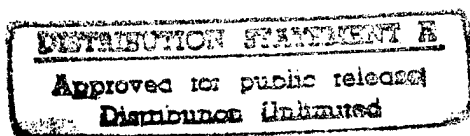


# Comparison of Separation Shock for Explosive and Nonexplosive Release Actuators on a Small Spacecraft Panel

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**COMPARISON OF SEPARATION SHOCK  
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# COMPARISON OF SEPARATION SHOCK FOR EXPLOSIVE AND NON-EXPLOSIVE RELEASE ACTUATORS ON A SMALL SPACECRAFT PANEL

## ABSTRACT

Functional shock, safety, overall system costs, and emergence of new technologies, have raised concerns regarding continued use of pyrotechnics on spacecraft. NASA Headquarters-Office of Chief Engineer requested Langley Research Center (LaRC) study pyrotechnic alternatives using non-explosive actuators (NEAs), and LaRC participated with Lockheed Martin Missile and Space Co. (LMMSC)-Sunnyvale, CA in objectively evaluating applicability of some NEA mechanisms to reduce small spacecraft and booster separation event shock. Comparative tests were conducted on a structural simulator using five different separation nut mechanisms, consisting of three pyrotechnics from OEA-Aerospace and Hi-Shear Technology and two NEAs from G&H Technology and Lockheed Martin Astronautics (LMA)-Denver, CO. Multiple actuations were performed with preloads up to 7000 pounds, 7000 being the comparison standard. All devices except LMA's NEA rotary flywheel-nut concept were available units with no added provisions to attenuate shock. Accelerometer measurements were recorded, reviewed, processed into Shock Response Spectra (SRS), and comparisons performed. For the standard preload, pyrotechnics produced the most severe and the G&H NEA the least severe functional shock levels. Comparing all results, the LMA concept produced the lowest levels, with preload limited to approximately 4200 pounds. Testing this concept over a range of 3000 to 4200 pounds indicated no effect of preload on shock response levels. This report presents data from these tests and the comparative results.

## 1.0 SUMMARY

Concerns arising from continued use of pyrotechnics on spacecraft led NASA Headquarters-Office of Chief Engineer to request Langley Research Center (LaRC) form a Pyrotechnic Alternatives Investigative Team. In February 1995 LaRC was invited to cooperatively participate with LMMSC in evaluating actuation shock produced by several pyrotechnic and non-pyrotechnic release devices. The tests would objectively investigate application of some non-explosive actuators (NEAs) to reduce small spacecraft and booster separation event shock by demonstrating NEA release mechanisms, comparing resulting levels with those from standard pyrotechnic devices, and evaluating effects of a different test panel mounting arrangement.

Tests were conducted at LMMSC on a structural simulator representing a current small spacecraft panel design--with and without mass loading. Five different release mechanisms were tested in multiple firings with preloads ranging from about 3000 to 7000 pounds, the latter being the comparison standard. With the exception of a LMA rotary flywheel-nut developmental NEA device, hereafter referred to as the Martin concept, all other separation devices were available, off-the-shelf units with no additional provisions to attenuate functional shock.

Accelerometer measurements were made on the panel face and frame, acceleration-time histories reviewed for validity, valid data processed into Shock Response Spectra (SRS), and the SRS data compared. As expected, comparisons for standard preloaded (7000 pound) release mechanisms indicated the most severe levels were produced by the pyrotechnic devices, while the G&H NEA device produced the lowest levels. The Martin concept clearly produced the lowest levels, but its maximum preload capability was limited to approximately 4200 pounds. However, results from testing this developmental device, where the preload range was 3000 to 4200 pounds, indicated there was no systematic effect raising shock levels with preload.

Panel in-plane strain energy release was found to significantly raise the in-plane SRS levels compared to those in the direction normal to the panel face. Normal direction levels were influential at low frequencies, but in-plane levels clearly dominated at frequencies above 600 to 800 Hz. This result was not device dependent, although some spectral differences were noted between the pyrotechnic and NEA devices. Impedance and transfer function data support consistency of the SRS directional response evaluations. This latter data should prove useful in translating these test results to other structures, providing similar data are available on those structures.

## 2.0 INTRODUCTION

Due to concerns arising from continued use of pyrotechnics on spacecraft, NASA Headquarters-Office of Chief Engineer, requested LaRC form a Pyrotechnic Alternatives Investigative Team. Reasons for this request included: high functional (actuation) shock levels; overall system costs; reusability, shrinking volume, weight and power budgets on smaller spacecraft; emergence and availability of new technologies; potentially hazardous nature of the materials involved; and several recent anomalies in which pyrotechnics could be suspect. Because of this activity, in February 1995, LaRC was invited to participate in a cooperative, cost sharing effort with LMMSC to evaluate functional shock produced by several pyrotechnic and non-pyrotechnic release devices. Consequently, LaRC initiated Task 31, "Low-Shock Booster Release

Limited data exist for determining component exposure to shock from payload separation devices on lightweight-rigid structures characteristic of current generation, commercial sized spacecraft. Release devices used on previous spacecraft structures are expected to produce shock levels above those for which many standard components have been qualified. A current LMMSC spacecraft, Commercial Remote Sensing Satellite (CRSS), employs separation devices mounted so a major portion of the strain energy released upon separation is in the mounting plane of some major components. Most current experience is with mounting release devices on external brackets, which convert release motion into transverse bending waves before the shock reaches most components of interest. Together, these situations provided a strong motivation to obtain test data for the LMMSC mounting configuration using current separation devices and prospective devices that promise to produce lower component shock levels. A shock test program was devised and carried out to obtain such data.

The Task's purpose was to objectively investigate application of some NEAs to reduce small spacecraft and booster separation event shock levels. The primary goal was to demonstrate NEA mechanisms for release functions, and determine severity and compare resulting shock levels with those produced by standard pyrotechnic devices. A secondary goal was to evaluate effects of the different release device panel mounting arrangement. LMMSC's initial planning included developing math models, making analytical shock predictions, comparing test results with predictions, and correlating results with the math models. Program resources and schedule precluded development of math models.

The resulting shock test program provided data from five different separation devices (all essentially separation nut designs) mounted as indicated (Figure 1) on a model of the CRSS Radial Panel. This panel was configured with mass simulators representing one of the more heavily loaded CRSS panels. Tests were also performed using three of the release devices on the same panel in a bare configuration (no mass simulators). The standard preload released in the tests was 7000 pounds, as measured by a load cell washer under the restraining bolt head. However, two of the devices tested were incapable of achieving this preload level. One of these, the Martin concept, showed considerable promise for producing low shock levels. To assess its shock level variation with preload, a range of preloads from 3000 to 4200 pounds was used for this device. Shock acceleration response level data were recorded at various points on the panel for each device actuated.

Additional tests were performed to measure release device input mounting impedance and installed accelerometer mounting block transfer functions. Such measurements are intended to aid in extrapolating the included test measurement results to other mounting and structural configurations. A detailed description of the test setup and procedure is provided as a further aid in interpreting test results. One possible method for performing such an extrapolation is described in Reference 1<sup>1</sup> which resulted from work performed on NASA contract NAS5-29452 as reported in Reference 2<sup>2</sup>.

### 3.0 TEST SETUP AND PROCEDURE

#### 3.1 Release Mechanisms

Five different release mechanisms, immediately available from several sources, were tested on a single test panel. Mechanisms ranged from state-of-the-art pyrotechnics (OEA [Ordnance Engineering Associates]-Aerospace 3/8-inch diameter and Hi-Shear Technology Corporation 8mm and 1/2-inch diameter standard separation nuts--figure 2) to NEA designs (G&H Technology, Incorporated and Martin concept rotary flywheel-nut 3/8-inch diameter separation devices--figure 3). To obtain meaningful data, multiple firings of each device were conducted.

With the exception of the Martin concept, all other separation nuts were available, off-the-shelf units with no additional provisions to attenuate actuation shock. The Martin concept (currently under patent disclosure) was an engineering feasibility demonstration unit. Fundamentally it consisted of a housing containing a multi-start, coarse threaded bolt, rotary nut, and locking mechanism. It was fully reusable, required minimal actuation energy, and functioned in less than 50 msec. Exclusive fabrication rights for the Martin concept are held by Starsys Research Corporation of Boulder, CO where the concept, now referred to as the Fast Acting Shockless Separation Nut (FASSN), is undergoing further development as a flight-weight unit. Under their Advanced Release Technologies Satellite (ARTS) II Program, the Naval Research Laboratory, Naval Center for Space Technology, Washington, DC is currently evaluating FASSN in a 1/2-inch diameter size with a preload capability of 10,000 to 13,000 pounds. Eventually Lockheed Martin plans to evaluate a similar device and may investigate a 1-inch diameter sized FASSN in the 50,000 to 70,000 pound preload category.

<sup>1</sup> NASA CR-183480; Shock Prediction Technology: Pyroshock Source Characteristics Study; S.L.Hancock, J.H.Shea, G.R.Dunbar, P.Chao, and A.W.York.

<sup>2</sup> NASA CR-183479; Shock Prediction Technology: Technical Manual; Y.A.Lee, D.R.Crowe, W.Henricks, and D.M.Park.

### 3.2 Test Panel Configurations

Tests were conducted at LMMSC on a structural simulator (Figure 1) representing a proposed Lockheed Martin Launch Vehicle (LMLV) CRSS Radial Panel--with and without mass loading. This panel was considered representative of a current small spacecraft design. The test unit consisted of a flat 1.5-inch thick honeycomb rectangular panel with overall dimensions of approximately 19-inches by 38-inches. The test unit was suspended by two bungee cords and prevented from excessive swinging by a third bungee attached to the bottom. Y orientation was perpendicular to the panel face, with X and Z in the plane of the panel.

The panel consisted of a honeycomb core, face sheets, and a frame. The honeycomb core was 4.5-pounds per cubic foot aluminum, and the face sheets were 0.032-inch thick 2024-T3 aluminum. The panel was framed by 0.080-inch 6061-T651 aluminum which formed a 1.5-inch wide channel with 1-inch legs. The face sheets were laid over and adhesively bonded to the 1-inch legs. The bottom cut-out (Figure 1) was the release interface site. This cut-out was framed by channel similar to that around the rest of the panel except the legs were 0.125-inch thick. The extension at the bottom of the cut-out frame, through which the release bolt passed, was a minimum of 5/8-inch thick aluminum. Tests were run in a bare panel configuration and in a configuration in which mass simulators were mounted to inserts through the panel face. Table 1 presents detailed conditions of all tests, devices tested, and the preload for each as determined by a load cell washer.

#### 3.2.1 Bare Panel Tests

Tests were run in the bare panel configuration for the OEA and G&H 3/8-inch, and the Hi-Shear 1/2-inch diameter devices. Due to limited availability of devices, only one test per device was run in the bare panel configuration.

#### 3.2.2 Mass Simulator Tests

Tests were conducted for all included separation devices with mass simulators attached to the panel. In general, three actuations were conducted for each device. However, the Martin concept was actuated seven times with preloads ranging from 3000 to 4200 pounds. Mass simulators were constructed of aluminum plate, having the same weight and footprint on the panel as the actual component. As shown on Figure 1, three simulators were used: two identical, 30-pound simulators were mounted on opposite sides of the panel; and a third 53-pound simulator was mounted nearer to the release interface.

### 3.3 Release Device Mounting

Separation system mounting design for this panel (Figure 1) is somewhat unique as the majority of strain energy released upon device actuation is along directions in the plane of the panel. Of particular interest in these tests was the distribution of shock loads among the different directions for this mounting configuration. Such motion excites different modal groups than the more usual, bracket mounted release mechanisms. The latter tends to primarily excite panel bending modes where components are mounted, resulting in the dominant shock levels being oriented normal to the panel's surface.

The release interface was represented by a 1/2-inch thick steel plate, 10-inches square, representing the launch vehicle simulator as shown on Figure 1. When a release device was actuated, this plate fell away thereby producing no secondary contact with the test panel. Separation devices were mounted so the nut and catcher fell away with the steel plate, the bolt staying with the test panel. Additionally, bolts attaching the nut to the plate were loose so the nut separated from the plate by approximately 1/16-inch. Videotape recordings made of each test verified clean separation.

### 3.4 Preload

The release devices had maximum preload capabilities ranging from about 3000 to 20,000 pounds. A 7000 pound preload was the comparison standard. In this Task, ranges of test parameters were minimized to obtain direct comparisons; however, based on bolt strength, the Hi-Shear 8mm pyrotechnically actuated separation nut was only capable of about 2700 pounds preload. The Martin concept was incapable of the desired preload. To help evaluate effects of preload, a series of tests were performed on the Martin concept in which only preload was varied. The remaining devices were tested at 7000 pounds preload. The load cell washer, from which preload was determined, was located under the bolt head on the panel side of the interface.

### 3.5 Accelerometer Locations and Types

Data acquisition included 13 accelerometer measurements on the panel's outer frame edge, to which the release device was mounted. Additionally, 23 accelerometer data measurements were obtained on the panel face, where components would usually be mounted. These latter accelerometers were mounted and data recording arranged so that panel instantaneous directional response could be determined. Adequate frequency response up to 10 kHz was available.

The locations of various accelerometer blocks are shown on Figure 1. There were eight pyramid-shaped triaxial blocks and six wedge-shaped biaxial blocks. Each was configured to provide normal (Y) and unambiguous in-plane (X and Z) instantaneous accelerations for the surface on which they were mounted. The X and Z accelerations could be combined to yield an instantaneous in-plane resultant, which should represent the maximum in-plane acceleration amplitude experienced at the measurement location.

Different accelerometers were used on different blocks to accommodate the expected environment. Where the highest levels were expected, Endevco type 7755 accelerometers, with a frequency response of + or - 5 percent from 10 Hz to 10 kHz and a maximum range of 50,000 g, were used on blocks 1,3 and 4. These accelerometers had an 11 kHz mechanical filter to prevent high frequency, high level accelerations from corrupting lower frequency data. Endevco type 2255 accelerometers, with a frequency response of + or - 5 percent from 20 Hz to 20 kHz and a maximum range of 20,000 g, were used on block 2. Endevco type 7250 accelerometers, with a frequency response of + or - 5 percent from 3 Hz to 20 kHz and a maximum range of 5,000 g, were used on the remaining blocks (pyramid blocks 5 through 8 and wedge blocks 9 through 14).

Accelerometers in locations 1 through 8 were mounted in a triaxial configuration on the pyramid-block mounts. The pyramid mounts were geometrically designed to co-locate the three accelerometer sensitive axes at the specimen surface (block mounting face). Locations 9 through 14 were mounted in a biaxial configuration using the wedge-block mounts. The wedge mounts also geometrically positioned the two accelerometers to produce co-incident sensitive axes at the specimen surface.

## **4.0 DATA ACQUISITION AND PROCESSING**

### **4.1 Shock Measurements**

The CRSS panel release mechanism shock measurement data were recorded using LMMSC's acoustic real-time data acquisition system for vibration and acoustic testing. The system is composed of accelerometer transducers, signal conditioning, anti-alias filters, digitizing and storage components. The signal digitization was performed at 50,000 samples per second with a resolution of 14 bits (1 in 16384).

#### **4.1.1 Time-Histories**

Basic shock data were recorded in the form of acceleration-time histories. Accelerometer blocks were shaped so the time phased data could be combined to obtain resultant acceleration-time histories in any direction. Particularly, acceleration-time history in the direction normal to the block mounting surface, and at least one direction in the plane of this surface could be determined for each block. The pyramid block permitted resolution of acceleration into two orthogonal directions in the plane of its mounting surface, as well as into an instantaneous resultant acceleration in that plane.

Response acceleration-time histories were reviewed to determine individual measurement validity. Data determined to be valid was further processed into SRS. SRS were computed using a standard dynamic amplification factor (Q) of 10 (5 percent of critical damping). Data reduction was performed in stages to take advantage of existing LMMSC post-processor software. First, accelerometer responses from each mounting block were vector summed to produce acceleration resultants in the three primary panel axes (X-Y-Z for the pyramid and Y-Z or X-Z for the wedge). These resultants were stored in ASCII data files, one per block-panel axis. Data from positions 1 through 8 were also vector summed to produce the in-plane (X-Z plane) resultants. Finally, the ASCII data were input to the SRS post-processor to produce the SRS output and plot data files.

Typical X-,Z- and Y-direction acceleration-time histories are shown on Figures 4 and 5. These are typical of results obtained from resolving pyramid block data into orthogonal components. Similar results were produced by such resolution of the two-dimensional wedge blocks. Figure 4 is an acceleration-time history taken from a test of the G&H NEA separation nut. Figure 5 is similar data taken from a test of the Martin concept. Exclusive of the maximum levels indicated, the first figure is more typical of separation nut acceleration-time histories (explosive or NEA) in that there is only a single pulse associated with release. Data from the Martin concept, shown in Figure 5, exhibits three distinct pulses, indicative of extended and multiple actions involved in the release process for this mechanism.

#### **4.1.2 Shock Response Spectra**

The ASCII data files were read into the processor, the anti-alias (11.2 kHz) filter transfer function was analytically removed and a six pole, 10 Hz AC coupling was performed. The SRS was generated from 100 to 10,000 Hz with 1/6th-octave filters. Positive, negative and noise floor SRS were computed. Files were also generated containing the time-history and envelope of the SRS.

## 4.2 Impedance Measurements

A series of tests to characterize dynamic behavior of the CRSS panel when subjected to pyrotechnic inputs was performed. These "tap" tests were performed using a Kistler instrumented hammer with an integral, calibrated load cell to tap on a bolt representing the release device bolt. A special hard tip was used to provide significant energy up to 10 kHz. An accelerometer placed on this bolt and the hammer's load cell enabled determination of an input impedance. The same accelerometers and locations as shown in Figure 1 were used throughout the release tests, but the mass simulators were removed. The response of these accelerometers were recorded during the tap tests to determine the transfer function relating their response to a general input excitation. A series of measurements were taken with the 3/8-inch diameter pyrotechnic-attachment point configuration. Then the hole was drilled to accept the 1/2-inch diameter pyrotechnic device, and another series of measurements taken.

The tests were performed by first, attaching a steel block (1.25-inch cube) at the panel's release device attachment point. The block was attached by first a 3/8- and later a 1/2-inch bolt, respectively, for the two series of tests. Excitation was provided by impacting the steel block with the instrumented hammer at approximately 1-second intervals for about 30 seconds. In addition to the accelerometers mounted on pyramid and wedge blocks that were used for the release tests, three accelerometers were mounted as close as possible to the impact point:

- a. A Z-accelerator was mounted at the top of the block-attachment bolt.
- b. An X- and Y-accelerator were mounted on the impact block opposite the impact point (refer to Figure 1 for the axis orientations).

These accelerometers, called "foot" accelerometers, were intended to yield data representing the mounting point impedance for this panel. Similar data for another installation should make the present results transferable.

The acceleration- and force-time histories were acquired by the LMMSC real-time data acquisition system. The data acquisition rate was 30,000 samples per second and 8-pole, 11.2 kHz, Butterworth, low-pass (anti-alias) filters were used. The impact levels were nominally 1500 pounds but varied between approximately 800 and 1900 pounds. Data analysis was performed with the signal analysis processor. The procedure was:

A peak detection system was used on the force-time histories to determine when impacts occurred. Exactly 2048 points were selected around each impact. Each time-history was inspected to assure there was a pre-trigger of at least 256 points and that there was only a single impact within the range of sample points. Response data from up to ten of the responses was retrieved for all "acceptable" time windows.

Transfer functions between responses and force input were calculated for each impact. These transfer functions were then averaged (using ten averages for the "3/8-inch bolt" test and at least seven averages for the "1/2-inch bolt" test).

The 1/6th-octave impedance was calculated from the transfer functions by:

1. Calculating the acceleration impulse function via inverse Fast Fourier Transform (FFT).
2. Subtracting off the average offset (AC coupling).
3. Multiplying by 386.4 to convert from a "g" calibration to inches/second/second.
4. Integrating to obtain the velocity impulse function.
5. Calculating the velocity transfer function by forward FFT.
6. Calculating the impedance by complex inversion of the velocity transfer function.

Determination of the 1/6th-octave impedance spectrum was completed by averaging the magnitude of the impedance-spectral components over each 1/6th-octave band. The same 1/6th-octave center frequencies were used for these calculations as for the SRS calculations.

## 5.0 DISCUSSION OF RESULTS

Overall measures of SRS produced by the devices were derived from the data and compared for accelerometers located on the panel face. Comparisons indicated the most severe levels were produced by the OEA device, followed by the Hi-Shear 1/2-inch diameter device. Of the devices capable of 7000 pound preload, the G&H NEA device produced the lowest levels. In these tests the Martin concept clearly produced the lowest levels, but its maximum preload capability was limited. Of the devices tested, LMMSC selected the Hi-Shear 1/2-inch diameter separation nut for further consideration. A comparison of results from the Martin concept for several preloads indicated there was no systematic effect of rising preload causing an increase in shock levels over the range tested. Such a result may eventually break down at some higher level of preload.

In-plane strain energy release was found to significantly raise the shock environment in-plane SRS levels compared to the normal direction levels. It was still found that the normal direction levels were influential at low frequencies, but in-plane levels were clearly dominant in the higher frequencies (above 600 to 800 Hz). This result was not device dependent, although some spectral differences can be noted between the pyrotechnic devices and NEAs. The SRS generally showed an increase with frequency, with only levels and local details varying with device. The panel's dynamic properties probably provide the dominant aspect to determining spectral shapes with the devices all providing broad band excitation, differing primarily in level only.

Impedance and transfer function data taken support the consistency of the SRS directional response evaluations. This data should prove useful in translating the test results contained herein to other structures, providing similar data are available on those structures. Comparative data used in this report are tabulated in Appendix A.

## 5.1 Shock Responses

SRS were determined for five different separation devices with the CRSS panel in the mass loaded configuration and for three different devices with the panel in the bare (unloaded) configuration. Data were resolved into normal (Y-axis) and in-plane (X- and Z-axis) as well as in-plane instantaneous resultant magnitude, before the SRS were calculated. The SRS were computed for each orthogonal axis and in-plane resultant, where such data were available, using the standard Q of 10. SRS data were subjected to statistical analysis using various groupings to obtain comparisons for the differences between devices and test condition effects.

Although data were taken and reduced to SRS form on the frame, only data from the face sheets were used in the analyses. It was anticipated that shock propagation in this panel, with the type of mounting used for the separation devices, would have been rather complex. The frame data were taken to enable the study of shock propagation for the panel in the event these complexities actually appeared. The test results did not indicate that such studies were warranted or necessary, so they were not performed. Only the non-frame, flat panel data are treated herein. These data represent the environment of panel mounted components.

### 5.1.1 Mass Loaded Panel Configuration (OEA, Hi-Shear 8mm and 1/2-inch, G&H and Martin Concept)

Data from all five separation devices were taken for the test panel configured with mass simulators. At least three tests were performed with each device for this panel configuration. Twenty-three accelerometer channels on the panel face were recorded for each test. The standard preload for these tests was 7000 pounds, as indicated by the load cell instrumentation. Two of the devices, the Hi-Shear 8mm device and Martin concept, were not capable of the standard preload. They were loaded to the maximum permissible preload, which was about 2700 pounds for the Hi-Shear 8mm device; and the Martin concept was tested over a range of preloads from 3000 to 4200 pounds, as indicated in Table 1. Assimilation of this mass of data into an interpretable form was the first order of the analysis process. A statistical approach was used for this purpose.

#### 5.1.1.1 Representative Response Levels

Data from any one grouping of measurements was assumed to behave as a log-normal random variable. Various axis groupings were constructed and log-normal statistical properties of these groups were compiled and compared. The groups were: acceleration normal to the panel surface (Y-axis, designated as nfy); orthogonal in-plane (X- and Z-axes, designated as nfxz); in-plane resultant (of X and Z components, designated as nrip); and combined normal and in-plane resultant levels. In computing the statistical properties, no segregation by location on the panel face was included. Nomenclature used includes; nf (no frame), and i or ip (in-plane). Figures 6 (a) through (e) show the comparisons of data groupings 95th percentile levels for each device and preload:

- (a) OEA 3/8-inch diameter pyrotechnic separation nut, 7000 pound preload.
- (b) Hi-Shear 1/2-inch diameter pyrotechnic separation nut, 7000 pound preload.
- (c) G&H 3/8-inch diameter NEA separation nut, 7000 pound preload.
- (d) Hi-Shear 8mm diameter pyrotechnic separation nut, 2700 pound preload.
- (e) Martin 3/8-inch diameter concept, 4000 and 4200 pound combined preload.

Figures 7 (a) through (e) show the same sequence of device results, but compare the maximum measured level in each grouping.

In both sets of above figures, it may be seen that the combined normal and in-plane resultant levels serve as a reasonable indicator of an upper bound level. The upper bound level is always this combination for the maximum measured levels of

Figures 7. This must be true because the in-plane resultant is greater than or equal to the X- or Z-direction maxima and the combined maximum bears the same relation to the normal and in-plane directions.

If the reader seeks differences in the directional SRS levels, it may be observed that the normal direction is somewhat more influential in the lower frequencies and the in-plane motion dominates the higher frequencies. It is suggested by the impedance measurements, discussed later, that one might expect that panel modes associated with bending waves, which involve out-of-plane motion, come to bear at lower frequencies than the shear and longitudinal wave modes. The reader is cautioned that a resonant phenomenon is not involved here, but when the transient motion produced by the release is spectrally resolved, the natural modes of the system will indicate pronounced motion in their frequency bands.

A few instances were noted where the X-Z direction maximum measured level appeared to exceed the in-plane resultant level. These were found to be instances where there had been a zero shift in the accelerometer calibration during the test. This shift was not apparent for the X- or Z- measurements alone, whereas it was for the in-plane measurement. The data had been eliminated from consideration in the latter and not the former and thereby caused the faulty indication. Inspection of the time-histories of the original data confirmed in all cases that the data were faulty when there was a difficulty of this nature.

Figures 8 (a) through (e) show the relation between the arithmetic mean, the log mean, the 95th percentile and the maximum measured levels for the same sequence of devices. The difference between the log mean and the 95th percentile is indicative of the standard deviation for the data. These data, the standard deviation, sample size and Gumbel Factor (a correction for statistical errors due to small sample size) are presented in tabular form in Appendix A, Table A-1, (a) through (e), for the same sequence of devices.

There is close correspondence between the maximum measured and 95th percentile levels. It may be seen from these figures that the maximum measured level is the upper bound of the 95th percentile at all but a few frequency ranges of relatively narrow extent. Further, exceedances in these frequency ranges are of relatively small extent. These facts indicate there is little data scatter. Since data were collected from the entire panel face, this indication reveals there is little spatial variation of the shock levels over the panel face.

#### **5.1.1.2 Comparison of Effects of Preload Level for the Martin Concept**

The Martin 3/8-inch diameter NEA concept was incapable of achieving the standard preload. It was tested over a range from 3000 to 4200 pounds. To assess effects of preload on results, these measurements are compared with one another. Combined normal and in-plane resultant levels are used as the basis for this comparison. Statistical features of these measurements are given in Appendix A, Table A-1, (e) through (i), for:

- (e) Combined 4200 and 4000 pound preload
- (f) 4200 pound preload
- (g) 4000 pound preload
- (h) 3500 pound preload
- (i) 3000 pound preload

The 95th percentile and maximum levels are shown in Figures 9 (a) and (b), respectively. The reader should note there is no clear trend associated with preload magnitude, as maximum measured SRS levels for 3000 pound are as great as those for the 4200 pound preload. Interpretation of the 95th percentile data is somewhat more difficult due to the small sample size producing more erratic indications.

#### **5.1.1.3 Comparison of Levels from Different Release Devices**

The SRS 95th percentile and maximum levels are compared for all devices as measured with the maximum preload achieved for that device. These are shown in Figures 10 (a) and (b), respectively. The ordering of levels for the different devices is the same for both the 95th percentile and maximum measured levels. The order from higher to lower levels is: OEA; Hi-Shear 1/2-inch; Hi-Shear 8mm; G&H; and the Martin concept. The Martin concept produced levels significantly lower than the others; however, its greatest preload was only 4200 pounds as compared to 7000 pounds for the OEA, Hi-Shear 1/2-inch and G&H devices. Such a difference in preloads could make a significant difference in the shock levels produced, although its variation over the range tested did not indicate a strong dependence on this parameter.

#### **5.1.2 Bare Panel Configuration (OEA, Hi-Shear 1/2-inch and G&H devices)**

Tests were performed using OEA, Hi-Shear 1/2-inch and G&H devices at a preload of 7000 pounds with the test panel devoid of mass simulators. Due to limited availability of release devices, it was possible to perform only one test for each

OEA and Hi-Shear 1/2-inch device with the panel in this configuration; however, three tests were performed with the G&H device. A similar procedure was followed for evaluating data from the bare panel tests as was done for the panel with mass simulators.

#### 5.1.2.1 Representative Response Levels

SRS acceleration levels measured on the panel face were grouped in the same axis directions as previously done for the mass simulator data. As before, these groups were subjected to statistical analysis. The 95th percentile data are compared in Figures 11, and Figures 12 for the maximum measured levels with data for the individual devices presented separately in the (a), (b) and (c) versions of these Figures, as follows:

- (a) OEA 3/8-inch diameter pyrotechnic separation nut.
- (b) Hi-Shear 1/2-inch diameter pyrotechnic separation nut.
- (c) G&H 3/8-inch diameter NEA separation nut.

The combined normal and in-plane directions grouping is again considered to best represent the levels produced by each device. However, results are not as clear as before because of the significantly smaller sample sizes in the measurements.

Figures 13 (a) through (c) show the relation between the arithmetic mean, log mean, 95th percentile and maximum measured levels for the same sequence of devices in the bare panel configuration. The difference between the log mean and 95th percentile is indicative of the standard deviation for the data. These data, the standard deviation, sample size and Gumbel Factor are presented in tabular form in Appendix A, Table A-II, (a) through (c), for the same sequence of devices.

Because of the small number of measurements, the 95th percentile levels are frequently greater than maximum measured levels for this series of tests of the OEA and Hi-Shear 1/2-inch devices. This is not the case for the G&H device, since three tests were performed with it in the bare panel configuration.

#### 5.1.2.2 Comparison of Levels from Different Release Devices

SRS acceleration levels from the three devices were compared by means of results from the combined normal and in-plane resultant measurements. Figure 14 (a) and (b) show comparisons between their 95th percentile and maximum measured levels, respectively. The relative levels, as indicated by either the 95th percentile or maximum measured SRS accelerations, indicate the highest output from the OEA device, followed by the Hi-Shear 1/2-inch diameter and G&H device, respectively. However, there appears little difference between the last two devices for these bare panel tests as compared to their relative levels for the panel with mass simulators (refer to Figures 9). The paucity of measurements for the Hi-Shear device in the bare panel configuration is probably a major factor in this apparent difference. It is likely that both the OEA and Hi-Shear device levels are inaccurately represented by the small sample size. Such likelihood is reinforced by the results obtained by comparing the bare and mass loaded panel SRS levels produced by these devices.

#### 5.1.3 Comparison of SRS Levels with the Bare and Mass Loaded Panel

Data representative of the SRS acceleration levels produced by the three devices that were tested on both the bare and mass loaded panel were compared. Figure 15 (a) and (b) show the 95th percentile and maximum measured levels, respectively, for the OEA, G&H and Hi-Shear 1/2-inch devices. This is a replot of data previously presented for each.

The reader may note for the first two devices, there are large frequency bands in which levels for the mass loaded panel exceed those for the bare panel. One is tempted to conjecture by referring to Figure 1, that all accelerometers used in compiling the statistics are in positions that are unshielded by the mass simulators. Furthermore, they may well be the recipient of energy reflected from these simulator bodies, and one might expect higher response levels to be produced. However, data for the G&H device follow the accepted behavior, and indicate the bare panel levels consistently exceed those for the mass loaded panel, as physical reasoning would lead one to expect. Recall that data for the G&H device represent a statistical sample which includes three test actuations of the device for each configuration. The mass loaded data for the OEA and Hi-Shear devices also represent data from three actuations, but the bare panel levels represent data from only one actuation of each. This is an indication that relative levels of the bare and mass loaded panels are not of the same confidence level in representing the expected results from these two devices, whereas, those for the G&H device are.

### 5.2 Impedance and Transfer Functions

Impedance data were calculated for the "foot" accelerometers mounted near the separation device for the test performed with the 3/8-inch bolt. Data from the 1/2-inch bolt test were not as good (the hammer hits and resulting data were erratic), so they have not been reduced to 1/6th-octave results.

The 1/6th-octave "foot" impedances for the three orthogonal directions resulting from excitation in these X-, Z- and Y- directions are shown in Figures 16, 17 and 18, respectively. The plotted data are also tabulated in Appendix A, Table A-III (a) through (c). The first two of these directions lies in the plane of the panel, while the Y-direction is normal to this plane. The general shapes of the impedance curves are similar for the X- and Z-direction excitations and responses, being consistent with no modes associated with motion in these directions below about 600 Hz. The Y-direction excitation impedances exhibit a character indicating modes associated with motion in this direction (probably bending) beginning in the neighborhood of 300 Hz. As was mentioned in describing the SRS results, the Y- (normal) direction of motion seemed to have the greater influence in the low frequencies and the in-plane motion seemed to dominate the higher frequencies.

The "foot" data are intended to represent the mounting point impedance for this panel. Similar data for another installation should enable estimation of the shock input energy obtained in these tests to that of the other installation, given proper dynamic models. The transfer function data for other test panel accelerometer blocks will be useful in constructing and validating such models.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

SRS results for accelerations on the face sheets, where components are mounted, were combined into axis groups and subjected to statistical analysis. It was found that variation of level over the panel face was relatively small, as indicated in the small standard deviation from the statistical analysis. Differences between normal and in-plane resultant levels were also small although some spectral differences were noted and are described below. A combination of these directional levels was found to fairly represent behavior of the individual devices, although there would be little qualitative difference noted in picking any of the groupings to represent a device.

Overall measures of shock levels (SRS's) produced by the devices were derived from the data and compared for accelerometers located on the panel face. These comparisons indicated the most severe levels were produced by the OEA device, followed by the Hi-Shear 1/2-inch diameter nut. Of the devices capable of 7000 pound preload, the G&H NEA device produced the lowest levels. The Martin concept clearly produced the lowest levels in the test series, but its maximum preload capability was only 4200 pounds.

A comparison of results from the Martin concept for preloads, from 3000 to 4200 pounds, indicated there was no systematic effect raising shock levels with preload for this device over the range tested. However, it is expected that such a result may break down at some higher level of preload or it may be only due to the small amount of data used.

In-plane strain energy release was found to significantly raise the in-plane SRS levels of the shock environment compared to the normal direction levels. It was still found that normal direction levels were influential at low frequencies, but in-plane levels were clearly dominant in the higher frequencies (above 600 to 800 Hz). This result is not device dependent, although some spectral differences can be noted between the pyrotechnic and NEA devices. The SRS trends showed an increase in level with frequency. The dynamic properties of the test panel probably provide the dominant aspect determining the spectral shapes with the devices all producing broad band excitation, differing primarily in level only.

Impedance and transfer function data taken support the consistency of SRS directional response evaluations. They are indicative of the presence of low frequency bending waves (beginning at about 300 Hz) and onset of shear and dilatation waves at the higher frequencies (600 to 800 Hz). This data should also prove useful in translating these test results to other structures, providing similar data are available on those structures.

Data used for comparison purposes in the report are tabulated in Appendix A which represent reduced test data.

## 7.0 ACKNOWLEDGMENTS

This effort was principally performed under Contract NAS1-19241, Task 31, at LMMSC by James P. Woolley, and the LaRC Task Monitor was Melvin H. Lucy, assisted by Ralph D. Buehrle. The point-of-contact (POC) and device provider for the Hi-Shear 8mm pyrotechnic separation nuts was Richard G. Webster. The POCs, device providers and refurbishers for the G&H NEA stored mechanical energy separation nut were John Bielinski and Wayne Powell. The Martin concept was supplied by Bill Nygren from the LAM-Denver Division. The authors express their gratitude to several individuals who contributed to the successful outcome of this program. Special thanks are due LMMSC's Messrs. Strether Smith and William Hollowell for their aid in data acquisition, analysis and post processing, and for their contributions to those report sections. LMMSC's Messrs. Myron Leigh and David Kreuger, who operated the data acquisition system and conducted the test operations, respectively, are responsible for the excellent quality of the data obtained from these tests. Finally, the coordination efforts of Messrs. Mike Otvos and Marc Gronet of LMMSC who set the stage for a seamless effort by the several organizations involved.

# Table 1 CRSS Radial Panel Development Pyro Shock Tests

| Run No. | Test No. | Type       | Time/Date    | Data File | Preload | Mass Sim | Video No. | Data Table                |
|---------|----------|------------|--------------|-----------|---------|----------|-----------|---------------------------|
| 1       | 1        | 3/8 G&H    | 10:38 27-Mar | L858E01   | 7000    | Yes      | 3         | A-1 (c)                   |
| 2       | 2        | 3/8 G&H    | 13:21 27-Mar | L858E02   | 7000    | Yes      | 4         |                           |
| 3       | 3        | 3/8 G&H    | 14:15 27-Mar | L858E03   | 7000    | Yes      | 5         |                           |
| 4       | 4        | 3/8 G&H    | 15:40 27-Mar | L858E04   | 7000    |          | 6         | A-2 (c)                   |
| 5       | 5        | 3/8 G&H    | 16:49 27-Mar | L858E05   | 7000    |          | 7         |                           |
| 6*      |          | 3/8 G&H    | 18:49 27-Mar |           | 7000    |          | 8         |                           |
| 7       | 6        | 3/8 G&H    | 18:56 27-Mar | L858E06   | 7000    |          | 9         | A-1 (d)                   |
| 8       | 7        | 8mm HiS    | 14:59 28-Mar | L858E07   | 2440    | Yes      | 10        |                           |
| 9       | 8        | 8mm HiS    | 10:30 31-Mar | L858E08   | 2670    | Yes      | 11        |                           |
| 10      | 9        | 8mm HiS    | 14:40 31-Mar | L858E09   | 2600    | Yes      | 12        | A-1 (a)                   |
| 11      | 10       | 3/8 OEA    | 14:23 03-Apr | L858E10   | 7000    | Yes      | 13        |                           |
| 12      | 11       | 3/8 OEA    | 10:54 12-Apr | L858E11   | 7000    | Yes      | 14        |                           |
| 13      | 12       | 3/8 OEA    | 13:30 12-Apr | L858E12   | 7000    | Yes      | 15        | A-2 (a)                   |
| 14      | 13       | 3/8 OEA    | 11:20 13-Apr | L858E13   | 7000    |          | 16        |                           |
| 15**    |          | 1/2 HiS    | 15:00 17-Apr |           | 7000    |          | 1         |                           |
| 16      | 14       | 1/2 HiS    | 09:38 18-Apr | L858E14   | 7000    |          | 18        | A-2 (b)                   |
| 17      | 15       | 1/2 HiS    | 14:00 18-Apr | L858E15   | 7000    | Yes      | 19        | A-1 (b)                   |
| 18      | 16       | 1/2 HiS    | 10:24 19-Apr | L858E16   | 7000    | Yes      | 20        |                           |
| 19      | 17       | 1/2 HiS    | 13:44 19-Apr | L858E17   | 7000    | Yes      | 21        |                           |
| 20***   |          | 3/8 Martin | 15:00 19-Apr |           | 2700    | Yes      | 22        |                           |
| 21      | M1       | 3/8 Martin | 10:23 20-Apr | L858M01   | 3000    | Yes      | 23        | A-1 (j) & (k)             |
| 22      | M2       | 3/8 Martin | 11:30 20-Apr | L858M02   | 3000    | Yes      | 24        |                           |
| 23      | M3       | 3/8 Martin | 12:39 20-Apr | L858M03   | 3000    | Yes      | 25        |                           |
| 24      | M4       | 3/8 Martin | 13:13 20-Apr | L858M04   | 3500    | Yes      | 26        |                           |
| 25      | M5       | 3/8 Martin | 13:40 20-Apr | L858M05   | 4000    | Yes      | 27        | A-1 (e),<br>A-1 (j) & (k) |
| 26      | M6       | 3/8 Martin | 14:00 20-Apr | L858M06   | 4000    | Yes      | 28        |                           |
| 27      | M7       | 3/8 Martin | 14:28 20-Apr | L858M07   | 4200    | Yes      | 29        |                           |
|         | F1       | X- Dir Tap |              |           |         |          |           | A-3 (a)                   |
|         | F2       | Z- Dir Tap |              |           |         |          |           | A-3 (b)                   |
|         | F3       | Y- Dir Tap |              |           |         |          |           | A-3 (c)                   |

\* Wire came loose on firing system - no release, no accl data retained.

\*\* Bolt Bottomed-out in sep nut - squib fired, no release, no accl data retained.

\*\*\* Preliminary release, no accl data recorded.

Note: 1) Because of inaccuracies of load washer, all preload values are approximate.

2) Impedance Test File Names: L858HAM1 thru HAM9. L858HAM4 thru HAM6 are retests of L858HAM1 thru HAM3.

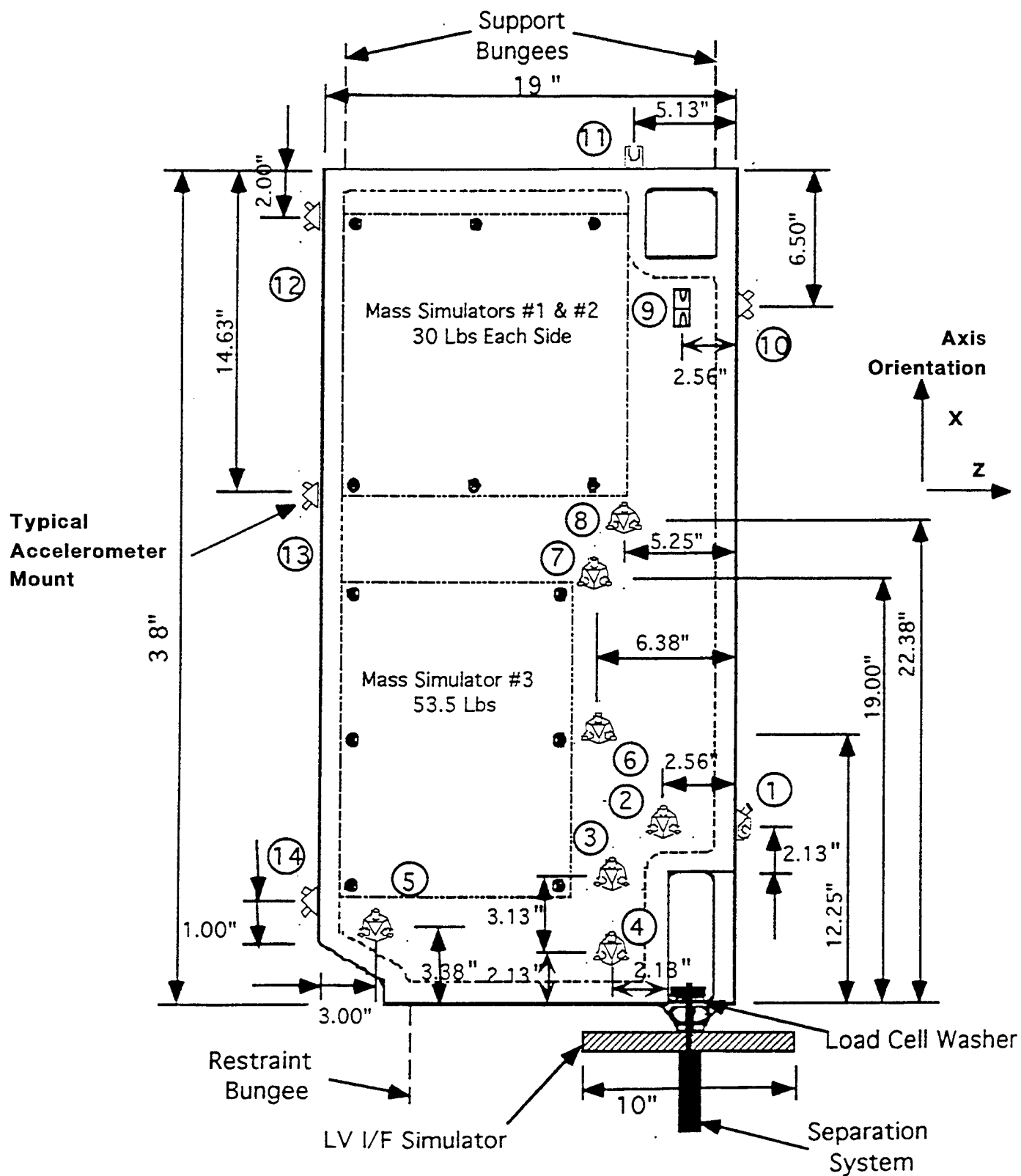


Figure 2. Test Panel with Masses and Accelerometer Block Locations.

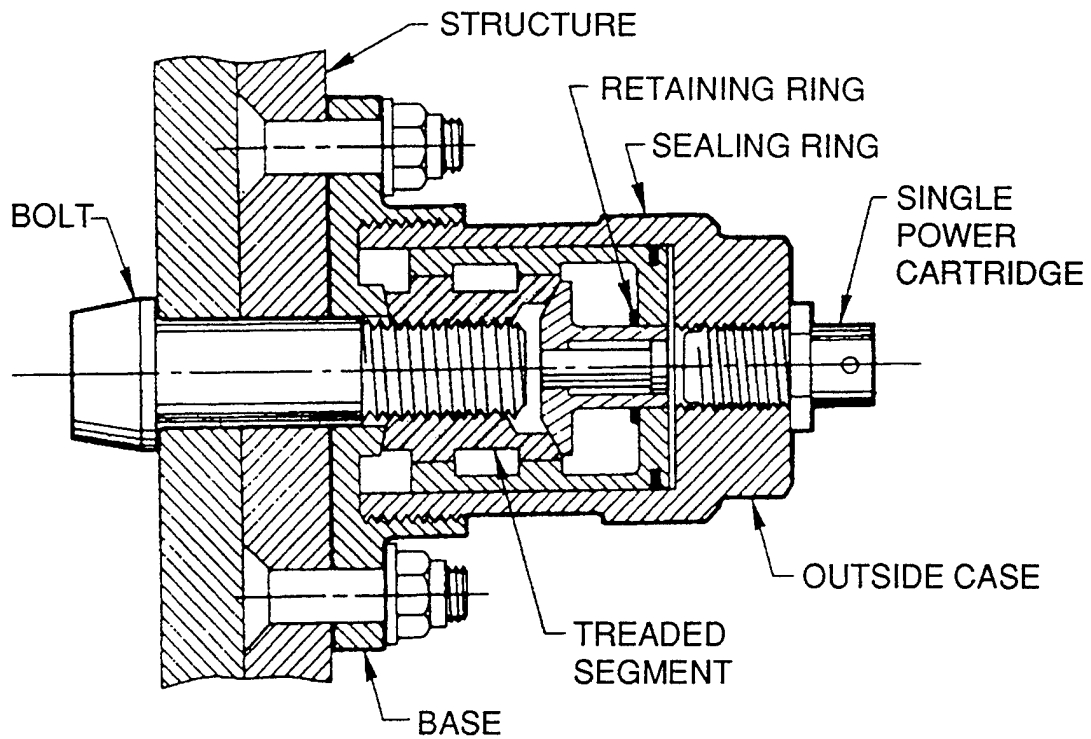


Figure 2. Typical Pyrotechnic Separation Nut (Hi-Shear Depicted).

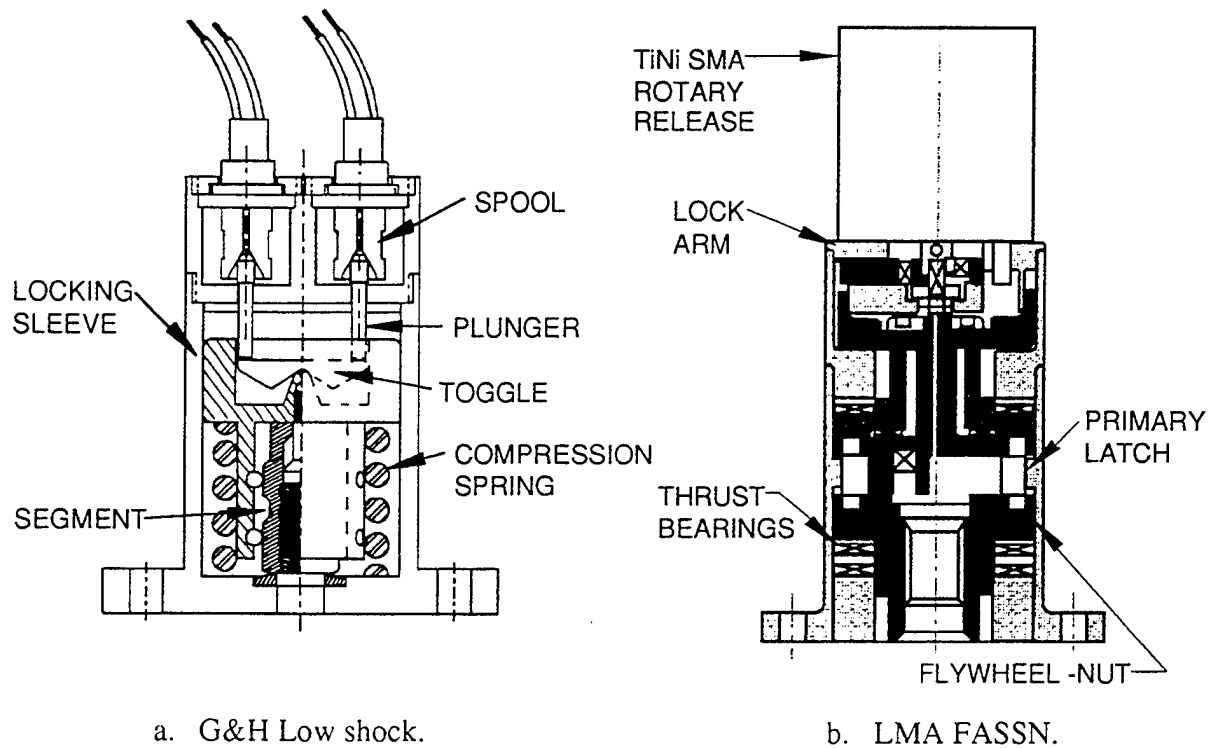


Figure 3. Non-Explosive Actuated Separation Devices.

CRSS Dev. PNL PYRO SHOCK #3  
 GNH 3/8" NON-EXPLOSIVE  
 TIME RANGE: 6.85 TO 7.01 Seconds

PLOT MADE ON  
 31-DEC-95 AT 15:21  
 TEST PERFORMED  
 27-MAR-95 AT 14:12

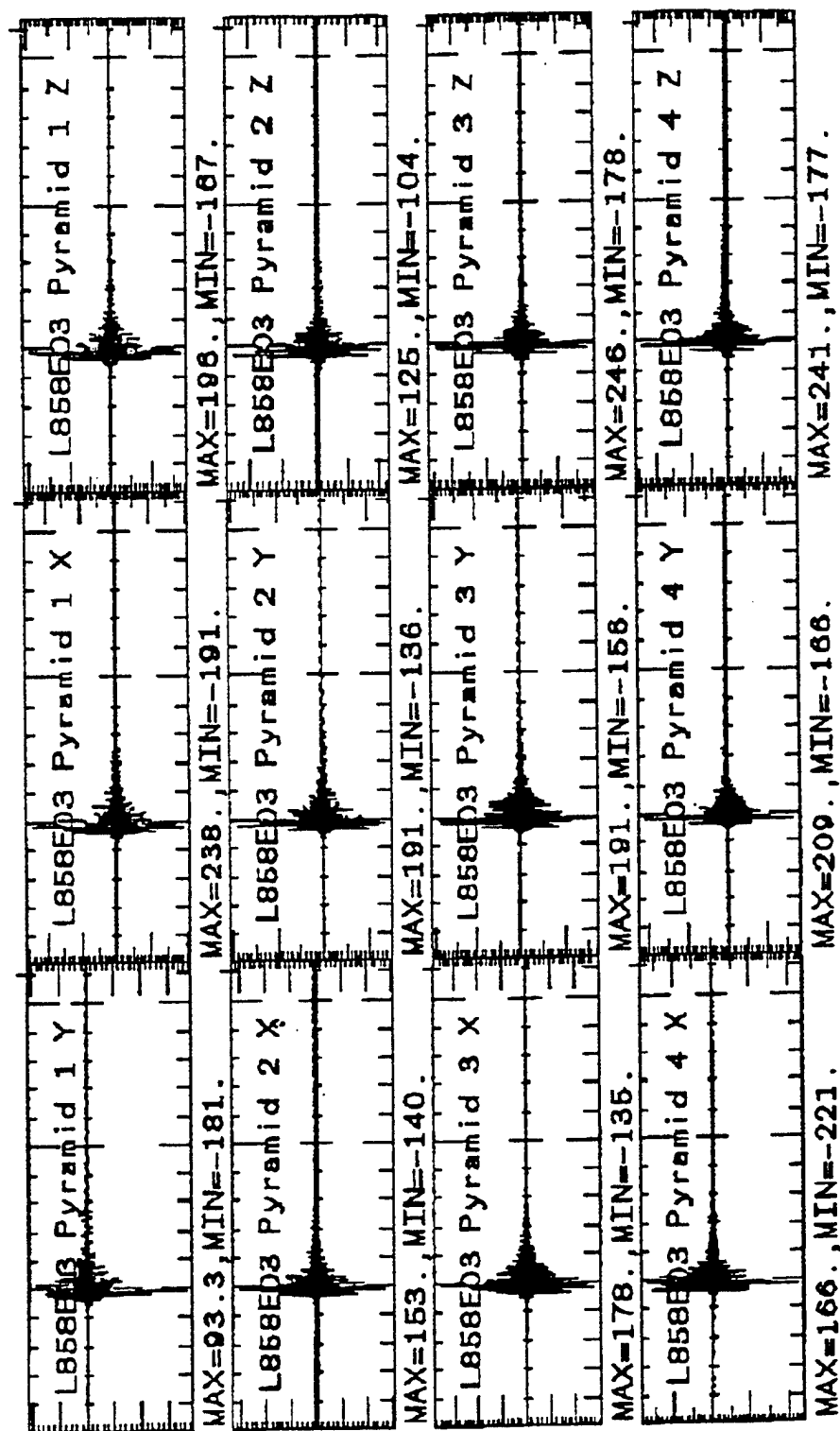


Figure 4. Typical X-, Y-, and Z-Direction Acceleration Time Histories from G&H Device.

CRSS DEV. PNL PYRO SHOCK TEST  
 MARTIN ELECT. SEP NUT, TEST #7  
 TIME RANGE: 3.37 TO 3.70 Seconds

PLOT MADE ON  
 25-APR-95 AT 16:26  
 TEST PERFORMED  
 20-APR-95 AT 14:51

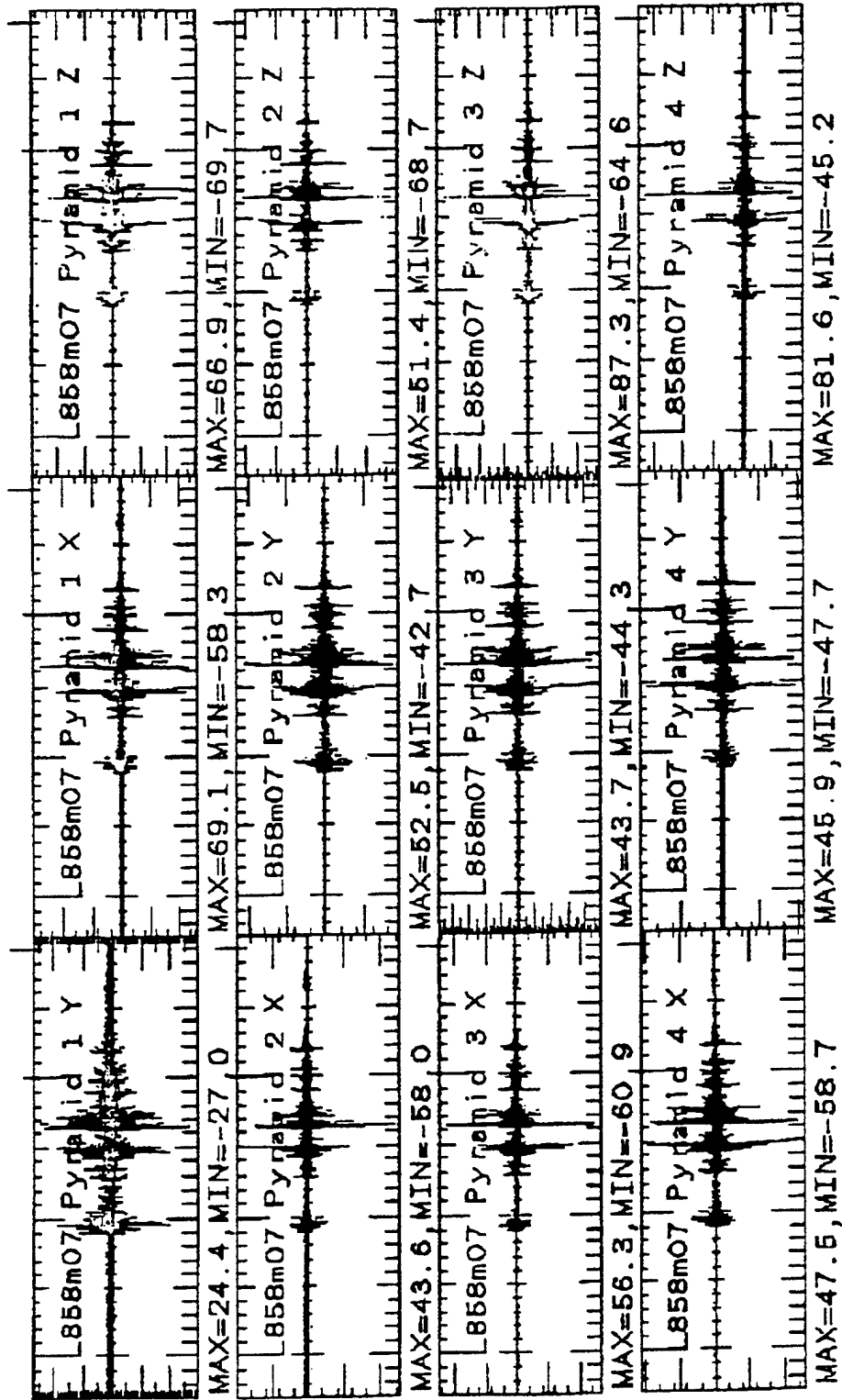


Figure 5. Typical X-, Y-, and Z-Direction Acceleration Time Histories from Martin Device.

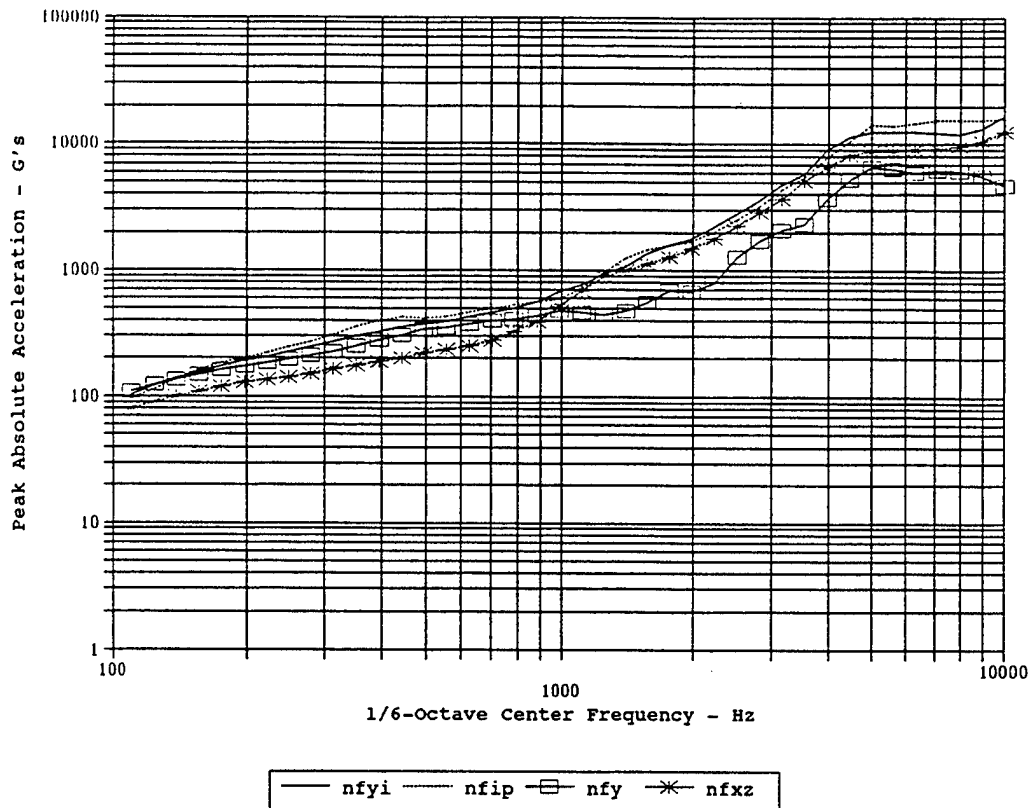


**Figure 6(a). OEA 3/8", with Masses, 7000 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

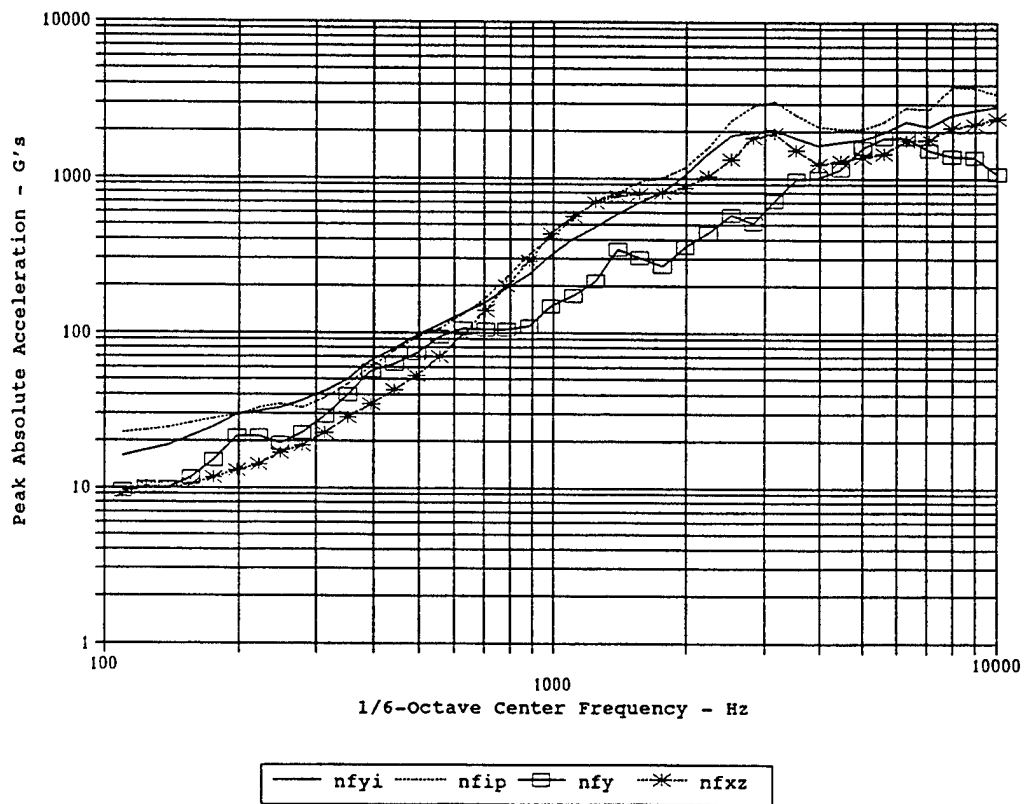


**Figure 6(b). HiS 1/2", with Masses, 7000 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

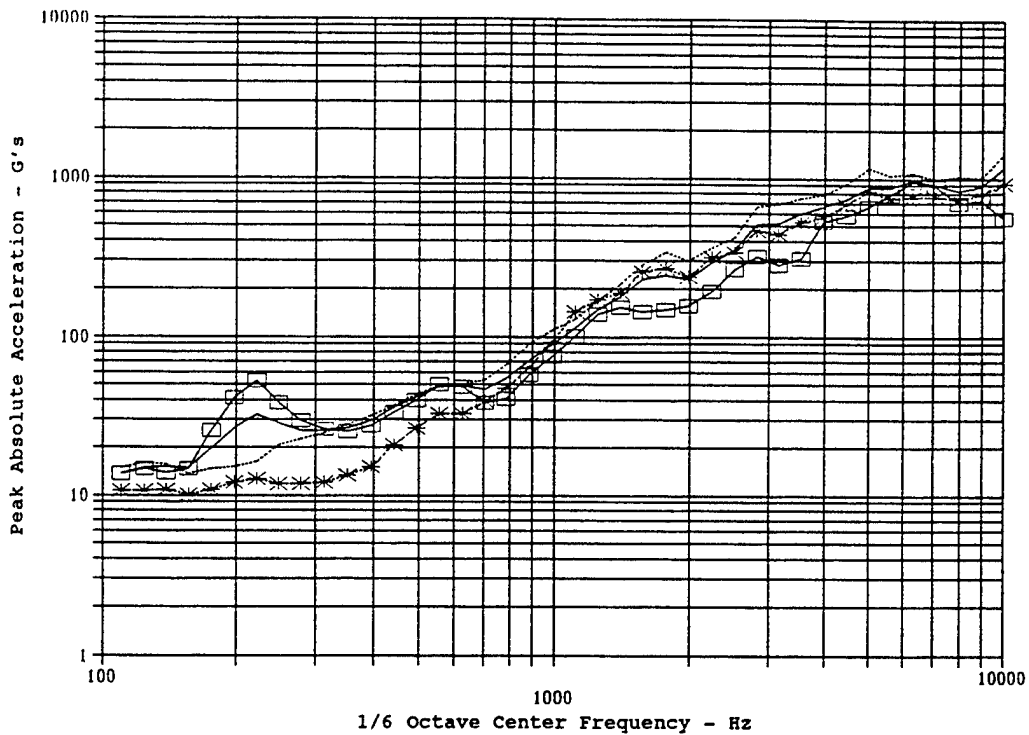


**Figure 6(c). G&H 3/8", with Masses, 7000 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

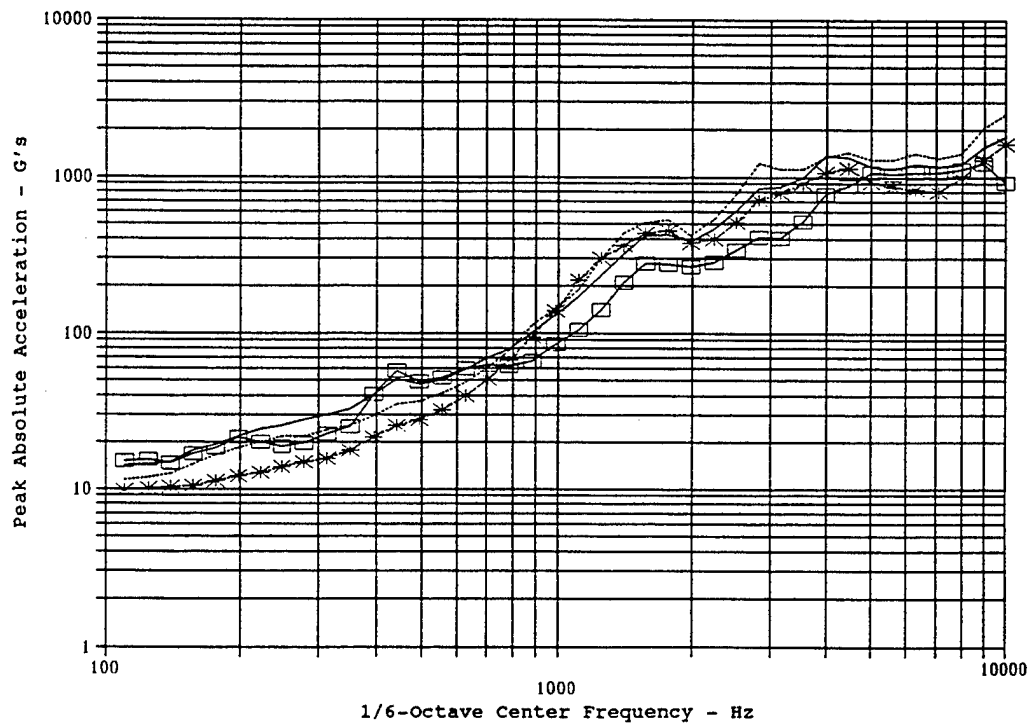
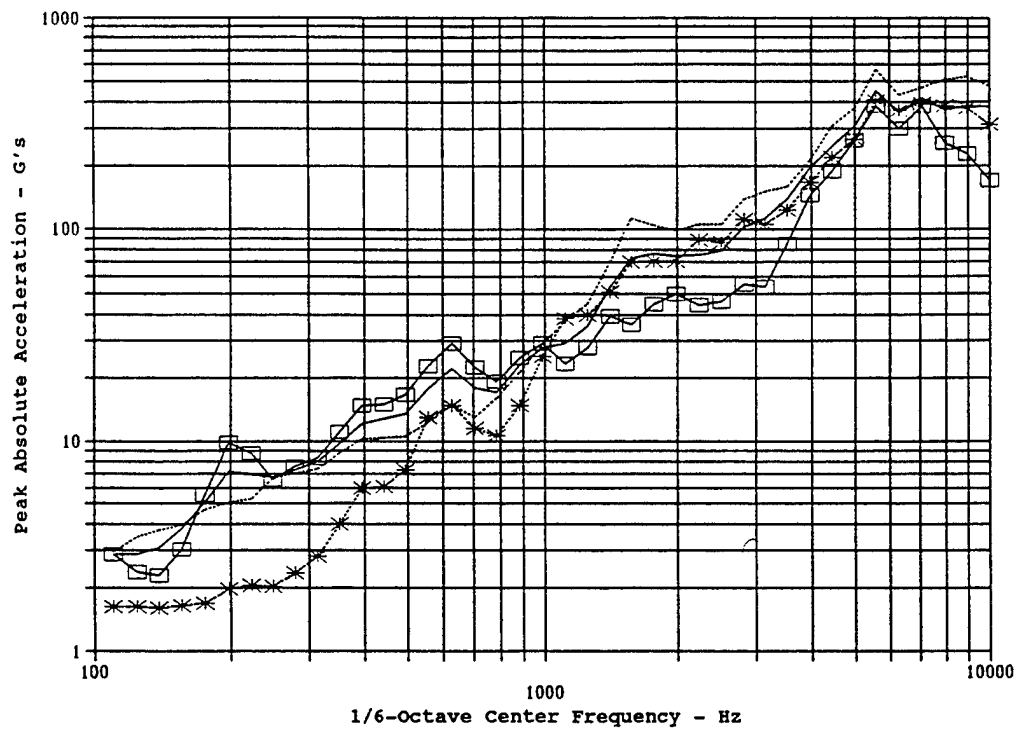


**Figure 6(d). HiS 8 mm, with Masses, 2700 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**



— yi4a — ip4a —□— y4a —\*— xz4a

**Figure 6(e). LM 3/8", with Masses, Combined 4000 & 4200 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

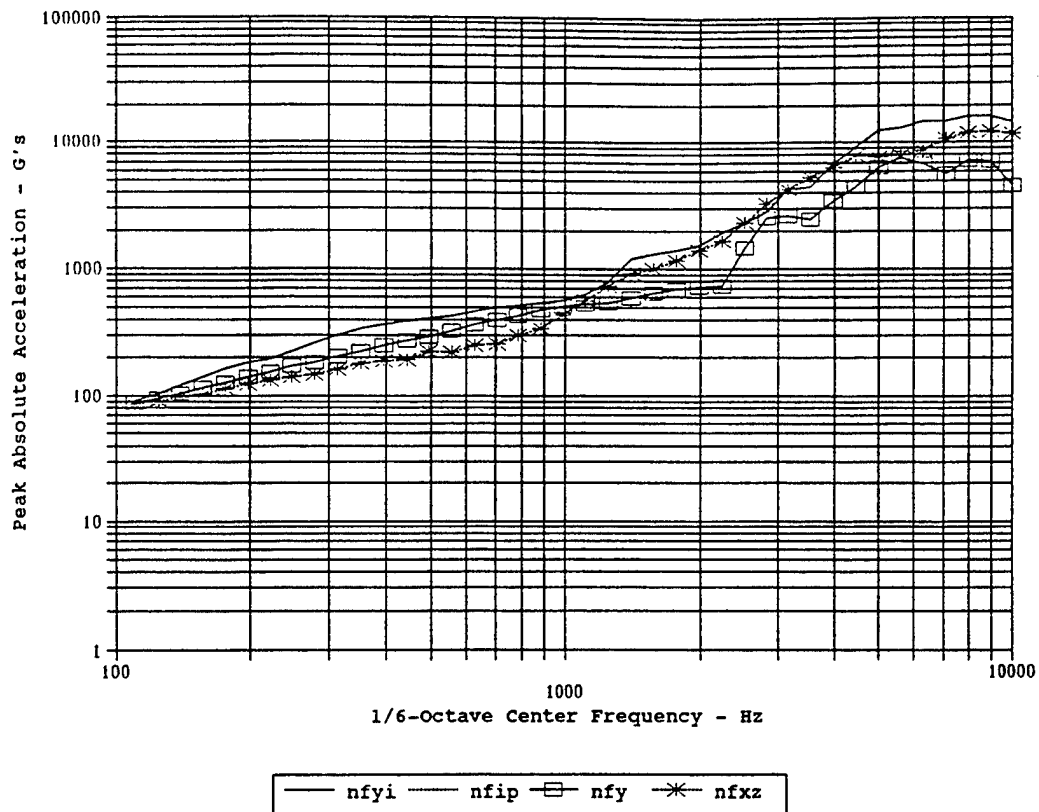


**Figure 7(a). OEA 3/8", with Masses, 7000 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

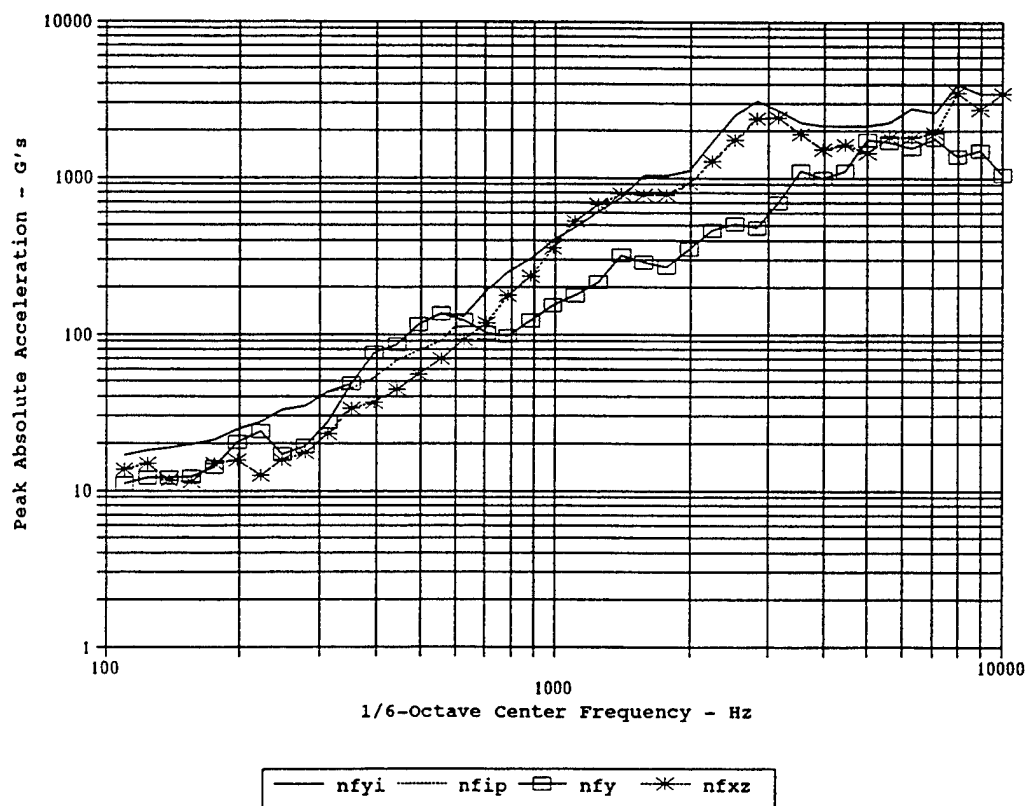


**Figure 7(b). HiS 1/2", with Masses, 7000 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

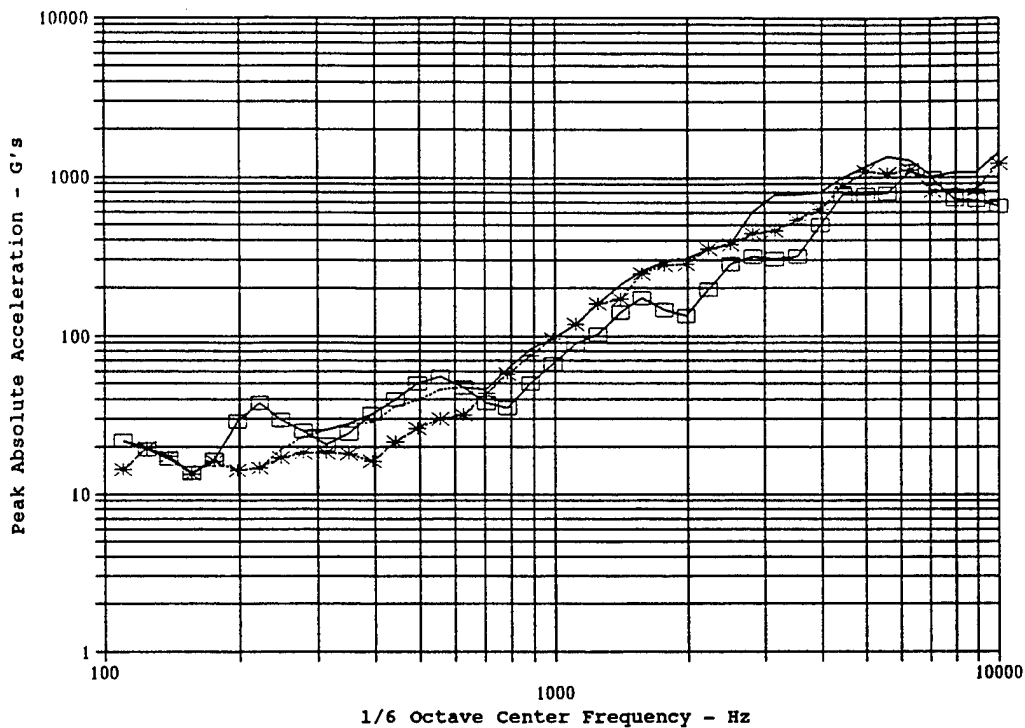


**Figure 7(c). G&H 3/8", with Masses, 7000 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

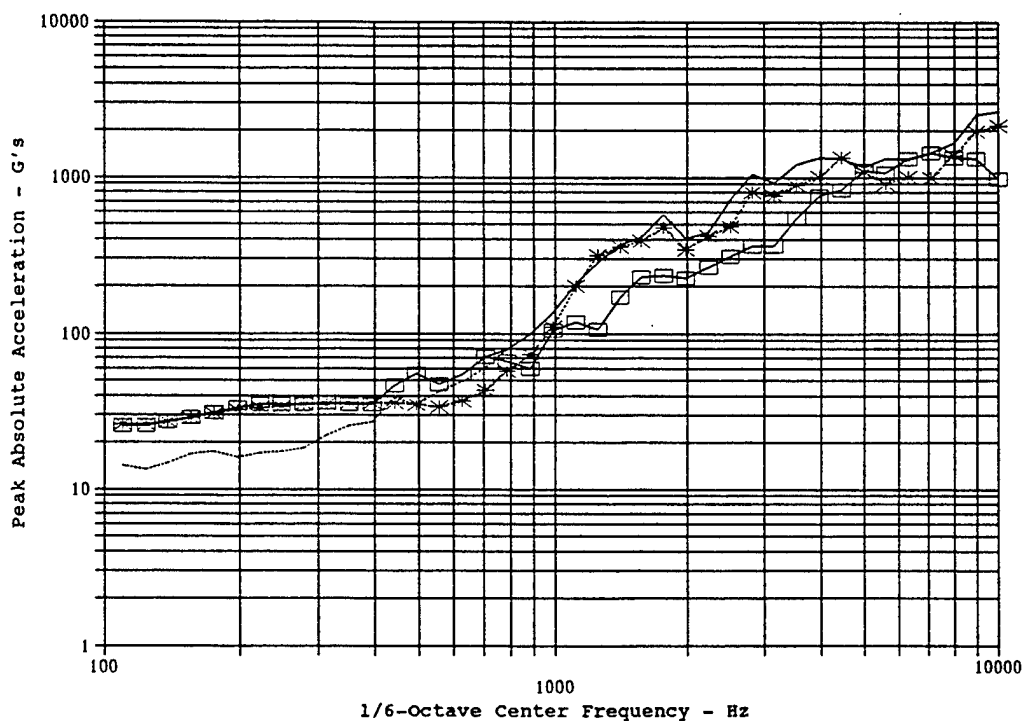


**Figure 7(d). HiS 8 mm, with Masses, 2700 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

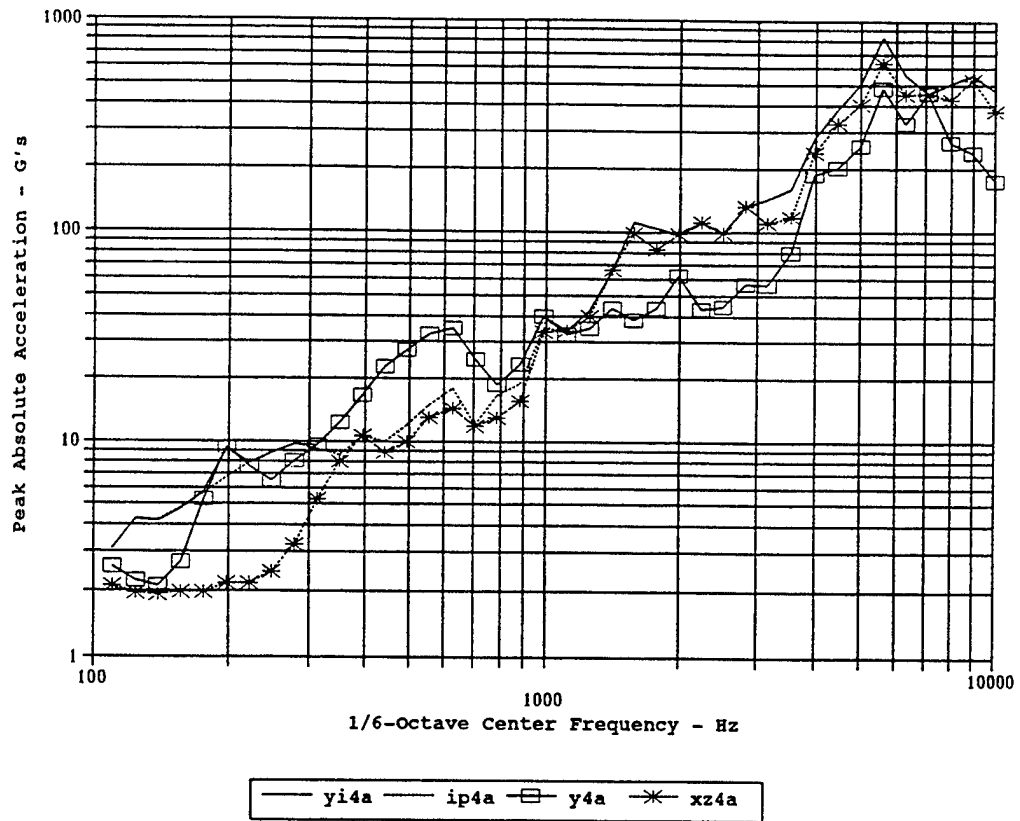
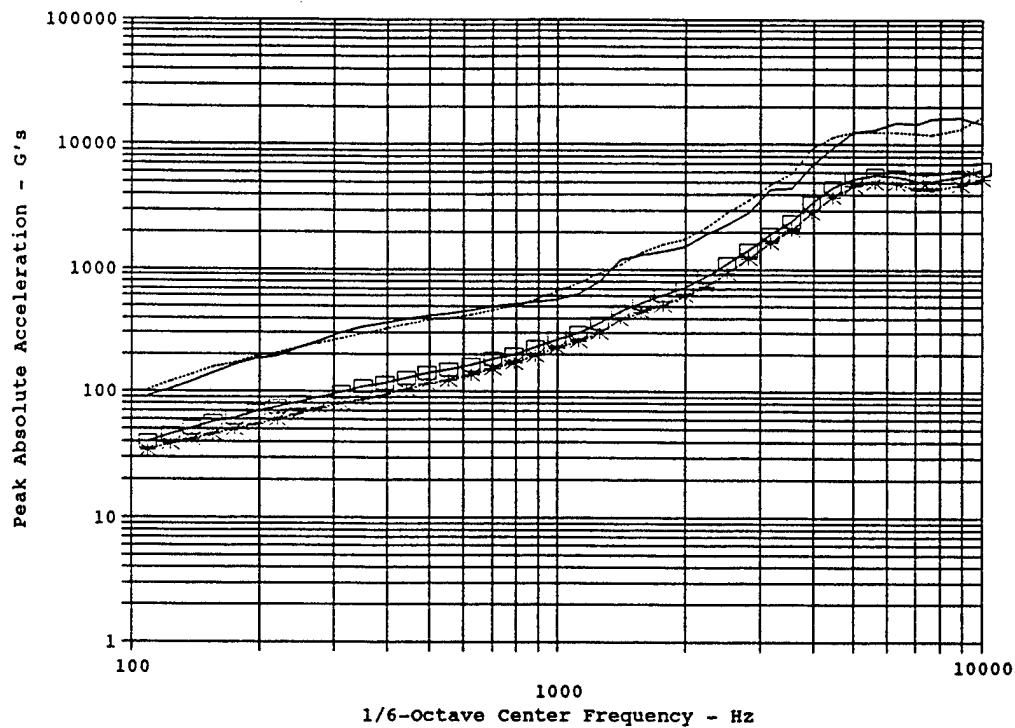
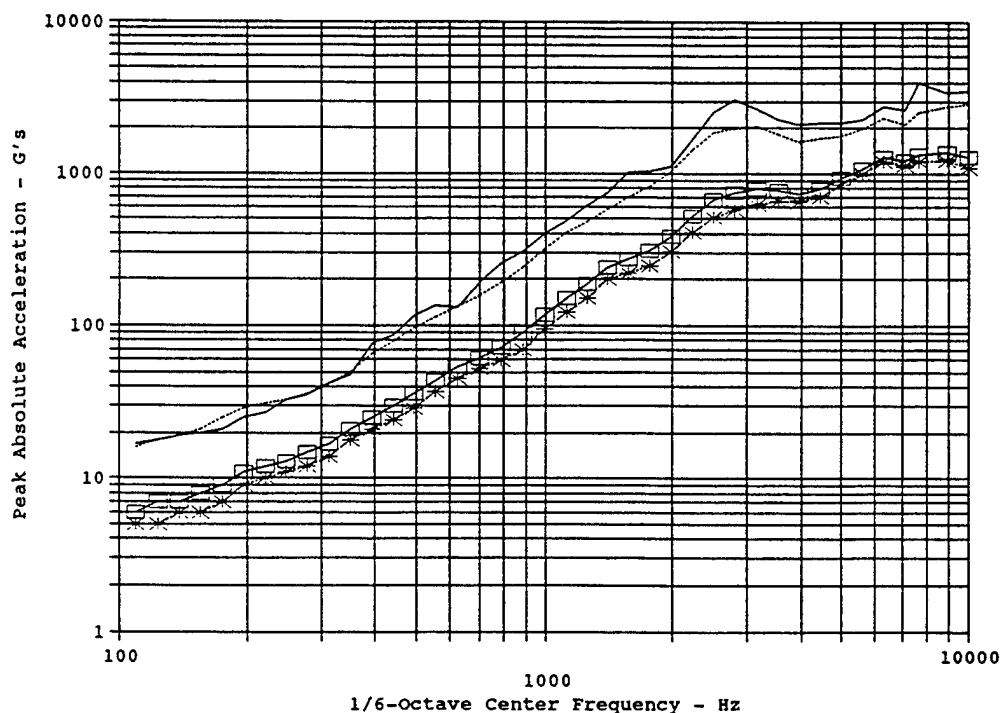


**Figure 7(e). LM 3/8", with Masses, Combined 4000 & 4200 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**



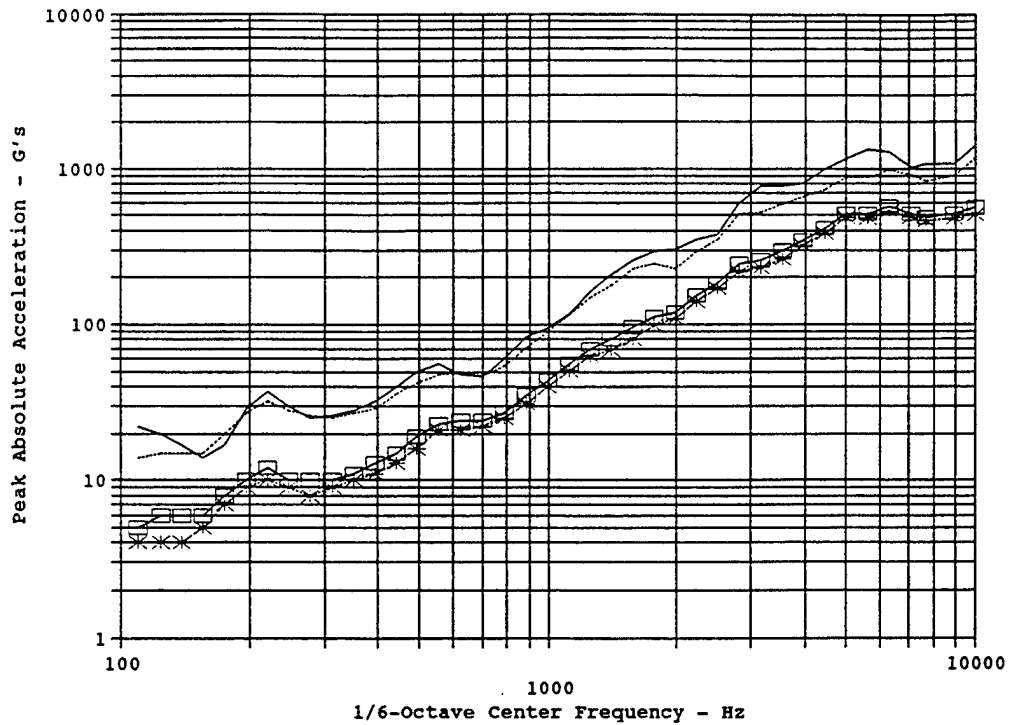
— Max nfyi      - - - 95th% nfyi      —□— Arith Mean nfyi      \*— Log Mean nfyi

**Figure 8(a). OEA 3/8", with Masses, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**



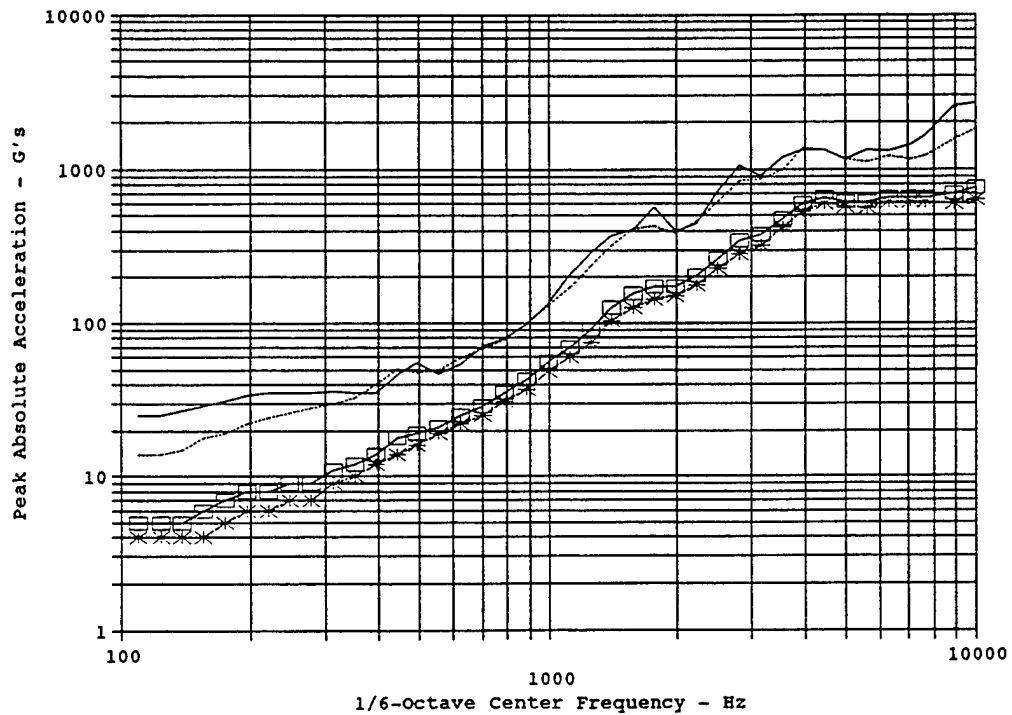
— Max nfyi      - - - 95th% nfyi      —□— Arith Mean nfyi      \*— Log Mean nfyi

**Figure 8(b). HiS 1/2", with Masses, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**



— Max nfyi      - - - 95th% nfyi      □ Arith Mean nfyi      \* Log Mean nfyi

**Figure 8(c). G&H 3/8", with Masses, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**



— Max nfyip      - - - 95th% nfyip      □ Arith Mean nfyip      \* Log Mean nfyip

**Figure 8(d). HiS 8 mm, with Masses, 2700 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**

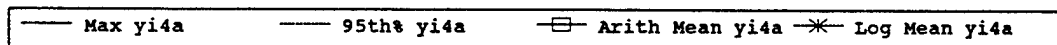
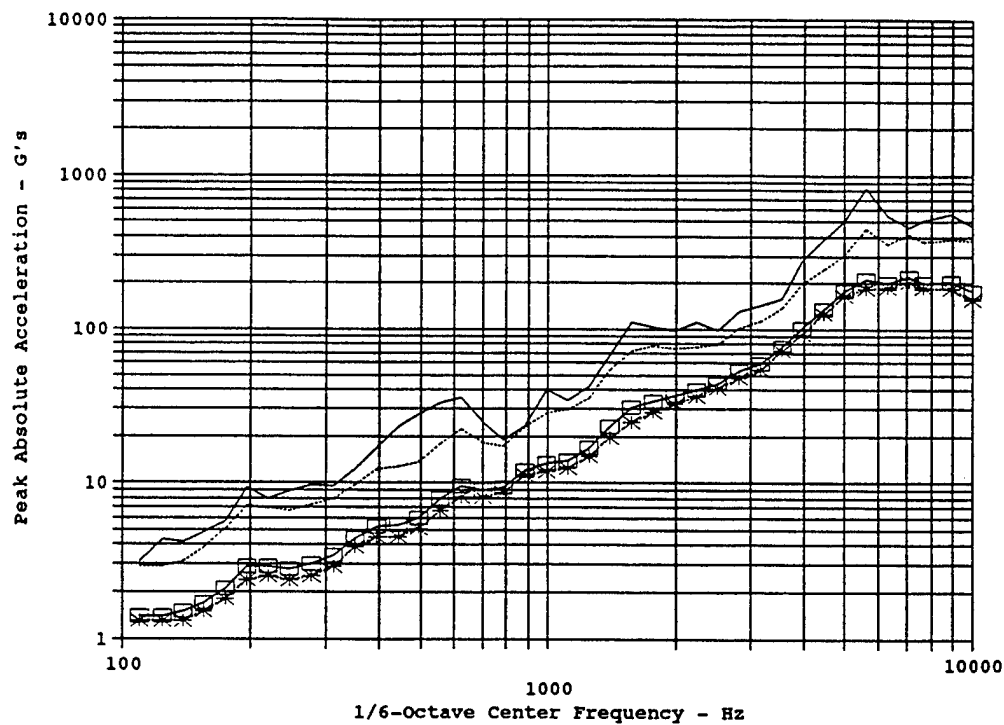


**Figure 8(e). LM 3/8", with Masses, Combined 4000 & 4200 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**

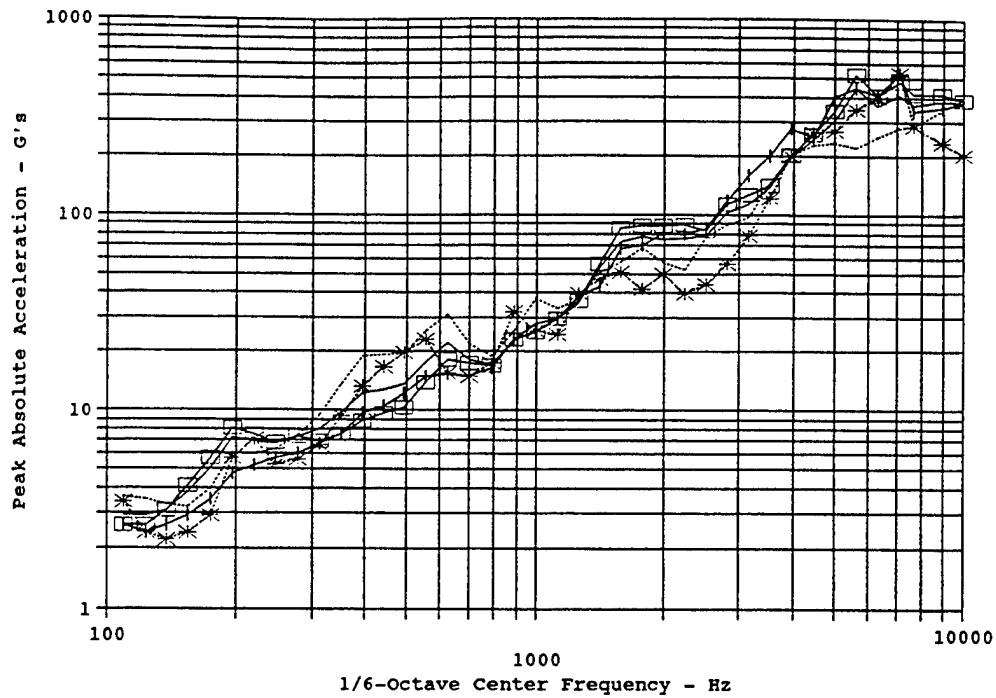


**Figure 9(a). LM 3/8", with Masses, Preload Comparison, Combined Normal & In-Plane Resultant, SRS (Q=10), 95th Percentile Levels.**

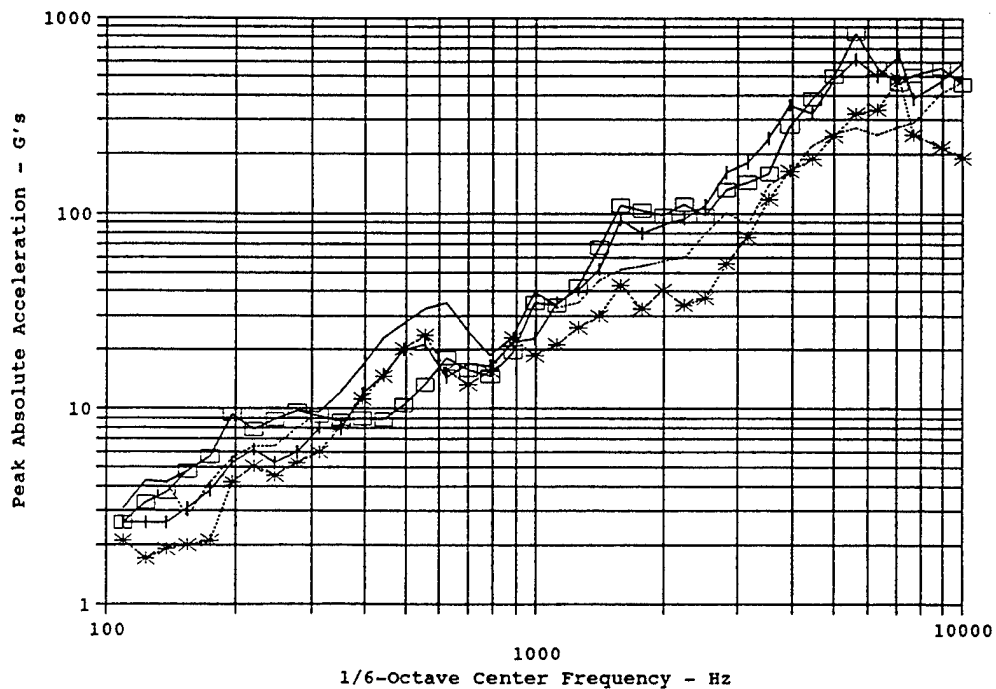


**Figure 9(b). LM 3/8", with Masses, Preload Comparison, Combined Normal & In-Plane Resultant, SRS (Q=10), Maximum Measured Levels.**

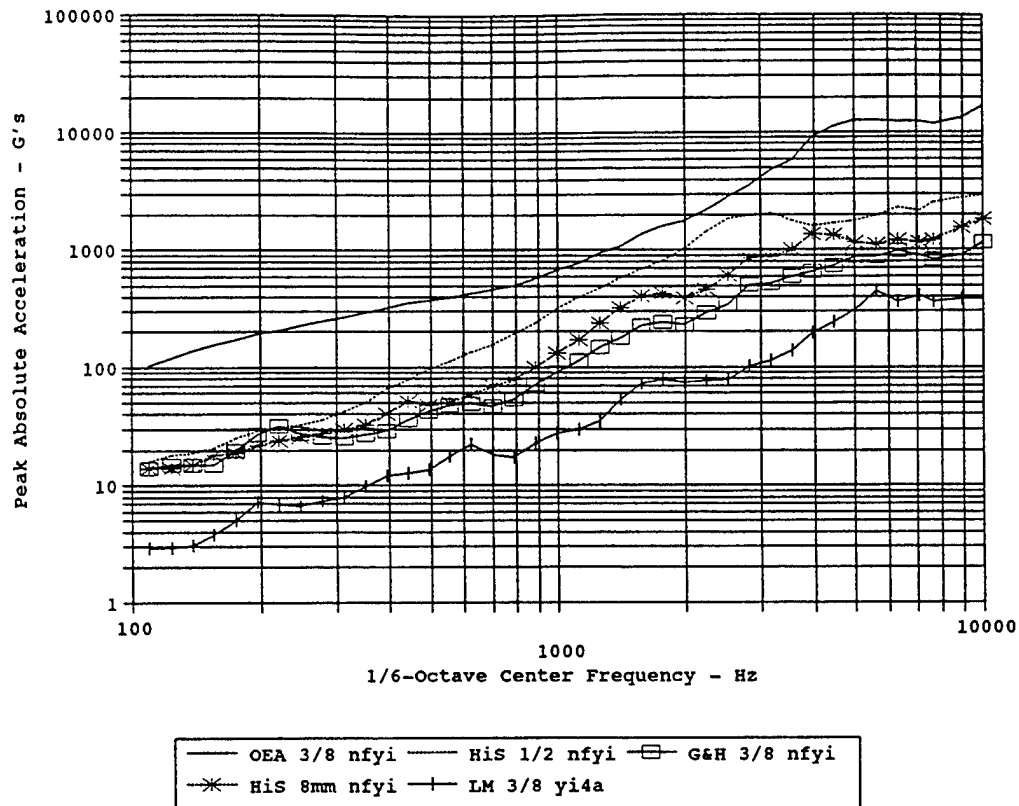


**Figure 10(a). Device Comparison, with Masses, Combined Normal & In-Plane Resultant, SRS (Q=10), 95th Percentile Levels.**

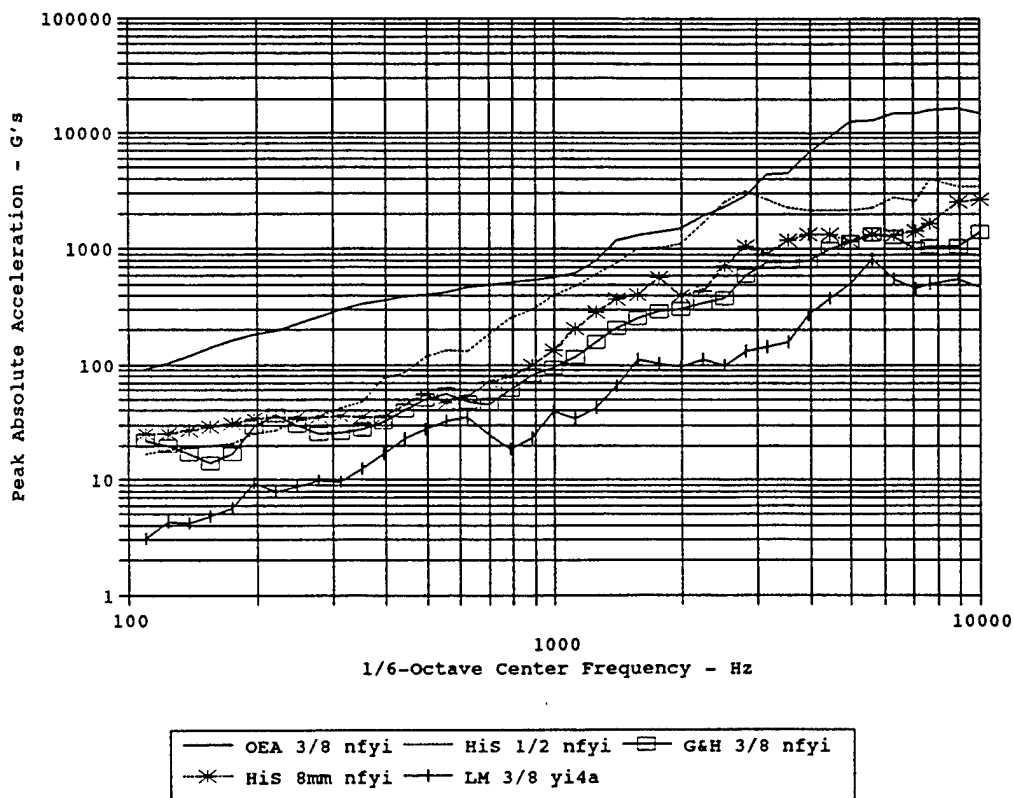


**Figure 10(b). Device Comparison, with Masses, Combined Normal & In-Plane Resultant, SRS (Q=10), Maximum Measured Levels.**

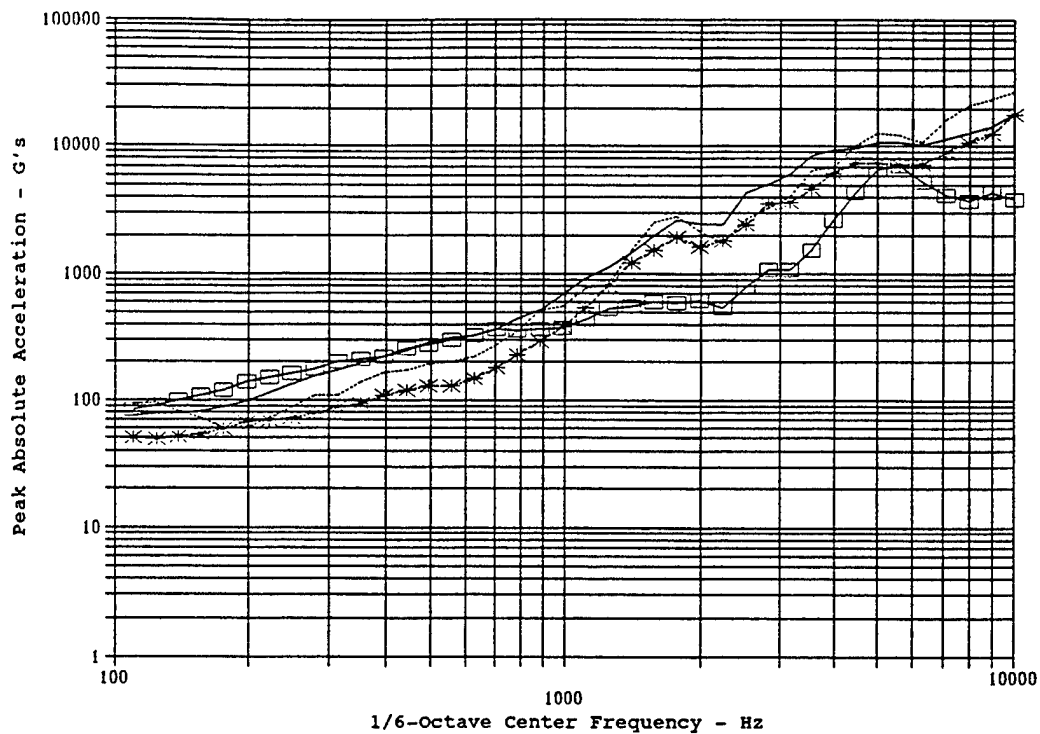


**Figure 11(a). OEA 3/8", Bare Panel, 7000 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

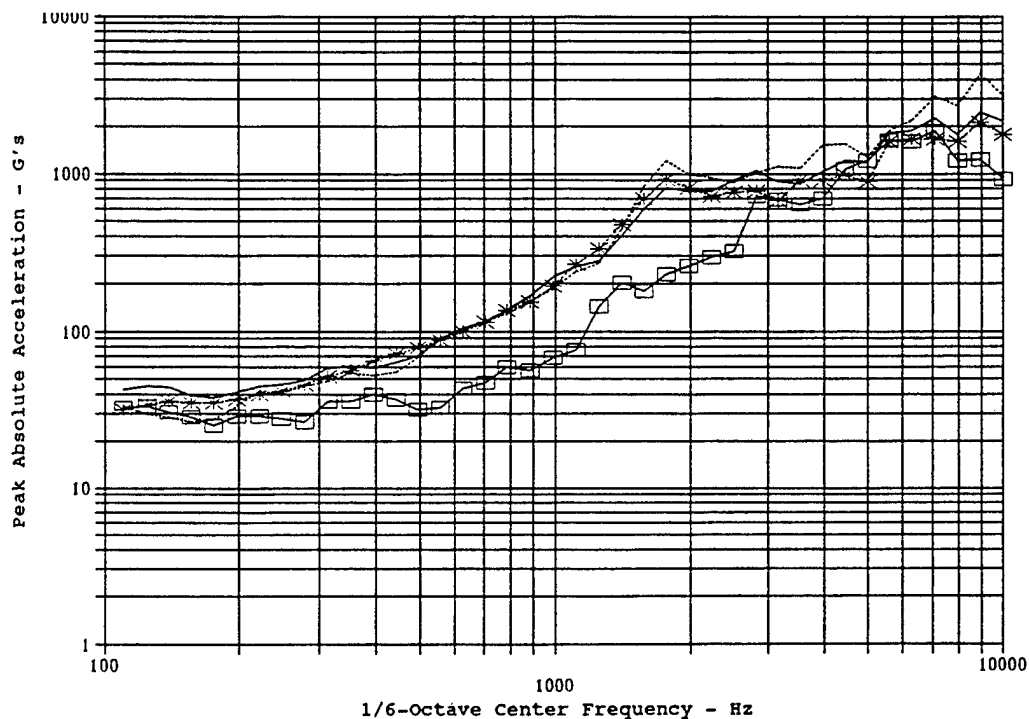


**Figure 11(b). HiS 1/2", Bare Panel, 7000 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

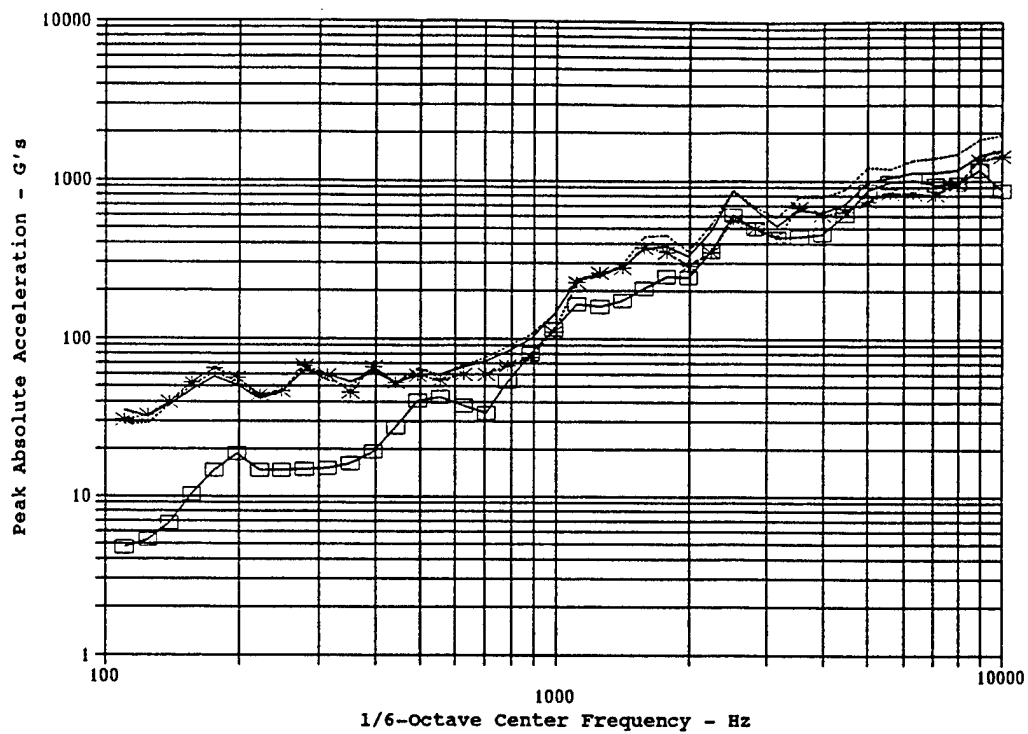


**Figure 11(c). G&H 3/8", Bare Panel, 7000 lb., Various Axis Groupings, SRS (Q=10), 95th Percentile Levels.**

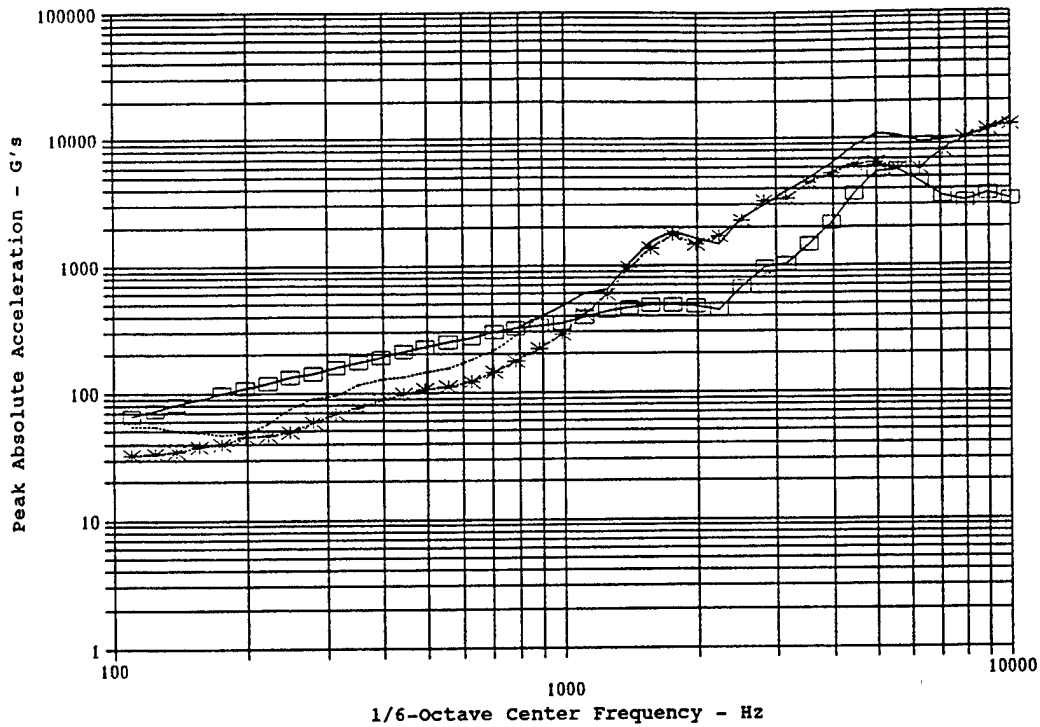


**Figure 12(a). OEA 3/8", Bare Panel, 7000 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

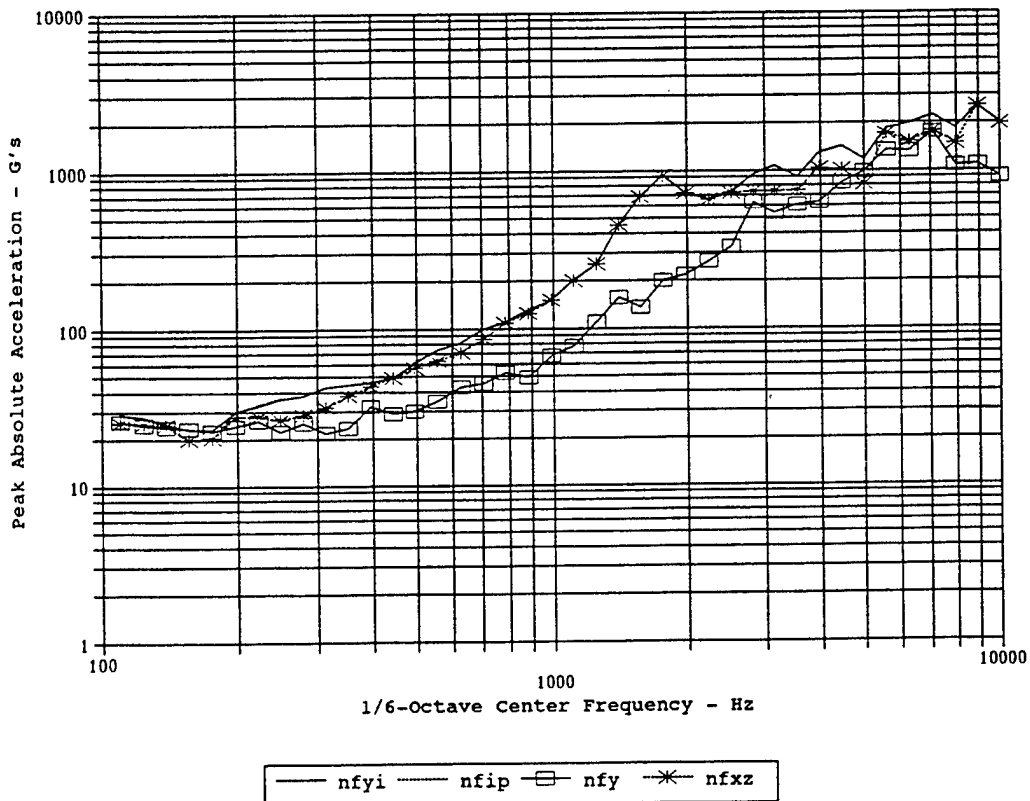


**Figure 12(b). HiS 1/2", Bare Panel, 7000 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

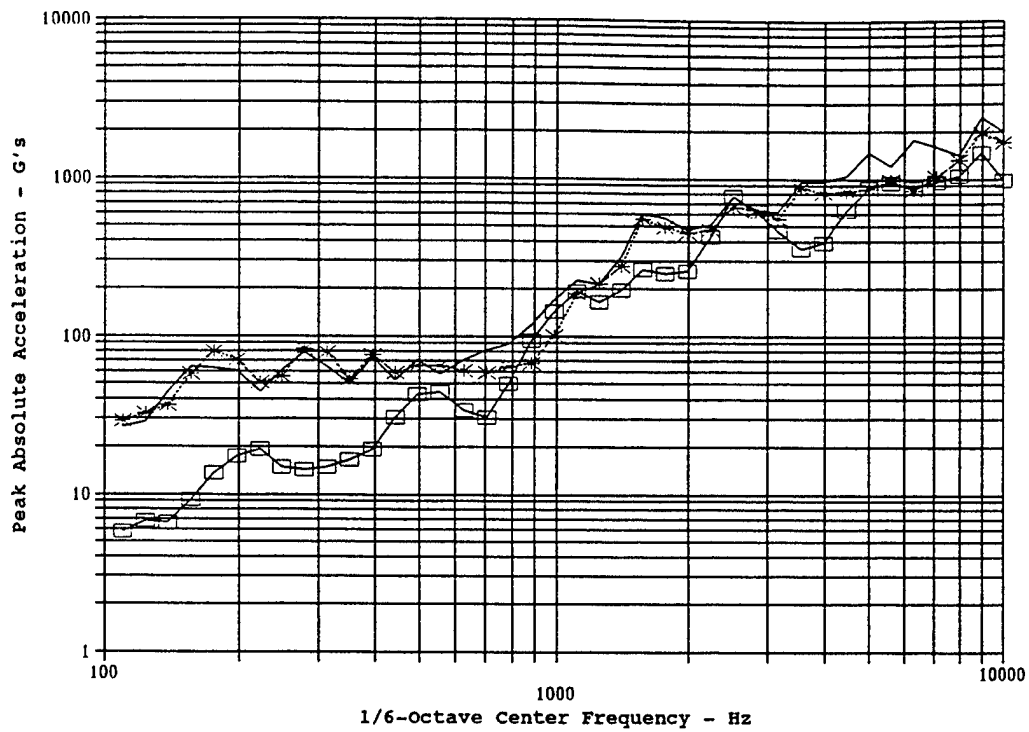


**Figure 12(c). G&H 3/8", Bare Panel, 7000 lb., Various Axis Groupings, SRS (Q=10), Maximum Measured Levels.**

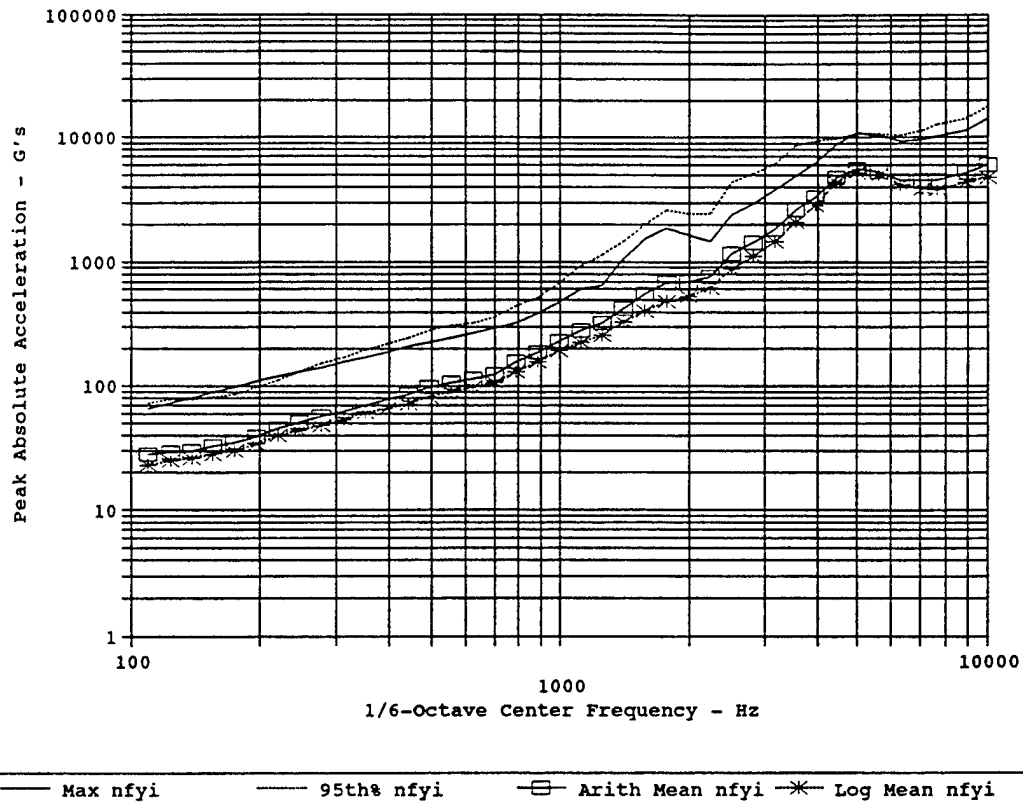


**Figure 13(a). OEA 3/8", Bare Panel, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**

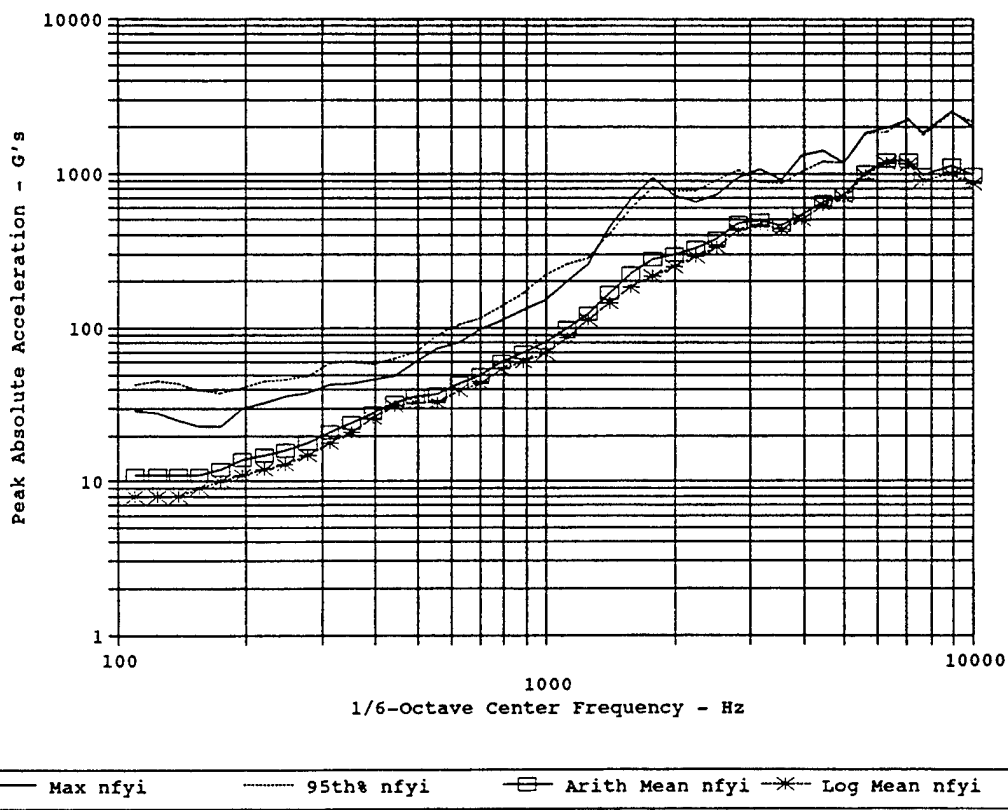
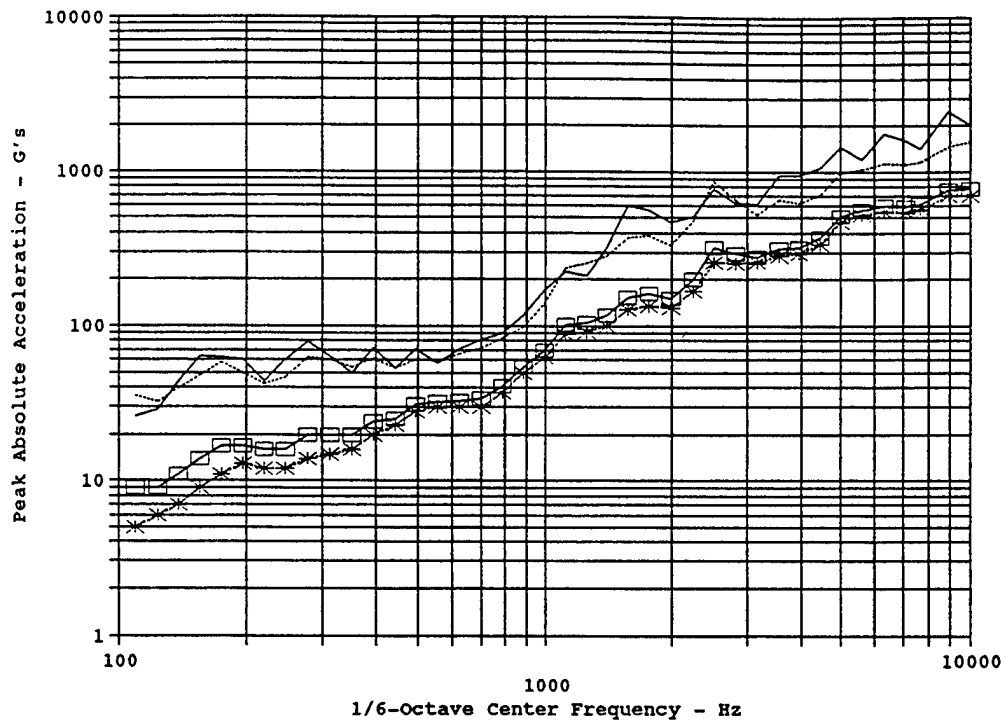


**Figure 13(b). HiS 1/2", Bare Panel, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**



— Max nfyi      - - - 95th% nfyi      □ Arith Mean nfyi      \* Log Mean nfyi

**Figure 13(c). G&H 3/8", Bare Panel, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Log-Normal Statistical Features.**

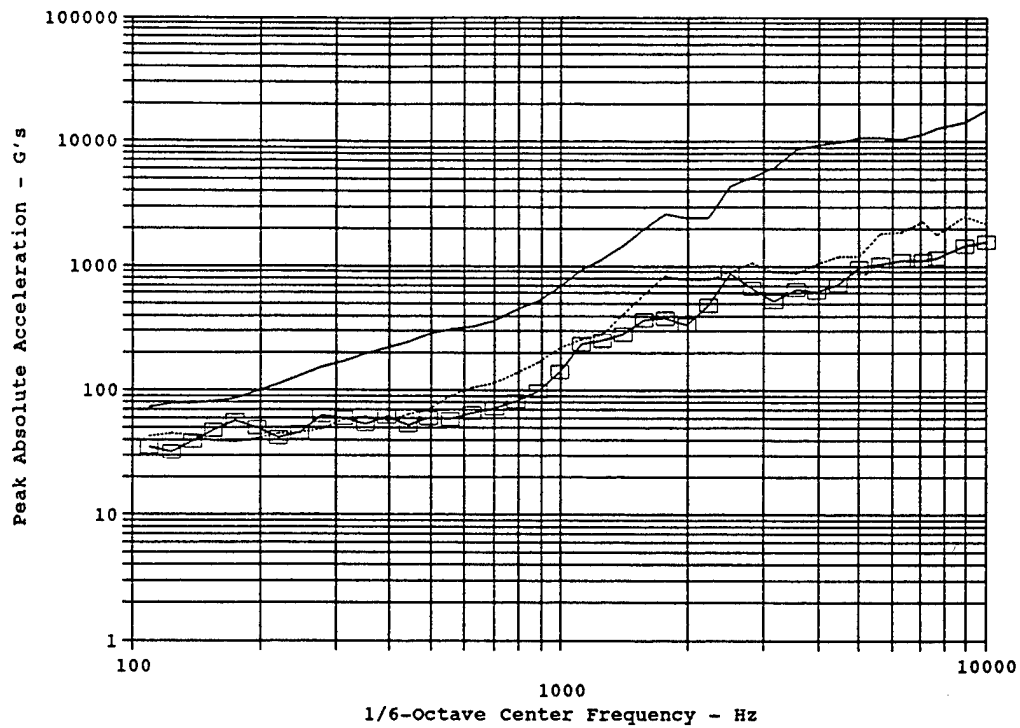


**Figure 14(a). Device Comparison, Bare Panel, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), 95th Percentile Levels.**

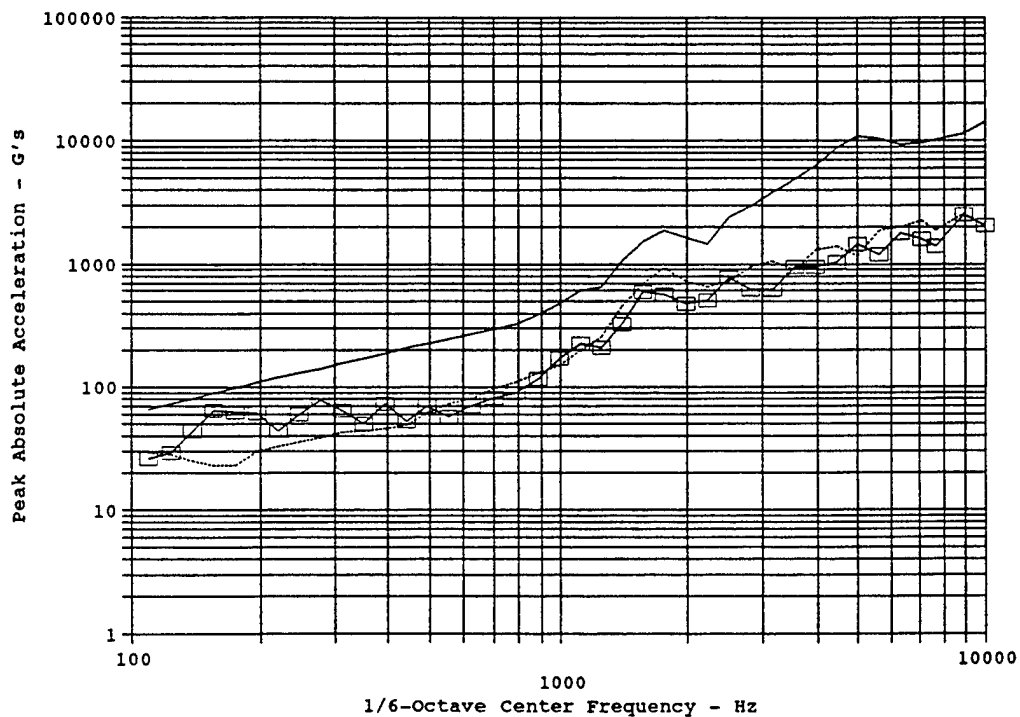


**Figure 14(b). Device Comparison, Bare Panel, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Maximum Measured Levels.**

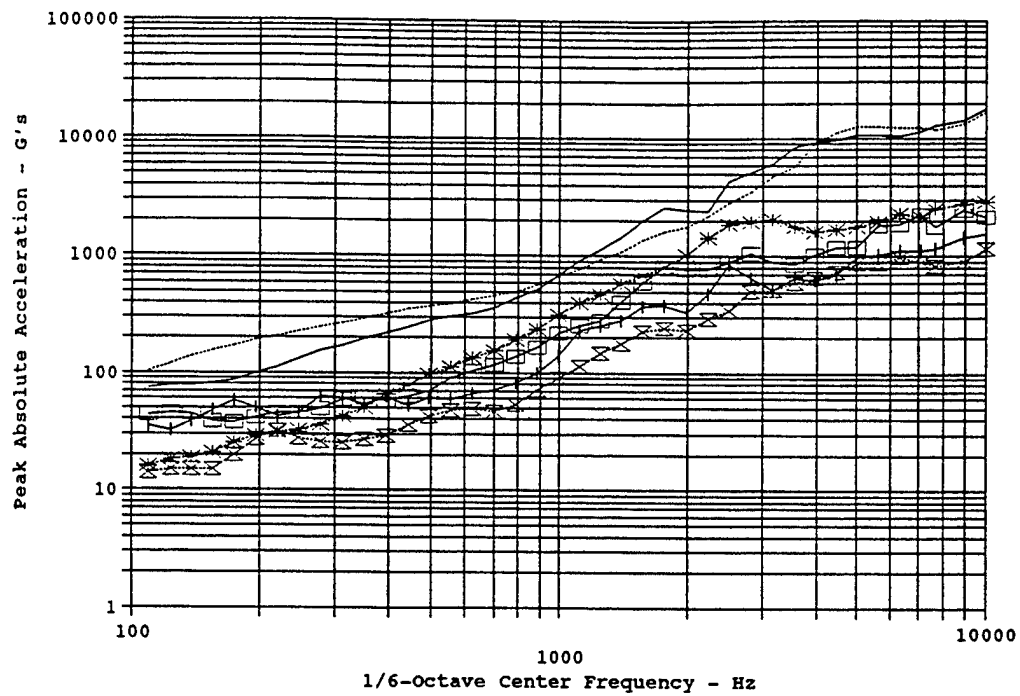


**Figure 15(a). Device Comparison, with & without Masses, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), 95th Percentile Levels.**

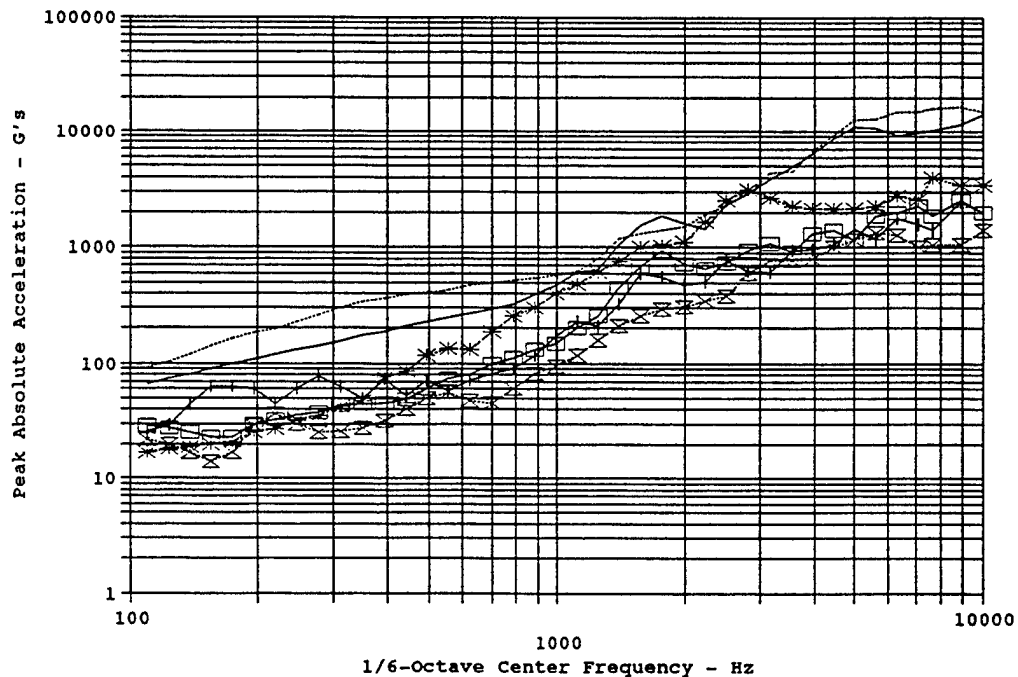


**Figure 15(b). Device Comparison, with & without Masses, 7000 lb., Combined Normal & In-Plane Resultant, SRS (Q=10), Maximum Measured Levels.**

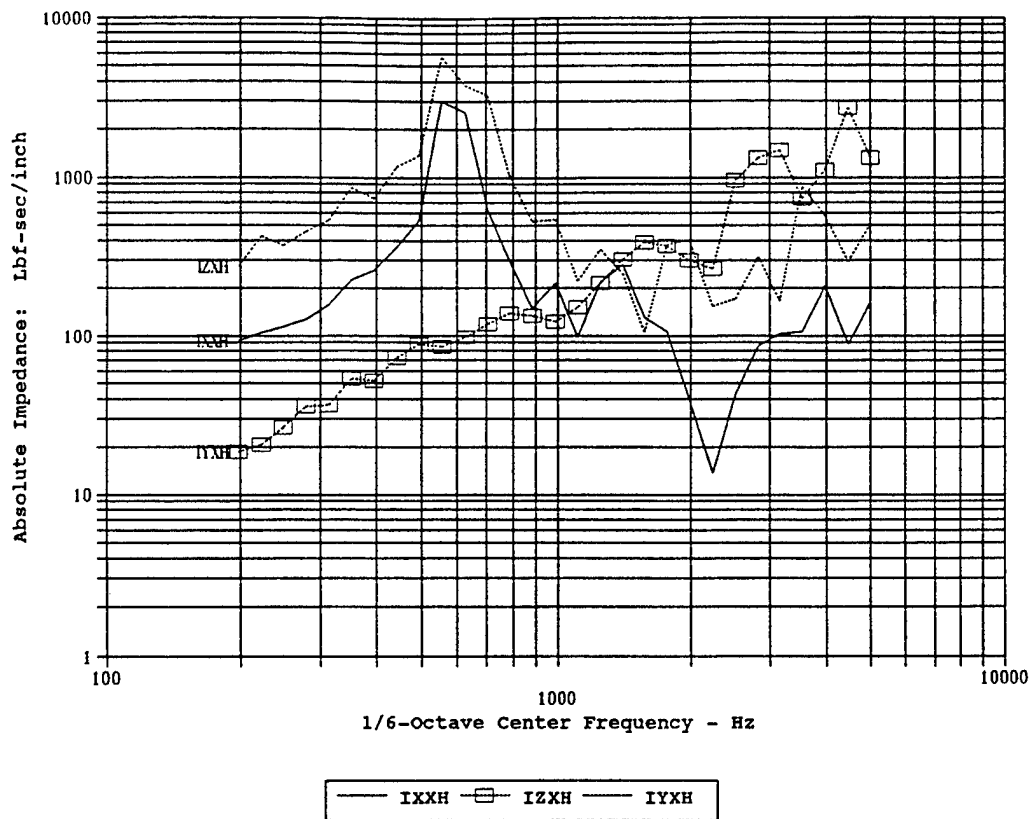


**Figure 16. 3/8" Release Device Mounting Point Impedances, X-Direction Tap.**

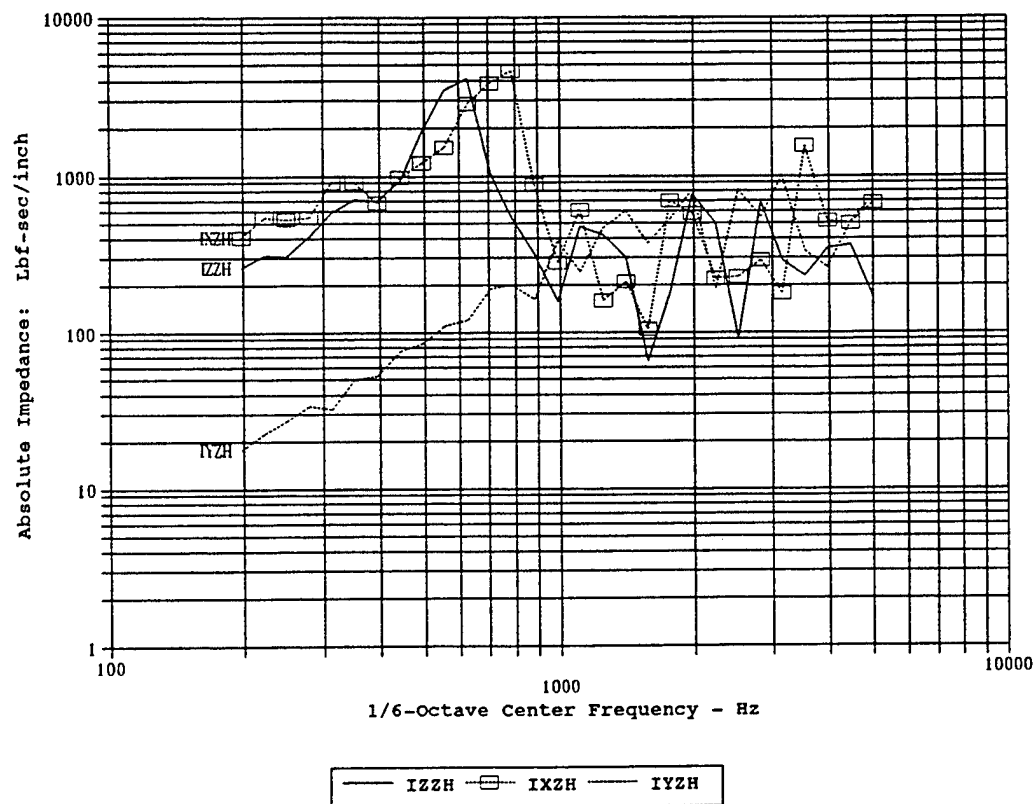


**Figure 17. 3/8" Release Device Mounting Point Impedances, Z-Direction Tap.**

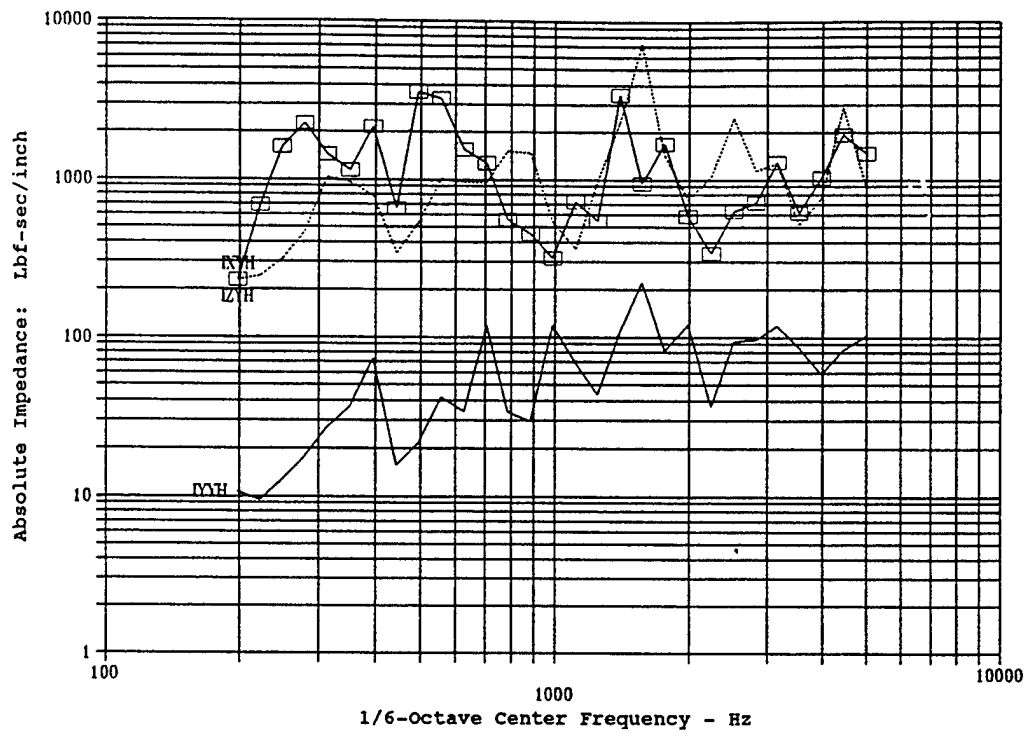


**Figure 18. 3/8" Release Device Mounting Point Impedances, Y-Direction Tap.**

| Freq<br>Hz | Arithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfyl | Maximum<br>nfyl | 95th<br>Percentile<br>nfyz | Maximum<br>nfyz |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|
| 110        | 40                         | 34                  | 1.861                 | 103                        | 92              | 97                         | 92              | 108                        | 88              | 81                         | 86              |
| 124        | 46                         | 38                  | 1.915                 | 121                        | 105             | 113                        | 105             | 124                        | 95              | 90                         | 91              |
| 139        | 51                         | 42                  | 1.933                 | 138                        | 121             | 134                        | 121             | 135                        | 105             | 99                         | 97              |
| 156        | 57                         | 46                  | 1.967                 | 156                        | 140             | 161                        | 140             | 149                        | 115             | 109                        | 101             |
| 175        | 62                         | 50                  | 1.987                 | 172                        | 164             | 184                        | 164             | 161                        | 128             | 119                        | 114             |
| 197        | 69                         | 55                  | 2.011                 | 193                        | 184             | 203                        | 184             | 173                        | 140             | 129                        | 124             |
| 221        | 75                         | 60                  | 1.996                 | 208                        | 195             | 220                        | 195             | 184                        | 155             | 135                        | 134             |
| 248        | 82                         | 66                  | 1.996                 | 227                        | 225             | 245                        | 225             | 199                        | 172             | 141                        | 143             |
| 278        | 90                         | 73                  | 1.973                 | 247                        | 260             | 265                        | 260             | 209                        | 186             | 151                        | 148             |
| 313        | 99                         | 80                  | 1.965                 | 268                        | 299             | 307                        | 299             | 226                        | 205             | 166                        | 163             |
| 351        | 109                        | 87                  | 1.992                 | 298                        | 339             | 355                        | 339             | 251                        | 226             | 178                        | 181             |
| 394        | 119                        | 95                  | 1.997                 | 327                        | 365             | 402                        | 365             | 279                        | 250             | 189                        | 189             |
| 442        | 130                        | 104                 | 1.980                 | 354                        | 391             | 428                        | 391             | 305                        | 272             | 202                        | 193             |
| 496        | 141                        | 115                 | 1.940                 | 375                        | 411             | 418                        | 411             | 342                        | 295             | 220                        | 225             |
| 557        | 151                        | 124                 | 1.907                 | 393                        | 430             | 428                        | 430             | 351                        | 328             | 237                        | 220             |
| 625        | 165                        | 137                 | 1.892                 | 427                        | 468             | 460                        | 468             | 374                        | 365             | 252                        | 251             |
| 702        | 184                        | 154                 | 1.851                 | 464                        | 500             | 492                        | 500             | 396                        | 395             | 282                        | 259             |
| 787        | 204                        | 174                 | 1.801                 | 497                        | 522             | 529                        | 522             | 409                        | 428             | 324                        | 298             |
| 884        | 230                        | 196                 | 1.816                 | 571                        | 545             | 562                        | 545             | 438                        | 475             | 389                        | 340             |
| 992        | 264                        | 226                 | 1.833                 | 668                        | 571             | 591                        | 571             | 477                        | 513             | 514                        | 431             |
| 1114       | 304                        | 258                 | 1.850                 | 776                        | 629             | 720                        | 629             | 463                        | 533             | 692                        | 572             |
| 1250       | 363                        | 304                 | 1.871                 | 931                        | 786             | 956                        | 786             | 446                        | 542             | 898                        | 732             |
| 1403       | 451                        | 384                 | 1.778                 | 1075                       | 1198            | 1253                       | 1198            | 474                        | 597             | 1012                       | 921             |
| 1575       | 533                        | 442                 | 1.880                 | 1367                       | 1293            | 1457                       | 1293            | 552                        | 643             | 1123                       | 1004            |
| 1768       | 614                        | 510                 | 1.895                 | 1601                       | 1392            | 1593                       | 1392            | 685                        | 688             | 1286                       | 1164            |
| 1984       | 714                        | 605                 | 1.816                 | 1760                       | 1507            | 1708                       | 1507            | 668                        | 715             | 1479                       | 1403            |
| 2227       | 869                        | 729                 | 1.851                 | 2195                       | 1917            | 2028                       | 1917            | 788                        | 733             | 1763                       | 1669            |
| 2500       | 1101                       | 925                 | 1.870                 | 2836                       | 2292            | 2496                       | 2292            | 1278                       | 1472            | 2252                       | 2331            |
| 2806       | 1423                       | 1205                | 1.834                 | 3566                       | 2831            | 3215                       | 2831            | 1702                       | 2501            | 2885                       | 3306            |
| 3150       | 1912                       | 1615                | 1.837                 | 4794                       | 4320            | 4392                       | 4320            | 2052                       | 2621            | 3679                       | 4314            |
| 3536       | 2419                       | 2075                | 1.781                 | 5830                       | 4454            | 5404                       | 4454            | 2319                       | 2464            | 5046                       | 5283            |
| 3969       | 3429                       | 2845                | 1.912                 | 9076                       | 6705            | 7929                       | 6705            | 3624                       | 3462            | 6614                       | 6397            |
| 4454       | 4534                       | 3848                | 1.831                 | 11360                      | 9302            | 10550                      | 9302            | 5208                       | 4444            | 8321                       | 7862            |
| 5000       | 5365                       | 4629                | 1.750                 | 12601                      | 12659           | 14386                      | 12659           | 6598                       | 6330            | 8822                       | 7779            |
| 5612       | 5670                       | 4944                | 1.692                 | 12663                      | 13062           | 14121                      | 13062           | 6330                       | 7503            | 8731                       | 7844            |
| 6300       | 5614                       | 4899                | 1.685                 | 12463                      | 14858           | 14501                      | 14858           | 5986                       | 6793            | 8999                       | 8724            |
| 7071       | 5161                       | 4369                | 1.780                 | 12253                      | 14822           | 15646                      | 14822           | 6148                       | 5742            | 9316                       | 10744           |
| 7637       | 5148                       | 4385                | 1.748                 | 11905                      | 16178           | 15537                      | 16178           | 6129                       | 7231            | 9670                       | 12043           |
| 8909       | 5654                       | 4818                | 1.765                 | 13314                      | 16467           | 15678                      | 16467           | 5553                       | 7110            | 10583                      | 12300           |
| 10000      | 6447                       | 5293                | 1.900                 | 16680                      | 14781           | 16034                      | 14781           | 4665                       | 4530            | 12471                      | 11813           |

**Table A-1(a): OEA 3/8", with Masses, 7000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 31 Gumbel Factor = 0.9194**

| Freq<br>Hz | Arithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfy | Maximum<br>nfy | 95th<br>Percentile<br>nfxz | Maximum<br>nfxz |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|---------------------------|----------------|----------------------------|-----------------|
| 110        | 6                          | 5                   | 1.946                 | 16                         | 17              | 23                         | 17              | 10                        | 11             | 9                          | 14              |
| 124        | 7                          | 5                   | 1.958                 | 18                         | 18              | 24                         | 18              | 10                        | 12             | 10                         | 15              |
| 139        | 7                          | 6                   | 1.955                 | 19                         | 19              | 24                         | 19              | 10                        | 12             | 10                         | 12              |
| 156        | 8                          | 6                   | 2.016                 | 21                         | 20              | 26                         | 20              | 12                        | 12             | 11                         | 12              |
| 175        | 9                          | 7                   | 1.998                 | 25                         | 21              | 28                         | 21              | 15                        | 14             | 12                         | 15              |
| 197        | 11                         | 9                   | 1.977                 | 29                         | 25              | 30                         | 25              | 21                        | 20             | 13                         | 16              |
| 221        | 12                         | 10                  | 1.866                 | 31                         | 27              | 33                         | 27              | 22                        | 24             | 14                         | 12              |
| 248        | 13                         | 11                  | 1.820                 | 33                         | 33              | 34                         | 33              | 20                        | 17             | 17                         | 16              |
| 278        | 15                         | 12                  | 1.837                 | 36                         | 35              | 33                         | 35              | 23                        | 19             | 19                         | 17              |
| 313        | 17                         | 14                  | 1.833                 | 42                         | 42              | 38                         | 42              | 29                        | 28             | 23                         | 23              |
| 351        | 21                         | 18                  | 1.809                 | 50                         | 48              | 46                         | 45              | 40                        | 48             | 29                         | 33              |
| 394        | 25                         | 21                  | 1.911                 | 66                         | 76              | 60                         | 52              | 57                        | 76             | 35                         | 37              |
| 442        | 30                         | 24                  | 1.981                 | 79                         | 86              | 77                         | 68              | 63                        | 86             | 43                         | 44              |
| 496        | 36                         | 29                  | 1.989                 | 96                         | 116             | 92                         | 79              | 74                        | 116            | 53                         | 55              |
| 557        | 44                         | 37                  | 1.899                 | 113                        | 135             | 106                        | 90              | 94                        | 135            | 69                         | 69              |
| 625        | 54                         | 45                  | 1.858                 | 134                        | 131             | 132                        | 131             | 106                       | 123            | 98                         | 93              |
| 702        | 62                         | 52                  | 1.878                 | 156                        | 190             | 167                        | 190             | 104                       | 103            | 139                        | 118             |
| 787        | 73                         | 59                  | 1.958                 | 192                        | 253             | 228                        | 253             | 104                       | 97             | 201                        | 176             |
| 884        | 89                         | 70                  | 2.016                 | 239                        | 305             | 321                        | 305             | 111                       | 123            | 290                        | 235             |
| 992        | 118                        | 94                  | 1.997                 | 315                        | 400             | 410                        | 400             | 149                       | 153            | 436                        | 358             |
| 1114       | 152                        | 121                 | 1.986                 | 403                        | 485             | 548                        | 485             | 175                       | 176            | 560                        | 526             |
| 1250       | 188                        | 151                 | 1.932                 | 478                        | 608             | 711                        | 608             | 213                       | 215            | 697                        | 668             |
| 1403       | 243                        | 202                 | 1.831                 | 585                        | 750             | 805                        | 750             | 343                       | 321            | 768                        | 794             |
| 1575       | 274                        | 221                 | 1.919                 | 693                        | 1017            | 938                        | 1020            | 306                       | 291            | 786                        | 780             |
| 1768       | 310                        | 246                 | 1.986                 | 818                        | 1026            | 1010                       | 1030            | 271                       | 269            | 797                        | 773             |
| 1984       | 385                        | 306                 | 2.009                 | 1040                       | 1109            | 1160                       | 1110            | 360                       | 352            | 868                        | 916             |
| 2227       | 521                        | 407                 | 2.048                 | 1429                       | 1667            | 1560                       | 1670            | 443                       | 464            | 1020                       | 1270            |
| 2500       | 672                        | 512                 | 2.088                 | 1861                       | 2510            | 2360                       | 2510            | 572                       | 507            | 1310                       | 1740            |
| 2806       | 749                        | 570                 | 2.029                 | 1972                       | 3104            | 2910                       | 3100            | 511                       | 478            | 1790                       | 2400            |
| 3150       | 795                        | 629                 | 1.952                 | 2032                       | 2682            | 3120                       | 2680            | 705                       | 703            | 1930                       | 2420            |
| 3536       | 777                        | 658                 | 1.768                 | 1786                       | 2274            | 2560                       | 2270            | 976                       | 1100           | 1520                       | 1900            |
| 3969       | 740                        | 643                 | 1.699                 | 1630                       | 2127            | 2130                       | 2130            | 1010                      | 993            | 1220                       | 1500            |
| 4454       | 790                        | 696                 | 1.666                 | 1703                       | 2136            | 2060                       | 2140            | 1150                      | 1110           | 1290                       | 1610            |
| 5000       | 923                        | 842                 | 1.526                 | 1767                       | 2164            | 2070                       | 2160            | 1570                      | 1740           | 1360                       | 1440            |
| 5612       | 1076                       | 1002                | 1.470                 | 1969                       | 2265            | 2290                       | 2270            | 1800                      | 1680           | 1430                       | 1790            |
| 6300       | 1271                       | 1186                | 1.459                 | 2300                       | 2778            | 2870                       | 2780            | 1810                      | 1550           | 1730                       | 1810            |
| 7071       | 1211                       | 1129                | 1.439                 | 2129                       | 2607            | 2790                       | 2610            | 1520                      | 1760           | 1760                       | 1950            |
| 7637       | 1325                       | 1187                | 1.547                 | 2552                       | 3992            | 3820                       | 3990            | 1390                      | 1350           | 2100                       | 3520            |
| 8909       | 1365                       | 1213                | 1.602                 | 2773                       | 3433            | 3840                       | 3430            | 1370                      | 1480           | 2210                       | 2760            |
| 10000      | 1277                       | 1094                | 1.739                 | 2888                       | 3469            | 3480                       | 3470            | 1070                      | 1040           | 2450                       | 3450            |

**Table A-1(b): HiS 1 1/2", with Masses, 7000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 45 Gumbel Factor = 0.9381**

| Freq<br>Hz | Arithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfyz | Maximum<br>nfyz |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|
| 110        | 5                          | 4                   | 2.042                 | 14                         | 22              | 15                         | 14              | 11                         | 14              |
| 124        | 6                          | 4                   | 2.013                 | 15                         | 20              | 16                         | 20              | 11                         | 20              |
| 139        | 6                          | 4                   | 2.002                 | 15                         | 17              | 16                         | 17              | 11                         | 17              |
| 156        | 6                          | 5                   | 1.853                 | 15                         | 14              | 14                         | 13              | 10                         | 13              |
| 175        | 8                          | 7                   | 1.882                 | 20                         | 17              | 15                         | 16              | 11                         | 16              |
| 197        | 10                         | 9                   | 1.907                 | 27                         | 29              | 15                         | 14              | 12                         | 14              |
| 221        | 12                         | 10                  | 1.995                 | 32                         | 37              | 16                         | 15              | 13                         | 15              |
| 248        | 10                         | 9                   | 1.972                 | 28                         | 30              | 21                         | 19              | 12                         | 17              |
| 278        | 10                         | 8                   | 1.926                 | 26                         | 25              | 22                         | 23              | 12                         | 18              |
| 313        | 10                         | 9                   | 1.867                 | 25                         | 26              | 25                         | 26              | 12                         | 18              |
| 351        | 11                         | 10                  | 1.794                 | 27                         | 28              | 28                         | 28              | 13                         | 18              |
| 394        | 13                         | 11                  | 4.757                 | 29                         | 32              | 31                         | 29              | 15                         | 16              |
| 442        | 15                         | 13                  | 1.793                 | 36                         | 40              | 37                         | 36              | 21                         | 22              |
| 496        | 19                         | 16                  | 1.703                 | 42                         | 50              | 43                         | 39              | 26                         | 26              |
| 557        | 23                         | 21                  | 1.619                 | 48                         | 56              | 49                         | 46              | 33                         | 30              |
| 625        | 24                         | 21                  | 1.601                 | 49                         | 48              | 50                         | 47              | 33                         | 32              |
| 702        | 24                         | 22                  | 1.542                 | 47                         | 46              | 54                         | 46              | 39                         | 43              |
| 787        | 27                         | 25                  | 1.563                 | 54                         | 61              | 66                         | 61              | 48                         | 58              |
| 884        | 35                         | 31                  | 1.597                 | 71                         | 83              | 89                         | 83              | 64                         | 74              |
| 992        | 44                         | 40                  | 1.591                 | 90                         | 95              | 110                        | 95              | 93                         | 95              |
| 1114       | 56                         | 51                  | 1.595                 | 115                        | 118             | 129                        | 118             | 144                        | 118             |
| 1250       | 70                         | 63                  | 1.639                 | 149                        | 161             | 167                        | 161             | 170                        | 161             |
| 1403       | 80                         | 69                  | 1.722                 | 179                        | 210             | 214                        | 210             | 190                        | 170             |
| 1575       | 97                         | 81                  | 1.802                 | 229                        | 258             | 285                        | 258             | 255                        | 249             |
| 1768       | 112                        | 98                  | 1.689                 | 245                        | 294             | 337                        | 294             | 268                        | 281             |
| 1984       | 120                        | 110                 | 1.520                 | 230                        | 306             | 301                        | 306             | 238                        | 284             |
| 2227       | 154                        | 141                 | 1.526                 | 296                        | 351             | 365                        | 351             | 314                        | 351             |
| 2500       | 185                        | 170                 | 1.512                 | 351                        | 379             | 419                        | 379             | 338                        | 379             |
| 2806       | 244                        | 216                 | 1.636                 | 511                        | 602             | 666                        | 602             | 462                        | 440             |
| 3150       | 258                        | 231                 | 1.582                 | 517                        | 776             | 686                        | 776             | 442                        | 457             |
| 3536       | 297                        | 266                 | 1.583                 | 596                        | 774             | 747                        | 774             | 523                        | 532             |
| 3969       | 348                        | 320                 | 1.514                 | 662                        | 798             | 783                        | 798             | 560                        | 623             |
| 4454       | 414                        | 386                 | 1.441                 | 732                        | 998             | 921                        | 998             | 688                        | 880             |
| 5000       | 513                        | 482                 | 1.410                 | 880                        | 1155            | 1151                       | 1155            | 825                        | 1092            |
| 5612       | 509                        | 477                 | 1.416                 | 878                        | 1327            | 1047                       | 1327            | 753                        | 1046            |
| 6300       | 568                        | 533                 | 1.415                 | 981                        | 1274            | 1074                       | 1274            | 757                        | 1103            |
| 7071       | 515                        | 484                 | 1.427                 | 904                        | 1006            | 984                        | 1006            | 767                        | 817             |
| 7637       | 488                        | 461                 | 1.401                 | 833                        | 1061            | 1026                       | 1061            | 737                        | 838             |
| 8909       | 510                        | 478                 | 1.432                 | 898                        | 1068            | 1007                       | 1068            | 792                        | 835             |
| 10000      | 564                        | 500                 | 1.623                 | 1168                       | 1407            | 1407                       | 1407            | 918                        | 1198            |

**Table A-1(c): G&H 3/8", with Masses, 7000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 45 Gumbel Factor = 0.9381**

| Freq<br>Hz | Arithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfyl | Maximum<br>nfyl | 95th<br>Percentile<br>nfyz | Maximum<br>nfyz |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|
| 110        | 5                          | 4                   | 2.152                 | 14                         | 25              | 11                         | 14              | 15                         | 25              | 10                         | 26              |
| 124        | 5                          | 4                   | 2.097                 | 14                         | 25              | 12                         | 13              | 15                         | 25              | 10                         | 26              |
| 139        | 5                          | 4                   | 2.097                 | 15                         | 27              | 12                         | 14              | 15                         | 27              | 10                         | 27              |
| 156        | 6                          | 4                   | 2.234                 | 18                         | 29              | 14                         | 17              | 17                         | 29              | 10                         | 29              |
| 175        | 7                          | 5                   | 2.165                 | 19                         | 31              | 16                         | 17              | 18                         | 31              | 11                         | 30              |
| 197        | 8                          | 6                   | 2.121                 | 22                         | 34              | 18                         | 16              | 21                         | 34              | 12                         | 32              |
| 221        | 8                          | 6                   | 2.171                 | 24                         | 35              | 20                         | 17              | 20                         | 35              | 13                         | 34              |
| 248        | 9                          | 7                   | 2.146                 | 26                         | 35              | 22                         | 17              | 19                         | 35              | 14                         | 34              |
| 278        | 9                          | 7                   | 2.127                 | 28                         | 35              | 22                         | 18              | 20                         | 35              | 15                         | 35              |
| 313        | 11                         | 9                   | 2.053                 | 30                         | 36              | 24                         | 22              | 23                         | 36              | 16                         | 35              |
| 351        | 12                         | 10                  | 1.977                 | 33                         | 35              | 26                         | 26              | 25                         | 35              | 18                         | 36              |
| 394        | 14                         | 12                  | 2.027                 | 40                         | 35              | 30                         | 27              | 40                         | 35              | 22                         | 36              |
| 442        | 18                         | 14                  | 2.070                 | 51                         | 46              | 35                         | 39              | 57                         | 46              | 26                         | 36              |
| 496        | 19                         | 16                  | 1.890                 | 48                         | 55              | 36                         | 35              | 49                         | 55              | 28                         | 35              |
| 557        | 21                         | 19                  | 1.756                 | 50                         | 47              | 41                         | 42              | 52                         | 47              | 32                         | 34              |
| 625        | 25                         | 22                  | 1.753                 | 59                         | 54              | 48                         | 49              | 59                         | 54              | 40                         | 37              |
| 702        | 29                         | 25                  | 1.767                 | 69                         | 71              | 60                         | 61              | 63                         | 71              | 51                         | 44              |
| 787        | 35                         | 31                  | 1.709                 | 78                         | 79              | 77                         | 79              | 62                         | 67              | 68                         | 57              |
| 884        | 43                         | 37                  | 1.760                 | 100                        | 99              | 111                        | 99              | 67                         | 60              | 94                         | 74              |
| 992        | 56                         | 49                  | 1.758                 | 131                        | 136             | 144                        | 136             | 84                         | 105             | 139                        | 110             |
| 1114       | 70                         | 60                  | 1.812                 | 170                        | 209             | 189                        | 209             | 105                        | 118             | 218                        | 201             |
| 1250       | 92                         | 75                  | 1.918                 | 237                        | 286             | 301                        | 286             | 140                        | 107             | 300                        | 318             |
| 1403       | 127                        | 104                 | 1.896                 | 321                        | 373             | 434                        | 373             | 212                        | 170             | 362                        | 358             |
| 1575       | 157                        | 127                 | 1.961                 | 415                        | 409             | 506                        | 409             | 281                        | 230             | 432                        | 390             |
| 1768       | 175                        | 144                 | 1.861                 | 428                        | 571             | 531                        | 571             | 274                        | 234             | 452                        | 475             |
| 1984       | 173                        | 152                 | 1.701                 | 387                        | 402             | 421                        | 402             | 266                        | 228             | 376                        | 345             |
| 2227       | 204                        | 177                 | 1.727                 | 463                        | 442             | 532                        | 442             | 283                        | 266             | 401                        | 416             |
| 2500       | 266                        | 229                 | 1.744                 | 608                        | 720             | 775                        | 720             | 339                        | 308             | 510                        | 483             |
| 2806       | 344                        | 281                 | 1.877                 | 850                        | 1053            | 1216                       | 1053            | 408                        | 365             | 707                        | 798             |
| 3150       | 376                        | 321                 | 1.758                 | 864                        | 917             | 1122                       | 917             | 406                        | 367             | 791                        | 758             |
| 3536       | 476                        | 423                 | 1.630                 | 998                        | 1202            | 1130                       | 1202            | 517                        | 545             | 915                        | 889             |
| 3969       | 604                        | 531                 | 1.706                 | 1358                       | 1328            | 1343                       | 1328            | 781                        | 756             | 1056                       | 1002            |
| 4454       | 662                        | 603                 | 1.567                 | 1327                       | 1324            | 1440                       | 1324            | 882                        | 829             | 1143                       | 1331            |
| 5000       | 616                        | 570                 | 1.491                 | 1151                       | 1156            | 1284                       | 1156            | 1063                       | 1110            | 926                        | 1077            |
| 5612       | 608                        | 563                 | 1.478                 | 1118                       | 1322            | 1290                       | 1322            | 1036                       | 1057            | 862                        | 908             |
| 6300       | 664                        | 616                 | 1.465                 | 1206                       | 1302            | 1409                       | 1291            | 1072                       | 1302            | 837                        | 1016            |
| 7071       | 655                        | 611                 | 1.434                 | 1152                       | 1436            | 1321                       | 1436            | 1070                       | 1432            | 807                        | 997             |
| 7637       | 659                        | 609                 | 1.478                 | 1210                       | 1653            | 1408                       | 1653            | 1118                       | 1327            | 984                        | 1374            |
| 8909       | 698                        | 601                 | 1.710                 | 1544                       | 2520            | 2032                       | 2520            | 1229                       | 1318            | 1290                       | 1956            |
| 10000      | 763                        | 634                 | 1.816                 | 1809                       | 2649            | 2527                       | 2649            | 930                        | 967             | 1628                       | 2157            |

**Table A-1(d): HiS 8 mm, with Masses, 2700 lb., SRS (Q=10), Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis Groupings. Number of Samples = 43 Gumbel Factor = 0.9360**

| Freq<br>Hz | Arithmetic<br>Mean<br>y14a | Log<br>Mean<br>y14a | Standard<br>Deviation | 95th<br>Percentile<br>y14a | Maximum<br>y14a | 95th<br>Percentile<br>ip4a | Maximum<br>ip4a | 95th<br>Percentile<br>y4a | Maximum<br>y4a | 95th<br>Percentile<br>xz4a | Maximum<br>xz4a |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|---------------------------|----------------|----------------------------|-----------------|
| 110        | 1.4                        | 1.3                 | 1.580                 | 2.9                        | 3.1             | 3                          | 3               | 3                         | 3              | 2                          | 2               |
| 124        | 1.4                        | 1.3                 | 1.589                 | 2.9                        | 4.3             | 3                          | 4               | 2                         | 2              | 2                          | 2               |
| 139        | 1.5                        | 1.3                 | 1.642                 | 3.1                        | 4.2             | 4                          | 4               | 2                         | 2              | 2                          | 2               |
| 156        | 1.7                        | 1.5                 | 1.697                 | 3.8                        | 4.8             | 4                          | 5               | 3                         | 3              | 2                          | 2               |
| 175        | 2.1                        | 1.8                 | 1.802                 | 5.1                        | 5.7             | 5                          | 6               | 5                         | 5              | 2                          | 2               |
| 197        | 2.9                        | 2.4                 | 1.880                 | 7.2                        | 9.3             | 5                          | 7               | 10                        | 9              | 2                          | 2               |
| 221        | 2.9                        | 2.5                 | 1.807                 | 6.9                        | 7.9             | 5                          | 8               | 9                         | 8              | 2                          | 2               |
| 248        | 2.8                        | 2.4                 | 1.795                 | 6.7                        | 8.8             | 7                          | 9               | 7                         | 6              | 2                          | 2               |
| 278        | 3                          | 2.5                 | 1.826                 | 7.3                        | 9.7             | 7                          | 10              | 8                         | 8              | 2                          | 3               |
| 313        | 3.4                        | 2.9                 | 1.791                 | 8                          | 9.6             | 7                          | 9               | 8                         | 10             | 3                          | 5               |
| 351        | 4.4                        | 3.9                 | 1.679                 | 9.7                        | 12.3            | 9                          | 9               | 11                        | 12             | 4                          | 8               |
| 394        | 5.3                        | 4.5                 | 1.755                 | 12.2                       | 16.8            | 10                         | 11              | 15                        | 17             | 6                          | 11              |
| 442        | 5.4                        | 4.5                 | 1.819                 | 12.8                       | 23              | 10                         | 10              | 15                        | 23             | 6                          | 9               |
| 496        | 6                          | 5.1                 | 1.745                 | 13.6                       | 27.6            | 11                         | 12              | 17                        | 28             | 7                          | 10              |
| 557        | 7.9                        | 6.7                 | 1.741                 | 17.8                       | 32.6            | 12                         | 15              | 23                        | 33             | 13                         | 13              |
| 625        | 9.6                        | 8.1                 | 1.772                 | 22.2                       | 35              | 15                         | 18              | 29                        | 35             | 15                         | 14              |
| 702        | 9                          | 8.1                 | 1.584                 | 18.1                       | 24.7            | 13                         | 12              | 23                        | 25             | 11                         | 12              |
| 787        | 9.4                        | 8.7                 | 1.469                 | 17.1                       | 18.7            | 16                         | 17              | 19                        | 19             | 11                         | 13              |
| 884        | 12                         | 11.1                | 1.523                 | 23.1                       | 23.4            | 21                         | 19              | 25                        | 23             | 15                         | 16              |
| 992        | 13.3                       | 11.8                | 1.632                 | 27.8                       | 39.7            | 29                         | 35              | 29                        | 40             | 26                         | 33              |
| 1114       | 14                         | 12.4                | 1.647                 | 29.6                       | 33.9            | 38                         | 34              | 24                        | 33             | 38                         | 34              |
| 1250       | 16.8                       | 14.9                | 1.638                 | 35.5                       | 42.4            | 45                         | 42              | 28                        | 35             | 40                         | 40              |
| 1403       | 23.1                       | 19.6                | 1.783                 | 54.1                       | 67              | 70                         | 67              | 39                        | 44             | 51                         | 67              |
| 1575       | 30.4                       | 24.8                | 1.850                 | 72.9                       | 110.7           | 113                        | 111             | 36                        | 38             | 70                         | 99              |
| 1768       | 33.4                       | 28.3                | 1.777                 | 77.5                       | 103.8           | 105                        | 104             | 45                        | 44             | 72                         | 83              |
| 1984       | 36.5                       | 32.3                | 1.621                 | 75.3                       | 98.1            | 99                         | 98              | 50                        | 62             | 71                         | 98              |
| 2227       | 39.9                       | 36.1                | 1.533                 | 76.4                       | 111.9           | 106                        | 112             | 44                        | 43             | 89                         | 112             |
| 2500       | 43.8                       | 40.7                | 1.455                 | 78.6                       | 98.8            | 105                        | 99              | 46                        | 44             | 87                         | 99              |
| 2806       | 53.3                       | 48.3                | 1.537                 | 102.6                      | 131.6           | 139                        | 132             | 56                        | 57             | 112                        | 132             |
| 3150       | 59.4                       | 54                  | 1.524                 | 113.1                      | 143.6           | 150                        | 144             | 54                        | 56             | 106                        | 110             |
| 3536       | 77                         | 71.8                | 1.455                 | 138.5                      | 158.3           | 159                        | 158             | 85                        | 80             | 124                        | 117             |
| 3969       | 102.6                      | 93.9                | 1.523                 | 196.5                      | 277.5           | 212                        | 278             | 144                       | 187            | 167                        | 235             |
| 4454       | 135.5                      | 125.7               | 1.460                 | 244.1                      | 385.9           | 307                        | 386             | 189                       | 202            | 218                        | 326             |
| 5000       | 176.8                      | 165.2               | 1.424                 | 307.1                      | 504.6           | 376                        | 505             | 264                       | 257            | 266                        | 404             |
| 5612       | 212.5                      | 183.8               | 1.664                 | 448.8                      | 835.6           | 574                        | 836             | 386                       | 482            | 405                        | 635             |
| 6300       | 201.4                      | 187                 | 1.453                 | 360.2                      | 552.9           | 435                        | 553             | 297                       | 328            | 362                        | 453             |
| 7071       | 221.7                      | 204                 | 1.496                 | 413.7                      | 458.8           | 469                        | 458             | 383                       | 459            | 396                        | 458             |
| 7637       | 201.6                      | 185.9               | 1.477                 | 368.2                      | 508.5           | 505                        | 508             | 255                       | 268            | 384                        | 428             |
| 8909       | 203.4                      | 185.6               | 1.512                 | 383.2                      | 558.4           | 529                        | 558             | 226                       | 235            | 375                        | 529             |
| 10000      | 179.1                      | 157.2               | 1.652                 | 378.9                      | 467.6           | 472                        | 468             | 169                       | 174            | 313                        | 372             |

**Table A-1(e): LM 3/8", with Masses, Combined 4000 & 4200 lb., SRS (Q=10), Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis Groupings. Number of Samples = 45 Gumbel Factor = 0.9381**

| Freq<br>Hz | Arithmetic<br>Mean<br>yi42 | Log<br>Mean<br>yi42 | Standard<br>Deviation | 95th<br>Percentile<br>yi42 | Maximum<br>yi42 |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|
| 110        | 1.6                        | 1.5                 | 1.592                 | 3.6                        | 3.1             |
| 124        | 1.6                        | 1.5                 | 1.586                 | 3.5                        | 4.3             |
| 139        | 1.6                        | 1.5                 | 1.527                 | 3.3                        | 4.2             |
| 156        | 1.8                        | 1.7                 | 1.369                 | 3.2                        | 2.8             |
| 175        | 2.1                        | 2                   | 1.441                 | 4                          | 4.2             |
| 197        | 2.8                        | 2.6                 | 1.557                 | 6                          | 5.6             |
| 221        | 3.1                        | 2.9                 | 1.484                 | 6                          | 6.5             |
| 248        | 3.2                        | 2.9                 | 1.500                 | 6.3                        | 6.5             |
| 278        | 3.4                        | 3.1                 | 1.583                 | 7.4                        | 8               |
| 313        | 4.4                        | 4                   | 1.576                 | 9.5                        | 9.6             |
| 351        | 6                          | 5.3                 | 1.644                 | 13.7                       | 12.3            |
| 394        | 7.6                        | 6.6                 | 1.748                 | 19                         | 16.8            |
| 442        | 7.7                        | 6.5                 | 1.767                 | 19.2                       | 23              |
| 496        | 8.5                        | 7.3                 | 1.680                 | 19.6                       | 27.6            |
| 557        | 11                         | 9.5                 | 1.689                 | 25.6                       | 32.6            |
| 625        | 12.9                       | 10.9                | 1.736                 | 31                         | 35              |
| 702        | 10                         | 8.9                 | 1.610                 | 21.8                       | 24.7            |
| 787        | 9.1                        | 8.2                 | 1.562                 | 19                         | 18.7            |
| 884        | 11.3                       | 10.1                | 1.633                 | 25.6                       | 23.4            |
| 992        | 15.3                       | 13.3                | 1.728                 | 37.5                       | 39.7            |
| 1114       | 15.4                       | 13.9                | 1.587                 | 33.3                       | 32.9            |
| 1250       | 17.9                       | 16.3                | 1.548                 | 37.2                       | 34.8            |
| 1403       | 25                         | 22.9                | 1.525                 | 51                         | 45.7            |
| 1575       | 27.4                       | 25.1                | 1.545                 | 57.2                       | 52.2            |
| 1768       | 31.5                       | 28.7                | 1.577                 | 68                         | 54              |
| 1984       | 30.7                       | 28.9                | 1.438                 | 57.5                       | 57.2            |
| 2227       | 31.1                       | 29.7                | 1.352                 | 52.6                       | 60.2            |
| 2500       | 42.7                       | 40.3                | 1.409                 | 77.2                       | 79.3            |
| 2806       | 50.8                       | 48.2                | 1.383                 | 89                         | 101.8           |
| 3150       | 52.5                       | 49.3                | 1.432                 | 97.4                       | 89.3            |
| 3536       | 75.5                       | 70.6                | 1.468                 | 145.9                      | 140.3           |
| 3969       | 93.3                       | 85.4                | 1.565                 | 199.4                      | 160.6           |
| 4454       | 118.8                      | 111.1               | 1.458                 | 227                        | 220.3           |
| 5000       | 141.9                      | 136.5               | 1.326                 | 232.8                      | 253.9           |
| 5612       | 130.4                      | 123.9               | 1.358                 | 221                        | 271.6           |
| 6300       | 157.1                      | 152                 | 1.301                 | 250                        | 250.5           |
| 7071       | 172.8                      | 166.6               | 1.322                 | 282.5                      | 278.1           |
| 7637       | 167.4                      | 159.7               | 1.358                 | 285                        | 290.9           |
| 8909       | 180.3                      | 166.4               | 1.480                 | 349.4                      | 410.3           |
| 10000      | 162.3                      | 138.6               | 1.739                 | 395                        | 467.6           |

**Table A-1(f): LM 3/8", with Masses, 4200 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 15 Gumbel Factor = 0.8688**

| Freq<br>Hz | Arithmetic<br>Mean<br>yi40 | Log<br>Mean<br>yi40 | Standard<br>Deviation | 95th<br>Percentile<br>yi40 | Maximum<br>yi40 |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|
| 110        | 1.3                        | 1.2                 | 1.555                 | 2.6                        | 2.6             |
| 124        | 1.3                        | 1.2                 | 1.570                 | 2.6                        | 3.3             |
| 139        | 1.4                        | 1.2                 | 1.686                 | 3.1                        | 3.7             |
| 156        | 1.7                        | 1.4                 | 1.823                 | 4.1                        | 4.8             |
| 175        | 2.1                        | 1.7                 | 1.959                 | 5.7                        | 5.7             |
| 197        | 2.9                        | 2.3                 | 2.034                 | 8.1                        | 9.3             |
| 221        | 2.8                        | 2.3                 | 1.939                 | 7.5                        | 7.9             |
| 248        | 2.6                        | 2.2                 | 1.896                 | 6.8                        | 8.8             |
| 278        | 2.8                        | 2.3                 | 1.909                 | 7.3                        | 9.7             |
| 313        | 2.9                        | 2.5                 | 1.781                 | 6.9                        | 9.2             |
| 351        | 3.7                        | 3.3                 | 1.586                 | 7.6                        | 8.7             |
| 394        | 4.2                        | 3.8                 | 1.601                 | 8.8                        | 9               |
| 442        | 4.2                        | 3.7                 | 1.694                 | 9.6                        | 8.8             |
| 496        | 4.8                        | 4.3                 | 1.635                 | 10.3                       | 10.5            |
| 557        | 6.3                        | 5.7                 | 1.638                 | 13.8                       | 13.3            |
| 625        | 8                          | 7                   | 1.701                 | 18.2                       | 18.3            |
| 702        | 8.5                        | 7.8                 | 1.573                 | 17.5                       | 15.7            |
| 787        | 9.6                        | 9                   | 1.425                 | 17                         | 14.8            |
| 884        | 12.3                       | 11.6                | 1.466                 | 23                         | 19.6            |
| 992        | 12.2                       | 11.1                | 1.577                 | 25.1                       | 35              |
| 1114       | 13.3                       | 11.6                | 1.672                 | 29.3                       | 33.9            |
| 1250       | 16.3                       | 14.3                | 1.684                 | 36.4                       | 42.4            |
| 1403       | 22.1                       | 18.2                | 1.886                 | 56.7                       | 67              |
| 1575       | 31.9                       | 24.7                | 2.003                 | 85.7                       | 110.7           |
| 1768       | 34.3                       | 28                  | 1.884                 | 87.3                       | 103.8           |
| 1984       | 39.3                       | 34.2                | 1.698                 | 88.3                       | 98.1            |
| 2227       | 44.3                       | 39.8                | 1.570                 | 89.4                       | 111.9           |
| 2500       | 44.4                       | 40.9                | 1.486                 | 83.3                       | 98.8            |
| 2806       | 54.6                       | 48.3                | 1.615                 | 114.1                      | 131.6           |
| 3150       | 62.9                       | 56.5                | 1.566                 | 126.2                      | 143.6           |
| 3536       | 77.7                       | 72.4                | 1.457                 | 142.2                      | 158.3           |
| 3969       | 107.3                      | 98.5                | 1.501                 | 204                        | 277.5           |
| 4454       | 143.9                      | 133.7               | 1.448                 | 259.5                      | 385.9           |
| 5000       | 194.3                      | 181.8               | 1.420                 | 340.8                      | 504.6           |
| 5612       | 253.5                      | 224                 | 1.610                 | 526.1                      | 835.6           |
| 6300       | 223.5                      | 207.4               | 1.464                 | 410.9                      | 552.9           |
| 7071       | 246.2                      | 225.8               | 1.523                 | 480.1                      | 458.8           |
| 7637       | 218.6                      | 200.6               | 1.505                 | 417.6                      | 508.5           |
| 8909       | 215                        | 196.1               | 1.521                 | 415.8                      | 558.4           |
| 10000      | 187.5                      | 167.4               | 1.602                 | 389.5                      | 455.4           |

**Table A-1(g): LM 3/8", with Masses, 4000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 30 Gumbel Factor = 0.9175**

| Freq<br>Hz | Arithmetic<br>Mean<br>yi35 | Log<br>Mean<br>yi35 | Standard<br>Deviation | 95th<br>Percentile<br>yi35 | Maximum<br>yi35 |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|
| 110        | 1.3                        | 1.2                 | 1.654                 | 3.4                        | 2.1             |
| 124        | 1.2                        | 1.1                 | 1.465                 | 2.4                        | 1.7             |
| 139        | 1.1                        | 1                   | 1.438                 | 2.2                        | 1.9             |
| 156        | 1.3                        | 1.2                 | 1.400                 | 2.4                        | 2               |
| 175        | 1.5                        | 1.4                 | 1.418                 | 2.9                        | 2.1             |
| 197        | 2.4                        | 2.1                 | 1.618                 | 5.7                        | 4.2             |
| 221        | 2.8                        | 2.5                 | 1.667                 | 7.1                        | 5.1             |
| 248        | 2.3                        | 2.1                 | 1.590                 | 5.3                        | 4.5             |
| 278        | 2.6                        | 2.4                 | 1.516                 | 5.6                        | 5.3             |
| 313        | 3.1                        | 2.9                 | 1.498                 | 6.6                        | 6               |
| 351        | 4.3                        | 4                   | 1.522                 | 9.4                        | 8.2             |
| 394        | 5.6                        | 5                   | 1.608                 | 13.3                       | 11.2            |
| 442        | 5.7                        | 4.8                 | 1.841                 | 16.6                       | 14.8            |
| 496        | 7                          | 5.9                 | 1.817                 | 19.8                       | 20.3            |
| 557        | 8.6                        | 7.2                 | 1.775                 | 23.3                       | 23.7            |
| 625        | 6.8                        | 6.2                 | 1.572                 | 15.5                       | 15.7            |
| 702        | 7.2                        | 6.7                 | 1.480                 | 14.9                       | 13.4            |
| 787        | 10.7                       | 10.4                | 1.288                 | 17.4                       | 15.6            |
| 884        | 16.5                       | 15.7                | 1.421                 | 32.1                       | 23.1            |
| 992        | 21.1                       | 11.4                | 1.486                 | 25.5                       | 18.6            |
| 1114       | 11.4                       | 10.5                | 1.509                 | 24.4                       | 21.4            |
| 1250       | 16.7                       | 15.2                | 1.594                 | 39.4                       | 25.8            |
| 1403       | 17.9                       | 16                  | 1.701                 | 47.3                       | 29.9            |
| 1575       | 21.1                       | 19                  | 1.631                 | 51.4                       | 42.9            |
| 1768       | 22.5                       | 21.5                | 1.384                 | 41.8                       | 32.5            |
| 1984       | 24.3                       | 22.8                | 1.464                 | 49.7                       | 40.6            |
| 2227       | 24.2                       | 23.6                | 1.287                 | 39.5                       | 34              |
| 2500       | 28.1                       | 27.4                | 1.266                 | 44.4                       | 37.2            |
| 2806       | 37.6                       | 36.9                | 1.230                 | 56.2                       | 55.6            |
| 3150       | 43.8                       | 42                  | 1.355                 | 77.9                       | 76.3            |
| 3536       | 63.7                       | 60.2                | 1.415                 | 122                        | 118.1           |
| 3969       | 107.5                      | 102.7               | 1.39                  | 200.9                      | 163.1           |
| 4454       | 150.5                      | 145.1               | 1.349                 | 266.9                      | 187.6           |
| 5000       | 192.4                      | 190                 | 1.183                 | 267.5                      | 248             |
| 5612       | 206.4                      | 199.7               | 1.313                 | 347.5                      | 323             |
| 6300       | 230.7                      | 222.5               | 1.333                 | 399.8                      | 338.7           |
| 7071       | 259.6                      | 242.6               | 1.467                 | 529.8                      | 485.3           |
| 7637       | 167.7                      | 162.1               | 1.323                 | 286.8                      | 250.8           |
| 8909       | 153.9                      | 150.9               | 1.235                 | 232.2                      | 218.3           |
| 10000      | 131.6                      | 128.8               | 1.247                 | 202                        | 192.8           |

**Table A-1(h): LM 3/8", with Masses, 3500 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 15 Gumbel Factor = 0.8688**

| Freq<br>Hz | Arithmetic<br>Mean<br>yi30 | Log<br>Mean<br>yi30 | Standard<br>Deviation | 95th<br>Percentile<br>yi30 | Maximum<br>yi30 |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|
| 110        | 1.2                        | 1.1                 | 1.610                 | 2.6                        | 2.6             |
| 124        | 1.2                        | 1.1                 | 1.565                 | 2.4                        | 2.6             |
| 139        | 1.2                        | 1.1                 | 1.661                 | 2.6                        | 2.6             |
| 156        | 1.3                        | 1.2                 | 1.676                 | 2.9                        | 3.1             |
| 175        | 1.6                        | 1.5                 | 1.648                 | 3.5                        | 3.8             |
| 197        | 2.1                        | 1.9                 | 1.695                 | 4.7                        | 5.3             |
| 221        | 2.3                        | 2                   | 1.712                 | 5.2                        | 6.2             |
| 248        | 2.4                        | 2.1                 | 1.775                 | 5.7                        | 5.3             |
| 278        | 2.5                        | 2.1                 | 1.802                 | 6                          | 6               |
| 313        | 2.9                        | 2.5                 | 1.758                 | 6.7                        | 8               |
| 351        | 3.6                        | 3.2                 | 1.631                 | 7.6                        | 7.9             |
| 394        | 4.4                        | 3.8                 | 1.696                 | 9.6                        | 11.8            |
| 442        | 4.5                        | 3.9                 | 1.764                 | 10.4                       | 14.9            |
| 496        | 5.2                        | 4.5                 | 1.770                 | 12.2                       | 20.1            |
| 557        | 6.7                        | 5.8                 | 1.720                 | 15                         | 21.3            |
| 625        | 7.1                        | 6.4                 | 1.651                 | 15.3                       | 14.4            |
| 702        | 7.6                        | 6.9                 | 1.549                 | 14.9                       | 16.9            |
| 787        | 9                          | 8.4                 | 1.465                 | 16.5                       | 16.5            |
| 884        | 12.3                       | 11.4                | 1.485                 | 22.9                       | 21.9            |
| 992        | 12.7                       | 11.6                | 1.566                 | 25.4                       | 22.8            |
| 1114       | 13.6                       | 11.9                | 1.680                 | 29.6                       | 35              |
| 1250       | 17.4                       | 15.2                | 1.706                 | 38.8                       | 41.1            |
| 1403       | 19.5                       | 16.9                | 1.705                 | 43.1                       | 51.7            |
| 1575       | 27.8                       | 22.6                | 1.866                 | 67.4                       | 92.5            |
| 1768       | 30.7                       | 26.2                | 1.747                 | 69.7                       | 79.6            |
| 1984       | 38.4                       | 34.4                | 1.623                 | 80.5                       | 87.2            |
| 2227       | 38.3                       | 34.1                | 1.621                 | 79.5                       | 94.7            |
| 2500       | 42.2                       | 37.9                | 1.586                 | 85                         | 109.4           |
| 2806       | 55.7                       | 49.1                | 1.649                 | 118                        | 160.5           |
| 3150       | 74.8                       | 66                  | 1.648                 | 158.5                      | 181.2           |
| 3536       | 100.5                      | 90.7                | 1.573                 | 200.6                      | 241.8           |
| 3969       | 133.8                      | 119.1               | 1.623                 | 278.3                      | 359.5           |
| 4454       | 140.3                      | 130.7               | 1.45                  | 250.7                      | 325.5           |
| 5000       | 207.8                      | 188.5               | 1.545                 | 404.5                      | 482.9           |
| 5612       | 224                        | 200.4               | 1.581                 | 447.6                      | 616.3           |
| 6300       | 216.8                      | 198.8               | 1.514                 | 411.7                      | 505             |
| 7071       | 257.3                      | 229.8               | 1.608                 | 528.6                      | 637.8           |
| 7637       | 183.8                      | 169.5               | 1.497                 | 344                        | 386.4           |
| 8909       | 193.4                      | 178                 | 1.489                 | 357.7                      | 473             |
| 10000      | 185.6                      | 166.4               | 1.580                 | 371.4                      | 585.9           |

**Table A-1(i): LM 3/8", with Masses, 3000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 45 Gumbel Factor = 0.9381**

| Freq<br>Hz | Aithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfyl | Maximum<br>nfyl | 95th<br>Percentile<br>nfyz | Maximum<br>nfyz |
|------------|---------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|----------------------------|-----------------|
| 110        | 28                        | 23                  | 1.810                 | 74                         | 66              | 94                         | 56              | 84                         | 66              | 50                         | 33              |
| 124        | 29                        | 25                  | 1.801                 | 78                         | 74              | 95                         | 55              | 91                         | 74              | 49                         | 33              |
| 139        | 30                        | 26                  | 1.762                 | 79                         | 81              | 83                         | 50              | 99                         | 81              | 52                         | 35              |
| 156        | 33                        | 28                  | 1.734                 | 82                         | 90              | 72                         | 50              | 108                        | 90              | 54                         | 38              |
| 175        | 35                        | 30                  | 1.714                 | 87                         | 99              | 60                         | 48              | 119                        | 99              | 59                         | 40              |
| 197        | 39                        | 34                  | 1.720                 | 99                         | 109             | 60                         | 48              | 138                        | 109             | 68                         | 45              |
| 221        | 46                        | 40                  | 1.710                 | 113                        | 120             | 72                         | 58              | 152                        | 120             | 68                         | 47              |
| 248        | 51                        | 44                  | 1.750                 | 131                        | 132             | 88                         | 75              | 162                        | 132             | 71                         | 50              |
| 278        | 57                        | 48                  | 1.807                 | 154                        | 142             | 109                        | 92              | 177                        | 142             | 79                         | 59              |
| 313        | 63                        | 54                  | 1.814                 | 173                        | 157             | 110                        | 95              | 203                        | 157             | 87                         | 69              |
| 351        | 71                        | 61                  | 1.834                 | 199                        | 174             | 140                        | 117             | 211                        | 174             | 94                         | 77              |
| 394        | 79                        | 66                  | 1.854                 | 222                        | 189             | 166                        | 127             | 221                        | 189             | 108                        | 87              |
| 442        | 86                        | 72                  | 1.877                 | 247                        | 210             | 171                        | 133             | 256                        | 210             | 120                        | 97              |
| 496        | 98                        | 82                  | 1.888                 | 284                        | 228             | 194                        | 146             | 272                        | 228             | 129                        | 107             |
| 557        | 107                       | 90                  | 1.883                 | 310                        | 249             | 204                        | 156             | 302                        | 249             | 130                        | 112             |
| 625        | 116                       | 98                  | 1.852                 | 327                        | 271             | 219                        | 182             | 330                        | 271             | 148                        | 123             |
| 702        | 127                       | 107                 | 1.864                 | 362                        | 298             | 275                        | 217             | 361                        | 298             | 181                        | 145             |
| 787        | 156                       | 132                 | 1.861                 | 444                        | 320             | 349                        | 277             | 354                        | 320             | 228                        | 177             |
| 884        | 187                       | 159                 | 1.834                 | 520                        | 391             | 521                        | 391             | 365                        | 333             | 292                        | 219             |
| 992        | 229                       | 191                 | 1.919                 | 685                        | 475             | 558                        | 475             | 376                        | 346             | 378                        | 286             |
| 1114       | 281                       | 226                 | 2.055                 | 923                        | 607             | 767                        | 607             | 433                        | 390             | 542                        | 407             |
| 1250       | 324                       | 258                 | 2.122                 | 1124                       | 650             | 822                        | 650             | 533                        | 432             | 812                        | 596             |
| 1403       | 426                       | 333                 | 2.122                 | 1449                       | 1051            | 1535                       | 1051            | 559                        | 464             | 1221                       | 966             |
| 1575       | 549                       | 406                 | 2.245                 | 1978                       | 1537            | 2544                       | 1537            | 600                        | 480             | 1517                       | 1367            |
| 1768       | 675                       | 486                 | 2.360                 | 2607                       | 1849            | 2819                       | 1849            | 588                        | 488             | 1945                       | 1733            |
| 1984       | 689                       | 527                 | 2.199                 | 2461                       | 1625            | 2186                       | 1625            | 620                        | 472             | 1639                       | 1458            |
| 2227       | 765                       | 618                 | 2.012                 | 2427                       | 1448            | 1720                       | 1448            | 547                        | 442             | 1819                       | 1713            |
| 2500       | 1163                      | 872                 | 2.279                 | 4372                       | 2367            | 2693                       | 2367            | 781                        | 680             | 2436                       | 2276            |
| 2806       | 1432                      | 1103                | 2.191                 | 5115                       | 2933            | 3314                       | 2933            | 1079                       | 959             | 3565                       | 3214            |
| 3150       | 1837                      | 1450                | 2.085                 | 6106                       | 3847            | 4129                       | 3847            | 1061                       | 1016            | 3675                       | 3333            |
| 3536       | 2614                      | 2076                | 2.058                 | 8522                       | 4898            | 6500                       | 4898            | 1521                       | 1457            | 4684                       | 4485            |
| 3969       | 3349                      | 2849                | 1.833                 | 9327                       | 6319            | 7003                       | 6319            | 2647                       | 2144            | 6270                       | 5268            |
| 4454       | 4727                      | 4379                | 1.502                 | 9710                       | 8674            | 10139                      | 8674            | 4372                       | 3685            | 7415                       | 6255            |
| 5000       | 5586                      | 5252                | 1.435                 | 10642                      | 10967           | 12712                      | 10967           | 6682                       | 5417            | 7373                       | 6419            |
| 5612       | 5316                      | 4946                | 1.484                 | 10713                      | 10591           | 12242                      | 10591           | 7152                       | 5744            | 7290                       | 5800            |
| 6300       | 4589                      | 4157                | 1.595                 | 10367                      | 9401            | 10789                      | 9401            | 5319                       | 4558            | 7315                       | 5821            |
| 7071       | 4555                      | 3938                | 1.732                 | 11538                      | 9648            | 16415                      | 9648            | 4222                       | 3474            | 9037                       | 8117            |
| 7637       | 4608                      | 3794                | 1.871                 | 12924                      | 10210           | 21477                      | 10210           | 3744                       | 3230            | 10699                      | 10157           |
| 8909       | 5242                      | 4357                | 1.841                 | 14384                      | 11570           | 23549                      | 11570           | 4368                       | 3695            | 12431                      | 11749           |
| 10000      | 5991                      | 4784                | 1.972                 | 18074                      | 14280           | 26800                      | 14280           | 3813                       | 3258            | 17640                      | 12885           |

**Table A-2(a): OEA 3/8", Bare Panel, 7000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 11 Gumbel Factor = 0.8407**

| Freq<br>Hz | Arithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfy | Maximum<br>nfy | 95th<br>Percentile<br>nfzx | Maximum<br>nfzx |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|---------------------------|----------------|----------------------------|-----------------|
| 110        | 11                         | 8                   | 2.489                 | 43                         | 29              | 33                         | 29              | 33                        | 26             | 32                         | 25              |
| 124        | 11                         | 8                   | 2.502                 | 45                         | 28              | 29                         | 28              | 33                        | 25             | 34                         | 25              |
| 139        | 11                         | 8                   | 2.444                 | 44                         | 25              | 28                         | 25              | 30                        | 24             | 36                         | 25              |
| 156        | 11                         | 9                   | 2.173                 | 39                         | 23              | 26                         | 20              | 29                        | 23             | 35                         | 20              |
| 175        | 12                         | 10                  | 2.083                 | 38                         | 23              | 27                         | 20              | 25                        | 23             | 35                         | 20              |
| 197        | 14                         | 11                  | 1.986                 | 41                         | 30              | 33                         | 30              | 29                        | 24             | 37                         | 28              |
| 221        | 15                         | 12                  | 2.004                 | 45                         | 33              | 42                         | 33              | 29                        | 26             | 40                         | 28              |
| 248        | 16                         | 13                  | 1.922                 | 46                         | 36              | 41                         | 36              | 28                        | 22             | 42                         | 26              |
| 278        | 18                         | 15                  | 1.868                 | 49                         | 38              | 45                         | 38              | 26                        | 25             | 46                         | 28              |
| 313        | 21                         | 18                  | 1.878                 | 59                         | 43              | 48                         | 43              | 35                        | 22             | 52                         | 32              |
| 351        | 24                         | 21                  | 1.740                 | 61                         | 44              | 54                         | 44              | 36                        | 23             | 56                         | 38              |
| 394        | 28                         | 26                  | 1.536                 | 58                         | 46              | 52                         | 46              | 39                        | 32             | 64                         | 43              |
| 442        | 33                         | 31                  | 1.466                 | 64                         | 49              | 55                         | 49              | 37                        | 29             | 73                         | 49              |
| 496        | 36                         | 33                  | 1.481                 | 70                         | 61              | 69                         | 61              | 32                        | 30             | 79                         | 56              |
| 557        | 37                         | 33                  | 1.706                 | 90                         | 74              | 89                         | 74              | 33                        | 35             | 88                         | 63              |
| 625        | 44                         | 39                  | 1.695                 | 105                        | 81              | 100                        | 81              | 43                        | 43             | 100                        | 72              |
| 702        | 50                         | 44                  | 1.671                 | 116                        | 99              | 115                        | 99              | 48                        | 45             | 113                        | 85              |
| 787        | 60                         | 54                  | 1.639                 | 137                        | 111             | 130                        | 111             | 59                        | 53             | 136                        | 107             |
| 884        | 70                         | 61                  | 1.713                 | 169                        | 131             | 154                        | 131             | 56                        | 49             | 153                        | 125             |
| 992        | 81                         | 68                  | 1.865                 | 221                        | 150             | 188                        | 150             | 68                        | 67             | 195                        | 150             |
| 1114       | 100                        | 86                  | 1.790                 | 258                        | 203             | 239                        | 203             | 76                        | 78             | 264                        | 199             |
| 1250       | 125                        | 113                 | 1.618                 | 281                        | 258             | 270                        | 258             | 144                       | 110            | 332                        | 258             |
| 1403       | 168                        | 147                 | 1.716                 | 407                        | 451             | 447                        | 451             | 205                       | 155            | 472                        | 451             |
| 1575       | 224                        | 183                 | 1.862                 | 595                        | 688             | 832                        | 688             | 180                       | 137            | 697                        | 688             |
| 1768       | 279                        | 216                 | 2.027                 | 822                        | 937             | 1200                       | 937             | 229                       | 201            | 927                        | 919             |
| 1984       | 299                        | 252                 | 1.808                 | 773                        | 722             | 988                        | 722             | 260                       | 219            | 817                        | 722             |
| 2227       | 328                        | 287                 | 1.693                 | 778                        | 653             | 937                        | 653             | 297                       | 266            | 728                        | 653             |
| 2500       | 378                        | 331                 | 1.700                 | 905                        | 733             | 879                        | 733             | 322                       | 325            | 762                        | 727             |
| 2806       | 473                        | 428                 | 1.608                 | 1053                       | 943             | 1007                       | 943             | 729                       | 625            | 771                        | 741             |
| 3150       | 497                        | 470                 | 1.397                 | 885                        | 1071            | 1099                       | 1071            | 686                       | 536            | 677                        | 732             |
| 3536       | 464                        | 435                 | 1.433                 | 860                        | 912             | 1075                       | 912             | 640                       | 603            | 911                        | 743             |
| 3969       | 543                        | 503                 | 1.464                 | 1035                       | 1296            | 1511                       | 1296            | 703                       | 628            | 901                        | 1033            |
| 4454       | 660                        | 621                 | 1.413                 | 1196                       | 1405            | 1545                       | 1405            | 1070                      | 828            | 967                        | 1008            |
| 5000       | 736                        | 711                 | 1.306                 | 1179                       | 1168            | 1268                       | 1168            | 1193                      | 970            | 897                        | 812             |
| 5612       | 1020                       | 971                 | 1.391                 | 1814                       | 1844            | 1852                       | 1844            | 1625                      | 1341           | 1584                       | 1697            |
| 6300       | 1204                       | 1170                | 1.275                 | 1854                       | 1980            | 2183                       | 1980            | 1600                      | 1312           | 1644                       | 1502            |
| 7071       | 1215                       | 1140                | 1.437                 | 2264                       | 2229            | 3122                       | 2229            | 1881                      | 1741           | 1654                       | 1776            |
| 7637       | 973                        | 914                 | 1.421                 | 1777                       | 1843            | 2692                       | 1843            | 1196                      | 1070           | 1586                       | 1468            |
| 8909       | 1124                       | 992                 | 1.621                 | 2477                       | 2536            | 4354                       | 2536            | 1233                      | 1088           | 2127                       | 2574            |
| 10000      | 972                        | 864                 | 1.622                 | 2157                       | 1992            | 3135                       | 1992            | 930                       | 904            | 1782                       | 1959            |

**Table A-2(b): HiS 1/2", Bare Panel, 7000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 15 Gumbel Factor = 0.8688**

| Freq<br>Hz | Arithmetic<br>Mean<br>nfyi | Log<br>Mean<br>nfyi | Standard<br>Deviation | 95th<br>Percentile<br>nfyi | Maximum<br>nfyi | 95th<br>Percentile<br>nfip | Maximum<br>nfip | 95th<br>Percentile<br>nfy | Maximum<br>nfy | 95th<br>Percentile<br>nfzx | Maximum<br>nfzx |
|------------|----------------------------|---------------------|-----------------------|----------------------------|-----------------|----------------------------|-----------------|---------------------------|----------------|----------------------------|-----------------|
| 110        | 9                          | 5                   | 2.929                 | 35                         | 26              | 29                         | 26              | 5                         | 6              | 31                         | 29              |
| 124        | 9                          | 6                   | 2.686                 | 32                         | 29              | 29                         | 29              | 5                         | 7              | 33                         | 32              |
| 139        | 11                         | 7                   | 2.610                 | 39                         | 44              | 37                         | 44              | 7                         | 7              | 40                         | 36              |
| 156        | 14                         | 9                   | 2.566                 | 48                         | 64              | 50                         | 64              | 10                        | 9              | 53                         | 58              |
| 175        | 17                         | 11                  | 2.520                 | 58                         | 63              | 60                         | 63              | 15                        | 14             | 65                         | 80              |
| 197        | 17                         | 13                  | 2.166                 | 50                         | 61              | 54                         | 61              | 19                        | 17             | 56                         | 71              |
| 221        | 16                         | 12                  | 2.009                 | 42                         | 44              | 44                         | 44              | 15                        | 19             | 44                         | 51              |
| 248        | 16                         | 12                  | 2.112                 | 46                         | 60              | 46                         | 60              | 15                        | 15             | 47                         | 56              |
| 278        | 20                         | 14                  | 2.330                 | 63                         | 79              | 65                         | 79              | 15                        | 14             | 68                         | 83              |
| 313        | 20                         | 15                  | 2.205                 | 60                         | 64              | 54                         | 64              | 15                        | 15             | 59                         | 79              |
| 351        | 20                         | 16                  | 2.017                 | 54                         | 50              | 50                         | 50              | 16                        | 17             | 46                         | 54              |
| 394        | 24                         | 20                  | 1.927                 | 62                         | 73              | 64                         | 73              | 19                        | 19             | 66                         | 76              |
| 442        | 25                         | 23                  | 1.613                 | 53                         | 53              | 52                         | 53              | 28                        | 31             | 52                         | 59              |
| 496        | 31                         | 28                  | 1.539                 | 60                         | 71              | 65                         | 71              | 41                        | 42             | 59                         | 66              |
| 557        | 32                         | 30                  | 1.480                 | 59                         | 57              | 58                         | 57              | 42                        | 44             | 54                         | 65              |
| 625        | 33                         | 30                  | 1.557                 | 66                         | 71              | 69                         | 71              | 38                        | 34             | 60                         | 61              |
| 702        | 34                         | 30                  | 1.658                 | 72                         | 82              | 76                         | 82              | 34                        | 31             | 60                         | 58              |
| 787        | 41                         | 37                  | 1.585                 | 83                         | 90              | 89                         | 90              | 54                        | 50             | 67                         | 64              |
| 884        | 54                         | 50                  | 1.476                 | 99                         | 117             | 107                        | 117             | 81                        | 94             | 76                         | 67              |
| 992        | 70                         | 63                  | 1.581                 | 141                        | 172             | 141                        | 172             | 113                       | 143            | 111                        | 100             |
| 1114       | 102                        | 88                  | 1.744                 | 235                        | 225             | 238                        | 225             | 165                       | 193            | 226                        | 186             |
| 1250       | 106                        | 92                  | 1.792                 | 255                        | 213             | 248                        | 213             | 159                       | 165            | 261                        | 214             |
| 1403       | 118                        | 100                 | 1.816                 | 284                        | 324             | 295                        | 324             | 175                       | 195            | 279                        | 280             |
| 1575       | 155                        | 129                 | 1.822                 | 370                        | 598             | 445                        | 598             | 207                       | 265            | 376                        | 554             |
| 1768       | 162                        | 136                 | 1.798                 | 381                        | 562             | 450                        | 562             | 247                       | 251            | 354                        | 489             |
| 1984       | 151                        | 132                 | 1.699                 | 335                        | 471             | 359                        | 471             | 242                       | 259            | 291                        | 452             |
| 2227       | 200                        | 167                 | 1.824                 | 481                        | 509             | 524                        | 509             | 357                       | 426            | 354                        | 475             |
| 2500       | 324                        | 260                 | 1.978                 | 861                        | 778             | 870                        | 772             | 605                       | 778            | 569                        | 659             |
| 2806       | 292                        | 254                 | 1.725                 | 662                        | 622             | 684                        | 608             | 501                       | 622            | 502                        | 641             |
| 3150       | 280                        | 260                 | 1.483                 | 519                        | 617             | 581                        | 617             | 433                       | 467            | 443                        | 551             |
| 3536       | 318                        | 283                 | 1.613                 | 654                        | 949             | 795                        | 949             | 441                       | 358            | 673                        | 874             |
| 3969       | 322                        | 292                 | 1.544                 | 625                        | 951             | 787                        | 951             | 460                       | 392            | 603                        | 812             |
| 4454       | 372                        | 339                 | 1.521                 | 707                        | 1044            | 878                        | 1044            | 604                       | 624            | 644                        | 826             |
| 5000       | 515                        | 472                 | 1.518                 | 982                        | 1451            | 1209                       | 1451            | 855                       | 869            | 739                        | 864             |
| 5612       | 558                        | 517                 | 1.488                 | 1038                       | 1200            | 1190                       | 1200            | 974                       | 935            | 837                        | 972             |
| 6300       | 602                        | 554                 | 1.494                 | 1120                       | 1781            | 1326                       | 1781            | 1009                      | 874            | 824                        | 844             |
| 7071       | 592                        | 545                 | 1.505                 | 1116                       | 1580            | 1393                       | 1580            | 942                       | 953            | 811                        | 1025            |
| 7637       | 618                        | 568                 | 1.500                 | 1157                       | 1403            | 1469                       | 1403            | 961                       | 1051           | 963                        | 1308            |
| 8909       | 763                        | 696                 | 1.515                 | 1444                       | 2477            | 1806                       | 2477            | 1158                      | 1454           | 1336                       | 1975            |
| 10000      | 775                        | 697                 | 1.576                 | 1550                       | 2018            | 1930                       | 2018            | 855                       | 976            | 1415                       | 1701            |

**Table A-2(c): G&H 3/8", Bare Panel, 7000 lb., SRS (Q=10),  
Log-Normal Statistical Features of Combined Normal & In-Plane, & Various Axis  
Groupings. Number of Samples = 44 Gumbel Factor = 0.9370**

| 1/6-Octave<br>Freq<br>Hz | X-Direction<br>Lbf-Sec/<br>Inch | Y-Direction<br>Lbf-Sec/<br>Inch | Z-Direction<br>Lbf-Sec/<br>Inch |
|--------------------------|---------------------------------|---------------------------------|---------------------------------|
| 197                      | 93.1                            | 18.8                            | 273.2                           |
| 221                      | 105                             | 20.7                            | 425.5                           |
| 248                      | 113.9                           | 26.7                            | 371.9                           |
| 278                      | 126.8                           | 35.7                            | 458.8                           |
| 312                      | 156.9                           | 36.2                            | 539.7                           |
| 351                      | 225.9                           | 53.4                            | 861.7                           |
| 394                      | 259.6                           | 52.1                            | 739.7                           |
| 442                      | 363.4                           | 72.2                            | 1157.6                          |
| 496                      | 534.8                           | 87.7                            | 1367.9                          |
| 557                      | 3009.6                          | 84.8                            | 5666.7                          |
| 625                      | 2570.9                          | 98.1                            | 3770.8                          |
| 702                      | 626.2                           | 117.9                           | 3254.8                          |
| 787                      | 302.6                           | 139.1                           | 1044.4                          |
| 884                      | 148.8                           | 133.9                           | 526.1                           |
| 992                      | 216.6                           | 123.3                           | 550.1                           |
| 1114                     | 96.6                            | 150.2                           | 221.6                           |
| 1250                     | 219.6                           | 214.6                           | 351.9                           |
| 1402                     | 286.8                           | 303.6                           | 248.8                           |
| 1574                     | 131.7                           | 389.8                           | 105.4                           |
| 1767                     | 107.1                           | 370.4                           | 373.7                           |
| 1984                     | 39.6                            | 299.5                           | 402.3                           |
| 2227                     | 13.6                            | 264.2                           | 154.9                           |
| 2500                     | 42.6                            | 961.3                           | 172.1                           |
| 2806                     | 85.8                            | 1305.8                          | 318                             |
| 3149                     | 103.4                           | 1460.4                          | 166.4                           |
| 3535                     | 106.8                           | 734.4                           | 874.7                           |
| 3968                     | 205.8                           | 1098                            | 574.8                           |
| 4454                     | 87.9                            | 2718.1                          | 292.3                           |
| 5000                     | 161.3                           | 1318                            | 505.2                           |

**Table A-3(a): "Foot" Impedances for 3/8" Mount, X-Direction Tap.**

| 1/6-Octave<br>Freq<br>Hz | X-Direction<br>Lbf-Sec/<br>Inch | Y-Direction<br>Lbf-Sec/<br>Inch | Z-Direction<br>Lbf-Sec/<br>Inch |
|--------------------------|---------------------------------|---------------------------------|---------------------------------|
| 197                      | 401                             | 17.8                            | 260.2                           |
| 221                      | 545.5                           | 22.6                            | 312.2                           |
| 248                      | 522.4                           | 27.1                            | 306                             |
| 278                      | 549.9                           | 33.7                            | 411                             |
| 312                      | 913.7                           | 32                              | 588.8                           |
| 351                      | 904.9                           | 49.8                            | 710.1                           |
| 394                      | 670.9                           | 52.4                            | 694.9                           |
| 442                      | 975.3                           | 76.7                            | 916.8                           |
| 496                      | 1211.7                          | 84.4                            | 1884.2                          |
| 557                      | 1516.7                          | 109.4                           | 3478.1                          |
| 625                      | 2856.5                          | 120.2                           | 4143.2                          |
| 702                      | 3818.5                          | 190.7                           | 1063.6                          |
| 787                      | 4550.9                          | 201.6                           | 545.7                           |
| 884                      | 880.6                           | 162.5                           | 315.8                           |
| 992                      | 279.8                           | 383.4                           | 157.8                           |
| 1114                     | 601.2                           | 243.5                           | 470.1                           |
| 1250                     | 159.4                           | 467.4                           | 417.8                           |
| 1402                     | 210.2                           | 600.4                           | 298.7                           |
| 1574                     | 104.1                           | 369                             | 65.3                            |
| 1767                     | 694.3                           | 524.5                           | 180.1                           |
| 1984                     | 570.9                           | 819.9                           | 766.9                           |
| 2227                     | 222.6                           | 189.7                           | 498.1                           |
| 2500                     | 224.5                           | 815.6                           | 90.9                            |
| 2806                     | 289.1                           | 543.5                           | 690.4                           |
| 3149                     | 177.5                           | 1017.5                          | 288.5                           |
| 3535                     | 1526.2                          | 332.7                           | 229.3                           |
| 3968                     | 514                             | 260.9                           | 346.5                           |
| 4454                     | 496.1                           | 508.9                           | 364.5                           |
| 5000                     | 676.1                           | 740.5                           | 169.2                           |

**Table A-3(b): "Foot" Impedances for 3/8" Mount, Z-Direction Tap.**

| 1/6-Octave<br>Freq<br>Hz | X-Direction<br>Lbf-Sec<br>Inch | Y-Direction<br>Lbf-Sec<br>Inch | Z-Direction<br>Lbf-Sec<br>Inch |
|--------------------------|--------------------------------|--------------------------------|--------------------------------|
| 197                      | 230.1                          | 10.6                           | 231.6                          |
| 221                      | 689.3                          | 9.4                            | 244.9                          |
| 248                      | 1593.1                         | 12.6                           | 309.7                          |
| 278                      | 2283.2                         | 17.8                           | 467.7                          |
| 312                      | 1435                           | 27.1                           | 1021.9                         |
| 351                      | 1134.5                         | 36.1                           | 964.6                          |
| 394                      | 2144.7                         | 73                             | 795.4                          |
| 442                      | 652.1                          | 15.7                           | 339.2                          |
| 496                      | 3545.2                         | 21.6                           | 525.2                          |
| 557                      | 3275.5                         | 41.6                           | 1002.7                         |
| 625                      | 1542.9                         | 34                             | 952.5                          |
| 702                      | 1278.8                         | 117.6                          | 953.8                          |
| 787                      | 559.8                          | 33.8                           | 1500.8                         |
| 884                      | 447.1                          | 29.7                           | 1446.6                         |
| 992                      | 318.7                          | 117.9                          | 535                            |
| 1114                     | 719.1                          | 68.9                           | 365.7                          |
| 1250                     | 549.2                          | 43.1                           | 971.3                          |
| 1402                     | 3452.3                         | 108.8                          | 2301.2                         |
| 1574                     | 945                            | 221                            | 7246.7                         |
| 1767                     | 1691.6                         | 82.2                           | 1409.1                         |
| 1984                     | 588.4                          | 119.3                          | 749.5                          |
| 2227                     | 336.3                          | 36.6                           | 1050                           |
| 2500                     | 630.8                          | 93.9                           | 2467                           |
| 2806                     | 709.8                          | 95.1                           | 1137.7                         |
| 3149                     | 1279.8                         | 119                            | 1259.1                         |
| 3535                     | 613.1                          | 86.5                           | 518.8                          |
| 3968                     | 1031.4                         | 59                             | 768.2                          |
| 4454                     | 1931.2                         | 83.2                           | 2908.4                         |
| 5000                     | 1454                           | 103                            | 876.7                          |

**Table A-3(c): "Foot" Impedances for 3/8" Mount, Y-Direction Tap.**

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                             |                                                                       | Form Approved<br>OMB No. 0704-0188      |  |
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| 1. AGENCY USE ONLY (Leave blank)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 2. REPORT DATE<br>December 1996                             | 3. REPORT TYPE AND DATES COVERED<br>Technical Memorandum              |                                         |  |
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| 13. ABSTRACT (Maximum 200 words)<br>Shock, safety, overall system costs, and emergence of new technologies have raised concerns regarding continued use of pyrotechnics on spacecraft. NASA Headquarters requested Langley Research Center (LaRC) study pyrotechnic alternatives using nonexplosive actuators (NEAs), and LaRC participated with Lockheed Martin Missile and Space Co. (LMMSC) in objectively evaluating applicability of some NEA mechanisms to reduce small spacecraft and booster separation event shock. Comparative tests were conducted on a structural simulator using five different separation nut mechanisms, three pyrotechnics from OEA Aerospace and Hi-Shear Technology and two NEAs from G & H Technology and LMMSC. Multiple actuations were performed with preloads up to 7,000 pounds, 7,000 being the standard. All devices except the LMMSC NEA rotary nut concept were available units with no added provisions to attenuate shock. Accelerometer measurements were recorded, reviewed, processed into Shock Response Spectra (SRS) and comparisons performed. For the standard preload, pyrotechnics were the most severe and the G & H NEA the least severe. Comparing all results, the LMMSC concept produced the lowest levels with preload limited to -4,200 pounds. Testing this concept over a range of 3,000 to 4,200 pounds indicated no effect on shock. This report presents data from these tests and the comparative results. |                                                             |                                                                       |                                         |  |
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