TWO ROUND ROBIN EXERCISES ON ROAD TRANSPORTATION DATA.

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Authors Biography

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. David has been working in the field of structural dynamics and environmental engineering for some 20 years. He is a member 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 two round robin exercises and undertook the assessment of the results.

Background

This paper presents the results of two round robin exercises undertaken under the auspices of the Transportation Stresses Working Group (TSWG) of the Committee of European Environmental Engineering Societies (CEEES). The first round robin exercises arose from a survey initiated in 1989. That survey polled some 33 European agencies and found that no general consensus existed as to how improved road transportation test severities could be derived. A round robin exercise was suggested as one method by which the range of methodologies in use could be determined. The first round robin exercise was completed in 1995 and the second is expected to be fully completed later this year. The results presented here concerning the second exercise are provisional information which are to be discussed at the next meeting of the TSWG.

The main aim of the first round robin exercise was to identify the range of methods used for the assessment of road transportation dynamic data. However, the round robin exercise 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 arose in the quantitative comparisons.

The second round robin exercise was intended to address a specific aspect identified as a concern in the first exercise. One of the surprising findings of the first exercise was the variations in methods the participants used to identify and quantify shocks from within the background vibration. This variation was reflected in a poor success rate at identifying and quantify the shocks. The late Karl-Heinz Hansen of the Gesellschaft fur Umweltsimulation (GUS) proposed an exercise to both specifically investigate this aspect and as a vehicle for improving vibration analysis skills. This proposal was subsequently expanded by the CEEES Transportation Stresses Working Group. The proposed aims and objectives of the second exercise were;

i. To evaluate the methods in current use to recognise and quantify shocks when embedded in vibration of the type expected from the transportation environment.

ii. To quantify the variations arising from the use of different methodologies. In particular to identify the degree of operator experience and skill required for the different methods.

iii. To generate progressively more difficult test cases against which experience and skill can be improved.

First Round Robin Exercise

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.

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. The original data was acquired 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.

A total of 22 agencies actively participated in the first 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 most are commonly involved in the derivation of test severities for the transport environment. The participating agencies were:

3K Akustikbyran AB
Bofors Electronics 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 (Bofors)
UTAC - Service Acoustique

Overview of Methods Used

The results from the first round robin exercise indicate that the various participants used a wide range of different methodologies. Whilst, "generic" similarity exists between several of the methods, different usage's and implementations meant that essentially none of the participants used an identical approach. It is beyond the scope of this paper to describe all the different methods used. However, the following overview of the approaches used gives a good indication of the four groups of methods used, all the participants used at least one of these analysis methods, most used several.

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.

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

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.

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

Comparison of Analysis Parameters.

Generally the variation between the different analysis parameters used was small. Moreover, much of the variation that did exist arose from the use of different bandwidths (which were selected by the participants) and the method used to compare those analyses (by the author).

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 in turn time variant. The second group of participants comprise those who used selective analyses but whose final 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.

The comparison of the Shock Response Spectra Analysis undertaken by eight participants, generally showed 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. 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 relatively simple. Some of these did not seem to be very reliable. Quite a few participants resorted to watching an oscilloscope to identify the worst case conditions. 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. It was this aspect of the first round robin that lead to the second round robin exercise.

Comparison of Test Severities

Probably the most interesting result of the first exercise relate 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 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.

A total of 13 participants derived test severities from the data supplied. Four of the participants used a multi-level vibration test programme. 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.

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 seems to have risen rapidly with the number of potential damage aspects considered. However, several participants demonstrated that such considerations are quite practical with current facilities.

As many participants did not base their quoted test severity on PSD analysis alone, to consider only this format would clearly not constitute a fair comparison of the test severities. For this reason the test severities were compared in terms of Power Spectral Densities, Amplitude Probability Densities, Fatigue Damage Spectra and Shock Response Spectra. In each case the test severities were compared both as originally supplied and adjusted to remove the effects of 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.

The comparison of specified Power Spectral Densities indicated a spread of test amplitudes 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 is somewhat misleading as several participants defined a multi-level test requirement. To alleviate this problem only the largest amplitude spectra were compared. The final comparison used 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" was apparent in resultant spread. However, even these variations in severity are still approaching two decades overall.

Second Round Robin Exercise

As already indicated the second round robin exercise arose from the apparently unreliable methods used to identify shocks in the first exercise. The limitations of the first exercise meant that it was not easy to quantify the variations that may occur due to the different approaches used by the participants to identify the worst case shock conditions. As the methods appeared to be highly dependant upon the dedication of the analyst it seemed reasonable to combine the investigatory exercise with a training activity.

Unlike the first exercise, it was decided, that the use of “real” world transportation data would not be advantageous. The use of theoretical data, it was argued, would more readily permit quantitative comparison of the results. Theoretical data would also permit a graded level of complexity of the data. Initially it was thought that the most convenient way of creating the data would be to use a commercial random vibration controller to generate the random vibration background onto which theoretical or measured shocks would be superimposed. However, it transpired that it as more convenient to write a specific FORTRAN computer program to generate both the random vibrations and the superimposed shocks. The methodology adopted by the program was basically identical to that used by a random vibration controller excepting that all the data blocks were separately generated and no peak limiting methods were implemented

The data for the second round robin exercise was circulated, in compressed form, on four computer discs. Each disc each contained a single data record, each of increasingly more complexity. The data records were essentially;

Record No 1 A simple (flat) random vibration signal onto which a number of similar half sine pulses are randomly superimposed. The random vibration spectrum was flat between 5 and 500 Hz with an amplitude of 0.01 g^2/Hz. On to this vibration five identical shocks were superimposed.

Record No 2. A shaped random vibration signal onto which a number of similar decaying sinusoidal pulses are randomly superimposed. The data on this disc comprised a random vibration spectrum flat between 10 and 40 Hz with an amplitude of 0.015 g^2/Hz falling to 0.00015 g^2/Hz at 500 Hz. This vibration spectrum is that of a UK Defence Standard for items transported by road vehicle. On to this vibration seven identical shocks were superimposed.

Record No 3 A shaped random vibration signal onto which a random distribution of different (frequency and amplitude) decaying sinusoidal pulses are randomly superimposed. The data on this disc comprised a random vibration spectrum defined by eight breakpoints. The spectrum is one of the wheeled vehicle vibration test spectra from Mil Std 810E. On to this vibration eight different shocks were superimposed.

Record No 4 A shaped non-stationary (varying rms with time) random vibration signal onto which a random distribution of different (frequency and amplitude) decaying sinusoidal pulses are randomly superimposed. The data on this disc comprised a random vibration spectrum defined by twenty one breakpoints. The spectrum is one of the wheeled vehicle vibration test spectra from Mil Std 810E. The overall amplitude of the vibrations vary along the length of the record. Onto the vibration sixteen different shocks were superimposed.

Results Required of Each Participant

The intent was that each participant such use what ever method they considered appropriate to analyse the data and derive a suitable test. There was no specified single right or wrong method. For each record the data required were;

1. A Power Spectral Density (PSD) of the underlying vibration record.
2. The number (and if possible approximate time location) of the shocks.
3. A definition of the 3 most severe shocks in each record.
4. A recommended test based on the shock and vibration data analysis.

Participants

Responses were received from nine participants. These were;

Bofors (Sweden)
DGA (France)
Faculte Poytechnique de Mons (Belguim)
Matra BAe Dynamics (France)
Ingemansson (Sweden)
Ingenieurburo fur Verpackung (Germany)
Packforsk (Sweden)
SAAB AB (Sweden)
Sulzer Innotec (Switzerland)

Assessment

As was expected almost everybody managed to correctly derive the severity of the background random vibration for the first three records (i.e. those with stationary vibrations). The accuracy of the derived severity been within the random error of the record. This was is not surprising as the effects of the few number of shock was relatively small in comparison to the duration of the vibrations.

The non-stationarity random vibration component of the fourth record was intended to introduce difficulties in identifying the shocks using simple criteria such as level crossing. Although not intended as a specific part of the exercise, the way the participants quantified the fourth, non-stationary, record was of interest. In fact most participants simple averaged though the entire record. However, a few attempted to investigate the degree of variation. The methods used included looking at the rms variations in different time windows and comparing the mean and peak hold spectra. Attempting to quantify the variations did not appear to have been attempted by any participant, but that is not unreasonable as the record were not really long enough for that.

Almost everybody found the shocks correctly in the first three records. These are summarised in Tables 1 to 3. Mostly this result was encouraging as it indicated shocks can be found in random vibrations with a reasonable degree of reliability. The methods used to find the shocks varied, but mainly use was made of visual identification frequently supported by some form of quantitative approach to set a upper threshold for the vibrations. That is “shocks” were deemed to occur when a specific level was exceeded. Several participants attempted to select (or in some cases justify) the selection threshold criteria by use of Amplitude Probability Density (APD). In this case the APD was used to establish the limit of the random vibration viz. when the vibrations ceased to be gaussian. Other participants used kurtosis as the basis of setting a threshold value.

Not applying a peak to rms limit of the computer programme used to create the random vibration was a little sneaky. That is because a threshold based upon a limited distribution of peaks (such as 3 times the rms) could not be relied upon. This is almost certainly the reason one participant identified more shocks than were actually included. Of course in the “real” world the distribution of random vibrations is rarely limited.

Nobody identified all the shocks in the last record. With that said almost all the participants found the same (and the most severe) shocks. It was never expected that the participants would identify all the shocks in this fourth record, rather a range of shocks as included to determine how well the participants would perform in these difficult conditions. The fact that the number of shocks found varied in the range from 7 to 11 (out of 16) suggests a reasonable degree of consistency. This result is not surprising given that the participants all used amplitude as a selection criteria. The non-stationary characteristics of the fourth record seriously limited the applicability of this approach.

For all four records the amplitudes of the most severe 3 shocks were, for all practical purposes, correctly derived, by all participants. This is encouraging as it implies a reasonable worst case shock test could be derived for each of the 4 problems.

The method of identifying the shocks by either visual or by setting a threshold criteria seems adequate when the random vibrations are stationary. However, even with stationary vibrations, the approach may have difficulties when the distributions of vibrations is effectively unlimited. This could be a particular problem with very long records i.e. were a high probability exists of a large peak to rms occurrence

Conclusions

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. The purpose of the two round robin exercises was to determine whether such severities can be reliably derived from measured data.

A wide range of methodologies were adopted by the various participants in the first round robin exercise. In fact identifying the range of methodologies was probably the most interesting result. 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 seems to have been the case regardless of the sophistication of the analysis technique used.

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 (although space prevents this been shown here). Of the approaches considered, the spread of results was the smallest from those who set amplitudes from Fatigue Damage Spectra. Although this may be 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 Probability Densities had a slightly greater variation in amplitude and a lot more variation in spectral shape. This later aspect seems attributable to the relatively "coarse" test definitions used.

If the variation in test severity found in the first 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 and repeatable test results are to be obtained from measured data some attention needs to be given to developing such documentation.

The second round robin exercise addressed a specific problem identified in the first exercise. The provisional results of this exercise indicate that identifying shocks in stationary vibration data can be identified relatively accurately. However, the identification becomes less reliable when the shocks are superimposed upon non stationary vibrations. Essentially all the participants used a threshold crossing approach, albeit using different methods to establish the appropriate threshold value.

	Participant								
	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9
Software used	Lescade/ Speedy	Own	NS	NS	DIADEM	Matview	NS	Dasylab	NS
Number of Shocks Found	5	5	5	5	5	5	5	5	5
Location Shock No 1 (s)	27.7 (1)	28 (2)	individual	28 (2)	28 (1)	28 (2)	28 (1)	28 (2)	28 (2)
Location Shock No 2 (s)	89.2 (2)	90 (3)	shocks	90 (1)	90 (2)	90 (1)	90 (2)	90 (1)	90 (1)
Location Shock No 3 (s)	173	173 (1)	not	173	173 (3)	173	-	173	173
Location Shock No 4 (s)	191(3)	191	identified	191 (3)	191	191 (3)	191 (3)	191 (3)	191 (3)
Location Shock No 5 (s)	263	264		263	263	263	-	263	263
Type of Pulse	Half Sine	½.½sine	Average	Half Sine	Half Sine	NS	Half sine	NS	NS
Amplitude (g)	25	24	23.4	NS	20.7 to 25.9	20.7 to 25.9	27	20.7 to 25.9	20.7 to 25.9
Duration (ms)	4	4	3.2	3.2	NS	NS	4.2	NS	by SRS
Test Details									
Number of Shocks	5	included	NS	NS	NS	NS	NS	NS	NS
Type of Shock	25	in	Half sine	NS	Half sine	NS	Half Sine	Half sine	NS
Shock Amplitude (g)	4	vibration	23.4	NS	25	NS	27	27	NS
Shock Duration (ms)	Half Sine	test	3.2	NS	4	NS	4.2	4.2	NS
Method of Deriving Test	MRS / FDS		NS	NS	visual	NS	visual	NS	NS
Shock ID Criteria	Kurtosis		NS	NS	threshold rms /CF	Visual >5xrms	>5xrms	visual	NS
Method of defining shock	SRS		NS	NS	SRS	NS	TH	NS	NS
Test Factor	1.4	NS	NS	NS	1.0	NS	1.0	1.0	NS
Vibration Test	Yes	NS	NS	NS	NS	NS	yes	yes	NS

(x) denotes identified order
NS = Not Specified

Table 1 Comparison of Shock Parameters for Record 1

	Participant								
	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9
Number of Shocks Found	10	7	7	7	7	7	7	7	7
Location Shock No 1 (s)	8	8	individual	8 (3)	8	8	-	8	8 (3)
Location Shock No 2 (s)	58	58	shocks	58	58	58	-	58	58
Location Shock No 3 (s)	72	72 (3)	not	72 (3)	72	72	-	72	72 (3)
Location Shock No 4 (s)	107	107	identified	107	107	107	-	107	107
Location Shock No 5 (s)	136	136 (2)		136 (3)	136 (1)	136 (1)	137 (1)	136 (1)	136 (2)
Location Shock No 6 (s)	202	202 (1)		202 (1)	202 (2)	202 (3)	201 (2)	202 (3)	202
Location Shock No 7 (s)	252	252		252 (2)	252 (3)	252 (2)	251 (3)	252 (2)	252 (1)
Location of Remainder (s)	34, 116, 165	-		-	-	-	-	-	-
Type of Pulse	half sine	average	average	decayingsine		NS	half sine	NS	NS
Amplitude (g)	17	15.5	16	NS	14.8 to 16.9	14.8 to 16.9	17	14.8 to 16.9	14.8 to 16.9
Duration (ms)	16	16	13.6	16	13.6	NS	16	NS	by SRS
Test Details									
Vibration Test	None	included	NS	NS	NS	NS	Yes	Yes	by SRS
Number of Shocks	7	in	NS	NS	NS	NS	NS	NS	
Type of Shock	17	vibration	half sine	NS	Trapizoid	NS	half sine	NS	
Shock Amplitude (g)	16	test	16	NS	17	NS	17	NS	
Shock Duration (ms)	Half Sine		13.6	NS	MNS	NS	16	NS	

Table 2 Comparison of Shock Parameters for Record 2

		Participant								
		No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9
Number of Shocks Found		8	7	8	8	8	8	8	8	8
Location Shock No 1 (s)		23	23	23	23 (2)	23	23 (3)	23 (1)	23	23
Location Shock No 2 (s)		68	68	68	68	68	68	-	68	68
Location Shock No 3 (s)		119 (1)	120 (1)	119 (3)	119 (3)	119	119	-	119	119
Location Shock No 4 (s)		158	158 (3)	158 (1)	158	158 (1)	158	-	158	158
Location Shock No 5 (s)		161		161	161	161	161	-	161	161
Location Shock No 6 (s)		208	208	208	208	208	208	-	208	208
Location Shock No 7 (s)		222 (2)	222 (2)	222 (2)	222 (1)	222 (2)	222 (2)	222 (2)	222	222
Location Shock No 8 (s)		281 (3)	281	281	281	281 (3)	281 (1)	281 (3)	281	281
Type of Pulse		Half Sine		Half Sine	Decaying Sine	-	-	-	NS	NS
Shock 1	Amplitude (g)	-10	By	7.4	ranked	7.4	12.3		12.3	6.6
	Duration (ms)	20	Time	33.6	by	45	NS	defined	NS	to
Shock 2	Amplitude (g)	12	History	11.88	pulse	11.9	11.8	by	11.8	12.3
	Duration (ms)	14	and	13.6	duration	13.6	NS	SRS	NS	by
Shock 3	Amplitude (g)	12.5	SRS	-9.4		12.3	10.1		10.1	SRS
	Duration (ms)	5		20.8		4	NS		NS	
Test Details										
Number ofShocks		8	NS	NS	NS	NS	NS		NS	NS
Type of Shock		2 x 4	half sine	NS	NS	by	NS	Half Sine	NS	
Amplitude (g)		2 x 4	12	NS	NS	SRS	NS	16	NS	
Duration (ms)		Half Sine	16	NS	NS		NS	11	NS	
Vibration Test		Yes	NS	NS	NS	NS	NS	Yes	Yes	

Table 3 Comparison of Shock Parameters for Record 3

		Participant								
		No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9
Number of Shocks Found		9	7	7	7		7	7	11	8
Location Shock No 1 (s)		64	64	64 (2)	64		64	-	64	64
Location Shock No 2 (s)		123	-	123	123		123	-	123	123
Location Shock No 3 (s)		147	147 (2)	147			147	-	147	147
Location Shock No 4 (s)		160	-	160	160		160 (3)	160 1)	160 (3)	160 (3)
Location Shock No 5 (s)		179 (1)	179 (1)	179 (1)	179		179 (1)	179 (2)	179 (1)	179 (1)
Location Shock No 6 (s)		199 (2)	199 (3)	199 (3)	199		199 (2)	199 (3)	199 (2)	199 (2)
Location Shock No 7 (s)		250	250		250		-	-	250	250
Location Shock No 8 (s)		313 (3)	313	313	313		313	-	313	313
Remaining Locations (s)		48	45		-		-	-	219, 288, 227	-
Type of Pulse		Half Sine	½½ sine	Half Sine			NS	-	NS	
Shock 1	Amplitude (g)	28	by	27.9	by		27.9		27.9	defined
	Duration (ms)	16	time	13.6	pulse		NS		NS	by
Shock 2	Amplitude (g)	17.5	history	14.2	duration		17.5	defined	17.5	SRS
	Duration (ms)	11	and	16			NS	by	NS	and
Shock 3	Amplitude (g)	16.5	SRS	17.5			16.7	SRS	16.7	Time
	Duration (ms)	8		9.6			NS		NS	History
Test Details										
Number of Shocks		3		NS	NS		NS	NS	NS	NS
Type of Shock		Half Sine	Half sine	NS	NS		NS	half sine	NS	NS
Shock Amplitude (g)		128	28	NS	NS		NS	35	NS	NS
Shock Duration (ms)		16	16	NS	NS		NS	18	NS	NS
Vibration Test				Yes	NS		NS	Yes	Yes	NS

Table 4 Comparison of Shock Parameters for Record 4