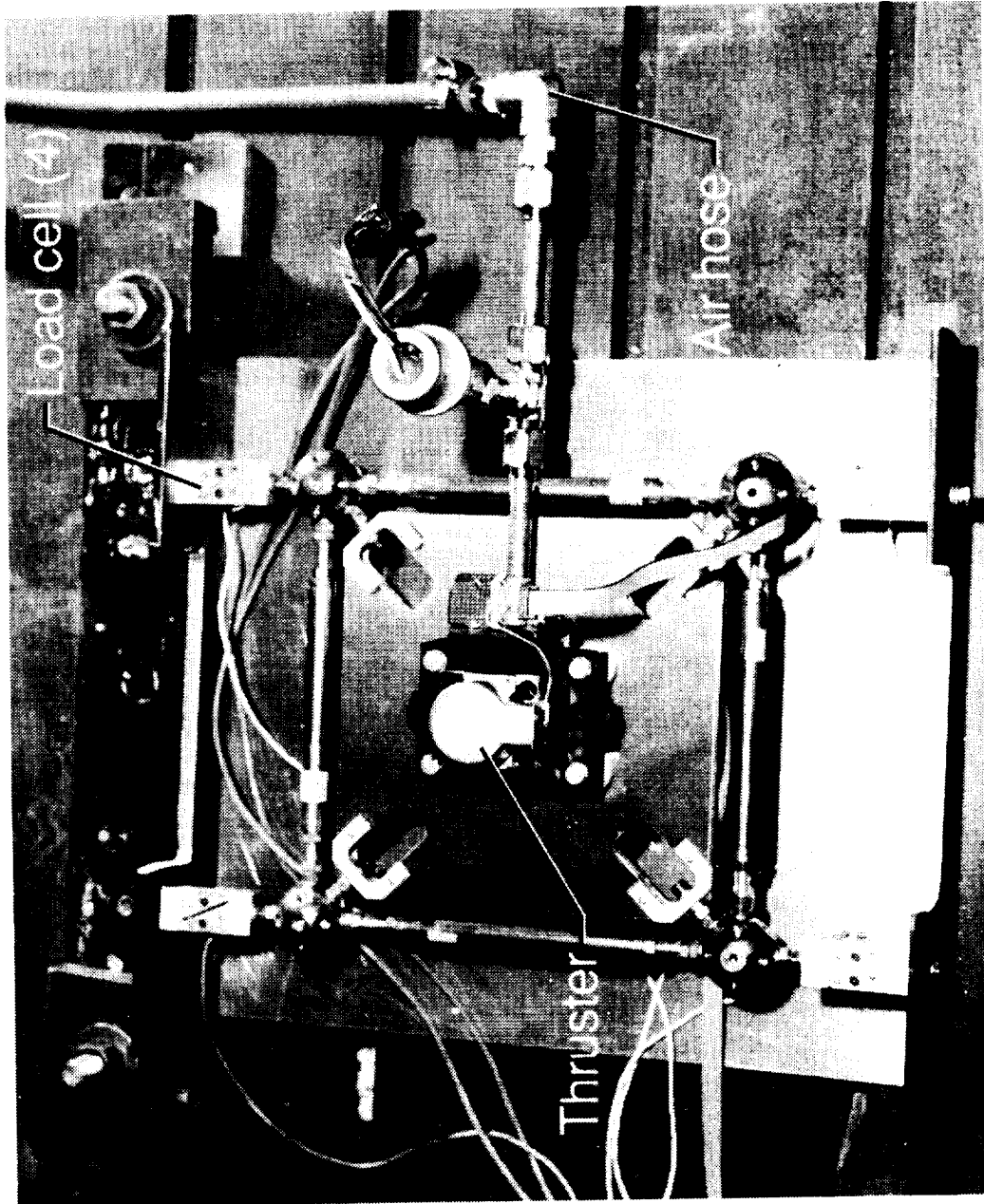


Figure 174. Thruster calibration set-up

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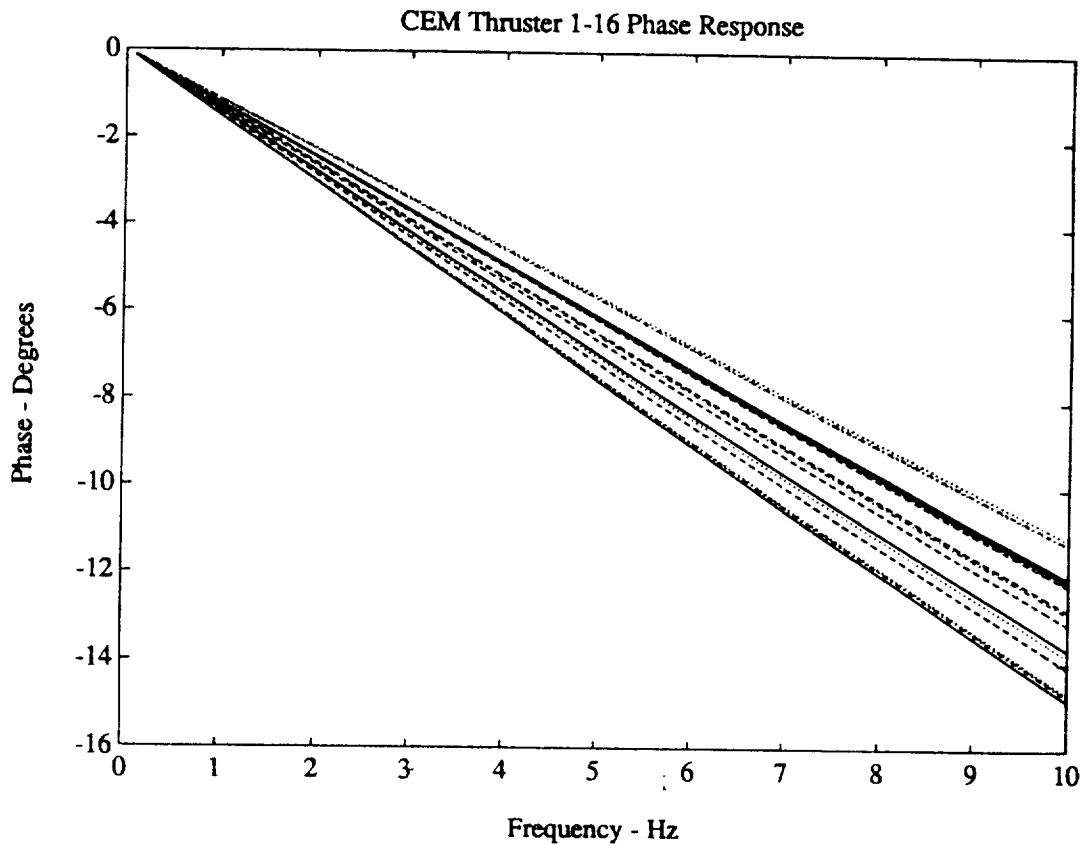
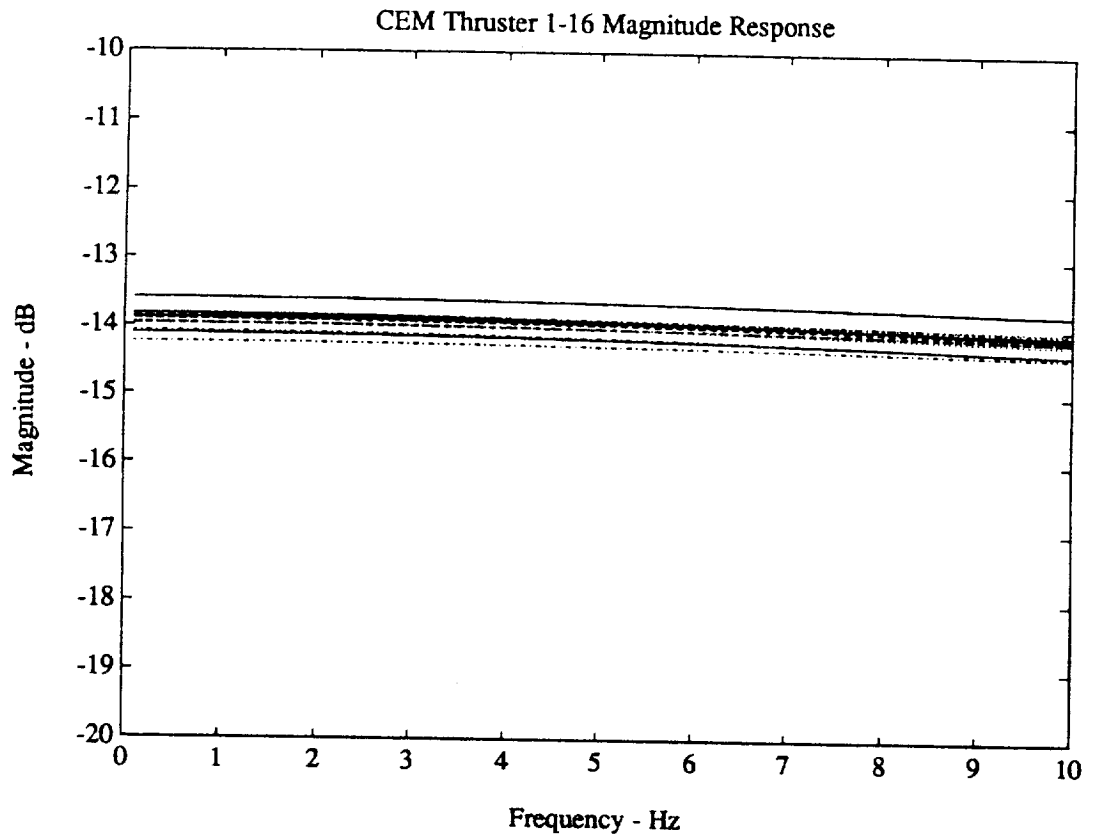


Figure 175. Bode diagram of first-order thruster models

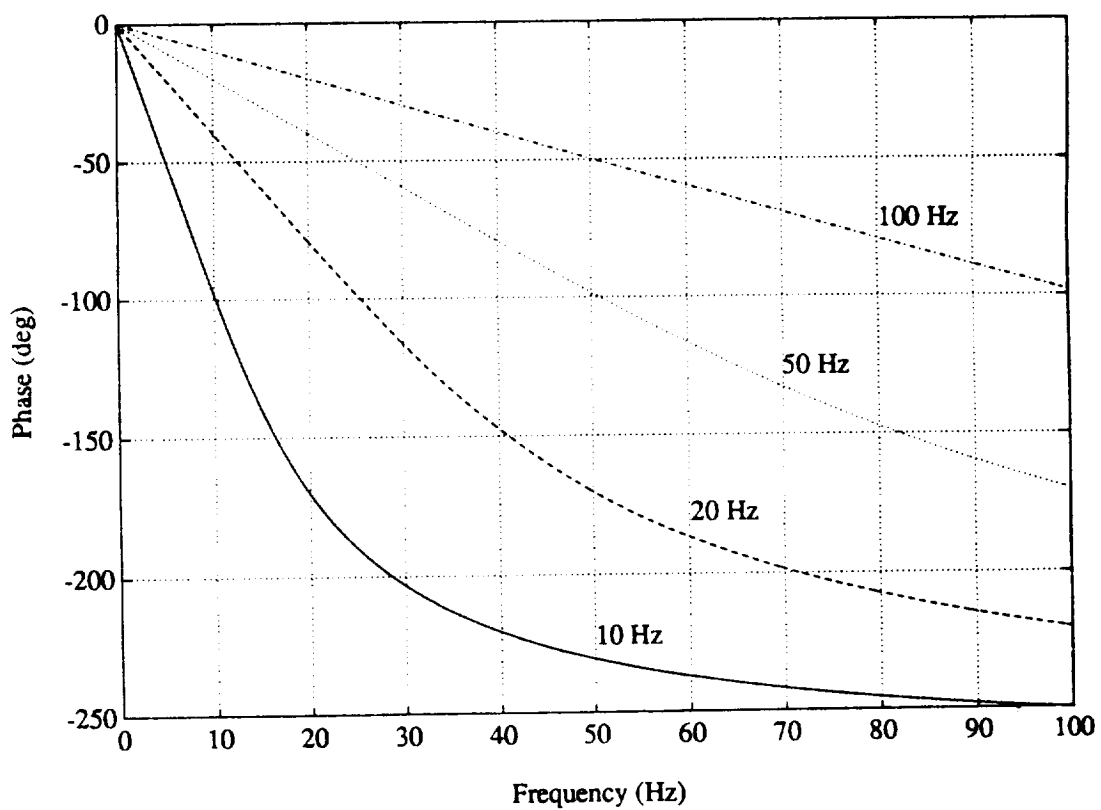
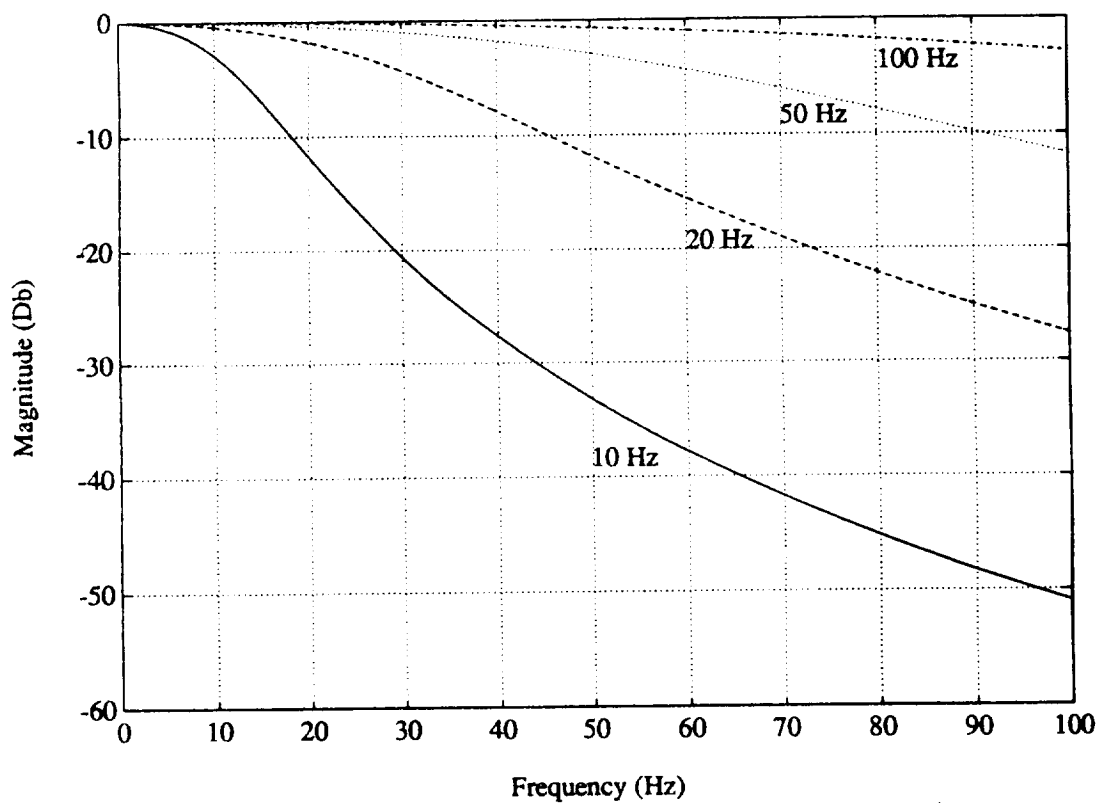


Figure 176. Bode diagram of CAMAC filters

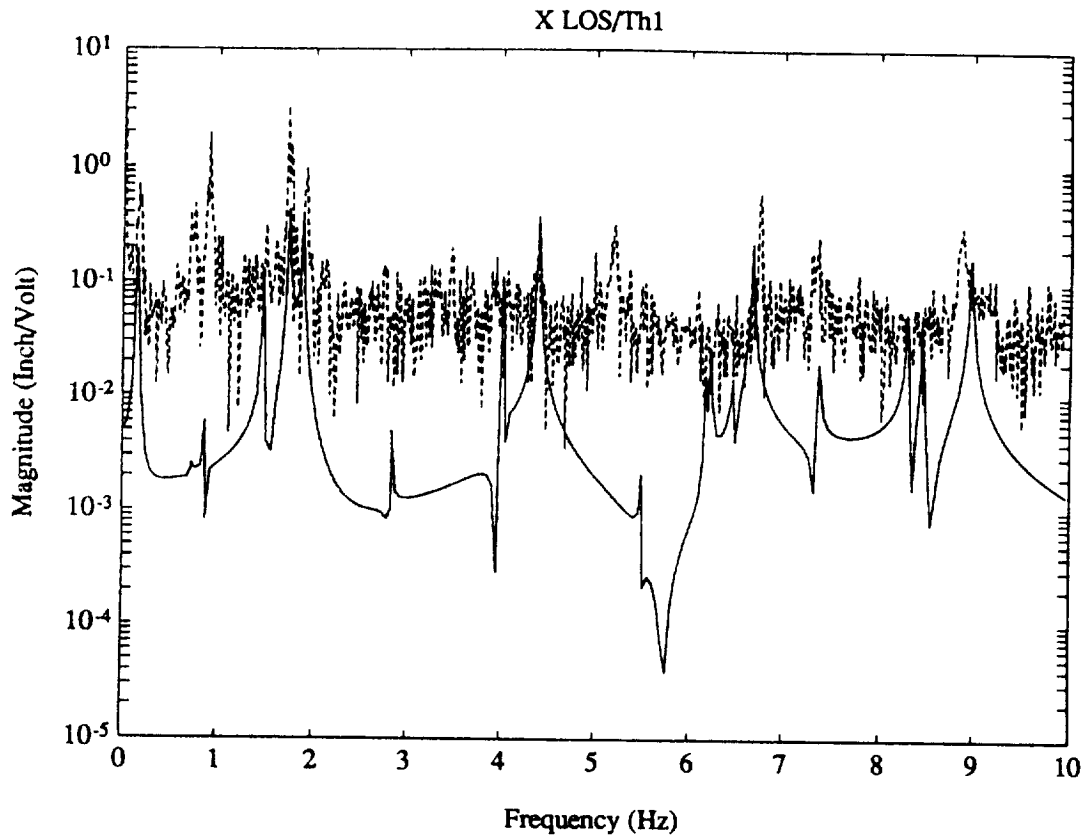


Figure 177. Bode magnitude plot of X-LOS / Thruster 1

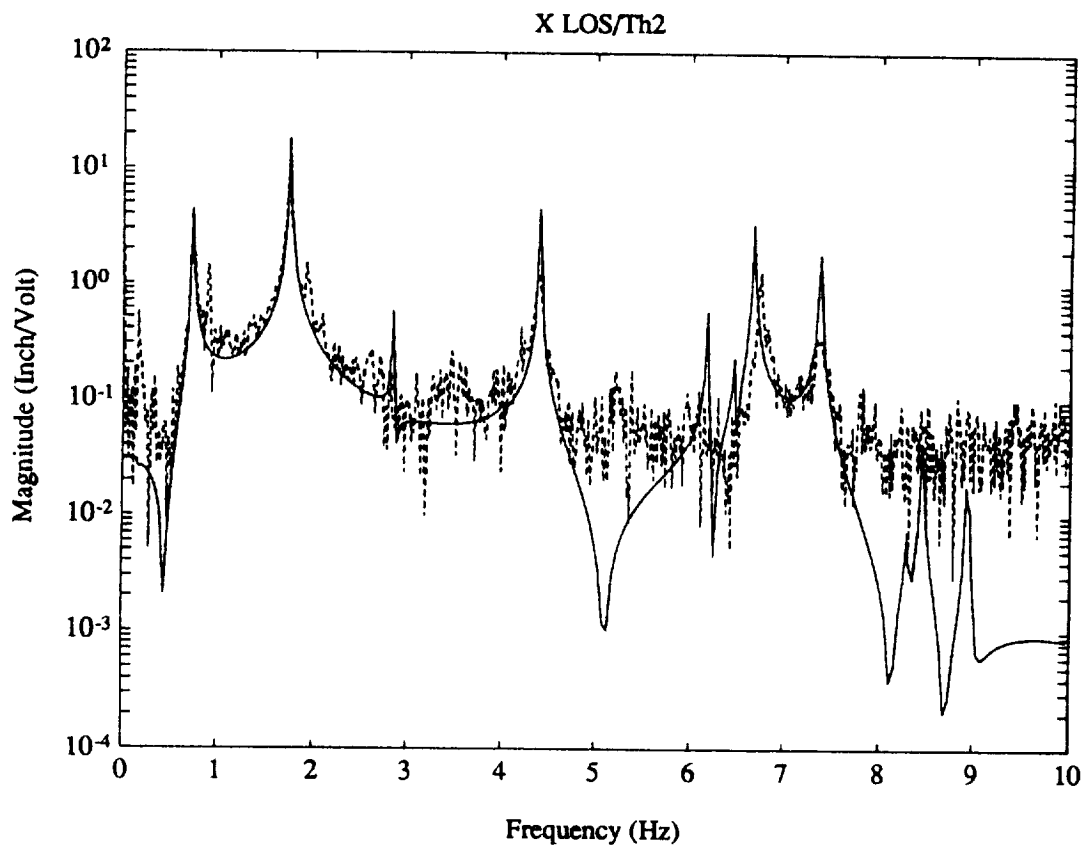


Figure 178. Bode magnitude plot of X-LOS / Thruster 2

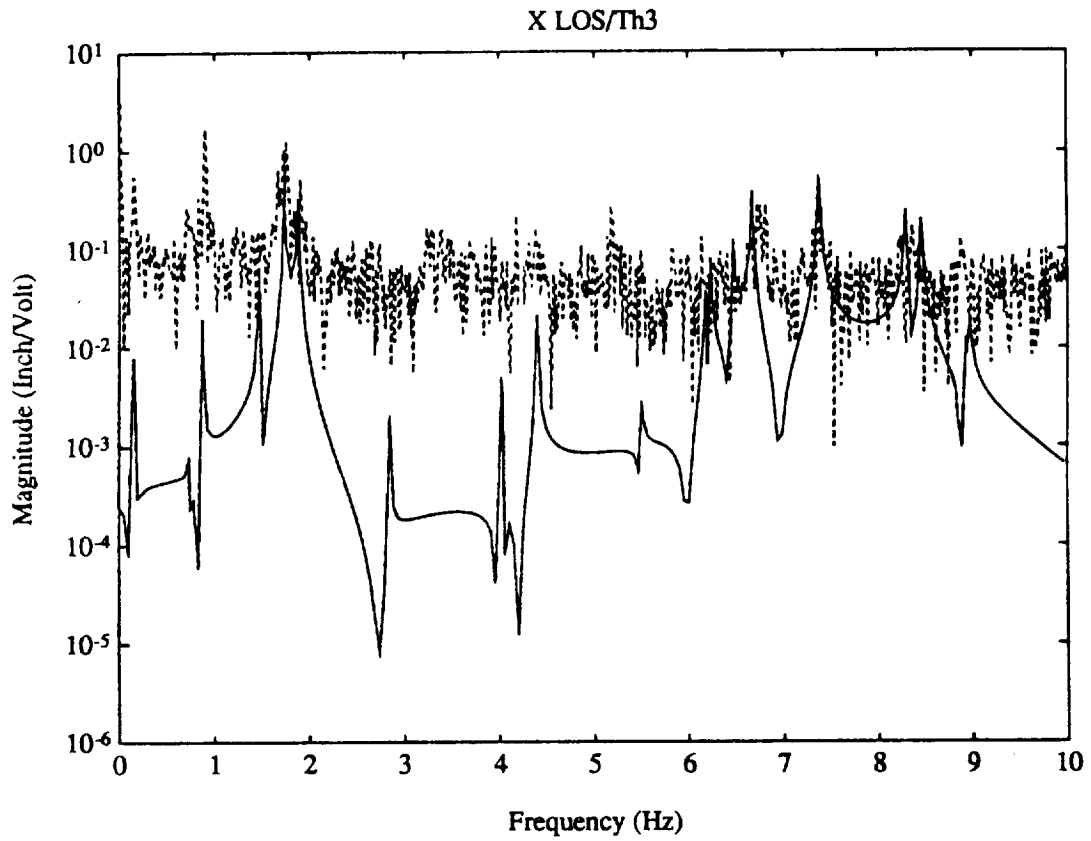


Figure 179. Bode magnitude plot of X-LOS / Thruster 3

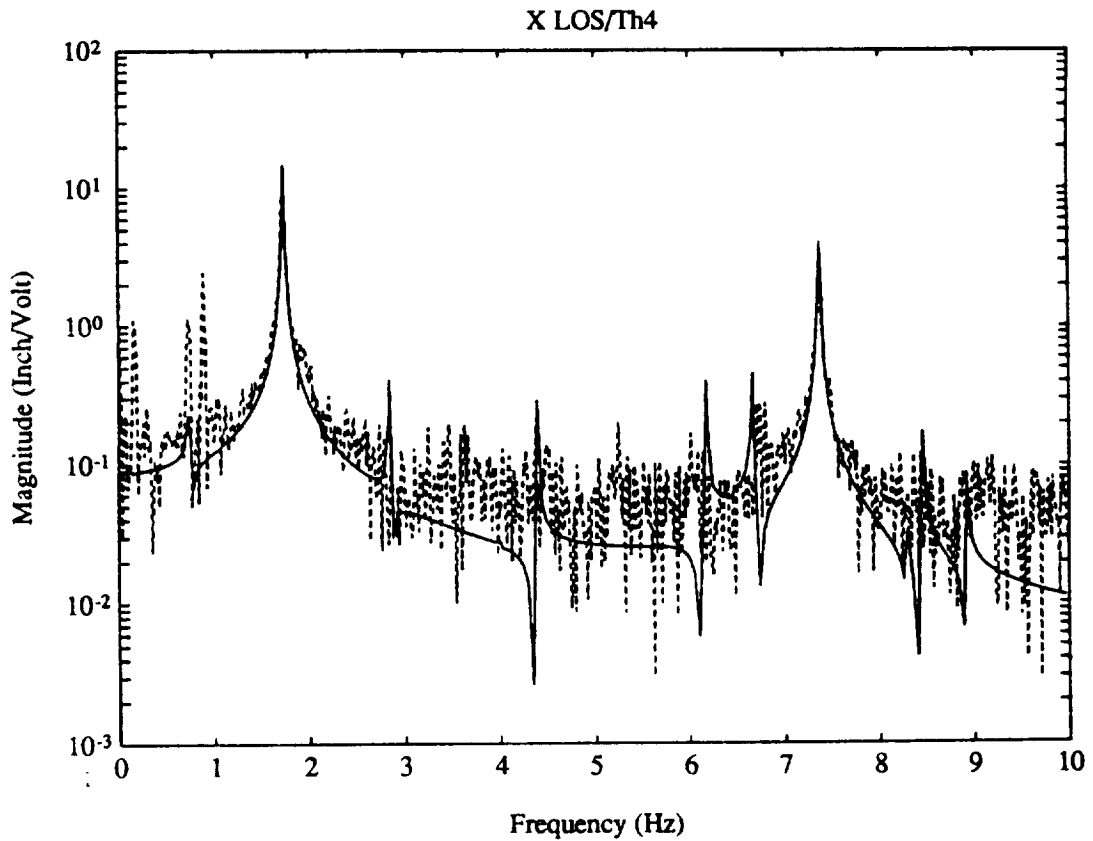


Figure 180. Bode magnitude plot of X-LOS / Thruster 4

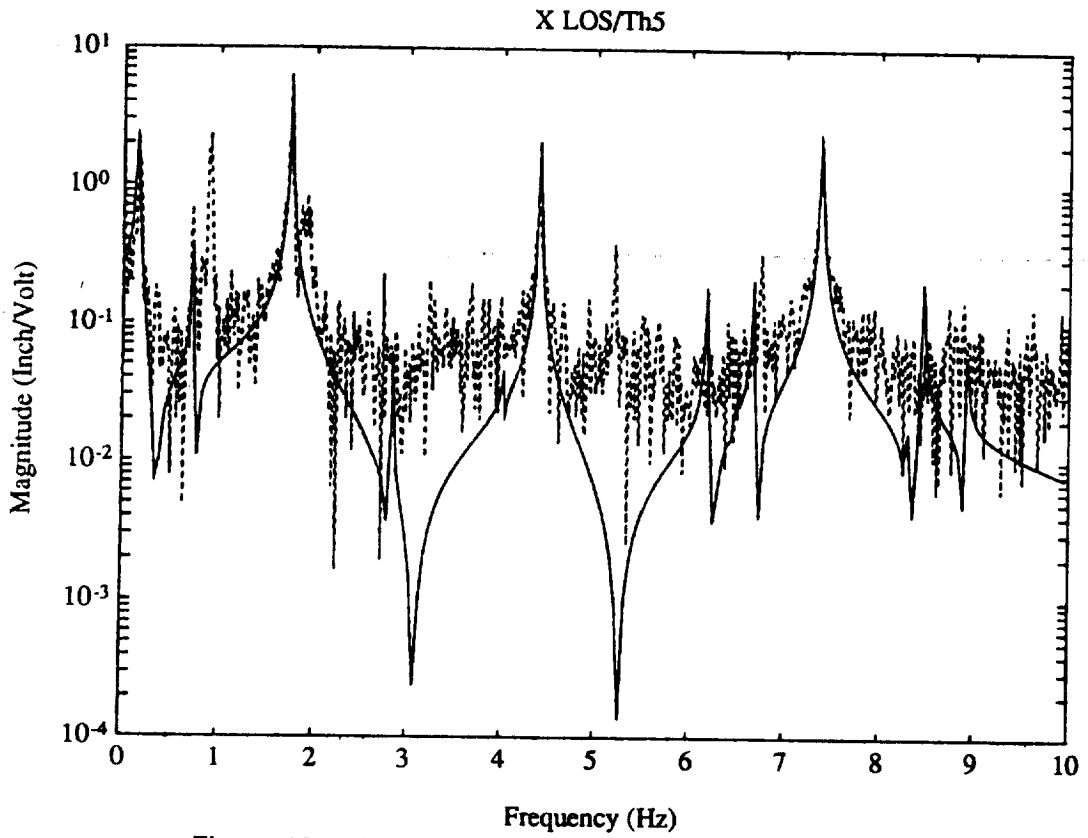


Figure 181. Bode magnitude plot of X-LOS / Thruster 5

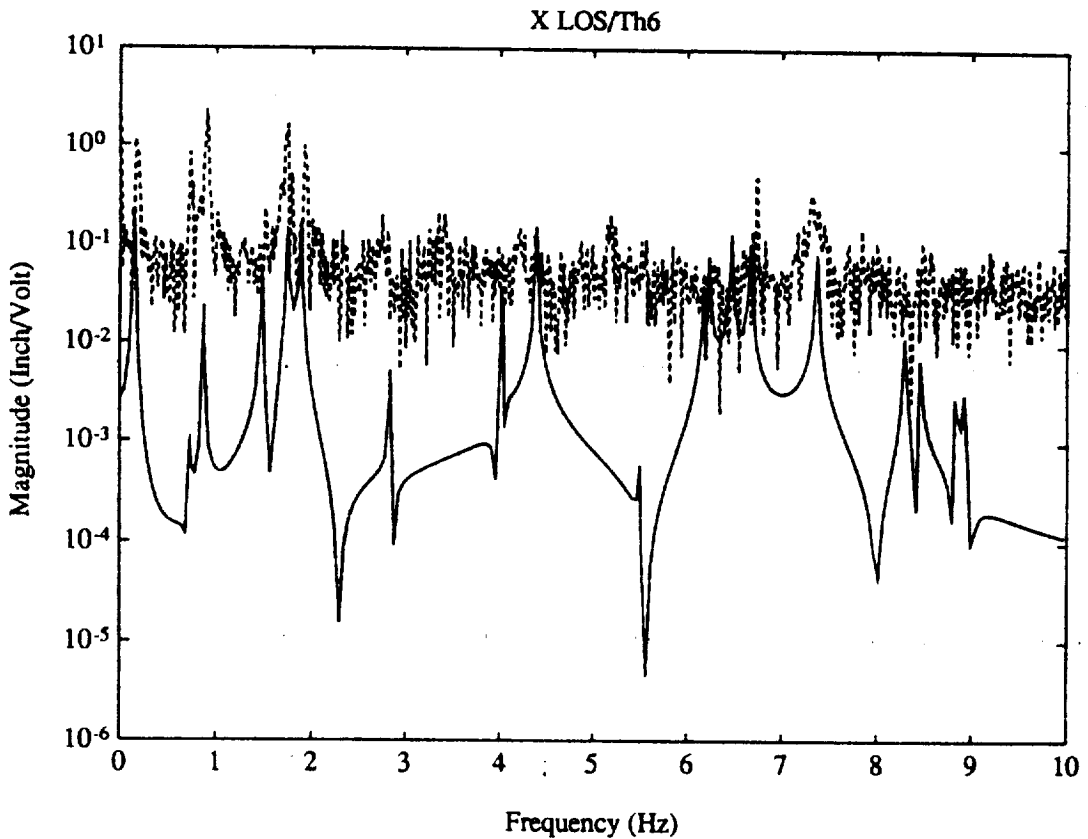


Figure 182. Bode magnitude plot of X-LOS / Thruster 6

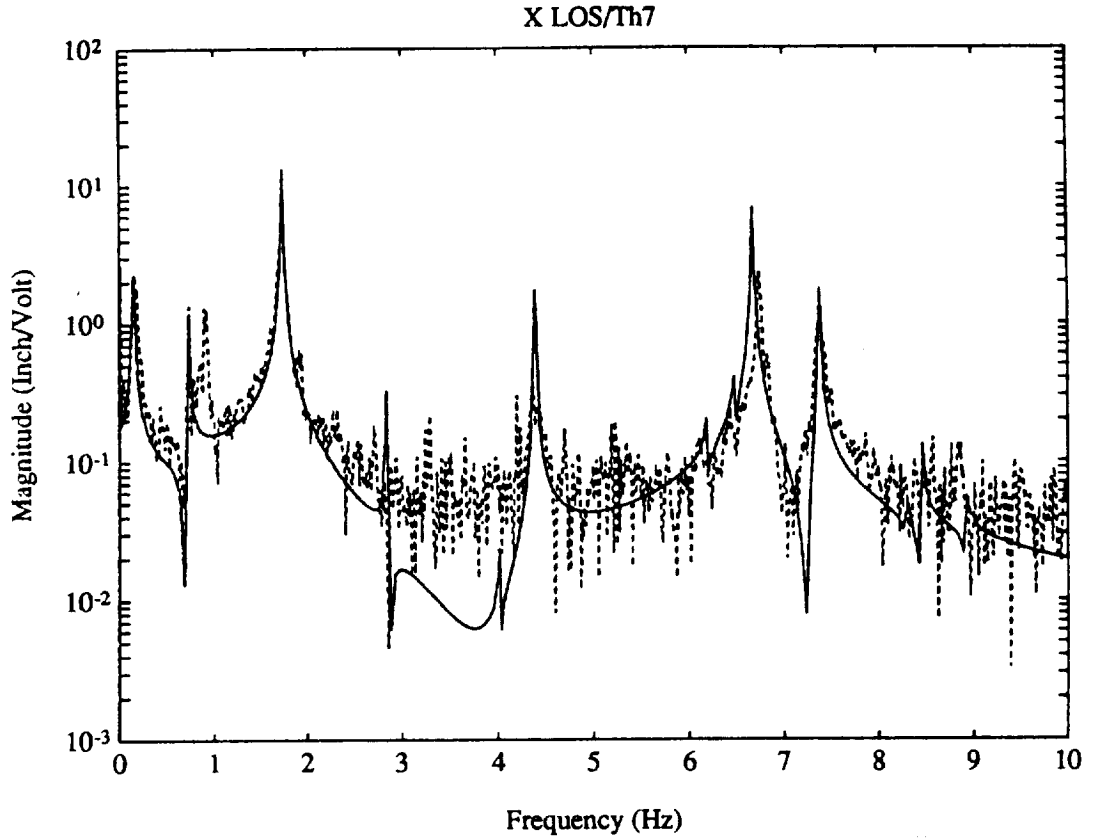


Figure 183. Bode magnitude plot of X-LOS / Thruster 7

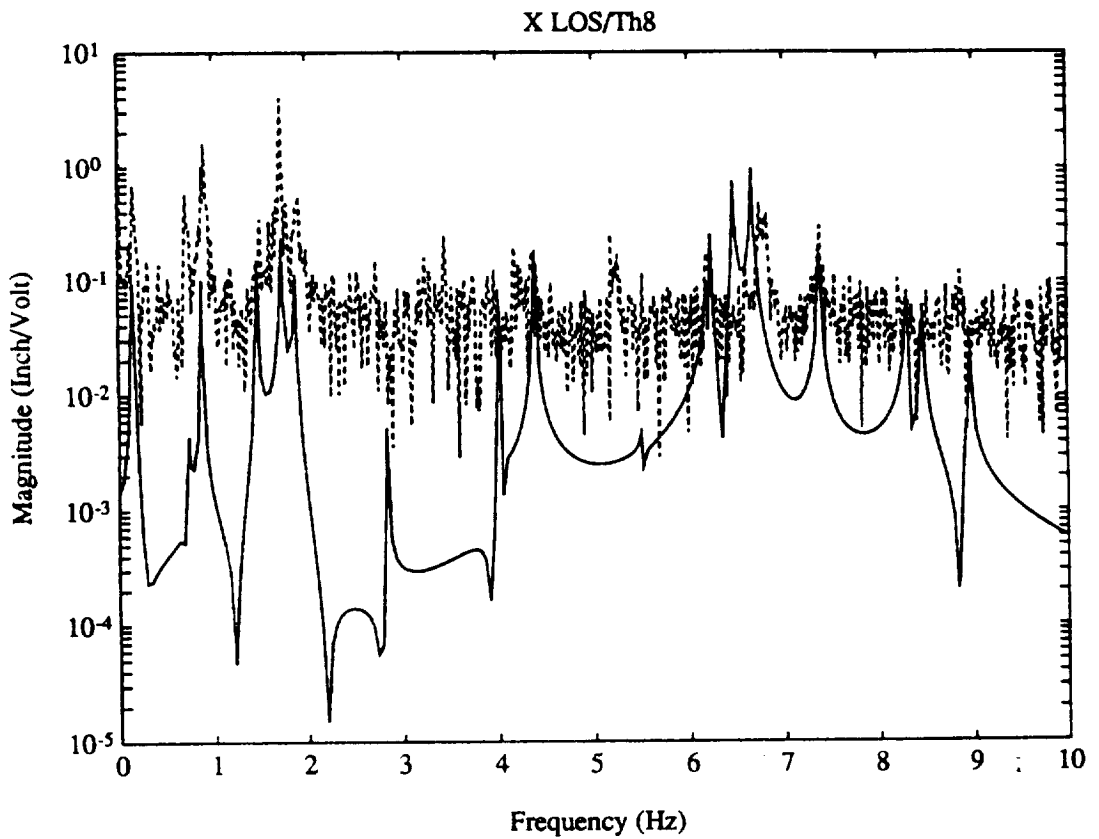


Figure 184. Bode magnitude plot of X-LOS / Thruster 8

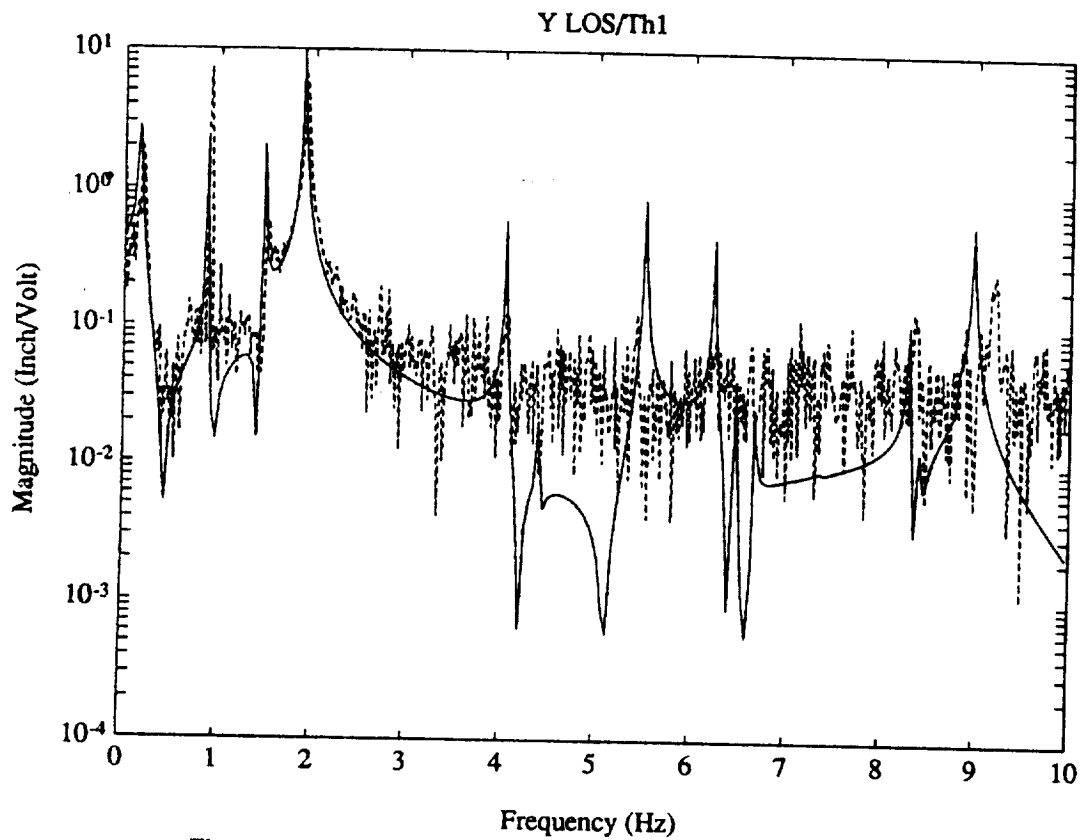


Figure 185. Bode magnitude plot of Y-LOS / Thruster 1

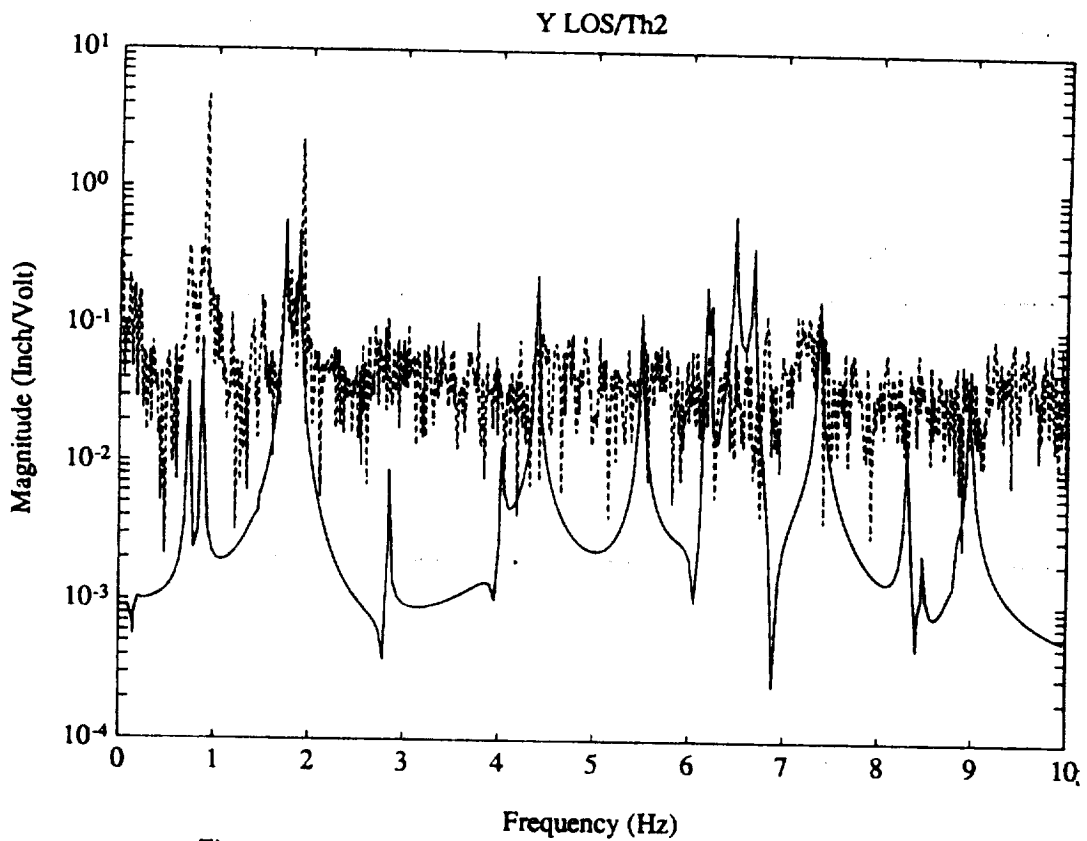


Figure 186. Bode magnitude plot of Y-LOS / Thruster 2

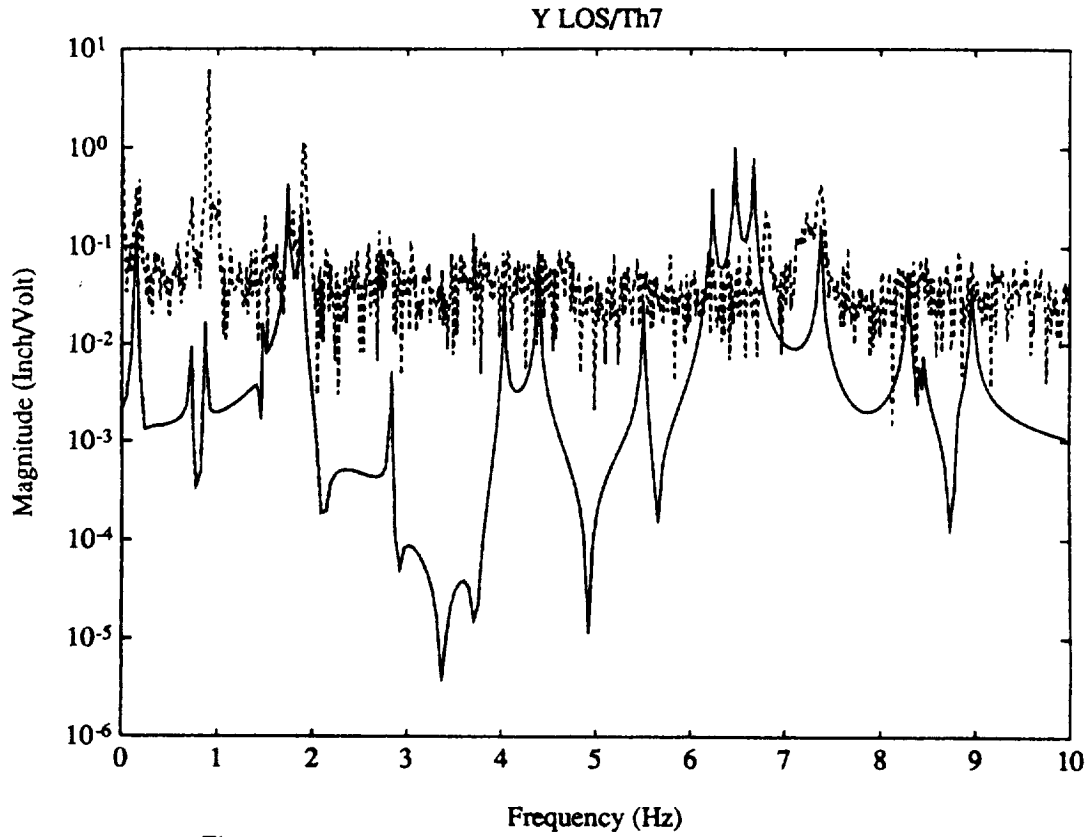


Figure 187. Bode magnitude plot of Y-LOS / Thruster 3

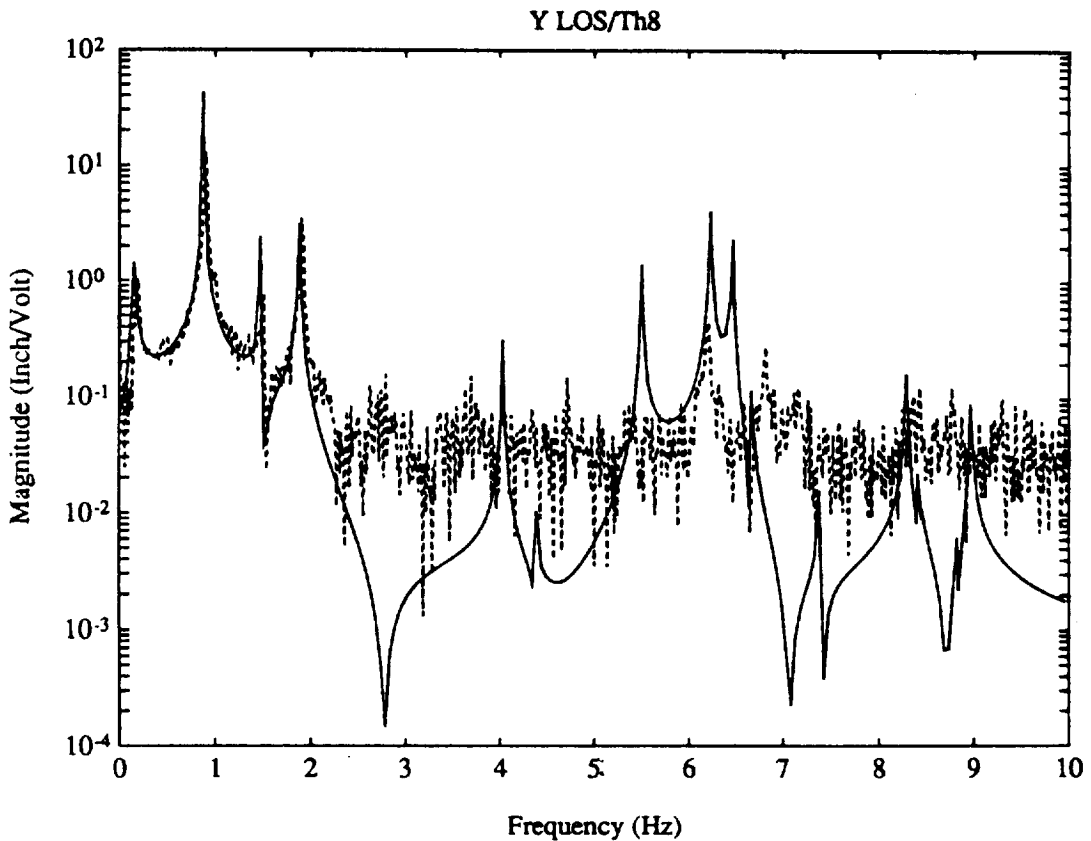


Figure 188. Bode magnitude plot of Y-LOS / Thruster 4

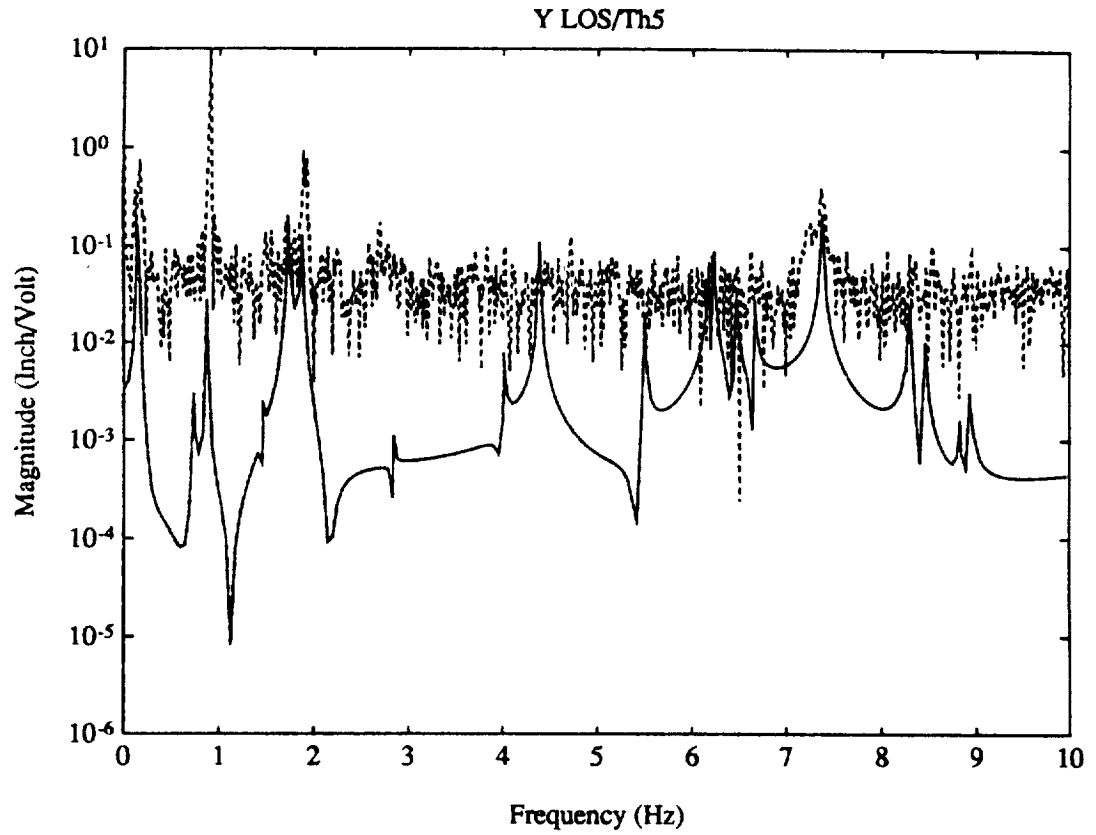


Figure 189. Bode magnitude plot of Y-LOS / Thruster 5

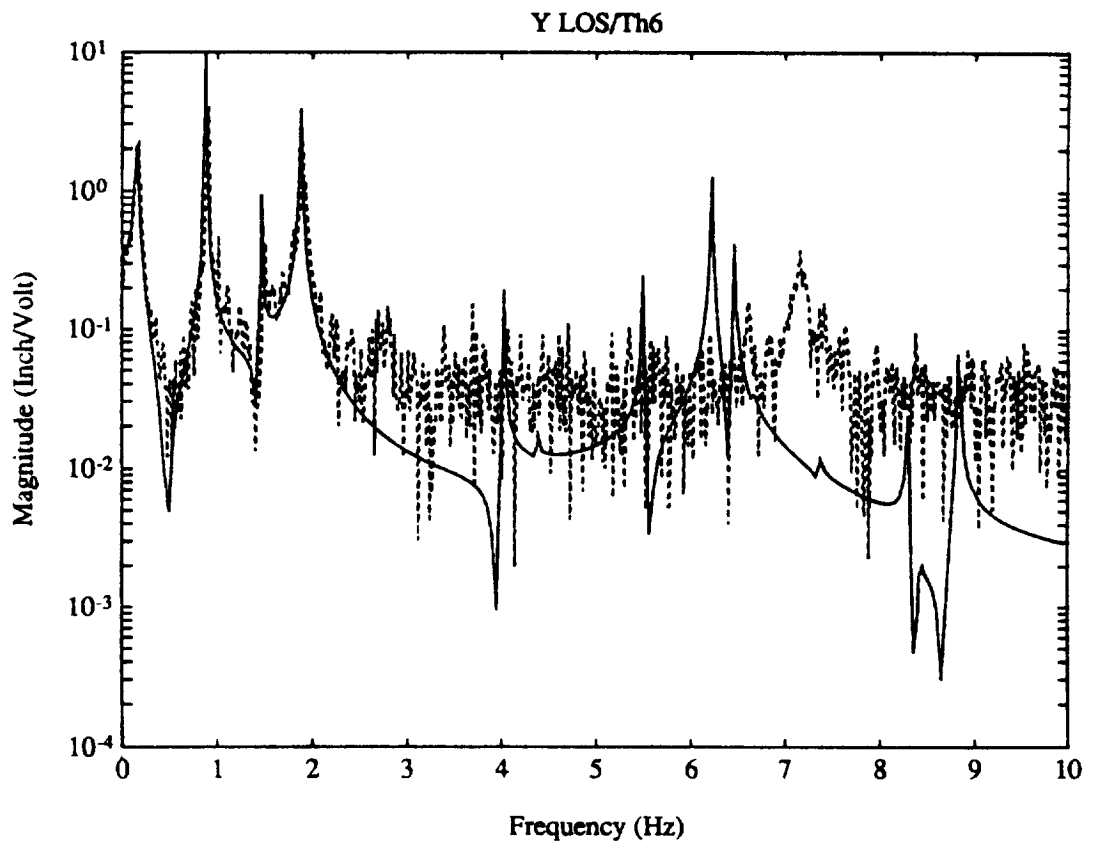


Figure 190. Bode magnitude plot of Y-LOS / Thruster 6

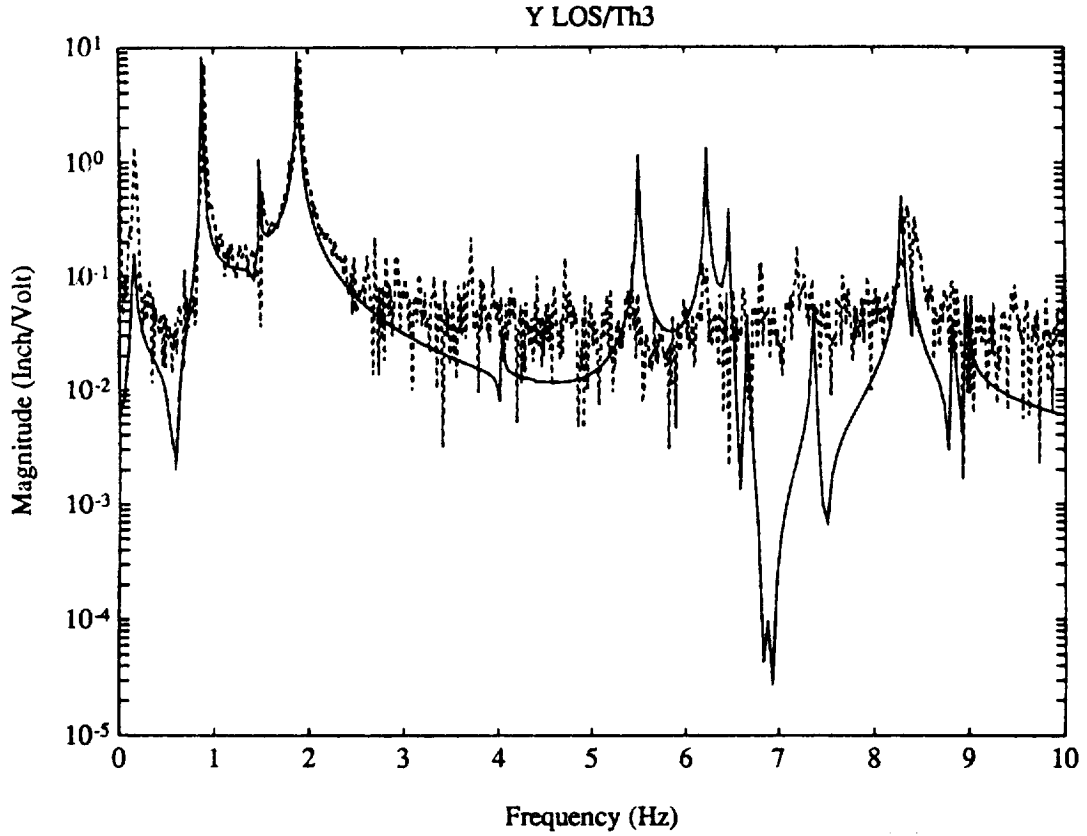


Figure 191. Bode magnitude plot of Y-LOS / Thruster 7

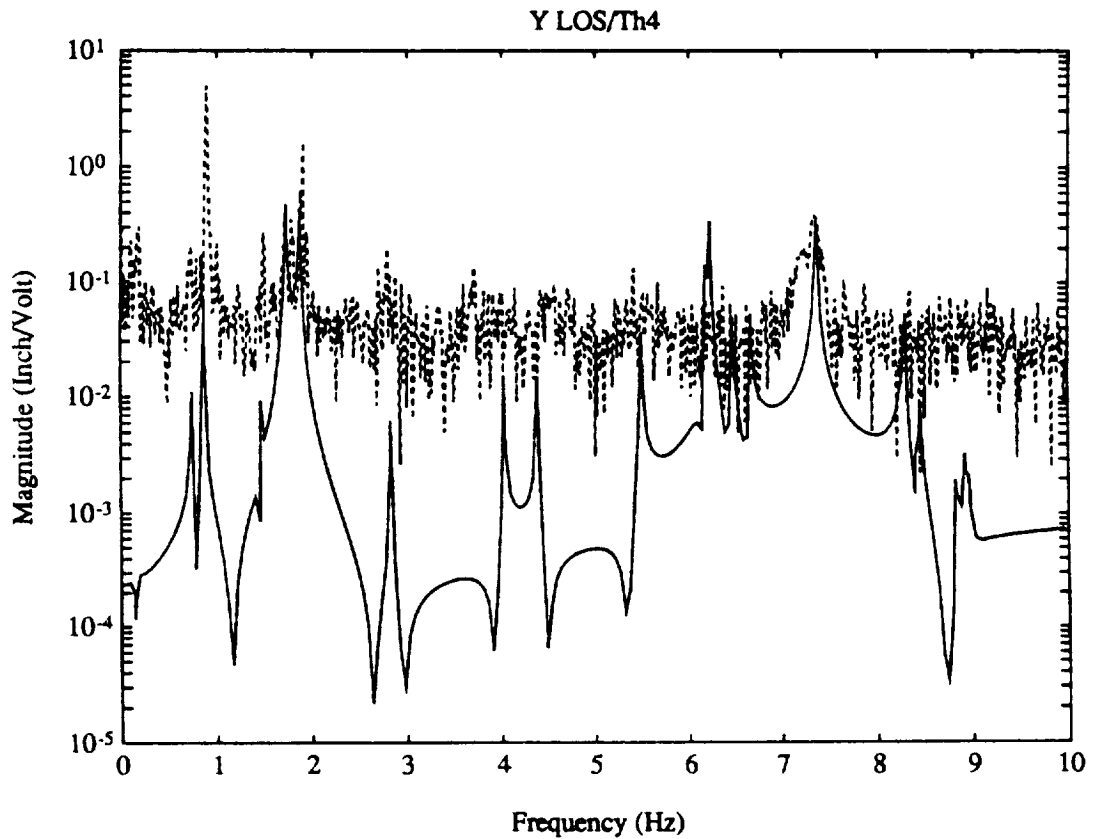


Figure 192. Bode magnitude plot of Y-LOS / Thruster 8

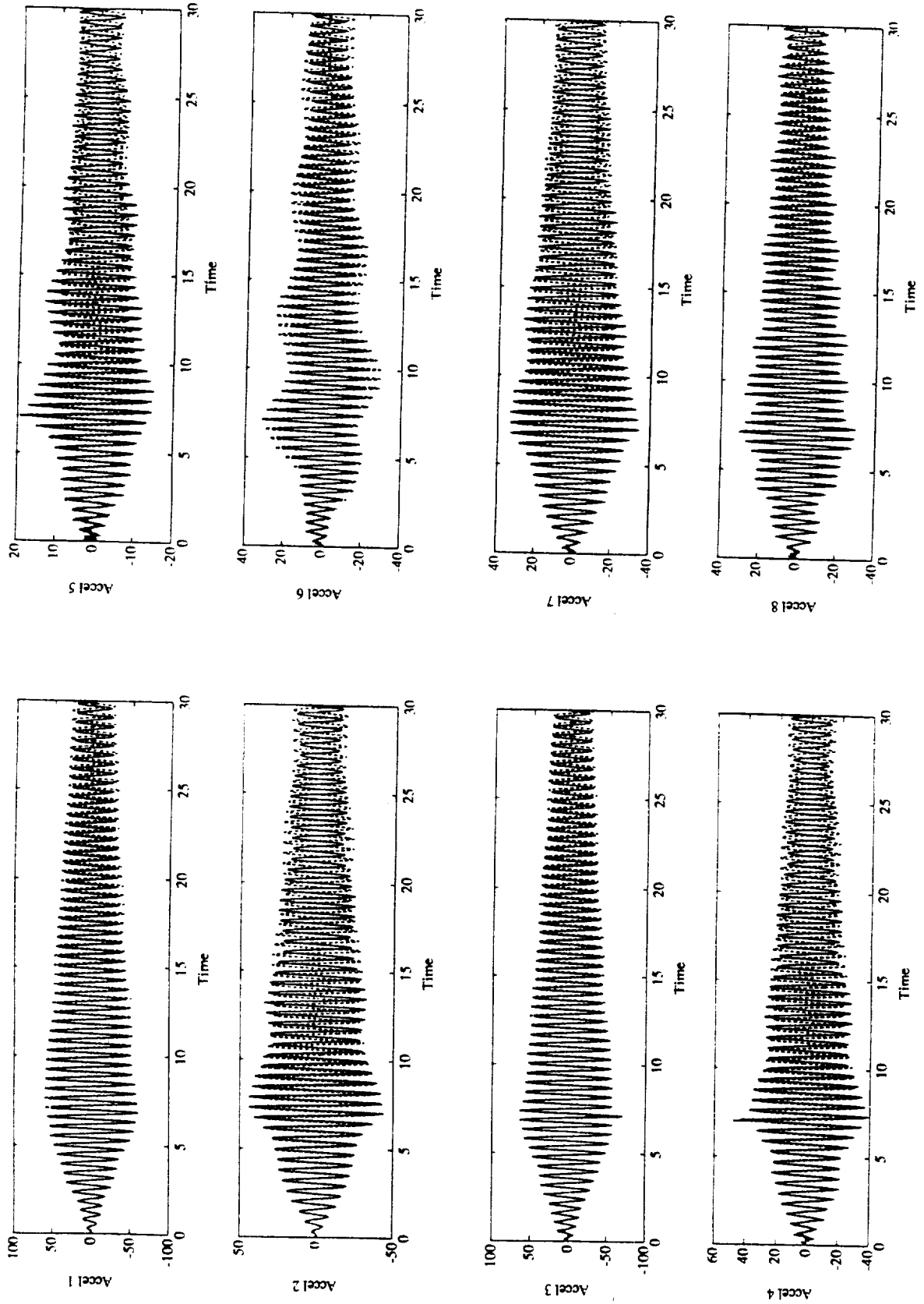


Figure 193. CEM open-loop acceleration response

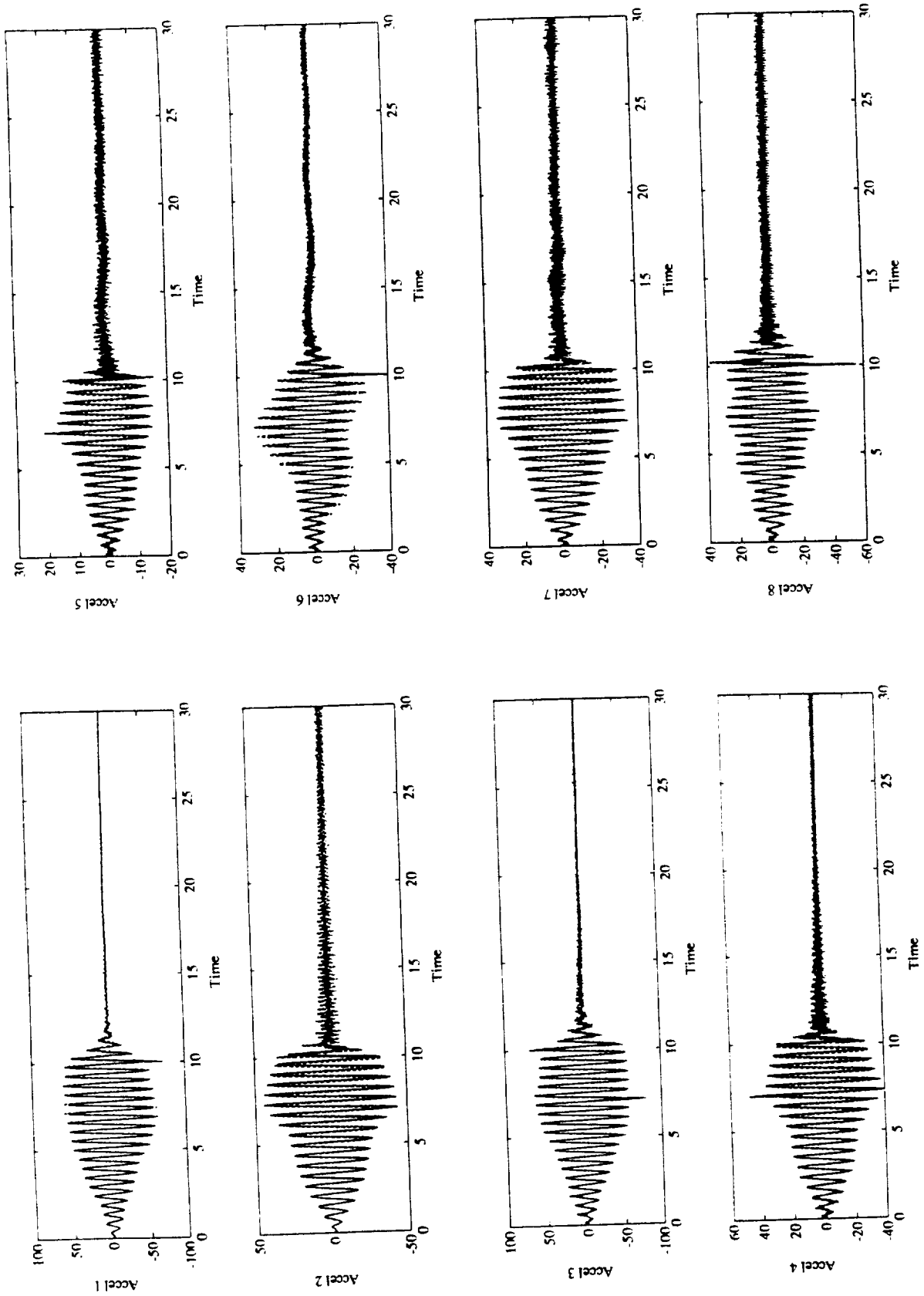


Figure 194. CEM closed-loop acceleration response

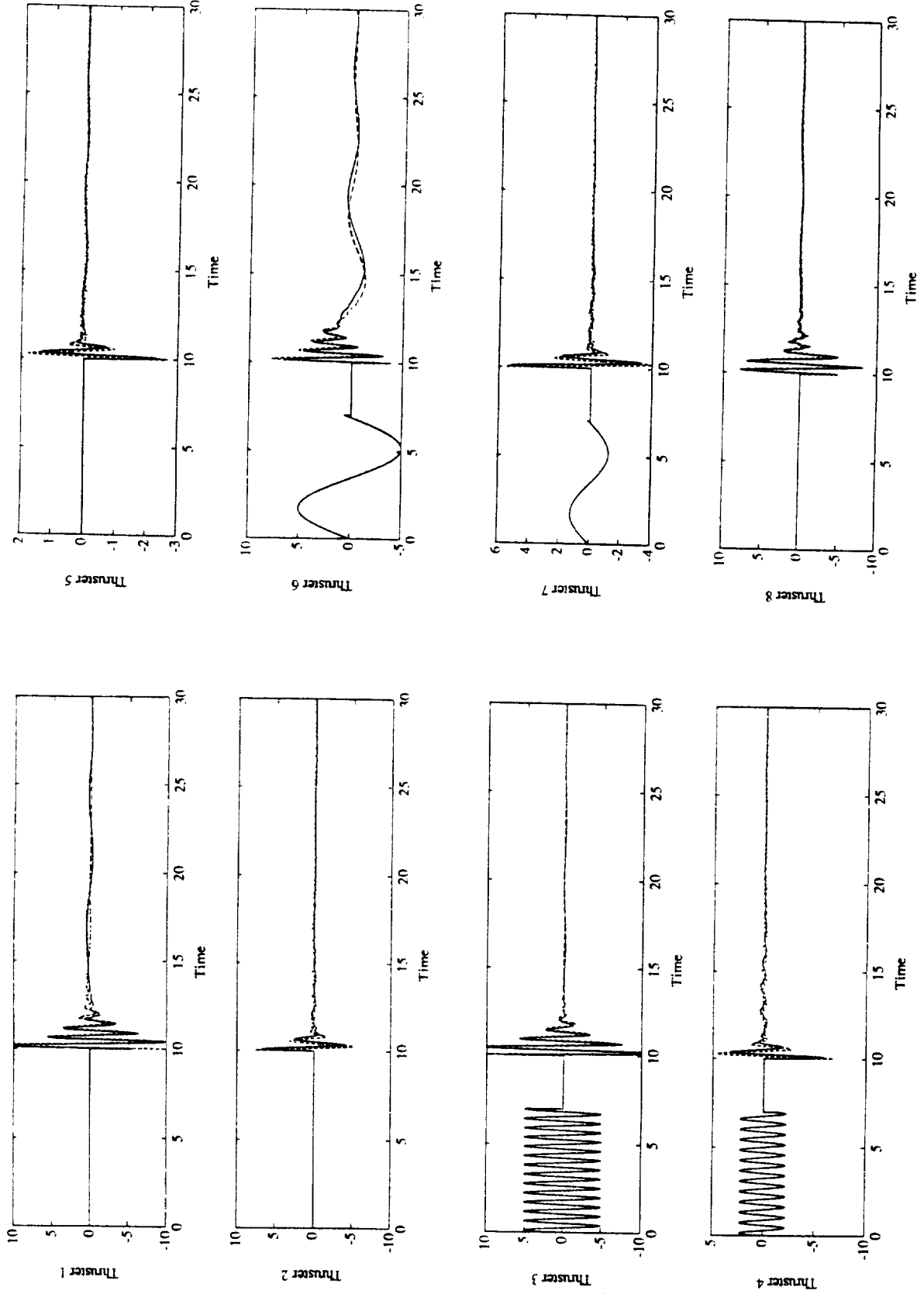


Figure 195. CEM closed-loop control commands

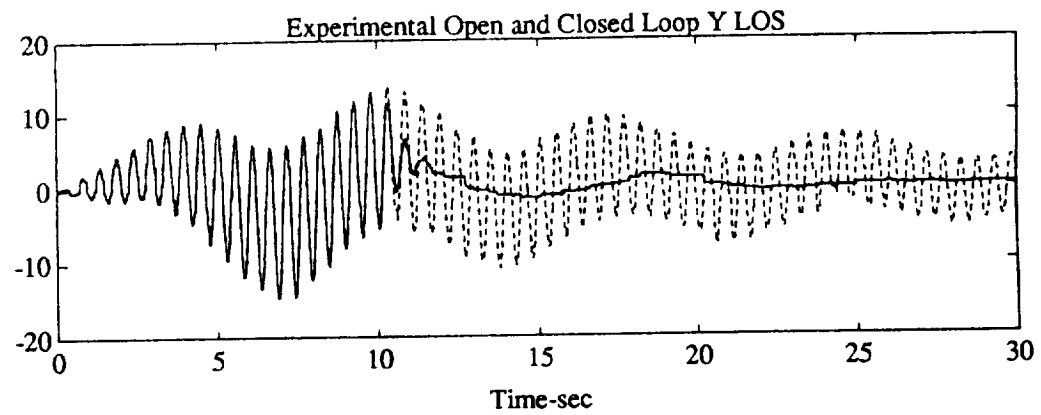
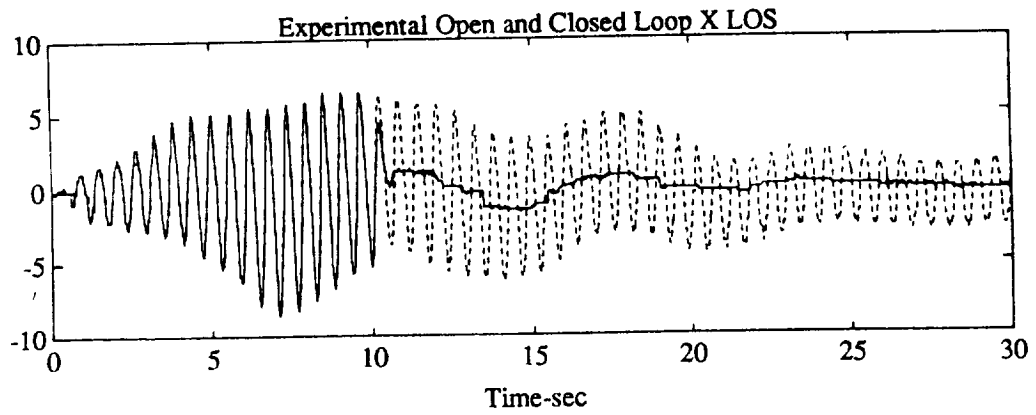


Figure 196. Experimental LOS time histories, open- and closed-loop

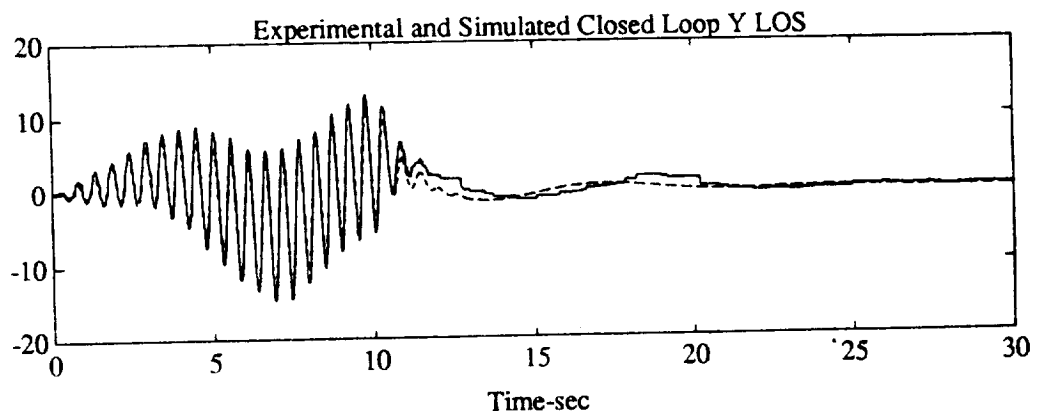
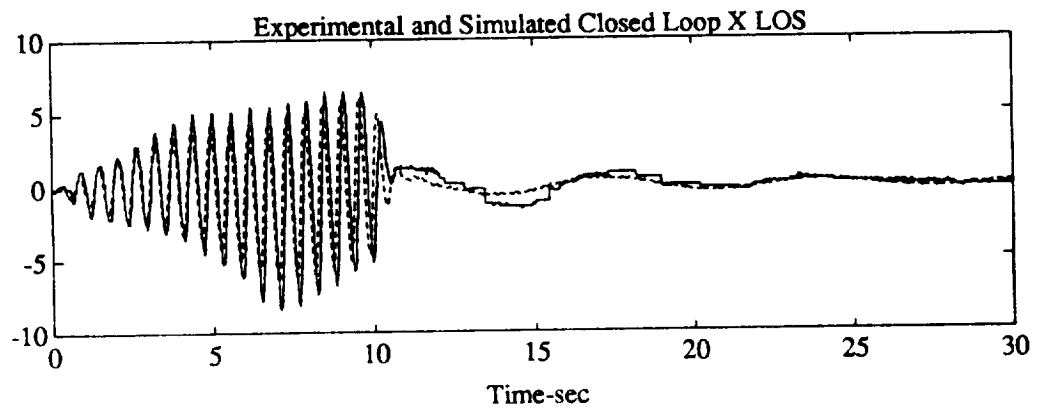


Figure 197. Experimental and simulation LOS time histories

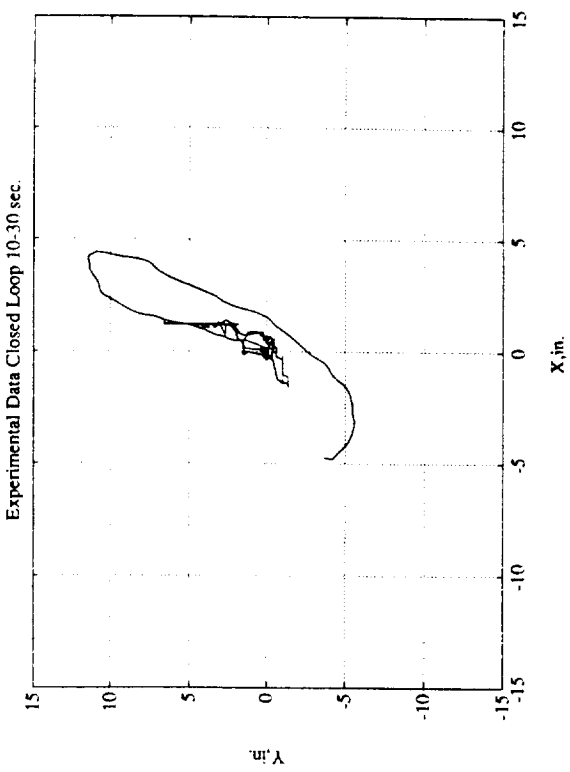
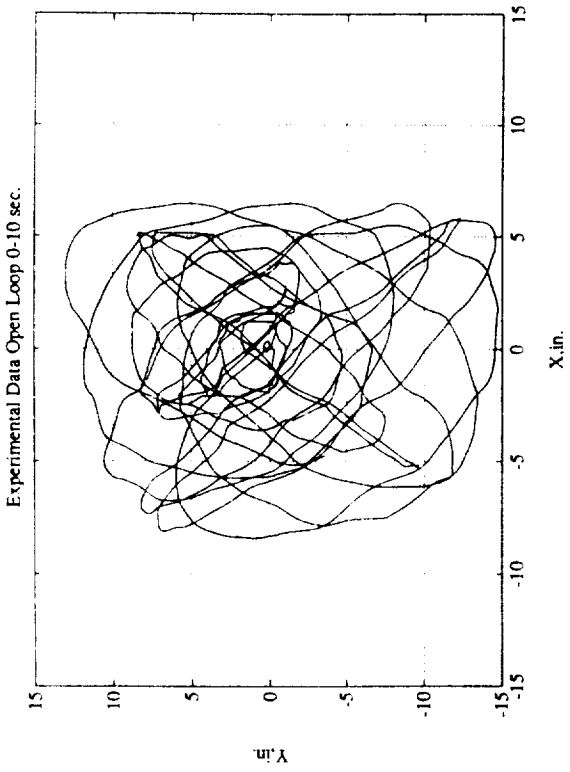
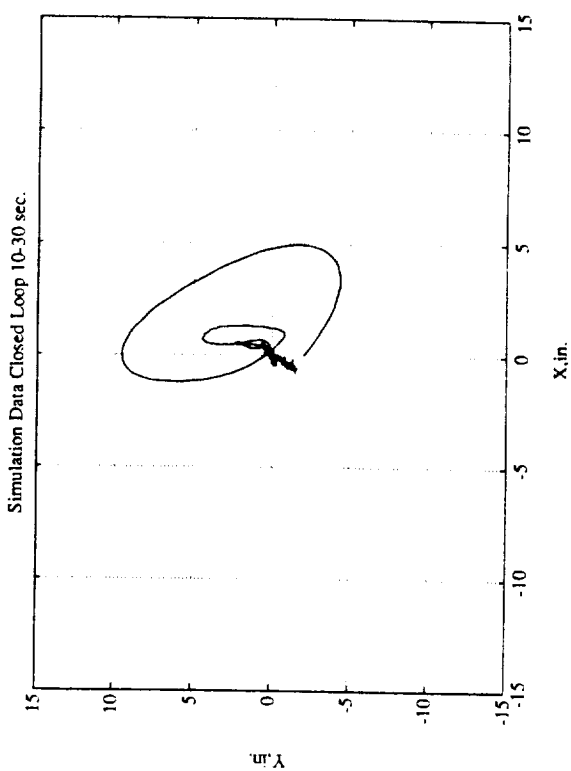
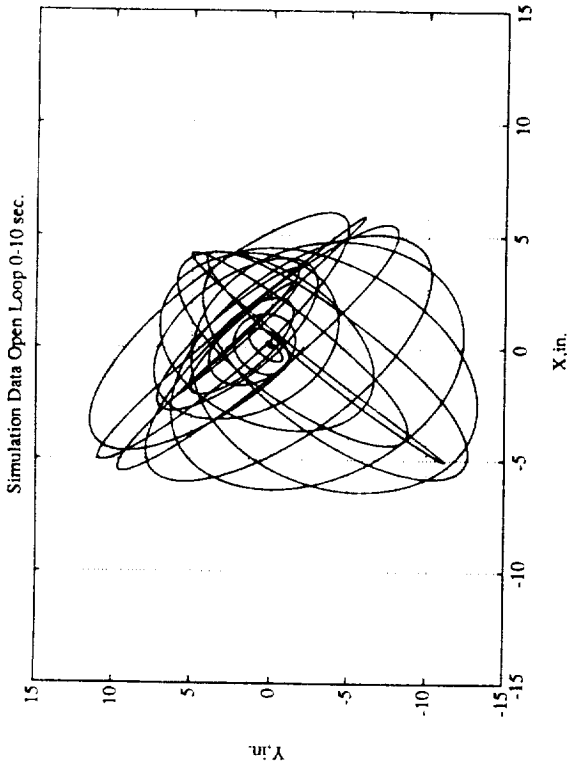


Figure 198. Experimental LOS pointing scoring

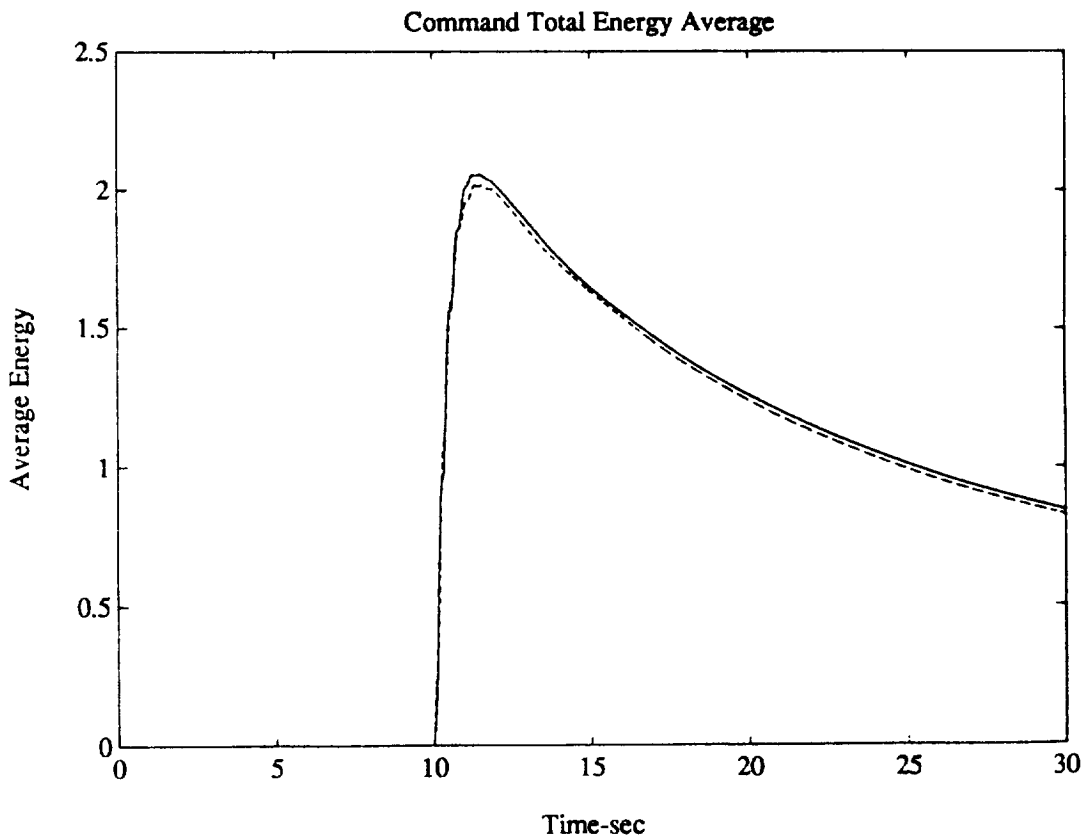
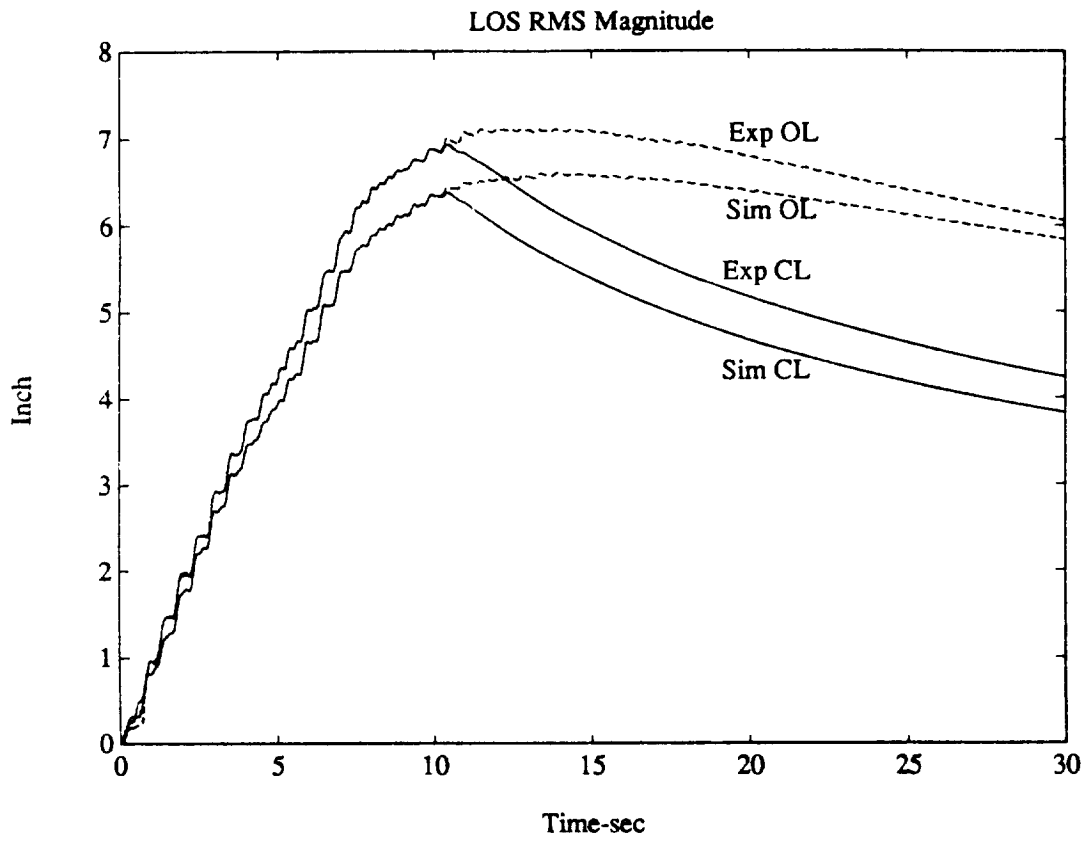


Figure 199. Running average of LOS pointing and control effort

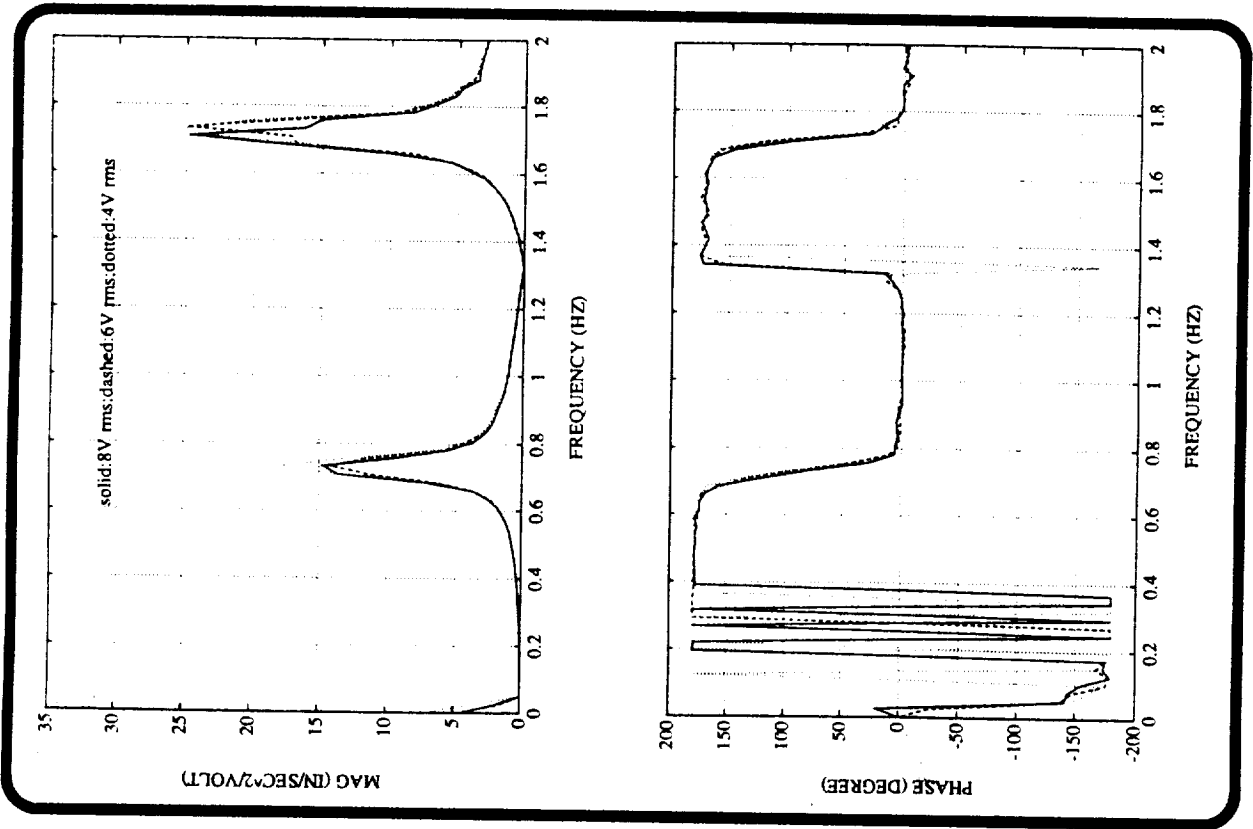


Figure 201. Effect of excitation level on response, Accelerometer 2 / Thruster 2

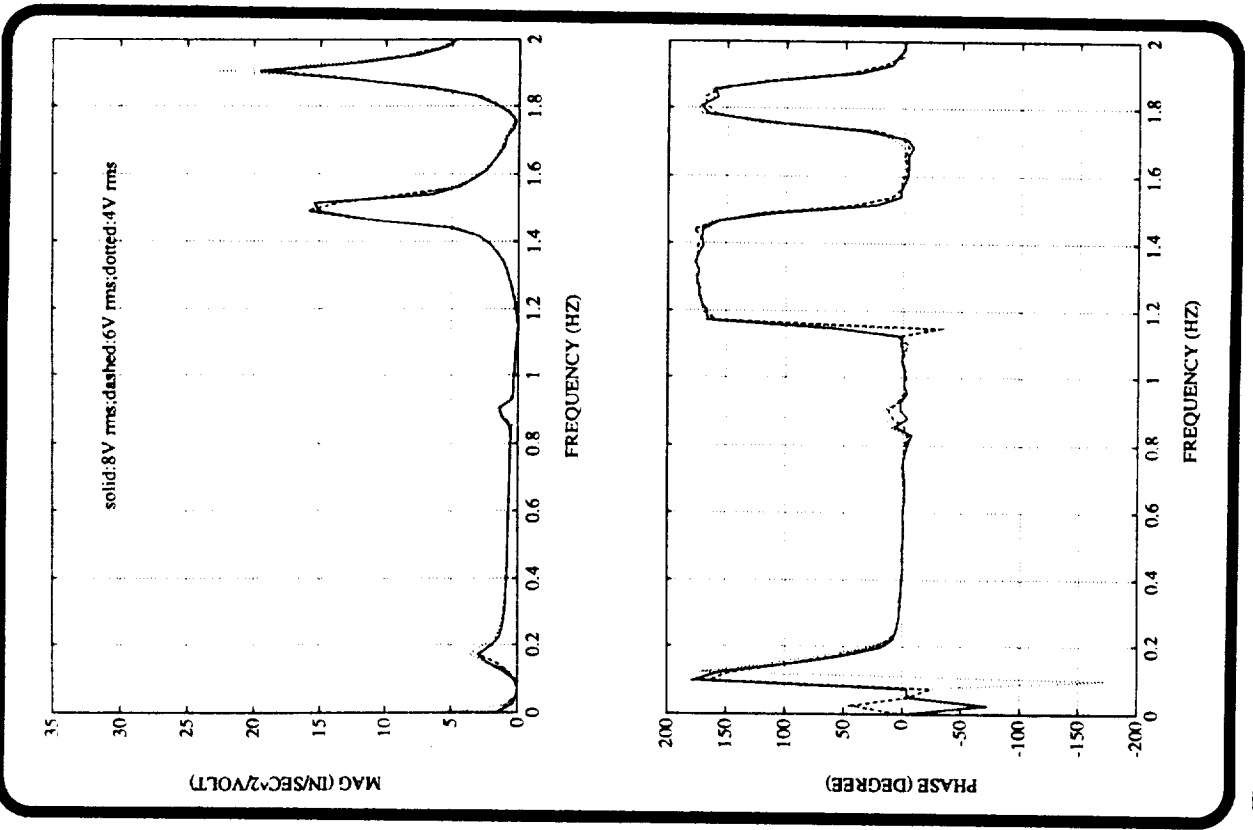


Figure 200. Effect of excitation level on response, Accelerometer 1 / Thruster 1

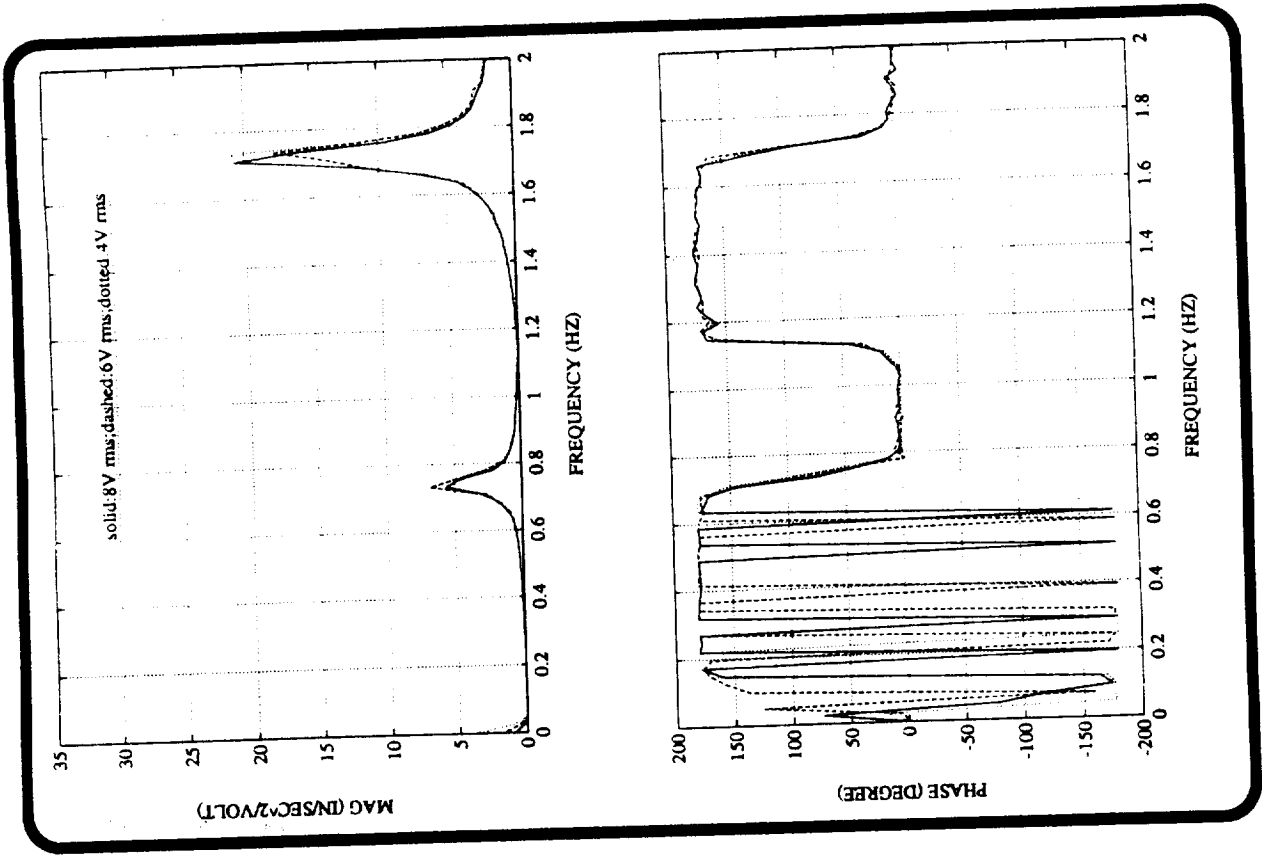


Figure 202. Effect of excitation level on response, Accelerometer 3 / Thruster 3

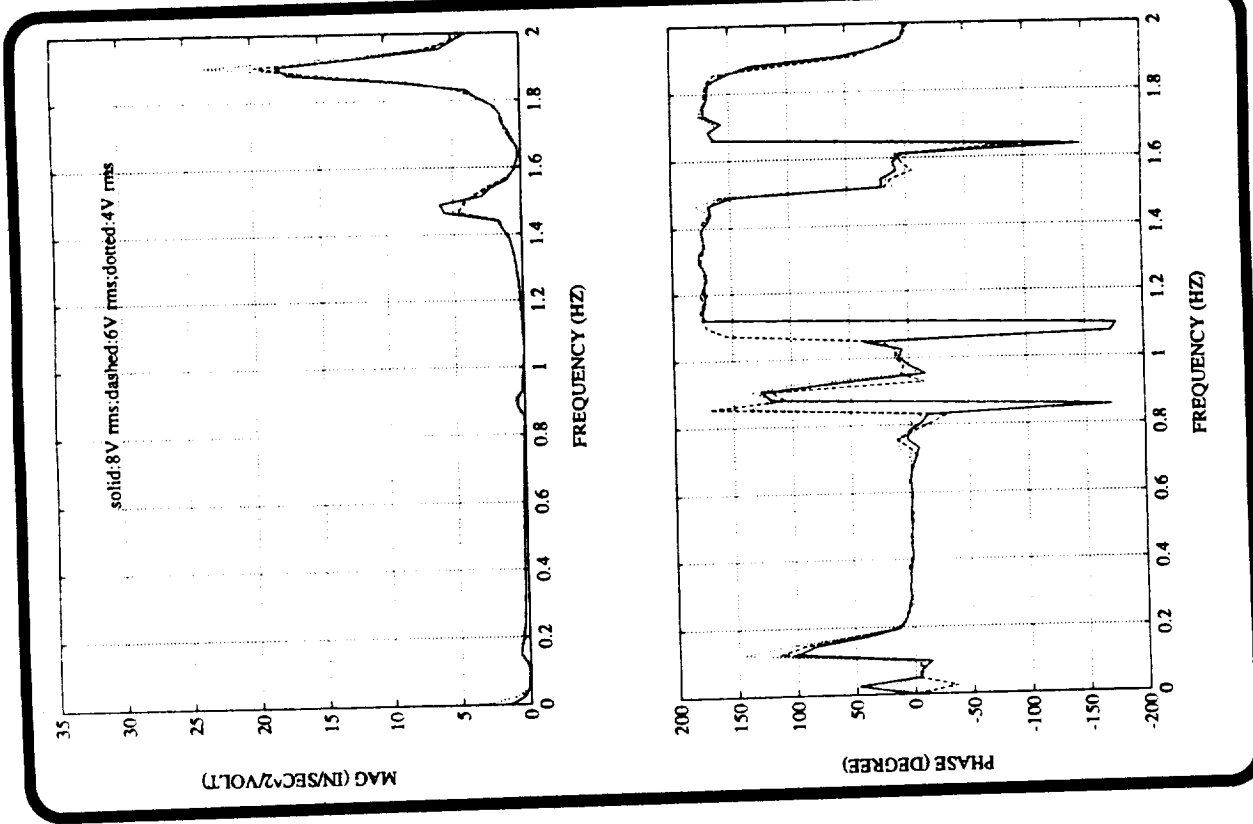


Figure 203. Effect of excitation level on response, Accelerometer 4 / Thruster 4

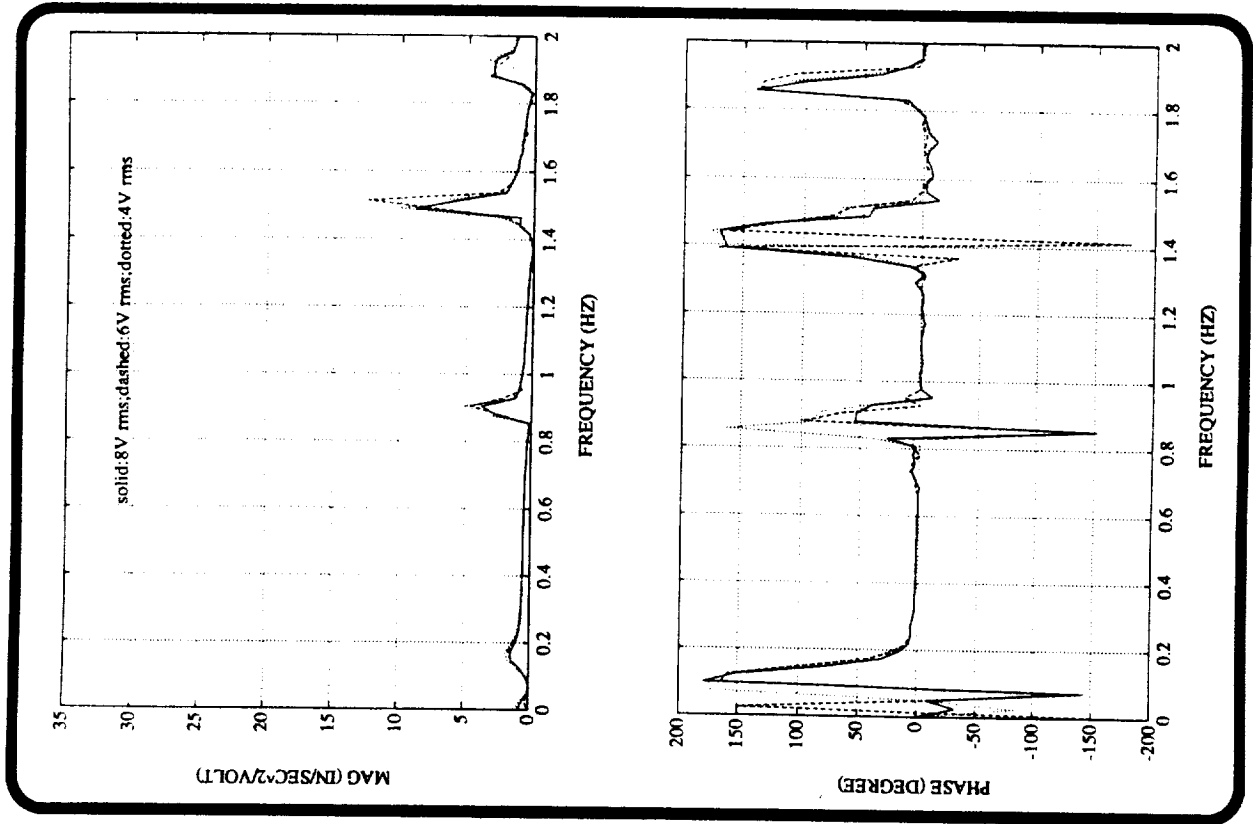


Figure 205. Effect of excitation level on response, Accelerometer 6 / Thruster 6

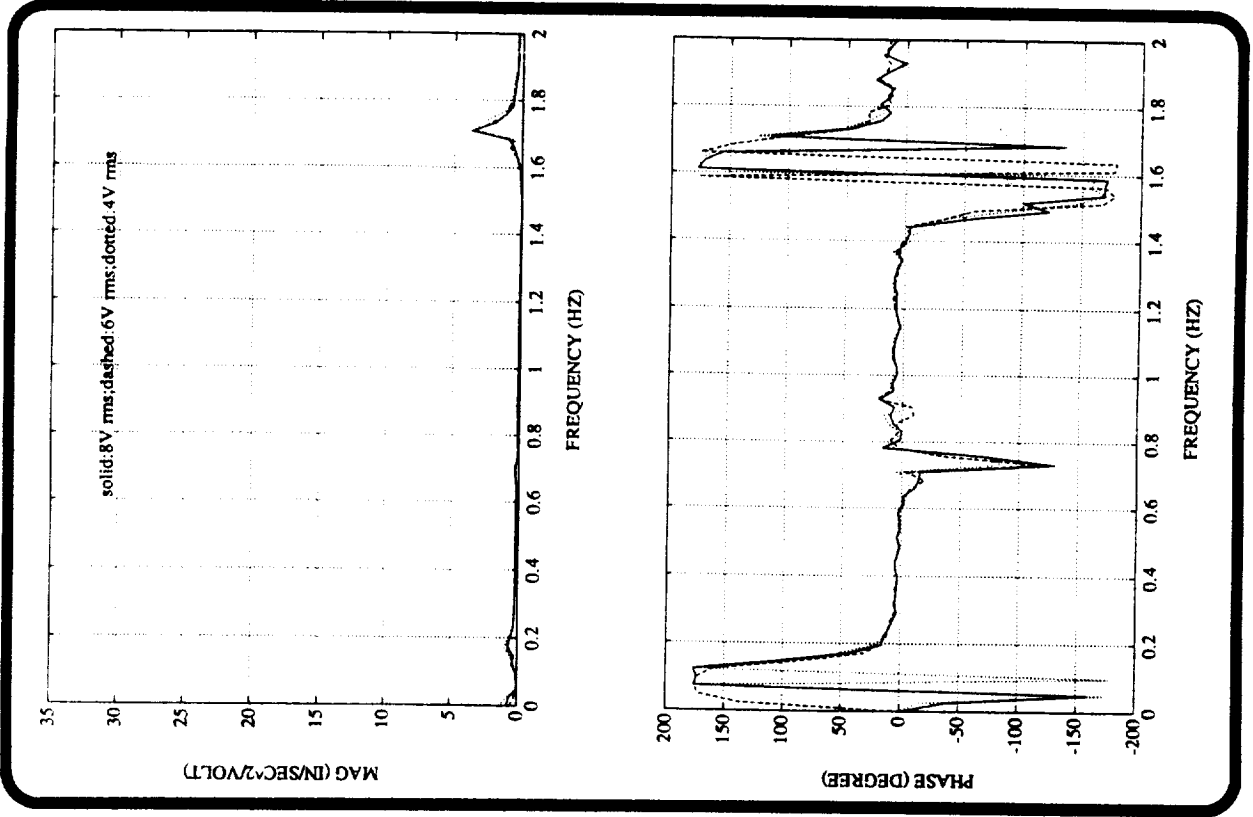
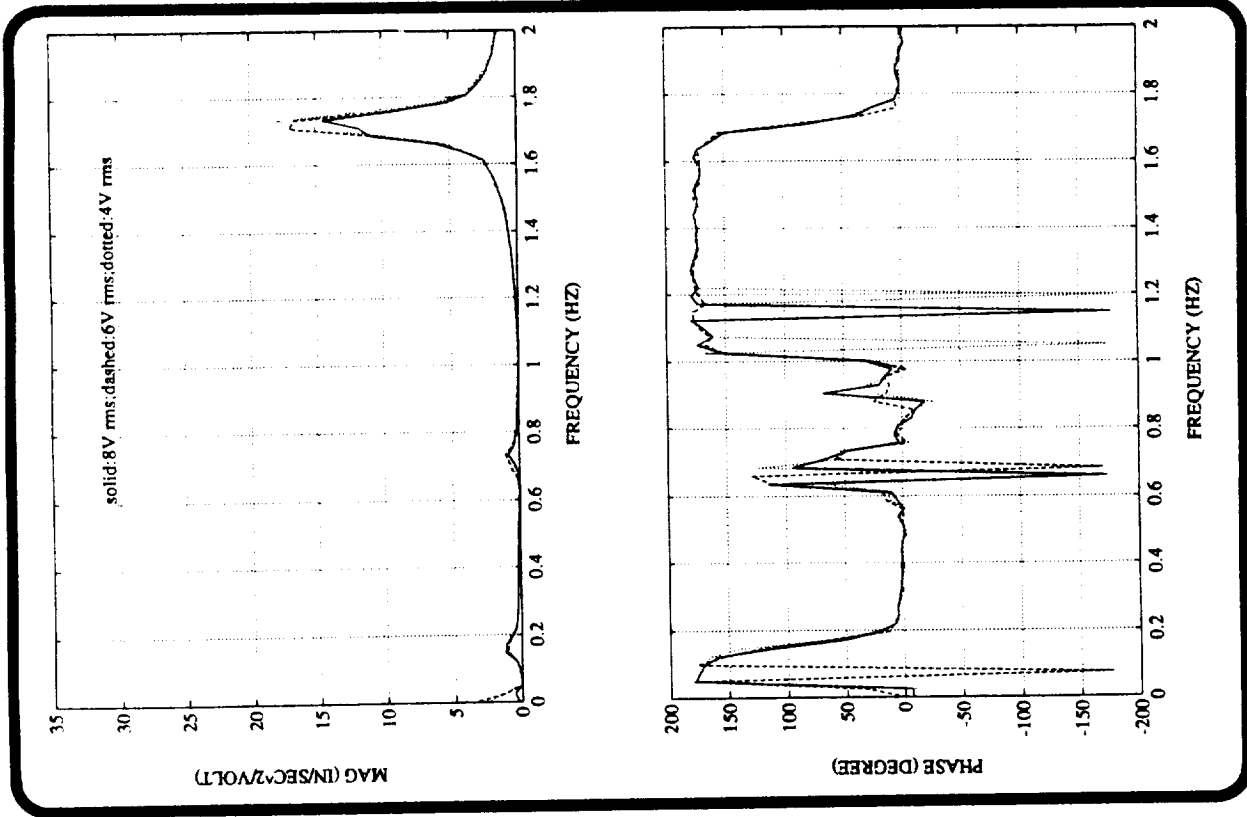
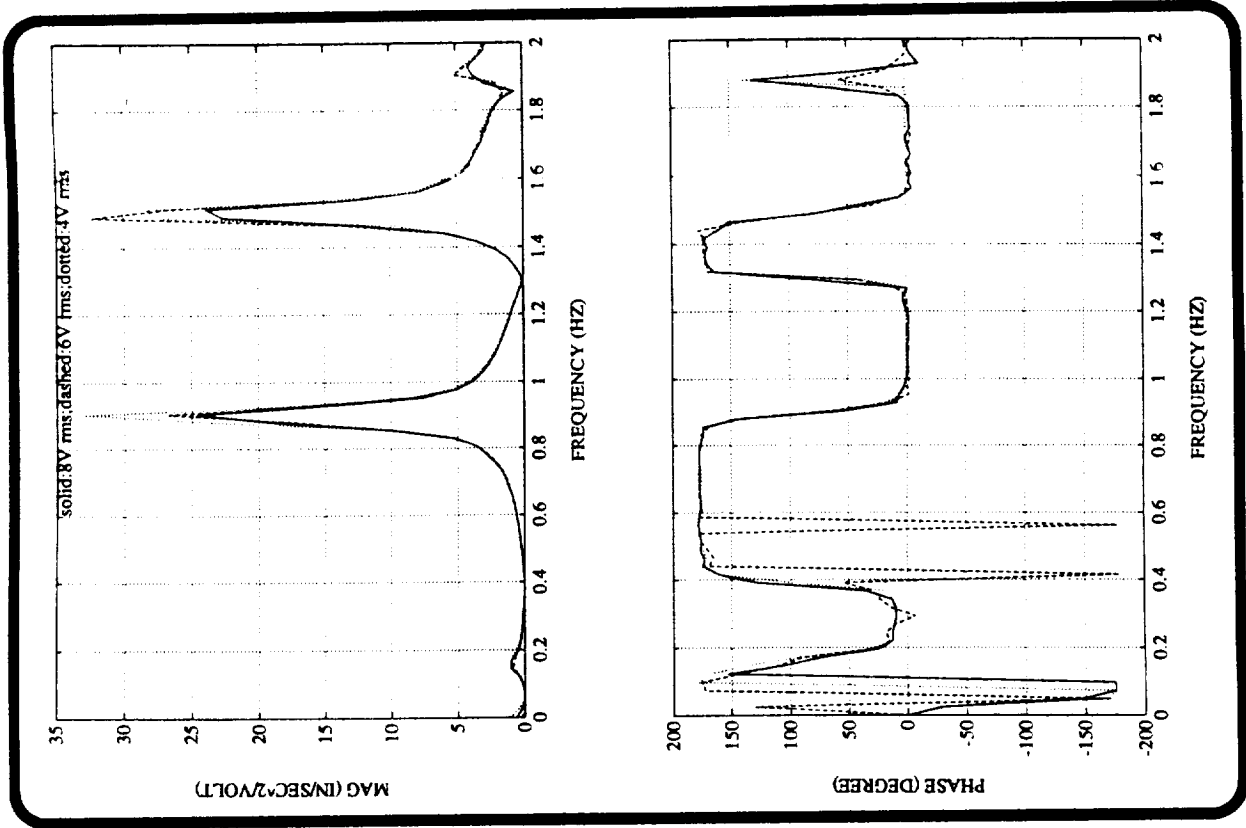


Figure 204. Effect of excitation level on response, Accelerometer 5 / Thruster 5

Figure 207. Effect of excitation level on response, Accelerometer 8 / Thruster 8

Figure 206. Effect of excitation level on response, Accelerometer 7 / Thruster 7



Appendix 1

The following listing is the source code used for real-time control of the CEM on the VAX 3200 computer. Note the A matrix is assumed to be 2X2 block diagonal. For any real A matrix, this can be performed by the MATLAB .m file given in Appendix 2.

```

program camblk5
  implicit integer(a-z)
  .....
** Camblk5 accesses the CAMAC crate to read from the ADC *
** channels and write to the DAC channels in real-time. *
** Control laws are implemented for use on the CSI *
** Evolutionary model. Limit checking on sensor inputs *
** and Thruster commands is performed. *
** Accelerometer and thruster command data are saved in *
** a user named MATLAB format binary file. *
**
** ----- PROGRAM MODIFICATIONS -----*
** 1.subroutine SAVEMAT added.(9-5-90) *
** *
** 2.excitation command options added.(10-22-90) *
** sinusoid,random,impulse,and cmd data file options *
** *
** 3.modified to allow overlap of excitation and *
** control phases of test. (10-24-90) *
** *
** 4.control law input modified (11-2-90) *
** deleted matrix headers for bc,cc,dc matrices to *
** allow easier controller implemetation. *
** *
** 5.control law input modified (11-9-90) *
** allows definition of controller input-output *
** vectors. *
** *
** 6.control law input modified to read in *
** Thruster scale factors (11-30-90) *
** *
** 7.subroutine state bug corrected (12-11-90) *
** *
** 8.changed CAMAC Write/Read to Read/Write *
** (1-7-91) *
** *
** 9.Added variable SEUSO and modified CPOT to allow *
** PSEUDO CLOSED LOOP TESTS (1-9-91) *
** *
** 10.Added a filtered excitation, control command *
** and sensor input capabilly.(1-31-91) *
** *
** 11.Added check for controller 'D' Matrix - if all *
** elements are 0 then D*y in CL Calc is bypassed *
** (2-8-91) *
** *
** 12.Modified sub...state to assume a tri-diagonal *

```

```

**      "A" Matrix (2-13-91)
**
**      13.Used D Matrix check to re-order control-state
**          calculation to state-control as required (2-26-91)*
**
**      14.Added 3 variables to accel array to save laser
**          detector grid X Y co-ordinates,and sig.pres.
**          (3-13-91)
**
**      15.Allowed actuator command saturation (3-18-91)
**
**      16.Changed filter routines to use double-precision
**          input/output variable type. (3-25-91)
**
**      17.Added routine to calculate sensor RMS level.
**          Flag in sub...sinit determines if RMS values are
**          calculated. If selected, data array accel is re-
**          placed with a time history of sensor RMS values.
**          (4-8-91)
**
**      18.Modified random excitation capability to allow
**          user to initialize random number generator seed -
**          ensures different random sequences for different
**          test runs if different seeds are initialized
**          (4-8-91)
.....

```

```

** This program requires process privileges (altpri,pfnmap,pswapm)

```

```

** define program common blocks **
    include 'camblk5.inc'

```

```

** define time variables **
    INTEGER*4 CUR_TIME1(2),CUR_TIME2(2),TIME_DIFFERENCE(2)
    ..      STATUS,SYS$GETTIM,LIB$GET_INPUT,SYS$BINTIM
    ..      LIB$SUBX,SYS$ASCTIM

```

```

** define local variables
    logical lflag(2)
    real*4   aclim(10),dclim,cmdsat
    double precision acc(11,11000),thcmd(8,11000)
    character name(8)*1
    character fname*20
    integer*4 kktr, maxdat, iover
    integer*4 type,mrows,ncols,imagf,namlen
    integer   rwflag,icount_overruns,iframe_overruns

```

```

** declare ctrlc variables **
    integer statt
    integer*2 input_chan
    integer*4 code
    structure /iostat_block/
        integer*2 iostat
        byte      transmit,

```

```

!         receive,
!         crfill,
!         lfill,
!         parity,
!         zero
end structure
record /iostat_block/ iosb
integer sys$assign, sys$qiw
logical*4 ctrlc_called
external ctrlc_ast
include '($iodef)'

data lflag/.false.,.false./
data aclim,cmdsat/8*700.,2*40.,10./
data kctr,lctr/1,0/
data icount_overruns /0/
data iframe_overruns /0/
ctrlc_called = .false.

** prepare for ctrlc **
  statt = sys$assign('sys$input',input_chan,,)
  if (.not. statt) call lib$signal (%val (statt))
  code = io$_setmode .or. io$m_ctrlcast
  statt = sys$qiw(%val(input_chan),%val(code),iosb,..
!     ctrlc_ast,ctrlc_called,...)
  if (.not. statt) call lib$signal (%val(statt))
  if (.not. iosb.iostat) call lib$signal (%val(iosb.iostat))

** initialize program variables **
  call sinit

** set data counter max value **
  maxdat = int(tsim/dt)

** set command max value for Thruster Command Limit **
  dclim=cmdsat+20.

** calculate sensor biases **
  call sbias

** Move up to realtime priority and lock process into memory
  call rt_lock (iostat)

  type *,'running realtime loop'

** Initialize and start KVV11-C realtime clock
  call wait_clock(dt,iover)

** get start time
  status=sys$gettim(cur_time1)

** enter realtime loop **
  do while ( t .lt. tsim )
    call wait_clock(dt,iover)

```

```

    if (iover.ne. 0) then
      icount_overruns = icount_overruns + 1
      if (iover.eq. 3) iframe_overruns = iframe_overruns + 1
    end if

** read sensor values from CAMAC crate **
    call ADCREAD(adcvolts,%val(11))

** write actuator commands to CAMAC crate
    call DACWRITE(dacvolts,%val(16))

** convert ADC volts to Engineering units, remove bias **
    do j=1,10
      accel(j)=(adcvolts(j)*asfeu(j))-bias(j)

** perform limit checking on sensor outputs **
      if (abs(accel(j)).gt.aclim(j)) then
        lflag(1)=.true.
      end if
    end do
    accel(11)=adcvolts(11)

** filter acceleration data if selected **
    if (infil.eq.1) call filterd(accel,accel,%val(8))

** define users controller input vector **
    do j=1,nsens
      conin(j)=accel(cidef(j))
    end do

** calculate sensor RMS noise levels if selected **
    if (rmsc.eq.1) call rms

** if no controller D matrix, calculate state equation
    if (dflag.eq..false.) call state

** execute excitation or control phase of test **
    if ((t.ge.exon).and.(t.le.exoff)) then
      call excite
    end if

    if (t.gt.exoff) then
      do j=1,8
        xcmd(j)=0.0
      end do
    end if

    if ((t.ge.con).and.(t.le.coff)) then
      call control
      do j=1,8
**      check commands for gross instability **
        if (abs(cmd(j)).gt.dclim) then
          lflag(2)=.true.
        end if
      end do
    end if

```

```

**          set cmd saturation if required **
          if (cmd(j).gt.+cmdsat) cmd(j) = cmdsat
          if (cmd(j).lt.-cmdsat) cmd(j) = -cmdsat
          end do
        end if

          if (t.gt.coff) then
            do j=1,8
              cmd(j)=0.0
            end do
          end if

** limit check closed loop actuator commands **
          do j=1,8
          end do

** exit realtime loop if limits are exceeded **
          if (lflag(1).or.lflag(2)) then
            goto 99
          end if

** define proper controller output vector **
          do j=1,nact
            conout(j)=cmd(codef(j))*seudo
          end do

** assign actuator commands to proper DAC channels **
** allows overlap of excitation and control phase of test **
          dacvolts(1)=conout(1)+xcmd(1)
          dacvolts(2)=conout(1)+xcmd(1)
          dacvolts(3)=conout(2)+xcmd(2)
          dacvolts(4)=conout(2)+xcmd(2)
          dacvolts(5)=conout(7)+xcmd(7)
          dacvolts(6)=conout(7)+xcmd(7)
          dacvolts(7)=conout(8)+xcmd(8)
          dacvolts(8)=conout(8)+xcmd(8)
          dacvolts(9)=conout(3)+xcmd(3)
          dacvolts(10)=conout(3)+xcmd(3)
          dacvolts(11)=conout(4)+xcmd(4)
          dacvolts(12)=conout(4)+xcmd(4)
          dacvolts(13)=conout(5)+xcmd(5)
          dacvolts(14)=conout(5)+xcmd(5)
          dacvolts(15)=conout(6)+xcmd(6)
          dacvolts(16)=conout(6)+xcmd(6)

** if controller has a D Matrix, update controller state equation **
          if (dflag.eq..true.) call state

** fill data arrays **
          do j=1,11
            acc(j,kktr)=accel(j)
          end do

```



```

        do j=1,8
            thcmd(j,kktr)=conout(j)+xcmd(j)
        end do

** increment data array counter **
        kktr = kktr + 1
        if (kktr .gt. 11000) then
            kktr=1
        endif

** increment test time **
        t = t + dt

    end do

99  if (lflag(1)) then
        type *, 'Acceleration Limit Exceeded'
    else if (lflag(2)) then
        type *, 'Thruster Command Limit Exceeded'
    end if

** get ending time **
        status=sys$gettim(cur_time2)

** command zero to all thrusters **
        do j=1,16
            dacvolts(j)=0.
        end do
        call dacwrite(dacvolts,%val(16))

        type *, 'exit realtime loop'
        type *, 'number of clock overruns =', icount_overruns
        type *, 'number of frame overruns =', iframe_overruns
        call rt_unlock(iostat)

** determine delta time
        status=lib$subx(cur_time2,cur_time1,time_difference)
        type *, 'time difference = ', time_difference(1)*1.0E-07

** ensure matlab data file length is correct **
        if (maxdat.gt.11000) maxdat=11000

** set matlab file header variables for accel data **
        type = 2000
        mrows = 11
        ncols = maxdat
        imagf = 0
        namlen = 4

** fill accel file name array **
        name(1) = 's'
        name(2) = 'e'
        name(3) = 'n'
        name(4) = '\0'

```

```

** prompt for matlab data file name **
type *,'Enter matlab data file name: '
read (*,'(a20)') fname
** open binary file for output **
open(unit=1,file=fname,status='new',form='unformatted'
.. recordtype='variable',recordsize=512)

** write acceleration data **
call savemat(type,mrows,ncols,imagf,namlen,name
.. acc,0,1,rwflg)

** set matlab file header variables for thruster data **
type = 2000
mrows = 8
ncols = maxdat
imagf = 0
namlen = 4

** fill thruster file name array **
name(1) = 'a'
name(2) = 'c'
name(3) = 't'
name(4) = '\0'

** write thruster command data **
call savemat(type,mrows,ncols,imagf,namlen,name
.. thcmd,0,1,rwflg)
** set matlab file header variables for dt **
type = 2000
mrows = 1
ncols = 1
imagf = 0
namlen = 3

** fill accel file name array **
name(1) = 'd'
name(2) = 't'
name(3) = '\0'

** write dt data **
call savemat(type,mrows,ncols,imagf,namlen,name
.. dt,0,1,rwflg)

close(unit=1,status='save')

if (rwflg.lt.0) then
write(6,*) 'Error during data write!'
end if

end

```

```

.....
subroutine sinit
*   - initializes all program variables
.....

** define program common blocks **
include 'cambk5.inc'

** define local variables
character fname*20
integer*4 nrec

data pi/3.1415296/
data asfeu,dsfeu,xdsfeu/8*77.2,-2.227,-2.231,1.0,8*1.0,8*1.0/
data tsim,dt,exon,exoff,con,coff,freq,amp/5,..0063,0.,10.
,11.,12.,8*0.,8*0./
data nstate,nact,nsens,seudo/16,8,8,1.0/
data dacvolts/16*0.0/
data adcvolts/11*0.0/
data conin,conout,codef,cidef/16*0.,1,2,3,4,5,6,7,8
,1,2,3,4,5,6,7,8/
data dflag/.false./

** read in test and controller initialization file **
type *,'Enter Name of Initialization File: '
read (*,'(a20)') fname
open(unit=2,file=fname,status='old')

read(2,*) tsim
read(2,*) dt
read(2,*) exon
read(2,*) exoff
read(2,*) xmode
read(2,*) freq(1),freq(2),freq(3),freq(4)
, freq(5),freq(6),freq(7),freq(8)
read(2,*) amp(1),amp(2),amp(3),amp(4)
, amp(5),amp(6),amp(7),amp(8)
read(2,*) con
read(2,*) coff
read(2,*) nstate
read(2,*) nact
read(2,*) nsens
read(2,*) (cidef(j),j=1,8)
read(2,*) (codef(j),j=1,8)
read(2,*) (dsfeu(j),j=1,8)
read(2,*) exfil,confil,infil
read(2,*) rMSC
read(2,*)
read(2,*) ((ac(i,j),i=1,nstate),j=1,nstate)
read(2,*) ((bc(i,j),i=1,nstate),j=1,nsens)
read(2,*) ((cc(i,j),i=1,nact),j=1,nstate)
read(2,*) ((dc(i,j),i=1,nact),j=1,nsens)

close(unit=2, status='save')

```

```

** check if external disturbance file is to be read in **
  if (xmode.eq.4) then
    type *, 'Enter Name of Excitation File: '
    read (*, '(a20)') fname
    open(unit=2, file=fname, status='old')
** read in thruster command data array **
    read(2, *) nrec
    do i=1, nrec
      read(2, *) (readcmd(i, j), j=1, 8)
    end do
    close(unit=2, status='save')
    type *, 'Enter EPOT: '
    read *, epot
  end if

** check if filtered excitation is to be used **
  if (exfil.eq.1) then
    type *, 'Enter Name of Ex Cmd Filter Data File: '
    read (*, '(a20)') fname
    open(unit=2, file=fname, status='old')
    read(2, *) xasize, xbsize
    read(2, *) (xafil(j), j=1, xasize)
    read(2, *) (xbfil(j), j=1, xbsize)
    read(2, *) (xdsfeu(j), j=1, 8)
    close(unit=2, status='save')

** initialize excitation filter routines **
    call sfilter1d(xafil, xbfil, %val(xasize), %val(xbsize))
    call make_noise(xcmd, %val(8))
  end if

** check if filtered control commands are to be used **
  if (confil.eq.1) then
    type *, 'Enter Name of Control Cmd Filter Data File: '
    read (*, '(a20)') fname
    open(unit=2, file=fname, status='old')
    read(2, *) casize, cbsize
    read(2, *) (cafil(j), j=1, casize)
    read(2, *) (cbfil(j), j=1, cbsize)
    close(unit=2, status='save')

** initialize control command filter routines **
    call sfilter2d(cafil, cbfil, %val(casize), %val(cbsize))
  end if

** check if filtered sensor input is to be used **
  if (infil.eq.1) then
    type *, 'Enter Name of Sensor Input Filter Data File: '
    read (*, '(a20)') fname
    open(unit=2, file=fname, status='old')
    read(2, *) iasize, ibsize
    read(2, *) (iafil(j), j=1, iasize)
    read(2, *) (ibfil(j), j=1, ibsize)
  end if

```

```
close(unit=2, status='save')

** initialize sensor filter routines **
    call sfilterd(iafil,ibfil,%val(iasize),%val(ibsizē))
end if

if (xmode.eq.2) then
    type*, 'Enter RANDOM NUMBER SEED - 9 digit, odd Integer: '
    read *, rseed
end if

    type *, 'Input CPOT: '
    read *, cpot
type *, 'Input 0 for PSEUDO CLOSED LOOP'
read *, pseudo
if (pseudo.ne.0.) pseudo = 1.

** check if controller D matrix is nonzero **
    do j=1,nact
        do i=1,nsens
            if(dc(j,i).ne.0.) then
                dflag=.true.
                go to 111
            end if
        end do
    end do
    111 continue

** initialize CAMAC crate memory_mapped I/O **
    call ADCREAD(adcvolts,%val(11))

    return
end
```

```
.....  
  subroutine sbias  
  *      - takes 1000 samples of adc data and calculates  
  *      sensor DC bias values.  
  .....  
  ** define program common blocks **  
    include 'cambk5.inc'  
  
  ** define local variables  
    real*4 sum(10),av  
    data  sum, av /10*0.,1000./  
  
  ** acquire bias data from CAMAC crate channels 1-10 **  
    do j=1,1000  
      call ADCREAD(adcvolts,%val(11))  
      do i=1,10  
        sum(i) = sum(i) + adcvolts(i)*asfeu(i)  
      end do  
    end do  
  
  ** calculate sensor bias in engineering units **  
    write(6,*) 'Sensor Biases are: '  
    do j=1,10  
      bias(j) = sum(j)/av  
      write(6,*) bias(j)  
    end do  
  
    return  
  end
```

```

.....
*
  subroutine excite
*   - calculates thruster excitation commands
.....
*
** define program common blocks **
  include 'cambk5.inc'

** define local variables **
  integer*4 randt(8),cmdindex
  data randt,cmdindex/8*0,1/

  do j = 1,8
    if (xmode.eq.1) then
*****   sinusoidal excitation **
          xcmd(j) = amp(j)*sin(freq(j)*2*pi*t)* xdsfeu(j)

    else if (xmode.eq.2) then
*****   random excitation **
          if(randt(j).eq.0) then
            if (ran(rseed).gt.0.5) then
              xcmd(j)=amp(j)*ran(rseed)*xdsfeu(j)
            else
              xcmd(j)=-amp(j)*ran(rseed)*xdsfeu(j)
            end if
          end if
          randt(j)=randt(j)+1
          if(randt(j).eq.freq(j)) randt(j)=0

    else if (xmode.eq.3) then
*****   impulse excitation **
          if((t.gt.exon).and.(t.lt.exon+freq(j)*dt)) then
            xcmd(j)=amp(j)*xdsfeu(j)
          else
            xcmd(j)=0.0
          end if

    else if (xmode.eq.4) then
*****   data file excitation **
          xcmd(j)=readcmd(cmdindex,j)*epot
        end if
    end do

    if (xmode.eq.4) then
      cmdindex=cmdindex+1
      if(cmdindex.gt.10000) cmdindex=1
    end if

    if (xmode.eq.5) then
      call make_noise(xcmd,%val(8))
    end if

```

```

** filter excitation commands if selected **
  if (exfil.eq.1) then
    do j=1,8
      xcmd(j)=xcmd(j)*xdsfeu(j)
    end do
    call filter1d(xcmd,xcmd,%val(8))
  end if

  return
end
```



```

.....
*
  subroutine control
*       - calculates controller output equation
.....
*
** define program common blocks **
  include 'cambk5.inc'

** define local variables **
  real*4 usum,utemp(8)

** calculate output equation **
  do 10 i=1,nact
    usum=0.
    do j=1,nstate
      usum = usum + cc(i,j)*xs(j)
    end do
    if (dflag) then
      do j=1,nsens
        usum= usum + dc(i,j)*conin(j)
      end do
    end if
    cmd(i)=usum*dsfeu(i)*cpot
  10 continue

** filter control commands if selected **
  if (confil.eq.1) call filter2d(cmd,cmd,%val(8))

  return
end

```

```

.....
*
  subroutine state
*           - updates controller state equation
.....
*
** define program common blocks **
  include 'camlk5.inc'

** define local variables **
  dimension xtemp(54)
  real*4 ssum,xtemp
  integer i,j,l,k
  data xtemp,l,k/54*0.,0,1/

  do i=1,nstate
    k=1
    ssum=0.
    if((i.eq.1).or.(i.eq.nstate)) then
      l=1
    else
      l=2
    end if

    if(i.gt.2) k=i-1

    do j=k,k+l
      ssum=ssum + ac(i,j)*xs(j)
    end do

    do j=1,nsens
      ssum=ssum + bc(i,j)*conin(j)
    end do
    xtemp(i)=ssum

  end do

  do j=1,nstate
    xs(j)=xtemp(j)
  end do

  return
end

```

```
      subroutine rms
.....
** subroutine to calculate root-mean-square (RMS) levels of *
** sensor data.
.....
** include common blocks **
   include 'cambk5.inc'

   do j=1,10
      ysq(j) = ysqo(j) + accel(j)*accel(j)
      if(t.eq.0) yrms(j) = 0.0
      if(t.gt.0) yrms(j) = sqrt(ysq(j)*dt/t)
      ysqo(j)=ysq(j)
      accel(j)=yrms(j)
   end do

   return
end
```

```

      subroutine savemat( type, mrows, ncols, imagf, namlen, name,
                        rpart, ipart, lunit, wtflg )

```

```

c
* SAVEMAT - A Fortran subroutine that writes a double-precision matrix
*   to a data file in the .MAT-file format used by MATLAB.
c
* Description of inputs:
c
* type- matrix type flag; considering the type flag as a
*   decimal integer, the ones decimal place is used to
*   indicate numeri* or textual interpretation of the
*   matrix data (0 for numeri* or 1 for textual);
*   the 1000's decimal place is used to indicate the
*   machine format for the matrix data (0 for Intel 80(2)86
*   based machines, 1 for Motorola 68000 based machines,
*   and 2 for Vax d format). For example, A flag of 1000 indicates
*   numeri* data in a 68000 machine format and a flag of
*   1001 indicates textual interpretation of the 68000
*   machine format data.
* mrows- number of rows in matrix
* ncols- number of columns in matrix
* imagf- imaginary flag; 0 for no imaginary part or 1 if the
*   data has an imaginary part
* namlen - number of characters in matrix name plus 1 (for zero
*   byte string terminator supplied by this routine)
* name- character array holding the matrix name. (Be sure
*   character array has room for the zero byte terminator)
* rpart- real part of matrix (mrows x ncols double precision
*   elements stored column wise)
* ipart      - imaginary part of matrix (only used if imagf = 1)
* lunit - logical unit number of output file
c
* Description of outputs:
c
* wtflg      - write flag; 0 = good write, -1 = error during file write
c
* NOTES :
c
* THE OUTPUT FILE MUST BE OPENED WITH THE FOLLOWING STATEMENT:
*   open(unit=lunit, file='file_name', form='unformatted',
*   recordtype='variable',recordsize=512)
*   (VAX FORTRAN IMPLEMENTATION)
*   Be sure that the 4 byte integer option is used when compiling
*   this routine and that SAVEMAT's integer arguments are 4 byte.
c
* Be sure to close the file when there are no more
* matrices to be saved.
c
* You may call SAVEMAT multiple times to write multiple matrices
* onto the output file before closing it.
c
* Author: S.N. Bangert 5-31-85
* Revised 10-27-88 SNB - Use binary open mode for efficiency

```

- * 20 byte header
 - integer*4 type, mrows, ncols, imagf, namlen
 - integer*4 ircl
- * character string for name (length of name plus one)
 - character name(*)*1
- * double precision data arrays
 - double precision rpart(*),ipart(*)
- * output file logical unit number
 - integer*4 lunit
- * write flag
 - integer*4 wtfll
- * zero byte needed to terminate variable name
 - byte zerobyte
 - data zerobyte /0/
 - data ircl/256/

mn =mrows*ncols
- * write header
 - write(lunit,err=999) type,mrows,ncols,imagf,namlen
- * write variable name
 - write(lunit,err=999) (name(i),i=1,namlen-1),zerobyte
- * write real part of variable
 - do 100 i=1,1+mn/ircl
 - 100 write(lunit,err=999)(rpart(j),j=1+(i-1)*ircl,min(i*ircl,mn))
- * write imaginary part of variable if any
 - if (imagf .eq. 1) then
 - do 101 i=1,1+mn/ircl
 - 101 write(lunit,err=999)(ipart(j),j=1+(i-1)*ircl,min(i*ircl,mn))
 - end if
- * good write
 - wtfll = 0
 - return
- * error during write
 - 999 wtfll = -1
 - return
 - end

Appendix 2

The following listing is a MATLAB .m file used to block diagonalize any real A state matrix and apply the proper transformation to the B, C, and D matrices.

```
% dglzed.m
% [ad,bd,cd,dd]=dglzed(a,b,c,d);
% ad: diagonalized a matrix
% bd: transformed b matrix
% cd: transformed c matrix
% dd: same as d matrix
% m-file to diagonalize the A matrix using its eigenvectors
% John Won (Jan 11, 1991)

function [ad,bd,cd,dd]=dglzed(a,b,c,d);
[v,e]=eig(a);
[na,nb]=size(b);
[nc,na]=size(c);
% generate the transformation matrix using eigenvectors
p=[];
i=1;
while i<na+1
    if imag(e(i,i))==0
        p=[p v(:,i)];
        i=i+1;
    else
        p=[p real(v(:,i)) imag(v(:,i))];
        i=i+2;
    end
end
% calculate the transformed matrices
a=p\ a * p;
b=p\ b;
c=c * p;
dd=d;
% set those small numbers due to computational errors to be zero
for i=1:na
    for j=1:na
        if abs(a(i,j))<1e-7*abs(max(max(a)))
            ad(i,j)=0.;
        else
            ad(i,j)=a(i,j);
        end
    end
end
for i=1:na
    for j=1:nb
        if abs(b(i,j))<1e-7*abs(max(max(b)))
            bd(i,j)=0.;
        else
            bd(i,j)=b(i,j);
        end
    end
end
end
```

```
for i=1:nc
  for j=1:na
    if abs(c(i,j))<1e-7*abs(max(max(c)))
      cd(i,j)=0.;
    else
      cd(i,j)=c(i,j);
    end
  end
end
end
```


125	0.98715322E+00
126	-.31413788E-01
155	0.31413788E-01
156	0.98715322E+00
187	0.98923526E+00
188	-.21853272E-01
217	0.21853272E-01
218	0.98923526E+00
249	0.99689982E+00
250	-.18695146E-01
279	0.18695146E-01
280	0.99689982E+00
311	0.99184704E+00
312	-.17307025E-01
341	0.17307025E-01
342	0.99184704E+00
373	0.98765766E+00
404	0.99509188E+00
405	-.29318861E-02
434	0.29318861E-02
435	0.99509188E+00
466	0.99537492E+00
497	0.99420862E+00
498	-.22659056E-02
527	0.22659056E-02
528	0.99420862E+00
559	0.99869319E+00
560	-.10980900E-02
589	0.10980900E-02
590	0.99869319E+00
621	0.93575759E+00
622	-.20621209E+00
651	0.20621209E+00
652	0.93575759E+00
683	0.99869173E+00
684	-.11009920E-02
713	0.11009920E-02
714	0.99869173E+00
745	0.97014265E+00
746	-.16250496E+00
775	0.16250496E+00
776	0.97014265E+00
807	0.97376230E+00
808	-.14982719E+00
837	0.14982719E+00
838	0.97376230E+00
869	0.95188594E+00
870	-.15897032E+00
899	0.15897032E+00
900	0.95188594E+00
901	0.23909748E-04
902	-.64514548E-04
903	-.23520259E-02
904	0.33458147E-03

905 0.59852881E-03
906 0.83510845E-03
907 -.12372106E-03
908 -.31926164E-03
909 -.96818566E-07
910 -.19414582E-06
911 -.74121230E-07
912 -.99156106E-06
913 0.46307624E-03
914 0.62749902E-06
915 -.11736572E-05
916 -.28290493E-03
917 -.24077622E-04
918 -.74118203E-04
919 -.12106044E-01
920 -.10172477E-01
921 -.11849189E-02
922 -.38034779E-02
931 0.17280795E-02
932 0.10899879E-02
933 -.10442158E-04
934 -.57256078E-04
935 -.66804856E-05
936 -.13543692E-05
937 0.79824189E-06
938 -.36626275E-05
939 -.10062389E-04
940 -.14877032E-03
941 -.58407091E-03
942 -.58548473E-03
943 -.21116195E-05
944 -.21077266E-03
945 0.65028026E-04
946 0.16426758E-05
947 0.25894494E-05
948 0.50003656E-05
961 -.22286955E-04
962 0.57261323E-04
963 0.20741116E-02
964 -.73096503E-04
965 0.26055172E-03
966 -.13428863E-02
967 -.38114179E-03
968 0.76137961E-03
969 0.72422299E-06
970 0.42855229E-06
971 -.99624683E-06
972 0.73226292E-06
973 -.38771273E-03
974 0.25521331E-05
975 -.32617665E-05
976 0.87589286E-04
977 0.78052749E-04
978 0.13490239E-03

991	-.13420334E-02
992	-.97548420E-03
993	-.33787635E-06
994	0.45504146E-04
995	-.45152961E-05
996	0.14132813E-04
997	0.21602526E-05
998	-.81400993E-05
999	0.16226765E-03
1000	0.55590120E-03
1001	-.49872907E-03
1002	-.15038685E-04
1003	0.44374412E-05
1004	0.17689155E-03
1005	-.67085834E-04
1006	-.21188083E-05
1007	-.25179103E-05
1008	-.42827831E-05
1021	-.44183560E-03
1022	-.36386893E-03
1023	0.44033432E-05
1024	0.17184236E-04
1025	0.47391995E-05
1026	-.97774849E-06
1027	-.17621222E-05
1028	-.12298005E-05
1029	-.10576891E-03
1030	-.89805095E-04
1031	-.98590134E-04
1032	0.26950929E-04
1033	-.25782892E-05
1034	-.99616104E-04
1035	0.16147844E-03
1036	0.36973113E-05
1037	0.57321001E-05
1038	0.63722327E-05
1051	0.80718864E-05
1052	-.30340176E-04
1053	-.10358657E-02
1054	0.18541594E-03
1055	0.63425102E-03
1056	0.48099323E-03
1057	-.10896115E-03
1058	-.67062336E-03
1059	-.48025549E-06
1060	-.57747328E-07
1061	0.57091390E-06
1062	-.50208696E-06
1063	0.19860234E-03
1064	-.45984916E-05
1065	0.22942993E-05
1066	-.47934647E-04
1067	0.15272060E-03
1068	0.33191105E-03

1073	-.12069733E-01
1074	-.10157454E-01
1081	0.12320715E-02
1082	0.86099671E-03
1083	-.34623445E-04
1084	-.42957706E-04
1085	-.14596123E-04
1086	0.15132423E-04
1087	0.86379208E-05
1088	-.41545908E-05
1089	0.49482371E-05
1090	-.16687729E-03
1091	0.31566879E-04
1092	-.19017897E-03
1093	0.13849452E-05
1094	-.23610125E-03
1095	0.20358335E-03
1096	0.28149213E-05
1097	0.72279906E-05
1098	0.85132466E-05
1105	-.71981075E-03
1106	-.39177234E-02
1111	0.19353906E-04
1112	0.31222167E-05
1113	-.20569836E-03
1114	-.69848445E-03
1115	-.24732378E-02
1116	0.24467173E-02
1117	0.15720343E-02
1118	-.22275889E-02
1119	-.28816313E-06
1120	-.38051334E-06
1121	0.62821991E-05
1122	-.21054555E-05
1123	0.79939384E-03
1124	0.48264626E-06
1125	-.87784933E-06
1126	-.33590348E-03
1127	0.10885428E-04
1128	0.21366941E-03
1137	-.68768279E-03
1138	-.39269294E-02
1139	0.11633537E-02
1140	0.38437558E-02
1141	-.82173037E-01
1142	-.31380240E+01
1143	0.66787115E-01
1144	0.20489595E+01
1145	0.34882944E+00
1146	-.30914394E-01
1147	-.22465157E+01
1148	-.28199633E-01
1149	-.12822016E+00
1150	0.32021346E+01

1151	0.92591549E-01
1152	-.25636403E+01
1153	-.77600724E+00
1154	-.51202240E-01
1155	0.26038833E+01
1156	-.25734716E-02
1157	-.38286884E+00
1158	-.11434865E+00
1159	0.75782533E+00
1160	0.79823423E-01
1161	0.23719125E-01
1162	-.15848396E+00
1163	-.10179310E+00
1164	-.94310560E+00
1165	-.50867170E+01
1166	0.72006491E-04
1167	0.37633278E+01
1168	-.20844634E-01
1169	-.59649606E-02
1170	-.19698037E+01
1171	-.50401358E-01
1172	-.55609354E+00
1173	0.14204198E+01
1174	-.29601690E-03
1175	-.83403560E+00
1176	0.63932910E-02
1177	0.28261051E-02
1178	0.90931529E+00
1179	0.46862568E-02
1180	0.10030160E+01
1181	-.32828227E-01
1182	-.10034983E-01
1183	0.98703382E+00
1184	-.93646288E-02
1185	0.51727440E-02
1186	0.23111661E+00
1187	-.25626603E-01
1188	-.39866813E+01
1189	0.38427992E+00
1190	0.15818597E-01
1191	-.13532663E+01
1192	0.12588490E-01
1193	0.19672071E-02
1194	0.10575586E+01
1195	0.14664549E-01
1196	0.55502252E+01
1197	0.86513605E+00
1198	0.22299080E-02
1199	0.26523486E+00
1200	0.61747691E-02
1201	0.46859137E-02
1202	0.57667165E+00
1203	-.11061650E-01
1204	-.70926912E+00

1205	-.38488499E-03
1206	0.13024206E+01
1207	-.29709241E-02
1208	-.38006608E+01
1209	0.64198247E+00
1210	0.15524827E-02
1211	0.11061614E+01
1212	0.41212593E-02
1213	0.11025826E-02
1214	-.10125766E+01
1215	-.13183185E-02
1216	0.27259148E+01
1217	-.18423635E+00
1218	0.14507310E-02
1219	-.96837763E+00
1220	0.19084599E-02
1221	0.75938968E-04
1222	0.16484819E+01
1223	0.52176366E-02
1224	0.19463004E+01
1225	0.40964885E+00
1226	-.33280952E-02
1227	-.26599380E+00
1228	-.28648441E-01
1229	-.53661944E-02
1230	-.51859153E+01
1231	-.39051489E-02
1232	-.20219078E+01
1233	-.27035449E+00
1234	-.31531957E-04
1235	-.90003364E+00
1236	0.50621383E-02
1237	0.50474129E+01
1238	0.39845482E-03
1239	0.11411894E+01
1240	0.44082460E-02
1241	-.12115654E-01
1242	-.47197900E+00
1243	-.33886100E-02
1244	0.44610183E+01
1245	-.12835978E-01
1246	-.13755215E+00
1247	0.14123845E-01
1248	0.97420232E-01
1249	-.33958797E+01
1250	0.31184362E-01
1251	-.34760949E+01
1252	-.33828923E-02
1253	-.23238285E-01
1254	0.45849946E-01
1255	0.20773977E-01
1256	-.59649401E-02
1257	-.11358343E+01
1258	0.57203192E-01

1259	-.11153571E+01
1260	-.54144333E-02
1261	0.23749479E+01
1262	-.10684896E-02
1263	0.74278088E+00
1264	0.12248499E-02
1265	-.21764995E-01
1266	-.28888933E+00
1267	-.20058760E-01
1268	0.17955612E+01
1269	0.33944149E+00
1270	-.14949679E-02
1271	-.15932586E+01
1272	0.18478699E-02
1273	-.47447428E-01
1274	-.32297996E+01
1275	-.48257914E-01
1276	-.44290023E+00
1277	-.26858302E+00
1278	0.10694463E-02
1279	0.13534899E+01
1280	-.98659569E-03
1281	0.95072699E-02
1282	0.27408600E+01
1283	0.99347701E-02
1284	0.46379287E+00
1285	0.64768293E-01
1293	0.76993379E-01
1301	0.21686687E+01
1309	0.42681722E+00
1322	0.84546160E-01
1330	0.10035082E+00
1339	0.17421364E+00
1347	0.17295027E-01
1356	0.27470720E+00
1364	0.26790892E-01
1372	-.63277845E+00
1380	0.79977669E-02

Appendix 4

The following data is the NASTRAN runstream for the CEM model used to compute the mass matrix and the stiffness matrix including differential stiffness due to gravity preload. This data runs under MSC Version 65, Rigid Format 64.

```

NASTRAN FILES=(DB01)
ID PHASE ZERO, CSI EVOLUTIONARY FEM
APP DISPLACEMENT
SOL 64
TIME 120
CEND
TITLE = PHASE-ZERO GROUND TEST BEAM, PZ0117 (1991)
SUBTITLE = TRUSS W/REFLECTOR AND 16 THRUSTERS
ECHO = UNSORT
LINE = 39
SPC = 100
TEMP(LOAD)=13
LOAD=262
SUBCASE 1
  LABEL=SPCF, GRAVITY AND TEMP LOAD
  PARAM NOMECH +1
  DISPLACEMENT=ALL
SUBCASE 2
  LABEL=K + DIFFERENTIAL K
  PARAM NOMECH -1
SUBCASE 3
  LABEL=DIFFERENTIAL K
SUBCASE 4
SUBCASE 5
SUBCASE 6
SUBCASE 7
  LABEL=FINAL ITERATION
  DISPL=ALL
  ELFORCE=ALL
  SPCFORCE=ALL
$ adjusted rfl rib density
$ RECALCULATED RIB A,I,J'S 90/11/19
$ DETERMINED NEW SPCF FOR REFLECTOR
$ renumbered cable brace elements consecutively
$ ADDED GRID PTS TO CENTER OF THRUSTER PLATES (16) AND LASER PLATE
$ DIVIDED PLATES INTO 4 TRIA3 PLATED
$ MOVED THRUSTER AND LASER MASS TO CENTER OF PLATES
$ UPDATED SENSOR WTS PROVIDED BY B.WILLIAMS 90/11/28
$ ADDED CABLE WEIGHTS 90/11/30
$ corrected cquad numbering for controller plates 90/12/03
$ corrected thruster air hose weight 90/12/03
$ changed strut properties to ken elliott's 91/01/03
$ changed to Mercedes Reaves reflector properties 91/01/09
$ determined new spc forces 91/01/10
$ added grid points 1001 t 1008 to form cube around fem 91/01/11
$ changed cbar 2089 t 2096 (connects between ribs & sensor plate)
$ to rods 91/01/17

```

```

BEGIN BULK
CORD2C      3      0 615.00 0.00000 56.110 590.22 0.00000 86.707+CS  3
+CS  3 645.60 0.00000 80.885
PARAM GRDPNT 0
PARAM COUPMASS1
PARAM KDIAG .15
PARAM MAXRATIO5.E+06
PARAM K6ROT 10.
SPC1  100  1245  396  480
SPC1  100  12456 481  482
SPC1  100  123456 395  479
SPC1  100  123456 1001 thru 1008
GRAV,200,0,386.,0.,0.,-1.
TEMPD,13,235.8
LOAD,262,1.,1.,62,1.,200
ECHOFF
force 62, 2001, 0, 3.5009,1.,0.,0.
force 62, 2001, 0, 0.5305,0.,1.,0.
force 62, 2001, 0, -2.2877,0.,0.,1.
force 62, 2002, 0, -1.0860,1.,0.,0.
force 62, 2002, 0, -0.6446,0.,1.,0.
force 62, 2002, 0, -1.1317,0.,0.,1.
force 62, 2003, 0, -1.1865,1.,0.,0.
force 62, 2003, 0, -0.6451,0.,1.,0.
force 62, 2003, 0, -1.0095,0.,0.,1.
force 62, 2004, 0, -1.0131,1.,0.,0.
force 62, 2004, 0, -0.1343,0.,1.,0.
force 62, 2004, 0, 0.7357,0.,0.,1.
force 62, 2005, 0, -1.6777,1.,0.,0.
force 62, 2005, 0, -0.6882,0.,1.,0.
force 62, 2005, 0, -0.5685,0.,0.,1.
force 62, 2006, 0, -1.3300,1.,0.,0.
force 62, 2006, 0, -0.3566,0.,1.,0.
force 62, 2006, 0, 0.2745,0.,0.,1.
force 62, 2008, 0, -0.6323,1.,0.,0.
force 62, 2008, 0, -0.0285,0.,1.,0.
force 62, 2008, 0, 0.6714,0.,0.,1.
force 62, 2009, 0, -0.5496,1.,0.,0.
force 62, 2009, 0, -0.0095,0.,1.,0.
force 62, 2009, 0, 0.6421,0.,0.,1.
force 62, 2010, 0, -0.0524,1.,0.,0.
force 62, 2010, 0, -0.0001,0.,1.,0.
force 62, 2010, 0, 0.0644,0.,0.,1.
force 62, 2011, 0, 12.3415,1.,0.,0.
force 62, 2011, 0, 6.5783,0.,1.,0.
force 62, 2011, 0, 9.9952,0.,0.,1.
force 62, 2014, 0, 2.9179,1.,0.,0.
force 62, 2014, 0, 1.2808,0.,1.,0.
force 62, 2014, 0, -2.7598,0.,0.,1.
force 62, 2015, 0, -0.3776,1.,0.,0.
force 62, 2015, 0, -1.5562,0.,1.,0.
force 62, 2015, 0, -0.5580,0.,0.,1.
force 62, 2016, 0, -0.4776,1.,0.,0.
force 62, 2016, 0, -1.5574,0.,1.,0.

```

force 62,	2016,	0,	-0.4353,0.,0.,1.
force 62,	2017,	0,	-0.8656,1.,0.,0.
force 62,	2017,	0,	-0.3243,0.,1.,0.
force 62,	2017,	0,	0.8554,0.,0.,1.
force 62,	2018,	0,	-0.9213,1.,0.,0.
force 62,	2018,	0,	-1.6615,0.,1.,0.
force 62,	2018,	0,	0.0440,0.,0.,1.
force 62,	2019,	0,	-0.9382,1.,0.,0.
force 62,	2019,	0,	-0.8609,0.,1.,0.
force 62,	2019,	0,	0.5918,0.,0.,1.
force 62,	2021,	0,	-0.6011,1.,0.,0.
force 62,	2021,	0,	-0.0688,0.,1.,0.
force 62,	2021,	0,	0.6968,0.,0.,1.
force 62,	2022,	0,	-0.5390,1.,0.,0.
force 62,	2022,	0,	-0.0230,0.,1.,0.
force 62,	2022,	0,	0.6505,0.,0.,1.
force 62,	2023,	0,	-0.0524,1.,0.,0.
force 62,	2023,	0,	-0.0002,0.,1.,0.
force 62,	2023,	0,	0.0645,0.,0.,1.
force 62,	2024,	0,	5.1120,1.,0.,0.
force 62,	2024,	0,	15.8813,0.,1.,0.
force 62,	2024,	0,	4.1401,0.,0.,1.
force 62,	2027,	0,	2.0933,1.,0.,0.
force 62,	2027,	0,	1.2808,0.,1.,0.
force 62,	2027,	0,	-3.4276,0.,0.,1.
force 62,	2028,	0,	0.6243,1.,0.,0.
force 62,	2028,	0,	-1.5562,0.,1.,0.
force 62,	2028,	0,	0.2533,0.,0.,1.
force 62,	2029,	0,	0.5250,1.,0.,0.
force 62,	2029,	0,	-1.5574,0.,1.,0.
force 62,	2029,	0,	0.3767,0.,0.,1.
force 62,	2030,	0,	-0.6567,1.,0.,0.
force 62,	2030,	0,	-0.3242,0.,1.,0.
force 62,	2030,	0,	1.0244,0.,0.,1.
force 62,	2031,	0,	0.1484,1.,0.,0.
force 62,	2031,	0,	-1.6615,0.,1.,0.
force 62,	2031,	0,	0.9103,0.,0.,1.
force 62,	2032,	0,	-0.3840,1.,0.,0.
force 62,	2032,	0,	-0.8609,0.,1.,0.
force 62,	2032,	0,	1.0407,0.,0.,1.
force 62,	2034,	0,	-0.5567,1.,0.,0.
force 62,	2034,	0,	-0.0689,0.,1.,0.
force 62,	2034,	0,	0.7327,0.,0.,1.
force 62,	2035,	0,	-0.5242,1.,0.,0.
force 62,	2035,	0,	-0.0229,0.,1.,0.
force 62,	2035,	0,	0.6624,0.,0.,1.
force 62,	2036,	0,	-0.0523,1.,0.,0.
force 62,	2036,	0,	-0.0002,0.,1.,0.
force 62,	2036,	0,	0.0646,0.,0.,1.
force 62,	2037,	0,	-5.1120,1.,0.,0.
force 62,	2037,	0,	15.8813,0.,1.,0.
force 62,	2037,	0,	-4.1401,0.,0.,1.
force 62,	2040,	0,	1.5103,1.,0.,0.
force 62,	2040,	0,	0.5305,0.,1.,0.

force 62,	2040,	0,	-3.8998,0.,0.,1.
force 62,	2041,	0,	1.3327,1.,0.,0.
force 62,	2041,	0,	-0.6446,0.,1.,0.
force 62,	2041,	0,	0.8270,0.,0.,1.
force 62,	2042,	0,	1.2340,1.,0.,0.
force 62,	2042,	0,	-0.6451,0.,1.,0.
force 62,	2042,	0,	0.9510,0.,0.,1.
force 62,	2043,	0,	-0.5092,1.,0.,0.
force 62,	2043,	0,	-0.1344,0.,1.,0.
force 62,	2043,	0,	1.1440,0.,0.,1.
force 62,	2044,	0,	0.9048,1.,0.,0.
force 62,	2044,	0,	-0.6882,0.,1.,0.
force 62,	2044,	0,	1.5228,0.,0.,1.
force 62,	2045,	0,	0.0079,1.,0.,0.
force 62,	2045,	0,	-0.3566,0.,1.,0.
force 62,	2045,	0,	1.3581,0.,0.,1.
force 62,	2047,	0,	-0.5254,1.,0.,0.
force 62,	2047,	0,	-0.0285,0.,1.,0.
force 62,	2047,	0,	0.7581,0.,0.,1.
force 62,	2048,	0,	-0.5138,1.,0.,0.
force 62,	2048,	0,	-0.0095,0.,1.,0.
force 62,	2048,	0,	0.6709,0.,0.,1.
force 62,	2049,	0,	-0.0521,1.,0.,0.
force 62,	2049,	0,	-0.0001,0.,1.,0.
force 62,	2049,	0,	0.0647,0.,0.,1.
force 62,	2050,	0,	-12.3415,1.,0.,0.
force 62,	2050,	0,	6.5783,0.,1.,0.
force 62,	2050,	0,	-9.9952,0.,0.,1.
force 62,	2053,	0,	1.5103,1.,0.,0.
force 62,	2053,	0,	-0.5305,0.,1.,0.
force 62,	2053,	0,	-3.8998,0.,0.,1.
force 62,	2054,	0,	1.3327,1.,0.,0.
force 62,	2054,	0,	0.6446,0.,1.,0.
force 62,	2054,	0,	0.8270,0.,0.,1.
force 62,	2055,	0,	1.2340,1.,0.,0.
force 62,	2055,	0,	0.6451,0.,1.,0.
force 62,	2055,	0,	0.9510,0.,0.,1.
force 62,	2056,	0,	-0.5092,1.,0.,0.
force 62,	2056,	0,	0.1344,0.,1.,0.
force 62,	2056,	0,	1.1440,0.,0.,1.
force 62,	2057,	0,	0.9048,1.,0.,0.
force 62,	2057,	0,	0.6882,0.,1.,0.
force 62,	2057,	0,	1.5228,0.,0.,1.
force 62,	2058,	0,	0.0079,1.,0.,0.
force 62,	2058,	0,	0.3566,0.,1.,0.
force 62,	2058,	0,	1.3581,0.,0.,1.
force 62,	2060,	0,	-0.5254,1.,0.,0.
force 62,	2060,	0,	0.0285,0.,1.,0.
force 62,	2060,	0,	0.7581,0.,0.,1.
force 62,	2061,	0,	-0.5138,1.,0.,0.
force 62,	2061,	0,	0.0095,0.,1.,0.
force 62,	2061,	0,	0.6709,0.,0.,1.
force 62,	2062,	0,	-0.0521,1.,0.,0.
force 62,	2062,	0,	0.0001,0.,1.,0.

force 62,	2062,	0,	0.0647,0.,0.,1.
force 62,	2063,	0,	-12.3415,1.,0.,0.
force 62,	2063,	0,	-6.5783,0.,1.,0.
force 62,	2063,	0,	-9.9952,0.,0.,1.
force 62,	2066,	0,	2.0933,1.,0.,0.
force 62,	2066,	0,	-1.2808,0.,1.,0.
force 62,	2066,	0,	-3.4276,0.,0.,1.
force 62,	2067,	0,	0.6243,1.,0.,0.
force 62,	2067,	0,	1.5562,0.,1.,0.
force 62,	2067,	0,	0.2533,0.,0.,1.
force 62,	2068,	0,	0.5250,1.,0.,0.
force 62,	2068,	0,	1.5574,0.,1.,0.
force 62,	2068,	0,	0.3767,0.,0.,1.
force 62,	2069,	0,	-0.6567,1.,0.,0.
force 62,	2069,	0,	0.3242,0.,1.,0.
force 62,	2069,	0,	1.0244,0.,0.,1.
force 62,	2070,	0,	0.1484,1.,0.,0.
force 62,	2070,	0,	1.6615,0.,1.,0.
force 62,	2070,	0,	0.9103,0.,0.,1.
force 62,	2071,	0,	-0.3840,1.,0.,0.
force 62,	2071,	0,	0.8609,0.,1.,0.
force 62,	2071,	0,	1.0407,0.,0.,1.
force 62,	2073,	0,	-0.5567,1.,0.,0.
force 62,	2073,	0,	0.0689,0.,1.,0.
force 62,	2073,	0,	0.7327,0.,0.,1.
force 62,	2074,	0,	-0.5242,1.,0.,0.
force 62,	2074,	0,	0.0229,0.,1.,0.
force 62,	2074,	0,	0.6625,0.,0.,1.
force 62,	2075,	0,	-0.0523,1.,0.,0.
force 62,	2075,	0,	0.0002,0.,1.,0.
force 62,	2075,	0,	0.0646,0.,0.,1.
force 62,	2076,	0,	-5.1120,1.,0.,0.
force 62,	2076,	0,	-15.8813,0.,1.,0.
force 62,	2076,	0,	-4.1401,0.,0.,1.
force 62,	2079,	0,	2.9178,1.,0.,0.
force 62,	2079,	0,	-1.2808,0.,1.,0.
force 62,	2079,	0,	-2.7598,0.,0.,1.
force 62,	2080,	0,	-0.3775,1.,0.,0.
force 62,	2080,	0,	1.5562,0.,1.,0.
force 62,	2080,	0,	-0.5580,0.,0.,1.
force 62,	2081,	0,	-0.4776,1.,0.,0.
force 62,	2081,	0,	1.5574,0.,1.,0.
force 62,	2081,	0,	-0.4353,0.,0.,1.
force 62,	2082,	0,	-0.8656,1.,0.,0.
force 62,	2082,	0,	0.3243,0.,1.,0.
force 62,	2082,	0,	0.8553,0.,0.,1.
force 62,	2083,	0,	-0.9213,1.,0.,0.
force 62,	2083,	0,	1.6615,0.,1.,0.
force 62,	2083,	0,	0.0440,0.,0.,1.
force 62,	2084,	0,	-0.9382,1.,0.,0.
force 62,	2084,	0,	0.8609,0.,1.,0.
force 62,	2084,	0,	0.5919,0.,0.,1.
force 62,	2086,	0,	-0.6011,1.,0.,0.
force 62,	2086,	0,	0.0688,0.,1.,0.

force 62,	2086,	0,	0.6968,0.,0.,1.
force 62,	2087,	0,	-0.5390,1.,0.,0.
force 62,	2087,	0,	0.0230,0.,1.,0.
force 62,	2087,	0,	0.6505,0.,0.,1.
force 62,	2088,	0,	-0.0524,1.,0.,0.
force 62,	2088,	0,	0.0002,0.,1.,0.
force 62,	2088,	0,	0.0645,0.,0.,1.
force 62,	2089,	0,	5.1120,1.,0.,0.
force 62,	2089,	0,	-15.8813,0.,1.,0.
force 62,	2089,	0,	4.1401,0.,0.,1.
force 62,	2092,	0,	3.5009,1.,0.,0.
force 62,	2092,	0,	-0.5305,0.,1.,0.
force 62,	2092,	0,	-2.2876,0.,0.,1.
force 62,	2093,	0,	-1.0860,1.,0.,0.
force 62,	2093,	0,	0.6446,0.,1.,0.
force 62,	2093,	0,	-1.1317,0.,0.,1.
force 62,	2094,	0,	-1.1865,1.,0.,0.
force 62,	2094,	0,	0.6451,0.,1.,0.
force 62,	2094,	0,	-1.0095,0.,0.,1.
force 62,	2095,	0,	-1.0131,1.,0.,0.
force 62,	2095,	0,	0.1343,0.,1.,0.
force 62,	2095,	0,	0.7357,0.,0.,1.
force 62,	2096,	0,	-1.6777,1.,0.,0.
force 62,	2096,	0,	0.6882,0.,1.,0.
force 62,	2096,	0,	-0.5685,0.,0.,1.
force 62,	2097,	0,	-1.3300,1.,0.,0.
force 62,	2097,	0,	0.3566,0.,1.,0.
force 62,	2097,	0,	0.2745,0.,0.,1.
force 62,	2099,	0,	-0.6323,1.,0.,0.
force 62,	2099,	0,	0.0285,0.,1.,0.
force 62,	2099,	0,	0.6714,0.,0.,1.
force 62,	2100,	0,	-0.5496,1.,0.,0.
force 62,	2100,	0,	0.0095,0.,1.,0.
force 62,	2100,	0,	0.6421,0.,0.,1.
force 62,	2101,	0,	-0.0524,1.,0.,0.
force 62,	2101,	0,	0.0001,0.,1.,0.
force 62,	2101,	0,	0.0644,0.,0.,1.
force 62,	2102,	0,	12.3415,1.,0.,0.
force 62,	2102,	0,	-6.5783,0.,1.,0.
force 62,	2102,	0,	9.9952,0.,0.,1.
force 62,	2123,	0,	-0.7568,1.,0.,0.
force 62,	2123,	0,	-0.5733,0.,1.,0.
force 62,	2123,	0,	-1.2648,0.,0.,1.
force 62,	2124,	0,	-0.1266,1.,0.,0.
force 62,	2124,	0,	-1.3841,0.,1.,0.
force 62,	2124,	0,	-0.7545,0.,0.,1.
force 62,	2125,	0,	0.7643,1.,0.,0.
force 62,	2125,	0,	-1.3841,0.,1.,0.
force 62,	2125,	0,	-0.0329,0.,0.,1.
force 62,	2126,	0,	1.3945,1.,0.,0.
force 62,	2126,	0,	-0.5733,0.,1.,0.
force 62,	2126,	0,	0.4773,0.,0.,1.
force 62,	2127,	0,	1.3945,1.,0.,0.
force 62,	2127,	0,	0.5733,0.,1.,0.

force 62, 2127, 0, 0.4773,0.,0.,1.
 force 62, 2128, 0, 0.7643,1.,0.,0.
 force 62, 2128, 0, 1.3841,0.,1.,0.
 force 62, 2128, 0, -0.0329,0.,0.,1.
 force 62, 2129, 0, -0.1266,1.,0.,0.
 force 62, 2129, 0, 1.3841,0.,1.,0.
 force 62, 2129, 0, -0.7545,0.,0.,1.
 force 62, 2130, 0, -0.7568,1.,0.,0.
 force 62, 2130, 0, 0.5733,0.,1.,0.
 force 62, 2130, 0, -1.2648,0.,0.,1.

\$ ADDED ADDITIONAL 8 GRID PTS ON EACH RIB AT R=64.2" 9/14/90

GRID, 1, 0, 0.0000, 5.0000, 5.0000
 GRID, 2, 0, 0.0000, -5.0000, 5.0000
 GRID, 3, 0, 0.0000, -5.0000, -5.0000
 GRID, 4, 0, 0.0000, 5.0000, -5.0000
 GRID, 5, 0, 10.0000, 5.0000, 5.0000
 GRID, 6, 0, 10.0000, -5.0000, 5.0000
 GRID, 7, 0, 10.0000, -5.0000, -5.0000
 GRID, 8, 0, 10.0000, 5.0000, -5.0000
 GRID, 9, 0, 20.0000, 5.0000, 5.0000
 GRID, 10, 0, 20.0000, -5.0000, 5.0000
 GRID, 11, 0, 20.0000, -5.0000, -5.0000
 GRID, 12, 0, 20.0000, 5.0000, -5.0000
 GRID, 13, 0, 30.0000, 5.0000, 5.0000
 GRID, 14, 0, 30.0000, -5.0000, 5.0000
 GRID, 15, 0, 30.0000, -5.0000, -5.0000
 GRID, 16, 0, 30.0000, 5.0000, -5.0000
 GRID, 17, 0, 40.0000, 5.0000, 5.0000
 GRID, 18, 0, 40.0000, -5.0000, 5.0000
 GRID, 19, 0, 40.0000, -5.0000, -5.0000
 GRID, 20, 0, 40.0000, 5.0000, -5.0000
 GRID, 21, 0, 50.0000, 5.0000, 5.0000
 GRID, 22, 0, 50.0000, -5.0000, 5.0000
 GRID, 23, 0, 50.0000, -5.0000, -5.0000
 GRID, 24, 0, 50.0000, 5.0000, -5.0000
 GRID, 25, 0, 60.0000, 5.0000, 5.0000
 GRID, 26, 0, 60.0000, -5.0000, 5.0000
 GRID, 27, 0, 60.0000, -5.0000, -5.0000
 GRID, 28, 0, 60.0000, 5.0000, -5.0000
 GRID, 29, 0, 70.0000, 5.0000, 5.0000
 GRID, 30, 0, 70.0000, -5.0000, 5.0000
 GRID, 31, 0, 70.0000, -5.0000, -5.0000
 GRID, 32, 0, 70.0000, 5.0000, -5.0000
 GRID, 33, 0, 80.0000, 5.0000, 5.0000
 GRID, 34, 0, 80.0000, -5.0000, 5.0000
 GRID, 35, 0, 80.0000, -5.0000, -5.0000
 GRID, 36, 0, 80.0000, 5.0000, -5.0000
 GRID, 37, 0, 90.0000, 5.0000, 5.0000
 GRID, 38, 0, 90.0000, -5.0000, 5.0000
 GRID, 39, 0, 90.0000, -5.0000, -5.0000
 GRID, 40, 0, 90.0000, 5.0000, -5.0000
 GRID, 41, 0,100.0000, 5.0000, 5.0000
 GRID, 42, 0,100.0000, -5.0000, 5.0000
 GRID, 43, 0,100.0000, -5.0000, -5.0000

GRID,	44,	0,100.0000,	5.0000,	-5.0000
GRID,	45,	0,110.0000,	5.0000,	5.0000
GRID,	46,	0,110.0000,	-5.0000,	5.0000
GRID,	47,	0,110.0000,	-5.0000,	-5.0000
GRID,	48,	0,110.0000,	5.0000,	-5.0000
GRID,	49,	0,120.0000,	5.0000,	5.0000
GRID,	50,	0,120.0000,	-5.0000,	5.0000
GRID,	51,	0,120.0000,	-5.0000,	-5.0000
GRID,	52,	0,120.0000,	5.0000,	-5.0000
GRID,	53,	0,130.0000,	5.0000,	5.0000
GRID,	54,	0,130.0000,	-5.0000,	5.0000
GRID,	55,	0,130.0000,	-5.0000,	-5.0000
GRID,	56,	0,130.0000,	5.0000,	-5.0000
GRID,	57,	0,140.0000,	5.0000,	5.0000
GRID,	58,	0,140.0000,	-5.0000,	5.0000
GRID,	59,	0,140.0000,	-5.0000,	-5.0000
GRID,	60,	0,140.0000,	5.0000,	-5.0000
GRID,	61,	0,150.0000,	5.0000,	5.0000
GRID,	62,	0,150.0000,	-5.0000,	5.0000
GRID,	63,	0,150.0000,	-5.0000,	-5.0000
GRID,	64,	0,150.0000,	5.0000,	-5.0000
GRID,	65,	0,160.0000,	5.0000,	5.0000
GRID,	66,	0,160.0000,	-5.0000,	5.0000
GRID,	67,	0,160.0000,	-5.0000,	-5.0000
GRID,	68,	0,160.0000,	5.0000,	-5.0000
GRID,	69,	0,170.0000,	5.0000,	5.0000
GRID,	70,	0,170.0000,	-5.0000,	5.0000
GRID,	71,	0,170.0000,	-5.0000,	-5.0000
GRID,	72,	0,170.0000,	5.0000,	-5.0000
GRID,	73,	0,180.0000,	5.0000,	5.0000
GRID,	74,	0,180.0000,	-5.0000,	5.0000
GRID,	75,	0,180.0000,	-5.0000,	-5.0000
GRID,	76,	0,180.0000,	5.0000,	-5.0000
GRID,	77,	0,190.0000,	5.0000,	5.0000
GRID,	78,	0,190.0000,	-5.0000,	5.0000
GRID,	79,	0,190.0000,	-5.0000,	-5.0000
GRID,	80,	0,190.0000,	5.0000,	-5.0000
GRID,	81,	0,200.0000,	5.0000,	5.0000
GRID,	82,	0,200.0000,	-5.0000,	5.0000
GRID,	83,	0,200.0000,	-5.0000,	-5.0000
GRID,	84,	0,200.0000,	5.0000,	-5.0000
GRID,	85,	0,210.0000,	5.0000,	5.0000
GRID,	86,	0,210.0000,	-5.0000,	5.0000
GRID,	87,	0,210.0000,	-5.0000,	-5.0000
GRID,	88,	0,210.0000,	5.0000,	-5.0000
GRID,	89,	0,220.0000,	5.0000,	5.0000
GRID,	90,	0,220.0000,	-5.0000,	5.0000
GRID,	91,	0,220.0000,	-5.0000,	-5.0000
GRID,	92,	0,220.0000,	5.0000,	-5.0000
GRID,	93,	0,230.0000,	5.0000,	5.0000
GRID,	94,	0,230.0000,	-5.0000,	5.0000
GRID,	95,	0,230.0000,	-5.0000,	-5.0000
GRID,	96,	0,230.0000,	5.0000,	-5.0000
GRID,	97,	0,240.0000,	5.0000,	5.0000

GRID,	98,	0,240.0000,	-5.0000,	5.0000
GRID,	99,	0,240.0000,	-5.0000,	-5.0000
GRID,	100,	0,240.0000,	5.0000,	-5.0000
GRID,	101,	0,250.0000,	5.0000,	5.0000
GRID,	102,	0,250.0000,	-5.0000,	5.0000
GRID,	103,	0,250.0000,	-5.0000,	-5.0000
GRID,	104,	0,250.0000,	5.0000,	-5.0000
GRID,	105,	0,260.0000,	5.0000,	5.0000
GRID,	106,	0,260.0000,	-5.0000,	5.0000
GRID,	107,	0,260.0000,	-5.0000,	-5.0000
GRID,	108,	0,260.0000,	5.0000,	-5.0000
GRID,	109,	0,270.0000,	5.0000,	5.0000
GRID,	110,	0,270.0000,	-5.0000,	5.0000
GRID,	111,	0,270.0000,	-5.0000,	-5.0000
GRID,	112,	0,270.0000,	5.0000,	-5.0000
GRID,	113,	0,280.0000,	5.0000,	5.0000
GRID,	114,	0,280.0000,	-5.0000,	5.0000
GRID,	115,	0,280.0000,	-5.0000,	-5.0000
GRID,	116,	0,280.0000,	5.0000,	-5.0000
GRID,	117,	0,290.0000,	5.0000,	5.0000
GRID,	118,	0,290.0000,	-5.0000,	5.0000
GRID,	119,	0,290.0000,	-5.0000,	-5.0000
GRID,	120,	0,290.0000,	5.0000,	-5.0000
GRID,	121,	0,300.0000,	5.0000,	5.0000
GRID,	122,	0,300.0000,	-5.0000,	5.0000
GRID,	123,	0,300.0000,	-5.0000,	-5.0000
GRID,	124,	0,300.0000,	5.0000,	-5.0000
GRID,	125,	0,310.0000,	5.0000,	5.0000
GRID,	126,	0,310.0000,	-5.0000,	5.0000
GRID,	127,	0,310.0000,	-5.0000,	-5.0000
GRID,	128,	0,310.0000,	5.0000,	-5.0000
GRID,	129,	0,320.0000,	5.0000,	5.0000
GRID,	130,	0,320.0000,	-5.0000,	5.0000
GRID,	131,	0,320.0000,	-5.0000,	-5.0000
GRID,	132,	0,320.0000,	5.0000,	-5.0000
GRID,	133,	0,330.0000,	5.0000,	5.0000
GRID,	134,	0,330.0000,	-5.0000,	5.0000
GRID,	135,	0,330.0000,	-5.0000,	-5.0000
GRID,	136,	0,330.0000,	5.0000,	-5.0000
GRID,	137,	0,340.0000,	5.0000,	5.0000
GRID,	138,	0,340.0000,	-5.0000,	5.0000
GRID,	139,	0,340.0000,	-5.0000,	-5.0000
GRID,	140,	0,340.0000,	5.0000,	-5.0000
GRID,	141,	0,350.0000,	5.0000,	5.0000
GRID,	142,	0,350.0000,	-5.0000,	5.0000
GRID,	143,	0,350.0000,	-5.0000,	-5.0000
GRID,	144,	0,350.0000,	5.0000,	-5.0000
GRID,	145,	0,360.0000,	5.0000,	5.0000
GRID,	146,	0,360.0000,	-5.0000,	5.0000
GRID,	147,	0,360.0000,	-5.0000,	-5.0000
GRID,	148,	0,360.0000,	5.0000,	-5.0000
GRID,	149,	0,370.0000,	5.0000,	5.0000
GRID,	150,	0,370.0000,	-5.0000,	5.0000
GRID,	151,	0,370.0000,	-5.0000,	-5.0000

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GRID, 183, 0,450.0000, -5.0000, -5.0000
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GRID, 186, 0,460.0000, -5.0000, 5.0000
GRID, 187, 0,460.0000, -5.0000, -5.0000
GRID, 188, 0,460.0000, 5.0000, -5.0000
GRID, 189, 0,470.0000, 5.0000, 5.0000
GRID, 190, 0,470.0000, -5.0000, 5.0000
GRID, 191, 0,470.0000, -5.0000, -5.0000
GRID, 192, 0,470.0000, 5.0000, -5.0000
GRID, 193, 0,480.0000, 5.0000, 5.0000
GRID, 194, 0,480.0000, -5.0000, 5.0000
GRID, 195, 0,480.0000, -5.0000, -5.0000
GRID, 196, 0,480.0000, 5.0000, -5.0000
GRID, 197, 0,490.0000, 5.0000, 5.0000
GRID, 198, 0,490.0000, -5.0000, 5.0000
GRID, 199, 0,490.0000, -5.0000, -5.0000
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GRID, 204, 0,500.0000, 5.0000, -5.0000
GRID, 205, 0,510.0000, 5.0000, 5.0000

GRID, 206,	0,510.0000,	-5.0000,	5.0000
GRID, 207,	0,510.0000,	-5.0000,	-5.0000
GRID, 208,	0,510.0000,	5.0000,	-5.0000
GRID, 209,	0,520.0000,	5.0000,	5.0000
GRID, 210,	0,520.0000,	-5.0000,	5.0000
GRID, 211,	0,520.0000,	-5.0000,	-5.0000
GRID, 212,	0,520.0000,	5.0000,	-5.0000
GRID, 213,	0,530.0000,	5.0000,	5.0000
GRID, 214,	0,530.0000,	-5.0000,	5.0000
GRID, 215,	0,530.0000,	-5.0000,	-5.0000
GRID, 216,	0,530.0000,	5.0000,	-5.0000
GRID, 217,	0,540.0000,	5.0000,	5.0000
GRID, 218,	0,540.0000,	-5.0000,	5.0000
GRID, 219,	0,540.0000,	-5.0000,	-5.0000
GRID, 220,	0,540.0000,	5.0000,	-5.0000
GRID, 221,	0,550.0000,	5.0000,	5.0000
GRID, 222,	0,550.0000,	-5.0000,	5.0000
GRID, 223,	0,550.0000,	-5.0000,	-5.0000
GRID, 224,	0,550.0000,	5.0000,	-5.0000
GRID, 225,	0,560.0000,	5.0000,	5.0000
GRID, 226,	0,560.0000,	-5.0000,	5.0000
GRID, 227,	0,560.0000,	-5.0000,	-5.0000
GRID, 228,	0,560.0000,	5.0000,	-5.0000
GRID, 229,	0,570.0000,	5.0000,	5.0000
GRID, 230,	0,570.0000,	-5.0000,	5.0000
GRID, 231,	0,570.0000,	-5.0000,	-5.0000
GRID, 232,	0,570.0000,	5.0000,	-5.0000
GRID, 233,	0,580.0000,	5.0000,	5.0000
GRID, 234,	0,580.0000,	-5.0000,	5.0000
GRID, 235,	0,580.0000,	-5.0000,	-5.0000
GRID, 236,	0,580.0000,	5.0000,	-5.0000
GRID, 237,	0,590.0000,	5.0000,	5.0000
GRID, 238,	0,590.0000,	-5.0000,	5.0000
GRID, 239,	0,590.0000,	-5.0000,	-5.0000
GRID, 240,	0,590.0000,	5.0000,	-5.0000
GRID, 241,	0,600.0000,	5.0000,	5.0000
GRID, 242,	0,600.0000,	-5.0000,	5.0000
GRID, 243,	0,600.0000,	-5.0000,	-5.0000
GRID, 244,	0,600.0000,	5.0000,	-5.0000
GRID, 245,	0,610.0000,	5.0000,	5.0000
GRID, 246,	0,610.0000,	-5.0000,	5.0000
GRID, 247,	0,610.0000,	-5.0000,	-5.0000
GRID, 248,	0,610.0000,	5.0000,	-5.0000
GRID, 249,	0,620.0000,	5.0000,	5.0000
GRID, 250,	0,620.0000,	-5.0000,	5.0000
GRID, 251,	0,620.0000,	-5.0000,	-5.0000
GRID, 252,	0,620.0000,	5.0000,	-5.0000
GRID, 253,	0,610.0000,	5.0000,	15.0000
GRID, 254,	0,610.0000,	-5.0000,	15.0000
GRID, 255,	0,620.0000,	-5.0000,	15.0000
GRID, 256,	0,620.0000,	5.0000,	15.0000
GRID, 257,	0,610.0000,	5.0000,	25.0000
GRID, 258,	0,610.0000,	-5.0000,	25.0000
GRID, 259,	0,620.0000,	-5.0000,	25.0000

GRID, 260,	0,620.0000,	5.0000,	25.0000
GRID, 261,	0,610.0000,	5.0000,	35.0000
GRID, 262,	0,610.0000,	-5.0000,	35.0000
GRID, 263,	0,620.0000,	-5.0000,	35.0000
GRID, 264,	0,620.0000,	5.0000,	35.0000
GRID, 265,	0,610.0000,	5.0000,	45.0000
GRID, 266,	0,610.0000,	-5.0000,	45.0000
GRID, 267,	0,620.0000,	-5.0000,	45.0000
GRID, 268,	0,620.0000,	5.0000,	45.0000
GRID, 269,	0,150.0000,	5.0000,	15.0000
GRID, 270,	0,150.0000,	-5.0000,	15.0000
GRID, 271,	0,160.0000,	-5.0000,	15.0000
GRID, 272,	0,160.0000,	5.0000,	15.0000
GRID, 273,	0,150.0000,	5.0000,	25.0000
GRID, 274,	0,150.0000,	-5.0000,	25.0000
GRID, 275,	0,160.0000,	-5.0000,	25.0000
GRID, 276,	0,160.0000,	5.0000,	25.0000
GRID, 277,	0,150.0000,	5.0000,	35.0000
GRID, 278,	0,150.0000,	-5.0000,	35.0000
GRID, 279,	0,160.0000,	-5.0000,	35.0000
GRID, 280,	0,160.0000,	5.0000,	35.0000
GRID, 281,	0,150.0000,	5.0000,	45.0000
GRID, 282,	0,150.0000,	-5.0000,	45.0000
GRID, 283,	0,160.0000,	-5.0000,	45.0000
GRID, 284,	0,160.0000,	5.0000,	45.0000
GRID, 285,	0,150.0000,	5.0000,	55.0000
GRID, 286,	0,150.0000,	-5.0000,	55.0000
GRID, 287,	0,160.0000,	-5.0000,	55.0000
GRID, 288,	0,160.0000,	5.0000,	55.0000
GRID, 289,	0,150.0000,	5.0000,	65.0000
GRID, 290,	0,150.0000,	-5.0000,	65.0000
GRID, 291,	0,160.0000,	-5.0000,	65.0000
GRID, 292,	0,160.0000,	5.0000,	65.0000
GRID, 293,	0,150.0000,	5.0000,	75.0000
GRID, 294,	0,150.0000,	-5.0000,	75.0000
GRID, 295,	0,160.0000,	-5.0000,	75.0000
GRID, 296,	0,160.0000,	5.0000,	75.0000
GRID, 297,	0,150.0000,	5.0000,	85.0000
GRID, 298,	0,150.0000,	-5.0000,	85.0000
GRID, 299,	0,160.0000,	-5.0000,	85.0000
GRID, 300,	0,160.0000,	5.0000,	85.0000
GRID, 301,	0,150.0000,	5.0000,	95.0000
GRID, 302,	0,150.0000,	-5.0000,	95.0000
GRID, 303,	0,160.0000,	-5.0000,	95.0000
GRID, 304,	0,160.0000,	5.0000,	95.0000
GRID, 305,	0,150.0000,	5.0000,	105.0000
GRID, 306,	0,150.0000,	-5.0000,	105.0000
GRID, 307,	0,160.0000,	-5.0000,	105.0000
GRID, 308,	0,160.0000,	5.0000,	105.0000
GRID, 309,	0,150.0000,	5.0000,	115.0000
GRID, 310,	0,150.0000,	-5.0000,	115.0000
GRID, 311,	0,160.0000,	-5.0000,	115.0000
GRID, 312,	0,160.0000,	5.0000,	115.0000
GRID, 313,	0,120.0000,	15.0000,	5.0000

GRID, 314,	0,130.0000,	15.0000,	5.0000
GRID, 315,	0,130.0000,	15.0000,	-5.0000
GRID, 316,	0,120.0000,	15.0000,	-5.0000
GRID, 317,	0,120.0000,	-15.0000,	5.0000
GRID, 318,	0,130.0000,	-15.0000,	5.0000
GRID, 319,	0,130.0000,	-15.0000,	-5.0000
GRID, 320,	0,120.0000,	-15.0000,	-5.0000
GRID, 321,	0,120.0000,	25.0000,	5.0000
GRID, 322,	0,130.0000,	25.0000,	5.0000
GRID, 323,	0,130.0000,	25.0000,	-5.0000
GRID, 324,	0,120.0000,	25.0000,	-5.0000
GRID, 325,	0,120.0000,	-25.0000,	5.0000
GRID, 326,	0,130.0000,	-25.0000,	5.0000
GRID, 327,	0,130.0000,	-25.0000,	-5.0000
GRID, 328,	0,120.0000,	-25.0000,	-5.0000
GRID, 329,	0,120.0000,	35.0000,	5.0000
GRID, 330,	0,130.0000,	35.0000,	5.0000
GRID, 331,	0,130.0000,	35.0000,	-5.0000
GRID, 332,	0,120.0000,	35.0000,	-5.0000
GRID, 333,	0,120.0000,	-35.0000,	5.0000
GRID, 334,	0,130.0000,	-35.0000,	5.0000
GRID, 335,	0,130.0000,	-35.0000,	-5.0000
GRID, 336,	0,120.0000,	-35.0000,	-5.0000
GRID, 337,	0,120.0000,	45.0000,	5.0000
GRID, 338,	0,130.0000,	45.0000,	5.0000
GRID, 339,	0,130.0000,	45.0000,	-5.0000
GRID, 340,	0,120.0000,	45.0000,	-5.0000
GRID, 341,	0,120.0000,	-45.0000,	5.0000
GRID, 342,	0,130.0000,	-45.0000,	5.0000
GRID, 343,	0,130.0000,	-45.0000,	-5.0000
GRID, 344,	0,120.0000,	-45.0000,	-5.0000
GRID, 345,	0,120.0000,	55.0000,	5.0000
GRID, 346,	0,130.0000,	55.0000,	5.0000
GRID, 347,	0,130.0000,	55.0000,	-5.0000
GRID, 348,	0,120.0000,	55.0000,	-5.0000
GRID, 349,	0,120.0000,	-55.0000,	5.0000
GRID, 350,	0,130.0000,	-55.0000,	5.0000
GRID, 351,	0,130.0000,	-55.0000,	-5.0000
GRID, 352,	0,120.0000,	-55.0000,	-5.0000
GRID, 353,	0,120.0000,	65.0000,	5.0000
GRID, 354,	0,130.0000,	65.0000,	5.0000
GRID, 355,	0,130.0000,	65.0000,	-5.0000
GRID, 356,	0,120.0000,	65.0000,	-5.0000
GRID, 357,	0,120.0000,	-65.0000,	5.0000
GRID, 358,	0,130.0000,	-65.0000,	5.0000
GRID, 359,	0,130.0000,	-65.0000,	-5.0000
GRID, 360,	0,120.0000,	-65.0000,	-5.0000
GRID, 361,	0,120.0000,	75.0000,	5.0000
GRID, 362,	0,130.0000,	75.0000,	5.0000
GRID, 363,	0,130.0000,	75.0000,	-5.0000
GRID, 364,	0,120.0000,	75.0000,	-5.0000
GRID, 365,	0,120.0000,	-75.0000,	5.0000
GRID, 366,	0,130.0000,	-75.0000,	5.0000
GRID, 367,	0,130.0000,	-75.0000,	-5.0000

GRID, 368, 0,120.0000,-75.0000, -5.0000
GRID, 369, 0,120.0000, 85.0000, 5.0000
GRID, 370, 0,130.0000, 85.0000, 5.0000
GRID, 371, 0,130.0000, 85.0000, -5.0000
GRID, 372, 0,120.0000, 85.0000, -5.0000
GRID, 373, 0,120.0000,-85.0000, 5.0000
GRID, 374, 0,130.0000,-85.0000, 5.0000
GRID, 375, 0,130.0000,-85.0000, -5.0000
GRID, 376, 0,120.0000,-85.0000, -5.0000
GRID, 377, 0,120.0000, 95.0000, 5.0000
GRID, 378, 0,130.0000, 95.0000, 5.0000
GRID, 379, 0,130.0000, 95.0000, -5.0000
GRID, 380, 0,120.0000, 95.0000, -5.0000
GRID, 381, 0,120.0000,-95.0000, 5.0000
GRID, 382, 0,130.0000,-95.0000, 5.0000
GRID, 383, 0,130.0000,-95.0000, -5.0000
GRID, 384, 0,120.0000,-95.0000, -5.0000
GRID, 385, 0,120.0000,105.0000, 5.0000
GRID, 386, 0,130.0000,105.0000, 5.0000
GRID, 387, 0,130.0000,105.0000, -5.0000
GRID, 388, 0,120.0000,105.0000, -5.0000
GRID, 389, 0,120.0000,-105.000, 5.0000
GRID, 390, 0,130.0000,-105.000, 5.0000
GRID, 391, 0,130.0000,-105.000, -5.0000
GRID, 392, 0,120.0000,-105.000, -5.0000
GRID, 393, 0,125.0000,105.0000, 5.0000
GRID, 394, 0,125.0000,-105.000, 5.0000
GRID, 395, 0,125.0000, 0.0000,803.5000
GRID, 396, 0,125.0000, 0.0000,178.7500
GRID, 397, 0,550.0000, 15.0000, 5.0000
GRID, 398, 0,560.0000, 15.0000, 5.0000
GRID, 399, 0,560.0000, 15.0000, -5.0000
GRID, 400, 0,550.0000, 15.0000, -5.0000
GRID, 401, 0,550.0000,-15.0000, 5.0000
GRID, 402, 0,560.0000,-15.0000, 5.0000
GRID, 403, 0,560.0000,-15.0000, -5.0000
GRID, 404, 0,550.0000,-15.0000, -5.0000
GRID, 405, 0,550.0000, 25.0000, 5.0000
GRID, 406, 0,560.0000, 25.0000, 5.0000
GRID, 407, 0,560.0000, 25.0000, -5.0000
GRID, 408, 0,550.0000, 25.0000, -5.0000
GRID, 409, 0,550.0000,-25.0000, 5.0000
GRID, 410, 0,560.0000,-25.0000, 5.0000
GRID, 411, 0,560.0000,-25.0000, -5.0000
GRID, 412, 0,550.0000,-25.0000, -5.0000
GRID, 413, 0,550.0000, 35.0000, 5.0000
GRID, 414, 0,560.0000, 35.0000, 5.0000
GRID, 415, 0,560.0000, 35.0000, -5.0000
GRID, 416, 0,550.0000, 35.0000, -5.0000
GRID, 417, 0,550.0000,-35.0000, 5.0000
GRID, 418, 0,560.0000,-35.0000, 5.0000
GRID, 419, 0,560.0000,-35.0000, -5.0000
GRID, 420, 0,550.0000,-35.0000, -5.0000
GRID, 421, 0,550.0000, 45.0000, 5.0000

GRID, 422, 0,560.0000, 45.0000, 5.0000
GRID, 423, 0,560.0000, 45.0000, -5.0000
GRID, 424, 0,550.0000, 45.0000, -5.0000
GRID, 425, 0,550.0000,-45.0000, 5.0000
GRID, 426, 0,560.0000,-45.0000, 5.0000
GRID, 427, 0,560.0000,-45.0000, -5.0000
GRID, 428, 0,550.0000,-45.0000, -5.0000
GRID, 429, 0,550.0000, 55.0000, 5.0000
GRID, 430, 0,560.0000, 55.0000, 5.0000
GRID, 431, 0,560.0000, 55.0000, -5.0000
GRID, 432, 0,550.0000, 55.0000, -5.0000
GRID, 433, 0,550.0000,-55.0000, 5.0000
GRID, 434, 0,560.0000,-55.0000, 5.0000
GRID, 435, 0,560.0000,-55.0000, -5.0000
GRID, 436, 0,550.0000,-55.0000, -5.0000
GRID, 437, 0,550.0000, 65.0000, 5.0000
GRID, 438, 0,560.0000, 65.0000, 5.0000
GRID, 439, 0,560.0000, 65.0000, -5.0000
GRID, 440, 0,550.0000, 65.0000, -5.0000
GRID, 441, 0,550.0000,-65.0000, 5.0000
GRID, 442, 0,560.0000,-65.0000, 5.0000
GRID, 443, 0,560.0000,-65.0000, -5.0000
GRID, 444, 0,550.0000,-65.0000, -5.0000
GRID, 445, 0,550.0000, 75.0000, 5.0000
GRID, 446, 0,560.0000, 75.0000, 5.0000
GRID, 447, 0,560.0000, 75.0000, -5.0000
GRID, 448, 0,550.0000, 75.0000, -5.0000
GRID, 449, 0,550.0000,-75.0000, 5.0000
GRID, 450, 0,560.0000,-75.0000, 5.0000
GRID, 451, 0,560.0000,-75.0000, -5.0000
GRID, 452, 0,550.0000,-75.0000, -5.0000
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GRID, 454, 0,560.0000, 85.0000, 5.0000
GRID, 455, 0,560.0000, 85.0000, -5.0000
GRID, 456, 0,550.0000, 85.0000, -5.0000
GRID, 457, 0,550.0000,-85.0000, 5.0000
GRID, 458, 0,560.0000,-85.0000, 5.0000
GRID, 459, 0,560.0000,-85.0000, -5.0000
GRID, 460, 0,550.0000,-85.0000, -5.0000
GRID, 461, 0,550.0000, 95.0000, 5.0000
GRID, 462, 0,560.0000, 95.0000, 5.0000
GRID, 463, 0,560.0000, 95.0000, -5.0000
GRID, 464, 0,550.0000, 95.0000, -5.0000
GRID, 465, 0,550.0000,-95.0000, 5.0000
GRID, 466, 0,560.0000,-95.0000, 5.0000
GRID, 467, 0,560.0000,-95.0000, -5.0000
GRID, 468, 0,550.0000,-95.0000, -5.0000
GRID, 469, 0,550.0000,105.0000, 5.0000
GRID, 470, 0,560.0000,105.0000, 5.0000
GRID, 471, 0,560.0000,105.0000, -5.0000
GRID, 472, 0,550.0000,105.0000, -5.0000
GRID, 473, 0,550.0000,-105.0000, 5.0000
GRID, 474, 0,560.0000,-105.0000, 5.0000
GRID, 475, 0,560.0000,-105.0000, -5.0000

GRID, 476, 0,550.0000,-105.000, -5.0000
 GRID, 477, 0,555.0000,105.0000, 5.0000
 GRID, 478, 0,555.0000,-105.000, 5.0000
 GRID, 479, 0,555.0000, 0.0000,803.5000
 GRID, 480, 0,555.0000, 0.0000,178.7500
 GRID, 481, 0,125.0000, 0.0000,777.0000
 GRID, 482, 0,555.0000, 0.0000,777.0000
 GRID, 485, 0,610.0000, 5.0000, 52.0600
 GRID, 486, 0,610.0000, -5.0000, 52.0600
 GRID, 487, 0,620.0000, -5.0000, 60.1600
 GRID, 488, 0,620.0000, 5.0000, 60.1600

\$ ADDED FOLLOWING GRID PTS. 90/11/28

GRID, 489, 0, 5.0, 0.0, 5.0
 GRID, 490, 0, 5.0, -5.0, 0.0
 GRID, 491, 0, 5.0, 0.0, -5.0
 GRID, 492, 0, 5.0, 5.0, 0.0
 GRID, 493, 0,155.0, 5.0,100.0
 GRID, 494, 0,160.0, 0.0,100.0
 GRID, 495, 0,155.0, -5.0,100.0
 GRID, 496, 0,150.0, 0.0,100.0
 GRID, 497, 0,155.0, 0.0,115.0
 GRID, 498, 0,325.0, 0.0, 5.0
 GRID, 499, 0,325.0, -5.0, 0.0
 GRID, 500, 0,325.0, 0.0, -5.0
 GRID, 501, 0,325.0, 5.0, 0.0
 GRID, 502, 0,615.0, 5.0, 40.0
 GRID, 503, 0,620.0, 0.0, 40.0
 GRID, 504, 0,615.0, -5.0, 40.0
 GRID, 505, 0,610.0, 0.0, 40.0

\$ END

ECHOON

GRID,1001, 0,-80., 390.,0.
 GRID,1002, 0,700., 390.,0.
 GRID,1003, 0,700.,-390.,0.
 GRID,1004, 0,-80.,-390.,0.
 GRID,1005, 0,-80., 390.,780.
 GRID,1006, 0,700., 390.,780.
 GRID,1007, 0,700.,-390.,780.
 GRID,1008, 0,-80.,-390.,780.

ECHOFF

GRID,2001, 3, 92.6563, 22.5000, 19.7947
 GRID,2002, 3, 81.7501, 22.5000, 15.0447
 GRID,2003, 3, 70.2500, 22.5000, 10.6072
 GRID,2004, 3, 58.7500, 22.5000, 6.7322
 GRID,2005, 3, 47.2500, 22.5000, 3.9197
 GRID,2006, 3, 35.7500, 22.5000, 1.8572
 GRID,2007, 3, 35.3500, 22.5000, 2.4375
 GRID,2008, 3, 26.5000, 22.5000, 0.8572
 GRID,2009, 3, 17.2500, 22.5000, 0.3572
 GRID,2010, 3, 8.0000, 22.5000, 0.3125
 GRID,2011, 3, 4.6000, 22.5000, 0.3125
 GRID,2012, 3, 8.0000, 22.5000, 0.0000
 GRID,2013, 3, 4.6000, 22.5000, 0.0000
 GRID,2014, 3, 92.6563, 67.5000, 19.7947

GRID,2015, 3, 81.7500, 67.5000, 15.0447
GRID,2016, 3, 70.2500, 67.5000, 10.6072
GRID,2017, 3, 58.7500, 67.5000, 6.7322
GRID,2018, 3, 47.2500, 67.5000, 3.9197
GRID,2019, 3, 35.7500, 67.5000, 1.8572
GRID,2020, 3, 35.3500, 67.5000, 2.4375
GRID,2021, 3, 26.5000, 67.5000, 0.8572
GRID,2022, 3, 17.2500, 67.5000, 0.3572
GRID,2023, 3, 8.0000, 67.5000, 0.3125
GRID,2024, 3, 4.6000, 67.5000, 0.3125
GRID,2025, 3, 8.0000, 67.5000, 0.0000
GRID,2026, 3, 4.6000, 67.5000, 0.0000
GRID,2027, 3, 92.6563,112.5000, 19.7947
GRID,2028, 3, 81.7500,112.5000, 15.0447
GRID,2029, 3, 70.2500,112.5000, 10.6072
GRID,2030, 3, 58.7500,112.5000, 6.7322
GRID,2031, 3, 47.2500,112.5000, 3.9197
GRID,2032, 3, 35.7500,112.5000, 1.8572
GRID,2033, 3, 35.3500,112.5000, 2.4375
GRID,2034, 3, 26.5000,112.5000, 0.8572
GRID,2035, 3, 17.2500,112.5000, 0.3572
GRID,2036, 3, 8.0000,112.5000, 0.3125
GRID,2037, 3, 4.6000,112.5000, 0.3125
GRID,2038, 3, 8.0000,112.5000, 0.0000
GRID,2039, 3, 4.6000,112.5000, 0.0000
GRID,2040, 3, 92.6563,157.5000, 19.7947
GRID,2041, 3, 81.7500,157.5000, 15.0447
GRID,2042, 3, 70.2501,157.5000, 10.6072
GRID,2043, 3, 58.7500,157.5000, 6.7322
GRID,2044, 3, 47.2500,157.5000, 3.9197
GRID,2045, 3, 35.7500,157.5000, 1.8572
GRID,2046, 3, 35.3500,157.5000, 2.4375
GRID,2047, 3, 26.5000,157.5000, 0.8572
GRID,2048, 3, 17.2500,157.5000, 0.3572
GRID,2049, 3, 8.0000,157.5000, 0.3125
GRID,2050, 3, 4.6000,157.5000, 0.3125
GRID,2051, 3, 8.0000,157.5000, 0.0000
GRID,2052, 3, 4.6000,157.5000, 0.0000
GRID,2053, 3, 92.6563,202.5000, 19.7947
GRID,2054, 3, 81.7500,202.5000, 15.0447
GRID,2055, 3, 70.2501,202.5000, 10.6072
GRID,2056, 3, 58.7500,202.5000, 6.7322
GRID,2057, 3, 47.2500,202.5000, 3.9197
GRID,2058, 3, 35.7500,202.5000, 1.8572
GRID,2059, 3, 35.3500,202.5000, 2.4375
GRID,2060, 3, 26.5000,202.5000, 0.8572
GRID,2061, 3, 17.2500,202.5000, 0.3572
GRID,2062, 3, 8.0000,202.5000, 0.3125
GRID,2063, 3, 4.6000,202.5000, 0.3125
GRID,2064, 3, 8.0000,202.5000, 0.0000
GRID,2065, 3, 4.6000,202.5000, 0.0000
GRID,2066, 3, 92.6563,247.5000, 19.7947
GRID,2067, 3, 81.7500,247.5000, 15.0447
GRID,2068, 3, 70.2500,247.5000, 10.6072

GRID,2069, 3, 58.7500,247.5000, 6.7322
GRID,2070, 3, 47.2500,247.5000, 3.9197
GRID,2071, 3, 35.7500,247.5000, 1.8572
GRID,2072, 3, 35.3500,247.5000, 2.4375
GRID,2073, 3, 26.5000,247.5000, 0.8572
GRID,2074, 3, 17.2500,247.5000, 0.3572
GRID,2075, 3, 8.0000,247.5000, 0.3125
GRID,2076, 3, 4.6000,247.5000, 0.3125
GRID,2077, 3, 8.0000,247.5000, 0.0000
GRID,2078, 3, 4.6000,247.5000, 0.0000
GRID,2079, 3, 92.6563,292.5000, 19.7947
GRID,2080, 3, 81.7500,292.5000, 15.0447
GRID,2081, 3, 70.2500,292.5000, 10.6072
GRID,2082, 3, 58.7500,292.5000, 6.7322
GRID,2083, 3, 47.2500,292.5000, 3.9197
GRID,2084, 3, 35.7500,292.5000, 1.8572
GRID,2085, 3, 35.3500,292.5000, 2.4375
GRID,2086, 3, 26.5000,292.5000, 0.8572
GRID,2087, 3, 17.2500,292.5000, 0.3572
GRID,2088, 3, 8.0000,292.5000, 0.3125
GRID,2089, 3, 4.6000,292.5000, 0.3125
GRID,2090, 3, 8.0000,292.5000, 0.0000
GRID,2091, 3, 4.6000,292.5000, 0.0000
GRID,2092, 3, 92.6563,337.5000, 19.7947
GRID,2093, 3, 81.7500,337.5000, 15.0447
GRID,2094, 3, 70.2500,337.5000, 10.6072
GRID,2095, 3, 58.7500,337.5000, 6.7322
GRID,2096, 3, 47.2500,337.5000, 3.9197
GRID,2097, 3, 35.7500,337.5000, 1.8572
GRID,2098, 3, 35.3500,337.5000, 2.4375
GRID,2099, 3, 26.5000,337.5000, 0.8572
GRID,2100, 3, 17.2500,337.5000, 0.3572
GRID,2101, 3, 8.0000,337.5000, 0.3125
GRID,2102, 3, 4.6000,337.5000, 0.3125
GRID,2103, 3, 8.0000,337.5000, 0.0000
GRID,2104, 3, 4.6000,337.5000, 0.0000
GRID,2106, 3, 0.0000, 0.0000, 2.4375
GRID,2107, 3, 7.3910, 0.0000, 0.0000
GRID,2108, 3, 8.1500, 37.8500, 0.0000
GRID,2109, 3, 7.3910, 90.0000, 0.0000
GRID,2110, 3, 8.1500,142.1500, 0.0000
GRID,2111, 3, 7.3910,180.0000, 0.0000
GRID,2112, 3, 8.1500,217.8500, 0.0000
GRID,2113, 3, 7.3910,270.0000, 0.0000
GRID,2114, 3, 8.1500,322.1500, 0.0000
GRID,2115, 3, 7.3910, 0.0000, 2.4375
GRID,2116, 3, 8.1500, 37.8500, 2.4375
GRID,2117, 3, 7.3910, 90.0000, 2.4375
GRID,2118, 3, 8.1500,142.1500, 2.4375
GRID,2119, 3, 7.3910,180.0000, 2.4375
GRID,2120, 3, 8.1500,217.8500, 2.4375
GRID,2121, 3, 7.3910,270.0000, 2.4375
GRID,2122, 3, 8.1500,322.1500, 2.4375

\$ ADDITIONAL GRIDS ADDED 90/9/14

GRID,2123, 3, 64.2000, 22.5000, 8.5690
GRID,2124, 3, 64.2000, 67.5000, 8.5690
GRID,2125, 3, 64.2000,112.5000, 8.5690
GRID,2126, 3, 64.2000,157.5000, 8.5690
GRID,2127, 3, 64.2000,202.5000, 8.5690
GRID,2128, 3, 64.2000,247.5000, 8.5690
GRID,2129, 3, 64.2000,292.5000, 8.5690
GRID,2130, 3, 64.2000,337.5000, 8.5690
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 CBAR, 926,13, 296, 297,0.,1.,1.
 CBAR, 927,13, 299, 302,0.,1.,1.
 CBAR, 928,13, 297, 304,0.,1.,1.

\$ BAY BREAK FOR THRUSTER

CBAR, 931,13, 307, 310,0.,1.,1.
 CBAR, 932,13, 305, 312,0.,1.,1.
 CBAR, 933, 3, 62, 269,1.,0.,1.
 CBAR, 934, 3, 65, 271,1.,0.,1.
 CBAR, 935, 3, 269, 274,1.,0.,1.
 CBAR, 936, 3, 271, 276,1.,0.,1.
 CBAR, 937, 3, 274, 277,1.,0.,1.
 CBAR, 938, 3, 276, 279,1.,0.,1.
 CBAR, 939, 3, 277, 282,1.,0.,1.
 CBAR, 940, 3, 279, 284,1.,0.,1.
 CBAR, 941, 3, 282, 285,1.,0.,1.
 CBAR, 942, 3, 284, 287,1.,0.,1.
 CBAR, 943, 3, 285, 290,1.,0.,1.
 CBAR, 944, 3, 287, 292,1.,0.,1.
 CBAR, 945, 3, 290, 293,1.,0.,1.
 CBAR, 946, 3, 292, 295,1.,0.,1.
 CBAR, 947, 3, 293, 298,1.,0.,1.
 CBAR, 948, 3, 295, 300,1.,0.,1.
 CBAR, 949, 3, 298, 301,1.,0.,1.
 CBAR, 950, 3, 300, 303,1.,0.,1.

\$ BAY BREAK FOR THRUSTER

CBAR, 953, 3, 306, 309,1.,0.,1.
 CBAR, 954, 3, 308, 311,1.,0.,1.
 CBAR, 955,12, 245, 253,1.,1.,0.
 CBAR, 956,12, 246, 254,1.,1.,0.
 CBAR, 957,12, 250, 255,1.,1.,0.
 CBAR, 958,12, 249, 256,1.,1.,0.
 CBAR, 959,12, 253, 257,1.,1.,0.
 CBAR, 960,12, 254, 258,1.,1.,0.
 CBAR, 961,12, 255, 259,1.,1.,0.
 CBAR, 962,12, 256, 260,1.,1.,0.
 CBAR, 963,12, 257, 261,1.,1.,0.
 CBAR, 964,12, 258, 262,1.,1.,0.
 CBAR, 965,12, 259, 263,1.,1.,0.
 CBAR, 966,12, 260, 264,1.,1.,0.
 CBAR, 967,12, 261, 265,1.,1.,0.
 CBAR, 968,12, 262, 266,1.,1.,0.
 CBAR, 969,12, 263, 267,1.,1.,0.
 CBAR, 970,12, 264, 268,1.,1.,0.
 CBAR, 971, 2, 253, 254,1.,0.,1.
 CBAR, 972, 2, 254, 255,1.,0.,1.
 CBAR, 973, 2, 255, 256,1.,0.,1.
 CBAR, 974, 2, 256, 253,1.,0.,1.
 CBAR, 975, 2, 257, 258,1.,0.,1.

CBAR, 976, 2, 258, 259,1.,0.,1.
CBAR, 977, 2, 259, 260,1.,0.,1.
CBAR, 978, 2, 260, 257,1.,0.,1.
CBAR, 979, 2, 261, 262,1.,0.,1.
CBAR, 980, 2, 262, 263,1.,0.,1.
CBAR, 981, 2, 263, 264,1.,0.,1.
CBAR, 982, 2, 264, 261,1.,0.,1.
CBAR, 983, 2, 265, 266,1.,0.,1.
CBAR, 984, 2, 266, 267,1.,0.,1.
CBAR, 985, 2, 267, 268,1.,0.,1.
CBAR, 986, 2, 268, 265,1.,0.,1.
CBAR, 987, 3, 253, 255,1.,0.,1.
CBAR, 988, 3, 258, 260,1.,0.,1.
CBAR, 989, 3, 261, 263,1.,0.,1.
CBAR, 990, 3, 266, 268,1.,0.,1.
CBAR, 991,13, 245, 256,0.,1.,1.
CBAR, 992,13, 250, 254,0.,1.,1.
CBAR, 993,13, 256, 257,0.,1.,1.
CBAR, 994,13, 254, 259,0.,1.,1.
CBAR, 995,13, 257, 264,0.,1.,1.
CBAR, 996,13, 259, 262,0.,1.,1.
CBAR, 999, 3, 246, 253,1.,0.,1.
CBAR, 1000, 3, 249, 255,1.,0.,1.
CBAR, 1001, 3, 253, 258,1.,0.,1.
CBAR, 1002, 3, 255, 260,1.,0.,1.
CBAR, 1003, 3, 258, 261,1.,0.,1.
CBAR, 1004, 3, 260, 263,1.,0.,1.
CBAR, 1007, 2, 49, 313,1.,0.,1.
CBAR, 1008, 2, 53, 314,1.,0.,1.
CBAR, 1009, 2, 56, 315,1.,0.,1.
CBAR, 1010, 2, 52, 316,1.,0.,1.
CBAR, 1011, 2, 313, 321,1.,0.,1.
CBAR, 1012, 2, 314, 322,1.,0.,1.
CBAR, 1013, 2, 315, 323,1.,0.,1.
CBAR, 1014, 2, 316, 324,1.,0.,1.
CBAR, 1015, 2, 321, 329,1.,0.,1.
CBAR, 1016, 2, 322, 330,1.,0.,1.
CBAR, 1017, 2, 323, 331,1.,0.,1.
CBAR, 1018, 2, 324, 332,1.,0.,1.
CBAR, 1019, 2, 329, 337,1.,0.,1.
CBAR, 1020, 2, 330, 338,1.,0.,1.
CBAR, 1021, 2, 331, 339,1.,0.,1.
CBAR, 1022, 2, 332, 340,1.,0.,1.
CBAR, 1023, 2, 337, 345,1.,0.,1.
CBAR, 1024, 2, 338, 346,1.,0.,1.
CBAR, 1025, 2, 339, 347,1.,0.,1.
CBAR, 1026, 2, 340, 348,1.,0.,1.
CBAR, 1027, 2, 345, 353,1.,0.,1.
CBAR, 1028, 2, 346, 354,1.,0.,1.
CBAR, 1029, 2, 347, 355,1.,0.,1.
CBAR, 1030, 2, 348, 356,1.,0.,1.
CBAR, 1031, 2, 353, 361,1.,0.,1.
CBAR, 1032, 2, 354, 362,1.,0.,1.
CBAR, 1033, 2, 355, 363,1.,0.,1.

CBAR, 1034, 2, 356, 364,1.,0.,1.
CBAR, 1035, 2, 361, 369,1.,0.,1.
CBAR, 1036, 2, 362, 370,1.,0.,1.
CBAR, 1037, 2, 363, 371,1.,0.,1.
CBAR, 1038, 2, 364, 372,1.,0.,1.
CBAR, 1039, 2, 369, 377,1.,0.,1.
CBAR, 1040, 2, 370, 378,1.,0.,1.
CBAR, 1041, 2, 371, 379,1.,0.,1.
CBAR, 1042, 2, 372, 380,1.,0.,1.
CBAR, 1043, 2, 377, 385,1.,0.,1.
CBAR, 1044, 2, 378, 386,1.,0.,1.
CBAR, 1045, 2, 379, 387,1.,0.,1.
CBAR, 1046, 2, 380, 388,1.,0.,1.
CBAR, 1047, 2, 50, 317,1.,0.,1.
CBAR, 1048, 2, 54, 318,1.,0.,1.
CBAR, 1049, 2, 55, 319,1.,0.,1.
CBAR, 1050, 2, 51, 320,1.,0.,1.
CBAR, 1051, 2, 317, 325,1.,0.,1.
CBAR, 1052, 2, 318, 326,1.,0.,1.
CBAR, 1053, 2, 319, 327,1.,0.,1.
CBAR, 1054, 2, 320, 328,1.,0.,1.
CBAR, 1055, 2, 325, 333,1.,0.,1.
CBAR, 1056, 2, 326, 334,1.,0.,1.
CBAR, 1057, 2, 327, 335,1.,0.,1.
CBAR, 1058, 2, 328, 336,1.,0.,1.
CBAR, 1059, 2, 333, 341,1.,0.,1.
CBAR, 1060, 2, 334, 342,1.,0.,1.
CBAR, 1061, 2, 335, 343,1.,0.,1.
CBAR, 1062, 2, 336, 344,1.,0.,1.
CBAR, 1063, 2, 341, 349,1.,0.,1.
CBAR, 1064, 2, 342, 350,1.,0.,1.
CBAR, 1065, 2, 343, 351,1.,0.,1.
CBAR, 1066, 2, 344, 352,1.,0.,1.
CBAR, 1067, 2, 349, 357,1.,0.,1.
CBAR, 1068, 2, 350, 358,1.,0.,1.
CBAR, 1069, 2, 351, 359,1.,0.,1.
CBAR, 1070, 2, 352, 360,1.,0.,1.
CBAR, 1071, 2, 357, 365,1.,0.,1.
CBAR, 1072, 2, 358, 366,1.,0.,1.
CBAR, 1073, 2, 359, 367,1.,0.,1.
CBAR, 1074, 2, 360, 368,1.,0.,1.
CBAR, 1075, 2, 365, 373,1.,0.,1.
CBAR, 1076, 2, 366, 374,1.,0.,1.
CBAR, 1077, 2, 367, 375,1.,0.,1.
CBAR, 1078, 2, 368, 376,1.,0.,1.
CBAR, 1079, 2, 373, 381,1.,0.,1.
CBAR, 1080, 2, 374, 382,1.,0.,1.
CBAR, 1081, 2, 375, 383,1.,0.,1.
CBAR, 1082, 2, 376, 384,1.,0.,1.
CBAR, 1083, 2, 381, 389,1.,0.,1.
CBAR, 1084, 2, 382, 390,1.,0.,1.
CBAR, 1085, 2, 383, 391,1.,0.,1.
CBAR, 1086, 2, 384, 392,1.,0.,1.
CBAR, 1087, 1, 313, 314,0.,1.,1.

CBAR, 1088, 1, 314, 315,0.,1.,1.
CBAR, 1089, 1, 315, 316,0.,1.,1.
CBAR, 1090, 1, 316, 313,0.,1.,1.
CBAR, 1091, 1, 321, 322,0.,1.,1.
CBAR, 1092, 1, 322, 323,0.,1.,1.
CBAR, 1093, 1, 323, 324,0.,1.,1.
CBAR, 1094, 1, 324, 321,0.,1.,1.
CBAR, 1095, 1, 329, 330,0.,1.,1.
CBAR, 1096, 1, 330, 331,0.,1.,1.
CBAR, 1097, 1, 331, 332,0.,1.,1.
CBAR, 1098, 1, 332, 329,0.,1.,1.
CBAR, 1099, 1, 337, 338,0.,1.,1.
CBAR, 1100, 1, 338, 339,0.,1.,1.
CBAR, 1101, 1, 339, 340,0.,1.,1.
CBAR, 1102, 1, 340, 337,0.,1.,1.
CBAR, 1103, 1, 345, 346,0.,1.,1.
CBAR, 1104, 1, 346, 347,0.,1.,1.
CBAR, 1105, 1, 347, 348,0.,1.,1.
CBAR, 1106, 1, 348, 345,0.,1.,1.
CBAR, 1107, 1, 353, 354,0.,1.,1.
CBAR, 1108, 1, 354, 355,0.,1.,1.
CBAR, 1109, 1, 355, 356,0.,1.,1.
CBAR, 1110, 1, 356, 353,0.,1.,1.
CBAR, 1111, 1, 361, 362,0.,1.,1.
CBAR, 1112, 1, 362, 363,0.,1.,1.
CBAR, 1113, 1, 363, 364,0.,1.,1.
CBAR, 1114, 1, 364, 361,0.,1.,1.
CBAR, 1115, 1, 369, 370,0.,1.,1.
CBAR, 1116, 1, 370, 371,0.,1.,1.
CBAR, 1117, 1, 371, 372,0.,1.,1.
CBAR, 1118, 1, 372, 369,0.,1.,1.
CBAR, 1119, 1, 377, 378,0.,1.,1.
CBAR, 1120, 1, 378, 379,0.,1.,1.
CBAR, 1121, 1, 379, 380,0.,1.,1.
CBAR, 1122, 1, 380, 377,0.,1.,1.
CBAR, 1123, 1, 385, 386,0.,1.,1.
CBAR, 1124, 1, 386, 387,0.,1.,1.
CBAR, 1125, 1, 387, 388,0.,1.,1.
CBAR, 1126, 1, 388, 385,0.,1.,1.
CBAR, 1127, 1, 317, 318,0.,1.,1.
CBAR, 1128, 1, 318, 319,0.,1.,1.
CBAR, 1129, 1, 319, 320,0.,1.,1.
CBAR, 1130, 1, 320, 317,0.,1.,1.
CBAR, 1131, 1, 325, 326,0.,1.,1.
CBAR, 1132, 1, 326, 327,0.,1.,1.
CBAR, 1133, 1, 327, 328,0.,1.,1.
CBAR, 1134, 1, 328, 325,0.,1.,1.
CBAR, 1135, 1, 333, 334,0.,1.,1.
CBAR, 1136, 1, 334, 335,0.,1.,1.
CBAR, 1137, 1, 335, 336,0.,1.,1.
CBAR, 1138, 1, 336, 333,0.,1.,1.
CBAR, 1139, 1, 341, 342,0.,1.,1.
CBAR, 1140, 1, 342, 343,0.,1.,1.
CBAR, 1141, 1, 343, 344,0.,1.,1.

CBAR, 1142, 1, 344, 341,0.,1.,1.
CBAR, 1143, 1, 349, 350,0.,1.,1.
CBAR, 1144, 1, 350, 351,0.,1.,1.
CBAR, 1145, 1, 351, 352,0.,1.,1.
CBAR, 1146, 1, 352, 349,0.,1.,1.
CBAR, 1147, 1, 357, 358,0.,1.,1.
CBAR, 1148, 1, 358, 359,0.,1.,1.
CBAR, 1149, 1, 359, 360,0.,1.,1.
CBAR, 1150, 1, 360, 357,0.,1.,1.
CBAR, 1151, 1, 365, 366,0.,1.,1.
CBAR, 1152, 1, 366, 367,0.,1.,1.
CBAR, 1153, 1, 367, 368,0.,1.,1.
CBAR, 1154, 1, 368, 365,0.,1.,1.
CBAR, 1155, 1, 373, 374,0.,1.,1.
CBAR, 1156, 1, 374, 375,0.,1.,1.
CBAR, 1157, 1, 375, 376,0.,1.,1.
CBAR, 1158, 1, 376, 373,0.,1.,1.
CBAR, 1159, 1, 381, 382,0.,1.,1.
CBAR, 1160, 1, 382, 383,0.,1.,1.
CBAR, 1161, 1, 383, 384,0.,1.,1.
CBAR, 1162, 1, 384, 381,0.,1.,1.
CBAR, 1163, 1, 389, 390,0.,1.,1.
CBAR, 1164, 1, 390, 391,0.,1.,1.
CBAR, 1165, 1, 391, 392,0.,1.,1.
CBAR, 1166, 1, 392, 389,0.,1.,1.
CBAR, 1167,13, 313, 315,0.,1.,1.
CBAR, 1168,13, 322, 324,0.,1.,1.
CBAR, 1169,13, 329, 331,0.,1.,1.
CBAR, 1170,13, 338, 340,0.,1.,1.
CBAR, 1171,13, 345, 347,0.,1.,1.
CBAR, 1172,13, 354, 356,0.,1.,1.
CBAR, 1173,13, 361, 363,0.,1.,1.
CBAR, 1174,13, 370, 372,0.,1.,1.
CBAR, 1175,13, 377, 379,0.,1.,1.
CBAR, 1176,13, 386, 388,0.,1.,1.
CBAR, 1177,13, 318, 320,0.,1.,1.
CBAR, 1178,13, 327, 325,0.,1.,1.
CBAR, 1179,13, 334, 336,0.,1.,1.
CBAR, 1180,13, 341, 343,0.,1.,1.
CBAR, 1181,13, 350, 352,0.,1.,1.
CBAR, 1182,13, 357, 359,0.,1.,1.
CBAR, 1183,13, 366, 368,0.,1.,1.
CBAR, 1184,13, 373, 375,0.,1.,1.
CBAR, 1185,13, 382, 384,0.,1.,1.
CBAR, 1186,13, 389, 391,0.,1.,1.
CBAR, 1187, 3, 49, 316,1.,0.,1.
CBAR, 1188, 3, 56, 314,1.,0.,1.
CBAR, 1189, 3, 316, 321,1.,0.,1.
CBAR, 1190, 3, 314, 323,1.,0.,1.
CBAR, 1191, 3, 321, 332,1.,0.,1.
CBAR, 1192, 3, 323, 330,1.,0.,1.
CBAR, 1193, 3, 332, 337,1.,0.,1.
CBAR, 1194, 3, 330, 339,1.,0.,1.
CBAR, 1195, 3, 337, 348,1.,0.,1.

CBAR, 1196, 3, 339, 346,1.,0.,1.
CBAR, 1197, 3, 348, 353,1.,0.,1.
CBAR, 1198, 3, 346, 355,1.,0.,1.
CBAR, 1199, 3, 353, 364,1.,0.,1.
CBAR, 1200, 3, 355, 362,1.,0.,1.
CBAR, 1201, 3, 364, 369,1.,0.,1.
CBAR, 1202, 3, 362, 371,1.,0.,1.
CBAR, 1203, 3, 369, 380,1.,0.,1.
CBAR, 1204, 3, 371, 378,1.,0.,1.
CBAR, 1205, 3, 380, 385,1.,0.,1.
CBAR, 1206, 3, 378, 387,1.,0.,1.
CBAR, 1207, 3, 51, 317,1.,0.,1.
CBAR, 1208, 3, 54, 319,1.,0.,1.
CBAR, 1209, 3, 317, 328,1.,0.,1.
CBAR, 1210, 3, 319, 326,1.,0.,1.
CBAR, 1211, 3, 328, 333,1.,0.,1.
CBAR, 1212, 3, 326, 335,1.,0.,1.
CBAR, 1213, 3, 333, 344,1.,0.,1.
CBAR, 1214, 3, 335, 342,1.,0.,1.
CBAR, 1215, 3, 344, 349,1.,0.,1.
CBAR, 1216, 3, 342, 351,1.,0.,1.
CBAR, 1217, 3, 349, 360,1.,0.,1.
CBAR, 1218, 3, 351, 358,1.,0.,1.
CBAR, 1219, 3, 360, 365,1.,0.,1.
CBAR, 1220, 3, 358, 367,1.,0.,1.
CBAR, 1221, 3, 365, 376,1.,0.,1.
CBAR, 1222, 3, 367, 374,1.,0.,1.
CBAR, 1223, 3, 376, 381,1.,0.,1.
CBAR, 1224, 3, 374, 383,1.,0.,1.
CBAR, 1225, 3, 381, 392,1.,0.,1.
CBAR, 1226, 3, 383, 390,1.,0.,1.
CBAR, 1227, 3, 49, 314,1.,0.,1.
CBAR, 1228, 3, 56, 316,1.,0.,1.
CBAR, 1229, 3, 314, 321,1.,0.,1.
CBAR, 1230, 3, 316, 323,1.,0.,1.
CBAR, 1231, 3, 321, 330,1.,0.,1.
CBAR, 1232, 3, 323, 332,1.,0.,1.
CBAR, 1233, 3, 330, 337,1.,0.,1.
CBAR, 1234, 3, 332, 339,1.,0.,1.
CBAR, 1235, 3, 337, 346,1.,0.,1.
CBAR, 1236, 3, 339, 348,1.,0.,1.
CBAR, 1237, 3, 346, 353,1.,0.,1.
CBAR, 1238, 3, 348, 355,1.,0.,1.
CBAR, 1239, 3, 353, 362,1.,0.,1.
CBAR, 1240, 3, 355, 364,1.,0.,1.
CBAR, 1241, 3, 362, 369,1.,0.,1.
CBAR, 1242, 3, 364, 371,1.,0.,1.
CBAR, 1243, 3, 369, 378,1.,0.,1.
CBAR, 1244, 3, 371, 380,1.,0.,1.
CBAR, 1245, 3, 378, 385,1.,0.,1.
CBAR, 1246, 3, 380, 387,1.,0.,1.
CBAR, 1247, 3, 54, 317,1.,0.,1.
CBAR, 1248, 3, 51, 319,1.,0.,1.
CBAR, 1249, 3, 317, 326,1.,0.,1.

CBAR, 1250, 3, 319, 328,1.,0.,1.
CBAR, 1251, 3, 326, 333,1.,0.,1.
CBAR, 1252, 3, 328, 335,1.,0.,1.
CBAR, 1253, 3, 333, 342,1.,0.,1.
CBAR, 1254, 3, 335, 344,1.,0.,1.
CBAR, 1255, 3, 342, 349,1.,0.,1.
CBAR, 1256, 3, 344, 351,1.,0.,1.
CBAR, 1257, 3, 349, 358,1.,0.,1.
CBAR, 1258, 3, 351, 360,1.,0.,1.
CBAR, 1259, 3, 358, 365,1.,0.,1.
CBAR, 1260, 3, 360, 367,1.,0.,1.
CBAR, 1261, 3, 365, 374,1.,0.,1.
CBAR, 1262, 3, 367, 376,1.,0.,1.
CBAR, 1263, 3, 374, 381,1.,0.,1.
CBAR, 1264, 3, 376, 383,1.,0.,1.
CBAR, 1265, 3, 381, 390,1.,0.,1.
CBAR, 1266, 3, 383, 392,1.,0.,1.
CBAR, 1267, 2, 221, 397,1.,0.,1.
CBAR, 1268, 2, 225, 398,1.,0.,1.
CBAR, 1269, 2, 228, 399,1.,0.,1.
CBAR, 1270, 2, 224, 400,1.,0.,1.
CBAR, 1271, 2, 397, 405,1.,0.,1.
CBAR, 1272, 2, 398, 406,1.,0.,1.
CBAR, 1273, 2, 399, 407,1.,0.,1.
CBAR, 1274, 2, 400, 408,1.,0.,1.
CBAR, 1275, 2, 405, 413,1.,0.,1.
CBAR, 1276, 2, 406, 414,1.,0.,1.
CBAR, 1277, 2, 407, 415,1.,0.,1.
CBAR, 1278, 2, 408, 416,1.,0.,1.
CBAR, 1279, 2, 413, 421,1.,0.,1.
CBAR, 1280, 2, 414, 422,1.,0.,1.
CBAR, 1281, 2, 415, 423,1.,0.,1.
CBAR, 1282, 2, 416, 424,1.,0.,1.
CBAR, 1283, 2, 421, 429,1.,0.,1.
CBAR, 1284, 2, 422, 430,1.,0.,1.
CBAR, 1285, 2, 423, 431,1.,0.,1.
CBAR, 1286, 2, 424, 432,1.,0.,1.
CBAR, 1287, 2, 429, 437,1.,0.,1.
CBAR, 1288, 2, 430, 438,1.,0.,1.
CBAR, 1289, 2, 431, 439,1.,0.,1.
CBAR, 1290, 2, 432, 440,1.,0.,1.
CBAR, 1291, 2, 437, 445,1.,0.,1.
CBAR, 1292, 2, 438, 446,1.,0.,1.
CBAR, 1293, 2, 439, 447,1.,0.,1.
CBAR, 1294, 2, 440, 448,1.,0.,1.
CBAR, 1295, 2, 445, 453,1.,0.,1.
CBAR, 1296, 2, 446, 454,1.,0.,1.
CBAR, 1297, 2, 447, 455,1.,0.,1.
CBAR, 1298, 2, 448, 456,1.,0.,1.
CBAR, 1299, 2, 453, 461,1.,0.,1.
CBAR, 1300, 2, 454, 462,1.,0.,1.
CBAR, 1301, 2, 455, 463,1.,0.,1.
CBAR, 1302, 2, 456, 464,1.,0.,1.
CBAR, 1303, 2, 461, 469,1.,0.,1.

CBAR, 1304, 2, 462, 470,1.,0.,1.
CBAR, 1305, 2, 463, 471,1.,0.,1.
CBAR, 1306, 2, 464, 472,1.,0.,1.
CBAR, 1307, 2, 222, 401,1.,0.,1.
CBAR, 1308, 2, 226, 402,1.,0.,1.
CBAR, 1309, 2, 227, 403,1.,0.,1.
CBAR, 1310, 2, 223, 404,1.,0.,1.
CBAR, 1311, 2, 401, 409,1.,0.,1.
CBAR, 1312, 2, 402, 410,1.,0.,1.
CBAR, 1313, 2, 403, 411,1.,0.,1.
CBAR, 1314, 2, 404, 412,1.,0.,1.
CBAR, 1315, 2, 409, 417,1.,0.,1.
CBAR, 1316, 2, 410, 418,1.,0.,1.
CBAR, 1317, 2, 411, 419,1.,0.,1.
CBAR, 1318, 2, 412, 420,1.,0.,1.
CBAR, 1319, 2, 417, 425,1.,0.,1.
CBAR, 1320, 2, 418, 426,1.,0.,1.
CBAR, 1321, 2, 419, 427,1.,0.,1.
CBAR, 1322, 2, 420, 428,1.,0.,1.
CBAR, 1323, 2, 425, 433,1.,0.,1.
CBAR, 1324, 2, 426, 434,1.,0.,1.
CBAR, 1325, 2, 427, 435,1.,0.,1.
CBAR, 1326, 2, 428, 436,1.,0.,1.
CBAR, 1327, 2, 433, 441,1.,0.,1.
CBAR, 1328, 2, 434, 442,1.,0.,1.
CBAR, 1329, 2, 435, 443,1.,0.,1.
CBAR, 1330, 2, 436, 444,1.,0.,1.
CBAR, 1331, 2, 441, 449,1.,0.,1.
CBAR, 1332, 2, 442, 450,1.,0.,1.
CBAR, 1333, 2, 443, 451,1.,0.,1.
CBAR, 1334, 2, 444, 452,1.,0.,1.
CBAR, 1335, 2, 449, 457,1.,0.,1.
CBAR, 1336, 2, 450, 458,1.,0.,1.
CBAR, 1337, 2, 451, 459,1.,0.,1.
CBAR, 1338, 2, 452, 460,1.,0.,1.
CBAR, 1339, 2, 457, 465,1.,0.,1.
CBAR, 1340, 2, 458, 466,1.,0.,1.
CBAR, 1341, 2, 459, 467,1.,0.,1.
CBAR, 1342, 2, 460, 468,1.,0.,1.
CBAR, 1343, 2, 465, 473,1.,0.,1.
CBAR, 1344, 2, 466, 474,1.,0.,1.
CBAR, 1345, 2, 467, 475,1.,0.,1.
CBAR, 1346, 2, 468, 476,1.,0.,1.
CBAR, 1347, 1, 397, 398,0.,1.,1.
CBAR, 1348, 1, 398, 399,0.,1.,1.
CBAR, 1349, 1, 399, 400,0.,1.,1.
CBAR, 1350, 1, 400, 397,0.,1.,1.
CBAR, 1351, 1, 405, 406,0.,1.,1.
CBAR, 1352, 1, 406, 407,0.,1.,1.
CBAR, 1353, 1, 407, 408,0.,1.,1.
CBAR, 1354, 1, 408, 405,0.,1.,1.
CBAR, 1355, 1, 413, 414,0.,1.,1.
CBAR, 1356, 1, 414, 415,0.,1.,1.
CBAR, 1357, 1, 415, 416,0.,1.,1.

CBAR, 1358, 1, 416, 413,0.,1.,1.
CBAR, 1359, 1, 421, 422,0.,1.,1.
CBAR, 1360, 1, 422, 423,0.,1.,1.
CBAR, 1361, 1, 423, 424,0.,1.,1.
CBAR, 1362, 1, 424, 421,0.,1.,1.
CBAR, 1363, 1, 429, 430,0.,1.,1.
CBAR, 1364, 1, 430, 431,0.,1.,1.
CBAR, 1365, 1, 431, 432,0.,1.,1.
CBAR, 1366, 1, 432, 429,0.,1.,1.
CBAR, 1367, 1, 437, 438,0.,1.,1.
CBAR, 1368, 1, 438, 439,0.,1.,1.
CBAR, 1369, 1, 439, 440,0.,1.,1.
CBAR, 1370, 1, 440, 437,0.,1.,1.
CBAR, 1371, 1, 445, 446,0.,1.,1.
CBAR, 1372, 1, 446, 447,0.,1.,1.
CBAR, 1373, 1, 447, 448,0.,1.,1.
CBAR, 1374, 1, 448, 445,0.,1.,1.
CBAR, 1375, 1, 453, 454,0.,1.,1.
CBAR, 1376, 1, 454, 455,0.,1.,1.
CBAR, 1377, 1, 455, 456,0.,1.,1.
CBAR, 1378, 1, 456, 453,0.,1.,1.
CBAR, 1379, 1, 461, 462,0.,1.,1.
CBAR, 1380, 1, 462, 463,0.,1.,1.
CBAR, 1381, 1, 463, 464,0.,1.,1.
CBAR, 1382, 1, 464, 461,0.,1.,1.
CBAR, 1383, 1, 469, 470,0.,1.,1.
CBAR, 1384, 1, 470, 471,0.,1.,1.
CBAR, 1385, 1, 471, 472,0.,1.,1.
CBAR, 1386, 1, 472, 469,0.,1.,1.
CBAR, 1387, 1, 401, 402,0.,1.,1.
CBAR, 1388, 1, 402, 403,0.,1.,1.
CBAR, 1389, 1, 403, 404,0.,1.,1.
CBAR, 1390, 1, 404, 401,0.,1.,1.
CBAR, 1391, 1, 409, 410,0.,1.,1.
CBAR, 1392, 1, 410, 411,0.,1.,1.
CBAR, 1393, 1, 411, 412,0.,1.,1.
CBAR, 1394, 1, 412, 409,0.,1.,1.
CBAR, 1395, 1, 417, 418,0.,1.,1.
CBAR, 1396, 1, 418, 419,0.,1.,1.
CBAR, 1397, 1, 419, 420,0.,1.,1.
CBAR, 1398, 1, 420, 417,0.,1.,1.
CBAR, 1399, 1, 425, 426,0.,1.,1.
CBAR, 1400, 1, 426, 427,0.,1.,1.
CBAR, 1401, 1, 427, 428,0.,1.,1.
CBAR, 1402, 1, 428, 425,0.,1.,1.
CBAR, 1403, 1, 433, 434,0.,1.,1.
CBAR, 1404, 1, 434, 435,0.,1.,1.
CBAR, 1405, 1, 435, 436,0.,1.,1.
CBAR, 1406, 1, 436, 433,0.,1.,1.
CBAR, 1407, 1, 441, 442,0.,1.,1.
CBAR, 1408, 1, 442, 443,0.,1.,1.
CBAR, 1409, 1, 443, 444,0.,1.,1.
CBAR, 1410, 1, 444, 441,0.,1.,1.
CBAR, 1411, 1, 449, 450,0.,1.,1.

CBAR, 1412, 1, 450, 451,0.,1.,1.
CBAR, 1413, 1, 451, 452,0.,1.,1.
CBAR, 1414, 1, 452, 449,0.,1.,1.
CBAR, 1415, 1, 457, 458,0.,1.,1.
CBAR, 1416, 1, 458, 459,0.,1.,1.
CBAR, 1417, 1, 459, 460,0.,1.,1.
CBAR, 1418, 1, 460, 457,0.,1.,1.
CBAR, 1419, 1, 465, 466,0.,1.,1.
CBAR, 1420, 1, 466, 467,0.,1.,1.
CBAR, 1421, 1, 467, 468,0.,1.,1.
CBAR, 1422, 1, 468, 465,0.,1.,1.
CBAR, 1423, 1, 473, 474,0.,1.,1.
CBAR, 1424, 1, 474, 475,0.,1.,1.
CBAR, 1425, 1, 475, 476,0.,1.,1.
CBAR, 1426, 1, 476, 473,0.,1.,1.
CBAR, 1427,13, 398, 400,0.,1.,1.
CBAR, 1428,13, 405, 407,0.,1.,1.
CBAR, 1429,13, 414, 416,0.,1.,1.
CBAR, 1430,13, 421, 423,0.,1.,1.
CBAR, 1431,13, 430, 432,0.,1.,1.
CBAR, 1432,13, 437, 439,0.,1.,1.
CBAR, 1433,13, 446, 448,0.,1.,1.
CBAR, 1434,13, 453, 455,0.,1.,1.
CBAR, 1435,13, 462, 464,0.,1.,1.
CBAR, 1436,13, 469, 471,0.,1.,1.
CBAR, 1437,13, 401, 403,0.,1.,1.
CBAR, 1438,13, 410, 412,0.,1.,1.
CBAR, 1439,13, 417, 419,0.,1.,1.
CBAR, 1440,13, 426, 428,0.,1.,1.
CBAR, 1441,13, 433, 435,0.,1.,1.
CBAR, 1442,13, 442, 444,0.,1.,1.
CBAR, 1443,13, 449, 451,0.,1.,1.
CBAR, 1444,13, 458, 460,0.,1.,1.
CBAR, 1445,13, 465, 467,0.,1.,1.
CBAR, 1446,13, 474, 476,0.,1.,1.
CBAR, 1447, 3, 224, 397,1.,0.,1.
CBAR, 1448, 3, 399, 225,1.,0.,1.
CBAR, 1449, 3, 397, 408,1.,0.,1.
CBAR, 1450, 3, 406, 399,1.,0.,1.
CBAR, 1451, 3, 408, 413,1.,0.,1.
CBAR, 1452, 3, 415, 406,1.,0.,1.
CBAR, 1453, 3, 413, 424,1.,0.,1.
CBAR, 1454, 3, 422, 415,1.,0.,1.
CBAR, 1455, 3, 424, 429,1.,0.,1.
CBAR, 1456, 3, 431, 422,1.,0.,1.
CBAR, 1457, 3, 429, 440,1.,0.,1.
CBAR, 1458, 3, 438, 431,1.,0.,1.
CBAR, 1459, 3, 440, 445,1.,0.,1.
CBAR, 1460, 3, 447, 438,1.,0.,1.
CBAR, 1461, 3, 445, 456,1.,0.,1.
CBAR, 1462, 3, 454, 447,1.,0.,1.
CBAR, 1463, 3, 456, 461,1.,0.,1.
CBAR, 1464, 3, 463, 454,1.,0.,1.
CBAR, 1465, 3, 461, 472,1.,0.,1.

CBAR, 1466, 3, 470, 463,1.,0.,1.
CBAR, 1467, 3, 222, 404,1.,0.,1.
CBAR, 1468, 3, 227, 402,1.,0.,1.
CBAR, 1469, 3, 404, 409,1.,0.,1.
CBAR, 1470, 3, 402, 411,1.,0.,1.
CBAR, 1471, 3, 409, 420,1.,0.,1.
CBAR, 1472, 3, 411, 418,1.,0.,1.
CBAR, 1473, 3, 420, 425,1.,0.,1.
CBAR, 1474, 3, 418, 427,1.,0.,1.
CBAR, 1475, 3, 425, 436,1.,0.,1.
CBAR, 1476, 3, 427, 434,1.,0.,1.
CBAR, 1477, 3, 436, 441,1.,0.,1.
CBAR, 1478, 3, 434, 443,1.,0.,1.
CBAR, 1479, 3, 441, 452,1.,0.,1.
CBAR, 1480, 3, 443, 450,1.,0.,1.
CBAR, 1481, 3, 452, 457,1.,0.,1.
CBAR, 1482, 3, 450, 459,1.,0.,1.
CBAR, 1483, 3, 457, 468,1.,0.,1.
CBAR, 1484, 3, 459, 466,1.,0.,1.
CBAR, 1485, 3, 468, 473,1.,0.,1.
CBAR, 1486, 3, 466, 475,1.,0.,1.
CBAR, 1487, 3, 225, 397,1.,0.,1.
CBAR, 1488, 3, 224, 399,1.,0.,1.
CBAR, 1489, 3, 397, 406,1.,0.,1.
CBAR, 1490, 3, 399, 408,1.,0.,1.
CBAR, 1491, 3, 406, 413,1.,0.,1.
CBAR, 1492, 3, 408, 415,1.,0.,1.
CBAR, 1493, 3, 413, 422,1.,0.,1.
CBAR, 1494, 3, 415, 424,1.,0.,1.
CBAR, 1495, 3, 422, 429,1.,0.,1.
CBAR, 1496, 3, 424, 431,1.,0.,1.
CBAR, 1497, 3, 429, 438,1.,0.,1.
CBAR, 1498, 3, 431, 440,1.,0.,1.
CBAR, 1499, 3, 438, 445,1.,0.,1.
CBAR, 1500, 3, 440, 447,1.,0.,1.
CBAR, 1501, 3, 445, 454,1.,0.,1.
CBAR, 1502, 3, 447, 456,1.,0.,1.
CBAR, 1503, 3, 454, 461,1.,0.,1.
CBAR, 1504, 3, 456, 463,1.,0.,1.
CBAR, 1505, 3, 461, 470,1.,0.,1.
CBAR, 1506, 3, 463, 472,1.,0.,1.
CBAR, 1507, 3, 222, 402,1.,0.,1.
CBAR, 1508, 3, 227, 404,1.,0.,1.
CBAR, 1509, 3, 402, 409,1.,0.,1.
CBAR, 1510, 3, 404, 411,1.,0.,1.
CBAR, 1511, 3, 409, 418,1.,0.,1.
CBAR, 1512, 3, 411, 420,1.,0.,1.
CBAR, 1513, 3, 418, 425,1.,0.,1.
CBAR, 1514, 3, 420, 427,1.,0.,1.
CBAR, 1515, 3, 425, 434,1.,0.,1.
CBAR, 1516, 3, 427, 436,1.,0.,1.
CBAR, 1517, 3, 434, 441,1.,0.,1.
CBAR, 1518, 3, 436, 443,1.,0.,1.
CBAR, 1519, 3, 441, 450,1.,0.,1.

CBAR, 1520, 3, 443, 452,1.,0.,1.
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 CBAR, 1522, 3, 452, 459,1.,0.,1.
 CBAR, 1523, 3, 457, 466,1.,0.,1.
 CBAR, 1524, 3, 459, 468,1.,0.,1.
 CBAR, 1525, 3, 466, 473,1.,0.,1.
 CBAR, 1526, 3, 468, 475,1.,0.,1.
 CROD, 1527,14, 481, 396
 CROD, 1528,14, 396, 393
 CROD, 1529,14, 396, 394
 CROD, 1530,14, 482, 480
 CROD, 1531,14, 480, 477
 CROD, 1532,14, 480, 478
 CBAR, 1535,11, 385, 393, 377
 CBAR, 1536,11, 393, 386, 378
 CBAR, 1537,11, 389, 394, 381
 CBAR, 1538,11, 394, 390, 382
 CBAR, 1539,11, 469, 477, 461
 CBAR, 1540,11, 477, 470, 462
 CBAR, 1541,11, 473, 478, 465
 CBAR, 1542,11, 478, 474, 466
 ECHCON
 \$ SMALL RFL PLATE
 CQUAD4, 1600, 40, 1, 2, 3, 4
 \$ THRUSTER PLATES FOLLOW
 \$ REVISED 90/11/28
 \$ MAIN TRUSS, FWD
 CTRIA3, 1601, 15, 1, 5,489
 CTRIA3, 1602, 15, 5, 6,489
 CTRIA3, 1603, 15, 6, 2,489
 CTRIA3, 1604, 15, 2, 1,489
 CTRIA3, 1605, 15, 2, 6,490
 CTRIA3, 1606, 15, 6, 7,490
 CTRIA3, 1607, 15, 7, 3,490
 CTRIA3, 1608, 15, 3, 2,490
 CTRIA3, 1609, 15, 4, 8,491
 CTRIA3, 1610, 15, 8, 7,491
 CTRIA3, 1611, 15, 7, 3,491
 CTRIA3, 1612, 15, 3, 4,491
 CTRIA3, 1613, 15, 1, 5,492
 CTRIA3, 1614, 15, 5, 8,492
 CTRIA3, 1615, 15, 8, 4,492
 CTRIA3, 1616, 15, 4, 1,492
 \$ TOWER TRUSS
 CTRIA3, 1621, 15,305,308,493
 CTRIA3, 1622, 15,308,304,493
 CTRIA3, 1623, 15,304,301,493
 CTRIA3, 1624, 15,301,305,493
 CTRIA3, 1625, 15,308,307,494
 CTRIA3, 1626, 15,307,303,494
 CTRIA3, 1627, 15,303,304,494
 CTRIA3, 1628, 15,304,308,494
 CTRIA3, 1629, 15,307,306,495
 CTRIA3, 1630, 15,306,302,495

CTRIA3, 1631, 15,302,303,495
 CTRIA3, 1632, 15,303,307,495
 CTRIA3, 1633, 15,306,305,496
 CTRIA3, 1634, 15,305,301,496
 CTRIA3, 1635, 15,301,302,496
 CTRIA3, 1636, 15,302,306,496
\$ MAIN TRUSS, MIDDLE
 CTRIA3, 1641, 15,129,133,498
 CTRIA3, 1642, 15,133,134,498
 CTRIA3, 1643, 15,134,130,498
 CTRIA3, 1644, 15,130,129,498
 CTRIA3, 1645, 15,130,131,499
 CTRIA3, 1646, 15,131,135,499
 CTRIA3, 1647, 15,135,134,499
 CTRIA3, 1648, 15,134,130,499
 CTRIA3, 1649, 15,132,131,500
 CTRIA3, 1650, 15,131,135,500
 CTRIA3, 1651, 15,135,136,500
 CTRIA3, 1652, 15,136,132,500
 CTRIA3, 1653, 15,129,132,501
 CTRIA3, 1654, 15,132,136,501
 CTRIA3, 1655, 15,136,133,501
 CTRIA3, 1656, 15,133,129,501
\$ RFL TRUSS
 CTRIA3, 1661, 15,265,268,502
 CTRIA3, 1662, 15,268,264,502
 CTRIA3, 1663, 15,264,261,502
 CTRIA3, 1664, 15,261,265,502
 CTRIA3, 1665, 15,268,267,503
 CTRIA3, 1666, 15,267,263,503
 CTRIA3, 1667, 15,263,264,503
 CTRIA3, 1668, 15,264,268,503
 CTRIA3, 1669, 15,266,267,504
 CTRIA3, 1670, 15,267,263,504
 CTRIA3, 1671, 15,263,262,504
 CTRIA3, 1672, 15,262,266,504
 CTRIA3, 1673, 15,266,265,505
 CTRIA3, 1674, 15,265,261,505
 CTRIA3, 1675, 15,261,262,505
 CTRIA3, 1676, 15,262,266,505
\$ LASER
 CTRIA3, 1681, 15,310,311,497
 CTRIA3, 1682, 15,311,312,497
 CTRIA3, 1683, 15,312,309,497
 CTRIA3, 1684, 15,309,310,497
\$ CONTROLLER PLATES 90/09/25
 CQUAD4, 1691, 15,101,102,103,104
 CQUAD4, 1692, 15,165,166,167,168
ECHOFF
\$ START REFLECTOR EID'S
 CBAR, 2001,16,2001,2002,0.,0.,1.
 CBAR, 2002,16,2014,2015,0.,0.,1.
 CBAR, 2003,16,2027,2028,0.,0.,1.
 CBAR, 2004,16,2040,2041,0.,0.,1.

CBAR, 2005,16,2053,2054,0.,0.,1.
CBAR, 2006,16,2066,2067,0.,0.,1.
CBAR, 2007,16,2079,2080,0.,0.,1.
CBAR, 2008,16,2092,2093,0.,0.,1.
CBAR, 2009,17,2002,2003,0.,0.,1.
CBAR, 2010,17,2015,2016,0.,0.,1.
CBAR, 2011,17,2028,2029,0.,0.,1.
CBAR, 2012,17,2041,2042,0.,0.,1.
CBAR, 2013,17,2054,2055,0.,0.,1.
CBAR, 2014,17,2067,2068,0.,0.,1.
CBAR, 2015,17,2080,2081,0.,0.,1.
CBAR, 2016,17,2093,2094,0.,0.,1.
\$ CBAR 2017 T 2024 UPDATED 90/09/25
CBAR, 2017,18,2003,2123,0.,0.,1.
CBAR, 2018,18,2016,2124,0.,0.,1.
CBAR, 2019,18,2029,2125,0.,0.,1.
CBAR, 2020,18,2042,2126,0.,0.,1.
CBAR, 2021,18,2055,2127,0.,0.,1.
CBAR, 2022,18,2068,2128,0.,0.,1.
CBAR, 2023,18,2081,2129,0.,0.,1.
CBAR, 2024,18,2094,2130,0.,0.,1.
\$ CBAR 2025 T 2032 UPDATED 90/09/25
CBAR, 2025,19,2004,2005,0.,0.,1.
CBAR, 2026,19,2017,2018,0.,0.,1.
CBAR, 2027,19,2030,2031,0.,0.,1.
CBAR, 2028,19,2043,2044,0.,0.,1.
CBAR, 2029,19,2056,2057,0.,0.,1.
CBAR, 2030,19,2069,2070,0.,0.,1.
CBAR, 2031,19,2082,2083,0.,0.,1.
CBAR, 2032,19,2095,2096,0.,0.,1.
CBAR, 2033,20,2005,2006,0.,0.,1.
CBAR, 2034,20,2018,2019,0.,0.,1.
CBAR, 2035,20,2031,2032,0.,0.,1.
CBAR, 2036,20,2044,2045,0.,0.,1.
CBAR, 2037,20,2057,2058,0.,0.,1.
CBAR, 2038,20,2070,2071,0.,0.,1.
CBAR, 2039,20,2083,2084,0.,0.,1.
CBAR, 2040,20,2096,2097,0.,0.,1.
CBAR, 2041,21,2006,2008,0.,0.,1.
CBAR, 2042,21,2019,2021,0.,0.,1.
CBAR, 2043,21,2032,2034,0.,0.,1.
CBAR, 2044,21,2045,2047,0.,0.,1.
CBAR, 2045,21,2058,2060,0.,0.,1.
CBAR, 2046,21,2071,2073,0.,0.,1.
CBAR, 2047,21,2084,2086,0.,0.,1.
CBAR, 2048,21,2097,2099,0.,0.,1.
CBAR, 2049,21,2008,2009,0.,0.,1.
CBAR, 2050,21,2021,2022,0.,0.,1.
CBAR, 2051,21,2034,2035,0.,0.,1.
CBAR, 2052,21,2047,2048,0.,0.,1.
CBAR, 2053,21,2060,2061,0.,0.,1.
CBAR, 2054,21,2073,2074,0.,0.,1.
CBAR, 2055,21,2086,2087,0.,0.,1.
CBAR, 2056,21,2099,2100,0.,0.,1.

CBAR, 2057,21,2009,2010,0.,0.,1.
 CBAR, 2058,21,2022,2023,0.,0.,1.
 CBAR, 2059,21,2035,2036,0.,0.,1.
 CBAR, 2060,21,2048,2049,0.,0.,1.
 CBAR, 2061,21,2061,2062,0.,0.,1.
 CBAR, 2062,21,2074,2075,0.,0.,1.
 CBAR, 2063,21,2087,2088,0.,0.,1.
 CBAR, 2064,21,2100,2101,0.,0.,1.
 CBAR, 2065,21,2010,2011,0.,0.,1.
 CBAR, 2066,21,2023,2024,0.,0.,1.
 CBAR, 2067,21,2036,2037,0.,0.,1.
 CBAR, 2068,21,2049,2050,0.,0.,1.
 CBAR, 2069,21,2062,2063,0.,0.,1.
 CBAR, 2070,21,2075,2076,0.,0.,1.
 CBAR, 2071,21,2088,2089,0.,0.,1.
 CBAR, 2072,21,2101,2102,0.,0.,1.

\$ END RIBS

CBAR, 2073,23,2010,2012,2062
 CBAR, 2074,23,2023,2025,2075
 CBAR, 2075,23,2036,2038,2088
 CBAR, 2076,23,2049,2051,2101
 CBAR, 2077,23,2062,2064,2010
 CBAR, 2078,23,2075,2077,2023
 CBAR, 2079,23,2088,2090,2036
 CBAR, 2080,23,2101,2103,2049

\$

CBAR, 2081,23,2011,2013,2063
 CBAR, 2082,23,2024,2026,2076
 CBAR, 2083,23,2037,2039,2089
 CBAR, 2084,23,2050,2052,2102
 CBAR, 2085,23,2063,2065,2011
 CBAR, 2086,23,2076,2078,2024
 CBAR, 2087,23,2089,2091,2037
 CBAR, 2088,23,2102,2104,2050

\$ START CONNECTORS BETWEEN RIBS AND SENSOR PLATE

\$ changed 2089 t 2096 to rods 91/01/17

crod, 2089,24,2006,2007
 crod, 2090,24,2019,2020
 crod, 2091,24,2032,2033
 crod, 2092,24,2045,2046
 crod, 2093,24,2058,2059
 crod, 2094,24,2071,2072
 crod, 2095,24,2084,2085
 crod, 2096,24,2097,2098

\$ START COMPRESSION MEMBERS BETWEEN PLATES, D=.375"

CBAR, 2097,30,2107,2115,1.,1.,0.
 CBAR, 2098,30,2109,2117,1.,1.,0.
 CBAR, 2099,30,2111,2119,1.,1.,0.
 CBAR, 2100,30,2113,2121,1.,1.,0.

\$ START TENSION CABLE AT TIP OF RIBS

CROD, 2101, 22, 2001, 2014
 CROD, 2102, 22, 2014, 2027
 CROD, 2103, 22, 2027, 2040
 CROD, 2104, 22, 2040, 2053

CROD, 2105, 22, 2053, 2066
 CROD, 2106, 22, 2066, 2079
 CROD, 2107, 22, 2079, 2092
 CROD, 2108, 22, 2092, 2001
 CTRIA3 2109 26 2107 2012 2013 0.
 CTRIA3 2110 26 2012 2108 2013 0.
 CTRIA3 2111 26 2108 2025 2026 0.
 CTRIA3 2112 26 2025 2109 2026 0.
 CTRIA3 2113 26 2109 2038 2039 0.
 CTRIA3 2114 26 2038 2110 2039 0.
 CTRIA3 2115 26 2110 2051 2052 0.
 CTRIA3 2116 26 2051 2111 2052 0.
 CTRIA3 2117 26 2111 2064 2065 0.
 CTRIA3 2118 26 2064 2112 2065 0.
 CTRIA3 2119 26 2112 2077 2078 0.
 CTRIA3 2120 26 2077 2113 2078 0.
 CTRIA3 2121 26 2113 2090 2091 0.
 CTRIA3 2122 26 2090 2114 2091 0.
 CTRIA3 2123 26 2114 2103 2104 0.
 CTRIA3 2124 26 2103 2107 2104 0.
 CTRIA3 2125 26 2104 2013 2107 0.
 CTRIA3 2126 26 2013 2026 2108 0.
 CTRIA3 2127 26 2026 2039 2109 0.
 CTRIA3 2128 26 2039 2052 2110 0.
 CTRIA3 2129 26 2052 2065 2111 0.
 CTRIA3 2130 26 2065 2078 2112 0.
 CTRIA3 2131 26 2078 2091 2113 0.
 CTRIA3 2132 26 2091 2104 2114 0.
 CTRIA3 2133 25 2098 2007 2115 0.
 CTRIA3 2134 25 2007 2020 2116 0.
 CTRIA3 2135 25 2020 2033 2117 0.
 CTRIA3 2136 25 2033 2046 2118 0.
 CTRIA3 2137 25 2046 2059 2119 0.
 CTRIA3 2138 25 2059 2072 2120 0.
 CTRIA3 2139 25 2072 2085 2121 0.
 CTRIA3 2140 25 2085 2098 2122 0.
 CTRIA3 2141 25 2115 2116 2007 0.
 CTRIA3 2142 25 2116 2117 2020 0.
 CTRIA3 2143 25 2117 2118 2033 0.
 CTRIA3 2144 25 2118 2119 2046 0.
 CTRIA3 2145 25 2119 2120 2059 0.
 CTRIA3 2146 25 2120 2121 2072 0.
 CTRIA3 2147 25 2121 2122 2085 0.
 CTRIA3 2148 25 2122 2115 2098 0.
 CTRIA3 2149 25 2115 2116 2106 0.
 CTRIA3 2150 25 2116 2117 2106 0.
 CTRIA3 2151 25 2117 2118 2106 0.
 CTRIA3 2152 25 2118 2119 2106 0.
 CTRIA3 2153 25 2119 2120 2106 0.
 CTRIA3 2154 25 2120 2121 2106 0.
 CTRIA3 2155 25 2121 2122 2106 0.
 CTRIA3 2156 25 2122 2115 2106 0.
 \$ START RFL SUPPORT BRACKET BEAMS
 CBAR, 2157,27, 265, 485,266

CBAR, 2158,27, 266, 486,267
 CBAR, 2159,27, 267, 487,268
 CBAR, 2160,27, 268, 488,265
 CBAR, 2161,28, 267, 488,485
 CBAR, 2162,28, 268, 487,486
 CBAR, 2163,28, 265, 486,487
 CBAR, 2164,28, 266, 485,488
 CBAR, 2165,28, 265, 488,487
 CBAR, 2166,28, 266, 487,488
 CBAR, 2167,29, 485, 488,487
 CBAR, 2168,29, 486, 487,488
 \$ RIBS WITH NEW GRID PTS. 90/09/25
 CBAR, 2169,19,2123,2004,0.,0.,1.
 CBAR, 2170,19,2124,2017,0.,0.,1.
 CBAR, 2171,19,2125,2030,0.,0.,1.
 CBAR, 2172,19,2126,2043,0.,0.,1.
 CBAR, 2173,19,2127,2056,0.,0.,1.
 CBAR, 2174,19,2128,2069,0.,0.,1.
 CBAR, 2175,19,2129,2082,0.,0.,1.
 CBAR, 2176,19,2130,2095,0.,0.,1.

ECHOON

\$ SPRINGS AT TOP OF SUSPENSION CABLE

CELAS2, 2201, 27.43, 395, 3, 481, 3
 CELAS2, 2202, 28.88, 479, 3, 482, 3

\$ 1/4" DIAM BOLTS WHICH CONNECT RFL; BASE PLATE TO SUPPORT STRUCTURE

CELAS2, 2211, 1.5E+08, 488, 1, 2108, 1
 CELAS2, 2212, 1.5E+08, 488, 2, 2108, 2
 CELAS2, 2213, 1.5E+08, 488, 3, 2108, 3
 CELAS2, 2214, 1.5E+08, 488, 4, 2108, 4
 CELAS2, 2215, 1.5E+08, 488, 5, 2108, 5
 CELAS2, 2216, 1.5E+08, 488, 6, 2108, 6
 CELAS2, 2217, 1.5E+08, 485, 1, 2110, 1
 CELAS2, 2218, 1.5E+08, 485, 2, 2110, 2
 CELAS2, 2219, 1.5E+08, 485, 3, 2110, 3
 CELAS2, 2220, 1.5E+08, 485, 4, 2110, 4
 CELAS2, 2221, 1.5E+08, 485, 5, 2110, 5
 CELAS2, 2222, 1.5E+08, 485, 6, 2110, 6
 CELAS2, 2223, 1.5E+08, 486, 1, 2112, 1
 CELAS2, 2224, 1.5E+08, 486, 2, 2112, 2
 CELAS2, 2225, 1.5E+08, 486, 3, 2112, 3
 CELAS2, 2226, 1.5E+08, 486, 4, 2112, 4
 CELAS2, 2227, 1.5E+08, 486, 5, 2112, 5
 CELAS2, 2228, 1.5E+08, 486, 6, 2112, 6
 CELAS2, 2229, 1.5E+08, 487, 1, 2114, 1
 CELAS2, 2230, 1.5E+08, 487, 2, 2114, 2
 CELAS2, 2231, 1.5E+08, 487, 3, 2114, 3
 CELAS2, 2232, 1.5E+08, 487, 4, 2114, 4
 CELAS2, 2233, 1.5E+08, 487, 5, 2114, 5
 CELAS2, 2234, 1.5E+08, 487, 6, 2114, 6

\$ air tubing stiffness at thruster locations

CELAS2, 2241, .175, 1, 1
 CELAS2, 2242, .127, 1, 2
 CELAS2, 2243, .200, 1, 3
 CELAS2, 2244, .175, 129, 1

CELAS2, 2245, .2606, 129, 2
CELAS2, 2246, .200, 129, 3
CELAS2, 2247, .175, 265, 1
CELAS2, 2248, .2606, 265, 2
CELAS2, 2249, .200, 265, 3
CELAS2, 2250, .175, 309, 1
CELAS2, 2251, .127, 309, 2
CELAS2, 2252, .200, 309, 3

\$ START JOINT LUMPED MASSES

\$ joint mass = ball mass (5.055e-04 lb-s**2/in)

CONM2, 3001, 1, 0.5.055e-4
CONM2, 3002, 2, 0.5.055e-4
CONM2, 3003, 3, 0.5.055e-4
CONM2, 3004, 4, 0.5.055e-4
CONM2, 3005, 5, 0.5.055e-4
CONM2, 3006, 6, 0.5.055e-4
CONM2, 3007, 7, 0.5.055e-4
CONM2, 3008, 8, 0.5.055e-4
CONM2, 3009, 9, 0.5.055e-4
CONM2, 3010, 10, 0.5.055e-4
CONM2, 3011, 11, 0.5.055e-4
CONM2, 3012, 12, 0.5.055e-4
CONM2, 3013, 13, 0.5.055e-4
CONM2, 3014, 14, 0.5.055e-4
CONM2, 3015, 15, 0.5.055e-4
CONM2, 3016, 16, 0.5.055e-4
CONM2, 3017, 17, 0.5.055e-4
CONM2, 3018, 18, 0.5.055e-4
CONM2, 3019, 19, 0.5.055e-4
CONM2, 3020, 20, 0.5.055e-4
CONM2, 3021, 21, 0.5.055e-4
CONM2, 3022, 22, 0.5.055e-4
CONM2, 3023, 23, 0.5.055e-4
CONM2, 3024, 24, 0.5.055e-4
CONM2, 3025, 25, 0.5.055e-4
CONM2, 3026, 26, 0.5.055e-4
CONM2, 3027, 27, 0.5.055e-4
CONM2, 3028, 28, 0.5.055e-4
CONM2, 3029, 29, 0.5.055e-4
CONM2, 3030, 30, 0.5.055e-4
CONM2, 3031, 31, 0.5.055e-4
CONM2, 3032, 32, 0.5.055e-4
CONM2, 3033, 33, 0.5.055e-4
CONM2, 3034, 34, 0.5.055e-4
CONM2, 3035, 35, 0.5.055e-4
CONM2, 3036, 36, 0.5.055e-4
CONM2, 3037, 37, 0.5.055e-4
CONM2, 3038, 38, 0.5.055e-4
CONM2, 3039, 39, 0.5.055e-4
CONM2, 3040, 40, 0.5.055e-4
CONM2, 3041, 41, 0.5.055e-4
CONM2, 3042, 42, 0.5.055e-4
CONM2, 3043, 43, 0.5.055e-4
CONM2, 3044, 44, 0.5.055e-4

CONM2, 3045, 45, 0,5.055e-4
CONM2, 3046, 46, 0,5.055e-4
CONM2, 3047, 47, 0,5.055e-4
CONM2, 3048, 48, 0,5.055e-4
CONM2, 3049, 49, 0,5.055e-4
CONM2, 3050, 50, 0,5.055e-4
CONM2, 3051, 51, 0,5.055e-4
CONM2, 3052, 52, 0,5.055e-4
CONM2, 3053, 53, 0,5.055e-4
CONM2, 3054, 54, 0,5.055e-4
CONM2, 3055, 55, 0,5.055e-4
CONM2, 3056, 56, 0,5.055e-4
CONM2, 3057, 57, 0,5.055e-4
CONM2, 3058, 58, 0,5.055e-4
CONM2, 3059, 59, 0,5.055e-4
CONM2, 3060, 60, 0,5.055e-4
CONM2, 3061, 61, 0,5.055e-4
CONM2, 3062, 62, 0,5.055e-4
CONM2, 3063, 63, 0,5.055e-4
CONM2, 3064, 64, 0,5.055e-4
CONM2, 3065, 65, 0,5.055e-4
CONM2, 3066, 66, 0,5.055e-4
CONM2, 3067, 67, 0,5.055e-4
CONM2, 3068, 68, 0,5.055e-4
CONM2, 3069, 69, 0,5.055e-4
CONM2, 3070, 70, 0,5.055e-4
CONM2, 3071, 71, 0,5.055e-4
CONM2, 3072, 72, 0,5.055e-4
CONM2, 3073, 73, 0,5.055e-4
CONM2, 3074, 74, 0,5.055e-4
CONM2, 3075, 75, 0,5.055e-4
CONM2, 3076, 76, 0,5.055e-4
CONM2, 3077, 77, 0,5.055e-4
CONM2, 3078, 78, 0,5.055e-4
CONM2, 3079, 79, 0,5.055e-4
CONM2, 3080, 80, 0,5.055e-4
CONM2, 3081, 81, 0,5.055e-4
CONM2, 3082, 82, 0,5.055e-4
CONM2, 3083, 83, 0,5.055e-4
CONM2, 3084, 84, 0,5.055e-4
CONM2, 3085, 85, 0,5.055e-4
CONM2, 3086, 86, 0,5.055e-4
CONM2, 3087, 87, 0,5.055e-4
CONM2, 3088, 88, 0,5.055e-4
CONM2, 3089, 89, 0,5.055e-4
CONM2, 3090, 90, 0,5.055e-4
CONM2, 3091, 91, 0,5.055e-4
CONM2, 3092, 92, 0,5.055e-4
CONM2, 3093, 93, 0,5.055e-4
CONM2, 3094, 94, 0,5.055e-4
CONM2, 3095, 95, 0,5.055e-4
CONM2, 3096, 96, 0,5.055e-4
CONM2, 3097, 97, 0,5.055e-4
CONM2, 3098, 98, 0,5.055e-4

CONM2, 3099, 99, 0.5.055e-4
CONM2, 3100, 100, 0.5.055e-4
CONM2, 3101, 101, 0.5.055e-4 \$controller plate
CONM2, 3102, 102, 0.5.055e-4 \$controller plate
CONM2, 3103, 103, 0.5.055e-4 \$controller plate
CONM2, 3104, 104, 0.5.055e-4 \$controller plate
CONM2, 3105, 105, 0.5.055e-4
CONM2, 3106, 106, 0.5.055e-4
CONM2, 3107, 107, 0.5.055e-4
CONM2, 3108, 108, 0.5.055e-4
CONM2, 3109, 109, 0.5.055e-4
CONM2, 3110, 110, 0.5.055e-4
CONM2, 3111, 111, 0.5.055e-4
CONM2, 3112, 112, 0.5.055e-4
CONM2, 3113, 113, 0.5.055e-4
CONM2, 3114, 114, 0.5.055e-4
CONM2, 3115, 115, 0.5.055e-4
CONM2, 3116, 116, 0.5.055e-4
CONM2, 3117, 117, 0.5.055e-4
CONM2, 3118, 118, 0.5.055e-4
CONM2, 3119, 119, 0.5.055e-4
CONM2, 3120, 120, 0.5.055e-4
CONM2, 3121, 121, 0.5.055e-4
CONM2, 3122, 122, 0.5.055e-4
CONM2, 3123, 123, 0.5.055e-4
CONM2, 3124, 124, 0.5.055e-4
CONM2, 3125, 125, 0.5.055e-4
CONM2, 3126, 126, 0.5.055e-4
CONM2, 3127, 127, 0.5.055e-4
CONM2, 3128, 128, 0.5.055e-4
CONM2, 3129, 129, 0.5.055e-4 \$mid thruster
CONM2, 3130, 130, 0.5.055e-4 \$
CONM2, 3131, 131, 0.5.055e-4 \$
CONM2, 3132, 132, 0.5.055e-4 \$
CONM2, 3133, 133, 0.5.055e-4 \$
CONM2, 3134, 134, 0.5.055e-4 \$
CONM2, 3135, 135, 0.5.055e-4 \$
CONM2, 3136, 136, 0.5.055e-4 \$mid thruster
CONM2, 3137, 137, 0.5.055e-4
CONM2, 3138, 138, 0.5.055e-4
CONM2, 3139, 139, 0.5.055e-4
CONM2, 3140, 140, 0.5.055e-4
CONM2, 3141, 141, 0.5.055e-4
CONM2, 3142, 142, 0.5.055e-4
CONM2, 3143, 143, 0.5.055e-4
CONM2, 3144, 144, 0.5.055e-4
CONM2, 3145, 145, 0.5.055e-4
CONM2, 3146, 146, 0.5.055e-4
CONM2, 3147, 147, 0.5.055e-4
CONM2, 3148, 148, 0.5.055e-4
CONM2, 3149, 149, 0.5.055e-4
CONM2, 3150, 150, 0.5.055e-4
CONM2, 3151, 151, 0.5.055e-4
CONM2, 3152, 152, 0.5.055e-4

CONM2, 3153, 153, 0,5.055e-4
CONM2, 3154, 154, 0,5.055e-4
CONM2, 3155, 155, 0,5.055e-4
CONM2, 3156, 156, 0,5.055e-4
CONM2, 3157, 157, 0,5.055e-4
CONM2, 3158, 158, 0,5.055e-4
CONM2, 3159, 159, 0,5.055e-4
CONM2, 3160, 160, 0,5.055e-4
CONM2, 3161, 161, 0,5.055e-4
CONM2, 3162, 162, 0,5.055e-4
CONM2, 3163, 163, 0,5.055e-4
CONM2, 3164, 164, 0,5.055e-4
CONM2, 3165, 165, 0,5.055e-4 \$controller plate
CONM2, 3166, 166, 0,5.055e-4 \$
CONM2, 3167, 167, 0,5.055e-4 \$
CONM2, 3168, 168, 0,5.055e-4 \$controller plate
CONM2, 3169, 169, 0,5.055e-4
CONM2, 3170, 170, 0,5.055e-4
CONM2, 3171, 171, 0,5.055e-4
CONM2, 3172, 172, 0,5.055e-4
CONM2, 3173, 173, 0,5.055e-4
CONM2, 3174, 174, 0,5.055e-4
CONM2, 3175, 175, 0,5.055e-4
CONM2, 3176, 176, 0,5.055e-4
CONM2, 3177, 177, 0,5.055e-4
CONM2, 3178, 178, 0,5.055e-4
CONM2, 3179, 179, 0,5.055e-4
CONM2, 3180, 180, 0,5.055e-4
CONM2, 3181, 181, 0,5.055e-4
CONM2, 3182, 182, 0,5.055e-4
CONM2, 3183, 183, 0,5.055e-4
CONM2, 3184, 184, 0,5.055e-4
CONM2, 3185, 185, 0,5.055e-4
CONM2, 3186, 186, 0,5.055e-4
CONM2, 3187, 187, 0,5.055e-4
CONM2, 3188, 188, 0,5.055e-4
CONM2, 3189, 189, 0,5.055e-4
CONM2, 3190, 190, 0,5.055e-4
CONM2, 3191, 191, 0,5.055e-4
CONM2, 3192, 192, 0,5.055e-4
CONM2, 3193, 193, 0,5.055e-4
CONM2, 3194, 194, 0,5.055e-4
CONM2, 3195, 195, 0,5.055e-4
CONM2, 3196, 196, 0,5.055e-4
CONM2, 3197, 197, 0,5.055e-4
CONM2, 3198, 198, 0,5.055e-4
CONM2, 3199, 199, 0,5.055e-4
CONM2, 3200, 200, 0,5.055e-4
CONM2, 3201, 201, 0,5.055e-4
CONM2, 3202, 202, 0,5.055e-4
CONM2, 3203, 203, 0,5.055e-4
CONM2, 3204, 204, 0,5.055e-4
CONM2, 3205, 205, 0,5.055e-4
CONM2, 3206, 206, 0,5.055e-4

CONM2, 3207, 207, 0.5.055e-4
CONM2, 3208, 208, 0.5.055e-4
CONM2, 3209, 209, 0.5.055e-4
CONM2, 3210, 210, 0.5.055e-4
CONM2, 3211, 211, 0.5.055e-4
CONM2, 3212, 212, 0.5.055e-4
CONM2, 3213, 213, 0.5.055e-4
CONM2, 3214, 214, 0.5.055e-4
CONM2, 3215, 215, 0.5.055e-4
CONM2, 3216, 216, 0.5.055e-4
CONM2, 3217, 217, 0.5.055e-4
CONM2, 3218, 218, 0.5.055e-4
CONM2, 3219, 219, 0.5.055e-4
CONM2, 3220, 220, 0.5.055e-4
CONM2, 3221, 221, 0.5.055e-4
CONM2, 3222, 222, 0.5.055e-4
CONM2, 3223, 223, 0.5.055e-4
CONM2, 3224, 224, 0.5.055e-4
CONM2, 3225, 225, 0.5.055e-4
CONM2, 3226, 226, 0.5.055e-4
CONM2, 3227, 227, 0.5.055e-4
CONM2, 3228, 228, 0.5.055e-4
CONM2, 3229, 229, 0.5.055e-4
CONM2, 3230, 230, 0.5.055e-4
CONM2, 3231, 231, 0.5.055e-4
CONM2, 3232, 232, 0.5.055e-4
CONM2, 3233, 233, 0.5.055e-4
CONM2, 3234, 234, 0.5.055e-4
CONM2, 3235, 235, 0.5.055e-4
CONM2, 3236, 236, 0.5.055e-4
CONM2, 3237, 237, 0.5.055e-4
CONM2, 3238, 238, 0.5.055e-4
CONM2, 3239, 239, 0.5.055e-4
CONM2, 3240, 240, 0.5.055e-4
CONM2, 3241, 241, 0.5.055e-4
CONM2, 3242, 242, 0.5.055e-4
CONM2, 3243, 243, 0.5.055e-4
CONM2, 3244, 244, 0.5.055e-4
CONM2, 3245, 245, 0.5.055e-4
CONM2, 3246, 246, 0.5.055e-4
CONM2, 3247, 247, 0.5.055e-4
CONM2, 3248, 248, 0.5.055e-4
CONM2, 3249, 249, 0.5.055e-4
CONM2, 3250, 250, 0.5.055e-4
CONM2, 3251, 251, 0.5.055e-4
CONM2, 3252, 252, 0.5.055e-4
CONM2, 3253, 253, 0.5.055e-4
CONM2, 3254, 254, 0.5.055e-4
CONM2, 3255, 255, 0.5.055e-4
CONM2, 3256, 256, 0.5.055e-4
CONM2, 3257, 257, 0.5.055e-4
CONM2, 3258, 258, 0.5.055e-4
CONM2, 3259, 259, 0.5.055e-4
CONM2, 3260, 260, 0.5.055e-4

CONM2, 3261, 261, 0,5.055e-4 \$thruster plate
CONM2, 3262, 262, 0,5.055e-4 \$
CONM2, 3263, 263, 0,5.055e-4 \$
CONM2, 3264, 264, 0,5.055e-4 \$
CONM2, 3265, 265, 0,5.055e-4 \$
CONM2, 3266, 266, 0,5.055e-4 \$
CONM2, 3267, 267, 0,5.055e-4 \$
CONM2, 3268, 268, 0,5.055e-4 \$thruster plate
CONM2, 3269, 269, 0,5.055e-4
CONM2, 3270, 270, 0,5.055e-4
CONM2, 3271, 271, 0,5.055e-4
CONM2, 3272, 272, 0,5.055e-4
CONM2, 3273, 273, 0,5.055e-4
CONM2, 3274, 274, 0,5.055e-4
CONM2, 3275, 275, 0,5.055e-4
CONM2, 3276, 276, 0,5.055e-4
CONM2, 3277, 277, 0,5.055e-4
CONM2, 3278, 278, 0,5.055e-4
CONM2, 3279, 279, 0,5.055e-4
CONM2, 3280, 280, 0,5.055e-4
CONM2, 3281, 281, 0,5.055e-4
CONM2, 3282, 282, 0,5.055e-4
CONM2, 3283, 283, 0,5.055e-4
CONM2, 3284, 284, 0,5.055e-4
CONM2, 3285, 285, 0,5.055e-4
CONM2, 3286, 286, 0,5.055e-4
CONM2, 3287, 287, 0,5.055e-4
CONM2, 3288, 288, 0,5.055e-4
CONM2, 3289, 289, 0,5.055e-4
CONM2, 3290, 290, 0,5.055e-4
CONM2, 3291, 291, 0,5.055e-4
CONM2, 3292, 292, 0,5.055e-4
CONM2, 3293, 293, 0,5.055e-4
CONM2, 3294, 294, 0,5.055e-4
CONM2, 3295, 295, 0,5.055e-4
CONM2, 3296, 296, 0,5.055e-4
CONM2, 3297, 297, 0,5.055e-4
CONM2, 3298, 298, 0,5.055e-4
CONM2, 3299, 299, 0,5.055e-4
CONM2, 3300, 300, 0,5.055e-4
CONM2, 3301, 301, 0,5.055e-4
CONM2, 3302, 302, 0,5.055e-4
CONM2, 3303, 303, 0,5.055e-4
CONM2, 3304, 304, 0,5.055e-4
CONM2, 3305, 305, 0,5.055e-4 \$thruster plate
CONM2, 3306, 306, 0,5.055e-4 \$
CONM2, 3307, 307, 0,5.055e-4 \$
CONM2, 3308, 308, 0,5.055e-4 \$
CONM2, 3309, 309, 0,5.055e-4 \$
CONM2, 3310, 310, 0,5.055e-4 \$
CONM2, 3311, 311, 0,5.055e-4 \$
CONM2, 3312, 312, 0,5.055e-4 \$thruster plate
CONM2, 3313, 313, 0,5.055e-4
CONM2, 3314, 314, 0,5.055e-4

CONM2, 3315, 315, 0,5.055e-4
CONM2, 3316, 316, 0,5.055e-4
CONM2, 3317, 317, 0,5.055e-4
CONM2, 3318, 318, 0,5.055e-4
CONM2, 3319, 319, 0,5.055e-4
CONM2, 3320, 320, 0,5.055e-4
CONM2, 3321, 321, 0,5.055e-4
CONM2, 3322, 322, 0,5.055e-4
CONM2, 3323, 323, 0,5.055e-4
CONM2, 3324, 324, 0,5.055e-4
CONM2, 3325, 325, 0,5.055e-4
CONM2, 3326, 326, 0,5.055e-4
CONM2, 3327, 327, 0,5.055e-4
CONM2, 3328, 328, 0,5.055e-4
CONM2, 3329, 329, 0,5.055e-4
CONM2, 3330, 330, 0,5.055e-4
CONM2, 3331, 331, 0,5.055e-4
CONM2, 3332, 332, 0,5.055e-4
CONM2, 3333, 333, 0,5.055e-4
CONM2, 3334, 334, 0,5.055e-4
CONM2, 3335, 335, 0,5.055e-4
CONM2, 3336, 336, 0,5.055e-4
CONM2, 3337, 337, 0,5.055e-4
CONM2, 3338, 338, 0,5.055e-4
CONM2, 3339, 339, 0,5.055e-4
CONM2, 3340, 340, 0,5.055e-4
CONM2, 3341, 341, 0,5.055e-4
CONM2, 3342, 342, 0,5.055e-4
CONM2, 3343, 343, 0,5.055e-4
CONM2, 3344, 344, 0,5.055e-4
CONM2, 3345, 345, 0,5.055e-4
CONM2, 3346, 346, 0,5.055e-4
CONM2, 3347, 347, 0,5.055e-4
CONM2, 3348, 348, 0,5.055e-4
CONM2, 3349, 349, 0,5.055e-4
CONM2, 3350, 350, 0,5.055e-4
CONM2, 3351, 351, 0,5.055e-4
CONM2, 3352, 352, 0,5.055e-4
CONM2, 3353, 353, 0,5.055e-4
CONM2, 3354, 354, 0,5.055e-4
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\$ end joint mass, start following
\$.011380 \$ THRUSTER MASS
\$.000124 \$ TRI-AXIAL STRUCTCELL ACC. MASS
\$.0066800 \$ air supply bracket and tubing mass

\$.0038860 \$ lumped mass for thruster controller
 \$.000554 \$ lumped mass for rate sensor (.2137# each)
 \$.012771 \$ mass for laser (4.93 #)
 \$.0492230 \$ rfl mirror
 \$.0002176 \$ rfl tip mass
 \$.0001285 \$ suspension cable lumped masses
 \$.0023850 \$ suspension cable lumped masses
 \$.000405 \$ lumped mass for servo acc. (.1565# each)

CONM2, 3501,	2,	0.,	.0004050	
CONM2, 3502,	3,	0.,	.0001240	
CONM2, 3503,	4,	0.,	.0001240	
CONM2, 3504,	8,	0.,	.0066800	
CONM2, 3505,	12,	0.,	.0066800	
CONM2, 3506,	27,	0.,	.0001240	
CONM2, 3507,	28,	0.,	.0001240	
CONM2, 3508,	51,	0.,	.0001240	
CONM2, 3509,	52,	0.,	.0001240	
CONM2, 3510,	58,	0.,	.0011070	
CONM2, 3511,	59,	0.,	.0005540	
CONM2, 3512,	66,	0.,	.0012150	
CONM2, 3513,	67,	0.,	.0001240	
CONM2, 3514,	68,	0.,	.0001240	
CONM2, 3515,	91,	0.,	.0001240	
CONM2, 3516,	92,	0.,	.0001240	
CONM2, 3517,	101,	0.,	.0038860	
CONM2, 3518,	102,	0.,	.0038860	
CONM2, 3519,	103,	0.,	.0038860	
CONM2, 3520,	104,	0.,	.0038860	
CONM2, 3521,	111,	0.,	.0001240	
CONM2, 3522,	112,	0.,	.0001240	
CONM2, 3523,	130,	0.,	.0004050	
CONM2, 3524,	131,	0.,	.0001240	
CONM2, 3525,	132,	0.,	.0001240	
CONM2, 3526,	136,	0.,	.0066800	
CONM2, 3527,	140,	0.,	.0066800	
CONM2, 3528,	155,	0.,	.0001240	
CONM2, 3529,	156,	0.,	.0001240	
CONM2, 3530,	165,	0.,	.0038050	
CONM2, 3531,	166,	0.,	.0038050	
CONM2, 3532,	167,	0.,	.0038050	
CONM2, 3533,	168,	0.,	.0038050	
CONM2, 3534,	179,	0.,	.0001240	
CONM2, 3535,	180,	0.,	.0001240	
CONM2, 3536,	203,	0.,	.0001240	
CONM2, 3537,	204,	0.,	.0001240	
CONM2, 3538,	218,	0.,	.0005540	
CONM2, 3539,	219,	0.,	.0011070	
CONM2, 3540,	227,	0.,	.0001240	
CONM2, 3541,	228,	0.,	.0001240	
CONM2, 3542,	250,	0.,	.0012150\$ 3x.000405	
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CONM2, 3546,	260,	0.,	.0066800	

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CONM2,	3552,	288,	0,.0001240
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CONM2,	3562,	393,	0,.0001285
CONM2,	3563,	394,	0,.0001285
CONM2,	3564,	396,	0,.0023850
CONM2,	3565,	396,	0,.0001240
CONM2,	3566,	431,	0,.0001240
CONM2,	3567,	435,	0,.0001240
CONM2,	3568,	471,	0,.0001240
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CONM2,	3573,	480,	0,.0001240
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CONM2,	3575,	489,	0,.0004050
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CONM2,	3583,	496,	0,.0113800
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 CONM2, 3618, 2092, 3.0002176 \$ corrected 91/01/23
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 CONM2, 3628, 2129, 3.0001240
 CONM2, 3629, 2130, 3.0001240
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 , 6.795, , 6.795, , , 13.591
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 \$.000908 - LARGE BLOCK HOLDING SERVO-ACC
 \$.002166 - THRUSTER AIR HOSE MASS
 \$.000858 & .000429 THRUSTER SIGNAL CABLE MASS
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$ truss mat1 cards
MAT1, 1, 1.E+07, .,333, 4.64E-04, 0.
MAT1, 2, 1.E+07, .,333, 4.14E-04, 0.
$ updated cable density 90/10/02
MAT1, 3, 3.E+07, .,300, .002846, 0.
MAT1, 4, 1.E+07, .,333, 0.
MAT1, 5, 3.E+07, .,300, 9.24E-04, 0.
$
$ reflector mat1 cards
MAT1,11, 1.0E+07,.,375E+07, .,0002539$,1.458-08
MAT1,12, 3.0E+07,.,11538+8, .,0004585,-2.535-6
MAT1,13, .30E+08,.,11538+8, .,0007332
MAT1,14, .65E+07,.,25000+7, .,0000512
MAT1,15, .10E+08,.,37509+7, .,0003375
MAT1,16, .10E+08,.,37509+7, .,0002539
$
$ truss pid cards
PBAR, 1, 1, .13370, 1.264e-3, 1.264e-3, 2.528e-3, 0.
PBAR, 2, 1, .13370, 1.264e-3, 1.264e-3, 2.528e-3, 0.
PBAR, 3, 2, .12400, 1.495e-3, 1.495e-3, 2.990e-3, 0.
$
$ 2X2X3/8 STEEL ANGLE FOR CABLE ATTACHMENT
PBAR,11, 5, 1.36, 0.48, 0.48, 0.070, 0.
PBAR,12, 1, .13370, 1.264e-3, 1.264e-3, 2.528e-3, 0.
PBAR,13, 2, .12400, 1.495e-3, 1.495e-3, 2.990e-3, 0.
PROD,14, 3, .00220, 5.20e-05
$
$ THRUSTER AND LASER PLATE
PSHELL,15, 4, .3024, 4
$
$ Mercedes' REFLECTOR
PBAR,16,11, .2900000, .0015104, .0325188, .0052215, 0.0
PBAR,17,11, .3375000, .0017578, .0512578, .0062110, 0.0
PBAR,18,11, .3840000, .0020000, .0754975, .0071797, 0.0
$PBAR,118,11,.,3988000, .0020770, .0845680, .0083083, 0.0
PBAR,19,11, .4300000, .0022396, .1060093, .0081380, 0.0
PBAR,20,11, .4775000, .0024870, .1451640, .0091276, 0.0

```

PBAR,21,11, .500000, .0026042, .1666667, .0104167, 0.0
PBAR,23,13, .0490873, .0001918, .0001918, .0003835, 0.0
PROD,22,12, .0007670, .0000000
PROD,24,13, .0283529, .0001280
\$
\$ SENSOR PLATE
PSHELL,25,14, .40807,14
\$
\$ CENTER PLATE
PSHELL,26,15, .37500,15
\$
\$ 3/4" DIAM ROD
PBAR,27,16, .4418 ,1.55E-02 ,1.55E-02 , 3.1E-02 , 0.
\$
\$ 1X1X5/16" AL ANGLE CROSS MEMBERS
PBAR,28,16, 0.339, 3.E-02 ,3.E-02 , .00439, 0.
\$
\$ 1X11/4X1/4" AL ANGLE THAT SUPPORTS BASE PLATE
PBAR,29,16, .5 ,3.97E-02 ,7.10E-02 , .1107 , 0.
\$
\$ PBAR 30 IS A 3/8" DIAM. STEEL MEMBER FOR ANTENNAE FIX
PBAR,30,13, .06627, .000971, .000971, .001942, 0.0
\$
\$ SMALL RFL END PLATE, UPDATED 90/10/02
PSHELL,40,13, .512367,13
ENDDATA

Appendix 5

The following NASTRAN runstream uses the mass and stiffness matrices stored in the data base DB01 (see Appendix 3) to calculate eigenvalues and eigenvectors. Note the constraints are changed to reflect the true boundary conditions. This runstream runs under MSC version 65 rigid format 63.

```

NASTRAN FILES=(DB01)
ID PHASE ZERO, SUSPENDED FROM CABLES
SOL 63
TIME 2000
diag 16
ALTER 1
param //c,n,nop/v,y,endgeom=1 $
PARAM //C,N,NOP/V,Y,SDRCUNIT=11 $
PARAM //C,N,NOP/V,Y,SDRCRCLN=16000 $
$
ALTER 67
DBFETCH /MPT,EPT,..,/MODEL/0//DBSET3 $
GP1 GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,
BGPDT,SIL/0/0/0 $
OUTPUT2 MPT,EPT//0/SDRCUNIT//SDRCRCLN $
OUTPUT2 CSTM,GPL,GPDT,GEOM2,GEOM4//0/SDRCUNIT//SDRCRCLN $
$
COND FINIS,ENDGEOM $
ALTER 71,71
$
ALTER 964 $
PARAML CSTM//C,N,PRESNCE////V,N,NOCSTM $
EQUIV OUGV1,BOUGV1/NOCSTM $
EQUIV OQG1,BOQG1/NOCSTM $
COND SKPCNVRT,NOCSTM $
SDR2 CASEDR,CSTMS,MPT,DIT,EQEXINS,,ETT,OLB1,BGPDTS,,QGB,
UGVB,EST,XYCDBDR/,BOQG1,BOUGV1,..,/APP1 $
LABEL SKPCNVRT $
OUTPUT2 LAMA//0/SDRCUNIT//SDRCRCLN $
OUTPUT2 BOUGV1,BOQG1,OES1,OEF1//0/SDRCUNIT//SDRCRCLN $
OUTPUT2 OSTR1//0/SDRCUNIT//SDRCRCLN $
ALTER 1067
OUTPUT2 OEFIT//0/SDRCUNIT//SDRCRCLN $
ALTER 1115 $
OUTPUT2 ONRGY1//0/SDRCUNIT//SDRCRCLN $
$
ALTER 1159
OUTPUT2 .....,/-9/SDRCUNIT $
CEND
METHOD=33
SEKR=ALL
SEMR=ALL
SPC=101
DISPLACEMENT(PUNCH)=ALL
OUTPUT(PLOT)
CSCALE=1.8

```

```

SET 1 = 1001 thru 1008
SET 30 = 1 THRU 500, 812 THRU 899, 955 THRU 986,
        1007 THRU 1166, 1267 THRU 1426, 1527 THRU 1542,
        1601 THRU 1692, 2041 THRU 2072, 2089 THRU 2100,
        2109 THRU 2168
PLOTTER NASPLT
AXES X,Y,Z
VIEW = 180.,0.,0.
PTITLE = FRONT VIEW
FIND SCALE, ORIGIN 1, SET 30
PLOT MODAL DEFORMATION,0,MAXI DEFO,SET 30,ORIGIN 1,SHAPE
$
AXES Y,X,Z
VIEW = 180.,0.,0.
PTITLE = SIDE VIEW
FIND ORIGIN 1
PLOT MODAL DEFORMATION,0,MAXI DEFO,SET 30,ORIGIN 1,SHAPE
$
AXES Z,X,Y
VIEW = 0.,0.,180.
PTITLE = TOP VIEW
FIND ORIGIN 1
PLOT MODAL DEFORMATION,0,MAXI DEFO,SET 30,ORIGIN 1,SHAPE
AXES X,Y,Z
VIEW = 180.,0.,0.
PTITLE = FRONT VIEW
FIND SCALE, ORIGIN 1, SET 30
PLOT MODAL DEFORMATION,MAXI DEFO,SET 30,ORIGIN 1,SHAPE
$
AXES Y,X,Z
VIEW = 180.,0.,0.
PTITLE = SIDE VIEW
FIND ORIGIN 1
PLOT MODAL DEFORMATION,MAXI DEFO,SET 30,ORIGIN 1,SHAPE
$
AXES Z,X,Y
VIEW = 0.,0.,180.
PTITLE = TOP VIEW
FIND ORIGIN 1
PLOT MODAL DEFORMATION,MAXI DEFO,SET 30,ORIGIN 1,SHAPE
BEGIN BULK
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
$
PARAM GRDPNT 0
SPC1 101 123456 395 479
SPC1 101 123456 1001 thru 1008
SPC1 101 12456 481 482
EIGR 33 SINV 0. 50. JIMB
+IMB MASS
ENDDATA

```


Column 13	Column 14	Column 15	Column 16	Column 17	Column 18
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
1.0000e+00	0	0	0	0	0
0	1.0000e+00	0	0	0	0
0	0	1.0000e+00	0	0	0
0	0	0	1.0000e+00	0	0
0	0	0	0	1.0000e+00	0
0	0	0	0	0	1.0000e+00
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
-1.3762e-01	0	0	0	0	0
0	-1.1277e-01	0	0	0	0
0	0	-6.5897e-02	0	0	0
0	0	0	-7.4065e-02	0	0
0	0	0	0	-1.4416e-01	0
0	0	0	0	0	-1.1831e-01

B (18,8)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
-9.0412e-02	-1.7503e-03	-2.2032e-03	8.6983e-04	7.2204e-01	7.6707e-02
-7.2842e-01	2.1216e-04	-7.4012e-01	1.9792e-04	2.8522e-03	-7.0804e-01
1.1157e+00	-2.6799e-04	6.2103e-02	9.7330e-05	5.9780e-02	-8.8555e-01
-2.3142e-04	-1.1076e+00	-1.5399e-04	-3.9490e-02	-8.7477e-02	2.3484e-04
5.9439e-05	-7.5943e-01	1.9928e-04	-7.4550e-01	-3.0950e-03	-3.4298e-04
-6.8777e-02	2.3805e-03	-2.5082e-01	2.0583e-03	8.2306e-04	3.0302e-01
-9.0841e-01	-9.2293e-04	4.7562e-01	4.0256e-03	9.0757e-04	-4.3450e-01
2.9426e-02	1.2695e+00	-2.6966e-02	-1.0421e+00	-3.8239e-01	1.0193e-02
9.4147e-01	-4.7622e-02	-9.0573e-01	4.2744e-02	1.2593e-02	3.8921e-01

Column 7	Column 8
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
7.2043e-01	-4.6856e-02
2.8556e-03	-6.2905e-01
5.9586e-02	5.9095e-01
-2.7368e-01	1.0451e-03
3.9825e-03	-1.1842e-03
5.0834e-04	1.3185e+00
-7.0441e-03	1.1182e+00
9.5012e-01	1.6953e-02
-2.2581e-02	3.1281e-01

C (8,18)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
7.7245e-02	6.3892e-01	-1.0611e+00	4.8696e-03	-1.3122e-03	2.0740e+00
1.4954e-03	-1.8609e-04	2.5487e-04	2.3307e+01	1.6766e+01	-7.1785e-02
1.8823e-03	6.4918e-01	-5.9063e-02	3.2403e-03	-4.3995e-03	7.5636e+00
-7.4315e-04	-1.7360e-04	-9.2566e-05	8.3096e-01	1.6458e+01	-6.2069e-02
-6.1689e-01	-2.5017e-03	-5.6854e-02	1.8407e+00	6.8328e-02	-2.4820e-02
-6.5536e-02	6.2104e-01	8.4221e-01	-4.9416e-03	7.5719e-03	-9.1377e+00
-6.1551e-01	-2.5047e-03	-5.6670e-02	5.7589e+00	-8.7921e-02	-1.5329e-02
4.0032e-02	5.5176e-01	-5.6203e-01	-2.1991e-02	2.6143e-02	-3.9760e+01

Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
7.7862e+01	-3.5096e+00	-1.3178e+02	7.8555e-03	9.5508e-02	-1.5233e-01
7.9107e-02	-1.5141e+02	6.6658e+00	1.5208e-04	-2.7818e-05	3.6589e-05
-4.0767e+01	3.2162e+00	1.2678e+02	1.9143e-04	9.7042e-02	-8.4790e-03
-3.4504e-01	1.2429e+02	-5.9830e+00	-7.5576e-05	-2.5951e-05	-1.3289e-05
-7.7790e-02	4.5607e+01	-1.7627e+00	-6.2735e-02	-3.7397e-04	-8.1618e-03
3.7242e+01	-1.2157e+00	-5.4479e+01	-6.6648e-03	9.2836e-02	1.2090e-01
6.0377e-01	-1.1332e+02	3.1607e+00	-6.2595e-02	-3.7442e-04	-8.1353e-03
-9.5844e+01	-2.0220e+00	-4.3785e+01	4.0711e-03	8.2479e-02	-8.0683e-02

Column 13	Column 14	Column 15	Column 16	Column 17	Column 18
3.1847e-05	-6.7027e-06	4.5322e-03	6.7281e-02	-4.2420e-03	-1.1139e-01
1.5242e-01	8.5638e-02	-1.5687e-04	6.8357e-05	-1.8301e-01	5.6342e-03
2.1191e-05	-2.2472e-05	1.6528e-02	-3.5227e-02	3.8873e-03	1.0716e-01
5.4345e-03	8.4067e-02	-1.3564e-04	-2.9816e-04	1.5023e-01	-5.0570e-03
1.2038e-02	3.4901e-04	-5.4237e-05	-6.7219e-05	5.5124e-02	-1.4899e-03
-3.2318e-05	3.8677e-05	-1.9968e-02	3.2181e-02	-1.4694e-03	-4.6047e-02
3.7663e-02	-4.4909e-04	-3.3498e-05	5.2172e-04	-1.3697e-01	2.6716e-03
-1.4382e-04	1.3354e-04	-8.6885e-02	-8.2819e-02	-2.4439e-03	-3.7009e-02

D (8,8)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
3.5007e+00	-6.8878e-03	-6.5971e-01	5.6295e-03	-9.1940e-04	2.6140e-01
-6.8878e-03	3.4174e+00	7.7127e-03	-7.1509e-01	-3.8808e-01	-4.5194e-03
-6.5971e-01	7.7127e-03	1.6618e+00	-9.4997e-03	-8.4551e-04	-1.6658e-01
5.6295e-03	-7.1509e-01	-9.4997e-03	1.6452e+00	4.0543e-01	4.9757e-03
-9.1940e-04	-3.8808e-01	-8.4551e-04	4.0543e-01	6.7897e-01	1.2671e-03
2.6140e-01	-4.5194e-03	-1.6658e-01	4.9757e-03	1.2671e-03	1.7236e+00
1.2391e-02	1.5061e+00	-8.6038e-03	-9.8264e-01	1.8407e-01	4.5186e-03
3.1031e-01	8.2638e-03	4.1973e-01	3.6531e-03	-8.3024e-04	-4.5921e-02

Column 7	Column 8
1.2391e-02	3.1031e-01
1.5061e+00	8.2638e-03
-8.6038e-03	4.1973e-01
-9.8264e-01	3.6531e-03
1.8407e-01	-8.3024e-04
4.5186e-03	-4.5921e-02
1.5008e+00	1.2062e-03
1.2062e-03	3.8341e+00

Appendix 7

The following MATLAB runstreams permit calculation of the LOS pointing of the CEM at the LaMOD detector location. The first .m file is losd.m. This file computes the physical laser and reflector coordinates assuming the modal coordinate time histories have already been computed. losd.m calls function los2 which performs the required optical transformations to simulate the laser position on the detector. Two supporting .m files for the los2 function are cprod.m and dcosine.m. In addition, the 'losc' variable used in the losd.m runstream is included. 'losc' consists of the mode shape coefficients at the laser and reflector for the first 40 modes.

```
%THIS LOSD.M FILE COMPUTES LOS POINTING IN VARIABLES X=DXWT(:,1),
Y=DXWT(:,2)
%ASSUMES MODAL STRUCTURAL DISPLACEMENTS x0 HAVE BEEN COMPUTED
%WITH THRUSTER DYNAMICS.

load losc; %[12, # of modes] transformation from modal to physical coordinates
           %of laser x,y,z,rx,ry,rz and reflector x,y,z,rx,ry,rz

[statep nactp]=size(sb);
xsp=statep/2;

losc=losc(:,1:xsp); %resize losc to be same as number of structural modes used

x1=x0(:,2*nactp+1:2*nactp+xsp);
[dimt dimdum]=size(x1);

losdat=zeros(dimt,12);
for kk=1:dimt;
    losdat(kk,:)=(losc*x1(kk,:))'; %physical motion of laser and detector
end

[dxwi,dxwt]=los2(losdat); % computes LOS error using function los2

axis ('square'); axis([-15 15 -15 15]);
plot(-dxwt(:,1),dxwt(:,2));title('LaMOD LOS - Simulation');
xlabel('X Displacement - Inches');ylabel('Y Displacement - Inches');
pause;
axis([1 2 3 4]);axis;
```

```

function [dxwi,dxwt]=los2(xxx)
% THIS FUNCTION COMPUTES THE LOS TIME HISTORIES ON MIRROR AND TARGET WALL
%   function [dxwt]=los(xxx)
% *****
% *****
% INPUT:          Modified by L. G. Horta 5-4-90
% *****
% *****
%   xxx(i,1:3) - deflection at laser source w.r.t. B-Frame at time `i'
%   xxx(i,4:6) - rotation angles at laser source w.r.t. B-Frame at time `i'
%   xxx(i,7:9) - deflection at mirror/truss junction w.r.t. B-Frame at time `i'
%   xxx(i,10:12)- rotation angles at mirror plane w.r.t. B-Frame at time `i'
%
% OUTPUTS:
%   dxwi - deviation of laser on target wall w.r.t. I-Frame(Inertial Frame)
%   dxwt - deviation of laser on target wall w.r.t. T-Frame (Target Frame)
%
% NOTES:
%   1. All Euler angles are assumed to be 1-2-3 Euler angles.
%   2. All angles in radians and lengths in inches.
%   3. The mirror center is chosen to be the coordinate center of the M-Frame.
%   4. B-Frame corresponds to the coord system used to generate NASTRAN model
%   5. The initial laser source unit vector (so) is computed by
%       subtracting the initial coord of laser source point from
%       the initial coord of mirror junct/M-Frame origin (xmbo-xso).
%       Physically, this means that initially the laser source is assumed to be
%       pointing at the mirror junction/M-Frame origin.
%
=====
=====

% INITIAL CONFIGURATIONS:

xbo=[0 0 0]';      % origin of B-Frame w.r.t. I-Frame
phi=[0 0 0]';     % relative orientation of B-Frame w.r.t. I-Frame
cphi=dcosine(phi); % direction cosine matrix of B-Frame

% initial location of laser source point w.r.t. B-Frame
xso=[155 0 115]'; % center of grid points (307, 308, 311, 312)

% mirror/M-Frame location, orientation
va=[615.00 0 56.110]'; % center of reflector frame wrt B-Frame
vb=[590.22 0 86.707]'; % point on reflector positive Z-axis wrt B-Frame
vc=[645.60 0 80.885]'; % point on reflector pos. X-Z plane wrt B-Frame
i3 = (vb-vb)/norm(vb-vb); % Z-axis unit vector of reflec frame wrt B-Frame
iac = (vc-va)/norm(vc-va);
i2 = cprod(i3,iac); % Y-axis unit vector of reflec frame wrt B-Frame
i2 = i2/norm(i2);
i1 = cprod(i2,i3); % X-axis unit vector of reflec frame wrt B-Frame
dcthetao=[i1,i2,i3]'; % ini direction cosine of M-Frame wrt B-Frame
% initially the same as the reflector frame
grid2106=[0 0 2.4375]'; % coord mirror center wrt reflector (3-18-91)
xmbo=va+dcthetao**grid2106; % coord of mirror center wrt B-Frame
xmio = xbo+cphi**xmbo; % coord of mirror center wrt I-Frame

```

```

% initial laser source unit vector w.r.t. B-Frame
so=xmbo-xso; so=so/norm(so);

% initial unit normal vector to mirror
nom=[0 0 1]'; % unit normal vector to mirror w.r.t. M-Frame
no=dcthetao*nom; % unit normal vector to mirror w.r.t. B-Frame

% T-Frame relative orientation
zeta=[pi 0 0]'; % relative orientation of T-Frame w.r.t I-Frame
dczeta=dcosine(zeta);

% target wall plane equation
twt=[0 0 1]'; % unit vector normal to target wall w.r.t. T-Frame
twi=dczeta*twt; % unit vector normal to target wall w.r.t. I-Frame
% hwall=300; % height of target wall w.r.t. main bay truss
hwall=648.5; % height of target plane wrt main truss (3-27-91)
% hwall=3000; % height of 250 feet
% hwall=30000; % height of .473 miles
% hwall=300000; % height of 4.73 miles
% hwall=1.2672e7; % height of 200. miles
xwdum=[700 0 hwall]'; % coord of an arbitrary pt on target plane w.r.t.I-Frame
cwi=twi*xwdum; % target wall plane equation coefficient w.r.t I-Frame

%
=====
=====

% POSITION OF LASER ON TARGET WALL FOR ZERO DEFLECTION:
tm=no; cm=no*xmbo;
xpb=xso+(cm-tm*xso)/(tm*so)*so; xpi=xbo+cphi*xpb;
rb=-1/(no*so)*so+2*no; ri=cphi*rb;
xwo=xpi+(cwi-twi*xpi)/(twi*ri)*ri;

% CONFIGURATION TIME HISTORIES:
[dimt,dimdum]=size(xxx);
for i=1:dimt;
dxs=xxx(i,1:3); % deflection of laser source wrt B-Frame
dxsi(i,:)=(cphi*dxs)'; % deflection of laser source wrt I-Frame
xs=xso+dxs; % coordinates of laser source wrt B-Frame
eta=xxx(i,4:6)'; % rotation angles of laser source wrt B-Frame
dxmb=xxx(i,7:9)'; % deflection of mirror junct. wrt B-Frame
xmb=xmbo+dxmb; % coordinate of mirror junction wrt B-Frame
theta=xxx(i,10:12)'; % rotation angles of mirror plane wrt B-Frame
ceta=dcosine(eta); % direction cosine matrix of laser source rotation
ctheta=dcosine(theta); % direction cosine matrix of mirror rotation
sb=ceta*so; % rotated laser source vector w.r.t B-Frame
nb=ctheta*no; % rotated unit normal vector to mirror w.r.t. B-Frame
tm=nb; cm=nb*xmb; % mirror plane equation coefficients w.r.t. B-Frame
xpb=xs+(cm-tm*xs)/(tm*sb)*sb; % intersec pt of laser on mirror w.r.t. B-Frame
xpi=xbo+cphi*xpb; % intersection point of laser on mirror w.r.t. I-Frame
dmpi(i,:)=xpi-xmio'; % deviation of laser point from mirror center (I-Frame)
rb=-1/(nb*sb)*sb+2*nb; % reflected laser vector w.r.t. B-Frame
ri=cphi*rb; % reflected laser vector w.r.t. B-Frame

```

```
xwi=(xpi+(cwi-twi*xpi)/(twi*ri)*ri);% laser on target wall wrt I-Frame
dxwi(i,:)=xwi-xwo'; % deviation of laser on target wall (I-Frame)
dct=dcosine(dcthetao*theta);
xmirror(i,:)=(dct*dcthetao*(xpb-xmb));% coord of laser on mirror wrt M-Frame
dxwt(i,:)=(dczeta*dxwi(i,:)); % deviation of laser on target w.r.t T-Frame
loserr(i)=norm(dxwt(i,:)); % LOS error
end
save newlos dxwt
```

```
function c=crossproduct(a,b)
% This function computes the vector cross product of vectors, a and b

c(1,1)=a(2)*b(3)-a(3)*b(2);
c(2,1)=a(3)*b(1)-a(1)*b(3);
c(3,1)=a(1)*b(2)-a(2)*b(1);
```

```

function c=dcosine(a)
% This function computes the direction cosine matrix from 1-2-3 Euler angles
%   a: 1-2-3 Euler angles (3x1) in radians
%   c: direction cosine matrix (3x3)
%
%=====
=====
c1=cos(a(1)); c2=cos(a(2)); c3=cos(a(3));
s1=sin(a(1)); s2=sin(a(2)); s3=sin(a(3));
c=[c3*c2      c3*s2*s1+s3*c1  -c3*s2*c1+s3*s1;
   -s3*c2     -s3*s2*s1+c3*c1  s3*s2*c1+c3*s1;
    s2      -c2*s1          c2*c1];
%
% linearized direction cosines:
% c=[ 1      a(3) -a(2);
%    -a(3)  1      a(1);
%      a(2) -a(1)  1 ];

```

Appendix 8

The following data are the variable 'losc' which relate the 40 modal coordinates to physical laser and reflector coordinates.

Mode No	Laser					
	x	y	z	rx	ry	rz
1	7.2022e-01	-4.6530e-02	-1.5096e-04	-2.1375e-05	-1.3596e-05	2.7745e-04
2	2.8584e-03	-6.1326e-01	2.0481e-04	-1.0523e-03	1.7243e-07	-3.5475e-05
3	5.9566e-02	5.8625e-01	-1.0533e-05	3.0927e-04	-1.7595e-06	-3.2898e-03
4	-3.2412e-01	1.1953e-03	-5.8329e-01	-1.0105e-05	-3.3591e-03	1.7172e-05
5	4.5152e-03	-1.3748e-03	-7.4653e-01	1.2732e-05	3.5530e-05	-5.8491e-07
6	6.1954e-04	1.5405e+00	2.5690e-03	-1.4803e-02	7.3507e-06	-5.3622e-04
7	-8.3230e-03	1.2961e+00	2.8257e-03	-1.1858e-02	-8.4947e-05	4.9241e-03
8	1.0912e+00	2.1597e-02	-2.2271e-01	-3.1008e-04	9.4007e-03	-2.9212e-04
9	-2.5788e-02	4.0599e-01	8.5706e-03	-6.2214e-03	-2.1471e-04	-6.9585e-03
12	-2.5190e-01	3.3107e-03	1.6073e-01	3.5369e-06	-2.9473e-03	4.6794e-05
16	-5.1322e-02	1.0993e-01	4.3409e-02	1.7864e-04	-6.5181e-04	1.0171e-03
17	-6.4235e-02	4.4750e-01	2.0639e-02	6.9847e-04	-6.9349e-04	4.0780e-03
19	-5.0732e-01	-4.3433e-02	5.9684e-01	3.5923e-05	-6.6583e-03	-2.5748e-04
22	1.2493e-02	-5.7483e-01	2.0985e-02	4.3229e-03	1.4536e-04	1.8435e-04
23	2.0267e-01	1.0810e-01	2.8854e-01	-1.3024e-03	2.2416e-03	-1.2503e-04
24	-1.2606e-01	-1.3722e+00	4.2444e-02	1.5851e-02	-1.3195e-03	1.2915e-03
25	-6.3016e-01	-1.4923e+00	-7.9325e-02	1.8809e-02	-7.0233e-03	1.1868e-03
26	-2.6565e+00	3.7161e-01	-1.4584e-01	-4.1962e-03	-2.9757e-02	-1.3049e-04
27	5.9831e-01	7.6048e-02	-3.9519e-01	-1.4990e-03	5.2361e-03	2.8440e-04
28	1.2938e-01	-4.5463e-01	-2.4082e-02	9.0797e-03	1.4025e-03	-4.1178e-03
29	6.2183e-02	-3.0200e-01	-4.3539e-03	6.1471e-03	7.0127e-04	-3.0440e-03
30	-1.5228e-01	8.3799e-02	4.2539e-02	-1.6873e-03	-1.8893e-03	8.8002e-04
31	4.0136e-03	1.7879e-02	-2.6149e-03	-3.7448e-04	4.4250e-05	2.7000e-04
32	1.1687e-01	-1.1815e-02	-3.8615e-02	2.2802e-04	1.4561e-03	-1.7312e-04
33	1.3693e-01	-3.6263e-01	-1.7544e-02	8.1377e-03	1.7350e-03	-5.1342e-03
37	4.9589e-01	2.1532e-02	2.0876e-02	-5.3304e-04	8.1977e-03	1.4265e-04
42	1.5078e-01	-9.2738e-03	-6.7545e-01	1.0485e-04	3.2802e-03	1.0054e-02
43	-3.1703e-02	1.5867e-02	3.3901e-01	-6.7148e-04	-8.9100e-04	2.0072e-02
47	1.5472e-02	-1.0215e-03	1.3361e-03	2.3017e-05	5.9638e-04	1.9645e-04
49	1.6821e-02	-1.9972e-03	7.9666e-04	6.0417e-05	6.5962e-04	4.8534e-04
51	3.6299e-01	1.5726e-02	-1.1829e-01	-8.9325e-04	9.4002e-03	-7.7340e-03
53	1.3497e-01	-1.1083e-01	-2.1519e-03	3.9465e-03	3.5908e-03	2.1085e-02
54	-9.2845e-02	1.2138e-01	-1.1746e-02	-4.3772e-03	-2.5254e-03	-2.1974e-02
64	-4.9887e-02	2.2195e-01	-2.8989e-02	-6.4235e-03	-1.8602e-03	1.3870e-02
65	-4.0576e-02	9.6106e-02	-2.1526e-02	-3.9407e-03	-1.2084e-03	-2.6013e-02
71	5.2906e-01	6.7761e-02	5.7193e-01	-2.8158e-03	1.8329e-02	-2.7449e-03
72	1.1411e-01	-2.4424e-01	8.9875e-02	1.0376e-02	3.7185e-03	5.5124e-02
80	1.2641e-01	3.1304e-02	-6.7740e-01	-1.5390e-03	5.9147e-03	-9.9595e-03
83	-2.5864e-01	1.0155e+00	1.9787e-02	-4.4246e-02	-8.9844e-03	-2.6269e-01
84	2.0360e-01	9.7398e-01	-3.9714e-03	-4.6785e-02	3.9231e-03	3.5340e-01

Reflector

Mode No	x	y	z	rx	ry	rz
1	7.2222e-01	7.5814e-02	1.4506e-05	2.5846e-05	1.0075e-05	2.7880e-04
2	2.8591e-03	-6.8875e-01	1.3704e-04	-1.0708e-03	2.1128e-07	-3.2889e-05
3	5.9803e-02	-8.7587e-01	-2.7347e-05	-2.5233e-04	8.7789e-07	-3.3297e-03
4	-1.5474e-01	4.3526e-04	9.2935e-01	-1.1934e-05	-3.7352e-03	4.1262e-06
5	-4.7880e-03	-6.4431e-04	-6.8829e-01	1.7694e-05	-9.3533e-05	-3.0762e-06
6	1.2365e-03	5.7522e-01	-2.6677e-04	-1.6050e-02	2.1101e-05	1.1472e-03
7	1.1403e-03	-6.4502e-01	-3.7125e-03	1.5505e-02	1.2363e-05	-7.3216e-03
8	-5.6880e-01	2.6643e-03	5.6757e-01	4.4041e-04	-1.0430e-02	2.3868e-04
9	1.9125e-02	2.0563e-01	-2.2327e-02	8.9695e-03	3.6741e-04	1.0952e-02
12	-1.0725e-01	-7.0550e-03	-4.5818e-02	-2.7673e-04	-4.5025e-03	5.0166e-04
16	-9.4885e-02	7.5643e-02	6.0479e-02	2.8066e-03	-1.7710e-03	-5.8697e-04
17	-7.8867e-03	3.1536e-01	4.4258e-03	1.1654e-02	-3.9475e-04	-2.0992e-03
19	-8.0116e-01	-4.1639e-02	2.1118e-01	-1.5744e-03	-1.7997e-02	-6.3864e-05
22	8.8948e-03	-1.3097e-01	1.3435e-02	1.6433e-02	1.4194e-04	8.1640e-03
23	-2.6956e-01	-8.1769e-02	4.8835e-01	1.8633e-03	-3.4883e-03	1.8393e-03
24	2.5882e-02	8.4931e-01	6.7749e-02	-2.0004e-02	1.9812e-04	-1.9478e-02
25	-5.2628e-02	-6.0808e-01	2.3298e-02	1.4257e-02	-1.8868e-03	1.4179e-02
26	1.4017e-03	1.0961e-01	2.0208e-01	-2.7312e-03	-3.5729e-03	-2.6632e-03
27	-1.0725e+00	7.9214e-02	1.2496e-03	-2.3445e-03	-2.2888e-02	-2.1726e-03
28	-7.5826e-02	3.9854e-02	-2.5715e-03	2.6909e-03	-1.4033e-03	2.3857e-03
29	-5.5150e-03	-9.7012e-02	-1.3854e-02	-1.5412e-03	3.4626e-04	-6.3530e-04
30	3.1130e-01	2.5068e-03	-5.2693e-02	1.0875e-04	9.5555e-03	-5.7028e-06
31	-7.1748e-03	2.7498e-01	4.0351e-03	-5.2383e-03	-1.6732e-04	-4.3595e-03
32	-2.1109e-01	-1.1710e-02	3.4677e-02	1.3091e-04	-3.5279e-03	1.3414e-04
33	1.3882e-03	-2.6681e-02	1.5238e-03	8.9311e-04	1.7033e-04	8.2805e-04
37	7.2670e-01	-3.3780e-02	7.1618e-01	3.9051e-03	2.2456e-02	3.0677e-03
42	4.1687e-02	-2.2222e-02	2.2090e-02	-8.9093e-03	7.4723e-03	-6.9306e-03
43	-3.3839e-02	-5.8799e-02	-4.3355e-02	-2.2153e-02	-4.8105e-03	-1.7202e-02
47	5.9704e-01	1.0311e-02	-3.9453e-01	-1.0974e-03	1.7651e-02	-8.7374e-04
49	8.5625e-01	4.7288e-04	-5.0518e-01	-3.6464e-04	2.8596e-02	-3.1202e-04
51	-1.3901e-01	-1.4652e-01	-3.3850e-01	2.3784e-02	-1.1386e-02	1.9409e-02
53	-5.1409e-02	-6.6712e-04	-4.0020e-02	-5.2285e-02	-4.5602e-03	-4.2412e-02
54	3.4379e-02	-2.8020e-01	5.9340e-03	3.4481e-02	3.2171e-03	2.8276e-02
64	2.1712e-02	5.4340e-02	-5.6223e-02	4.1276e-02	-2.8875e-02	3.3435e-02
65	-1.7496e-03	-2.0814e-01	-2.0303e-02	-1.3543e-01	-5.2853e-03	-1.0968e-01
71	1.2672e-01	3.6524e-02	3.4147e-01	1.1824e-02	-4.2355e-02	9.5634e-03
72	3.4616e-02	-3.7218e-01	1.8002e-02	-9.7915e-02	-8.2578e-03	-7.9051e-02
80	-2.4056e-02	-7.1658e-03	2.8081e-01	-8.2359e-04	1.4717e-03	-6.5729e-04
83	-6.8644e-02	-8.8724e-02	-1.4653e-02	-7.1625e-03	6.1725e-03	-5.7916e-03
84	4.1747e-02	-2.9191e-02	2.0906e-03	-2.0866e-03	-3.0736e-03	-1.6837e-03

Appendix 9

The x and y LOS coordinates of the laser beam projection on the detector may be computed with the linearized model coefficients given below. These coefficients multiply the displacement modal coordinates for the 40 modes as shown.

Mode No	X-LOS	Y-LOS
1	7.5017e-01	7.3545e-02
2	2.9983e-03	3.4266e-03
3	6.2907e-02	-8.5521e-01
4	-2.8924e+00	2.5047e-02
5	-1.6456e-01	-1.1360e-02
6	2.3384e-02	9.9433e+00
7	1.1789e-01	-1.8760e+00
8	-2.5342e+01	-8.0595e-01
9	7.6660e-01	-2.1148e+01
12	-2.5093e+00	-3.8995e-02
16	-1.6990e+00	-4.4206e-01
17	2.5970e-01	-2.2108e+00
19	-1.6490e+01	8.6304e-01
22	3.8866e-02	-1.6585e+01
23	-7.5181e+00	-2.6544e+00
24	1.7096e+00	2.8328e+01
25	5.1529e+00	-1.6371e+01
26	2.7889e+01	3.2162e+00
27	-3.7039e+01	3.1777e+00
28	-3.4738e+00	-7.1290e+00
29	-3.1738e-01	-1.3215e+00
30	1.4959e+01	7.4840e-01
31	-2.8099e-01	6.6605e+00
32	-6.4865e+00	-3.4649e-01
33	-1.7171e+00	-6.0580e+00
37	2.0146e+01	-4.5544e+00
42	5.4635e+00	2.1705e+01
43	-4.9433e+00	4.8419e+01
47	2.3366e+01	1.5357e+00
49	3.7953e+01	9.9280e-01
51	-2.5221e+01	-3.7464e+01
53	-9.9625e+00	8.6914e+01
54	7.0291e+00	-6.6610e+01
64	-3.5632e+01	-3.5191e+01
65	-5.5665e+00	1.3438e+02
71	-7.5487e+01	-1.7625e+01
72	-1.4838e+01	1.8020e+02
80	-5.6691e+00	-1.0195e+01
83	1.8054e+01	-2.8666e+02
84	-8.3473e+00	3.8753e+02

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13. ABSTRACT (Maximum 200 words) A testbed for the development of Controls-Structures Interaction (CSI) technology to improve space science platform pointing is described. The evolutionary nature of the testbed will permit the study of global line-of-sight pointing in phases 0 and 1, whereas, multi-payload pointing systems will be studied beginning with phase 2. The design, capabilities and typical dynamic behavior of the phase 0 version of the CSI evolutionary model (CEM) is documented in this report for investigators both internal and external to NASA. The model description includes line-of-sight pointing measurement, testbed structure, actuators, sensors and real-time computers, as well as finite element and state space models of major components.				
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