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This revision of ATM 927 presents the results of parametric studies accomplished from 12/1/70 thru 1/29/71 on selection of isolators for soft mounting of the LSPE explosive pallet. This revision and the effort reported herein was necessitated by an invalid assumption regarding the original isolators and several changes in the pallet geometry.

This revision also recommends that the vibration isolators be:

A. N-5210 (Modified) manufactured by Barry Controls, Inc., and

B. 156 PLT-16, manufactured by Lord Manufacturing Co.

1.0 Assumptions

i.) The model used in this analysis is based upon the weights and center of mass data of 11/20/70, Package 1-4, with a total weight of 19.38 lbs.

ii.) The outside envelope dimensions are based upon the print of 1/8/71, Print No. 07038.

iii.) There is no constraint at locations 2 and 3 (Figure 1.0) in the Y-Axis. This is the correction to the previous assumption that the isolators could be preloaded so that there would be restraints at these locations.

iv.) Mount stiffnesses, i.e. the radial or axial stiffnesses, are based on manufacturers information on the dynamic rather than static stiffness values.

v.) The elastomeric material in all mounts studied was a highly damped silicone. A modal damping value of 0.15 was assumed throughout the analysis.

vi.) The explosive packages and pallet comprised a rigid body having six degrees of freedom, and the mounts were considered the only flexible elements.

vii.) The Barry mounts, series 5200, were assumed to be modified by the use of a silicone elastomer. This change did not affect the published dynamic characteristics of the mount.

2.0 Input Data and Results

The mathematical model was built from the physical system shown in Figure 2.0. Table 2.0 presents the geometric data measured from the c.g. based coordinate system associated with this model. Tables 2.1 thru 2.6 present the basic data utilized in the twenty computer runs made in this study. The letter designations for the various matrices and vectors correspond to those in the original ATM. Table 2.7 is a summary of the dynamic stiffness characteristics of all of the mounts considered and utilized in this study. Table 2.8 summarizes the computer runs made and the mount combinations utilized in each run. Runs 10 & 11 were Y-Axis, 6 Hz dwell runs to evaluate the low frequency response.

The output response is summarized in Figures 2.1 - 2.4 and Tables 2.9 thru 2.11. The Figures 2.1 - 2.3 are plots of all the data points presented in Table 2.10. The solid curve is a plot of the specification data for the Design and Qualification of the explosive package. The term "Maxi-Max" means that the values presented are the maximums of the system, regardless of the input axes. Figure 2.4 shows the Maxi-Max response of four coordinates to the random input.

Before examining the response data it is necessary to examine the isolator's function, and the isolator's survival. The isolator's function is to soft mount the package so that the sine and random responses do not exceed the values given by system design specifications, Figure 2.5. In order to accomplish this, it is necessary to find a mount combination that has translational natural frequencies of about 20 Hz, and that groups all natural frequencies (translational as well as rotational) below 40 Hz. This, by itself, is relatively easy. However, the mounts must also survive while accomplishing this task. This means that the mounts must neither be statically overloaded nor dynamically overdriven.

The condition of static overload, relative to this study, meant that any mount chosen for use at location 1 (the end utilizing a clevis) had to be able to withstand between 4 and 8 lbs. in the X and Z directions, and 19.38 lbs. in the Y-direction.

The condition of dynamically overdriving the mounts is the critical condition. If an elastomeric mount is overdriven, it generates a considerable amount of heat and rapidly disintegrates. Both Lord and Barry indicated that for mounts of the type considered in this study, loaded at their "rated load", any double amplitude displacement (D. A. D.) in excess of the mounts static deflections could lead to failure in a few minutes, and faster if the D. A. D. were increased. For this study, the worst condition occurs during the required 6 Hz dwell test (10 sec. duration) at a level of 1.5 g (.82" D. A. D.)

The Design and Qualification Spec. places a 2.0 g upper limit on this condition. However, a 2 g response to a 1.5 g input at 6 Hz would give a relative motion across the isolators of .28" D. A. D. This is excessive.

Therefore, the mount combination finally choosen had to be a compromise between being able to completely isolate the critical components in the explosive packages while maintaining their structural integrity during the 6 Hz dwell test.

We now return to the output data of the study. A review of the Maxi-Max data (Table 2.9) shows that the 5210/156 PLT-16 mount combination exceeds the specification on component design at one location, u^1_x. A detailed study of this condition showed that the frequency band width above the .07 g^2/hz level was 9 Hz wide (Figure 2.4). Further investigation revealed that the overall G_{RMS} at this location, for an input in the X-direction, was 1.33 compared to the Specification value of 5.5 G_{RMS} (Table 2.10). Therefore, it was considered that this mount combination best satisfied the isolation condition.

The low frequency response was also examined (Table 2.11) to ascertain the chances of the mounts failing during the low frequency testing. The transmissibilities of the system at 6 Hz are given in Table 2.11. The G_{out} are also given and are clearly well below the 2.0 g limit. The last column gives the relative motion across the mounts in D. A. D. Since this table is a Maxi-Max response, the values occur when the input and output are in the same direction.

There are three critical locations, u_y^1, u_x^2, and u_z^2.

The u_y^1 coordinate is the only one reacting the loads in the Y-axis, since locations 2 and 3 (Figure 2.0) have bullet pins that offer no restraint in this axis. The static load limit on this mount (Barry 5210, modified) is 25 lbs, giving a radial (Y-direction) limit deflection of 0.084" D.A. This mount has a maximum travel (in the axial direction) of about 0.25" D.A. We are underloading the mount by 20%, statically. Thus, the mount should survive a 10 sec dwell at 6 Hz.

The u_x^2 & u_z^2 coordinates are radial coordinates to the two Lord 156 PLT-16 mounts. The static load on these mounts is between 4 and 8 lbs. in the X and Z axes. Although this type mount is rated at 16 lbs. (with a static deflection of .1875 inches) Lord recommends underloading by a factor of 3 to 4 when the 156 series is manufactured in this BTR elastomer (a silicone rubber.) Thus we are overloading these mounts. However, to offset this problem and to obtain more material to dissipate energy, we are also utilizing a "snubber" colar which only affects large amplitude motions, i.e., the type that will occur at 6 Hz and does not affect the mount's characteristics otherwise. Therefore, we should expect these mounts to survive a 10 sec, 6 Hz dwell test.

3.0 Conclusions

A review of all data indicates that the Barry N-5210/Lord 156 PLT-16 Mount combination should satisfactorally isolate the critical components of the explosive packages from the damaging random input above 40 Hz.

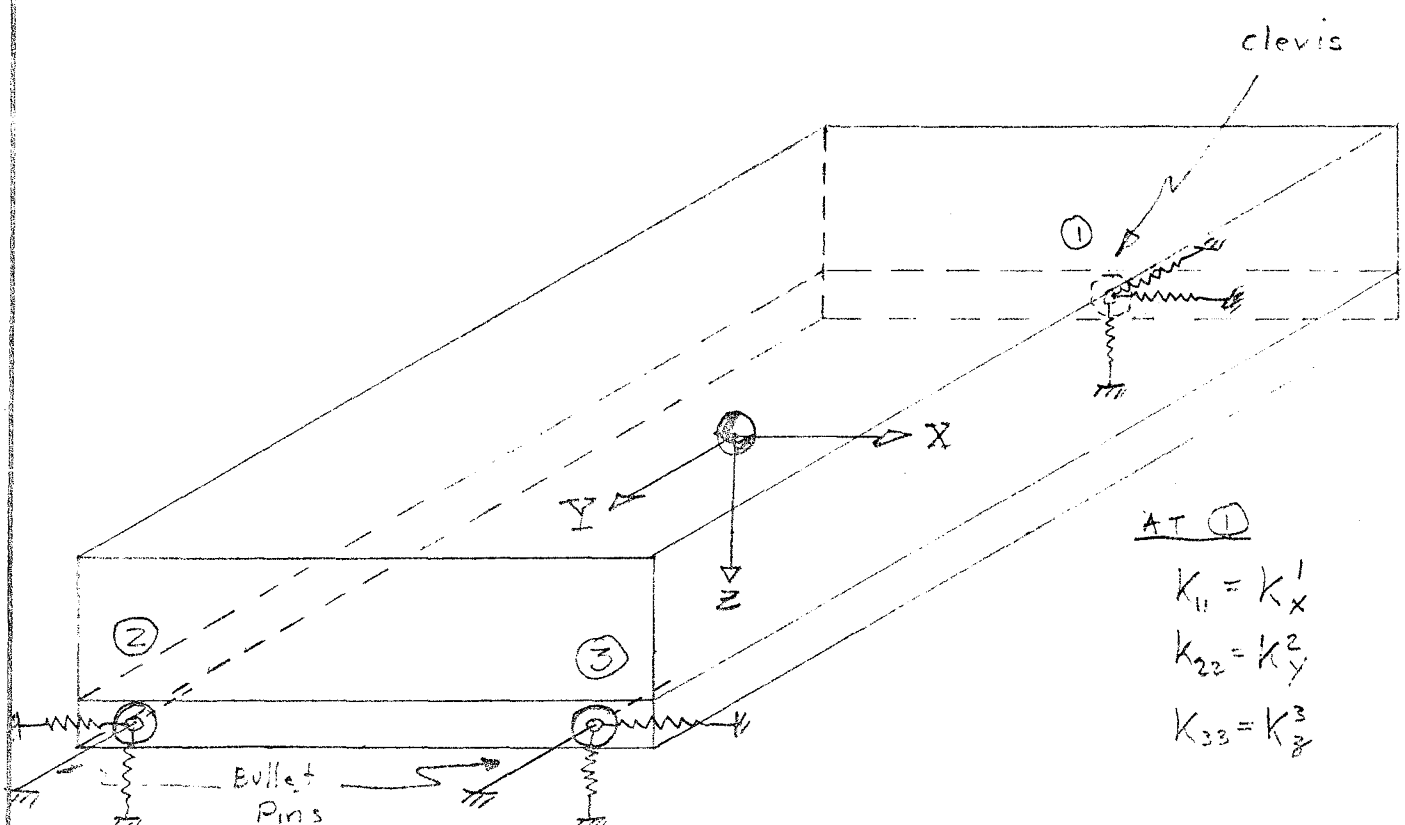
The data also shows that the design criteria is the sinusoidal input, rather than the 3σ random G_{RMS}. The design load factors are:

Limit Load Factor = 6g

Ultimate Load Factor = 9g

A potential problem does exist at 6 Hz. Due to a lack of test data on either type of mount with such a large input, there is no way of predicting the life expectancy of either type of mount. Therefore, spare mounts will be purchased to insure that the flight hardware will not have mounts that are fatigued. During testing, frequent inspections will be necessary. The monitoring of static deflections, mount temperatures and frequency characteristics will have to be accomplished to be used as indicators of potential trouble.

FIGURE 2.0 VIEW OF LSPE EXPLOSIVE PACKAGE SHOWING ISOLATOR STIFFNESS



AT ①

$K_{11} = K_x^1$

$K_{22} = K_y^2$

$K_{33} = K_z^3$

AT ②

$K_{44} = K_x^2$

$K_{55} = 0$

$K_{66} = K_z^2$

AT ③

$K_{77} = K_x^3$

$K_{88} = 0$

$K_{99} = K_y^3$

NOTE: K_{55} & K_{88} BOTH = 0 DUE TO SLIDING FIT ON BULLET PINS

Figure 2.1

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Axis: X - INPUT

X-AXIS RESPONSE

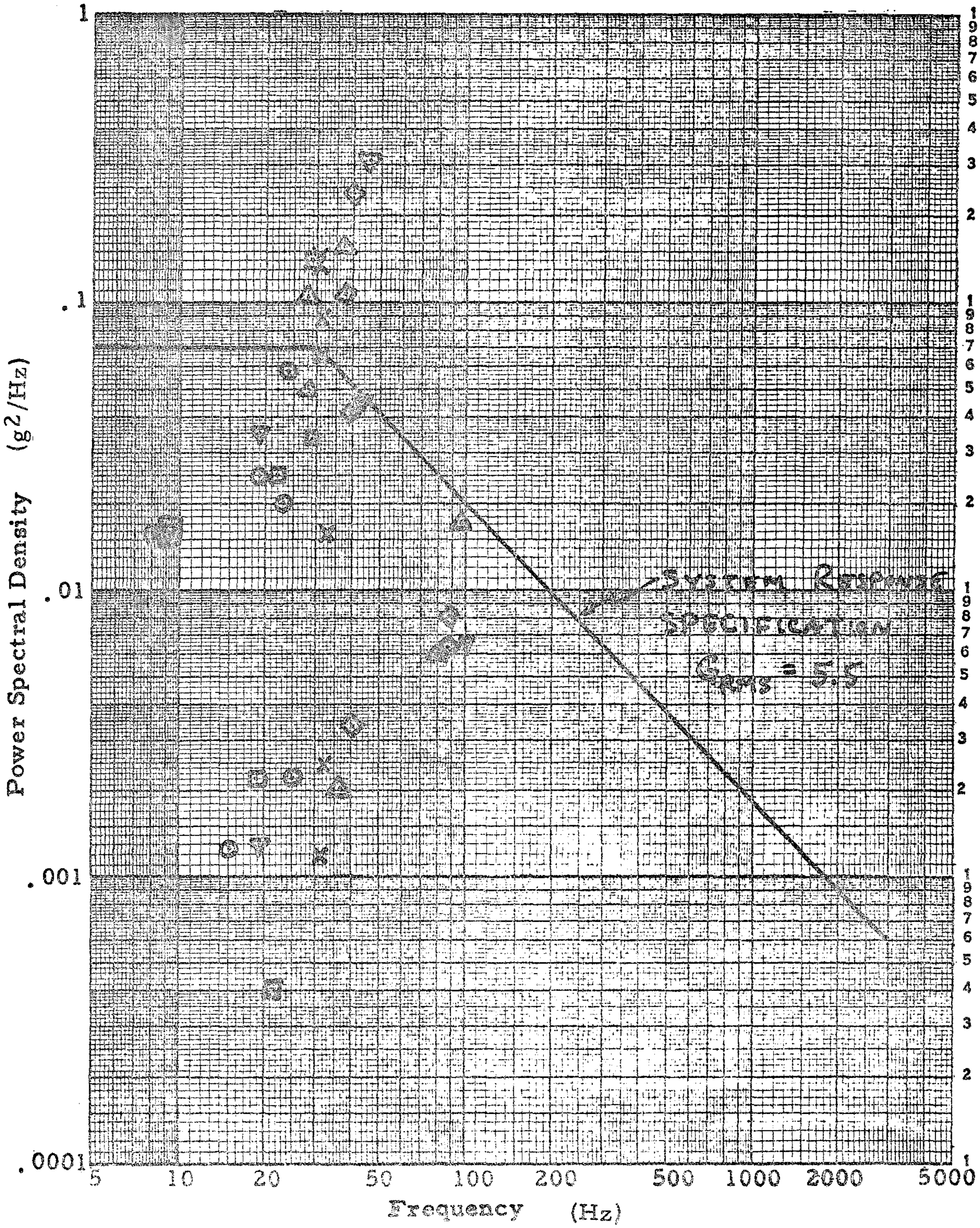

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Figure 2.2

Axis: Y - INPUT

Y-AXIS RESPONSE

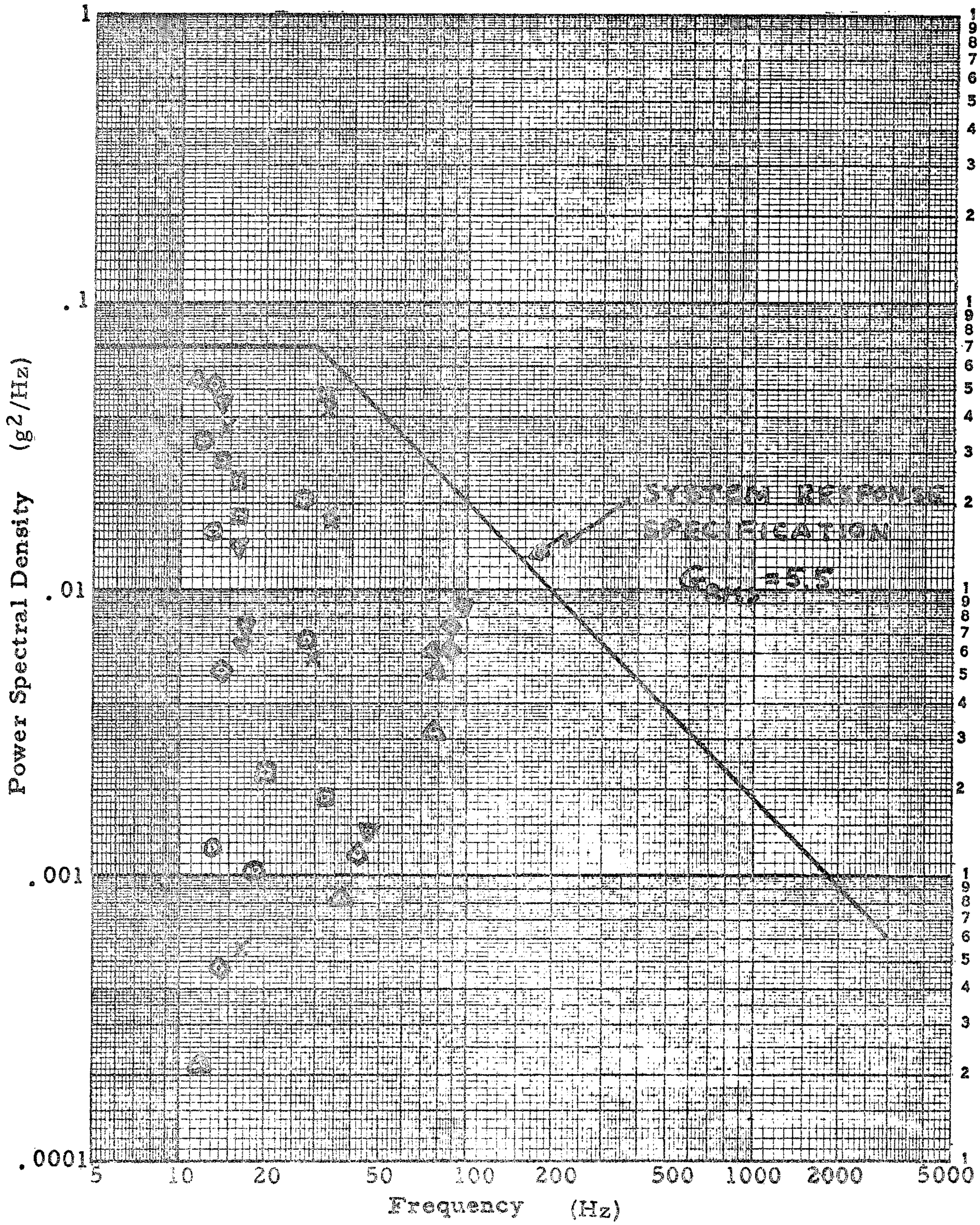

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Figure 2.3

Axis: Z-INPUT

Z-AXIS RESPONSE

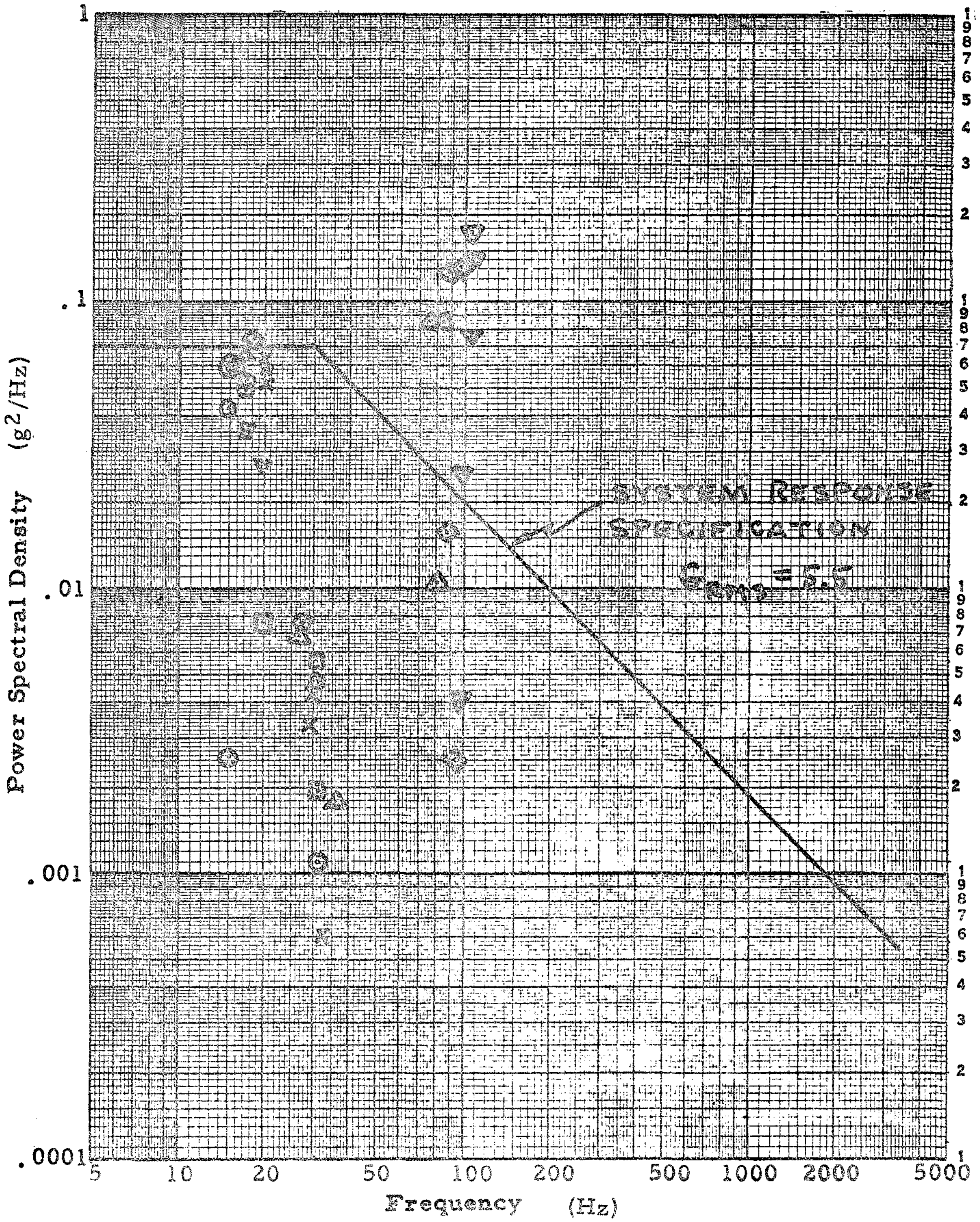

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Figure 2.4

COMPUTED RESPONSE OF ISOLATOR MOUNTED EXPLOSIVE MODULE (FINAL CHOICE)

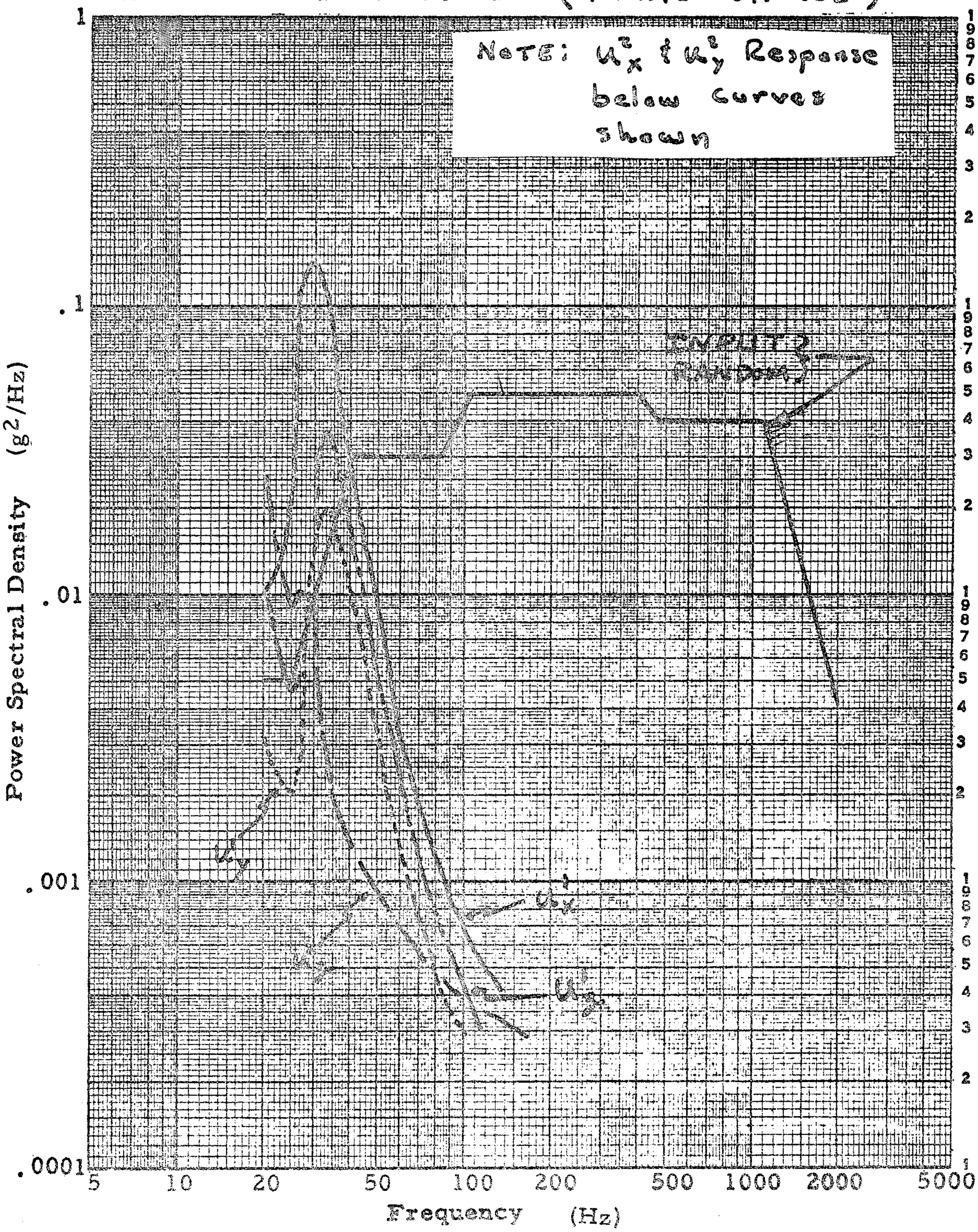

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FIGURE 2.5

DESIGN and QUAL VIBRATION LEVELS (SPEC.)
SINE & RANDOM

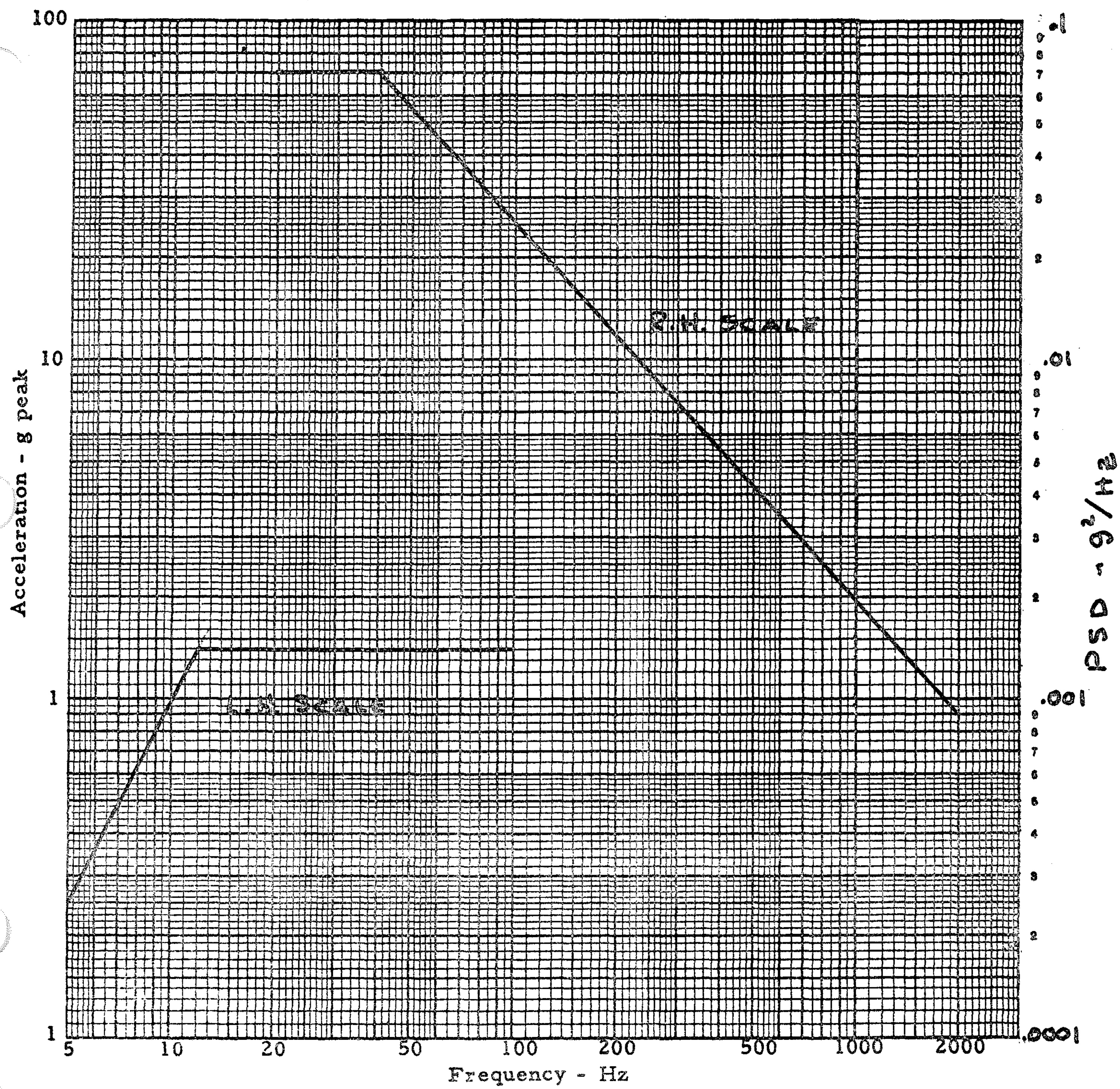

Table 2.1 Transformation Matrix for Conversion Between $\{x\}$ and $\{u\}$ coordinates.

$$
[A]_{9 \times 6} = \begin{bmatrix}
1.0 & & & & 3.895 & 9.23 \\
 & 1.0 & & & & \\
 & & & -3.895 & & .82 \\
 & & 1.0 & -9.23 & -.82 & \\
1.0 & & & & 3.895 & -6.3 \\
 & 1.0 & & -3.895 & & 3.555 \\
 & & 1.0 & 6.3 & 3.555 & \\
1.0 & & & & 3.895 & -6.3 \\
 & 1.0 & & -3.895 & & 5.195 \\
 & & 1.0 & 6.3 & -5.195 &
\end{bmatrix}
$$

Where

$$\{u\} = [A]\{x\}$$

Table 2.0 Geometric Data Utilized

A. Physical Dimensions of System (Envelope)

Length = 15.53 in

Width = 8.75 in

Heigth = 7.75 in

Weight = 19.38 lbs

Mass = $.0504 \frac{\text{lb-sec}^2}{\text{ft}}$

B. Distances of support locations from C.G. of System

Location 1

x = .82"

y = -9.23"

z = 3.895"

Location 2

x = -3.555"

y = 6.3"

z = 3.895"

Location 3

x = 5.195"

y = 6.3"

z = 3.895"

Table 2. 2 Transformation Matrix for $\{x\}$ to $\{u'\}$ coordinates

$$[B] = \begin{bmatrix} .40567 & 0 & 0 & .59433 & -.44514 & .44514 \\ .05281 & 1 & -.25081 & -.052801 & .125402 & .125402 \\ 0 & 0 & .40567 & 0 & .390881 & .203452 \\ 0 & 0 & -.064392 & 0 & .032196 & .032196 \\ 0 & 0 & 0 & 0 & .114286 & -.114286 \\ .0643915 & 0 & 0 & -.0643915 & 0 & 0 \end{bmatrix}$$

Where

$$\{x\} = [B]\{u'\}$$

Note:

$\{u'\}$ are generalized coordinates

Table 2. 3 Mass Matrix in $\{x\}$ Coordinate system

$$[m] = \begin{bmatrix} .0502 & & & & & \\ & .0504 & & & & \\ & & .0504 & & & \\ & & & 1.43816 & & \\ & & & & 0.88653 & \\ & & & & & 1.6892 \end{bmatrix}$$

Table 2.4 Transformed Mass Matrix Common to All Computer Runs

1.54385E-2	2.66117E-3	-6.67435E-4	5.00712E-3	-8.76749E-3	9.43493E-3
2.66117E-3	.0504	-1.26406E-2	-2.66117E-3	6.32028E-3	6.32028E-3
-6.67435E-4	-1.26406E-2	1.74276E-2	6.67435E-4	3.42506E-3	-4.07032E-4
5.00712E-3	-2.66117E-3	6.67435E-4	2.49473E-2	-1.36677E-2	1.30003E-2
-8.76749E-3	6.32028E-3	3.42506E-3	-1.36677E-2	3.15495E-2	-1.52742E-2
9.43493E-3	6.32028E-3	-4.07032E-4	1.30003E-2	-1.52742E-2	2.59352E-2

Where

$$[M] = [B]^T [m] [B]$$

Table 2.5 Diagonal Stiffness Matrix Based on $\{u\}$ Coordinates

$$[K]_{9 \times 9} = \begin{bmatrix} k_x^1 & & & & & & & & \\ & k_y^1 & & & & & & & \\ & & k_z^1 & & & & & & \\ & & & k_x^2 & & & & & \\ & & & & k_y^2 & & & & \\ & & & & & k_z^2 & & & \\ & & & & & & k_x^3 & & \\ & & & & & & & k_y^3 & \\ & & & & & & & & k_z^3 \end{bmatrix}$$

Where

$$[F^u]_{9 \times 1} = [k]_{9 \times 9} \{u\}_{9 \times 1}$$

Table 2. 6 The Stiffness Matrix

$$[K]_{6 \times 6} = \begin{bmatrix} k_x^1 & & & & & \\ & k_y^1 & & & & \\ & & k_z^1 & & & \\ & & & k_x^2 + k_x^3 & & \\ & & & & k_z^2 & \\ & & & & & k_z^3 \end{bmatrix}$$

The individual values of the k's vary according to the isolator combination utilized. See Table 2. 7 for data.

Table 2.7 Summary of Stiffnesses Used

Mount Type	kx	ky	kz
156 PLT-13	120	120	120
156 PLT-16	150	150	150
150 PLT-18	580	290	580
150 PLT-24	760	380	760
150 PLT-30	960	480	960
5205	240	400	240
5210	360	600	360
6300-11	230	230	230

Note: i) All stiffness Values in lbs/in.

ii) kx and kz are radial directions in mount coordinates

iii) ky is the axial direction in mount coordinates

Table 2.8 Mount Combinations Utilized in the Parametric Study

Run No.	Input Axis	Type Mount Used at Location 1	2	3
1	x	150 PLT-30	156 PLT-16	156 PLT-16
2	y	150 PLT-30	156 PLT-16	156 PLT-16
3	z	150 PLT-30	156 PLT-16	156 PLT-16
4	x	150 PLT-24	156 PLT-16	156 PLT-16
5	y	150 PLT-24	156 PLT-16	156 PLT-16
6	z	150 PLT-24	156 PLT-16	156 PLT-16
7	x	150 PLT-18	156 PLT-16	156 PLT-16
8	y	150 PLT-18	156 PLT-16	156 PLT-16
9	z	150 PLT-18	156 PLT-16	156 PLT-16
10	y	150 PLT-18	156 PLT-16	156 PLT-16
11	y	150 PLT-24	156 PLT-16	156 PLT-16
12	x	5210	156 PLT-16	156 PLT-16
13	y	5210	156 PLT-16	156 PLT-16
14	z	5210	156 PLT-16	156 PLT-16
15	x	5205	156 PLT-13	156 PLT-13
16	y	5205	156 PLT-13	156 PLT-13
17	z	5205	156 PLT-13	156 PLT-13
18	x	5210	6300-11	6300-11
19	y	5210	6300-11	6300-11
20	z	5210	6300-11	6300-11

Mount Combination	U_x^1 Sine	U_x^1 Random	U_y^1 Sine	U_y^1 Random	U_z^1 Sine	U_z^1 Random	U_x^2 Sine	U_x^2 Random	U_z^2 Sine	U_z^2 Random	U_z^3 Sine	U_z^3 Random
Barry 5210 Lord 156 PLT-16	5.2	.14	3.59	.029	4.0	.036	3.4	.025	4.88	.053	4.76	.0503
Barry 5210 Barry 6300-11	4.69	.14	4.1	.037	4.8	.051	3.77	.089	5.15	.059	5.37	.064
Barry 5205 Lord 156 PLT-13	5.16	.059	3.8	.033	4.36	.0423	3.37	.025	5.18	.0595	5.07	.0608
Lord 150 PLT-18 Lord 156 PLT-16	3.84	.055	4.96	.055	3.2	.086	5.04	.104	5.5	.067	4.7	.083
Lord 150 PLT-24 Lord 156 PLT-16	4.24	.24	4.85	.052	3.01	.129	5.12	.109	5.7	.0737	5.0	.1307
Lord 150 PLT-30 Lord 156 PLT-16	4.84	.312	4.5	.045	3.4	.176	4.02	.036	6.0	.078	4.3	.143
Lord 156 PLT-16 Lord 156 PLT-16	5.8	.075	3.64	.034	4.86	.058	2.66	.0157	2.78	.023	2.29	.015

TABLE 2.9 MAXI-MAX RESPONSE OF SYSTEM TO X-Y-Z INPUTS

TABLE 2.10. SINE & RANDOM RESPONSE TO X-Y-Z AXIS INPUTS

Mount Combinations	Program Coordination	Model Coordinates	X-AXIS INPUT Max Sine Response (G's)	Response Freq * (Hz)	Max Random PSD Resp. (g^2/Hz)	Total Random Response (G_{RMS})	Y-AXIS INPUT Max Sine Response (G)	Response Frequency Hz	Max Random PSD Response (g^2/Hz)	Total Random Response (G_{RMS})	Z-AXIS INPUT Max Sine Response (G's)	Response Frequency (Hz)	Max Random PSD Resp. (g^2/Hz)	Total Random Response (G_{RMS})	COMMENTS
Barry 5210 (1 ea) Lord 156 PLT-16 (2 ea)	1	U_x^1	5.2	28	.14	1.35	.5	32	.0019	.141	.55	31	.00198	.1516	
	2	U_y^1	.33	22	.00023	.0904	3.59	14	.029	.728	.96	30	.00586	.304	
	3	U_z^1	.7	19	.0022	.158	2.67	31	.049	.787	4.0	17	.036	.864	
	4	U_x^2	3.4	22	.025	.762	1.02	20	.0023	.148	1.73	19	.0066	.236	
	5	U_z^2	1.9	12/9	.016	.465	2.86	16	.018	.512	4.88	18	.053	.726	
	6	U_z^3	2.7	22/29	.034	.707	3.27	16	.024	.528	4.76	18	.0503	.762	
Barry 5210 (1 ea) Barry (300-11 (2 ea)	1	U_x^1	4.69	30	.14	1.311	.5	17	.0056	.127	.866	30	.0043	.2168	
	2	U_y^1	.134	31	.0012	.033	4.1	15	.037	.744	.291	31	.00061	.0928	
	3	U_z^1	.88	21/32	.0025	.202	2.4	32	.043	.749	4.8	20	.051	.826	
	4	U_x^2	3.77	29/31	.089	1.11	.39	25/29	.0057	.0977	1.13	22/29	.00339	.229	
	5	U_z^2	2.45	11.6/32	.0163	.572	1.74	16/33	.018	.497	5.15	20	.059	.778	
	6	U_z^3	3.4	29/31	.069	.908	1.85	16/33	.017	.499	5.37	20	.064	.876	
Barry 5200 (1 ea) Lord 156 PLT-13 (2 ea)	1	U_x^1	5.16	24	.059	.937	.5	13/28	.0068	.097	.717	22	.0011	.123	
	2	U_y^1	.276	23/25	.0022	.0504	3.8	12	.033	.583	1.07	15	.00256	.171	
	3	U_z^1	.757	16	.0013	.1222	2.6	26	.021	.546	4.36	15	.0423	.675	
	4	U_x^2	3.37	15	.025	.673	.69	19	.001	.0986	1.46	17	.0048	.191	
	5	U_z^2	1.81	14/8	.016	.402	2.4	13	.0126	.375	5.18	15	.0595	.653	
	6	U_z^3	3.03	23	.0204	.584	2.68	13	.016	.393	5.07	15	.0608	.698	

*Note: If only one value, it applies to both sine and random PSD Resp.
If two values, then freq. on left goes with sine & freq. on rt. with Random

TABLE 2.10 (CON'T) SINE & RANDOM RESPONSE TO X-Y-Z AXIS INPUTS

Mount Combinations	Program Coordinates	Model Coordinates	X-AXIS INPUTS: Max Sine Response (G)	Response Freq (Hz)	Max Random PSD Resp. (g^2/Hz)	Total Random Response (G_{RMS})	Y-AXIS INPUTS: Max Sine Response (G)	Response Frequency (Hz)	Max Random PSD Response (g^2/Hz)	Total Random Response (G_{RMS})	Z-AXIS INPUT: Max Sine Response (G)	Response Frequency (Hz)	Max Random PSD Resp. (g^2/Hz)	Total Random Response (G_{RMS})	COMMENTS
Lord 150 PLT-18 (1 ea) Lord 156 PLT-16 (2 ea)	1	U_x^1	3.84	37	.155	1.492	.28	36	.00083	.1197	.7	19/36	.00178	.646	
	2	U_y^1	.43	37	.002	.238	4.96	11.6	.0546	.568	.889	81	.0105	.895	
	3	U_z^1	.664	79	.0059	.484	.62	78	.0052	.442	3.2	18/79	.086	1.844	
	4	U_x^2	5.04	28	.104	1.08	.315	12	.00022	.0798	1.5	20/27	.068	.682	
	5	U_z^2	3.9	25/28	.05	1.069	1.04	12/78	.0032	.365	5.5	17.6	.067	2.76	
	6	U_z^3	2.04	10/96	.017	.627	1.09	12/78.	.00616	.49	4.7	18/81	.083	4.19	
Lord 150 PLT-24 (1 ea) Lord 156 PLT-16 (2 ea)	1	U_x^1	4.24	40	.24	1.866	.3	41	.0012	.148	.55	20/94	.0025	.671	
	2	U_y^1	.506	41	.0034	.2905	4.85	13	.0522	.611	1.14	19/89	.016	1.05	
	3	U_z^1	.67	87/88	.0064	.5276	.67	88	.0063	.517	3.01	89	.129	2.333	
	4	U_x^2	5.12	27/28	.109	1.203	.47	14	.005	.0996	1.6	21/28	.00703	.7061	
	5	U_z^2	3.711	25/42	.043	1.104	1.54	14	.0052	.439	5.7	19	.0737	2.985	
	6	U_z^3	2.04	18/88	.008	.6704	1.55	14/89	.0074	.577	5.0	19/91	.1307	4.471	
Lord 150 PLT-30 (1 ea) Lord 156 PLT-16 (2 ea)	1	U_x^1	4.84	45	.312		.32	45	.0014		.46	97	.0038		
	2	U_y^1	.775	19	.0013		4.5	14	.045		1.4	18/97	.025		
	3	U_z^1	.614	94/100	.0064		.7	97	.0089		3.4	97/103	.176		
	4	U_x^2	4.02	19/19	.036		.85	17	.0074		3.5	19.8	.027		
	5	U_z^2	1.9	46	.0496		1.82	16	.0066		6.0	22/106	.078		
	6	U_z^3	2.07	17/9	.016		1.72	15	.014		4.3	19/106	.143		

Table 2.11 6 Hz Dwell Response of the 5210/156 Plt-16 Mounts

Location	Transmissibility	G_{out}	D.A.D. out	Relative Motion
u_x^1	1.111	1.6665	.9	.08
u_y^1	1.139	1.7085	.98	.16
u_z^1	1.088	1.632	.88	.06
u_x^2	1.222	1.833	1.0	.18
u_z^2	1.242	1.863	1.02	.20
u_z^3	1.087	1.6305	.88	.06

Notes

i) Input = 1.5 g or .82" D.A.D.

ii) Input/Output are in phase