A ROUND ROBIN EXERCISE ON ROAD TRANSPORTATION DATA.

D.P. Richards and B.E. Hibbert
Hunting Engineering Ltd UK.

Authors Biography

Brian Hibbert is the Engineering Director of Hunting Engineering Ltd, Ampthill, UK. Hunting Engineering is an aerospace company best known for the development of airborne weapon systems. It is a member of the Hunting group of companies. Brian is a past chairman of the UK Society of Environmental Engineers and currently holds the position of Vice-president. He is also the chairman of the Transportation Stresses Working Party of the Committee of European Environmental Engineering Societies. In that role he was responsible for instigating the work reported in this paper.

David Richards is the Head of Structural Dynamics at Hunting Engineering Ltd. The Structural Dynamics group undertakes structural dynamic analysis, vibration assessment and dynamic loading analysis for both the Company's products and other agencies. Dave has been working in the field of structural dynamics and environmental engineering for some 16 years. He is chairman of the Joint MOD/Industry working group tasked with compiling the mechanical and vibration aspects of Defence Standard 00-35. He co-ordinated the day to day activity of the round robin exercise and undertook the assessment of the results.

Abstract

This paper presents the results of a round robin exercise recently undertaken under the auspices of the Transportation Stresses working group of the Committee of European Environmental Engineering Societies (CEEES). A total of 22 agencies from 6 different European countries participated in this work. Each participant undertook analysis of an identical piece of measured data. The majority of the participants reported analysis of the data, many also derived test severities. This paper presents a basic comparison of the responses and assesses the results.

Keywords

Road Transportation, Vibration Analysis, Test Severity Derivation, Comparison.

Background

1. The concept of the CEEES road transportation round robin exercise arose from a survey initiated in March 1989 [Ref 1]. That survey polled various European agencies for their views on aspects of road transportation vibration and shock. A significant percentage of the 33 agencies, who responded, considered that existing specifications relating to road transportation were inadequate. Moreover, a number felt that the use of such specifications often resulted in overtesting. The survey also suggested that no general consensus existed as to how improved test severities could be derived. Taken together, these findings indicated the benefits of a round robin exercise that would both determine the range of methodologies in use, and also compare their respective results.

The Requirements of the Round Robin Exercise

2. The aim of the round robin exercise was to identify the range of methods in use to assess road transportation dynamic data. It was also intended to quantify any variations arising from the use of different methodologies. The intent was that each participant should utilise what ever method they considered appropriate. To this end the requirements for active participation were set so as not to influence the participant's choice of approach. In practice this meant imposing relatively few constraints. As a consequence some limitations are imposed on the quantitative comparisons.

3. As not all potential participants routinely derive test severities, two levels of participation were established. These were;

> a. The data analysis option. Each participant was required to undertake data analysis of the information supplied using whatever methods they consider most appropriate.
>
> b. The derivation of test severities. Each participant was required to utilise the data supplied to derive test severities using whatever method they consider most appropriate.

Participation

4. A total of 22 agencies actively participated in the round robin exercise. The range of participating agencies has proved to be quite varied covering industrial, government and education sectors. The participants originate from six European countries and more than half are commonly involved in the derivation of test severities for the transport environment. The participating agencies were:

Bofors Electronics AB
3K Akustikbyran AB
British Aerospace PLC
British Telecom PLC
CEA/CESTA
Cranfield Institute of Technology
DNV Ingemansson AB
Ericson Radar Electronics AB
Fraunhofer-Institut fur Chemishe Technologie
Fraunhofer-Institut fur Materialfluss and Logistik
Ed Furrer
Giat Industries
Hunting Engineering Ltd
Lucas Automotive Proving Laboratory
Matra
Oerlikon-Contraves AG
Packforsk (Swedish Packaging Research Institute)
RAFEAL (Logistics Division)
SAAB
Swedish National Testing and Research Institute SP
Swedish Ordnance
UTAC - Service Acoustique

The Transportation Data

5. For the purpose of the exercise identical dynamic data were supplied to all the participating agencies. These data were derived from a real road transportation measurement exercise. It was selected so as to present the participants with as many realistic problems as possible. In particular the data was fairly lengthy (its duration was approximately 52 minutes) and time variant (non-stationary).

6. The vibration data supplied originated from an exercise of work undertaken to establish maximum response severities of a 10 tonne 4x4 vehicle. This vehicle is essentially a normal 10 tonne flatback lorry fitted with hydraulic crane and 4 wheel drive. It is intended for use mainly in on-road applications, but has some off-road capabilities. For this measurement programme two items of payload were loaded totalling around 1.5 tonne. Both items were well restrained by means of tensioned chains.

7. The original measurements were undertaken by the Flight Systems and Measurement Laboratories at Cranfield Institute of Technology in the UK. They also prepared and checked that data supplied to each participant. The data supplied contained four channels of information. This information was vibration from three axes (vehicle vertical, lateral and axial) measured from accelerometers fitted to the vehicle payload bed. The fourth item of data was vehicle velocity. This was derived from an optical transducer fitted to monitor propeller shaft rotational velocity.

8. The measurement used for the exercise was from a local journey that started at the Hunting Engineering site. The journey used several types of road before arriving at a nearby Motorway (freeway) junction. Without stopping the vehicle turned around and returned by the same route. This total journey covered a distance of around 40Km (25miles) taking around 52 minutes.

9. A time history for the vertical response axis is shown in Figure 1. Both the inward and outward phases of the journey can be identified. At one point in the journey the vehicle encountered road works forcing it to stop for a few minutes. This can be seen in both outward and return phases.

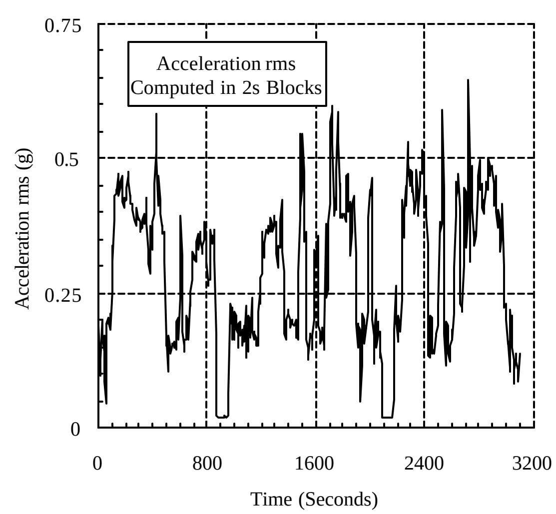

Figure 1 Time History of rms Values

Overview of Methods Used

10. The results from the round robin exercise indicate that the various participants used a wide range of different methodologies. Although this was partially expected the amount of variation was still surprising. Whilst, "generic" similarity exists between several of the methods, different usage's and implementations meant that essentially none of the participants used identical methods. It is beyond the scope of this paper to describe all the different methods used. However, to understand the comparison of results from these methods it is necessary to establish an overview of approaches used.

11. The approaches used can be considered to fall into the following four generic methods (all the participants used at least one of these analysis methods, most used several);

a. Power Spectral Density. All the participants used Power Spectral Densities (PSDs) at some point in either the analysis process or in the derivation of test severities. Around two thirds of the participants undertook analysis of either the entire vibration record or a substantial part of it. A few used PSD analyses to set the test severities directly. However, many used PSD analyses to identify the "shape" of the test spectra and used other methods to derive a suitable amplitude. A number of participants undertook PSD analyses of selected portions of the total vibration record. In this case not only did the method of selection vary between participants but also the method of combining these into a test.

b. Amplitude Probability Densities, Distributions and Level Crossing. A number of participants used either Amplitude Probability Densities (APDs), Probability Distribution Functions (PDFs) or level crossing analysis. In general such analysis was used to determine the amplitude of the test. The corresponding "shape" of the spectrum been established from the PSD analysis.

c. Fatigue Damage Spectra. Some participants described the transport environment by means of Fatigue Damage Spectra (FDS). These were used as the basis for generating a PSD test spectrum that would give an equivalent FDS.

d. Shock Response Spectra, Maximum Response Spectra. A good proportion of the participants who defined a shock test computed Shock Response Spectra (SRS). However, a number of others also used this method to ascertain the maximum responses of idealised equipment. The amplitudes of their test spectra were then set to

Participant No	Summary of Analysis Procedures Used								
	rms v time	PSD		Peak Hold	SRS	Level Crossing	Probability Density	Probability Distribution	Fatigue Damage
		All	Partial						
1	yes	yes			yes	yes			
2		yes			yes				
3		yes		yes			yes		
4	yes		yes		yes				yes
5		yes		yes				yes	
6	yes	yes			yes				
7	yes		yes						yes
8	yes	yes							
9	yes	yes	yes		yes				
10	yes	yes		yes					
11	yes	yes	yes		yes		yes		
12	yes	yes	yes		yes				yes
13	yes	yes		yes	yes			yes	
14		yes							
15	yes	yes		yes	yes		yes	yes	
16									
17			yes						
18			yes			yes			

Table 1 Summary of Analysis Procedures Used

produce similar maximum responses. In a limited number of cases a hybrid of SRS and APD/ Level crossing methods was adopted. All the participants who used FDS also used Maximum Response Spectra (MRS) to ensure maximum responses were achieved in the test.

12. Between the participants the majority of the mechanism that seem likely to cause equipment failure or damage appear to have been considered. However no single method appears to derive a test that was theoretically able to replicate all potential damage aspects of the environment. A good example is the participants who used Fatigue Damage Spectra to match the fatigue damage of the test with that accrued in the actual environment. Their procedure also attempted to matched the Power Density Spectra and the Peak Responses. However, their test did not necessarily result in the same distribution of amplitudes as that which occurred in the real environment. A similar observation can be made with the participants who used Amplitude Probability Densities, Probability Distribution Functions or level crossing. In those cases Fatigue Damage was unlikely to be accurately matched.

13. Most of the participants appeared to be aware that the test they derived was unable to perfectly replicate all aspects of the environment. However, a number commented that the methods they had utilised could be further enhanced. In those cases the current major restriction was the computing time required to derive such enhanced test severities.

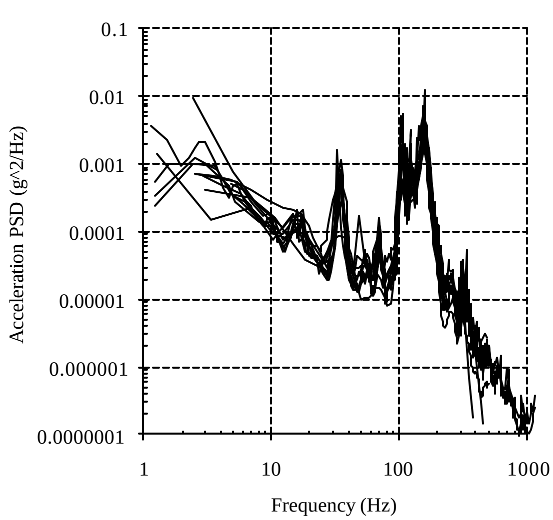

Figure 2 Comparison of PSD Analysis From Participants Who Analysed the Entire Record

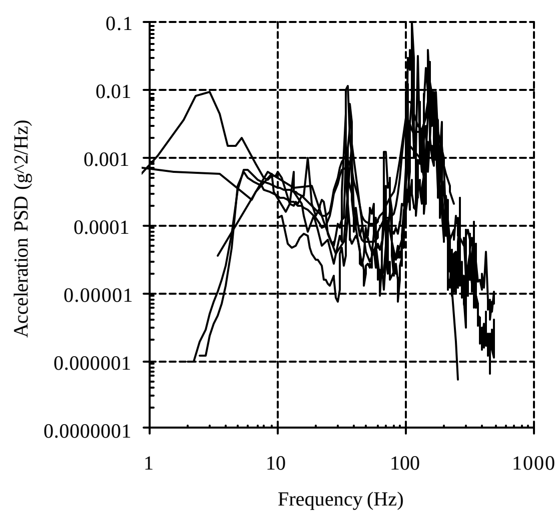

Figure 3 Comparison of PSD Analysis From Participants Who Analysed Partial Record

Comparison of Analysis Parameters.

14. One of the few requirements set at the beginning of the work was that the participants should supply information on the basic parameters used in data acquisition and preliminary data analysis. This was included to give an idea how the various participants set up their analyses and how they dealt the non-stationarity aspects. The type of information requested was the ADC sample rate, anti-aliasing filter characteristics, analysis bandwidth, resolution and size of FFT used.

15. From the information supplied one of the most surprising aspects was the spread of the sample rates, bandwidths and resolution used. This occurred even though most participants undertook preliminary work to establish the validity of the parameters they finally used. Clearly the criteria used to justify a selection of sample rates, bandwidths and resolution are highly user specific. This aspect may bear more consideration in the future. Also surprising was the range of sizes of Fast Fourier Transform (FFT) used.

16. A summary of the different analysis methods used by the various participants is shown in Table 1, whilst, selected analyses are compared in Figures 2 to 4. Figure 2 compares the PSD analyses from the participants who considered the entire record. As will be seen the variation between the different analyses is small. Moreover, much of the variation that does exist arises from the differing bandwidths used (by the participants) and the method used to compare these analyses (by the authors).

Participant No	Details of Proposed Tests			Summary of Methodologies Used			Test Factor
	Vibration Test		Shock Test	Basis of Vibration Test Definition			
	No of points	Multi-level	Test	Shape	Amplitude	Duration	
1	12	yes (2/3)	in vibration	Overall PSD	Level Crossing	equiv. cycles	
2	12	no	in vibration	equivalent PSD	equivalent PSD	not known	98% data
3	22	no	none	peak hold	peak hold	not known	
4	not known	no	yes	PSD and FDS	PSD and FDS	equiv. FDS	
5	2 pole filter	yes (3)	yes	PSD & peak hold	APD	APD	
6	6	no	in vibration	PSD	SRS	level crossing	50x time,1.44 on amplitude
7	15	no	yes	Derived from FDS	FDS	FDS	
8	5	no	none	PSD	Selected PSD	not known	2 on amplitude
9	86	no	yes				1.4 on amplitude
10	-	-	not known	PSD & Pk hold	PSD & Pk hold	not known	
11	13	yes (4)	yes	Selected PSD	selected PSD	rms occurrence rate	
12	not known	not known	yes	Derived from FDS	FDS	FDS	
13	12	yes(3)	none	PSD	APD	APD	1.2 on amplitude
14	-	-	-	-	-	-	
15	9	yes	none	PSD	APD	APD	4 on rms; 16 on PSD
16	-	-	-	-	-	-	
17	16	no	none	PSD	PSD	equivalent cycles	28 on tine: 1.3 on rms
18	12	no	yes	PSD	PSD & Level Cross		

Table 2 Summary of Proposed Tests and Methodologies Used To Used to Derive Them

17. Figure 3 compares the PSD analyses from the six participants who undertook analysis of selective portions of the data. It will be noticed that the variation here is significantly greater than in the previous case. Consideration of the PSD analyses suggests two distinct groupings. The first arises from participants who selected very specific (and short duration) portions of the total record. Consideration of these analyses is quite interesting in that they exhibit a number of narrow bands of much greater amplitude than those indicated from analysis of the complete record. These narrow bands are almost certainly the periodic components related to the vehicle engine and drive system. The observed variation in frequency of these components probably arises because the three participants selected different portions of the record. That is the frequency of these components is related to vehicle speed that is time variant. The second group of participants comprises those who used selective analyses comprise but whose analyses are a composite of several periods of the entire record. These analyses show significantly less frequency detail than the first group, but generally the amplitudes are greater than for those from analysis of the entire record.

18. Shown in Figure 4 is a comparison of the Shock Response Spectra Analysis undertaken by eight participants. This figure generally shows a fairly large variation. However, this may not be unreasonable when it is realised that some of the analyses are derived from quite different events in the record. Moreover, some arise from a single selected transient while others represent a significant portion of the record.

Comparison of Test Severities

19. Probably the most interesting result of the exercise relates to the comparison of test severities derived from the measured data. Such interest arises because many specifications currently advocate the derivation of test data from measured information rather than utilise "cook

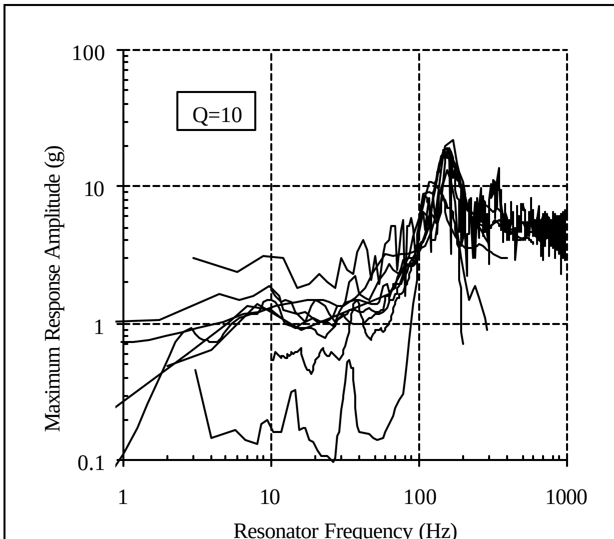

Figure 4 Comparison of Measured Shock Response Spectra

book" severities. The derivation of severities in this way is often suggested as a route to enhanced simulation of the actual environmental conditions. Clearly this exercise was a good opportunity to determine the repeatability of such a process when undertaken by different agencies.

20. A total of 13 of the participants derived test severities from the data supplied. A summary of the tests specified and the methods used to derive them are presented in Table 2. All 13 participants defined a test for the vertical axis, however, only 6 did so for the other two axes (this was in line with the original requirement which suggested that participants concentrate on the vertical axis). For the major portion of this comparison only the vertical vehicle axis will be considered.

21. Unfortunately space does not allow the vibration test severities defined by each of the 13 participants to be presented here. However, the overall root mean squares and the test durations are presented in Table 3. Any test conservatism quantified by the participants is indicated in Table 2. Four of the participants did not use a single PSD to define the test. Rather, they used a multi-level vibration test programme.

22. A total of 7 participants indicated that they would augment the vibration test with a shock test. Mostly the shock test was defined in terms of half sine pulses, although one participant specified a trailing edge saw tooth pulse. Two participants defined the shock test in terms of a Shock Response Spectra. A total of 5 participants indicated that no additional shock test was required as the vibration test adequately encompassed the observed transients.

23. A fair comparison of the test severities defined by each participant was not possible using PSD values alone. This

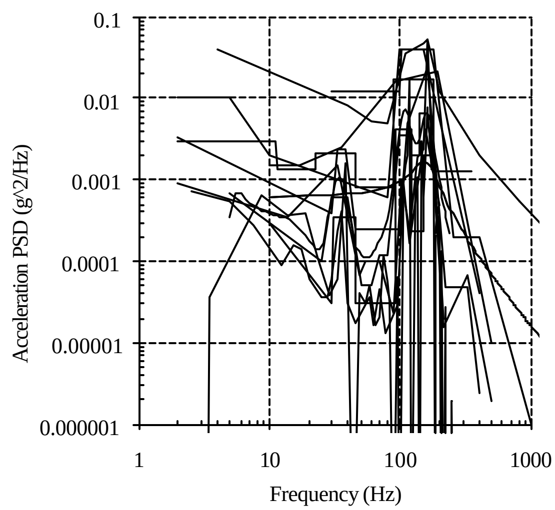

Figure 5 Comparison of PSD Test Severities Proposed by Participants

is because PSDs do not inherently incorporate all the aspects considered by the participants. For this reason the test severities were compared in terms of Power Spectral Densities, Amplitude Probability Densities, Probability Distribution Functions, Fatigue Damage Spectra, Shock Response Spectra and Maximum Response Spectra. In each case the test severities were compared both as originally supplied and adjusted to remove the effects of

Participant	Overall Root Mean Squares (g)				Test Duration (s)			
No	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4
1	0.43	1.37	-	-	1703	0.41	-	-
2	-	-	-	-	-	-	-	-
3	0.375	-	-	-	-	-	-	-
4	0.53	-	-	-	600	-	-	-
5	0.54	0.37	0.15	-	461	1389	923	-
6	1.717	-	-	-	1500	-	-	-
7	0.61	-	-	-	155	-	-	-
8	2.02	-	-	-	-	-	-	-
9	0.7	-	-	-	180	-	-	-
10	-	-	-	-	-	-	-	-
11	0.307	0.308	0.387	0.481	1245	1110	630	15
12	-	-	-	-	-	-	-	-
13	0.221	0.679	0.951	-	56.25	120	11.25	-
14	-	-	-	-	-	-	-	-
15	2.01	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	0.637	-	-	-	7200	-	-	-
18	2.395	-	-	-	-	-	-	-

Table 3 Summary of Test Durations and rms Values

test conservatism. Unfortunately, not all participants were able to quantify the test conservatism incorporated, and this compensation has not been possible for all participant's contributions.

Comparison of Power Spectral Densities

24. Although all the participants used PSDs to define the tests considerable differences still occurred in the manner by which the tests were defined. With only the odd exception, the test requirements are not specified to anything like the same bandwidth as used for the analyses. In fact, a notable aspect of the comparison is the "coarseness" of the test spectra. This is not unexpected as traditionally random vibration tests are defined in terms of only a few spectral "breakpoints". The various participants used a range of stratagems to reduce the detailed measured spectra to a "courser" test description.

25. Originally the PSDs as specified by the participants for the vertical vehicle axis were compared. This comparison indicated the spread of amplitudes was in excess of three decades for a large proportion of the frequency range. This was significantly greater than indicated from the root mean square values alone. However, this comparison somewhat confusing because several participants defined a multi-level test requirement. To alleviate this problem only the largest amplitude spectra were compared.

26. Figure 5 shows the largest vibration test spectra from each participant with the overall amplitude modified (factored) to account for the different amounts of test conservancy incorporated into the test severity. A clearly discernible "mean value" can be seen through the centre of the spread. However, even the variations in severity are still approaching two decades overall.

27. In order to identify whether a particular generic method is more accurate and repeatable than the others, the contributions were separated into four groups. Similar comparisons were made for each of the different methods of comparison, however, only the PSD based comparisons are addressed in this paper. The division of the test severities into the four groupings were based upon the prime method used by the participant to set test amplitudes. These were;

> Group A. Power Spectral Densities. The test spectra from the four participants who used Power Spectral Densities as the prime bases for setting test amplitudes show little consistency in amplitude. This seems to be because of the different approaches used "envelope" the measured data.
>
> Group B. Amplitude Probability Densities, Probability Distribution Functions and Level Crossing methods. The amplitudes from the four participants who used APDs, PDFs or level crossing methods show a better consistency than those who used PSDs alone.
>
> Group C. Fatigue Damage Spectra. The group who used Fatigue Damage Spectra had the most consistent severities. This is almost certainly because the each participant, in this group, used almost the same method. It could well be that this method handles aspects such as non-stationarity more consistently than the other methods.
>
> Group D. Shock Response Spectra. and Peak Hold Spectra. Only two participants used SRS or Peak Hold Spectra. The variation between the two was considerable. However, as both used different approaches the outcome is not particularly surprising.

Comparison of Amplitude Probabilities

28. An alternative approach used to compare the test severities was to utilise Amplitude Probability Densities (APDs) and Probability Distribution Functions (PDFs). The APDs and PDFs have been derived from the Power Spectral Densities proposed by the participants. When multi-level vibration tests were defined, the different amplitudes were apportioned according to the ratio of test durations. In many instances the APDs and PDFs also include contributions from the additional shock test specified by the participants.

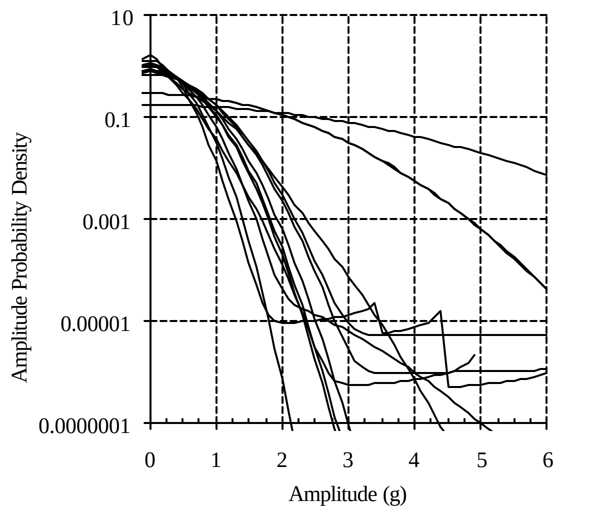

Figure 6 Comparison of Amplitude Probability Densities Derived From Test Severities

29. Figure 6 shows the Amplitude Probability Densities derived from the tests specified by 13 participants. All the values shown were computed assuming an effectively unlimited occurrence of peaks in the vibration test. Moreover, they have been factored to account for the different levels of test conservatism. The figure appears to show three distinct groups of participants. The first group is made up of the four participants who only defined a single random vibration test. The second group are those that used either multi-level random and/or additional shock testing. The third group is made up of the four participants who used a single random vibration test spectrum but enveloped the transient peaks by increasing the rms of the test. The APDs from three of the latter participants (although only two are discernible) are the upper group on the figure.

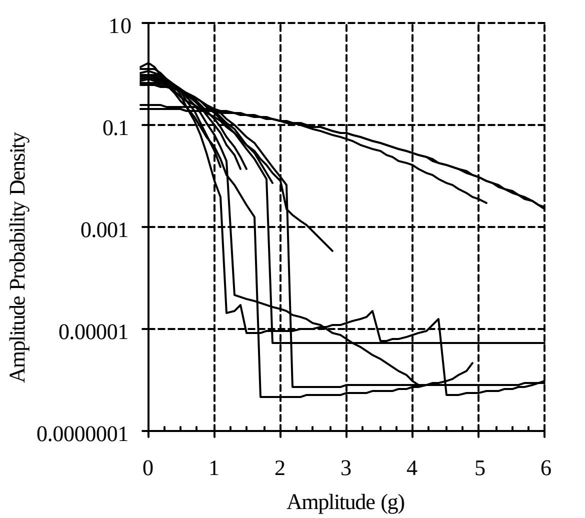

Figure 7 Comparison of Amplitude Probability Densities With Peak Occurrences of Vibration Test Limited to Three Times the rms.

30. In practical no discernible difference seemed to exist between those that used multi-level vibration and those that used additional shock test. The subset who used only a single vibration amplitude indicates a clearly limited peak amplitude that did not encompass the largest amplitude measured responses. The group of participants who attempted to encompass the transient peaks using a single random vibration spectrum are significantly different from the previous subset. This would seem to suggest that the participants who used a single vibration level attempted to either replicate the high probability levels and the lower amplitudes, or the low probability levels and high amplitudes.

31. With only the odd exception none of the participants indicated the maximum peak to root mean square ratio they would expect from the test equipment. Unfortunately, many vibration controllers limit the occurrence of peaks to around three times the rms. For the purpose of the initial comparison no limit was set. However, out of interest, the normal practical limit was imposed. The effects of this are shown in Figure 7 which is otherwise comparable to Figure 6. The effects of this truncation are clearly dramatic. The advantage of using multi-level vibration and/or additional shock testing is clearly seen. However, it also would appear that, with only the odd exception, truncating the peaks to 3 times the rms was not considered by the participants when setting the test severities. This is suggested by the way many of the curves exhibit dramatic step changes. In fact a few curves no longer envelope equivalent measured data. It was anticipated that the effect of truncating the peaks to three times the rms would have less effect for those participants who used both multi-level vibration and additional shock tests, however, this was not the case.

Comparison of Fatigue Damage Spectra

32. Further comparison of the test severities was undertaken using Fatigue Damage Spectra (FDS). The Fatigue Damage Spectra were computed using a computer program kindly supplied by CEA/CESTA. The FDS are particularly useful in this application because they are a measure of potential equipment damage. Moreover, the values of FDS values incorporate the specified test duration in their computation. The Fatigue Damage Spectra have only been computed from the vibration tests specified because the shocks make very little contribution. For multi-level vibration tests the FDS values used are the sum of each severity level.

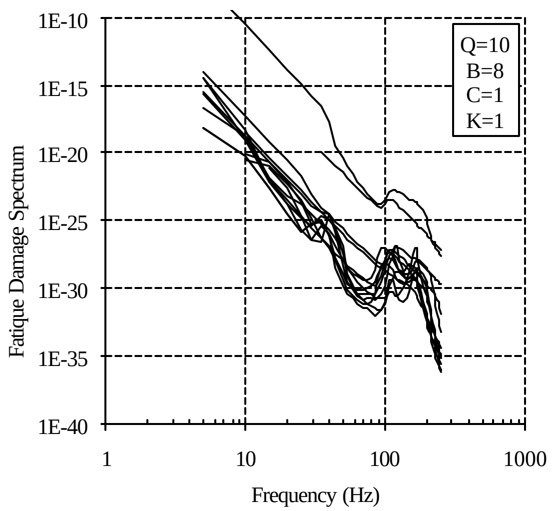

Figure 8 Comparison of Fatigue Damage Spectra Derived From Test Severities

33. Figure 8 shows the Fatigue Damage Spectra for the tests specified by 13 participants. Once again the Spectra shown are the values after the effects of the different factors for test conservatism have been accounted for. For the majority of the contributions the spread of results looks relatively narrow. However, this is mainly due to the scales used in the figure. In reality the spread would be considered unacceptable. In the most extreme case the most damaging test would have accrued ten million times as much fatigue damage as the least damaging test. The "main grouping" of curves still indicates a difference in damage of a thousand. In this case the effect of removing the factors of test conservatism was quite marked with the two "high" values arising from participants who indicated no factor. They illustrate quite well how the effects of test conservatism, incorporated on PSD levels, can be significantly different when considering other damage criteria.

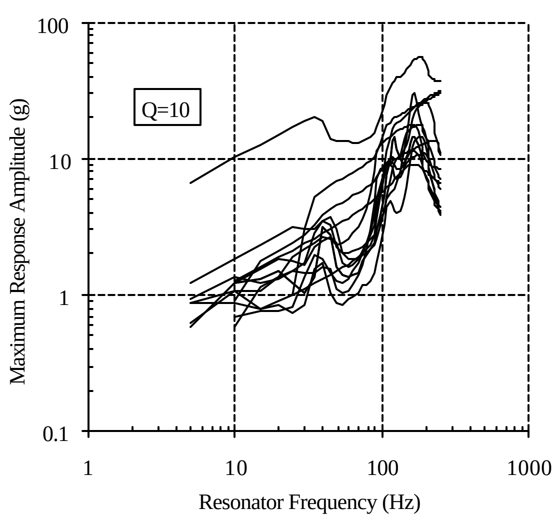

Figure 10 Comparison of Maximum Response Spectra Derived From Vibration Test Severities

Comparison of Shock Response Spectra

34. The values of Shock Response Spectra (SRS) and Maximum Response Spectra (MRS) were computed from both the specified vibration tests and the specified shock tests. The MRS values from the vibration tests were computed using the computer program supplied by CEA/CESTA. The values of SRS were computed from the shock tests. The values used in the comparison are the most severe of the two. In practice the MRS from the vibration test dominated in some cases and the SRS from the shock test in others.

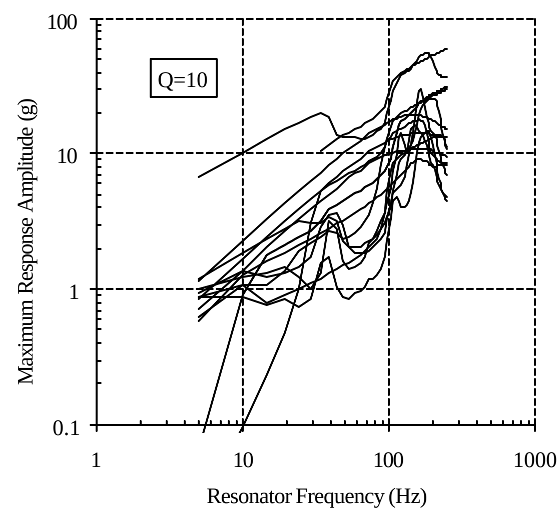

Figure 9 Comparison of Shock Response Spectra and Maximum Response Spectra Derived From Test Severities

35. Figure 9 compares the SRS/MRS values for the tests specified by 13 participants. Once again the spread of results is considerable. However, in this case it is made worse because the characteristic shape of the MRS arising from the vibration test differs to that of the SRS from the shock tests. Compensating for the effects of different levels of test conservatism does not reduce the overall spread of values.

36. Figures 10 and 11 separately compare the maximum response amplitudes from the vibration and shock tests

after factoring for differences in test conservatism. These figures would suggest that the spread of maximum response amplitudes is similar in both cases. Moreover, the maximum response amplitudes from the vibration and shock test are quite similar. This probably only occurs because no testing limitations have been imposed on the vibration test in the computation of MRS values.

General Observations

37. A wide range of methodologies was adopted by the various participants. In fact the range of methodologies was probably the most interesting result of this round robin exercise. Several of the participants attempted to use techniques that would make the derivation of test severities "automatic". However, few actually appear to have succeeded in this. Others conceded that judgement and manual selection of data could significantly reduce the time scales of the task. For this reason it does appear that, at least for "difficult" data of the type supplied for this exercise, the experience and expertise of the data analyst has a considerable impact on the end result. This appears to have been the case regardless of the sophistication of the analysis technique used.

38. Comparison of the results of the analyses of the data generally shows a reasonable variation. Given the difficult data supplied to the participants, obtaining identical analysis results was not realistically anticipated. Whilst the resultant variation is not unrealistic, the variation in parameters used to conduct the analyses was slightly surprising. The analyses compared in this paper do not give a full indication of the extent to which participants investigated the data. Several participants undertook quite detailed investigations of the data, i.e. investigating velocity/severity relationships. A number identified information in the data not previously noticed.

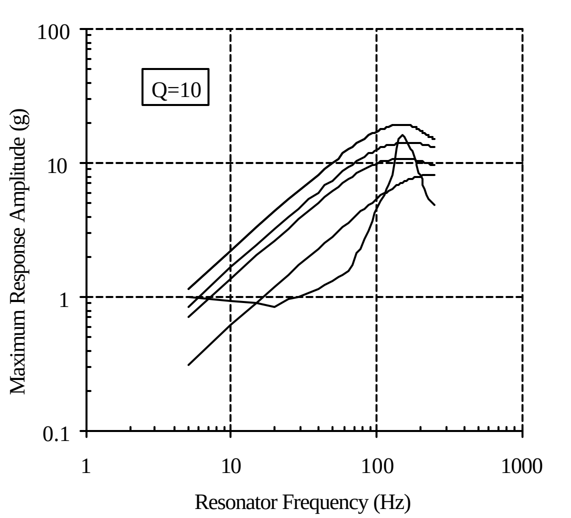

Figure 11 Comparison of Shock Response Spectra Derived From Shock Test Severities

39. One item of information requested of each participant was an estimate of the errors and/or confidence levels in the analysis. Even after being prompted for this information, fewer than expected supplied it. Generally, the values that were supplied related to the simpler analysis methods, with little response from those using the more sophisticated methods. It is acknowledged that making such estimates is time consuming. Moreover, requesting this information may have been unreasonable given the considerable effort already expended by many on the exercise. However, this aspect probably requires more detailed future consideration.

40. The variation in test severities defined by 13 participants is surprisingly large. Some of this variation appears to partly arise from the test conservancy incorporated in the test requirements. However, much of this variation seems to originate from the methodology and assumptions used to derive test severities. With this said, none of the four generic approaches, used by participants, appears to produce significantly different results. Of the approaches considered, the spread of results was the smallest from those who set amplitudes from Fatigue Damage Spectra. This is in part because these participants used a relatively fine resolution to define the test spectra. However, it may also be attributed to the fact that these participants adopted an essentially identical procedure. The group who used Amplitude Probabilities had slightly more variation in amplitude and a lot more variation in spectral shape. This later aspect may be attributed to the relatively "coarse" test definition used.

41. Although an estimate of the effort expended on the work was not requested, it is clear for the comments made by a few participants, that it varied considerably. A few participants indicated that they only spent a day or so of effort in the derivation of the test severities. Most of these added the caveat implying that this was typical of the effort they would normally be allowed to expend on deriving tailored test severities. At the other end of the scale a few participants expended more than 100 hours of computer time in deriving the test severities. How much manual effort was required is not clear, but in some cases it was clearly very significant.

42. The identification of shocks or transient responses from within the vibratory data seemed to cause the participants some difficulty. More particularly the methods used by many participants to identify shocks were often considerably simpler than the methods used to assess the vibration aspects. Some of these did not seem to be very

reliable. Quite a few participants resorted to the use of oscilloscopes to identify the worst case conditions. The participants who used APDs, PDFs and level crossings were able to quantify the distribution of shock amplitudes, but still were often unable to actually locate the worst case from with the complete record. A few participants divided the total record into blocks of a few seconds duration. They then plotted means and peaks from within each block. This allowed the identification of the highest peak response to within a single block. All the methods appear to be highly dependant upon the dedication of the analyst. This does not seem appropriate for a parameter that may have a significant potential to damage equipment.

Concluding Comments

43. Many specifications and requirements are now insisting that environmental test severities are based upon measured data. The implication of this is that test severities based upon measured data are more reliable than more traditional "cook book" severities. If the variation in test severity found in this round robin exercise are indicative of real world variations then the confidence that such test severities are reliable must be brought into question. The most repeatable results seem to occur when a reasonably well documented procedure exists. Unfortunately, relatively few documents exist which set out guidance to assist the analyst in the derivation of test severities from measured data. This work would suggest that if reliable test results are to be obtained from measured data some attention needs to be given to developing such documentation.

44. The differing degrees of test conservatism used by the participants is a cause of some concern. The majority of the participants were skilled analysts often with many years practical experience with a wide range of products. The fact that they still utilised such a wide variation of test conservatism would suggest that considerable difference in objective and opinion exists. In almost all other applications conservatism (factors) is usually well documented. This does not seem to be the case for environmental testing. Clearly some potential exists here for suitable guidance information.

45. Many of the participants who set test severities appear to have attempt to either replicate the environment or the effects of the environment. In either case many participants realised that replicating just the measured PSD profile is inadequate. A surprising number of participants attempted to replicate the damage potential of two or even three aspects of the environment. Typically these were either fatigue, peak amplitudes, amplitude distribution and spectral distribution. The cost in terms of analysis effort and computing power rose rapidly the more potential damage aspects that were considered. However, several participants demonstrated that such considerations are quite practical with current facilities. Likely future improvements in computing capabilities should mean that improved methodologies will be viable for most applications.

References

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