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December 1994

Calibration of a Six-Degree-of-Freedom Acceleration Measurement Device

Prepared by

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Cambridge, MA 02142

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This report describes the calibration of a six-degree-of-freedom acceleration measurement system designed for use in the measurement of linear and angular head accelerations of anthropomorphic dummies during crash tests. The calibration methodology, developed earlier, uses several different prime movers to extract the necessary information to characterize the system completely. The device calibrated consisted of any array of nine linear accelerometers in a non-coplaner (3-2-2-2) configuration. The calibration was carried out in the Naval Biodynamics Laboratory in New Orleans, LA.

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PREFACE

This report describes the calibration of a six-degree-of-freedom acceleration measurement system designed for use in the measurement of linear and angular head accelerations of anthropomorphic dummies during crash test conditions. The work was sponsored by the U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA), Office of Research and Development. The work was performed by the Volpe National Transportation Systems Center (VNTSC), Office of Systems Engineering, Vehicle Crashworthiness Division under Project Plan Agreement HS176.

The calibration methodology used was developed earlier and uses several different prime movers to extract the necessary information to characterize the system completely. The device itself consisted of an array of nine linear accelerometers in a non-coplaner (3-2-2-2) configuration. The calibration was carried out under a Reimbursable Agreement with the Naval Biodynamics Laboratory in New Orleans, LA. Mr. Mark Haffner, the NHTSA sponsor, provided critical guidance and support throughout the performance of this work.

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METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

PB95-181889

TABLE OF CONTENTS

SECTION **PAGE**

APPENDICES

LIST OF FIGURES

1. INTRODUCTION

The purpose of the work reported here was to implement a methodology developed earlier (Ref 1) for calibrating a six-degree-of-freedom acceleration measurement device. The device, consisting of an array of nine linear accelerometers, hereafter referred to as the NAP (nine accelerometer package), was designed to be mounted within the head of an anthropomorphic dummy to measure the linear and angular acceleration of the head during impact testing. The NAP used has a non-coplaner (3-2-2-2) configuration which has been shown to be the most reliable implementation of this technique. This particular configuration provides signals that are directly proportional to the angular accelerations without the need to estimate angular velocities. In actual practice, however, small measurement errors do occur. The purpose of the calibration performed here is to demonstrate these errors and provide a technique for correcting the data. (See Reference 1 for details.)

2. ACCELEROMETER PACKAGE

A nine accelerometer, six-degree-of-freedom impact measurement device was designed and fabricated at the NBDL. The accelerometer mount, shown in Figure 1, was machined from a

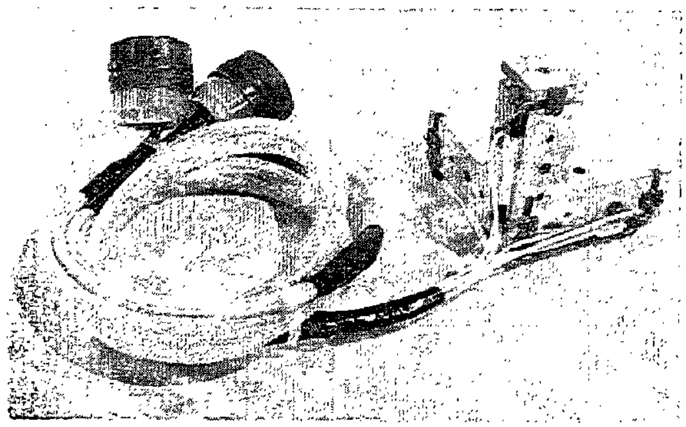


FIGURE 1. THE NAP PACKAGE

monolithic block of aluminum to maximize its stiffness. The accelerometer mount has three 2.75" arms. Cross-section of the arms is 0.875"x 0.875". At the root where all three arms meet, there is a 0.375" radius. One of the design objectives was the elimination of any resonant modes in the 0-1000 Hz region. A detailed modal analysis of the mount was performed and the results are included as an addendum to this Section. It is obvious from the result of the analysis that the goal was met.

The accelerometers selected for the system were Entran EGA series flanged subminiature accelerometers with a full scale range of ± 500 g's. In order to accurately position the accelerometers on the mount, the manufacturer was tasked to maintain a tight width tolerance of +0.00" and -0.002" from the nominal 0.145" width. Grooves were machined on the mount at the target location of each accelerometer. The groove width is 0.146" with a tolerance of

-0.00" and +0.002", yielding a maximum "slop" of 0.005". The accelerometers were placed in the grooves and fastened in place via a pair of 0-80 screws. The mounting holes were located such that the sensitive axis of each accelerometer intersects the appropriate package coordinate axis.

In addition to location and orientation which were controlled by package design, two other important parameters are sensitivity and frequency response of the accelerometers. Piezoresistive accelerometers of the type used in this project, utilize solid-state active bridge elements. The sensitivity (units/g) of this type of accelerometer can vary considerably from unit to unit. Since the equations of angular motion derived for the 3-2-2-2 NAP consist of linear combinations of four accelerometers, the sensitivities have to be normalized prior to combining the individual outputs. In an attempt to avoid the normalization requirement, the accelerometer specifications were written requiring all sensitivities to be matched within ± 1%. The nine units actually used in the NAP have the sensitivities shown in Table 1. The accelerometers are well within

TABLE 1. ACCELEROMETER SENSITIVITIES

Accelerometer ID	Sens. (mv/g)	Dev. from. Mean
P15	0.3315	-0.00187
P13	0.3299	-0.00347
P14	0.3356	+0.00223
P12	0.3320	-0.00137
CP06	0.3350	+0.00163
P11	0.3350	+0.00163
P04	0.3350	+0.00163
P05	0.3312	-0.00127
FP06	0.3352	+0.00165
Mean:	0.33337	
σ:	2.19E-03	
%σ:	0.219%	

specifications and the mean value can be used as the sensitivity for all accelerometers with the introduction of almost no error. The sensitivity uniformity across accelerometers is depicted pictorially in Figure 2. Note that in order to make the absolute deviations from the mean visible, they are multiplied by a factor of ten in the plot.

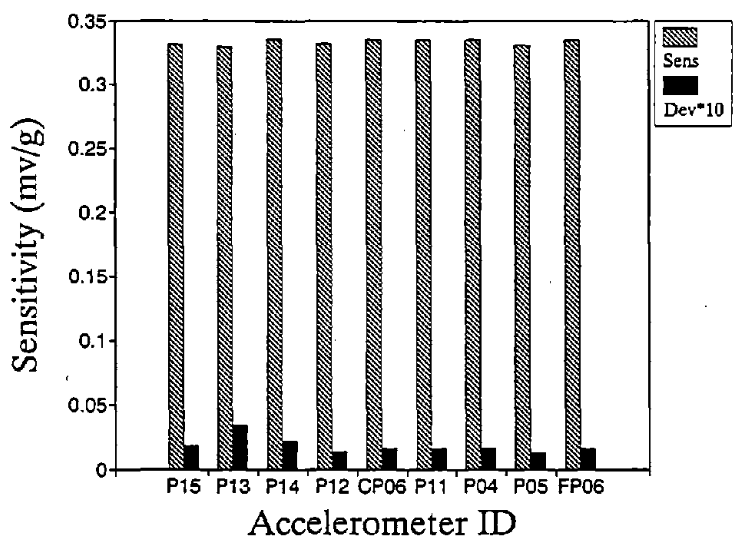


FIGURE 2. ACCELEROMETER SENSITIVITY

Almost all miniature accelerometers utilize a cantilever beam on which are bonded solid state strain gages. The deflection of the beam under g-loading imparts strain into the gages, thus generating an output. The accelerometers therefore exhibit the characteristics of a second order system, i.e. their response is described by a second order differential equation. The frequency characteristics of linear accelerometers when used in pairs to measure angular acceleration is very important. If the frequency response is not well matched for the pair, small differences in phase shift can cause large errors in the measurement of angular acceleration. One way to avoid the problem is to use undamped accelerometers, because undamped systems have very little phase shift below resonance. Undamped transducers, however, can easily have their resonant frequency excited during transient experiments such as an impact event. If this occurs, at best the signal conditioners will almost certainly saturate, causing loss of the data. At worst the transducer will be destroyed. One technique to circumvent this problem is to utilize transducers with very high natural frequencies, well beyond the frequency range of any expected components of the measurand. However, mechanically this implies very stiff beams of low deflections, and consequently the sensitivity of such transducers is very low, necessitating very large signal conditioner gains. Such high gains can introduce a whole new set of problems.

Damped accelerometers eliminate the resonance problem, but they have significant phase shift well below their natural frequency, thus requiring a careful matching of phase shift characteristics. This is very difficult to accomplish in overdamped or critically damped transducers. A compromise solution utilized for this project was to use slightly underdamped accelerometers, with an overshoot of 2.5 ± 0.5 db, with a flat response (within 0.5 db) at least to 1000 Hz and the resonant peak around 4000 Hz. According to a company representative, this is the frequency response region where the manufacturer has the best chance of success matching responses of accelerometer pairs. The frequency response of each of the nine accelerometers used in the NAP is illustrated in Appendix D.

As will be shown later, the three components of angular acceleration require six sets of differences (or sums) of accelerometer pairs. The accelerometers were installed on the NAP as to best match the frequency responses of the pairs needed to compute these combinations.

3. IMPLEMENTATION OF EQUATIONS AND SIGNAL CONDITIONING

The "raw" data generated by the NAP consist of the output of the nine individual accelerometers. The calibration and error determination procedure (Ref. 1) however assumes package outputs, i.e., three linear and three angular accelerations along and about three orthogonal axes.

The idealized package outputs for a 3-2-2-2 configuration NAP were originally derived by Padgaonkar and King in a now classic paper (Ref. 2). Such a package generates two sets of redundant equations:

$$\dot{\omega}_x=\frac{(A_{z2}-A_{z0})}{\rho_y}-\omega_y\omega_z$$

$$\dot{\omega}_y=\frac{-(A_{z1}-A_{z0})}{\rho_x}+\omega_x\omega_z$$

$$\dot{\omega}_z=\frac{(A_{y1}-A_{y0})}{\rho_x}-\omega_x\omega_y$$

and:

$$\dot{\omega}_x=\frac{-(A_{y3}-A_{y0})}{\rho_z}+\omega_y\omega_z$$

$$\dot{\omega}_y=\frac{(A_{x3}-A_{x0})}{\rho_z}-\omega_x\omega_z$$

$$\dot{\omega}_z=\frac{-(A_{x2}-A_{x0})}{\rho_y}+\omega_x\omega_y$$

By adding the corresponding equation pairs, the crosscoupling terms cancel and the following equations are obtained:

$$\dot{\omega}_x = \frac{(A_{z2}-A_{z0})}{2\rho_y} - \frac{(A_{y3}-A_{y0})}{2\rho_z}$$

$$\dot{\omega}_y = \frac{(A_{x3}-A_{x0})}{2\rho_z} - \frac{(A_{z1}-A_{z0})}{2\rho_x}$$

$$\dot{\omega}_z = \frac{(A_{Y1}-A_{Y0})}{2\rho_x} - \frac{(A_{x2}-A_{x0})}{2\rho_y}$$

The NAP built for this project has identical moment arms, i.e.,

$$\rho_x = \rho_y = \rho_z = \rho \quad .$$

Making this substitution and renaming the accelerometers according to the numbering scheme of Figure 1-1, Appendix B-2 of Reference 1, the above equations become:

$$\dot{\omega}_x = \frac{(A_7+A_2)}{2\rho} - \frac{(A_3+A_9)}{2\rho}$$

$$\dot{\omega}_y = \frac{(A_3+A_8)}{2\rho} - \frac{(A_1+A_4)}{2\rho}$$

$$\dot{\omega}_z = \frac{(A_1+A_5)}{2\rho} - \frac{(A_2+A_6)}{2\rho}$$

The above is one of several forms the equations can take and the difference-of-sums form was selected for implementation convenience. Since in this configuration 2ρ is a constant term common to all terms of the equations , it can be treated as a scale factor and lumped with accelerometer sensitivity. In this manner it does not have to be dealt with explicitly. The x,y and z linear accelerations are usually obtained from accelerometers 1, 2, and 3 located at the vertex of the NAP, and are given by

$$\ddot{x}=A_1 \quad \ddot{y}=A_2 \quad \ddot{z}=A_3 \; .$$

Piezoresistive accelerometers are bridge-type devices and thus their outputs are relatively low-level differential signals. In order to maximize signal-to-noise ratio and to simplify the making of measurements, it is desirable to convert these outputs to high-level, single-ended signals via high-quality instrumentation amplifiers. A package consisting of nine Precision Monolithics Inc.'s AMP01 precision low-noise instrumentation amplifiers was fabricated. The amplifiers were "burned-in" for over 200 hours and the design featured wide-range offset control. A fixed gain of 200 was selected as sufficient to boost the output of the accelerometers to reasonable levels, obtained via ± 0.005% precision 600 ohm gain resistors. A picture of the package is shown in Figure 3 and a schematic in

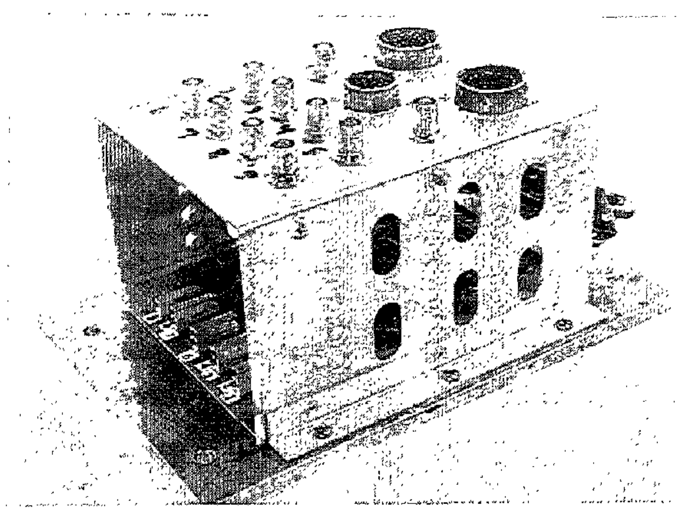


FIGURE 3. SIGNAL CONDITIONING PACKAGE

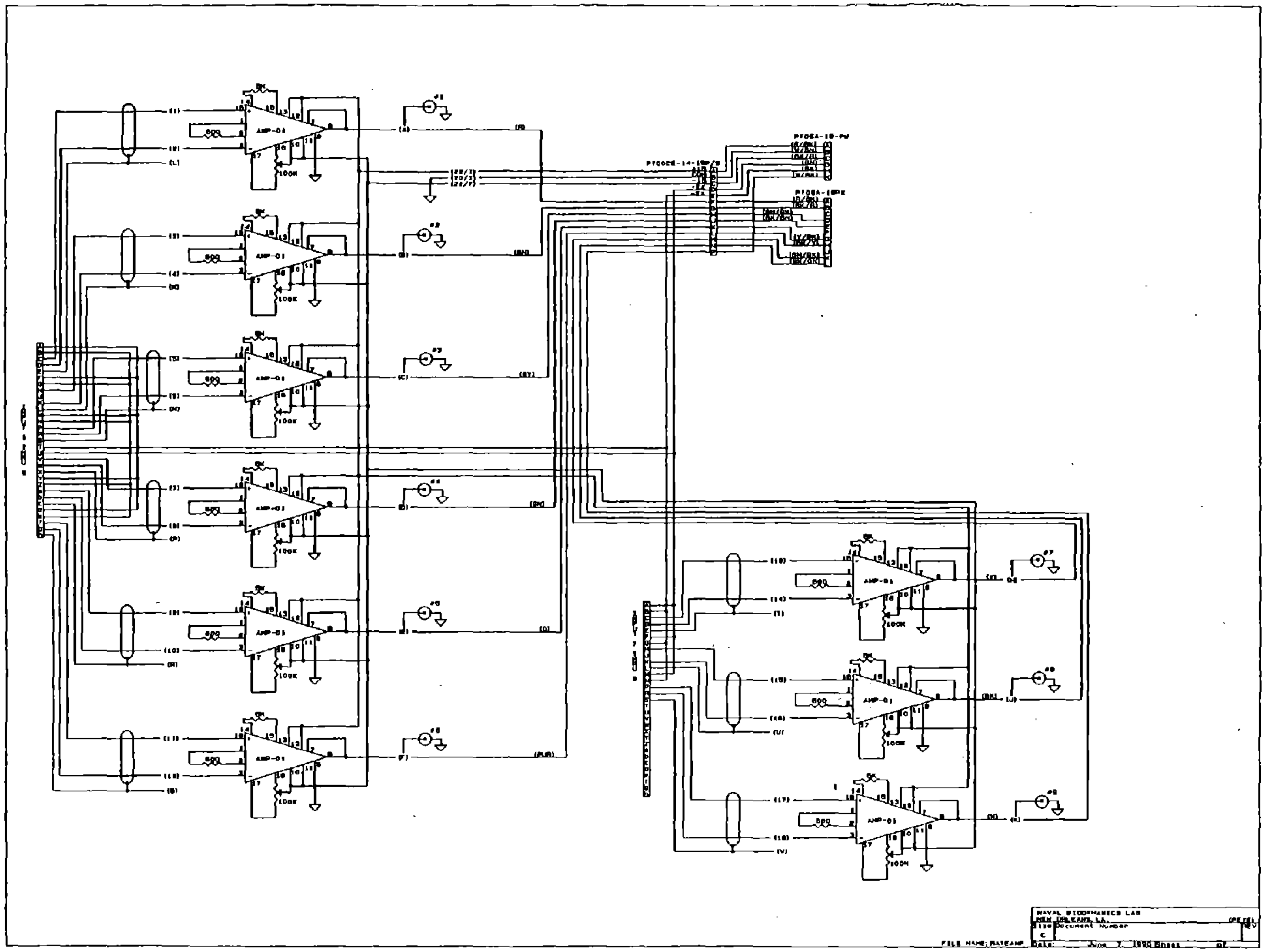


FIGURE 4. SIGNAL CONDITIONING SCHEMATIC

Figure 4. The Common Mode Rejection Ratio of the amplifiers at the selected gain of 200 was measured to be in excess of 115 db.

In addition to having to meet stringent electrical specifications, the package had to be mechanically rugged, because it had to be installed on the rate table for the rate test and thus subjected to substantial centripetal accelerations. Had the package not been so mounted, all eighteen differential outputs of the accelerometers (2 outputs per unit) would have to be brought out of the rate table via the latter's slip rings, and the table does not have that many rings.

The instrumentation amplifier package outputs #1 through #9 as shown in Figure 4 provide the outputs A1-A9 identified in the motion equations. There remains to implement the appropriate combinations of these outputs to generate the three angular acceleration components. This was implemented using the setup shown in Figure 5. Three Tektronix AM501A operational amplifiers, installed in a Tektronix TM500 power supply/enclosure were used to perform the simple arithmetic operations required. The amplifiers were configured as unity-gain adder/subtractors. Accuracy of the computations was assured by use of high-precision (±0.005%) summing and feedback resistors. A 22 pf capacitor was added in parallel with the feedback resistors to limit the bandwidth of the amplifiers to approximately 7.5 Khz.

The six required outputs are now all available simultaneously; only the task of providing scaling factors remains. It was stated earlier that the accelerometers used are sufficiently well matched that the mean sensitivity of all of them can be used as a generic scale factor. Thus for the linear acceleration outputs one obtains:

$$0.3337\frac{mv}{g}\ X\ 200 = 66.67\frac{mv}{g}$$

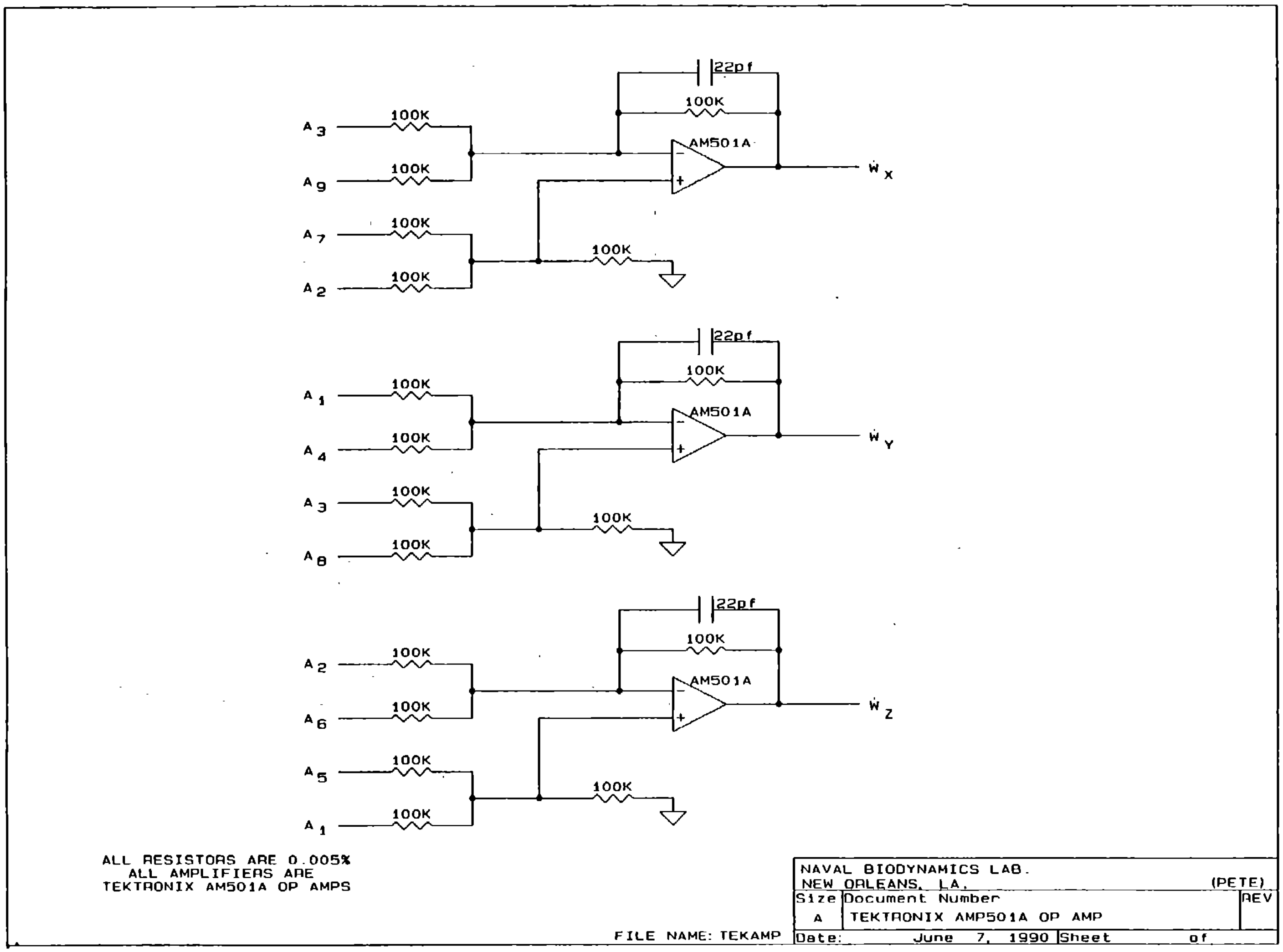


FIGURE 5. ARITHMETIC MODULE SCHEMATIC

The value of ρ for subject package is 2.23 inches. If one assumes uniform circular motion about the package origin and that an accelerometer 2.23 inches from the origin "sees" 1 g or 32.2 ft/s^2, this is equivalent to 173.27 rad/s^2 because:

$$\dot{\omega} = A_T \cdot R \quad ,$$

i.e., the angular acceleration is the product of the tangential acceleration and the radius. One can now obtain the angular sensitivity of the package:

$$\frac{32.2\ ft/s^2}{2.23\ in/12\ in/ft} = 173.27\ rad/s^2$$

$$\frac{66.67\ mv}{173.27\ rad/s^2} = 0.3848\ mv/rad/s^2$$

4. TEST DEVICES

The test sequences for the determination of accelerometer error coefficients as described in Appendix B of Reference 1 consist of six different types of tests:

1. Static, i.e., exposure to a ±1g field.
2. Linear sinusoidal vibration at several discrete frequencies.
3. Constant angular velocity, aligned axis.
4. Sinusoidal rotary motion, aligned axis.
5. Constant angular velocity, misaligned axis.
6. Sinusoidal rotary motion, misaligned axis.

These tests require four different types of test devices to impart the desired inputs into the accelerometer package. The static tests were performed using an Ideal-Aerosmith Model 221300-3 tilt table (Figure 6) modified to provide a full ±90 degrees of rotation from the level position. This table features

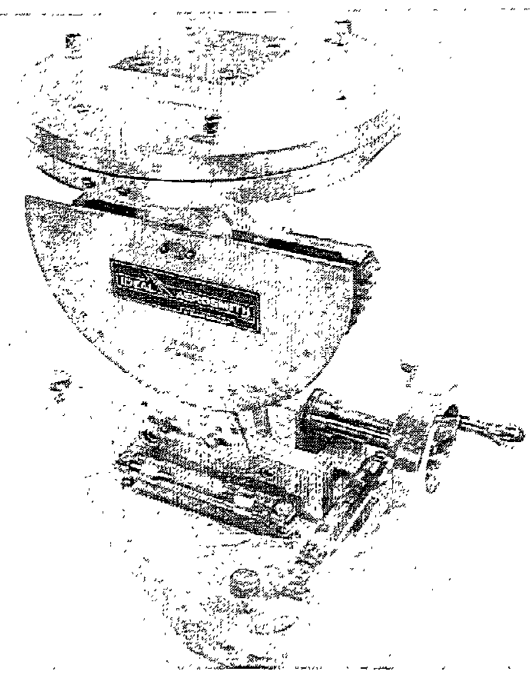


FIGURE 6. TILT TABLE

precision bubble levelers and an angular readout with a resolution of ±0.1 degree.

Test sequence #2, which consisted of vibrating the package linearly along each of its axis at several frequencies, was performed on an Unholtz-Dickie Model 201 electrodynamic shaker (Figure 7), capable of inputs to a test specimen of up to 100 g's at 1000 Hz.

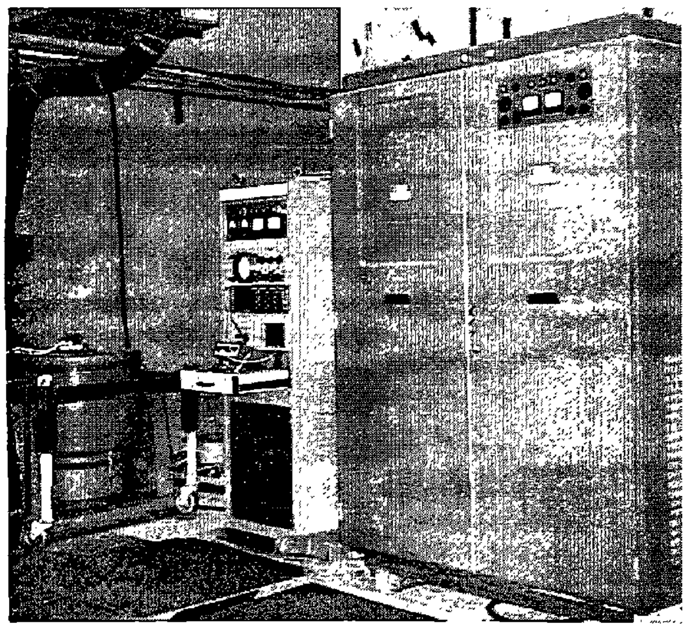


FIGURE 7. LINEAR SHAKER & CONTROLLER

The shaker was driven by a Tektronix FG 507 Function Generator. Test sequences #3 and #5 were performed on an Inland Motors Model 822 rate table (centrifuge) (Figure 8), capable of spin rates of up to 5000 deg/sec. It has a 24" diameter surface and is thus capable of generating up to 250 g's of centripetal acceleration on its periphery. For subject tests however, this capability was not required, as the objective was to have the rate table's spin axis project through the origin of the NAP. For this purpose, two interface modules were machined (Figure 9), one for test sequence #3, the other a 30° wedge for test sequence #5.

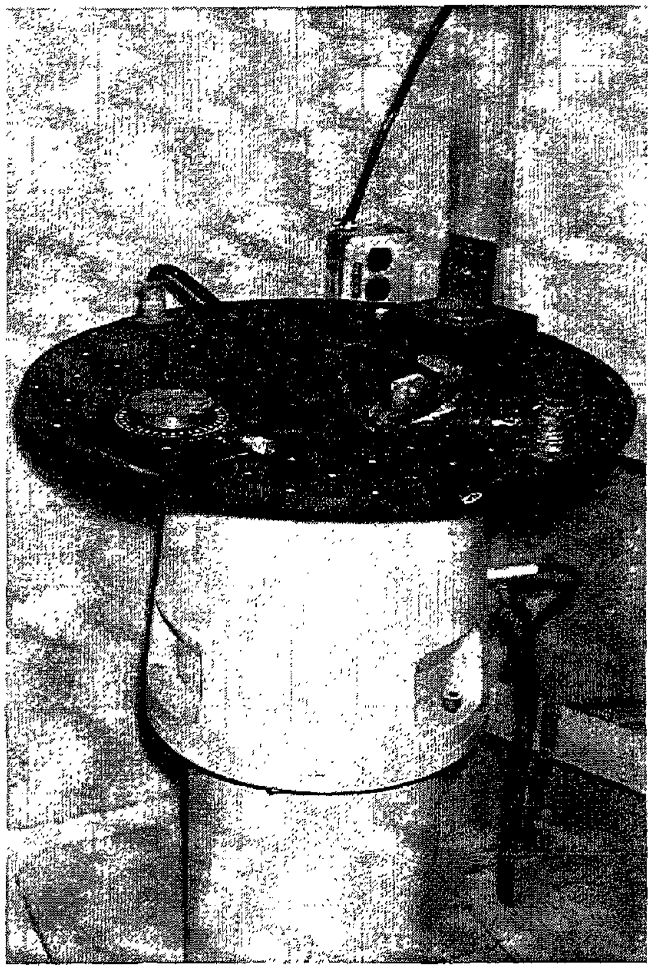


FIGURE 8. RATE TABLE

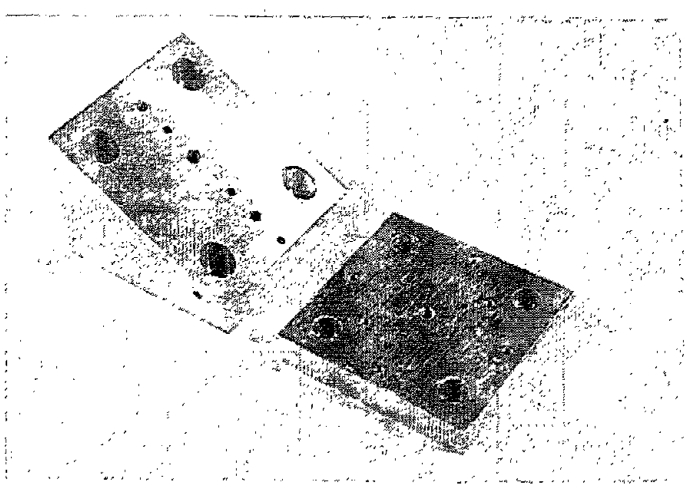


FIGURE 9. INTERFACE FIXTURES

Finally, a Team Corporation hydraulically-powered angular shaker capable of ±40° periodic motion about its spin axis was used for test sequences #4 and #6. The test device consists of a RL110 rotary actuator powered by a HPS65 20 gpm hydraulic power supply and mounted on a seismic mass (Figure 10). The system's control console is shown in Figure 11. The same interface fixtures used on the rate table (Figure 9) were used for these tests.

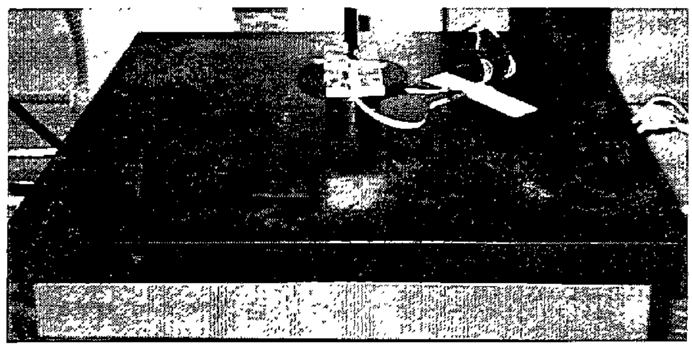


FIGURE 10. ANGULAR SHAKER

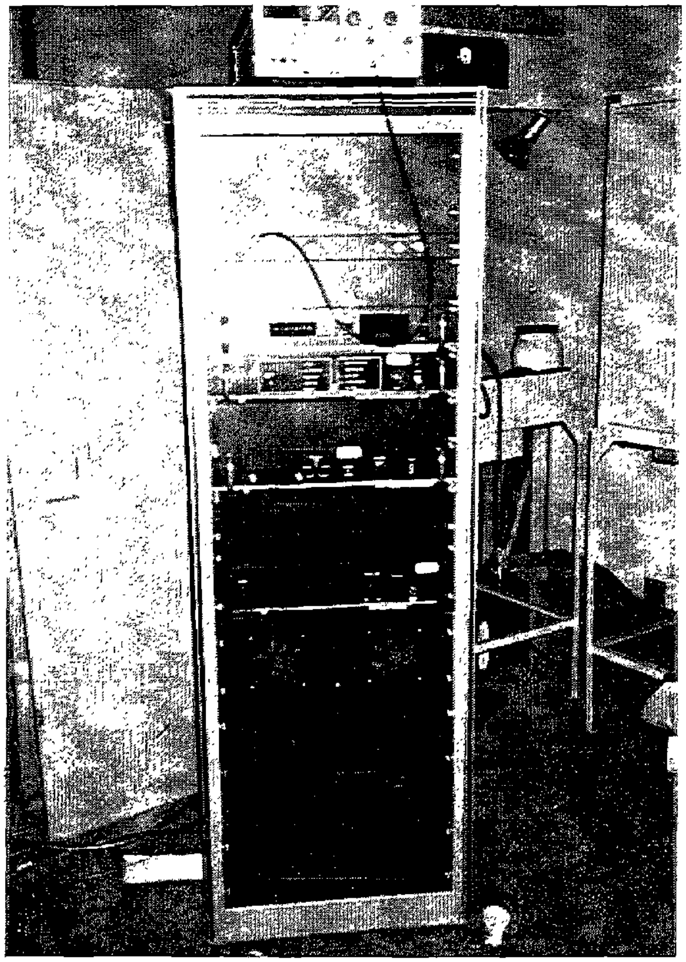


FIGURE 11. CONTROL CONSOLE

5. DATA ACQUISITION SYSTEM

The NAP calibration procedure required that two types of measurements be made:

a. DC Volts: The readings were made during the static (±1 g) tests and during the rate table tests.

b. AC volts: These readings were made during the dynamic sequences, i.e., linear and angular shaker tests.

The data acquisition system configured to make these measurements is depicted in Figure 12. A Hewlett-Packard 3457A 6-1/2 digit digital multimeter equipped with a HP44492 10-channel scanner was interfaced with a Texas Microsystems Inc. PC-compatible microcomputer via an IEEE-488 parallel bus. All control functions and data transfers took place via this bus.

The data acquisition and control software was written in the ASYST programming language, a product of Asyst Software Technologies, Inc., in a user-friendly, interactive menu format. The entire acquisition procedure consists of the sequence of seven screens depicted in Figures 13 through 19, which are self-explanatory. The program acquires the data, generates an information header, and computes some simple statistics, as shown in Table 2 and summarized in Appendix B. This information, in addition to being printed out, is saved in LOTUS 1-2-3 files on the hard disk and can be manipulated by any of the spreadsheet's data reduction and analysis features if necessary. Permanent storage of the data is on diskettes.

A second set of measurements were also made during the angular and linear shaker tests, using the setup shown in Figure 20. The main advantage of using such an Spectrum Analyzer is that the spectral response data are obtained on-line immediately.

TABLE 2. SAMPLE OUTPUT - DIGITAL DATA ACQUISITION SYSTEM

RUNID : TEST1-X
RUNDES: -G INTO X AXIS
DATE : 01/08/90
S/S/C : 10.0000
MODE : DCV
START : 14:07:46.16
DUR : 5 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
1	-0.4200	0.4700	0.4000	-5.2100	1.5200	-1.5500
2	-0.4200	0.4800	0.4100	-5.2000	1.4900	-1.5300
3	-0.4200	0.4700	0.4100	-5.2000	1.5200	-1.5500
4	-0.4300	0.4800	0.4100	-5.2000	1.5200	-1.5500
5	-0.4300	0.4900	0.4000	-5.1900	1.5200	-1.5500
6	-0.4200	0.4800	0.3800	-5.2000	1.5200	-1.5600
7	-0.4300	0.5000	0.4100	-5.1200	1.5300	-1.4800
8	-0.4000	0.5500	0.4400	-5.1300	1.5300	-1.4800
9	-0.4000	0.5600	0.4400	-5.1300	1.5300	-1.4800
10	-0.4000	0.5700	0.4400	-5.1300	1.5200	-1.4800
11	-0.4100	0.5600	0.4300	-5.1300	1.5300	-1.4800
12	-0.4000	0.5700	0.4300	-5.1300	1.5200	-1.4800
13	-0.4100	0.5700	0.4400	-5.1300	1.5300	-1.4800
14	-0.4000	0.5600	0.4300	-5.1300	1.5300	-1.4800
15	-0.4000	0.5600	0.4300	-5.1200	1.5200	-1.4800
16	-0.4100	0.5600	0.4300	-5.1200	1.5200	-1.4900
17	-0.4100	0.5600	0.4300	-5.1200	1.5200	-1.4800
18	-0.4100	0.5800	0.3900	-5.1700	1.5100	-1.5400
19	-0.4300	0.4700	0.3900	-5.2000	1.5200	-1.5500
20	-0.4200	0.4700	0.4000	-5.1800	1.5200	-1.5400
21	-0.4300	0.4700	0.3800	-5.2000	1.5200	-1.5400
22	-0.4400	0.4700	0.3800	-5.1900	1.5200	-1.5100
23	-0.4300	0.4800	0.4100	-5.2000	1.5200	-1.5400
24	-0.4200	0.4800	0.4000	-5.1700	1.5100	-1.5400
25	-0.4200	0.4700	0.4000	-5.1900	1.5100	-1.5300
26	-0.4300	0.4700	0.4100	-5.2000	1.5200	-1.5400
27	-0.4300	0.4800	0.4000	-5.2000	1.5300	-1.5400
28	-0.4200	0.4800	0.4000	-5.2000	1.5200	-1.5400
29	-0.4300	0.4700	0.4000	-5.2000	1.5200	-1.5100
30	-0.4300	0.4800	0.3900	-5.2000	1.5200	-1.5100
31	-0.4200	0.4800	0.3900	-5.1900	1.5100	-1.5100
32	-0.4200	0.4800	0.4000	-5.1900	1.5200	-1.5400
33	-0.4300	0.4800	0.4000	-5.1700	1.5200	-1.5400
34	-0.4300	0.4700	0.4000	-5.1900	1.5000	-1.5400
35	-0.4300	0.4700	0.4000	-5.1600	1.5200	-1.5400
36	-0.4200	0.4800	0.4000	-5.1900	1.5200	-1.5300
37	-0.4200	0.4800	0.4100	-5.2000	1.5300	-1.5400
38	-0.4300	0.4800	0.4000	-5.2000	1.5200	-1.5200
39	-0.4200	0.4800	0.3900	-5.2000	1.5200	-1.5400
40	-0.4200	0.4800	0.4100	-5.2000	1.5100	-1.5300
41	-0.4300	0.4800	0.4100	-5.1900	1.5200	-1.5400
42	-0.4300	0.4800	0.4000	-5.2000	1.5000	-1.5400
43	-0.4200	0.4700	0.3800	-5.1800	1.5000	-1.5500
44	-0.4200	0.4800	0.4100	-5.2000	1.5100	-1.5500
45	-0.4200	0.4800	0.3800	-5.1900	1.5200	-1.5600
46	-0.4300	0.4800	0.4100	-5.1900	1.5200	-1.5500
47	-0.4200	0.4900	0.4100	-5.1700	1.5000	-1.4900
48	-0.3900	0.5600	0.4300	-5.1500	1.5300	-1.4800
49	-0.4100	0.5600	0.4400	-5.1300	1.5200	-1.4800
50	-0.4100	0.5600	0.4300	-5.1200	1.5300	-1.4800

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.4400	0.4700	0.3800	-5.2100	1.4900	-1.5600
max	-0.3900	0.5800	0.4400	-5.1200	1.5300	-1.4800
avg	-0.4194	0.5016	0.4083	-5.1740	1.5186	-1.5212

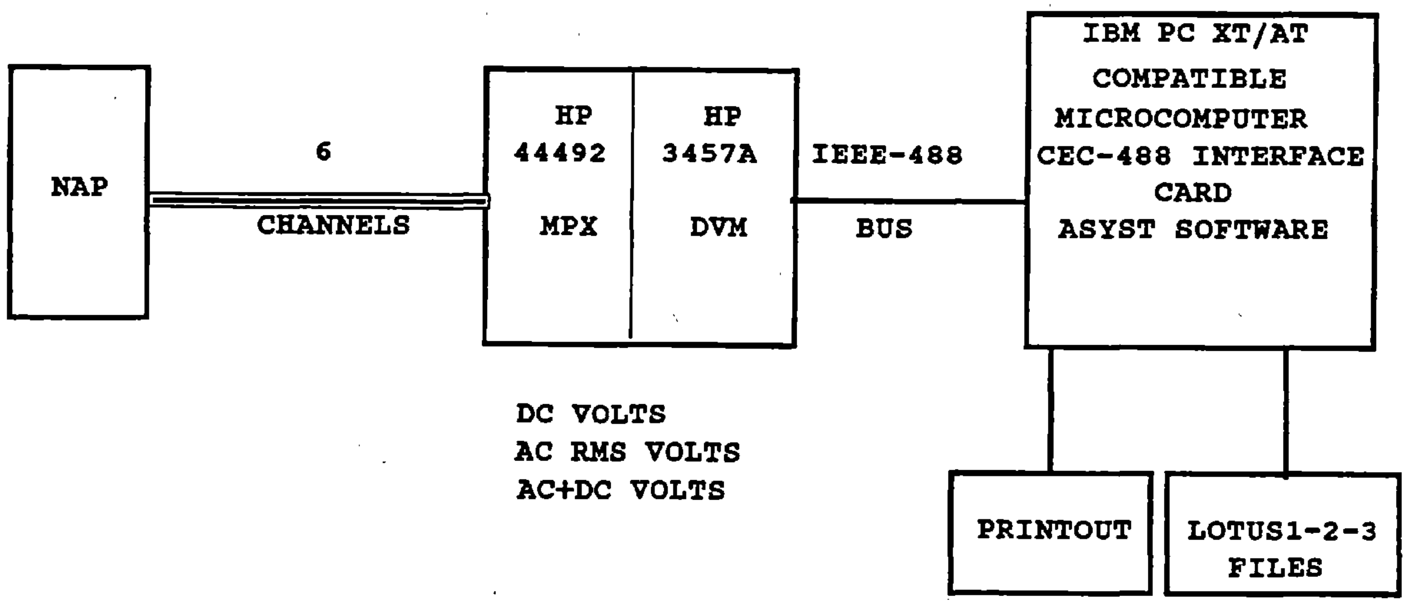


FIGURE 12. DIGITAL VOLTMETER BASED DATA ACQUISITION SYSTEM

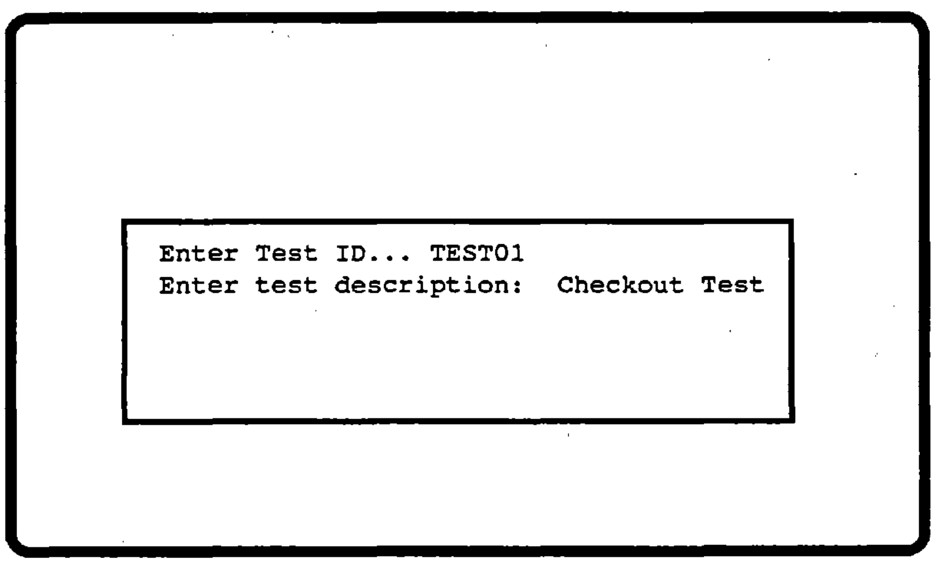


FIGURE 13. DATA ACQUISITION SYSTEM - SCREEN NO. 1

```
Select a DVM mode:  1
   1) DC volts
   2) AC volts
   3) AC+DC volts
```

FIGURE 14. DATA ACQUISITION SYSTEM - SCREEN NO. 2

```
Select Acquisition Rate-10 or 50 S/S/C 10
Enter length of test in sec(can't exceed 420) 30
```

FIGURE 15. DATA ACQUISITION SYSTEM - SCREEN NO. 3

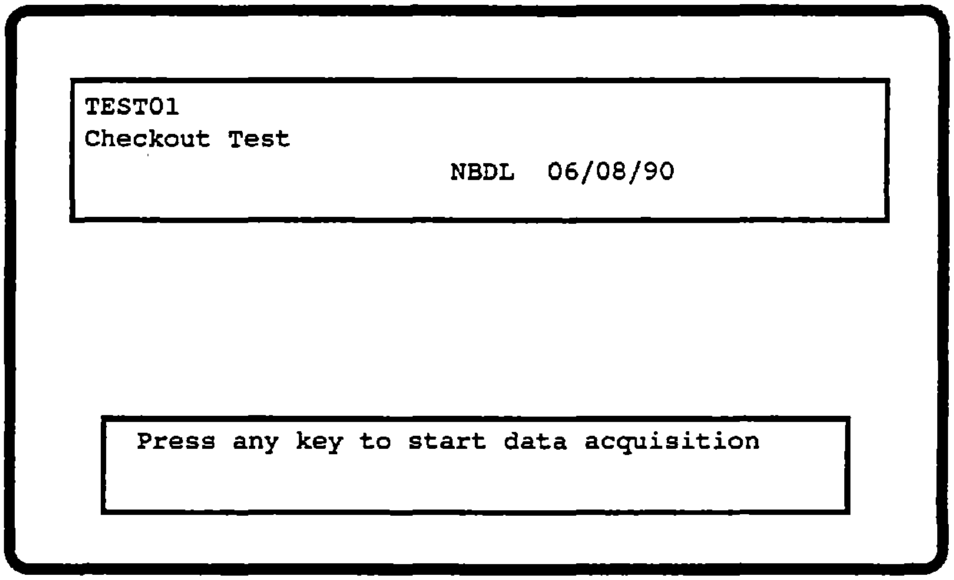


FIGURE 16. DATA ACQUISITION SYSTEM - SCREEN NO. 4

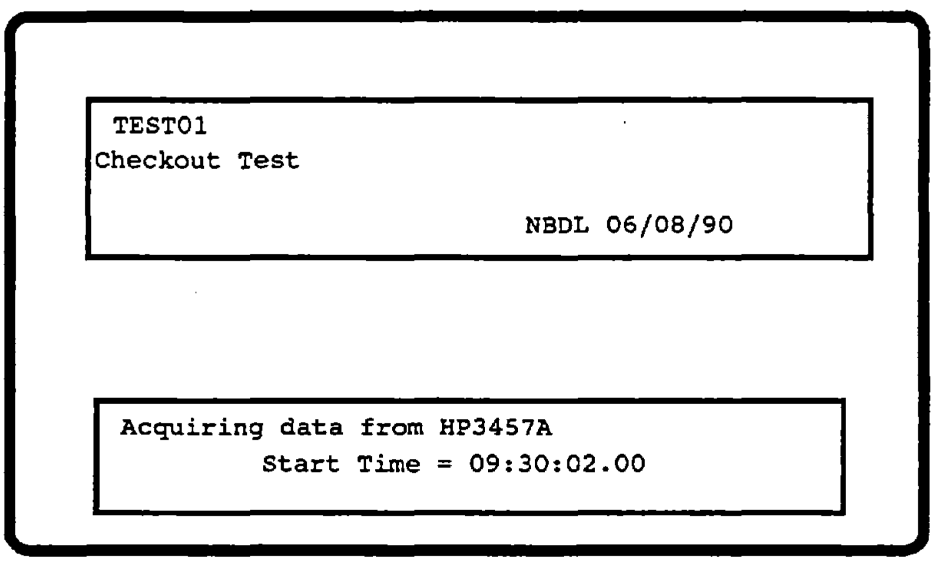


FIGURE 17. DATA ACQUISITION SYSTEM - SCREEN NO. 5

```
TEST01
Checkout Test
                              NBDL  06/08/90


     Test completed!

                         Start Time = 09:30:02.00
                         End Time =   09:40:32.02
```

FIGURE 18. DATA ACQUISITION SYSTEM - SCREEN NO. 6

```
Data have been written to: LOTUS file TEST01.WKS
                           ASYST file TEST01.DAT

Enter GO to start another test, BYE to exit ASYST
OK_
```

FIGURE 19. DATA ACQUISITION SYSTEM - SCREEN NO. 7

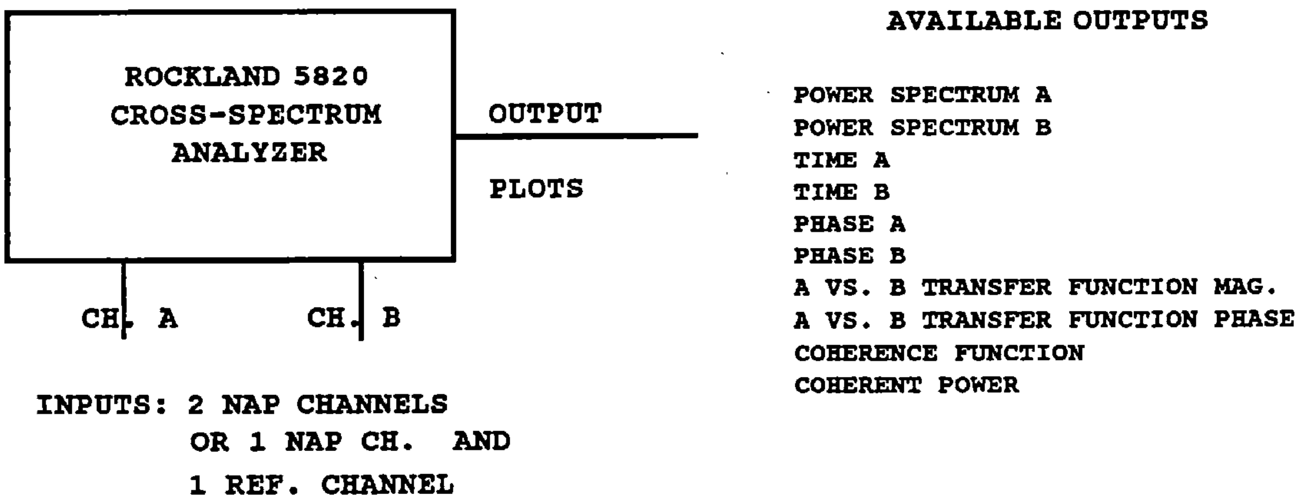


FIGURE 20. DYNAMIC TEST SETUP

6. CONCLUSIONS

Part of the calibration methodology proposed in Reference 1 was based upon the assumption that the transducer under test could be driven in a purely sinusoidal fashion by the various prime movers available. This was not the case, however, because the actual motion was always distorted, exhibiting significant harmonics above the fundamental driver frequency. To examine the response of the system to the fundamental driver frequency, a spectrum analyzer was used, allowing the user to examine the behavior of the transducer in the bandwidth of interest, i.e., at frequencies expected in a typical automotive impact test. In the tests that generated constant outputs (no sinusoidal motion), a digital voltmeter based data acquisition system was used.

Although the calibration required here was quite extensive and time consuming, in general, depending upon the particular transducer mechanism and configuration, some of the coefficients will not be significant and need not be part of the calibration. Further experience will dictate when this elimination will be possible. The results of the calibration are given in Appendix A and summarized in Figure A-4. Measurements taken indicated that a number of the coefficients were very small and hence were set to zero. The bias coefficients AL0, BL0, CL0, AA0, BA0 and CA0 can and should be electronically adjusted to zero, although it was not done in this calibration. The coefficients for the ω^2 terms were found to be small and were set to zero. In subsequent calibrations of this type of configuration, it may be possible to omit the computation of these terms although further laboratory experience is required before such a determination can be made.

In summary, the techniques employed in the calibration of the NAP were easily implemented and represent a reasonable approach to the calibration of a six-degree-of-freedom acceleration measurement device. Experience with the particular system in question is required to determine which coefficients are important and which are not.

APPENDIX A
CALIBRATION RESULTS

A.1 LABORATORY AND FIELD SYSTEM EQUATIONS

The laboratory and field equations for the nine-accelerometer system and the relationships among them are shown in Figures A-1, A-2 and A-3 respectively.

$$\dot{\gamma}_x = \dot{\omega}_x + AA0 + AA1\dot{\omega}_x + AA2\dot{\omega}_y + AA3\dot{\omega}_z + AA4\omega_x^2 + AA5\omega_y^2 + AA6\omega_z^2 + AA7\omega_x\omega_y + AA8\omega_x\omega_z + AA9\omega_y\omega_z + AA10\ddot{x} + AA11\ddot{y} + AA12\ddot{z}$$

$$\dot{\gamma}_y = \dot{\omega}_y + BA0 + BA1\dot{\omega}_x + BA2\dot{\omega}_y + BA3\dot{\omega}_z + BA4\omega_x^2 + BA5\omega_y^2 + BA6\omega_z^2 + BA7\omega_x\omega_y + BA8\omega_x\omega_z + BA9\omega_y\omega_z + BA10\ddot{x} + BA11\ddot{y} + BA12\ddot{z}$$

$$\dot{\gamma}_z = \dot{\omega}_z + CA0 + CA1\dot{\omega}_x + CA2\dot{\omega}_y + CA3\dot{\omega}_z + CA4\omega_x^2 + CA5\omega_y^2 + CA6\omega_z^2 + CA7\omega_x\omega_y + CA8\omega_x\omega_z + CA9\omega_y\omega_z + CA10\ddot{x} + CA11\ddot{y} + CA12\ddot{z}$$

$$\ddot{X} = \ddot{x} + AL0 + AL1\dot{\omega}_x + AL2\dot{\omega}_y + AL3\dot{\omega}_z + AL4\omega_x^2 + AL5\omega_y^2 + AL6\omega_z^2 + AL7\omega_x\omega_y + AL8\omega_x\omega_z + AL9\omega_y\omega_z + AL10\ddot{x} + AL11\ddot{y} + AL12\ddot{z}$$

$$\ddot{Y} = \ddot{y} + BL0 + BL1\dot{\omega}_x + BL2\dot{\omega}_y + BL3\dot{\omega}_z + BL4\omega_x^2 + BL5\omega_y^2 + BL6\omega_z^2 + BL7\omega_z\omega_y + BL8\omega_x\omega_z + BL9\omega_y\omega_z + BL10\ddot{x} + BL11\ddot{y} + BL12\ddot{z}$$

$$\ddot{Z} = \ddot{z} + CL0 + CL1\dot{\omega}_x + CL2\dot{\omega}_y + CL3\dot{\omega}_z + CL4\omega_x^2 + CL5\omega_y^2 + CL6\omega_z^2 + CL7\omega_x\omega_y + CL8\omega_x\omega_z + CL9\omega_y\omega_z + CL10\ddot{x} + CL11\ddot{y} + CL12\ddot{z}$$

FIGURE A-1. LABORATORY SYSTEM EQUATIONS

$$
\begin{aligned}
\dot{\omega}_x = \; & \dot{\gamma}_x + DA0 + DA1\dot{\gamma}_x + DA2\dot{\gamma}_y + DA3\dot{\gamma}_z \\
& + DA4\gamma_x^2 + DA5\gamma_y^2 + DA6\gamma_z^2 \\
& + DA7\gamma_x\gamma_y + DA8\gamma_x\gamma_z + DA9\gamma_y\gamma_z \\
& + DA10\ddot{X} + DA11\ddot{Y} + DA12\ddot{Z}
\end{aligned}
$$

$$
\begin{aligned}
\dot{\omega}_y = \; & \dot{\gamma}_y + EA0 + EA1\dot{\gamma}_x + EA2\dot{\gamma}_y + EA3\dot{\gamma}_z \\
& + EA4\gamma_x^2 + EA5\gamma_y^2 + EA6\gamma_z^2 \\
& + EA7\gamma_x\gamma_y + EA8\gamma_x\gamma_z + EA9\gamma_y\gamma_z \\
& + EA10\ddot{X} + EA11\ddot{Y} + EA12\ddot{Z}
\end{aligned}
$$

$$
\begin{aligned}
\dot{\omega}_z = \; & \dot{\gamma}_z + FA0 + FA1\dot{\gamma}_x + FA2\dot{\gamma}_y + FA3\dot{\gamma}_z \\
& + FA4\gamma_x^2 + FA5\gamma_y^2 + FA6\gamma_z^2 \\
& + FA7\gamma_x\gamma_y + FA8\gamma_x\gamma_z + FA9\gamma_y\gamma_z \\
& + FA10\ddot{X} + FA11\ddot{Y} + FA12\ddot{Z}
\end{aligned}
$$

$$
\begin{aligned}
\ddot{x} = \; & \ddot{X} + DL0 + DL1\dot{\gamma}_x + DL2\dot{\gamma}_y + DL3\dot{\gamma}_z \\
& + DL4\gamma_x^2 + DL5\gamma_y^2 + DL6\gamma_z^2 \\
& + DL7\gamma_x\gamma_y + DL8\gamma_x\gamma_z + DL9\gamma_y\gamma_z \\
& + DL10\ddot{X} + DL11\ddot{Y} + DL12\ddot{Z}
\end{aligned}
$$

$$
\begin{aligned}
\ddot{y} = \; & \ddot{Y} + EL0 + EL1\dot{\gamma}_x + EL2\dot{\gamma}_y + EL3\dot{\gamma}_z \\
& + EL4\gamma_x^2 + EL5\gamma_y^2 + EL6\gamma_z^2 \\
& + EL7\gamma_x\gamma_y + EL8\gamma_x\gamma_z + EL9\gamma_y\gamma_z \\
& + EL10\ddot{X} + EL11\ddot{Y} + EL12\ddot{Z}
\end{aligned}
$$

$$
\begin{aligned}
\ddot{z} = \; & \ddot{Z} + FL0 + FL1\gamma_x + FL2\gamma_y + FL3\gamma_z \\
& + FL4\gamma_x^2 + FL5\gamma_y^2 + FL6\gamma_z^2 \\
& + FL7\gamma_x\gamma_y + FL8\gamma_x\gamma_y + FL9\gamma_y\gamma_z \\
& + FL10\ddot{X} + FL11\ddot{Y} + FL12\ddot{Z}
\end{aligned}
$$

FIGURE A-2. FIELD SYSTEM EQUATIONS

$$
\begin{bmatrix} \dot{\gamma}_x \\ \dot{\gamma}_y \\ \dot{\gamma}_z \\ \ddot{X} \\ \ddot{Y} \\ \ddot{Z} \end{bmatrix} = \begin{bmatrix} AA0 \\ BA0 \\ CA0 \\ AL0 \\ BL0 \\ CL0 \end{bmatrix} + [A+I] \begin{bmatrix} \dot{\omega}_x \\ \dot{\omega}_y \\ \dot{\omega}_z \\ \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} + \begin{bmatrix} \omega_x^2 \\ \omega_y^2 \\ \omega_z^2 \\ \omega_x\omega_y \\ \omega_x\omega_z \\ \omega_y\omega_z \end{bmatrix}
$$

Laboratory Equations

$$
\begin{bmatrix} \dot{\omega}_x \\ \dot{\omega}_y \\ \dot{\omega}_z \\ \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = [A+I]^{-1} \begin{bmatrix} \dot{\gamma}_x \\ \dot{\gamma}_y \\ \dot{\gamma}_z \\ \ddot{X} \\ \ddot{Y} \\ \ddot{Z} \end{bmatrix} - [A+I]^{-1}[B] \begin{bmatrix} \omega_x^2 \\ \omega_y^2 \\ \omega_z^2 \\ \omega_x\omega_y \\ \omega_x\omega_z \\ \omega_y\omega_z \end{bmatrix} - [A+I]^{-1} \begin{bmatrix} AA0 \\ BA0 \\ CA0 \\ AL0 \\ BL0 \\ CL0 \end{bmatrix}
$$

Field Equations

FIGURE A-3. LABORATORY AND FIELD EQUATIONS (MATRIX FORM)

The matrix values determined in the laboratory calibration are as follows (Figure A-4):

$$\begin{bmatrix} AAO \\ BAO \\ CAO \\ ALO \\ BLO \\ CLO \end{bmatrix} = \begin{bmatrix} -6103 \\ 1528 \\ -3518 \\ -11.969 \\ 7.870 \\ 7.240 \end{bmatrix}$$

$$A+I = \begin{bmatrix} 1 & 0.04365^* & 0.04169^* & -6.218 & -2.420 & 10.684 \\ 0 & 1 & 0.03236^* & -12.843 & -5.670 & -6.978 \\ 0 & 0 & 1 & 11.985 & -13.604 & 2.810 \\ 0.0005449^* & 0.0008314^* & 0.001496^* & 1.02399 & -0.06831 & 0.02455 \\ 0.0008608^* & 0.0019657^* & 0.0017437^* & -0.002113 & 1 & 0.05433 \\ 0 & 0.0004289^* & 0.0003734 & 0.023714 & -0.01462 & 1 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 0.1440 & -0.1459 & 0.4419 \\ 0 & 0 & 0 & 0.04314 & 0.1379 & 0 \\ 0 & 0 & 0 & 0 & -0.1700 & 0 \\ 0 & 0.0010394 & 0.0008835 & 0.0006946 & -0.0008210 & 0 \\ 0.0007935 & 0 & 0.0008640 & 0 & 0 & 0.0002321 \\ 0.0008100 & 0.0007470 & 0 & 0 & 0.0005207 & -0.0005004 \end{bmatrix}$$

* Uncertain sign. Must be determined prior to using the system in tests.

FIGURE A-4. CALIBRATION MATRIX RESULTS

A.2 CALIBRATION SUMMARY

A nine-accelerometer system was calibrated at the Naval Biodynamics Laboratory (NBDL) in New Orleans with the methodology described earlier. As originally conceived, the methodology employed linear and angular shake tables driven with sinusoidal forcing functions. Operating at moderate amplitudes in a frequency domain similar to that which is expected in a typical head impact situation, the output of the shake tables was not purely sinusoidal and in some cases was severely distorted. The additional harmonics added uncertainty to the validity of the readings from the digital multimeter (Appendix B) which was set up to read true RMS values. The objective, with regard to calculating system coefficient values, was to obtain an accurate measurement at the fundamental driving frequency, which was chosen to be within the expected information bandwidth of a typical head impact. A spectrum analyzer was used to evaluate the sensitivities at specific frequencies. The spectrum analyzer yields information on the driving frequency and all the additional harmonics generated. Employing the spectrum analyzer resulted in changes in the original methodology for obtaining coefficient values and in some cases greatly simplified the procedure.

There are two ways to approach the issue of sensitivity calibration of the transducers. The first is to presume some nominal sensitivity close to the actual sensitivity and then do all the coefficient calculations based upon this assumption. The degree to which the nominal sensitivity is incorrect will be compensated for in the values calculated for the coefficients. The second method is to actually measure the sensitivity of each transducer and then use these values as a basis for the rest of the calculations. The first method is considerably easier and was used throughout. The nominal sensitivity for the linear acceleration measurements was 0.06667 volt/g and for the angular acceleration measurements was 0.0003848 volt/rad/sec^2. An

ENDEVCO angular accelerometer was used as a reference in tests #4 and #6. It had the following sensitivities:

@ 80 Hz	7.6 mv/rad/s^2
@ 150 Hz	7.7 mv/rad/s^2
@ 250 Hz	8.1 mv/rad/s^2

In the following tables, the coefficient values that are thought to be the best estimate under the conditions of the testing are highlighted in bold type.

Test #1 determines 24 of the 72 required coefficients. Data were taken both on the digital multimeter and the spectrum analyzer. The data taken for coefficients AL0, BL0, CL0, AA0, BA0 and CA0 at the 1g level (test #1) were thought to be the least noisy and therefore the best estimate for the computation of these coefficients. The coefficients determined in test #1 are also determined in test #3 and test #5 as shown below.

As an example, consider a gravitational input along the positive and negative y-axis of the transducer (test 1C-Y and test 1D-Y in Appendix B). The governing equations for the measured accelerations along the x-axis are:

$$\ddot{x} = AL0 - AL11\ddot{y} = -0.7938v.$$

and:

$$\ddot{x} = AL0 + AL11\ddot{y} = -0.8038v.$$

so:

$$2AL0 = -1.5976v.$$

and:

$$AL0 = -0.7988v. \times \frac{1g}{0.06667v.} = -11.981g$$

Other coefficients are similarly derived.

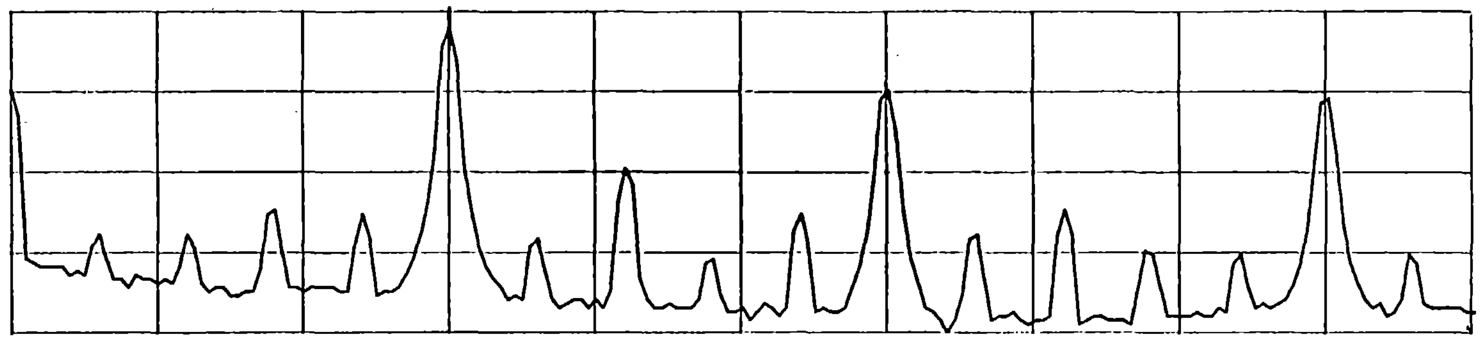
Coefficient Value	Test #	Comments
AL0 = -12.016 g	1A/B	(+g and -g inputs to x-axis)
= -11.981 g	1C/D	(+g and -g inputs to y-axis)
= -11.911 g	1E/F	(+g and -g inputs to z-axis)
= -11.969 g		**(mean for Test #1)**
= -11.627 g	3A	
= -12.599 g	3D	
= -12.386 g	3G	
= -12.260 g	5A	
= -11.786 g	5D	
= -11.531 g	5G	
BL0 = 7.836 g	1A/B	(+g and -g inputs to x-axis)
= 7.920 g	1C/D	(+g and -g inputs to y-axis)
= 7.855 g	1E/F	(+g and -g inputs to z-axis)
= 7.870 g		**(mean for Test #1)**
= 7.869 g	3A	
= 8.457 g	3D	
= 7.575 g	3G	
= 8.511 g	5A	
= 7.893 g	5D	
= 8.298 g	5G	
CL0 = 7.219 g	1A/B	(+g and -g inputs to x-axis)
= 7.237 g	1C/D	(+g and -g inputs to y-axis)
= 7.263 g	1E/F	(+g and -g inputs to z-axis)
= 7.240 g		**(mean for Test #1)**
= 7.179 g	3A	
= 7.182 g	3D	
= 7.863 g	3G	
= 7.491 g	5A	
= 7.791 g	5D	
= 7.200 g	5G	
AA0 = -6065 rad/s^2	1A/B	(+g and -g inputs to x-axis)
= -6107 rad/s^2	1C/D	(+g and -g inputs to y-axis)
= -6137 rad/s^2	1E/F	(+g and -g inputs to z-axis)
= -6103 $\mathbf{rad/s^2}$		**(mean for Test #1)**
= -4629 rad/s^2	3A	(anomalous data)
= -4554 rad/s^2	3D	(anomalous data)
= -6156 rad/s^2	3G	
= -6190 rad/s^2	5A	
= -6003 rad/s^2	5D	
= -6070 rad/s^2	5G	

BAO	= 1543 rad/s^2	1A/B	(+g and -g inputs to x-axis)
	= 1551 rad/s^2	1C/D	(+g and -g inputs to y-axis)
	= 1490 rad/s^2	1E/F	(+g and -g inputs to z-axis)
	= 1528 rad/s^2		**(mean for Test #1)**
	= 1546 rad/s^2	3A	
	= 1654 rad/s^2	3D	
	= 1452 rad/s^2	3G	
	= 1565 rad/s^2	5A	
	= 1433 rad/s^2	5D	
	= 1712 rad/s^2	5G	

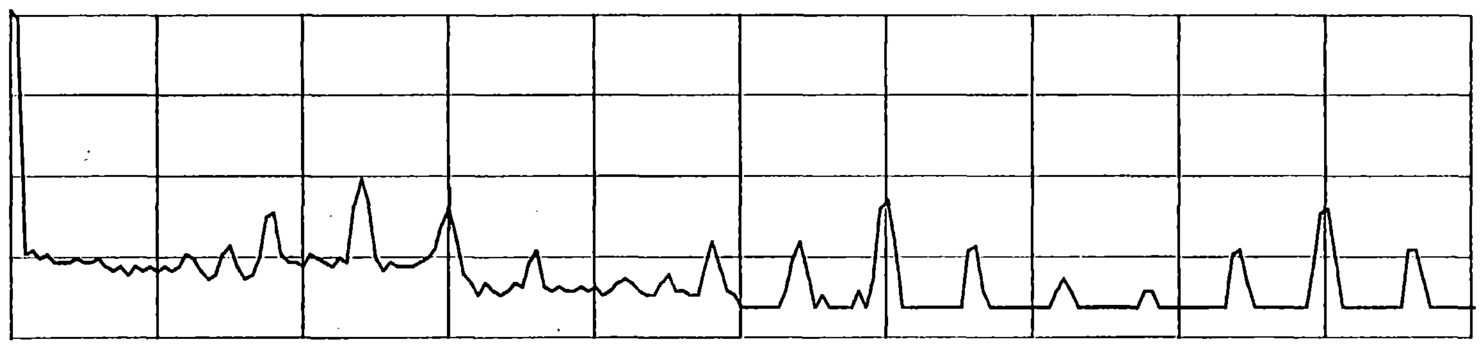
CAO	= -3536 rad/s^2	1A/B	(+g and -g inputs to x-axis)
	= -3517 rad/s^2	1C/D	(+g and -g inputs to y-axis)
	= -3500 rad/s^2	1E/F	(+g and -g inputs to z-axis)
	= -3518 rad/s^2		**(mean for Test #1)**
	= -3554 rad/s^2	3A	
	= -3541 rad/s^2	3D	
	= -3521 rad/s^2	3G	
	= -3610 rad/s^2	5A	
	= -3597 rad/s^2	5D	
	= -3556 rad/s^2	5G	

With minimal electronics, the above bias coefficients could (and probably should, as they are quite large) be adjusted to zero prior to using the system in tests.

In the following tests, the sign of the coefficient is determined from the results of test #1, while the best estimate for its value is taken from spectral analysis in test #2 at a frequency that is within the anticipated information bandwidth of a typical head impact. In the spectral analysis data, the system was driven at 150 Hz and coefficient values were computed at this frequency as well at harmonics of 300 Hz and 450 Hz. Signal to noise ratios are larger in the measurements taken at the driven frequency and the driven frequency is also within the information bandwidth expected. In these tests, and others that follow, sensitivity appears to be somewhat dependent on frequency which is not compensated for under the current calibration methodology. On this basis, the best estimate for the value of each of the coefficients is chosen from the measurements taken at the driven frequency. Typical data from the spectrum analyzer is shown in Figure A-5. In this case, the transducer is being driven along the x-axis with a fundamental frequency of 150 Hz. It is assumed



PWR SPECT A : 4.7dBV 150.0 HZ N: 16 F: 2.5HZ
SPAN: 0.000HZ -500.00HZ SN: 20dBV FS: 10.00dBV 20dB/



PWR SPECT B :- 48.8dBV 150.0 HZ N: 16 F: 2.5HZ
SPAN: 0.000HZ -500.00HZ SN: 20dBV FS:- 1.00dBV 20dB/

(A = X Acceleration, B = Y Acceleration, Driven Frequency = 150 Hz)

FIGURE A-5. TYPICAL SPECTRAL DATA

that the accelerometers at the origin of the cluster are accurate measures of the linear acceleration there. In this case:

$$\omega = 150\ Hz$$

$$A = \ddot{X} = 4.7\ db$$

$$B = \ddot{Y} = -48.8\ db$$

$$BL10 = \frac{B}{A}(actual\ magnitudes) = 0.002113$$

Other coefficients are similarly derived.

AL10	**= 0.02399**	1A/B	(+g and -g inputs to x-axis)
BL10	= -0.04199	1A/B	(+g and -g inputs to x-axis)
	= 0.002113	2	(data sheet #2L - ω = 150 Hz)
	= -0.002113		**(best estimate from above)**
CL10	= 0.007496	1A/B	(+g and -g inputs to x-axis)
	= 0.023714	2	(data sheet #3L - ω = 150 Hz)
	= 0.023714	**2**	**(best estimate from above)**
AA10	= -18.225 $rad/s^2/g$	1A/B	(+g and -g inputs to x-axis)
	= 6.218 $rad/s^2/g$	2	(data sheet #4L - ω = 150 Hz)
	= 9.198 $rad/s^2/g$	2	(data sheet #5L - ω = 300 Hz)
	= 19.439 $rad/s^2/g$	2	(data sheet #6L - ω = 450 Hz)
	= -6.218 $rad/s^2/g$	**2**	**(best estimate from above)**
BA10	= -53.230 $rad/s^2/g$	1A/B	(+g and -g inputs to x-axis)
	= 12.843 $rad/s^2/g$	2	(data sheet #7L - ω = 150 Hz)
	= 5.805 $rad/s^2/g$	2	(data sheet #8L - ω = 300 Hz)
	= 4.556 $rad/s^2/g$	2	(data sheet #9L - ω = 450 Hz)
	= -12.843 $rad/s^2/g$	**2**	**(best estimate from above)**
CA10	= 40.284 $rad/s^2/g$	1A/B	(+g and -g inputs to x-axis)
	= 11.985 $rad/s^2/g$	2	(data sheet #10L - ω = 150 Hz)
	= 12.408 $rad/s^2/g$	2	(data sheet #11L - ω = 300 Hz)
	= 18.998 $rad/s^2/g$	2	(data sheet #12L - ω = 450 Hz)
	= 11.985 $rad/s^2/g$	**2**	**(best estimate from above)**
AL11	= -0.07496	1C/D	(+g and -g inputs to y-axis)
	= 0.06383	2	(data sheet #12L - ω = 150 Hz)
	= -0.06383	**2**	**(best estimate from above)**

BL11	= −0.28935	1C/D	(+g and −g inputs to y-axis)
	= 0.0		**(anomalous data - set to zero)**
CL11	= −0.01949	1C/D	(+g and −g inputs to y-axis)
	= 0.01462	2	(data sheet #13L - ω = 150 Hz)
	= −0.01462	**2**	**(best estimate from above)**
AA11	= −22.854 rad/s^2/g	1C/D	(+g and −g inputs to y-axis)
	= 2.420 rad/s^2/g	2	(data sheet #14L - ω = 150 Hz)
	= 6.364 rad/s^2/g	2	(data sheet #15L - ω = 300 Hz)
	= 8.887 rad/s^2/g	2	(data sheet #16L - ω = 450 Hz)
	= −2.420 rad/s^2/g	**2**	**(best estimate from above)**
BA11	= −14.031 rad/s^2/g	1C/D	(+g and −g inputs to y-axis)
	= 5.670 rad/s^2/g	2	(data sheet #17L - ω = 150 Hz)
	= 8.199 rad/s^2/g	2	(data sheet #18L - ω = 300 Hz)
	= 25.626 rad/s^2/g	2	(data sheet #19L - ω = 450 Hz)
	= −5.670 rad/s^2/g	**2**	**(best estimate from above)**
CA11	= −7.522 rad/s^2/g	1C/D	(+g and −g inputs to y-axis)
	= 13.604 rad/s^2/g	2	(data sheet #20L - ω = 150 Hz)
	= 21.311 rad/s^2/g	2	(data sheet #21L - ω = 300 Hz)
	= 31.897 rad/s^2/g	2	(data sheet #22L - ω = 450 Hz)
	= −13.604 rad/s^2/g	**2**	**(best estimate from above)**
AL12	= 0.21439	1E/F	(+g and −g inputs to z-axis)
	= 0.02455	2	(data sheet #24L - ω = 150 Hz)
	= 0.02455	**2**	**(best estimate from above)**
BL12	= 0.01949	1E/F	(+g and −g inputs to z-axis)
	= 0.05433	2	(data sheet #25L - ω = 150 Hz)
	= 0.05433	**2**	**(best estimate from above)**
CL12	= −0.2264	1E/F	(+g and −g inputs to z-axis)
	= 0.0		**(anomalous data - set to zero)**
AA12	= 47.010 rad/s^2/g	1E/F	(+g and −g inputs to z-axis)
	= 10.684 rad/s^2/g	2	(data sheet #26L - ω = 150 Hz)
	= 17.129 rad/s^2/g	2	(data sheet #27L - ω = 300 Hz)
	= 23.642 rad/s^2/g	2	(data sheet #28L - ω = 450 Hz)
	= 10.684 rad/s^2/g	**2**	**(best estimate from above)**
BA12	= −38.722 rad/s^2/g	1E/F	(+g and −g inputs to z-axis)
	= 6.978 rad/s^2/g	2	(data sheet #29L - ω = 150 Hz)
	= 11.713 rad/s^2/g	2	(data sheet #30L - ω = 300 Hz)
	= 15.265 rad/s^2/g	2	(data sheet #31L - ω = 450 Hz)
	= −6.978 rad/s^2/g	**2**	**(best estimate from above)**
CA12	= 35.641 rad/s^2/g	1E/F	(+g and −g inputs to z-axis)
	= 2.810 rad/s^2/g	2	(data sheet #32L - ω = 150 Hz)
	= 7.059 rad/s^2/g	2	(data sheet #33L - ω = 300 Hz)
	= 24.186 rad/s^2/g	2	(data sheet #34L - ω = 450 Hz)
	= 2.810 rad/s^2/g	**2**	**(best estimate from above)**

In the following tests on the rate table, any coefficient with significant uncertainty of value (like opposite signs in redundant tests, e.g., BA4, BA5) or data considered to be anomalous, was presumed to be zero. Coefficients with units of g/rad/s^2 with values less than .001 (e.g., AL4) were presumed to be zero.

AA4	= 0.02131	3B	(ω = 3000 d/s, anomalous data)
	= 0.04106	3C	(ω = 1500 d/s, anomalous data)
	= 0.03119		(mean for Test #3)
	= 0.0		**(set to zero)**
BA4	= -0.02285	3B	(ω = 3000 d/s)
	= 0.04782	3C	(ω = 1500 d/s)
	= 0.0		**(set to zero - anomalous)**
CA4	= 0.003119	3B	(ω = 3000 d/s)
	= 0.02131	3C	(ω = 1500 d/s)
	= 0.01221		(mean for Test #3)
	= 0.0		**(set to zero)**
AL4	= -0.0000330 g/rad/s^2	3B	(ω = 3000 d/s)
	= -0.0003195 g/rad/s^2	3C	(ω = 1500 d/s)
	= -0.0001763 g/rad/s^2		(mean for Test #3)
	= 0.0		**(set to zero)**
BL4	= 0.0007515 g/rad/s^2	3B	(ω = 3000 d/s)
	= 0.0008355 g/rad/s^2	3C	(ω = 1500 d/s)
	= 0.0007935 g/rad/s^2		**(mean for Test #3)**
CL4	= 0.0008415 g/rad/s^2	3B	(ω = 3000 d/s)
	= 0.0007785 g/rad/s^2	3C	(ω = 1500 d/s)
	= 0.0008100 g/rad/s^2		**(mean for Test #3)**
AA5	= -2.499	3E	(ω = 1500 d/s, anomalous data)
	= -0.6479	3F	(ω = 3000 d/s, anomalous data)
	= 0.0		**(set to zero)**
BA5	= -0.08940	3E	(ω = 1500 d/s)
	= -0.06294	3F	(ω = 3000 d/s)
	= -0.07617		(mean for Test #3)
	= 0.0		**(set to zero)**
CA5	= -0.01065	3E	(ω = 1500 d/s)
	= -0.006237	3F	(ω = 3000 d/s)
	= -0.008444		(mean for Test #3)
	= 0.0		**(set to zero)**
AL5	= 0.0010904 g/rad/s^2	3E	(ω = 1500 d/s)
	= 0.0009870 g/rad/s^2	3F	(ω = 3000 d/s)
	= 0.0010394 g/rad/s^2		**(mean for Test #3)**

BL5	= 0.0000795 $g/rad/s^2$	3E	(ω = 1500 d/s)
	= 0.0000150 $g/rad/s^2$	3F	(ω = 3000 d/s)
	= 0.0000473 $g/rad/s^2$		(mean for Test #3)
	= 0.0		**(set to zero)**
CL5	= 0.0007620 $g/rad/s^2$	3E	(ω = 1500 d/s)
	= 0.0007320 $g/rad/s^2$	3F	(ω = 3000 d/s)
	= 0.0007470 $g/rad/s^2$		**(mean for Test #3)**
AA6	= -0.008316	3H	(ω = 1500 d/s)
	= -0.031965	3I	(ω = 3000 d/s)
	= -0.02014		(mean for Test #3)
	= 0.0		**(set to zero)**
BA6	= 0.05223	3H	(ω = 1500 d/s)
	= -0.02963	3I	(ω = 3000 d/s)
	= 0.0		**(set to zero - anomalous)**
CA6	= -0.001559	3H	(ω = 1500 d/s)
	= 0.03015	3I	(ω = 3000 d/s)
	= 0.0		**(set to zero - anomalous)**
AL6	= 0.0008880 $g/rad/s^2$	3H	(ω = 1500 d/s)
	= 0.0008775 $g/rad/s^2$	3I	(ω = 3000 d/s)
	= 0.0008835 $g/rad/s^2$		**(mean for Test #3)**
BL6	= 0.0009405 $g/rad/s^2$	3H	(ω = 1500 d/s)
	= 0.0007875 $g/rad/s^2$	3I	(ω = 3000 d/s)
	= 0.0008640 $g/rad/s^2$		**(mean for Test #3)**
CL6	= 0.0000750 $g/rad/s^2$	3H	(ω = 1500 d/s)
	= 0.0000135 $g/rad/s^2$	3I	(ω = 3000 d/s)
	= 0.0000443 $g/rad/s^2$		(mean for Test #3)
	= 0.0		**(set to zero)**

All of the coefficients for the ω^2 terms in the laboratory equations for angular acceleration are quite small. This is expected as these errors are presumably due to geometric offsets of the involved accelerometers from the system coordinate axes. Since the measurements for angular acceleration are measured with paired accelerometers with virtually the same offsets, these errors are small. On several occasions in test #3 values of these coefficients had opposite signs when measured at 1500 d/s and 3000 d/s suggesting that the measurements are subject to considerable uncertainty and noise. The largest of these coefficients was BA5 = -0.07617 as measured in tests #3E and #3F.

As an example of the error that results from this worst case term, consider the following example:

ω_y is a half sine acceleration pulse with:

A (amplitude) = 10,000 rad/s^2
t (duration) = 0.01 sec.

The accumulated angular velocity over the duration of this half sine pulse is:

$\omega_y = 2(A)/(2\pi x f) = 2(10{,}000)/(2\pi x 50) = 63.66$ rad/s

$\omega_y^2 = 4{,}053$ rad/s^2

so the contribution from the term with BA5 is:

$BA5(\omega_y^2) = 308.7$ rad/s^2

% error = 100(308.7/10,000) = 3.1%

So the error from this worst case coefficient for the ω_y^2 term is about 3.0 percent at the end of the pulse. At the peak of the pulse it is about 1.5 percent. Given the small size of these coefficients and the uncertainty of sign in several of them, it is reasonable to set them to zero, remembering that a more severe pulse than the above example will cause a larger angular velocity and consequently larger errors from the ω^2 terms. The error will increase as the square of the increase in the amplitude or duration of the pulse.

The situation is somewhat different in the equations for the measurement of linear acceleration. The measurements for X, Y and Z are taken from individual accelerometers and the error contributions due to offsets from the system coordinate system are significant. This is especially so when computing the head injury criteria (HIC). Test #3 gives values for BL4, CL4, AL5, CL5, AL6 and BL6. AL4, BL5 and CL6 are coefficients for the ω^2 terms when the system is spun around the sensitive axis. The values computed for these three coefficients are extremely small and may reasonably be set to zero.

The following coefficients were determined on the rate table in Test #5.

AA7	=	0.1331	5H	(ω = 1500 d/s)
	=	0.1549	5I	(ω = 3000 d/s)
	=	**0.1440**		**(mean for Test #5)**
BA7	=	0.05605	5H	(ω = 1500 d/s)
	=	0.03022	5I	(ω = 3000 d/s)
	=	**0.04314**		**(mean for Test #5)**
CA7	=	0.01755	5H	(ω = 1500 d/s)
	=	-0.03631	5I	(ω = 3000 d/s)
	=	**0.0**		**(set to zero - anomalous)**
AL7	=	0.0006806 g/rad/s^2	5H	(ω = 1500 d/s)
	=	0.0007085 g/rad/s^2	5I	(ω = 3000 d/s)
	=	**0.0006946 g/rad/s^2**		**(mean for Test #5)**
BL7	=	-0.000091 g/rad/s^2	5H	(ω = 1500 d/s)
	=	-0.0000135 g/rad/s^2	5I	(ω = 3000 d/s)
	=	**0.0**		**(set to zero)**
CL7	=	-0.0000573 g/rad/s^2	5H	(ω = 1500 d/s)
	=	0.0000371 g/rad/s^2	5I	(ω = 3000 d/s)
	=	**0.0**		**(set to zero - anomalous)**
AA8	=	-0.1736	5E	(ω = 1500 d/s)
	=	-0.1182	5F	(ω = 3000 d/s)
	=	**-0.1459**		**(mean for Test #5)**
BA8	=	0.1155	5E	(ω = 1500 d/s)
	=	0.1603	5F	(ω = 3000 d/s)
	=	**0.1379**		**(mean for Test #5)**
CA8	=	-0.2417	5E	(ω = 1500 d/s)
	=	-0.09808	5F	(ω = 3000 d/s)
	=	**-0.1700**		**(mean for Test #5)**
AL8	=	-0.0009967 g/rad/s^2	5E	(ω = 1500 d/s)
	=	-0.0006453 g/rad/s^2	5F	(ω = 3000 d/s)
	=	**-0.0008210 g/rad/s^2**		**(mean for Test #5)**
BL8	=	-0.0000876 g/rad/s^2	5E	(ω = 1500 d/s)
	=	0.0001727 g/rad/s^2	5F	(ω = 3000 d/s)
	=	**0.0**		**(set to zero)**
CL8	=	0.0004879 g/rad/s^2	5E	(ω = 1500 d/s)
	=	0.0005535 g/rad/s^2	5F	(ω = 3000 d/s)
	=	**0.0005207 g/rad/s^2**		**(mean for Test #5)**
AA9	=	0.7039	5B	(ω = 1500 d/s)
	=	0.1799	5C	(ω = 3000 d/s)
	=	**0.4419**		**(mean for Test #5)**

BA9	= 0.009435	5B	(ω = 1500 d/s)
	= -0.01075	5C	(ω = 3000 d/s)
	= 0.0		**(set to zero - anomalous)**
CA9	= 0.01072	5B	(ω = 1500 d/s)
	= 0.004873	5C	(ω = 3000 d/s)
	= 0.007797		(mean for Test #5)
	= 0.0		**(set to zero)**
AL9	= -0.0000741 g/rad/s^2	5B	(ω = 1500 d/s)
	= 0.0001938 g/rad/s^2	5C	(ω = 3000 d/s)
	= 0.0		**(set to zero - anomalous)**
BL9	= 0.0002055 g/rad/s^2	5B	(ω = 1500 d/s)
	= 0.0002586 g/rad/s^2	5C	(ω = 3000 d/s)
	= 0.0002321 g/rad/s^2		**(mean for Test #5)**
CL9	= -0.0004953 g/rad/s^2	5B	(ω = 1500 d/s)
	= -0.0005055 g/rad/s^2	5C	(ω = 3000 d/s)
	= -0.0005004 g/rad/s^2		**(mean for Test #5)**

The following coefficients were determined with the spectrum analyzer:

Coefficient		Test No.	Measured @	Driven @	Data Sheet
BA1	= 0.001972	4X/4AX	80 Hz	80 Hz	#12
	= 0.3428	4X/4AX	400 Hz	80 Hz	#13
	= 0.7762	4X/4AX	400 Hz	80 Hz	#14
	= 0.004315	4	150 Hz	150 Hz	#5
	= 0.4365	4	447.5 Hz	150 Hz	#6
	= 0.02427	4BX/4CX	250 Hz	250 Hz	#19
	= 0.3467	4BX/4CX	500 Hz	250 Hz	#20
	= 0.3981	4BX/4CX	750 Hz	250 Hz	#21
	= 0.001972	4X/4AX	(best estimate from above)		
	= 0.0		**(set to zero)**		
CA1	= 0.007943	4X/4AX	80 Hz	80 Hz	#15
	= 0.003162	4	150 Hz	150 Hz	#7
	= 0.2884	4	447.5 Hz	150 Hz	#8
	= 0.02985	4BX/4CX	250 Hz	250 Hz	#22
	= 0.3020	4BX/4CX	500 Hz	250 Hz	#23
	= 0.1380	4BX/4CX	750 Hz	250 Hz	#24
	= 0.007943	4X/4AX	(best estimate from above)		
	= 0.0		**(set to zero)**		

AA2	=	0.04365	4D/4E	80 Hz	80 Hz	#53
	=	0.05129	4D/4E	240 Hz	80 Hz	#54
	=	0.6237	4D/4E	397.5 Hz	80 Hz	#55
	=	0.04677	4BY	150 Hz	150 Hz	#42
	=	0.05370	4BY	300 Hz	150 Hz	#43
	=	0.1679	4BY	450 Hz	150 Hz	#44
	=	0.05888	4Y/4AY	250 Hz	250 Hz	#32
	=	0.02541	4Y/4AY	750 Hz	250 Hz	#33
	=	**0.04365**	**4D/4E**	**(best estimate from above)**		
CA2	=	0.006531	4D/4E	80 Hz	80 Hz	#56
	=	0.09120	4D/4E	240 Hz	80 Hz	#57
	=	0.7161	4D/4E	397.5 Hz	80 Hz	#58
	=	0.01585	4BY	150 Hz	150 Hz	#45
	=	0.2317	4BY	300 Hz	150 Hz	#46
	=	0.5623	4BY	450 Hz	150 Hz	#47
	=	0.09120	4Y/4AY	250 Hz	250 Hz	#34
	=	0.8710	4Y/4AY	500 Hz	250 Hz	#35
	=	0.2600	4Y/4AY	750 Hz	250 Hz	#36
	=	0.006531	4D/4E	(best estimate from above)		
	=	**0.0**		**(set to zero)**		
AA3	=	0.04169	4Z/4AZ	80 Hz	80 Hz	#63
	=	0.04732	4Z/4AZ	240 Hz	80 Hz	#64
	=	0.1585	4Z/4AZ	397.5 Hz	80 Hz	#65
	=	0.04027	4BZ/4CZ	150 Hz	150 Hz	#72
	=	0.05957	4BZ/4CZ	300 Hz	150 Hz	#73
	=	0.2786	4BZ/4CZ	450 Hz	150 Hz	#74
	=	0.05129	4DZ/4EZ	250 Hz	250 Hz	#81
	=	0.2317	4DZ/4EZ	500 Hz	250 Hz	#82
	=	0.1413	4DZ/4EZ	750 Hz	250 Hz	#83
	=	**0.04169**	**4Z/4AZ**	**(best estimate from above)**		
BA3	=	0.03236	4Z/4AZ	80 Hz	80 Hz	#66
	=	0.05012	4Z/4AZ	240 Hz	80 Hz	#67
	=	0.3890	4Z/4AZ	397.5 Hz	80 Hz	#68
	=	0.03236	4BZ/4CZ	150 Hz	150 Hz	#75
	=	0.06310	4BZ/4CZ	300 Hz	150 Hz	#76
	=	0.1950	4BZ/4CZ	450 Hz	150 Hz	#77
	=	**0.03236**	**4Z/4AZ**	**(best estimate from above)**		

Not enough data was taken to determine the signs of AA2, AA3 and BA3. This can be done with a dual trace oscilloscope prior to using the system.

The following coefficients were determined from digital multimeter readings:

AL1	=	0.0005203 g/rad/s	4X	80 Hz
	=	0.0005695	4BX	250 Hz
	=	**0.0005449 g/rad/s^2**		**(mean for Test #4)**

BL1	= 0.0008438 $g/rad/s^2$	4X	80 Hz
	= 0.0008777 $g/rad/s^2$	4BX	250 Hz
	= 0.0008608 $g/rad/s^2$		**(mean for Test #4)**
CL1	= 0.0000892 $g/rad/s^2$	4X	80 Hz
	= 0.0002491 $g/rad/s^2$	4BX	250 Hz
	= 0.0001692 $g/rad/s^2$		(mean for Test #4)
	= 0.0		**(set to zero)**
AL2	= 0.0009031 $g/rad/s^2$	4D	80 Hz
	= 0.0007597 $g/rad/s^2$	4Y	250 Hz
	= 0.0008314 $g/rad/s^2$		**(mean for Test #4)**
BL2	= 0.0022700 $g/rad/s^2$	4D	80 Hz
	= 0.0016613 $g/rad/s^2$	4Y	250 Hz
	= 0.0019657 $g/rad/s^2$		**(mean for Test #4)**
CL2	= 0.0004586 $g/rad/s^2$	4D	80 Hz
	= 0.0003991 $g/rad/s^2$	4Y	250 Hz
	= 0.0004289 $g/rad/s^2$		**(mean for Test #4)**
AL3	= 0.001464 $g/rad/s^2$	4Z	80 Hz
	= 0.001527 $g/rad/s^2$	4DZ	250 Hz
	= 0.001496 $g/rad/s^2$		**(mean for Test #4)**
BL3	= 0.0017444 $g/rad/s^2$	4Z	80 Hz
	= 0.0017430 $g/rad/s^2$	4DZ	250 Hz
	= 0.0017437 $g/rad/s^2$		**(mean for Test #4)**
CL3	= 0.0003685 $g/rad/s^2$	4Z	80 Hz
	= 0.0003783 $g/rad/s^2$	4DZ	250 Hz
	= 0.0003734 $g/rad/s^2$		**(mean for Test #4)**

AA1, BA2 and CA3 have been set to zero. (The gain of the measurements for angular acceleration is presumed to be as the linear sensitivity and moment arms would dictate.)

APPENDIX B

DIGITAL MULTIMETER DATA

(Each set of summary data presented represents 50 readings)

HP3457A DATA ACQUISITION

RUNID : TEST1A-X
RUNDES: G INPUT ALONG +X AXIS
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 14:47:20.59
DUR : 5 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8800	0.5200	0.4800	-2.3300	0.6100	-1.3800
max	-0.8600	0.5300	0.4900	-2.3200	0.6200	-1.3700
avg	-0.8694	0.5252	0.4807	-2.3268	0.6142	-1.3760
sigma	0.0051	0.0050	0.0025	0.0046	0.0050	0.0049

HP3457A DATA ACQUISITION

RUNID : TEST1B-X
RUNDES: G INPUT ALONG -X AXIS
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 14:49:49.50
DUR : 5 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7400	0.5100	0.4700	-2.3500	0.5600	-1.3500
max	-0.7300	0.5200	0.4900	-2.3400	0.5800	-1.3400
avg	-0.7328	0.5196	0.4817	-2.3408	0.5732	-1.3450
sigma	0.0045	0.0020	0.0048	0.0028	0.0053	0.0050

HP3457A DATA ACQUISITION

RUNID : TEST1C-Y
RUNDES: G INPUT ALONG +Y AXIS
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 14:53:47.10
DUR : 5 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8000	0.4800	0.4800	-2.3500	0.5900	-1.3600
max	-0.7900	0.4900	0.4900	-2.3400	0.6100	-1.3500
avg	-0.7938	0.4806	0.4841	-2.3410	0.6024	-1.3506
sigma	0.0049	0.0024	0.0049	0.0028	0.0049	0.0025

HP3457A DATA ACQUISITION

RUNID : TEST1D-Y
RUNDES: G INPUT ALONG -Y AXIS
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 14:57:06.26
DUR : 5 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8100	0.5700	0.4800	-2.3600	0.5800	-1.3600
max	-0.8000	0.5800	0.4900	-2.3500	0.6000	-1.3500
avg	-0.8038	0.5754	0.4811	-2.3586	0.5916	-1.3564
sigma	0.0049	0.0050	0.0031	0.0036	0.0042	0.0048

HP3457A DATA ACQUISITION

RUNID : TEST1E-Z
RUNDES: G INPUT ALONG +Z AXIS
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 15:01:35.73
DUR : 5 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8100	0.5200	0.4300	-2.3900	0.5800	-1.3700
max	-0.8000	0.5300	0.4400	-2.3700	0.6000	-1.3500
avg	-0.8084	0.5224	0.4326	-2.3796	0.5882	-1.3606
sigma	0.0037	0.0043	0.0044	0.0029	0.0049	0.0029

HP3457A DATA ACQUISITION

RUNID : TEST1F-Z
RUNDES: G INPUT ALONG -Z AXIS
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 15:04:06.11
DUR : 5 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7900	0.5200	0.5300	-2.3500	0.5500	-1.3400
max	-0.7700	0.5300	0.5400	-2.3400	0.5700	-1.3300
avg	-0.7798	0.5250	0.5357	-2.3434	0.5584	-1.3332
sigma	0.0024	0.0050	0.0050	0.0048	0.0042	0.0046

HP3457A DATA ACQUISITION

RUNID : TEST2-X
RUNDES: AC OUTPUTS FOR INPUT ALONG X 150 HZ
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACV
START : 12:48:41.59
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	1.7800	0.6700	0.1200	3.0200	1.5800	1.4900
max	1.9100	0.7900	0.1400	3.1200	1.5900	1.5200
avg	1.8998	0.7694	0.1335	3.0734	1.5860	1.5002
sigma	0.0182	0.0159	0.0056	0.0213	0.0049	0.0059

HP3457A DATA ACQUISITION

RUNID : TEST2A-X
RUNDES: AC+DC OUTPUTS FOR INPUT ALONG X 150 HZ
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACDCV
START : 12:52:32.94
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	1.8900	0.7300	0.4100	2.8800	1.6800	1.6400
max	1.9200	0.7500	0.4200	2.9000	1.6900	1.6600
avg	1.9110	0.7390	0.4198	2.8952	1.6812	1.6502
sigma	0.0046	0.0073	0.0015	0.0049	0.0031	0.0055

HP3457A DATA ACQUISITION

RUNID : TEST2B-Y
RUNDES: AC OUTPUTS FOR INPUT ALONG Y 150 HZ
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACV
START : 13:25:35.31
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.1400	2.3300	0.5300	1.8200	1.8700	1.5000
max	0.4300	2.7800	0.5500	1.8500	1.8800	1.5200
avg	0.4188	2.3660	0.5346	1.8370	1.8710	1.5132
sigma	0.0401	0.0609	0.0054	0.0069	0.0031	0.0052

HP3457A DATA ACQUISITION

RUNID : TEST2C-Y
RUNDES: AC+DC OUTPUTS FOR INPUT ALONG Y 150 HZ
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACDCV
START : 13:22:59.26
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.7100	2.0200	0.6500	2.8000	1.6700	1.7400
max	0.7900	2.0300	0.6700	2.8200	1.6900	1.7600
avg	0.7814	2.0246	0.6585	2.8072	1.6788	1.7460
sigma	0.0113	0.0050	0.0069	0.0055	0.0040	0.0056

HP3457A DATA ACQUISITION

RUNID : TEST2D-Z
RUNDES: AC OUTPUTS FOR INPUT ALONG Z-AXIS FOR 150 HZ INPUT
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACV
START : 14:01:13.83
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0700	0.8000	1.9400	1.2300	2.1300	1.2800
max	0.3800	1.2400	1.9600	1.2800	2.1900	1.2900
avg	0.3732	0.8102	1.9524	1.2424	2.1570	1.2852
sigma	0.0434	0.0615	0.0047	0.0112	0.0128	0.0050

HP3457A DATA ACQUISITION

RUNID : TEST2E-Z
RUNDES: AC+DC OUTPUTS FOR INPUT ALONG Z-AXIS FOR 150 HZ INPUT
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACDCV
START : 14:05:25.50
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.6700	0.5300	2.0800	2.1900	1.6800	1.6000
max	0.7400	0.5500	2.1000	2.2000	1.7000	1.6200
avg	0.7308	0.5372	2.0911	2.1972	1.6910	1.6122
sigma	0.0098	0.0049	0.0063	0.0043	0.0043	0.0045

HP3457A DATA ACQUISITION

RUNID : TEST3A-X
RUNDES: RATE TABLE TEST, X-AXIS ALIGNED WITH SPIN AXIS. STATIC
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 10:43:51.13
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7900	0.5200	0.4700	-1.7900	0.5900	-1.3700
max	-0.7700	0.5300	0.4800	-1.7800	0.6000	-1.3600
avg	-0.7752	0.5246	0.4785	-1.7812	0.5950	-1.3676
sigma	0.0054	0.0050	0.0036	0.0034	0.0050	0.0043

HP3457A DATA ACQUISITION

RUNID : TEST3B-X
RUNDES: RATE TABLE TEST, X-AXIS ALIGNED WITH SPIN AXIS. 3000
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 10:54:38.75
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7900	0.6500	0.6200	-1.7700	0.5400	-1.3900
max	-0.7700	0.6700	0.6400	-1.7500	0.6000	-1.3400
avg	-0.7812	0.6620	0.6320	-1.7588	0.5708	-1.3644
sigma	0.0052	0.0049	0.0054	0.0040	0.0128	0.0123

HP3457A DATA ACQUISITION

RUNID : TEST3C-X
RUNDES: RATE TABLE TEST, X-AXIS ALIGNED WITH SPIN AXIS. 1500 D
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 11:09:57.71
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8000	0.5600	0.5100	-1.7800	0.5900	-1.3700
max	-0.7800	0.5700	0.5200	-1.7700	0.6300	-1.3500
avg	-0.7898	0.5628	0.5141	-1.7704	0.6076	-1.3620
sigma	0.0032	0.0045	0.0049	0.0015	0.0083	0.0052

HP3457A DATA ACQUISITION

RUNID : TEST3D-Y
RUNDES: RATE TABLE TEST, Y-AXIS ALIGNED WITH SPIN AXIS STATIC
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 11:44:56.25
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8500	0.5600	0.4700	-1.7600	0.6300	-1.3700
max	-0.8300	0.5700	0.4800	-1.7500	0.6400	-1.3600
avg	-0.8400	0.5638	0.4787	-1.7524	0.6366	-1.3624
sigma	0.0020	0.0049	0.0034	0.0040	0.0048	0.0044

HP3457A DATA ACQUISITION

RUNID : TEST3E-Y
RUNDES: RATE TABLE TEST, Y-AXIS ALIGNED WITH SPIN AXIS 1500D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 11:51:01.89
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8000	0.5600	0.5100	-2.4300	0.6100	-1.3800
max	-0.7800	0.5700	0.5200	-2.4000	0.6200	-1.3500
avg	-0.7902	0.5674	0.5135	-2.4116	0.6130	-1.3652
sigma	0.0024	0.0044	0.0048	0.0067	0.0046	0.0071

HP3457A DATA ACQUISITION

RUNID : TEST3F-Y
RUNDES: RATE TABLE TEST, Y-AXIS ALIGNED WITH SPIN AXIS 3000D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 11:53:30.35
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.6700	0.5600	0.6000	-2.4500	0.5600	-1.4000
max	-0.6500	0.5800	0.6200	-2.4100	0.5800	-1.3500
avg	-0.6596	0.5666	0.6130	-2.4360	0.5702	-1.3690
sigma	0.0045	0.0051	0.0051	0.0095	0.0073	0.0113

HP3457A DATA ACQUISITION

RUNID : TEST3G-Z
RUNDES: RATE TABLE TEST, Z-AXIS ALIGNED WITH SPIN AXIS STATIC
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 12:24:47.27
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8300	0.5000	0.5200	-2.3800	0.5500	-1.3600
max	-0.8200	0.5100	0.5300	-2.3600	0.5700	-1.3500
avg	-0.8258	0.5050	0.5246	-2.3690	0.5588	-1.3550
sigma	0.0049	0.0050	0.0050	0.0035	0.0037	0.0050

HP3457A DATA ACQUISITION

RUNID : TEST3H-Z
RUNDES: RATE TABLE TEST, Z-AXIS ALIGNED WITH SPIN AXIS 1500D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 12:26:40.96
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7900	0.5400	0.5200	-2.4000	0.5600	-1.3600
max	-0.7800	0.5500	0.5400	-2.3400	0.5900	-1.3400
avg	-0.7852	0.5480	0.5278	-2.3712	0.5726	-1.3554
sigma	0.0050	0.0040	0.0046	0.0140	0.0056	0.0054

HP3457A DATA ACQUISITION

RUNID : TEST3I-Z
RUNDES: RATE TABLE TEST, Z-AXIS ALIGNED WITH SPIN AXIS 3000D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 12:28:26.14
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.6700	0.6400	0.5100	-2.4400	0.5000	-1.3400
max	-0.6500	0.6600	0.5300	-2.3700	0.5400	-1.3100
avg	-0.6654	0.6488	0.5220	-2.4026	0.5276	-1.3232
sigma	0.0057	0.0047	0.0049	0.0173	0.0097	0.0076

HP3457A DATA ACQUISITION

RUNID : TEST4-D
RUNDES: AC OUTPUTS FOR INPUT ABOUT Y-AXIS AT 80 HZ
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 13:28:30.58
DUR : 50 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
Run summary						
	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0500	0.8000	0.1800	2.5200	2.0800	1.2800
max	0.3700	1.3600	0.1900	2.6800	2.1400	1.3400
avg	0.3610	0.8254	0.1898	2.6670	2.0986	1.3070
sigma	0.0446	0.0766	0.0015	0.0072	0.0092	0.0182

HP3457A DATA ACQUISITION

RUNID : TEST4-E
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT Y-AXIS AT 80 HZ
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 13:31:22.38
DUR : 50 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
Run summary						
	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5900	0.6400	0.4500	2.8600	2.0100	1.5200
max	0.6700	0.6500	0.4600	2.8700	2.0400	1.5500
avg	0.6566	0.6496	0.4557	2.8682	2.0250	1.5346
sigma	0.0105	0.0020	0.0050	0.0038	0.0058	0.0095

HP3457A DATA ACQUISITION

RUNID : TEST4-X
RUNDES: AC OUTPUTS FOR INPUT ABOUT X=AXIS 80 HZ INPUT FREQUENC
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 09:35:16.49
DUR : 50 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
Run summary						
	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0500	0.6500	0.1400	3.7000	1.4900	1.2900
max	0.3700	1.1600	0.1500	3.9600	1.5300	1.3000
avg	0.3550	0.6634	0.1498	3.9380	1.5018	1.2990
sigma	0.0437	0.0711	0.0015	0.0063	0.0037	0.0028

HP3457A DATA ACQUISITION

RUNID : TEST4-Y
RUNDES: AC OUTPUTS FOR INPUT ABOUT Y-AXIS 250 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 11:44:33.24
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.1500	0.8000	0.1900	2.8700	2.7800	1.3800
max	0.3800	0.9200	0.2000	2.9200	2.8000	1.4000
avg	0.3732	0.8032	0.1972	2.9068	2.7906	1.3874
sigma	0.0322	0.0169	0.0045	0.0061	0.0064	0.0081

HP3457A DATA ACQUISITION

RUNID : TEST4-Z
RUNDES: AC OUTPUTS FOR INPUT ABOUT Z-AXIS FOR 80 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 14:02:41.93
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.1000	0.6500	0.1300	2.8800	1.5000	2.0700
max	0.5900	1.0400	0.1400	3.1000	1.5300	2.1200
avg	0.5610	0.6624	0.1339	3.0832	1.5030	2.1018
sigma	0.0666	0.0542	0.0049	0.0067	0.0043	0.0100

HP3457A DATA ACQUISITION

RUNID : TEST4A-X
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT X-AXIS 80 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 09:38:31.20
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5000	0.5200	0.4000	3.5300	1.5600	1.4400
max	0.6100	0.5400	0.4100	3.5600	1.5700	1.4500
avg	0.6056	0.5248	0.4085	3.5456	1.5604	1.4430
sigma	0.0156	0.0054	0.0036	0.0065	0.0020	0.0046

HP3457A DATA ACQUISITION

RUNID : TEST4A-Y
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT Y-AXIS 250 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 11:46:43.90
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.6000	0.6500	0.4400	3.1200	2.6700	1.5900
max	0.6500	0.6600	0.4500	3.1300	2.6900	1.6100
avg	0.6488	0.6524	0.4493	3.1278	2.6840	1.5988
sigma	0.0071	0.0043	0.0025	0.0043	0.0058	0.0065

HP3457A DATA ACQUISITION

RUNID : TEST4A-Z
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT Z-AXIS FOR 80 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 14:09:33.87
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5900	0.5700	0.4900	2.7700	1.5900	2.1500
max	0.8300	0.6100	0.5000	2.7800	1.6000	2.1700
avg	0.8036	0.5820	0.4974	2.7766	1.5960	2.1640
sigma	0.0337	0.0057	0.0044	0.0047	0.0049	0.0057

HP3457A DATA ACQUISITION

RUNID : TEST4B-X
RUNDES: AC OUTPUTS FOR INPUTS ABOUT X-AXIS 250 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 10:29:40.00
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.1500	0.6400	0.1700	4.1700	1.6000	1.4200
max	0.4300	0.7600	0.1900	4.2300	1.6300	1.4400
avg	0.4150	0.6498	0.1807	4.2058	1.6114	1.4312
sigma	0.0380	0.0163	0.0038	0.0147	0.0081	0.0060

HP3457A DATA ACQUISITION

RUNID : TEST4B-Y
RUNDES: AC OUTPUTS FOR INPUT ABOUT Y-AXIS 150 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 12:23:26.36
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0800	0.7900	0.1700	2.6400	2.0800	1.3100
max	0.3800	1.2000	0.1800	2.7800	2.1300	1.3500
avg	0.3640	0.8054	0.1757	2.7686	2.0982	1.3344
sigma	0.0407	0.0565	0.0050	0.0051	0.0084	0.0099

HP3457A DATA ACQUISITION

RUNID : TEST4B-Z
RUNDES: AC OUTPUTS FOR INPUT ABOUT Z-AXIS FOR 150 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 14:50:30.42
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0900	0.6600	0.1300	2.8200	1.5200	2.1200
max	0.5900	1.1400	0.1500	3.0600	1.5500	2.1700
avg	0.5692	0.6814	0.1409	3.0498	1.5238	2.1492
sigma	0.0688	0.0657	0.0035	0.0050	0.0048	0.0073

HP3457A DATA ACQUISITION

RUNID : TEST4C-X
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT X-AXIS 250 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 10:32:10.44
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5400	0.5400	0.4300	4.0200	1.6700	1.5800
max	0.6700	0.5600	0.4400	4.0500	1.6800	1.6000
avg	0.6590	0.5470	0.4370	4.0380	1.6770	1.5914
sigma	0.0175	0.0050	0.0046	0.0070	0.0045	0.0046

HP3457A DATA ACQUISITION

RUNID : TEST4C-Z
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT Z-AXIS FOR 150 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 14:53:06.84
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5900	0.5800	0.4900	2.7700	1.6100	2.1800
max	0.8300	0.6100	0.5000	2.7800	1.6300	2.2000
avg	0.8088	0.5878	0.4924	2.7794	1.6196	2.1872
sigma	0.0323	0.0054	0.0043	0.0020	0.0044	0.0049

HP3457A DATA ACQUISITION

RUNID : TEST4D-Z
RUNDES: AC OUTPUTS FOR INPUT ABOUT Z-AXIS FOR 250 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 15:14:54.68
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.1000	0.6600	0.1400	2.8300	1.5300	2.2300
max	0.6200	1.1000	0.1500	3.0200	1.5700	2.2500
avg	0.5974	0.6814	0.1465	3.0110	1.5402	2.2462
sigma	0.0712	0.0600	0.0048	0.0050	0.0039	0.0046

HP3457A DATA ACQUISITION

RUNID : TEST4E-Z
RUNDES: AC+DC OUTPUTS FOR INPUT ABOUT Z-AXIS FOR 250 HZ INPUT
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 15:17:56.15
DUR : 50 SECONDS

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.6000	0.5900	0.4900	2.7800	1.6300	2.2700
max	0.8500	0.6200	0.5000	2.7900	1.6500	2.2900
avg	0.8354	0.5952	0.4983	2.7828	1.6410	2.2790
sigma	0.0340	0.0061	0.0038	0.0045	0.0037	0.0035

HP3457A DATA ACQUISITION

RUNID : TEST4F-Z
RUNDES: AC+DC OUTPUTS FOR MISALIGNED AXES AT 250 HZ
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACDCV
START : 16:26:47.86
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5800	0.6000	0.4600	3.3600	1.8400	1.5600
max	0.6800	0.6100	0.4700	3.3800	1.8600	1.5700
avg	0.6664	0.6058	0.4643	3.3680	1.8522	1.5658
sigma	0.0131	0.0049	0.0050	0.0071	0.0055	0.0048

HP3457A DATA ACQUISITION

RUNID : TEST4G-Z
RUNDES: AC OUTPUTS FOR MISALIGNED AXES INPUT AT 250 HZ
DATE : 01/10/90
S/S/C : 1.0000
MODE : ACV
START : 16:44:45.39
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0600	0.7600	0.1600	3.3700	1.7400	1.4000
max	0.4000	1.2900	0.1800	3.5500	1.7600	1.4200
avg	0.3852	0.7820	0.1709	3.5330	1.7484	1.4118
sigma	0.0467	0.0727	0.0041	0.0115	0.0065	0.0054

HP3457A DATA ACQUISITION

RUNID : TEST5A-X
RUNDES: MISALIGNED RATE TEST X-AXIS // TO BLOCK STATIC
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 12:53:04.68
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.8300	0.5600	0.4900	-2.3900	0.5900	-1.4000
max	-0.8100	0.5700	0.5100	-2.3800	0.6100	-1.3800
avg	-0.8174	0.5674	0.4996	-2.3818	0.6022	-1.3890
sigma	0.0048	0.0044	0.0029	0.0038	0.0045	0.0037

HP3457A DATA ACQUISITION

RUNID : TEST5B-X
RUNDES: MISALIGNED RATE TEST X-AXIS // TO BLOCK 1500D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 12:56:14.95
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7800	0.5700	0.5300	-2.4800	0.5800	-1.4300
max	-0.7600	0.5800	0.5500	-2.4500	0.6000	-1.3400
avg	-0.7702	0.5732	0.5350	-2.4622	0.5866	-1.3902
sigma	0.0068	0.0047	0.0054	0.0074	0.0061	0.0201

HP3457A DATA ACQUISITION

RUNID : TEST5C-X
RUNDES: MISALIGNED RATE TEST X-AXIS // TO TABLE 3000D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 12:59:04.01
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6
Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.6600	0.5800	0.6300	-2.4900	0.6400	-1.4300
max	-0.6400	0.6000	0.6500	-2.4400	0.6900	-1.3500
avg	-0.6498	0.5864	0.6420	-2.4640	0.6732	-1.3912
sigma	0.0062	0.0059	0.0049	0.0136	0.0112	0.0185

HP3457A DATA ACQUISITION

RUNID : TEST5D-Y
RUNDES: MISALIGNED RATE TEST, Y-AXIS // TO TABLE STATIC
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 13:28:52.11
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7900	0.5200	0.5100	-2.3200	0.5400	-1.3900
max	-0.7800	0.5300	0.5200	-2.3000	0.5600	-1.3700
avg	-0.7858	0.5262	0.5193	-2.3100	0.5516	-1.3840
sigma	0.0049	0.0049	0.0025	0.0015	0.0052	0.0053

HP3457A DATA ACQUISITION

RUNID : TEST5E-Y
RUNDES: MISALIGNED RATE TEST Y-AXIS // TO TABLE 1500D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 13:21:29.90
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7400	0.5500	0.5100	-2.3200	0.5300	-1.3700
max	-0.7300	0.5800	0.5300	-2.2600	0.5500	-1.3400
avg	-0.7358	0.5666	0.5193	-2.2902	0.5384	-1.3564
sigma	0.0049	0.0055	0.0057	0.0128	0.0065	0.0057

HP3457A DATA ACQUISITION

RUNID : TEST5F-Y
RUNDES: MISALIGNED RATE TEST Y-AXIS // TO TABLE 3000D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 13:23:41.01
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.6200	0.6600	0.5100	-2.3400	0.4500	-1.3600
max	-0.6100	0.6800	0.5200	-2.2800	0.5000	-1.3300
avg	-0.6136	0.6672	0.5128	-2.3046	0.4784	-1.3392
sigma	0.0048	0.0066	0.0045	0.0151	0.0139	0.0083

HP3457A DATA ACQUISITION

RUNID : TEST5G-Z
RUNDES: MISALIGNED RATE TEST Z-AXIS // TO TABLE STATIC
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 13:53:18.40
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7800	0.5500	0.4700	-2.3400	0.6500	-1.3700
max	-0.7600	0.5600	0.4900	-2.3300	0.6700	-1.3600
avg	-0.7688	0.5532	0.4800	-2.3356	0.6586	-1.3684
sigma	0.0043	0.0047	0.0021	0.0050	0.0042	0.0038

HP3457A DATA ACQUISITION

RUNID : TEST5H-Z
RUNDES: MISALIGNED RATE TEST Z-AXIS // TO TABLE 1500D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 13:55:15.06
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7800	0.5800	0.5100	-2.3600	0.6400	-1.3800
max	-0.7600	0.5900	0.5200	-2.3400	0.6700	-1.3600
avg	-0.7704	0.5822	0.5176	-2.3508	0.6522	-1.3704
sigma	0.0053	0.0041	0.0043	0.0039	0.0092	0.0055

HP3457A DATA ACQUISITION

RUNID : TEST5I-Z
RUNDES: MISALIGNED RATE TEST Z-AXIS // TO TABLE 3000D/S
DATE : 01/26/90
S/S/C : 10.0000
MODE : DCV
START : 13:57:09.91
DUR : 5 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	-0.7900	0.6600	0.6100	-2.4300	0.6100	-1.3700
max	-0.7700	0.6700	0.6300	-2.3900	0.6900	-1.3200
avg	-0.7774	0.6630	0.6220	-2.4064	0.6448	-1.3518
sigma	0.0052	0.0046	0.0054	0.0071	0.0165	0.0105

HP3457A DATA ACQUISITION

RUNID : TEST6B-Z
RUNDES: AC OUTPUTS FOR MISALIGNED AXES FOR 150 HZ INPUT - PARA
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACV
START : 08:53:44.91
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0300	0.7300	0.1400	3.3600	1.6900	1.3100
max	0.3600	1.5000	0.1500	3.8000	1.7300	1.3500
avg	0.3460	0.7532	0.1461	3.7478	1.6976	1.3296
sigma	0.0453	0.1068	0.0049	0.0337	0.0063	0.0090

HP3457A DATA ACQUISITION

RUNID : TEST6C-Z
RUNDES: AC+DC OUTPUTS FOR MISALIGNED AXES AT 150 HZ - PARALLEL
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACDCV
START : 08:56:25.51
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.5800	0.5100	0.4100	3.4700	1.7500	1.4800
max	0.6700	0.5300	0.4300	3.5000	1.7800	1.4900
avg	0.6586	0.5224	0.4204	3.4826	1.7628	1.4872
sigma	0.0118	0.0051	0.0029	0.0092	0.0080	0.0045

HP3457A DATA ACQUISITION

RUNID : TEST6D-Z
RUNDES: AC OUTPUTS FOR MISALIGNED AXES AT 80 HZ - PARALLEL AXI
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACV
START : 09:49:43.60
DUR : 50 SECONDS

Ch 1 Ch 2 Ch 3 Ch 4 Ch 5 Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.0300	0.7800	0.1500	3.3000	1.6900	1.3700
max	0.3800	1.6400	0.1600	3.9900	1.8100	1.4000
avg	0.3628	0.8058	0.1567	3.8198	1.7312	1.3902
sigma	0.0477	0.1192	0.0047	0.1238	0.0251	0.0070

HP3457A DATA ACQUISITION

RUNID : TEST6E-Z
RUNDES: AC+DC OUTPUTS FOR MISALIGNED AXES AT 80 HZ - PARALLEL
DATE : 01/11/90
S/S/C : 1.0000
MODE : ACDCV
START : 09:53:16.33
DUR : 50 SECONDS

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6

Run summary

	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6
min	0.6400	0.5300	0.4200	3.6400	1.7300	1.5800
max	0.7200	0.5500	0.4300	3.7100	1.7600	1.5900
avg	0.7158	0.5422	0.4263	3.6774	1.7452	1.5850
sigma	0.0118	0.0046	0.0048	0.0184	0.0077	0.0050

APPENDIX C

MODAL ANALYSIS OF ACCELEROMETER MOUNT

C1. INTRODUCTION

The objective of this analysis was to determine the first mode of the accelerometer base for a six-degree-of-freedom (DOF) accelerometer package. There was concern that the structural resonance of this base would be within the frequency range of the accelerometer package.

C2. HARDWARE DESCRIPTION

The accelerometer base is illustrated in Figure C-1 and consists of three orthogonal arms attached to ground at the midsection of one of the arms. The original design was made of aluminum with arms that were 2.75" in length. Other designs that are under consideration are an aluminum base with 2.25" arms and a nylon 6/6 base with 2.75" arms. Material properties are given in Table C-1. The nylon used in this analysis is an unreinforced nylon hence the low modulus of elasticity. A glass- or carbon-fiber reinforced nylon would have a higher modulus and thus would be stiffer and have a higher first mode. Note that the nylon properties are for dry nylon at ambient temperature. Structural properties for nylons degrade with an increase in temperature and relative humidity.

TABLE C-1. MATERIAL PROPERTIES

Material	Tensile Modulus (psi)	Poisson's Ratio ν	Density (lb/in3)
Aluminum	10e6	0.33	0.098
Nylon 6/6	0.41e6	0.40	0.042

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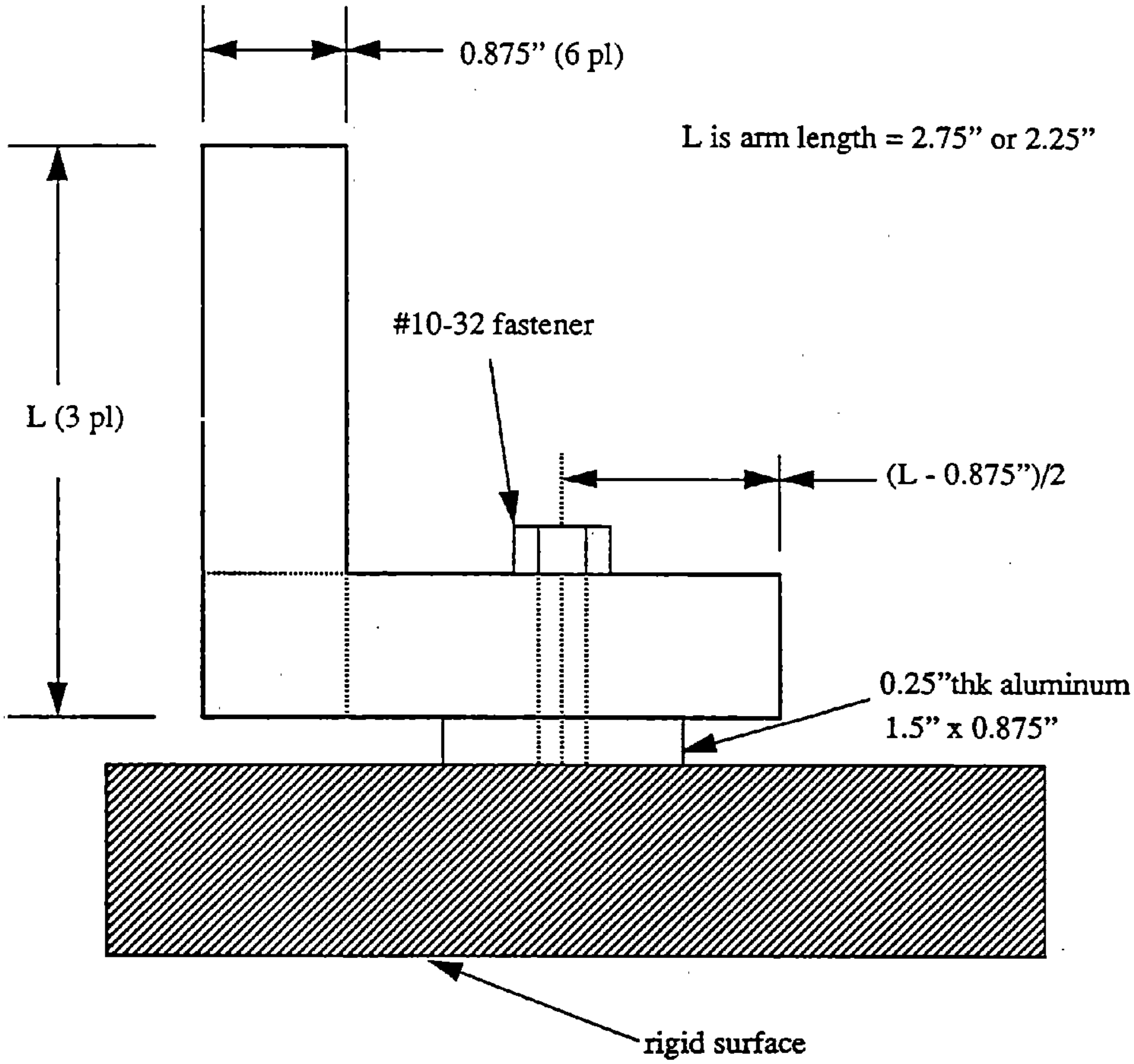

FIGURE C-1. ACCELEROMETER MOUNTING BASE

C3. ANALYSIS METHOD AND RESULTS

Two finite element models were developed--one a simple beam model to give a rough estimate and the other a brick model to determine if any more accuracy could be achieved by using a more complex model. SAP is the finite element code used in this analysis.

C3.1 BEAM MODEL

As a first estimate, a simple finite element model of the base was developed. The model consisted of 29 nodes and 21 beam elements. (See Figure C-2.) Timoshenko beams (which include shear deformation) were used since the arms are relatively short in comparison to their cross-section. A node at the bolt location was constrained in 6 DOF to approximate the boundary conditions.

Table C-2 gives the results of this analysis. The first mode of the system is 1628 Hz and is the two free arms twisting on the one fixed arm. Mode shape plots are given in Appendix C1 for the first four modes.

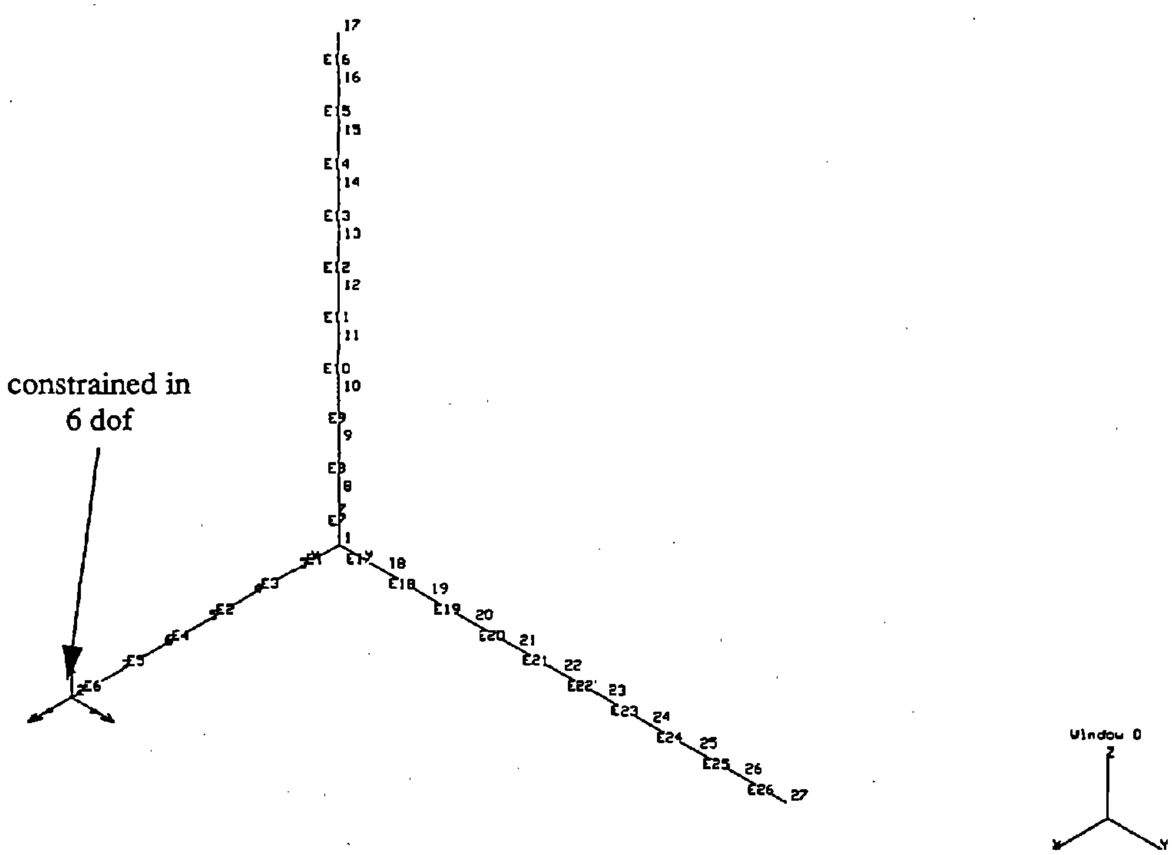

FIGURE C-2. BEAM MODEL

TABLE C-2 NATURAL FREQUENCIES FOR BEAM MODEL MODE DESCRIPTION

Mode Description	Frequency
Torsion of X arm	1628
Bending of X arm	2273
Bending of X arm	2584
Bending of Y-Z arms	4091

C3.2 BRICK MODEL

A brick model of the structure was developed to provide a more accurate representation of the boundary conditions. This model is shown in Figure C-3 and consists of 2107 nodes and 1512 brick elements. The bolt constraint was approximated by constraining the nodes through the thickness at the bolt location in the appropriate arm (x direction arm).

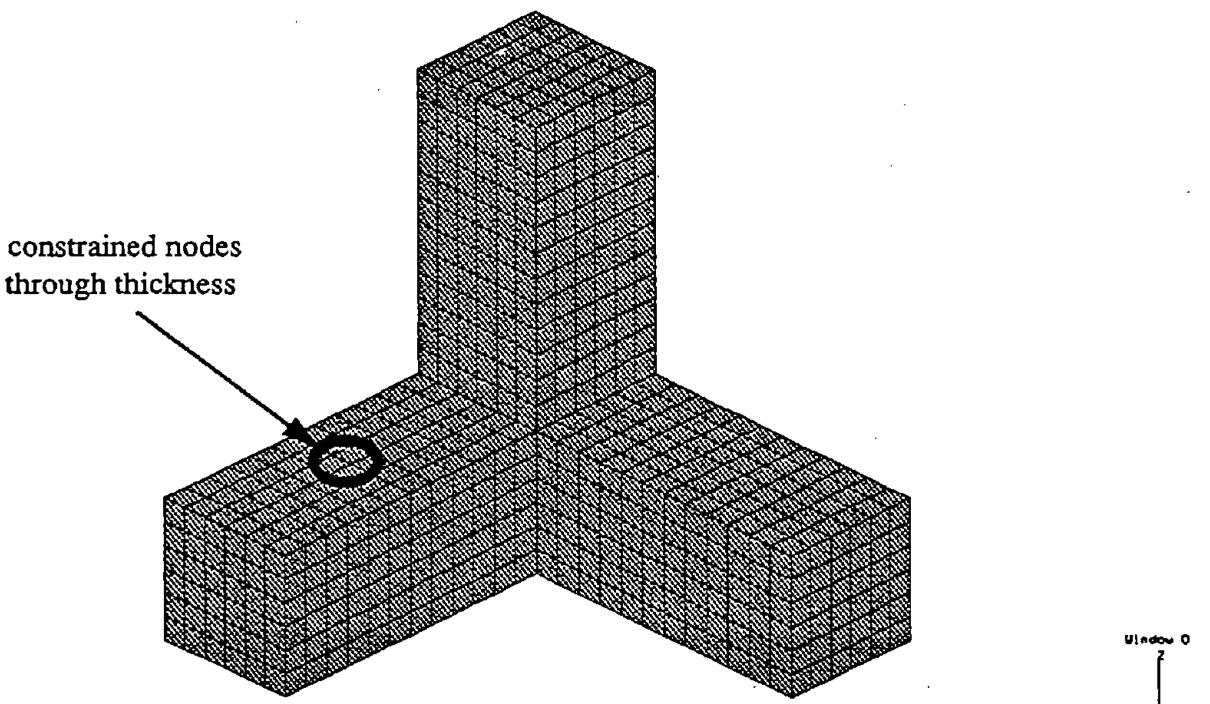

FIGURE C-3. BRICK MODEL

Results are shown in Table C-3. Note that the first mode for the brick model is only about five percent higher than the beam model first mode. Given the difference in complexity of the models, a five percent difference is negligible. A plot of the first mode for the brick model is shown in Appendix C2.

TABLE C-3 NATURAL FREQUENCIES FOR BRICK MODEL

Mode Description	Frequency
Torsion of X arm	1713
Bending of X arm	2093
Bending of X arm	2548
Bending of Y-Z arms	5085

C3.3 COMPARISON OF DESIGNS

Two other cases were analyzed using the model shown in Figure C-3: an aluminum base with 2.25" arms and a nylon base with 2.75" arms. The first mode for each of these designs is shown in Table C-4.

Table C-4
First Mode Comparison (Brick Model) for Different Base Designs

Design	Frequency (Hz)
Aluminum with 2.75" arms	1713
Aluminum with 2.25" arms	2679
Nylon with 2.75" arms	531

Note that the first mode of the nylon design could have been predicted fairly accurately by considering the difference in material properties from aluminum. Since frequency is proportional to the square root of stiffness/mass then the nylon frequency, f_n, can be predicted from the aluminum frequency, f_a = 1713 Hz, by the equation:

$$f_n = f_a\sqrt{\frac{E_n/E_a}{\rho_n/\rho_a}} = 1713\sqrt{\frac{(0.41e6)/(10e6)}{(0.042)/(0.098)}} = 530\ Hz$$

where E is tensile modulus and ρ is density.

C4. CONCLUSIONS/RECOMMENDATIONS

From the results shown in Table C-2, the aluminum with 2.25" arms would be the best choice of these three designs if natural frequency were the only requirement. Other factors such as sensitivity of the angular accelerometers (mounted at the ends of the arms) have to be considered, however, when considering arm length since a greater arm length will improve sensitivity.

The analysis shows that unreinforced nylon is a poor choice especially considering that the material properties used were a "best case" in that it was dry nylon at ambient temperature. A glass or carbon-fiber-reinforced nylon would be a better choice since it would have a higher modulus of elasticity (E) with little difference in weight. To get away from the temperature and relative humidity problems, fiber-reinforced PEEK or PES might be worth considering.

APPENDIX C1

BEAM MODEL MODE SHAPES

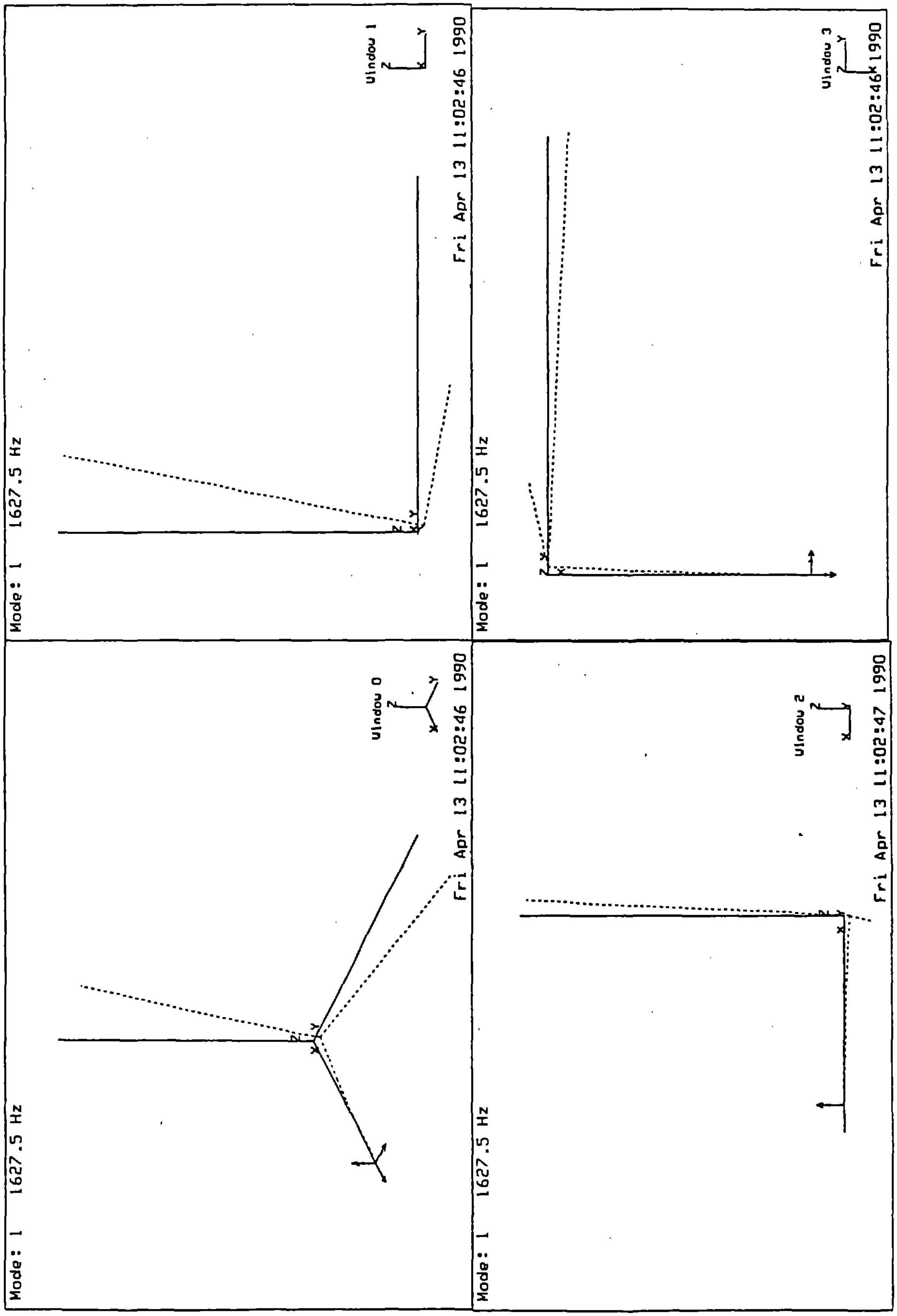

FIGURE C-4. BEAM MODEL - MODE SHAPE #1

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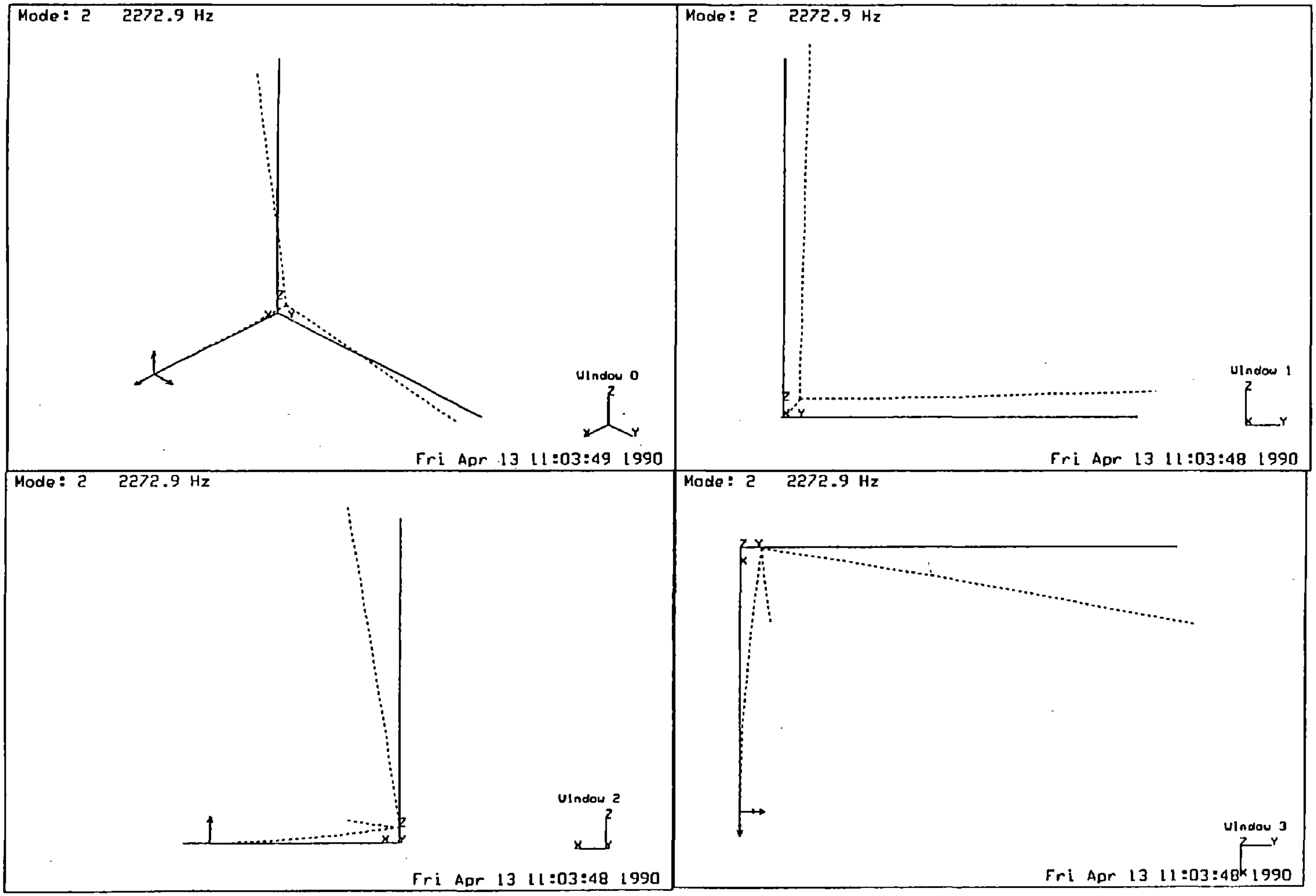


FIGURE C-5. BEAM MODEL - MODE SHAPE #2

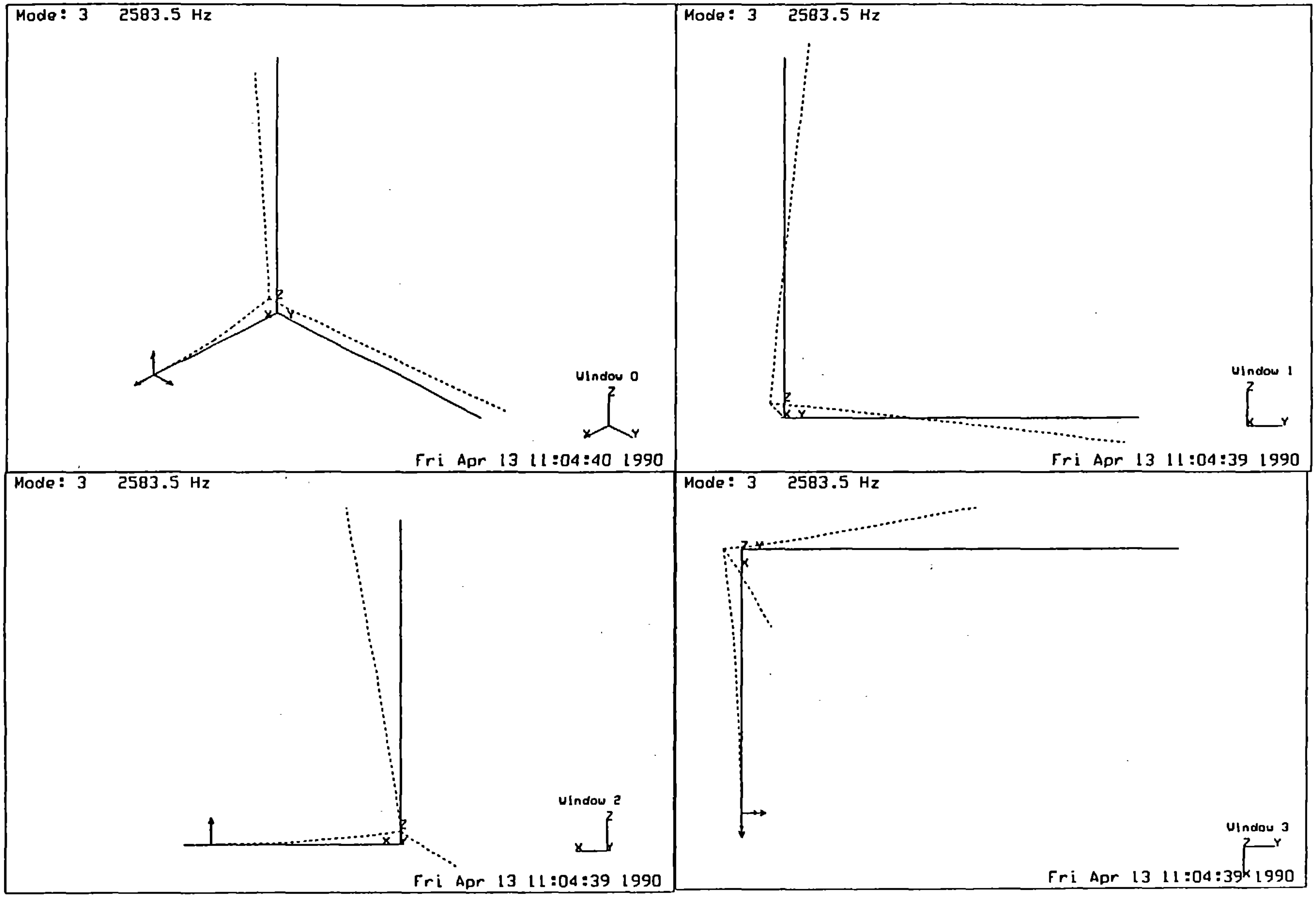


FIGURE C-6. BEAM MODEL - MODE SHAPE #3

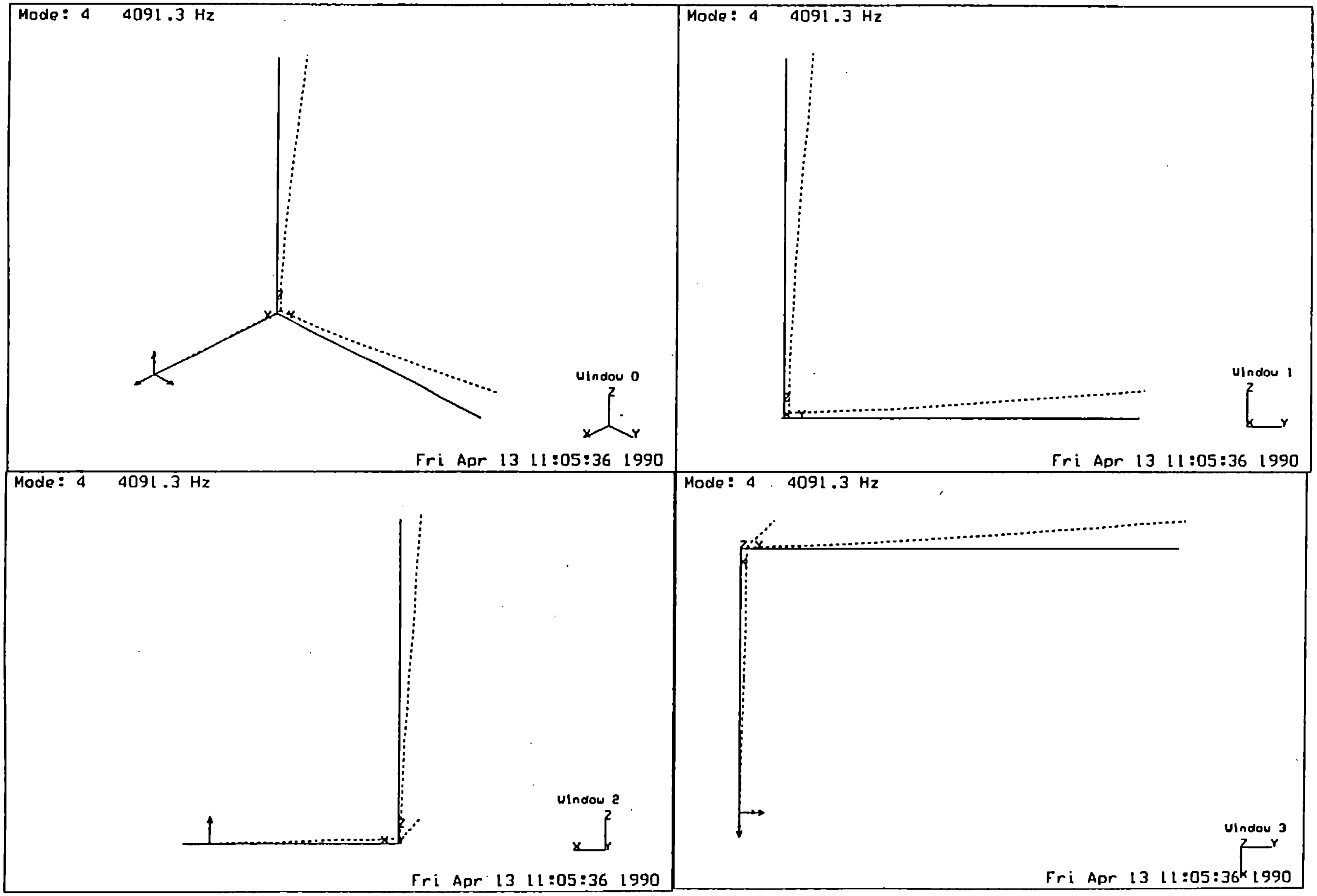


FIGURE C-7. BEAM MODEL - MODE SHAPE #4

APPENDIX C2

BRICK MODEL MODE SHAPES

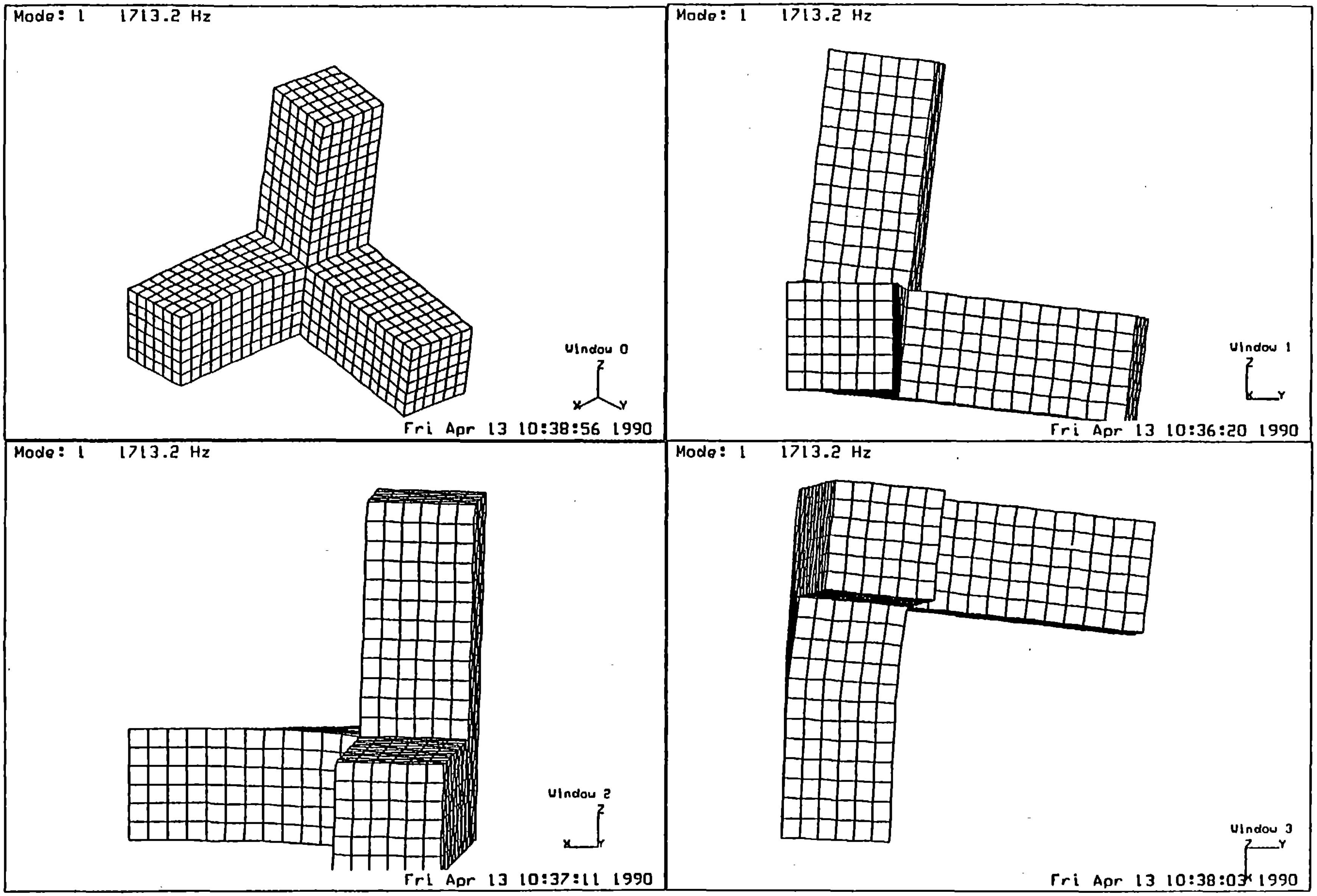


FIGURE C-8. BRICK MODEL - MODE SHAPE #1

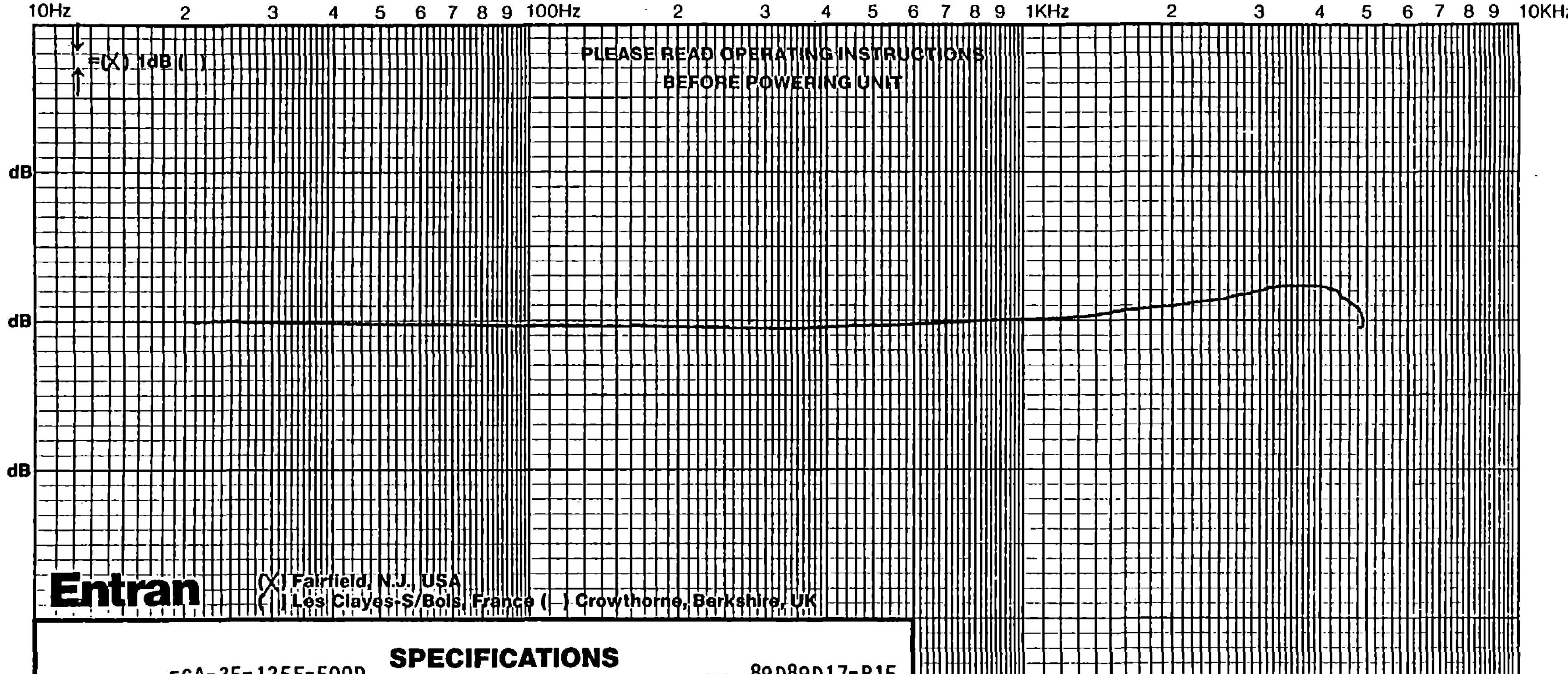
APPENDIX D

ACCELEROMETER CERTIFICATES OF CALIBRATION

MODEL: [illegible] AXIS: ___ S/N: [illegible]
CAL EQUIPMENT S/N'S: ACC: 129 DVM: 4622287
Entran by: M Cal. Date: 4/29/89 QC: ___ FO#: 16100C-1
Property of: ___ PO: ___

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



Entran (X) Fairfield, N.J. USA
( ) Les Clayes-S/Bois, France ( ) Crowthorne, Berkshire, UK

SPECIFICATIONS

Model : EGA-35-125F-500D S/N: 89D89D17-P15
Range : ±500g Limit: ±2500g Axis:
Temperature Range, Compensated: 50 to 150°F Operating: -40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

[1,2] Non-Linearity	±1%	[1] Hysteresis:		[2] X-axis	
[1] Zero		[1] Therm. Z	±1%FS/100°F	[2] TSS	±2.5%/100°F
R Cal		with		across	
Output	.3315mV/g	with In	10.00VDC	Max. In	12.0 VDC
Ref. Temp	75F	Ref. Hz	100	[4] Approx. fn.:	
Tested with:				S/N:	
Output		with In		Max. In	
[3] Input Ω	1216	[3] Output Ω	1160	See Over	( )

ACCELEROMETER WIRING

To Module: 18" Total: 4.5 ft.
+In: (X) Red ( ) +Out: (X) Grn ( )
( ) Grn & Blue
-In: (X) Blk ( ) -Out: (X) Wht ( )
Connector: Mate:

ELECTRONICS

Signal In Conn	:	Mate	:
+Sensor Power	:	+Signal In	:
-Sensor Power	:	-Signal In	:
Amp Out Conn	:	Mate	:
+Supply	:	+Signal Out	:
-Supply	:	-Signal Out	:
(For ±15V Input, Do not use unipolar 30V power supply)		Common	:

(3)

FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output Impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

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MODEL: EGA-35-125F-500D **AXIS:** ____ **S/N:** [illegible]

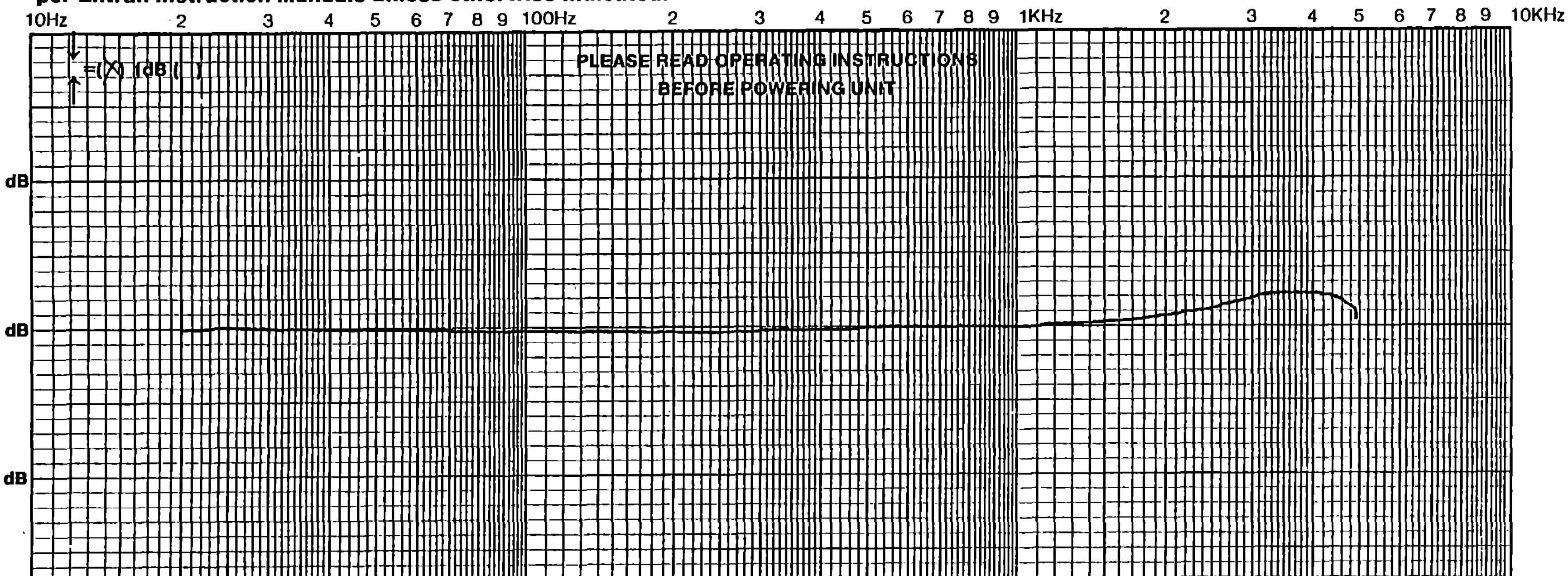
CAL EQUIPMENT S/N'S: ACC: 129 DVM: 4622287

Entran by: [illegible] **Cal. Date:** 4/29/89 **QC:** (3 Q.C.) **FO#:** 16110C-1

Property of: ____ **PO:** ____

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



Entran (X) Fairfield, N.J. USA ( ) Les Clayes-S/Bois, France ( ) Crowthorne, Berkshire, UK

SPECIFICATIONS

Model : EGA-35-125F-500D		S/N:	89D89D17-P13
Range : ±500g	Limit: ±2500g	Axis:	
Temperature Range, Compensated:	50 to 150°F	Operating:	-40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

[1,2]Non-Linearity:	±1%	[1]Hysteresis:		[2]X-axis :	
[1]Zero :		[1]Therm. Z :	±1%FS/100°F	[2]TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	.3299 mV/g	with In :	10.00VDC	Max. In :	12.0 VDC
Ref. Temp :	75F	Ref. Hz :	100	[4]Approx. In.:	
Tested with:				S/N:	
Output :		with In :		Max. In :	
[3]Input Ω :	1145	[3]Output Ω :	452	See Over : ( )	

ACCELEROMETER WIRING

To Module: 18" Total: 4.5 ft.

+In: (X) Red ( ) +Out: (X) Grn ( ) ( ) Grn & Blue

-In: (X) Blk ( ) -Out: (X) Wht ( )

Connector: Mate:

ELECTRONICS

Signal In Com :		Mate :	
+Sensor Power :		+Signal In :	
-Sensor Power :		-Signal In :	
Amp Out Com :		Mate :	
+Supply :		+Signal Out :	
-Supply :		-Signal Out :	
(For ±15V Input, Do not use unipolar 30V power supply)		Common :	

(7R)

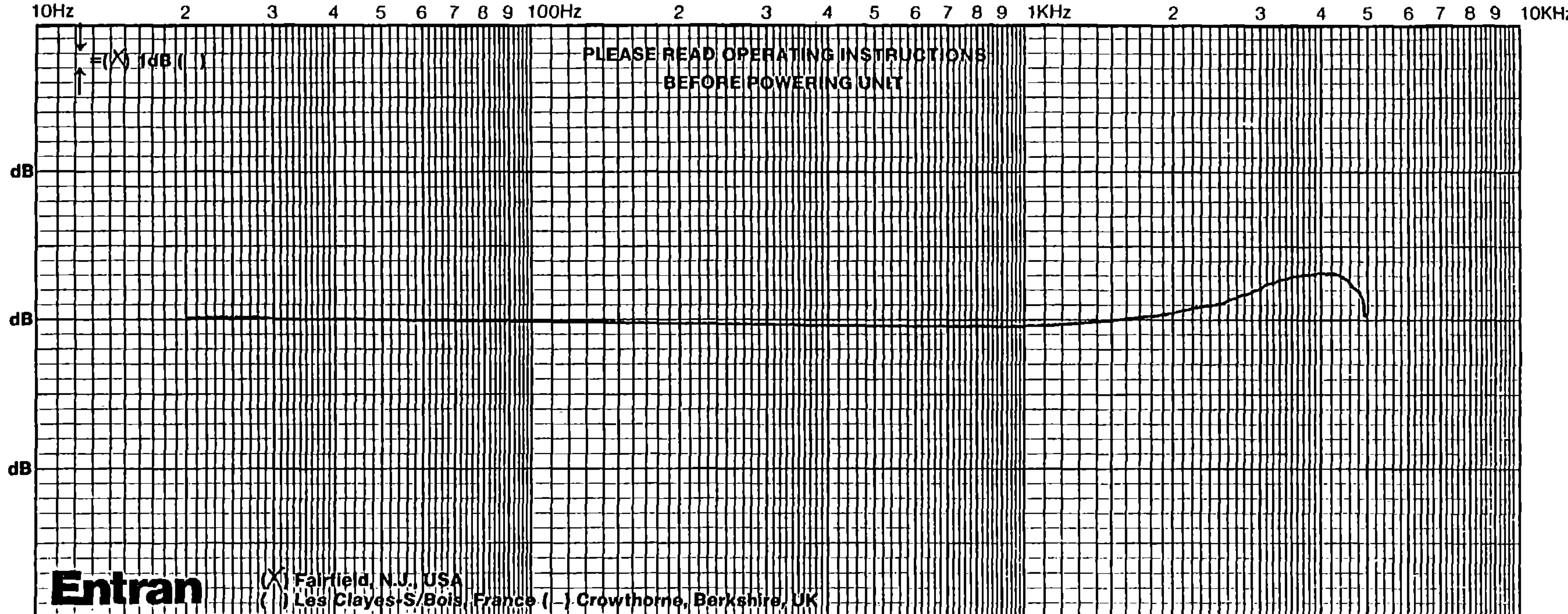
FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1]If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2]Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3]Input/Output impedance is recorded for transducer alone if separate item from electronics. [4]In means Resonant Frequency.

MODEL: EGA-35-125F-500D **AXIS:** ____ **S/N:** 89D89D17-P14
CAL EQUIPMENT S/N'S: ACC 109 DVM #622287
Entran by: ___ **Cal. Date:** 4/24/89 **QC:** ___ **FO#:** 16100C-1
Property of: ____________ **PO:** ____________

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



SPECIFICATIONS

Model : EGA-35-125F-500D S/N: 89D89D17-P14
Range : ±500g Limit: ±2500g Axis:
Temperature Range, Compensated: 50 to 150°F Operating: -40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

[1,2]Non-Linearity :	±1%	[1]Hysteresis:		[2]X-axis :	
[1]Zero :		[1]Therm. Z :	±1%FS/100°F	[2]TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	.3356 mV/g	with In :	18.00VDC	Max. In :	12.0 VDC
Ref. Temp :	75F	Rel. Hz :	100	[4]Approx. fn.:	
Tested with:				S/N:	
Output :		with In :		Max. In :	
[3]Input Ω :	1160	[3]Output Ω :	440	See Over : ( )	

ACCELEROMETER WIRING

To Module: 18" Total: 4.5 ft.
+In: (X) Red ( ) +Out: (X) Grn ( )
( ) Grn & Blue
-In: (X) Blk ( ) -Out: (X) Wht ( )
Connector: Mate:

ELECTRONICS

Signal In Conn :		Mate :	
+Sensor Power :		+Signal In :	
-Sensor Power :		-Signal In :	
Amp Out Conn :		Mate :	
+Supply :		+Signal Out :	
-Supply :		-Signal Out :	
(For ±15V Input, Do not use unipolar 30V power supply)		Common :	

(2)

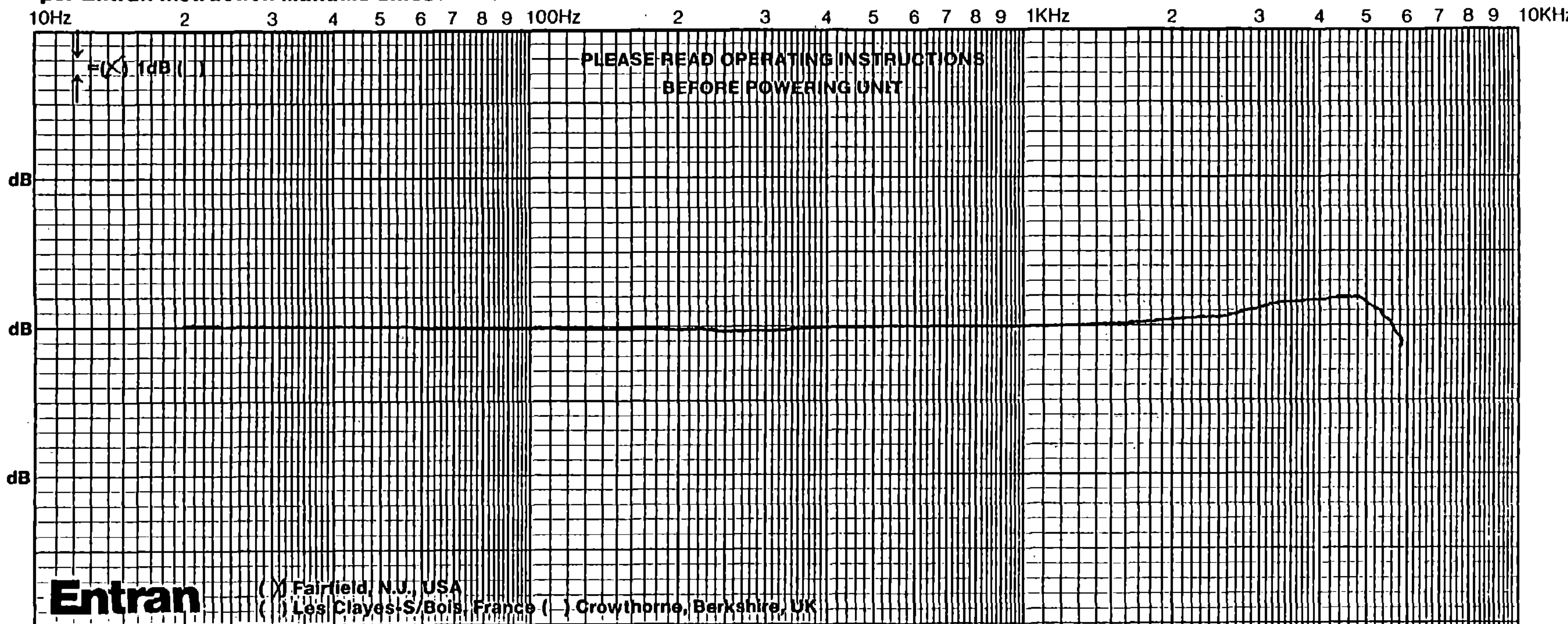
FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1]If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2]Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3]Input/Output impedance is recorded for transducer alone if separate item from electronics. [4]fn means Resonant Frequency.

MODEL: [illegible] **AXIS:** ___ **S/N:** [illegible]
CAL EQUIPMENT S/N'S: ACC 189 DVM 4622287
Entran by: M **Cal. Date:** 4/28/85 **QC:** [illegible] **FO#:** 16100C-1
Property of: ___ **PO:** ___

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



SPECIFICATIONS

Model : EGA-35-125F-500D S/N: 89D89D17-P12
Range : ±500g Limit: ±2500g Axis:
Temperature Range, Compensated: 50 to 150°F Operating: -40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

1,2 Non-Linearity :	±1%	1 Hysteresis:		2 X-axis :	
1 Zero :		1 Therm. Z :	±1%FS/100°F	2 TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	.332 mV/g	with In :	10.00VDC	Max. In :	12.0 VDC
Ref. Temp :	75F	Ref. Hz :	110	4 Approx. fn :	
Tested with:				S/N:	
Output :		with In :		Max. In :	
3 Input Ω :	1141	3 Output Ω :	465	See Over : ( )	

ACCELEROMETER WIRING

To Module: 18'' Total: 4.5 ft.
+In: (X) Red ( ) +Out: (X) Grn ( )
( ) Grn & Blue
-In: (X) Blk ( ) -Out: (X) Wht ( )
Connector: Mate:

ELECTRONICS

Signal In Com :	Mate :
+Sensor Power :	+Signal In :
-Sensor Power :	-Signal In :
Amp Out Com :	Mate :
+Supply :	+Signal Out :
-Supply :	-Signal Out :
(For ±15V Input, Do not use unipolar 30V power supply)	Common :

(41)

FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output Impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

MODEL: EGA-35-125F-500D **AXIS:** ____ **S/N:** 89D89C29-P06

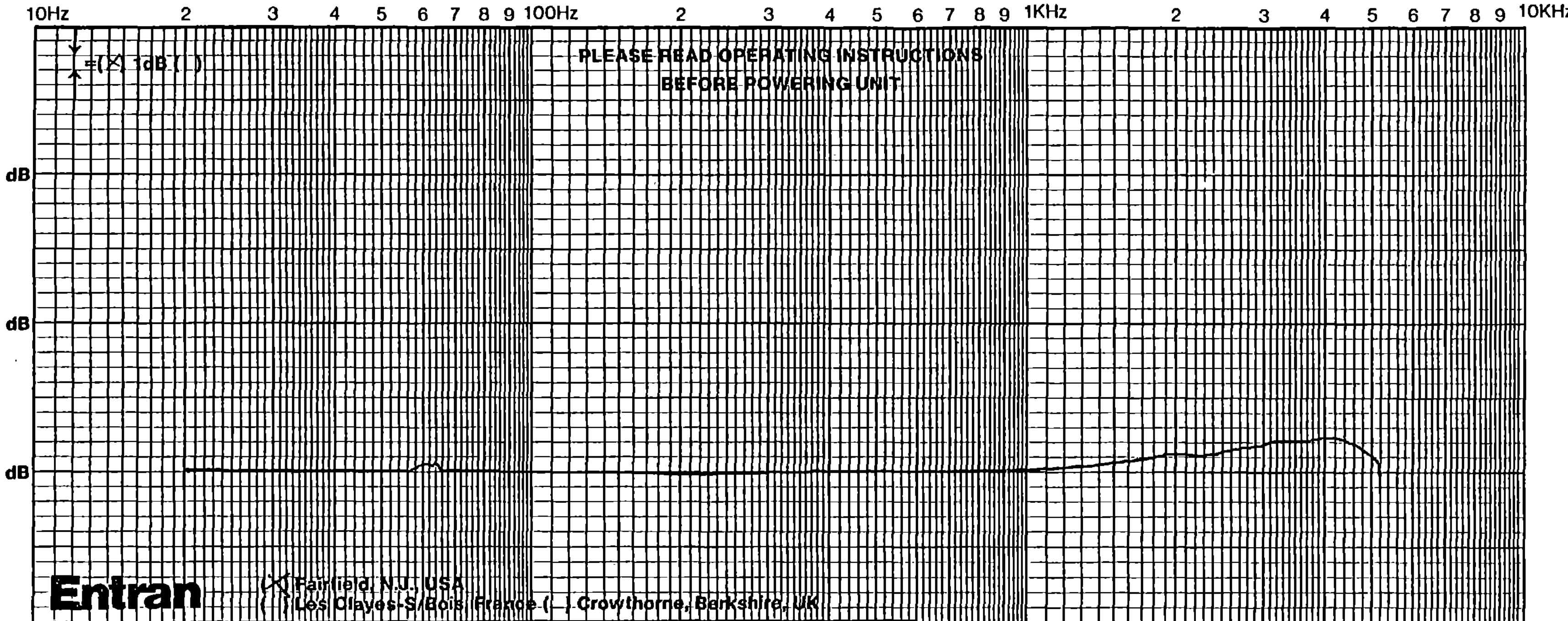
CAL EQUIPMENT S/N'S: ACC 412 DVM 77630

Entran by: [illegible] **Cal. Date:** 4/24/89 **QC:** [illegible] **FO#:** 16100

Property of: ____ **PO:** ____

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



SPECIFICATIONS

Model	: EGA-35-125F-500D			S/N:	89D89C29-P06
Range	: ±500g	Limit:	±2500g	Axis:	
		Temperature Range, Compensated:	50 to 150°F	Operating:	-40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

1,2 Non-Linearity	: ±1%FS	1 Hysteresis:		2 X-axis	:
1 Zero	:	1 Therm. Z	: ±1%FS/100°F	2 TSS	: ±2.5%/100°F
R Cal	:	with	:	across	:
Output	: 0.335 mV/g	with In	: 10.0 VDC	Max. In	: 12.0 VDC
Ref. Temp	: 75°F	Ref. Hz	: 100	4 Approx. fn.:	
Tested with:				S/N:	
Output	:	with In	:	Max. In	:
3 Input Ω	: 1596	3 Output Ω	: 493	See Over	: ( )

ACCELEROMETER WIRING

To Module: 18" — Total: 4.5 ft.

+In: (X) Red ( ) — +Out: (X) Grn ( ) ( ) Grn & Blue

-In: (X) Blk ( ) — -Out: (X) Wht ( )

Connector: — Mate:

ELECTRONICS

Signal In Conn	:	Mate	:
+Sensor Power	:	+Signal In	:
-Sensor Power	:	-Signal In	:
Amp Out Conn	:	Mate	:
+Supply	:	+Signal Out	:
-Supply	:	-Signal Out	:
(For ±15V Input, Do not use unipolar 30V power supply)		Common	:

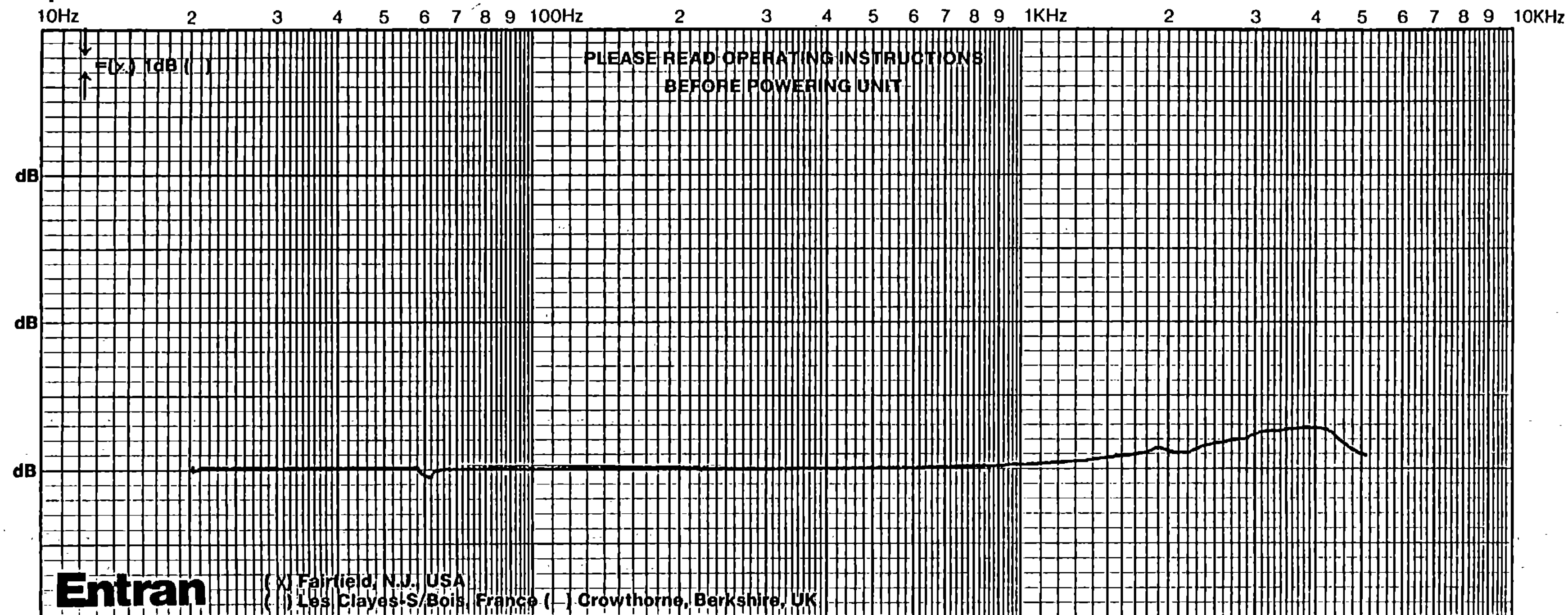
FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output Impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

MODEL: EGA-35-125F-500D **AXIS:** ____ **S/N:** 89E89D17-P11
CAL EQUIPMENT S/N'S: ACC 412 DVM 77630
Entran by: CD **Cal. Date:** 5/2/89 **QC:** ____ **FO#:** 16100
Property of: ____ **PO:** ____

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



SPECIFICATIONS

Model : EGA-35-125F-500D S/N: 89E89D17-P11
Range : ±500g Limit: ±2500g Axis:
Temperature Range, Compensated: 50°F to 150°F Operating: -40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

[1,2] Non-Linearity :	±1%	[1] Hysteresis:		[2] X-axis :	
[1] Zero :		[1] Therm. Z :	±1%FS/100°F	[2] TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	0.335 mV/g	with In :	10.0 VDC	Max. In :	12.0 VDC
Ref. Temp :	73°F	Ref. Hz :	100	[4] Approx. fn:	
Tested with:				S/N:	
Output :		with In :		Max. In :	
[3] Input Ω :	1069	[3] Output Ω :	447	See Over : ( )	

ACCELEROMETER WIRING

To Module: 18" Total: 4½ Ft.
+In: (x) Red ( ) +Out: (x) Grn ( )
( ) Grn & Blue
-In: (x) Blk ( ) -Out: (x) Wht ( )
Connector: Mate:

ELECTRONICS

Signal In Com :		Mate :	
+Sensor Power :		+Signal In :	
-Sensor Power :		-Signal In :	
Amp Out Com :		Mate :	
+Supply :		+Signal Out :	
-Supply :		-Signal Out :	
(For ±15V Input, Do not use unipolar 30V power supply)		Common :	

(5)

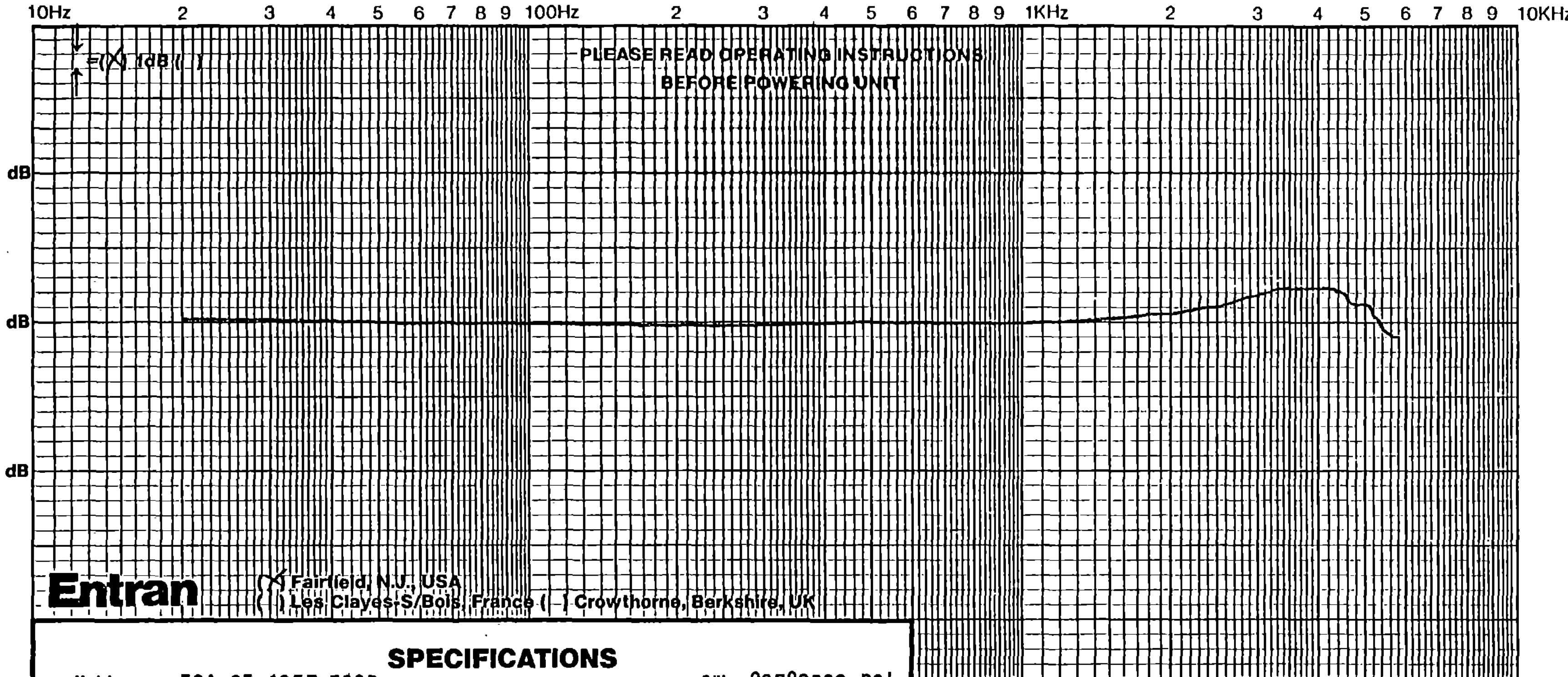
FORM NO 2CAL-A-UNIV SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output Impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

MODEL: EGA-35-125F-500D **AXIS:** ___ **S/N:** [illegible]
CAL EQUIPMENT S/N'S: ACC: 129 DVM: 34764091
Entran by: SH **Cal. Date:** 5/12/89 **QC:** [illegible] **FO#:** 16100C
Property of: ___ **PO:** [illegible]

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



SPECIFICATIONS

Model :	EGA-35-125F-500D	S/N:	89E89D29-P04
Range :	±500g	Limit:	±2500g
		Axis:	
Temperature Range, Compensated:	50 to 150°F	Operating:	-40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

1,2 Non-Linearity :	±1%F.S.	1 Hysteresis:		2 X-axis :	
1 Zero :		1 Therm. Z :	±1%FS/100°F	2 TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	.3350	with In :	10.00 VDC	Max. In :	12.0 VDC
Ref. Temp :	75°F	Ref. Hz :	100	4 Approx. fn :	
Tested with:				S/N:	
Output :		with In :		Max. In :	
3 Input Ω :	1570	3 Output Ω :	432	See Over : ( )	

ACCELEROMETER WIRING

To Module:	18"	Total:	4.5ft.
+In: (X) Red ( )		+Out: (X) Grn ( )	
		( ) Grn & Blue	
-In: (X) Blk ( )		-Out: (X) Wht ( )	
Connector:		Mate:	

ELECTRONICS

Signal In Com :		Mate :	
+Sensor Power :		+Signal In :	
-Sensor Power :		-Signal In :	
Amp Out Com :		Mate :	
+Supply :		+Signal Out :	
-Supply :		-Signal Out :	
(For ±15V Input, Do not use unipolar 30V power supply)		Common :	

(1)

FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output Impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

MODEL: [illegible] **AXIS:** ___ **S/N:** [illegible]

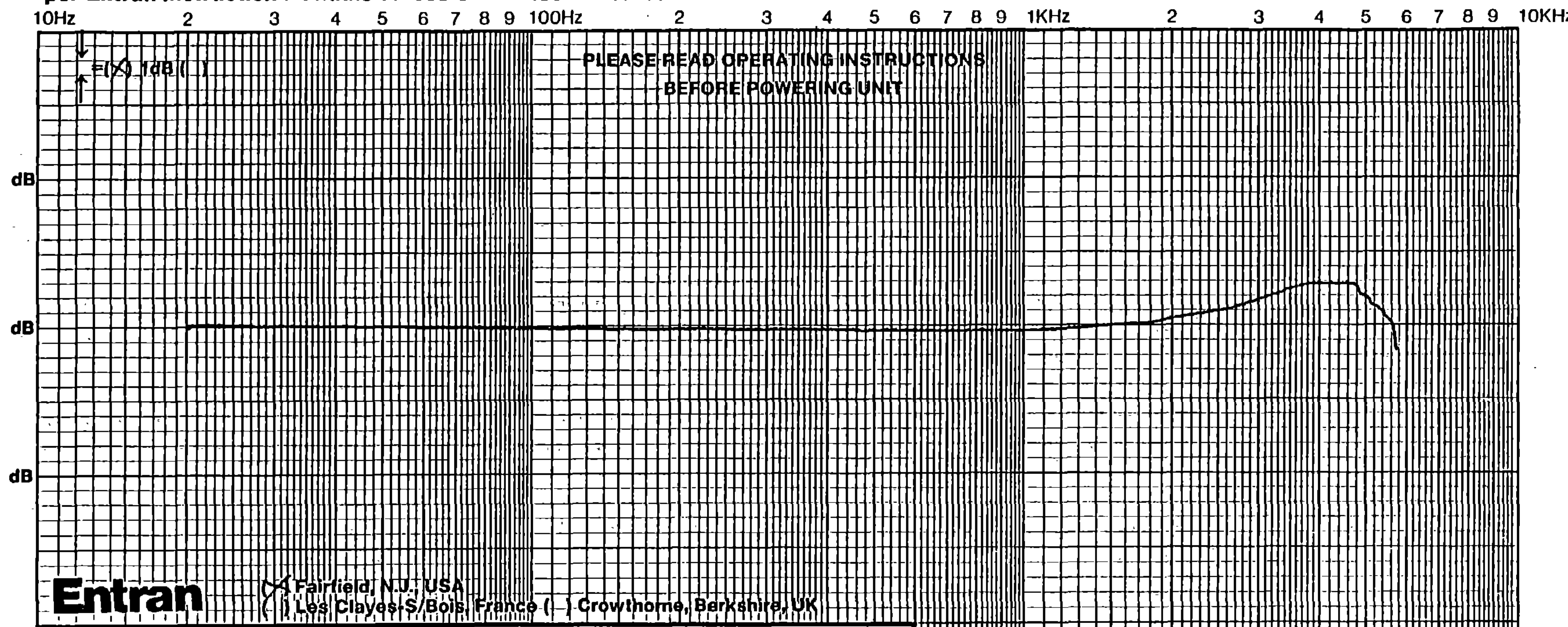
CAL EQUIPMENT S/N'S: ACC : 129 DVM : 3476,4091

Entran by: SH **Cal. Date:** 5/12/89 **QC:** 2 (QC) **FO#:** 16100C

Property of: ______ **PO:** ______

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



SPECIFICATIONS

Model : EGA-35-125F-500D   S/N: 89E89D29-P05

Range : ±500g   Limit: ±2500g   Axis:

Temperature Range, Compensated: 50 to 150°F   Operating: -40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

1,2 Non-Linearity :	±1%F.S.	1 Hysteresis:		2 X-axis :	
1 Zero :		1 Therm. Z :	±1%FS/100°F	2 TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	.3312	with In :	10.00VDC	Max. In :	12.0 VDC
Ref. Temp :	75°F	Ref. Hz :	100	4 Approx. fn.:	
Tested with:				S/N:	
Output :		with In :		Max. In :	
3 Input Ω :	1131	3 Output Ω :	436	See Over : ( )	

ACCELEROMETER WIRING

To Module: 18"   Total: 4.5 ft.

+In: (X) Red ( )   +Out: (X) Grn ( )

( ) Grn & Blue

-In: (X) Blk ( )   -Out: (X) Wht ( )

Connector: Mate:

ELECTRONICS

Signal In Com :		Mate :	
+Sensor Power :		+Signal In :	
-Sensor Power :		-Signal In :	
Amp Out Com :		Mate :	
+Supply :		+Signal Out :	
-Supply :		-Signal Out :	
(For ±15V Input, Do not use unipolar 30V power supply)		Common :	

(9)

FORM NO. 2CAL-A-UNIV
SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output Impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

MODEL: EGA-35-125F-500D **AXIS:** ___ **S/N:** 89F89F08-P06

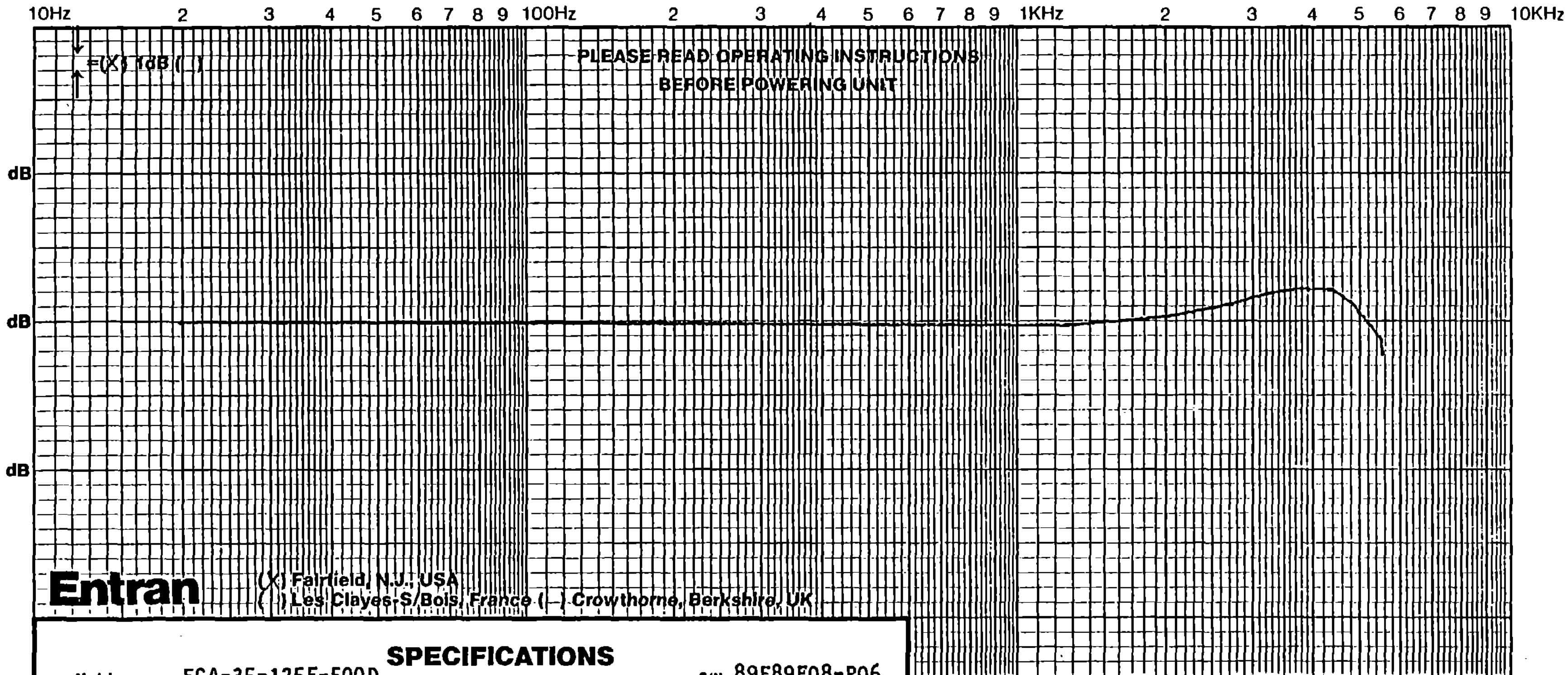
CAL EQUIPMENT S/N'S: ACC: 129 DVM: 34764091

Entran by: PT **Cal. Date:** 6/22/89 **QC:** ___ **FO#:** 16100

Property of: ___ **PO:** ___

CERTIFICATE OF CALIBRATION

This instrument has been calibrated against a working standard which is directly traceable to a National Standard. All data interpreted per Entran Instruction Manuals unless otherwise indicated.



Entran (X) Fairfield, N.J. USA
( ) Les Clayes-S/Bois, France ( ) Crowthorne, Berkshire, UK

SPECIFICATIONS

Model : EGA-35-125F-500D S/N: 89F89F08-P06

Range : ±500g Limit: ±2500g Axis:

Temperature Range, Compensated: 50° to 150°F Operating: -40 to 250°F

CALIBRATION DATA

Subject to 10,000g Shock In: ( ) Sensitive Axis Only ( ) All Axes

1,2 Non-Linearity :	±1%	1 Hysteresis:		2 X-axis :	
1 Zero :		1 Therm. Z :	±1%FS/100°F	2 TSS :	±2.5%/100°F
R Cal :		with :		across :	
Output :	.3350 mV/g	with In :	10.00VDC	Max. In :	12.0 VDC
Ref. Temp :	75F	Ref. Hz :	100	4 Approx. fn.:	
Tested with:				S/N:	
Output :		with In :		Max. In :	
3 Input Ω :	1060	3 Output Ω :	488	See Over : ( )	

ACCELEROMETER WIRING

To Module: 18" Total: 4½'

+In: (X) Red ( ) +Out: (X) Grn ( )

( ) Grn & Blue

-In: (X) Blk ( ) -Out: (X) Wht ( )

Connector: Mate:

ELECTRONICS

Signal In Com :		Mate :	
+Sensor Power :		+Signal In :	
-Sensor Power :		-Signal In :	
Amp Out Com :		Mate :	
+Supply :		+Signal Out :	
-Supply :		-Signal Out :	
(For ±15V Input, Do not use unipolar 30V power supply)		Common :	

(b)

FORM NO. 2CAL-A-UNIV SEMI-LOGARITHMIC

[1] If calibrated data equals or exceeds data sheet specifications, value shown is the data sheet value unless purchase order specifies actual calibrated value. [2] Value given is by manufacturing design and not calibrated unless purchase order specifies actual calibrated value. TSS is Thermal Sensitivity Shift. [3] Input/Output impedance is recorded for transducer alone if separate item from electronics. [4] fn means Resonant Frequency.

REFERENCES

1. Gordon Plank, Herbert Weinstock, Michael Coltman, Harvey Lee, "Methodology for the Calibration of and Data Acquisition with a Six-Degree-of-Freedom Acceleration Measurement Device." Technical Report DOT-TSC-NHTSA-88-3, Transportation Systems Center, Cambridge MA, 1989.

2. A. J. Padgaonkar, K. W. Krieger and A. I. King, "Measurement of Angular Acceleration of a Rigid Body Using Linear Accelerometers." Journal of Applied Mechanics, Paper No. 75-APMB-3 pp. 1-5, June 1975.

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