METHOD 516.5

SHOCK

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METHOD 516.5

SHOCK

NOTE: Tailoring is essential. Select methods, procedures, and parameter levels based on the tailoring process described in Part One, paragraph 4, and Appendix C. Apply the general guidelines for laboratory test methods described in Part One, paragraph 5 of this standard.

1. SCOPE.

1.1 Purpose.

Shock tests are performed to:

a. provide a degree of confidence that materiel can physically and functionally withstand the relatively infrequent, non-repetitive shocks encountered in handling, transportation, and service environments. This may include an assessment of the overall materiel system integrity for safety purposes in any one or all of the handling, transportation, and service environments;

b. determine the materiel's fragility level, in order that packaging may be designed to protect the materiel's physical and functional integrity; and

c. test the strength of devices that attach materiel to platforms that can crash.

1.2 Application.

Use this method to evaluate the physical and functional performance of materiel likely to be exposed to mechanically induced shocks in its lifetime. Such mechanical shock environments are generally limited to a frequency range not to exceed 10,000 Hz and a time duration of not more than 1.0 second. (In most cases of mechanical shock the significant materiel response frequencies will not exceed 2,000 Hz and the duration of materiel response will not exceed 0.1 second.) The materiel response to the mechanical shock environment will, in general, be highly oscillatory, of short duration, and have a substantial initial rise time with large positive and negative peak amplitudes of about the same order of magnitude.[1] The peak responses of materiel to mechanical shock will, in general, be enveloped by a decreasing form of exponential function in time. In general, mechanical shock applied to a complex multi-modal materiel system will cause the materiel to respond to (1) forced frequencies imposed on the materiel from the external excitation environment, and (2) the materiel's resonant natural frequencies either during or after application of the excitation. Such response may cause:

a. materiel failure as a result of increased or decreased friction between parts, or general interference between parts;

b. changes in materiel dielectric strength, loss of insulation resistance, variations in magnetic and electrostatic field strength;

c. materiel electronic circuit card malfunction, electronic circuit card damage, and electronic connector failure. (On occasion, circuit card contaminants having the potential to cause short circuit may be dislodged under materiel response to shock.);

d. permanent mechanical deformation of the materiel as a result of overstress of materiel structural and non-structural members;

e. collapse of mechanical elements of the materiel as a result of the ultimate strength of the component being exceeded;

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[1] For high impact velocity shock, e.g., penetration shocks, there may be significantly less or no oscillatory behavior with substantial area under the acceleration response curve.

f. accelerated fatiguing of materials (low cycle fatigue);

g. potential piezoelectric activity of materials, and

h. materiel failure as a result of cracks in fracturing crystals, ceramics, epoxies, or glass envelopes.

1.3 Limitations.

a. This method does not include the effects of shock experienced by materiel as a result of pyrotechnic device initiation. For this type of shock see method 517, Pyroshock.

b. This method does not include the effects experienced by materiel to very high level localized impact shocks, e.g., ballistic impacts. For this type of shock, devise specialized tests based on experimental data, and consult method 522, Ballistic Shock.

c. This method does not include the high impact shock effects experienced by materiel aboard a ship. Consider performing shock tests for shipboard materiel in accordance with MIL-S-901 (reference k).

d. This method does not include the effects experienced by fuse systems. Perform shock tests for safety and operation of fuses and fuse components in accordance with MIL-STD-331 (reference l).

e. This method does not include the effects experienced by materiel that is subject to high pressure wave impact, e.g., pressure impact on a materiel surface as a result of firing of a gun. For this type of shock and subsequent materiel response, devise specialized tests based on experimental data and consult method 519.5, Gunfire Vibration.

f. This method does not include the shock effects experienced by very large extended materiel, e.g., building pipe distribution systems, over which varied parts of the materiel may experience different and unrelated shock events. For this type of shock, specialized tests based on experimental data must be devised.

g. This method does not include special provisions for performing shock tests at high or low temperatures. Perform tests at room ambient temperature unless otherwise specified. Guidelines found in this section of the standard, however, may be helpful in setting up and performing shock tests at high or low temperatures.

h. This method does not include engineering guidelines related to unplanned test interruption as a result of test equipment or other malfunction. Generally, if an interruption occurs during a shock pulse input, repeat that shock pulse input. Care must be taken to ensure stresses induced by the interrupted pulse do not invalidate subsequent test results. It is incumbent on all test facilities that data from such interruptions be recorded and analyzed before continuing with the test sequence. In addition, the overall integrity of the materiel must be inspected to ensure pre-shock test materiel integrity.

2. TAILORING GUIDANCE.

2.1 Selecting the Shock Method.

After examining requirements documents and applying the tailoring process in Part One of this standard to determine where mechanical shock environments are foreseen in the life cycle of the materiel, use the following to confirm the need for this method and to place it in sequence with other methods.

2.1.1 Effects of shock.

Mechanical shock has the potential for producing adverse effects on the physical and functional integrity of all materiel. In general, the level of adverse effects increases with both the magnitude and the duration of the shock environment. Durations of shock that correspond with natural frequency periods of the materiel and/or periods of major frequency components in input shock environment waveforms that correspond with natural frequency periods of the materiel will magnify the adverse effects on the materiel's overall physical and functional integrity.

2.1.2 Sequence among other methods.

a. General. See Part One, paragraph 5.5.

b. Unique to this method. Sequencing among other methods will depend upon the type of testing i.e., developmental, qualification, endurance, etc and the general availability of test items for test. Normally, schedule shock tests early in the test sequence, but after any vibration tests.

   (1) If the shock environment is deemed particularly severe, and the chances of materiel survival without major structural or functional failure are small, the shock test should be first in the test sequence. This provides the opportunity to redesign the materiel to meet the shock requirement before testing to the more benign environments with potential cost savings.

   (2) If the shock environment is deemed severe but the chances of the materiel survival without structural or functional failure is good, perform the shock test after vibration and thermal tests, allowing the stressing of the test item prior to shock testing to uncover combined vibration, temperature, and shock environmental failures.

   (3) In cases in which the shock test levels are deemed less severe than the vibration test levels, the shock tests may be deleted from the testing sequence.

   (4) There are often advantages to applying shock tests before climatic tests, provided this sequence represents realistic service conditions. Test experience has shown that climate-sensitive defects often show up more clearly after the application of shock environments. However, internal or external thermal stresses may permanently weaken materiel resistance to vibration and shock that may go undetected if shock tests are applied before climatic tests.

2.2 Selecting a Procedure.

This method includes eight test procedures.

a. Procedure I - Functional Shock.

b. Procedure II - Materiel to be packaged.

c. Procedure III – Fragility.

d. Procedure IV - Transit Drop.

e. Procedure V - Crash Hazard.

f. Procedure VI - Bench Handling.

g. Procedure VII - Rail Impact.

h. Procedure VIII - Catapult Launch/Arrested Landing.

2.2.1 Procedure selection considerations.

Based on the test data requirements, determine which test procedure, combination of procedures, or sequence of procedures is applicable. In many cases, one or more of the procedures will apply. Consider all shock environments anticipated for the materiel during its life cycle, both in its logistic and operational modes. When selecting procedures, consider:

a. The operational purpose of the materiel. From requirement documents, determine the operations or functions to be performed by the materiel before, during and after the shock environment.

b. The natural exposure circumstances. Procedures I through VII specify single shocks which result from momentum exchange between materiel or materiel support structures and another body. Procedure VIII (catapult launch) contains a sequence of two shocks separated by a comparatively short duration vibration, i.e., transient vibration. Procedure VIII (Catapult Launch/Arrested Landing) may be considered a single shock followed by a transient vibration.

c. Data required. The test data required to document the test environment and to verify the performance of the materiel before, during, and after test.

d. Procedure sequence. Refer to paragraph 2.1.2.

2.2.2 Difference among procedures.

a. Procedure I - Functional Shock. Procedure I is intended to test materiel (including mechanical, electrical, hydraulic, and electronic) in its functional mode and to assess the physical integrity, continuity and functionality of the materiel to shock. In general, the materiel is required to function during the shock and to survive without damage to shocks representative of those that may be encountered during operational service.

b. Procedure II - Materiel to be packaged. Procedure II is to be used when materiel will require a shipping container. It specifies a minimum critical shock resistance level to a handling drop height. The shock definition may be furnished to a package designer as a design criterion. This procedure is not intended for the test of extremely fragile materiel, e.g., missile guidance systems, precision-aligned test equipment, gyros, inertial guidance platforms, etc. For extremely fragile materiel where quantification of shock resistance is required Procedure III should be considered. See paragraph 2.3 below for processing techniques useful in expressing shock resistance criteria.

c. Procedure III - Fragility. Procedure III is used to determine a materiel’s ruggedness or fragility so that packaging can be designed for the materiel, or so the materiel can be redesigned to meet transportation and/or handling requirements. This procedure is used to determine the critical shock conditions at which there is reasonable chance of structural and/or functional system degradation. To achieve the most realistic criteria, perform the procedure at environmental temperature extremes. See paragraph 2.3 below for processing techniques useful in expressing shock fragility criteria.

d. Procedure IV - Transit Drop. Procedure IV is intended for materiel either outside of or within its transit or combination case, or as prepared for field use (carried to a combat situation by man, truck, rail, etc.). This procedure is used to determine if the materiel is capable of withstanding the shocks normally induced by loading and unloading when it is (1) outside of its transit or combination case, e.g., during routine maintenance, when being removed from a rack, being placed in its transit case, etc., or (2) inside its transit or combination case. Such shocks are accidental, but may impair the functioning of the materiel. This procedure is not intended for shocks encountered in a normal logistic environment as experienced by materiel inside shipping containers and defined in the materiel’s life cycle profile (see Procedure II – Materiel to be Packaged).

e. Procedure V - Crash Hazard. Procedure V is for materiel mounted in air or ground vehicles that could break loose from its mounts, tiedowns or containment configuration during a crash and present a hazard to vehicle occupants and bystanders. This procedure is intended to verify the structural integrity of materiel mounts, tiedowns or containment configuration during simulated crash conditions. The test should be used to verify the overall structural integrity of the materiel, i.e., parts of the materiel are not ejected under the shock. This procedure is not intended for materiel transported as cargo for which method 513.5, Acceleration, or method 514.5, Vibration, could be applied.

f. Procedure VI - Bench Handling. Procedure VI is intended for materiel that may typically experience bench handling, bench maintenance, or packaging. It is used to determine the ability of the materiel to withstand representative levels of shock encountered during typical bench handling, bench maintenance, or packaging. Such shocks might occur during materiel repair. This procedure may include testing for materiel with protrusions that may be easily damaged without regard to gross shock on the total materiel. The nature of such testing is highly specialized and must be performed on a case-by-case basis, noting the configuration of the materiel protrusions and the case scenarios for damage during such activities as bench handling, maintenance, and packaging. This procedure is appropriate for medium-to-large test materiel out of its transit or combination case that has a maximum dimension greater than approximately 23 cm (9 inches). Small materiel systems, in general, will be tested to higher levels during Procedure IV, Transit Drop.

g. Procedure VII - Rail Impact. Procedure VII is intended to test materiel that will be transported by rail; to determine the effect of normal railroad car impacts that occur during rail shipment, to verify the structural integrity of the materiel, and to evaluate the adequacy of the tiedown system and the tiedown procedures. All items are to be tested at their maximum gross weight (fully loaded) rating unless otherwise specified in the transportability requirements for the materiel. This procedure is not intended for the separate testing of small, individually packaged pieces of materiel that would normally be shipped (and tested) when mounted on a pallet, or as part of a larger materiel. For such tests, the references provide guidance on environments measured during rail impact that may be useful in specially tailored laboratory testing.

h. Procedure VIII - Catapult Launch/Arrested Landing. Procedure VIII is intended for materiel mounted in or on fixed-wing aircraft that are subject to catapult launches and arrested landings. For catapult launch, materiel may experience a combination of initial shock followed by a low level transient vibration of some duration having frequency components in the neighborhood of the mounting platform's lowest frequencies, and concluded by a final shock according to the catapult event sequence. For arrested landing, materiel may experience an initial shock followed by a low level transient vibration of some duration having frequency components in the neighborhood of the mounting platform's lowest frequencies.

2.2.3 Test interruption.

a. General. See Part One, paragraph 5.11 of this standard.

b. Specific to this method. Interruption of a shock test is unlikely to generate any adverse effects. Normally, continue the test from the point of interruption.

2.3 Determine Test Levels and Conditions.

Having selected this method and relevant procedures (based on the materiel's requirements documents and the tailoring process), complete the tailoring process by identifying appropriate parameter levels, applicable test conditions, and test techniques for the selected procedures. Base these selections on the requirements documents, the Life Cycle Environmental Profile, Operational Environment Documentation (see Part One, figure 1-1), and information provided with this procedure. Consider the following when selecting test levels:

2.3.1 General considerations – Terminology and illustration for complex transient.

a. Shock. Shock is the term applied to a comparatively short time moderately high level force impulse input to materiel. For this method materiel response acceleration will generally be the experimental variable of measurement. However, this does not preclude other variables of materiel response measurement such as velocity, displacement, strain, force, or pressure from being used and processed in an analogous manner, as long as the interpretation of the measurement variable is clear and the measurement instrumentation configuration is validated, e.g., measurements made within the significant frequency range of the materiel response, etc. Figure 516.5-1 displays a moderately complex extended measured shock response acceleration time history that might, based upon the judgement of a trained analyst and the objectives of the test, reasonably be decomposed into several independent shocks. There are several useful measurement estimates of duration, amplitude, and frequency for describing the time-varying response behavior of the materiel. Four useful descriptive estimates are defined in detail with references in the Part One, Appendix D (Terminology), and will be discussed here briefly for characterizing the materiel response (1) Effective Transient Duration (T_e), (2) Shock Response Spectra (SRS), (3) Energy Spectral Density (ESD), and (4) Fourier Spectra (FS).

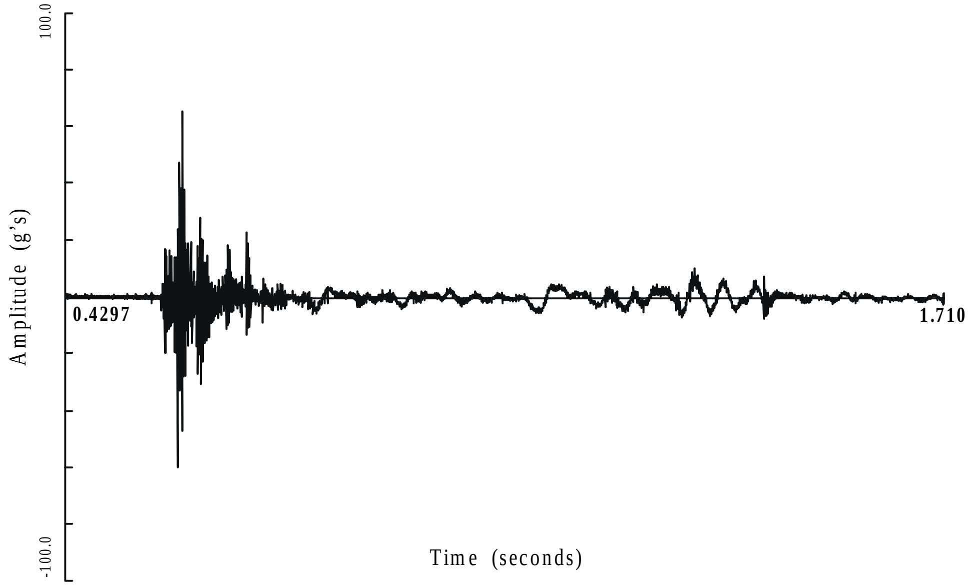


FIGURE 516.5-1. Sample shock response acceleration time history.

(1) Effective shock duration (T_E/T_e): For Procedures I and V the effective shock duration, T_E, is defined to be the minimum length of time which contains all time history magnitudes exceeding in absolute value 1/3 of the peak magnitude, A_p, associated with the shock event. An additional definition of effective shock duration, T_e, (potentially more useful for complex measured transients that are to be processed), will be the minimum length of time that contains at least 90% of the root-mean-square (RMS) time history amplitudes exceeding in value 10% of the peak RMS magnitude associated with the shock event. Figure 516.5-2 illustrates the effective shock durations T_E and T_e on a truncated form of the shock time history depicted on figure 516.5-1. Because of the complex and extended nature of the shock, T_E and T_e are nearly identical. For less complex shock time histories this is usually not the case (see Annex B of this method). The 90% requirement in T_e precludes extending the shock over times that include noise spikes of amplitude greater than 10% of the peak RMS magnitude. It is important to note that the RMS estimate is a function of the length of the record over which the estimate is made. For a moving average estimate the length of average should always be greater than 10% of T_e or an equivalent time constant for exponential averaging. Figure 516.5-3 provides an estimate of the short time average RMS of the time history depicted on figure 516.5-2 along with T_e (and T_E from figure 516.5-2). On figure 516.5-3 the short time averaging time is about 13% of T_e. In most cases, the judgement of an experienced analyst will be satisfactory in determining the effective duration, T_E or T_e, in place of a rigorously applied analytical definition. For determination of the effective shock duration, T_e, for any processing of measured transient time history data, it is important that (a) information inherent in the complex transient is preserved and (b) information related to instrumentation noise is minimized.

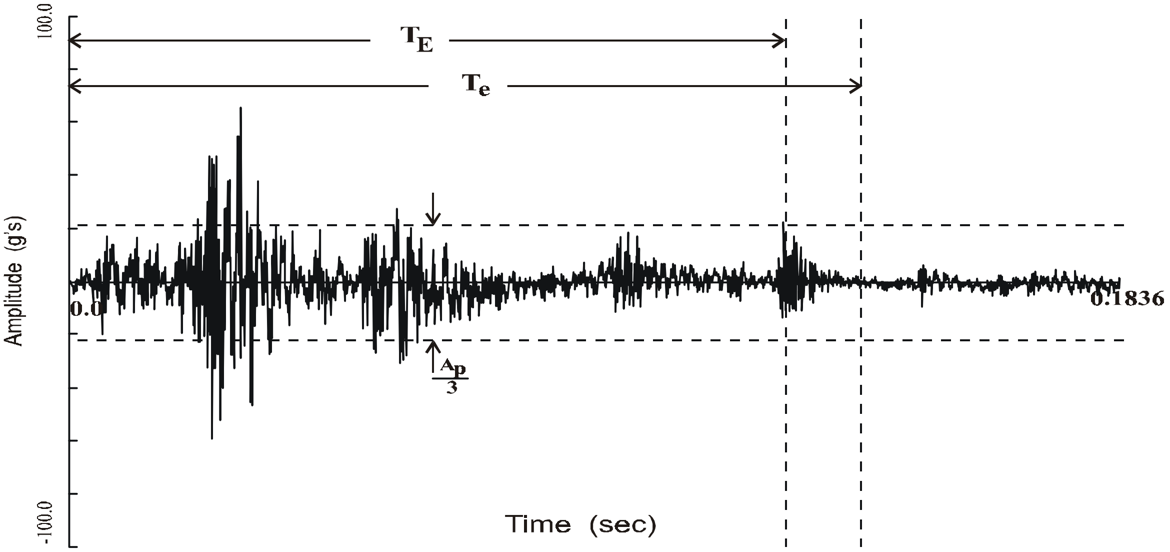


FIGURE 516.5-2. Truncated sample shock response acceleration time history effective durations T_E and T_e.

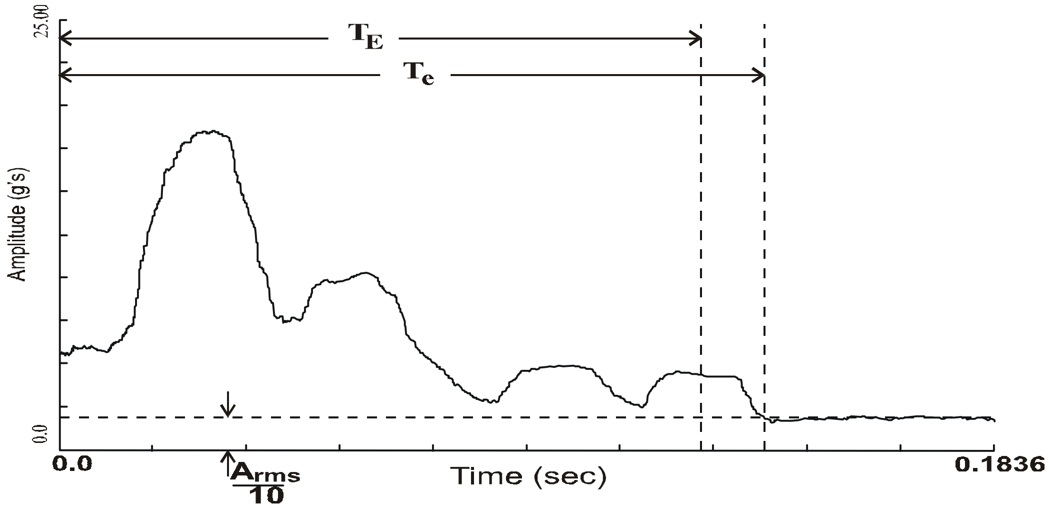


FIGURE 516.5-3. Truncated sample shock acceleration time history short time average RMS (averaging time approximately 13% of T_e).

(2) Shock Response Spectrum (SRS): The SRS value at a given undamped natural oscillator frequency, f_n, describes the maximum response of the mass of a damped single degree of freedom system (SDOF) at this frequency to a shock base input time history of duration T_e. Damping of the SDOF is expressed in terms of a "Q" (quality factor) value where a Q of 50 represents 1% critical damping; a Q of 10, 5% critical damping; and a Q of 5, 10% critical damping of the SDOF. For processing of shock response data, the absolute acceleration maximax SRS has become primary analysis descriptor. In this measurement description of the shock, the maximax acceleration values are plotted on the ordinate with the undamped natural frequency of the SDOF with base input plotted along the abscissa. The frequency range over which the SRS is computed extends from a lowest frequency of interest up to a frequency at which the flat portion of the spectrum has been reached. This latter upper frequency requirement helps ensure no high frequency content in the spectrum is neglected. The lowest frequency of interest is determined by the frequency response characteristics of the materiel under test. For f_{min}, the lowest frequency of interest, the SRS is computed over a time interval T_e or $1/2f_{min}$, (whichever is the greatest) starting with the first amplitude rise of the shock. A more complete description of the shock (potentially more useful for shock damage assessment, but not widely accepted) can be obtained by determining the maximax pseudo-velocity response spectrum and plotting this on four-coordinate paper where, in pairs of orthogonal axes, the maximax pseudo-velocity response spectrum is represented by the ordinate, with the undamped natural frequency being the abscissa and the maximax absolute acceleration along with maximax pseudo-displacement plotted in a pair of orthogonal axes, all plots having the same abscissa. The maximax pseudo-velocity at a particular SDOF undamped natural frequency is thought to be more representative of the damage potential for a shock since it correlates with stress and strain in the elements of a single degree of freedom system (reference b). If the testing is to be used for laboratory simulation, use a Q value of ten and a second Q value of 50 in the processing. Using two Q values, a damped value and a value corresponding to light damping, provides an analyst with information on the potential spread of materiel response. It is recommended that the maximax absolute acceleration SRS be the primary method of display for the shock, with the maximax pseudo-velocity SRS the secondary method of display and useful in cases in which it is desirable to be able to correlate damage of simple systems with the shock. Figure 516.5-4 displays the maximax acceleration SRS for the shock time history displayed on figure 516.5-2 over the effective shock duration, T_e, displayed on figure 516.5-3. Figure 516.5-5 displays the corresponding maximax pseudo-velocity SRS.

(3) Energy Spectral Density (ESD): The ESD estimate, the properly scaled magnitude of the Fourier Transform of the total shock, is computed at a uniform set of frequencies and displayed as a two-dimensional plot of amplitude versus frequency. The amplitude units are "units^2-sec/Hz." In determining the ESD estimate, it is important that the Fast Fourier Transform block size is selected such that all the shock event is contained within the block; but excessive noise beyond the effective duration, T_e, of the shock be removed by zero-padding the transform block, i.e., replacing noise data values by zeros. The ESD description is useful for comparing the distribution of energy within the frequency band among several shocks. Figure 516.5-6 displays the ESD estimate for the shock time history of figure 516.5-2. For an ESD estimate, the percentage of normalized random error in the ordinate is 100%. By either (1) averaging n adjacent ESD ordinates or (2) averaging n independent, but statistically equivalent ESD estimates, the percentage of normalized random error can be decreased by $1/\sqrt{n}$.

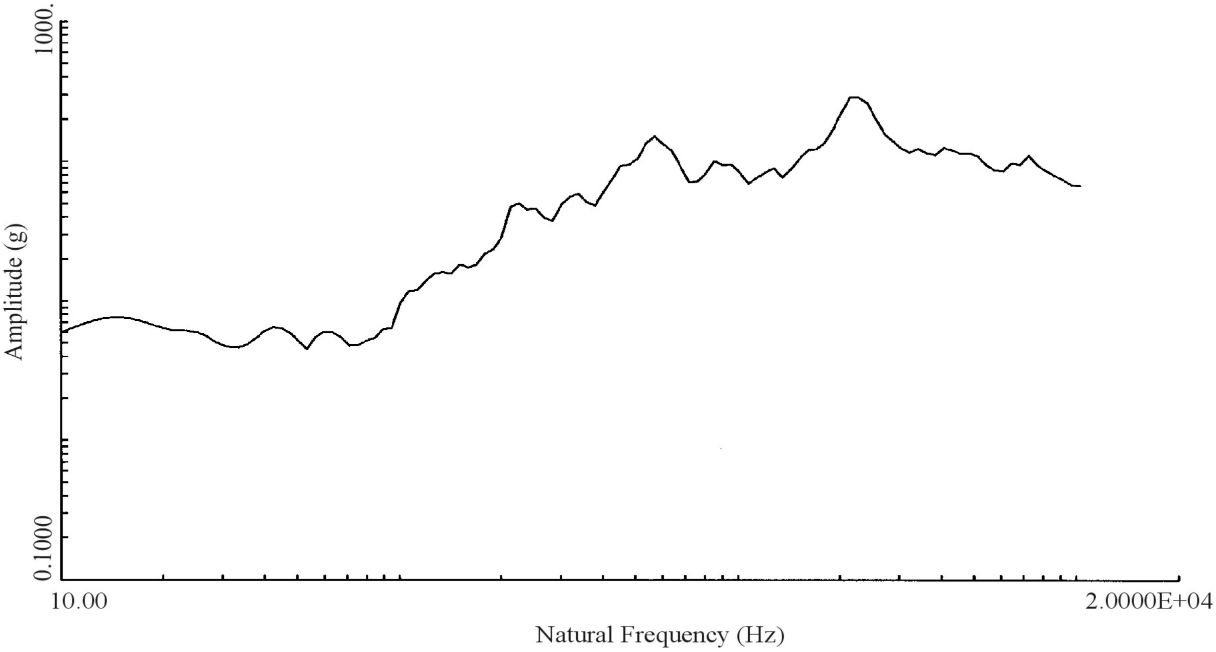


FIGURE 516.5-4. Sample shock response acceleration maximax SRS.

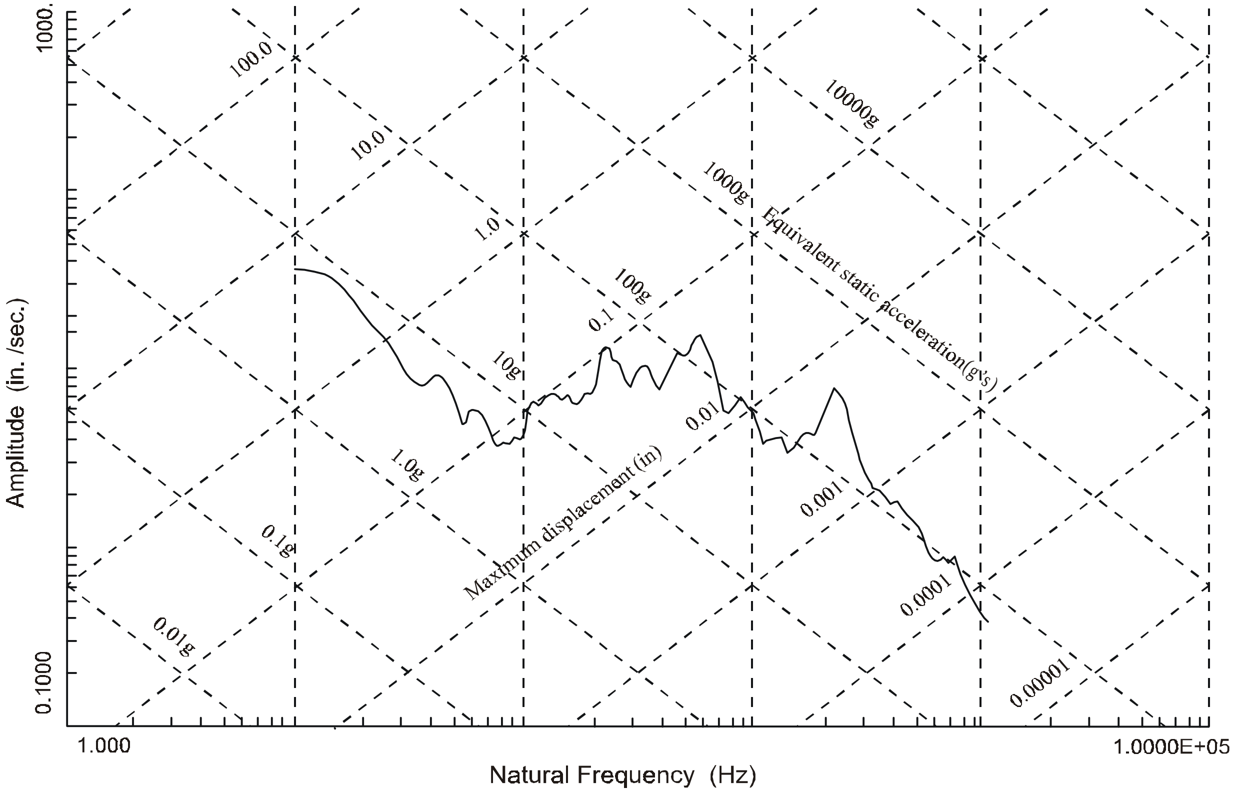


FIGURE 516.5-5. Sample shock response acceleration pseudo-velocity SRS.

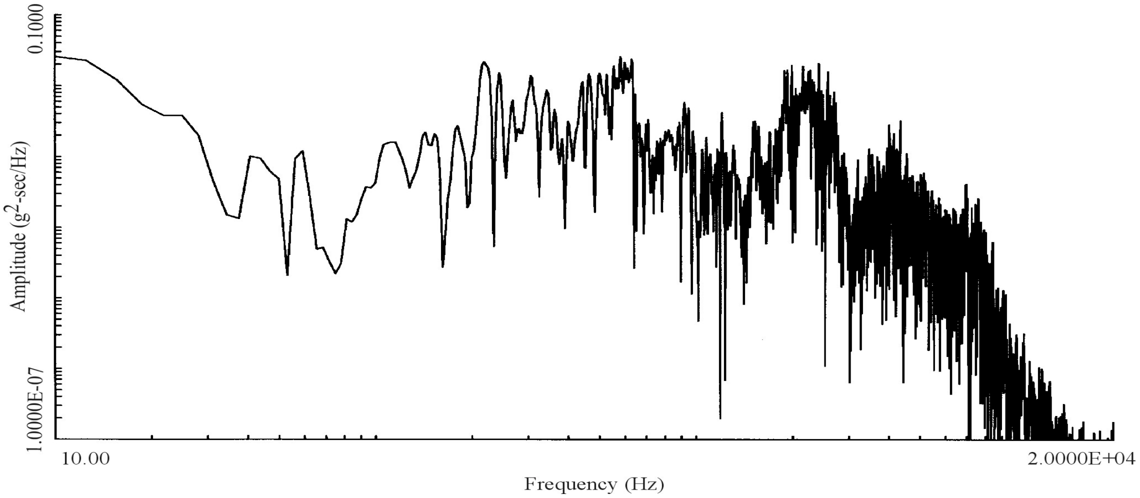


FIGURE 516.5-6. Sample shock response acceleration ESD estimate.

(4) Fourier Spectra (FS): The FS estimate, the properly scaled square root of the magnitude of the Fourier Transform of the total shock, is computed at a uniform set of frequencies and displayed as a two-dimensional plot of amplitude versus frequency. The amplitude units are "units-sec." In determining the FS estimate, it is important that the Fast Fourier Transform block size is selected such that all of the shock event is contained within the block, but excessive noise beyond the effective duration, T_e of the shock be removed by zero-padding the transform block. The FS description is useful for noting outstanding frequency components within the overall frequency band among shocks. Figure 516.5-7 displays the FS estimate for the shock time history of figure 516.5-2. For an FS estimate, the percentage of normalized random error in the ordinate is 100%. By either (1) averaging n adjacent FS ordinates or (2) averaging n independent but statistically equivalent FS estimates, the percentage of normalized random error can be decreased by $1/\sqrt{n}$.

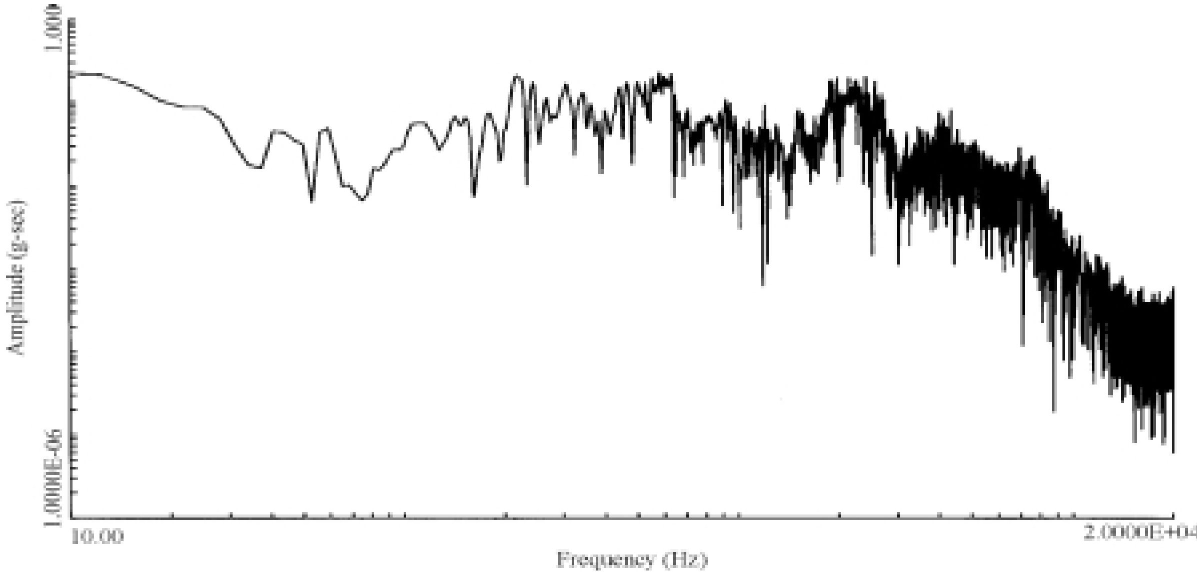


FIGURE 516.5-7. Sample shock response acceleration FS estimate.

b. Shock/Random Vibration. In general, any one test procedure will not be required along any axis for which a sufficiently severe random vibration test procedure is required, provided that system integrity requirements are comparable. Random vibration test severity is sufficient if the shock response spectrum over a short duration of the signal based upon a three-sigma Gaussian acceleration response of a SDOF, exceeds the shock test response spectrum everywhere in the specified range of natural frequencies. The Q value to be used in the analysis is generally taken to be ten, which is equivalent to five percent of critical viscous damping. The three-sigma shock response spectrum for the random test is given, as a function of natural frequency of the SDOF, by

$$A(f) = 3\left[\left(\frac{\pi}{2}\right)G(f)\,fQ\right]^{\frac{1}{2}}$$

in units of acceleration, where G(f) is the acceleration ASD at frequency f (reference a). Annex C of this method discusses the relationship between ASD levels and corresponding SRS levels for purposes of substituting a comparatively high level random vibration test for a relatively low level shock test.

c. Statistical Estimate Processing. At times it may be convenient or even necessary to combine equivalently processed response estimates in some statistical manner. Reference g discusses some options in statistically summarizing processed results from a series of tests. The best option is dependent upon the size of sample in general. Processed results from the SRS, ESD, or FS are typically logarithmically transformed to provide estimates that are more normally distributed. This transformation is important since often very few estimates are available from a test series and the probability distribution of the untransformed estimates cannot be assumed to be normally distributed. In virtually all cases, combination of processed results will fall under the category of small sample statistics and need to be considered with care with other parametric or less powerful nonparametric methods of statistical analysis. Annex 516.5A addresses the appropriate techniques for the statistical combination of processed test results as a function of the size of the sample.

d. Other Processing. Other descriptive processes that tend to decompose the shock into component parts, e.g., product model, time domain moments, wavelets, etc., may be useful, but are beyond the scope of this document.

2.3.2 Test conditions.

Derive the test SRS and T_e from statistical processing of (1) time history measurements of the materiel's functional environment, (2) from a carefully scaled measurement of a dynamically similar environment, (3) from prediction, or (4) from a combination of sources. For tailoring purposes, every attempt needs to be made to obtain measured data under conditions similar to service environment conditions in the Life Cycle Profile. In test SRS and T_e derivation and subsequent execution rank from the most desirable to the least desirable as follows:

- measured data summarized and shock created by way of direct reproduction of the measured data under shaker waveform control;
- measured data summarized and shock synthesized by way of a complex transient making sure that measured T_e is approximately the test T_e, and the measured waveform is similar to the synthesized waveform, i.e., amplitude and zero crossing similarity.
- no measured data but previous SRS estimates available and shock synthesized by way of a complex transient with T_e specified in some reasonable way taking into consideration the natural frequency response characteristics of the materiel;
- no measured data but classical pulse shock descriptions available for use in reproducing the shock. (The use of classical pulse description is unacceptable unless use of such pulses can be justified on the basis of analysis.)

a. Measured data available. T_e required for the test will be determined by examining representative time history measurements. T_e will extend from the first significant response time history point to the analytically derived T_e or to the noise floor of the instrumentation system, whichever is shortest. SRS required for the test will be determined from analytical computations. For $T_e < \frac{1}{2f_{min}}$, T_e for test may be extended to $\frac{1}{2f_{min}}$. The SRS analysis will be performed on the AC coupled time history for Q = 10 at a sequence of natural frequencies spaced at 1/12 octave or less spacing to span at least 5 to 2,000 Hz.

(1) When a sufficient number of representative shock spectra are available, an appropriate statistical enveloping technique should be employed to determine the required test spectrum with a statistical basis (see Annex A of this method). The T_e for test should be taken as the maximum of the T_e or $\frac{1}{2f_{min}}$, which ever is greater.

(2) When insufficient measured data are available for statistical analysis, an increase over the maximum of the available spectral data should be used to establish the required test spectrum. This should account for stochastic variability in the environment and uncertainty in any predictive methods employed. The degree of increase is based on engineering judgment and should be supported by rationale. In these cases, it is often convenient to envelope the SRS estimates and proceed to add either a 3dB or 6dB margin to the SRS, depending on the degree of test level conservativeness desired (see Annex A paragraph A3.2. of this method). The T_e for test should be taken as the maximum of the T_e or $\frac{1}{2f_{min}}$, which ever is greater.

b. Measured data not available. If a measured data base is not available, then for Procedure I - Functional shock and Procedure V - Crash hazard, employ the applicable SRS spectrum from figure 516.5-8 as the test spectrum for each axis, provided T_e of the test shock time history falls between the values in the accompanying table (516.5-I). This spectrum approximates that of the perfect terminal-peak sawtooth pulse. It is highly recommended that the test be performed with a waveform that is composed of either (1) a superposition of damped sinusoids with selected properties at a finite number of designated frequencies or (2) a superposition of amplitude modulated sine waves with selected properties at a finite number of designated frequencies, such that this waveform has an SRS that approximates the SRS on figure 516.5-8 where the duration of this waveform is a maximum of T_e provided in table 516.5-I. In reality, any complex test transient is suitable if it equals or exceeds this spectrum requirement over the frequency range of 5 to 2000 Hz, and meets the duration requirement. Use of the classical terminal-peak sawtooth pulse and the classical trapezoidal pulse is the least permissible test alternative in the case of no data being available (see paragraph 2.3.2c). In cases in which there is a vibration requirement for the materiel in addition to a shock requirement it may be possible to perform the vibration test in lieu of the shock test in the tailoring procedure. An example of this form of tailoring is contained in Procedure I - Functional Shock. Figure 516.5-9 provides two ASD curves to be used for comparison with specified ASD test environments to determine if random vibration is of sufficient severity to be used in lieu of measured or specified shock levels. The SRS for stationary random environments developed from these ASD curves, envelopes the appropriate SRS spectra on figure 516.5-8. For some empirical justification of this, see Annex C of this method.

c. Classical shock pulses. Unless the procedure requires the use of a classical shock pulse, the use of such a pulse is not acceptable unless it can be demonstrated that measured data is within the tolerances of the classical shock pulses. Only two classical shock pulses are defined for testing in the method – the terminal peak sawtooth pulse and the trapezoidal pulse. The terminal peak sawtooth pulse along with its parameters and tolerances is provided on figure 516.5-10 and is an alternative for testing in Procedure I - Functional shock and Procedure V - Crash hazard.

TABLE 516.5-I. Test shock response spectra for use if measured data are not available.

Test Category	Peak Acceleration (g's)	T_e (ms)	Cross-over Frequency (Hz)
Functional Test for Flight Equipment	20	15-23	45
Functional Test for Ground Equipment	40	15-23	45
Crash Hazard Test for Flight Equipment	40	15-23	45
Crash Hazard Test for Ground Equipment	75	8-13	80

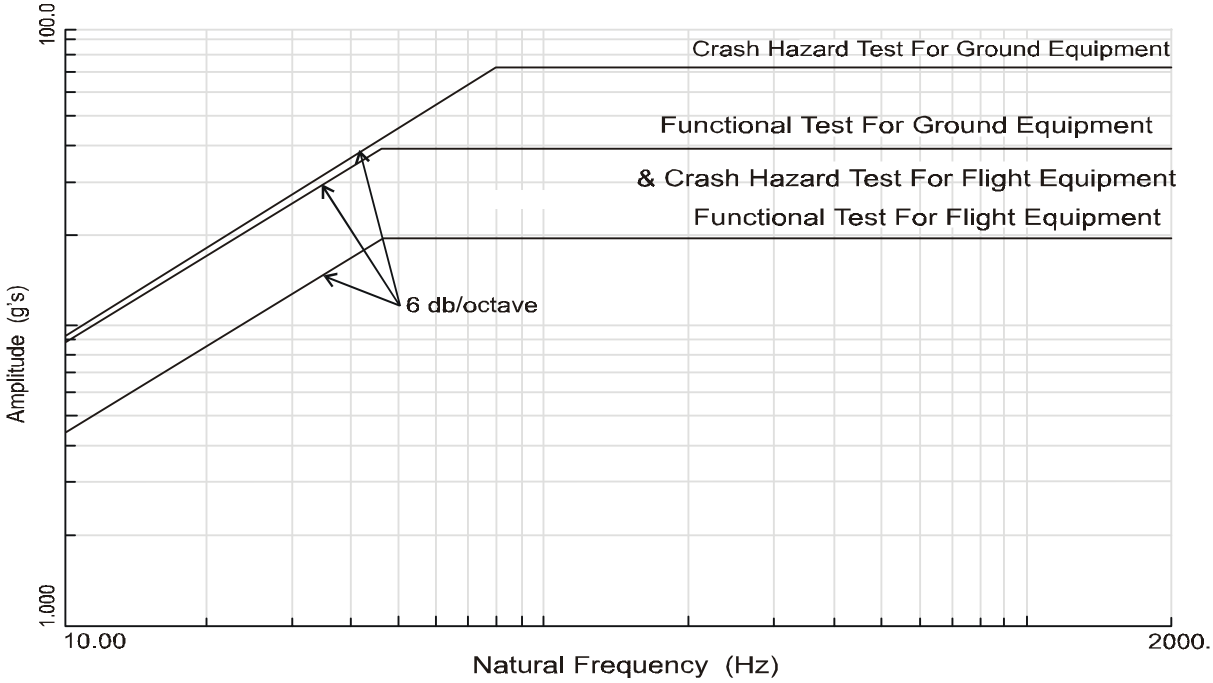


FIGURE 516.5-8. Test SRS for use if measured data are not available (for Procedure I - Functional Shock & Procedure V - Crash Hazard).

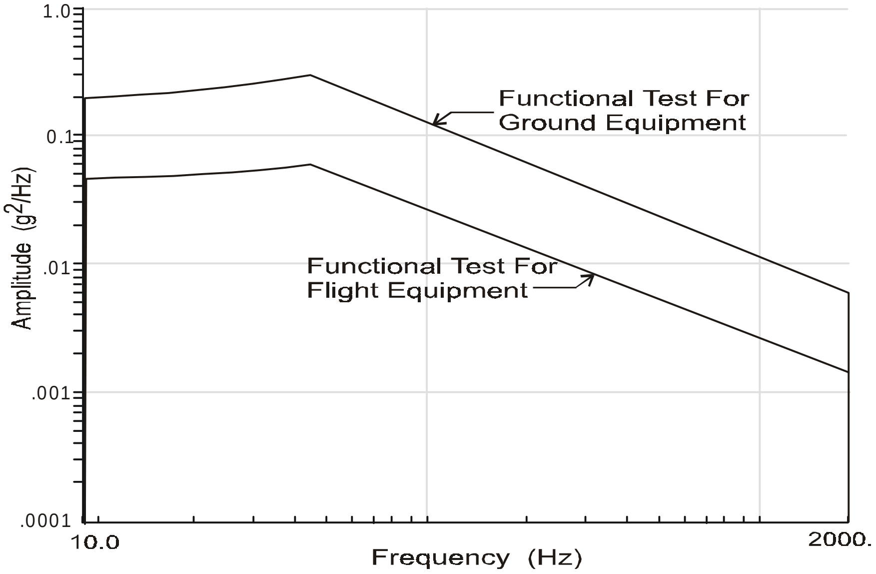
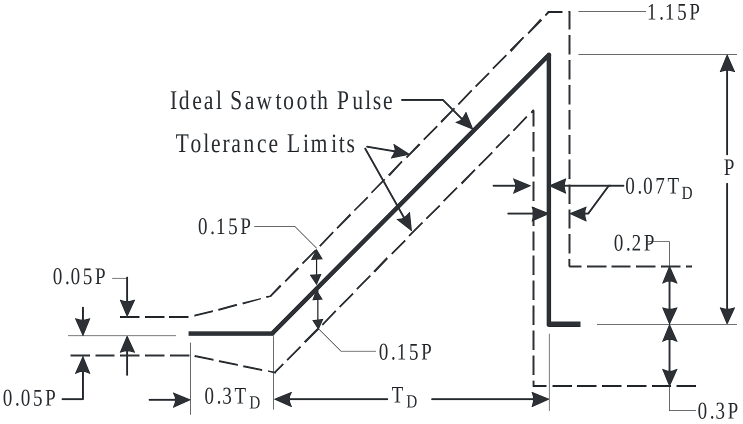


FIGURE 516.5-9. Random test input ASD yielding equivalent test SRS spectrum shown on figure 516.5-8 (for Procedure I - Functional Shock).



*NOTE: Include in the time history display a time about 3*T_D *long with a pulse located approximately in the center. The peak acceleration magnitude of the sawtooth pulse is P and its duration is* T_D*. Ensure the measured acceleration pulse is contained between the broken line boundaries and the measured velocity change (which may be obtained by integration of the acceleration pulse) is within the limits of* $V_i \pm 0.1\ V_i$*, where* V_i *is the velocity change associated with the ideal pulse which equals 0.5* $T_D P$*. Extend the integration to determine velocity change from 0.4* T_D *before the pulse, to 0.1* T_D *after the pulse.*

FIGURE 516.5-10. Terminal peak sawtooth shock pulse configuration and its tolerance limits (for use when shock response spectrum analysis capability is not available in Procedure I – Functional Shock and Procedure V Crash Hazard).

The trapezoidal pulse along with its parameters and tolerances is provided on figure 516.5-11 and is an alternative for testing in Procedure II - Materiel to be Packaged, and Procedure III - Fragility.

2.3.3 Test axes and number of shock events – general considerations.

Subject the test item to a sufficient number of suitable shocks to meet the specified test conditions at least three times in both directions along each of three orthogonal axes. A suitable test shock for each direction of each axis is defined to be one classical shock pulse or complex transient pulse that yields a response spectrum that is within the tolerances of the required test spectrum over the specified frequency range, and when the effective duration of the shock is within twenty percent of the specified T_e value. Determine the spectra for positive and negative maximum accelerations (either maximum absolute or equivalent static), generally at Q = 10, and at least 1/12-octave frequency intervals. If the required test spectrum can be satisfied simultaneously in both directions along an axis, three shock repetitions will satisfy the requirement for that axis. If the requirement can only be satisfied in one direction, i.e., polarity consideration for classical shock inputs, it is permissible to change the test setup and impose three additional shocks to satisfy the spectrum requirement in the other direction. Setup change possibilities are to (1) reverse the polarity of the test shock time history or (2) to reverse the test item orientation (in general, for complex transient pulses, reversal of the polarity of the test shock time history will not significantly affect the test levels). The following guidelines may also be applied for either classical shock pulses or complex transient pulses.

a. For materiel that is likely to be exposed only rarely to a given shock event, perform one shock for each appropriate environmental condition: one shock per axis minimum or two shocks per axis if polarity charge is a consideration. For large velocity change shock conditions, perform one shock for each appropriate environmental condition.

b. For materiel that is likely to be exposed more frequently to a given shock event and there is little available data to substantiate the number of shocks, apply three or more at each environmental condition based on the anticipated in-service use, three shocks per axis minimum or six shocks per axis if polarity charge is a consideration.

c. If the test item has no significant low frequency modal response then it is permissible to allow the low frequency portion of the SRS to fall out of tolerance in order to satisfy the high frequency portion of the SRS provided the high frequency portion begins at least one octave below the first natural mode frequency of the test item. Keep the duration within tolerance.

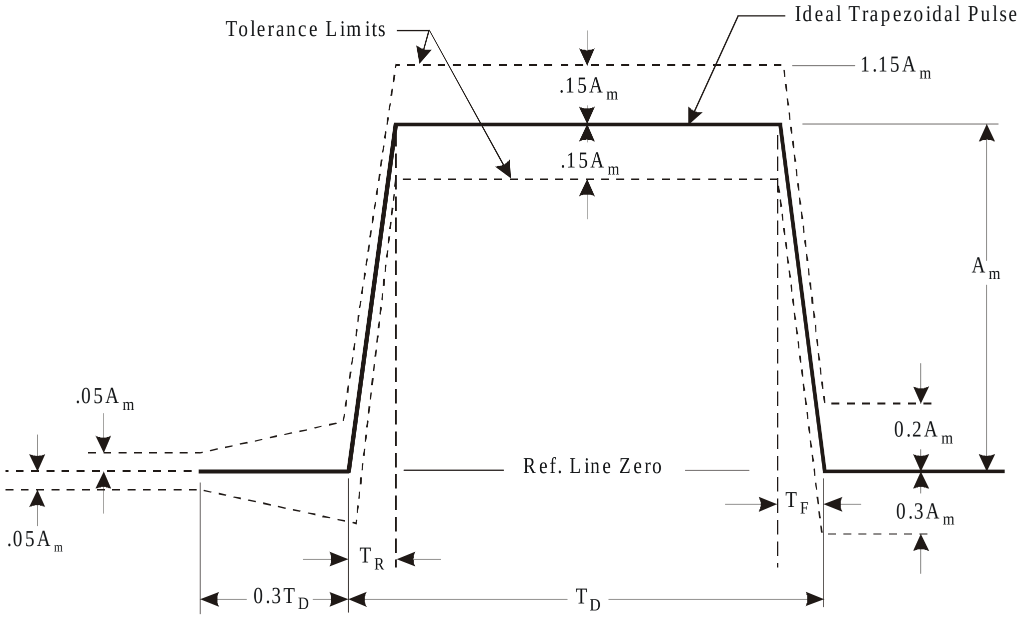
d. If the test item has significant low frequency modal response, then it is permissible to allow the duration of the complex transient pulse to fall out of tolerance in order to satisfy the low frequency portion of the SRS provided the duration of the complex transient pulse does not exceed $T_e + \frac{1}{2f_{min}}$. If the duration of the complex transient pulse must exceed $T_e + \frac{1}{2f_{min}}$ in order to have the low frequency portion of the SRS within tolerance, then a new shock procedure must be used.

2.3.4 Test axes and number of shock events – special consideration for complex transients only.

It is well established that there is no unique synthesized complex transient pulse satisfying a given SRS. In synthesizing a complex transient pulse from a given SRS and this complex transient pulse either (1) exceeds the capability of the shock application system (usually in displacement or velocity), or (2) the duration of the complex transient pulse is more than 20% longer than T_e, some compromise in spectrum or duration tolerance may be necessary. It is unacceptable to decompose a SRS into a low frequency component (large velocity and displacement) and a high frequency component to meet a shock requirement. Often an experienced analyst may be able to specify the input parameters to the complex transient pulse synthesis algorithm in order to satisfy the requirement for which the shock application system manufacturer "optimum" solution will not. The following guidelines may be applied.

a. If the test item has no significant low frequency modal response, it is permissible to allow the low frequency portion of the SRS to fall out of tolerance in order to satisfy the high frequency portion of the SRS, provided the high frequency portion begins at least one octave below the first natural mode frequency of the test item. Keep the duration within tolerance.

b. If the test item has significant low frequency modal response, it is permissible to allow the duration of the complex transient pulse to fall out of tolerance in order to satisfy the low frequency portion of the SRS, provided the duration of the complex transient pulse does not exceed $T_e + 1/(2f_{min})$ where the latter term is one half the period of the lowest frequency of interest (f_{min}) in the SRS analysis. If the duration of the complex transient pulse must exceed $T_e + 1/(2f_{min})$ in order to have the low frequency portion of the SRS within tolerance, use a new shock procedure.



NOTE: Include in the time history display a time about $3T_D$ long with a pulse located approximately in the center. The peak acceleration magnitude of the trapezoidal pulse is A_m and its duration is T_D. Ensure the measured acceleration pulse is between the broken line boundaries and the measured velocity change (which may be obtained by integration of the acceleration pulse) is within the limits of $V_i \pm 0.1\ V_i$, where V_i is the velocity change associated with the ideal pulse that approximately equals $0.5\ A_m g(2T_D - T_R - T_F)$. The integration to determine velocity change extends from $0.4T_D$ before the pulse to $0.1\ T_D$ after the pulse. Ensure the rise (T_R) and fall (T_F) times are less than or equal to $0.1T_D$.

FIGURE 516.5-11. Trapezoidal shock pulse configuration and its tolerance limits (for use when shock response spectrum analysis capability is not available in Procedure II – Materiel to be Packaged, and Procedure III - Fragility).

2.4 Test Item Configuration.

(See Part One, paragraph 5.8.) The configuration of the test item strongly affects test results. Use the anticipated configuration of the materiel in the life cycle profile. As a minimum, consider the following configurations:

a. In a shipping/storage container or transit case.

b. Deployed in the service environment.

3. INFORMATION REQUIRED.

3.1 Pretest.

The following information is required to conduct a shock test.

a. General. Information listed in Part One, paragraphs 5.7, 5.9, and 5.11 of this standard, and Appendix A, Tasks 405 and 406.

b. Specific to this method.

  (1) Test fixture modal survey procedure.

  (2) Test item/fixture modal survey procedure.

  (3) Shock environment. Either:

    (a) the predicted SRS or the complex shock pulse synthesis form (superposition of damped sinusoids, amplitude modulated sine waves, or other) specifying spectrum shape, peak spectrum values, spectrum break points, and pulse duration, or
    (b) the measured data selected for use in conjunction with the SRS synthesis technique outlined in the procedures. (If the SRS synthesis technique is used, ensure both the spectral shape and synthesized shock duration are as specified.), or
    (c) the measured data that are input as a compensated waveform into a shaker/shock system under direct waveform control.

  (4) Techniques used in the processing of the input and the response data.

3.2 During Test.

Collect the following information during conduct of the test:

a. General. Information listed in Part One, paragraph 5.10 and in Part One, Appendix A, Tasks 405 and 406 of this standard.

b. Specific to this Method. Information related to failure criteria for test materiel under acceleration for the selected procedure or procedures. Pay close attention to any test item instrumentation and the manner in which the information is received from the sensors. For large velocity shock, ensure instrumentation cabling does not add noise to measurements as a result of cable movement.

3.3 Post-test.

Record the following post-test information.

a. General. Information listed in Part One, paragraph. 5.13 of this standard, and in Part One, Appendix A, Tasks 405 and 406.

b. Specific to this method.

  (1) Duration of each exposure and number of exposures.

  (2) Status of the test item after each visual examination.

  (3) Response time histories and the information processed from these time histories. In general, under-processed information, the absolute acceleration maximax SRS and the pseudo-velocity SRS should be supplied as a function of single degree of freedom oscillator undamped natural frequency. In certain cases, the ESD and FS may be supplied.

  (4) Test item and/or fixture modal analysis data.

4. TEST PROCESS.

4.1 Test Facility.

Use a shock-producing apparatus capable of meeting the test conditions as determined according to the appropriate paragraphs of this method. The shock apparatus may be of the free fall, resilient rebound, nonresilient rebound, hydraulic, compressed gas, electrodynamic shaker, electrohydraulic shaker, rail car or other activating types capable of eliciting test item response over the time, amplitude and frequency ranges specified. For all types of shock-producing apparatus, careful attention needs to be paid to the time, amplitude, and frequency ranges over which the apparatus is capable of delivering a shock input. For example, an electrodynamic shaker can suitably reproduce synthesized shock records from 5 Hz to 3000 Hz; however, an electrohydraulic shaker may have only a DC to 500 Hz controllable frequency reproduction range. Procedures II and III require test apparatus capable of producing relatively large displacement. Procedure VII is a special test setup utilizing rail cars and provides both moderately high response frequencies along with very low frequency response. Procedure VIII for catapult launch is best satisfied by application of two shock pulses with an intervening "transient vibration."

4.2 Controls.

4.2.1 Calibration.

The shock apparatus will be user calibrated for conformance with the specified test requirement from the selected procedure where the response measurements will be made with traceable laboratory calibrated measurement devices. Conformance to test specifications will, in general, use a "calibration load" in the test setup. The calibration load will, in general, be a mass/stiffness simulant of the test item. "Mass/stiffness simulants" imply that the modal dynamic characteristics of the test item are replicated to the extent possible in the simulant – particularly those modal dynamic characteristics that may interact with the modal dynamic configuration of the fixturing and/or the test device. For calibration, produce two consecutive input applications to a calibration load which satisfy the test conditions outlined in Procedures I, II, III, V, VI, or VIII. Procedure IV is not a calibrated test and Procedure VII has a unique set of prescribed calibration procedures. After processing the measured response data from the calibration load and verifying that it is in conformance with the test specification tolerances, remove the calibration load and perform the shock test on the test item. Use of calibration loads for setup is highly recommended in all cases.

4.2.2 Tolerance.

For test validation, use the tolerances specified under each individual procedure, along with the guidelines provided below. In cases in which such tolerances cannot be met, establish achievable tolerances that are agreed to by the cognizant engineering authority and the customer prior to initiation of test. In any case, where tolerances are established independently of the guidance provided below, establish those tolerances that are within the limitations of the specified measurement calibration, instrumentation, signal conditioning, and data analysis procedures.

4.2.2.1 Classical pulses and complex transient pulses-time domain.

For the classical pulses of the terminal-peak sawtooth pulse and the trapezoidal pulse tolerance limits on the time domain representation of the pulses (both for amplitude and duration) are as specified on figure 516.5-10 and figure 516.5-11, respectively. For complex transient pulses specified in the time domain the major peaks and valleys of the measured pulses, (peaks and valleys within 75% of the maximum peak and valley specified, respectively) 90% of the peak and valley levels are to be within ±10% of the specified peaks and valleys, respectively. This tolerance limit assumes that the shock test machine is able to replicate the specified shock accurately under a waveform control procedure. Such time domain specification is useful for shock replication from measured data and for fragility tests performed using a electrodynamic or electrohydraulic test machine. Inherent in the tolerance specification is the assumption that the measured peak and valley sequence is ordered as the specified peak and valley time history peak and valley sequence.

4.2.2.2 Complex transient pulses-SRS.

For complex transient pulses specified by way of the maximax SRS on figure 516.5-8 and for the other complex transient pulses specified from measured data generally the tolerances are specified in terms of amplitude over a specified frequency bandwidth and a tolerance on the pulse duration. If prior measured data is available or a series of shocks are performed all acceleration maximax SRS computed with a one-twelfth octave frequency resolution are to be within –1.5 dB and +3dB over a minimum of 90% of the overall frequency bandwidth from 10 Hz to 2 kHz. For the remaining 10% part of the frequency band all SRS are to be within –3dB and +6dB. The duration of the complex transient is to be within ±20% of the effective duration of the measured pulse, T_e. In addition, the following guidance is provided for use of (1) the pseudo-velocity response spectra and (2) multiple measurements to specify a shock environment. All tolerances are specified on the maximax acceleration SRS. Any tolerances specified on the pseudo-velocity response spectra must be derived from the tolerances on the maximax acceleration SRS and be consistent with those tolerances including tolerance on the duration of the pulse. The test tolerances are stated in terms of single measurement tolerance. For an array of measurements defined in terms of a "zone" (reference g) amplitude tolerance may be specified in terms of an average of the measurements within a "zone." It should be noted, however, this is in effect a relaxation of the single measurement tolerance and that individual measurements may be substantially out of tolerance while the average is within tolerance. In general, when specifying test tolerances based on averaging for more than two measurements within a zone, the tolerance band should not exceed the 95/50 one-sided normal tolerance upper limit computed for the logarithmically transformed SRS estimates nor be less than the mean minus 1.5dB. Any use of "zone" tolerances and averaging must have support documentation prepared by a trained analyst. Tolerance on the duration of the pulse shall apply to the input pulse duration to the measurement array.

4.3 Instrumentation.

In general, acceleration will be the quantity measured to meet the specification. On occasion other devices may be employed, e.g., linear displacement/voltage transducer, force gage, laser velocimeter, rate gyro, etc. In these cases give special consideration to the instrument specification to satisfy the calibration, measurement, and analysis requirements. Calibrate all measurement instrumentation to traceable national calibration standards (see Part One, paragraph 5.3.2). In addition, instrumentation to measure test item function may be required. In this case, obtain suitable calibration standards and adhere to them.

a. Accelerometer.

   (1) Transverse sensitivity of less than or equal to 5%.

   (2) An amplitude linearity within 10% from 5% to 100% of the peak acceleration amplitude required for testing.

   (3) For Procedures I, II, III, IV, V, VI, and VIII, a flat frequency response within ±10% across the frequency range 2 Hz - 2000 kHz.

   (4) For cases in which response below 2 Hz is desired, piezoresistive accelerometer measurement is required with a flat frequency response within ±10% across the measurement specification bandwidth.

   (5) The measurement device and its mounting will be compatible with the requirements and guidelines provided in reference f.

b. Other measurement devices. Any other measurement devices used to collect data must be demonstrated to be consistent with the requirements of the test, in particular, the calibration and tolerance information provided in paragraph 4.2.

c. Signal conditioning. Use only signal conditioning that is compatible with the instrumentation requirements on the test and is compatible with the requirements and guidelines provided in reference f. In particular, filtering of the analog voltage signals will be consistent with the time history response requirements (in general, demonstrable linearity of phase throughout the frequency domain of response) and the filtering will be so configured that anomalous acceleration data caused by clipping will not be misinterpreted as response data. In particular, use extreme care in filtering the acceleration signals at the amplifier output. The signal into the amplifier should never be filtered for fear of filtering bad measurement data and the inability to detect the bad measurement data. The signal from the signal conditioning must be anti-alias filtered before digitizing.

4.4 Data Analysis.

a. An analog anti-alias filter configuration will be used that will:

   (1) not alias more than a 5 percent measurement error into the frequency band of interest.

   (2) have linear phase-shift characteristics in the data passband.

(3) have a pass band uniform to within one dB across the frequency band of interest (see paragraph 4.3).

b. In subsequent processing of the data, use any additional digital filtering that is compatible with the anti-alias analog filtering. In particular, additional digital filtering must maintain phase linearity for processing of shock time histories.

c. Analysis procedures will be in accordance with those requirements and guidelines provided in reference f. In particular, validate the shock acceleration amplitude time histories according to the procedures in reference f. Integrate each amplitude time history to detect any anomalies in the measurement system, e.g., cable breakage, amplifier slew rate exceedance, data clipped, unexplained accelerometer offset, etc., before processing the response time histories. If anomalies are detected, discard the invalid measured response time history data.

4.5 Test Execution.

4.5.1 Preparation for test.

4.5.1.1 Preliminary guidelines.

Prior to initiating any testing, review the pretest information in the test plan to determine test details (e.g., procedure, calibration load, test item configuration, measurement configuration, shock level, shock duration, number of shocks applied). Note all details of the test validation procedures.

4.5.1.2 Pretest checkout.

After calibration of the excitation input device and prior to conducting the test, perform a pretest checkout of the test item at standard ambient conditions to provide baseline data. Conduct the checkout as follows:

Step 1. Conduct a complete visual examination of the test item with special attention to stress areas or areas identified as being particularly susceptible to damage and document the results.
Step 2. Where applicable, install the test item in its test fixture.
Step 3. Conduct a test item operational check in accordance with the approved test plan and document the results for compliance with Part One, paragraph 5.15.
Step 4. If the test item operates satisfactorily, proceed to the first test. If not, resolve the problem and restart at Step 1.

4.5.1.3 Procedures overview.

Paragraphs 4.5.2 through 4.5.9 provide the basis for collecting the necessary information concerning the system under shock. For failure analysis purposes, in addition to the guidance provided in Part One, paragraph 5.14, each procedure contains information to assist in the evaluation of the test results. Analyze any failure of a test item to meet the requirements of the system specifications, and consider related information such as follows in paragraphs 4.5.2 through 4.5.9.

4.5.2 Procedure I - Functional Shock.

The intent of this test is to disclose equipment malfunction that may result from shocks experienced by materiel during use in the field. Even though materiel has successfully withstood even more severe shocks during shipping or transit shock tests, there are differences in support and attachment methods and in functional checking requirements that make this test necessary. Tailoring of the test is required when data are available, can be measured, or can be estimated from related data using accepted dynamic scaling techniques. When measured field data are not available for tailoring, use the information on figure 516.5-8 and the accompanying table 516.5-I to define the shock test system input SRS. In the calibration procedure, the calibration load will be subject to a properly compensated complex waveform in accordance with the SRS described above for electrodynamic or electrohydraulic shock testing. In general, tests using classical pulses, e.g., half-sine, terminal peak saw tooth, etc., are unacceptable unless it can be demonstrated during tailoring that the field shock environment approximates such a form. If all other testing resources have been exhausted it will be permissible to use the information on figure 516.5-10 for the terminal peak sawtooth for testing. However, such testing must be performed in a positive and negative direction to assure meeting the spectrum requirements on figure 516.5-8 in both the positive and negative direction. In cases in which the test item has been exposed to random vibration prior to shock testing, figure 516.5-9 presents ASD requirements that provide for “equivalent test SRS.” If the prior random vibration levels meet or exceed the ASD levels provided on figure 516.5-8, the functional shock test may be waived under approval of the cognizant test authority, however, functional test requirements must be the same between the vibration and the proposed shock test.

4.5.2.1 Controls.

Figure 516.5-8 provides predicted input SRS for the functional shock test for use when measured data are not available, and when the test item configuration falls into one of two specified categories – (1) flight equipment, or (2) ground equipment. The duration, T_e, is defined in paragraph 2.3.1, and is specified in table 516.5-I. Figure 516.5-9 provides the predicted random vibration test input ASD’s that yield the equivalent SRS given on figure 516.5-8. If the prior random vibration levels meet or exceed the ASD levels provided on figure 516.5-9, the functional shock test may be waived. Functional test requirements must be the same between the vibration and the shock tests.

TABLE 516.5-II. Terminal peak sawtooth pulse test parameters (refer to figure 516.5-10).

Test	Minimum Peak Value (P) g's		Nominal Duration (T_D) ms	
	Flight Vehicle Equipment[1] a	Ground Equipment b	Flight Vehicle Equipment [1] c	Ground Equipment d
Functional Test	20	40[2]	11	11

[1] Shock parameters a and c: Recommend for materiel not shock-mounted and weighing less than 136 kg (300 lbs).

[2] For materiel mounted only in trucks and semi-trailers, use a 20g peak value.

4.5.2.2 Test tolerances.

For complex transients from measured data, ensure that test tolerances are consistent with the general guidelines provided in paragraph 4.2.2 with respect to the information provided in table 516.5-I and accompanying figure 516.5-8. For random test input ASD yielding an equivalent test SRS spectrum, the lower tolerance band on the ASD of figure 516.5-9 is to be –1dB over the entire frequency band of interest with no specification for the upper tolerance band (generally when the equivalence testing is used it is because the vibration requirement is substantially more severe than that defined by the ASD spectra on figure 516.5-9). Annex C provides additional information related to the empirical spread of the maximax SRS for Q=5 given the ASD inputs on figure 516.5-9.

For classical pulse testing, the test tolerances are specified on figure 516.5-10 with respect to information in table 516.5-II.

4.5.2.3 Procedure I.

Step 1. Select the test conditions and calibrate the shock test apparatus as follows:

a. Select accelerometers and analysis techniques that meet or exceed the criteria outlined in paragraph 4.3 of reference f.

b. Mount the calibration load to the shock test apparatus in a configuration similar to that of the test item. If the materiel is normally mounted on vibration/shock isolators, ensure the corresponding test item isolators are functional during the test. If the shock test apparatus input waveform is to be compensated via input/output impulse response function for waveform control, exercise care to details in the calibration configuration and the subsequent processing of the data.

c. Perform calibration shocks until two consecutive shock applications to the calibration load produce waveforms that meet or exceed the derived test conditions consistent with the test tolerances in paragraph 4.5.2.2 for at least the test direction of one axis.

d. Remove the calibration load and install the test item on the shock apparatus.

Step 2. Perform a pre-shock functional check of the test item.

Step 3. Subject the test item (in its operational mode) to the test shock input.

Step 4. Record necessary data to show that the shock met or exceeded desired test levels within the specified tolerances in paragraph 4.5.2.2. This includes test setup photos, test logs, and photos of actual shocks from the transient recorder or storage oscilloscope. For shock and vibration isolated assemblies inherent within the test item, make measurements and/or inspections to assure these assemblies did not impact with adjacent assemblies. If required, record the data to show that the materiel functions satisfactorily during shock.

Step 5. Perform a post test functional check on the test item. Record performance data.

Step 6. Repeat steps 2, 3, 4, and 5 three times for each orthogonal test axis if the SRS form of specification is used. If the classical shock form of specification is used, subject the test item to both a positive and a negative input pulse. If the SRS waveform satisfies both the pulse time history tolerance, and the SRS test tolerance, proceed to test with polarity considerations (a total of six shocks in each orthogonal axis). If one or both of the test pulse's time history or SRS falls outside the pulse time history tolerance or the SRS test tolerance, continue to tailor the pulses until both test tolerances are met. If both test tolerances cannot be met simultaneously, choose to satisfy the SRS test tolerance.

Step 7. Document the test sequence.

4.5.2.4 Analysis of results.

In addition to the guidance in Part One, paragraph 5.14, the following information is provided to assist in the evaluation of the test results. Consider any interruption of the materiel functions during or after the shock in relationship to the materiel's functional test requirements.

4.5.3 Procedure II - Materiel to be Packaged.

The intent of this test is to ensure the functionality of materiel after it has been inadvertently dropped before, during, or after a packaging process. In general, such input to the materiel produces large velocities and large changes in velocity. For this procedure, the classical trapezoidal pulse may be used on properly calibrated drop machines if the large velocity/velocity change exceeds that available on standard electrodynamic and electrohydraulic test equipment. However, if the large velocity/velocity change is compatible with the capabilities of electrodynamic and/or electrohydraulic test equipment consideration should be given to tailoring the shock according to a complex transient for application on the electrodynamic or electrohydraulic test equipment. Using the classical trapezoidal pulse on electrodynamic and/or electrohydraulic test equipment is acceptable if there is no available measured data contrary to the response time history form for this approach. In any case, when data are available or can be measured, or can be estimated from related data, tailor the test using accepted dynamic scaling techniques.

4.5.3.1 Controls.

For application of the classical trapezoidal pulse subject the unpackaged test item in a nonoperational mode to a series of trapezoidal 30-g shock pulses, i.e., A_m = 30g, having a time duration (in seconds) to be determined from table 516.5-III and the equation

$$T_D = \frac{2\sqrt{2\frac{h}{g}}}{A_{m/g}} = \frac{2\sqrt{2gh}}{A_m}$$

where h is the design drop height and g is the acceleration of gravity. The equation for T_D assumes a 100% elastic rebound.

TABLE 516.5-III. Trapezoidal pulse parameters (refer to figure 516.5-11).

Test	Peak Value (A_m) g's	Nominal Duration (T_D) (sec)
Packaged Shock	30	$\frac{2\sqrt{2gh}}{A_m}$

TABLE 516.5-IV. Suggested drop height for Procedure II.

Package Gross Weight, kg (lb)	Type of Handling	Design Drop Height, cm (in)	Maximum Test Item Velocity Change* cm/s (in/s)
0 to 9.1 (0 to 20)	Manual	76 (30)	772 (304)
9.2 to 18.2 (21 to 40)	Manual	66 (26)	719 (283)
18.3 to 27.2 (41 to 60)	Manual	61 (24)	691 (272)
27.4 to 36.3 (61 to 80)	Manual	46 (18)	600 (236)
36.4 to 45.4 (81 to 100	Manual	38 (15)	546 (215)
45.5 to 68.1 (101 to 150	Mechanical	31 (12)	488 (192)
68.2 to 113.5 (151 to 250)	Mechanical	26 (10)	447 (176)
113.6 - (251 -)	Mechanical	20 (8)	399 (157)

*For an assumed 100% elastic rebound.

The pulse will be in accordance with figure 516.5-11. A programmable shock machine or a long stroke electrohydraulic shaker will more than likely be required to reproduce these test conditions because of the substantial displacement and velocity requirements. The trapezoidal pulse shape was chosen because:

(1) computation of velocity change it produces (for comparison with design drop height is much easier to make and more reproducible than most shock spectrum synthesis routines that allow for more general pulses).

(2) trapezoidal pulse shape provides an upper bound on primary and maximax SRS for a given peak acceleration input level where the primary SRS is defined to be the SRS over the duration of the pulse only.

For a tailored test using a complex waveform with SRS shock control, ensure the test input to the item is within specified test tolerances.

4.5.3.2 Test tolerances.

For complex transients from measured data, ensure that test tolerances are consistent with the general guidelines provided in paragraph 4.2.2. For classical pulse testing, ensure the test tolerances specified in figure 516.5-11 with respect to the information provided in table 516.5-III are satisfied.

4.5.3.3 Procedure II.

Step 1. Calibrate the shock machine as follows:

a. Mount the calibration load to the test apparatus in a configuration similar to that of the actual test item. Use a fixture similar in shape and configuration to the shock attenuation system that will support the materiel in its shipping container. The fixture should be as rigid as possible to prevent distortion of the shock pulse input to the test item. If the test apparatus input waveform is to be compensated via input/output impulse response function, exercise care to details in the calibration configuration and the subsequent processing of the data.

b. Perform calibration shocks until two consecutive shock applications to the calibration load reproduce waveforms that are within the test tolerance specification.

Step 2. Remove the calibration load and install the actual test item on the shock apparatus.

Step 3. Perform a pre-shock functional test of the test item.
Step 4. Subject the test item to the test pulse.
Step 5. Record necessary test data to include test setup photos, test logs, and photos of the actual test pulse from a transient recorder or storage oscilloscope.
Step 6. Perform a post shock functional test of the test item.
Step 7. For classical trapezoidal shock waveform repeat steps 3, 4, 5, and 6 once in each direction for three orthogonal axes with positive and negative polarity (six shocks total). For a complex shock waveform repeat steps 3, 4, 5, and 6 once in each direction for three orthogonal axes (three shocks total).
Step 8. Document the results including plots of the measured test response waveforms and any pre- or post shock functional anomalies.

4.5.3.4 Analysis of results.

In addition to the guidance in Part One, paragraph 5.14, the following information is provided to assist in the evaluation of the test results. In the evaluation consider any damage to the shock mounts or the internal structural configuration of the test item which may provide a cause for the development of a failure analysis course of action to consider retrofit or redesign.

4.5.4 Procedure III - Fragility.

The intent of this test is to determine (1) the maximum level of input to which the materiel can be exposed and still continue to function as required by its operational guide without damage to the configuration or, (2) determine the minimum level of input on which exposure to a higher level of input will most likely result in either functional failure or configuration damage. Determination of the fragility level is accomplished by starting at a benign level of shock and proceeding to increase the level of shock to the test item until:

a. failure of the test item occurs.
b. a predefined test objective is reached without failure of the test item.
c. a critical level of shock is reached that indicates failure is certain to occur at a higher level of shock.

(c. implies that an analysis of the materiel has been completed prior to testing, that critical elements have been identified with their "stress thresholds", and a failure model of the materiel relative to the shock input level has been developed. In addition, during the test the "stress thresholds" of these critical elements can be monitored and input to a failure model to predict failure at a given shock input level.) In general, such input to the materiel produces large velocities and large changes in velocity. For this procedure, the classical trapezoidal pulse may be used on properly calibrated drop machines, if the large velocity/velocity change exceeds that available on standard electrodynamic and electrohydraulic test equipment. However, if the large velocity/velocity change is compatible with the capabilities of electrodynamic and/or electrohydraulic test equipment, consideration should be given to tailoring the shock according to a complex transient for application on the electrodynamic or electrohydraulic test equipment. Using trapezoidal pulse on electrodynamic and/or electrohydraulic test equipment is acceptable if there is no available data, providing shock input information that is tailorable to a complex transient. For testing, note that there is a single parameter (peak amplitude of the shock input) to define the fragility level holding the maximum velocity change of the test shock approximately constant. In the case of SRS synthesis, maximum velocity change is not as well defined, nor as important, nor as easily controllable as for the classical trapezoidal pulse. Tailoring of the test is required when data are available, can be measured, or can be estimated from related data using accepted dynamic scaling techniques. An inherent assumption in the fragility test is that damage potential increases linearly with input shock level. If this is not the case, other test procedures may need to be employed for establishing materiel fragility levels.

4.5.4.1 Controls.

a. Select a design drop height, h, based on measurement of the materiel’s shipping environment, or from table 516.5-IV when measured data are unavailable. (A design drop height is the height from which the materiel might be dropped in its shipping configuration and be expected to survive.) A maximum test item velocity change may be taken from table 516.5-IV or determined by using the following relationship:

$$\Delta V = 2\sqrt{2gh}$$

where
ΔV = maximum product velocity change cm/s (in/s) (summation of impact velocity and rebound velocity)
h = design drop height cm (in)
g = 980.6 cm/s^2 (386 in/s^2)

The maximum test velocity change assumes 100% rebound. Programming materials, other than pneumatic springs, may have less than 100% rebound, so the maximum test velocity needs to be decreased accordingly. If the maximum test velocity specified is used for drop table shock machine programming materials other than pneumatic springs, the test is conservative (an overtest), and the maximum test item velocity is a bounding requirement.

b. Set the shock machine to a maximum acceleration level (A_m) well below the anticipated fragility level (see table 516.5-V). Determine the appropriate pulse duration from the design drop height, h, and the expression for T_D in paragraph 4.5.3.1. If an initial value for A_m does not exist, use 15g's. If no damage occurs, increase A_m incrementally while holding the maximum test item velocity change constant (i.e., decrease the pulse duration) until damage to the test item occurs. This will establish the materiel's critical acceleration fragility level.

c. Test levels used in this procedure represent the correlation of the best information currently available from research and experience. If more applicable test level data become available, they should be used (reference c). In particular, if data are collected on a materiel drop and the SRS of the environment computed, a scaled version of the SRS could be used to establish the acceleration fragility level with respect to a measured environment on electrodynamic or electrohydraulic test equipment, provided the displacement and velocity limitations of the test equipment are not exceeded, and the maximum test item velocity change can be held approximately constant. In addition to the maximax acceleration response spectra, compute the pseudovelocity response spectra.

4.5.4.2 Test tolerances.

It is assumed that the instrumentation noise in the measurements is low so that tolerances may be established. For complex transients from measured data, ensure that test tolerances are consistent with the general guidelines provided in paragraph 4.2.2. For classical pulse testing, ensure the test tolerances specified on figure 516.5-11 with respect to the information provided in table 516.5-V are satisfied.

TABLE 516.5-V. Trapezoidal pulse test parameters (refer to figure 516.5-11).

Test	Peak Value (A_m) g's	Nominal Duration (T_D) (sec)
Fragility	10 to 50	$\frac{2\sqrt{2gh}}{A_m}$

4.5.4.3 Procedure III.

This test is designed to build up in severity until a test item failure occurs or a predetermined goal is reached. It may be necessary to switch axes between each shock event unless critical axes are determined prior to test. In general, all axes of importance will be tested at the same level before moving to another level. The order of test activity and the calibration requirements for each test setup should be clearly established in the test plan. It is also desirable to preselect the steps in severity based on knowledge of the materiel item or the test environment and document this in the test plan. It is important to note that unless critical stress thresholds are analytically predicted and instrumentation used to track stress threshold buildup, there is no rational way to estimate the potential for stress threshold exceedance at the next shock input level. The following procedures, one for a classical pulse and the other for a complex transient, are written as if the test will be conducted in one axis alone. In cases where more test axes are required the procedure should be modified accordingly.

a. Classical Pulse. This part of the procedures assumes that the classical pulse approach is being used to establish the fragility level by increasing the drop height of the test item thereby increasing the ΔV directly. The fragility level is given in terms of the measurement variable – peak acceleration of the classical pulse.

Step 1. Mount the calibration load to the test apparatus in a configuration similar to that of the actual test item. Use a fixture similar in configuration to the interface of the shock attenuation system (if any) that will support the materiel. The fixture should be as rigid as possible to prevent distortion of the shock pulse input to the test item.

Step 2. Perform calibration shocks until two consecutive shock applications to the calibration load reproduce the waveforms that are within the specified test tolerances. If response to the calibration shock is nonlinear with respect to shock input level, then other test procedures may need to be applied to establish materiel fragility levels depending upon the extent of the nonlinearity prior to reaching the "stress threshold".

Step 3. Select a drop height low enough to assure that no damage will occur. For drop heights other than those in table 516.5-IV the maximum velocity change can be taken to be

$$\Delta V = 2\sqrt{2gh}$$

Where
ΔV = maximum test item velocity change, cm/s (in/s) (assumes full resilient rebound of test item)
h = drop height, cm (in)
g = acceleration of gravity 981 cm/s^2 (386 in/s^2)

Step 4. Mount the test item in the fixture. Inspect and functionally test the item to document the pre-test condition.

Step 5. Perform the shock test at the selected level and examine the recorded data to assure the test is within tolerance.

Step 6. Visually examine and functionally test the materiel to determine if damage has occurred. If damage is found or pre-established goals have been reached, go to Step 10.

Step 7. If it is required to determine the fragility of the test item in more than one axis then proceed to test the item in the other axes (before changing the drop height).

Step 8. If the test item integrity is preserved, select the next drop height.

Step 9. Repeat steps 5 through 8 until the test objectives have been met.

Step 10. Document the results correlating the drop height with the measurement variable selected to define the fragility level. If the test item is damaged in one axis during test then replace the test item with an identically configured test item and proceed in testing starting at Step 4.

b. Synthesized Pulse. This part of the procedure assumes that the fragility level is some function of the peak acceleration level determined from a maximax acceleration SRS of a complex transient. For a complex transient specified in the time domain this procedure could use the peak acceleration of the time history to define the fragility level.

Step 1. Mount the calibration load to the test apparatus in a configuration similar to that of the actual test item. Use a fixture similar in configuration to the interface of the shock attenuation system (if any) that will support the materiel. The fixture should be as rigid as possible to prevent distortion of the shock pulse input to the test item.

Step 2. Perform calibration shocks until two consecutive shock applications to the calibration load reproduce maximax acceleration SRS that are within the specified test tolerances. If response to the calibration shock is nonlinear with respect to shock input level then other test procedures may need to be applied to establish materiel fragility levels depending upon the extent of the nonlinearity prior to reaching the "stress threshold".

Step 3. Select a peak maximax acceleration SRS level low enough to assure that no damage will occur.

Step 4. Mount the test item in the fixture. Inspect and functionally test the item to document the pre-test condition.

Step 5. Perform the shock test at the selected level and examine the recorded data to assure the test maximax acceleration SRS is within tolerance.

Step 6. Visually examine and functionally test the materiel to determine if damage has occurred. If damage is found or pre-established goals have been reached, go to Step 10.

Step 7. If it is required to determine the fragility of the test item in more than one axis then proceed to test the item in the other axes (before changing the peak maximax acceleration SRS level).

Step 8. If the test item integrity is preserved, select the next predetermined peak maximax acceleration SRS level.

Step 9. Repeat steps 5 through 8 until the test objectives have been met.

Step 10. Document the results recording the peak maximax acceleration SRS to define the fragility level. If the test item is damaged in one axis during test, then replace the test item with an identically configured test item and proceed in testing starting at Step 4.

4.5.4.4 Analysis of results.

Refer to the guidance in Part One, paragraph 5.14, to assist in the evaluation of the test results. The outcome of a successful fragility test is one specified measurement level of test item failure to each test axis. Consider that if the test item fails either functionally or structurally at the lowest level of testing and there is no provision for testing at lower levels, then the test item's fragility level is indeterminate.

4.5.5 Procedure IV - Transit Drop.

The intent of this test is to determine the structural and functional integrity of the materiel to a transit drop in its transit or combination case. Perform all tests with a quick release hook or drop tester. In general, there is no instrumentation calibration for the test and measurement information is minimized, however, if measurements are made, the maximax acceleration SRS and the pseudovelocity SRS will define the results of the test, along with the measurement amplitude time history.

4.5.5.1 Controls.

Test levels for this test are shown in table 516.5-VI. Test the item in the same configuration that is used in a transportation, handling or a combat situation. For test items under 45kg (100 pounds), the 26-drop requirement (table 516.5-VI) may be divided among up to five samples of the same test item in any combination. Toppling of the item following impact will occur in the field and, therefore, toppling of the test item following its initial impact should not be restrained as long as the test item does not leave the required drop surface. Levels for this test were set by considering how materiel in the field might commonly be dropped. (For example, a light item might be carried by one man, chest high; thus it could drop 122 cm (48 inches).) Field data have shown that a typical piece of man-portable materiel will be dropped from heights up to 122 cm an average of four to six times during its life cycle. The 26-drop requirement exists to ensure each vulnerable position (faces, edges, and corners) of a typical test item receives an impact.

4.5.5.2 Test tolerances.

Ensure the test height of drop is within 2.5% of the height of drop as specified in table 516.5-VI.

4.5.5.3 Procedure IV.

Step 1. After performing a visual inspection and operational check for baseline data, install the test item in its transit or combination case as prepared for field use (if measurement information is to be obtained,install and calibrate such instrumentation in this step.)

Step 2. From paragraph 4.5.5.1 and table 516.5-VI, determine the height of the drops to be performed, the number of drops per test item, and the drop surface.

Step 3. Perform the required drops using the apparatus and requirements of paragraph 4.5.5.1 and table 516.5-VI notes. Recommend visually and/or operationally checking the test item periodically during the drop test to simplify any follow-on failure evaluation that may be required.
Step 4. Document the impact point or surface for each drop and any obvious damage.
Step 5. Following completion of the required drops, visually examine the test item(s).
Step 6. Document the results.
Step 7. Conduct an operational checkout in accordance with the approved test plan.
Step 8. Document the results for comparison with data obtained in Step 1, above (if measurement information was obtained during the drop examine the time history traces and process them in this step according to procedures outlined in the test plan).

4.5.5.4 Analysis of results.

Refer to the guidance in Part One, paragraph 5.14, to assist in the evaluation of the test results. In general, analysis of results will consist of visual and operational comparisons for before test and after test. Measurement instrumentation and subsequent processing of acceleration time history information can provide valuable information related to response characteristics of the test item and statistical variation in the shock environment.

4.5.6 Procedure V - Crash Hazard.

The intent of this procedure is to disclose structural failures of materiel or mounts for materiel in air or ground vehicles that may present a hazard to personnel or other materiel if the materiel breaks loose from its mount during or after a vehicle crash. The test in this procedure is intended to verify that materiel mounting and/or restraining devices will not fail, and that sub-elements are not ejected during crash situations. Attach the test item to its shock fixture by its in-service mounting or tiedowns.

4.5.6.1 Controls.

Use figure 516.5-8 as the test spectrum for the axis of test with the effective shock duration, T_e, between 15 and 23 milliseconds for flight materiel, and between 8 and 13 milliseconds for ground materiel. If shock spectrum analysis capabilities are not available, the classical terminal peak sawtooth pulse on figure 516.5-10 may be used as an alternative to a complex transient waveform developed from the SRS on figure 516.5-8. Table 516.5-VII provides the parameters for the terminal peak sawtooth pulse. An aircraft crash level of 40 g's is based on the assumption that, during a survivable crash, localized g levels can approach 40 g's. Ground transportation vehicles are designed with a higher safety factor and, therefore, must sustain a much higher g level with correspondingly higher specified test levels.

TABLE 516.5-VI. Transit drop test.

Weight of Test Item & Case kg (lbs)	Largest Dimension, cm (in)	Notes	Height of Drop, h cm (in)	Number of Drops
Under 45.4 (100) Manpacked or man-portable	Under 91 (36)	A/	122 (48)	Drop on each face, edge and corner; total of 26 drops D/
	91 & over	A/	76 (30)	
45.4 - 90.8 (100 – 200) inclusive	Under 91	A/	76 (30)	Drop on each corner; total of eight drops
	91 & over	A/	61 (24)	
90.8-454 (200 – 1000) inclusive	Under 91	A/	61 (24)	
	91 – 152 (36 – 60)	B/	61 (24)	
	Over 152	B/	61 (24)	
Over 454	No limit	C/	46 (18)	Drop on each bottom edge. Drop on bottom face or skids; total of five drops

NOTES:

A/ Perform drops from a quick-release hook or drop tester. Orient the test item so that, upon impact, a line from the struck corner or edge to the center of gravity of the case and contents is perpendicular to the impact surface.

B/ With the longest dimension parallel to the floor, support the transit, or combination case with the test item within, at the corner of one end by a block 13 cm (five inches) in height, and at the other corner or edge of the same end by a block 30 cm (12 inches) in height. Raise the opposite end of the case to the specified height at the lowest unsupported corner and allow it to fall freely.

C/ While in the normal transit position, subject the case and contents to the edgewise drop test as follows (if the normal transit position is unknown, orient the case so the two longest dimensions are parallel to the floor):

Edgewise drop test: Support one edge of the base of the case on a sill 13-15 cm (five to six inches) in height. Raise the opposite edge to the specified height and allow it to fall freely. Apply the test once to each edge of the base of the case (total of four drops).

D/ If desired, divide the 26 drops among no more than five test items (see paragraph 4.5.5.1).

TABLE 516.5-VII. Terminal peak sawtooth pulse test parameters (refer to figure 516.5-10).

Test	Minimum Peak Value (P) g's		Nominal Duration (T_D) ms	
	Flight Vehicle Equipment [1/] a	Ground Equipment b	Flight Vehicle Equipment [1/] c	Ground Equipment d
Crash Hazard	40	75	11	6

[1/] Shock parameters a and c : Recommend for materiel not shock-mounted and weighing less than 136 kg (300 lbs).

4.5.6.2 Test tolerances.

For complex waveform replication based upon SRS, ensure the test tolerances are within those specified for the SRS in paragraph 4.2.2. For the classical pulse terminal peak sawtooth pulse described in table 516.5-VII, ensure the waveform is within the tolerances specified on figure 516.5-10.

4.5.6.3 Procedure V.

Step 1. Secure the test item mount to the shock apparatus by its in-service mounting configuration. Use a test item that is dynamically similar to the materiel, or a mechanically equivalent mockup. If a mockup is used, it will represent the same hazard potential, mass, center of mass, and mass moments about the attachment points as the materiel being simulated. (If measurement information is to be collected, mount and calibrate the instrumentation.)

Step 2. Perform two shocks in each direction (as determined in paragraph 2.3.3) along three orthogonal axes of the test item for a maximum of 12 shocks.

Step 3. Perform a physical inspection of the test setup. Operation of the test item is not required.

Step 4. Document the results of the physical inspection including an assessment of potential hazards created by either materiel breakage or structural deformation or both. Process any measurement data according to the maximax acceleration SRS or the pseudovelocity SRS.

4.5.6.4 Analysis of results.

Refer to the guidance in Part One, paragraphs 5.14 and 5.17, to assist in the evaluation of the test results. If measurement information was obtained process this in accordance with paragraph 4.5.6.3, Step 4.

4.5.7 Procedure VI - Bench handling.

The intent of this test is to determine the ability of materiel to withstand the usual level of shock associated with typical bench maintenance or repair. Use this test for any materiel that may experience bench or bench-type maintenance. This test considers both the structural and functional integrity of the materiel.

4.5.7.1 Controls.

Ensure the test item is a fully functional representative of the materiel. Raise the test item at one edge 100 mm (4 in) above a solid wooden bench top or until the chassis forms an angle of 45° with the bench top or until point of balance is reached, whichever is less. (The bench top must be at least 4.25 cm (1.675 inches) thick.) Perform a series of drops in accordance with specifications. The heights used during this test are defined by examining the typical drops that are commonly made by bench technicians and assembly line personnel.

4.5.7.2 Test tolerances.

Ensure the test height of drop is within 2.5% of the height of drop as specified in paragraph 4.5.7.1.

4.5.7.3 Procedure VI.

Step 1. Following a functional and physical checkout, configure the item as it would be for servicing, e.g., with the chassis and front panel assembly removed from its enclosure. Position the test item as it would be for servicing. Generally, the test item will be non-operational during the test.

Step 2. Using one edge as a pivot, lift the opposite edge of the chassis until one of the following conditions occurs (whichever occurs first).

a. The lifted edge of the chassis has been raised 100 mm (4 in) above the horizontal bench top.
b. The chassis forms an angle of 45° with the horizontal bench top.
c. The lifted edge of the chassis is just below the point of perfect balance. Let the chassis drop back freely to the horizontal bench top. Repeat using other practical edges of the same horizontal face as pivot points, for a total of four drops.

Step 3. Repeat Step 2 with the test item resting on other faces until it has been dropped for a total of four times on each face on which the test item could be placed practically during servicing.

Step 4. Visually inspect the test item.

Step 5. Document the results.
Step 6. Operate the test item in accordance with the approved test plan.
Step 7. Document the results for comparison with data obtained in step 1, above.

4.5.7.4 Analysis of results.

Refer to the guidance in Part One, paragraph 5.14, to assist in the evaluation of the test results. In general, any functional or physical (mechanical or structural) change of configuration from Step 1 in paragraph 4.5.7.3 must recorded and analyzed.

4.5.8 Procedure VII - Rail impact.

4.5.8.1 Controls.

The Department of Defense (DoD) uses this test to determine the effect of normal railroad car impacts that occur during rail shipment, to verify the structural integrity of the materiel, and to evaluate the adequacy of the tiedown system and the tiedown process.

a. Test facility/equipment.

   (1) Buffer railcars. Empty cars are preferred for use as the buffer or struck cars. However, loaded cars may also be used with prior approval by the Director, Military Traffic Management Command Transportation Engineering Agency (MTMCTEA), ATTN: MTTE-DPE, 720 Thimble Shoals Blvd., Suite 130, Newport News, VA 23606-2574. (MTMCTEA is the designated DoD agent for land transportation (AR 70-44).) In either case, the total weight of the buffer cars is to be at least 113,400 kg (250,000 lbs). The first buffer car must be a standard draft gear car. The remaining buffer cars should have standard draft gear, if possible. The following are required to perform the rail impact test:

   (2) A test railcar, equipped with chain tiedowns and end-of-car cushioned draft gear, unless other railcar types are approved by MTMCTEA. Some materiel may require other types of railcars for testing to be representative of the intended shipping methods.

NOTE: Cushioned draft gear is a significant change from previous equipment requirements.

   (3) One locomotive.

   (4) A minimum 61 m (200 ft) length of reasonably level, tangent track is required between the buffer cars and test car to allow acceleration of locomotive and test car to specified impact speeds.

   (5) If the alternate procedure (see paragraph 4.5.8.3b) is used to conduct the test, use a tangent track with a slight grade in lieu of a locomotive.

b. Preparation for test.

   (1) Load and secure the test item as would be done for actual rail transport. If safety or other reasons preclude the use of a test item representative of the actual materiel, use a substitute test item that is equal in weight and general character to the materiel. Prior to using a substitute test item, obtain approval from MTMCTEA.

   (2) The materiel developer is responsible for the development of transportation procedures and instructions and is responsible for coordinating these with and obtaining approval from MTMCTEA well in advance of rail impact testing. Mount the test item as would be done in actual service and in accordance with the standard loading and bracing methods shown in Section No. 6 of the Rules Governing the Loading of Department of Defense Materiel on Open Top Cars (procure copies from the Publications Department, Association of American Railroads, 50 F Street N. W., Washington, DC 20001-1530, (202) 639-2211). Do not use more than four tiedown provisions, typically two at each end of the test item. Apply the first tiedown from each provision as near as possible to, but without exceeding 45 degrees from the horizontal (when viewed from the side). Apply additional tiedowns to the next available tiedown point on the flatcar. Apply chains to the railcar near side (do not cross chains). All tiedown procedures require approval by MTMCTEA prior to testing. Only

use an arrangement of the test item and its blocking and tiedown to be tested that is identical to that proposed or approved by MTMCTEA.

(3) Unless otherwise specified in the transportability requirements for the materiel, perform the test with the test item at its maximum gross weight (fully loaded) rating.

c. Test setup.

(1) Buffer cars must have their air and hand brakes set. This provides a more conservative test. Cars must be bunched to compress all slack and cushioning in the couplings, if any. The struck end of first buffer car must have standard draft gear.

(2) Locate the test car between the buffer cars and the locomotive.

(3) Install one of the following timing devices (or equivalent) to obtain the impact speed of the test car.

(a) An electric timer capable of measuring within 0.16 km/h (±0.1 mph): Place the switch contacts on the track in accordance with manufacturer's instructions.
(b) A stop watch and torpedoes: when used, measure the torpedo locations. Place the first torpedo beyond the face of the knuckle on the first buffer car and located one foot more than the distance between the leading axle and knuckle face on the test car. Place the second torpedo 6.7 m (22 ft) along the track from the first torpedo. The relationship of time lapse versus speed for travel of a distance of 6.7 m (22 ft) is shown in table 516.5-VIII.
(c) Radar: In order to obtain an accurate speed, position the operator of the radar in line with the direction of impact or as otherwise recommended by the radar manufacturer.

(4) Photograph the test setup including any securement items. This may be a valuable tool if there is any subsequent failure of the items of securement.

4.5.8.2 Test tolerances.

Ensure test tolerances are in accordance with tolerances specified in paragraph 4.5.8.1 and the test plan.

4.5.8.3 Procedure VII.

a. General considerations for main procedure.

(1) Brief the train crew on the procedure. Delegate one person to advise the appropriate member of the train crew when moves are to be made. Instruct all participants and observers to take precautions for their personal safety and observe safety practices of the carrier and/or company conducting the test. If desired, perform a test run without impacting the test item to establish accuracy of speed.

(2) Subject the test item to four impacts, the first three of which are in the same direction and at speeds of 6.4, 9.7, and 13 km/h (4, 6, and 8 mph) respectively, each speed with a tolerance of +0.8, -0.0 km/h (0.5 mph).

(3) Perform the fourth impact at 13 km/h (+0.8, -0.0 km/h) and impact the opposite end of the test car from the first three impacts. If it is not possible to turn the test car because of track layout, this may be accomplished by running the test item car to the opposite end of the buffer cars and impacting as above.

(4) If the lading or securement items loosen or fail during the test, photograph and document these items. If it appears necessary to adjust the lading or securement items to continue the test, correct the restraint and restart the test beginning with the 6.4 km/h (4 mph) impact.

(5) Pull the rail car carrying the test item a sufficient distance from the buffer cars. Next, push the test load car toward the buffer cars until the desired speed is obtained, and release it so it rolls freely into the buffer cars having knuckles positioned for coupling.

(6) If the materiel can be shipped in two orientations (such as lengthwise and crosswise on the rail car), repeat the four impacts for each orientation.

b. General considerations for alternate procedure.

(1) A section of track can be calibrated using a test car and either radar or another speed-measuring device. Release the test car from the designated starting point and allow it to roll freely down the inclined track. For radar, a crew member riding the test car is in radio contact with the radar operator who reads off the car speed to the rider. For other than radar, follow the same concept. The rider drops markers at track-side to indicate locations at which the desired speeds are obtained. After determining the 8 mph mark, stop the test car by use of the hand brake. Ensure no other cars are present on the test track during the calibration process. Repeat the process two times to ensure the accuracy of speed locations. If it is difficult for the rider to safely drop the markers and stop the car using the hand brake, use a free rolling locomotive for the initial calibration when markers are dropped with the locomotive's brakes applied after reaching 8 mph as indicated by radar. Then release the test car from the same starting point and make adjustments in markers if needed prior to impacting.

(2) After determining speed locations, perform impacts by locating the buffer cars at the proper location for desired impact speed and releasing the test car from the designated starting point. This requires moving the buffer cars every time a different speed is required.

(3) Use speeds and the direction of impacts as outlined in paragraph 4.5.8.3a.

(4) In lieu of positioning of the buffer cars at various positions on the track, release the test car from calibrated positions on the inclined track that correspond to the desired speeds.

(5) If the lading or securement items loosen or fail during the test, photograph and document these items. If it appears necessary to adjust the lading or securement items to continue the test, correct the restraint and restart the test beginning with the 6.4 km/h impact.

c. Additional requirements.

(1) Repeat any impacts that are below the required test speeds. If any readjustment of the lading or reconditioning of the bracing or items of securement is necessary, correct, photograph and document the problem(s), correct the restraint and restart the entire test beginning with the 6.4 km/h impact. Accept any impacts above the required test speed providing the test item satisfies the requirements of paragraph 4.5.8.4.

(2) If the tiedown chains or chock blocks become loose during the test, photograph and document the problem(s). The test director will notify MTMCTEA of the modifications required, and jointly decide if a retest will be required.

TABLE 516.5-VIII. Impact test time speed (miles per hour - based on 22’0” rail).

TIME SPEED SECS. MPH	TIME SPEED SECS. MPH	TIME SPEED SECS. MPH	TIME SPEED SECS. MPH
1.0 - 15.0	4.0 - 3.8	7.0 - 2.1	10.0 - 1.5
1.1 - 13.6	4.1 - 3.7	7.1 - 2.1	10.1 - 1.5
1.2 - 12.5	4.2 - 3.6	7.2 - 2.1	10.2 - 1.5
1.3 - 11.5	4.3 - 3.5	7.3 - 2.0	10.3 - 1.5
1.4 - 10.7	4.4 - 3.4	7.4 - 2.0	10.4 - 1.4
1.5 - 10.0	4.5 - 3.3	7.5 - 2.0	10.5 - 1.4
1.6 - 9.4	4.6 - 3.3	7.6 - 2.0	10.6 - 1.4
1.7 - 8.8	4.7 - 3.2	7.7 - 1.9	10.7 - 1.4
1.8 - 8.3	4.8 - 3.1	7.8 - 1.9	10.8 - 1.4
1.9 - 7.9	4.9 - 3.1	7.9 - 1.9	10.9 - 1.4
2.0 - 7.5	5.0 - 3.0	8.0 - 1.9	11.0 - 1.4
2.1 - 7.1	5.1 - 2.9	8.1 - 1.9	11.1 - 1.4
2.2 - 6.8	5.2 - 2.9	8.2 - 1.8	11.2 - 1.3
2.3 - 6.5	5.3 - 2.8	8.3 - 1.8	11.3 - 1.3
2.4 - 6.3	5.4 - 2.8	8.4 - 1.8	11.4 - 1.3
2.5 - 6.0	5.5 - 2.7	8.5 - 1.8	11.5 - 1.3
2.6 - 5.8	5.6 - 2.7	8.6 - 1.7	11.6 - 1.3
2.7 - 5.6	5.7 - 2.6	8.7 - 1.7	11.7 - 1.3
2.8 - 5.4	5.8 - 2.6	8.8 - 1.7	11.8 - 1.3
2.9 - 5.2	5.9 - 2.5	8.9 - 1.7	11.9 - 1.3
3.0 - 5.0	6.0 - 2.5	9.0 - 1.7	12.0 - 1.3
3.1 - 4.8	6.1 - 2.5	9.1 - 1.6	12.1 - 1.2
3.2 - 4.7	6.2 - 2.4	9.2 - 1.6	12.2 - 1.2
3.3 - 4.5	6.3 - 2.4	9.3 - 1.6	12.3 - 1.2
3.4 - 4.4	6.4 - 2.3	9.4 - 1.6	12.4 - 1.2
3.5 - 4.3	6.5 - 2.3	9.5 - 1.6	12.5 - 1.2
3.6 - 4.2	6.6 - 2.3	9.6 - 1.6	12.6 - 1.2
3.7 - 4.0	6.7 - 2.2	9.7 - 1.5	12.7 - 1.2
3.8 - 3.9	6.8 - 2.2	9.8 - 1.5	12.8 - 1.2
3.9 - 3.8	6.9 - 2.2	9.9 - 1.5	12.9 - 1.2

NOTE: Cargo requiring extraordinary attention, e.g., nuclear, one-of-a-kind, high value, or key military materiel, may justify changes to the test procedure and criteria; the developer or Program Manager must identify these, and they must be approved by the Director, Military Traffic Management Command Transportation Engineering Agency (MTMCTEA), ATTN: MTTE-DPE, 720 Thimble Shoals Blvd., Suite 130, Newport News, VA 23606-2574 (or its European equivalent).

4.5.8.4 Analysis of results.

Refer to the guidance in Part One, paragraphs 5.14 and 5.17, to assist in the evaluation of the test results. The test item fails this test if the test item or any item that is attached to it, or that is included as an integral part of the test item, breaks free, loosens, or shows any sign of permanent deformation beyond specification tolerances. Likewise, the test item and its subassemblies must be operationally effective after the test. If tiedown securement items break or displace substantially, photograph and document the problem areas for evaluation of the procedures and materials used. The test director and MTMCTEA jointly decide if any failed securement items require reconfiguring and, if so, whether a complete retest is required. If the test item fails, the necessary required action will be determined jointly by the parties involved. For retests, use new tiedown material to eliminate additive effects and, if possible, a new test item.

4.5.9 Procedure VIII - Catapult Launch/Arrested Landing.

The intent of this test is to verify the functionality and structural integrity of materiel mounted in or on fixed wing aircraft that are subject to catapult launches and arrested landings.

4.5.9.1 Controls.

a. Measured data not available. Whenever possible, derive the test conditions from measured data on applicable carrying aircraft (see Part One, paragraph 5.6, as well as the tasks at the end of Part One in Appendix A for information on the use of field/fleet data), since shock responses can be affected by local influences such as wing and fuselage bending modes, pylon interfaces, and structural damping. While the pulse amplitudes associated with this environment are generally low, the long periods of application and high frequency of occurrence have the potential to cause significant dynamic and/or low cycle fatigue damage in improperly designed materiel. A typical aircraft may fly as many as 200 sorties per year, of which more than two-thirds involve catapult launches and arrested landings. However, for laboratory test purposes, 30 simulated catapult/arrested landing events in each of two axes (longitudinal and vertical) should provide confidence that the majority of significant defects will be identified for remedial action. If acceptable field-measured data are not available, the following guidance is offered in which sinusoidal burst is used to simulate each catapult or launch event. This time history has been simplified to a constant amplitude sine burst of 2-second duration for simulation. In paragraph 4.5.9.1a(5) measured data seems to indicate that response in the horizontal direction can be comparable to that in the vertical direction. For testing purposes, it is permissible to reduce the maximum amplitude in the horizontal direction to 75% of that in the vertical direction.

(1) Wave shape: damped sine wave.

(2) Wave frequency: determined by structural analysis of the specific aircraft and frequency of the fundamental mode.

(3) Burst amplitude: determined by structural analysis of the specific aircraft, the frequency of the fundamental mode and the location of the materiel relative to the shape of the fundamental mode.

(4) Wave damping (quality factor): Q = 20.

(5) Axis: vertical, horizontal, longitudinal.

(6) Number of bursts: determined by the specific application (for example, 30 bursts, each followed by a 10 second rest period).

b. Measured data available. If acceptable field measured data are available, the following guidance is offered in which the catapult event is simulated by two shocks separated by a transient vibration, and the arrested landing event by one shock followed by transient vibration. The catapult launch/arrested landing shock environment differs from other typical shock events in that it is a transient periodic vibration (roughly sinusoidal) at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Typical catapult launch shock time histories are shown on figure 516.5-12. These data represent measured acceleration response in the vertical, horizontal and longitudinal directions of a store component mounted on the pylon of a platform. The data are DC coupled and lowpass filtered at 70 Hz. All three time histories demonstrate an initial transient, followed by a transient vibration (nearly two seconds long), and concluded by a final transient. The longitudinal axis provides a profile of the DC catapult acceleration which in general will not be important for testing purposes and can be removed by high pass filtering the time history at a frequency less than 10% of the lowest significant frequency in the maximax acceleration SRS. Procedures for accomplishing this filtering may necessarily be iterative (unless Fourier transform information is used) with high pass filtering beginning at a comparatively high frequency and decreasing until the most significant SRS low frequency is identified. In general, catapult acceleration response will display two shock events corresponding to initial catapult load application to the aircraft and catapult release from the aircraft separated by an oscillatory acceleration. Both the initial and the final shock events have a distinct oscillatory nature. It is essential that this test be run as a series of two shock transients separated by a two second period of time in which transient vibration may be input. Typical arrested landing shock time histories are shown on figure 516.5-13. These data represent measured acceleration response in the vertical, horizontal and longitudinal directions of a store component mounted on the pylon of a platform. The data are DC coupled and low pass filtered at 70 Hz. All three time histories demonstrate an initial transient, followed by a transient vibration (nearly three seconds long). It is clear that the longitudinal time history has a comparatively large DC component that may be filtered out for test specification development. The term 'transient vibration' is introduced here because of the duration of the event being not typical of a shock event.

Note : Transient vibrations. For precise laboratory simulation Procedure VIII may require consideration of the concept of a transient vibration in processing and replication of the form of time history from measured data. For long duration transient environments (durations on the order of one second or more), it may be useful to process the response time history by estimating the envelope function, a(t), and proceeding to compute a maximax Autospectral Density Estimate (ASD), assuming short portions of the response time history behave in the same manner as stationary random data. Estimation of this form falls under the category of nonstationary time history processing and will not be considered further in this method. For a precise definition of transient vibration see Part One, Appendix D. The importance of the transient vibration phenomenon is that (1) it has the form of a shock (short duration and substantial time varying amplitude), (2) it can be mathematically modeled in a precise way, and (3) it can be used in stochastic simulation of certain shock environments. In general, shocks have their significant energy in a shorter time frame than transient vibrations, while transient vibrations allow for time history enveloping functions other than the exponential envelope form often times displayed in shocks as a result of resonant response decay to an impact.

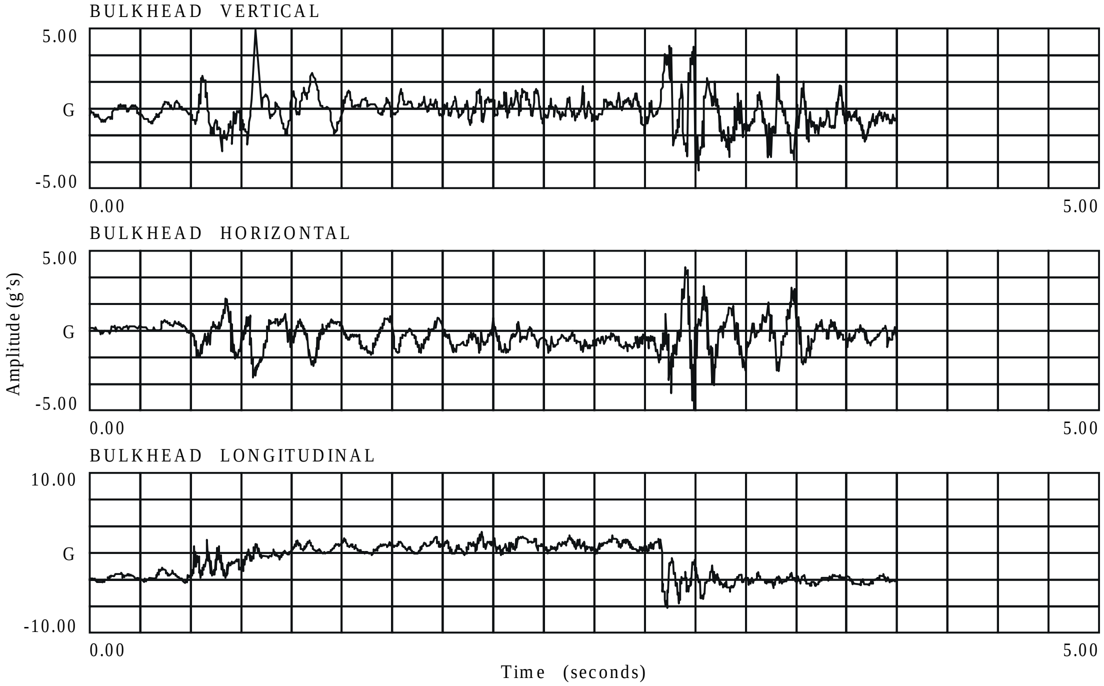


FIGURE 516.5-12. Sample measured store three axis catapult launch component response acceleration time histories.

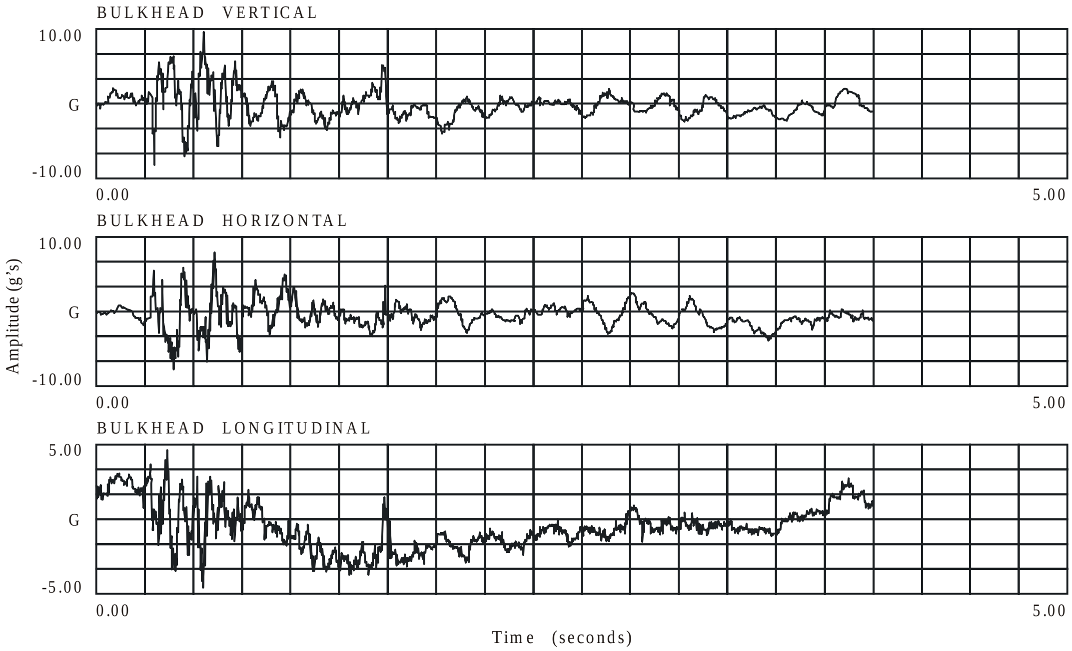


FIGURE 516.5-13. Sample measured store three axis arrested landing component response acceleration time histories.

4.5.9.2 Test tolerances.

For cases in which measured data are not available and waveforms are generated from dynamic analysis of the configuration, ensure the waveform tolerances are within the time history test tolerances specified for waveforms in paragraph 4.2.2. For cases in which measured data are available, ensure the SRS for the test response is within the SRS tolerances specified in paragraph 4.2.2. For transient vibration, ensure the waveform peaks and valleys are within the tolerances given for waveforms in paragraph 4.2.2 or as provided in the test specification.

4.5.9.3 Procedure VIII.

Step 1. Mount the test item to its shock/vibration fixture on the shock device for the first test axis.

Step 2. Attach instrumentation as required in the approved test plan.

Step 3. Conduct an operational checkout and visual examination in accordance with the approved test plan.

Step 4. a. If no measured field data are available, apply short transient sine waves of several cycles to the test item in the first test axis. (Each short transient sine wave of several cycles represents a single catapult or arrested landing event.) Follow each burst by a rest period to prevent unrepresentative effects. Operate the test item in its appropriate operational mode while bursts are applied.

b. If measured field data are available, either apply the measured response data under shaker system wave form control (see method 519.5, Annex A), or process the catapult as two shocks separated by a transient vibration, and the arrested landing as a shock followed by a transient vibration.

Step 5. If the test item has not malfunctioned during testing, conduct an operational checkout and visual examination in accordance with the approved test plan. If a failure has occurred, it may be desirable to perform a thorough visual examination before proceeding with the operational checkout to avoid initiating additional hardware damage. When a failure occurs, consider the nature of the failure and corrective action along with the purpose of the test (engineering information or contractual compliance) in determining whether to restart the test or to continue from the point of interruption.

Step 6. Repeat steps 1 through 5 for the second test axis.

Step 7. Document the test including amplitude time history plots, and notes of any test item functional or structural degradation.

4.5.9.4 Analysis of results.

In addition to the guidance in Part One, paragraphs 5.14 and 5.17, and Part One, Appendix A, Tasks 405 and 406, in the evaluation consider any failure of the structural configuration of the test item, mount or launcher that may not directly impact failure of the functioning of the materiel but that would lead to failure under in-service conditions.

5. REFERENCE/RELATED DOCUMENTS.

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e. Piersol, A.G., Analysis of Harpoon Missile Structural Response to Aircraft Launches, Landings and Captive Flight and Gunfire. Naval Weapons Center Report #NWC TP 58890. January 1977.

f. Handbook for Dynamic Data Acquisition and Analysis, IES-RP-DTE012.1, Institute of Environmental Sciences, 940 East Northwest Highway, Mount Prospect, Illinois 60056

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i. Schock, R. W. and W. E. Paulson, TRANSPORTATION A Survey of Shock and Vibration Environments in the Four Major Modes of Transportation, Shock and Vibration Bulletin #35, Part 5, February 1966.

j. Ostrem, F. E., TRANSPORTATION AND PACKAGING A Survey of the Transportation Shock and Vibration Input to Cargo, Shock and Vibration Bulletin #42, Part 1, January 1972.

k. MIL-S-901, “Shock Tests, H.I. (High Impact), Shipboard Machinery, Equipment and Systems, Requirements for.”

l. MIL-STD-331, “Fuze and Fuze Components, Environmental and Performance Tests for.”

ANNEX A

STATISTICAL CONSIDERATIONS FOR DEVELOPING LIMITS ON PREDICTED AND PROCESSED DATA

1. SCOPE.

1.1 Purpose.

This Annex provides information relative to the statistical characterization of a set of data for the purpose of defining an upper limit of the data set related to statistical/probabilistic considerations.

1.2 Application.

Information in this Annex is generally applicable to frequency domain estimates that are either predicted based on given information or time domain measurements processed in the frequency domain according to an appropriate technique i.e., for stationary random vibration the processing would be an ASD, for a very short transient the processing could be an SRS , ESD, or FS. Given estimates in the frequency domain information in this Annex will allow the establishment of upper limits of the data in a statistically correct way.

2. DEVELOPMENT.

2.1 Basic Estimate Assumptions.

Prediction estimates, measurement estimates, or a combination of prediction and measurement estimates may be considered in the same manner. It is assumed that uncertainty in individual measurements (processing error) does not effect the limit considerations. For measured field data digitally processed such that estimates of the SRS, ESD, FS, or ASD are obtained for single sample records, it becomes useful to examine and summarize the overall statistics of "similar" estimates selected in a way so as to not bias the summary statistics. To ensure the estimates are not biased, the measurement locations might be chosen randomly, consistent with the measurement objectives. Similar estimates may be defined as (1) estimates at a single location on materiel that has been obtained from repeated testing under essentially identical experimental conditions; (2) estimates on a system that have been obtained from one test, where the estimates are taken (a) at several neighboring locations displaying a degree of response homogeneity or (b) in "zones" i.e., points of similar response at varying locations; or (3) some combination of (1) and (2). In any case, it is assumed that there is a certain degree of homogeneity among the estimates across the frequency band of interest. This latter assumption generally requires that (1) the set of estimates for a given frequency have no significant “outliers” that can cause large sample variance estimates and (2) larger input stimulus to the system from which the measurements are taken implies larger estimate values.

2.2 Basic Estimate Summary Preprocessing.

There are two ways in which summaries may be obtained. The first way is to utilize an "enveloping" scheme on the basic estimates to arrive at a conservative estimate of the environment, and some qualitative estimate of the spread of basic estimates relative to this envelope. This procedure is dependent upon the judgment of the analyst and, in general, does not provide consistent results among analysts. The second way is to combine the basic estimates in some statistically appropriate way and infer the statistical significance of the estimates based upon probability distribution theory. Reference g summarizes the current state of knowledge relative to this approach and its relationship to determining upper limits on sets of data. In general, the estimates referred to and their statistics are related to the same frequency band over which the processing takes place. Unfortunately, for a given frequency band, the statistics behind the overall set of estimates are not easily accessible because of the unknown distribution function of amplitudes for the frequency band of interest. In most cases the distribution function can be assumed to be normal, provided the individual estimates are transformed to a "normalizing" form by computing the logarithm to the base ten of the estimates. For ESD and FS estimates, the averaging of adjacent components (assumed to be statistically independent) increases the number of degrees of freedom in the estimates while decreasing the frequency resolution with the possible introduction of statistical bias in the estimates. For ASD estimates, averaging of adjacent components can be useful provided the bias error in the estimate is small; i.e., the resolution filter bandwidth is a very small fraction of the overall estimate bandwidth. For SRS estimates, because they are based on maximum response of a single-degree-of-freedom system as its natural frequency is varied, adjacent estimates tend to be statistically dependent and therefore not well smoothed by averaging unless the SRS is computed for very narrow frequency spacing. In such cases, smoothing of SRS estimates is better accomplished by reprocessing the original time history data at a broader natural frequency spacing, e.g., 1/6th octave as opposed to 1/12th octave. There is no apparent way to smooth dependent SRS estimates mathematically when reprocessing cannot be performed, and the acceptable alternative is some form of enveloping of the estimates. The larger the sample size the closer the logarithm transform of the estimates is to the normal distribution unless there is a measurement selection bias error in the experiment. Finally, it is important to note that generally, before application, the upper limits obtained in the paragraphs to follow are smoothed by straight line segments intersecting at spectrum “breakpoints”. No guidance is provided in this annex relative to this “smoothing” or “enveloping” procedure, e.g., whether estimates should be clipped or enveloped and the relationship of the bandwidth of the estimates to the degree of clipping, etc., except that such smoothing should be performed only by an experienced analyst. Reference g discusses this further.

2.3 Parametric Upper Limit Statistical Estimate Assumptions.

In all the formulas for the estimate of the statistical upper limit of a set of N predictions or measurements,

$$\{ x_1, x_2, \ldots\ldots x_N \},$$

it is assumed that (1) the estimates will be logarithm transformed to bring the overall set of measurements closer to those sampled of a normal distribution and (2) the measurement selection bias error is negligible. Since the normal and “t” distribution are symmetric, the formulas below apply for the lower bound by changing the sign between the mean and the standard deviation quantity to minus. It is assumed here that all estimates are at a single frequency or for a single bandwidth, and that estimates among bandwidths are independent so that each bandwidth under consideration may be processed individually, and the results summarized on one plot over the entire bandwidth as a function of frequency. For

$$y_i = \log_{10}(x_i) \qquad i = 1,2,\ldots\ldots,N$$

Mean estimate for true mean, μ_y is given by

$$m_y = \frac{1}{N}\sum_{i=1}^{N} y_i$$

and the unbiased estimate of the standard deviation for the true standard deviation σ_y is given by

$$s_y = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - m_y\right)^2}{N-1}}$$

2.3.1 NTL - Upper normal one-sided tolerance limit.

The upper normal one-sided tolerance limit on the proportion β of population values that will be exceeded with a confidence coefficient, γ, is given by NTL(N, β, γ), where

$$\mathrm{NTL}(N,\beta,\gamma) = 10^{m_y + s_y k_{N,\beta,\gamma}}$$

where $k_{N,\beta,\gamma,}$ is the one-sided normal tolerance factor given in table 516.5A-I for selected values of N, β and γ. NTL is termed the upper one-sided normal tolerance interval (of the original set of estimates) for which 100 β% of the values will lie below the limit with 100 γ % confidence. For $\beta = 0.95$ and $\gamma = 0.50$, this is referred to as the 95/50 limit.

The following table from reference g contains the k value for selected N, β, γ. In general this method of estimation should not be used for small N with values of β and γ close to 1 since it is likely the assumption of the normality of the logarithm transform of the estimates will be violated.

TABLE 516.5A-I. Normal tolerance factors for upper tolerance limit.

N	**γ = 0.50**			**γ = 0.90**			**γ = 0.95**		
	β = 0.90	**β = 0.95**	**β = 0.99**	**β = 0.90**	**β = 0.95**	**β = 0.99**	**β = 0.90**	**β = 0.95**	**β = 0.99**
3	1.50	1.94	2.76	4.26	5.31	7.34	6.16	7.66	10.55
4	1.42	1.83	2.60	3.19	3.96	5.44	4.16	5.14	7.04
5	1.38	1.78	2.53	2.74	3.40	4.67	3.41	4.20	5.74
6	1.36	1.75	2.48	2.49	3.09	4.24	3.01	3.71	5.06
7	1.35	1.73	2.46	2.33	2.89	3.97	2.76	3.40	4.64
8	1.34	1.72	2.44	2.22	2.76	3.78	2.58	3.19	4.35
9	1.33	1.71	2.42	2.13	2.65	3.64	2.45	3.03	4.14
10	1.32	1.70	2.41	2.06	2.57	3.53	2.36	2.91	3.98
12	1.32	1.69	2.40	1.97	2.45	3.37	2.21	2.74	3.75
14	1.31	1.68	2.39	1.90	2.36	3.26	2.11	2.61	3.58
16	1.31	1.68	2.38	1.84	2.30	3.17	2.03	2.52	3.46
18	1.30	1.67	2.37	1.80	2.25	3.11	1.97	2.45	3.37
20	1.30	1.67	2.37	1.76	2.21	3.05	1.93	2.40	3.30
25	1.30	1.67	2.36	1.70	2.13	2.95	1.84	2.29	3.16
30	1.29	1.66	2.35	1.66	2.08	2.88	1.78	2.22	3.06
35	1.29	1.66	2.35	1.62	2.04	2.83	1.73	2.17	2.99
40	1.29	1.66	2.35	1.60	2.01	2.79	1.70	2.13	2.94
50	1.29	1.65	2.34	1.56	1.96	2.74	1.65	2.06	2.86
∞	1.28	1.64	2.33	1.28	1.64	2.33	1.28	1.64	2.33

2.3.2 NPL - Upper normal prediction limit.

The upper normal prediction limit is the value of x (for the original data set) that will exceed the next predicted or measured value with confidence coefficient γ, and is given by

$$\mathrm{NPL}(N,\gamma) = 10^{\,m_y + s_y \sqrt{1+\frac{1}{N}}\; t_{N-1;\alpha}}$$

where $\alpha = 1 - \gamma$. $t_{N-1;\,\alpha}$ is the Student t distribution variable with N-1 degrees of freedom at the 100 α = 100(1-γ) percentage point of the distribution. This estimate, because of the assumptions behind its derivation, requires careful interpretation relative to measurements made in a given location or over a given zone (reference g).

2.4 Nonparametric Upper Limit Statistical Estimate Assumptions.

If there is some reason to believe that the data after it has been logarithm-transformed will not be sufficiently normally distributed to apply the parametric limits defined above, then consideration must be given to nonparametric limits, i.e., limits that are not dependent upon assumptions concerning the distribution of estimate values. In this case there is no need to transform the data estimates. All of the assumptions concerning the selection of estimates are applicable for nonparametric estimates. With additional manipulation, lower bound limits may be computed.

2.4.1 ENV – Upper limit.

The maximum upper limit is determined by selecting the maximum estimate value in the data set.

$$\mathrm{ENV}(N) = \max\{\, x_1, x_2, \ldots\ldots x_N \,\},.$$

The main disadvantage of this estimate is that the distributional properties of the estimate set are neglected so that no probability of exceedance of this value is specified. In the case of outliers in the estimate set, ENV(N) may be far too conservative. ENV(N) is also sensitive to the bandwidth of the estimates.

2.4.2 DFL – Upper distribution-free tolerance limit.

The distribution-free tolerance limit that utilizes the original untransformed sample values is defined to be the upper limit for which at least the fraction β of all sample values will be less than the maximum predicted or measured value with a confidence coefficient of γ. This limit is based on order statistic considerations.

$$\mathrm{DFL}\left(N,\beta,\gamma\right) = x_{\max}; \gamma = 1 - \beta^{N}$$

where $x_{\max}$ is the maximum value of the set of estimates, β, is the fractional proportion below $x_{\max}$, and γ is the confidence coefficient. N, β and γ are not independently selectable. That is

(1) Given N and assuming a value of β, $0 \le \beta \le 1$, the confidence coefficient can be determined.

(2) Given N and γ, the proportion β can be determined.

(3) Given β and γ, the number of samples can be determined such that the proportion and confidence can be satisfied (for statistical experiment design).

DFL(N,β,γ) may not be meaningful for small samples of data, $N \le 13$, and comparatively large β, $\beta > 0.95$. DFL(N,β,γ) is sensitive to the estimate bandwidth.

2.4.3 ETL – Upper empirical tolerance limit.

The empirical tolerance limit uses the original sample values and assumes the predicted or measured estimate set is composed of N measurement points over M frequency resolution bandwidths for a total of NM estimate values. That is

$$\{x_{11}, x_{12}, \ldots, x_{1M};\ x_{21}, x_{22}, \ldots, x_{2M};\ x_{N1}, x_{N2}, \ldots x_{NM}\}$$

where m_j is the average estimate at the jth frequency bandwidth over all N measurement points

$$m_j = \frac{1}{N}\sum_{i=1}^{N} x_{ij} \qquad j = 1, 2, \ldots, M.$$

m_j is used to construct an estimate set normalized over individual frequency resolution bandwidths. That is

$$\{u\} = \{u_{11}, u_{12}, \ldots\ldots, u_{1M}, u_{21}, u_{22}, \ldots, u_{2M}, u_{N1}, u_{N2}, \ldots.., u_{NM}\}$$

$$\text{where :} \qquad u_{ij} = \frac{x_{ij}}{m_j} \qquad i = 1, 2, \ldots, N;\ j = 1, 2, \ldots, M$$

The normalized estimate set, {u}, is ordered from smallest to largest and

$u_\beta = u_{(k)}$ where $u_{(k)}$ is the k^{th} ordered element of set {u} for $0 < \beta = \frac{k}{MN} \le 1$

is defined. For each resolution frequency bandwidth, then

$$\mathrm{ETL}(\beta) = u_\beta m_j = x_{\beta j} \qquad j = 1, 2, \ldots, M$$

Using m_j implies that the value of ETL(β) at j exceeds β % of the values with 50% confidence. If a value other than m_j is selected, the confidence level may increase. It is important that the set of estimates is homogeneous to use this limit, i.e., they have about the same spread in all frequency bands. In general, the number of measurement points, N, should be greater than 10 to apply this limit.

3. EXAMPLE.

3.1 Input Test Data Set.

Table 516.5A-II represents a homogeneous table of normally distributed numbers of unity variance around a mean value of 3.5 with N=14 rows and M=5 columns (rows could represent fourteen individual test measurements and columns could represent test values over five individual frequency bandwidths). Table 516.5A-II is used in the upper limit determinations in paragraphs 3.2 and 3.3.

3.2 Parametric Upper Limits.

The upper normal one-sided tolerance limit (NTL) is computed as 95/50 limit with 50% confidence that at least 95% of the values will lie below this limit for $k_{N,\ \beta,\ \gamma} = 1.68$ from table 516.5A-I. The upper normal prediction limit (NPL) is computed with a 95 confidence coefficient at the 95% point of the distribution where $t_{N-1;\alpha} = t_{13;0.05} = 1.771$. Figure 516.5A-1 displays the data and figure 516.5A-2 displays the two parametric upper limits. Note the degree of conservativeness in the normal prediction upper limit over the normal tolerance limit.

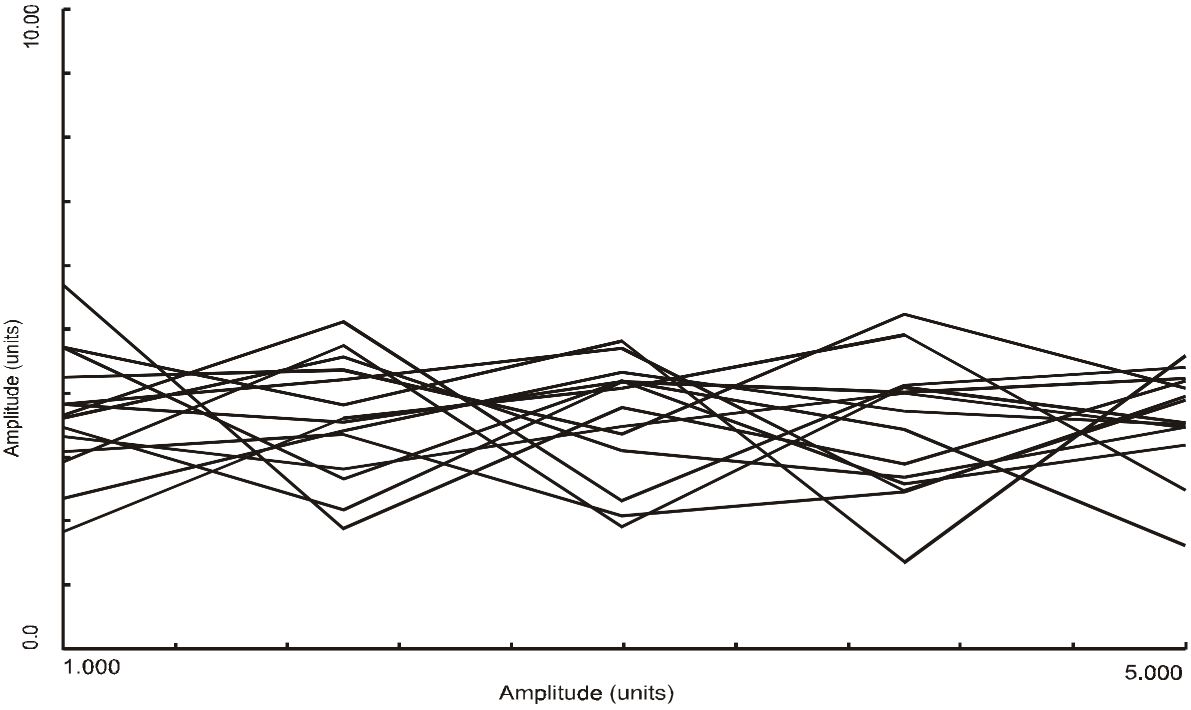

FIGURE 516.5A-1. Input test data set.

3.3 Nonparametric Upper Limits.

The envelope limit (ENV) along with the upper distribution-free tolerance limit (DFL) for β proportion of the population set at 0.95 and γ confidence coefficient of 0.51 for N=14 samples is displayed on figure 516.5A-2. This represents one curve with two interpretations. The 95% upper empirical tolerance limit (ETL) is also displayed on figure 516.5A-2 where at least 95% of the values will be exceeded by this limit with 50% confidence. The data is displayed on figure 516.5A-2 for comparison purposes.

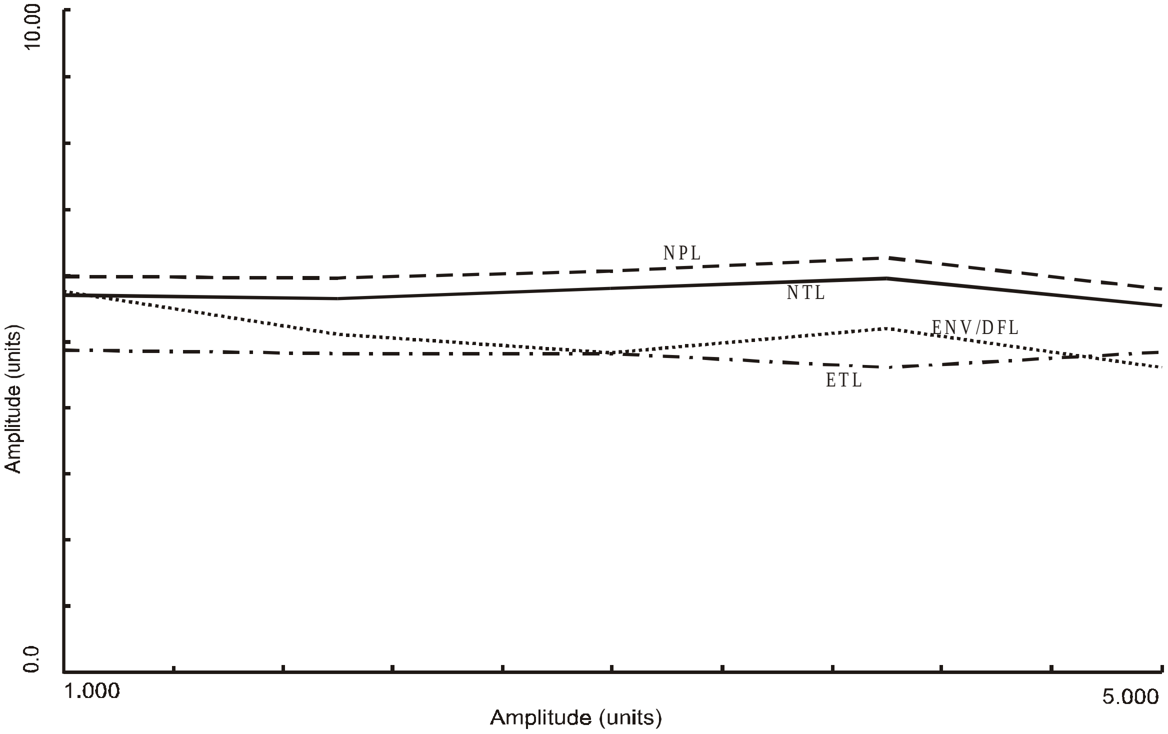

FIGURE 516.5A-2. Parametric and non-parametric upper limits.

3.4 Observations.

The "flatness" of the upper limits on figure 516.5A-2 attests to the homogeneity of the data in table 516.5A-II. It is apparent from figure 516.5A-2 that the upper limits for the parameters selected are not "statistically equivalent". Of the two upper limit estimates the NTL is favored if it can be established that the logarithm transform of the data set is approximately normally distributed. The closeness of the nonparametric envelopes attests also to the homogeneity of the data in table 516.5A-II in addition to demonstrating, for this case at least, the nonstatistical ENV, the statistically based DFL and the ETL basically agree with regard to the upper limit magnitude. For nonhomgeneous data sets ETL would not be expected to agree with ENV or DFL. For small data sets, ETL may vary depending upon if "k" rounds upward or downward.

3.5 MATLAB m-function "ul."

Following is a MATLAB function "ul" for computing the specified upper limit and any associated parameters. the desired upper limit is input through str_in with associated parameters in par_in. The N by M matrix of data values is input in the N by M matrix X_in. The output upper limit is in X_ul with selected parameters computed within the function in par_out. The following function has been verified with the data matrix supplied in table 516.5A-2 of this Annex. Before applying the user should clearly understand the input and verify the m-function with a simple example. The input displayed in table 516.5A-II was generated with the following MATLAB command:

```
X_in = randn(14,5) + 3.5;
```

```
function [par_out,X_ul] = ul(str_in,par_in,X_in)
%
% ul.m - MATLAB m-function for determining a data array upper limit
%                       11-May-1999
%
%
% Input Information :
%
% str_in - input string specifying the desired upper limit and transform
%
% par_in - input parameters for desired upper limit
%
% X_in - a N by M matrix of data values. N rows in X_in representing individual
%        measurement points. M columns in X_in representing independently
%        processed values. For a specified logarithm transformation of X_in, all
%        the values in X_in must be positive. For ETL the mean value for a column
%        of X_in must not be zero.
% NTL
%     str_in(1:4) = 'NTLL' --> normal tolerance upper limit with log transform of X_in
%     str_in(1:4) = 'NTLN' --> normal tolerance upper limit of X_in
%     par_in = [N M k_N_Beta_Gamma] --> k_N_Beta_Gamma - one sided normal
%              tolerance interval table value with Beta portion and Gamma confidence
% NPL
%     str_in(1:4) = 'NPLL' --> normal prediction upper limit with log transform of X_in
%     str_in(1:4) = 'NPLN' --> normal prediction upper limit of X_in
%     par_in = [N M Gamma] --> 0 < Gamma=(1-alpha) < 1 - confidence coefficient
%     par_out(1) = t_value --> value of t(N-1;alpha)
% ENV
%     str_in(1:4) = 'ENVN' --> maximum upper limit
%     par_in = [N M]
% DFL
%     str_in(1:4) = 'DFLN' --> distribution free upper limit
%     par_in = [N M B G]    --> for B = 0 or Beta - portion of population
%     par_in = [N M B G]    --> for G = Gamma or 0 - confidence coefficient
%     par_out(1) = Beta  - if par_in(3) = 0 and par_in(4) = Gamma
%     par_out(1) = Gamma - if par_in(3) = Beta and par_in(4) = 0
% ETL
%     str_in(1:4) = 'ETLN' --> empirical tolerance upper limit
%     par_in = [N M Beta]  --> 0 < Beta < 1 where Beta = portion of population
%                              less than the upper limit
%     par_out(1) = u_Beta  --> ordered value corresponding to Beta
%
%
% Output Information :
%
% par_out - output parameters (if any)
% X_ul    - a 1 by M data vector specifying the desired upper limit
%
%
N = par_in(1);
                                  if N > 1
N_1 = N - 1;
M = par_in(2);
NM = N * M;
par_ou(1)=0;
X_ul=zeros(1,M);
if str_in(4:4) == 'L'
   X_t = log10(X_in);
else
   X_t = X_in;
end
%%% mean of N rows over M columns of X_t
m = mean(X_t);
%%% standard deviation of N rows over M columns of X_t
s = std(X_t);
%%% zero par_out and X_ul
par_out(1) = 0;
X_ul=zeros(1,M);
%%%%%%%%%%%%%%%%%%%%%%%%% NTL - Normal Tolerance Limit %%%%%%%%%%%%%%%%%%%%%%%%%
if str_in(1:3) == 'NTL'
k_N_Beta_Gamma = par_in(3);
  if str_in(4:4) == 'L'
    for i = 1:M
      X_ul(i) = 10^(m(i) + k_N_Beta_Gamma*s(i));
    end
  else
      X_ul = m + k_N_Beta_Gamma*s;
  end
end
%%%%%%%%%%%%%%%%%%%%%%%% NPL - Normal Prediction Limit %%%%%%%%%%%%%%%%%%%%%%%%
if str_in(1:3) == 'NPL'
t_value = tinv(par_in(3),N_1);
  if str_in(4:4) == 'L'
    for i = 1:M
      X_ul(i) = 10^(m(i) + s(i) * sqrt(1 + 1/N) * t_value);
    end
  else
      X_ul = m + (sqrt(1 + 1/N) * t_value)*s;
  end
par_out(1)=t_value;
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%% ENV - Maximum Limit %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if str_in(1:3) == 'ENV'
X_ul = nanmax(X_in);
end
%%%%%%%%%%%%%%%%%%%%%%%% DFL - Distribution Free Limit %%%%%%%%%%%%%%%%%%%%%%%%
if str_in(1:3) == 'DFL'
  if 1 > par_in(3) > 0
    Gamma = 1 - ( par_in(3) ^ N )
    par_out(1) = Gamma;
  end
  if 1 > par_in(4) > 0
    Beta = ( ( 1 - par_in(4) ) ^ (1/N) )
    par_out(1) = Beta;
  end
  if par_out(1) > 0
    X_ul = nanmax(X_in);
  else
    STMT='improper Beta/Gamma input :: exit function ul'
  end
end
%%%%%%%%%%%%%%%%%%%%%%% ETL - Empirical Tolerance Limit %%%%%%%%%%%%%%%%%%%%%%%
if str_in(1:3) == 'ETL'
%%% normalize with respect to the column mean
X=zeros(1,NM);
X_o=zeros(1,NM);
for i = 1:N
   for j = 1:M
      X(j+(i-1)*M)=X_in(i,j)/m(j);
   end
end
%%% order X
X_o=sort(X);
ul_index = ceil( par_in(3) * NM )
  if NM >= ul_index > 0
    ul = X_o(ul_index)
    par_out(1) = ul;
    X_ul = ul * m;
  else
    STMT = 'improper Beta input :: exit function ul'
  end
end
                                  else
                                  STMT = 'N < 2 :: exit function ul'
                                  end
%
% end of function ul
```

FIGURE 516.5A-3. MATLAB m-function "ul" for upper limit determination.

TABLE 516.5A-II. Input test data set.

3.0674	3.3636	2.0590	2.4435	3.8803
1.8344	3.6139	4.0711	4.9151	2.4909
3.6253	4.5668	3.1001	2.6949	3.4805
3.7877	3.5593	4.1900	4.0287	3.4518
2.3535	3.4044	4.3156	3.7195	3.5000
4.6909	2.6677	4.2119	2.5781	3.1821
4.6892	3.7902	4.7902	1.3293	4.5950
3.4624	2.1638	4.1686	3.4408	1.6260
3.8273	4.2143	4.6908	2.4894	3.9282
3.6746	5.1236	2.2975	4.1145	4.3956
3.3133	2.8082	3.4802	4.0077	4.2310
4.2258	4.3580	3.3433	5.1924	4.0779
2.9117	4.7540	1.8959	4.0913	3.5403
5.6832	1.9063	3.7573	2.8564	4.1771

4. RECOMMENDED PROCEDURES.

4.1 Recommended Statistical Procedures for Upper Limit Estimates.

Reference g provides a detailed discussion of the advantages and disadvantages of estimate upper limits. The guidelines in this reference will be recommended here. In all cases plot the data carefully with a clear indication of the method of establishing the upper limit and the assumptions behind the method used.

a. When N is sufficiently large, i.e., $N \geq 7$ establish the upper limit by using the expression for the DFL for a selected $\beta \geq 0.90$ such that $\gamma \geq 0.50$.

b. When N is not sufficiently large to meet the criterion in (a), establish the upper limit by using the expression for the NTL. Select β and $\gamma \geq 0.50$. Variation in β will determine the degree of conservativeness of the upper limit.

c. For $N > 10$ and a confidence coefficient of 0.50, the upper limit established on the basis of ETL is acceptable and may be substituted for the upper limit established by DFL or NTL. It is important when using ETL to examine and confirm the homogeneity of the estimates over the frequency bands.

4.2 Uncertainty Factors.

Uncertainty factors may be added to the resulting upper limits if confidence in the data is low or the data set is small. Factors on the order of 3 dB to 6 dB may be added. Reference g recommends a 5.8 dB uncertainty factor (based on “flight-to-flight” uncertainties of 3 dB and “point-to-point” uncertainties of 5 dB) be used with captive carry flight measured data to determine a maximum expected environment using a normal tolerance limit. It is important that all uncertainties be clearly defined and that uncertainties are not superimposed upon estimates that already account for uncertainty.

ANNEX B

EFFECTIVE SHOCK DURATION

1. SCOPE.

1.1 Purpose.

This annex provides a basis and justification for the selection of the definition of an effective shock duration, T_e.

1.2 Application.

Information in this annex is directed towards selection of an effective shock duration for laboratory testing based upon measured data. Replication of field measured environments in the laboratory by use of synthesized complex transients on shaker control systems requires (1) satisfaction of the field measured SRS amplitude and (2) correspondence between the duration of the field measured transient and the laboratory synthesized transient. In certain cases it may be apparent that one amplitude-varying shock over a long duration may actually be two or more distinct shocks over the duration. The requirements for deciding if field measured data should be replicated in the laboratory as a single shock or as multiple shocks are (1) a clear understanding of the physical phenomenon behind the field measured environment along with an understanding of the frequency characteristics of the test item, and (2) the judgement of an experienced analyst.

2. DEVELOPMENT.

2.1 Assumptions on Shock Envelope Development.

The shock duration is essentially determined by the form of the envelope of the absolute value of the measured peaks of the shock time history. This tacitly assumes that for a shock time history the distribution of the positive and negative peaks of the shock time history are essentially the same, i.e., the shock time history is symmetrical with respect to polarity. It should be clear that the envelope of these peaks in general is a complex piecewise continuous function that has no simple analytical description. Figure 516.5B-1a displays a typical shock time history along with its envelope and two sets of vertical lines – one indicating the duration of T_E and the other the duration of T_e. Figure 516.5B-1b displays short time average RMS along with one set of vertical lines indicating the duration of T_e. In the development to follow it is assumed that the measured shock transient peak distribution in time has an initial segment characterized by a rise time (t_r) and a following segment characterized by a decay time (t_d) where in general $t_d > t_r$. It is assumed that the envelope of the initial peak amplitude distribution normalized to the absolute value of the maximum peak acceleration, Ap, is of a third order polynomial form

$$e_r(t) = a_1\left(\frac{t}{t_r}\right) + a_2\left(\frac{t}{t_r}\right)^2 + a_3\left(\frac{t}{t_r}\right)^3 \qquad 0 \le t \le t_r \text{ and } a_1 + a_2 + a_3 = 1$$

It is assumed that the envelope of the trailing segment is characterized by a simple exponentially decaying function normalized to Ap

$$e_j(t) = e^{\alpha\left(\frac{t}{t_r}-1\right)} \qquad t_r \le t \le t_r + t_j$$

The initial segment has three degrees of freedom for fitting whereas the trailing segment has one degree of freedom. The segments will, in general, have a much more complex form than is representable by the simple expressions $e_r(t)$ and $e_j(t)$. In general, the SRS amplitudes in the high frequency region are more sensitive to the initial segment form than the trailing segment form whereas the low frequency SRS amplitudes are sensitive to both the duration of the trailing segment and to the form of the trailing segment.

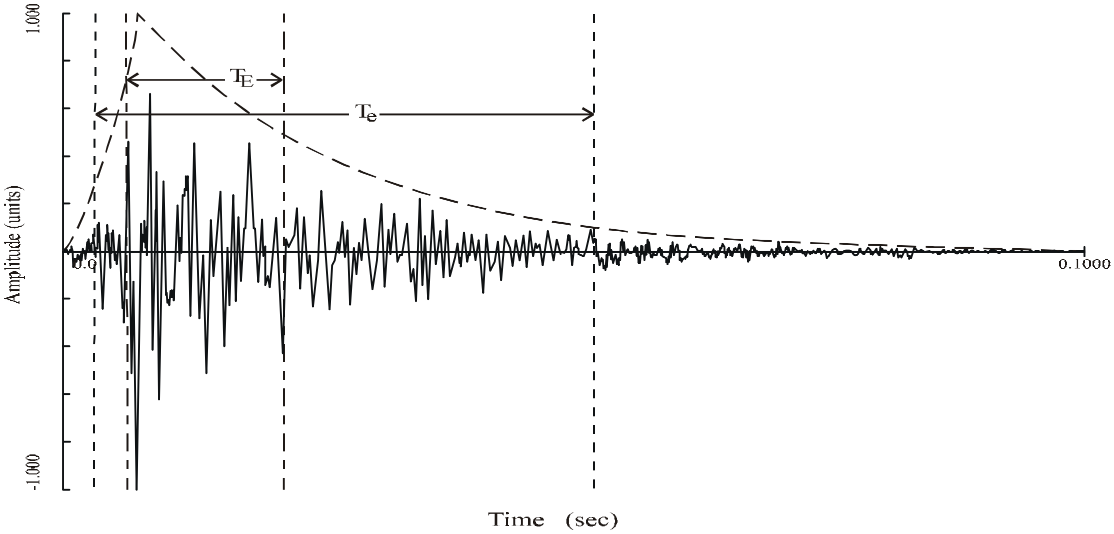

FIGURE 516.5B-1a. Typical shock time history with envelope, T_E and T_e.

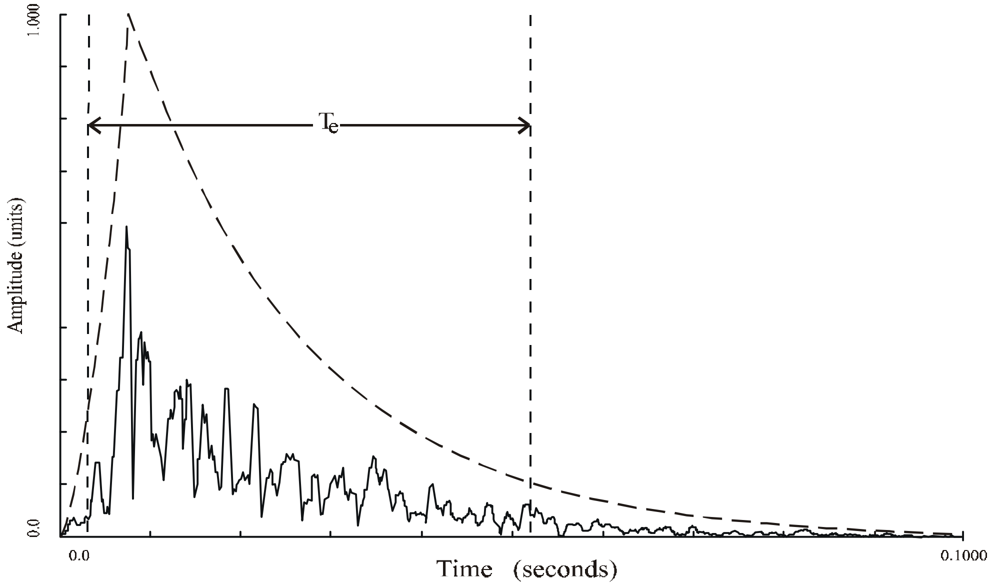

FIGURE 516.5B-1b. Typical shock time history RMS with envelope and T_e.

2.2 T_e versus T_E.

T_E was defined in MIL-STD-810E to be "the minimum length of time that contains all data magnitudes exceeding 1/3 of the peak magnitude associated with the shock event." In this document, T_e is defined to be the minimum length of time that contains at least 90% of the root-mean-square (RMS) time history amplitudes exceeding in value 10% of the peak RMS magnitude associated with the shock event. Figure 516.5B-2 provides a scatter plot of T_E versus T_e for shocks simulated according to the envelope forms above and provides a visual correlation between the two durations. From this statistical simulation, on this particular simple form of pulse, it can be concluded that the median ratio of T_e to T_E is 2.62 with 95% of the ratios lying between 1.71 and 5.43.

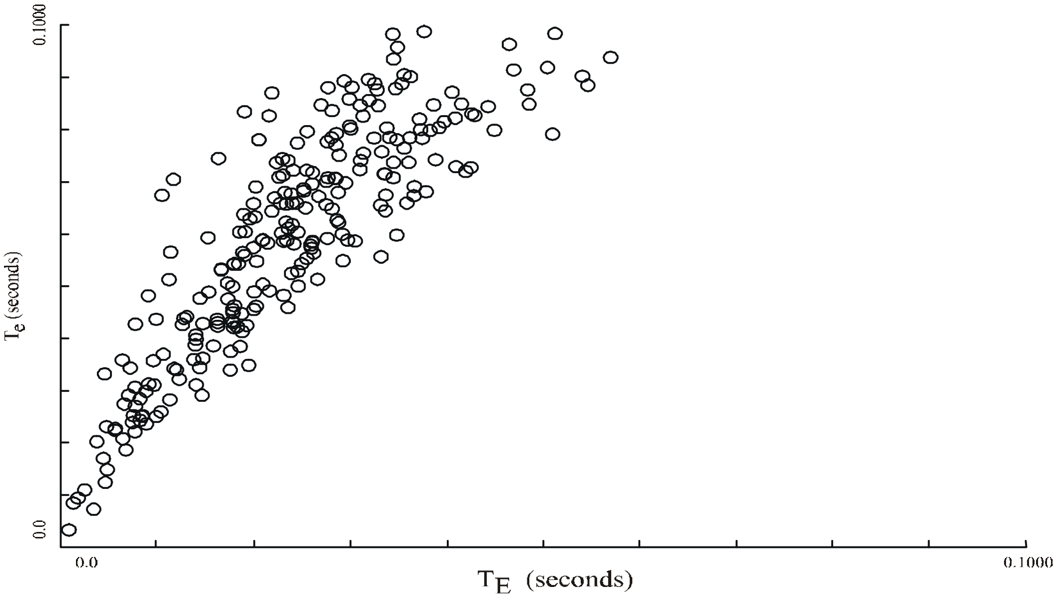

FIGURE 516.5B-2. Scatter plot T_E versus T_e

NOTE: Median Ratio T_e/T_E 2.62 with 95% of Ratios between 1.71 and 5.43.

3. RECOMMENDED PROCEDURES FOR SYNTHESIS AND ANALYSIS.

3.1 Synthesis Recommended for T_e.

Table 516.5-I contains the recommended values of T_e replacing the T_E values in previous editions of MIL-STD-810. Use these values of T_e. for guidance in specifying the duration of a synthesized complex transient for laboratory testing. In general T_e may be considered to be approximately 2.5 T_E.

3.2 Synthesis Uncertainty Factors for T_e.

Table 516.5-I contains the uncertainty factors in the effective duration, T_e. Use these uncertainty factors for T_e for guidance in specifying the duration of a synthesized complex transient for laboratory testing.

3.3 Analysis Relationship to T_e.

For computation of the SRS of the shock event (for durations in which $T_e > \dfrac{1}{2f_{min}}$ where f_{min} is the minimum SRS frequency of interest), taper the beginning and the end of the shock event to zero amplitude and extend the time of the computation over the tapers and the duration T_e. Computation of the ESD or FT of the shock event must have a minimum block size of length equivalent to the duration, T_e and be zero padded to eliminate excess noise in the estimates based upon the judgement of an experienced analyst.

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ANNEX C

AUTOSPECTRAL DENSITY WITH EQUIVALENT TEST SHOCK RESPONSE SPECTRA

1. SCOPE.

1.1 Purpose.

This Annex provides information for determination if a field measured or predicted stationary random vibration ASD provides an environment that exceeds that for a field measured or predicted shock.

1.2 Application.

For field measured or predicted ASD data from high level stationary random vibration, if the data representative time history is such that it exceeds substantially the measured or predicted shock environment time history, the random vibration test may be considered to provide an adequate test for the shock environment. Perform only the stationary random vibration test.

2. DEVELOPMENT.

2.1 Assumptions on Autospectral Density.

Figure 516.5-9 provides two ASD plots for functional tests for ground materiel and flight materiel. Figures 516.5C-1a and 516.5C-1b provide the associated simulated Gaussian stationary amplitude time history segments over a 25 ms period of time for the ground materiel and the flight materiel, respectively.

2.2 Assumptions on Shock Response Spectra.

Figures 516.5C-2a and 516.5C-2b provide the associated SRS plots for 250 simulations of the time histories on figure 516.5C-1a and 516.5C-1b, respectively. In particular, the SRS plots represent the mean SRS and the upper and lower distribution free tolerance intervals based upon a 98% proportion of population with a 92% confidence coefficient and the SRS spectra specified on figure 516.5-8. The SRS were computed for a Q=5 over approximately one second time interval, i.e., 10 times the period of the lowest frequency represented on figure 516.5-9.

3. RECOMMENDED PROCEDURES.

3.1 Recommended for ASD.

For measured stationary random vibration data, compute the ASD and compare with the ASD of figure 516.5-9. If the measured ASD exceeds the ASD in this figure at every frequency with a maximum 5 Hz analysis filter bandwidth, perform only the random vibration test on the equipment.

3.2 Recommended for SRS.

For measured stationary random vibration data compute the ASD and compare with the ASD of figure 516.5-9. If the measured ASD does not exceed the ASD on this figure at every frequency with a maximum 5 Hz analysis filter bandwidth, sample the measured random vibration data and proceed to compute an SRS over a selected period of time no shorter than 10 times the period of the lowest frequency represented on figure 516.5-9. If the SRS exceeds the SRS of figure 516.5-8 at every frequency, consider the random vibration test adequate. If the SRS does not exceed the SRS of figure 516.5-8 at every frequency, proceed to generate a complex transient from either field measured or predicted SRS data in order to test the equipment for shock.

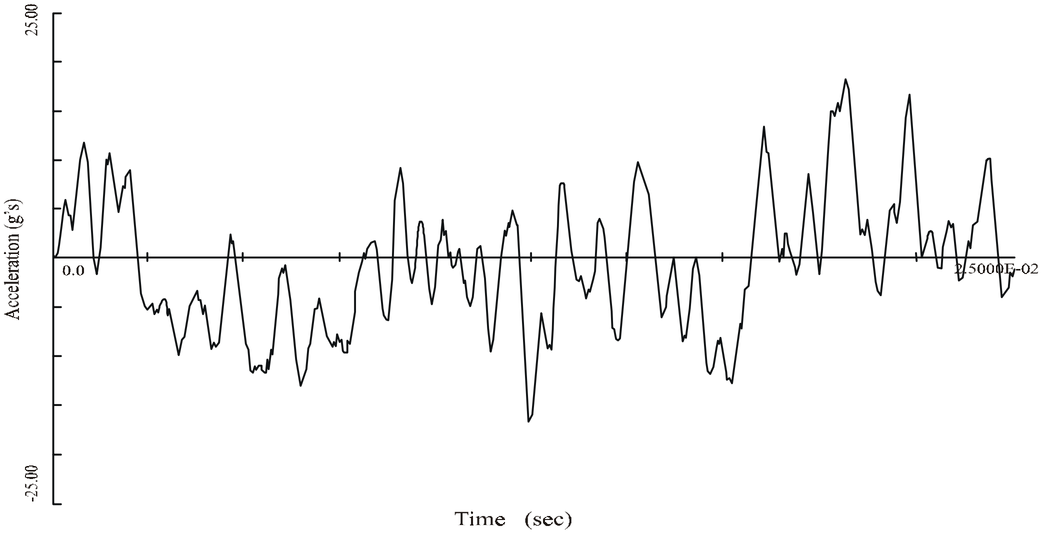

FIGURE 516.5C-1a. Sample Gaussian time history for functional test for ground materiel.

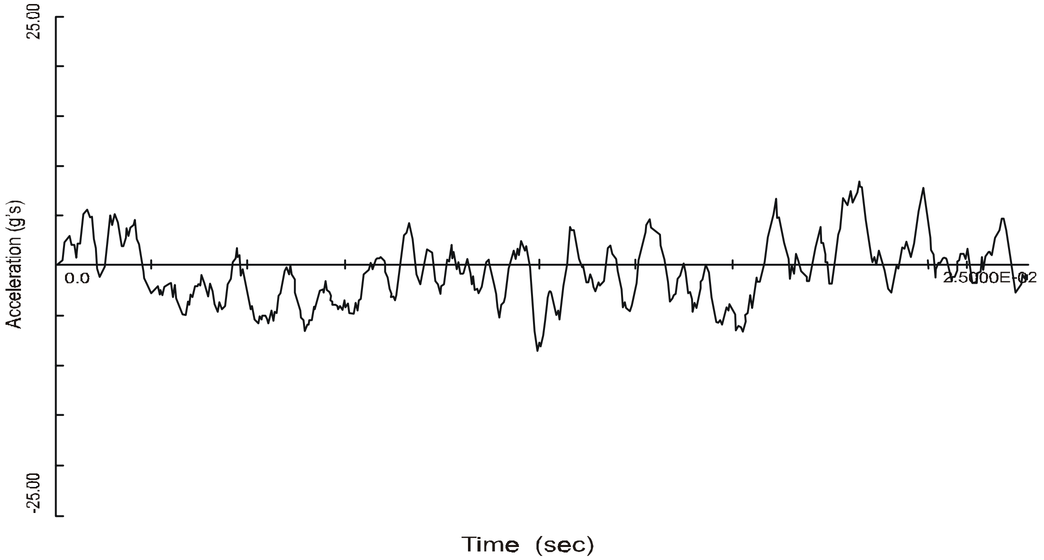

FIGURE 516.5C-1b. Sample Gaussian time history for functional test for flight materiel.

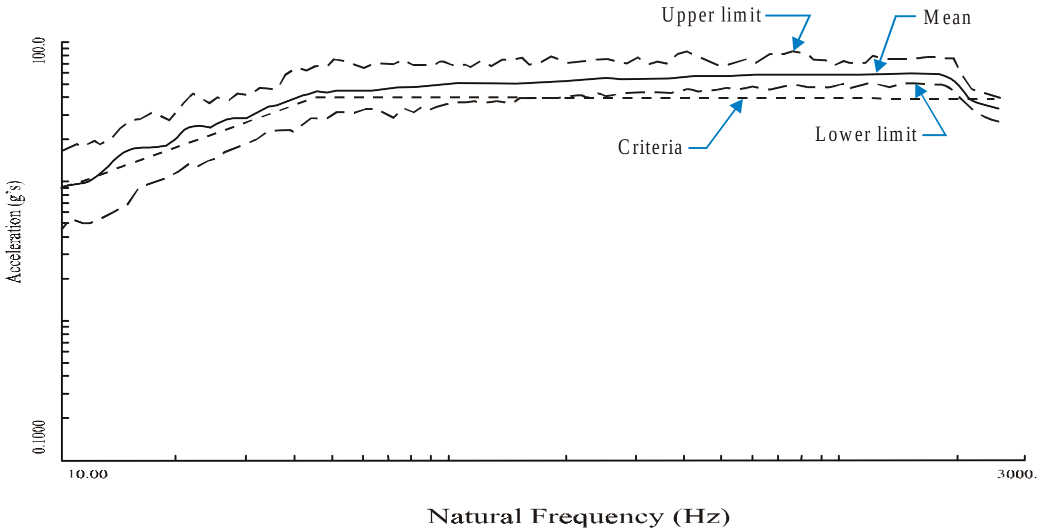

FIGURE 516.5C-2a. SRS comparison for functional test for ground materiel.

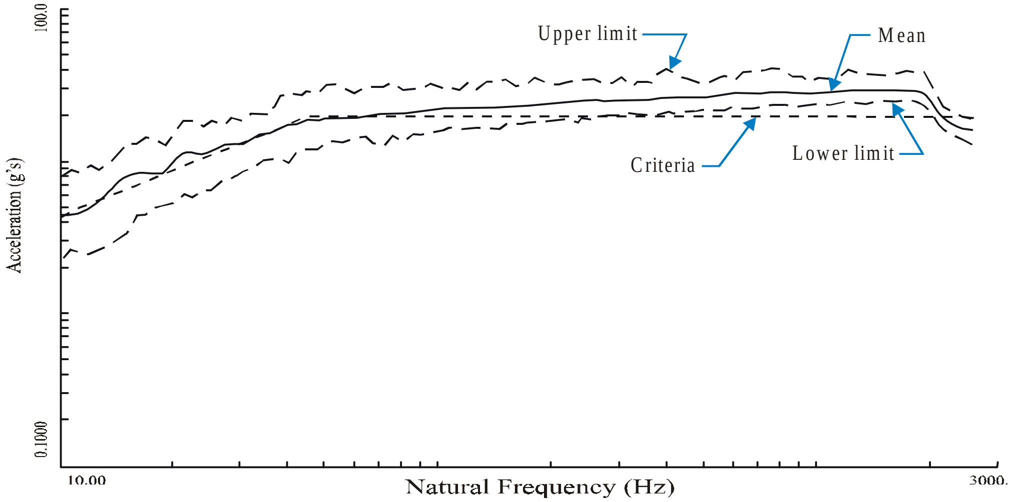

FIGURE 516.5C-2b. SRS comparison for functional test for flight materiel.

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