X-321-74-174

NASA TM X- 71091

A STATISTICAL APPROACH TO ESTABLISHING SUBSYSTEM ENVIRONMENTAL TEST SPECIFICATIONS

(NASA-TM-X-71091) A STATISTICAL APPROACH TO ESTABLISHING SUBSYSTEM ENVIRONMENTAL TEST SPECIFICATIONS (NASA) 27 p HC $4.00 CSCL 22B

N76-22272

Unclas
G3/18 27493

W. BRIAN KEEGAN

JUNE 1974

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

For information concerning availability
of this document contact:

Technical Information Division, Code 250
Goddard Space Flight Center
Greenbelt, Maryland 20771

(Telephone 301-982-4488)

X-321-74-174

A STATISTICAL APPROACH TO ESTABLISHING SUBSYSTEM ENVIRONMENTAL TEST SPECIFICATIONS

W. Brian Keegan

June 1974

Goddard Space Flight Center
Greenbelt, Maryland

A STATISTICAL APPROACH TO ESTABLISHING SUBSYSTEM ENVIRONMENTAL TEST SPECIFICATIONS

W. Brian Keegan
Structural Dynamics Branch
Test and Evaluation Division

ABSTRACT

Results are presented of a research task to evaluate structural responses at various subsystem mounting locations during spacecraft level test exposures to the environments of mechanical shock, acoustic noise and random vibration. This statistical evaluation is presented in the form of recommended subsystem test specifications for these three environments as normalized to a reference set of spacecraft test levels, and are thus suitable for extrapolation to a set of different spacecraft test levels. The recommendations are dependent upon a subsystem's mounting location in a spacecraft, and information is presented on how to determine this mounting "zone" for a given subsystem.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

TABLES

ILLUSTRATIONS

PRECEDING PAGE BLANK NOT FILMED

CONTENTS (continued)

PRECEDING PAGE BLANK NOT FILMED

A STATISTICAL APPROACH TO ESTABLISHING SUBSYSTEM ENVIRONMENTAL TEST SPECIFICATIONS

INTRODUCTION

In this day of escalating costs, the specification of realistic environmental test levels has assumed increased importance. In order to extract as much value as possible from the procurement dollar, project managers justifiably demand test levels that are simultaneously high enough to provide the required reliability for successful flight performance and low enough to preclude inducing unrealistic test failures. This report presents what is felt to be a cost effective method for defining such environmental test specifications at a period in a spacecraft program when they can be utilized for design through the application of statistical analysis techniques.

The scope of this report is limited to "subsystem" specifications and by "subsystem" is meant any unit below the spacecraft level which is environmentally tested at that level of assembly. To relate this to the formal nomenclature established in Ref. (1), the term "subsystem" used here, could be either a spacecraft "system", "component", or "assembly".

The discussion here is limited to response to the environments of mechanical shock, acoustic noise and random vibration. While the environment of sinusoidal vibration is also of importance, it is felt that statistical response prediction techniques are not as satisfactory as response prediction techniques which either utilize a mathematical model or draw upon prior experience with spacecraft that are similarly constructed when developing sinusoidal subsystem specifications. Generally speaking, sine vibration is a lower frequency phenomenon and therefore more amenable to techniques which predict responses of a particular design rather than relying on predictions about the "average" spacecraft. Relying on ones experience to estimate damping values, a modal analysis of a rather simple mathematical model will produce reasonably accurate response predictions in the frequency range of the primary spacecraft resonant frequencies. It is for this reason therefore that predicted responses to spacecraft sinusoidal vibration inputs are not included in this report.

The desire for cost-effective specifications led to a review particularly of the approach to the environments treated here to see if the simulation characteristics of the subsystem test program could be improved while still specifying environmental tests that were reasonably straightforward to perform. The objective was to define this better test program without requiring major expenditures in new laboratory equipment or personnel training so as not to negate the potential cost-savings that would accrue from less re-design and re-test effort associated with the elimination of unrealistic failures due to overtest.

The organization of this report is such as to always discuss responses at subsystem mounting locations in terms of some spacecraft level environmental test input. As such, it assumes that the responses induced by the spacecraft level tests are realistic and that the various environmental exposures which comprise the spacecraft test program are adequate. It is recognized that the spacecraft random vibration test or acoustic test, applied singly, has shortcomings as discussed in Reference 2 and 3. Except for the few precautionary steps advised in the section entitled "Applications", however, this report does not attempt to comment on current spacecraft test practices, but rather it accepts the current practices and develops a subsystem test program based on them.

DISCUSSION

In most instances encountered at Goddard, the test specifications serve also as design criteria, particularly for subsystems. Representative specifications are required prior to the completion of spacecraft structural design and thus prior to the knowledge of the spacecraft structural transmission characteristics. Such preliminary specifications must, therefore, be based on an "average" or "typical" response at the subsystem mounting locations, a requirement that is especially amenable to statistical analysis.

Zoning of Spacecraft Structure

There was available at Goddard large quantities of data measured at various subsystem locations during the spacecraft level test of many different spacecraft to the environments of mechanical shock, acoustic noise, and random vibration. Since it seemed unreasonable to force all subsystems into the same category for environmental test level recommendations the concept of "zoning" was employed whereby the spacecraft was subdivided into several typical subsystem mounting areas, each possessing its characteristic type of response to the various environments. An exploded view of a typical spacecraft is provided in Figure 1 to illustrate those portions of the structure which are included in each of the four zones that are defined as follows:

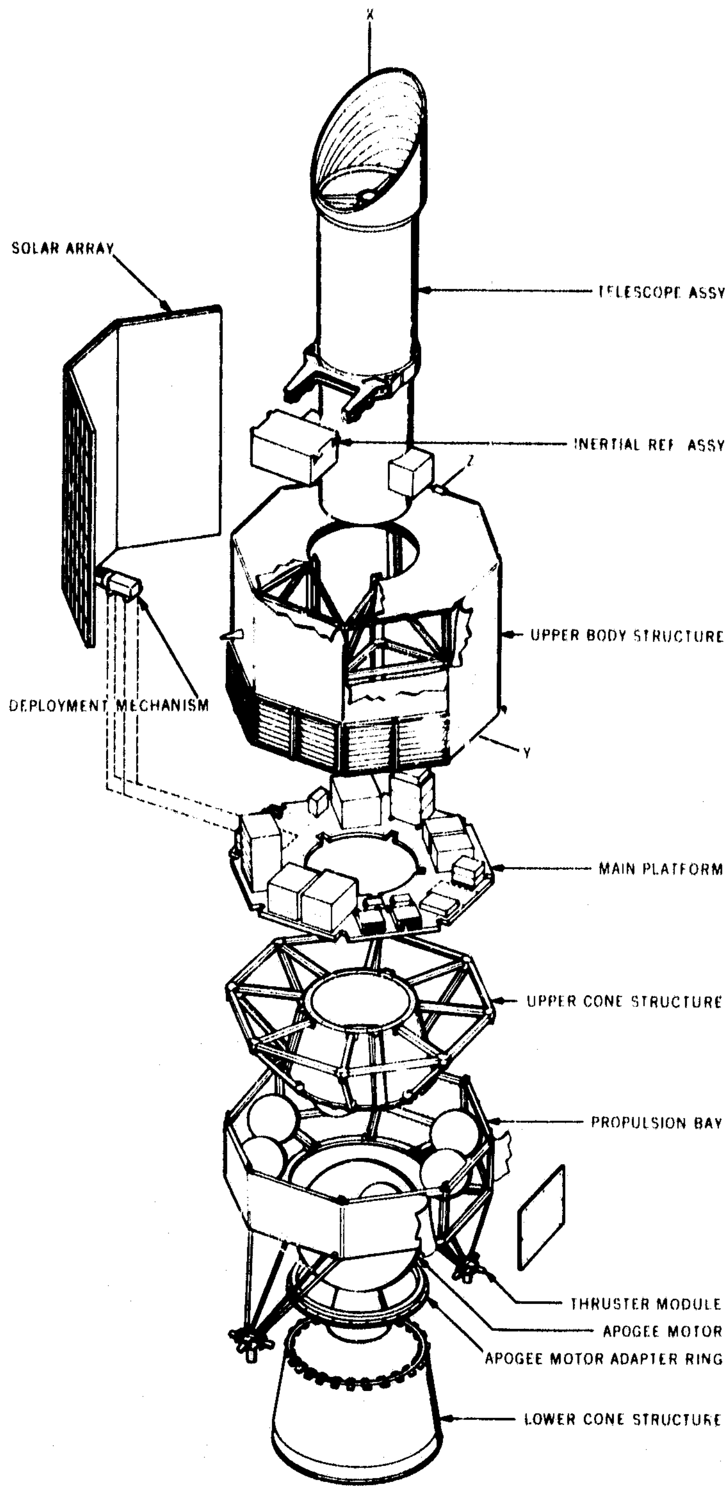

Figure 1. Exploded View of Typical Spacecraft.

Zone 1 – <u>primary structure within two feet of the spacecraft/launch vehicle interface,</u> (such as the Lower Cone Structure and the Apogee Motor Adapter Ring of Figure 1). Responses of subsystems mounted in this zone to the environment of mechanical shock are extremely high because of their proximity to the spacecraft separation plane and the resultant high pyrotechnically induced shock transients produced during the spacecraft/launch vehicle separation sequence. Zone 1 responses to acoustics are usually low since the reverberant acoustic field which excites the external spacecraft shell is attenuated as it travels inward through the spacecraft to excite the components mounted in this zone. Zone 1 responses to random vibration meanwhile are reasonably severe and the resultant acceleration spectral density usually looks much like the input spectrum specified for control of the test, since they are close enough to the control interface that the spacecraft structural transmission characteristics neither significantly amplify nor attenuate the input vibration levels, except in the regions of local resonances.

Zone 2 – <u>primary spacecraft structure more than two feet from the spacecraft/launch vehicle interface,</u> (such as the Propulsion Bay truss structure, the Upper Cone Structure, and the Upper Body truss structure of Figure 1). Responses of subsystems mounted in this zone to the environment of mechanical shock are reasonably high. This is so even though they are somewhat removed from the source of the most severe pyrotechnic shock transient since the transmission path to these mounting areas usually contains few if any mechanical interfaces. Responses to the environments of acoustic noise and random vibration meanwhile can be most simply characterized as resembling those of Zone 1 and for essentially the same reasons. Therefore a distinction between these zones was made only for the mechanical shock environment, as will be seen when the results of the statistical analysis are presented later in this report.

Zone 3 – <u>secondary spacecraft structure internal to the spacecraft outer shell,</u> (such as the Main Platform and the equipment mounting shelves internal to the Telescope Assembly of Figure 1). Such secondary structure is usually designed expressly for mounting subsystems, and includes items such as honeycomb panels, equipment shelves and the like where the majority of a spacecraft's subsystems are to be mounted. Responses of subsystems mounted in this zone to the envornment of mechanical shock can usually be described as moderate. The peak G level of the exciting transient is still rather high but it has been significantly attenuated since leaving the source by the mechanical interfaces encountered along the structural transmission path. The vibratory responses in this zone to acoustic noise are rather severe.

Both low - and mid-frequency responses are significant due to the direct acoustic excitation and the structure borne vibration induced by the acoustic excitation of the outer shell. The high-frequency response falls off rapidly due both to the fact that the acoustic levels roll off in this range and that the structure simply tends not to respond to high-frequency excitation. The response of Zone 3 subsystems to spacecraft level random vibration inputs is similar to that for acoustic noise and are usually characterized by an acceleration spectral density that is reasonably high in the low-and mid-frequency ranges, because of the excitation of the spacecraft's primary and secondary resonant modes, and has rolled off in the high-frequency range (above 1000 Hz) since the spacecraft tends to act as a low pass filter above its resonant modes.

Zone 4 – external spacecraft shell structure, (such as the outer skins of the Propulsion Bay, Upper Body Structure and Telescope Assembly as well as the Solar Arrays of Figure 1). Subsystems included in this zone are those mounted on booms or solar panels and those mounted on the spacecraft outer shell itself. The response of subsystems mounted in this zone to the environment of mechanical shock is usually mild unless it is in close proximity to some secondary pyrotechnic device. This response, however, is not so mild that a mechanical shock test is not required but is mild enough so as to be only a minor consideration in the design of the subsystem. The response to acoustic excitation in this zone is rather significant since subsystems mounted here are directly exposed to the acoustic field. Conversely, the response to random vibration is relatively mild since at most frequencies, other than those of the primary spacecraft resonant modes, the structure attenuates the excitation introduced at the base of the spacecraft.

The response descriptions contained above are best characterizes as intuitive. Data will be presented later that provide actual comparisons between the various zones as a result of the statistical analysis.

Digitization of Response Data

As previously stated all data used in the study were measured responses at subsystem mounting locations during spacecraft level environmental exposures. Data from mechanical shock tests consisted of responses to the spacecraft/launch vehicle separation event and were in the form of acceleration shock response spectra for Q equal to 10. The data from acoustic noise and random vibration tests were in the form of acceleration spectral density using narrow band resolution. The resolution of the statistical analysis was one-third octave thereby providing 15 discrete points between 200 and 5000 Hz at which to compute statistical responses to the mechanical shock environment and 21 points between 20 and 2000 Hz at which to compute statistical responses to the acoustic noise and random vibration environments. For the shock data the digitized magnitude was the shock spectrum value computed at the center frequency of each one-third octave band. For the acoustic and random data the digitized magnitude was the peak acceleration spectral density in each one-third octave band minus 3dB. So as to not introduce any conservative bias into the digitization process it had been felt that the best value to select was the actual PSD value at the center frequency of each band. Precise definition of this value, however, proved most difficult in many instances because the PSD was changing rapidly, thereby necessitating a different approach. From a sample of approximately 100 trials it was determined that the peak value minus 3dB was on the average a close approximation of the actual PSD value at the center frequency of the band and therefore this method of digitization was the one utilized. A summary of all data included in the study is provided in Table 1. In all, 320 channels of data were used which represented responses measured on spacecraft covering the entire weight range and varieties of structural type encountered on GSFC managed programs.

Prior to performing the statistical analysis it was necessary to normalize all subsystem response data to a reference spacecraft test level. For the mechanical shock environment precise normalization was not possible since there was no easy way to define a reference system level shock. All shock data included in the study was, however, taken during spacecraft separation tests using a tensioned V-band clamp and multiple bolt cutters to initiate the separation sequence. As such, the results of the analysis represent the response to a "typical" spacecraft separation event. For the acoustic noise and random vibration environments, reference spacecraft levels were readily obtainable from Ref. 4. All acoustic test responses were normalized to the octave band spectrum presented in Figure 2a. The reference spectrum shape within each octave band was flat; that is, the noise levels in each of the three one-third octave bands were equal to one another. All random vibration test responses were normalized to the acceleration density spectrum presented in Figure 2b. It must be remembered that all recommendations made later in this report are made with respect to these reference spacecraft test levels.

Distribution of Response Data

As the first step in performing the statistical analysis, it had to be determined whether the collection of data from the several diverse spacecraft into an aggregate was warranted thereby providing assurance that heterogeneous groups of

Table 1

Test Data Included in Statistical Response Analysis

Spacecraft	Weight (Kg)	No. of Data Channels										
		Shock				Acoustics			Random			Total
		Zone 1	Zone 2	Zone 3	Zone 4	Zone 1 & 2	Zone 3	Zone 4	Zone 1 & 2	Zone 3	Zone 4	
Nimbus	771	1	10	12	6	-	-	-	-	-	-	29
OSO	272	3	4	20	-	2	4	-	-	-	-	33
Tiros	272	4	8	10	-	-	-	-	-	-	-	22
IMP	363	9	-	12	2	-	-	-	3	8	12	46
IDCSP	272	6	-	-	-	-	-	-	-	-	-	6
SMS	635	6	6	22	-	-	-	-	-	-	-	34
ATS	499	8	5	2	-	-	-	-	-	-	-	15
OAO	2087	-	13	10	-	-	1	7	-	-	2	33
OGO	635	-	-	-	-	9	29	3	10	29	3	83
San Marco	363	-	-	-	-	-	-	1	-	-	-	1
RAE	363	-	-	-	-	-	9	-	-	9	-	18
	Total	37	46	88	8	11	43	11	13	46	17	320

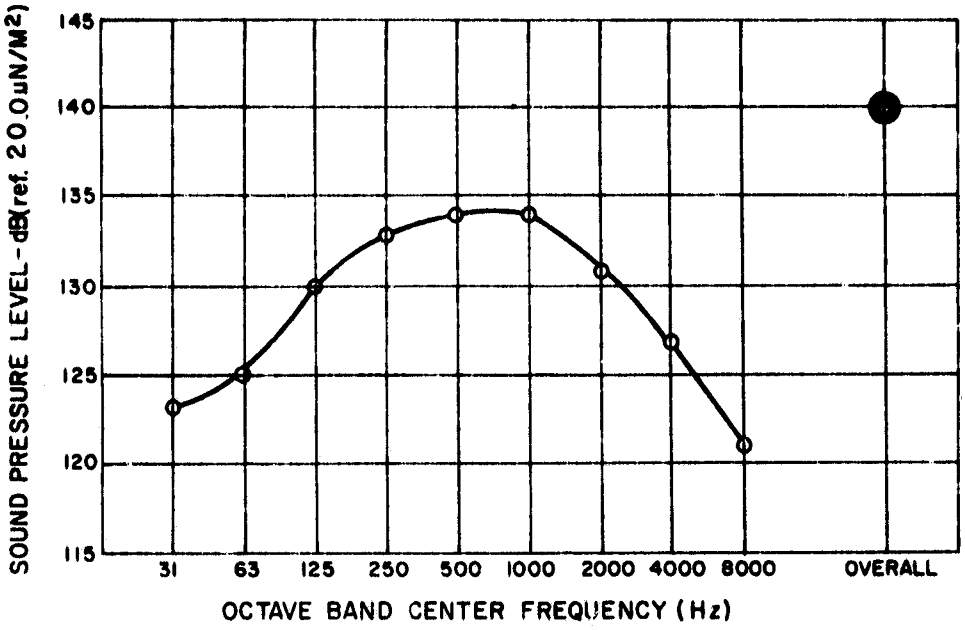

Figure 2-a. Reference Acoustic Noise Environment.

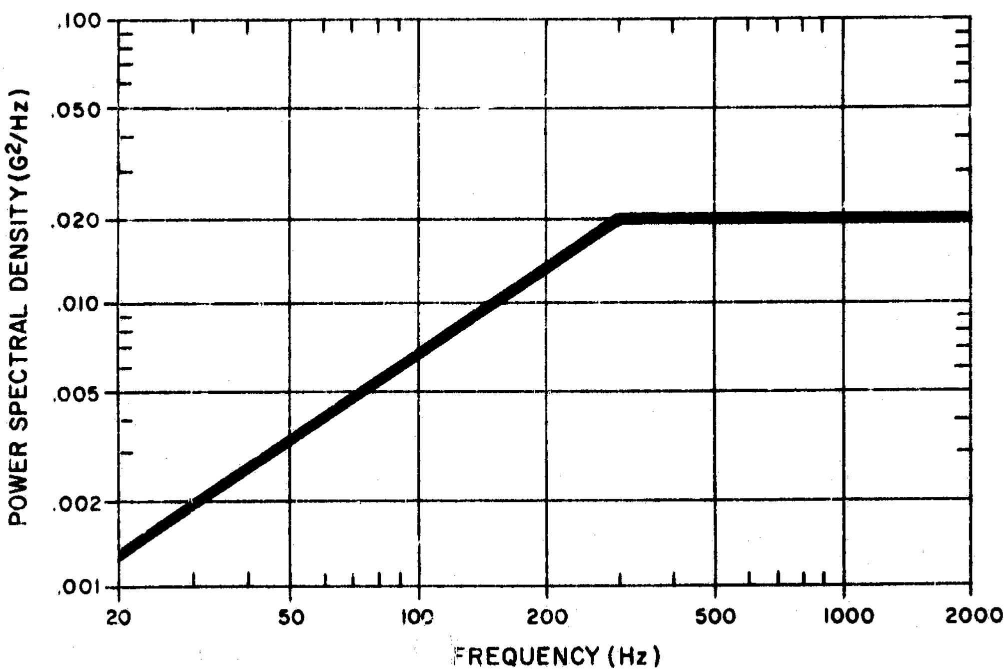

Figure 2-b. Reference Random Vibration Environment.

data had not simply been forced together purely for the convenience of defining a single recommended test level. Although no rigorous statistical analysis was undertaken to verify the homogeneity of data from different spacecraft, several empirical observations were felt to justify grouping all the data into one population. When observing the distribution of data for any given environment from a particular zone at a specific frequency one could observe clustering of the data from each individual spacecraft, not so much so that the range of data from one spacecraft did not overlap the ranges of data from several other spacecraft, but enough so that the variance of data from any single spacecraft was significantly less than the variance of the total population. The mean values of the data from the individual spacecraft were well scattered about the population mean. When observing the entire spectral bandwidth it was found that the ratio of any particular spacecraft mean to the population mean varied with frequency and was on the average close to unity. Therefore, when considering the entire frequency range, the data from the various spacecraft could be described as being well mixed with none being noticably biased in either direction thereby justifying the assemblage of data from the many different spacecraft into one large population.

Initial statistical treatment of the data consisted of computing the mean and standard deviation of the responses to each environment at each frequency in each zone. Next, two representative frequencies from each of three zones for each of the three environments were selected and their distributions plotted to facilitate the subsequent determination of which combination of the calculated parameters equaled the desired probability level of response at which it was desired to establish the recommended subsystem specification. Figure 3a presents a log-normal probability plot for response data from Zones 1, 2, and 3 at 1000 Hertz to the pyrotechnic shock environment. If the distribution were precisely log-normal a straight line could be passed through all of the data points for any one zone. The actual data points fitted a straight line well enough that a conclusion that the distribution was log-normal was certainly warranted. The results at 500 Hertz were equally as good. Figures 3b and 3c present log-normal probability plots of Zone 3 response data at 500 and 1000 Hz to acoustic noise and random vibration inputs respectively. Both figures substantiate classifying the observed data as having a log-normal distribution. The evaluation of Zones 2 and 4 response to random vibration and acoustic inputs did not agree quite as well with a log-normal distribution as does the data shown but this was disregarded since those distributions were constructed from a maximum of 17 samples, whereas the distributions shown in Figure 3 were constructed from a minimum of 37 samples.

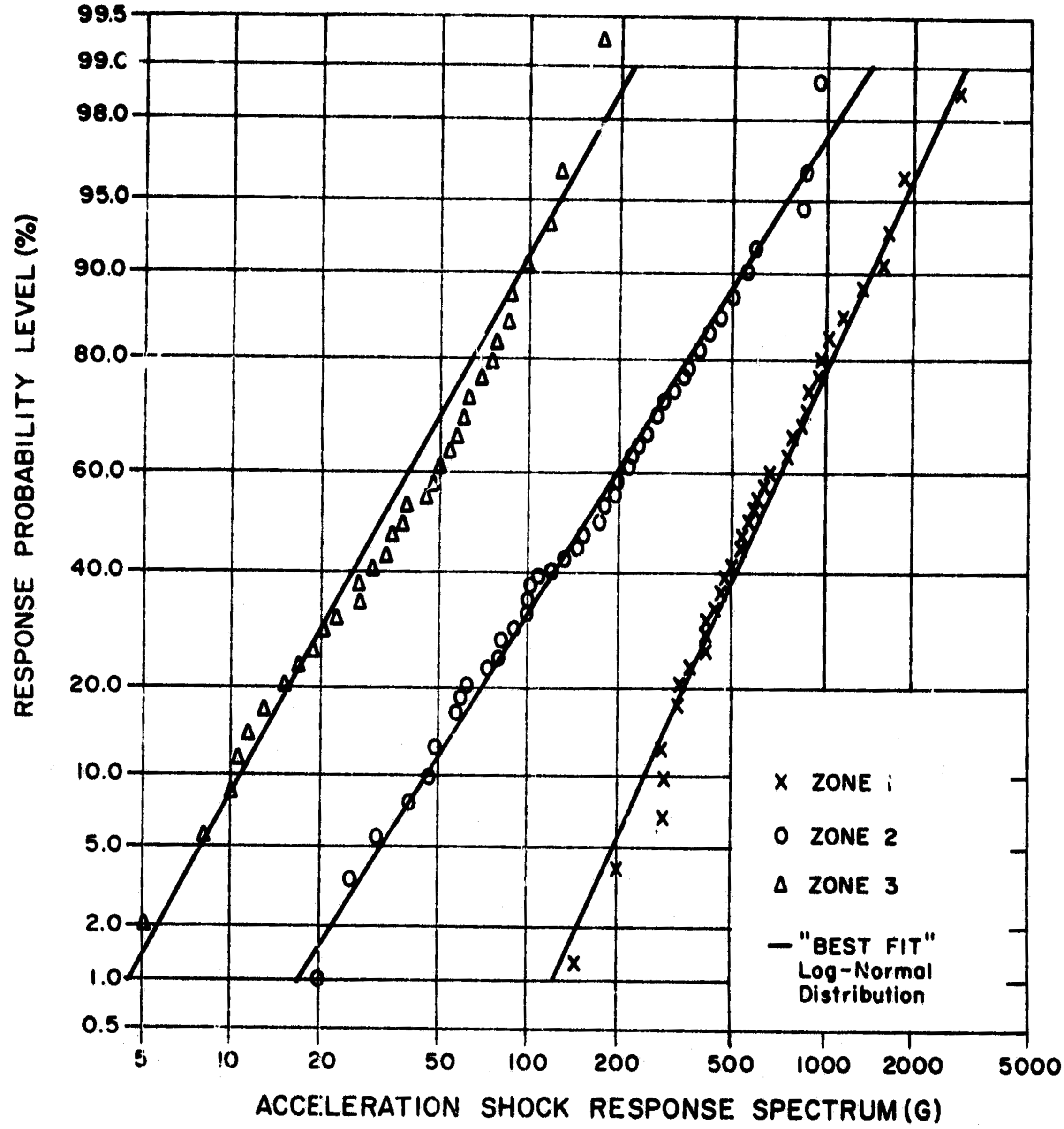

Figure 3-a. Probability Distribution of Subsystem Response at 1000 Hz to Reference Pyrotechnic Shock Environment.

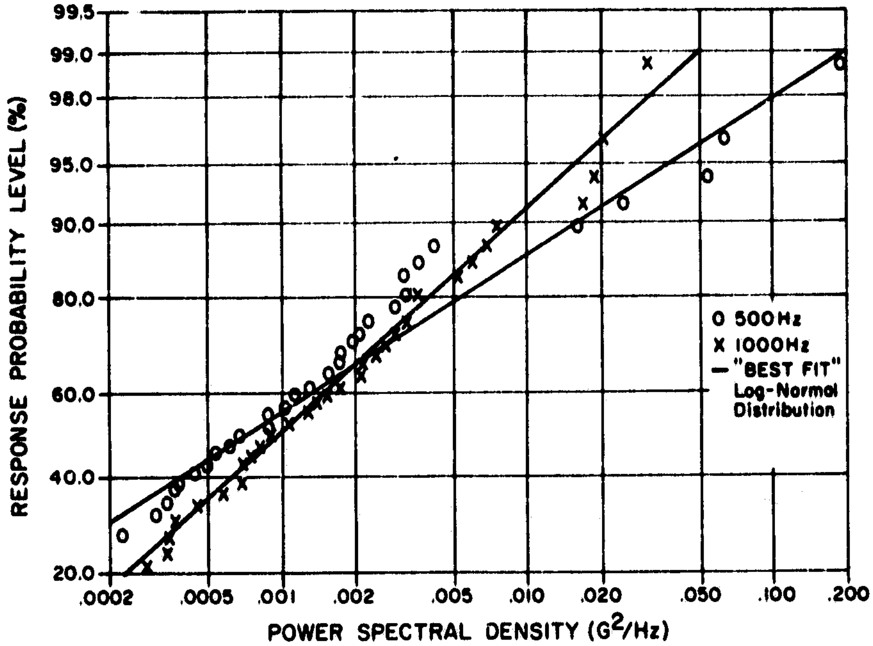

Figure 3-b. Probability Distribution of Zone 3 Subsystem Response to Reference Acoustic Environment.

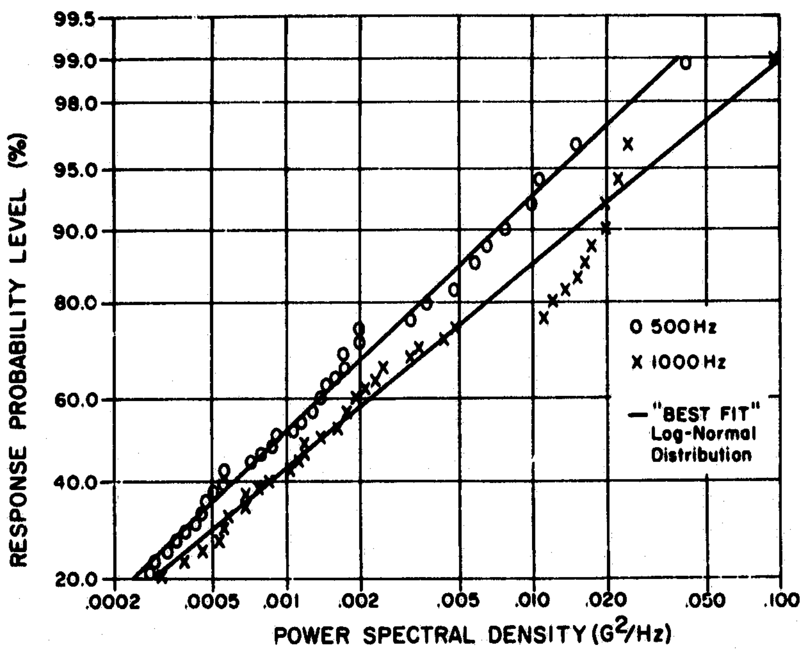

Figure 3-c. Probability Distribution of Zone 3 Subsystem Response to Reference Random Vibration Environment.

Selection of "Desired" Test Level

Having plotted the distribution of the data it then had to be decided at what percentage probability response level it was desired to set the recommended subsystem test specifications. To rephrase this question in converse terms, it had to be determined what percentage of the time it was acceptable to see a subsystem respond during spacecraft test to a higher level than that to which it had been tested as a subsystem. Too high a probability level for the subsystem test and the result would be a large number of unrealistic subsystem test failures. Too low a probability for the subsystem test and the result would be a large number of failures during spacecraft level environmental tests. A probability level of 95 percent was selected as the target for defining subsystem test levels, because it seemed intuitively to be a good number, although it was admittedly somewhat arbitrary. The actual level would of necessity vary because of the pragmatisms involved in constructing any test specification. It was further realized that this 95 percent level might not be optimal from the cost effectiveness viewpoint; and one of the follow-on efforts to this study will be to determine whether it or some other probability level is better from the standpoint of total program environmental test cost.

Further evaluation of the response distributions and the tabulated means and standard deviations of the responses showed that the value of the mean plus twice the standard deviation consistently fell between the 93 and 96 percent probability level response on the "best-fit" line for a log-normal distribution on the probability plot. It was thus determined that the mean plus twice the standard deviation was a good estimator of the 95 percent probability level response and would be used to define the desired subsystem test level.

It should be noted that the probability response level being discussed above concerns the probability of a given subsystem responding to a certain level during a spacecraft test at the reference spacecraft level environmental input and is unrelated to the probability level of the environment at which one chooses to define his spacecraft test.

Questions regarding environmental probability levels, acceptance test magnitudes and design qualification margins are therefore not considerations in this report.

RESULTS

Mechanical Shock Recommendations

The results of the statistical analysis of the shock data are presented in Figure 4 for each zone as a function of frequency in terms of the 95 percent probability response levels which as previously stated were defined as the desired subsystem test levels.

The actual recommended subsystem levels for the pyrotechnic shock environment due to spacecraft/launch vehicle separation are presented in Figure 5 for each zone in terms of a shock spectrum value computed for Q equal to 10. The recommendations are the same for each of the three axes in which the subsystems are to be tested. These profiles were constructed by smoothing the desired test levels somewhat but since the results of the statistical analysis for the shock responses were rather smooth as a function of frequency, only in Zone 2 below 500 Hz did these recommended profiles vary from the desired test level by more than 1 dB. It will be noticed from this figure that as one travels away from the shock source, the shock level is attenuated across the entire frequency spectrum. One additional consideration in determining subsystem shock test levels is their proximity to other pyrotechnic devices, which may influence their test levels and may even become a subsystem design consideration. Such secondary pyrotechnic devices have not been considered in the test recommendations made here, but should be considered, if they exist, when developing a subsystem test program.

The preferred method of conducting subsystem shock tests is to utilize an electrodynamic shaker in conjunction with some type of shock spectrum synthesis equipment to develop a complex transient whose shock response spectrum matches the one specified for the required damping value. For laboratories with such equipment this is a relatively straight-forward process. The fact that the spectral damping of Q equal to 10 may not precisely represent the damping co-efficient in the subsystem to be tested is not a serious problem since the variation in the shock response spectrum of the simulated environment as a function of the analysis damping value is approximately the same as the variation observed in the shock response spectrum of the service environment.

Traditionally, there has been an optional high-frequency sinusoidal sweep permitted as an alternative for those laboratories that do not have the capability for shock spectrum synthesis. This sine sweep has been more of a screening test than any rigorous attempt to induce similar responses. In this case, however, an attempt was made to derive "equivalent" sinusoidal levels for Zones 3 and 4 from the statistically derived shock spectra presented in Figure 4. In so doing difficulties were encountered.

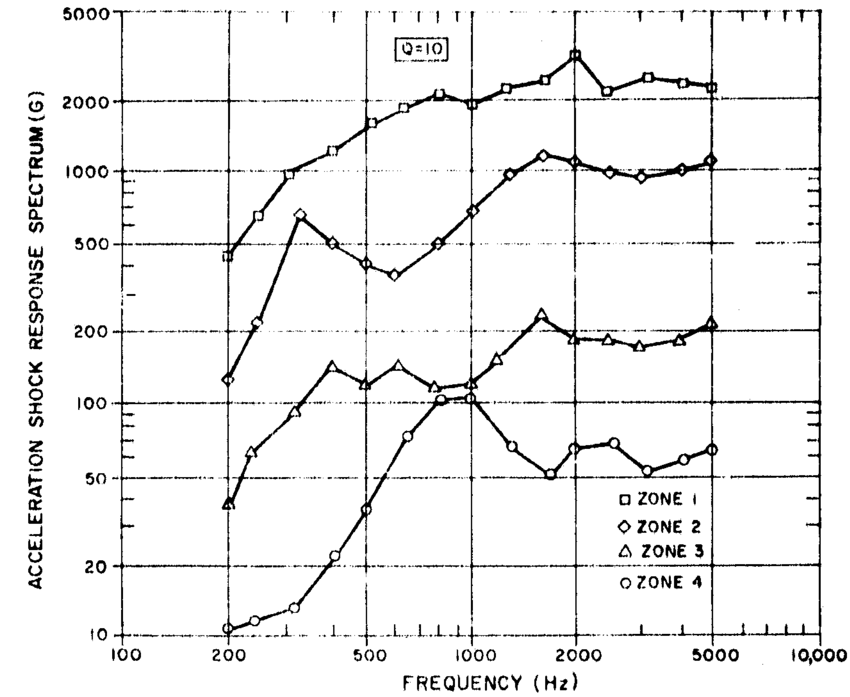

Figure 4. 95 Percent Probability Response to Spacecraft Separation Shock Environment.

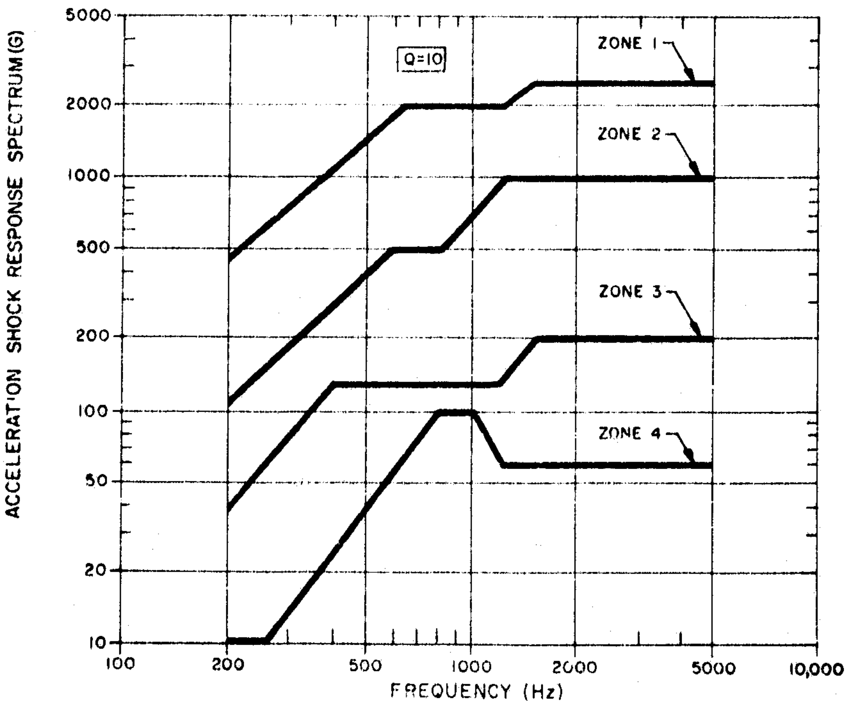

Figure 5. Shock Spectrum Recommendations for Subsystem Response to Reference Shock Environment.

When utilizing a sinusoidal sweep to duplicate responses induced by some desired shock spectrum, the desired sweep profile is derived by dividing the shock spectrum by the amplification factor (Q) with which it was computed. Unlike the flight environment, however, the shock spectrum of a sinusoidal sweep varies directly as the Q with which it is analyzed. Therefore, when one is using a shock spectrum to derive sinusoidal sweep test levels one must be certain that the amplification used in the analysis of the flight environment data is representative of the subsystems that will be tested to the resulting vibration specification.

In attempting to apply this procedure to the statistically derived shock spectra previously discussed, problems arose. The amplification factor of Q equal to 10 had been assumed to be representative of subsystems with high-frequency resonances. This was due perhaps to the knowledge that a Q of 10 was representative of major structural modes which were encountered below 200 Hz and a desire to maintain the same amplification factor for the high-frequency (above 200 Hz) pyrotechnic shock specifications. Dividing the shock spectra by 10 to obtain vibration levels produced sinusoidal specifications that from an intuitive standpoint had to be classified as unrealistically high.

Imposition of these high levels had to be weighed against the relatively successful past practice of using a 5G sinusoidal sweep from 200 to 2000 Hz which had apparently been an effective screen since very few subsystem failures had been encountered during the spacecraft level shock test.

One possible explanation for this apparent contradiction was that the pyrotechnic shock environment was so insignificant that it produced no failures in the spacecraft test even though the subsystem may have been severely undertested at the subsystem level. A more probable explanation, however, was that the amplification of 10 was significantly incorrect for subsystems with high frequency resonances. This was felt to be due in part to the inaccuracies of using a single-degree-of-freedom analogy to predict the response of a complex subsystem that responds in multiple resonant modes and in part to the fact that a Q of 10 is often just a poor estimate of the inherent subsystem damping. An in-house test program is currently underway to evaluate and determine the most realistic damping coefficient for spacecraft subsystems. It is recognized, however, that the determination of a single value may be impractical, and that a series of such values may be necessary, each of which is representative of a particular class of subsystem hardware. The results of this follow on task and the recommended high frequency sinusoidal profile which is "equivalent" to the shock spectra presented here, if any, will be issued in a separate report at a later date.

Acoustic Noise and Random Vibration Recommendations

The results of the statistical analysis of the responses to acoustic noise are presented in Figure 6 for each zone as a function of frequency, again in terms of the 95 percent probability response levels. The actual recommended subsystem random levels which simulate responses to the reference acoustic environment are presented in Figure 7 for Zones 1 through 4. Here again the recommendations are the same for all axes. It will be noticed that Zones 1 and 2 have been combined into one recommended level, as was mentioned previously, because there was little observed difference between the responses in the two zones and by combining them it improved the accuracy of the statistical analysis by increasing the number of samples in this particular population. In establishing these actual recommendations, factors such as the shaping capability of the random vibration equalizer and the degree of difficulty of the test setup had to be considered. The profiles were constructed so that the recommended test level at most one-third octave center frequencies did not differ from the desired level by more than 3 dB except for Zone 4 below 200 Hz where in seemed unreasonable to recommend a test level lower than that for Zone 3. Additionally, within the considerations mentioned above, the recommended levels were tailored to minimize the variance between them and the desired test levels. It will be noted from Figure 6 that as one travels outward through the spacecraft, the test level increases. This is in good agreement with the intuitive judgements expressed earlier during the definition of the various spacecraft zones, in that as one moves closer to the source of the acoustic excitation he expects the vibratory response to increase.

The 95 percent probability response levels to the reference random vibration excitation are presented in Figure 8. The recommended subsystem random vibration levels for all axes which simulate the responses to the reference environment are presented in Figure 9 for Zones 1 through 4. Again it will be noted that Zones 1 and 2 have been combined for the same reasons as previously mentioned. Additionally the recommended levels for Zones 3 and 4 are equal. This is so only by coincidence because the same profile happened to fit the results of the statistical analysis from both zones equally well. The high-frequency amplification observed in the recommendations for Zones 1 and 2 are felt to be due to the excitation of local resonances of the primary spacecraft structural elements. It will be noticed that these high levels at the high-frequencies are filtered out as you pass through the structure because they do not appear in the recommended levels for Zones 3 and 4. Conversely amplification is noticed in the Zones 3 and 4 levels in the low-and mid-frequency regions and is felt to be due to the excitation of both the major structural modes of the spacecraft as well as the resonant modes of the secondary structure to which most of the subsystems in these zones are mounted.

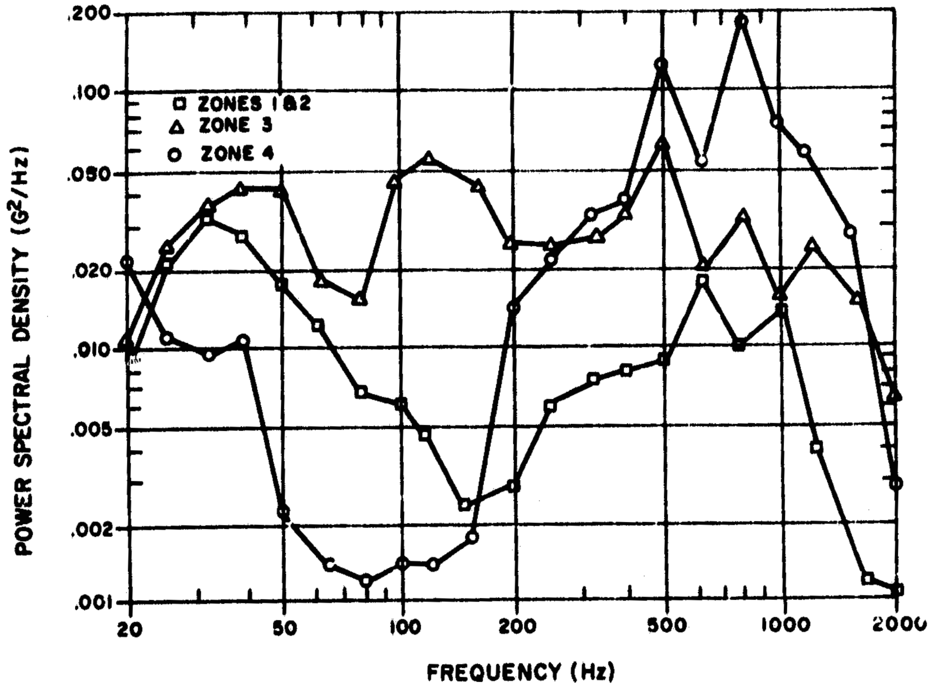

Figure 6. 95 Percent Probability Response to Reference Acoustic Noise Environment.

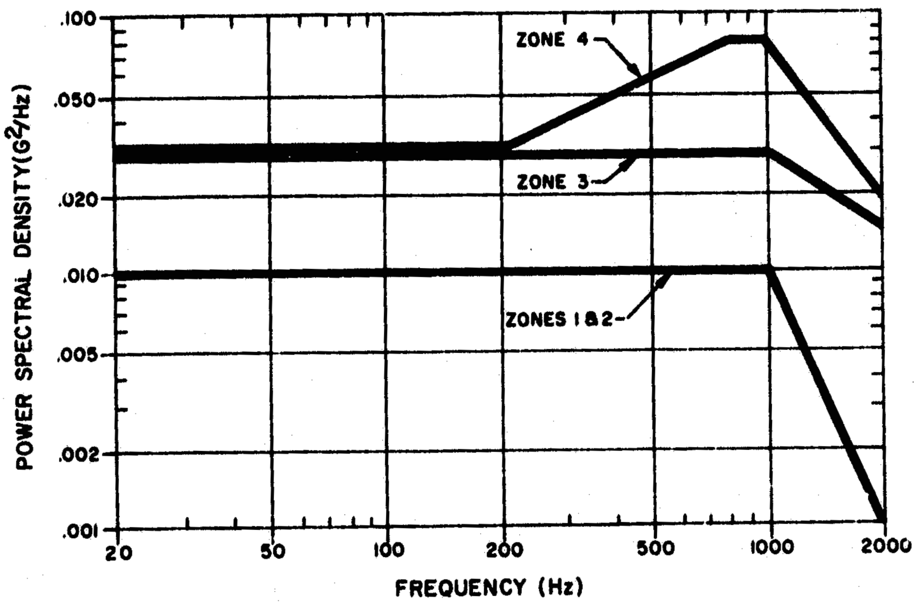

Figure 7. Random Vibration Recommendations for Subsystem Response to Reference Acoustic Environment

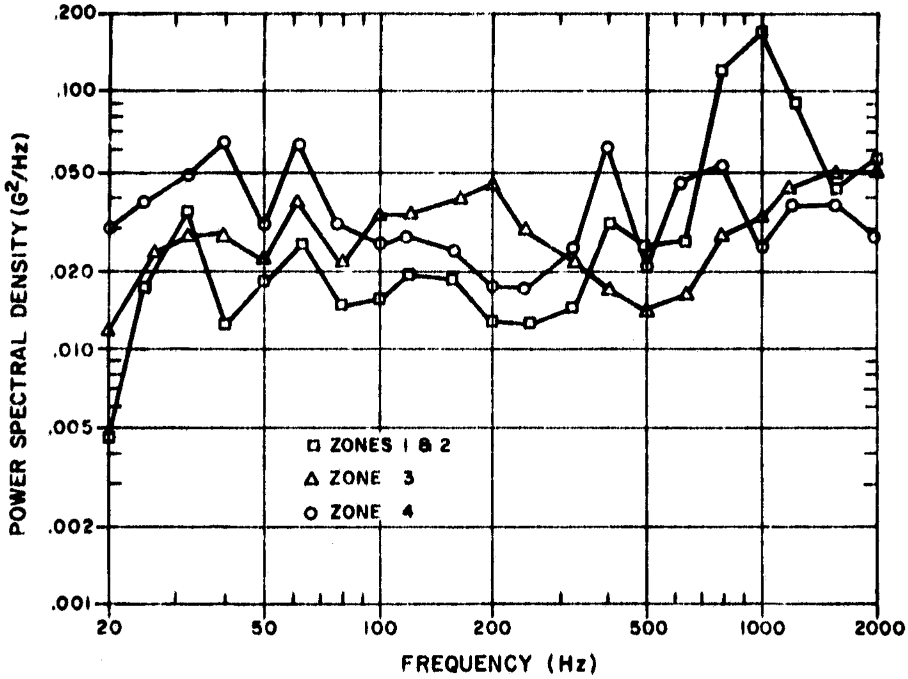

Figure 8. 95 Percent Probability Response to Reference Random Vibration Environment.

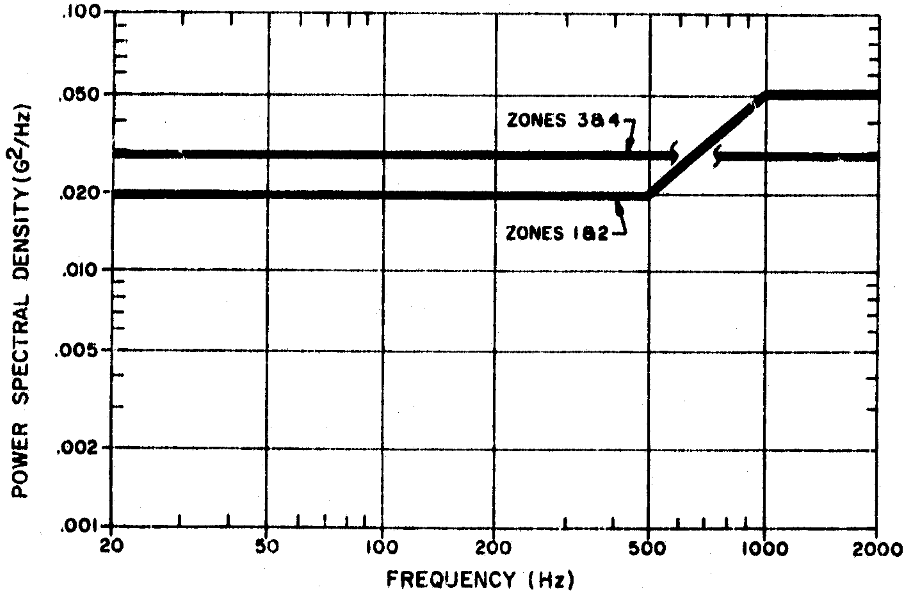

Figure 9. Random Vibration Recommendations for Subsystem Response to Reference Random Vibration Environment.

An interesting comparison that can be drawn at this point concerns the relative vibratory responses induced throughout the various portions of a spacecraft by acoustic noise and random vibration. The primary rationale for performing spacecraft level random vibration tests has been to simulate the acoustic environment (discounting the directly transmitted mechanical excitation from rocket engine vibration which is usually rather small). The reference acoustic and random spacecraft test levels of Figures 2a and 2b were taken from a GSFC specification for one of the commonly used launch vehicles. These reference levels were established before this statistical analysis had been conducted. The random vibration levels were intended to induce responses throughout the spacecraft similar to those induced by the acoustic noise levels. The accuracy with which that intention was met could now be tested by comparing the results of the statistical analysis for supposedly equivalent random vibration and acoustic excitations. Figure 10 presents this comparison as a function of frequency for each zone in terms of an A/R ratio, which is defined as the 95 percent response level to the reference acoustic excitation divided by the 95 percent response level to the reference random vibration excitation. This plot has been smoothed somewhat in that the A/R value plotted at any given one-third octave center frequency is actually the average A/R value of that band and two adjacent bands, the next lower frequency and the next higher. As can be seen, the results from Zones 1 and 2 show an A/R of less than 0.5 in the low-and mid-frequency range, increase slightly at 630 and 800 Hz and fall off sharply above 1000 Hz thus saying that in these spacecraft zones random vibration is a more efficient response generator than acoustic noise. In Zone 3, although it varies between 0.5 and 2.0, the A/R ratio is approximately 1.0 over the entire frequency range (although it does fall off a little above 1000 Hertz) thus saying that both methods of excitation are approximately equally efficient response generators. In Zone 4 while the A/R ratio is less than 1.0 in the low-frequencies, it is approximately 2.0 over a large percentage of the bandwidth. Two general comments can be made regarding this figure. One, the results agree with the intuitive response descriptions presented earlier, and two, while for a majority of spacecraft subsystems the spacecraft level random vibration test will generate satisfactory responses, there are potentially serious deficiencies in using random vibration at the spacecraft level as an attempt to duplicate responses to acoustic noise throughout the entire spacecraft structure. Additionally, the figure serves to highlight the fact that one must consider a subsystem's mounting location in the spacecraft when establishing a subsystem environmental test program.

APPLICATIONS

The results presented here are ready to be applied to future spacecraft programs, which are about to enter the design phase. When applying them however one

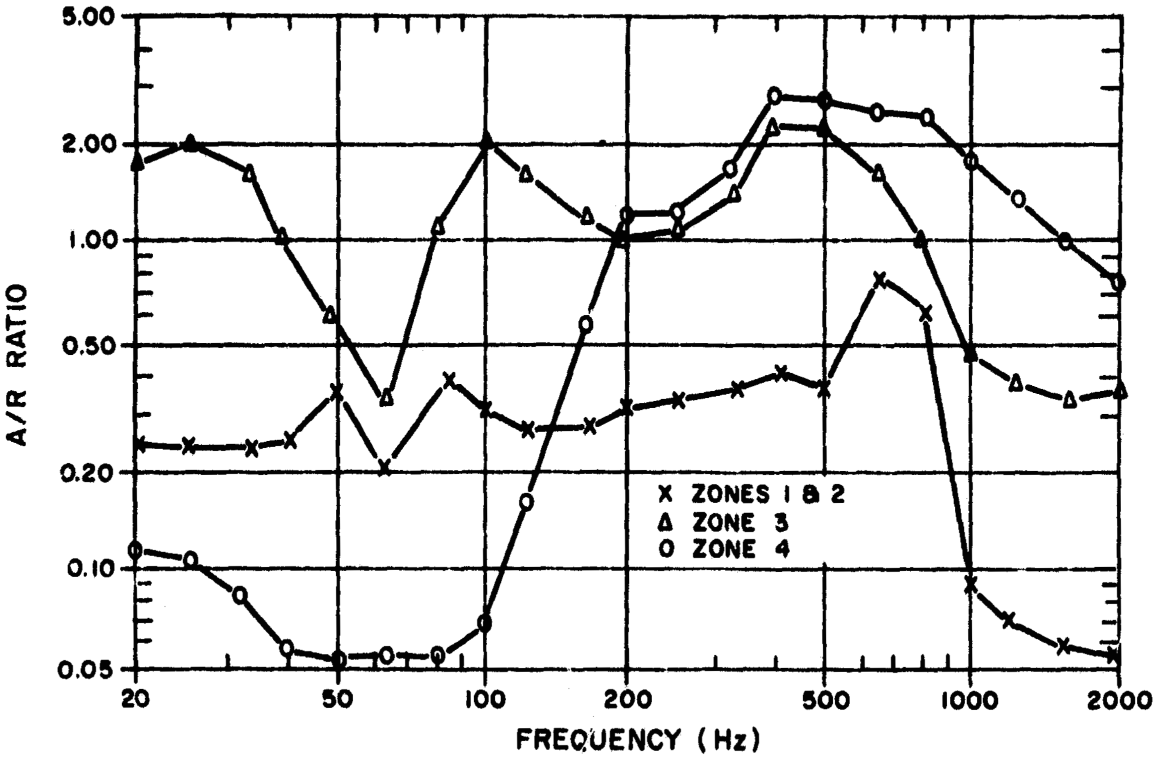

Figure 10. Comparison of Responses During System Level Acoustic and Random Vibration Tests.

should be mindful of the following comments regarding general subsystem test philosophy and the suggestions for applying these statistical findings.

First, subsystem random vibration levels are recommended here which are intended to be a simulation of the excitation produced by the acoustic environment. In general, such random vibration inputs at the subsystem level will provide an adequate test for simulating the effects of acoustics, but no subsystem test program should be developed without careful examination of each subsystem's peculiarities to see whether or not acoustics testing is warranted in some instances. An example of hardware in which acoustics testing would be preferred over random vibration would be a large light-weight antenna structure mounted external to the spacecraft structural shell where high responses to acoustics and relatively low vibratory responses would be anticipated. Another example, in which acoustic testing would be recommended <u>in addition to</u> random vibration would be a scientific instrument with thin film windows in which the high-frequency random vibration inputs may not be sufficiently well transmitted through the subsystem structure to adequately stimulate the thin film windows.

The second point to be emphasized is that one should consider the launch environment as well as the spacecraft level environmental test program when defining subsystem level tests. If during the planned spacecraft level tests a particular piece of hardware will not be excited to the levels expected during launch then it is recommended that the subsystem test program compensate for the deficiencies of the spacecraft test program. An example of such an instance would be a scientific instrument mounted near the external shell of the spacecraft. If no spacecraft level acoustics test is planned, then the possibility exists that the launch acoustics will induce random vibration levels at the input to the instrument in excess of those encountered during the spacecraft level random vibration test. If the subsystem test program has been designed merely to reproduce the anticipated responses during spacecraft level tests, it could be an inadequate subsystem test, since it has not additionally considered the potential responses encountered during launch.

If one wishes to use the results of this statistical analysis to predict a given subsystem response level for some other acoustic noise or random vibration spacecraft test level, one may simply make a linear extrapolation from the results presented in this report based on the difference as a function of frequency between those system test levels and the reference system test levels used here. As a basis for that extrapolation, however, one should use the 95 percent probability response levels for each zone presented in Figures 6 and 8 and apply the considerations for the operational limitations of laboratory equipment and personnel to the results of this extrapolation process. Thus one will do all "smoothing" only one time and that after all extrapolations have been made rather than before as would occur if one used the recommended test levels for the reference environment, which are presented in Figures 7 and 9, as the basis for extrapolation.

On programs where these results are used as a basis for deriving subsystem test specifications, it is recommended that the actual structural transmission characteristics be measured on an engineering model spacecraft at the earliest possible time in order to assess the accuracy of the statistically derived subsystem levels. As information becomes available on programs to which these results have been applied as to the suitability or non-suitability of using these methods to develop subsystem specifications, it would be appreciated if the author of this report would be kept informed so that the results presented here may be revised or updated as necessary.

REFERENCES

1. "GSFC Specification for Contractor Malfunction Reporting" GSFC Specification S-312-P-1 dated 24 March 1970.

2. "A Comparitive Evaluation of Test Methods to Simulate Acoustic Response of Shroud Enclosed Spacecraft Structures", Memorandum Report #731-13 by Frank J. On dated 6 August 1973.

3. "A Comparison of Acoustic and Random Vibration Testing of Spacecraft", by William F. Bangs, 1974 Proceedings of Institute of Environmental Sciences.

4. "General Environmental Test Specification for Spacecraft and Components", GSFC Specification S-320-G-1 dated 1 October 1969.