METHOD 516.8

SHOCK

> **NOTE:** Tailoring is essential. Select methods, procedures, and parameter levels based on the tailoring process described in Part One, paragraph 4.2.2, and its Annex C. Apply the general guidelines for laboratory test methods described in Part One, paragraph 5 of this Standard.

Due to extensive revision to this method, no change bars have been provided.

1. SCOPE.

1.1 Purpose.

Shock tests are performed to:

a. Provide a degree of confidence that materiel can physically and functionally withstand the 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, stowage, or mounting configurations may be designed to protect the materiel's physical and functional integrity.

c. Test the strength of devices that attach materiel to platforms that may be involved in a crash situation and verify that the material itself does not create a hazard or that parts of the materiel are not ejected during a crash situation.

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 duration of not more than 1.0 second. (In most cases of mechanical shock, the significant materiel response frequencies will not exceed 4,000 Hz, and the duration of materiel response will not exceed 0.1 second.)

1.3 Limitations.

This method does not include:

a. The effects of shock experienced by materiel as a result of pyrotechnic device initiation. For this type of shock, see Method 517.3, Pyroshock.

b. The effects experienced by materiel to very high level localized impact shocks, e.g., ballistic impacts. For this type of shock, see Method 522.2, Ballistic Shock.

c. The high impact shock effects experienced by materiel aboard a ship due to wartime service. Consider performing shock tests for shipboard materiel in accordance with MIL-DTL-901 (paragraph 6.1, reference c).

d. The effects experienced by fuse systems. Perform shock tests for safety and operation of fuses and fuse components in accordance with MIL-STD-331 (paragraph 6.1, reference d).

e. 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, see Method 519.8, Gunfire Shock.

f. 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, devise specialized tests based on analytical models and/or experimental measurement data.

g. Special provisions for performing combined mechanical/climatic environment tests (e.g. shock tests at high or low temperatures). Guidelines found in the climatic test methods may be helpful in setting up and performing combined environment tests.

h. Shocks integrated with transient vibration that are better replicated under Time Waveform Replication (TWR) methodology. See Method 525.2.

i. Guidance on equivalence techniques for comparison of shock and vibration environments. Method 516, Annex C (Autospectral Density with Equivalent Test Shock Response Spectra) that was in previous revisions of MIL-STD-810 has been removed.

j. Repetitive shocks associated with unrestrained cargo in ground transport vehicles that may be best replicated under loose cargo transportation methodology. See Method 514.8, Procedure II.

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 damage potential is a function of the amplitude, velocity, and the duration of the shock. Shocks with frequency content that correspond with materiel natural frequencies will magnify the adverse effects on the materiel's overall physical and functional integrity.

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 (for high velocity impact shock, e.g., penetration shocks, there may be significantly less or no oscillatory behavior with substantial area under the acceleration response curve). 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 of a transient nature imposed on the materiel from the external excitation environment, and (2) the materiel's resonant natural frequencies either during or after application of the external excitation environment. 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.

f. Accelerated fatiguing of materials (low cycle fatigue).

g. Potential piezoelectric activity of materials.

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

2.1.2 Sequence Among Other Methods.

a. <u>General.</u> Use the anticipated life cycle sequence of events as a general sequence guide (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 with the following additional guidelines:

(1) If the shock environment is deemed particularly severe, and the chances of materiel survival without structural or operational 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.

(2) If the shock environment is deemed severe, but the chance 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 mechanical and thermal failures.

(3) 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.

Table 516.8-I summarizes the eight test procedures covered in the Method with respect to the applicable configurations and operation states of the unit under test.

Table 516.8-I. Shock Test Procedures and Configurations Summary.

Procedure	Description	Packaged	Unpackaged	Operational	Non-Operational
I	Functional Shock		X	X	
II	Transportation Shock	X	X		X
III	Fragility		X		X
IV	Transit Drop	X	X		X
V	Crash Hazard Shock		X		
VI	Bench Handling		X		X
VII	Pendulum Impact	X			X
VIII	Catapult Launch/Arrested Landing		X	X	X

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 are based on single shock events that result from momentum exchange between materiel or materiel support structures and another body. Procedure VIII (Catapult Launch/Arrested Landing) contains a sequence of two shocks separated by a comparatively short duration transient vibration for catapult launch, and a single shock for arrested landing.

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.

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 and after the shock, and to survive without damage resulting from shocks representative of those that may be encountered during operational service.

b. Procedure II - Transportation Shock. Procedure II is used to evaluate the response of an item or restraint system to transportation environments that create a repetitive shock load. The procedure uses a classical terminal peak sawtooth, either measured or a synthetic shock waveform, to represent the shock excitation portion of the transportation scenario. The shock can be a repetitive event of similar amplitude, or an irregular event that varies in amplitude and frequency bandwidth. Ground vehicle transportation is a common source for transportation shock. Procedure II is not equivalent or a substitute for Method 514.8, Secured Cargo Vibration or Category 5, Loose Cargo, or other Method 516.8 shock test procedures.

c. Procedure III - Fragility. Procedure III is used early in the item development program to determine the materiel's fragility level, in order that packaging, stowage, or mounting configurations may be designed to protect the materiel's physical and functional integrity. This procedure is used to determine the critical shock conditions at which there is chance of structural and/or operational system degradation based upon a systematic increase in shock input magnitudes. To achieve the most realistic criteria, perform the procedure at environmental temperature extremes.

d. Procedure IV - Transit Drop. Procedure IV is a physical drop test, and 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 bulk cargo shipping containers (ISO, CONEX, etc.). See Procedure II (Transportation Shock), and Procedure VII (Pendulum Impact).

e. Procedure V - Crash Hazard Shock Test. 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. Use this test to verify the overall structural integrity of the materiel, i.e., parts of the materiel are not ejected during the shock. In some instances, the crash hazard can be evaluated by a static acceleration test (Method 513.8, Procedure III, or a transient shock (Method 516.8, Procedure V)). The requirement for one or both procedures must be evaluated based on the test item.

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 such environments. This procedure is appropriate for materiel out of its transit or combination case. 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 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.

g. Procedure VII – Pendulum Impact. Procedure VII is intended to test the ability of large shipping containers to resist horizontal impacts, and to determine the ability of the packaging and packing methods to provide protection to the contents when the container is impacted. This test is meant to simulate accidental handling impacts, and is used only on containers that are susceptible to accidental end impacts. The pendulum impact test is designed specifically for large and/or heavy shipping containers that are likely to be handled mechanically rather than manually.

NOTE: The rail impact test, formerly Procedure VII, has been moved to Method 526.2.

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

2.3 Determine Test Levels and Conditions.

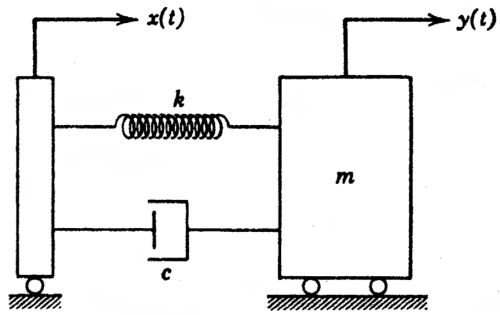
Having selected this Method and relevant procedures (based on the materiel's requirements documents and the tailoring process), complete the tailoring process by identifying appropriate parameter levels, applicable test conditions, and test techniques for the selected procedures. Base these selections on the requirements documents, the Life Cycle Environmental Profile (LCEP), and information provided with the appropriate procedure. Many laboratory shock tests are conducted under standard ambient test conditions as discussed in Part One, paragraph 5. However, when the life cycle events being simulated occur in environmental conditions significantly different than standard ambient conditions, consider applying those environmental factors during shock testing. Individual climatic test procedures of this Standard include guidance for determining levels of other environmental loads. For temperature-conditioned environmental tests, (high temperature tests of explosive or energetic materials in particular), consider the materiel degradation due to extreme climatic exposure to ensure the total test program climatic exposure does not exceed the life of the materiel. (See Part One, paragraph 5.19.). Consider the following when selecting test levels:

2.3.1 General Considerations - Terminology and Processing Procedures with Illustration.

Much of the core terminology associated with shock testing is addressed in the following topics: (1) the ***shock model***, (2) laboratory shock test options including tailoring when measured data are available, (3) single shock event characterization (in particular the crucial issue of shock duration with detailed additional information supplied in Annex A), (4) procedures for single shock event with multiple channel measurement processing for laboratory tests, (5) reference to statistical and probabilistic summary information for multiple shock events over possible multiple related measurements provided in Annex C, and (6) references to more advanced analysis techniques for characterizing a shock environment and its effects on materiel. Information in Annex C is crucial for processing measured data and test specification development.

2.3.1.1 The Shock Model.

This paragraph is essential to understanding the nature of the shock environment applied to materiel. The ***shock model*** represents materiel with a shock input defined by a comparatively short time and a moderately high-level impulse. The duration of the input is usually much less than the period of the fundamental frequency of the mounted materiel, and the amplitude of the input is above peaks of extreme materiel vibration response levels. Generally, the impulse input is distributed to the materiel surface or body directly or, more commonly, to the materiel through its mounts to a primary structure. It is difficult to directly measure such an impulse in time versus magnitude. When the impulse is applied to the materiel through its mounting points to a structure, a simple base-excited single-degree-of-freedom (SDOF) linear system can serve as a shock model for the materiel at a single resonant frequency of the materiel. Figure 516.8-1 displays such a system with the mass representing the materiel, and the combination spring/damper representing the path that supplies the impulse to the materiel. This model is used to define the Shock Response Spectra (SRS) considered throughout the subparagraphs of 2.3.1 and Annex A. Figure 516.8-1 displays the second order differential equations of motion that justify base input impulse specified as displacement/velocity. The solution can be in terms of absolute mass motion acceleration, or in terms of relative motion between the base and the mass. For an assumed base input acceleration measurement, the second-order differential equation of motion is "solved" by filtering the shock acceleration using a series of SDOF systems based upon a ramp-invariant digital filter algorithm (paragraph 6.1, reference i). The SRS is provided by a plot of natural frequency (undamped SDOF natural frequency) versus specified mass response amplitude, and is obtained as the output of the SDOF bandpass filters when the transient shock time history acceleration serves as the input to the base. Materiel response acceleration, (usually measured at a materiel mount location or, less preferably, at a materiel subcomponent with potential for local resonant response), will generally be the variable used in characterization of the effects of the shock. This does not preclude other variables of materiel response such as velocity, displacement, or strain from being used and processed in an analogous manner, as long as the interpretation of the measurement variable is clear, and the measurement/signal conditioning configuration is valid, e.g., measurements made within the significant frequency range of materiel response, etc. If, for example, base input velocity is obtained from measurement, all relative and absolute quantities will be transformed from those based upon base input acceleration (see Annex A). It can be established that stress within materiel at a particular location is proportional to the velocity of the materiel at that same location (paragraph 6.1, references e and f). For the SDOF model, this implies that stress within the materiel is proportional to the relative velocity between the base and the mass, and not the absolute velocity of the mass. Annex A discusses the modeling of SDOF systems in more detail, and places emphasis on the fact that materiel with many resonant modes can often be thought of in terms of a series of independent SDOF systems as defined at the resonant frequencies of the materiel.



Base Input SDOF Differential Equation of Motion:

For $x(t)$ base input motion coordinate and $y(t)$ mass absolute motion coordinate

$$m\ddot{y}(t) + c\dot{y}(t) + ky(t) = kx(t) + c\dot{x}(t)$$

where for

$$m\ddot{y}(t) + c\left[\dot{y}(t) - \dot{x}(t)\right] + k\left[y(t) - x(t)\right] = 0$$

with

$$F_m(t) + F_c(t) + F_k(t) = 0$$

for

$F_m(t)$ = inertial force on mass m

$F_c(t)$ = viscous damping force related to viscous damping coefficient c

$F_k(t)$ = linear spring force related to linear spring stiffness coefficient k

If

$$z(t) = y(t) - x(t)$$

then

$$m\ddot{z}(t) + c\dot{z}(t) + kz(t) = -m\ddot{x}(t)$$

or

$$\ddot{z}(t) + (c/m)\dot{z}(t) + (k/m)z(t) = -\ddot{x}(t)$$

Figure 516.8-1. Base input SDOF system model for shock considerations.

2.3.1.2 Laboratory Shock Test Options.

The following paragraphs address the various options for conduct of laboratory shock tests. Consideration will be discussed regarding availability of field data.

2.3.1.2.1 Summary.

For any configured materiel, ideally there exist "representative" field measurements of shock to which the materiel might be exposed during its life according to the LCEP. The eight procedures in this Method generally describe the scenarios in which field shock to materiel may occur. The procedures go beyond scenarios, and suggest default drop, default pulses, and/or default SRSs for applying laboratory shock. These "defaults" may have originated from field measurement data on some generic materiel in a particular configuration that were summarized and documented at one time, but this documentation no longer exists. Such lack of documentation leaves this Method with some procedures that are based upon the best laboratory test information currently available. The reality is that obtaining accurate item specific field measurements can be difficult, cost prohibitive, or not possible to acquire in a timely manner. However, to the maximum extent possible, tests based on measured data are the recommended option before use of the provided default test criteria.

> **NOTE**: For materiel design and development, the option of tailoring of a laboratory shock test ***from field measurement information*** is superior to any of the test procedures within this Method, and should be the first laboratory test option. This assumes that the measurement data bandwidth and the laboratory test bandwidths are strictly compatible.

2.3.1.2.2 Test Implementation Options.

Table 516.8-II summarizes the options for the eight laboratory test procedures. The options are defined as follows:

a. "TWR" (Time Waveform Replication), means that the measurement time history will be reproduced on the laboratory exciter with "minimal amplitude time history error" according to Method 525.2 Typically implemented using special shock package software for replication.

b. "Drop" is an explicit free fall drop event.

c. "Classical Pulse" refers to classical pulses to be used in testing. Classical pulses defined within this method are the terminal peak sawtooth, trapezoidal and half-sine pulses. This category is generally employed when suitable field measurement information is unavailable, and traditional testing is relied upon.

d. "SRS" refers to cases in which an SRS is used for the test specification, and exciter shock is synthesized based upon amplitude modulated sine waves or damped sinusoids. This category may be based on the SRS equivalent of a classical pulse to reduce adverse effects associated with conducting classical shock testing on a shaker, or may be defined based upon an ensemble of measured field data. The application notes in Annex A paragraph A.1.3 are important for defining the appropriate duration for the synthesized SRS pulse.

From Table 516.8-II, it is clear that the test procedures are divided according to use of TWR, drop test procedures, classical pulses, or synthesized waveforms from SRS. TWR is considered the most realistic as it is based upon direct replication of field measured data. Software vendors have generally incorporated an option for TWR within their "shock package," so that it is unnecessary to plan testing under specialized TWR software as called out in Methods 525.2 and 527.2, however, both of these Methods provide insight into tolerance and scaling related to a more general TWR methodology.

Table 516.8-II. Laboratory Test Options.

Procedure		Test Methodology					
		Drop[1]	Classical Pulse			SRS	TWR
			Half-Sine[2]	Trapezoidal	TP Sawtooth		
I	Functional Shock		X		X	X	X
II	Transportation Shock				X	X	X
III	Fragility			X		X	
IV	Transit Drop	X					
V	Crash Hazard Shock[3]				X	X	X
VI	Bench Handling	X					
VII	Pendulum Impact[4]	X					
VIII	Catapult Launch/ Arrested Landing[5]						X

Note 1. *The Drop test includes vertical free fall towers, impact machines, and other test methods with similar equipment.*

Note 2. *High Speed Craft is a special case of Functional Shock that is specified in terms of classical half-sine.*

Note 3. *In some cases the Crash Hazard Shock may be evaluated by a constant acceleration, see paragraph 2.2.2e.*

Note 4. *Pendulum Impact is a test item with horizontal motion that impacts a stationary barrier.*

Note 5. *A Catapult Launch/Arrested Landing test can be based on a measured waveform or a two second damped (Q=20) sine burst of required amplitude and frequency, see the test procedure.*

2.3.1.2.3 Tailoring When Measured Data Are Available - General Discussion.

Since test tailoring to field measured data is considered a superior technique for shock testing, information and guidelines in this and subsequent paragraphs are very important. Beyond the classical pulse, two techniques of shock replication in the laboratory are possible.

a. The first technique takes a measurement shock, and conditions it for direct waveform replication on the laboratory exciter. Conditioning may consist of bandwidth limiting via lowpass, highpass, or bandpass filtering, and re-sampling into an ASCII or other general file format. Vendor packages may have this capability within the "shock package" or in a special "Time Waveform Replication (TWR) package".

b. The second technique takes a measurement shock, computes an SRS estimate, and subsequently uses this SRS estimate to synthesize a representative time domain reference using a "wavelet" or a damped sine-based synthesis approach. In order to maintain a reasonable correlation between the effective pulse durations in the field measured and laboratory synthesized signals, in addition to the SRS reference to be synthesized, the test operator will require knowledge of the basic temporal characteristics of the time domain signal(s) from which the reference SRS is computed. More on this subject follows in Annex A Paragraph 1.3.

In summary, when test tailoring based upon available field measured data is employed, there are basically two laboratory test options available (assuming that repetition of the laboratory shock is under the guidance of the LCEP). Depending on the conditions of the test in which the data was acquired and the intended use for the data, the typical application of TWR or SRS test methods are described below.

a. TWR.

(1) Measured shock is a single shock field measurement or highly repeatable multiple shock field measurement.

(2) Complex shocks.

(3) Adequate measurement or ability to predict time histories at relevant locations in order to have adequate information at mounting locations of the test article.

(4) Examples of such measurements are catapult launches, aircraft landing, and gunfire loads.

NOTE: The bandwidth of the measurement shock and the ability of the laboratory exciter system to "replicate the bandwidth" is an important consideration under TWR. TWR input time histories may be band-limited, and yet the materiel response may have broader bandwidth as a result of mounting. This area has not been studied to any extent, and can be a function of the materiel and its mounting. Time history bandwidths that exceed the laboratory exciter bandwidth place a rather severe limitation on use of TWR for laboratory testing.

b. SRS.

(1) Single or multiple shock measurements where SRS values fit to a statistical distribution. Confirmation of statistical trend must be made.

(2) Sensor placement is sparse relative to the area in which it is to characterize.

(3) The shock load is known to have a statistically high variance.

(4) An example of SRS preference would be the shock assigned to a ground vehicle's hull as a function of multiple terrains.

Scaling for conservatism is ill-defined, but may be applied at the discretion of the analyst.

NOTE: SRS synthesis requires not only the SRS estimate, but (1) a general amplitude correspondence with field measured or a predicted pulse, and (2) an estimate of the field measured or predicted pulse duration. In general, synthesis is applicable only for "simple shocks" (see Annex A paragraphs 1.2-1.3) with high frequency information very near the peak amplitude, i.e., for shocks whose rms duration is short. By the nature of the composition of the synthesized shock (i.e., damped sinusoids or "wavelets"), it is possible to inappropriately extend the duration of a time history that matches a given SRS to an indefinitely long time. Note also that when measurement data are available, certain shocks, in particular "complex shocks" (see Annex B), may only be adequately applied under TWR.

2.3.2 Test Conditions.

When defining shock test levels and conditions, every attempt needs to be made to obtain measured data under conditions similar to service environment conditions in the Life Cycle Environmental Profile. Consider the following test execution ranking from the most desirable to the least desirable as follows:

a. TWR: Measured time histories summarized, and laboratory exciter shock created by way of direct reproduction of one or more selected time histories under exciter waveform control (see Method 525).

b. SRS based on Measured Data: Measured time histories summarized in the form of an SRS and laboratory exciter shock synthesized by way of a complex transient making sure that effective shock durations (T_e and T_E) for the test pulse are consistent with the measured data and the character of the synthesized waveform is "similar" to the measured time histories with respect to amplitude and zero crossings (see Annex A Paragraph 1.3 for a discussion and example of effective shock durations).

c. SRS in the absence of Measured Data: No measured time histories but previous SRS estimates available, and laboratory exciter shock synthesized by way of a complex transient such that effective shock durations (T_e and T_E) are specified taking into consideration the nature of the environment and the natural frequency response characteristics of the materiel (see Annex A Paragraphs 1.3 and 1.4).

d. Classical Shock Pulse: No measured time histories, but classical pulse shock descriptions available for use in reproducing the laboratory exciter shock (see Paragraph 2.3.2.3).

2.3.2.1 SRS Based on Measured Data

When measured data is available, the SRS required for the test will be determined from analytical computations. T_e and T_E required for the test will be determined from statistical processing of time history measurements of the materiel's environment (see Annex A, Paragraph 1.3). Unless otherwise specified, 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 to span a minimum bandwidth of 5 Hz to 2,000 Hz.

a. When a sufficient number of representative shock spectra are available, employ an appropriate statistical enveloping technique to determine the required test spectrum with a statistical basis (see Annex C of this Method).

b. When insufficient measured time histories are available for statistical analysis (only one or two time histories of like character), use an increase over the maximum of the available SRS spectra to establish the required test spectrum (if two spectra are available, determine a maximum envelope according to the ENV procedure of Annex C). The resulting spectra should account for stochastic variability in the environment, and uncertainty in any predictive methods employed. The degree of increase over measured time history spectra is based on engineering judgment, and should be supported by rationale. In these cases, it is often convenient to add either a 3 dB or 6 dB margin to the enveloped SRS, depending on the degree of test level conservatism desired (see Annex C, paragraph 4.2). Effective durations T_e and T_E for test should be taken as the respective maximums as computed from each of the measured time histories.

2.3.2.2 SRS in the Absence of Measured Data

If measured data is not available, the SRS and the corresponding values of T_e and T_E may be derived from (1) a carefully scaled measurement of a dynamically similar environment, (2) structural analysis or other prediction methods, or (3) from a combination of sources. For Procedure I (Functional Shock with Terminal Peak Sawtooth Reference Criteria), and Procedure V (Crash Hazard Shock), employ the applicable SRS spectrum from Figure 516.8-2 as the test spectrum for each axis, provided T_e and T_E of the test shock time history is in compliance with the accompanying Table 516.8-III. This spectrum approximates that of the perfect terminal-peak sawtooth pulse. General guidance for selecting the crossover frequency, F_{co}, for any classical pulse is to define it as the lowest frequency at which the corresponding SRS magnitude reaches the convergence magnitude (the constant magnitude reached in the high frequency portion of the SRS) for the damping ratio of interest. Once F_{co} is defined, the effective duration considered in the complex pulse synthesis is then defined as $T_E \leq 2/F_{co}$. This guidance allows for a longer effective duration than previous versions of this standard that were found to be too restrictive. Refer to Annex A paragraph 1.3 for additional guidance on customizing the bandwidth of the SRS and corresponding values of T_e and T_E as required.

It is recommend that the test be performed with a waveform that is synthesized from either (1) a superposition of damped sinusoids with selected properties at designated frequencies, or (2) a superposition of various amplitude modulated sine waves with selected properties at designated frequencies, such that this waveform has an SRS that approximates the SRS on Figure 2. In reality, any complex test transient with major energy in the initial portion of the time trace is suitable if it is within tolerance of this spectrum requirement over the minimum frequency range of 10 to 2000 Hz, and meets the duration requirements. Implementing a classical terminal-peak sawtooth pulse or trapezoidal pulse on a vibration exciter are the least permissible test alternatives. In the case in which a classical pulse is given as the reference criteria, it is permissible to synthesize a complex pulse based on the SRS characteristics of the referenced classical pulse. In such cases, T_e and T_E should be defined as in Table 516.8-III.

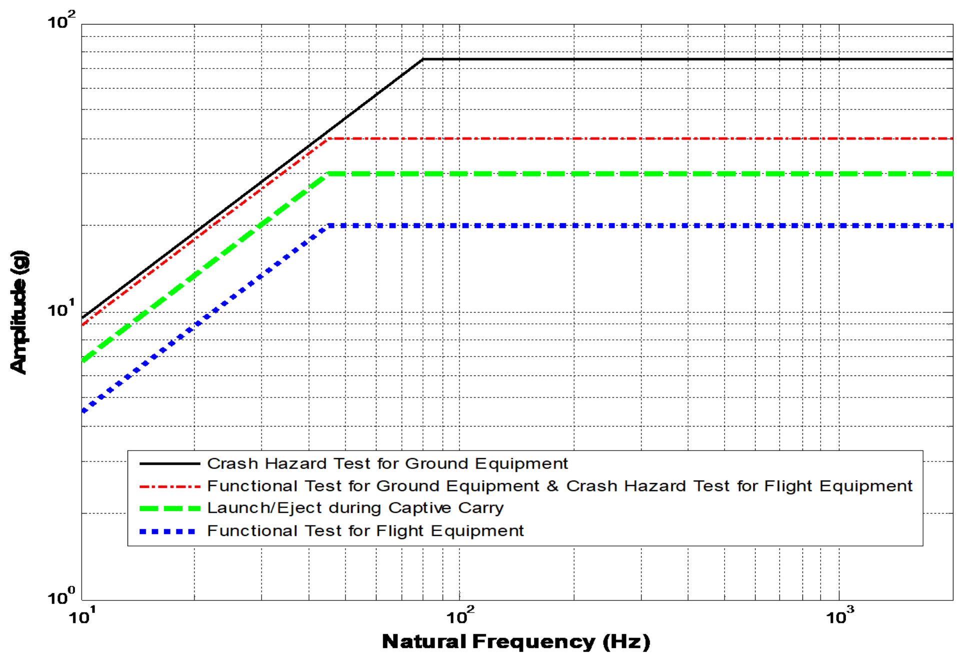


Figure 516.8-2. Test SRS for use if measured data are not available (for Procedure I - Functional Shock, and Procedure V - Crash Hazard Shock).

Table 516.8-III. Test shock response spectra for use if measured data are not available.

Test Category	Peak Acceleration (G-Pk)	T_e (ms)[1]	T_E (ms)[1]	Cross-over Frequency F_{co} (Hz)
Functional Test for Flight Equipment	20	$2.5/f_{min}$	$2/F_{co}$	45
Functional Test for Ground Equipment[2]	40	$2.5/f_{min}$	$2/F_{co}$	45
Launch/Eject During Captive Carry	30	$2.5/f_{min}$	$2/F_{co}$	45
Crash Hazard Shock Test for Flight Equipment	40	$2.5/f_{min}$	$2/F_{co}$	45
Crash Hazard Shock Test for Ground Equipment	75	$2.5/f_{min}$	$2/F_{co}$	80

Note 1: *The default value for f_{min} is 10 Hz as shown in Figure 516.8-2. Refer to guidance in paragraphs 4.2.2.2.c and 4.2.2.2.d to customize the bandwidth of the SRS and corresponding values of T_e and T_E.*

Note 2. *For materiel mounted only in trucks and semi-trailers, use a 20G peak value.*

2.3.2.3 Classical Shock Pulse

Classical shock pulses (e.g., half-sine, terminal peak sawtooth, or trapezoidal) may be defined by (1) time history measurements of the materiel's environment, (2) from a carefully scaled measurement of a dynamically similar environment, (3) from structural analysis or other prediction methods, or (4) from a combination of sources. The terminal peak sawtooth is often referenced due to its relatively flat spectral characteristics in the SRS domain as approximated in Figure 516.8-2. In the event that a-priori information regarding rise time of the transient event being considered is determined to be a critical parameter, consider a half-sine pulse or a trapezoidal pulse with a tailored rising edge in lieu of the terminal peak sawtooth. Shock pulse substitution (e.g., half-sine in lieu of terminal peak sawtooth) requires adjustment in the amplitude such that the velocity of the substituted shock pulse is equivalent to the original specification. The resulting over-test or under-test with respect to the difference in the SRS must be considered, documented, and approved by the appropriate testing authority. If a classical shock pulse is defined in lieu of more complex measured time history data it must be demonstrated that SRS estimates of the classical shock pulse are within the tolerances established for the SRS estimates of the measured time history data. In most cases, classical shock pulses will be defined as one of the following:

a. Terminal Peak Sawtooth Pulse: The terminal peak sawtooth pulse along with its parameters and tolerances are provided in Figure 516.8-3, and is an alternative for testing in Procedure I - Functional Shock, Procedure II - Transportation Shock and Procedure V - Crash Hazard Shock Test.

b. Trapezoidal Shock Pulse: The trapezoidal pulse along with its parameters and tolerances is provided in Figure 516.8-4. The trapezoidal pulse is specified for Procedure III - Fragility.

c. Half-Sine Shock Pulse: The half-sine pulse along with its parameters and tolerances is provided in Figure 516.8-5. The Half-Sine Pulse is specified for Procedure I – High Speed Craft Functional Shock. As discussed in paragraph 2.3.2.3.1, the half-sine pulse is often used in lieu of other classical pulses based upon equipment availability and or limitations.

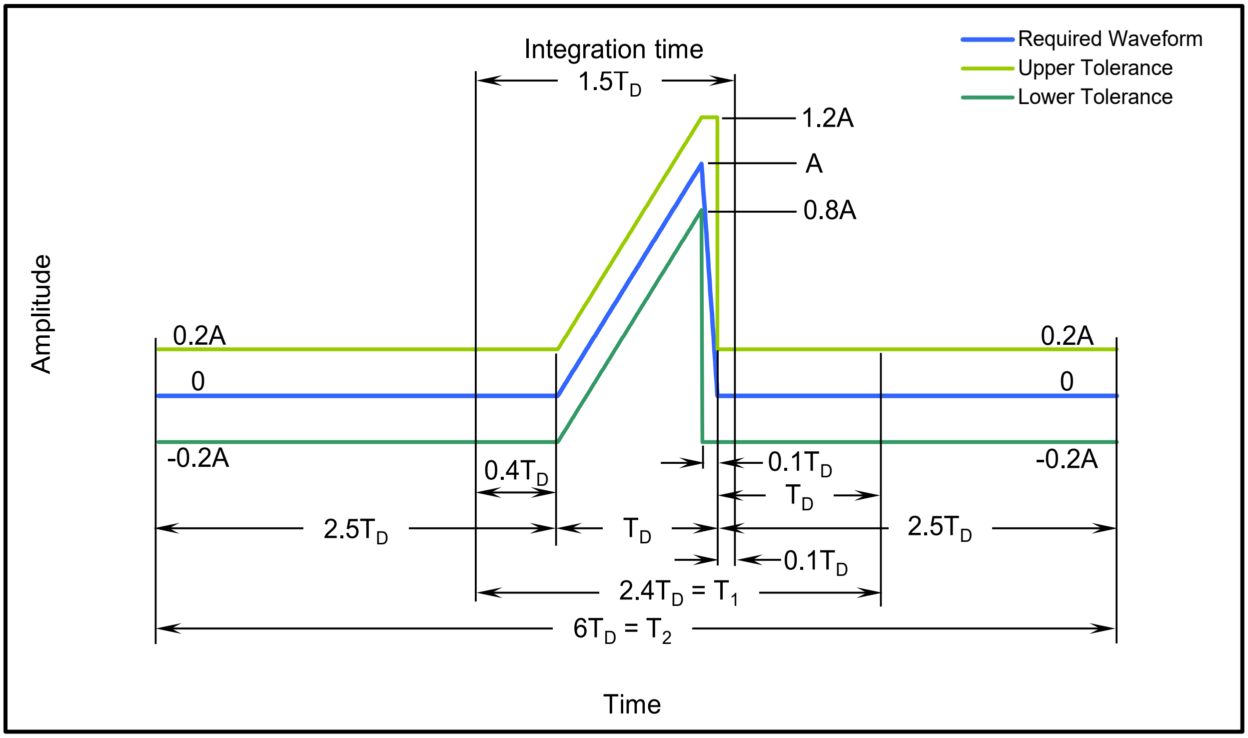


Figure 516.8-3. Terminal peak sawtooth shock pulse configuration and its tolerance limits.

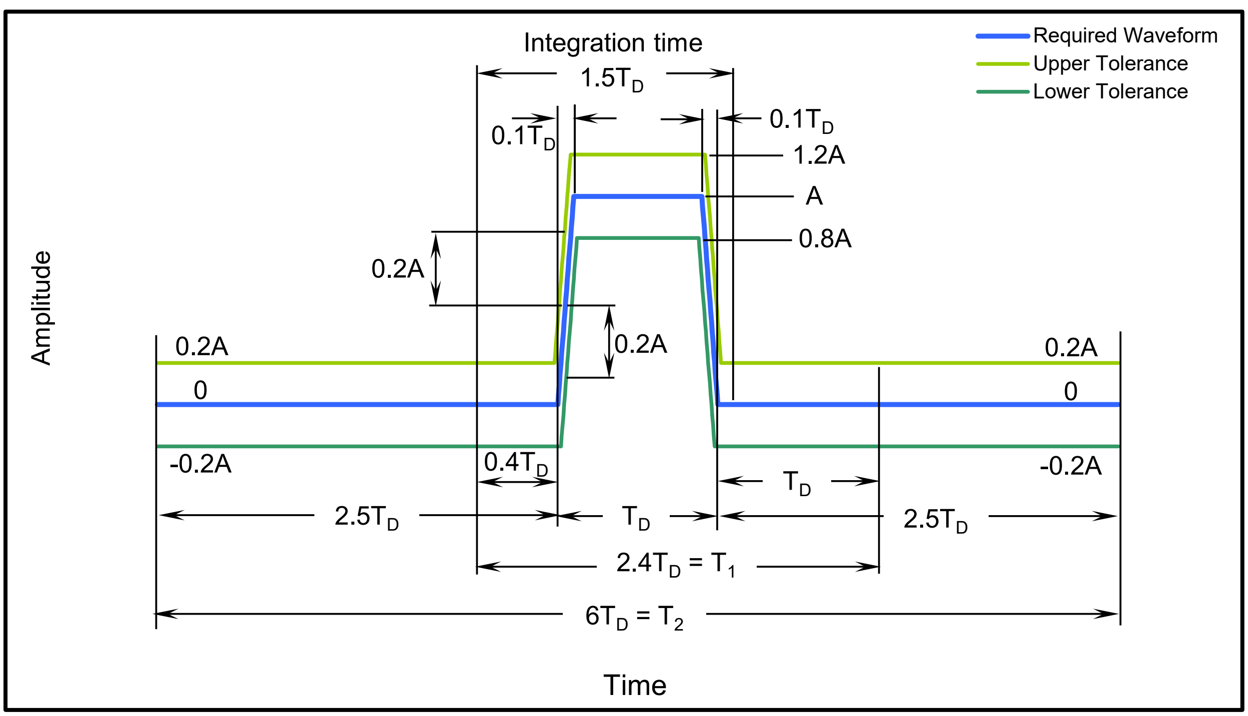


Figure 516.8-4. Trapezoidal shock pulse configuration and tolerance limits.

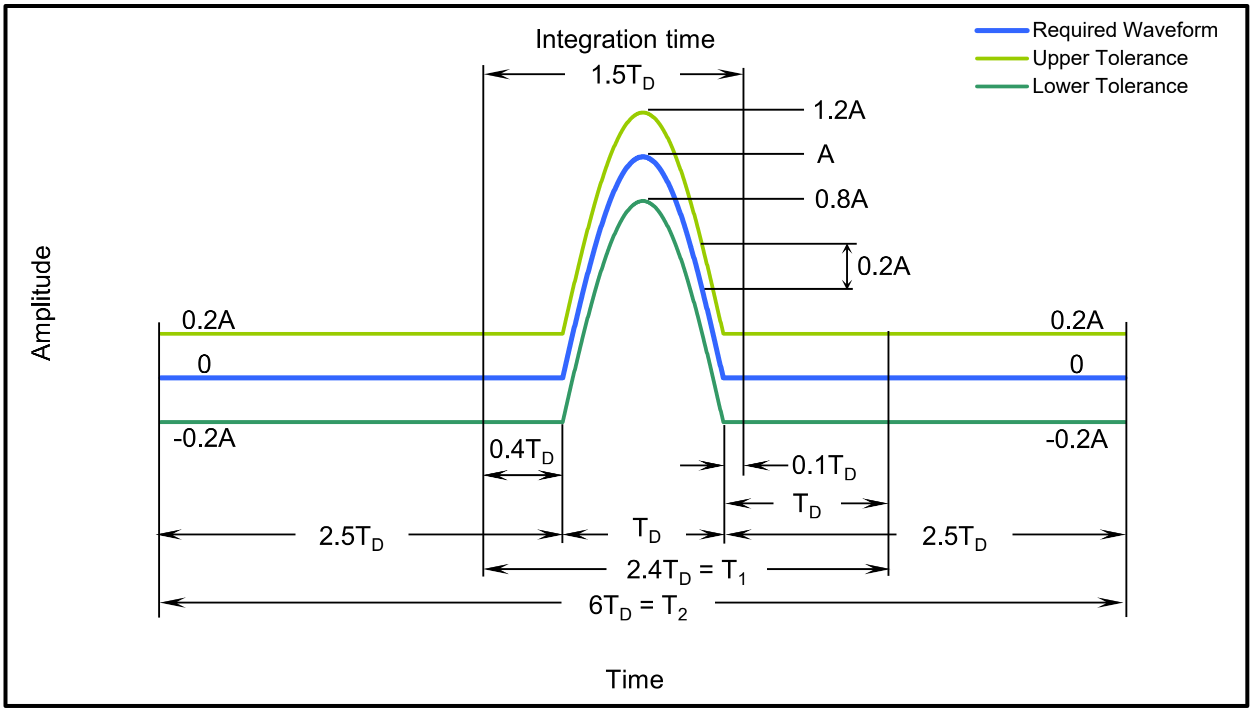


Figure 516.8-5. Half-Sine shock pulse configuration and tolerance limits.

Key to Figures 516.8-3 through 516.8-5:

T_D: duration of nominal pulse (tolerance on T_D is ± 10%).
A: peak acceleration of nominal pulse
T_1: minimum time duration which the pulse shall be monitored for shocks produced using a conventional mechanical shock machine.
T_2: minimum time during which the pulse shall be monitored for shocks produced using a vibration exciter.

The duration associated with the post-pulse slope of a terminal peak sawtooth and durations associated with the pre and post slopes of a trapezoidal pulse should be less than 10% T_D.

The tolerance on velocity, due to combined effects of any amplitude and/or duration deviations from the nominal pulse, is limited to +/- 20% of the pulse's nominal velocity.

2.3.2.3.1 Classical Shock Pulses (Mechanical Shock Machine).

It is recognized that conducting a terminal peak sawtooth or trapezoidal pulse on a mechanical shock machine requires the use of special programmers (e.g., lead or gas programmers) and requires higher impact velocity than equivalent half-sine shocks since the half-sine pulse contains significant rebound velocity that is not characteristic of the terminal peak sawtooth pulse. Such programmers or high velocity shock machines are not available in all laboratories. In such cases, it may be necessary to resort to the use of more readily available programmers used in the conduct of half-sine shock pulses. When substitution of shock pulses is necessary, follow the general guidance of maintaining equivalent velocity to that of the original reference pulse.

2.3.2.3.2 Classical Shock Pulses (Vibration Exciter).

If a vibration exciter is to be employed to conduct a test with a classical shock pulse, it will be necessary to optimize the reference pulse such that the net velocity and displacements are zero. Unfortunately, the need to compensate the reference pulse distorts the temporal and spectral characteristics, resulting in two specific problems that will be illustrated through example using a terminal peak sawtooth (the same argument is relevant for any classical pulse test to be conducted on a vibration exciter). First, any pre and/or post-pulse compensation will be limited by the ± 20 percent tolerances given in Figures 516.8-3 to 516.8-5. Second, as illustrated by the pseudo-velocity SRS in Figure 516.8-6, the velocities in the low frequency portion of the SRS will be significantly reduced in amplitude. Also, there is generally an area of increased amplitude associated with the duration of the pre- and post-test compensation. Observe that the low frequency drop-off in SRS levels between the compensated and uncompensated pulse is readily identifiable and labeled f_{low}. Likewise, the frequency at which the compensated and uncompensated pulses converge is readily identifiable and labeled f_{hi}. The drop-off at f_{low} is considered to be acceptable if and only if the lowest resonant frequency of the item being tested, f_1, is at least one octave greater than f_{low}. The amount of gain in the region $f_{low} \le f \le f_{hi}$ is directly related to the duration and magnitude of the compensation pulse and the percent of critical damping employed in the SRS computation (Q=10 in Figure 516.8-6). The potential for over-test in this spectral band must also be carefully considered prior to proceeding.

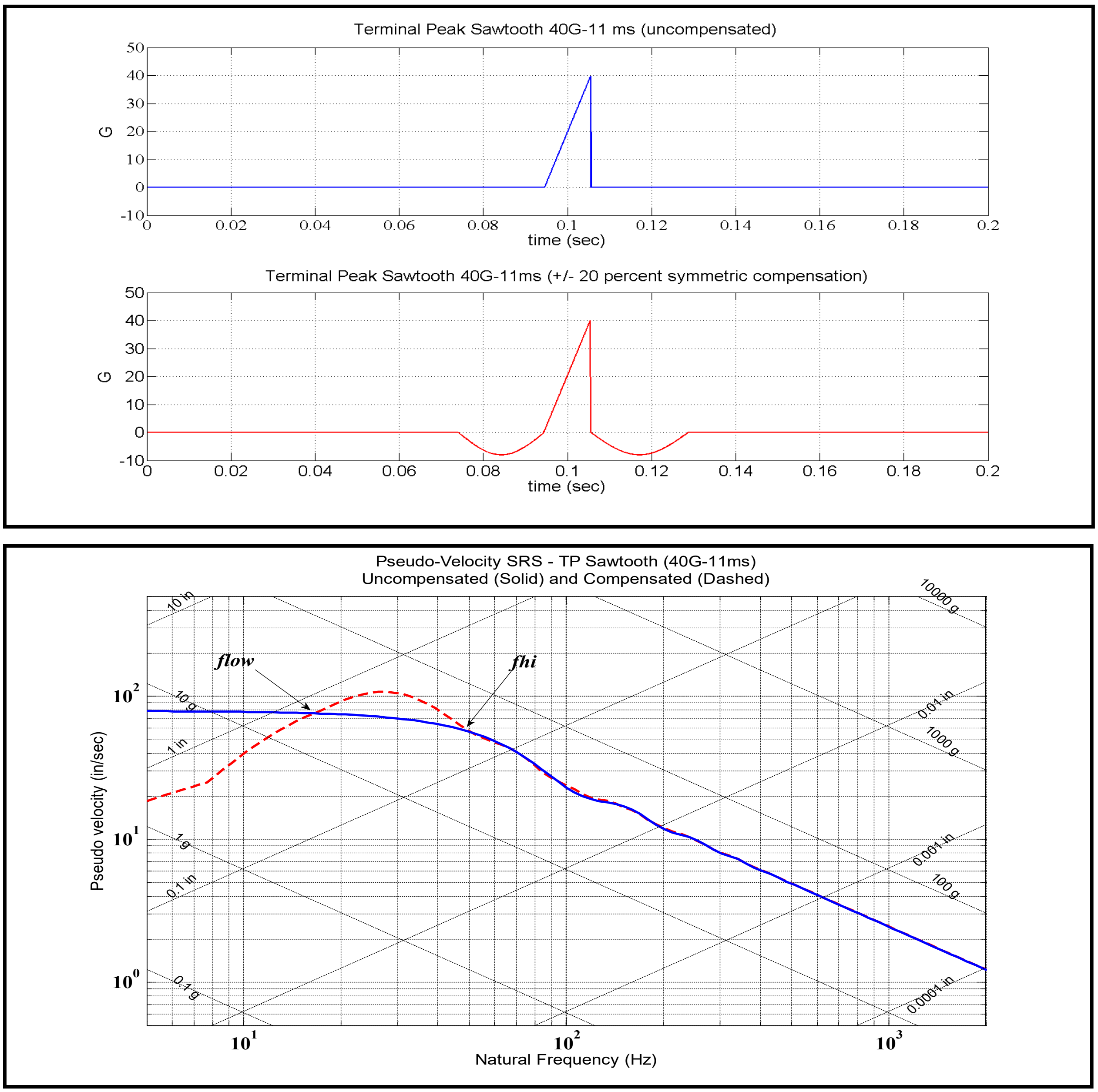


Figure 516.8-6. Illustration of temporal and spectral distortion associated with a compensated classical terminal peak sawtooth.

2.3.3 Test Axes and Number of Shock Events - General Considerations.

Generally, the laboratory test axes and the number of exposures to the shock events should be determined based upon the LCEP. However as a minimum requirement, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions 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 has an effective duration within the tolerance of T_E as defined in paragraph 4.2.2.2. In general, complex transient pulses generated by modern control systems will be symmetric and the maximax positive and negative SRS levels will be the same. However, this must be verified for each shock event by computing the spectra for positive and negative maximum (i.e., maximum and minimum) accelerations, 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 (i.e., symmetric pulse), one shock event will satisfy a single shock requirement for that axis in both directions. If the requirement can only be satisfied in one direction (e.g., polarity consideration for classical shock inputs, non-symmetric complex transient pulses), it is permissible to change the test setup and impose an additional shock to satisfy the spectrum requirement in the other direction. This may be accomplished by either reversing the polarity of the test shock time history or reversing the test item orientation. 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 a minimum of one shock in each direction of each axis. For shock conditions with a high potential of damage (e.g., large velocity change associated with the shock event, fragile test article), perform no more than one shock in each direction of each axis. Note that some high velocity shock tests with safety implications (i.e., crash hazard) may require two shocks in each direction of each axis.

b. For materiel likely to be exposed more frequently to a given shock event, and there are little available data to substantiate the number of shocks, apply a minimum of three shocks in each direction of each axis.

2.3.3.1 Special Considerations for Complex Transients.

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 percent longer than T_E, some compromise in spectrum or duration tolerance may be necessary. It is unacceptable to decompose an SRS into a low frequency component (high velocity and displacement), and a high frequency component (low velocity and displacement) 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. Refer to paragraphs 4.2.2.2.c and 4.2.2.2.d.

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 environmental 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 in Part One, Annex A, Task 405.

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.

(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.).

(c) The measured data that are input as a compensated waveform into an exciter/shock system under Time Waveform Replication (TWR). (See Method 525.2.)

(d) Specified test parameters for transit drop and fragility shock.

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

(5) Note all details of the test validation procedures.

c. Tailoring. Necessary variations in the basic test procedures to accommodate LCEP requirements and/or facility limitations.

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, Annex A, Task 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.

c. If measurement information is obtained during the test, examine the time histories and process according to procedures outlined in the test plan.

3.3 Post-Test.

The following information shall be included in the test report.

a. General. Information listed in Part One, paragraph. 5.13 of this Standard; and in Part One, Annex A, Task 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) All 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 and, if available, a mounted item/fixture modal analysis.

(5) Any deviation from the test plan or default severities (e.g., drop surface).

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, non-resilient rebound, hydraulic, compressed gas, electrodynamic exciter, servo-hydraulic exciter, or other capable configuration. 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, electrodynamic exciters can suitably reproduce synthesized shock records from 5 Hz to 2000 Hz or above; however, a servo-hydraulic exciter may have only a DC to 500 Hz controllable frequency range. Procedures II and III require test apparatus capable of producing relatively large displacement. Procedure VII is a special test setup in that large containers impact a rigid barrier. Procedure VIII for catapult launch is best satisfied by application of two shock pulses with an intervening "transient vibration" for which TWR Method 525.2 may be appropriate. Generally, shock on either electrodynamic or servo-hydraulic exciters will be controlled using classical shock, SRS shock, or time waveform replication control software.

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 may require use of a "calibration load" in the test setup. If the calibration load is required, it will generally 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 that satisfy the test conditions outlined in Procedures I, II, III, V, or VIII. 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 to guard against excessive over test or unproductive under test is highly recommended in all cases.

4.2.2 Tolerances.

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 cases, in which tolerances are established independently of the guidance provided below, establish these tolerances 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 in this Method, tolerance limits on the time domain representation of the pulses are as specified in Figures 516.8-3 through 516.8-5. If a classical shock pulse is defined in lieu of more complex measured time history data it must be demonstrated that SRS estimates of the classical shock pulse are within the tolerances established for the SRS estimates of the measured time history data. For complex transient pulses ***specified*** in the time domain, it is assumed that testing will be performed under TWR (Method 525.2), and that the tolerance guidance related to that Method will be used.

4.2.2.2 Complex Transient Pulses-SRS.

For a complex transient pulse specified by way of the maximax SRS, e.g., Figure 516.8-2, the frequency domain and time domain tolerances are specified in terms of a tolerance on the SRS amplitude values over a specified frequency bandwidth and a tolerance on the effective pulse duration. If a series of shocks are performed, all acceleration maximax SRS shall be computed at the center frequency of one-twelfth octave bands with a default damping quality factor Q of 10 (5 percent critical damping factor). Tolerances on the individual points (values associated with each one-twelfth octave center frequency) are to be within -1.5 dB and +3 dB over a minimum of 90 percent of the overall values in the frequency bandwidth from 10 Hz to 2000 Hz. For the remaining part of the frequency band, all SRS values are to be within -3 dB and +6 dB (this places a comparatively narrow tolerance on the major frequency band of interest, but allows a wider tolerance on 10 percent of this frequency band and a wider tolerance on the SRS above 2 KHz). Note that if an SRS is within tolerance for both SRS-minimum and SRS-maximums, the pulse is considered symmetric. While the reference criteria is often limited in bandwidth as a result of excitation equipment limitations, the analyst may require response data to be viewed through the bandwidth at which the SRS amplitude flattens. The duration of the complex transient is defined by T_e and T_E as discussed in Annex A paragraph 1.3 and shall have a tolerance of $0.8T_E \le T_E \le 1.2T_E$. 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.

a. 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. (For three-coordinate paper, the pseudo-velocity tolerance can be determined by placing tolerance bands along the SRS acceleration axis, and then extracting the tolerance values along the ordinate for the pseudo-velocity SRS tolerance.) Note that SRS estimates scale directly in amplitude, i.e., multiplication of the time history by a factor is translated directly into multiplication of the SRS estimate by the same factor.

b. The test tolerances are stated in terms of a single measurement tolerance, i.e., each individual laboratory test must fit within the tolerance bands to provide a satisfactory test. For an array of measurements defined in terms of a "zone" (paragraph 6.1, reference b), amplitude tolerance may be specified in terms of an average of the measurements within a "zone". However, this is, in effect, a relaxation of the single measurement tolerance in 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 1.5 dB. Any use of "zone" tolerances and averaging must have support documentation prepared by a trained analyst. The tolerance on the duration of the test pulse when more than one measurement is present, may be specified either as a percentage of the harmonic mean of the pulses (the nth root of the product of the n durations as defined by $T_{E\,j}$ for $j = 1, 2, ..., n$ i.e., $T_E = \sqrt[n]{\prod_{j=1}^{n} T_{E\,j}}$), or on some statistical based measure taking account of the variance of the effective durations. For example, a 95/50 two-sided normal tolerance limit will provide the upper and lower limits of duration for which it is expected that 95 percent of future measurements will fall with 50 percent confidence coefficient. 10 percent of the difference in these limits might be a reasonable duration tolerance. For further possible ways of statistically defining specification of duration tolerance see Annex C).

c. 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, f_1, of the mounted test item. Recall that $f_{\min}$ was defined to be one octave below f_1. The reference pulse synthesis should be conducted such that as much of the spectrum below $f_{\min}$ remains in tolerance as possible without exceeding the specified duration T_E.

d. If the test item has significant low frequency modal response, it is permissible to allow the duration of the complex transient pulse to fall outside of the T_E range (provided in Table 516.8-III), in order to satisfy the low frequency portion of the SRS. The effective duration contained in Table 516.8-III may be increased by as much as $1/(2f_{\min})$ in addition to T_E, (e.g., $T_E + 1/(2f_{\min})$), in order to have the low frequency portion of the SRS within tolerance. 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.

4.3 Test Interruption.

Test interruptions can result from two or more situations, one being from malfunction of the shock apparatus or associated laboratory test support equipment. The second type of test interruption results from malfunction of the test item itself during operational checks.

4.3.1 Interruption Due To Laboratory Equipment Malfunction.

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

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

4.3.2 Interruption Due To Test Item Operation Failure.

Failure of the test item(s) to function as required during operational checks presents a situation with several possible options.

a. The preferable option is to replace the test item with a "new" one and restart from Step 1.

b. A second option is to repair the failed or non-functioning component or assembly of the test item with one that functions as intended, and restart the entire test from Step 1.

> **NOTE**: When evaluating failure interruptions, consider prior testing on the same test item, and consequences of such.

4.4 Instrumentation.

In general, acceleration will be the quantity measured to meet a specification, with care taken to ensure acceleration measurements can be made that provide meaningful data. Always give special consideration to the measurement instrument amplitude and frequency range specifications in order to satisfy the calibration, measurement and analysis requirements. With regard to measurement technology, accelerometers, strain gages and laser Doppler vibrometers are commonly used devices for measurement. In processing shock data, it is important to be able to detect anomalies. For example, it is well documented that accelerometers may offset or zero-shift during mechanical shock, pyroshock, and ballistic shock (paragraph 6.1, references m, n, and s). Additional discussion on this topic is found in the pyro shock and ballistic shock methods. A part of this detection is the integration of the acceleration amplitude time history to determine if it has the characteristics of a physically realizable velocity trace. For mechanical shock various accelerometers are readily available which may or may not contain mechanical isolation. Transducer performance continues to improve with time, however, inventories across all laboratories may not be of the latest generation, and thereby making detailed calibrations critical in understanding individual transducer performance.

a. Accelerometers. Ensure the following:

(1) Amplitude Linearity: It is desired to have amplitude linearity within 10 percent over the entire operating range of the device. Since accelerometers (mechanically isolated or not) may show zero-shift (paragraph 6.1, reference o), there is risk in not characterizing these devices over their entire amplitude range. To address these possible zero-shifts, high pass filtering (or other data correction technique) may be required. Such additional post-test correction techniques increases the risk of distorting the measured shock environment. Consider the following in transducer selection:

(a) It is recognized that accelerometers may have both non-linear amplification and non-linear frequency content below 10,000 Hz (paragraph 6.1, reference o). In order to understand the non-linear amplification and frequency characteristics, it is recommended that shock linearity evaluations be conducted at intervals of 20 to 30 percent of the rated amplitude range (inclusive of the maximum rated range) of the accelerometer to identify the actual amplitude and frequency linearity characteristics and useable amplitude and frequency range. If a shock based calibration technique is employed, the shock pulse duration for the evaluation is calculated as:

$$T_D = \frac{1}{2 f_{\max}}$$

Where T_D is the duration (baseline) of the acceleration pulse and f_{max} is the maximum specified frequency range for the accelerometer. For mechanical shock, the default value for f_{max} is 10,000 Hz.

(b) For cases in which response below 2 Hz is desired, a piezoresistive accelerometer measurement is required.

(2) Frequency Response: A flat response within ± 5 percent across the frequency range of interest is required. Since it is generally not practical or cost effective to conduct a series of varying pulse width shock tests to characterize frequency response, a vibration calibration is typically employed. For the case of a high range accelerometer with low output, there may be SNR issues associated with a low level vibration calibration. In such cases a degree of engineering judgment will be required in the

evaluation of frequency response with a revised requirement for flat frequency response to be within ± 1 dB across the frequency range of interest.

(3) Accelerometer Sensitivity: The sensitivity of a shock accelerometer is expected to have some variance over its large amplitude dynamic range.

(a) If the sensitivity is based upon the low amplitude vibration calibration, it is critical that the linearity characteristics of the shock based "Amplitude Linearity" be understood such that an amplitude measurement uncertainty is clearly defined.

(b) Ideally, vibration calibration and shock amplitude linearity results should agree within 10 percent over the amplitude range of interest for a given test.

(4) Transverse sensitivity should be less than or equal to 7 percent.

(5) The measurement device and its mounting will be compatible with the requirements and guidelines provided in paragraph 6.1, reference a.

(6) Piezoelectric or piezoresistive accelerometers may be used for mechanical shock in scenarios in which levels are known to be within the established (verified through calibration) operating range of the transducer, thereby avoiding non-linear amplification and frequency content.

b. Other Measurement Devices.

(1) 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.

(2) Signal Conditioning. Use only signal conditioning that is compatible with the instrumentation requirements of the test, and is compatible with the requirements and guidelines provided in paragraph 6.1, reference a. In particular, filtering of the analog voltage signals will be consistent with the time history response requirements (in general, demonstrable linearity within ± 5º of phase throughout the desired 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. Never filter the signal into the amplifier for fear of filtering erroneous measurement data, and the inability to detect the erroneous measurement data. The signal from the signal conditioning must be anti-alias filtered before digitizing as defined in Annex A paragraph 1.1.

4.5 Data Analysis.

a. 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. Re-sampling for SRS computational error control is permitted using standard re-sampling algorithms.

b. Analysis procedures will be in accordance with those requirements and guidelines provided in paragraph 6.1, reference a. In particular, validate the shock acceleration amplitude time histories according to the procedures in paragraph 6.1, reference a. Use integration of time histories 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. For unique and highly valued measured data, a highly trained analyst may be consulted concerning the removal of certain anomalies but, generally, this will leave information that is biased by the technique for removal of the anomaly.

4.6 Test Execution.

4.6.1 Preparation for Test.

Test preparation details will be procedure specific as discussed in the previous paragraphs. Ensure that all test specific equipment such as fixturing, environmental conditioning equipment, instrumentation and acquisition equipment has been properly calibrated, validated and documented.

4.6.1.1 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, climatic conditions, and number of shocks to be applied, as well as the information in paragraph 3.1 above). Note all details of the test validation procedures.

4.6.1.2 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 (Part One, paragraph 5.1.a) 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.

4.6.1.3 Procedures' Overview.

Paragraphs 4.6.2 through 4.6.9 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 4.6.2 through 4.6.9. It is critical that any deviations to the test or test tolerances must be approved by the appropriate test authority and must be clearly documented in the test plan and final report.

4.6.2 Functional Shock (Procedure I).

The intent of this test is to disclose materiel malfunction that may result from shocks experienced by materiel during use in the field. Even though materiel may have 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 (for scaling guidance see Method 525.2). When measured field data are not available for tailoring, use the information in Figure 516.8-2 and the accompanying Table 516.8-III to define the shock test system input SRS or Tables 516.8-IV-VI for classical pulse definitions. 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 servo-hydraulic shock testing. In general, tests using classical pulses, e.g., terminal peak sawtooth, etc., are unacceptable unless it can be demonstrated during tailoring that the field shock environment time trace approximates such a form. If all other testing resources have been exhausted, it will be permissible to use the information on Table 516.8-IV-VI for employing a classical pulse. However, such testing must be performed in both a positive and negative direction to assure meeting the spectrum requirements on Figure 516.8-2 in both the positive and negative direction.

Table 516.8-IV. Terminal peak sawtooth default test parameters for Procedures I -Functional Test (refer to Figure 516.8-3).

Test	Reference Peak Value and Pulse Duration A_m (G-Pk) & T_D (ms)					
	Flight Vehicle Materiel[1]		Weapon Launch[1,2] Captive Carry		Ground Materiel[1,3]	
Procedure I - Functional	20 G	11 ms	30 G	11 ms	40 G	11 ms

Note 1. *For material that is shock mounted or weighing more than 136 kg (300 lbs), an 11 ms half-sine pulse of such amplitude that yields an equivalent velocity to the default terminal peak sawtooth may be employed. Equivalent Velocity Relationship:* $A_{m(halfsine)} = (\pi/4)A_{m(sawtooth)}$

Note 2. *Launch Shock is a special case of Functional Shock (see paragraph 6.1k)*

Note 3. *For materiel mounted only in trucks and semi-trailers, use a 20G peak value.*

A special category of functional shock has been established for Navy high speed craft (HSC). Tables 516.8-V and 516.8-VI document two functional standardized laboratory shock test requirements to mitigate the risk of equipment malfunction or failure of hard mounted electrical and electronics equipment in HSC due to wave impacts (reference paragraph 6.1, reference p). These test requirements are applicable for equipment with internal vibration mounts, but not applicable for equipment on shock mounts (paragraph 6.1, reference q) or for shock isolated seats (paragraph 6.1, reference r).

Two types of half-sine shock tests are required to minimize the risk of equipment malfunction or failure in HSC. The first test, (HSC-I), is to be repeated three times in each direction of the three mutually orthogonal axes. The second test, (HSC-II), employs a lower severity shock pulse which is to be repeated 800 times in each direction per axis with the nominal spacing between pulses set at 1-second intervals (in the event the previous transient has not completely decayed within the nominal 1-second, contact the proper test authority for further guidance).

HSC equipment orientation during testing should represent realistic conditions in which the equipment may experience wave impact shock. Dominant wave impact shock loads occur only in craft axes +Z (vertical up), -X (aft), and +/- Y (port/starboard). Equipment that can be installed in any orientation should be tested in positive and negative test orientations for all three equipment axes. The +X and –Z craft orientations should be omitted during Procedure I testing for equipment installed only in a vertical up orientation.

Table 516.8-V. High Speed Craft - Standardized Requirements[1] (refer to Figure 516.8-5).

Test[2]	Half-Sine Pulse	
	Amplitude	Duration
HSC-I	20 G	23 ms
HSC-II	5 G	23 ms

Note 1. *The half-sine classical pulse specified for HSC may not be substituted by an SRS equivalent complex pulse.*

Note 2. *For equipment mounted ONLY in the Z (vertical up) direction, with the exception of equipment mounted on a mast, arch, or cabin top, HSC-I X (negative aft) and +/-* Y (port/starboard)*axis amplitudes may be reduced to 10 G.*

For unique situations (e.g., high value or fragile components) where general cross platform use at any location is not anticipated, the 20 G HSC-I default amplitude may be modified as defined in Table 516.8-VI (the pulse duration will remain at 23 ms).

Table 516.8-VI: Limited Application Requirements by Craft Size[1]

Craft Size		Location		
Length (ft)	**Weight (Klbs)**	**Longitudinal Center of Gravity (LCG)**	**Coxswain**	**Bow**
65-85	105-160	10 G	15 G	20 G
40-70	35-70	10 G	15 G	15 G
35-40	14-25	15 G	15 G	20 G

Note 1. *The half-sine classical pulse specified for HSC may not be substituted by an SRS equivalent complex pulse.*

4.6.2.1 Test Controls - Functional Shock (Procedure I).

Table 516.8-IV provides general classical shock references for functional shock. Figure 516.8-2 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 durations, T_e and T_E, are defined in Annex A paragraph 1.3, and are specified in Table 516.8-III. Tables 516.8-V and VI provide classical shock defaults for the special case of HSC.

4.6.2.2 Test Tolerances - Functional Shock (Procedure I).

For complex transients from measured data, ensure test tolerances are consistent with the general guidelines provided in paragraph 4.2.2 with respect to the information provided in Table 516.8-III and accompanying Figure 516.8-2.

For classical pulse testing, the test tolerances are specified on Figures 516.8-3 thru 5 with respect to default information in Tables 516.8-IV-VI.

4.6.2.3 Test Procedure - Functional Shock (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 6.1, reference a.

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 4.6.2.2 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 operational check of the test item. If the test item operates satisfactorily, proceed to Step 3. If not, resolve the problems and repeat this step.

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

Step 4 Record necessary data to show the shock met or exceeded desired test levels within the specified tolerances in paragraph 4.6.2.2. 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 operational check of the test item. Record performance data. If the test item does not operate satisfactorily, follow the guidance in paragraph 4.3.2 for test item failure.

Step 6 Repeat Steps 2, 3, 4, and 5 two additional times if the SRS form of specification is used and the synthesized pulse is symmetric (yielding a total of three shocks in each orthogonal axis). If the SRS based time history is not symmetric, shock in both positive and negative polarities are required (yielding a total of six shocks in each orthogonal axis). If the classical shock form of specification is used, subject the test item to both a positive and a negative input pulse (a total of six shocks in each mutually orthogonal axis).

Step 7 Perform a post-test operational check on the test item. Record performance data, document the test sequence, and see paragraph 5 for analysis of results.

4.6.3 Transportation Shock (Procedure II).

The Transportation Shock test procedure is representative of the repetitive low amplitude shock loads that occur during logistical or tactical materiel transportation. Vibration testing excludes transient events, thus Procedure II functions with vibration testing to sequentially represent the loads that may occur. The default testing configuration is a packaged or unpackaged test item(s) in a non-operational configuration. The test procedure may also be applied to evaluate the influence of shock loading on a cargo restraint system, or an operational test item if required. The test plan should define the operational mode and testing in commercial manufacturer packaging, as fielded materiel, or a bare item that is secured or installed on the transport platform. A default classical terminal peak sawtooth shock test sequence is defined in Table 516.8-VII. Alternatively, the shock waveform applied can be tailored with measured data and implemented via shock replication techniques such as Method 525.2, Time Waveform Replication. Transportation shock tests can frequently be completed following a vibration test using an electrodynamic or servo-hydraulic test system, and the same test setup configuration.

Table 516.8-VII Procedure II - Transportation shock test sequence[1, 2, 3].

On Road (5000 km)[4] Terminal Peak Sawtooth Pulse Duration: 11 ms			**Off Road (1000 km)[4]** Terminal Peak Sawtooth Pulse Duration: 5 ms	
Amplitude (G-Pk)	Number of Shocks		Amplitude (G-Pk)	Number of Shocks
5.1	42		10.2	42
6.4	21		12.8	21
7.6	3		15.2	3

Note 1: *The shocks set out in Table 516.8-VII must always be carried out together with ground transportation vibration testing as specified in Method 514.8, Category 4 and/or Category 20.*

Note 2: *The above tabulated values may be considered for both restrained cargo and installed materiel on wheeled and tracked vehicles. Transportation shock associated with two-wheeled trailers may exceed off-road levels as defined.*

Note 3: *The shock test schedule set out in Table 516.8-VII can be undertaken using either terminal peak sawtooth pulses applied in each sense of each orthogonal axis, or a synthesis based on the corresponding SRS that encompasses both senses of each axis.*

Note 4: *The above number of shocks is equivalent to the following distances: a) On-road vehicles: 5000 km; b) Off-road vehicles: 1000 km. If greater distances are required, more shocks must be applied in multiples of the figures above.*

4.6.3.1 Test Controls - Transportation Shock (Procedure II).

Table 516.8-VII provides the transportation shock criteria for use when measured data are not available. The durations T_e and T_E for SRS based waveform synthesis are defined in Annex A Paragraph 1.3. Table 516.8-VII is representative of wheeled ground vehicles, but is not characteristic of specific vehicles or a transportation scenario. The default shock severities shown in Table 516.8-VII have application when the purpose of the test is to address scenarios in which damage is dependent upon multiple cycle events. The levels in Table 516.8-VII were derived from classical half-sine pulses defined in paragraph 6.1, reference h. The classical half-sine pulses were converted to terminal peak sawtooth with equivalent velocities. The terminal peak sawtooth was selected due to its relatively flat SRS characteristics above the roll-off frequency. In the event field data are available, tailor the test per the LCEP.

4.6.3.2 Test Tolerances - Transportation Shock (Procedure II).

For complex transients from measured data, ensure 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 516.8-3, with respect to the information provided in Table 516.8-VII, are satisfied.

4.6.3.3 Test Procedure - Transportation Shock (Procedure II).

Generally, either the primary road or the secondary/off road shock sequence is preformed, not both sequences. Complete testing at all applicable shock amplitudes in Table 516.6-VII for the number of shocks indicated, or as defined in the test plan. The lowest amplitude shock tests are typically performed first, followed by the higher amplitude tests. If testing is required in more than one axis, repeat the procedure below for each axis and sequence of shock amplitudes.

Step 1 Calibrate the test equipment as follows:

a. Mount the calibration load to the test equipment and fixture in a configuration similar to that of the actual test item. The test setup and fixture should prevent distortion of the shock waveform.

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

c. For electrodynamic test systems or other equipment with a stored drive signal, repeat the calibration to other required test amplitudes and store the drive signal. Allow sufficient time between shocks for the previous shock event to fully decay.

Step 2 Remove the calibration load and install the test item on the test equipment.

Step 3 Perform a pre-test inspection of the test item, and an operational test if required.

Step 4 Subject the test item to the shock test sequence, and perform intermediate inspections or checkouts as required between shock events. Allow sufficient time between shocks for the previous shock event to fully decay.

Step 5 If testing is required at a different amplitude, return to Step 3, or if the sequence is complete, proceed to Step 6.

Step 6 Perform a post-test inspection of the test item, and operational test if required. Document the results, including plots of response waveforms and any pre- or post-shock anomalies. See paragraph 5 for analysis of results.

4.6.4 Fragility (Procedure III).

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) 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 as defined by a single parameter, e.g., G-level or velocity change, and proceeding to increase the level of shock by increasing the single parameter value to the test item (base input model) 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.

It is important in performing a fragility test to recognize that "level of input" must correlate in some positive way with the potential for materiel degradation. It is well recognized that materiel stress is directly related to materiel velocity such as might occur during vibration/shock (see paragraph 6, references e and f) and, in particular, to change in materiel velocity denoted as ΔV. Pulse duration that relates to the fundamental mode of vibration of the materiel is a factor in materiel degradation. For a drop machine with a trapezoidal pulse program, there is a simple relationship between the three variables: pulse maximum amplitude A_m (G-pk), pulse velocity change ΔV [m/sec^2 (in/sec^2)], pulse duration T_D (seconds), and $g = 9.81 \text{m/s}^2$ $\left(386.09 \text{in}/\text{sec}^2\right)$ as provided by the following formula for the trapezoidal pulse in Figure 516.8-4 (the rise time T_R and fall time T_F should be kept to the minimum duration possible to minimize the resulting increase in velocity not associated with duration T_D):

$$A_m g = \frac{\Delta V}{T_D} \ \ (from\ \Delta V = A_m g T_D),\ \ \Delta V = 2\sqrt{2gh}\ and\ T_D = \frac{2\sqrt{2gh}}{A_m g}$$

$$(technically\ \Delta V = A_m g(T_D - 0.5T_R - 0.5T_F) \cong A_m g T_D\ for\ T_D \gg T_R, T_F$$

It is clear that if ΔV is to be increased incrementally until failure has occurred or is imminent, it is possible to either increase T_D, A_m or both. Since T_D relates to the period of the first mounted natural frequency of the materiel (and generally failure will occur when the materiel is excited at its lower mounted natural frequencies), it is required that the test be conducted by increasing the peak amplitude, A_m, of the test alone, leaving T_D fixed.

Figure 516.8-7 provides the 100 percent rebound ΔV versus drop height h based upon the simple relationship $h = (\Delta V)^2/g$. Holding T_D fixed and incrementally increasing ΔV provides a direct relationship between A_m and ΔV with T_D serving as a scale factor.

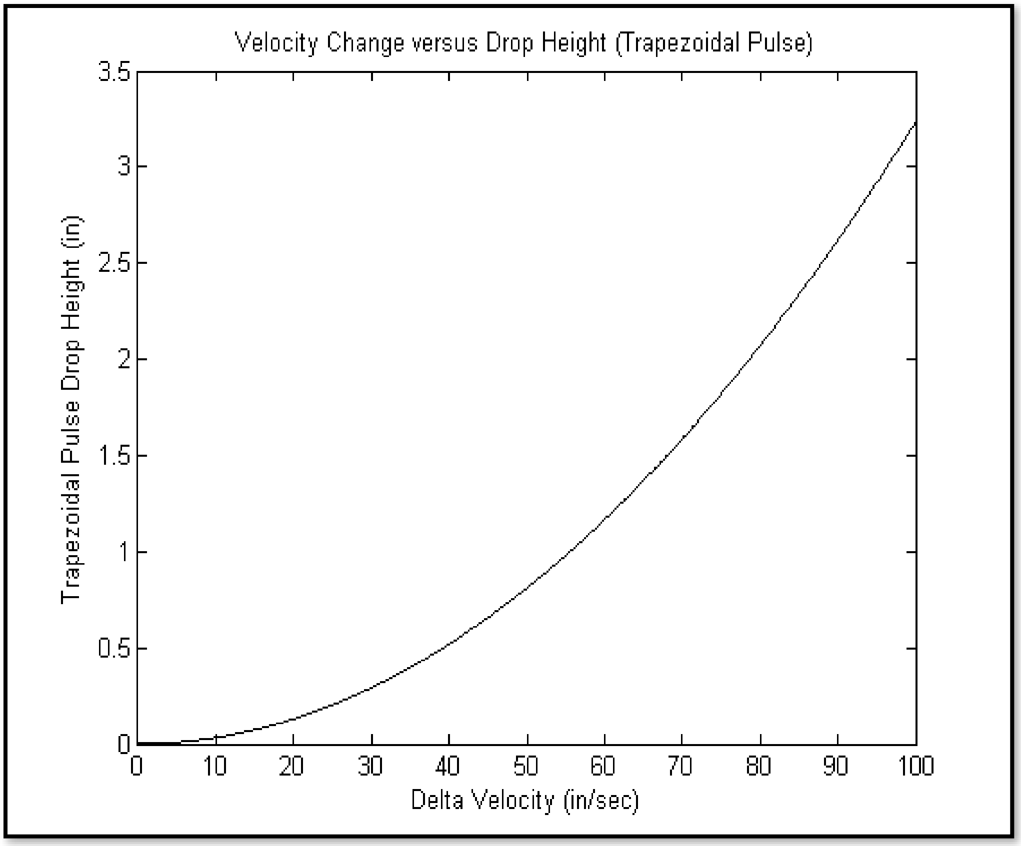


Figure 516.8-7. Fragility Shock Trapezoidal Pulse: velocity change versus drop height.

Table 516.8-VIII. Fragility Shock Trapezoidal pulse parameters (refer to Figure 516.8-4).

Test	Peak Value[1] (A_m) G's	Nominal Duration[2] (T_D) (sec)
Fragility	10-50	$T_D = \frac{2\sqrt{2gh}}{A_m g} = \frac{2\sqrt{2h/g}}{A_m}$

***Note 1**: A_m is dependent upon drop height "h." Typical range is provided (refer to paragraph 4.6.4).*
***Note 2**: "h" units: m (in) and g=9.81 m/s^2 (386.09 in/sec^2).*

For a complex transient, there is no simple relationship between peak acceleration, pulse duration, and a change in velocity. It is assumed here that for a complex transient, velocity change is related to a significant difference between successive instantaneous peaks. (This can be determined with some effort by selecting positive and negative thresholds for which a few, e.g., five or fewer, positive and negative peaks alternate over suitably short periods of time.) In this case, change in velocity is not so much an instantaneous change upon impact, but may be a successive set of changes occurring at significant periods lower than those of acceleration. (Recall that velocity is a $1/(2\pi f)$ scaling of the acceleration frequency domain information.) For test materiel where a degree of precision is needed in specifying the level of input and correlation of the shock effects on the materiel with the level of input, simple base input SDOF modeling is suggested with subsequent integration of the equations of motion to determine the relative velocity and displacement. Simply scaling the peak acceleration level (in effect the square-root of the energy) of the pulse likewise scales the velocity change directly for a linear system. The same relationship between the variables holds, except now a "distribution" of velocity change in the complex transient must be considered as opposed to a single large velocity change as in the case of the trapezoidal pulse.

Paragraph 4.6.4.c above implies that an analysis of the materiel has been completed prior to testing, that critical elements have been identified with their "stress thresholds," and that 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. If the large velocity/velocity change exceeds that available on standard electrodynamic and/or servo-hydraulic test equipment, for this procedure the classical trapezoidal pulse may be used on properly calibrated drop machines. However, if the large velocity/velocity change is compatible with the capabilities of electrodynamic and/or servo-hydraulic test equipment, consider tailoring the shock according to a complex transient for application on the electrodynamic or servo-hydraulic test equipment. Using a trapezoidal pulse on electrodynamic and/or servo-hydraulic test equipment is acceptable (accounting for pre- and post-exciter positioning) if there are no available data providing shock input information that is tailorable to a complex transient. In summary, there is a single parameter (peak amplitude of the shock input) to define the fragility level holding the duration of the shock, T_D, approximately constant. In the case of SRS synthesis, maximum velocity change is not as well defined, 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 used for establishing materiel fragility levels.

4.6.4.1 Test Controls – Fragility (Procedure III).

a. Specify the duration of the shock, T_D, as it relates to the first fundamental mode of the materiel. Select a design drop height, h, based on measurement of the materiel's shipping environment, or from Transit Drop Tables 516.8-IX thru 516.8-XI as appropriate to the deployment environment 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.) The maximum test item velocity change may then be determined by using the following relationship for 100% rebound:

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

where,

ΔV = maximum product velocity change m/s (in/s) (summation of impact velocity and rebound velocity)
h = design drop height in m (in)
g = 9.81 m/s^2 (386.09 in/s^2)

The maximum test velocity change assumes 100 percent rebound. Programming materials, other than pneumatic springs, may have less than 100 percent 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 over-test), and the maximum test item velocity is a bounding requirement.

b. Set the shock machine to an acceleration level (A_m) as determined based upon T_D and ΔV, well below the anticipated fragility level. If no damage occurs, increase A_m incrementally (along with ΔV) while holding the pulse duration T_D constant until damage to the test item occurs. This will establish the materiel's critical acceleration fragility (or velocity change) level.

c. Test levels used in this procedure represent the correlation of the best information currently available from research and experience. Use more applicable test level data if they become available (paragraph 6.1, reference g). 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 servo-hydraulic test equipment, provided the displacement and velocity limitations of the test equipment are not exceeded. In addition to the maximax acceleration response spectra, compute the pseudo-velocity response spectra.

4.6.4.2 Test Tolerances – Fragility (Procedure III).

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 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 516.8-4, with respect to the information provided in Table 516.8-VIII, are satisfied.

4.6.4.3 Test Procedure – Fragility (Procedure III).

This test is designed to build up in severity as measured in peak acceleration or velocity change 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 pre-select the steps in severity based on knowledge of the materiel item or the test environment, and document this in the test plan. 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, modify the procedure accordingly.

a. Classical Pulse. This part of the procedure 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 while holding the pulse duration as a function of the materiel modal characteristics a constant. In using this procedure, estimate the first mode mounted frequency of the materiel in order to specify the pulse duration T_D.

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, 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 an initial drop height low enough to assure that no damage will occur by selecting a fraction of the anticipated service drop height established from Transit Drop Tables 516.8-IX thru 516.8-XI. The maximum velocity change can be taken to be:

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

Where:

ΔV = maximum test item velocity change, m/s (in/s) (assumes full resilient rebound of test item)

h = drop height, m (in.)

g = acceleration of gravity 9.81 m/s^2 (386.09 in/s^2)

Step 4 Mount the test item in the fixture. Perform an operational check and document the pre-test condition. If the test item operates satisfactorily, proceed to Step 5. If not, resolve the problems and repeat this step.

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 operationally check the test item to determine if damage has occurred. If the test item does not operate satisfactorily, follow the guidance in paragraph 4.3.2 for test item failure.

Step 7 If it is required to determine the fragility of the test item in more than one axis, proceed to test the item (Steps 4-6) 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 4 through 8 until the test objectives have been met.

Step 10 Perform a post shock operational test of the test item. See paragraph 5 for analysis of results. Document the results, including plots of the measured test response waveforms, and any pre- or post-shock operational anomalies.

b. Synthesized Pulse. This part of the procedure assumes that the fragility level is some function of the peak acceleration level that correlates with a maximax acceleration SRS of a complex transient base input (because stress relates to velocity a peak pseudo-velocity level determined from a maximax pseudo-velocity SRS of a complex transient is preferable). For a complex transient specified in the time domain, this procedure generally uses 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 or pseudo-velocity SRS that are within the specified test tolerances. If response to the calibration shock is nonlinear with respect to shock input level, other test procedures along with simple modeling 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 (or pseudo-velocity) SRS level low enough to assure no damage will occur.

Step 4 Mount the test item in the fixture. Inspect and operationally test the item to document the pre-test condition. If the test item operates satisfactorily, proceed to Step 5. If not, resolve the problems and repeat this step.

Step 5 Perform the shock test at the selected level, and examine the recorded data to assure the test maximax acceleration (or pseudo-velocity) SRS is within tolerance.

Step 6 Visually examine and operationally check the test item to determine if damage has occurred. If so, follow the guidance in paragraph 4.3.2 for test item failure.

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

Step 8 If the test item integrity is preserved, select the next predetermined peak maximax acceleration (or pseudo-velocity) SRS level.

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

Step 10 Perform a post shock operational test of the test item. See paragraph 5 for analysis of results. Document the results, including plots of the measured test response waveforms and any pre- or post-shock operational anomalies.

4.6.5 Transit Drop (Procedure IV).

The intent of this test is to determine the structural and functional integrity of the materiel to a transit drop either outside or in its transit or combination case. In general, there is no instrumentation requirement for the test and measurement information is minimized, however, if measurements are made, the maximax acceleration SRS and the pseudo-velocity SRS will define the results of the test, along with the measurement amplitude time history.

4.6.5.1 Test Controls - Transit Drop (Procedure IV).

Test levels for this test are based on information provided in Tables 516.8-IX thru 516.8-XI. Test the item in the same configuration that is used in transportation, handling, or a combat situation. 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. Conduct all drops using a quick release hook, or drop tester. Use of a standardized impact surface is recommended for test repeatability because the surface configuration can influence test results. For most drop test requirements, steel plate on reinforced concrete is the default impact surface. The plate shall be homogenous material with a minimum thickness of 3 inches (76 mm) and Brinell hardness of 200 or greater. The plate shall be uniformly flat within commercial mill production standards, level within 2 degrees, and free of surface irregularities that may influence impact results. The concrete shall have a minimum compressive strength of 2500 psi (17 MPa), and be reinforced as required to prevent fracture during testing. In high velocity hazard classification drop scenarios (e.g. 40 ft) it is necessary for the concrete strength be 4000 psi with a minimum thickness of 24 inches. The steel plate shall be bonded and/or bolted to the concrete to create a uniform rigid structure without separation. The concrete foundation plus the impact plate mass shall be a minimum of 20 times the mass of the test item. The plate surface dimensions shall be sufficiently large to provide direct and secondary rotational impacts, and if possible rebound impacts. Guidance systems which do not reduce the impact velocity may be employed to ensure correct impact angle; however the guidance shall be eliminated at a sufficient height above the impact surface to allow unimpeded fall and rebound. Use of armor plate or similar composition steel plate is recommended to improve steel surface durability and prevent impact indentation and cuts. The impact surface shall be free from standing water, ice, or other material during testing. The most severe damage potential is impact with a non-yielding mass that absorbs minimal energy. Thus, use of a single monolithic impact mass is recommended to reduce energy transfer into the mass rather than the test item. The impact mass rigidity and energy transfer can be evaluated by measurement of the mass acceleration during testing.

Tables 516.8-IX thru 516.8-XI provide default drop conditions for transport from manufacturer to the end of its service life. Table 516.8-IX (Logistic Transit Drop Test) includes drop scenarios generally associated with non-tactical, logistical transport based on weight and test item dimensions. Table 516.8-X (Tactical Transport Drop Test) includes drop scenarios generally associated with tactical transport beyond the theatre storage area. As a default, the criteria for the tactical transport drop tests are to meet all performance requirements. For items that are incapable of meeting performance requirements, adjustments may be made to the drop height or configuration to accommodate the item performance limitations. If the drop conditions are modified, restrictions may be placed on the deployment of the item. Ensure an adequate test is performed and all deviations from this procedure are properly documented. Table 516.8-XI (Severe Tactical Transport Drop Test) includes severe drop scenarios, and the item is considered to have passed if it did not explode, burn, spread propellant or explosive material as a result of dropping, dragging or removal of the item for disposal. Other drop scenarios in the LCEP should be considered.

Realistic variations to the default values provided in Tables 516.8-IX thru 516.8-XI may be permitted when justified; e.g. large/complex systems in which specific handling considerations are identified in the LCEP may supersede the default levels provided.

Figure 516.8-8 illustrates the standard drop orientations as referenced in Tables 516.8-IX thru 516.8-XI. Figure 516.8-9 illustrates typical edge and corner drop configurations for large packages as discussed in Notes 2-4 of Table 516.8-IX.

Table 516.8-IX. Logistic Transit Drop Test[1].

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) Man-packed or man-portable	Under 91 (36)		122 (48)	Drop on each face, edge and corner; total of 26 drops[5]
	91 (36) & over		76 (30)	
45.4 - 90.8 (100 – 200) inclusive	Under 91		76 (30)	Drop on each corner; total of eight drops
	91 (36) & over		61 (24)	
90.8-454 (200 – 1000) inclusive	Under 91		61 (24)	
	91 – 152 (36 – 60)	2	61 (24)	
	Over 152 (over 60)	2	61 (24)	
Over 454 (1000)	No limit	3 4	46 (18)	Drop on each bottom edge. Drop on bottom face or skids; total of five drops

Note 1: *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. The default drop surface is steel backed by concrete. Concrete or 5 cm (2 in) plywood backed by concrete may be selected if (a) a concrete or wood surface is representative of the most severe service conditions or (b) it can be shown that the compressive strength of the impact surface is greater than that of the test item impact point(s). Note that the shorter shock duration associated with the steel impact surface may not excite all test item resonant modes.*

Note 2: *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.*

Note 3: *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).

Note 4: *For shelters without shock attenuated skids, the drop height may be reduced to 15 cm (6 in) with a 10 cm (4 in) sill for edgewise drops.*

Note 5: *If desired, divide the 26 drops among no more than five test items (see paragraph 4.6.5.1).*

Table 516.8-X. Tactical Transport Drop Test.

Scenario	Category	Impact Velocity (m/sec)	Drop Height[1] (m)	Configuration	# Drops / Orientation[3,6]		Impact Surface
Ship Transport	Storage and transport to theatre storage area, transport by ship	5.4 (17.7 ft/sec)	1.5m (5 ft)	Packaged[6]	(minimum of 3)	Flat bottom and two faces.[4]	Steel[7,8] backed by concrete
Unpackaged Handling	Infantry and man-carried equipment	5.4 (17.7 ft/sec)	1.5m (5 ft)	Unpackaged	5	Flat bottom, two faces[4] and two edges[5]	Steel[7,8] backed by concrete
Packaged Handling	Loading and offloading from side of transport vehicle - transport by truck, forklift, & helicopter	6.4 (21 ft/sec)	2.1m (7 ft)	Packaged[6]	5		Steel[7,8] backed by concrete
Helicopter	Underslung load, quick release onto land or ship	6.4 (21 ft/sec)	2.1m (7 ft)	Packaged[6]	1	Flat bottom	Steel[7,8] backed by concrete
Parachute Drop[2]	Low velocity drop	8.7 (28.5 ft/sec)	3.8m (12.6 ft)	Packaged with appropriate honeycomb or other shock absorbing system used in delivery	1	Flat bottom	Concrete
Parachute Drop	High velocity drop	27.3 (90 ft/sec)	38.1m (125 ft)				Concrete

Note 1: *The test is not intended to encompass all credible accident conditions or severe mishandling conditions. Where the drop heights quoted are exceeded by those specified elsewhere in the table or for other phases of Service, the higher values should be substituted.*

Note 2: *Drop heights are provided for simulated parachute drops. This test may not fully address certain effects that can occur during parachute drops in high wind conditions. Consider different drop height and angles of impact to address these issues. Drop from aircraft may be required for airdrop certification.*

Note 3: *Sufficient assets are required to test in each of the orientations specified. Five standard drop orientations are listed in Table XII and illustrated in Figure 8. Consider other drop orientations if expected to have a greater damage potential. Expose each item to no more than 2 drops.*

Note 4: *For munitions, the two faces shall be the forward and aft ends of the munition.*

Note 5: *For munitions, the two edges shall be at 45 degrees on the forward and aft ends.*

Note 6: *Unpackaged if required by LCEP or Test Plan.*

Note 7: *The default drop surface is steel backed by concrete. Concrete or 5 cm (2 in) plywood backed by concrete may be selected if (a) a concrete or wood surface is representative of the most severe service conditions or (b) it can be shown that the compressive strength of the impact surface is greater than that of the test item impact point(s). Note that the shorter shock duration associated with the steel impact surface may not excite all test item resonant modes.*

Note 8: *A steel impact surface shall have a Brinell hardness of at least 200. For test items less than 454 kg (1000 lbs) the steel plate shall be at least 2.5 cm (1 in) thick, otherwise it shall be at least 7.6 cm (3 in) thick.*

Table 516.8-XI. Severe Tactical Transport Drop Test.

<table>
<tr><th>Scenario</th><th>Category</th><th>Impact Velocity (m/sec)</th><th>Drop Height (m)</th><th>Configuration</th><th colspan="2"># Drops / Orientation[4,5]</th></tr>
<tr><td>Helicopter</td><td>External Carriage on Helicopter</td><td>6.4
(21 ft/sec)</td><td>2.1m
(7 ft)</td><td>Unpackaged</td><td rowspan="4">5</td><td rowspan="4">Flat Bottom, two faces[2] and two edges[3]</td></tr>
<tr><td>Military Land Vehicles</td><td>Includes weapons loading and off loading</td><td>7.7
(25.3 ft/sec)</td><td>3.05m
(10 ft)</td><td>Unpackaged</td></tr>
<tr><td>Aircraft</td><td>External Carriage on Fixed Wing Aircraft</td><td>7.7
(25.3 ft/sec)</td><td>3.05m
(10 ft)</td><td>Unpackaged</td></tr>
<tr><td>Crane</td><td>Accidental Crane Drop</td><td>15.5
(50.9 ft/sec)</td><td>12.2m
(40 ft)</td><td>Packaged[1]</td></tr>
<tr><td>Ship Transport</td><td>Shipboard Loading</td><td>15.5
(50.9 ft/sec)</td><td>12.2m
(40 ft)</td><td>Packaged[1]</td><td>(minimum of 3)</td><td>Flat Bottom and two faces.[2]</td></tr>
<tr><td>Ship Aircraft Carrier</td><td>Shipboard Loading and Handling</td><td>22.1
(72.5 ft/sec)</td><td>25m
(82 ft)</td><td>Packaged[1]</td><td>5</td><td>Flat Bottom, two faces[2] and two edges[3]</td></tr>
</table>

Note 1: *Unpackaged if required by LCEP or Test Plan.*

Note 2: *For munitions, the two faces shall be the forward and aft ends of the munition.*

Note 3: *For munitions, the two edges shall be at 45 degrees on the forward and aft ends.*

Note 4: *Sufficient assets are required to test in each of the orientations specified. Five standard drop orientations are shown listed in Table 10 and illustrated in Figure 8. Other drop orientations should be considered if expected to have a greater damage potential. Each item should be exposed to no more than 2 drops.*

Note 5: *The default drop surface is steel backed by concrete. Concrete or 5 cm (2 in) plywood backed by concrete may be selected if (a) a concrete or wood surface is representative of the most severe service conditions or (b) it can be shown that the compressive strength of the impact surface is greater than that of the test item impact point(s). Note that the shorter shock duration associated with the steel impact surface may not excite all test item resonant modes.*

Table 516.8-XII. Five standard drop test orientations.

Drop	Rectangular Packages	Cylindrical Packages
1	Flat Bottom	Horizontal (Side 1)
2	Face 1: (Left End)	Face 1: (Fwd End/Top)
3	Face 2: (Right End)	Face 2: (Aft End/Bottom)
4	Edge 1: (Bottom Right End Edge)	Edge 1: (Aft End Bottom Edge (45 Deg))
5	Edge 2: (Top Left Edge)	Edge 2: Fwd End Top Edge (45 Deg))

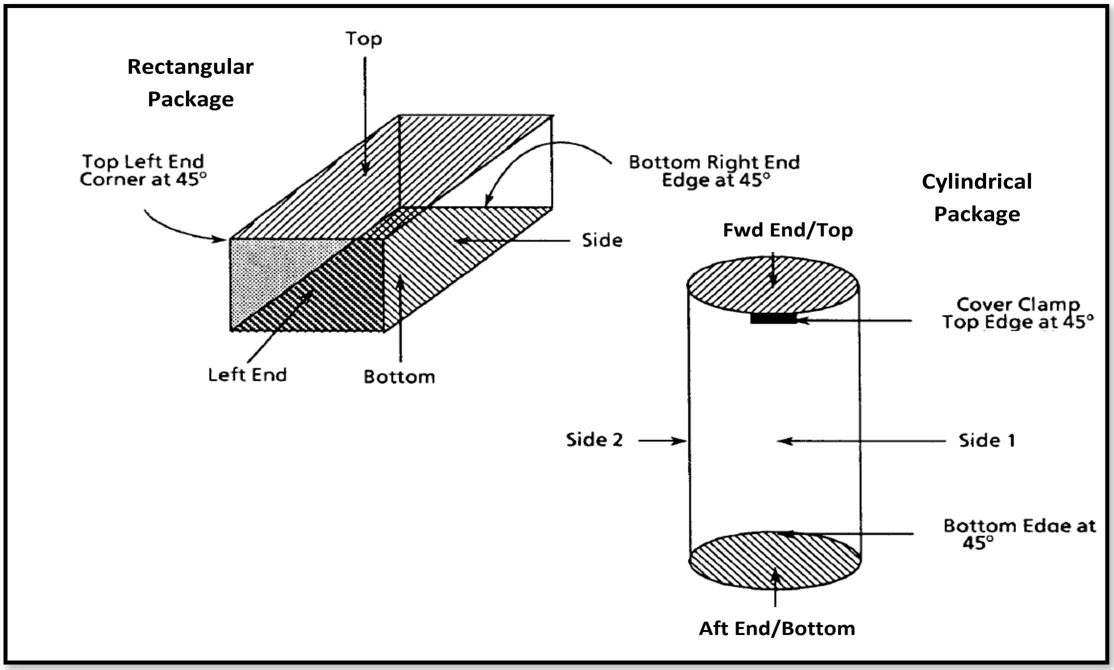


Figure 516.8-8. Standard drop orientations for rectangular and cylindrical packages.

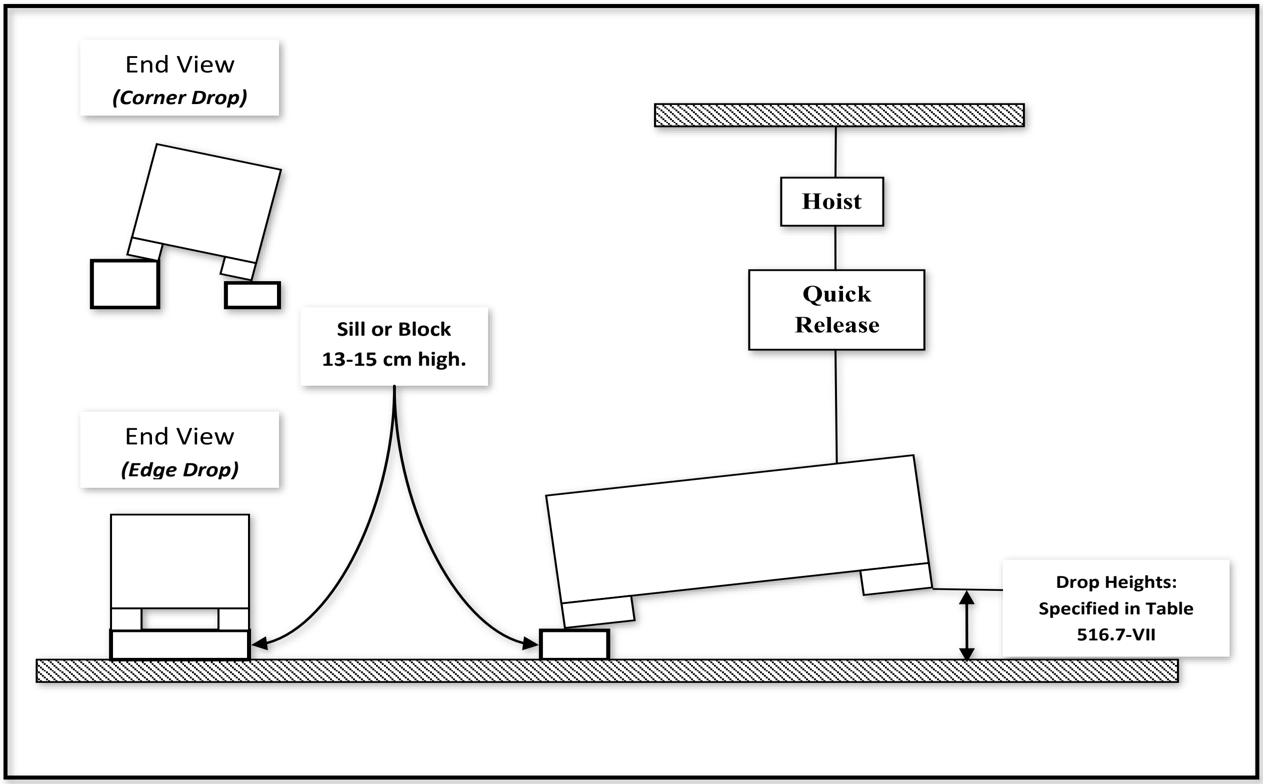


Figure 516.8-9. Illustration of edge drop configuration (corner drop end view is also illustrated).

4.6.5.2 Test Tolerances - Transit Drop (Procedure IV).

Ensure the test height of drop is within 2.5 percent of the height of drop as specified in Tables 516.8-IX through 516.8-XI.

4.6.5.3 Test Procedure - Transit Drop (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). If the test item operates satisfactorily, proceed to Step 2. If not, resolve the problems and repeat this step.

Step 2 From paragraph 4.6.5.1 and Tables 516.8-IX-516.8-XI, determine the height of the drops to be performed, drop orientation, the number of drops per test item, and the drop surface.

Step 3 Perform the required drops using the apparatus and requirements of paragraphs 4.6.5 and 4.6.5.1 and Tables 516.8-IX through 516.8-XI notes. Recommend visually and/or operationally checking the test item periodically during the drop test to simplify any follow-on evaluation that may be required. If any degradation is noted, see paragraph 4.3.2.

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), and document the results.

Step 6 Conduct an operational checkout in accordance with the approved test plan. See paragraph 5 for analysis of results.

Step 7 Document the results for comparison with data obtained in Step 1, above.

4.6.6 Crash Hazard Shock (Procedure V).

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. This test 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 tie-downs.

For materiel weighing less than 227 g (8 ounces) it may be permissible to omit the crash hazard test if it is determined that personnel expected to be in the vicinity of the test article are equipped with sufficient Personal Protective Equipment -PPE (i.e., helmets with visors) such that risk of significant bodily injury is determined to be highly unlikely. In addition to the item's mass, assess overall material properties and geometry when considering omitting Procedure V. Final decisions in such cases are left to the discretion of the responsible safety authority, and based upon the case-specific hazard analysis.

4.6.6.1 Test Controls - Crash Hazard Shock (Procedure V).

Use Table 516.8-III and Figure 516.8-2 as the test spectrum and effective durations. If shock spectrum analysis capabilities are not available, a classical pulse may be used as an alternative to a complex transient waveform developed from the SRS in Figure 516.8-2. Table 516.8-XIII provides the parameters for the default terminal peak sawtooth. 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 516.8-XIII. Terminal peak sawtooth default test parameters for Procedure V – Crash Hazard (refer to Figure 516.8-3).

Test	Minimum Peak Value and Pulse Duration A_m (G-Pk) & T_D (ms)			
	Flight Vehicle Materiel[1]		Ground Materiel[1]	
Procedure V -Crash Hazard	40 G	11 ms	75 G	6 ms

Note 1. *For materiel that is shock-mounted or weighing more than 136 kg (300 lbs), an 11 ms half-sine pulse of such amplitude that yields an equivalent velocity to the default terminal peak sawtooth may be employed.*

4.6.6.2 Test Tolerances - Crash Hazard Shock (Procedure V).

For complex waveform replication based on SRS, ensure the test tolerances are within those specified for the SRS in paragraph 4.2.2. For the classical terminal peak sawtooth and half-sine options defined in Table 516.8-XIII, ensure the waveform is within the tolerances specified in Figures 516.8-3 and 5.

4.6.6.3 Test Procedure - Crash Hazard Shock (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.

4.6.7 Bench Handling (Procedure VI).

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.

4.6.7.1 Test Controls - Bench Handling (Procedure VI).

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.

4.6.7.2 Test Tolerances - Bench Handling (Procedure VI).

Ensure the test height of drop is within 2.5 percent of the height of drop as specified in paragraph 4.6.7.1.

4.6.7.3 Test Procedure - Bench Handling (Procedure VI).

Step 1 Following an operational 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. If the test item operates satisfactorily, proceed to Step 2. If not, resolve the problems and repeat this Step. 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. See paragraph 5 for analysis of results.

Step 7 Document the results for comparison with data obtained in Step 1, above.

4.6.8 Pendulum Impact (Procedure VII).

The test item (large shipping container) may consist of a box, case, crate or other container constructed of wood, metal, or other material, or any combination of these for which ordinary box tests are not considered practical or adequate. Unless otherwise specified, large containers are those that measure more than 152cm (60 in.) on any edge or diameter, or those when loaded have gross weights in excess of 70kg (154 lbs).

4.6.8.1 Test Controls - Pendulum Impact (Procedure VII).

a. The pendulum impact tester consists of a platform suspended from a height at least 5m (16.4 ft) above the floor by four or more ropes, chains, or cables; and a bumper comprised of a flat, rigid concrete or masonry wall, or other equally unyielding flat barrier. The bumper is at least 46cm (18.1 in) high; wide enough to make full contact with the container end, and has sufficient mass to resist the impacts without displacement. The impact surface is oriented perpendicular to the line of swing of the platform. The platform is large enough to support the container or pack, and when hanging free, has its top surface approximately 23cm (9.1 in) above the floor, and its leading edge at least 8cm (3.1 in) from the surface of the bumper. The suspension chains are vertical and parallel so that when the platform is pulled straight back, it will rise uniformly but remain at all times horizontal and parallel to the floor (see Figure 516.8-10).

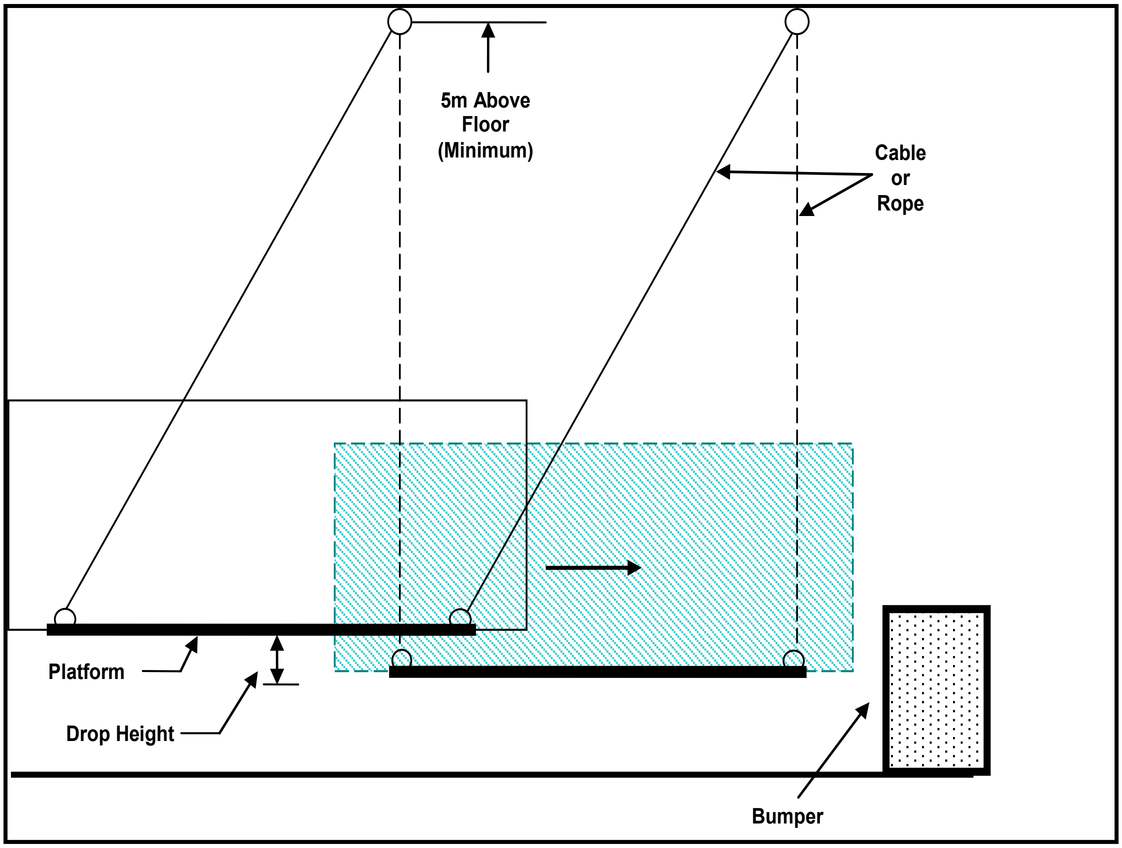


Figure 516.8-10. Pendulum impact test.

b. The drop height shall be determined for the required horizontal impact velocity based on the transfer of potential to kinetic energy ($h = v^2/2g$). Unless otherwise specified, the vertical height is a drop of 23 cm (9 in.) that results in a velocity of 2.13m/sec (7 ft/sec) at impact.

c. Load the test item (container) with the interior packing and the actual contents for which it was designed. If use of the actual contents is not practical, a dummy load may be substituted to simulate such contents in weight, shape, and position in the container. Block and brace the contents, or dummy load, and cushion them in place as for shipment. When the pendulum impact test is performed to evaluate the protection provided for the contents, the rigidity of a dummy load should closely approximate that of the actual contents for which the pack was designed.

4.6.8.2 Test Tolerances - Pendulum Impact (Procedure VII).

Ensure the vertical drop height is within 2.5 percent of the required height.

4.6.8.3 Test Procedure - Pendulum Impact (Procedure VII).

Step 1 If required, perform a pretest operational checkout in accordance with the test plan. Install accelerometers and other sensors on the test item, as required.

Step 2 Place the test item on the platform with the surface that is to be impacted projecting beyond the front end of the platform so that the specimen just touches the vertical surface of the bumper.

Step 3 Pull back the platform so that the center of gravity of the pack is raised to the prescribed height, and then release it to swing freely so that the surface of the container impacts against the bumper. Unless otherwise specified, the vertical height is a drop of 23cm (9 in.) that results in a velocity of 2.13m/sec (7 ft/sec) at impact.

Step 4 Examine the test item and record obvious damage. If the container is undamaged, rotate it 180 degrees and repeat Step 3. When the test is conducted to determine satisfactory performance of a container or pack, and unless otherwise specified, subject each test item to one impact to each side and each end that has a horizontal dimension of less than 3m (9.8 ft).

Step 5 Record any changes or breaks in the container, such as apparent racking, nail pull, or broken parts, and their locations. Carefully examine the packing (blocks, braces, cushions, or other devices) and the contents, and record their condition. If required, perform a post-test operational checkout in accordance with the test plan. See paragraph 5 for analysis of results.

4.6.9 Catapult Launch/Arrested Landing (Procedure VIII).

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.

4.6.9.1 Test Controls - Catapult Launch/Arrested Landing (Procedure VIII).

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 Annex 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 at the selected materiel frequency (usually the first fundamental mode of the loaded aircraft wing). For testing purposes, it is permissible to reduce the maximum amplitude in the horizontal direction to 75 percent 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 in Figure 516.8-11. 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 two seconds long), and concluded by a final transient. The longitudinal axis provides a profile of the DC catapult acceleration that, 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 percent 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 516.8-12. 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 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, Annex 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.

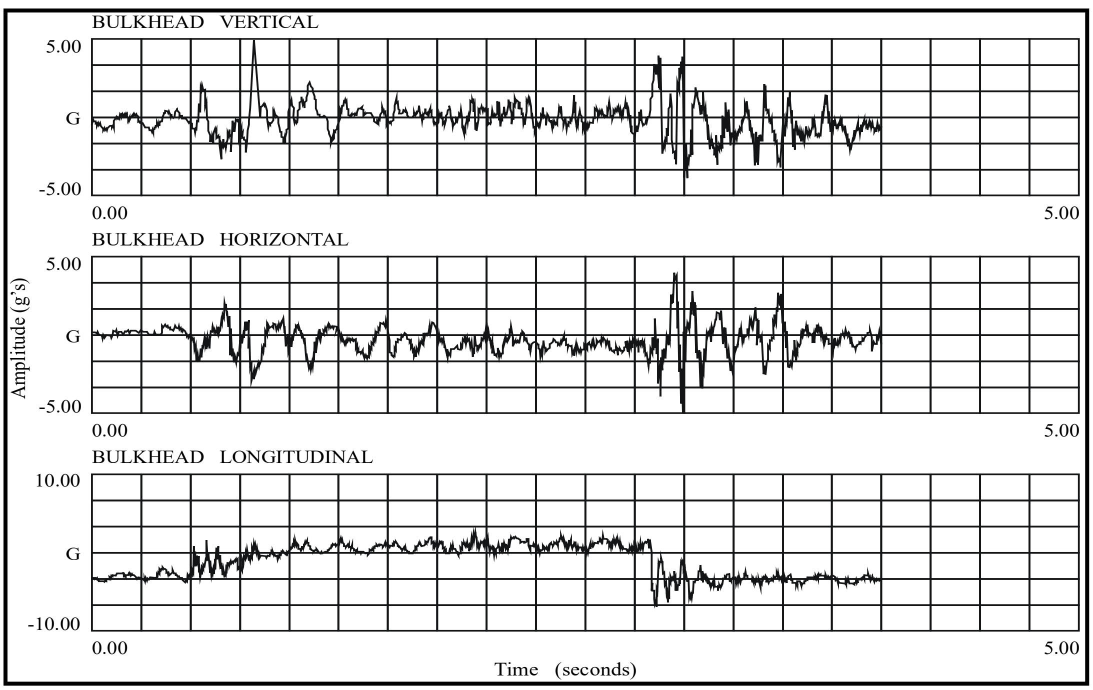


Figure 516.8-11. Sample measured store three axis catapult launch component response acceleration time histories.

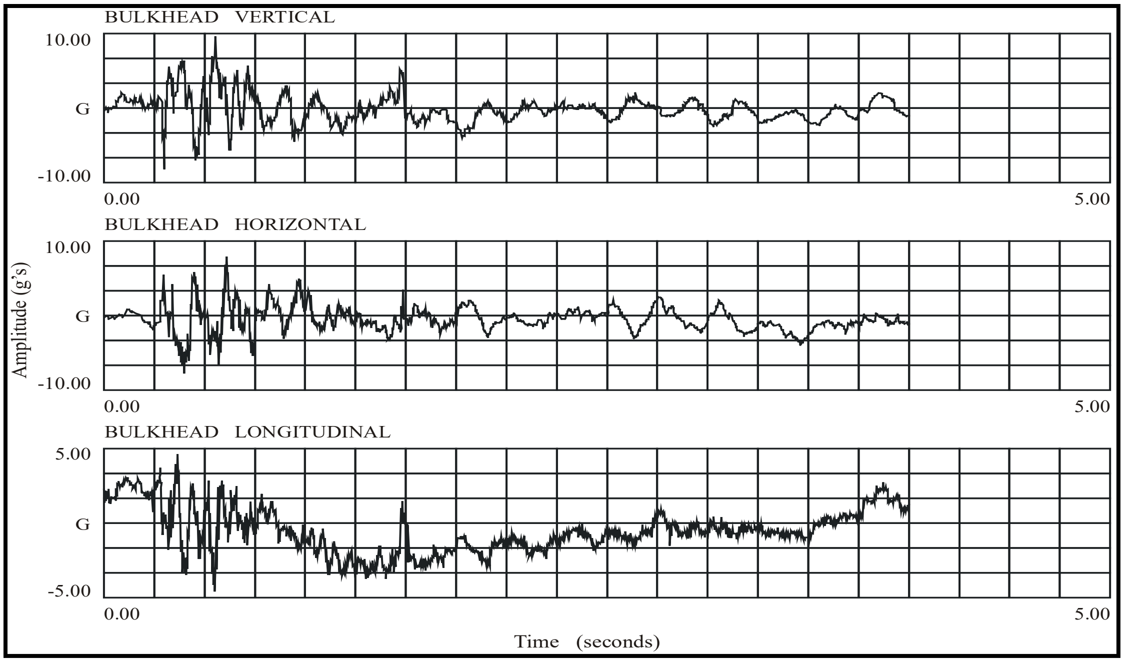


Figure 516.8-12. Sample measured store three axis arrested landing component response acceleration time histories.

4.6.9.2 Test Tolerances - Catapult Launch/Arrested Landing (Procedure VIII).

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.

4.6.9.3 Test Procedure - Catapult Launch/Arrested Landing (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. If the test item operates satisfactorily, proceed to Step 4. If not, resolve the problems and repeat this step.

Step 4a 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. If the test item fails to operate as intended, follow the guidance in paragraph 4.3.2 for test item failure.

Step 4b If measured field data are available, either apply the measured response data under exciter system time waveform control (see Method 525.2), or process the catapult as two shocks separated by a transient vibration, and the arrested landing as a shock followed by a transient vibration. Operate the test item in its appropriate operational mode while bursts are applied. If the test item fails to operate as intended, follow the guidance in paragraph 4.3.2 for test item failure.

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. If the test item does not operate satisfactorily, follow the guidance in paragraph 4.3.2 for test item failure.

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

Step 7 Document the test results including amplitude time history plots, and notes of any test item operational or structural degradation. See paragraph 5 for analysis of results.

5. ANALYSIS OF RESULTS.

In addition to the specific guidance provided in the test plan and the general guidance provided in Part One, paragraphs 5.14 and 5.17; and Part One, Annex A, Task 406, refer to the below paragraphs for supplemental test analysis information. Analyze any failure of a test item to meet the requirements of the materiel specifications.

a. Procedure I (Functional Shock) - Consider any interruption of the materiel operation during or after the shock in relationship to the materiel's operational test requirements. (See paragraph 4.3.2.)

b. Procedure II (Transportation Shock) - Consider any damage to the shock mounts or the internal structural configuration of the test item that may provide a cause for the development of a failure analysis course of action to consider retrofit or redesign.

c. Procedure III (Fragility) - The outcome of a successful fragility test is one specified measurement level of test item failure for each test axis along with the duration of the shock. Consider that if the test item fails either operationally or structurally at the lowest level of testing, and there is no provision for testing at lower levels, the test item's fragility level is indeterminate.

d. Procedure IV (Transit Drop) - In general, analysis of results will consist of visual and operational comparisons for before 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.

e. Procedure V (Crash Hazard Shock) - If measurement information was obtained, process this in accordance with paragraph 4.6.6.3, Step 4.

f. Procedure VI (Bench Handling) - In general, any operational or physical (mechanical or structural) change of configuration from Step 1 in paragraph 4.6.7.3 must be recorded and analyzed.

g. Procedure VII (Pendulum Impact) – In general, analysis of the results will consist of visual inspections and any operational comparisons before and after the test. Check for operability and inspect for physical damage of the contents (except when using a dummy load). Damage to the exterior shipping container that is the result of improper interior packaging, blocking, or bracing is cause for rejection. Structural damage to the exterior shipping container that results in either spilling of the contents or failure of the container in subsequent handling is cause for rejection. Assess whether a substantial amount of shifting of the contents within the shipping container created conditions likely to cause damage during shipment, storage, and reshipment of the container. Minor container damage such as chipping of wood members, dents, paint chipping, is not cause for rejection. If recorded, acceleration time histories or other sensor data can provide valuable information related to the response characteristics of the test item.

h. Procedure VIII (Catapult Launch/Arrested Landing) - Consider any failure of the structural configuration of the test item, mount, or launcher that may not directly impact failure of the operation of the materiel, but that would lead to failure under in-service conditions.

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c. MIL-DTL-901, “Detail Specification – Shock Tests, H.I. (High Impact), Shipboard Machinery, Equipment and Systems, Requirements for”, 20 June 2017.

d. MIL-STD-331, “Fuzes, Ignition Safety Devices and Other Related Components, Environmental and Performance Test for”, May 2017.

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Requests for other defense-related technical publications may be directed to the Defense Technical Information Center (DTIC), ATTN: DTIC-BR, Suite 0944, 8725 John J. Kingman Road, Fort Belvoir VA 22060-6218, 1-800-225-3842 (Assistance--selection 3, option 2), http://www.dtic.mil/dtic/; and the National Technical Information Service (NTIS), Springfield VA 22161, 1-800-553-NTIS (6847), http://www.ntis.gov/.

METHOD 516.8, ANNEX A

MEASUREMENT SYSTEM CHARACTERIZATION AND BASIC PROCESSING

1. SINGLE SHOCK EVENT MEASUREMENT SYSTEM CHARACTERIZATION AND BASIC PROCESSING

The following paragraphs discuss basic measurement system acquisition characteristics, followed by a discussion on the correct identification of the parts of a measured shock (in particular the duration of a shock). Information in Annex A is essential for the processing of measured data for a laboratory test specification.

1.1 Measurement System and Signal Conditioning Parameters

The data recording instrumentation shall have flat frequency response to the maximum frequency of interest (f_{Max}). If f_{Max} is not specified, a default value of 10 KHz is recommended for acquisition at each measurement location. Defining f_{AA} as the 3dB half-power point cut-off frequency of the low-pass analog anti-alias filter, $f_{\max} < f_{AA}$ is implied to maintain flat frequency response. The digitizing rate must be at least 2.5 times the filtering frequency f_{Max}. Note that when measurements of peak amplitude are used to qualify the shock level, a sample rate of at least 10 times the filtering frequency (100 thousand samples per second for the default case) is required. For SRS considerations a measurement shock should be acquired at 10 times the filtering frequency or resampled to 10 times the filtering frequency.

It is imperative that a responsibly designed signal conditioning system be employed to reject possibility of any aliasing. Analog anti-alias filters must be in place before the digitizing portion of the signal conditioning system. The selected anti-alias filtering must have an amplitude attenuation of 50 dB or greater, and a pass band flatness within one dB across the frequency bandwidth of interest for the measurement (see Figure 516.8-1a). Subsequent re-sampling for either up-sampling (interpolation) or down-sampling (decimation) must be in accordance with standard practices and consistent with the analog anti-alias configuration.).

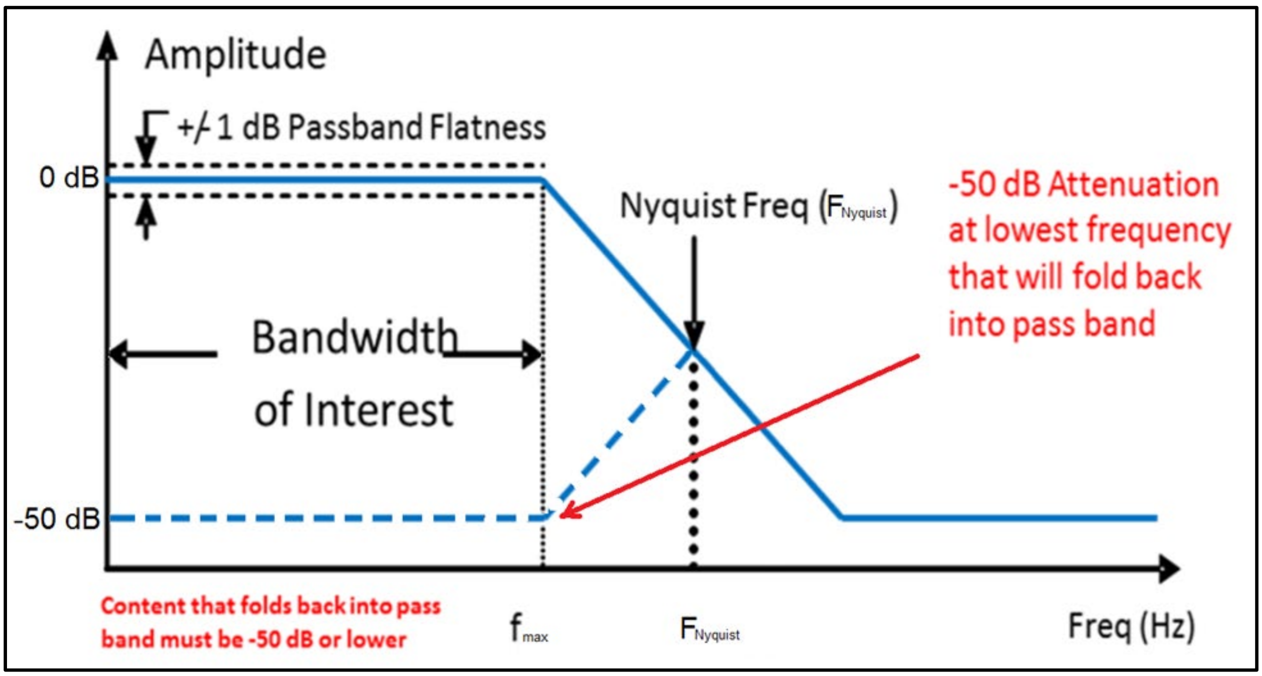

Figure 516.8A-1a. Filter attenuation (conceptual, not filter specific).

The end to end alias rejection of the final digitized output must be shown to meet the requirements in Figure 516.8 A-1a. The anti-alias characteristics must provide an attenuation of 50 dB or greater for frequencies that will fold back into the bandwidth of interest (passband). Generally, for validly acquired digital shock time history data spectral data including SRS plots are only presented for frequencies within the passband (up to f_{Max}). However, this restriction is not to constrain digital data validation procedures that require assessment of digitally acquired data to the Nyquist frequency (either for the initial Analog to Digital Conversion (ADC) or subsequent re-sampled sequences). It should be noted that it is possible that certain sensor/signal conditioning systems may display substantial "out-of-band" frequency content, i.e., greater than f_{Max} but less than the Nyquist frequency, in digital processing. For example, a Fourier spectra estimate over the duration of the shock may display "general signal" to "noise" that seemingly contradicts the filter attenuation criterion displayed in Figure 516.8A-1a. In this case the signal conditioning system must be subject to the "verification of alias rejection" described in the paragraph to follow. If the signal conditioning system is verified as non-aliasing then the substantial frequency content between f_{Max} and the Nyquist frequency can be digitally filtered out if desired.

Verification of alias rejection should start by establishing the dynamic range within the pass band in terms of the signal to noise ratio (SNR). The voltage based $SNR = 20\log_{10}(V_{FullScale}/V_{Noisefloor})$ must be ≥ 60dB. Once sufficient SNR is verified, establishing the alias rejection characteristics may be determined using an input sine wave with a magnitude of 0.5 * full scale range and at the lowest frequency range that can impinge i.e., be aliased into f_{Max}, and then confirming (using the IEEE 1057 sine wave test procedure or through inspection of the time domain data) that the alias rejection is sufficient at this frequency for the signal conditioning system.

For a conventional multi-bit ADC such as flash or successive approximation design, if a 100 thousand sample/second digitizing rate is used, for example, then $f_{Nyquist}$= 50 KHz. Theory says that if a signal above the Nyquist Ratio is present, it will "fold over" into a frequency below the Nyquist ratio. The equation is:

Fa = absolute value [(Fs*n)-F], where

Fa = frequency of "alias"

F = frequency of input signal

Fs = sample rate

n = integer number of sample rate (Fs) closest to input signal frequency (F)

Hence, the lowest frequency range that can fold back into the 10 KHz passband is from 90 KHz to 110 KHz.

It should be noted that Sigma Delta (SD) digitizers "oversample" internally at a rate several times faster than the output data rate and that analog anti-alias filtering is still required. For illustrative purposes, consider an example for a SD digitizer with a bandwidth of interest up to 10 KHz that samples internally at $f_s = 800$ thousand samples/second. The internal analog based Nyquist frequency by definition is 400 KHz, hence the analog anti-alias filter should attenuate 50 dB or more content that can fold back into the 10 KHz pass band (790 KHz to 810 KHz and similar bands that are higher in frequency). Figure 516.8A-1b illustrates sampling frequencies, Nyquist frequencies, and frequency bands that can fold back into the bandwidth of interest for both conventional and over sampling digitizers, such as the Sigma Delta. Observe that for the example SD design, there is significant bandwidth above the 10 KHz desired f_{Max} and the Nyquist rate that is not useable due primarily to quantization error, an artifact of the single bit SD design. The output of a SD ADC will be digitally filtered and resampled yielding a new effective sampling rate f_{DR} which in turn yields a new Nyquist rate for the decimated signal of $f_{DR}/2$. Through careful selection the digital filter cutoff frequency, the majority of noise between $f_{DR}/2$ and f_s is removed while maintaining a nearly flat frequency response through f_{Max}. The SD oversampling rate $OSR = f_s/f_{DR}$, which is directly correlated to dynamic range, is one of several design parameters for a SD ADC. Most reputable vendors will provide a detailed specification sheet associated with their products, however, it is strongly recommended that one verifies aliasing rejection and noise floor characteristics as recommended above prior to employing any signal conditioning/digitizing system in the acquisition of critical field data.

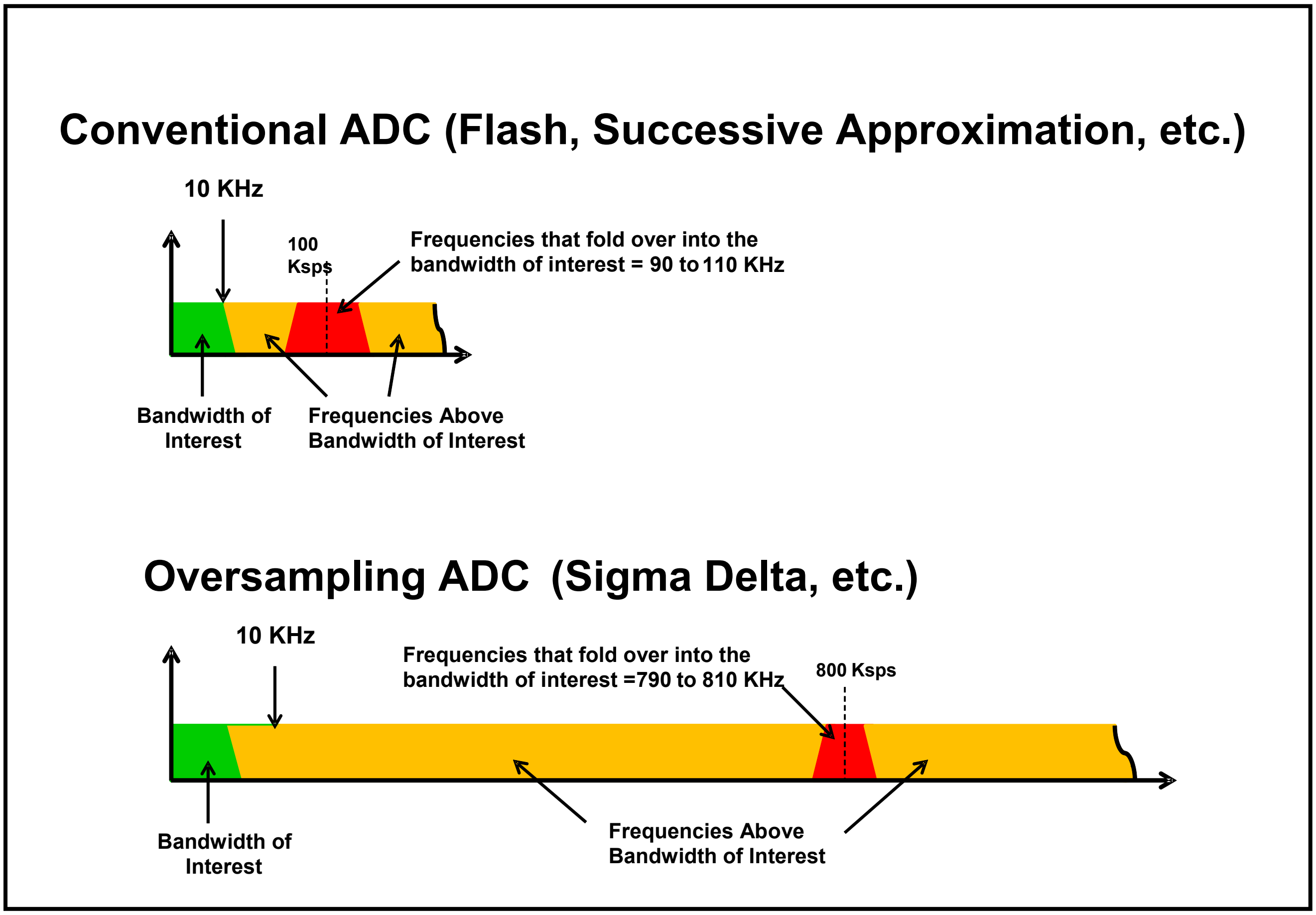

Figure 516.8A-1b Illustration of sampling rates and out of band "fold over" frequencies for Conventional and Oversampling (Sigma-Delta) based data acquisition systems.

1.2 Measurement Shock Identification

A "simple shock" is being addressed in this Method (excluding Procedure VIII and the example of a complex shock provided in Annex B), i.e., the impulse force input defines a single "event" arising from a characteristic phenomenon. A "simple shock" is defined by a measurement, e.g., acceleration, with three characteristic regions:

a. An initial low amplitude stationary random measurement termed ***the measurement system noise floor***.

b. A series of erratic high amplitude decaying measurement amplitudes termed ***the shock***.

c. A comparatively low level stationary measurement at or just above the instrumentation noise floor termed ***the post-shock noise floor***.

> **NOTE:** If periodic components or non-Gaussian behavior are present in ***the measurement system noise floor,*** the signal conditioning system needs to be examined. If periodic components are present in ***the post-shock noise floor*** but the general amplitude is relatively stationary, it is indicative of mounting/materiel resonance response. A trained analyst needs to decide the importance of such resonance information in a laboratory test specification. This decision should be based upon the lowest mounted fundamental frequency of the materiel. In general, shock information should not be unduly extended in order to accommodate the full extent of the resonant "ringing" behavior.

It is always imperative that the data be carefully analyzed to ensure the measurement is free of corruption, and the nature of the event is physically well grounded. This subject is discussed in greater detail in Annex B.

The example that follows will illustrate initial time domain assessment of a typical transient acceleration time history. Annex B will provide frequency domain and more advanced assessment. Figure 516.8A-2 displays the measurement shock that will be considered for proper processing in both the time and frequency domain. The phenomenon producing the shock has initial high frequency/high energy input, followed by a form of ringing or resonance decay. The measurement shock exists between 617 milliseconds and 1560 milliseconds.

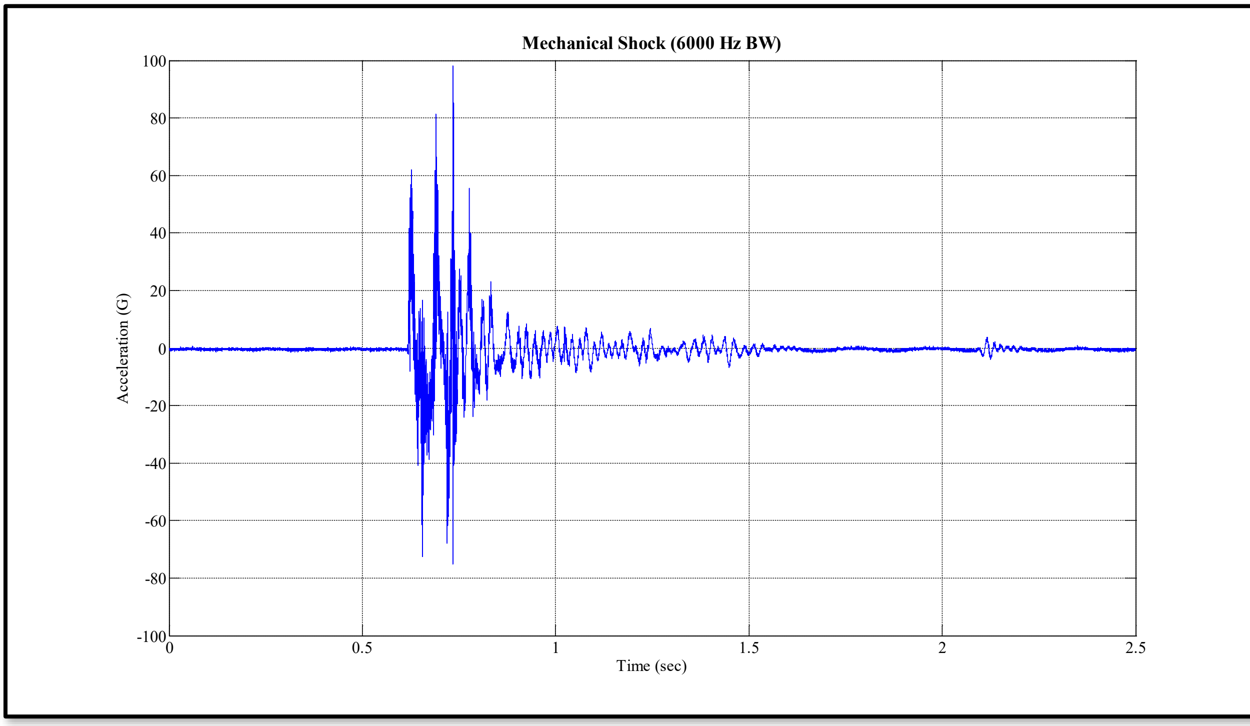

Figure 516.8A-2. Example acceleration time history.

1.3 Effective Pulse Duration for Non-Classical Shocks

When considering the two non-classical shock alternatives discussed in paragraph 1.2, the analyst (and ultimately test operator), will need to consider the effective durations (including the overall shock duration (T_e) and the concentration of energy duration (T_E)) for the pulse to be replicated. In the case in which TWR is selected as the implementation method, the duration of the transient event is straightforward. The test operator should simply identify the pre-pulse and post-pulse noise floor levels that will indicate reasonable start and end times for the TWR based event. In the case in which a reference transient is to be synthesized based upon an SRS reference, the SRS reference must come with recommended effective durations established by the analyst review of the data ensemble used to develop the SRS reference. The analyst may view the effective durations of a transient event from a number of perspectives. However, the final guidance on effective durations provided to the test operator with the reference SRS should be simplified to manageable parameters to which the test operator will be able to implement efficiently. Providing the test operator both the shock duration T_e and the concentration of energy duration T_E is recommended for any SRS based laboratory shock test. With the SRS magnitude controlling the synthesized pulse magnitude and both T_e and T_E defining energy distribution, the synthesized pulse should resemble a measured pulse having the same SRS. The concept of effective durations is discussed further in the following paragraphs. Annex B contains more information on determining T_e and T_E based upon easily computed "instantaneous root-mean-square" computations.

As mentioned in paragraph 1.2, a "simple shock" (refer to Figure 516.8A-3), is defined in terms of three time intervals:

a. The first time interval; T_{pre} is usually well defined and occurs prior to the shock where the measurement represents the ***measurement system noise floor***.

b. The second interval; T_e is termed the ***shock duration*** and is defined as the duration from the zero crossing for the first measurement acceleration "above the instrumentation noise floor" until the perceived "termination" of the ***shock***. This interval contains the interval with the highest concentration of energy, T_E , defined as the minimum length of time that contains any time history magnitudes exceeding in absolute value $\frac{|A_{Pk}|}{CF}$ (see detailed discussion below).

c. The third time interval; T_{post} is the time from the "termination" of the ***shock*** until the measurement signal approaches or reaches levels of the ***measurement system noise floor***. (In general, shocks over reasonable characterization/identification times seldom decay to the levels of the pre-shock noise floor.) This third time interval can be termed the ***post-shock noise floor*** that is above, but includes the ***measurement system noise floor.***

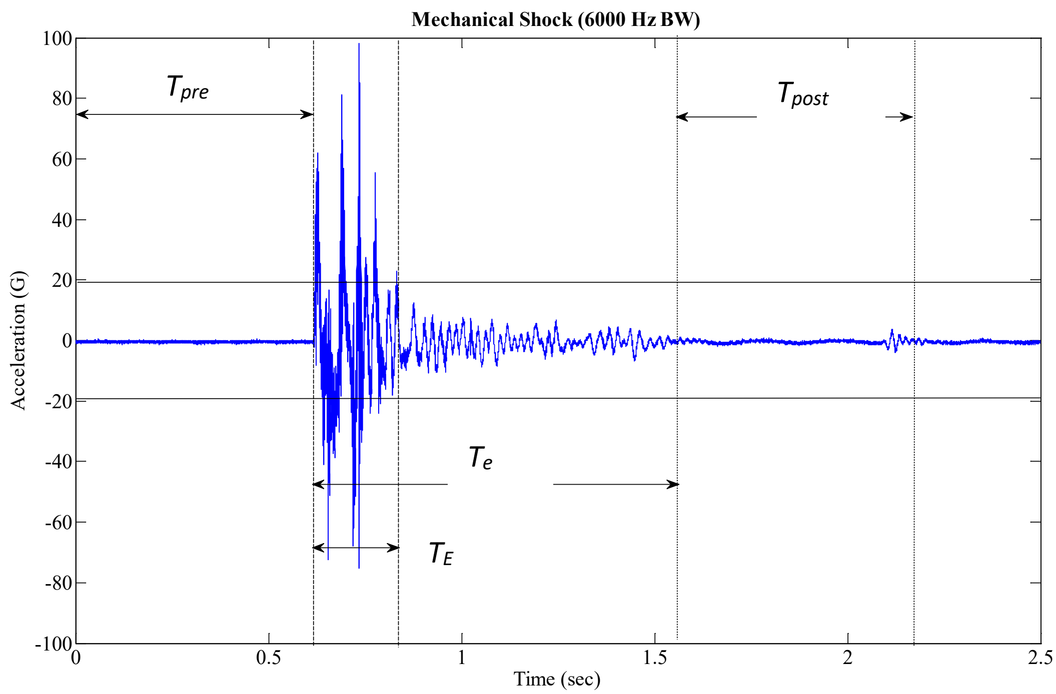

Figure 516.8A-3. Example simple shock time history with segment identification.

In general, for further processing it is convenient, if possible, to select the interval T_{pre} of duration equal to T_{post} and these intervals should be reasonably comparable or equal in length to T_e. The same amount of "time/amplitude" information is available in all three intervals.

1.3.1 Calculation of T_e.

There is historical precedence in which the shock duration T_e was defined as, "the minimum length of continuous time that contains the root-mean-square (RMS) time history amplitudes exceeding in value ten percent of the peak RMS amplitude associated with the shock event. The short-time averaging time for the unweighted RMS computation is assumed to be between ten and twenty percent of T_e." The previous definitions also included discussion relative to the relationship between T_e and T_E at which point it was recognized that this relationship is dependent upon the "shape" of the true RMS of the time history. Although the previous definition of T_e is a useful analysis tool, T_e is now defined from the zero crossing for the first measurement acceleration "above the instrumentation noise floor" until the perceived "termination" of the shock as discussed above. This parameter provides a reasonable bound on the interval in which the reference time history contains measurable energy levels above the noise floor. In synthesizing the reference pulse for an SRS based laboratory test, the user should set the window length, (time-domain block size), containing the reference signal to T_e or the nearest programmable interval greater than T_e. Observe that unlike the field measurements, the noise floor of the synthesized signal will actually be zero. Zero padding outside of the interval T_e will have no effect on the SRS computation. In the event T_e (the shock duration) is not provided, define $T_e = \frac{2.5}{f_{\min}}$ where $f_{\min}$ is the lowest frequency in the reference SRS (this will allow a minimum duration sufficient to allow up to 5 half-cycles of the lowest frequency component in the reference time history. T_e includes both the primary "concentration of energy" and an "extension of energy" duration.

1.3.2 Calculation of T_E.

T_E represents a "concentration of energy" duration. There is historical precedence in which T_E was defined to be the minimum length of time that contains any time history magnitudes exceeding in absolute value one-third of the shock peak magnitude absolute value, i.e., $\frac{|A_{Pk}|}{3}$, associated with the reference time history. This assumes the shock peak amplitude, A_{Pk}, has been validated, e.g., it is not an "instrumentation noise spike." A definition of T_E that considers the crest factor, $CF = A_{Pk} / RMS$, associated with the single shock or shock data ensemble from the reference SRS is defined. The crest factor is computed in small intervals over the duration T_e, (e.g. $T_e / 10$), and the "maximum crest factor" computed on the individual intervals is defined as CF. This yields a revised definition of T_E based on the minimum length of time that contains any time history magnitudes exceeding in absolute value $\frac{|A_{Pk}|}{CF}$. Even though the crest factor is a stationary random vibration concept applied when Gaussian or particularly non-Gaussian time histories are considered in stationary random vibration, it can be justified for use in terms of a shock if it is realized that peak amplitudes are of a random nature and come at random times. All amplitudes less than the last amplitude greater than $\frac{|A_{Pk}|}{CF}$ define a time of ***between*** greater energy concentration and lesser energy concentration that can be quite robust. The analyst must however be immune from selecting a random amplitude spike time far from the major energy concentration, i.e., too strict an application of the concept for determining T_E. Generally, the larger the CF the greater T_E so selection of several $CF's$ and comparing $T_E's$ is recommended. For several shocks, i.e., an ensemble, varying CF and assembling a table of $T_E's$ should provide the analyst a robust method for establishing duration T_E for synthesis. Plots of CF versus T_E would indicate the sensitivity between the two variables. In the event T_E is not provided, the test operator should assume the CF to be 3, and synthesize a pulse such that T_E for the synthesized reference time history is characterized by T_E based on the minimum length of time that contains any time history magnitudes exceeding in absolute value of $\frac{|A_{Pk}|}{3}$. Having established a nominal value for T_E, the synthesis of a representative pulse shall have a tolerance of $0.8T_E \le T_E \le 1.2T_E$.

1.3.3 Implementation Considerations.

In summary, it is desired that the reference transient synthesized based upon an SRS reference has reasonably similar temporal characteristics to that of the field data from which the SRS reference was derived. The analyst developing SRS based test criteria should carefully investigate the effective duration of the ensemble of transient events from which the final test criteria was based, and document the results along with the SRS. The laboratory technician synthesizing the reference pulse should then be able to consider the variables, CF, T_e and T_E, associated with effective duration in the synthesis process. As an example, the above durations and associated time intervals are displayed for the typical simple shock in Figure 516.8A-3 where the pre-shock noise floor $T_{pre} \triangleq 0 \rightarrow 0.617\ sec$ and the post-shock noise floor is defined as $T_{post} \triangleq \left(T_{pre} + T_e\right)$ to $\left(T_{pre} + T_e\right) + T_{pre}$. T_{pre} and T_{post} were taken to be the same duration for processing comparison convenience. $T_e = 0.943$ sec, is identified by the dashed lines between 0.617 and 1.56 seconds. The maximum crest factor, computed in intervals of $T_e/10$ was computed to be $CF \cong 5$. $|A_{pk}|/CF$ is identified by the horizontal lines based on $CF \cong 5$ and $|A_{pk}| = 98.17G$ (that occurred at time $T_{pk} = 0.735$ sec). $T_E \cong 0.230\ sec$ is identified by the interval between the first occurrence of $|A_{pk}|/CF$ that occurs at approximately 0.625 seconds and the last occurrence of $|A_{pk}|/CF$ that occurs at approximately 0.860 seconds.

1.4 Shock Response Spectrum

The SRS, either acceleration maximax SRS estimates or the pseudo-velocity maximax SRS, is the primary "frequency domain" descriptor that links time history shock amplitudes to some physical model, i.e., the shock model. The below paragraphs will provide a description of the SRS options in addition to SRS estimates that may be used to imply the validity of the measured shock information.

1.4.1 Processing Guidelines

The maximax SRS value at a given undamped natural oscillator frequency, f_n, describes the maximum response (positive, negative, primary, and residual) of the mass of a damped single degree of freedom (SDOF) system at this frequency to a shock base input time history, e.g., acceleration, of duration T_e (see Figure 516.8-1 for the appropriate model). Damping of the SDOF is typically expressed in terms of a "Q" (quality factor). Common selections for Q are Q=50 that represents 1 percent critical damping; a Q =10 that represents 5 percent critical damping; and a Q=5 that represents 10 percent critical damping of the SDOF. For processing of shock response data, the absolute acceleration maximax SRS has become the primary analysis descriptor. In this description of the shock, the maximax acceleration values are plotted on the ordinate with the undamped natural frequency of the base input to the SDOF system plotted along the abscissa. The frequency range over which the SRS is computed, (i.e., natural frequencies of the SDOF system filters) as a minimum, includes the data signal conditioning bandwidth, but should also extend below and above this bandwidth. In general, the "SRS Natural Frequency Bandwidth" extends from an octave below the lowest frequency of interest, up to a frequency at which the "flat" portion of the SRS spectrum has been reached (that may require going an octave or more above the upper signal conditioning bandwidth). This latter SRS upper frequency $f_{SRS\max}$ requirement helps ensure no high frequency content in the spectrum is neglected, and is independent of the data bandwidth upper frequency, $f_{\max}$. As a minimum, this SRS upper frequency should exceed $f_{\max}$ by at least ten percent, i.e., $1.1f_{\max}$. The lowest frequency of interest is determined by the frequency response characteristics of the mounted materiel under test. Define f_1 as the first mounted natural frequency of the materiel (by definition, f_1 will be less than or equal to the first natural frequency of a materiel component such as a circuit board) and, for laboratory testing purposes, define the lowest frequency of interest as $f_{\min} < f_1/2$, (i.e., $f_{\min}$ is at least one octave below f_1). $f_{SRS\min}$ can then be taken as $f_{\min}$. The maximax SRS is to be computed over the time range T_e and over the frequency range from $f_{\min}$ to $f_{SRS\max} > 1.1 f_{\max}$. From paragraph 1.1 above, the $f_{\max}$ relationship to f_{AA} is defined, however for SRS computation, if $F_s < 10 f_{SRS\max}$ the time history must be re-sampled to $Fs_r > 10 f_{SRS\max}$. The SRS frequency spacing in $\left[f_{\min}, 1.1 f_{\max} \right]$ is left to the discretion of the analyst, but should not be coarser that one-twelfth octave and, in general, of a proportional band spacing as opposed to a fixed band spacing (proportional band spacing is more in tune with the materiel modal frequency spacing, and results in fewer natural frequencies for processing).

A more complete description of the shock (potentially more useful for shock damage assessment) can be obtained by determining the maximax pseudo-velocity response spectrum. The maximax pseudo-velocity may be plotted on log-log paper with the abscissa as SDOF natural frequency, and the ordinate as pseudo-velocity in units of velocity. Alternatively, a more complete description of the shock (potentially more useful for shock damage assessment) 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 (SDOF natural frequency). This form of a pseudo-velocity SRS plot, as seen in Figure 516.8A-4, is widely accepted in Civil Engineering earthquake ground motion specifications, but historically has not been as common for mechanical shock display or specification.

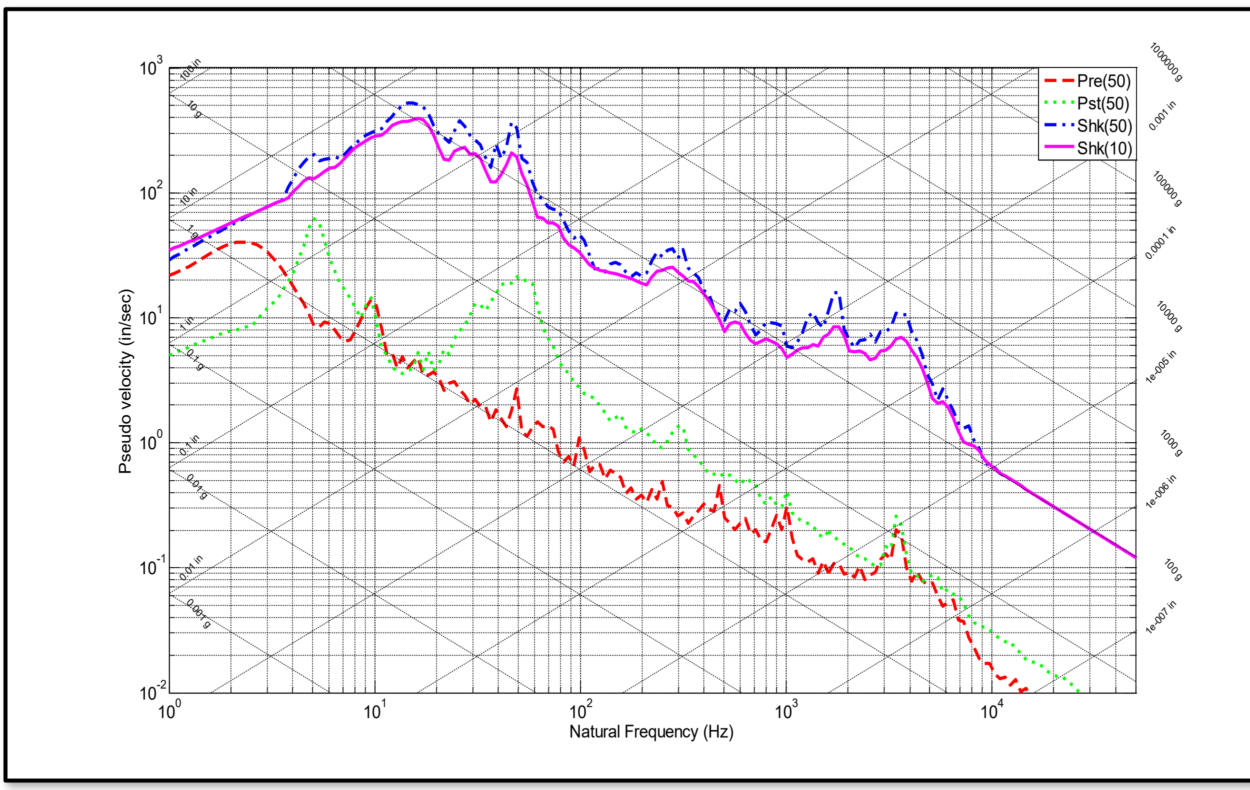

Figure 516.8A-4. Maximax pseudo-velocity SRS estimates for shock and noise floor segments.

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 (paragraph 7.1, references e and f). In the laboratory testing to meet a given specification with undesignated Q, use a Q value of 10 and a second Q value of 50 for comparison in the processing (see Figure 516.8A-4). Using two Q values, a damped value and a value corresponding to light damping provides an analyst with information on the potential spread of maximum materiel response. Recommend 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. This is useful in cases in which it is desirable to be able to correlate damage of simple systems with the shock. Two additional recommendations related to the validity of the measurement are as follows:

a. A pre-shock SRS of the ***measurement system noise floor*** over interval T_{pre} should be computed along with the return to noise floor interval T_{post} , i.e., ***post-shock noise floor***, and displayed on the same plot. These noise SRSs help to confirm the overall validity of the measurement if the "Pre" and "Post" times allow adequate accuracy for the SRS estimates, i.e., SRS estimates over very short time segments may not provide representative maximax SRS amplitudes at low natural frequencies. These SRS estimates should be computed at the Q=50 damping value (see Figure 516.8A-4). Refer to Annex B, paragraph 3 for additional guidance on establishing criteria for defining the noise floor.

b. For the ***shock*** segment, both the maximum positive and maximum negative acceleration and pseudo-velocity SRS estimates should be plotted for a minimum Q value of 10 over the frequency range for which the ***shock*** SRS values are displayed (see Figure 516.8A-5). The positive and negative SRS estimates should be very similar in nature as discussed in paragraph 1.4.2 and illustrated through example in Figures 516.8A-5&6. The low Q value should be able to detect acceleration time history anomalies similar to the time history integration. If positive and negative SRS maximax values are disparate, this could be an indicator of potential measurement system signal conditioning problems.

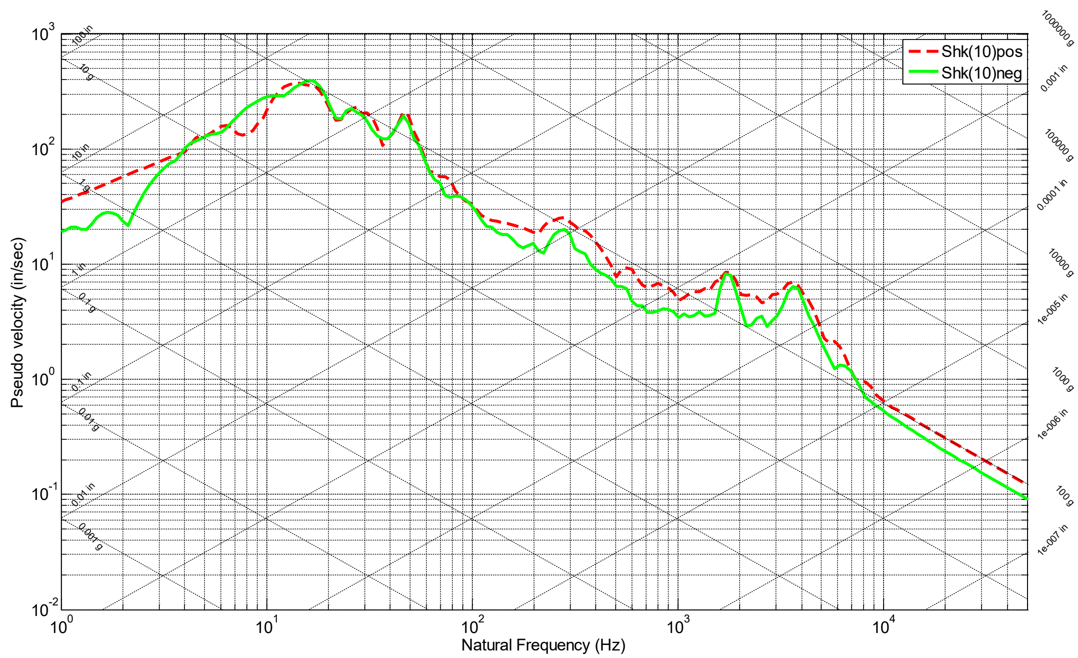

Figure 516.8A-5. *Shock* maximum and minimum pseudo-velocity SRS estimates.

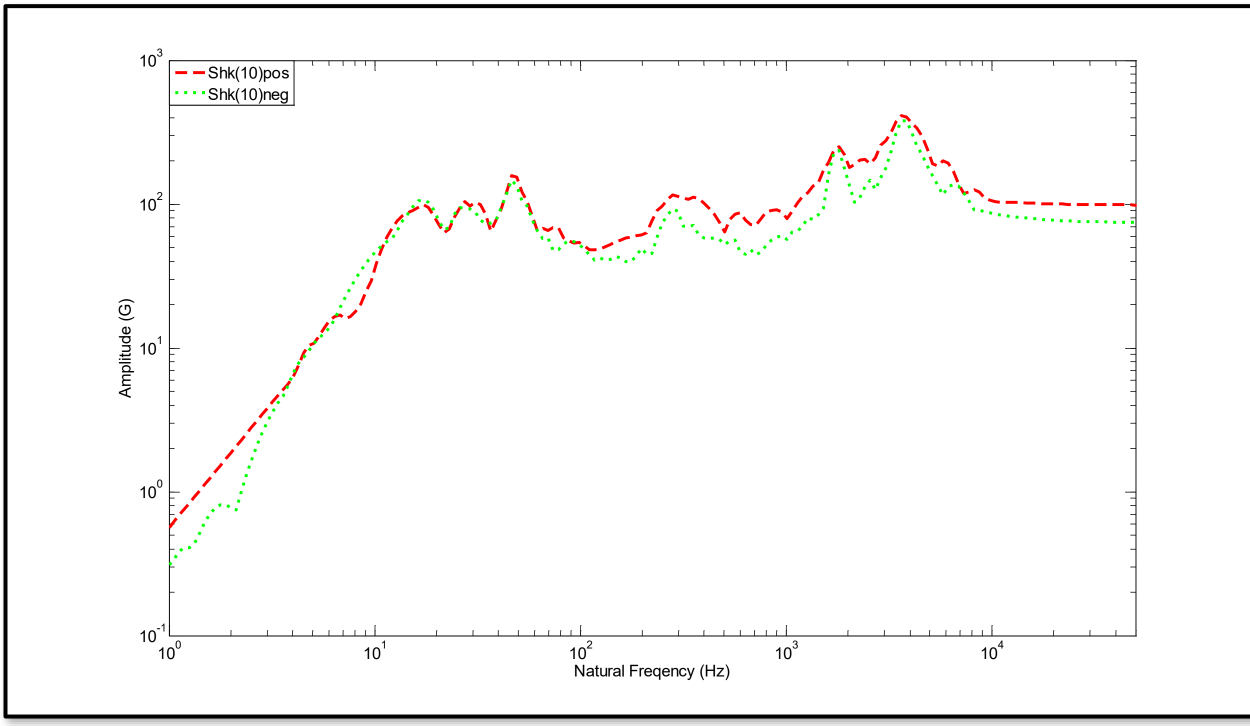

Figure 516.8A-6. ***Shock*** **maximum and minimum acceleration SRS estimates**.

1.4.2 Processing Example

For the shock time history displayed in Figure 516.8A-3, the sample rate was 51200 samples per second. The bandwidth of the data was from DC to 6000 Hz. The bandwidth of interest was from 10 Hz to 6000 Hz. The time history was re-sampled to 102,400 Hz to ensure a reasonable SRS computation thru 10 KHz as discussed in paragraph 1.4.1. The SRS estimates are actually plotted to 50 KHz to illustrate convergence at the low and high frequency extremes. Since even the slightest of bias error influences velocity estimates computed from acceleration data, it is recommended that minor DC bias should be corrected as required prior to performing pseudo velocity calculations (a severe bias error in the acceleration time may indicate more serious issues such as amplifier and/or transducer saturation leading to data validity concerns). Quality factors of 10 and 50 were used for computation of the acceleration and pseudo-velocity maximax SRS estimates except where noted. Except where noted, the computations were made with the standard ramp-invariant filter set. The abscissa of the plots is the undamped natural frequency of the SDOF system at a one-twelfth-octave band spacing.

Figure 516.8A-7 contrasts the ***shock*** maximax acceleration SRS for the Q values of 10 and 50, and for both ***measurement system noise floor*** and ***post-shock noise floor*** for a Q of 50. Figure 516.8A-4 provides the related information for the maximax pseudo-velocity SRS estimates. As expected, the shock is substantially greater than either noise floor SRS estimates. Ideally, the noise floor SRS should be 12dB or more below the acceleration SRS of the shock event across the frequency range of interest.

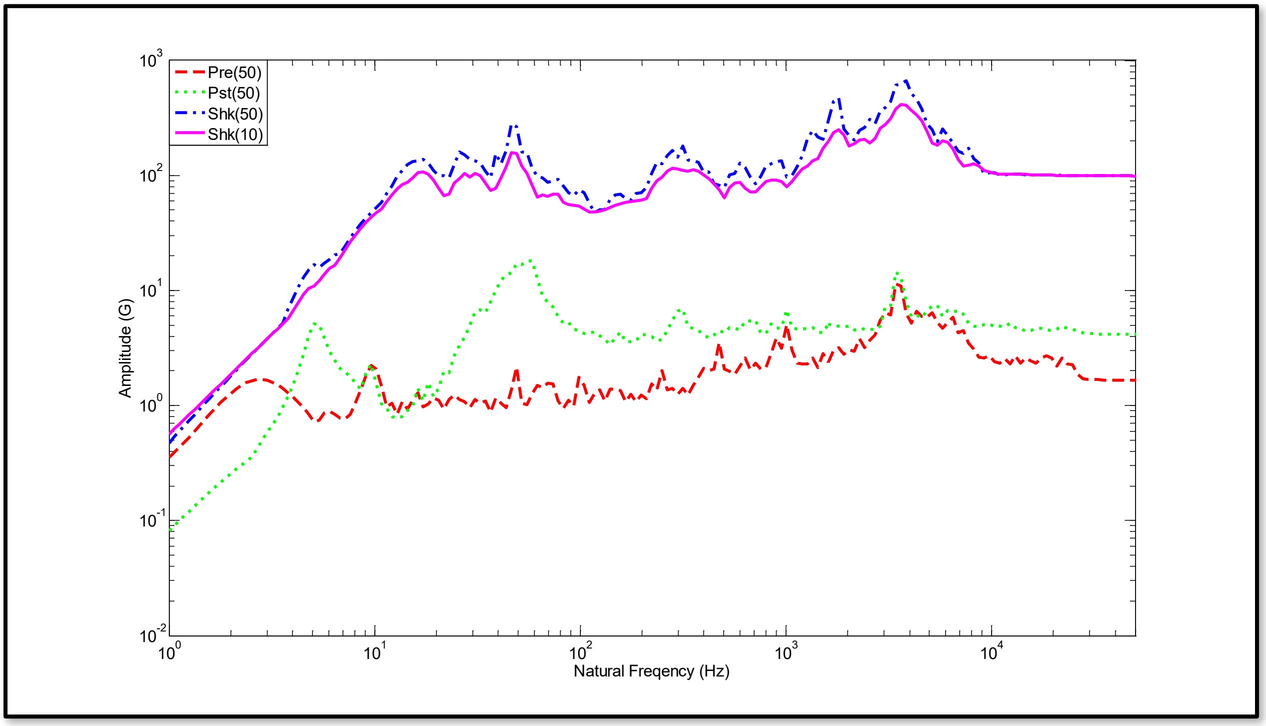

Figure 516.8A-7. Maximax acceleration SRS estimates for shock and noise floor segments.

As a time history validity check, Figure 516.8A-5 and Figure 516.8A-6 provides the positive and negative SRS estimates. It is noted that in these two figures neither the positive nor negative SRS value dominates the other; that would imply the time history information is valid.

1.5 Frequency Domain Identification Energy Spectral Density (ESD)

The ESD estimate is a properly scaled squared magnitude of the Fourier Transform of the total shock. Its counterpart, the Fourier Spectra (FS) is, in effect, the square root of the ESD, and may be useful for display but will not be discussed here. The importance of the ESD estimate is its properties relative to input/output system computations. That is for two acceleration measurements related as input and output, either (1) an estimate of the transfer function (magnitude/phase) between the input and output is possible, or (2) a transmissibility estimate (magnitude alone) can be determined by ratioing the output ESD over the input ESD. Further details and illustration of ESD estimates are provided in Annex B.

1.6 Single Event / Multiple Channel Measurement Processing Guidelines

When multiple measurements are made for a single configuration, generally pre-processing should proceed as if multiple channel analysis is to be performed. In particular, the pre-shock noise floor, the shock event, and the post-shock noise floor should be of the same duration, and this duration for the shock event should be determined based upon the "longest" duration measurement. Since SRS and ESD processing are generally insensitive to differences in the duration of significant energy content, such selection will allow multi-channel processing. It is imperative that for cross-energy spectral density estimates and energy transfer function estimates, the pre-processing, e.g., event selection durations, filtering, etc., on all measurement channels be the same. Pre-processing across multiple measurement channels involving integration of acceleration to determine velocity needs to correspond to the physics of the configuration. For high signal-to-noise ratios, useful information can be obtained from cross-spectral and transfer function estimates even though random error is high.

1.7 Measurement Probabilistic / Statistical Summary

Recommend that, whenever possible, two or more equivalently processed response measurements or test estimates be combined in some statistical manner for summary. This summary then can be used for test specification purposes to provide a level of confidence that the important information in the measurement or test has been captured. Paragraph 7.1, reference b, discusses some options in statistically summarizing processed results from a series of measurements or tests. The best summary option is generally dependent on the size of sample. Processed results from the SRS or ESD are typically logarithmically transformed to provide estimates that tend to be more normally distributed, e.g., estimates in dB. 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 C addresses the appropriate techniques for the statistical combination of processed test results as a function of the size of the sample and provides an example.

1.8. Other Processing

Other descriptive processes that tend to decompose the shock into component parts, e.g., product model, time domain moments (TDM), wavelets, SRS modal and power energy methods (PEM), etc., may be useful, but details of such descriptive processes are beyond the scope of this document, and generally fall in the area of analytical modeling. TDM and PEM show promise of being able to characterize and compare individual shocks among sets of similar shock time traces and perhaps provide insight into cause of materiel failure from shock. TDM (paragraph 7.1, reference k) assessment provides for characterization of the "form" of measured response with respect to both time and frequency. PEM (paragraph 7.1, reference l) attempts to estimate the energy absorbed within a simple modal structure of the materiel when the materiel's base attachment is the source of the shock input (or power input) to the materiel. PEM seems most useful for power comparison among similar measurements for shock, and has units (force*velocity) that relate to damage potential when applied to base motion relative to mass motion.

METHOD 516.8, ANNEX B

GUIDELINES FOR ADDITIONAL SHOCK TIME HISTORY VALIDATION AND PROCESSING

1. INTRODUCTION.

This Annex provides additional guidelines for shock time history assessment including validation, i.e., to detect any measurement system anomalies that would invalidate the measurement. For massive field shock measurement programs where time and budget constraints do not allow validation of individual shocks, at least one shock time history from each measurement channel needs to be individually validated, and careful examination of the time history for each subsequent shock from the measurement channel be examined for gross anomalies. Consistency relative to the test specification for processed information is acceptable as long as any inconsistency is investigated under shock time history validation. For example, the Normal Tolerance Limit (Annex C) when properly applied should be used only for collections of SRS estimates that have a similar shape; otherwise the variance is inflated beyond what might exist for field measured data under repeated experimental measurements.

2. COMPLEX SHOCKS.

This Method and this Annex are focused upon simple shocks such as in Figure 516.8-A1 (and repeated below as Figure 516.8B-1). Many shocks are not simple in nature. Figure 516.8B-2 displays a complex shock. The phenomenon producing this shock would appear to have three "rebounds." If it can be traced to a distinct phenomenon, the last of the four shocks might be separated out as a simple shock from the other three. A trained analyst and a clear understanding of the shock producing phenomenon are needed to justify any such decomposition of this complex shock. It probably would not be possible to use SRS synthesis for laboratory test, leaving TWR as the only option for laboratory testing. Cases in which it would appear that several "simple shocks" are in series should rely upon a trained analyst to identify individual "simple shocks" in concert with goals of the characterization, analysis, and specification. Any decomposition of a series of shocks should be related to the phenomenon producing the shock. For example, a catapult shock represents a non-simple shock that could be specified as two independent simple shocks, separated in time by approximately three seconds with an intervening transient vibration. See Figure 516.8-11. Gunfire Shock, Method 519.8, presents information on a repeated shock, the repetition rate being the gun-firing rate. The direct replication method is preferred over the synthesis method when non-simple shocks are being considered.

Generally, this Method has no recommendations beyond the use of TWR for laboratory test specification and laboratory testing for such complex shocks. It is important to maintain the integrity of the complex shock to the extent possible.

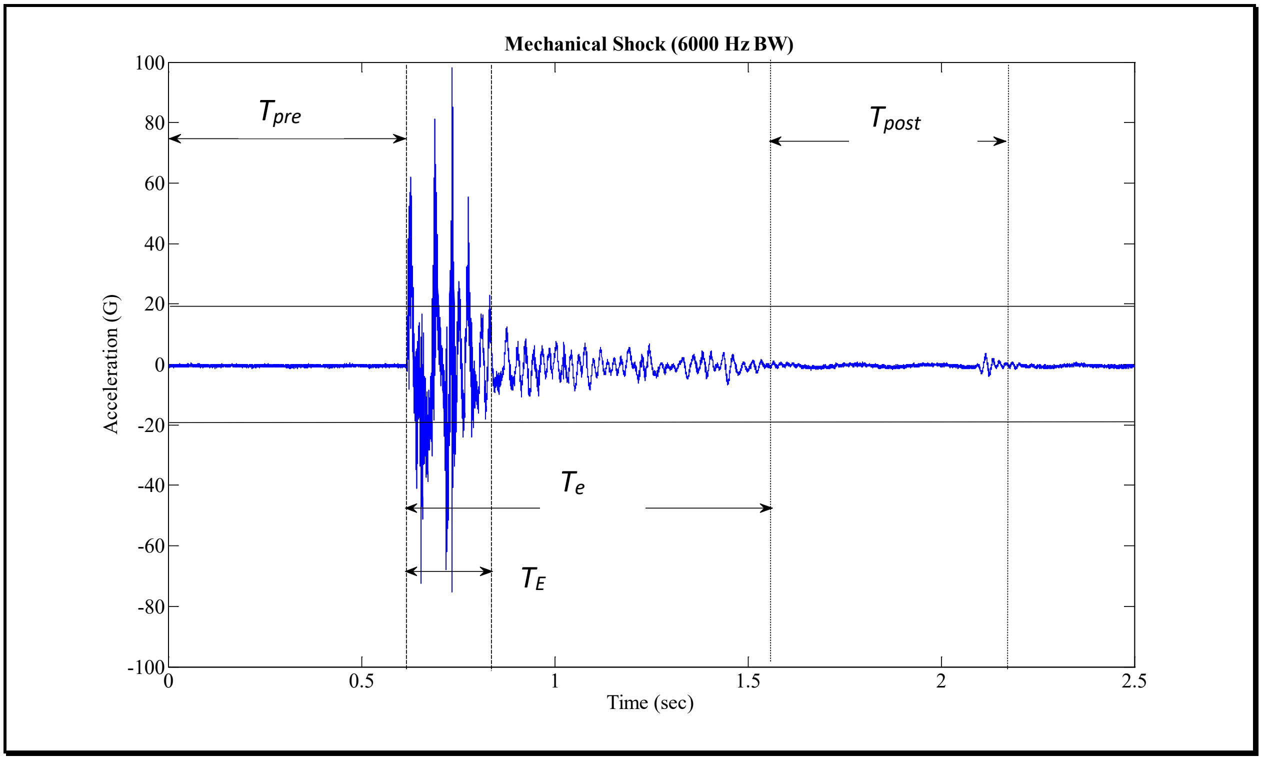

Figure 516.8B-1. Shock time history with segment identification and T_e and T_E time intervals illustrated.

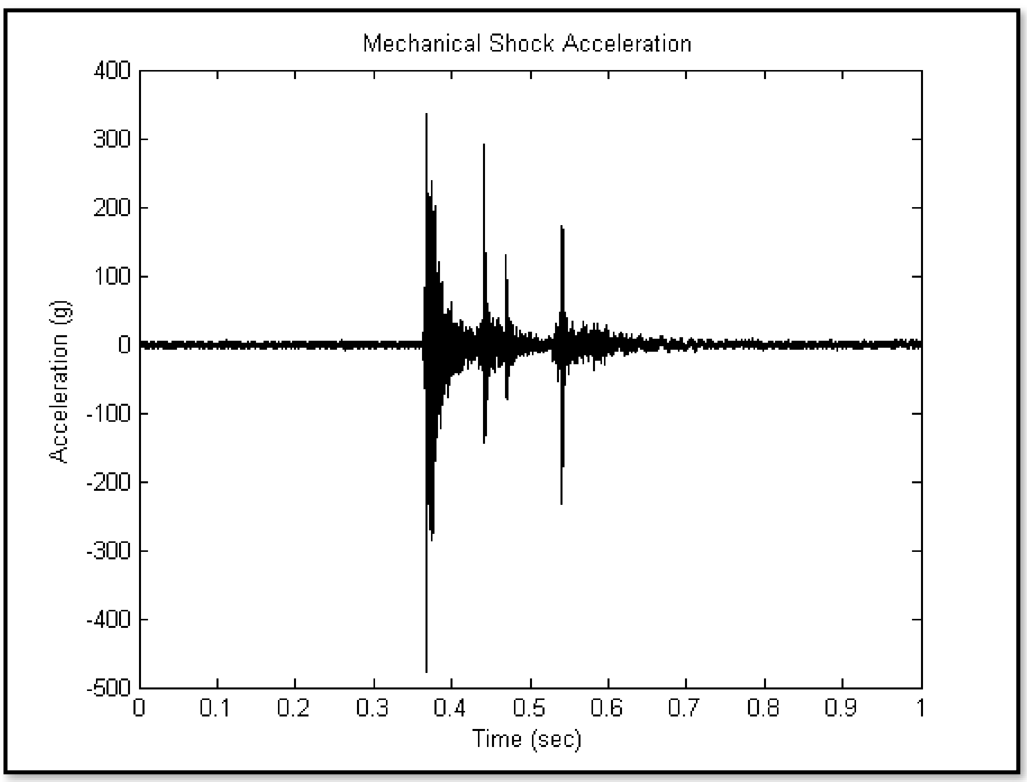

Figure 516.8B-2. A complex shock.

3. ADDITIONAL SIMPLE SHOCK PROCESSING AND VALIDATION.

3.1 Introduction.

In Annex A paragraph 1.3 of this method, the simple shock time segment for the instrumentation noise floor, the shock and the post shock noise floor are identified. In addition T_e and T_E are specified. Since the SRS is the primary analysis descriptor, both maximax acceleration and maximax pseudo-velocity estimates of the segments are displayed and interpreted. For verification purposes, the shock maximax positive and negative SRS estimates are displayed. Comparability of these estimates showed no signs of the shock being invalid. In this paragraph the following analysis will be undertaken providing (1) additional analysis of the shock, and (2) additional information regarding the validity of the shock. In particular:

a. The time history instantaneous root-mean-square.

b. The shock velocity and displacement displayed.

c. The time history ESD estimate displayed.

Annex A paragraphs 1.7-1.8 of this Method reference more advanced processing that is applicable to a single simple shock or useful in summarizing the information in an ensemble of shocks. No such advanced processing is provided in this Method.

3.2 Instantaneous Root-Mean-Square (RMS).

The "instantaneous rms" provides useful information that may not be apparent from examining the amplitude time history. In order to establish shock time intervals for processing, it is useful to consider the *"instantaneous rms"* of a measurement level. For the measurement $a(t)\quad 0 \le t \le T$, the *instantaneous rms* level is defined over the same interval as follows: $a_{irms}(t) = \sqrt{a^2(t)} \ge 0$ for $0 \le t \le T$, where *"irms"* stands for "*instantaneous root-mean-square level"*. It is assumed that any DC offset in a digitized measurement signal, $a(t)$, has been removed prior to computing a_{irms}. Figure 516.8B-3 displays the irms in absolute terms and in dB. In the dB display, no negative values are displayed. Observe that a_{irms} is computed point by point. Therefore, $\left|A_{pk}\right|$ as referenced in paragraph 1.3 in Annex A of this method, will be the maximum computed a_{irms}.

From the example of Figure 516.8B-3, it is clear that the "signal" approaches 40 dB, while the "noise floor" is on the order of 3 dB, roughly a signal-to-noise ratio of 37 dB. Relative to identifying the time of the beginning of the *post-shock noise floor*, T_{Post}, it is a matter for an experienced analyst in concert with the objectives of the shock assessment. Almost assuredly, post-shock instantaneous rms is greater than the pre-shock instantaneous rms, i.e., $a_{irms}(T_{Post}) > a_{irms}(t)$ for $t \le T_{Pre}$ since the measurement seldom returns to the *measurement system noise floor* levels because of change of boundary conditions as a result of the shock. If there is indication of periodic behavior in the time trace for $t > T_{Pk}$, the analyst must decide if analysis over this periodic "ringing" behavior is important for the shock specification. For SRS shock synthesis, it will be difficult to capture such periodic behavior and duplicate it in testing. For waveform replication, this periodic "ringing" behavior should be retained over a minimum of ten cycles if possible. For establishing the end of the range of T_e for a simple "well-behaved," i.e., sharply decaying shocks, it is recommended that the analyst examine times t at which $a_{irms}(t)$ for $t > T_{Pk}$ is at least 20dB (preferably 40 dB) below $a_{irms}(T_{Pk})$, and based upon judgment, select the zero-crossing for defining the end of beginning of T_e (or beginning of T_{Post}). Generally, criteria for defining and automatically determining T_{Post} are left to the discretion of the analyst, and selection of T_{Post} is much more inconsequential in analysis than selection of T_{Pre}. An estimate of the *measurement system noise floor* level will be useful in establishing T_{Post}. If arbitrary specification of $a_{irms}(t)$ levels is not feasible, then a relatively robust way of specifying the end of a *shock* and the beginning of the *post-shock noise floor* is to begin at the end of the measured data, *T,* and compute the mean rms signal level until a noticeable change in level is apparent. This can be accomplished by selecting an averaging time, e.g., ~5 percent of the estimated duration of the *shock,* and computing a moving average of time history values in the *measurement system noise floor* and *post-shock noise floor,* where the average is shifted at least ten times within an averaging time window and ideally computing the average at each time point. Usually, plotting these rms levels leads to simple identification of T_{Post}. Specifying the normalized random error for the rms estimate can enhance this procedure.

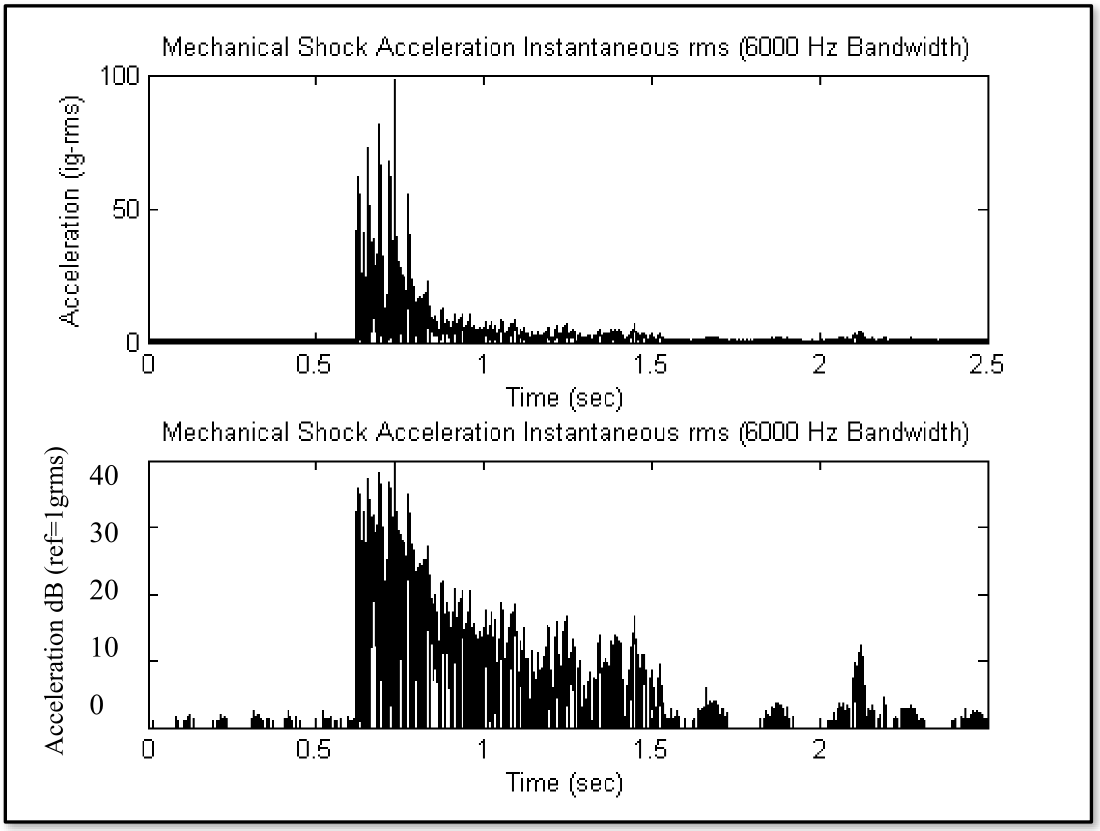

Figure 516.8B-3. Shock time history instantaneous root-mean-square.

This error is given by $\varepsilon_r = 1/2\sqrt{BT}$ for B the bandwidth and T the averaging time. A 95 percent confidence interval is defined by $\left[\hat{\sigma}_x\left(1-2\varepsilon_r\right) \le \sigma_x \le \hat{\sigma}_x\left(1+2\varepsilon_r\right)\right]$. For $\varepsilon \approx 0.025$, then $\left[0.95\hat{\sigma}_x \le \sigma_x \le 1.05\hat{\sigma}_x\right]$. Estimating both the *measurement system noise floor* and *post-shock noise floor* levels (standard deviations) for a specified normalized random error, e.g., 0.025, computing the 95 percent confidence intervals and determining the degree of overlap of the *measurement system noise floor* and *post-shock noise floor* confidence intervals can provide an analytical criterion for specifying the ed of a shock. Excessive noise that may not be Gaussian in form in the *post-shock noise floor* may be an indication of a degraded instrumentation signal conditioning system as a result of the shock, e.g., broken accelerometer sensing element, amplifier slew rate exceeded, etc. In this case, the post-shock integrity of the measurement system needs to be validated (see paragraph 4 below).

If such computation and subsequent displays are not available, the assessment for the end of the shock, and beginning of the post-shock noise floor can be determined based on examination of a representative sample of the positive and negative peaks in the time history (usually starting from the end of the measurement and avoiding single spurious "noise spikes") without regard to sign. In this case, the maximum peak (positive or negative) can be estimated in absolute units, and then a -20 dB, -30 dB, and -40 dB level down from the validated peak A_{pk}, estimated by $-y = 20\log_{10}\left(\left|A_{pk}\right|/\left|A\right|\right)$ for y the desired dB decrement, and A representing either a positive or negative peak.

Because of the need to balance the normalized random error with the normalized bias error to determine optimum averaging times, it is not recommended that the instantaneous rms values be smoothed through short-time-averaging.

3.3 Shock Velocity/Displacement Validation Criteria.

Two steps are necessary for examining an unprocessed acceleration time history for purposes of validation.

a. The first step is to clearly define the bandwidth of the measurement time history. The signal conditioning configuration and the ESD estimate to be discussed in paragraph 3.4 (below) will be helpful. The time history bandwidth will determine if TWR is a laboratory test option.

b. The second step relates to integration of the time history to see if the velocity and displacement make physical sense. Velocity can usually be determined from direct integration of the shock acceleration after the shock has had its mean removed (velocity begins at zero and ends at zero), or has been high pass filtered to remove any DC component and other very low frequency information. Subsequent removal of the velocity mean or DC information in the velocity allows integration of the velocity to get displacement. As a minimum requirement, shock acceleration time traces should be integrated to provide velocity, and the velocity should have a clear physical interpretation, e.g., oscillatory behavior and near zero velocity at the "beginning" and the "end" of the shock. Velocity tends to be quite sensitive to sensor or signal conditioning anomalies that invalidate measurements. Integration of the velocity to obtain displacement should be considered an extended requirement, and reasonable values for displacement should be apparent. The ***form*** of velocity (or displacement) with respect to oscillatory behavior needs to be examined for reasonableness. That is, a ***form*** of velocity that displays little oscillatory behavior should be suspect. Figure 516.8B-4 displays velocity computed via mean removal alone. Figure 516.8B-5 displays the results of integrating velocity to arrive at displacement. For displacement, "DC" removal was performed on the velocity time history. Examination of both these plots, knowing the physical nature of the test, shows (1) reasonableness of peak amplitudes, and range from positive to negative values, (2) distinct and substantial oscillatory behavior during the "shock," and (3) characteristic pre- and post- shock noise floor behavior. It would appear that the bandlimited measurement does not have readily identifiable anomalies, and the acceleration time trace can be considered valid for further processing that is designed to either support or refute this validation.

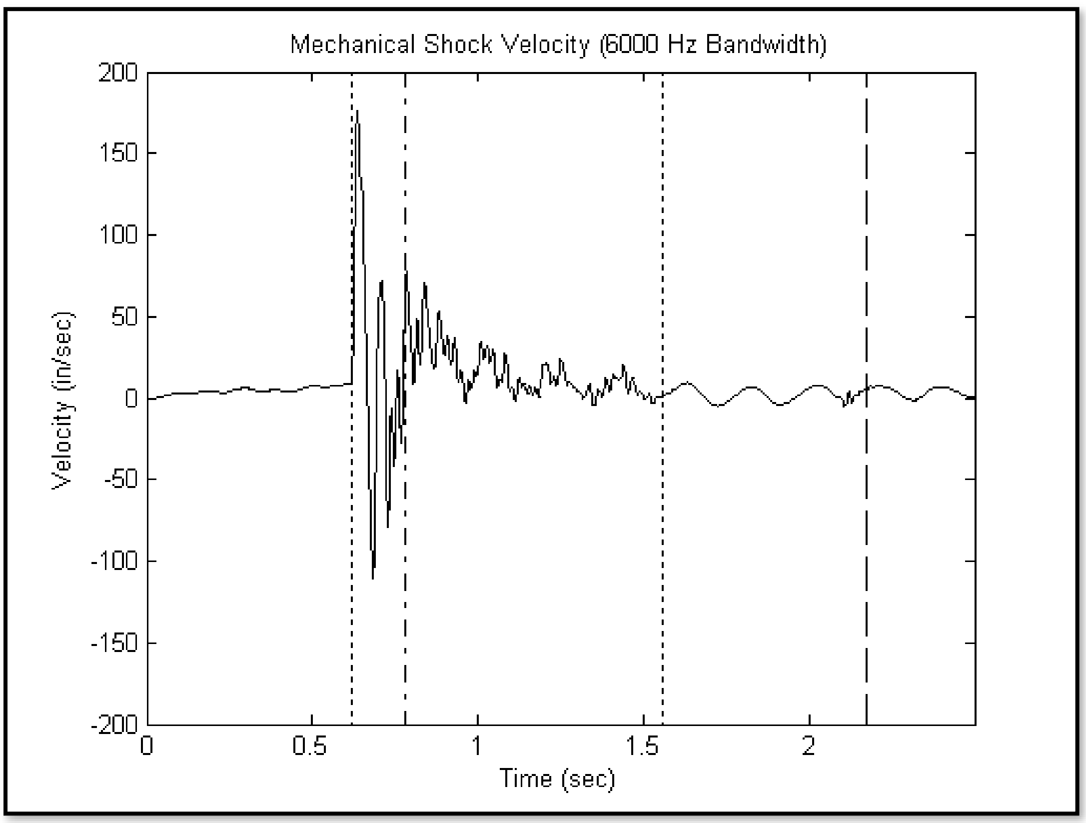

Figure 516.8B-4. Measurement velocity via integration of mean (DC) removed acceleration.

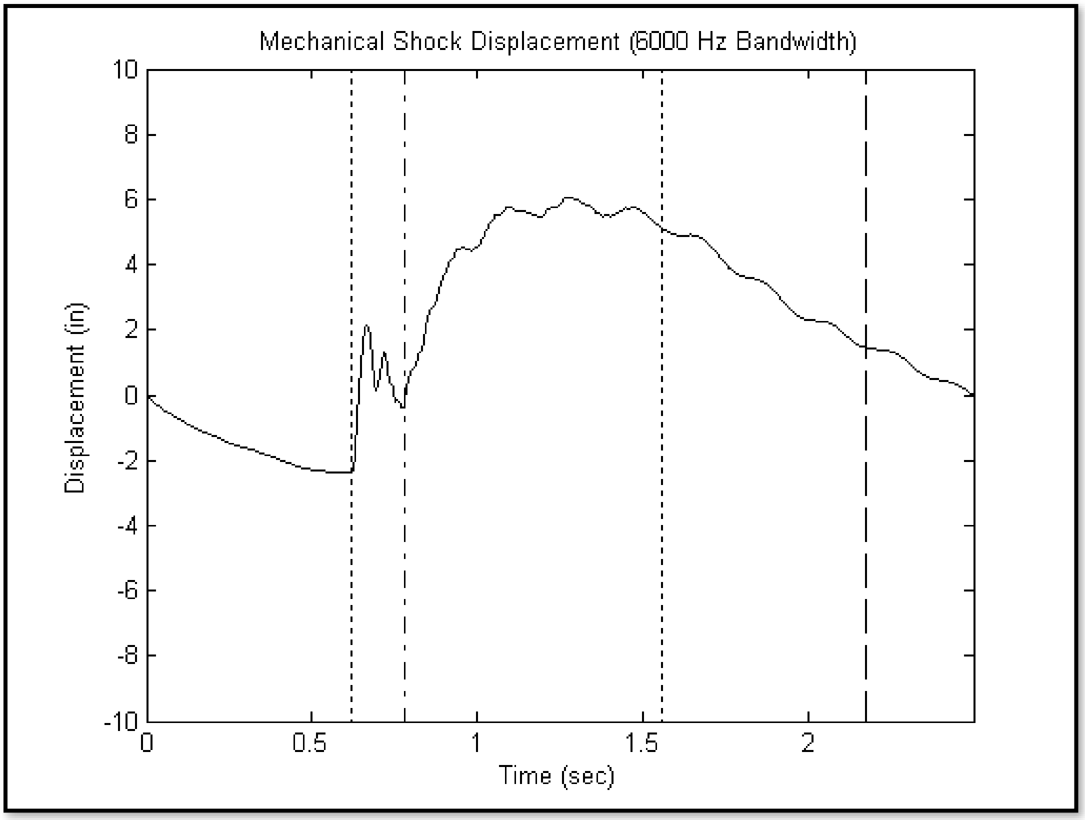

Figure 516.8B-5. Measurement displacement via integration of velocity after mean (DC) removal.

At this point in the analysis, if the velocity and displacement validation checks, particularly the velocity validation check, do not seem to correspond with the physics of the test, a detailed investigation of the reason for this discrepancy must be instigated. For example, velocities that are not physically realizable call for such an investigation. For one of a kind and expensive tests, it may be possible to recover meaningful data based upon advanced processing techniques.

3.4 ESD Estimate.

The ESD is a single block periodiogram sampled at a uniform set of frequencies distributed over the bandwidth of interest, and displayed as a two-dimensional plot of amplitude units ($\text{"units}^2 - \text{sec}/\text{Hz"}$) versus frequency in Hz. In determining the estimate, the Fast Fourier Transform block size must include the entire shock above the measurement system noise floor, interval T_e, otherwise the low frequency components will be biased. Selection of an analysis filter bandwidth may require padding with zeros beyond the effective duration, T_e. Zero padding results in a frequency interpolation of the ESD estimate. Generally, a rectangular window will be assumed in the time domain, however, other windows are permissible, e.g., Kaiser, as long as the analyst understands the effects of the window shape in the frequency domain, since time domain multiplication results in frequency domain convolution. The ESD description is useful for comparing the distribution of energy within selected frequency bands among several shocks, provided the analysis frequency bandwidth is the same, and it is realized that the estimates have approximately 100% normalized random error. Figure 516.8B-6 displays the ESD estimate for the shock time history in Figure 516.8B-1. By either (1) averaging n adjacent ESD ordinates (keeping estimate bias a minimum), or (2) averaging n independent, but statistically equivalent ESD estimates, the percentage of normalized random error can be decreased by a factor of $1/\sqrt{n}$. Frequency averaging for periodiogram estimates is well defined in reference 6.1j. ESD estimates for noise floor segments tend not to be particularly useful for examining the validity of the measurement system because of the nondescript behavior of the noise floor.

For validation purposes, the ESD estimate should display proper frequency domain characteristics. In particular, the DC region should be rolled-off if the DC time history component has been removed, and the maximum bandwidth levels should be rolled-off if aliasing is not present. If the maximum bandwidth levels show an increase, it is quite possible that aliasing is present provided the time history has not been previously filtered. An ESD estimate needs to be computed on a high-passed time history that has been not bandlimited by digital filtering in any way.

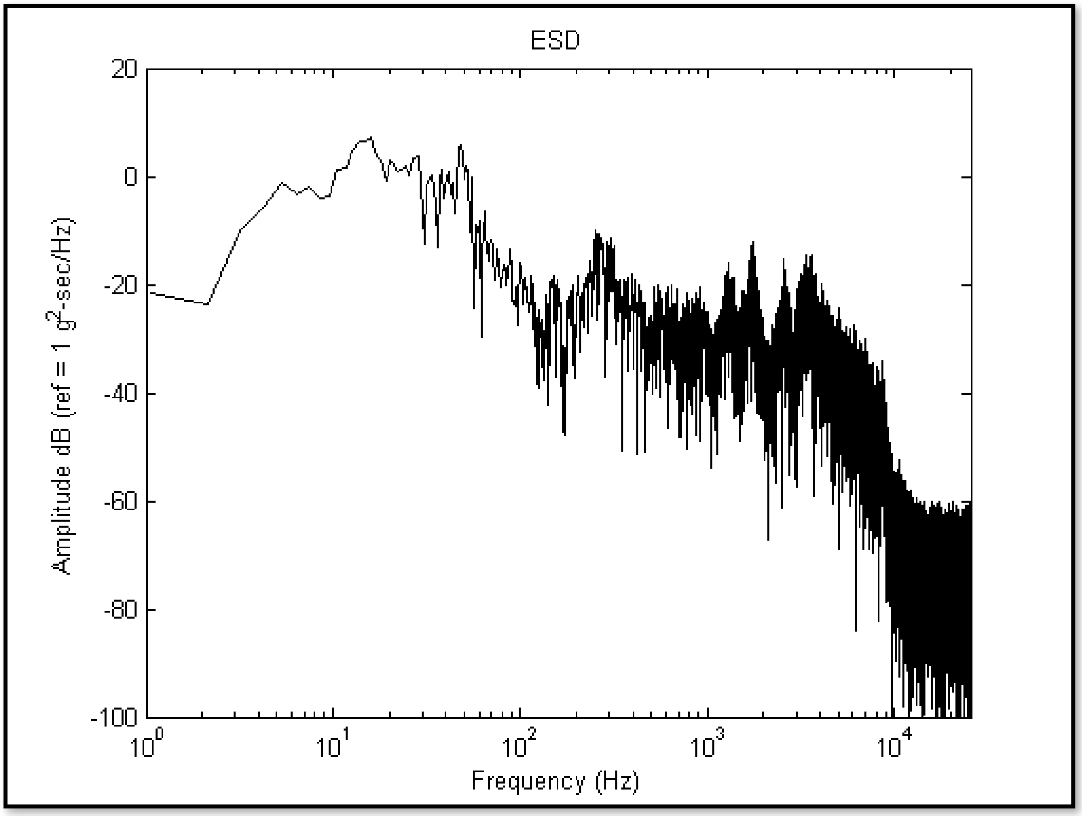

Figure 516.8B-6. Shock ESD estimate.

4. SHOCK IDENTIFICATION AND ANOMALOUS MEASUREMENT BEHAVIOR.

In the course of examination of some 216 mechanical shocks from a single test series (reference paragraph 6.1.c) the variation in time history form is substantial, and requires the judgment of an analyst for development of a specification for which shock synthesis for an electrodynamic exciter might be appropriate. Figures 516.8B-7 through 9 display typical anomalous time histories related to signal conditioning or transducer problems. The identification of the problem is assumed, and generally based upon a visual examination of the time history.

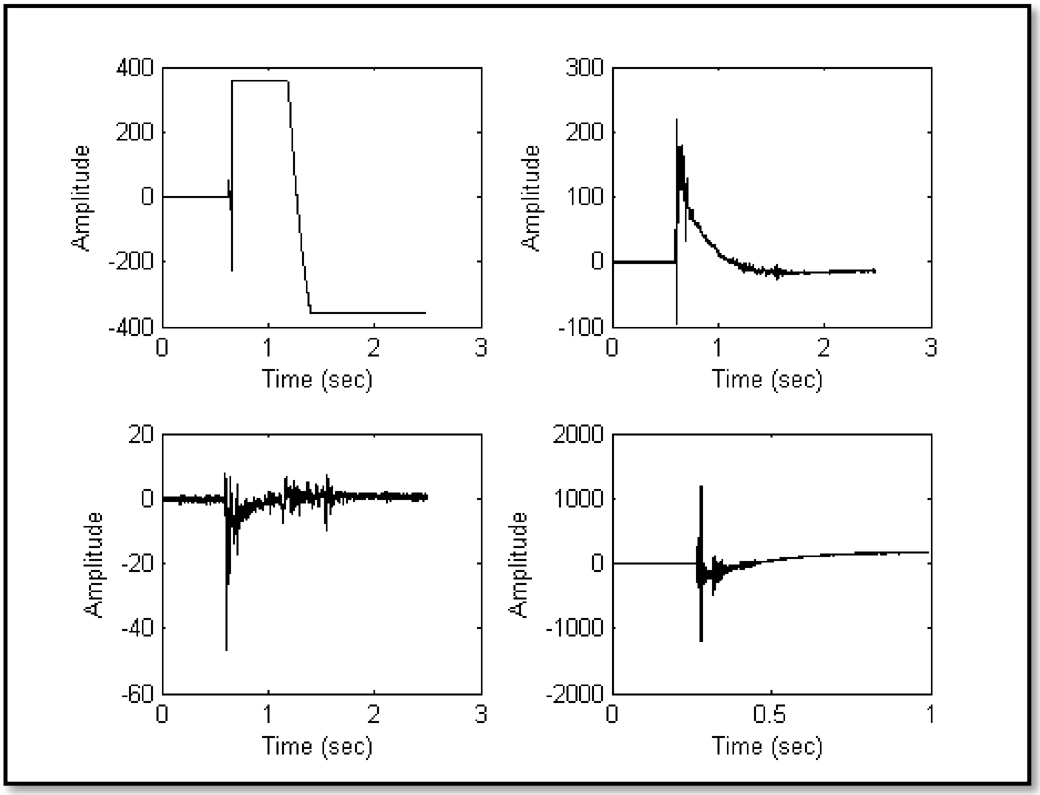

Figure 516.8B-7. Measurement input overdriving the signal conditioning with clipping.

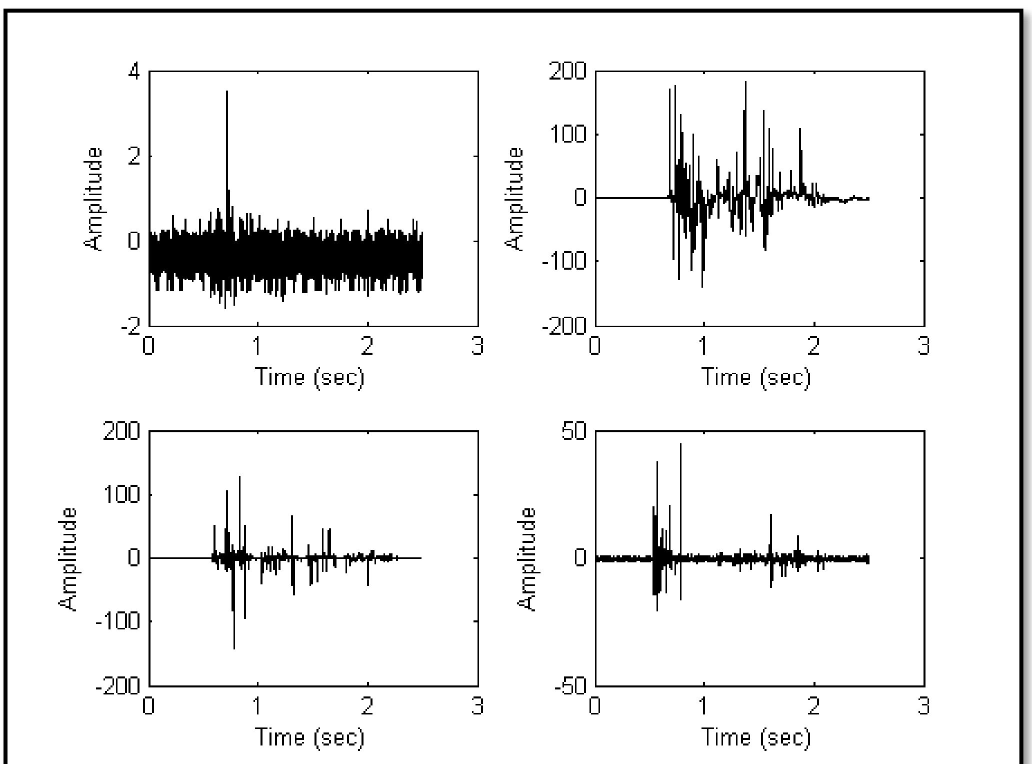

Figure 516.8B-8. Noisy or missing measurement signals.

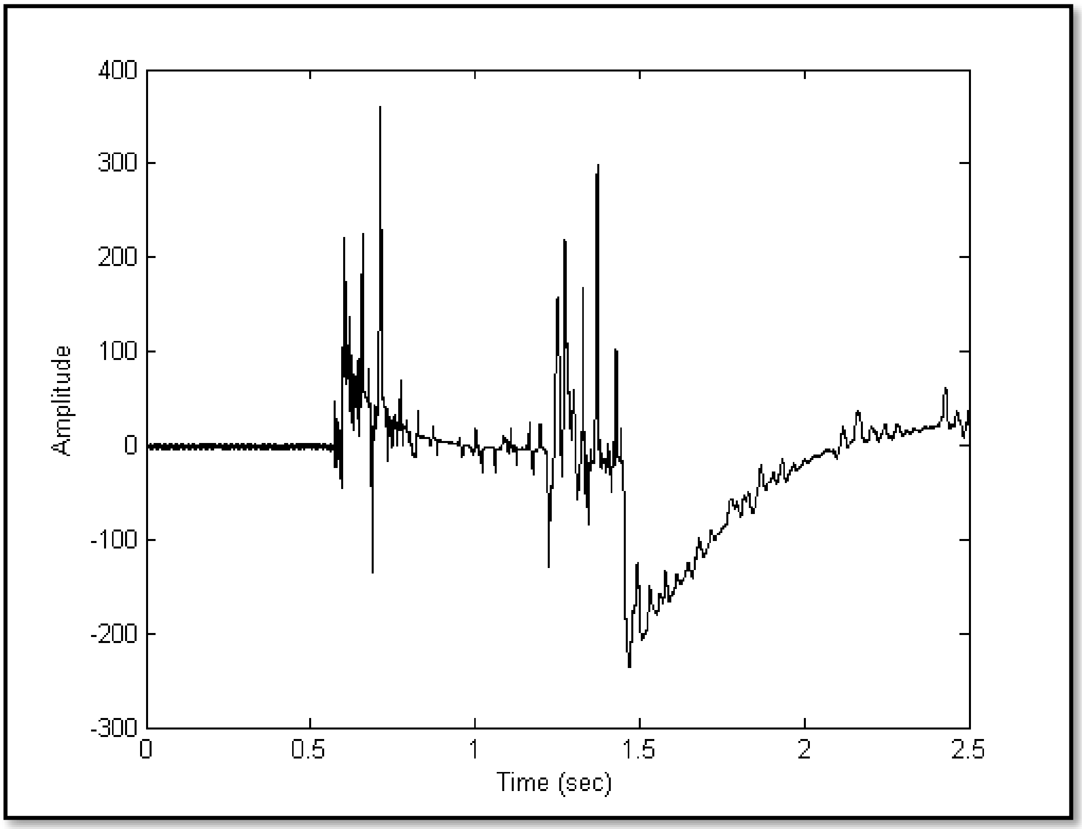

Figure 516.8B-9. Combination amplifier overdriving and noise.

Based on similar displays, all of these time histories must be rejected and the source of the problem identified before continuing to make measurements. Figure 516.8B-8 illustrates noise in the system that could be from a loose connector or even a missing sensor. Once again, measurement time histories of this form need to be rejected. Measurement time histories with a few clearly identified noise "spikes" may often be "corrected" by a trained analyst and used.

Finally, Figure 516.8B-9 illustrates a combination of amplifier over driving and noise corruption. Once again, this measurement must be rejected.

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METHOD 516.8, ANNEX C

STATISTICAL AND PROBABILISTIC CONSIDERATIONS FOR DEVELOPING LIMITS ON PREDICTED AND PROCESSED DATA ESTIMATES

1. SCOPE.

1.1 Purpose.

This Annex provides information relative to the statistical and probabilistic characterization of a set of data for the purpose of defining an "upper limit" on the data set. Such an upper limit may be subsequently used for an enveloping procedure for specification development (this Annex provides no guidance on "enveloping procedures," where an "enveloping procedure" is defined as a procedure providing polynomial interpolation of spectral information for break point definition used directly in exciter control). Although limit estimates defined below may be applicable over a range of different independent variables it will be assumed for convenience that the independent variable is labeled "frequency". (For other independent variables, e.g., time, serial correlation in the estimates may need to be accounted for in establishing limits.) It is assumed that input is empirical and representative of one of more random processes with unknown probabilistic specification (i.e., if the probabilistic structure of the random processes is known, statistical considerations contained herein would not be pertinent.)

1.2 Application.

Information in this Annex is generally applicable to two or more frequency domain estimates that are either predicted based on given information, or on time domain measurements processed in the frequency domain according to an appropriate technique, e.g., 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 on a data set in a statistically correct way with potential for probabilistic interpretation. Statistically based lower limits may be established on a data set of positive amplitude; e.g., ASD or SRS estimates, by inverting the amplitudes and proceeding as in the case of establishment of upper limits, subsequently inverting the resulting 'upper limit' for the desired statistically based lower limit. When using a dB representation of amplitude, the process of inversion represents a change in sign for the amplitude, and subsequent application of the 'upper limit' procedure such that with sign reversal results in the desired statistically based lower limit.

2. DEVELOPMENT.

2.1 Limit Estimate Set Selection.

It is assumed that the analyst has clearly defined the objective of the prediction and/or measurement assessment, i.e., to provide a statistically viable limit estimate. 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 affect the limit considerations. For measured field data digitally processed such that estimates of the ASD, SRS, ESD, or FS are obtained for single sample records, it is imperative to summarize the overall statistics of "similar" estimates selected in a way so as to not bias the limits. Since excessive estimate variance at any independent variable value may lead to overly conservative or meaningless limits depending upon the procedure selected, this choice of "similar estimates" is a way of controlling the variance in the final limit estimates. To ensure that similar estimates are not physically biased, the measurement locations might be chosen randomly, consistent with the measurement objectives. Likewise, 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 materiel 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 "materiel zones," i.e., points of similar response at varying locations, or (3) some combination of (1) and (2). In any case, similar estimates assume that there is a certain degree of homogeneity among the estimates across the frequency band of interest.

2.2 Estimate Processing Considerations.

Once the set of "similar estimates" has been identified the following list of assumptions can be used to ensure limit determination is meaningful.

a. All estimates are defined over the same bandwidth and at the same independent variable (this is referred to as a "fixed design").

> **NOTE:** A "random design" allows the independent variable to vary among estimates and requires principles of distribution-free non-parametric regression techniques to assess the relationship among the estimates.

b. The uncertainty or error in individual estimate processing (random or bias processing error) does not significantly affect limit considerations.

> **NOTE:** For Fourier based estimates such as ASD, ESD or FS, the estimate accuracy will be defined in terms of statistical degrees of freedom. For example, a basic periodogram estimate has two statistical degrees of freedom, but through block averaging (in time) using the Welch procedure or averaging of adjacent frequencies (in frequency), the statistical degrees of freedom in the estimate can be increased with subsequent decrease in estimate random error, but potential increase in corresponding estimate bias error. It is important in making estimates that the processing error be minimized (or optimized) in some sense through either extending (if possible) the stationary random time history processing length, or by increasing the estimate bandwidth by frequency averaging. In the case of non-Fourier based estimates such as the SRS, there is little guidance on processing bandwidth selection, except that based upon physical considerations for single-degree-of-freedom systems. In these cases, recommend selection of different damping factors along with bandwidths, and comparing the limits.

c. Individual estimates from a given measurement are uncorrelated with one another, i.e., there is no serial correlation with respect to the independent variable.

> **NOTE:** For Fourier based estimates, this assumption is usually fulfilled because of the "orthogonality" of the Fourier transform. For non-Fourier based estimates, e.g., SRS, some serial correlation in estimates is unavoidable.

d. Transformed estimates often are more in line with the assumptions behind the limit determination procedures. For example, using a logarithm transform to yield the estimates in dB will generally leave the estimate set at a given frequency closer to being normally distributed.

e. Near "optimal limit estimates" may be determined potentially by reprocessing available time trace information through change in the spacing of the independent variable, i.e., the analysis bandwidth. For the case of prediction, this would mean interpolation of the given prediction estimates.

f. Parametric and non-parametric based limit estimates are available. The analyst should select one or more limit estimates that best aligns with (a) the desired interpretation of the limit assessment, and (b) the character of the set of "similar estimates".

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 processed estimates at a single frequency within the overall estimate bandwidth,

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

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 516.8C-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 percent of the values will lie below the limit with 100 γ percent confidence. For $\beta = 0.95$ and $\gamma = 0.50$, this is referred to as the 95/50 limit.

Table 516.8C-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	2.75	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	2.07	2.57	3.53	2.35	2.91	3.98
11	1.32	1.70	2.40	2.01	2.50	3.44	2.28	2.82	3.85
12	1.32	1.69	2.39	1.97	2.45	3.37	2.21	2.74	3.75
13	1.31	1.69	2.39	1.93	2.40	3.31	2.16	2.67	3.66
14	1.31	1.68	2.38	1.90	2.36	3.26	2.11	2.61	3.58
15	1.31	1.68	2.38	1.87	2.33	3.21	2.07	2.57	3.52
16	1.31	1.68	2.38	1.84	2.30	3.17	2.03	2.52	3.46
17	1.31	1.68	2.37	1.82	2.27	3.14	2.00	2.49	3.41
18	1.30	1.67	2.37	1.80	2.25	3.11	1.97	2.45	3.37
19	1.30	1.67	2.37	1.78	2.23	3.08	1.95	2.42	3.33
20	1.30	1.67	2.37	1.77	2.21	3.05	1.93	2.40	3.30
21	1.30	1.67	2.36	1.75	2.19	3.03	1.91	2.37	3.26
22	1.30	1.67	2.36	1.74	2.17	3.01	1.89	2.35	3.23
23	1.30	1.67	2.36	1.72	2.16	2.99	1.87	2.33	3.21
24	1.30	1.67	2.36	1.71	2.15	2.97	1.85	2.31	3.18
25	1.30	1.67	2.36	1.70	2.13	2.95	1.84	2.29	3.16
26	1.30	1.66	2.36	1.69	2.12	2.94	1.82	2.28	3.14
27	1.30	1.66	2.35	1.68	2.11	2.92	1.81	2.26	3.12
28	1.30	1.66	2.35	1.67	2.10	2.91	1.80	2.25	3.10
29	1.29	1.66	2.35	1.66	2.09	2.90	1.79	2.23	3.08
30	1.29	1.66	2.35	1.66	2.08	2.88	1.78	2.22	3.06
32	1.29	1.66	2.35	1.64	2.06	2.86	1.76	2.20	3.03
34	1.29	1.66	2.35	1.63	2.05	2.84	1.74	2.18	3.01
36	1.29	1.66	2.35	1.62	2.03	2.82	1.72	2.16	2.98
38	1.29	1.66	2.35	1.61	2.02	2.81	1.71	2.14	2.96
40	1.29	1.66	2.35	1.60	2.01	2.79	1.70	2.13	2.94
42	1.29	1.66	2.34	1.59	2.00	2.78	1.69	2.11	2.92
44	1.29	1.66	2.34	1.58	1.99	2.77	1.67	2.10	2.91
46	1.29	1.66	2.34	1.57	1.98	2.76	1.66	2.09	2.89
48	1.29	1.66	2.34	1.57	1.97	2.74	1.65	2.08	2.88
50	1.29	1.65	2.34	1.56	1.97	2.73	1.65	2.07	2.86
55	1.28	1.64	2.33	1.54	1.94	2.70	1.62	2.04	2.83
60	1.28	1.64	2.33	1.53	1.93	2.68	1.60	2.02	2.80
65	1.28	1.64	2.33	1.52	1.91	2.67	1.59	2.00	2.78
70	1.28	1.64	2.33	1.51	1.90	2.65	1.58	1.99	2.76
75	1.28	1.64	2.33	1.50	1.89	2.64	1.57	1.97	2.74
80	1.28	1.64	2.33	1.49	1.88	2.63	1.56	1.96	2.73
85	1.28	1.64	2.33	1.48	1.88	2.62	1.55	1.95	2.71
90	1.28	1.64	2.33	1.48	1.87	2.61	1.54	1.94	2.70
95	1.28	1.64	2.33	1.47	1.86	2.60	1.53	1.93	2.69
100	1.28	1.64	2.33	1.47	1.86	2.60	1.52	1.92	2.68
500	1.28	1.64	2.33	1.36	1.74	2.44	1.38	1.76	2.47
1000	1.28	1.64	2.33	1.34	1.71	2.41	1.35	1.73	2.43
∞	1.28	1.64	2.33	1.34	1.71	2.41	1.35	1.73	2.43

The table (Table 516.8C-I) from paragraph 6.1, reference b, 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.

2.3.2 NPL - Upper Normal Prediction limit.

The upper normal prediction limit (NPL) 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

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

where $\alpha = 1 - \gamma$. $t_{N-1;\alpha}$ is the student t distribution variable with N-1 degrees of freedom at the $100\,\alpha = 100(1-\gamma)$ 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 estimate zone (paragraph 6.1, reference b).

2.4 Non-parametric Upper Limit Statistical Estimate Procedures.

If there is some reason to believe that the estimate at a given frequency, after they have been logarithm-transformed, will not be sufficiently normally distributed to apply the parametric limits defined above, 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 Envelope (ENV) - Upper Limit.

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

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

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 Distribution Free Limit (DFL) - Upper Distribution-Free Tolerance Limit.

The distribution-free tolerance limit that uses 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.

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

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

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

b. Given N and γ, the proportion β can be determined.

c. 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, $N \leq 13$, and comparatively large β, $\beta > 0.95$. DFL(N,β,γ) is sensitive to the estimate bandwidth.

2.4.3 Empirical Tolerance Limit (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 analysis 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

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

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

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

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

Using m_j implies that the value of ETL(β) at j exceeds β percent of the values with 50 percent 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, apply this limit only if the number of measurement points, N, is greater than 10.

3. EXAMPLE.

3.1 Input Test Data Set.

Table 516.8C-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 data sets). Table 516.8C-II is used in the upper limit determinations in paragraphs 3.2 and 3.3 below.

Table 516.8C-II. Input test data set.

Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5
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

3.2 Parametric Upper Limits.

The upper normal one-sided tolerance limit (NTL) is computed as 95/50 limit with 50 percent confidence that at least 95 percent of the values will lie below this limit for $k_{N,\beta,\gamma} = 1.68$ from Table 516.8C-I. The upper normal prediction limit (NPL) is computed with a 95 confidence coefficient at the 95 percent point of the distribution where $t_{N-1;\alpha} = t_{13;0.05} = 1.771$. Figure 516.8C-1 displays the data, and Figure 516.8C-2 displays the two parametric upper limits.

NOTE: The degree of conservativeness in the normal prediction upper limit over the normal tolerance limit.

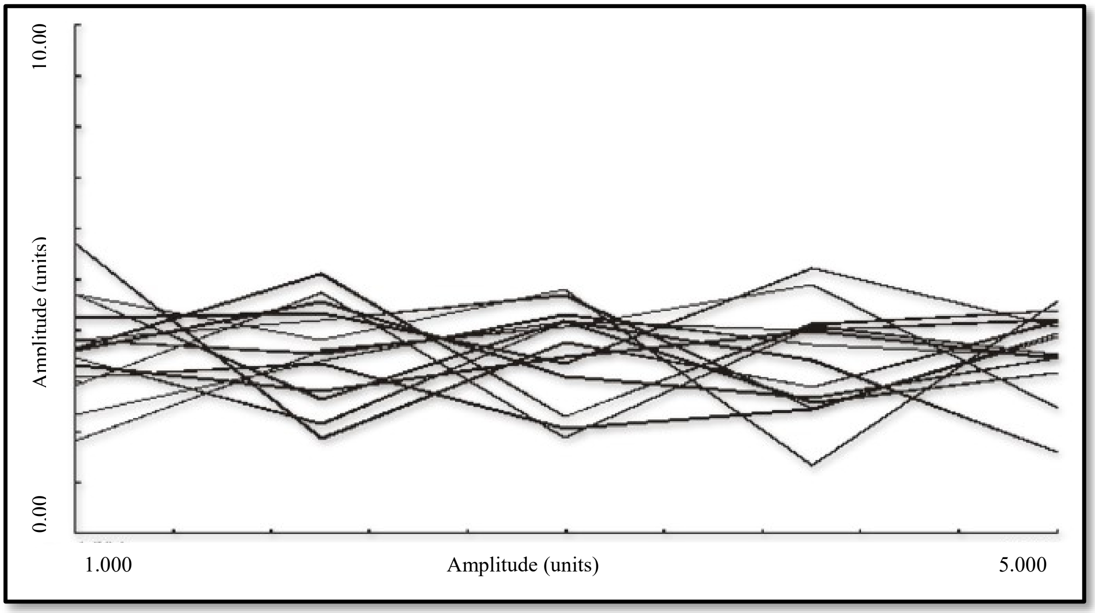

Figure 516.8C-1. Input test data set.

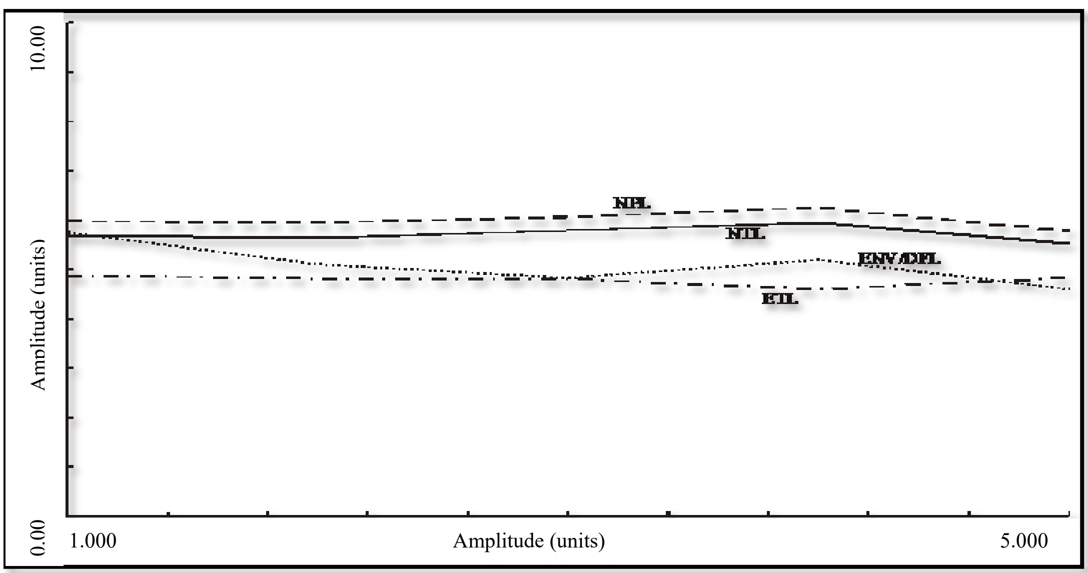

Figure 516.8C-2. Parametric and non-parametric upper limits.

3.3 Non-parametric 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 in Figure 516.8C-2. This represents one curve with two interpretations. The 95 percent upper empirical tolerance limit (ETL) is also displayed on Figure 516.8C-2 where at least 95 percent of the values will be exceeded by this limit with 50 percent confidence. The data are displayed on Figure 516.8C-2 for comparison purposes.

3.4 Observations.

The "flatness" of the upper limits on Figure 516.8C-2 attests to the homogeneity of the data in Table 516.8C-II. It is apparent from Figure 516.8C-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 516.8C-II in addition to demonstrating, for this case at least, the non-statistical ENV, the statistically based DFL and the ETL basically agree with regard to the upper limit magnitude. For non-homogeneous data sets ETL would not be expected to agree with ENV or DFL. For small data sets, ETL may vary depending upon if parameter k rounds upward or downward.

4. RECOMMENDED PROCEDURES.

4.1 Recommended Statistical Procedures for Upper Limit Estimates.

Paragraph 6.1, reference b, provides a detailed discussion of the advantages and disadvantages of estimate upper limits. The guidelines in this reference are recommended. 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. Paragraph 6.1, reference b 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.