METHOD 519.8

GUNFIRE SHOCK

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METHOD 519.8

GUNFIRE 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 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.

1.1Purpose.

Gunfire shock tests are performed to provide a degree of confidence that materiel can structurally and functionally withstand the relatively infrequent, short duration transient high rate repetitive shock input encountered in operational environments during the firing of guns.

1.2 Application.

Use this Method to evaluate the structural and functional performance of materiel likely to be exposed to a gunfire shock environment in its lifetime. This test Method is applicable when materiel is required to demonstrate its adequacy to resist a "gunfire schedule" environment without unacceptable degradation of its structural integrity and functional performance ("gunfire schedule" here refers to the firing rate, the number of rounds fired in a given firing, and the number of firing events). The gunfire environment may be considered to be a high rate repetitive shock having form of a substantial transient vibration produced by (1) an airborne gun muzzle blast pressure wave impinging on the materiel at the gun firing rate, (2) a structure-borne repetitive shock transmitted through structure connecting the gun mechanism and the materiel, and/or a combination of (1) and (2). The closer the materiel surface is to direct pressure pulse exposure, the more likely the measured acceleration environment appears as a repetitive shock producing "very short" rise time and rapid decay of materiel response, and the less role the structure-borne repetitive shock contributes to the overall materiel response environment. The farther the materiel surface is from direct pressure pulse exposure, the more the measured acceleration environment appears as a structure-borne high rate repetitive shock (or a substantial transient vibration) with some periodic nature that has been filtered by the structure intervening between the gun mechanism and the materiel. Repetitive shock applied to a complex multi-modal materiel system will cause the materiel to respond (1) at forced frequencies imposed on the materiel from the external excitation environment, and (2) to the materiel's resonant natural frequencies either during or immediately after application of the external excitation. Such response may cause:

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

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

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

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 element being exceeded.

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

g. Potential piezoelectric activity of materials.

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

1.3 Limitations.

This Method provides limited information with regard to the prediction of input levels to materiel based only on the gun parameters and the geometrical configuration between the gun and materiel. Procedure III is provided for purposes of preliminary materiel design when no other information is available. The shock form of time trace information generated in Procedure III may be tested under Time Waveform Replication (TWR) as a recommended practice. It may not be possible to replicate some operational service gunfire materiel response environments because of impedance mismatches. In particular, laboratory fixture limitations or other physical constraints may prevent the satisfactory application of gunfire-induced excitation to a test item in the laboratory. In addition, this Method:

a. Does not provide guidelines for separating air-borne from structure-borne excitation input to materiel. It is important that a trained structural dynamicist examine the structural configuration and any measured data to determine the transmission path(s) from the gun excitation source to the materiel.

b. Does not provide guidance on techniques for isolation of the materiel from the source of excitation.

c. Does not provide guidance on materiel design to avoid unacceptable structural or functional materiel degradation during gun firing, e.g., shock isolation.

d. Does not include the repetitive shock effects experienced by large extended materiel, e.g., airframe structural systems over which varied parts of the materiel may experience spatially correlated external excitation. For this type of repetitive shock, with degrees of input and response spatial correlation from the external excitation, specialized tests based on experimentally measured data must be employed.

e. Does not include provisions for performing gunfire tests at high or low temperatures including the extreme temperature environment directly related to the gunfire pressure wave emission and subsequent materiel absorption of this thermal energy. Perform tests at standard ambient temperature unless otherwise specified. However, thermal energy generated from the gun blast pressure wave may be an important design consideration for materiel close to the gun muzzle.

f. Is not intended to simulate blast pressure or acoustic effects on materiel as a result of exposure to gunfire environment. This Method assumes materiel acceleration as the measurement variable but does not limit consideration to other materiel input/response variables, e.g., force.

g. In general, it provides limited guidance on materiel response to gun excitation from simultaneous firing of more than one gun.

h. Does not address benign gunfire shock environments where materiel input or response may be a form of transient random vibration, with peak root-mean-square levels below the levels of materiel qualification to stationary random vibration as determined by the square root of the area under the Autospectral Density Estimate (ASD).

i. Does not provide guidance on "single shot" gunfire response from large guns e.g., Navy ship guns. For such gunfire response representing basically a single shock to materiel, guidance in Method 516 is applicable.

2. TAILORING GUIDANCE.

2.1 Selecting the Gunfire Shock Method.

After examining requirements documents and applying the tailoring process in Part One of this Standard to determine where exposure to a gunfire shock environment is 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 a Gunfire Shock Environment.

Exposure to a gunfire shock environment has the potential for producing adverse effects on the structural and functional integrity of all materiel including in-service operational capability. The probability of adverse effects increases with the blast energy of the gun, proximity of the materiel to the gun, and the duration of the gunfire shock environment. The gunfire firing rate and the duration of gunfire shock environment exposure that correspond with natural frequencies of the mounted materiel (along with its sub-harmonics and super-harmonics) will magnify the adverse effects on the materiel's overall integrity.

2.1.2 Sequence among Other Methods.

a. General. 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., design developmental, qualification, endurance, etc., and the general availability of test items. Normally, schedule gunfire shock tests early in the test sequence, but after significant levels of vibration, thermal, and mechanical shock tests. For thermal testing include any potential transient thermal effects from gunfire on the materiel. Note that in the Life Cycle Environmental Profile (LCEP) gunfire shock is represented as a series of events according to a "gunfire schedule," such that the total exposure time is usually substantially less than exposure to random vibration environment(s).

(1) If the gunfire shock environment is deemed particularly severe and the chances of materiel survival without major structural and/or functional failure are small, perform the gunfire shock test first in the test sequence. This provides the opportunity to redesign the materiel to meet the gunfire shock requirement before testing to the potentially more benign vibration and/or mechanical shock environments.

(2) If the gunfire environment is considered severe, but the probability of the materiel survival without structural and/or functional failure is good, perform the gunfire shock test after vibration, thermal, and mechanical shock tests, allowing the stressing of the test item to long duration environments prior to gunfire shock testing. This order of testing is intended to uncover combined temperature and vibration/shock environmental failures. (There are often advantages to applying gunfire shock tests before climatic tests, provided the sequence represents realistic service conditions. Climate-sensitive defects often show up more readily after the application of severe gunfire shock environments. However, internal or external thermal stresses may permanently weaken materiel resistance to vibration, mechanical shock, and gunfire shock that may go undetected if gunfire shock tests are applied before climatic tests.)

(3) In cases in which the gunfire shock test levels are deemed less severe than the vibration test levels, the gunfire shock tests may be deleted from the testing sequence. However, credible modeling and analysis procedures must be employed that lead to concluding that gunfire shock levels are actually less severe than vibration test levels. This may require the predicted or measured gunfire shock environment be of the form of a short duration transient vibration with some periodic structure, as opposed to a replicated shock, and that the short duration transient vibration be analyzed in accordance with either stationary vibration procedures or procedures related to processing the product model for non-stationary environments.

(4) It is never acceptable to automatically conclude that gunfire shock test levels are less severe than mechanical shock test levels. Gunfire shock is of a repeated shock nature at the firing rate of the gun as opposed to a single mechanical shock. Methods for comparing the severity of shock, e.g., SRS, cannot be credibly used to assess the severity of test levels between gunfire shock and simple mechanical shock.

(5) The gunfire shock environment may affect materiel performance when materiel is tested simultaneously to other environmental conditions such as vibration, temperature, humidity, pressure, etc. If materiel is known to be sensitive to a combination of environments, test to those environments simultaneously (possibly superimposing the gunfire shock environment on the random vibration environment). If it is impractical to test to a combination of environments simultaneously, and where it is necessary to evaluate the effects of the gunfire shock environment together with other environments, expose a single test item to all relevant environmental conditions in turn. In general, gunfire shock may occur at any time during the specified operational conditions, so sequence it as close as practical to the sequencing defined in the life cycle environmental profile. If in doubt, as recommended in this paragraph, conduct gunfire shock testing immediately after completing any vibration and mechanical shock testing.

2.2 Selecting a Procedure.

This Method includes three procedures. Gunfire shock testing to significant environmental levels is generally limited by the guidelines provided in Method 525.2, Time Waveform Replication. In particular, all the guidelines in Method 525.2 relative to time trace scaling and simulation must be strictly adhered to. If the materiel, because of its distance from the gun, may be exposed to a gunfire shock environment even lower than measured vibration levels from other sources, separate testing to a gunfire shock environment may not be necessary to ensure materiel integrity. It is absolutely essential field measured time trace information representing particular materiel response to the gunfire shock environment be examined before guidelines found in Method 525.2 are applied. There are few, if any, reliable analytical techniques for accurately predicting low levels of materiel response to gunfire shock environment, except for obvious physical configuration assessment, e.g., the gun is on the opposite side of the aircraft fuselage from the materiel. Consider low gunfire shock environments as transient vibration environments rather than long duration stationary random vibration environments because of LCEP gunfire scheduling. Perform testing to transient vibration environments in accordance with Method 525.2. To execute laboratory testing this Method provides for the following three procedures:

Procedure I: MEASURED MATERIEL INPUT/RESPONSE TIME HISTORY UNDER TWR

Procedure II: SRS GENERATED SHOCK TIME HISTORY PULSE SEQUENCE UNDER TWR

Procedure III: STOCHASTICALLY GENERATED MATERIEL INPUT FROM PRELIMINARY DESIGN SPECTRUM UNDER TWR

2.2.1 Procedure Selection Considerations.

Based on test or preliminary design 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. For example, Procedure I may be the basis when measured gunfire response data are available. Procedure II will be required if measurement information is processed with the SRS as distinct shocks or as a SRS of the overall shock and measurement time history information is no longer available. If measurement time history information is available then Procedure I is recommended. For procedures in which there is a general lack of field measured data, Procedure III may be used to predict the gunfire repetitive shock environment and a gunfire shock time history produced under two ad hoc processes described in Procedure III. Consider all gunfire shock environments anticipated for the materiel during its life cycle, in its operational modes. When selecting procedures, consider:

a. Measured Materiel Response Available. If field measured time trace materiel input/response data are available, it is recommended that this information be used in development of a test specification. Generally, the test specification will require that laboratory testing be in accordance with the guidelines provided in Method 525.2. Generally, Method 525.2 is the only method suitable for measured time traces that have the form of a repetitive shock at the firing rate of the gun over a given duration in the gunfire schedule.

b. Measured Materiel Response Unavailable. If field measured time trace data for materiel are unavailable, the following considerations are important.

    (1) First, there are no known reliable means of predicting gunfire shock materiel input/response based on gun and materiel configuration descriptions. Previous versions of MIL-STD-810 beginning with MIL-STD-810C provided a means of developing a predicted Sine-on-Random (SOR) vibration test spectrum based upon several gun/materiel configuration parameters. Information for predicting the SOR spectrum is thought to be too limited to be reliable.

    (2) Second, it is recognized that in the early design and development of materiel, some guidance on levels of input excitation to the materiel are needed, and generally vibration or mechanical shock levels are not appropriate when significant materiel response to gunfire shock is anticipated.

    (3) Third, the methodology for analysis of the measured response to gunfire shock was a major weakness in development of the predicted SOR spectrum. A SOR model is inadequate for modeling a repetitive pulse environment. The primary inadequacy in the modeling is the accurate representation of the repetitive pulse rise time. Four harmonically-related sine components added to stationary random vibration provide for a consistent rise time well below that for a repetitive shock environment, and appear to be too long for significant gunfire shock input excitation or even measured materiel response. Recent gunfire shock measurement data reveals substantial rise time

responses and the sensitivity of the form of a single gunfire shock time trace to gun/materiel configuration.

(4) Finally, there is a methodology that allows use of the predicted SOR spectrum information in the form of a repetitive pulse. This methodology requires preliminary design procedures be in accordance with that for repetitive shock at predicted SOR spectrum levels. This philosophy has been adopted for the stochastic prediction incorporated in Procedure III.

As a rationale related note on Procedure III, even though the set of measured data available in the mid-1970s was small for the extended prediction philosophy that was developed, there was hesitation in discarding the information in previous versions of MIL-STD-810. Accordingly (in light of the unavailability of other information to confirm the prediction methodology), use of the predicted information (SOR spectrum) in the form of a repetitive shock for preliminary design purposes, is acceptable. Part of the reasoning behind this is that the predicted information tends to scale correctly from a strictly logical point of view. Annex C provides guidelines for specifying preliminary repetitive shock based design environments from the prediction algorithm provided in this Annex. The materiel designer must be prepared to design to a form of repetitive shock input to the materiel at the gunfire rate.

It is assumed in applying any of the three procedures, the dynamics of the materiel are well known; in particular, the resonances of the materiel and the relationship of these resonances to the gun firing rate and its harmonics. In addition, it is assumed that any vibration/shock isolation characteristics between gun and materiel configuration are understood. Improper test procedure selection and execution may result in either a non-conservative materiel under-test, or a substantial materiel over-test. These procedures can be expected to cover a substantial range of testing related to materiel exposed to gunfire shock environment. In summary:

For severe materiel response to gunfire shock environment with measured time trace data, use Procedure I or Procedure II in conjunction with Method 525.2.

For benign materiel response to gunfire determined from measured time trace data, examine the need for testing to gunfire shock when other vibration or mechanical environments are prescribed. If the need persists, consider testing to a transient vibration environment under the guidelines in Method 525.2.

For no measured materiel response time history data, use the methodology outlined in Procedure III to predict preliminary gunfire repetitive shock levels and in an ad hoc manner generate repetitive shock time histories.

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

d. The natural exposure circumstances. Materiel response to a gunfire shock environment is heavily dependent upon the caliber of the gun and the physical configuration of the gun relative to the materiel.

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

f. Procedure sequence. Refer to paragraph 2.1.2.

2.2.2 Difference among Procedures.

a. Procedure I. **MEASURED MATERIEL INPUT/RESPONSE TIME HISTORY UNDER TWR.** Measured in-service gunfire shock environment for materiel is replicated under laboratory exciter waveform control (Method 525.2 TWR) to achieve a near exact reproduction of the measured in-service gunfire shock environment. Test philosophy includes selection of the time trace or traces to be replicated according to the scope of the test. Use the guidelines provided in Annex A and in Method 525.2.

b. Procedure II. **SRS GENERATED SHOCK TIME HISTORY PULSE SEQUENCE UNDER TWR.** This procedure is based on former processing measured gunfire shock in terms of the SRS applied either to individual gunfire pulses or the SRS applied to the overall gunfire pulse sequence (it is assumed that time history information is no longer available for application of Procedure I). It is critical that percent of critical damping considered in computation of the SRS is known. The gunfire rate of interest must also be defined. The gunfire rate will define a parameter T_e. Ideally, the "concentration of energy", T_E will also be provided (see Method 516.8 for a discussion of $T_e\ and\ T_E$). If the SRS is applied to individual gunfire pulses some form of "enveloping" the individual SRS estimates may be employed as described in Method 516.8 Annex B. In either case a single SRS estimate is obtained that can be used to generate a single shock pulse time history based upon waveform synthesis or other technology. This single shock pulse time history then can be concatenated into a shock pulse series and run under TWR. Stochastic variations with departures from single pulse generation are permitted.

c. Procedure III. **STOCHASTICALLY GENERATED MATERIEL INPUT FROM PRELIMINARY DESIGN SPECTRUM UNDER TWR.** This procedure is ad hoc, lacking necessary field measured time trace information, and a last resort to providing guidelines for design of materiel to resist a gunfire shock environment. Only time trace forms for design are given, and it is not suggested that testing be performed to these forms for materiel qualification purposes. The shortcomings of previous MIL-STD-810 versions and use of prediction methods are outlined in paragraph 2.2.1. The inability to develop a database useful for prediction is unfortunate, and the reluctance to discard what little prediction information that is available has resulted in this procedure. The idea behind this procedure is that the true nature of either air-borne or structure-borne gunfire shock is impulsive in nature at the gunfire rate. Any initial design of materiel must be on the basis of a repetitive shock pulse as opposed to stationary random vibration with added sine components. Annex C provides an outline of limited procedures that stochastically generate pulse time traces for preliminary design when no measured gunfire shock information is available.

2.3 Determine Test Levels and Conditions.

Having selected this Method and relevant procedure(s) (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 and the LCEP, and information provided with this procedure. Consider the following when selecting test levels.

2.3.1 General Considerations.

Establish the test severities using available measured gunfire shock time trace data from a similar gun/materiel configuration, or measured gunfire shock time trace data acquired directly from an environmental measurement program. When these data are not available, some limited information on test severities and guidance may be found in Annex C. The procedure selected may not provide an adequate test for the complete environment; thus, a supporting assessment may be necessary to compliment the test results.

2.3.2 Test Conditions.

In all cases care must be taken to replicate the measured environmental materiel response data that may require establishing the correct interface impedances. When measured data are not available, the input to the materiel or the materiel response must be in accordance with that defined in Procedure III for prediction. 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 conditions, consider applying those environmental factors during testing.

2.3.3 Test Axes and Number of Gunfire Shock Events.

The test axes should be in accordance with the physical configuration for the in-service environment. Material response to gunfire pressure pulses will generally involve testing in axes normal to the primary pressure pulse emanation axis. Materiel response to structure-borne vibration will generally involve testing in all axes. The number of gunfire events should be in accordance with the Life-Cycle Environmental Profile document. In general, it is permissible to test using Single-Exciter/Single-Axis (SESA), Method 525.2 (TWR) methodology in all axes of concern. However, for particularly sensitive materiel whereby the operational integrity of the materiel must be ensured with a high degree of confidence, testing may be performed under the guidelines of Multiple-Exciter/Multiple-Axis (MEMA) methodology given under Method 527.2. Under highly specialized conditions, when materiel degradation under gunfire shock is very likely, it may be necessary to consider multiple gunfire events according to LCEP gunfire schedules modeled probabilistically as Poisson in nature, with either a stationary or non-stationary gunfire event rate.

Generally, because of the unique character of gunfire shock, it is not acceptable to “scale” individual measured gunfire time traces in the time domain in order to achieve test conservativeness and reduce test repetitions. However, for frequency domain ensembles of a set of gunfire time histories e.g., a SRS ensemble, it is possible to summarize the ensemble in the frequency domain and use the summary to create an acceptable laboratory test time history for TWR. Generally, the created laboratory test time history will be distinct from measurements forming the ensemble but representative of what might possibly be a future measurement.

2.4 Test Item Configuration. (See Part One, Paragraph 5.8.)

Configure the test item for gunfire shock testing as would be anticipated during in-service use, including particular attention to the details of the in-service mounting of the materiel to the platform. Gunfire response is sensitive to the details of the materiel/platform configuration and input impedances.

2.5 Controls.

The dynamic excitation is controlled to within specified bounds by sampling the dynamic response of the test item at specific locations. These locations may be at, or in close proximity to the materiel fixing points (controlled input tests), or at defined points on the materiel (controlled response tests). For this Method, either (1) the test excitation is significant and controlled under TWR test methodology (Method 525.2 for SESA or Method 527.2 for MEMA), or (2) the test excitation is benign and controlled under either standard random vibration test methodology (Method 514.8 with application of the information in reference e for upper limit determination strategies).

2.5.1 Control Options.

2.5.1.1 Open/Closed Loop

For significant gunfire shock environments (and possibly benign transient vibration environments), the test for any of the procedures is typically of short duration, and is performed after appropriate compensation of the exciter analog voltage input drive waveform. Longer sequences of gunfire events may be controlled in a closed loop mode under TWR. (For example, the “real-time” control offered under TWR software). All testing is in accordance with guidelines in Method 525.2 (SESA) or Method 527.2 (MEMA). For benign gunfire environments, not considered as transient vibration, the test for any of the procedures is performed in a closed loop spectrum control in accordance with guidelines in Method 514.8 (SESA) or Method 527.2 (MEMA).

2.5.1.2 Single Point Control.

Single point control SESA is a minimum requirement for all procedures. For significant gunfire shock environments, select a single point to represent the materiel fixing point from which the field-measured data were obtained, or upon which predictions are based. Tolerance specification is developed around a comparison between the “reference” time trace (measured or stochastically generated), and the “control” time trace measured in the laboratory. All testing is in accord with the guidelines of Method 525.2. For benign non-transient vibration gunfire environments, follow guidelines provided in Method 514.8 using single point spectrum control. It is highly recommended that additional measurement channels be employed in the vicinity of the control point for comparison purposes to minimize single point calibration errors.

2.5.1.3 Multiple Point Control.

Where multiple axis information is available then multiple axis TWR (MEMA) may be performed where the materiel is of an extended nature, and measurements at multiple points are needed to ensure the integrity in the reproduction of the environment. All testing should be performed under the guidelines of Method 527.2 for multi-exciter testing under TWR. For benign non-transient gunfire environments, follow guidelines provided in Method 527.2 for MEMA spectrum control.

2.5.2 Control Methods.

2.5.2.1 Waveform Control.

Perform significant gunfire shock environment testing for all three procedures using TWR guidelines provided in Method 525.2 (SESA) or Method 527.2 (MEMA).

2.5.2.2 Spectrum Control.

Benign non-transient vibration gunfire environment testing is to be performed using standard random vibration guidelines provided under Method 514.8 (SESA) or Method 527.2 (MEMA).

3. INFORMATION REQUIRED.

3.1 Pretest.

The following information is required to conduct a gunfire test for a significant gunfire shock environment. (In this section SESA is assumed, however obtain the same pretest information if MEMA testing is required, and Method 527.2 MEMA is substituted for Method 525.2 SESA. In addition, if the gunfire environment is benign non-transient vibration, see Method 514.8 for SESA or Method 527.2 for MEMA spectrum control.).

a. General. Information listed in Part One, paragraphs 5.7, 5.8, and 5.9; and Annex A, Task 405 of this Standard.

b. Specific to this Method.

(1) Knowledge of the test fixture, test item, and combined test fixture/test item modal frequencies, and their relationship to the gunfire rate. Ideally, this would consist of an experimental modal survey for the test configuration including fixturing. If this is not practical, a supporting analytical assessment of the modal characteristics of the test configuration needs to be developed and interpreted by a trained analyst.

(2) Gunfire environment according to the gunfire schedule defining the number of individual firing events. Either:

(a) Measured time traces that are input directly as compensated waveforms into an exciter system under TWR control Method 525.2 (SESA) (Method 527.2 MEMA) for Procedure I.

(b) Time traces generated based on SRS reference criteria as compensated waveforms into an exciter system under TWR control Method 525.2 (SESA) (Method 527.2 MEMA) for Procedure II.

(c) Measured gun/materiel mechanical and geometrical parameters that have been specified, and predicted SOR spectrum derived. The predicted SOR form of spectrum is then used to generate a repetitive shock time trace input to the materiel at the gunfire rate.

(3) Techniques used in the processing of the input, and the materiel response data including means of satisfying the prescribed tolerance limits.

(4) An analog anti-alias filter configuration will be used that will:

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

(b) Have linear phase-shift characteristics in the data passband.

(c) Have a passband uniform to within one dB across the frequency band of interest (see paragraph 4.3).

(5) In subsequent processing of the data, use any additional filtering that is compatible with the anti-alias analog filtering. In particular, additional digital filtering must maintain phase linearity for processing gunfire time traces for Procedure I. In checking for test tolerance satisfaction, use the principles outlined in Method 525.2 - in particular, bandpass filter the control time trace to the bandwidth of the reference time trace or, alternatively, match the bandpass filter characteristics of the control time trace to the measured time trace.

(6) Generally, there are three bandwidths of concern: (1) the field measured time trace bandwidth based upon the instrumentation signal conditioning configuration, (2) the reference time trace to be used in testing (5 Hz to 2kHz), and (3) the measured control time trace from the test that may have energy exceeding 2kHz. Test tolerance procedures must compare common bandwidth information. Common bandwidths may be established by digital filtering between either (1) the field measured time trace and the measured test control time trace, or (2) the test reference time trace and the bandlimited control time trace. The procedures for establishing common bandwidths are provided in Method 525.2.

(7) For all Procedures, the measured or generated time history trace should be over-sampled by a factor of 10. Ideally, for 2 kHz data, a sample rate of 20,480 (with a linear phase anti-alias filter set at

2.5 kHz) will be suitable. For spectral computations, a maximum 5 Hz analysis filter bandwidth is recommended.

(8) Analysis procedures will be in accordance with those requirements and guidelines provided in paragraph 6.1, reference a. In particular, the test item response acceleration time histories will be qualified according to the procedures in paragraph 6.1, reference b. In severe cases of response acceleration, it may be necessary that each time history be integrated to detect any anomalies in the measurement system, e.g., cable breakage, amplifier slew-rate exceedance, data clipped, unexplained accelerometer offset, etc. The integrated amplitude time histories will be compared against criteria given in paragraph 6.1, reference b.

c. Tailoring. Necessary variations in the basic test procedures to accommodate LCEP requirements.

3.2 During Test.

Collect the following information during conduct of the gunfire test for a significant gunfire shock environment. (In this section SESA is assumed, however obtain the same test information if MEMA testing is required and Method 527.2 MEMA (TWR) is substituted for Method 525.2 SESA. In addition, if the gunfire environment is benign and non-transient vibration, see Method 514.8 for SESA, or Method 527.2 for MEMA spectrum control).

a. General. Information in Part One, paragraph 5.10; and in Part One, Annex A, Task 405 and 406 of this Standard.

b. Specific to this Method. Information related to failure criteria. Other environmental conditions at which testing is to be carried out if other than at standard laboratory conditions, and the specific features of the test assembly (exciter, fixture, interface connections, etc.). For test validation purposes, record achieved test parameters, deviations from pre-test procedures including parameter levels, any procedural anomalies, and any test failures. Save in digital form the reference, control, and monitoring acceleration time traces for post-test processing, including test tolerance verification, under the guidelines provided in Method 525.2.

3.3 Post-Test.

The following post test data shall be included in the test report. (In this section SESA is assumed; however, obtain the same pretest information if MEMA testing is required, and Method 527.2 MEMA TWR is substituted for Method 525.2 SESA. In addition, if the gunfire environment is benign and non-transient vibration, see Method 514.8 for SESA or Method 527.2 for MEMA spectrum control).

a. General. Information listed in Part One, paragraph. 5.13; and in Annex A, Task 406 of this Standard.

b. Specific to this Method.

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

(2) Functional and physical integrity of the test item after each test based upon operational testing and visual examination.

(3) Reference, control, and monitor time traces along with the information processed from these time traces to ensure test tolerances were met in the course of testing (see Method 525.2).

(4) Results of operational checks.

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

4. TEST PROCESS.

4.1 Test Facility.

Prior to initiating any testing, review the pretest information in the test plan to determine test details (e.g., procedure, calibration load (dynamically similar materiel testing using a dynamic simulant for test waveform compensation), test item configuration, measurement configuration, gunfire level, gunfire duration, number of repetitions of gunfire event to be applied). Examine all details of the test validation procedures. Use fixturing that simulates actual in-service mounting attachments (including vibration isolators and fastener torque, if appropriate). Install all the connections (cables, pipes, etc.) in a way that they impose stresses and strains on the test item similar to those encountered in service. In certain cases, consider the suspension of the test item for low frequency apparatus to avoid complex test fixture resonances that may coincide with measured materiel gunfire response resonant frequencies.

For significant gunfire shock environments, use a test facility, including all auxiliary equipment, capable of providing the specified gunfire materiel response environments within the tolerances stated in paragraph 4.2. This will require a test facility with vendor supplied Time Waveform Replication capability able to perform testing in accordance with guidelines provided in either Method 525.2 or Method 527.2. In addition, use measurement transducers, data recording, and data reduction equipment capable of measuring, recording, analyzing, and displaying data sufficient to document the test and to acquire any additional data required. Unless otherwise specified, perform the specified gunfire tests and take measurements at standard ambient conditions as specified in Part One, paragraph 5.1.For benign non-transient vibration gunfire environments, any test facility capable of meeting the test guidelines in Method 514.8 (SESA) or Method 527.2 (MEMA) spectrum control will be suitable.

4.2 Controls.

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 piezoelectric accelerometers may offset or zero-shift during mechanical shock, pyroshock, and ballistic shock (paragraph 6.1, references h and i). 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. All measurement instrumentation must be calibrated to traceable national calibration standards (see Part One, paragraph 5.3.2). In addition, instrumentation to measure test item function may be required. In this case, obtain suitable calibration standards and adhere to them.

a. <u>Accelerometers</u>. Ensure the following:

(1) Amplitude Linearity: It is desired to have amplitude linearity within 10 percent from 5 percent to 100 percent of the peak acceleration amplitude required for testing. Since mechanically isolated piezoelectric accelerometers (mechanically isolated or not) may show zero-shift (paragraph 6.1, reference j), there is risk to not characterizing these devices at 5 percent of the peak amplitude. 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 mechanically isolated accelerometers may have both non-linear amplification and non-linear frequency content below 10,000 Hz (paragraph 6.1, reference j). 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 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.

(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 5 percent.

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

(6) Unless it is clearly demonstrated that a piezoelectric accelerometer (mechanically isolated or not) can meet the shock requirements and is designed for oscillatory shock (not one-sided shock pulses), recommend piezoresistive accelerometers be used for high intensity shock events in which oscillatory response is anticipated. Piezoelectric accelerometers may be used 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 b. In particular, filtering of the analog voltage signals will be consistent with the time history response requirements (in general, demonstrable linearity of phase throughout the frequency domain of response), and the filtering will be so configured that anomalous acceleration data caused by clipping will not be misinterpreted as response data. In particular, use extreme care in filtering the acceleration signals at the amplifier output. 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 (see Method 516.8 Shock Annex A).

The complete test parameter control chains (checking, compensation, servings, recording, etc.) should not produce uncertainties exceeding one third of the tolerances specified in paragraphs 4.2.1 through 4.2.4. Because of the nature of the gunfire environment, tolerances may be given in the time, amplitude, and frequency domain according to the processing requirements of the procedure. Knowledge of the bandwidth of the reference and control time traces will be important, and an assessment of the out-of-band energy provided by limitations of impedance matching and fixture resonances will be important. In Procedures I and II, it is assumed that the test item response measurement data collected are representative of the true environment, and not a function of the local materiel configuration, e.g., local resonances that may not be controllable to the tolerances in paragraphs 4.2.1 through 4.2.4. Use test fixturing that will ensure test item response in other axes does not exceed twenty-five percent of the test item response in the test axis when measured in the time, amplitude, or frequency domain. Methods 525.2 and 527.2 provide guidelines on test tolerance specification under TWR and, in most cases, these test tolerances will be adequate for gunfire testing. The test tolerance guidelines provided below assume stochastic ensemble processing formulation, whereby there is variation in time, but the frequency domain content remains the same over the ensemble of pulses. These test tolerance guidelines may be superseded by more time trace form appropriate guidelines in Methods 525.2 or 527.2. In conjunction with satisfaction of test tolerances, a dynamic simulant for the test materiel is initially recommended to compensate the input waveform. In addition, an appropriate time trace compensation strategy may be applied to optimize the TWR input to the stimulant, and applied in subsequent testing of the materiel.

4.2.1 MEASURED MATERIEL INPUT/RESPONSE TIME HISTORY UNDER TWR (PROCEDURE I)

a. Time domain. Generally, reference and control time traces are perfectly correlated so that there is no requirement under Method 525.2.

b. Amplitude domain. Ensure materiel time history major positive and negative response peaks are within ±10 percent of the measured gunfire time history peaks. Ensure the root-mean-square level of the point-by-point difference between the control and reference time traces is less than ±5 percent of the combined control/reference peak time traces for a short-time average time not to exceed 10 percent of the gun fire rate.

c. Frequency domain. Compute a low frequency resolution average Energy Spectral Density (ESD) estimate over the ensemble created from the materiel time history response that is within ± 3dB of the average ESD estimate computed over the ensemble created from the measured gunfire time history over at least 90 percent of the frequency range. In cases in which an ensemble from the data cannot be created, compute an ASD estimate of the time history records for comparison, provided the data are appropriately windowed (usually with a 10 percent tapered cosine window, a Kaiser window or frequency averaging) to reduce spectral leakage. The tolerances for the ASD analysis are ± 3dB over at least 90 percent of the frequency range. In addition require that overall root-mean-square levels are within 10 percent.

4.2.2 SRS GENERATED SHOCK TIME HISTORY PULSE SEQUENCE UNDER TWR (PROCEDURE II)

a. Time domain. Ensure the duration of every generated pulse is within 2.5 percent of the duration obtained from the predicted gunfire rate if stochastic ensemble generation methodology is implemented. Ensure the duration of the gun firing event is within 0.5 percent of the overall duration if the stochastic time trace generation methodology is implemented.

b. Amplitude domain. Ensure materiel time history major positive and negative response peaks are within ±10 percent of the predicted gunfire time history peaks. Ensure that the root-mean-square level of the point-by-point difference between the control and reference time traces is less than ±5 percent of the combined control/reference peak time traces for a short-time average time not to exceed 0.1 of the gunfire pulse period.

c. Frequency domain. For a reference synthesized pulse time history trace based on a SRS, compute the SRS of a representative pulse or series of pulses and compare to classical SRS tolerances addressed in Method 516.8.

4.2.3 STOCHASTICALLY GENERATED MATERIEL INPUT FROM PRELIMINARY DESIGN SPECTRUM UNDER TWR (PROCEDURE III)

If this procedure requires follow-on testing only time and frequency domain requirements are used.

a. Time domain. Ensure the duration of every generated pulse is within 2.5 percent of the duration obtained from the specified gunfire rate.

b. Frequency domain. Ensure the SOR spectrum developed for the pulses is within ±3dB of the predicted SOR spectrum over the entire frequency band of interest. In general, this will be based upon an estimate of the ASD from which the Time Domain Windowed Pulse (TDWP) or Random-Modulated-Harmonic-Pulse (RMHP) are created.

4.3 Test Interruption.

If interruption occurs during gunfire shock test input, repeat that gunfire shock test input. Ensure stresses induced by the interrupted gunfire shock test do not invalidate subsequent test results. It is incumbent on all test facilities that data from such interruptions be recorded and analyzed before continuing with the test sequence. In the case of any interruption, the test item must be re-inspected prior to restarting the test to ensure test item integrity**.**

Test interruptions can result from two or more situations, one being from failure or malfunction of associated laboratory test equipment. The second type of test interruption results from failure or malfunction of the test item itself during required or optional performance checks.

4.3.1 Interruption from Failure or Malfunction of Associated Laboratory Test Equipment.

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

b. Specific to this Method. If there is an unscheduled interruption, restore/replace laboratory test equipment and reinitiate the test being conducted at the time of failure or malfunction using the same test item.

4.3.2 Interruption Due To Test Item Operation Failure.

Failure of the test item(s) to function as required during mandatory or optional performance checks during testing 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 replace / repair the failed or non-functioning component or assembly 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 Test Execution.

The following actions along with steps, alone or in combination, provide the basis for collecting necessary information concerning the durability and function of a test item in a gunfire shock environment.

4.4.1 Preparation for Test.

4.4.1.1 Pretest Checkout.

After appropriate compensation of the excitation input device (with possibly a dynamic simulant), and prior to conducting the test, perform a pretest checkout of the test item at standard ambient conditions to provide baseline data. Conduct the checkout as follows:

Step 1 Conduct a complete visual examination of the test item with special attention to stress areas or areas identified as being particularly susceptible to damage and document the results.

Step 2 Install the test item in its test fixture.

Step 3 Conduct a test item operational check in accordance with the approved test plan, along with simple tests for ensuring the response measurement system is responding properly. If the test item operates satisfactorily, proceed to the appropriate procedure. If not, resolve the problems and repeat this Step. Document the results for compliance with information contained in Part One, paragraph 5.9.

Step 4 If the test item integrity has been verified, proceed to the first test. If not, resolve the problem and restart at Step 1.

4.4.1.2 Procedure Overview.

Paragraphs 4.4.2 through 4.4.4 provide the basis for collecting the necessary information concerning the test item in a gunfire shock environment. 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 based on the guidelines in Part One, paragraph 5.14. For test interruption, follow the guidelines in paragraph 4.3.

4.4.1.3 Test Item Considerations.

Test items can vary from individual materiel items to structural assemblies containing several items of materiel of different types.

a. General. Unless otherwise specified in the individual test plan, attach the test item to the vibration exciter by means of a rigid fixture capable of transmitting the repetitive shock conditions specified. Ensure the fixture inputs repetitive shock to racks, panels, and/or vibration isolators to simulate as accurately as possible the repetitive shock transmitted to the materiel in service and to the measured gunfire shock environment. When required, ensure materiel protected from repetitive shock by racks, panels, and/or vibration isolators also passes the appropriate test requirements with the test item hard-mounted to the fixture.

b. Subsystem testing. When identified in the test plan, subsystems of the materiel may be tested separately. The subsystems can be subjected to different gunfire shock environment levels according to the measured time trace data. In this case, ensure the test plan stipulates the gunfire shock levels from measured time trace data specific to each subsystem.

c. Test item operation. Refer to the test plan to determine whether the test item should be in operation. Because continuous gunfire shock testing can cause unrealistic damage to the test item (e.g., unrealistic heating of vibration isolators), interrupt the excitations by periods of rest defined by the test plan and in accordance with the LCEP.

4.4.2 Procedure I - MEASURED MATERIEL INPUT/RESPONSE TIME HISTORY UNDER TWR

4.4.2.1 Controls.

This procedure assumes that measured materiel input/response data are available in digital form, and this input/response data will be replicated in the laboratory on the test item. This procedure may include the concatenation of several files of measured reference time traces.

4.4.2.2 Test Tolerances.

Ensure test tolerances are in accordance with those specified in paragraph 4.2.

4.4.2.3 Procedure Steps.

Step 1 Precondition the test item in accordance with paragraphs 4.2 and 4.4.1.

Step 2 Choose control strategy and control and monitoring points in accordance with paragraph 2.5.

Step 3 Perform operational checks in accordance with paragraph 4.4.1.

Step 4 Mount the test item on the vibration exciter or use some other means of suspension in accordance with paragraph 4.4.4.1.

Step 5 Determine the time trace representation of the vibration exciter drive signal required to provide the desired gunfire shock materiel acceleration input/response on the test item. (Refer to Annex A.)

Step 6 Apply the drive signal as an input voltage, and measure the test item acceleration response at the selected control/monitoring point.

Step 7 Verify that the test item response is within the allowable tolerances specified in paragraph 4.2.1.

Step 8 Apply gunfire shock simulation for on and off periods and total test duration in accordance with the test plan. Perform operational checks in accordance with the test plan. If there is failure in test item operational performance, stop the test, assess the failure, and decide upon the appropriate course of action to proceed with testing to complete the test plan. Follow the guidance in paragraph 4.3.2.

Step 9 Repeat the previous steps along each of the other specified axes, and record the required information.

4.4.2.4 Analysis of Results.

Refer to the guidance in Part One, paragraph 5.14, to assist in the evaluation of the test results. In addition, a display of the measured test item response time trace and analysis called for in paragraph 4.2.1 to satisfy the test tolerances.

4.4.3 Procedure II - SRS Generated Shock time history pulse sequence under TWR

4.4.3.1 Controls.

This procedure assumes that generated input/response data are available in digital form, has been deterministically modeled after the SRS procedure described in Method 516.8 and the generated sample function input/response data will be replicated in the laboratory on the test item.

4.4.3.2 Test Tolerances.

Ensure test tolerances are in accordance with those specified in paragraph 4.2.

4.4.3.3 Procedure Steps.

Step 1 Generate a deterministic representation of the field measured materiel input/response data. In general, this will involve an off-line procedure designed to generate an ensemble of deterministic pulses based on measured data for input to the vibration exciter as a single time trace of concatenated pulses or a single deterministic time trace (refer to Annex B).

Step 2 Precondition the test item in accordance with the test plan.

Step 3 Choose control strategy and control and monitoring points in accordance with paragraph 2.5.

Step 4 Perform operational checks in accordance with paragraph 4.4.4.1.

Step 5 Mount the test item on the vibration exciter (or use some other means of suspension) in accordance with paragraph 4.4.4.1.

Step 6 Determine the time trace representation of the vibration exciter drive signal required to provide the desired gunfire shock materiel acceleration input/response on the test item.(Refer to Annex B).

Step 7 Apply the drive signal as an input voltage, and measure the test item acceleration input/response at the selected control/monitoring point.

Step 8 Verify that the test item response is within the allowable tolerances specified in paragraph 4.2.2.

Step 9 Apply gunfire shock simulation for on and off periods, and total test duration in accordance with the test plan. Perform operational checks in accordance with the test plan. If there is failure in test item operational performance stop the test, assess the failure, and decide upon the appropriate course of action to proceed with testing to complete the test plan. Follow the guidance in paragraph 4.3.2.

Step 10 Repeat the previous steps along each of the other specified axes, and record the required information.

4.4.3.4 Analysis of Results.

Refer to the guidance in Part One, paragraph 5.14, to assist in the evaluation of the test results. In addition, a display of the measured test item response time trace and analysis called for in paragraph 4.2.2 to satisfy the test tolerances.

4.4.4 Procedure III - Stochastically generated Materiel Input from Preliminary Design spectrum under TWR

4.4.4.1 Controls.

This procedure assumes that the gun/materiel parameters are available for derivation of a predicted SOR test spectrum. This procedure also assumes given the predicted spectrum, a Time Domain Windowed Pulse or Random-Modulated-Harmonic-Pulse time trace can be developed having the same estimated spectrum with minimized harmonic distortion. Developing either the Time Domain Windowed Pulse (TDWP) or the Random Modulated Harmonic Pulse (RMHP) time trace requires a trained analyst and specialized software. It makes no provision for actual testing. For actual testing to the Time Domain Windowed Pulse or Random-Modulated-Harmonic-Pulse time trace use Procedure I as if stochastic simulation of a field measured environment has been performed.

Step 1 Specify the gun/materiel parameters and generate the predicted SOR spectrum (See Annex C.)

Step 2 Generate a Time Domain Windowed Pulse or Random-Modulated-Harmonic-Pulse time trace with the specified predicted spectrum.

Step 3 For materiel design considerations analyze the Time Domain Windowed Pulse or Random-Modulated-Pulse time trace according to procedures appropriate for a repetitive shock and use this analysis for consideration in preliminary materiel design. Typically:

(a) Transient vibration root-mean-square peak levels along with a normalized ASD estimate will be used in specifying the acceleration environment for the materiel design

(b) Single pulse ASD or equivalently ESD estimates will be made on the response to the Time Domain Windowed Pulse or Random-Modulated-Pulse time trace (either under ensemble representation or as an overall time trace) and be used in specifying a gunfire shock environment for materiel design.

Step 4 If testing is required, generate the equivalent Time Domain Windowed Pulse or Random Modulated Harmonic Pulse time trace environment (refer to Annex C.), and go to Procedure I for testing while recording the required information.

5. ANALYSIS OF RESULTS.

In addition to the guidance provided in Part One, paragraphs 5.14 and 5.17, Annex A, Task 406, refer to the "Analysis of results" paragraph in the front part of this Method. Analyze any failure of a test item to meet the requirements of the materiel specifications. In addition, a display of the measured test item response time trace and analysis as called for in paragraph 4.2 to satisfy the test tolerances.

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(Copies of Department of Defense Specifications, Standards, and Handbooks, and International Standardization Agreements are available online at https://assist.dla.mil.

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METHOD 519.8, ANNEX A

GUIDELINES FOR PROCEDURE I - MEASURED MATERIEL INPUT/RESPONSE TIME HISTORY UNDER TWR

1. SCOPE.

1.1 Purpose.

This Annex provides (1) pre-processing procedures for Method 525.2 (SESA) TWR laboratory test for gunfire shock environment, (2) an illustration of direct reproduction (in a laboratory test) of in-service measured materiel input/response time trace data on a force exciter under Method 525.2, (3) test tolerance limit assessment for guidelines provided in Method 525.2 and a rationale and procedure for stochastic generation of gunfire shock time traces from measured information. This annex assumes that the testing facility is fully qualified to perform the Single-Exciter/Single-Axis (SESA) Procedure in Method 525.2. For potential extensions of Procedure I to either Multi-Exciter/Single-Axis (MESA) or Multi-Exciter/Multi-Axis (MEMA), use guidelines in Method 527.2.

1.2 Application.

This procedure is essential for accurate time trace replication of single point input to materiel that may be characterized as an in-service measured gunfire shock. Because of the repetitive non-stationary nature of the gunfire shock environment, this is possibly the only known procedure that will provide precision in laboratory testing. Acceleration is considered the measurement variable in the discussion to follow, although other variables may be used, provided the dynamic range of the measured materiel response is consistent with the dynamic range of the force exciter used as the test input device. Testing is performed in order to ensure materiel physical and functional integrity during a specific measured gunfire shock event, and to provide confidence that materiel will demonstrate the same integrity under similar in-service events.

2. DEVELOPMENT.

2.1 Basic Considerations for Environmental Determination.

In-service measured data collection is performed with properly instrumented materiel where the measurements are made at pre-selected points either as input to the materiel or as response from the materiel. If the measurement points are on the materiel then the measurement points exhibit minimum local resonances, yet the measurement locations will allow the detection of significant overall materiel resonances. The measurement locations may be determined prior to an in-service measurement effort by examination of random vibration data on the materiel using various accelerometer mounting locations and fixture configurations (the in-service measurement or reference point should be the same as the laboratory control point). The in-service measured data should be DC coupled (preferably), or at least high pass filtered below the most significant frequency that can be replicated in the laboratory. For an electrohydraulic exciter, information close to DC in the measurement time trace can be replicated, however, for an electrodynamic exciter measurement data high pass filtered above 5 Hz will be acceptable. The measurement time trace should be sampled at ten times the highest frequency of interest, with appropriate anti-alias filtering applied (this applies for either direct digital recording or digitizing an analog voltage signal from a recording device). The measured time history trace should be examined for any evidence of signal clipping, or any accelerometer performance anomalies, e.g., zero shifting. If there is indication of accelerometer measurement anomalies, the potentially corrupted acceleration time trace should be carefully examined according to the procedures used in validation of mechanical shock data (see paragraph 6.1 reference b). For example time trace integration to examine velocity and displacement characteristics and the computation of sample probability density function (PDF) estimates may provide information on invalid time traces. If there is no indication of accelerometer anomalies, digitally band pass filter the in-service measured time trace consistent with the exciter replication bandwidth, and place it in a digital file designated the reference time trace for TWR testing under Method 525.2 (SESA). This procedure for preparing the reference time trace for TWR is usually performed with a personal computer (PC) with signal processing capability. A test of gunfire shock replication on an electrodynamic exciter using Procedure I under guidelines in Method 525.2 is provided for illustration purposes below. Application of test tolerance assessment for Procedure I is illustrated.

2.2 Test Configuration.

A specially instrumented unidentified test item is installed in a laboratory vibration fixture and mounted on an electrodynamic exciter. The test item employed during the laboratory testing is of the same general materiel configuration that was used to collect the gunfire shock materiel response information during an in-service test performed specifically for measurement data collection. The in-service test and laboratory replication included accelerometer measurement locations that were correlated.

2.3 Creating a Digital File of the Measured Gunfire Shock Input to the Materiel.

A first step is to formulate a test strategy and carefully examine the available measured time trace information designed to satisfy the test strategy. Usually, selection of a test strategy is based upon the materiel LCEP. The test strategy may consist of selection of the maximum measured environment for replication according to some criteria, e.g., peak acceleration, maximum energy, etc. The test strategy may also consist of selection of several levels of measured environment to be run sequentially in proportion to the level of the particular environment expected in the LCEP. For the illustration, the maximum measured level that provided gunfire shock transition from 2000 rounds/minute to 4000 rounds/minute was selected based upon a visual inspection of the in-service test measured data. Figure 519.8A-1 provides an unprocessed time trace from a measured in-service digital recording. The time trace is from the same gun/materiel configuration, for the same event and in one of three mutually orthogonal axes termed the horizontal axis. The in-service measurement was made on a digital recorder with simultaneous channel record capability in the multiple axes with a sample rate of 102400 sps, and an anti-alias filter set at 8000 Hz. The time trace measurement bandwidth exceeds the bandwidth of the exciter system to be used for replication.

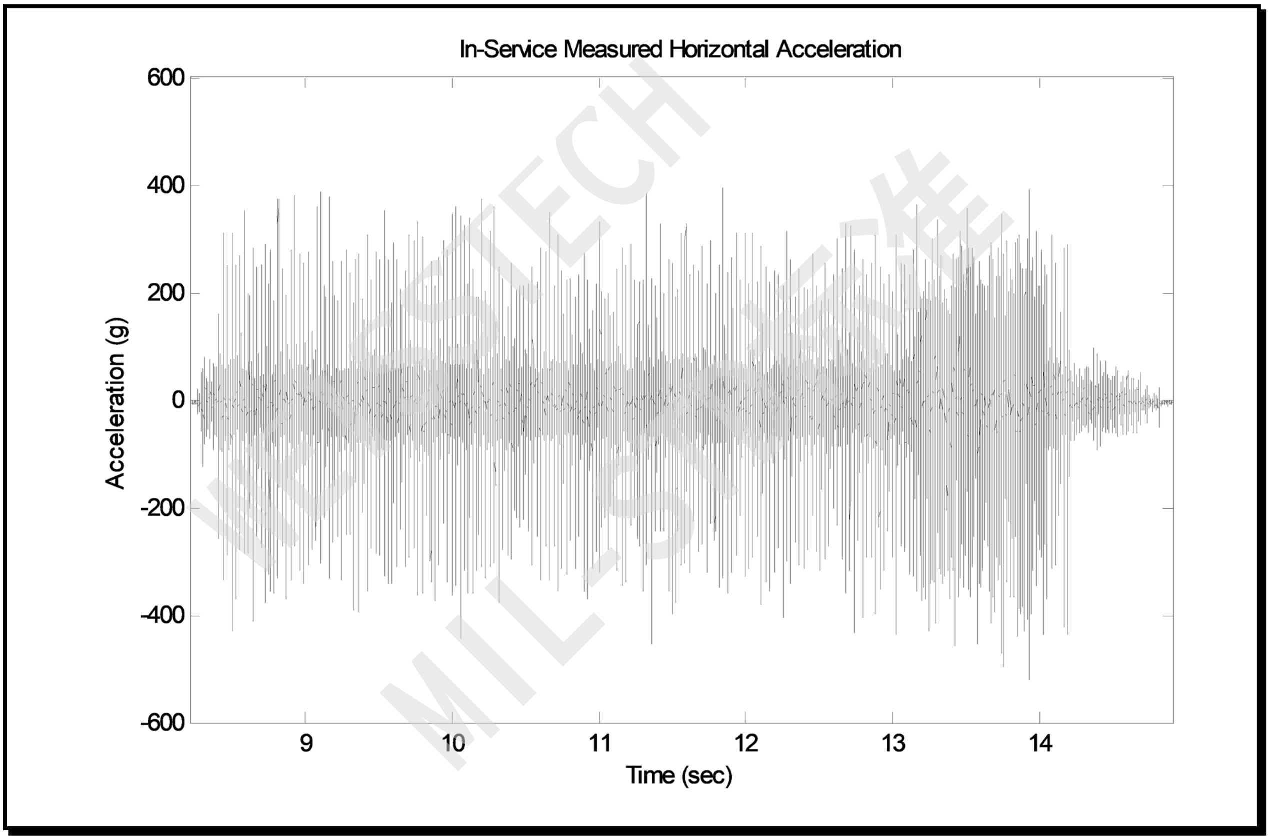

Figure 519.8A-1. In-service measured gunfire shock: unprocessed time trace (2000 round/min and 4000 round/min).

The **second step** in the measured environment replication process is to determine a laboratory test bandwidth, and to provide one or more specific digitized measured in-service time traces. The measured in-service time trace must be sampled (or interpolated from an adequate measurement bandwidth) at a minimum of ten times the highest frequency of interest for testing in order to best capture peak time trace information. The laboratory test bandwidth for the electrodynamic exciter is 10 Hz to 2000 Hz.

2.4 Replicating the Measured Gunfire Shock Materiel Input in Laboratory Test.

Once the test strategy has been formulated and the measured time trace obtained digitally, as a **third step,** the band limited time trace is input to the vendor supplied TWR hardware/software that drives an electrodynamic exciter. Guidelines for performing the test are provided in Method 525.2 and will not be repeated here. As outlined in paragraph 4.2, if such testing is critical for materiel qualification, a dynamic simulant of the materiel may be used to compensate the exciter system for the input time trace. Once this compensation is complete, the dynamic simulant is replaced by the test item. Figure 519.8A-2 provides the reference, control, and difference time traces as a result of the testing to the band-limited reference time trace. Note that visual comparison of the reference and control time traces reveals the same character and the same general magnitude. The difference time trace computed by subtracting the reference time trace from the control time trace (see Method 525.2) reveal substantial peak and valley differences indicative of out-of-band energy within the control time trace as a result of impedance and boundary condition mismatch. For this illustrative test series, (1) a dynamic simulant was not used for reference time trace compensation, and (2) an optimum control strategy for additional compensation was not employed. Despite impedance and boundary condition mismatches, the general test error could have been reduced by employing a better compensation strategy.

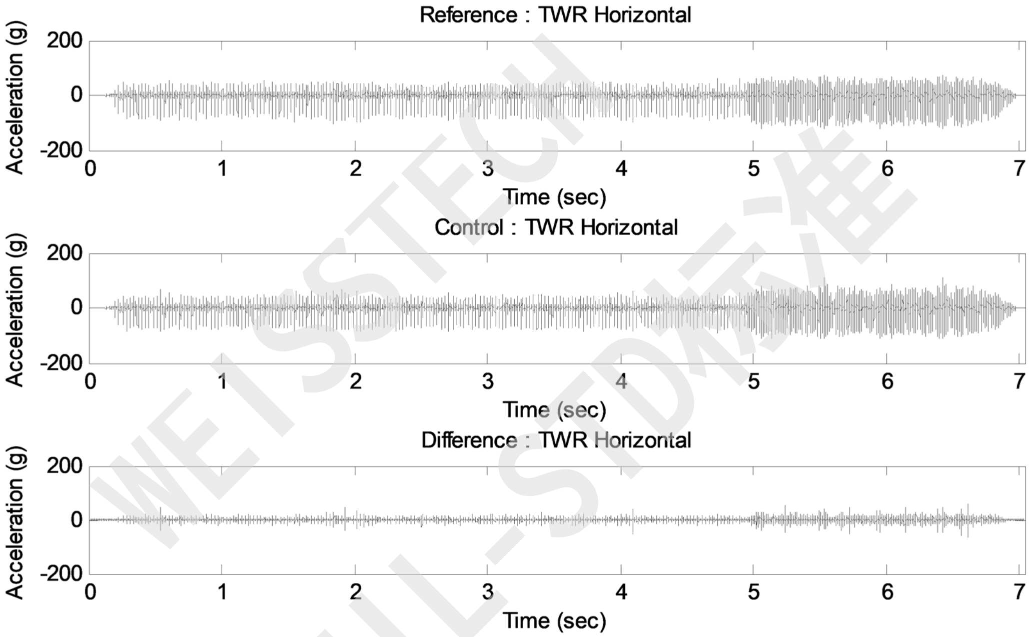

Figure 519.8A-2. Unprocessed TWR test reference, control, and difference time traces (10 Hz to 2000 Hz 25600 sps).

Figure 519.8A-2 represents all of the unprocessed time trace information available at the end of the test under the TWR test strategy, except for the compensated exciter drive time trace not displayed here.

2.5 Post-Test Processing.

For illustrative purposes, the **fourth step** is post-test processing of the reference, control, and difference time traces to determine if test tolerances established beforehand have been satisfied. In certain test situations, the vendor supplied software estimates of "test replication error," along with visual time trace inspection, is sufficient for concluding that the test objectives have been met (and this relates to the philosophy behind TWR testing as described in Method 525.2). In other test situations, a detailed comparison of the reference time trace with the control/monitor time traces may be required to demonstrate compliance with test tolerances. In this latter case, to demonstrate test tolerance compliance, post-test processing independent of vendor software must be performed. For repetitive non-stationary form time traces from gunfire shock, a thorough post-processing assessment is performed best under pulse ensemble considerations. For this illustration, only the control time trace was processed for test tolerance satisfaction verification; monitor time traces were of no concern. Any monitor time traces of interest should be processed in the same manner as the control time trace (reference, control and monitor time traces must all be phase correlated as discussed in Method 525.2).

This Annex provides a summary of post-processing the time traces as a single entity but, depending upon the test tolerance formulation for test verification, either ensemble or single entity considerations may be used. Annex B will illustrate the more comprehensive ensemble approach to processing where stochastic simulation is the goal.

Initially, the reference and control time trace information from the TWR test is limited to the frequency band of interest. This bandpass filtering of the control time trace removes out-of-band energy. Figure 519.8A-3 displays the test control time trace before and after band-limiting between 10 Hz and 2000 Hz. The bottom plot is the measured control time trace. Note that the control time trace is reduced in amplitude. Band-limiting was performed using a third order Butterworth bandpass filter applied in the forward and backward directions for maintaining proper filter phase relationships.

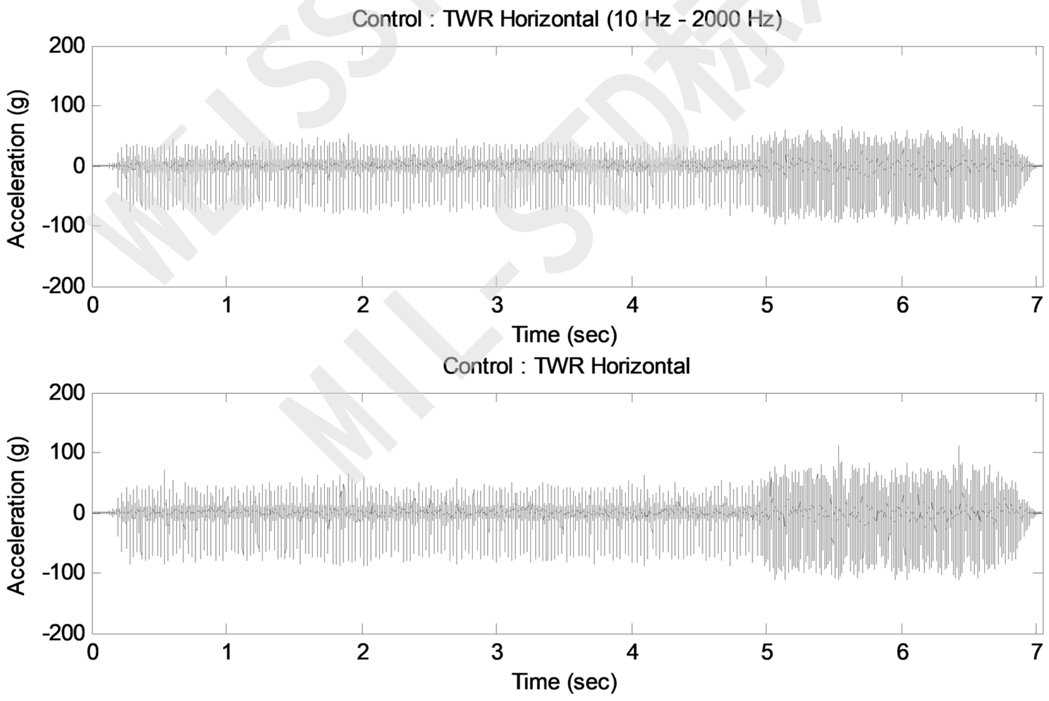

Figure 519.8A-3. Bandlimited (10 Hz to 2000 Hz) and unprocessed TWR test control time traces.

For the vendor software used in the TWR test, the phase relationship between the reference and control time traces is preserved (based upon a check of the cross-correlation function estimate between the control and reference time traces). Thus, one can proceed to compute the post-processed difference time trace by subtracting the reference time trace from the control time trace. Figure 519.8A-4 displays in high resolution six arbitrarily selected pulses for the reference, control and difference time traces for the 2000 round/minute gunfire rate. Figure 519.8A-5 provides the same information for the 4000 round/minute gunfire rate. In these two figures, even though the difference time trace scale is ten percent of the reference/control time scale, the difference time trace is generally not of a Gaussian form, and has generally large values correlated with peaks in the reference time trace.

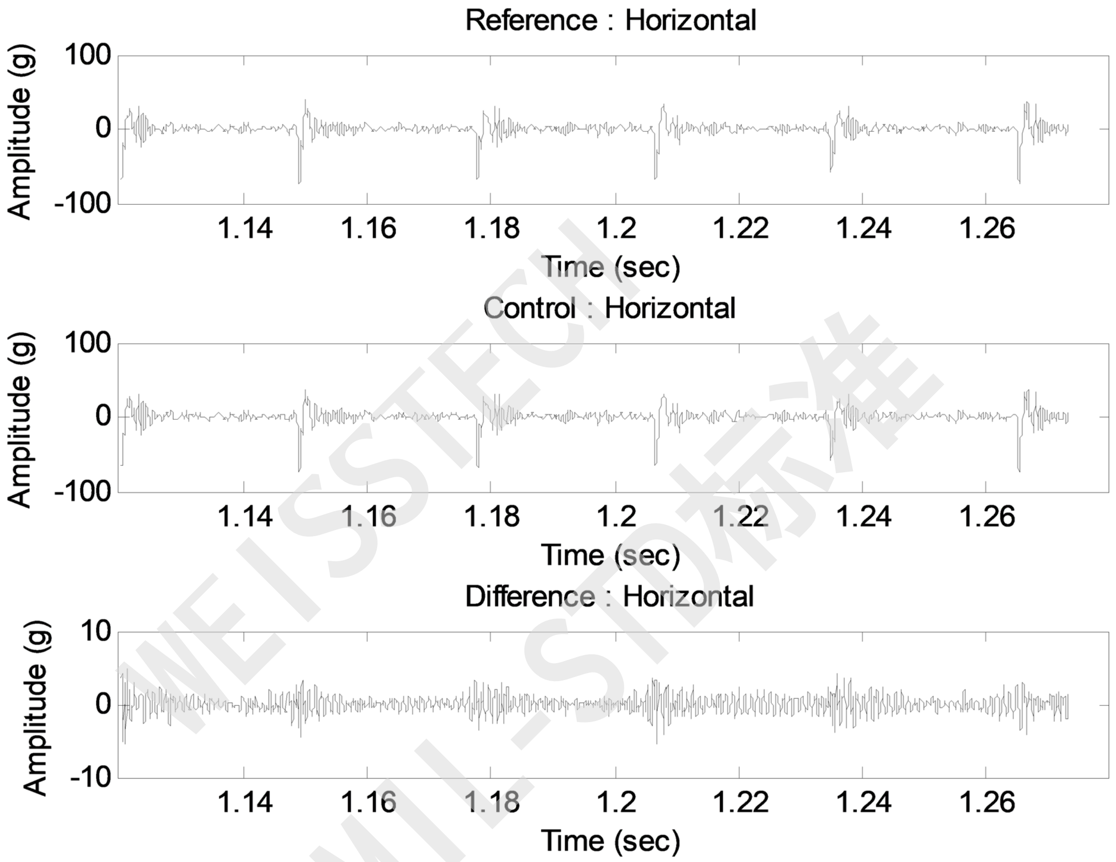

Figure 519.8A-4. High resolution representative members for the pulse ensembles (2000 rounds/minute).

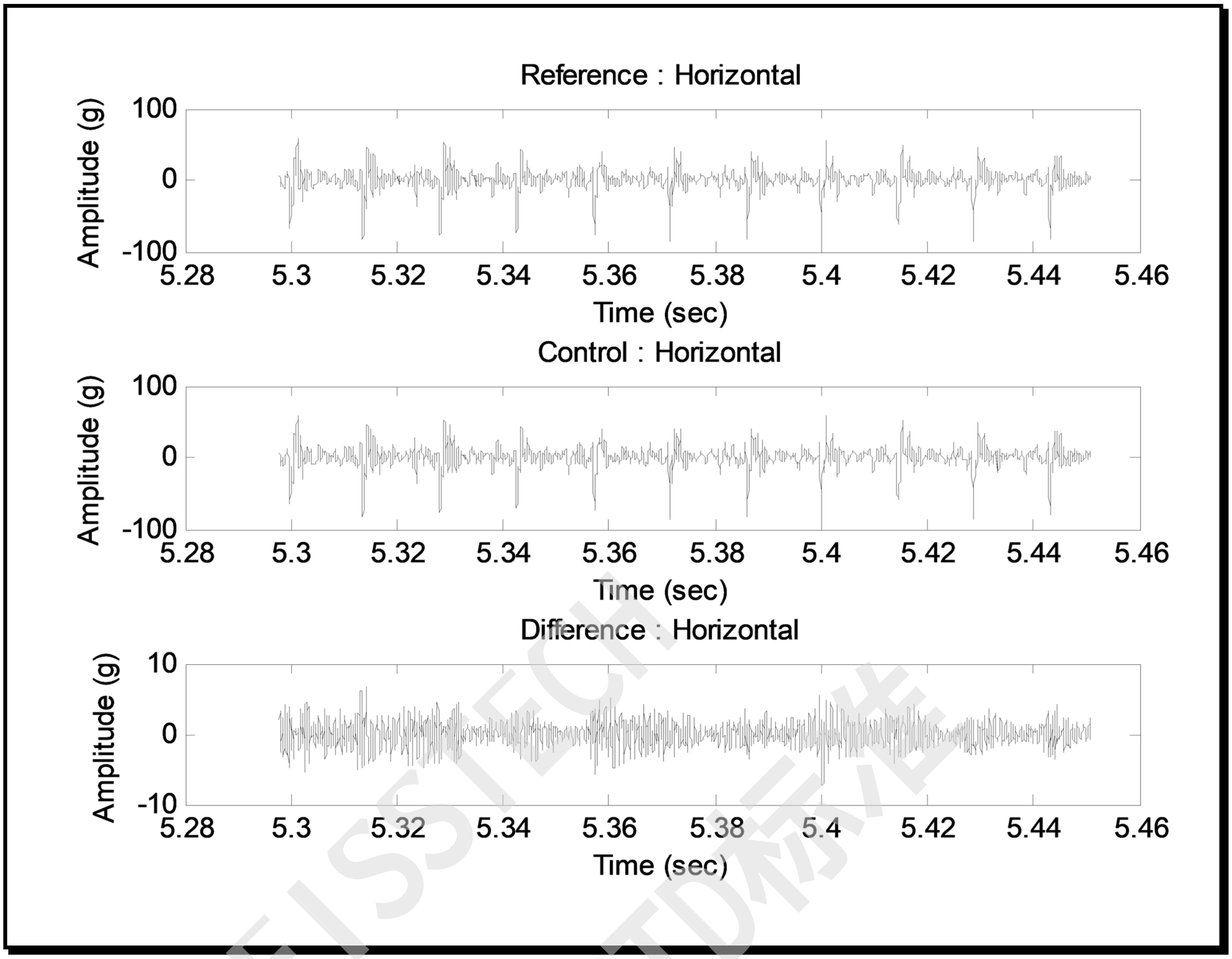

Figure 519.8A-5. High resolution representative members for the pulse ensembles (4000 rounds/minute).

Method 525.2 provides basic guidance on test tolerance specification but, in general, Method 525.2 requires that test tolerance criteria be tailored according to the form of time trace that is being replicated. For the gunfire shock environment, test tolerances are most meaningfully established in the time domain for the entire time trace (for ensemble processing pulse ensemble time based statistics along with frequency domain ESD estimates for both gunfire rates would provide supplementary criteria).

For test tolerance assessment the following test tolerance criteria are established:

a. Short-Time-Average-Root-Mean-Square (STARMS) of the ***control time trace*** and of the ***reference time trace***, when differenced, be less in absolute value than 1.0 dB (approximately 12 percent) at 90 percent of the STARMS estimate points when the difference is referenced to the maximum STARMS for the reference time trace. The *short-time averaging time* is not to exceed 0.1 of the gunfire pulse period. In addition plot of the cross-correlation estimate between control and reference for STARMS, i.e., for rms levels, is to be within 0.90 at 90 percent of the STARMS estimate points. (This tolerance criterion relates to the rms estimate differences between the control and reference time traces - it tends to be quite broad.)

b. STARMS applied to the ***difference time trace*** is to be less than -15 dB (approximately 1.8 percent) when referenced to the maximum STARMS reference time trace level at 90 percent of the STARMS estimate points. The *short-time averaging time* is not to exceed 0.1 of the gunfire pulse period. (This tolerance criterion in effect compares the "noise" as represented by the difference time trace to the "signal" as represented by maximum STARMS of the reference time trace.)

c. Ideally the ***difference time trace*** amplitudes are Gaussian distributed. Usually this is never the case. It is required that qq-plot magnitudes beyond Gaussian three-sigma positive and negative limits not exceed the following:

For positive (negative) long tail distribution greater than 1.0 dB (approximately +12 percent) when referenced to the maximum absolute reference time trace positive (negative) peak, and;

For positive (negative) short tail distribution less than - 1.0 dB (approximately - 11 percent) when referenced to the maximum absolute reference time trace positive (negative) peak.

These test tolerance criteria are designed to compare reference and control time traces based upon their perfect correlation in time. If there exists a phase difference between the time traces, then none of the above test tolerance criteria are valid. If these test tolerance criteria can be satisfied, the test performance will be established.

Figure 519.8A-6 displays STARMS level difference between control and reference time traces where the short-time averaging time was selected to be 0.1*60/4000 = 0.0015 seconds over the entire time trace, and the maximum reference rms level was 100 g-rms. For each of the short-time-average rms estimates, the cross-correlation estimate between reference and control was computed and displayed.

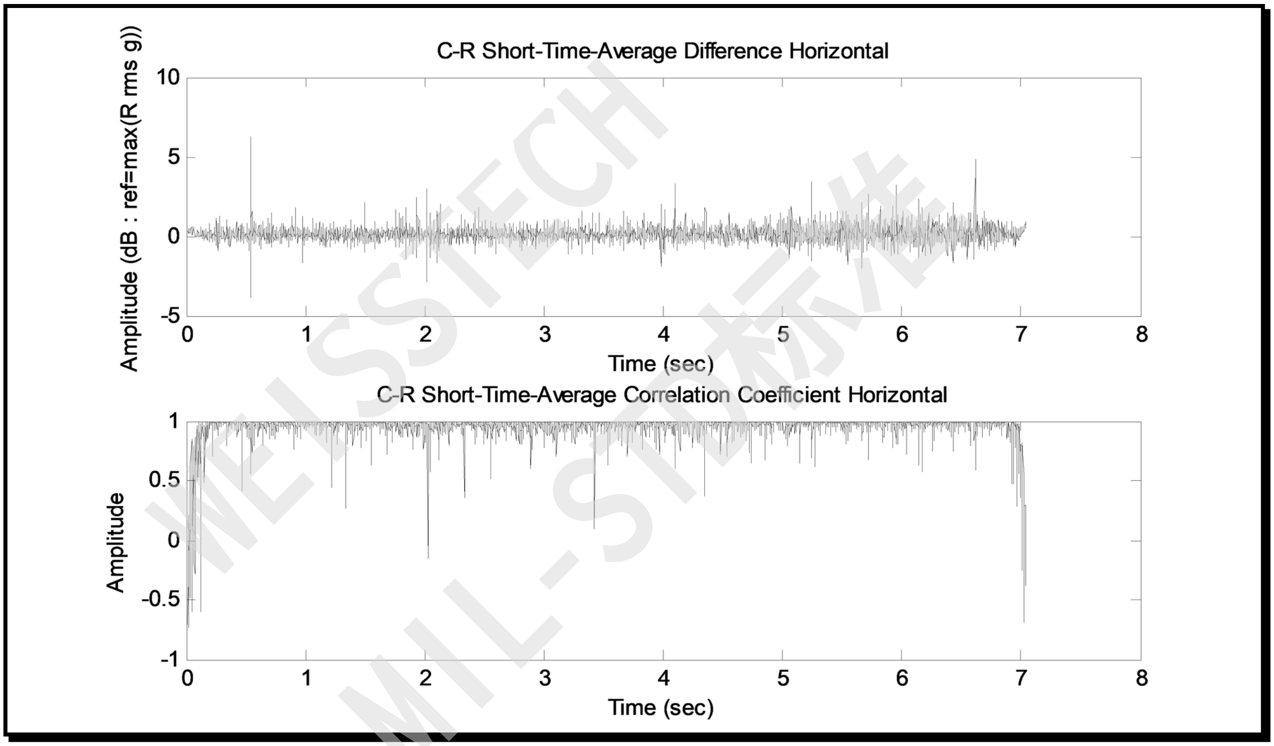

Figure 519.8A-6. STARMS difference between control and reference with cross-correlation estimate. (Difference: ref = 45.1 g-rms /cross-correlation)

Figure 519.8A-7 displays STARMS for the difference time trace, where the short-time averaging time was selected to be 0.1*60/4000 = 0.0015 seconds over the entire time trace, and the maximum reference rms level was 45.1 g-rms.

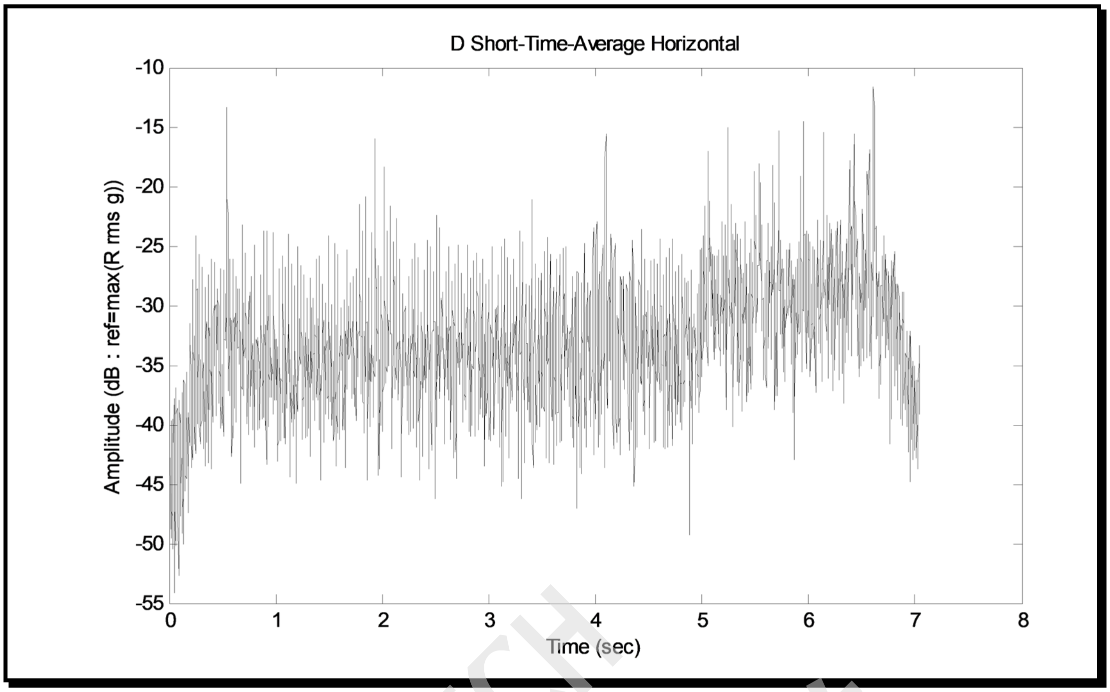

Figure 519.8A-7. STARMS for difference time trace.(Difference: ref = 45.1 g-rms)

The qq-plot for the difference time trace is displayed in Figure 519.8A-8, along with the three-sigma Gaussian limits. It is clear that the difference time trace is not Gaussian distributed, but has a long tail structure. This appears to be characteristic of most all TWR tests, and somewhat complicates tolerance specification. But for reference peak amplitudes on the order of 100g in the negative and positive directions, generally the maximum differences are within 1dB of the peak reference magnitudes.

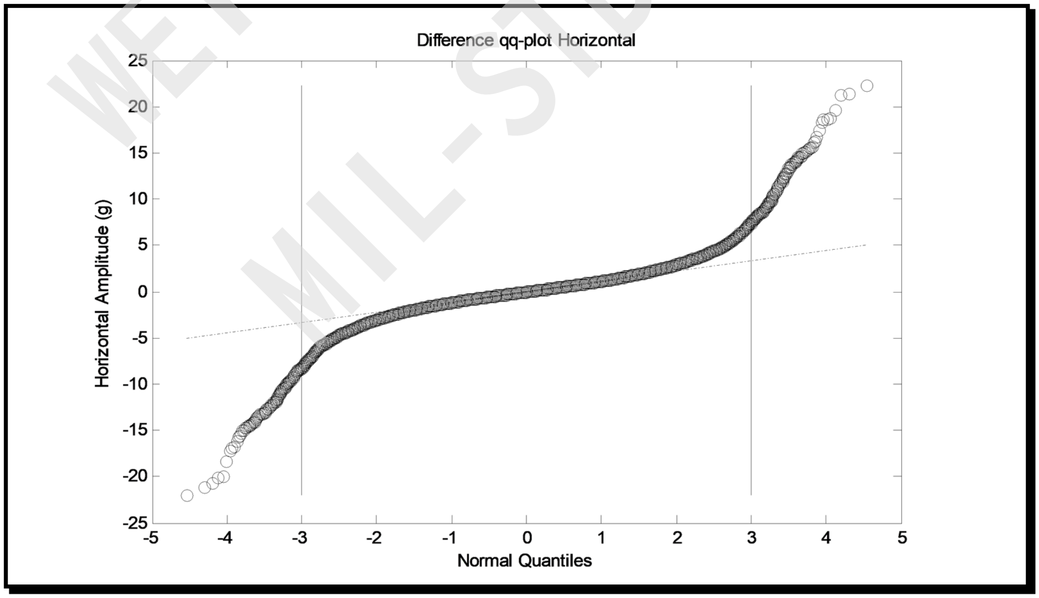

Figure 519.8A-8. qq-plot for Gaussian versus difference time trace.

Figure 519.8A-9 displays cross-plot information for reference versus control time traces. It is unclear how this information can be used for establishing test tolerance. Simple confidence intervals around a straight line fit of the cross plot points is difficult to interpret, and is contrary to intuition. Typically such confidence intervals as a result of straight-line regression fits are a minimum distance apart for values near zero, and a maximum distance apart near the end points or peaks. For TWR testing, the larger differences or errors tend to be for values near zero where noise has a greater effect on the "signal" defined by the reference time trace.

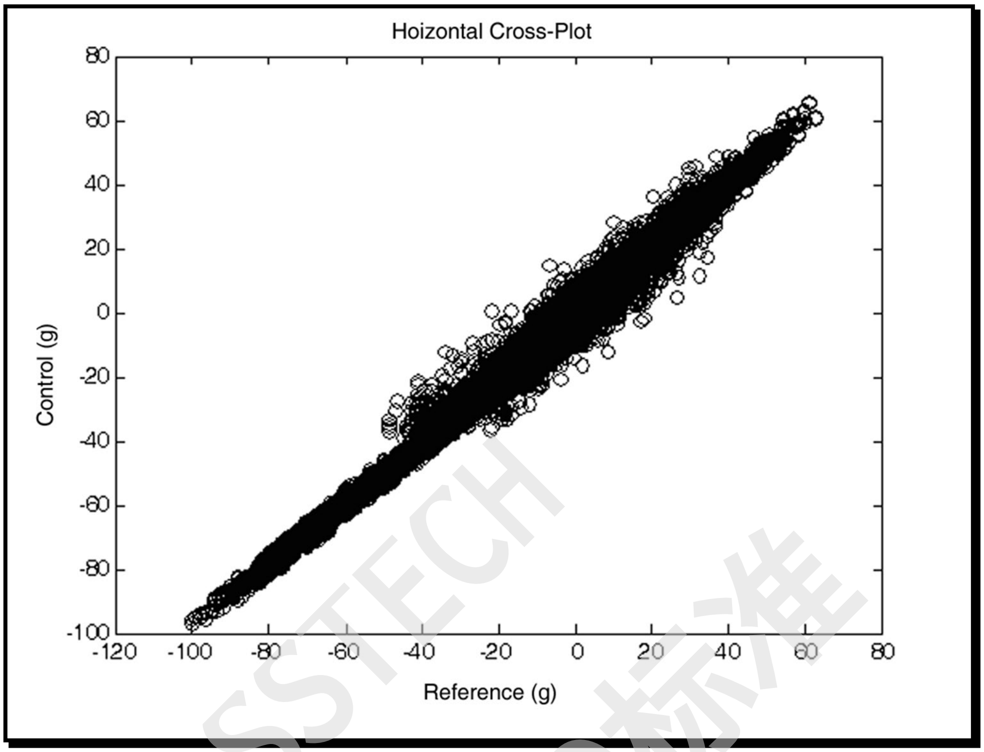

Figure 519.8A-9. Reference versus control cross-plot.

Figure 519.8A-10 provides some initial information on the relationship between the reference and control peak structure. Detailed modeling of peak structure could be performed here, however, two basic considerations must be examined. First, an assumption that peak information is vital to the integrity of the test materiel must be established (peak time trace information is generally only loosely correlated with test materiel integrity - the pseudo-velocity shock response spectrum represents materiel stress better). Second, a decision must be made as to if the unprocessed (non-band limited) control time trace, or the processed (band limited) control time trace is to be compared with the reference time trace relative to peak information. Peak modeling and subsequent interpretation must consider both assumption and decision. In this Annex, a simple time trace plot along with a normal qq-plot is provided for the difference between a reference time trace peak (or valley), and the corresponding control time trace value (that may not represent a peak or valley response). Reference and control time traces have a common bandwidth. Statistics of this somewhat "stationary" appearing serial set of random variables (not a uniformly sampled time trace) are also provided in Table 519.8A-1.

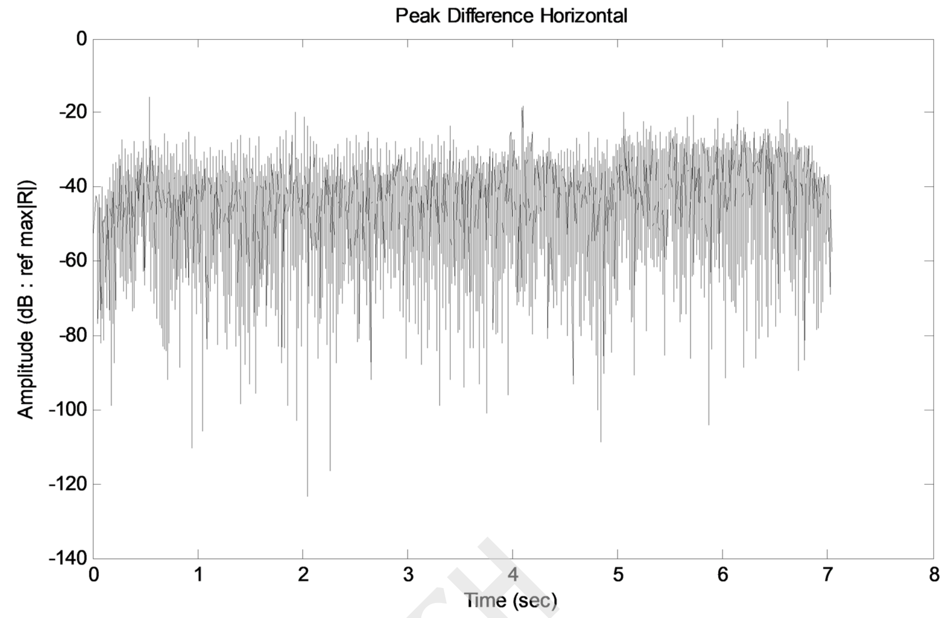

Figure 519.8A-10a. Peak statistic difference.

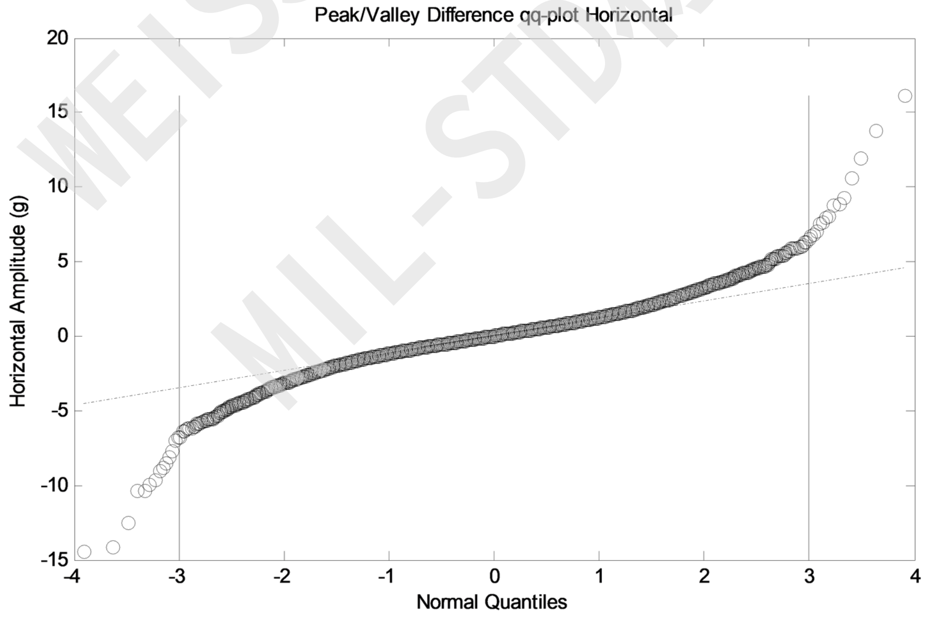

Figure 519.8A-10b. Peak/valley statistic difference - qq-plot.

The minimum, maximum, mean, standard deviation, skewness, and kurtosis of the peak statistic difference serial time sample is provided in the Table 519.8A-I.

Table 519.8A-I. Peak statistic difference statistics.

Minimum peak difference	-14.48
Maximum peak difference	16.14
Mean peak difference	0.07
Root-Mean-Square peak difference	1.53
Skewness for peak difference	-0.06
Kurtosis for peak difference	10.17

2.6 Conclusion.

2.6.1 General Remarks.

Procedure I defines a test rationale that provides substantial confidence in the materiel integrity under gunfire shock. In fact, for single point materiel response measurements on comparatively simple dynamic materiel, the method of direct replication of in-service measured materiel response is tailoring sensitive and near "optimal. "The main disadvantage of Procedure I is that there is no obvious way to statistically manipulate (basically "scale-up") the measured materiel input/response data to ensure a "conservative test." As discussed in Method 525.2, the "optimal" assumption regarding a single field measured time trace is that it represents the mean time trace or 0.5 confidence coefficient from the underlying random process it represents, i.e., if an ensemble of realizations of the underlying random process is available, the available single field measured time trace is a valid estimate of the mean of the underlying random process, or under a probabilistic framework, a single unique measured time trace must be assumed to representative of the mean of the underlying random process, assuming an infinite collection of such time traces could be collected under identical circumstances.

Procedure I is optimum when more than one measured gunfire shock environment is available, and the gunfire shock environments are concatenated into a sequence representative of the LCEP in-service conditions.

2.6.2 Stochastic Generation.

In cases in which multiple gunfire replications are required from limited measurement information there exist approaches to generating stochastic time history traces. Smallwood (reference h) and Merritt (reference g) both propose pulse ensemble approaches to replication of gunfire time traces based upon measured information. Both of these procedures, Smallwood in the frequency domain and Merritt in the time domain, required that the measurement information be provided in the form of an ensemble of pulses with "correlated" time history information i.e., the ensemble of pulses were precisely "lined up" in time based upon time history correlation procedures. Both of these procedures described in detail in the references provided reliable methods for providing a stochastic generation of gunfire time trace records for laboratory testing. With the advent of "wavelet" procedures. that are localized in time, manipulation of either pulse ensemble detail wavelet coefficients or the entire measurement gunfire time trace information at some level of "wavelet detail" can be used to stochastically (as a result of wavelet coefficient manipulation) employed to generate a new gunfire shock realization that is as "close" to the measurement as desired. Wavelet coefficient manipulation because of the wavelet localization properties can be used to artificially scale measurement information to produce more conservative test scenarios. No guidelines can be provided here for implementation of wavelet based stochastic generation of time history traces, however, any stochastic manipulation and time trace reproduction under TWR must be consistent with the test tolerances provided in Methods 525.2 or 527.2.

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METHOD 519.8, ANNEX B

GUIDELINES FOR PROCEDURE II - SRS GENERATED SHOCK TIME HISTORY PULSE SEQUENCE UNDER TWR

1. SCOPE.

1.1 Purpose.

The purpose of Procedure II is to provide an alternative gunfire shock testing philosophy when only an SRS computed from a gunfire event is provided. In cases in which a measurement time history is available Procedure I must be used without exception. An estimate of the available time history SRS cannot be used to provide an alternative gunfire test to Procedure I, utilizing Procedure II. To implement this procedure the following three pieces of information are required:

1. An SRS (termed a "Target SRS") and associated damping as computed over a specified natural frequency bandwidth. (This SRS may be from a measurement previously processed from time history data that is no longer available or from an SRS that is of a generic nature).
2. The fundamental firing rate of the gun.
3. The duration of the "gunfire event" indicating the number of pulses to be concatenated for the proposed TWR testing (as defined per the LCEP).

As is likely to be the case, the SRS display, i.e., natural frequency versus maximax SRS estimate, may extend beyond the test frequency bandwidth for the TWR implementation. This is particularly true for low natural frequency display and very high natural frequency display. For low natural frequency display, this may be the result of processing a gunfire time history or defining a generic reference extending much beyond the period of the firing rate. For high natural frequency display this may be a result of gunfire response extending well beyond electrodynamic exciter capabilities.

Procedure II requires input from Method 516.8 relative to (1) proper synthesis of deterministic time histories from SRS estimates with representative shock duration, and (2) laboratory test SRS tolerance limits. In addition, since the testing will be implemented under TWR, TWR testing options from Method 525.2 may also be applicable. From Method 516.8 the SRS "sine-beat procedure" or "damped sine procedure" provide an algorithmic methodology for generating a single deterministic pulse time history from the SRS estimate. Typically, this generated pulse matching the SRS will extend well beyond the period related to the gun firing rate.

An SRS estimate provided for a single pulse from a gunfire shock event is unacceptable for gunfire shock testing and any such proposed testing relative to single pulses must follow the philosophy and guidelines of Method 516.8.

This Annex assumes that the testing facility is fully qualified to provide a deterministic pulse based upon SRS considerations as outlined in Method 516.8, synthesizing the pulse train and providing additional manipulation in order to perform the Single-Exciter/Single-Axis (SESA) TWR Procedure in Method 525.2 with the analytically generated reference time history.

1.2 Application.

This Annex addresses a method for laboratory gunfire shock replication under TWR based upon SRS specification alone. This application begins with a single deterministic shock pulse generated based upon the SRS "sine-beat" or "damped sine" vendor procedure which is then concatenated to the duration of the specified "gunfire event". In general an SRS determined over the deterministic concatenated pulse train will not be within tolerance as specified for shock in Method 516.8 for the lower natural frequencies. There are a variety of means of bringing the concatenated pulse train within tolerance. One such procedure is go generate a bandlimited random time history, scaling to a correct amplitude based upon SRS estimate considerations and then adding the bandlimited random time history to the concatenated deterministic pulse train file. This results in a form of impulsive shock random time history. The resulting time history should provide an SRS estimate within SRS tolerance called out in Method 516.8 for standard shock. It is noted that the advantage accrued via the SRS procedure is that SRS based laboratory test tolerances are readily available and easily understood (see Method 516.8). However, in TWR execution of the test, time history test tolerances under TWR, Method 525.2, must be observed. That is both the SRS tolerances for overall test satisfaction according to the specification and TWR test tolerances for execution of the test are applicable, with SRS test tolerances of first concern for specification satisfaction. The major limitation of the procedure is that SRS information at frequencies below the gunfire rate based upon the proposed test length (in terms of number of pulses at the gunfiring rate) can only be accounted for in an ad hoc manner.

2. BASIC CONSIDERATIONS FOR GENERATION OF A DETERMINISTIC GUNFIRE SHOCK TIME HISTORY FROM A SRS ESTIMATE.

2.1 Introduction.

It is assumed that an SRS over a given natural frequency bandwidth is available for description of the gunfire shock event assumed to be a product of a form of replicated shock and TWR is the prescribed method of test. It is assumed that the natural frequency bandwidth is compatible with the laboratory test apparatus i.e., electrodynamic or electro hydraulic exciter. Procedure II will be illustrated for a generic SRS gunfire shock specification.

2.2 Single Gunfire Shock Event with SRS Specification.

Figure 519.8B-1 illustrates a generic maximax SRS representing a “gunfire event” with “event” implying “replicated shock” at the gunfire rate. The SRS is termed the “Target SRS” implying that this SRS must be satisfied in the testing procedure within tolerances provided in Method 516.8. The gunfire rate is specified as 50 Hz providing a fundamental pulse repetition at 20 millisecond time intervals. The natural frequency bandwidth is from 10 to 2000 Hz. All SRS computations in the example were computed with a one-twelfth octave resolution and Q=10. For this example, assume the gunfire schedule calls for firing 10 bursts of 1 second duration i.e., 50 pulses and a gunfire schedule separation of 2 seconds between bursts. For this specification the natural frequency bandwidth is compatible with the bandwidth of the electrodynamic exciter for Method 525.2 TWR testing.

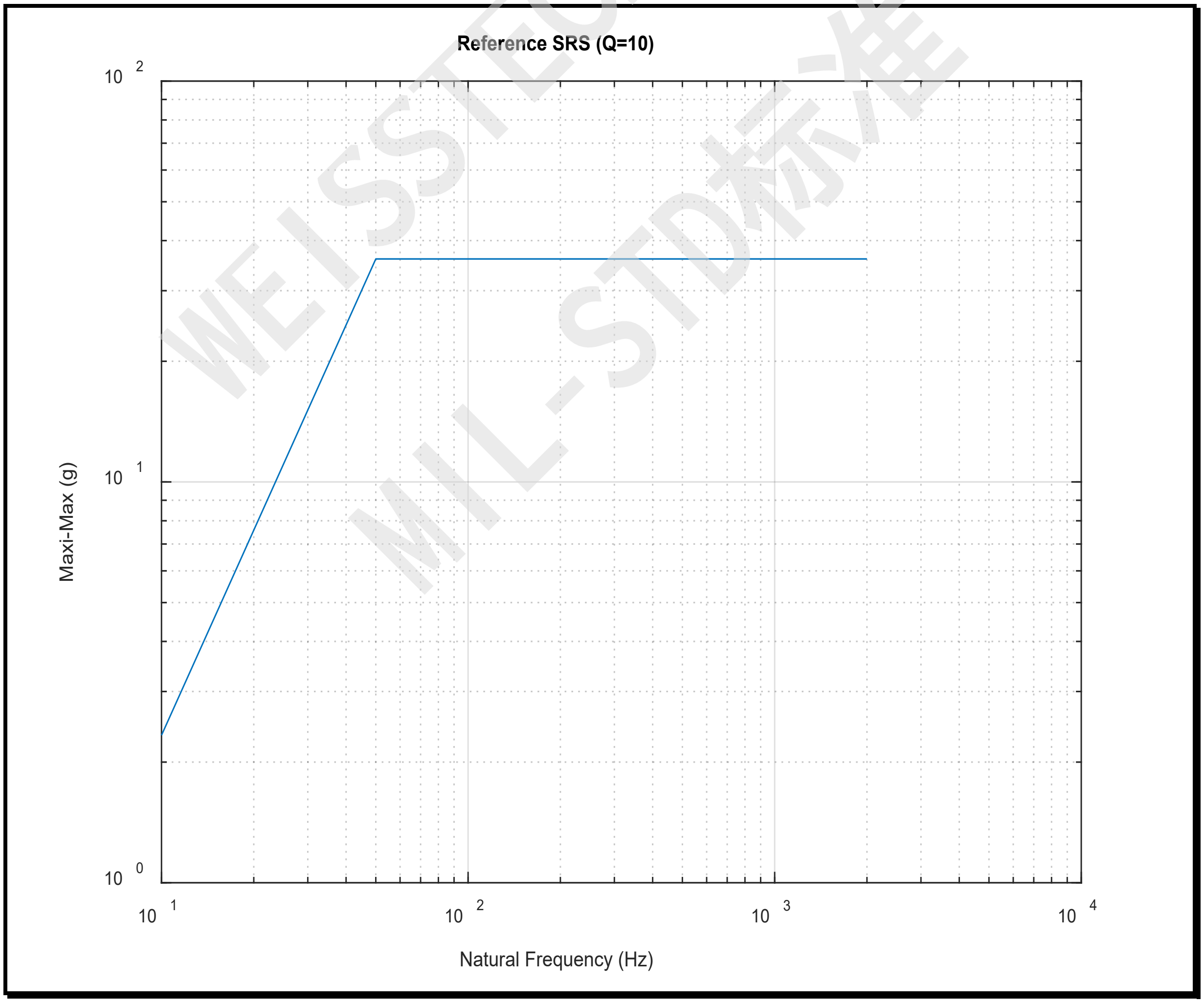

Figure 519.8B-1. Generic example gunfire SRS reference.

Figure 519.8B-2 displays a single deterministic pulse that has been generated from the Method 516.8 SRS algorithm implemented via the “sine-beat” procedure over 0.02 seconds (the period of the gunfire). Due to the short duration associated with the period of an individual frequency component, the low frequency limit in the synthesis is recommended to be one to two octaves above the gunfire frequency. This will allow inclusion of a reasonable number of cycles of the lower frequency components in the synthesis process. The resulting synthesis illustrated in Figure 519.8-B-2 was based on the reference SRS of Figure 519.8B-1 between 200 and 2000 Hz. It is noted that valid SRS information existing below the low frequency limit (200 Hz in this example) has been suppressed in the analytically generated pulse. The low SRS natural frequencies are artifacts of the variations between individual pulses in the original multiple shot measured time history. The low frequency information will be synthesized in a subsequent step.

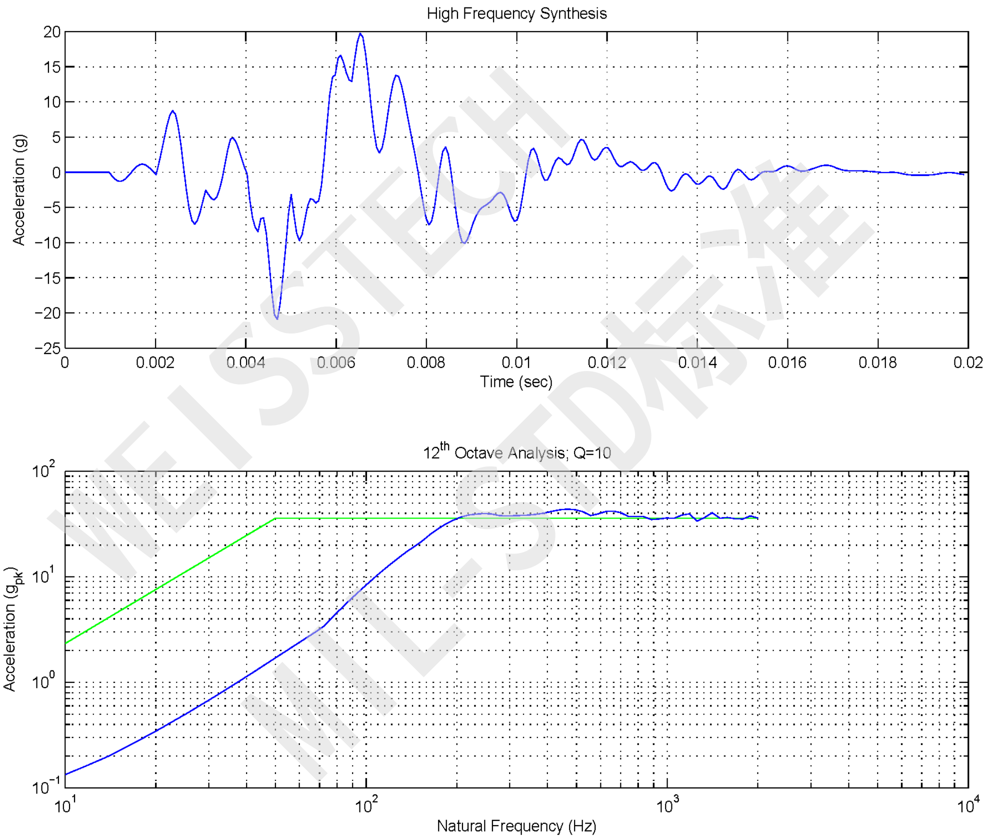

Figure 519.8B-2. Deterministic SRS sine-beat synthesized pulse (extended over 20 milliseconds for 50 Hz gunfiring rate).

Figure 519.8B-3 displays the concatenated pulse to the specified duration (1 second bursts for this example). This concatenated pulse representing the “gunfire event” provides an SRS estimate as compared to the specified SRS. The prescribed duration of the concatenation will artificially introduce some low natural frequency SRS information but usually not enough information such that the SRS tolerance in Method 516.8 will be met. Guidance on addressing the low frequency portion of the SRS follows.

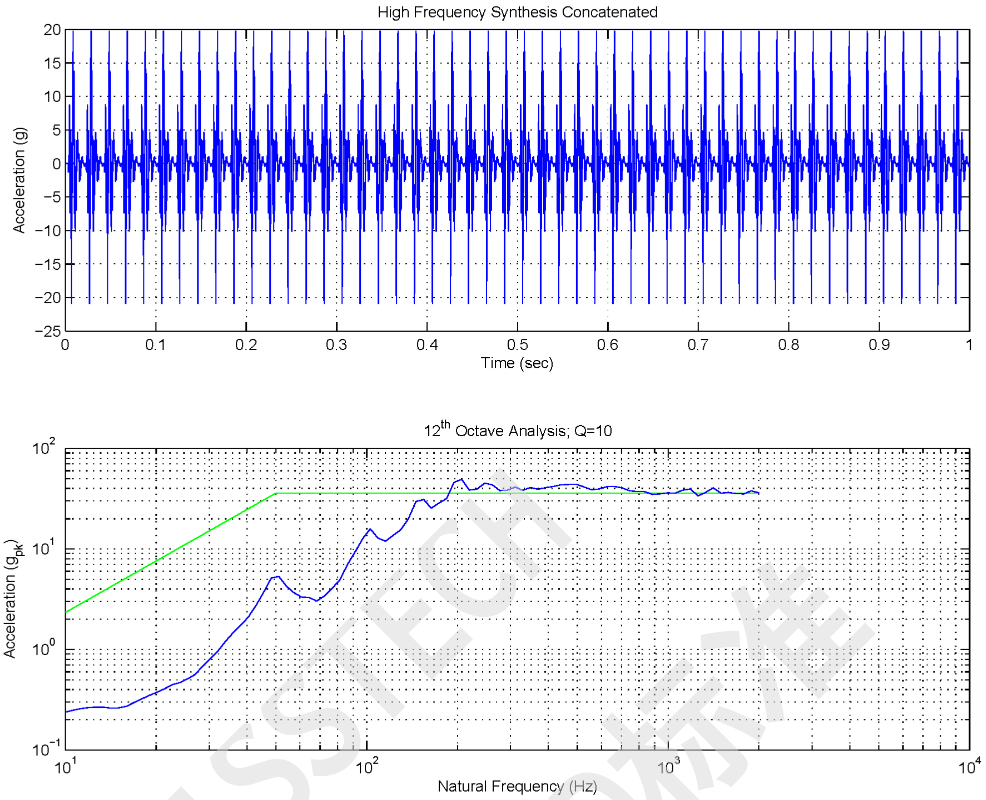

Figure 519.8B-3. Concatenated high-frequency synthesis (200 -2000 Hz)

From the SRS plot in Figure 519.8B-3 it is clear that additional manipulation needs to take place to meet the low natural frequency SRS tolerance levels. There exist several ways in which the SRS information in the low natural frequencies can be enhanced. A suggested method is to employ a time history "Additive Model" by adding a properly scaled bandlimited random time history of duration of the "gunfire event to the concatenated time history displayed in Figure 519.8B-3. Figure 519.8B-4 displays such a random time history bandlimited between 10 Hz and just under 200 Hz over a one second time interval that meets the SRS characteristics of the reference SRS. The low frequency synthesis is recommended to have a maximum frequency content that falls one or two bins below the minimum frequency of the high frequency synthesis to avoid excessive overlap associated with the twelfth octave filter banks.

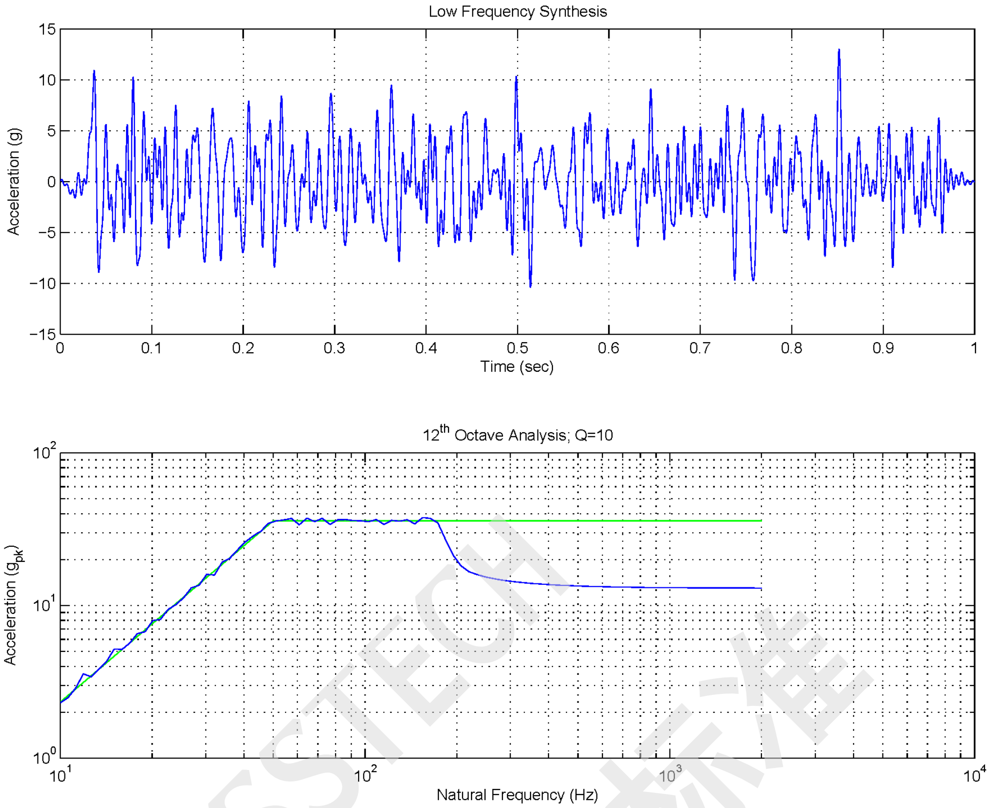

Figure 519.8B-4. Bandlimited random synthesis (10 Hz – 200 Hz).

Figure 519.8B-5 displays the effects of the low frequency synthesis of Figure 519.8B-4 added to the concatenated pulse in Figure 519.8B-3. The resulting time history provided in Figure 519.8B-5 is a first iteration of a possible reference to be used for the TWR testing. The lower plot in Figure 519.8B-5 displays the difference between the SRS specification and the SRS for the analytical generation to be executed under TWR as described in Method 525.2. Slight iterations on the high frequency synthesis are possible if it is determined that the original iteration is not sufficiently close to the desired reference.

Once an acceptable one second reference time history has been established, it is just a matter of programming the TWR software to repeat the one second record ten times with two seconds between each event as specified per the LCEP in the introductory paragraph of this example.

It should also be clear that the manipulation involved in this process requires that of a trained analyst. Once a reference time history has been synthesized and accepted by the appropriate test authority, the resulting time history may be used as a common reference in the event multiple laboratories are involved in conduct of a common test.

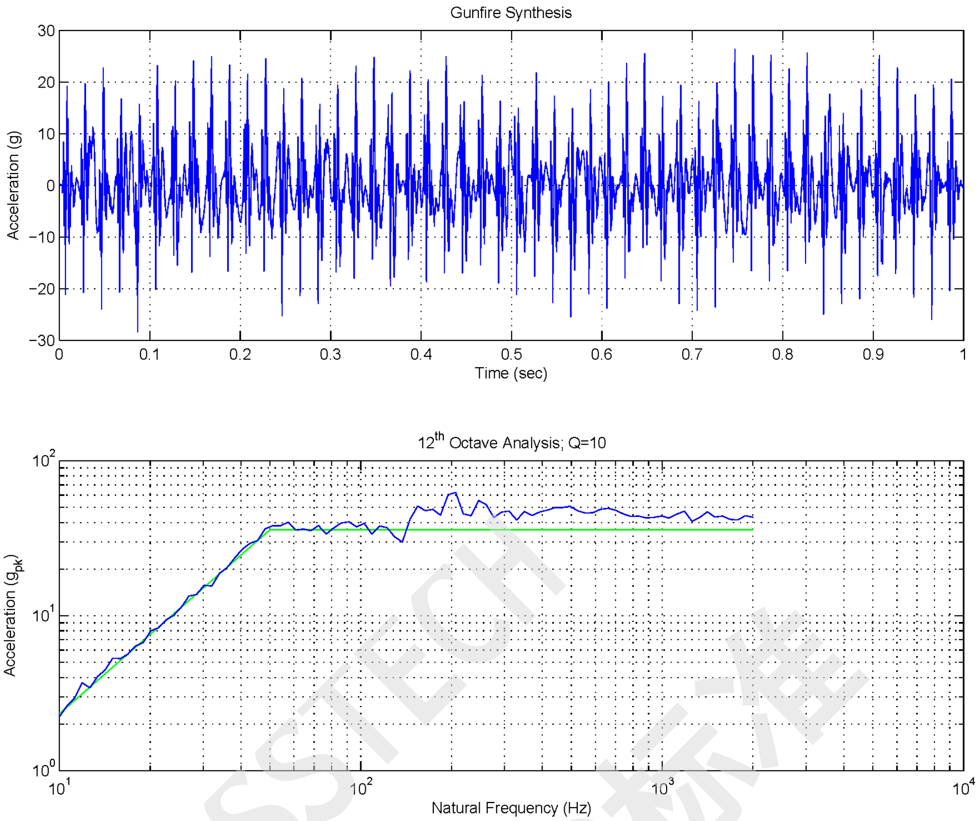

Figure 519.8B-5. Synthesized one-second gunfire shock pulse train reference per additive model.

2.3 Multiple Gunfire Shock Events with SRS Considerations.

When multiple gunfire shock events for SRS estimates are provided then laboratory testing may proceed as in paragraph 2.2 for a single gunfire shock event applied by each of the multiple gunfire shock events.

One acceptable means of providing a form of stochastic implementation of the SRS procedure is to create deterministic SRS sine-beat based pulse time histories based upon SRS estimates for independent gunfire event time histories. That is, for each gunfire event a series of "sine-beat pulses" is generated and concatenated into one overall pulse time history. The statistical variation in the individual gunfire events can be represented by this procedure. This procedure can also be used to produce a very large number of unique and statistically independent overall gunfire time history events by Monte-Carlo sampling of the SRS sine beat generation.

3. CONCLUSION.

It is generally unusual to have an SRS estimate for a gunfire event without the accompanying measurement time history, however, if this is the case Procedure II must be applied. In all cases where measurement time history trace information is available Procedure I must be applied. When an ensemble of SRS estimates are available from multiple independent gunfiring events a certain degree of statistical processing may be introduced via enveloping of the set of SRS estimates or even in detail modeling each SRS with an SRS beat generation form of deterministic time history.

METHOD 519.8, ANNEX C

GUIDELINES FOR PROCEDURE III - STOCHASTICALLY GENERATED MATERIEL INPUT FROM PRELIMINARY DESIGN SPECTRUM

1. SCOPE.

This Annex provides the option of using predicted gunfire vibration in the form of a Sine-on-Random (SOR) spectrum when measured data are not available. Information in this Annex is to ensure materiel mounted in an aircraft with onboard guns can withstand the predicted environmental acceleration levels caused by (1) pulse overpressures emitting from the muzzle of the gun impinging upon materiel support structure, and (2) structure-borne vibration. The first portion of this Annex constitutes a reformatting of Method 519.5, Gunfire Vibration, Aircraft, in MIL-STD-810F with a limited number of enhancements. The second portion of this Annex briefly describes two methodologies for taking a predicted spectrum and generating a form of "shock pulse" acceleration time history of arbitrary length whose ASD estimate matches the predicted spectrum and can be implemented using Method 525.2 Time Waveform Replication (TWR). The two methodologies represent time domain and frequency domain implementations of standard Fourier based techniques.

Note that the predicted spectrum has a continuous part and a discrete part consisting of a fundamental frequency/amplitude and three additional components with frequencies at harmonic ratios to the fundamental. The SOR is a more limited and specific terminology and implies vibration controller implementation.

PART 1 - SPECTRUM PREDICTION METHODOLOGY FOR PRELIMINARY MATERIEL DESIGN

1. SCOPE

1.1 Purpose.

This Annex provides the option of using predicted gunfire vibration (Sine-on-Random [SOR]) data (when measured data are not available), to ensure materiel mounted in an aircraft with onboard guns can withstand the predicted environmental acceleration levels caused by (1) pulse overpressures emitting from the muzzle of the gun impinging upon materiel support structure, and (2) structure-borne vibration. (This Annex constitutes a reformatting of Method 519.5, Gunfire Vibration, Aircraft, in MIL-STD-810F with a limited number of enhancements.) This Annex also provides the option for using high level random vibration (measured data are available) when the measured data spectrum displays no outstanding discrete harmonic components.

1.2 Application.

This Annex is applicable only for aircraft gunfire and materiel mounted in an aircraft with onboard guns. Guidance in this Annex is to be used only if in-service measured materiel response data are not available, or will not be available in the early stages of a development program. This Annex is not intended to justify the use of SOR or narrowband random-on-random for cases in which measured data display a broadband spectra along with components at discrete frequencies. Use the information in this Annex only if it is vital to the design of the materiel. If there is a possibility of obtaining early measurements of the materiel response mounted on the in-service platform, supplant the severities developed using the information in this Annex with the severities estimated from the materiel response under in-service measurements, and one of the other procedures used for testing. In particular, if the measured materiel response in-service environment has the character of high level broadband random vibration with no characteristics conducive to application of Procedure II or Procedure III, then:

a. Apply Procedure I in the form of transient vibration, or

b. Submit the test item to a specified level of high level broadband random vibration (based on ASD estimates of the measured in-service materiel response) over a period of time, consistent with low cycle fatigue assumptions in accelerated testing or as specified in the test plan (see Method 514.8).

This technique is based upon obtaining the predicted SOR spectrum, using the four sine components in phase to develop the envelope of the form of a pulse, and using the predicted spectrum as stationary random vibration that can be enveloped to provide a pulse form time trace that can be used for preliminary design of materiel where no addition information is available. This technique is not intended to develop a pulse that can be concatenated and used for testing under TWR.

1.3 Limitations.

This Annex is not intended to justify the use of SOR or narrowband random-on-random for cases in which measured data displays a broadband spectra along with components at discrete frequencies.

2. DEVELOPMENT.

2.1 Introduction.

This Annex is essentially a reorganized reproduction of the information contained in reference g. of paragraph 6.1, with some additional guidance. Mention of the pulse method in paragraph 6.2, reference f, is included, and provides insight into the use of the pulse method in conjunction with a predictive rationale. Procedure III differs from the other two procedures in that it is a result of a prediction procedure developed on the basis of an analysis of a comparatively small set of measured gunfire materiel response data. The predicted spectrum, therefore, provides estimates of materiel vibration response that may be substantially different from in-service measured vibration response of a particular materiel. For a particular materiel and gun/materiel configuration, materiel response to gunfire is generally not amenable to accurate prediction. The prediction methodology provided below is generally subject to a large degree of uncertainty with respect to test level. This uncertainty is very apparent in gunfire configurations where the gun is less than a meter (3.3 ft) from the materiel.

2.2 Predicting Gunfire Vibration Spectra.

Gunfire vibration prediction spectra consist of a broadband spectrum representative of an ASD estimate from stationary random vibration, along with four harmonically related sine waves. Figure 519.8C-1 provides a generalized vibration spectrum for gunfire-induced vibration that defines the predicted response of materiel to a gunfire environment. It is characterized by four single frequency harmonically related (sine) vibration peaks superimposed on a broadband random vibration spectrum. The vibration peaks are at frequencies that correspond to the nominal gunfire rate and the first three harmonics of the gun firing rate. The specific values for each of the parameters shown on Figure 519.8C-1 can be determined from Table 519.8C-I, Table 519.8C-II, Table 519.8C-III, and Figures 519.8C-2 through -8. The suggested generalized parametric equation for the three levels of broadband random vibration, T_j, defining the spectrum on Figure 519.8C-1, is given in dB for g^2/Hz (reference to 1 g^2/Hz) as:

$$10\log_{10}(Tj) = 10\log_{10}(N\,F_1\,E) + H + M + W + J + B_j - 53\text{ dB} \quad j=1, 2, 3 \qquad \text{Equation (C-1)}$$

where the parameters are defined in Table 519.8C-I.The suggested generalized parametric equation for the four levels of single frequency (sine) vibration defining the spectrum on Figure 519.8C-1 is given in dB for g^2/Hz (reference to 1 g^2/Hz) as

$$10\log_{10}(Pi) = 10\log_{10}(T_3) + K_i + 17\text{ dB} \quad i=1, 2, 3, 4 \qquad \text{Equation (C-2)}$$

where the parameters are defined in Table 519.8C-I.

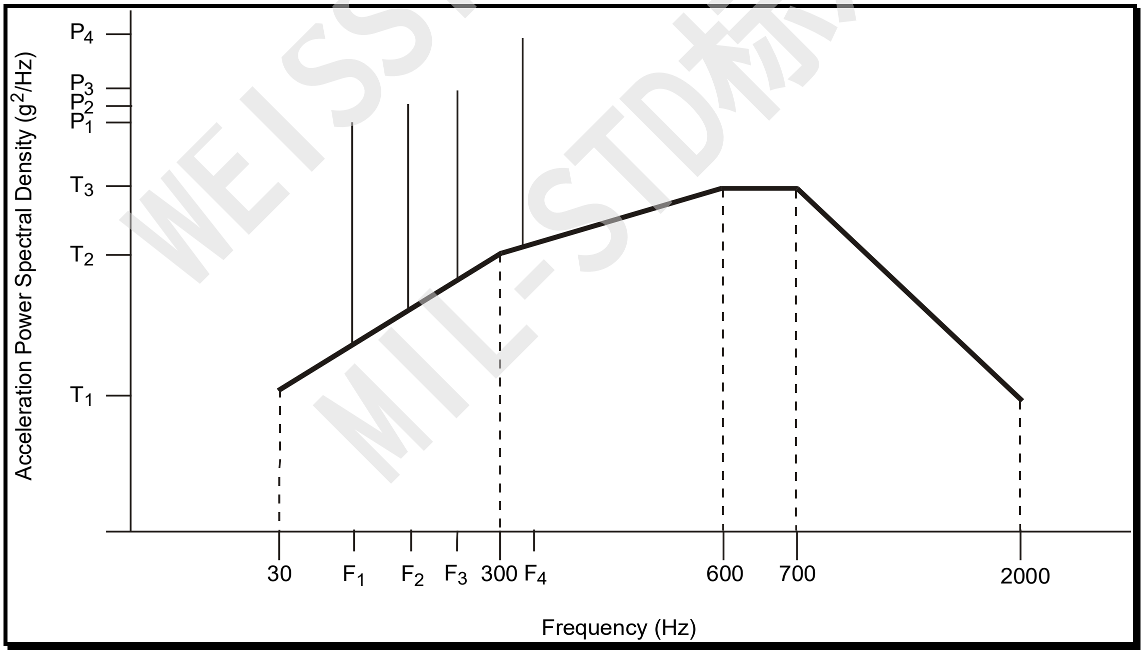

Figure 519.8C-1. Generalized gunfire induced vibration spectrum shape.

Table 519.8C-I. Suggested generalized parametric equations for gunfire-induced vibration.

$$10 \log_{10} (T_j) = 10 \log_{10} (NF_1E) + H + M + W + J + B_j - 53 \text{ dB}$$

$$10 \log_{10} (P_i) = 10 \log_{10} (T_3) + K_i + 17 \text{ dB}$$

for

N	Maximum number of closely spaced guns firing together. For guns that are dispersed on the host aircraft, such as in wing roots and in gun pods, separate vibration gunfire test spectra are determined for each gun location. The vibration levels, for test purposes, are selected for the gun that produces the maximum vibration levels.
E	Blast energy of gun (see Table 519.8C-III).
H	Effect of gun standoff distance, h (see Figure 519.8C-4).
M	Effect of gun location M = 0 unless a plane normal to the axis of the gun barrel and located at the muzzle of the gun does not intersect the aircraft structure, then M = -6 dB.
W	Effect of weight of the equipment to be tested (use Figure 519.8C-5).If the weight of the materiel is unknown, use W = 4.5 kilograms (10 lbs).
J	Effect of the materiel's location relative to air vehicle's skin (use Figures 519.8C-2 and 519.8C-6).
B_j	Effect of vector distance from the gun muzzle to the materiel location (see Figure 519.8C-7).
F_1	Gunfiring rate where F_1 = fundamental frequency from Table 519.8C-II ($F_2 = 2F_1$, $F_3 = 3F_1$, $F_4 = 4F_1$)
T_j	Test level in g^2/Hz
P_i	Test level for frequency F_i in g^2/Hz (where i = 1 to 4)
K_i	Effect of vector distance on each vibration peak, P_i (see Figure 519.8C-8).

Note: These equations are in metric units. The resultant dB values are relative to 1 g^2/Hz.

Table 519.8C-II. Typical gun configurations associated with aircraft classes.

Aircraft/Pod	Gun (Quantity)	Location	Firing Rate		Capacity
			Rnds/Min	Rnds/Sec	
A-4	MK12 (2)	Wing roots	1000	16.6	100/Gun
A-7D	M61A1 (1)	Nose, left side	4000 & 6000	66.6 & 100	1020
A-10	GAU-8/A (1)	Nose	2100 & 4200	35 & 70	1175
A-37	GAU-2B/A (1)	Nose	6000	100	1500
F-4	M61A1 (1)	Nose	4000 & 6000	66.6 & 100	638
F-5E	M39 (2)	Nose	3000	50	300/Gun
F-5F	M39 (1)	Nose	3000	50	140
F-14	M61A1 (1)	Left side of nose	4000 & 6000	66.6 & 100	676
F-15	M61A1 (1)	Right wing root	4000 & 6000	66.6 & 100	940
F-16	M61A1 (1)	Left wing root	6000	100	510
F-18	M61A1 (1)	Top center of nose	4000 & 6000	66.6 & 100	570
F-111	M61A1 (1)	Underside of fuselage	5000	83.3	2084
GEPOD 30	GE430 (1) (GAU-8/A)	POD	2400	40	350
SUU-11/A	GAU-2B/A (1)	POD	3000 & 6000	50 & 100	1500
SUU-12/A	AN-M3 (1)	POD	1200	19	750
SUU-16/A	M61A1 (1)	POD	6000	100	1200
SUU-23/A	GAU-4/A (1)	POD	6000	100	1200

Table 519.8C-III. Gun specifications.

Gun	Gun Caliber, c		Blast Energy, E (J)*
	mm	in	
GAU-2B/A	7.62	0.30	6,700
GAU-4/A	20	0.79	74,600
GAU-8/A	30	1.18	307,500
AN-M3	12.7	0.50	26,000
M3	20	0.79	83,000
M24	20	0.79	80,500
M39	20	0.79	74,600
M61A1	20	0.79	74,600
MK11	20	0.79	86,500
MK12	20	0.79	86,500

*joules (J) x 0.7376 = foot-pounds

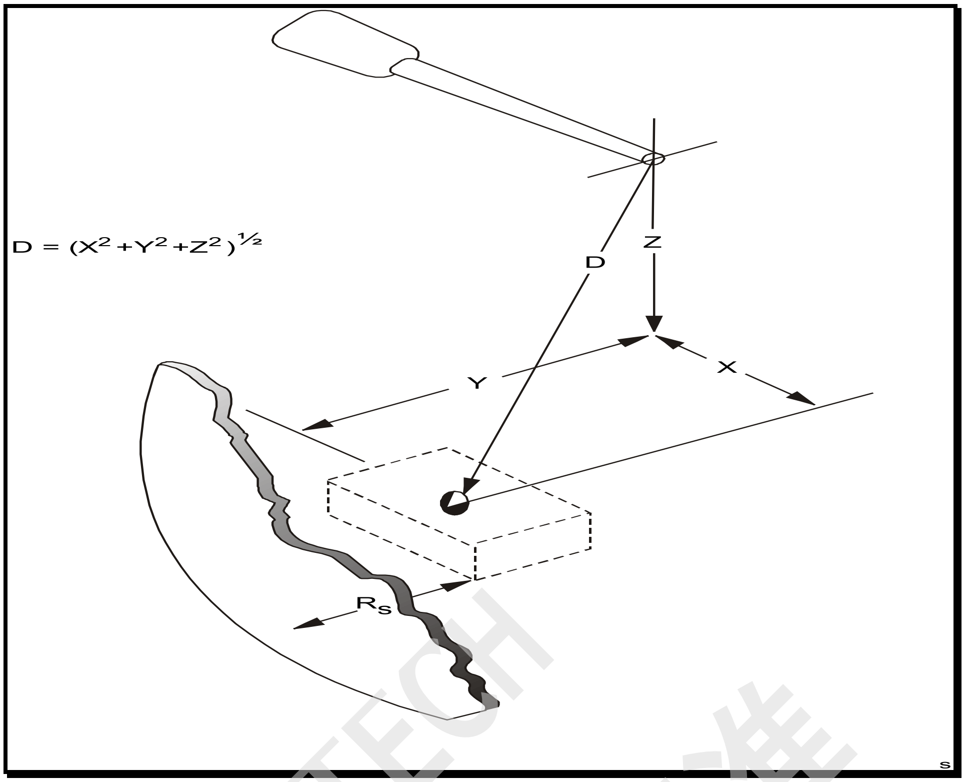

Figure 519.8C-2. The distance parameter (D) and the depth parameter (R_s)

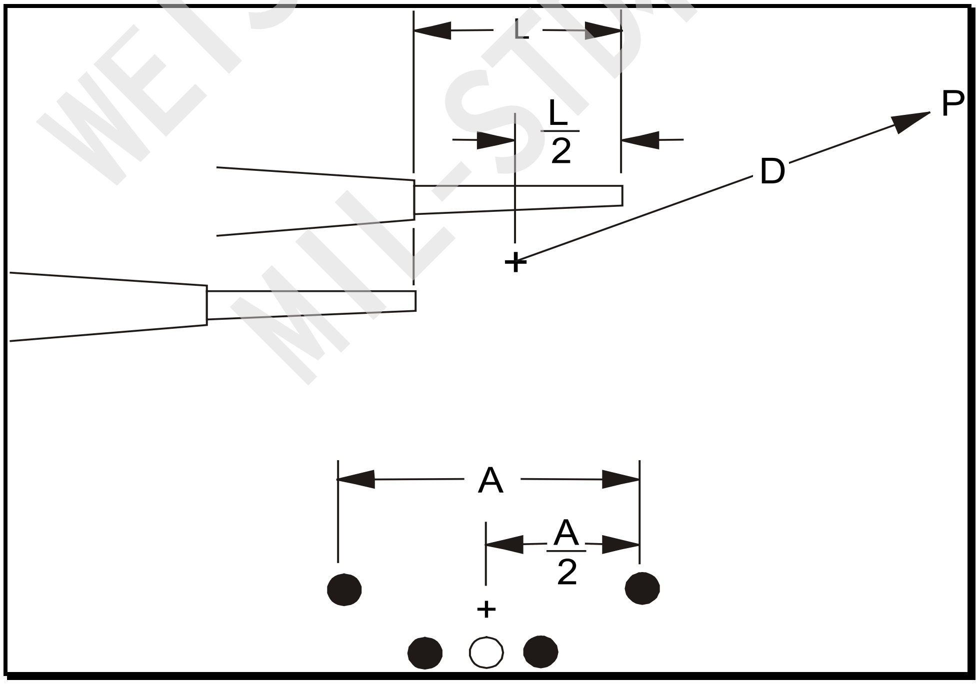

Figure 519.8C-3. Multiple guns, closely grouped.

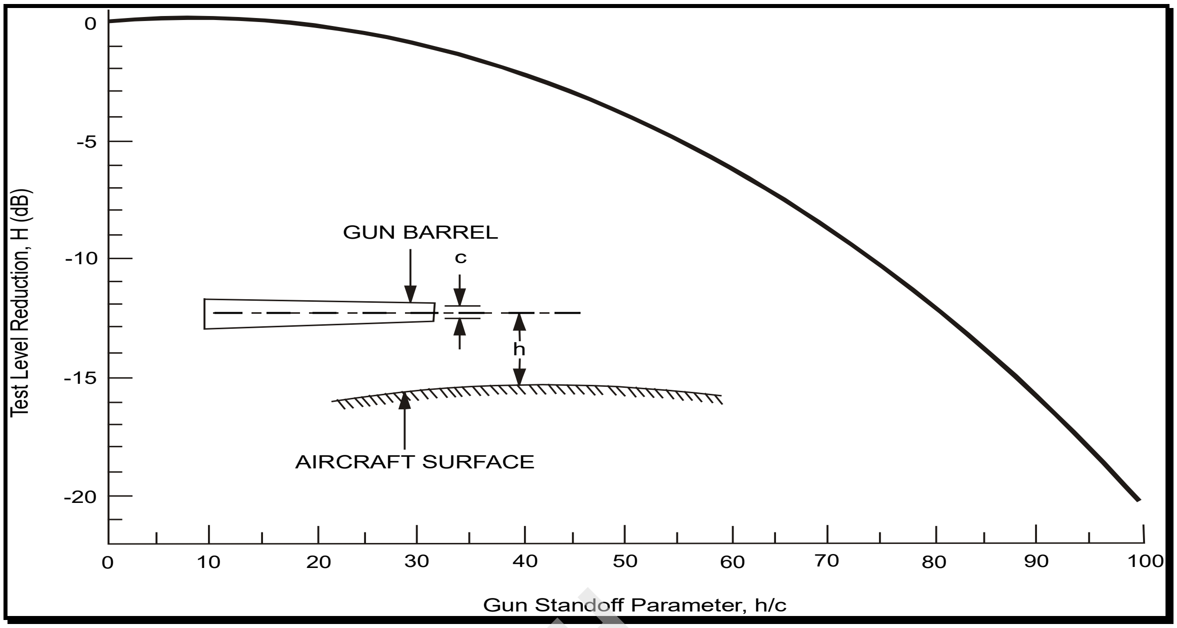

Figure 519.8C-4. Test level reduction due to gun standoff parameter.

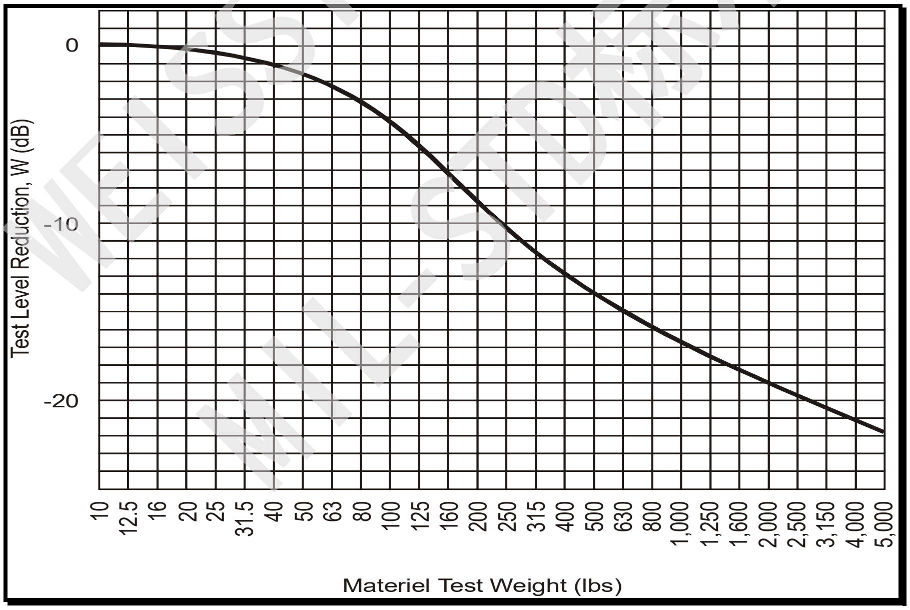

Figure 519.8C-5. Test level reduction due to materiel mass loading.

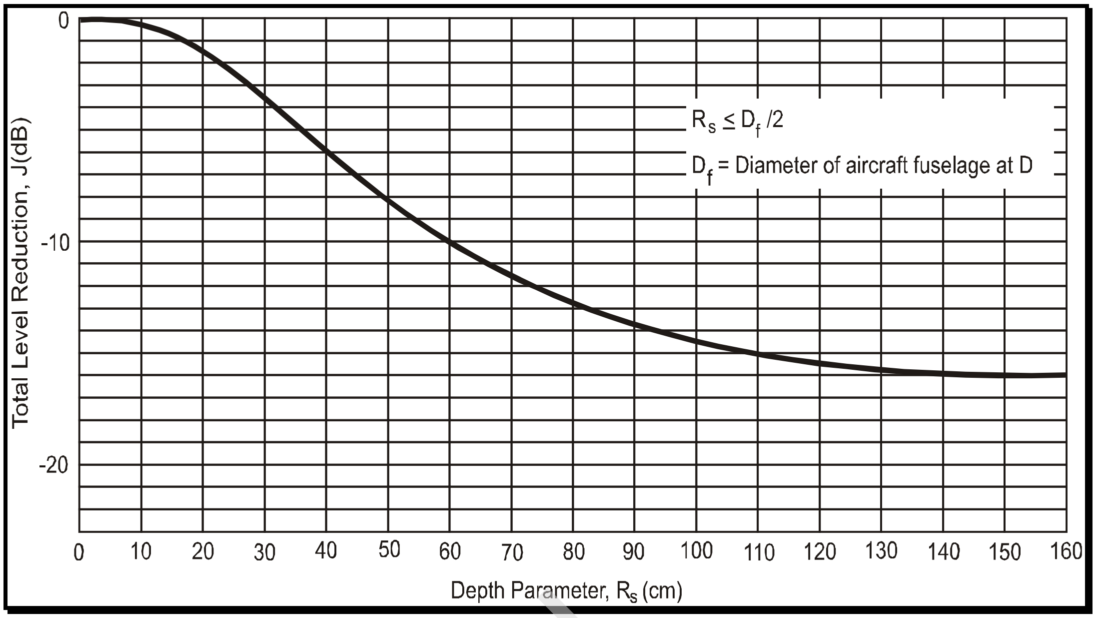

Figure 519.8C-6. Test level reduction due to depth parameter.

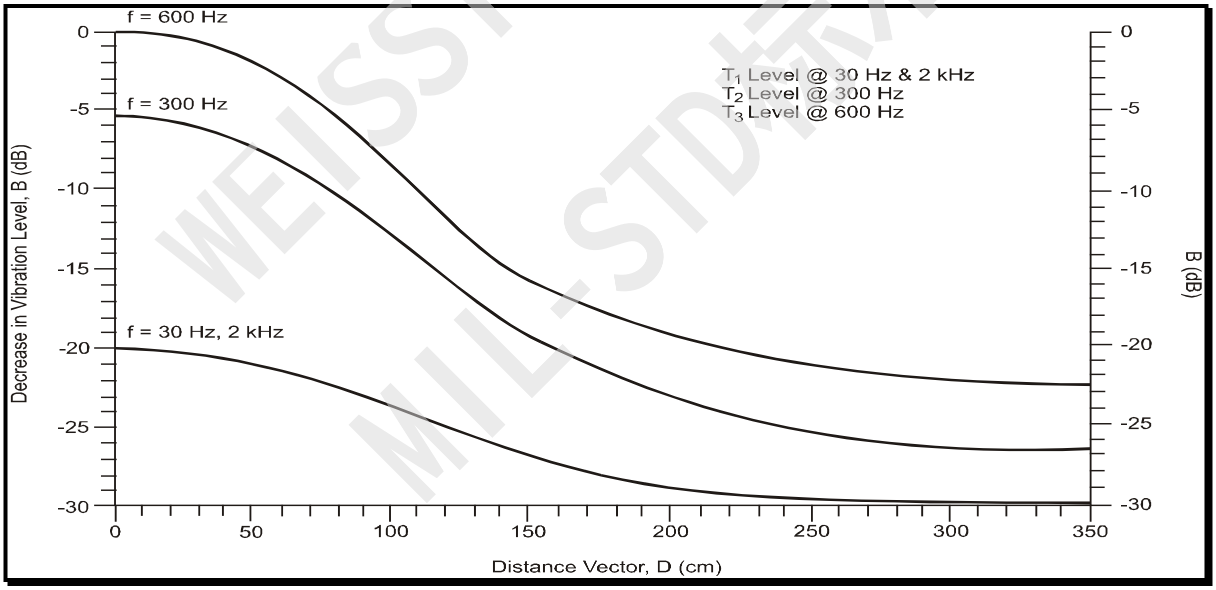

Figure 519.8C-7. Decrease in vibration level with vector distance from gun muzzle.

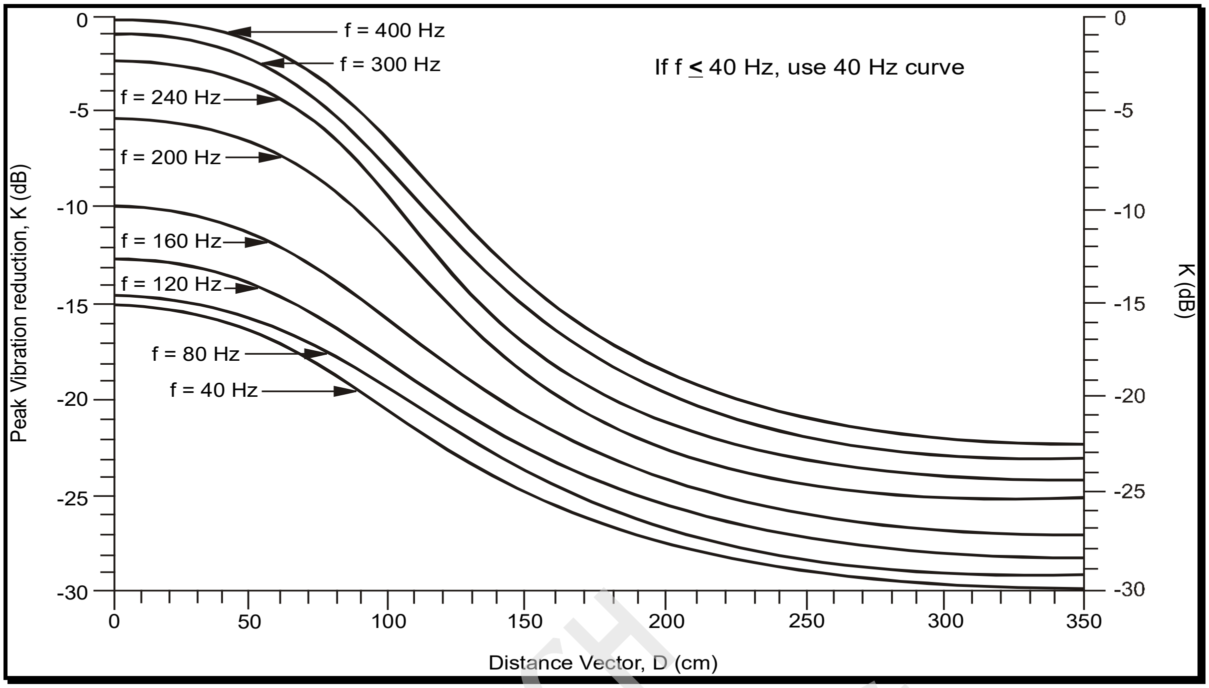

Figure 519.8C-8. Gunfire peak vibration reduction with distance.

The key geometrical relations used to determine the predicted vibration spectra are the following four geometrical factors:

a. Vector distance (D). The vector distance from the muzzle of the gun to the mean distance between materiel support points as shown on Figure 519.8C-2. For configurations involving multiple guns, the origin of vector D is determined from the centroidal point of the gun muzzle, as shown on Figure 519.8C-3. Figure 519.8C-7 and Figure 519.8C-8 provide for spectra reduction factors related to D for the random spectra and the discrete frequency spectra, respectively.

b. Gun standoff distance (h). The distance normal to the aircraft's surface as shown on Figure 519.8C-4.

c. Depth parameter (R_s). The distance normal to the aircraft's skin to the materiel location inside the aircraft. If R_s is unknown, use R_s = 7.6 cm (3 in.) (see Figure 519.8C-2). Figure 519.8C-6 provides spectra reduction factors related to R_s.

d. Gun caliber. Table 519.8C-III defines the gun caliber parameter, c, in millimeters and inches. For this procedure, base the vibration peak bandwidths consistent with windowed Fourier processing on in-service measured materiel response data if available. When such in-service data are not available, the vibration peak bandwidths can be calculated as:

For cases where the gun firing rate changes during a development program or the gun may be fired at a sweep rate, it is desirable to either (1) perform sinusoidal sweeps within the proposed bandwidth for the fundamental and each harmonic, or (2) apply narrowband random vibration levels provided the sweep frequency bandwidth is not too large. This technique may over-predict those frequencies where the attachment structure or materiel responses become significantly nonlinear. Likewise, for those cases in which the attachment structure or materiel resonances coincide with the frequencies in the gunfire environment, the materiel vibration response could be under-predicted. The practitioner should clearly understand the options available and inherent limitations in the vibration control system software.

2.3 Duration of Test.

Use a duration for the gunfire vibration test in each of the three axes that is equivalent to the expected total time the materiel will experience the environment in in-service use. This duration may be conservatively estimated by multiplying the expected number of aircraft sorties in which gun firing will occur by the maximum amount of time that gun firing can occur in each sortie. The number of sorties in which gunfire will occur will be associated with planned aircraft training and combat use rates, but will generally be in the vicinity of 200 to 300 sorties. The maximum time of gunfire per sortie can be determined from Table 519.8C-II by dividing total rounds per aircraft by the firing rate. When a gun has more than one firing rate, perform the test using both firing rates, with test time at each firing rate based on the expected proportion of time at each firing rate for in-service use. The guns carried by an aircraft are generally fired in short bursts that last a few seconds. Testing to a gunfire environment should reflect a form of in-service use in compliance with the test plan. For example, vibration could be applied for two seconds followed by an eight-second rest period during which no vibration is applied. This two-second-on/eight-second-off cycle is repeated until the total vibration time equals that determined for the aircraft type and its in-service use. This cycling will prevent the occurrence of unrealistic failure modes due to vibration isolator overheating or buildup of materiel response in continuous vibration. Intermittent vibration can be achieved by several means including (1) the interruption of the exciter input signal, and (2) a waveform replication strategy for transient vibration discussed in Annex A.

2.4 Spectrum Generation Techniques.

Using the prediction method gunfire materiel response vibration may be characterized by broadband random vibration with four vibration peaks that occur at the first three harmonics and the fundamental frequency of the firing rate of the onboard guns. Part 2 of this annex prescribes two methodologies for practically implementing this in laboratory testing. Virtually all modern vibration control system software packages contain a provision for performing a gunfire vibration test based on this form of predicted SOR spectra. Use of the procedures for generating and executing a SOR test is no longer permissible.

PART 2 – IMPLEMENTATION OF PREDICTED SPECTRUM METHODOLOGY FOR PRELIMINARY MATERIEL DESIGN

1. SCOPE.

1.1 Purpose.

The purpose of Part 2 of Annex C is to provide ad hoc methods for taking a predicted form of SOR spectrum and generating a time history having the form of a repeated shock with an ASD estimate that matches both the continuous and discrete spectrum. The repeated shock has the same period as the frequency of the fundamental harmonic of the predicted spectrum.

There are at least two ad hoc methodologies for generating repetitive shock time histories matching a form of SOR spectrum. Both methodologies are described briefly in this Annex. The first methodology is termed a Time Domain Windowed Pulse (TDWP) and the second methodology is termed a Random Modulated Harmonic Pulse (RMHP). The form of implementation in both methodologies is strikingly similar but differs in fundamental ways. TDWP relies upon a time domain windowing with an exponential window that has frequency components outside the principal gunfire bandwidth. The RMHP relies upon frequency domain implementation and development of a random pulse form with correct frequency domain properties. The methodologies are termed ad hoc since there is no attempt to “fit” a gunfire measurement time history. Both techniques provide a time history that has the outward appearance of a repetitive pulse gunfire environment.

1.2 Time Domain Windowed Pulse (TDWP).

1.2.1 Introduction.

This ad hoc methodology uses the fact that predicted spectrum has a fundamental frequency and it is assumed that this fundamental frequency dominates the time history generation. A properly normalized exponential form window having a period corresponding to the fundamental period of the predicted spectrum allows time domain windowing of a stationary time history with the predicted continuous/discrete spectrum and generates a form of “repeated shock” at the gun firing rate. The three harmonics of the fundamental represented in the predicted spectrum provide correct amplitudes for the discrete spectrum. This methodology is effective because in general the frequency content of the discrete spectrum is fundamentally “stochastically independent” of the frequency content of the continuous spectrum with the exponential window providing the correct fundamental frequency and the three harmonics are unaffected when viewed as convolution of the exponential window in the frequency domain with the harmonic frequencies.

1.2.2 Outline of Implementation.

The following steps are outlined for implementation. A detailed discussion is found in Reference 6.1.k.

a. Generate a normalized deterministic pulse of exponential form of duration of the period of the fundamental of the predicted spectrum

b. Generate a stationary random bandlimited Gaussian time history of arbitrary duration

c. Shape the spectrum of the band limited time Gaussian time history to the shape of the continuous spectrum and add discrete components at the three harmonic frequencies.

d. Multiply the deterministic exponential pulse block times the stationary time history with the correct continuous/discrete spectrum block by block

e. Compute the ASD estimate and compensate for any resulting harmonic distortion

f. Execute the time history under TWR according to the LCEP gunfire event description

1.3 Random Modulated Harmonic Pulse (RMHP).

1.3.1 Introduction.

This ad hoc methodology uses the fact that predicted spectrum has an associated harmonic pulse composed of the four fundamental frequencies. It is assumed that these four discrete frequency components add and are of zero phase with respect to one another. This construction provides a form of "harmonic pulse". Since the continuous and discrete spectrums are stochastically independent of one another they can be added to provide the exact predicted spectrum. However, as it is easy to demonstrate the resulting "additive" model does not have time history characteristics of a measured gunfire pulse such as high kurtosis. If the generated pulse is multiplied by the Gaussian time history with the appropriate continuous spectrum i.e., the deterministic pulse is modulated by the random time history, and any distortion from the predicted spectrum is removed in the frequency domain the resulting time history has a form or random time history with a degree of kurtosis differing from typical random vibration kurtosis. Analysis of the generated time history reveals an underlying "random pulse" where the fundamental and harmonic components have a non-zero relative phase. The stochastic generation must be such that the fundamental and three harmonic frequencies coincide with FFT Fourier frequencies (which is not a severe limitation).

1.3.2. Outline of Implementation.

The following steps are taken for implementation. A detailed discussion is found in Reference 6.1.l.

a. Generate a deterministic pulse composed of zero phase summation of the fundamental and three harmonic components of the predicted spectrum. Choose the digital sequence sample rate such that it has the harmonic frequencies coincide with FFT Fourier frequency lines i.e., the Fourier frequencies.

b. Generate a stationary random bandlimited Gaussian time history of arbitrary duration

c. Shape the stationary random bandlimited Gaussian time history to the continuous spectrum provided by the prediction.

d. Modulate the deterministic pulse by multiplying it by blocks of stationary random time history

e. Using the FFT over a long portion of time history correct the harmonic components lying on the Fourier frequencies to the correct amplitudes leaving the phase as random (this may be a iterative procedure)

f. Execute the time history under TWR according to the LCEP gunfire event duration

Note: This methodology introduces kurtosis differing from stationary random vibration kurtosis into the testing and is random in the sense that the underlying pulse in the generated time history generally is un-symmetric and does not have zero boundary conditions.

2. RECOMMENDED PROCEDURES.

2.1 Recommended Procedure.

For aircraft vibration for materiel mounted in the aircraft with no available measured data, use this procedure with the prediction methodology implemented with the TDWP or RMHP.

2.2 Uncertainty Factors.

This procedure contains two sources of uncertainty. First, there is uncertainty in application of the SOR prediction methodology and determining a SOR spectrum. Second, there is uncertainty in transferring information in the SOR prediction methodology to a form of laboratory test that might be appropriate for materiel design considerations.

2.2.1 SOR Prediction Methodology Uncertainty.

There is substantial uncertainty in general levels because of the sensitivity of the gunfire environment to gun parameters and geometrical configuration. It may be appropriate to increase levels or durations in order to add a degree of conservativeness to the testing. Change in levels, durations, or both for the sake of increasing test conservativeness must be backed up with rationale and supporting assessment documentation. Since extreme spectra prediction levels do not necessarily provide test inputs that correlate with measured data (for the same geometrical configuration), the uncertainty in damage potential is increased substantially as the predicted spectra increase in level; i.e., testing with this procedure may be quite un-conservative.

2.2.2 Stochastic TWR Generation Uncertainty.

There is uncertainty in the stochastic implementation of either TDWP or RMHP. Materiel response to gunfire environment either via air borne or structure borne stimulation is complex in part because of the transmission path and the medium through which the “gunfire pulse” must travel to impact the materiel. Neither TDWP nor RMHP can account for the physical phenomenon or its effects on the materiel. TDWP can control certain time domain properties by variation in the exponential pulse and is transparent in this manner. TDWP is generally for high level gunfire response where there is a substantial regularity in the pulse structure even though this pulse structure i.e., the exponential window could easily be varied deterministically or stochastically. RMHP is more uncontrolled but may be able to satisfy some of the higher order correlation information contained in gunfire records, in particular any periodically correlated aspects of gunfire, even though this has not been studied extensively. The random generated pulses can be generated, characterized, and stored for a more refined stochastic simulation. Just by repeated stochastic generation portions of time history record can be identified with targeted kurtosis values. Either technique can be said to be totally uncertain relative to what measurements might be obtained based upon the SOR prediction configuration.

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