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GUNFIRE SHOCK

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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.

1. SCOPE.

1.1 Purpose.

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 and the number of rounds fired in a given firing). The gunfire environment may be considered to be a high rate repetitive shock having form of a substantial transient vibration produced by (1) an air-borne 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 high 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: materiel failure as a result of increased or decreased friction between parts, or general interference between parts;

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

b. 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);

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

d. collapse of mechanical elements of the materiel as a result of the ultimate strength of the element being exceeded.

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

f. potential piezoelectric activity of materials; and

g. 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) in Procedure II but this is not 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:

a. This method 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. This method does not provide guidance on techniques for isolation of the materiel from the source of excitation.

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

d. This method 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. This method 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. This method 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 this method provides limited guidance on materiel response to gun excitation from simultaneous firing of more than one gun

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

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 subharmonics and superharmonics) will magnify the adverse effects on the materiel's overall integrity.

2.1.2 Sequence among other methods.

a. General. See Part One, paragraph 5.5.

b. Unique to this method. Sequencing among other methods will depend upon the type of testing, i.e., 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 level vibration, thermal and mechanical shock tests. For thermal testing include any potential transient thermal effects from gunfire on the materiel. Note that in the 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 to uncover combined, vibration, temperature and shock environmental failures. (There are often advantages to applying gunfire shock tests before climatic tests, provided this 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 nonstationary 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, Time Waveform Replication, or perhaps a shock procedure that allows repetition of individual pulses at the firing rate of the gun. In particular, all the guidelines in Method 525 relative to time trace scaling and simulation must be strictly adhered to. If gunfire measurement data for materiel response reveals that the effects of the gunfire shock environment on materiel is in accordance with stationary random vibration, stationary random vibration modeled as sine-on-random or stationary random vibration modeled as narrowband-random-on-random, perform testing in accordance with guidelines in Method 514.6. In this latter case, 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, and 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 514.6 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. Low gunfire shock environments should be considered as transient vibration environments rather than long duration stationary random vibration environments because of LCEP gunfire scheduling. Testing to transient vibration environments should also be performed in accordance with Method 525.

a. Procedure I: Direct Reproduction of Measured Materiel Input/Response Time Trace Data Under Guidelines Provided in Method 525 for Time Waveform Replication (TWR).

b. Procedure II: Stochastically Generated Materiel Input/Response Based Upon Measured Time Trace Information.

c. Procedure III: Stochastically Predicted Materiel Shock Input for Preliminary Design Based Upon Predicted Sine-on-Random Spectrum.

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 is available, but Procedure II will be required to justify the stochastic generation of a multitude of statistically independent gunfire schedules for testing. As a result of lack of field measured data, Procedure III may be used to predict the gunfire repetitive shock environment, and Procedure II may be used in the preliminary materiel design phase to test to the predicted gunfire shock levels (although such laboratory testing is not recommended practice). 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, this information must 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. Generally Method 525 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, then the following considerations are important.

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

      (a) Only a few acceleration measurements were made on certain configurations even though the analyzed data was extrapolated over a broad range of gun/materiel configurations. Pressure measurement correlation with acceleration measurements was not a consideration.

      (b) The acceleration time traces were made using mid 1970’s measurement and signal conditioning technology.

(c) The analysis performed on the time traces assumed stationary random vibration with embedded sine harmonic components. It is unclear from the analysis if the presence of sine harmonic components was verified by more recent signal processing techniques. The limited analysis performed leaves open the possibility that the true measured environment could be represented as *narrow band random-on-random*, or by other means as will be discussed in Annex C. The nonstationary nature of the measured time traces, e.g., repetitive shock, was not considered in the spectral analysis techniques used in the mid 1970's.

(d) The distinction between air-borne and structure-borne excitation input to the materiel does not appear to have been considered in formulating the predicted spectrum. It is unclear as to the point of application of the sine-on-random vibration environment to the materiel (input to the base of the materiel from the exciter head or exciter slip table is generally assumed).

(e) The rationale for modeling the predicted response as a sine-on-random spectrum was not provided and more recent acceleration time trace measurements reveal the inadequacy of such a rationale. It is demonstrated in Annex C that sine-on-random specification does not lead to a unique nor optimum time trace form.

(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 sine-on-random spectrum. A sine-on-random 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 reveal substantial rise time response 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 sine-on-random spectrum information in the form of a repetitive pulse . This methodology requires that preliminary design procedures be in accordance with that for repetitive shock at predicted sine-on-random spectrum levels. This philosophy is adopted for the stochastic prediction incorporated in Procedure III.

Of the five inadequacies in the prediction methodology as initially set forth in MIL-STD-810C, the most serious is the assumption of the stationary sine-on-random vibration model for laboratory testing.

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. It has been concluded that (in light of the unavailability of other information to confirm the prediction methodology), use of the predicted information (sine-on-random 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 Annex D. 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 gunfiring rate and its harmonics. In addition, any vibration/shock isolation characteristics between gun and materiel configuration are understood. Improper test procedure selection and execution may result in either an unconservative materiel undertest, or a substantial materiel overtest. 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.

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.

For no measured materiel response time trace data, use the methodology outlined in Procedure III to predict preliminary gunfire repetitive shock levels.

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. Direct Reproduction of Measured Materiel Input/Response Time Trace Information under Guidelines Provided in Method 525 for Time Waveform Replication (TWR).

Measured in-service gunfire shock environment for materiel is replicated under laboratory exciter waveform control (Method 525 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 Method 525.

b. Procedure II. Stochastically Generated Materiel Input/Response Based Upon Measured Time Trace Information:

This procedure is based upon either (1) direct stochastic generation of time traces appropriate for Method 525 that are "equivalent" in severity to in-service measured time trace information, or (2) a procedure that may be justified for properly distributing uncertainty, and for conservative testing (but in accordance with the principles of random process theory). It is possible, in the latter case, that measured time trace information is available for a configurationally-similar gun/materiel configuration, and that this can be used with appropriate rationale in the form of predicted time trace information. In general, this procedure requires use of simulation techniques that preserve the elements of random process theory, and allows scaling of time trace information only in accordance with guidelines provided in Method 525 (and summarized in Annex E of this method). Essential information for this procedure, including a detailed discussion of time trace scaling, is provided in Annex B and Annex E.

c. Procedure III. Stochastically Predicted Materiel Input for Preliminary Design Based Upon Predicted Sine-on-Random Spectrum

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 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 with Annex D provides a limited procedure that stochastically generates 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 Life Cycle Environmental Profile (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 and Annex D. 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.

2.3.3 Test axes and number of gunfire 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. Material 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 (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 in MIL-STD-810G. 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” measured gunfire time traces in order to achieve test conservativeness and reduce test repetitions.

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 for SESA or Method 527 for MEMA), or (2) the test excitation is benign and controlled under either standard random vibration test methodology (Method 514.6) or Method 525 for transient vibration. If the effects of transient vibration (even at benign levels) are deemed important, the TWR test methodology should be used (Method 525 or Method 527). Control under SRS shock methodology (generation of time trace that matches a specified SRS) is not acceptable. Helpful test tolerance information for specification is provided in Methods 514.6, 525, 527, and Annex E.

a. For Procedures I and II, the vibration exciter is operated in an “open loop” SESA TWR configuration with materiel response replication at a single point.

b. For Procedure III, if testing of a preliminary design is required, the pulse train matching the sine-on-random spectrum may be generated stochastically, and Procedure II applied. It is unusual for any of the procedures to require a MEMA test configuration, but controls provided in Method 527 should be applied if warranted by the configuration or measured data.

2.5.1 Control options.

2.5.1.1 Open/Closed loop.

For significant gunfire shock environment (and possibly benign transient vibration environment), the test for any of the procedures is of short duration, and is performed in an open loop mode after appropriate compensation of the exciter analog voltage input drive waveform. All testing is in accordance with guidelines in Method 525 (SESA) or

Method 527 (MEMA). For benign gunfire environment, 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 514.6 (SESA) or Method 527 (MEMA).

2.5.1.2 Single point control.
Single point control SESA is a minimum requirement for all procedures. For significant gunfire shock environment, 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. For benign non-transient vibration gunfire environment follow guidelines provided in Method 514 using single point spectrum control.

2.5.1.3 Multiple point control.
For Procedures I and II, multiple axis TWR (MEMA) may be performed where the materiel is extended, 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 for multi-exciter testing under TWR. For benign non-transient gunfire environment follow guidelines provided in Method 527 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 (SESA) or Method 527 (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 514.6 (SESA) or Method 527 (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 MEMA is substituted for Method 525 SESA. In addition if the gunfire environment is benign non-transient vibration, see Method 514.6 for SESA or Method 527 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 a exciter system under TWR control Method 525 (SESA) (Method 527 MEMA) for Procedure I.

(b) analytical time traces representing measured data that has been statistically processed, stochastically generated, and perhaps scaled appropriately, that are input as compensated waveforms into a exciter system under TWR control Method 525 (SESA) (Method 527 MEMA) for Procedure II.

(c) measured gun/materiel mechanical and geometrical parameters that have been specified and predicted Sine-on-Random spectrum derived. The predicted Sine-on-Random 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 (5 Hz to 2 kHz).

(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 Procedures I and II. In checking for test tolerance satisfaction, use the principles outlined in Method 525 - 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) **Note**: 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 is provided in Method 525.

(7) For Procedures I and II, the 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 a. 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 slewrate exceedance, data clipped, unexplained accelerometer offset, etc. The integrated amplitude time histories will be compared against criteria given in paragraph 6.1, reference a.

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 MEMA (TWR) is substituted for Method 525 SESA. In addition, if the gunfire environment is benign and non-transient vibration, see Method 514.6 for SESA, or Method 527 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 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.

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 MEMA TWR is substituted for Method

525 SESA. In addition, if the gunfire environment is benign and non-transient vibration, see Method 514 for SESA or Method 527 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).

(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 environment 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 or Method 527. 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 514.6 (SESA) or Method 527 (MEMA) spectrum control will be suitable.

4.2 Controls.

In general, acceleration will be the quantity measured to meet specification with care taken to ensure acceleration measurements can be made that provide meaningful data (paragraph 6.1, reference a). Give special consideration to the measurement instrumentation amplitude and frequency range specifications in order to satisfy the measurement and analysis requirements. 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. Accelerometer.

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

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

(3) For all gunfire test procedures, a flat frequency response within ±10 percent across the frequency range 5 – 2 kHz. The measurement devices may be of the piezoelectric or piezoresistive type.

(4) For cases in which response below 2 Hz is desired, piezoresistive accelerometer measurements are required with a flat frequency response within ±10 percent across the frequency range DC-2 kHz.

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

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

c. Signal conditioning. Use signal conditioning compatible with the instrumentation requirements on the materiel. In particular, filtering will be consistent with the response time history requirements. Use signal conditioning requirements in accordance with the guidelines provided in paragraph 6.1, reference a. Use extreme care in filtering the acceleration signals at the amplifier output. Do not filter the signal into the amplifier for fear of filtering bad measurement data and the inability to detect the bad measurement data. The signal from the signal conditioning must be anti-alias filtered before digitizing.

All measurement devices are to be calibrated in accordance with standard calibration procedures. The complete test parameter control chains (checking, compensation, servoing, 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 is representative of the true environment and not a function of the local materiel configuration, e.g., local resonances which 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 and 527 provide guidelines on test tolerance specification under TWR and, in most cases, these test tolerances will be adequate for gunfire test. 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 or 527. 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 Direct Reproduction of Measured Materiel Input/Response Time Trace Data Under Guidelines Provided in Method 525 for Time Waveform Replication (TWR)

a. Time domain. Generally reference and control time traces are perfectly correlated so that there is no requirement under Method 525 (Method 527)

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 that the root-mean-square level of the point-by-point difference between the control and reference time traces is less than ±5 percent the combined control/reference peak time traces for a short-time average time not to exceed 0.01 of the duration of the gunfire test.

c. Frequency domain. Compute a low frequency resolution average 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 is appropriately windowed (usually with a 10% 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 Stochastically Generated Materiel Input/Response Based Upon Measured Time Trace Information

a. Time domain. Ensure the duration of every generated pulse is within 2.5 percent of the duration obtained from the measured gunfire rate if stochastic ensemble generation methodology is implemented. Ensure the duration of the gunfiring 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 measured 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 0.01 of the duration of the gunfire test.

c. Frequency domain. Compute a low frequency resolution average ESD estimate over the ensemble created from the materiel time history response that is within ± 3dB (power – see Part One, Annex D) 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 is appropriately windowed (usually with a 10% 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.

4.2.3 Stochastically Predicted Materiel Input for Preliminary Design Based Upon Predicted Sine-on-Random Spectrum

If this procedure requires follow-on testing use Procedure II. Otherwise only time and frequency domain requirements are used for providing preliminary gunfire shock materiel design.

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 sine-on-random spectrum developed for the pulses is within ±3dB of the predicted sine-on-random spectrum over the entire frequency band of interest. In general this will be based upon an estimate of the ASD from which the Random-Modulated- Pulses 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 addition, the test item must be inspected prior to test to ensure pre-gunfire 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.

a. 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.

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

c. 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 is or is not 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 - Direct Reproduction of Measured Materiel Input/Response Time Trace Information under Guidelines Provided in Method 525 for Time Waveform Replication (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 file 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 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 4.4.1.

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 - Stochastically Generated Materiel Input/Response Based Upon Measured Time Trace Information

4.4.3.1 Controls.
This procedure assumes that measured input/response data is available in digital form, has been stochastically modeled, perhaps scaled and the generated sample function input/response data will be replicated in the laboratory on the test item. This procedure may include the concatenation of several stochastically generated reference time traces.

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

Step 2. Precondition in accordance with paragraphs 4.2 and 4.4.1.

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 4.4.1.

Step 5. Mount the test item on the vibration exciter (or use some other means of suspension) in accordance with paragraph 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 function 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 Predicted Materiel Input for Preliminary Design Based Upon Predicted Sine-on-Random Spectrum

4.4.4.1 Controls.

This procedure assumes that the gun/materiel parameters are available for derivation of a predicted Sine-on-Random test spectrum. This procedure also assumes given the Sine-on-Random spectrum a Random-Modulated-Pulse time trace can be developed having the same Sine-on-Random spectrum with minimized harmonic distortion. Developing the Random-Modulated-Pulse time trace requires a trained analyst and specialized software. It makes no provision for actual testing. For actual testing to the Random-Modulated-Pulse time trace use Procedure II as if stochastic simulation of a field measured environment has been performed.

Step 1. Specify the gun/materiel parameters and generate the predicted Sine-on-Random spectrum (See Annex D.)

Step 2. Generate a Random-Modulated-Pulse time trace with the specified Sine-on-Random spectrum.

Step 3. For materiel design considerations analyze the 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, or

(b) SRS estimates will be made on the Random-Modulated-Pulse time trace (either under ensemble representation or as an overall time trace) and be used in specifying a shock environment for materiel design.

Step 4. If testing is required generate the equivalent Random-Modulated-Pulse time trace environment. (refer to Annex C.), and go to Procedure II 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 each of the test procedures included in 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 4.2.4 to satisfy the test tolerances.

6. REFERENCE/RELATED DOCUMENTS

6.1 Referenced Documents.

a. Handbook for Dynamic Data Acquisition and Analysis, IEST-RP-DTE012.1, Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

b. MIL-STD-810C Method 519.2

c. MIL-STD-810F Method 519.6

d. Merritt, Ronald G., "Assessment of Gunfire Environment Under Cyclostationary Assumptions", 78th Shock and Vibration Symposium, Philadelphia, PA, November 2007.

e. Piersol, Allan G., Determination of Maximum Structural Responses From Predictions or Measurements at Selected Points, Proceedings of the 65th Shock and Vibration Symposium, Volume I, SAVIAC, 1994. Shock & Vibration Information Analysis Center (SAVIAC), Three Chopt Rd. (Suite 110), Richmond, VA 23229.

6.2 Related Documents.

a. IEST RP on Gunfire - Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

b. MIL-STD-810D Method 519.3, MIL-STD-810E Method 519.4, 14 July 1989.

c. NATO STANAG 4370, Environmental Testing. Allied Environmental Conditions and Test Procedure (AECTP) 400, Mechanical Environmental Tests (under STANAG 4370), Method 405.

d. Harris, C., and C. E. Crede, eds., Shock and Vibration Handbook, 5th Edition, NY, McGraw-Hill, 2000.

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

f. J. S. Bendat and A. G. Piersol, Random Data: Analysis and Measurement Procedures, 3rd edition, John Wiley & Sons Inc., New York, 2000

g. Merritt, R. G., "A Note on Prediction of Gunfire Environment Using the Pulse Method," IEST, 40th ATM, Ontario, CA, May 1999. Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

h. R. G. Merritt, Simulation of Ensemble Oriented Nonstationary Processes, Part 2 Proceedings of 1994 IES 40th Annual Technical Meeting, Chicago, IL, May 1994; Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

i. D. O. Smallwood, Gunfire Characterization and Simulation Using Temporal Moments, Proceedings of the 65th Shock and Vibration Symposium, Volume 1, San Diego, CA, November 1994.

j. R. G. Merritt, An Example of the Analysis of a Sample Nonstationary Time History, Proceedings of 1994 IES 40th Annual Technical Meeting, Chicago, IL, May 1994; Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

k. D. O. Smallwood, Characterization and Simulation of Gunfire with Wavelets, Proceedings of the 69th Shock and Vibration Symposium, Minneapolis, MN, October 1998.

l. D. O. Smallwood, Characterization and Simulation of Gunfire with Wavelets, Shock and Vibration, Volume 6, November 2, 1998, IOS Press, The Netherlands.

m. Merritt, R.G. and S.R. Hertz, Aspects of Gunfire, Part 1- Analysis, Naval Weapons Center, China Lake, CA 93555-6100, NWC TM 6648, Part 1, October 1990.

n. Merritt, R.G. and S.R. Hertz, Aspects of Gunfire, Part 2- Simulation, Naval Weapons Center, China Lake, CA 93555-6100, NWC TM 6648, Part 2, September 1990.

(Copies of Department of Defense Specifications, Standards, and Handbooks, and International Standardization Agreements are available online at http://assist.daps.dla.mil/quicksearch/ or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

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METHOD 519.6 ANNEX A

Guidelines for Procedure I - Direct Reproduction of Measured Materiel Input/Response Time Trace Information Under Guidelines Provided in Method 525 for Time Waveform Replication (TWR)

1. SCOPE.

1.1 Purpose.

This Annex provides (1) pre-processing procedures for Method 525 (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, and (3) test tolerance limit assessment for guidelines provided in Method 525. This annex assumes that the testing facility is fully qualified to perform the Single-Exciter/Single-Axis (SESA) Procedure in Method 525. For potential extensions of Procedure I to either Multi-Exciter/Single-Axis (MESA) or Multi-Exciter/Multi-Axis (MEMA), use guidelines in Method 527.

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 acceptable test results. 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 Environment 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). In processing, the in-service measured data is 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 both direct digital recording or digitizing an analog voltage signal from a recording tape). 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 a). 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 (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 is provided for illustration purposes below. Even though the gunfire shock measurements are substantial, similar results would be obtained for lesser magnitude measurements for other configurations. 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 519.6A-1 provides an unprocessed time trace from measurement 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.

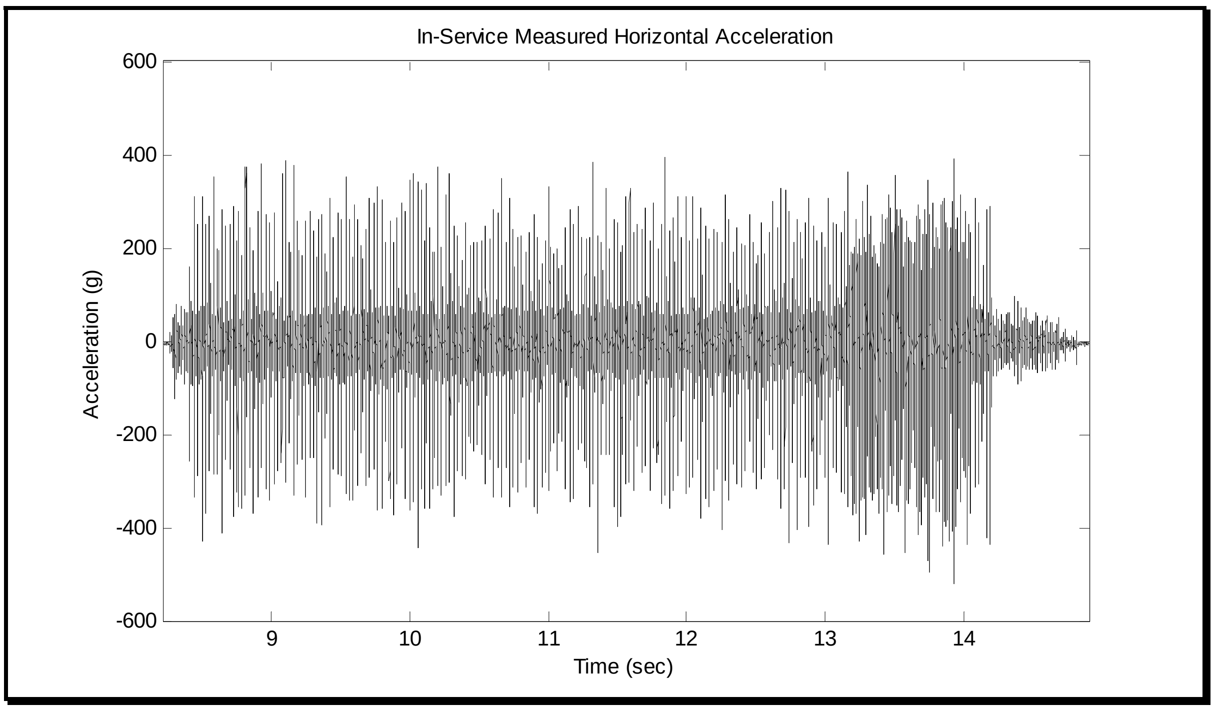

Figure 519.6A-1. In-service measured gunfire shock: Unprocessed time trace (2000 rnd/min and 4000 rnd/min).

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 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 519.6A-2 provides the reference, control and difference time traces as a result of the testing to the bandlimited 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) 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.

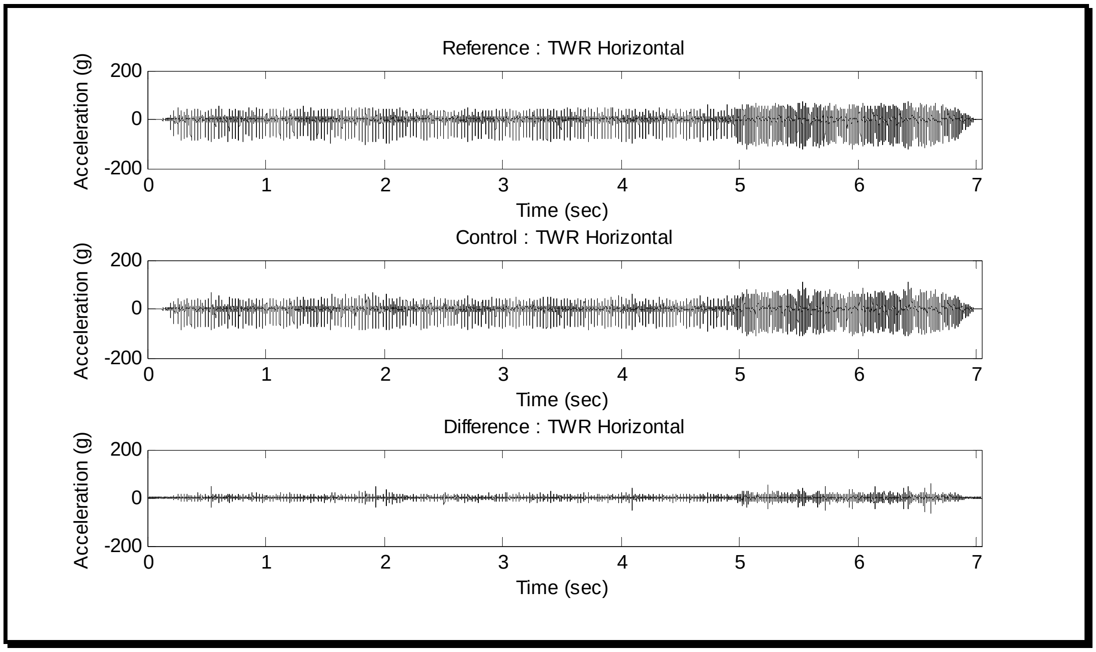

Figure 519.6A-2 Unprocessed TWR test reference, control and difference time traces (10 Hz to 2000 Hz 25600 sps).

Figure 519.6A-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). 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 nonstationary 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).

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 519.6A-3 displays the test control time trace before and after bandlimiting between 10 Hz and 2000 Hz. The bottom plot in each figure is the measured control time trace. Note that the control time trace is reduced in amplitude. Bandlimiting was performed using a third order Butterworth bandpass filter applied in the forward and backward directions for maintaining proper filter phase relationships.

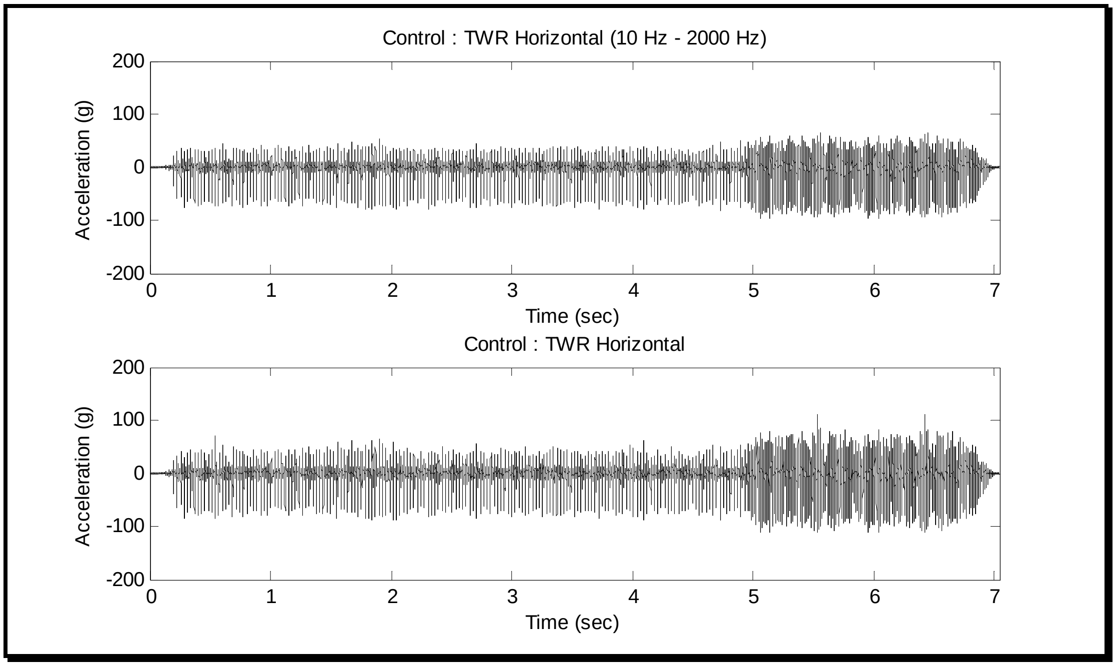

Figure 519.6A-3. Bandlimited (10 Hz to 2000 Hz) and unprocessed TWR test control time traces.

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 519.6A-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 519.6A-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.

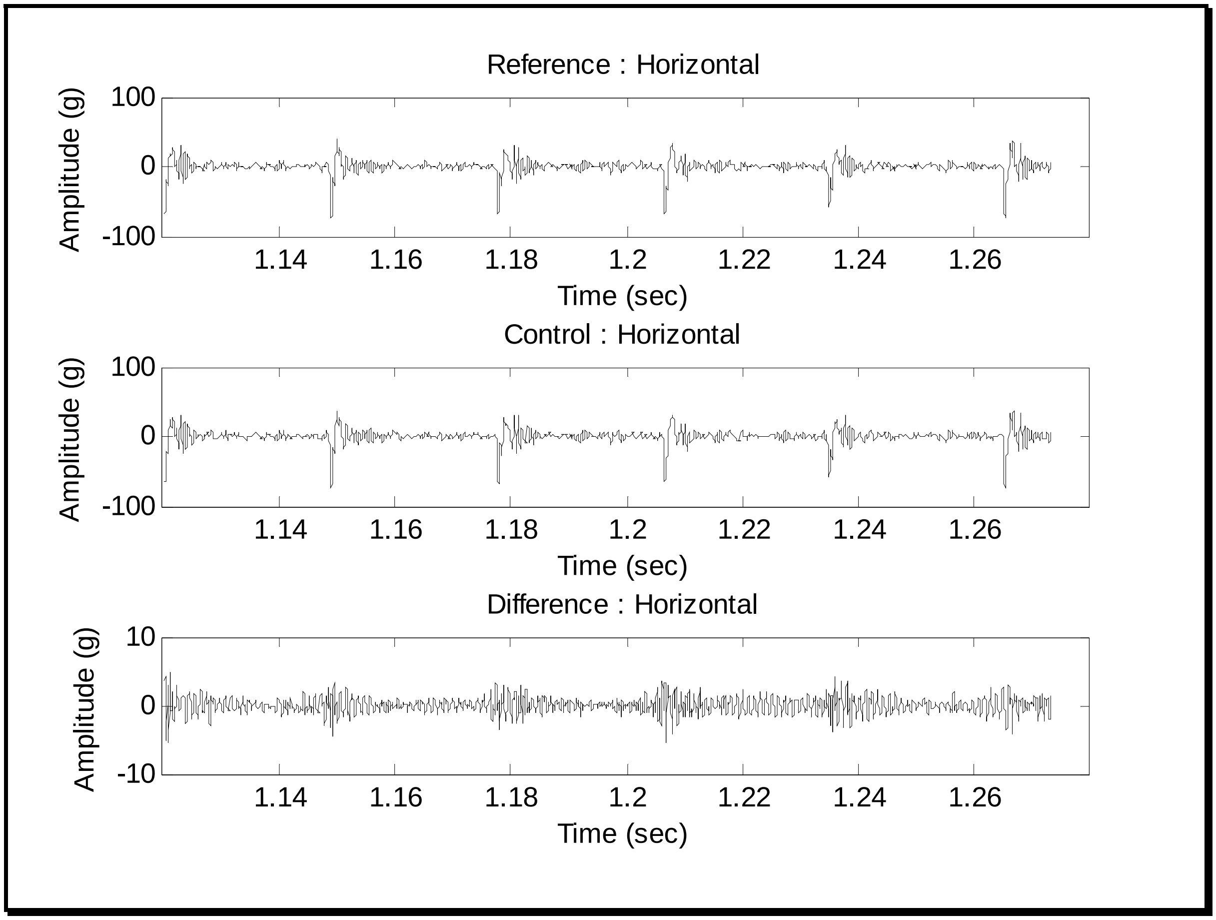

Figure 519.6A-4. High resolution representative members for the pulse ensembles (2000 round/minute).

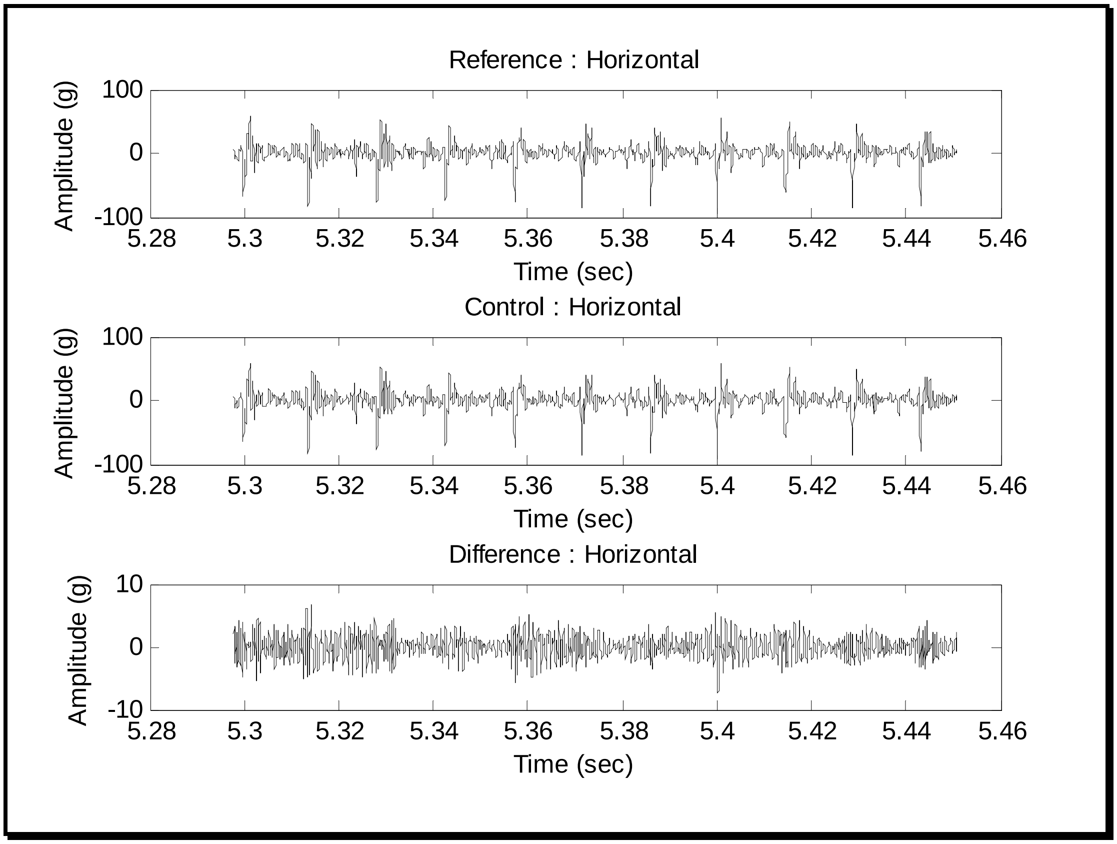

Figure 519.6A-5. High resolution representative members for the pulse ensembles (4000 round/minute).

Method 525 provides basic guidance on test tolerance specification but, in general, Method 525 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:

(1) 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 26%) 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, be within 0.90 at 90 percent of the STARMS estimate points. (This tolerance criteria relates to the rms estimate differences between the control and reference time traces - it tends to be quite broad.)

(2) STARMS applied to the ***difference time trace*** be less than -15 dB (approximately 3%) 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 criteria 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.)

(3) 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 +26%) 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 –20%) 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 519.6A-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.

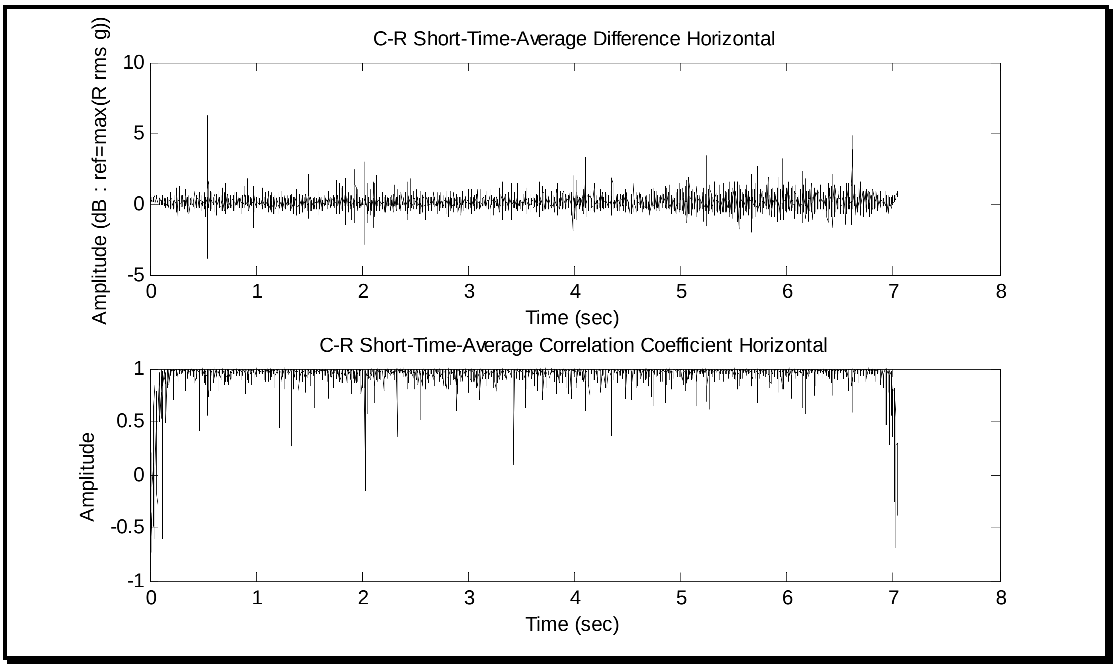

Figure 519.6A-6. STARMS difference between control and reference with cross-correlation estimate.
(Difference: ref = 45.1 g-rms /Cross-Correlation)

Figure 519.6A-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.

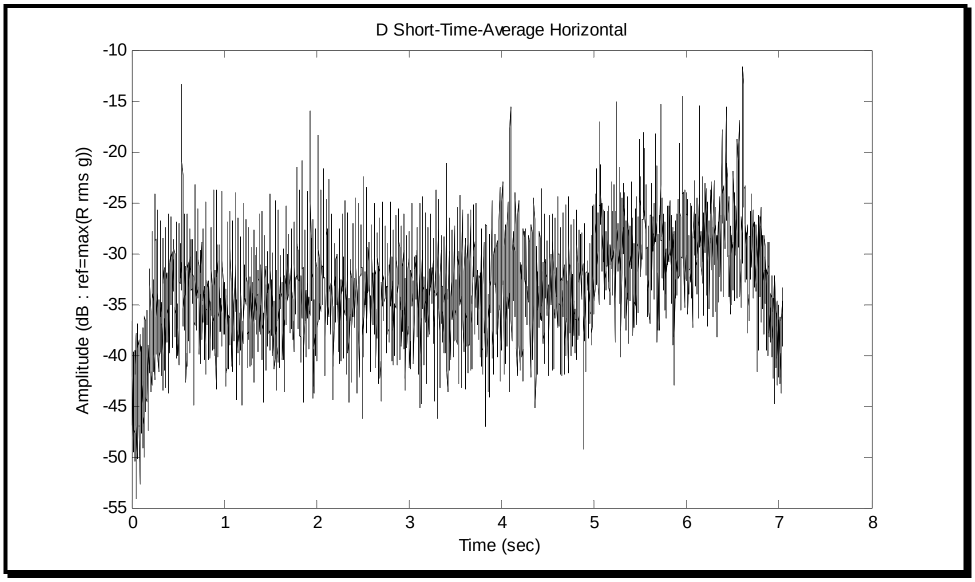

Figure 519.6A-7. STARMS for difference time trace. (Difference: ref = 45.1 g-rms)

The qq-plot for the difference time trace is displayed in Figure 519.6A-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.

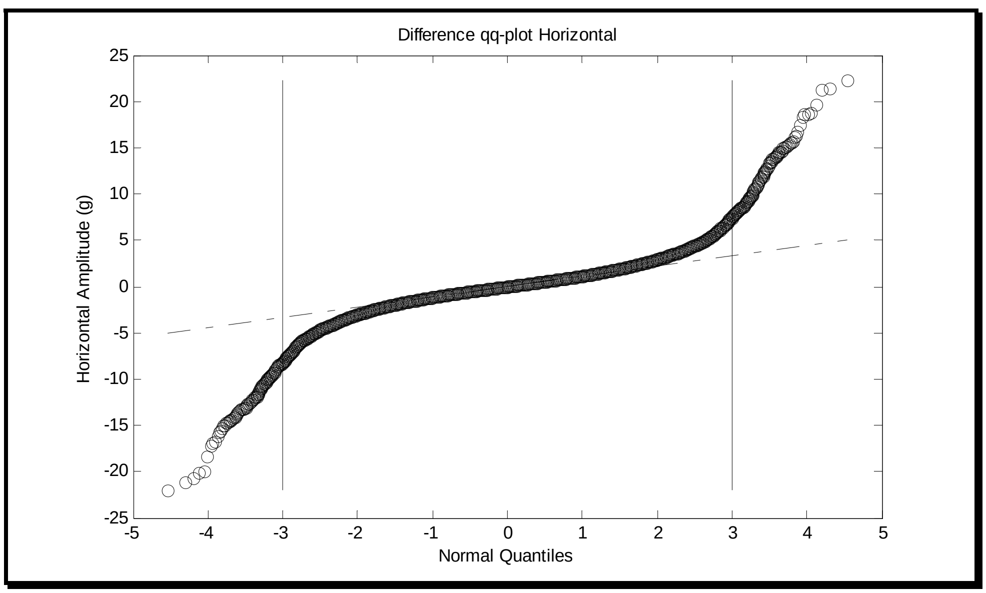

Figure 519.6A-8. qq-plot for Gaussian versus difference time trace.

Figure 519.6A-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.

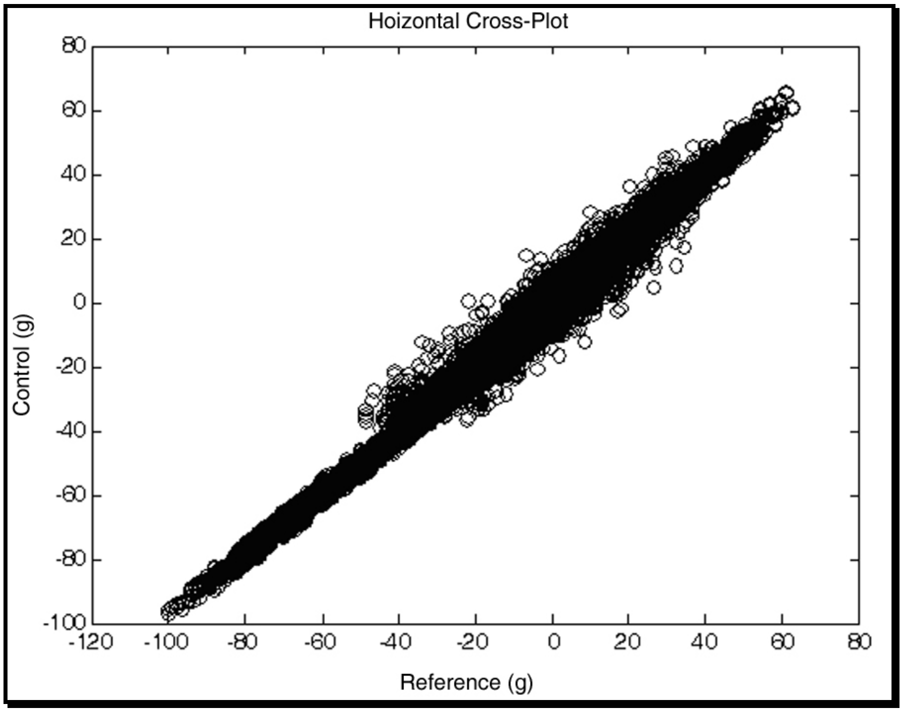

Figure 519.6A-9 Reference versus Control Cross-Plot

Figure 519.6A-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-bandlimited) control time trace, or the processed (bandlimited) 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 A-1.

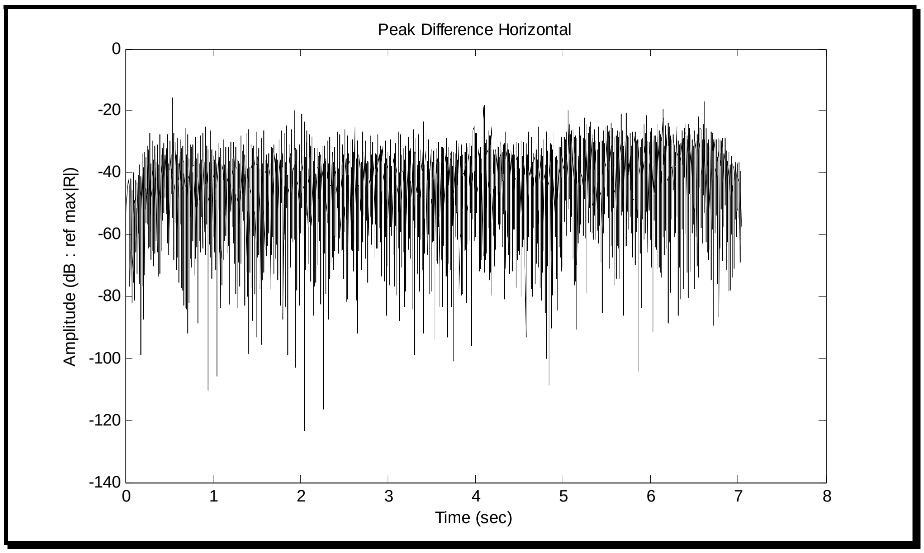

Figure 519.6A-10a. Peak statistic difference.

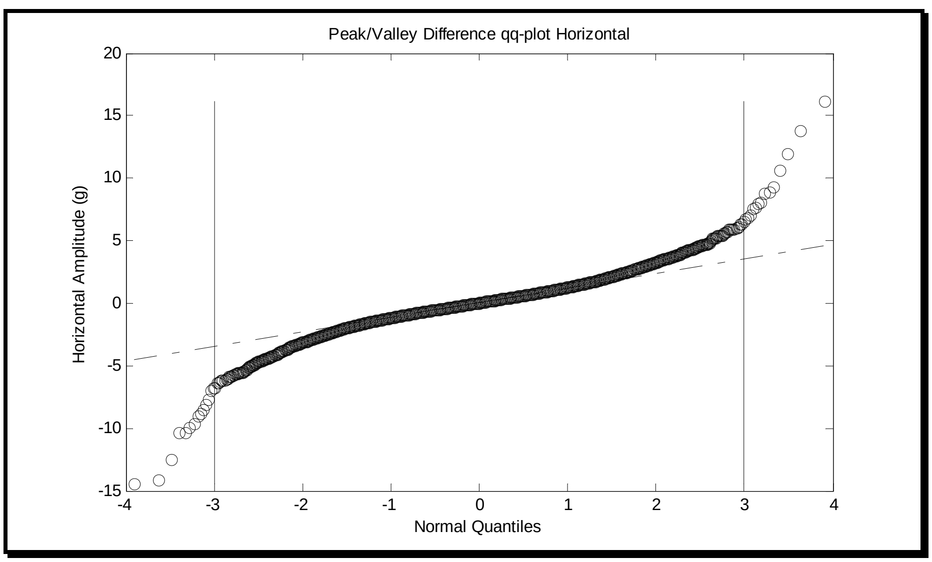

Figure 519.6A-10b. Peak/valley statistic difference - qq-plot.

The minimum, maximum, mean, standard deviation, skewness, and kurtosis of the peak statistic difference serial time sample is provided in the following table.

Table 519.6A-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.

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, 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.

METHOD 519.6 ANNEX B

Guidelines for Procedure II - Stochastically Generated Materiel Input/Response Based Upon Measured Time Trace Information

1. SCOPE.

1.1 Purpose.

This Annex provides an algorithmic methodology for generating a stochastically generated time trace based upon one or more measured gunfire shock time traces. It is assumed that simple replication of the measured gunfire shock time trace(s) on a laboratory vibration exciter under Time Waveform Replication (TWR) does not provide a comprehensively satisfactory test for the gunfire shock environment specified in the LCEP. This Annex can be used in conjunction with Annex E to establish a basis for scaling of measured time trace information for test "level" variation, but does not recommend any "ad hoc" scaling methods as defined in Annex E. This Annex assumes that the testing facility is fully qualified to perform the Single-Exciter/Single-Axis (SESA) TWR Procedure in Method 525. For extensions of this procedure to either Multi-Exciter/Single-Axis (MESA) or Multi-Exciter/Multi-Axis (MEMA), use Method 527.

1.2 Application.

This Annex addresses two methods for laboratory gunfire stochastic replication – one based upon ensemble representation and the other considers a time trace as a single entity. The stochastic generation of a gunfire shock time trace is generally independent in details of the measured gunfire shock time trace upon which it is based. For gunfire shock environment, typically the measured acceleration levels are so substantial that stochastic generation of time traces that vary in "details" is inconsequential. An alternative way of stating this is that under TWR test philosophy, the effect of gunfire shock on material will be the same whether the measured time trace is used or a stochastically generated time trace from measured data is used. Thus the importance of this Annex is insight (1) into means of nonstationary time trace stochastic generation.

Guidelines provided in Procedure II are based upon one of three approaches that are schematically displayed in Figure 519.6B-1,

(1) In the first approach a single measured gunfire shock time trace is available that is representative for LCEP gunfire shock requirements. Stochastic generation is required to vary the details of the single measured time trace in some statistically measurable way.

(2) In the second approach two or more measured gunfire shock time traces are available and representative for LCEP gunfire shock requirements. Depending upon the number of available measurements either:

- (a) a reliable measure of the underlying random process variance and deterministic component are available, and the time traces pooled to provide information for stochastic simulation of individual gunfire shock time traces or,
- (b) the underlying random process deterministic and random component cannot be reliably established, and stochastic generation of the individual gunfire traces is necessary according to (1).

(3) In the third approach a single measured gunfire shock time trace is available but not totally representative of the LCEP gunfire shock requirements e.g., the measured time trace may not be considered to be an environmental extreme. In this case stochastic generation may take place and either

- (a) the measured or the stochastically generated gunfire shock time trace (see (1)) is scaled in some manner appropriate to the form of gunfire shock or,
- (b) the measured time trace may be scaled in an "ad hoc" manner based upon information and procedures external to this method. Scaling strategies will be discussed in Annex E.

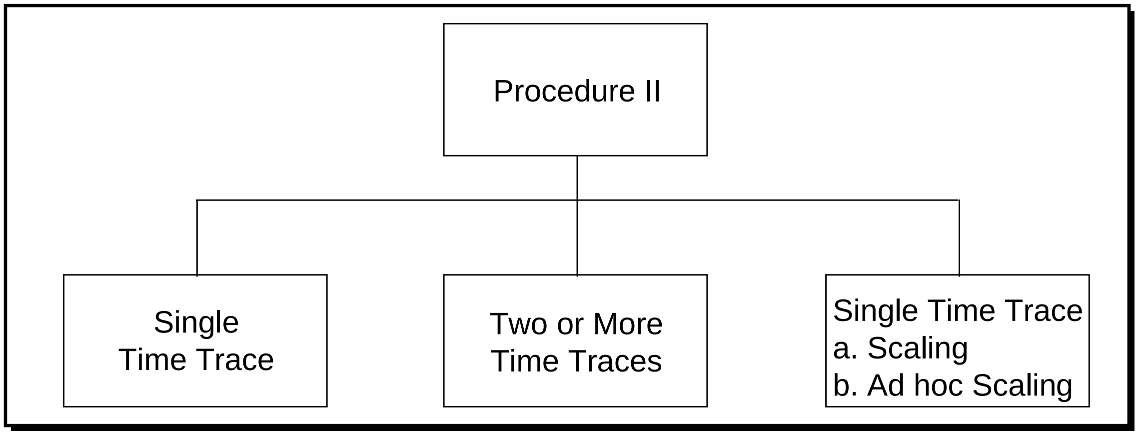

Figure 519.6B-1. Three Approaches to Procedure II Stochastic Laboratory Testing.

Paragraph 2 of this Annex describes the problem of stochastic generation in general, and presents the measured time trace under consideration. Paragraph 3 provides an algorithmic procedure for simulation of a single gunfire shock time trace that has an ensemble representation (***Pulse Ensemble*** algorithm). Paragraph 4 provides an algorithmic procedure for simulation of a single gunfire shock time trace irrespective of the ensemble representation (***Time Trace*** algorithm). Paragraph 5 summarizes gunfire shock testing philosophy.

2. BASIC CONSIDERATIONS FOR STOCHASTIC GENERATION OF A TIME TRACE FROM A SINGLE MEASUREMENT.

2.1 Introduction.

a. Two "algorithms" illustrated in this Annex may be used for stochastic generation given a single gunfire shock measurement time trace. The first algorithm, termed *Pulse Ensemble*, decomposes the single time trace into an ensemble of individual pulses, and proceeds to stochastically generate individual pulses that then may be concatenated into a continuous time trace of unspecified duration. The second methodology, termed "*Time Trace*," uses internal time trace statistics of the overall measured time trace to provide a basis for appropriately generating a stochastic version of the measured time trace. The *Pulse Ensemble* algorithm allows for scaling of the deterministic component and the random component separately (Annex E). The *Time Trace* algorithm provides no obvious way to scale, since deterministic and random components are not explicit. Any scaling would be "ad hoc" (Annex E). These algorithms assume a limited amount of measured time trace information, perform some sort of decomposition generally with orthogonal components, use the statistics of the "coefficients" of the decomposition to provide information on the underlying random process, manipulate the coefficients in some statistically defined way, invert the decomposition by waveform reconstruction based upon the new set of coefficients to arrive at a sample time trace that is consistent with the unknown underlying random process that generated the measured time trace information.

b. Fourier, Wavelet, Karhuen-Loeve and Generalized Linear Model decompositions (and subsequent reconstructions to the extent possible) seem suitable for generating an unlimited number of individual gunfire pulses or ensembles of gunfire pulses with statistics consistent with those of the measured time trace(s). Unless the unknown underlying field generated random process is well characterized by more than one sample time trace, stochastic generation will only reflect the properties of the field measured time trace providing information to the stochastic generation. As indicated above and will be discussed in paragraph 5 of this Annex, this implies that stochastic generation may provide little real added value in laboratory testing under TWR philosophy over repetition of the measured time trace(s). Figure 519.6B-2 provides a schematic of the basic stochastic simulation algorithms presented in this Annex.

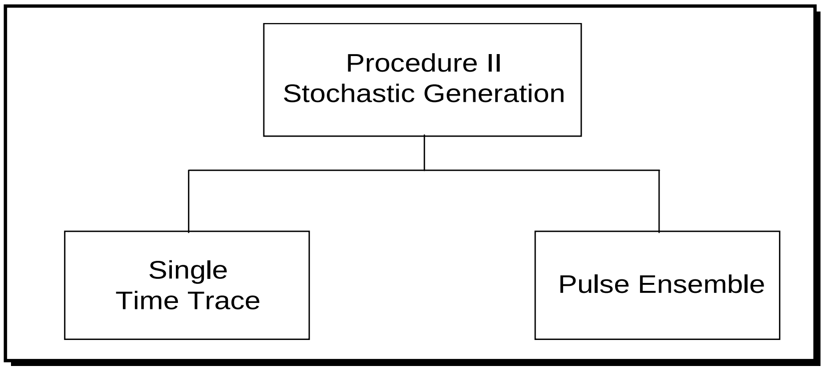

Figure 519.6B-2. Two algorithms for stochastic generation of laboratory gunfire shock.

In presenting the ***Pulse Ensemble*** and ***Time Trace*** algorithms, it is assumed that one or more measured time traces have been validated, and have been pre-processed according to procedures in Annex A such that they can be used under Method 525 for measured gunfire shock replication. It is also assumed that a test scenario has been devised as a part of Procedure II and calls for testing to N independent realizations of the measured time trace or traces. For illustration purposes a single measured time trace will be considered for stochastic simulation.

2.2 Gunfire Time Trace for Illustration.

Figure 519.6B-3 provides the single measured gunfire shock time trace that has been band limited between 10 Hz and 2000 Hz, and has a pulse ensemble representation for illustrating the ***Pulse Ensemble*** algorithm.

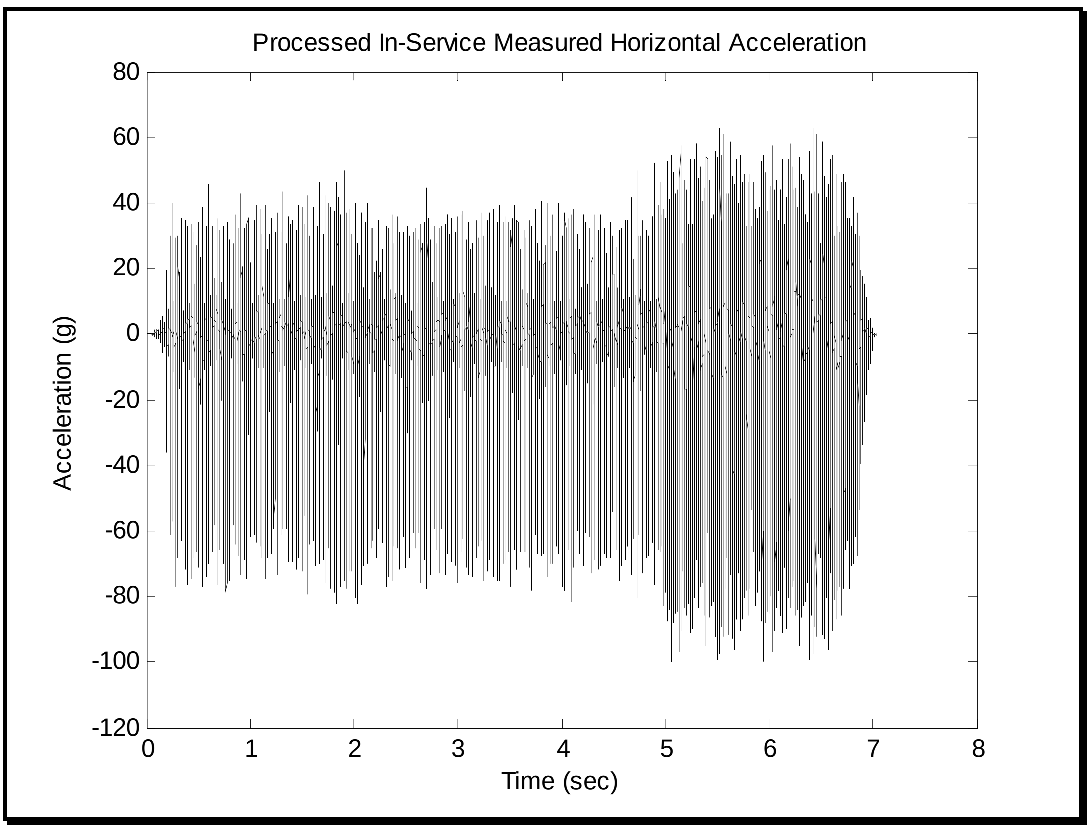

Figure 519.6B-3. Pre-processed gunfire shock measured time trace.

The overall measured time trace is decomposed into a series of pulses by careful examination of the corresponding characteristics of the overall time trace at an increment of time corresponding to the inverse of the gunfire rate. For the 2000 rnd/min firing rate, this provides pulse ensemble members approximately 30 milliseconds in duration, while for the 4000 rnd/min each pulse ensemble member is approximately 15 milliseconds in duration. This Annex does not provide any particular guidance in the formation of such pulse ensembles, except to say good time trace correlation must exist among the pulse ensembles to form a valid pulse ensemble. A starting point is to examine the overall time trace peak structure, and a five millisecond time window surrounding each peak for good time trace "likeness" or correlation. This, coupled with the known firing rate of the gun, should allow creation of a pulse ensemble at the gunfire rate. Figure 519.6B-4 provides the pulse ensemble representation statistics for both the 2000 rnd/min and 4000 rnd/min gunfire rates. The "Ensemble Mean" designation provides display of the gunfire trace *deterministic component,* and the "Ensemble Std" designation displays the square root of the variance of the gunfire trace *random component.* 2000 rnd/min and 4000 rnd/min show some self-similarity of form on a different time scale. At the 2000 rnd/min gunfire rate there are 164 individual pulses for defining the pulse ensemble, and at the 4000 rnd/min gunfire rate there are 59 individual pulses.

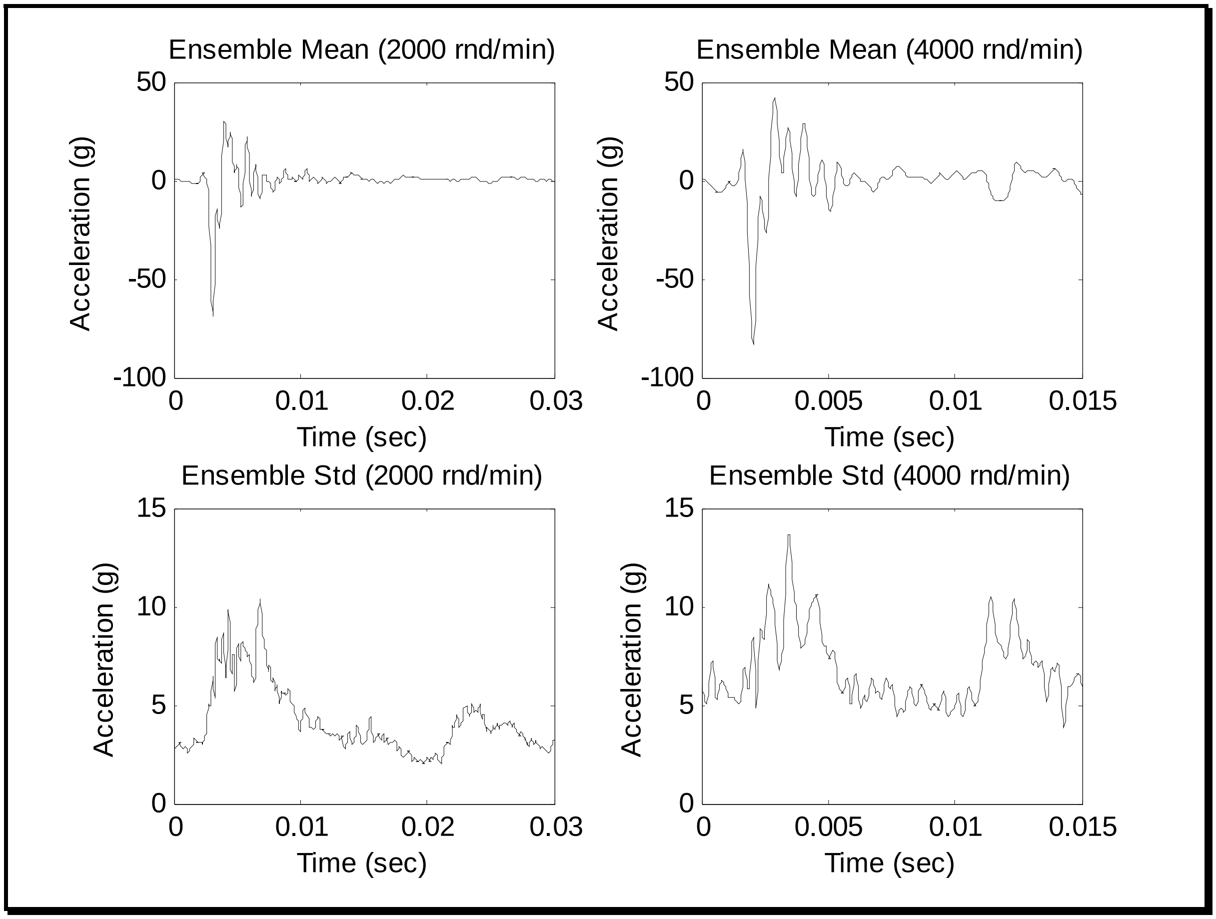

Figure 519.6B-4. Pre-processed gunfire shock measured time trace pulse ensemble statistics.

For the ***Pulse Ensemble*** algorithm, the overall time trace in Figure 519.6B-3 must be decomposed into two ensembles representing the two gunfire rates. For reference purposes that will be useful in this Annex, the two ensembles are "re-composed" into a "continuous" time trace, and Figure 519.6B-5 displays two measured time traces developed by concatenating the pulse ensembles. That is, after the pulse ensembles were created (creation may have required measured time trace zero-padding, truncation or some other means of fixing up the ends of the pulses to get uniform length), the concatenated time traces were developed by merely placing the ensemble members end-to-end. Thus the term "Concatenated Measured Time Trace" and a time trace representation that is more "uniform in time" than the original measured time trace.

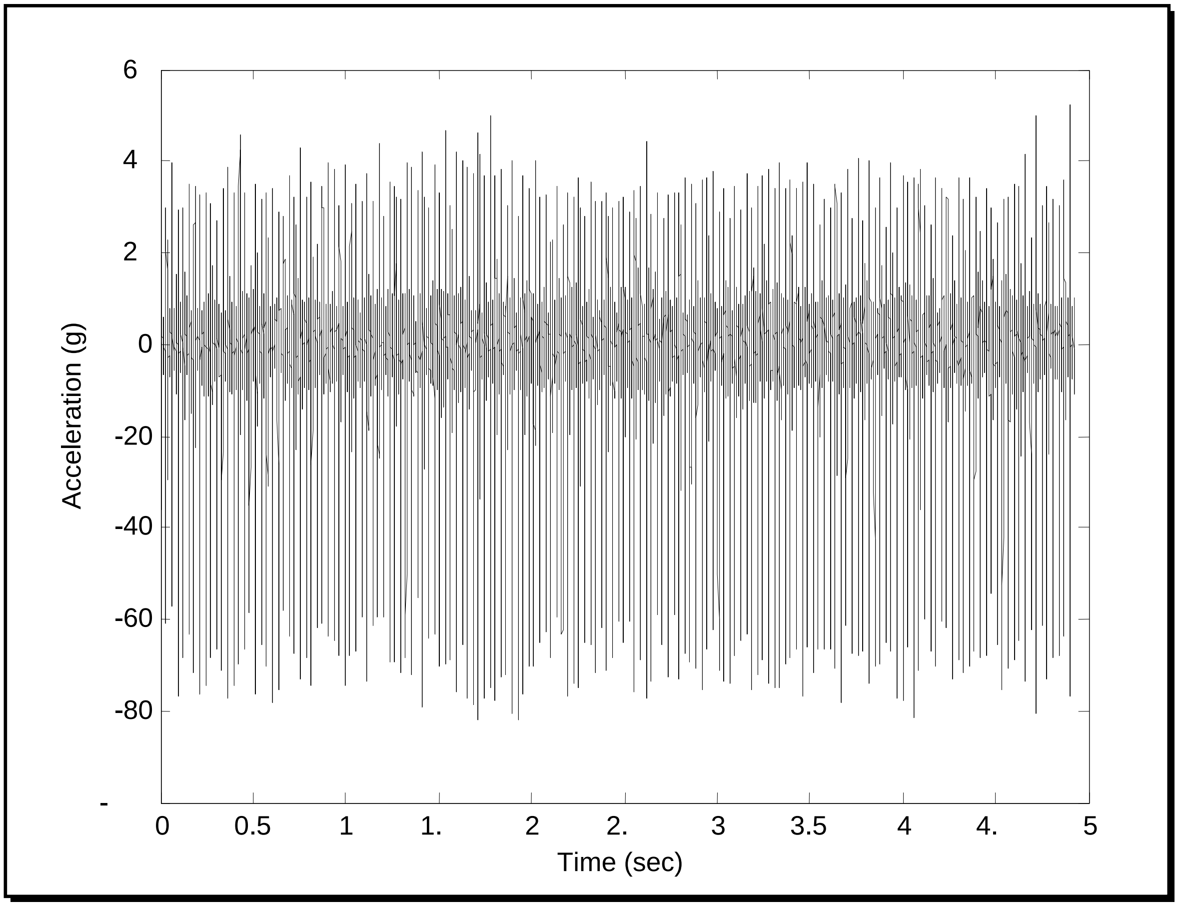

Figure 519.6B-5a. Concatenated measured gunfire shock time trace (2000 rnd/min).

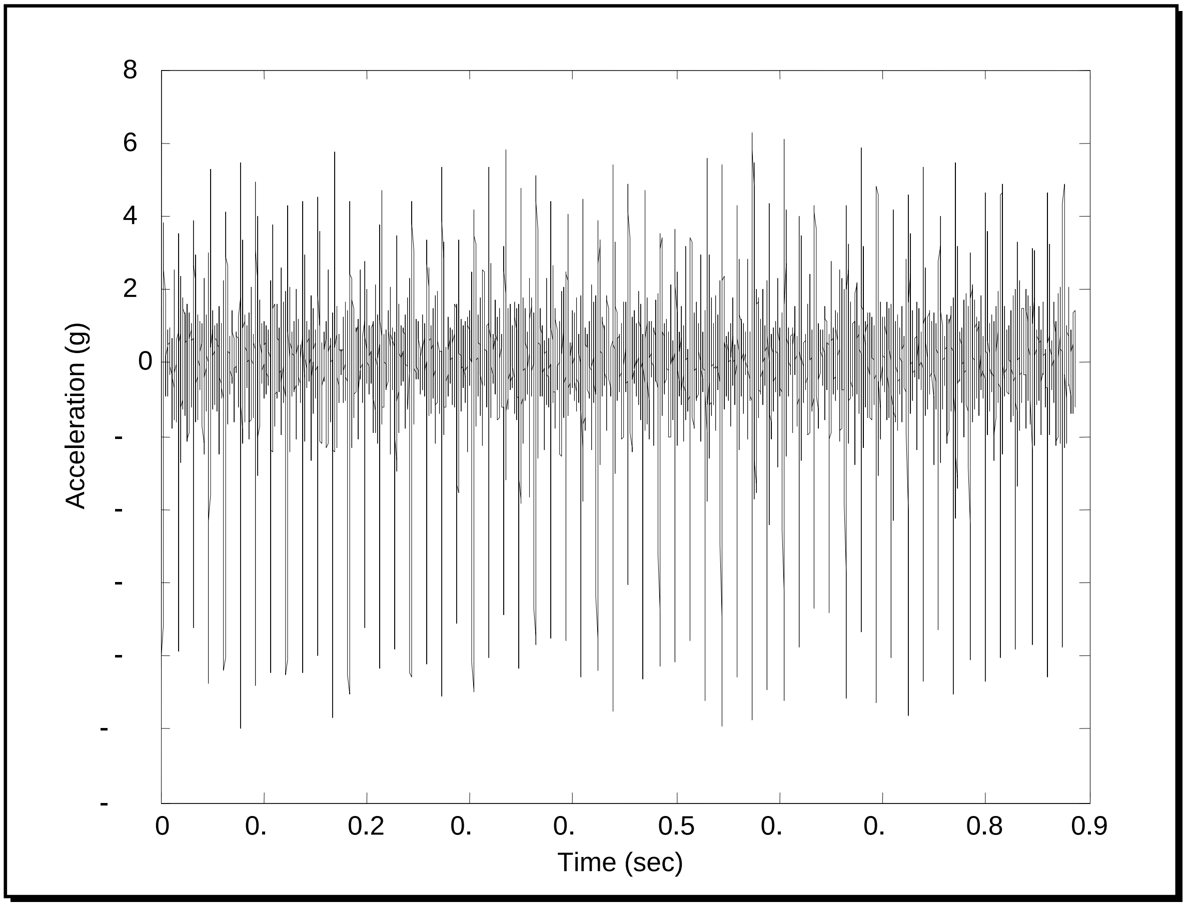

Figure 519.6B-5b. Concatenated measured gunfire shock time trace (4000 rnd/min).

3. PULSE ENSEMBLE ALGORITHM FOR STOCHASTIC GENERATION.

3.1 Algorithm.

The first algorithm assumes a ***Pulse Ensemble*** representation for the measured gunfire shock time trace. Stochastic generation will be based upon examining the deterministic and random components of the ensemble separately using Wavelet decomposition and subsequent reconstruction. This algorithm allows for a convenient generation of an unlimited number of pulses that may subsequently be concatenated to provide a stochastic gunfire shock time trace for testing. The wavelet simulation methodology provided in paragraph 6.2, references k and l, provide excellent references for the ***Pulse Ensemble*** algorithm. In general the reference emphasizes two concepts. First, wavelet decomposition provides statistically independent coefficient information at differing levels to manipulate and, second, the significant coefficients are approximately normally distributed.

For a given time trace, Wavelet decomposition implies determination of coefficients for an "analysis filter bank," and Wavelet reconstruction implies an inverse Wavelet transform based upon coefficients for a "synthesis filter bank." The properties of Wavelet functions and their related coefficients are very robust with respect to manipulation as a result of their independence. The explicit goal of stochastic gunfire shock time trace generation is *" to provide a statistically based time trace that has the appearance of a measured time trace but yet is not perfectly correlated with the measured time trace from which it was generated."*

Generation of a single stochastic pulse is accomplished as follows with the ***analysis filter*** and ***synthesis filter*** terminology used:

a. For analysis filter considerations:

(1) determine Wavelet transform coefficients for the deterministic component and each member of the random component ensemble.

(2) remove any high frequency noise in the deterministic component, i.e., smooth the deterministic component, by the Wavelet process of “de-noising”.

(3) determine Wavelet transform coefficients for each member of the random component ensemble.

b. For the analysis filter coefficient manipulation leading to the synthesis filter coefficients

(1) examine the statistical properties of the random component Wavelet coefficients over the ensemble and over the levels of Wavelet decomposition.

(2) map the random component Wavelet coefficients to a Gaussian distribution that has a zero mean and a standard deviation corresponding to the coefficient sample standard deviation. Any de-noising of the random components may also be performed here (it is important to remove edge effects that result in discontinuities at beginning and end of individual pulse random components). This in effect determines a new set of wavelet coefficients for the random component ensemble. It is noted that such a mapping keeps the properties of the new wavelet coefficients “close” to the properties of the old wavelet coefficients and this is why the reconstructed waveform “looks” much like the original waveform.

c. For the synthesis filter considerations

(1) using the new set of wavelet coefficients, reconstruct the individual pulse random component ensemble by way of the inverse wavelet transform.

(2) add the deterministic component to each member of this ensemble to form the stochastically generated ensemble of pulses corresponding to the original pulse ensemble.

These three steps complete the process of stochastic generation. Paragraph 6.1 reference d provides a careful discussion of certain analysis or decomposition and synthesis or reconstruction subtleties that are not covered here.

3.2 Illustration.
Figures 519.6B-6a,b and c provide the coefficients for the Wavelet decomposition (db15) of the deterministic component, composite random component and the standard deviation of the random component, respectively, for 2000 rnd/min ensemble. Similar results could be displayed for the 4000 rnd/min ensemble. The Dubauchies Wavelet (db15 – MATLAB@R Wavelet Toollbox) is employed here to make results comparable to paragraph 6.1 reference d. The mean and standard deviation for each of the four decomposition coefficient levels is contained in Table 519.6B-1. It is clear that cA4, cD4 and cD3 represent sizeable analysis filter coefficients, and since a Wavelet transform is a linear transform (paragraph 6.1, reference d), these three sets of coefficients will play a major role in synthesis of time trace waveforms.

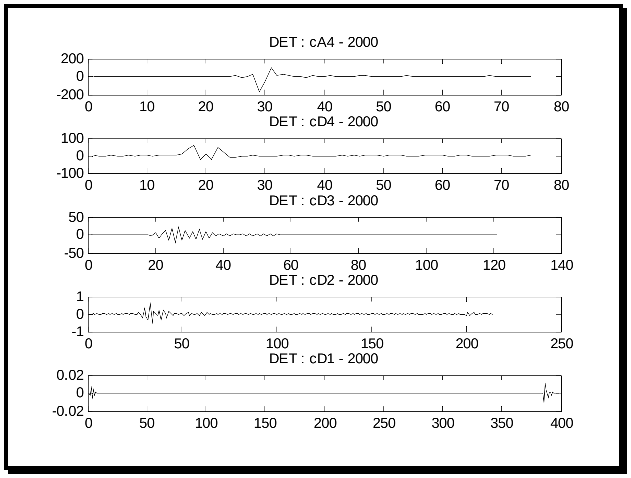

Figure 519.6B-6a. Wavelet decomposition for deterministic component, (db15) (2000 rnd/min).

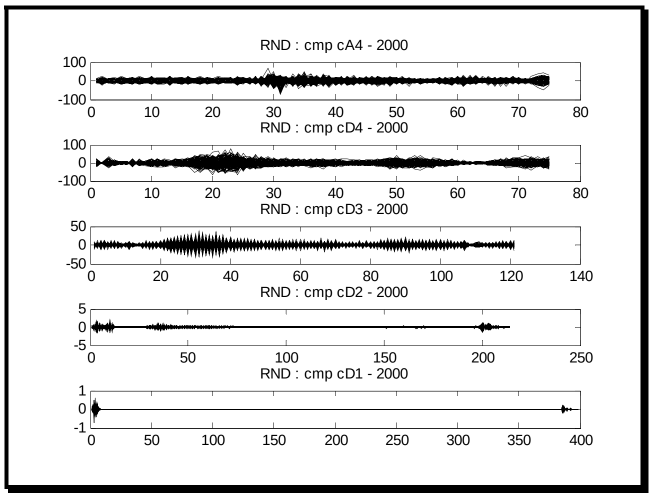

Figure 519.6B-6b. Composite wavelet decomposition for random component, (db15) (2000 rnd/min).

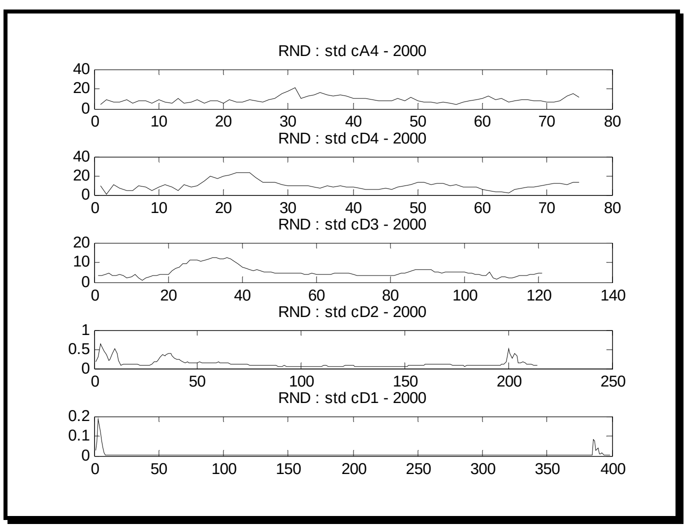

Figure 519.6B-6c. Wavelet decomposition for random component standard deviation, (db15) (2000 rnd/min).

Table 519.6B-1. Mean and standard deviation of wavelet decomposition levels.

	2000	4000
cA4/3	-0.1852/23.1675	-3.8734/29.1515
cD4	-0.0919/ 7.6572	-
cD3	-0.0013/ 6.8660	-0.0145/ 8.8194
cD2	0.0000/ 0.0521	0.0000/ 0.0909
cD1	0.0000/ 0.0018	0.0000/ 0.0017

Figure 519.6B-7 provides qq-plots for each of the level coefficient sets that essentially determine the mapping of coefficients between the analysis filter and the synthesis filter. Note that the coefficient sets are large since they range over all the random component ensemble members for each level.

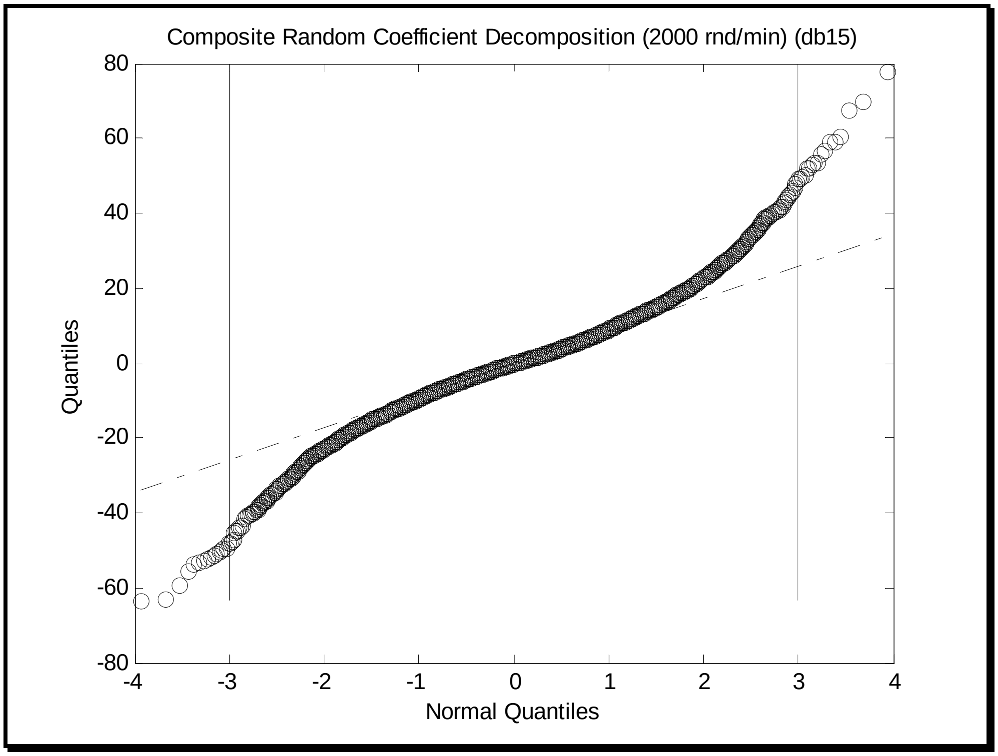

Figure 519.6B-7a. qq-Plot for composite random component decomposition, 2000 rnd/min.

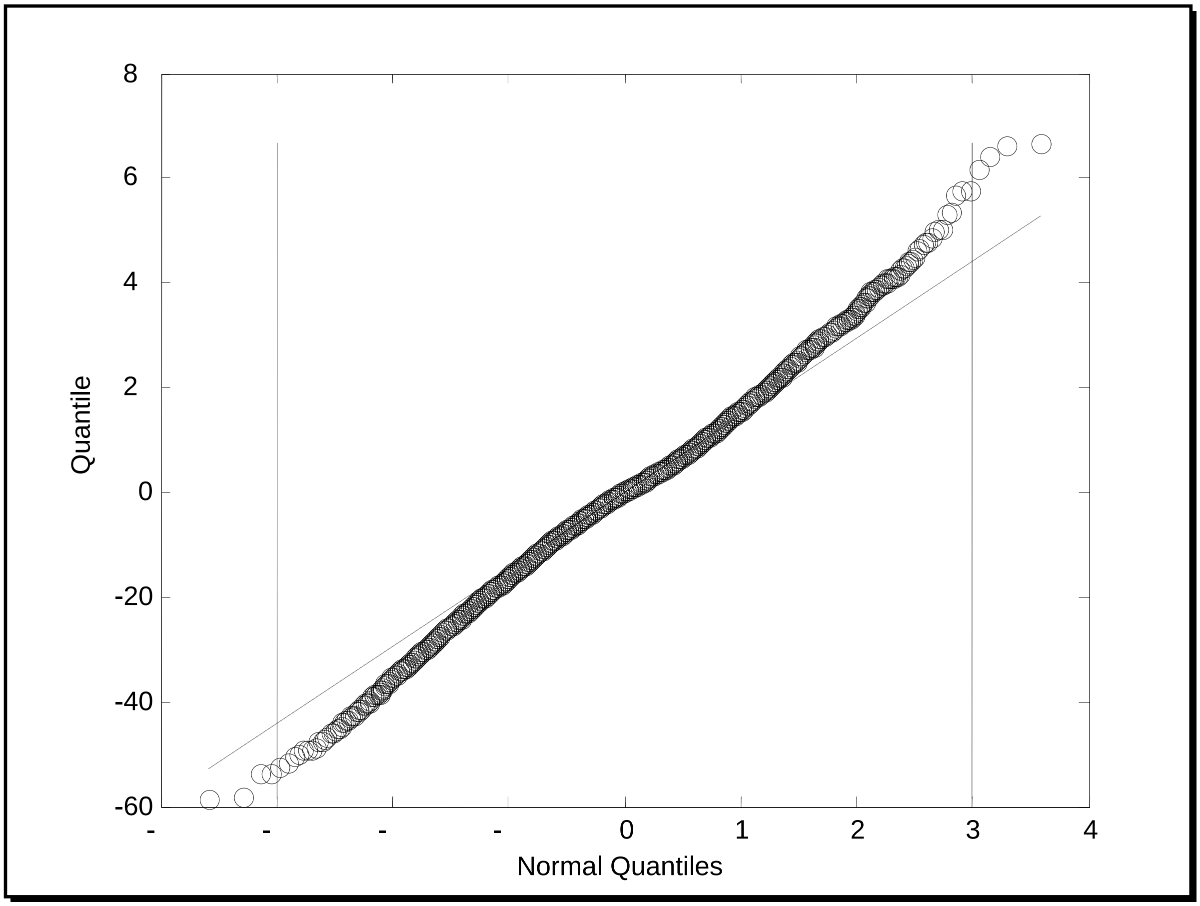

Figure 519.6B-7b. qq-Plot for composite random component decomposition 4000 rnd/min.

Figure 519.6B-8 displays ensemble based information for stochastic generation that corresponds to the information in Figure 519.6B-4 and Figure 519.6B-9 time trace information corresponding to information in Figure 519.6B-5.

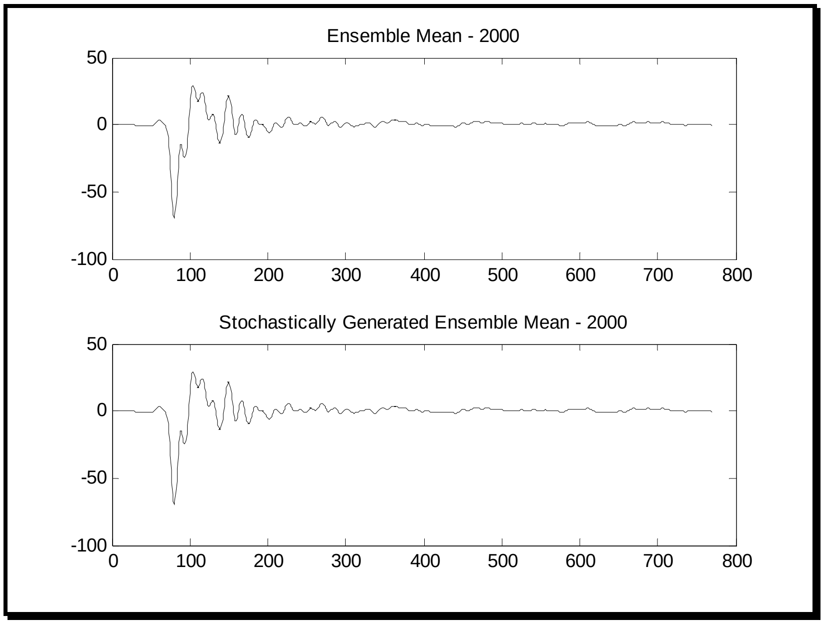

Figure 519.6B-8a. Ensemble and stochastically generated pulse ensemble deterministic component (2000 rnd/min).

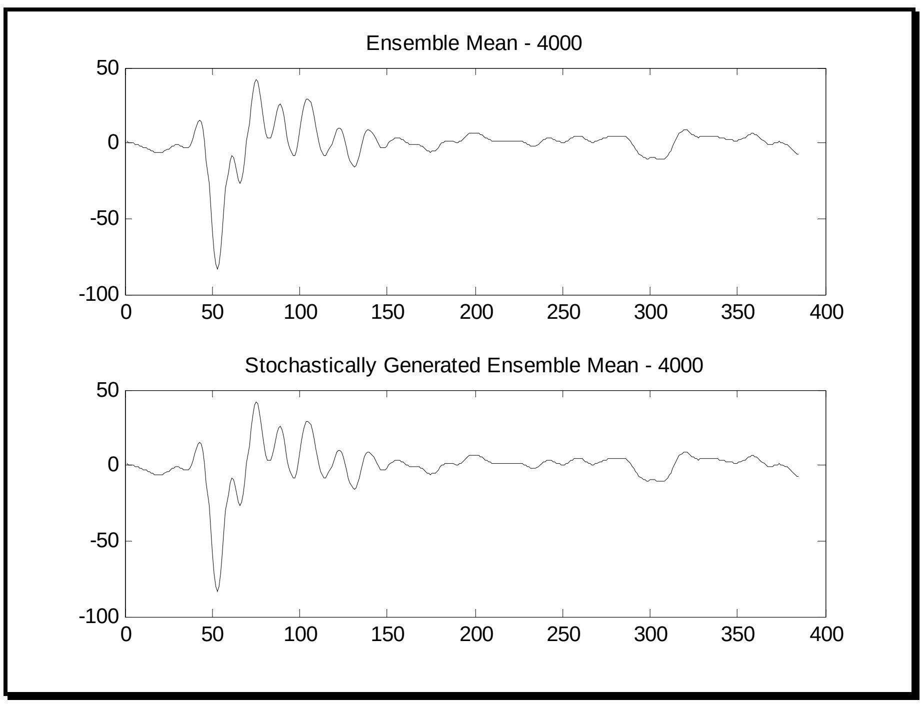

Figure 519.6B-8b. Ensemble and stochastically generated pulse ensemble deterministic component (4000 rnd/min).

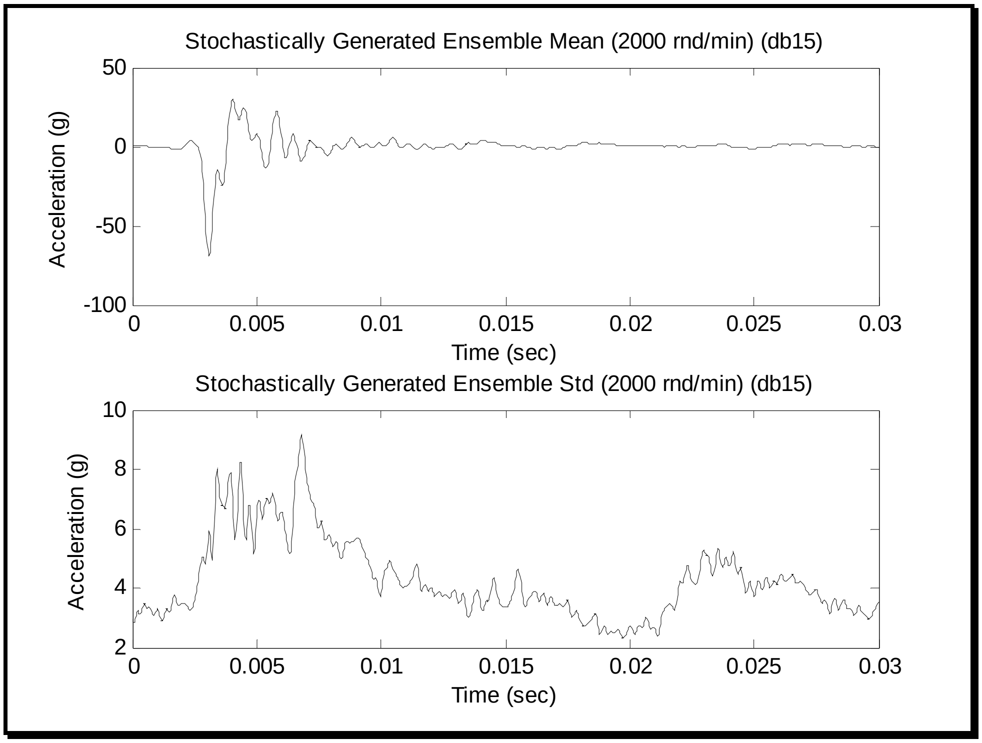

Figure 519.6B-8c. Ensemble and stochastically generated pulse ensemble random component standard deviation (2000 rnd/min).

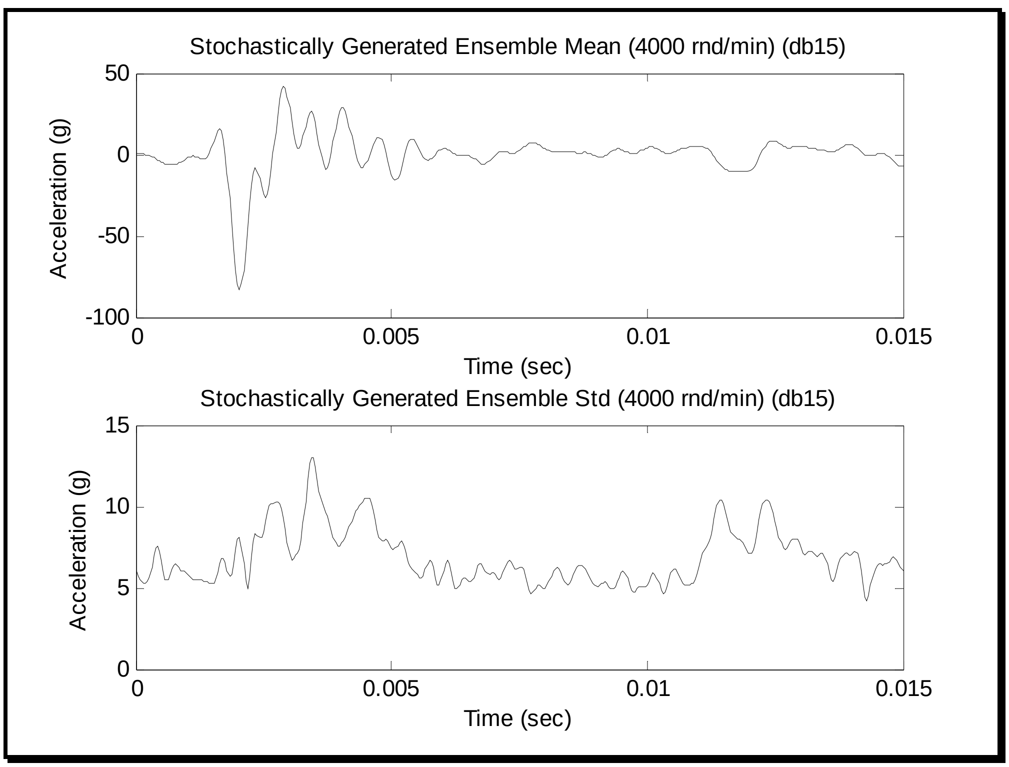

Figure 519.6B-8d. Ensemble and stochastically generated pulse ensemble random component standard deviation (4000 rnd/min)

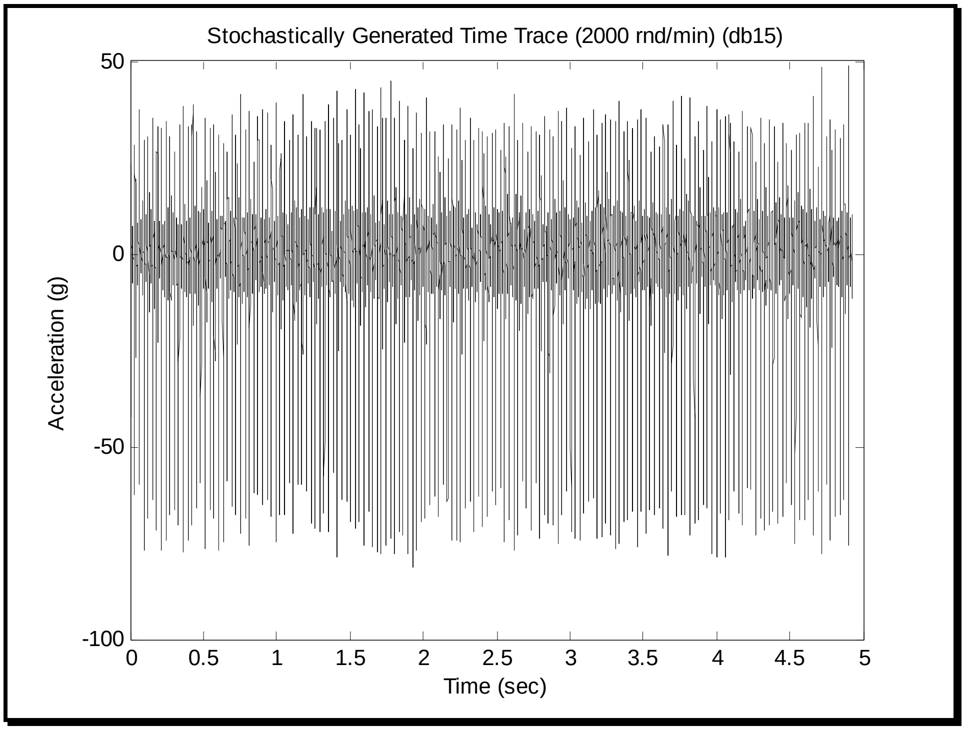

Figure 519.6B-9a. Stochastically generated gunfire shock time trace (2000 rnd/min).

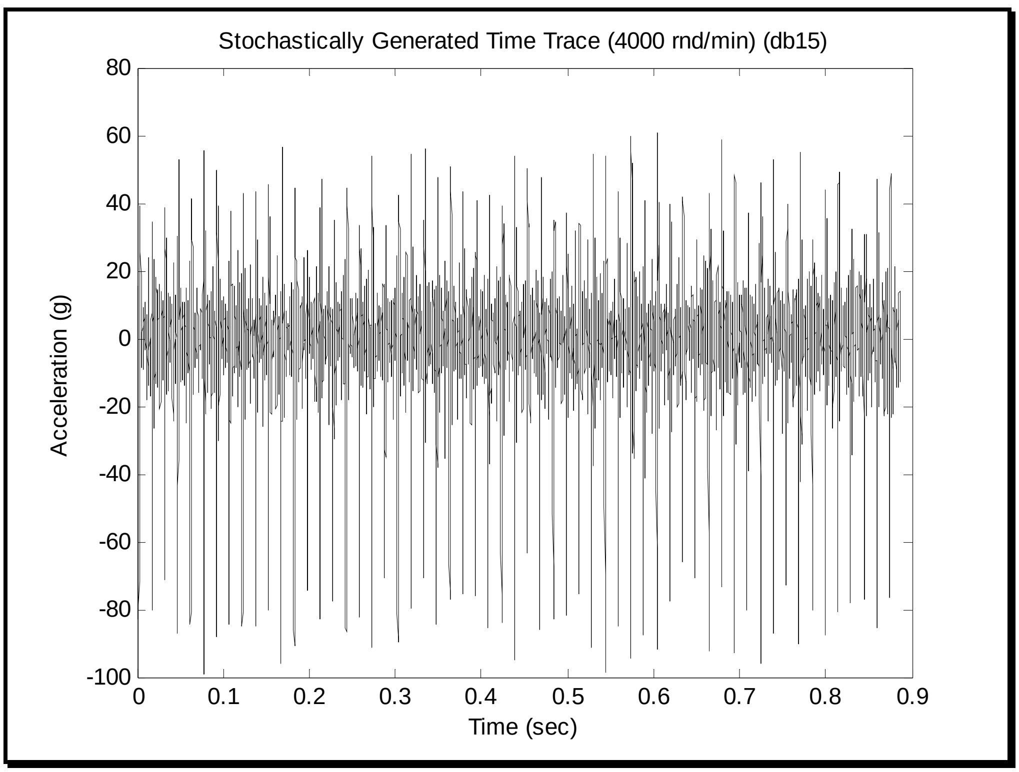

Figure 519.6B-9b. Stochastically generated gunfire shock time trace (4000 rnd/min).

Figure 519.6B-10 provides cross plot information for the measured and stochastically generated time traces in Figure 519.6B-9. Paragraph 6.1, reference d provides an extended analysis of the cross-plot may be provided where the times of a selected segment of the cross-plot are modeled by a Poisson probability model. For homogeneity of the cross-plot display it is important that the Poisson probability model be stationary. This, in effect, indicates that time trace differences should have certain homogeneity in modeling.

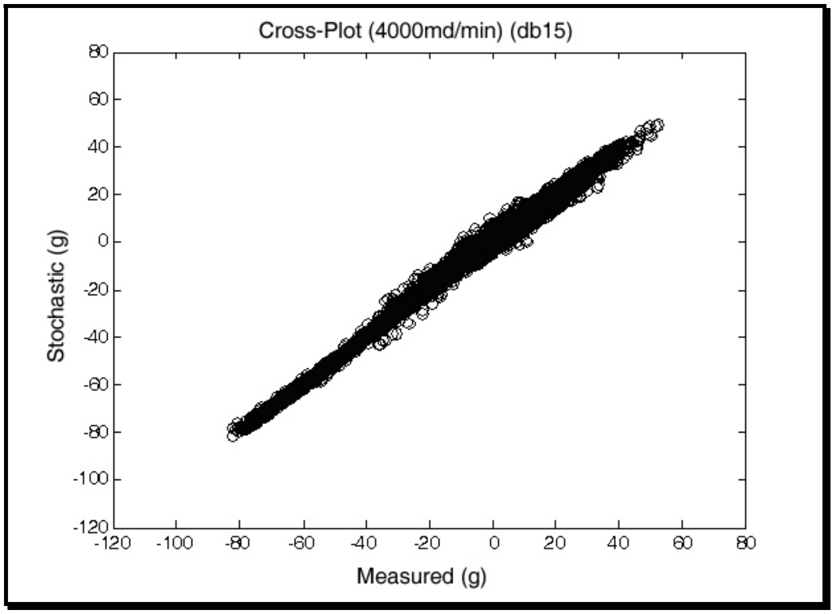

Figure 519.6B-10a. Cross-plot comparison between measured and stochastically generated time traces: Gunfire shock (2000 rnd/min).

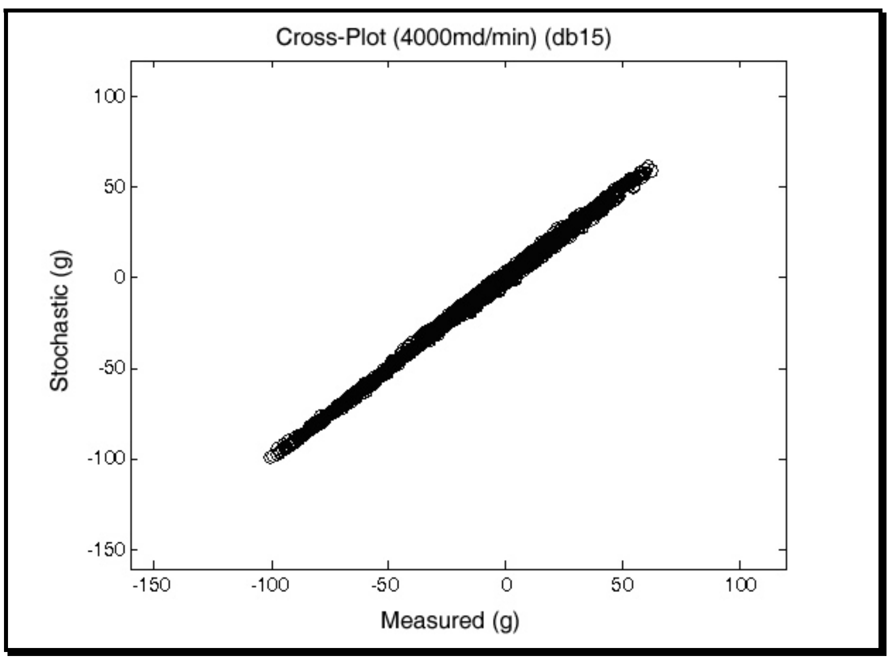

Figure 519.6B-10b. Cross-plot comparison between measured and stochastically generated time traces, gunfire shock (4000 rnd/min).

Figure 519.6B-11 provides a qq-plot of the difference between the measured and stochastically generated time traces. These plots are similar in form to qq-plot of difference between the reference and control time traces displayed in Annex A (Figure 519.6A-8.).

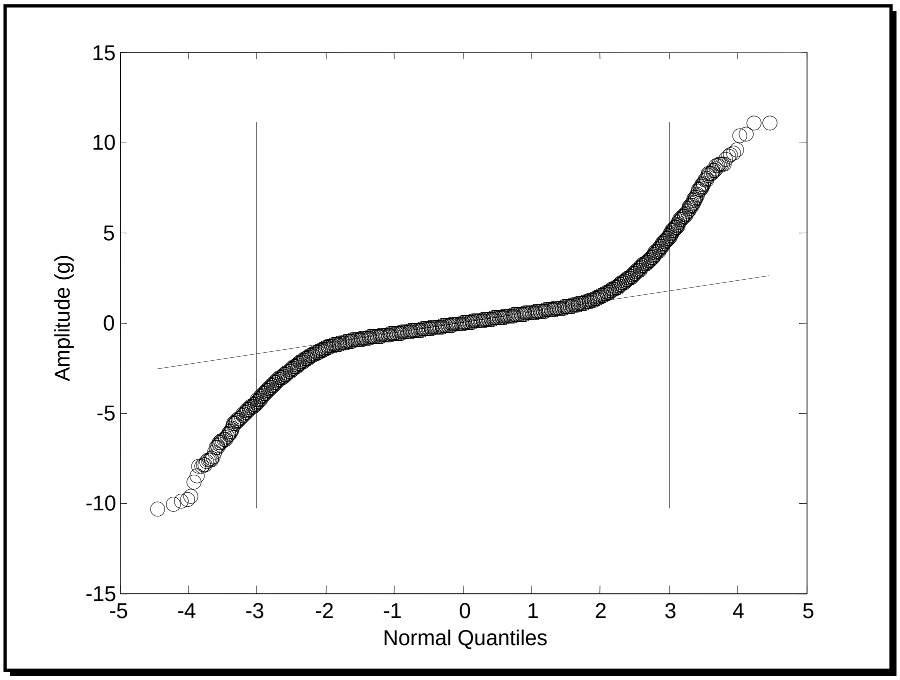

Figure 519.6B-11a. qq-plot, gunfire shock time trace difference (2000 rnd/min).

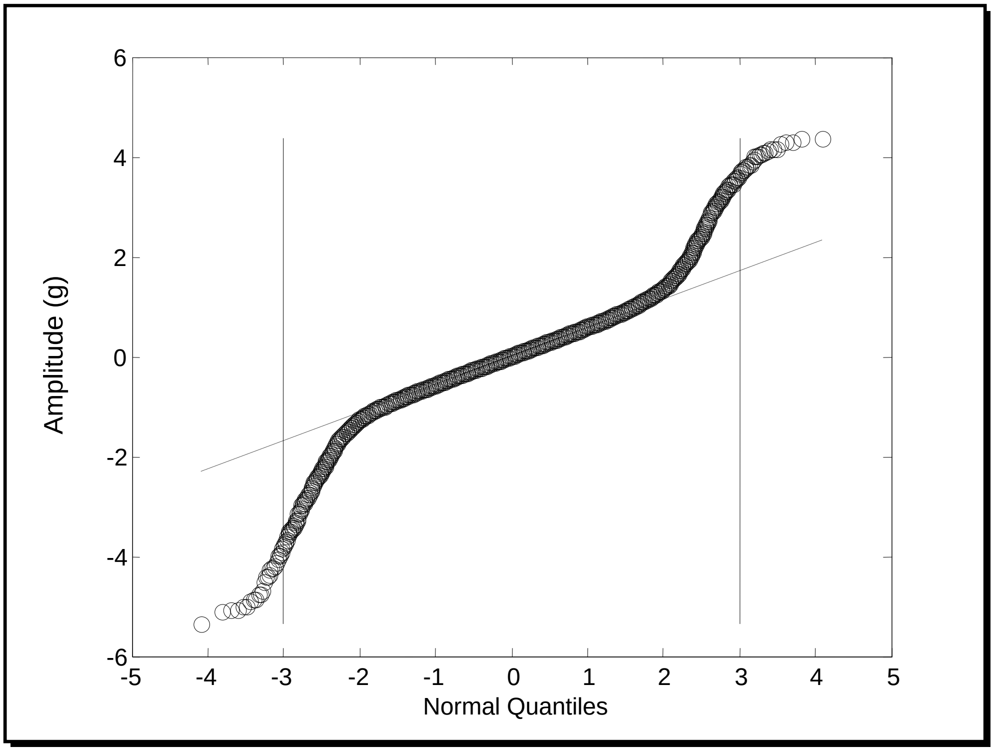

Figure 519.6B-11b. qq-plot, gunfire shock time trace difference (4000 rnd/min).

This concludes discussion of the ***Pulse Ensemble*** algorithm for stochastic time trace generation.

4. TIME TRACE ALGORITHM FOR STOCHASTIC GENERATION OF GUNFIRE SHOCK.

4.1 Algorithm

Creation of an ensemble of pulses can be time consuming since the pulses must be precisely phase correlated if there is no "timing pulse" to indicate the beginning of an ensemble member. This paragraph demonstrates the stochastic generation of a time trace measured from a single gunfire event. The advantage of this algorithm in stochastic generation is substantial, however there are two a drawbacks. The first drawback is that there is some loss of time trace generation flexibility in stringing together an indefinite number of individual pulses. The second drawback is related to scaling of gunfire time traces, i.e., for proper scaling the need to scale the deterministic component and random component individually. When the overall time trace is decomposed, it is difficult to decide on what wavelet detail levels need to be reconstructed to provide an estimate of the deterministic component.

The major advantages are as follows:

(1) no need to create a pulse ensemble so analysis can be mechanized.

(2) no loss of important details and introduction of an artificial periodicity (the gun mechanism never outputs at a uniform rate and errors of a millisecond are not uncommon).

(3) ability to easily handle different firing rates within one gunfire time trace.

(4) ability to extract stings of pulses and concatenate these to form an indefinite length time trace.

(5) ability to more effectively use the power of the Wavelet method by choosing different wavelet sets and avoiding edge effects.

In the technique presented here, the entire measured time trace is wavelet transformed using the Daubuchies wavelet "db20." There are a maximum number of twelve levels of decomposition according to the pyramid algorithm. The decomposition coefficients for the measured time trace are then statistically "mapped" to a new set of decomposition coefficients that represent new decomposition levels. The new decomposition levels are then used in wavelet transform reconstruction operation to arrive at a "stochastic realization" of the original measured time trace. This realization has the same general character of the original time trace, but the details are different. The extent of the variation of the manifestation to the original is directly dependent upon the form of mapping between the measured decomposition coefficients and the new set of decomposition coefficients. This mapping may be either deterministic, statistical or a combination of deterministic and statistical. Figure 519.6B-2 provides a schematic of the ***Time Trace*** algorithm.

As in paragraph 3.1 of this Annex, generation of a single stochastic pulse is accomplished as follows with the ***analysis filter*** and ***synthesis filter*** terminology used:

a. For analysis filter considerations:

   (1) Determine Wavelet transform coefficients for the entire time trace.

   (2) Remove any high frequency noise in the Wavelet transform by the Wavelet process of "de-noising".

b. For the analysis filter coefficient manipulation leading to the synthesis filter coefficients:

   (1) Examine the statistical properties of the Wavelet coefficients over the time trace, and over the levels of Wavelet decomposition

   (2) Map the time trace Wavelet coefficients to a Gaussian distribution that has a zero mean and a standard deviation corresponding to the coefficient sample standard deviation. Any de-noising of the time trace may also be performed here (it is important to remove edge effects that result in discontinuities at beginning and end of the time trace). This in effect determines a new set of wavelet coefficients for the time trace. It is noted that such a mapping keeps the properties of the new wavelet coefficients "close" to the properties of the old wavelet coefficients, and this is why the reconstructed waveform "looks" much like the original waveform.

c. For the synthesis filter considerations

   (1) Using the new set of wavelet coefficients, reconstruct the time trace by way of the inverse wavelet transform.

These three steps complete the process of stochastic generation. It is possible for the illustration to follow that the steps in the algorithm could be expanded upon and wavelet packets used to model separately the 2000 rnd/min and

4000 rnd/min portions of the overall time trace. It is important to realize that Wavelet modeling is very flexible, and even selection of the correct wavelet to be used in processing may not be apparent.

4.2 Illustration.

Figure 519.6B-12 provides an overview of the approximation and all the detail level coefficients plotted as one time trace. The lower level detail coefficients are generally small when compared to the higher level detail coefficients and the approximation coefficients.

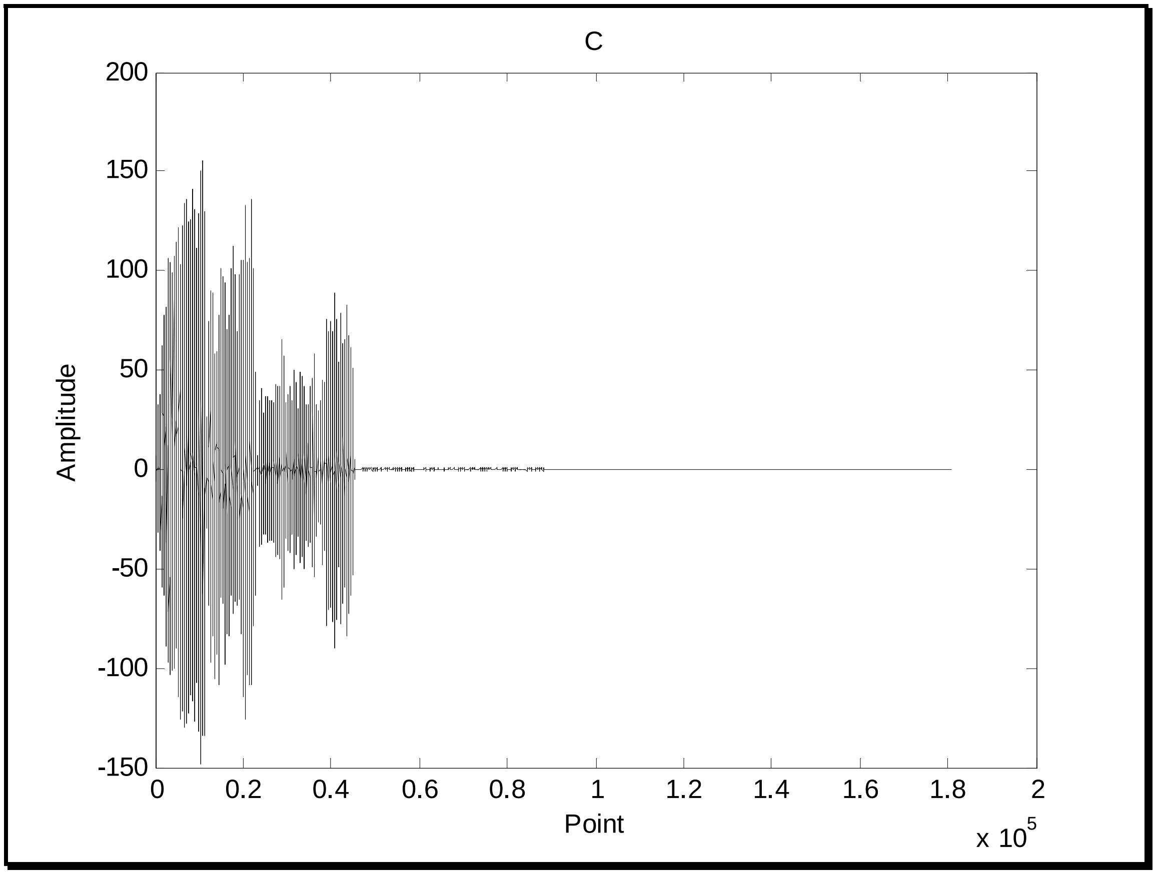

Figure 519.6B-12. db20 Approximation plus decomposition coefficients for the time trace in Figure 519.6B-3.

Figure 519.6B-13 provides detail coefficients at level 4 and level 8 for the db20 decomposition. It is clear from this Figure that the decompositions are substantially different between levels and between 2000 rnd/min and 4000 rnd/min segments.

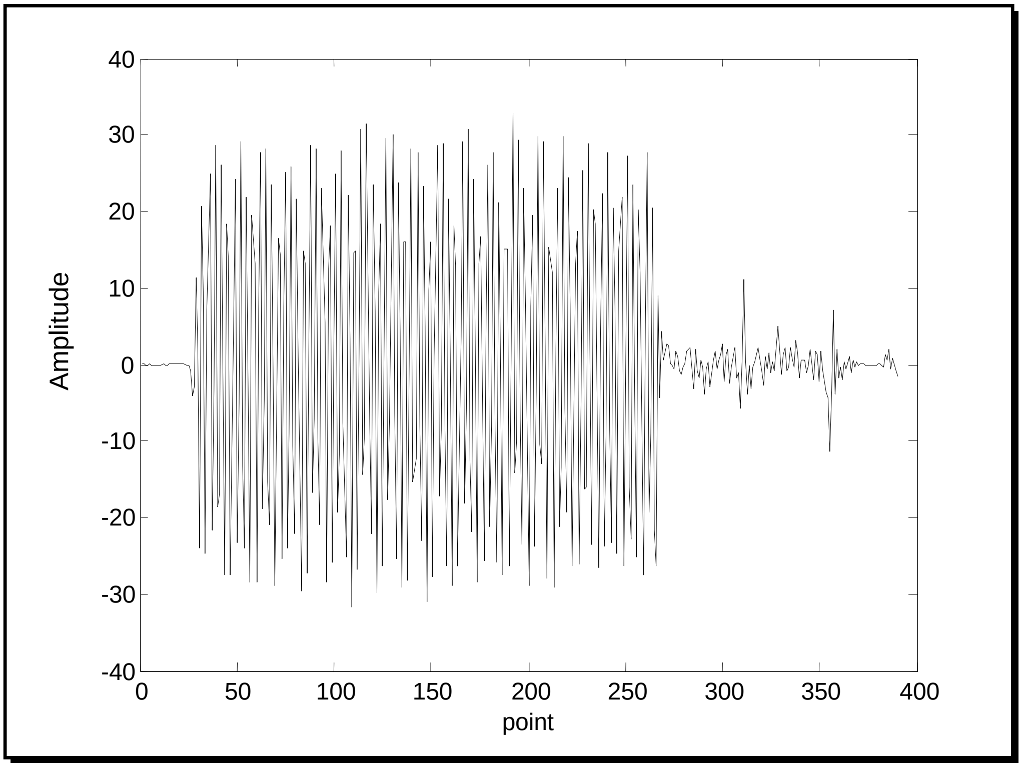

Figure 519.6B-13a. Sample wavelet decomposition at level cD4.

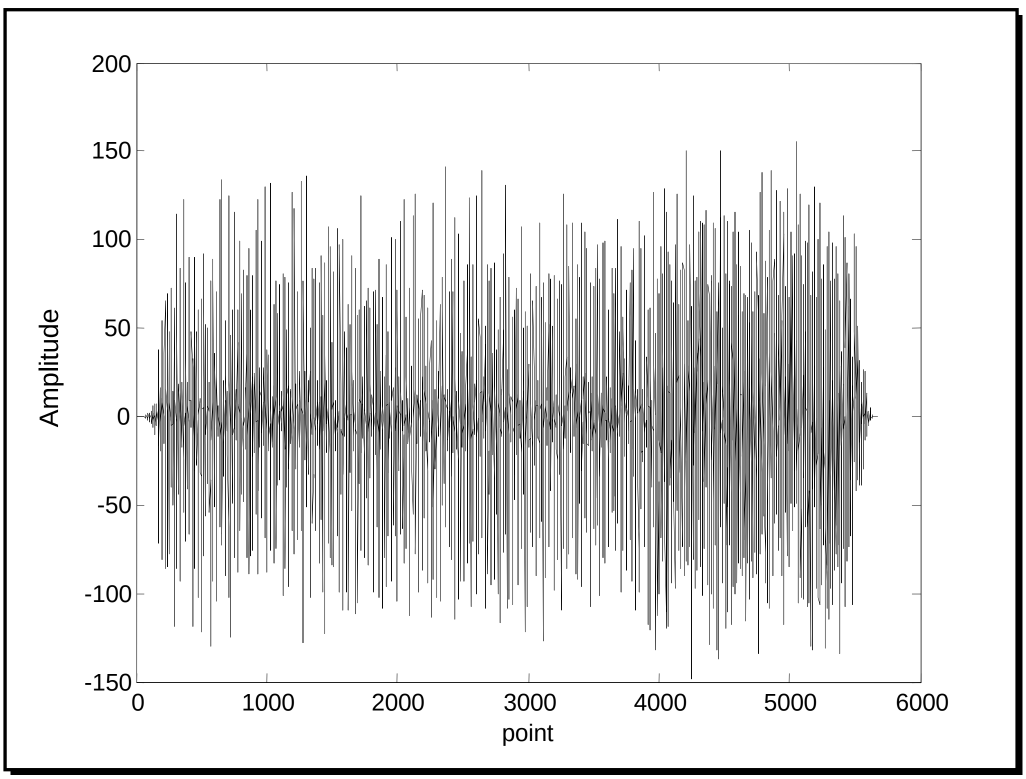

Figure 519.6B-13b. Sample decomposition at level cD8.

Figure 519.6B-14 displays the detail normalized cumulative coefficient distributions for the selected levels. These were determined by ordering the coefficients, computing the mean and standard deviation and then proceeding to subtract the mean and divide by the standard deviation.

For cD_i the ith wavelet decomposition level mcD_i and scD_i the mean and standard devation estimates for cD_i, define $cDN_i = \frac{\left(cD_i - mcD_i\right)}{scD_i}$

It is clear that the detail level coefficient distributions are different for the higher order detail coefficients. The lower order detail coefficients tend to have longer tails probably due to "edge effects" within the time trace itself.

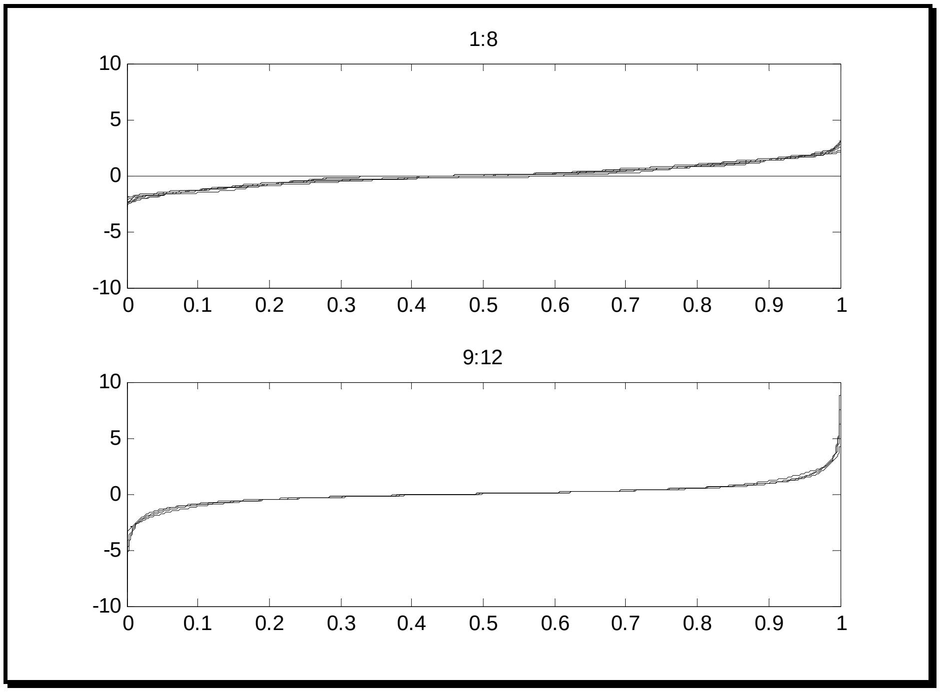

Figure 519.6B-14. Cumulative coefficient distributions for details Level 1:8 and 9:12.

These coefficient estimates are in effect mapped into a different set of coefficient estimates that are used in the wavelet reconstruction. There is no particular guidance on how to define the detail level coefficient mapping. Once the approximation and the new detail coefficients at all levels were generated by mapping, the inverse db20 wavelet transform was used to reconstruct the stochastically generated time traces. The stochastically generated time trace along with cross plot against the original time trace is provided in Figure 519.6B-15.

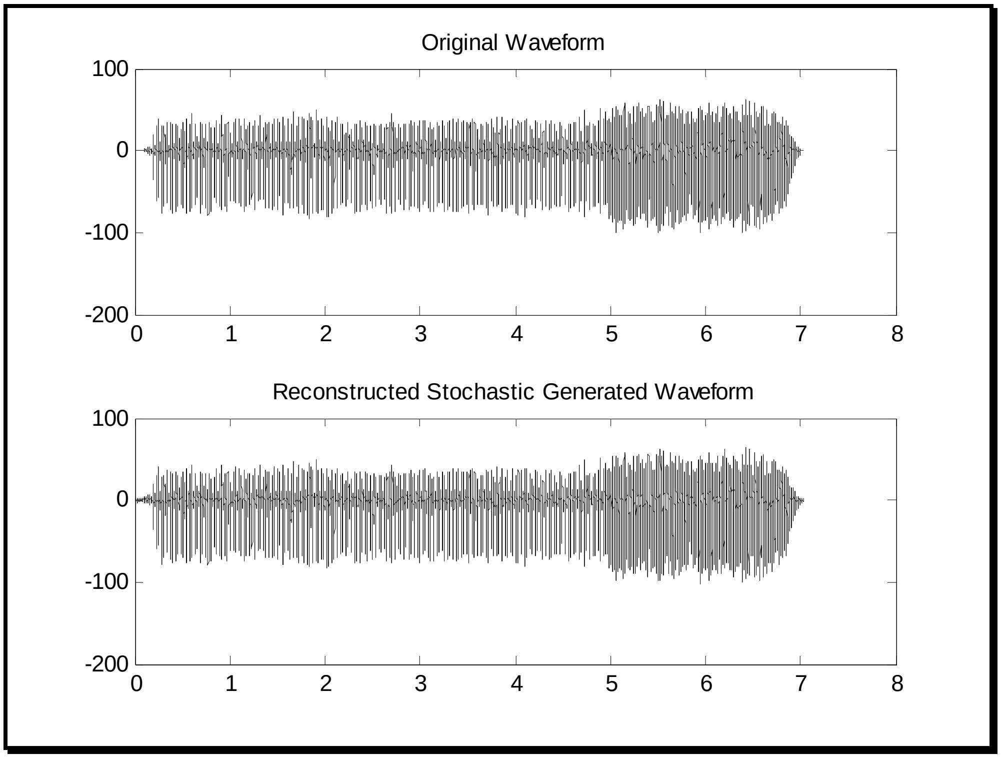

Figure 519.6B-15a. Stochastic generation - time trace with cross-plot.

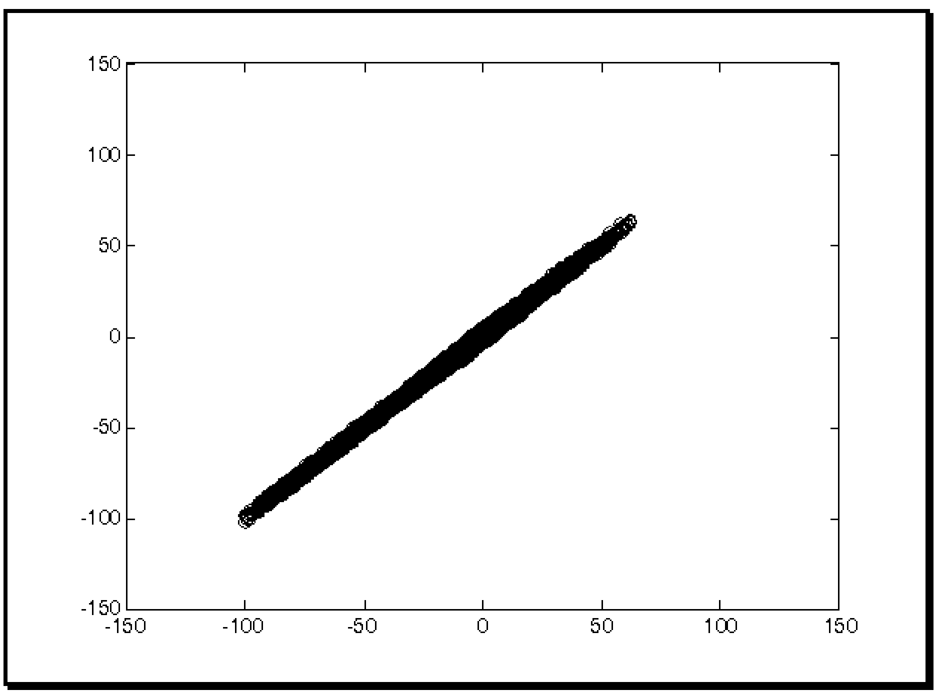

Figure 519.6B-15b. Cross-plot for stochastic generation - time trace with cross-plot.

The cross-plot in Figure 519.6B-16 can be contrasted with the cross-plots in paragraph 3. This concludes demonstration of the ***Time Trace*** algorithm.

5. CONCLUSION.

The “details” of a single measured time trace can be adjusted through the three step process of Wavelet (1) decompostion, (2) coefficient manipulation and (3) reconstruction. At this time the significance of this to the broader scheme of gunfire shock simulation is unknown. It is desirable to measure several statistically independent time traces, statistically combine them in some way and then through the statistics of combination extract (stochastically simulate) new time traces that represent the measurement set of time traces. For gunfire shock this has not been accomplished and remains a future area of research and development. This concludes Annex B.

METHOD 519.6 ANNEX C

GUIDELINES FOR PROCEDURE III – STOCHASTICALLY PREDICTED SHOCK INPUT FOR PRELIMINARY DESIGN BASED UPON PREDICTED SINE-ON-RANDOM SPECTRUM

1. SCOPE.

1.1 Purpose.

This Annex assumes that no field measured gunfire shock time trace information exists for the specified materiel/gun mechanical and geometrical configuration parameters. The Annex also assumes that the four component Sine-on-Random "gunfire vibration" prediction method in MIL-STD-810C through MIL-STD-810F provides accurate spectrum information related to specified materiel/gun mechanical, and geometrical configuration parameters. For preliminary mechanical/electronic design purposes, this Annex provides a basis for stochastically generating a materiel input time trace pulse ensemble. Once this ensemble has been generated, it may be used for preliminary design and potentially for preliminary test under TWR, but must be validated by measured data before final materiel design and subsequent qualification testing takes place. For preliminary test Procedure II is applied to the analytically generated pulse train. Information in this Annex is consistent with information in the previous two Annexes in that it assumes that materiel exposure to gunfire is of the form of a repetitive shock, and preliminary design considerations must take this into account. In particular it is recommended that preliminary mechanical and electronic design criteria be based upon either (1) a statistically generated envelope of pseudo-velocity shock response spectra (PV-SRS), or (2) a means by which repetitive shock time trace wave forms are used for evaluating stresses. No guidance is provided in this annex relative to preliminary design methodology.

1.2 Application.

For materiel mechanical and electronic design, in conjunction with exposure to gunfire shock, it is imperative that the designer has some basis for the design. In particular, it is important that the designer use design techniques well adapted to (1) time trace waveform description, (2) pseudo-velocity shock response spectra representation, or (3) description in the frequency domain using Fourier techniques, e.g., energy spectral density estimates. This Method is titled Gunfire Shock in order to emphasize response shock nature, i.e., short rise time, high positive/negative oscillatory character, periodic alternating time domain enhancement/attenuation, etc. The only widely known procedure for prediction of gunfire environment is the work performed in the mid 1970s by Sevy and Clark, and first proposed in MIL-STD-810C Method 519.2 (paragraph 6.1 reference b). Even though the technique set forth here is limited, it is believed that through simple modeling, it is possible to provide realistic time trace information having the same harmonic/random spectra predicted by the synthesis from Sevy and Clark's analysis. This time trace/SRS/Energy information can then be usefully applied for preliminary design purposes and perhaps preliminary testing. It is essential that in the overall materiel design and qualification process that measured gunfire shock time trace information be collected and compared with the predicted time trace information.

2. DEVELOPMENT.

2.1 Overview.

For establishing a basis for the development to follow Annex C from MIL-STD-810F, is provided in Annex D. Annex D provides the methodology by which input of gun/materiel mechanical and geometrical parameters results in a Sine-on-Random autospectral density output. Figure 519.6C-1 provides a schematic of the process. The term *"Gunfire Vibration"* is used here in place of *"Gunfire Shock"* used throughout this method, since the output of the prediction methodology can be considered a vibration (stationary random vibration with added sine components) performed on a laboratory exciter using vendor software and this is consistent with the terminology in Annex D.

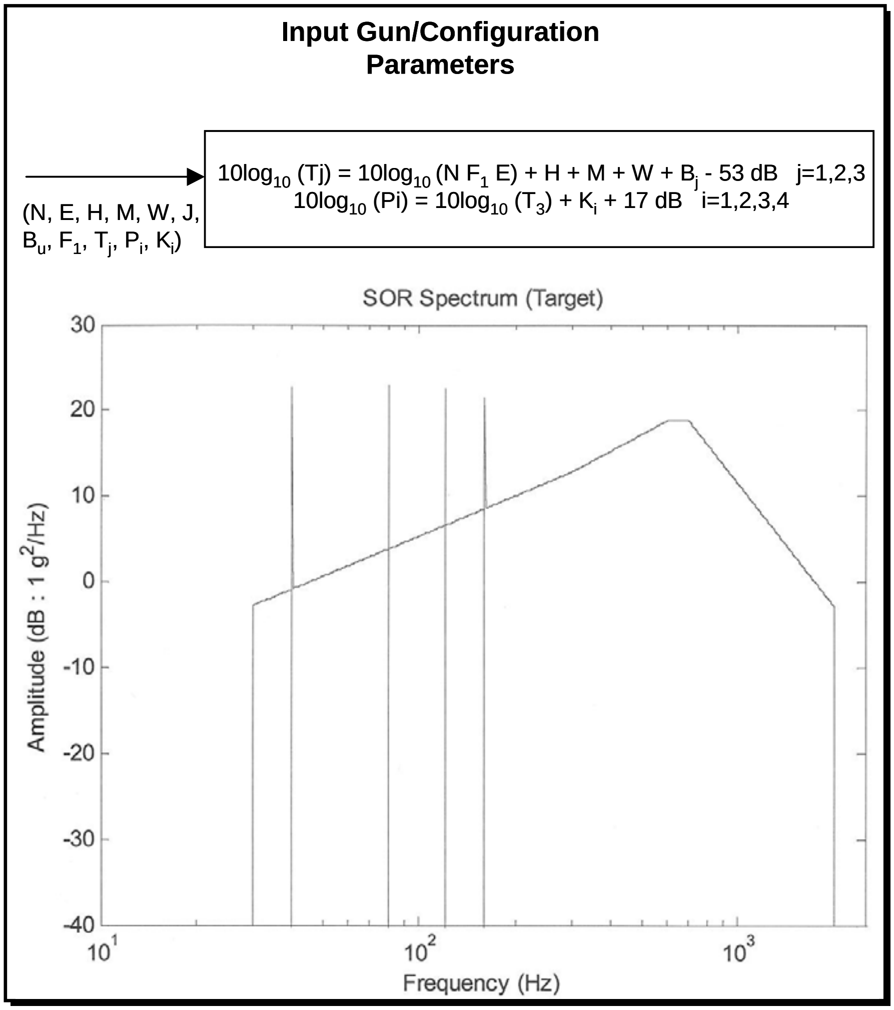

Figure 519.6C-1. Gunfire vibration prediction methodology.

The SOR spectra provided in Figure 519.6C-1 can be satisfied by two analytical models – an "additive model" and a "multiplicative model." Equation C-1 provides the two models.

$x_{SOR}(t) = m(t) + \mathrm{r}(t)$

and

$x_{RMP}(t) = r(t)\,\mathrm{m}(t)$ Equation (C-1)

$m(t)$ - pulse time varying mean component

(four harmonic components)

$r(t)$ – random component

It is assumed that $m(t)$ represents the deterministic sine component structure consisting of four harmonically related sine components and that $r(t)$ represents a zero mean stationary random time trace having the correct ASD as specified in Equation 519.6D-1. In paragraph 2.2 it will be demonstrated that the SOR spectrum in Figure 519.6C-1 can be satisfied by either model and that the "multiplicative model" tends to provide time traces that better represent repetitive shock produced by gunfire.

2.2 Illustration.

Following is an illustration of the generation of a RMP time trace and comparison with the SOR time trace. Details are provided in reference 6.1d., Figure 519.6B-2 provides a plot of an SOR spectrum that will be referred to as the

“Target Spectrum”. This spectrum was derived from some typical gun configuration parameters and the equations 519.6D-1 and 519.6D-2.

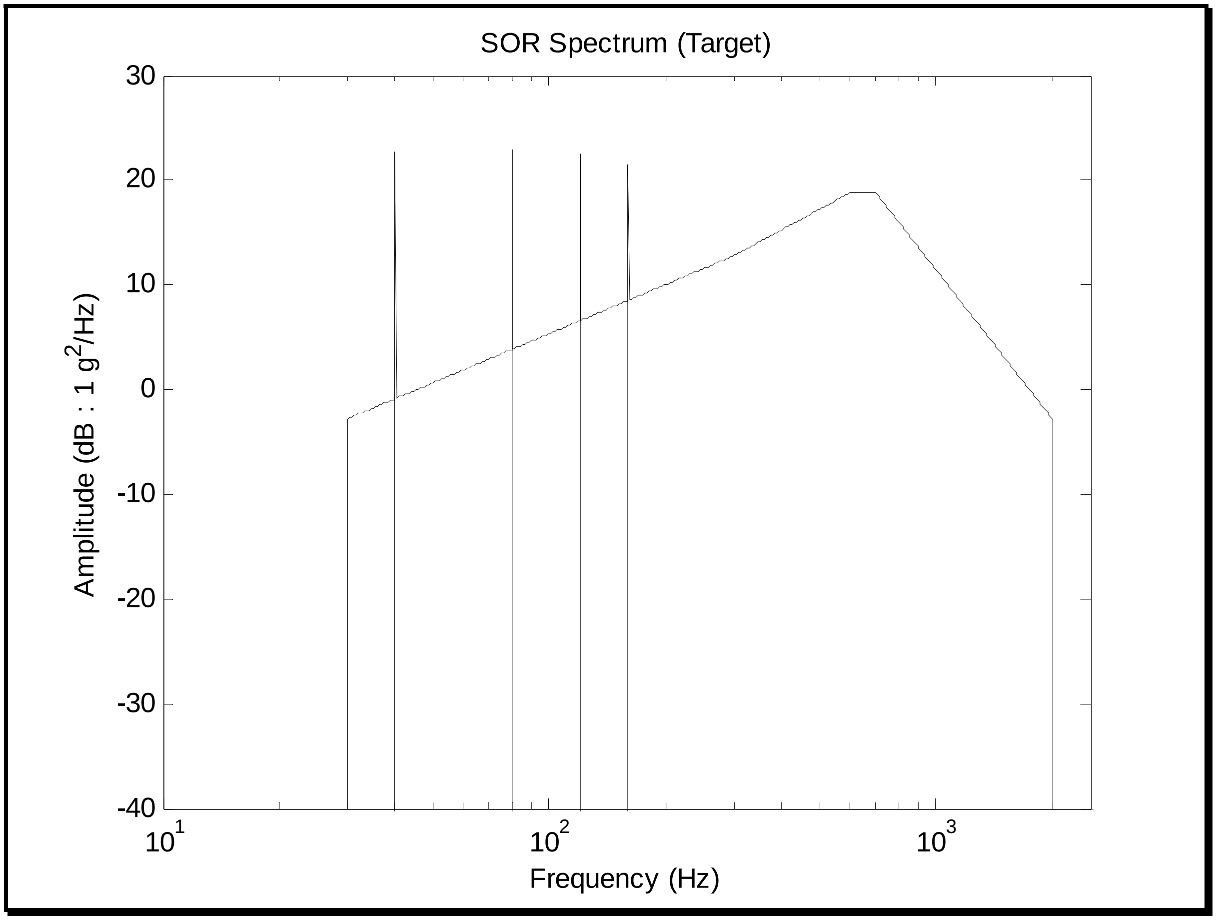

Figure 519.6C-2. Illustration SOR “Target Spectrum”.

The next three figures provide the basic components used to generate the time traces. Figure 519.6C-3 provides a plot of the deterministic component $m(t)$ that is common to both the SOR and RMP models. Figure 519.6B-4 displays the random components from SOR and RMP that produce ASD estimates comparable to the target ASD depicted in Figure 519.6B-2. The random components between SOR and RMP are dissimilar by virtue of the ways in which they were generated i.e., the models in equation C-1 were “fit” to the spectrum in Figure 519.6C-2. Finally, Figure 519.6C-5 displays single sample pulses from both models. Generally the rise time(s) from RMP are substantially greater than those from SOR.

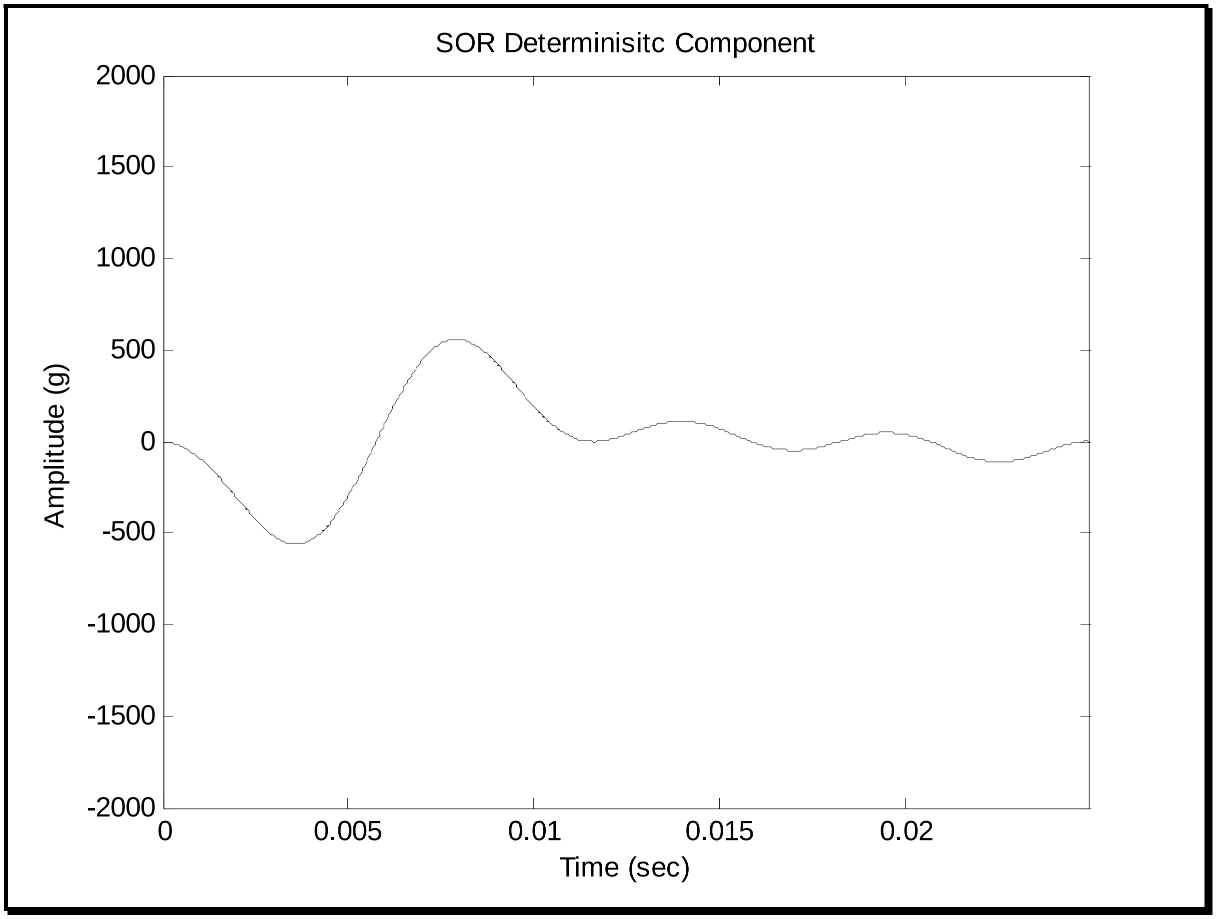

Figure 519.6C-3. SOR/RMP Model Deterministic Component $m(t)$ (Single Pulse).

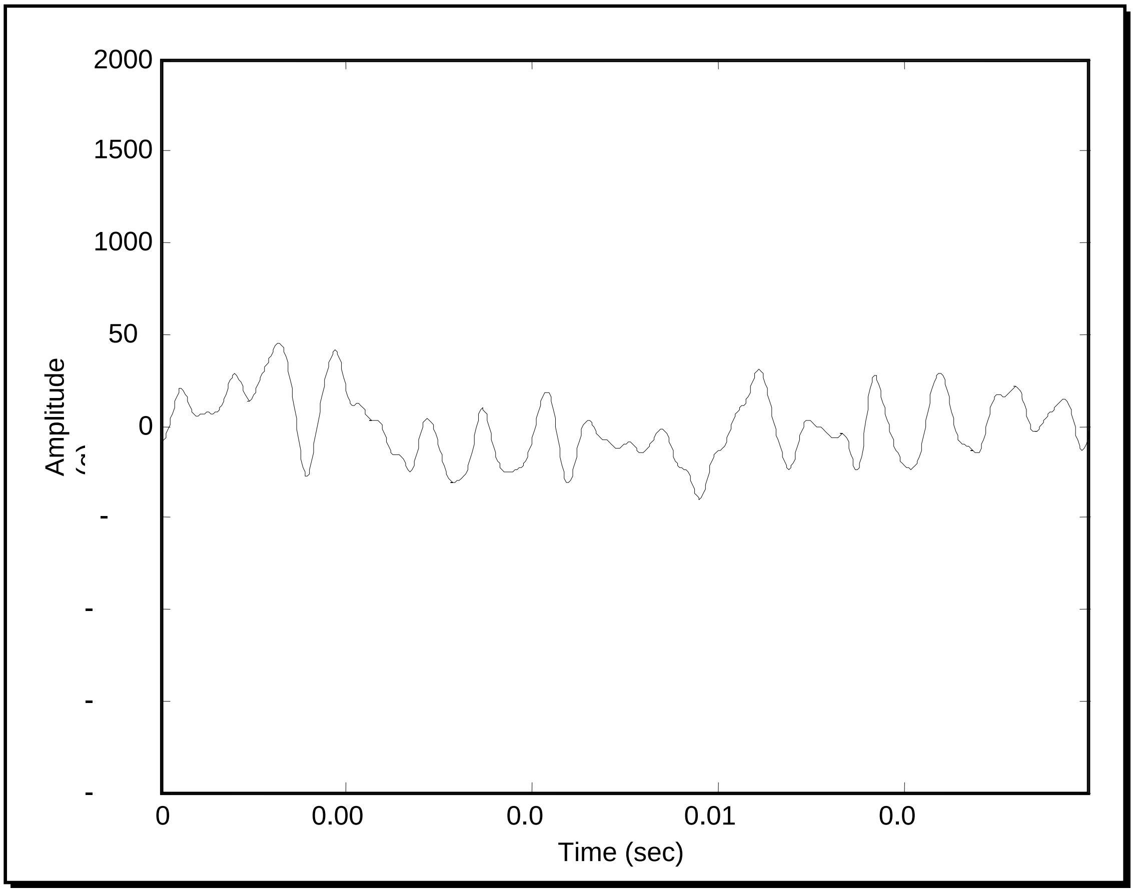

Figure 519.6C-4a. Sample Model SOR Random Components $r(t)$ (Single Pulse).

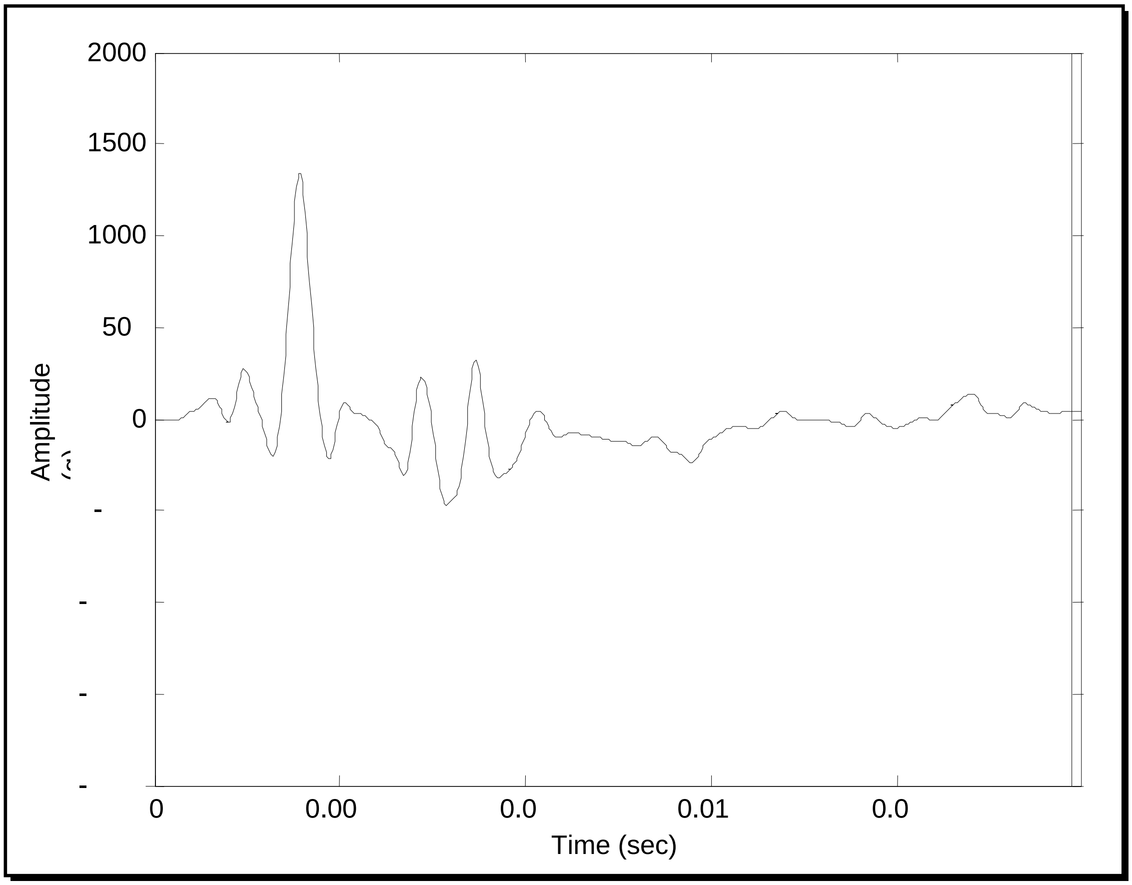

Figure 519.6C-4b. Sample RMP Model Random Components $r(t)$ (Single Pulse).

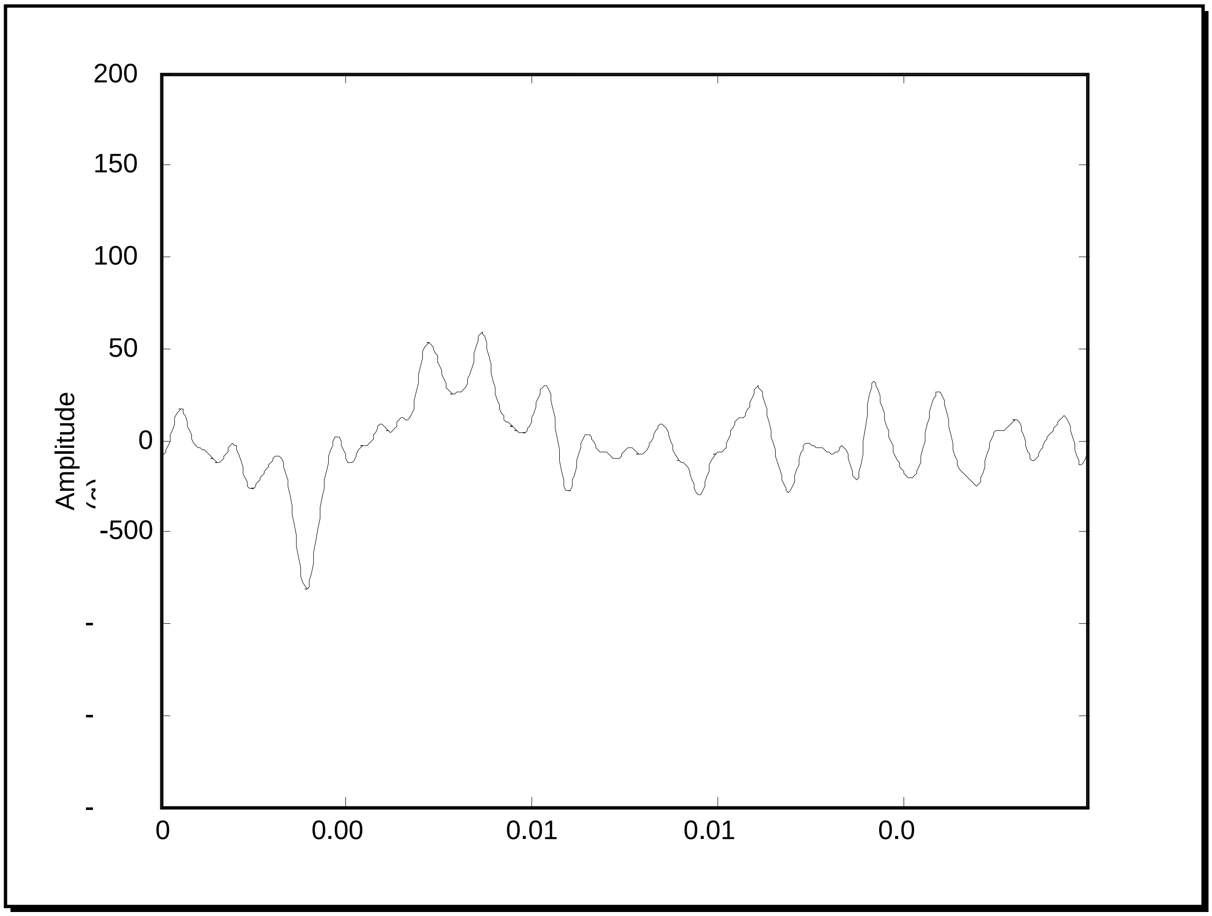

Figure 519.6C-5a. Sample model (single pulse) (SOR) ($x(t) = m(t) + r(t)$).

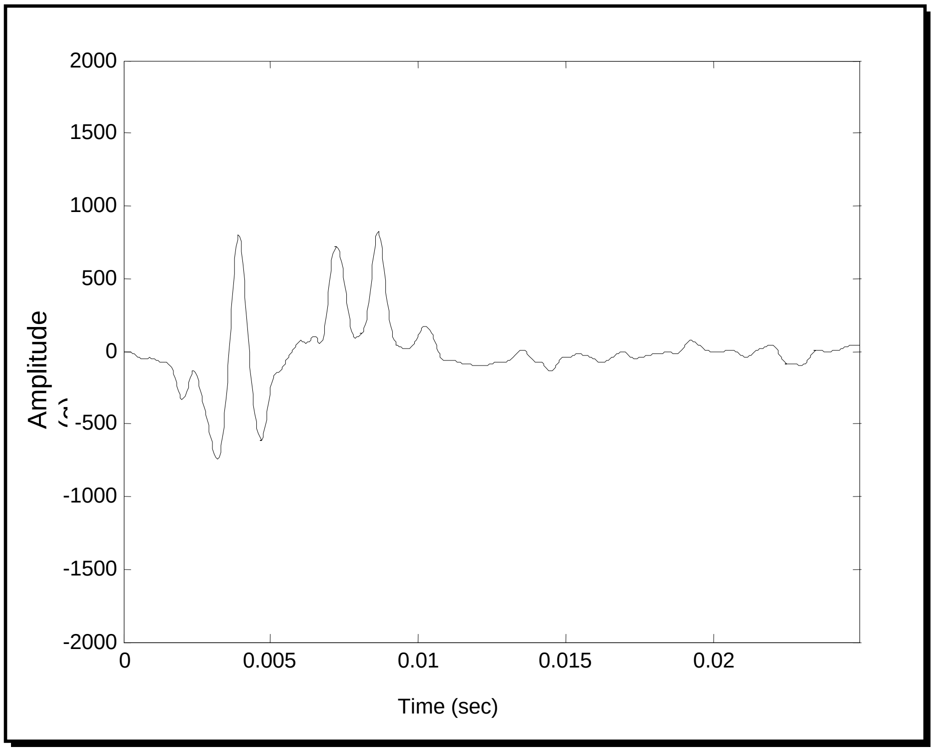

Figure 519.6C-5b. Sample model (single pulse) (RMP $x(t) = r(t)m(t)$).

Figure 519.6C-6 provides a high resolution display of three pulses randomly generated while Figure 519.6C-7 provides a similar plot for the entire generated time trace. It is quite obvious in appearance that RMP provides time traces with more distinct shock pulse characteristics.

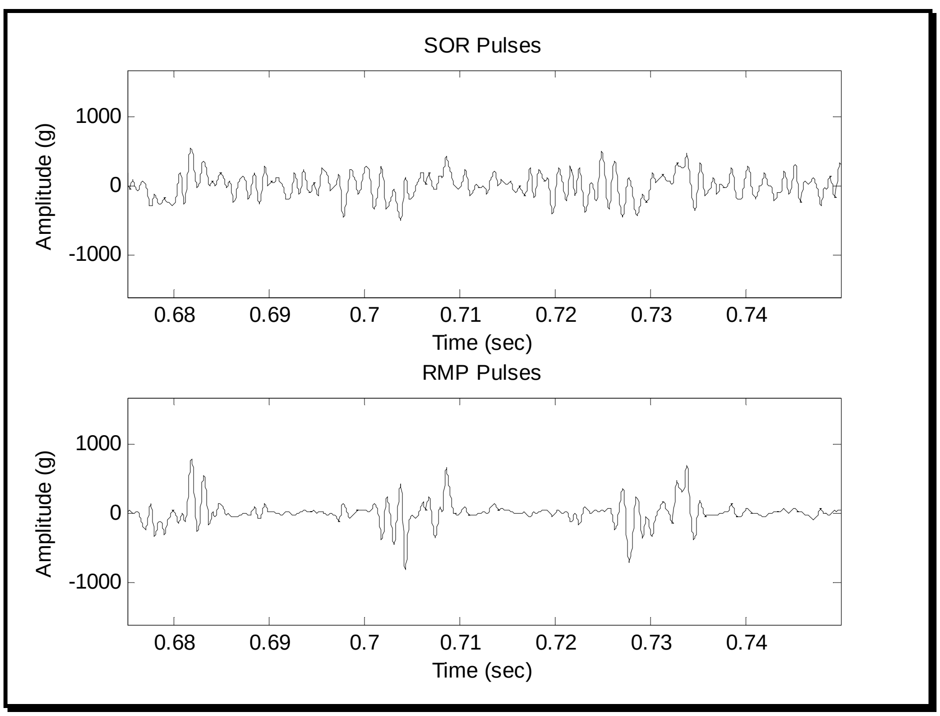

Figure 519.6C-6. High resolution sample model pulse train (three pulses).

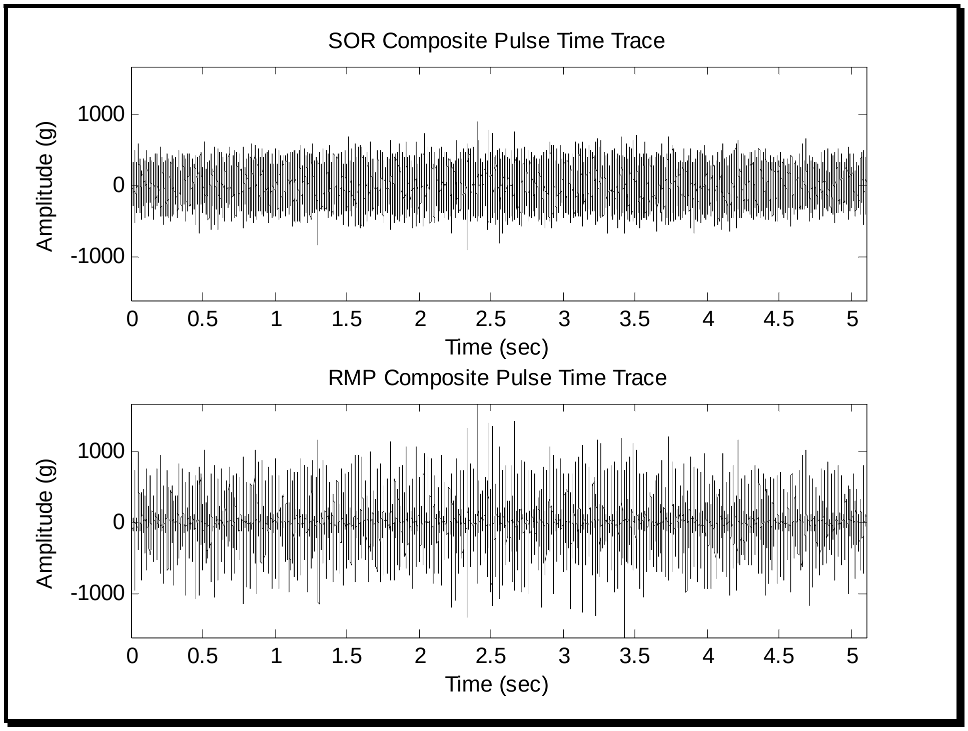

Figure 519.6C-7. Sample model pulse train.

Figure 519.6C-8 verifies that the time traces approximate the target ASD provided in Figure 519.6B-2.

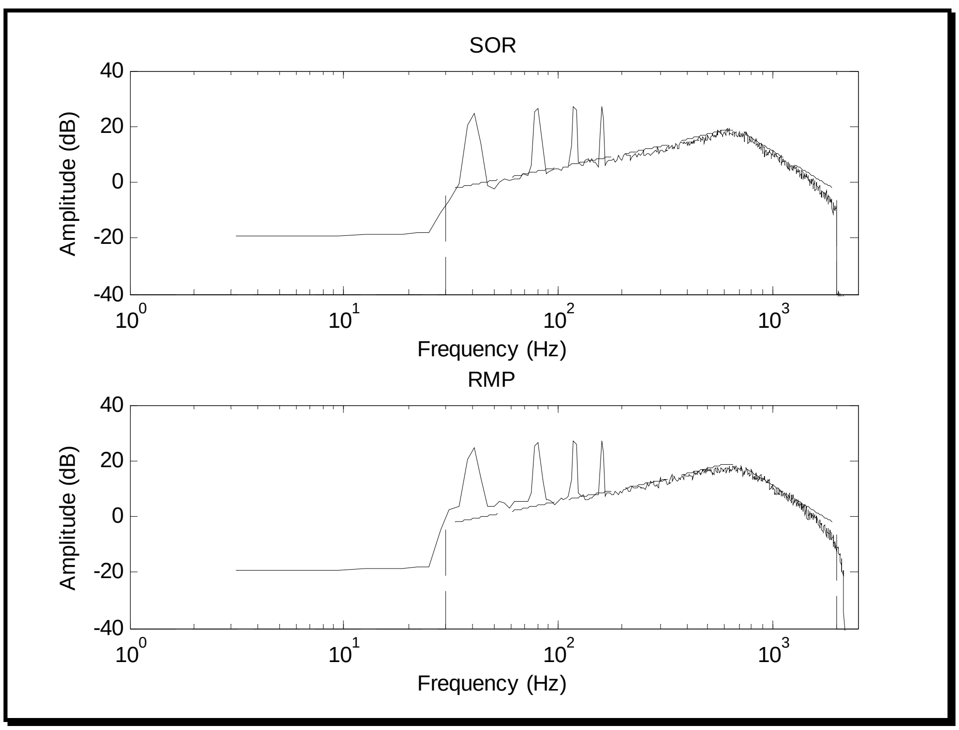

Figure 519.6C-8. ASD model verification.

Figure 519.6C-9 provides ensemble estimates of the deterministic component, the standard deviation of the random component and the time-varying root-mean-square. Examining the figures it is clear that (1) the deterministic components for SOR and RMP are very similar, (2) the standard deviation of the RMP ensemble is truly time varying and (3) any time-varying character in SOR root-mean-square levels is a product of the time-varying deterministic component.

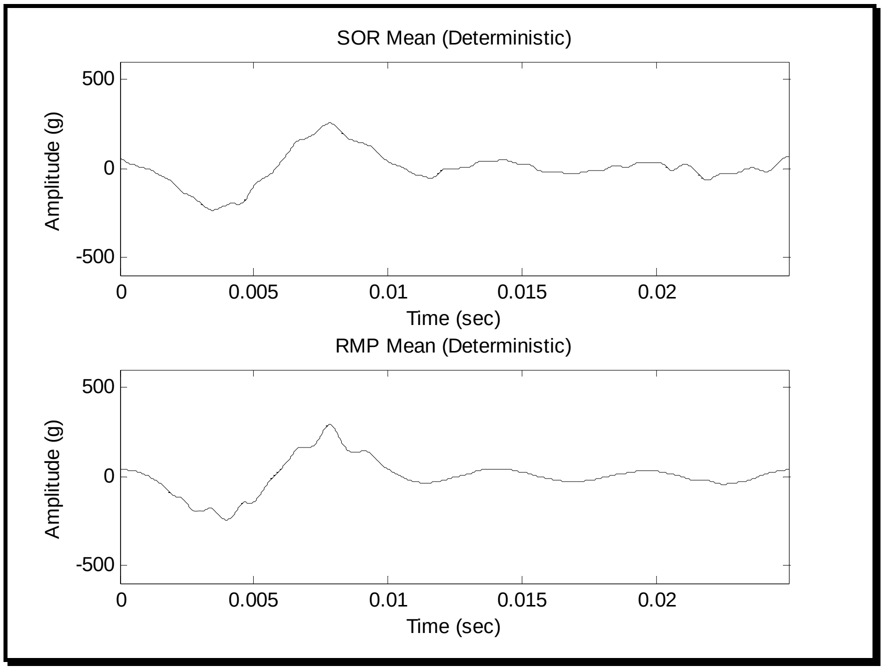

Figure 519.6C-9a. Pulse ensemble statistics - deterministic component $m(t)$.

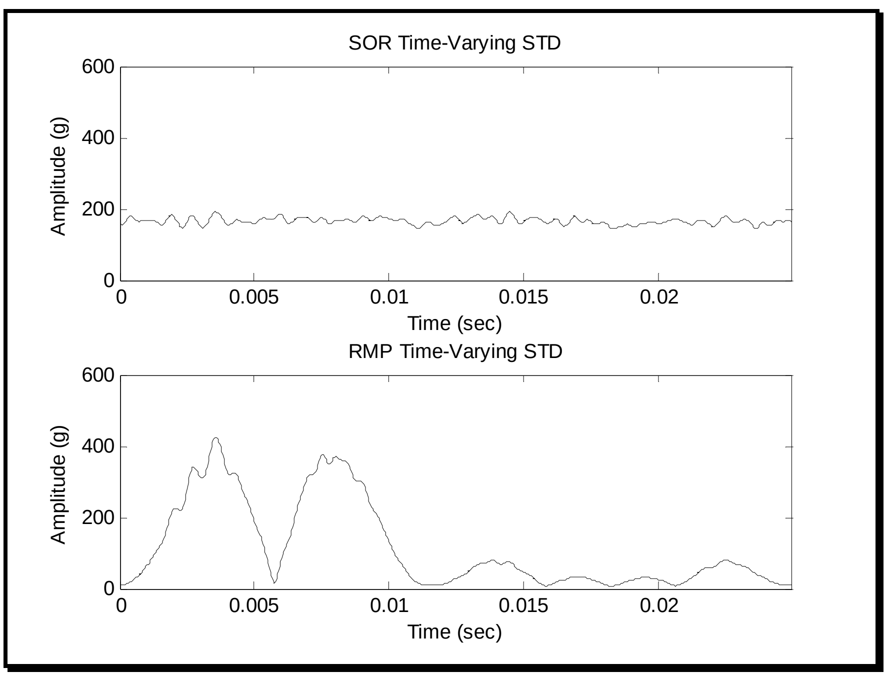

Figure 519.6C-9b. Pulse ensemble statistics - standard deviation of random component $r(t)$.

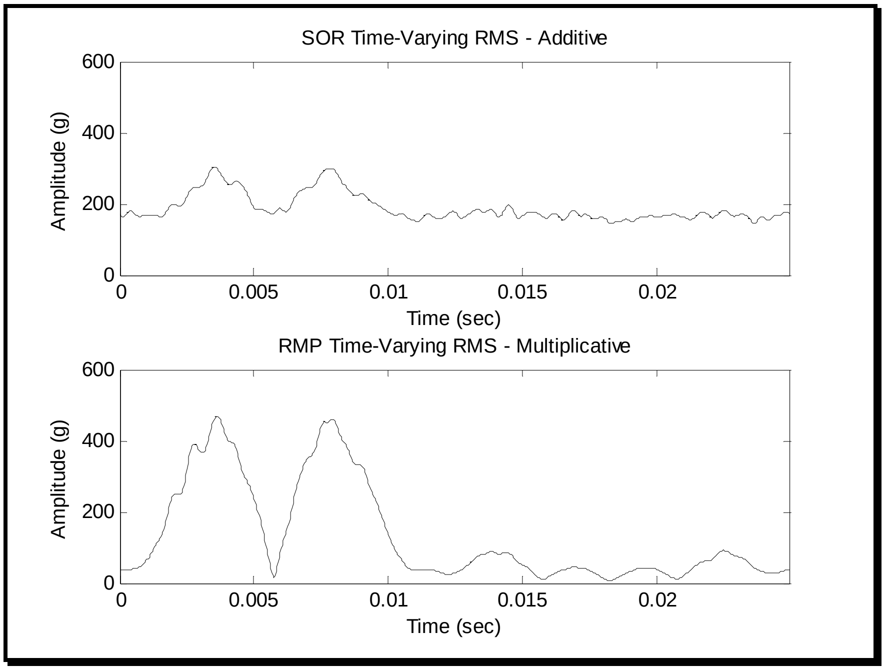

Figure 519.6C-9c. Pulse ensemble statistics - root-mean-square $\sqrt{\left(m(t)+r(t)\right)^2}$ **.**

Figure 519.6C-10 provides ensemble Pseudo-Velocity SRS estimates for the ensemble and for the entire time trace. The shock characteristics of RMP are apparent from these figures.

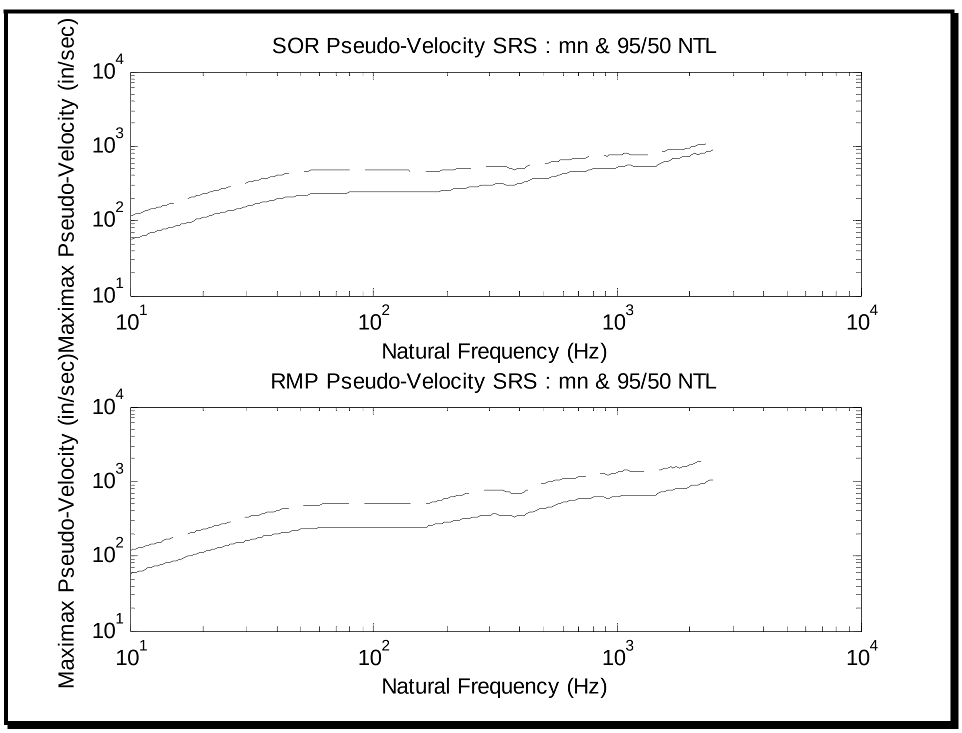

Figure 519.6C-10a. Pseudo-velocity shock response spectra for pulse ensemble with 95/50 NTL

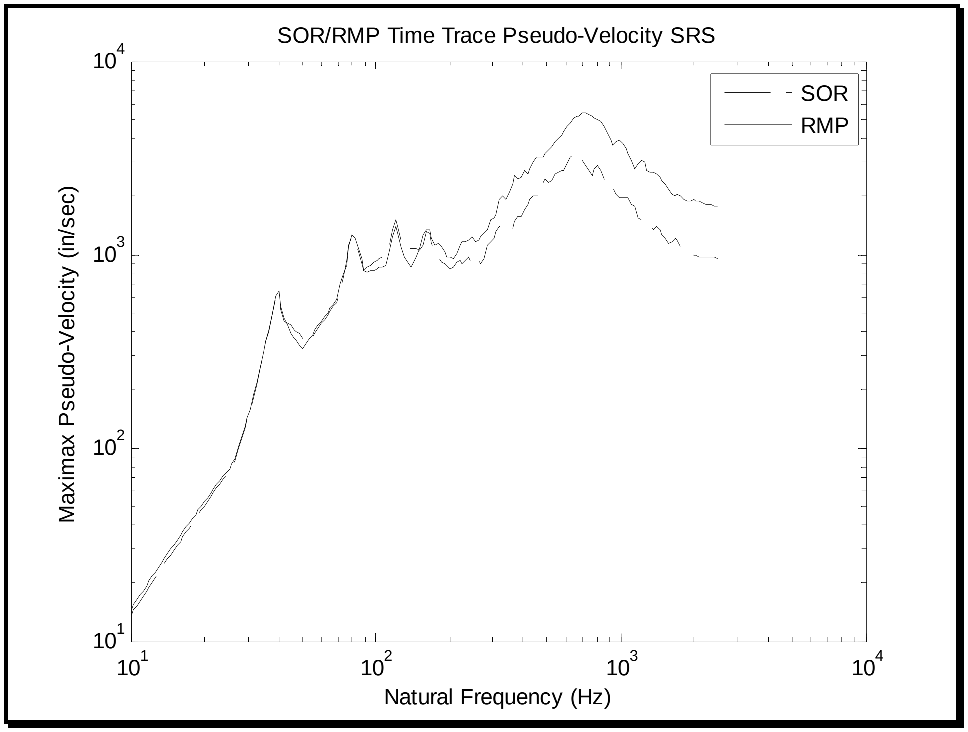

Figure 519.6C-10b. Pseudo-velocity shock response spectra for time trace.

Other subtleties in the differences between time trace generations are provided in Reference 6.1d including a discussion of the cyclostationary properties.

3. CONCULSIONS.

For materiel preliminary design considerations it is recommended for a conservative estimate of the gunfire environment that RMP be implemented to provide time traces that are at least in appearance representative of measured gunfire response. These time traces generated under RMP may be decomposed into an ensemble of pulses or taken as an entire time trace. Design considerations associated with a repetitive shock pulse must be used for preliminary design.

METHOD 519.6 ANNEX D

SINE-ON-RANDOM SPECTRUM PREDICTION METHODOLOGY FOR PRELIMINARY MATERIEL DESIGN

Note: This Annex was taken directly from MIL-STD-810F and is in support of the information contained in Annex C. As such, this Annex has not been edited to make it totally compliant with MIL-STD-810G. References and procedure information refer back to MIL-STD-810F.

1. SCOPE.

1.1 Purpose.

This Annex provides the option of using predicted gunfire vibration data (when measured data is not available), to ensure that materiel mounted in an aircraft with onboard guns can withstand the vibration 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 519.4, Gunfire Vibration, Aircraft, in MIL-STD-810E 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 is 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 sine-on-random or narrowband random-on-random for cases in which measured data displays 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 severity's developed using the information in this Annex with the severity's 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 514.6).

This technique is based upon obtaining the predicted sine-on-random 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 sine-on-random 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 a. of paragraph 2.5. with some additional guidance. Mention of the pulse method in paragraph I-4.4.1 of paragraph 6.1, reference c, has not been included, but is covered in paragraph 6.1, reference b. that provides insight into the use of the pulse method in conjunction with a predictive rationale. Procedure IV differs from the other three 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 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 519.6D-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 gunfiring rate. The specific values for each of the parameters shown on Figure 519.6D-1 can be determined from Table 519.6D-I, Table 519.6D-II, Table 519.6D-III, and Figures 519.6-2 through 8. The suggested generalized parametric equation for the three levels of broadband random vibration, T_j, defining the spectrum on Figure 519.6D-1 is given in dB for g^2/Hz (reference to 1 g^2/Hz) as

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

where the parameters are defined in Table 519.6D-I. The suggested generalized parametric equation for the four levels of single frequency (sine) vibration defining the spectrum on Figure 519.6D-1 is given in dB for g^2/Hz (reference to 1 g^2/Hz) as

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

where the parameters are defined in Table 519.6D-I.

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

Vector distance (D). The vector distance from the muzzle of the gun to the mean distance between materiel support points as shown on Figure 519.6D-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 519.6D-3. Figure 519.6D-7 and Figure 519.6D-8 provide for spectra reduction factors related to D for the random spectra and the discrete frequency spectra, respectively.

Gun standoff distance (h). The distance normal to the aircraft's surface as shown on Figure 519.6D-4.

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 (see Figure 519.6D-2). Figure 519.6D-6 provides spectra reduction factors related to R_s.

Gun caliber ©. Table 519.6D-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:

$$BW_{3dB} = (\pi\, F^{1/2})/4 \qquad \text{Equation (D-3)}$$

for

BW_{3dB} = the bandwidth at a level 3dB (factor of 2) below the peak ASD level

F = the fundamental frequency or one of the harmonics F_1, F_2, F_3, or F_4

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, 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 utilization 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 519.6D-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.
Gunfire materiel response vibration is 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. Virtually all modern vibration control system software packages contain a provision for performing a gunfire vibration test based on this form of predicted sine-on-random spectra. The details of these software packages are in general proprietary, but the practitioner is expected to have a clear understanding of the capabilities and limitations of the software. On occasion it has been noted that the dynamic range required to produce and control a specified gunfire spectrum is beyond the ability of some available vibration controllers. A way of solving this problem is to enter into the vibration controller the desired broadband random spectrum with its strong vibration peaks. At those frequencies that have the intense vibration peaks, sine waves may be electronically added to the input of the vibration exciter amplifier. Ensure the amplitude of these sine waves is such that the vibration levels produced at those frequencies is slightly less than the desired spectrum level. The vibration controller can make the final adjustment to achieve the needed test level. It is important to note that P_i is in terms of g^2/Hz and not g's, (care must be exercised in specifying the amplitude of the sine waves in g's or equivalently input voltage corresponding to a g level). This means of environment replication allows the gunfire vibration test to be done closed loop with commonly available laboratory test equipment and control system software.

2.5 Reference/Related Documents.
See paragraph 6.1 in the front of this Method.

3. RECOMMENDED PROCEDURES.

3.1 Recommended Procedure.
For aircraft vibration for materiel mounted in the aircraft with no available measured data, use this procedure with the prediction methodology. For cases in which available measured data demonstrate only broadband high level vibration with no "discrete" components, use this procedure.

3.2 Uncertainty Factors.
This procedure includes 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 unconservative.

TABLE 519.6D-I. Suggested generalized parametric equations for gunfire-induced vibration.

$10 \log_{10} (T_j) = 10 \log_{10} (NF_1E) + H + M + W + J + B_j - 53$ dB	
$10 \log_{10} (P_i) = 10 \log_{10} (T_3) + K_i + 17$ 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 519.6D-III).
H	Effect of gun standoff distance, h (see Figure 519.6D-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 519.6D-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 519.6D-2 and 519.6D-6).
B_j	Effect of vector distance from the gun muzzle to the materiel location (see Figure 519.6D-7).
F_1	Gunfiring rate where F_1 = fundamental frequency from Table 519.6D-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 519.6D-8).

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

TABLE 519.6D-II. Typical gun configurations associated with aircraft classes.

Aircraft/Pod	Gun (Quantity)	Location	Firing Rate Rnds/Min	Firing Rate Rnds/Sec	Capacity
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 519.6D-III. Gun specifications.

Gun	Gun Caliber, c		Blast Energy, E (J)*
	mm	in	
GAU-2B/A	7.62	.30	6,700
GAU-4/A	20	.79	74,600
GAU-8/A	30	1.18	307,500
AN-M3	12.7	.50	26,000
M3	20	.79	83,000
M24	20	.79	80,500
M39	20	.79	74,600
M61A1	20	.79	74,600
MK11	20	.79	86,500
MK12	20	.79	86,500

* joules (J) x 0.7376 = foot-pounds

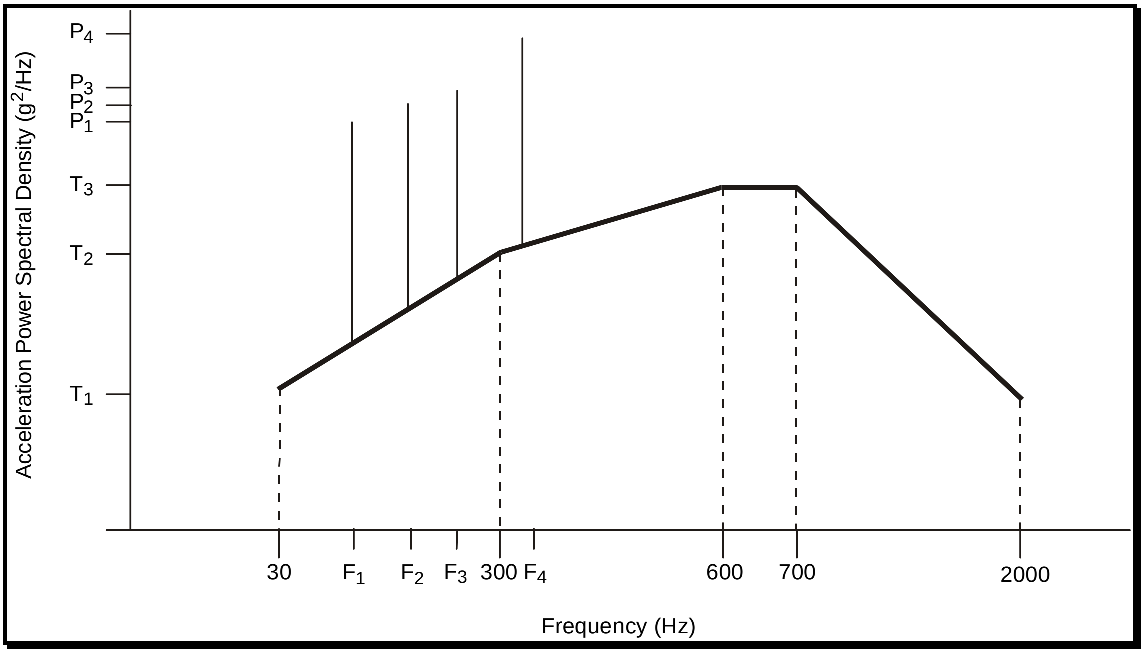

FIGURE 519.6D-1. Generalized gunfire induced vibration spectrum shape.

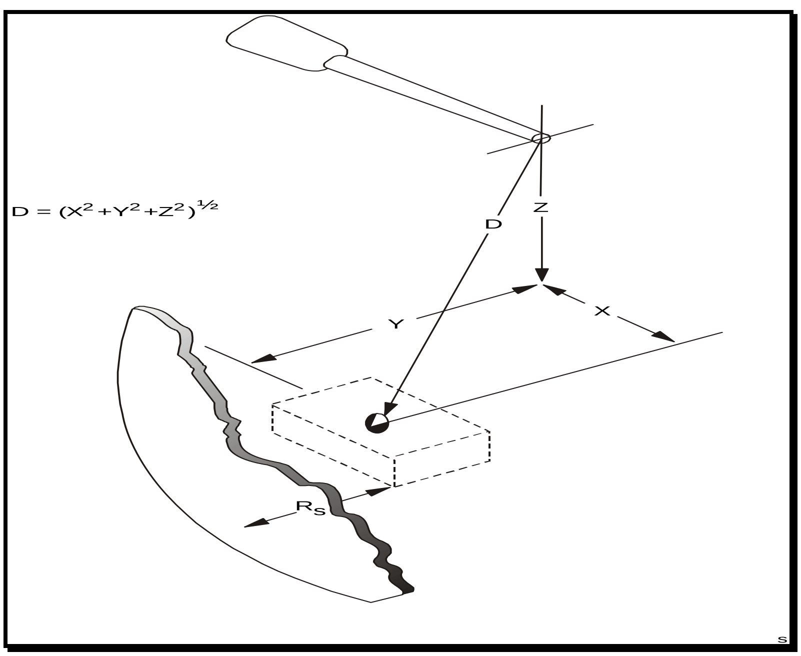

FIGURE 519.6D-2. The distance parameter (D) and the depth parameter (R_s)

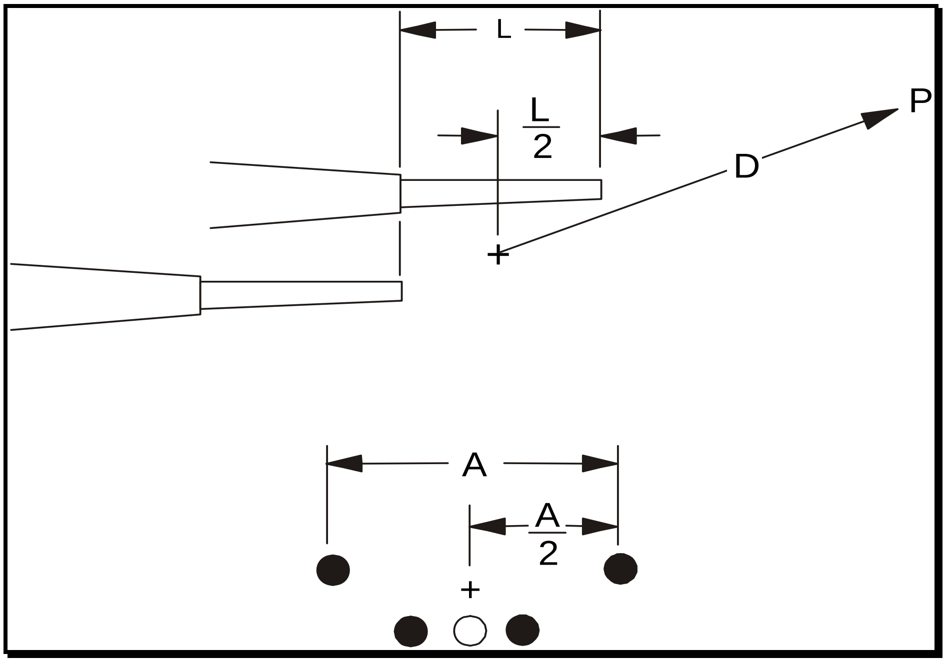

FIGURE 519.6D-3. Multiple guns, closely grouped.

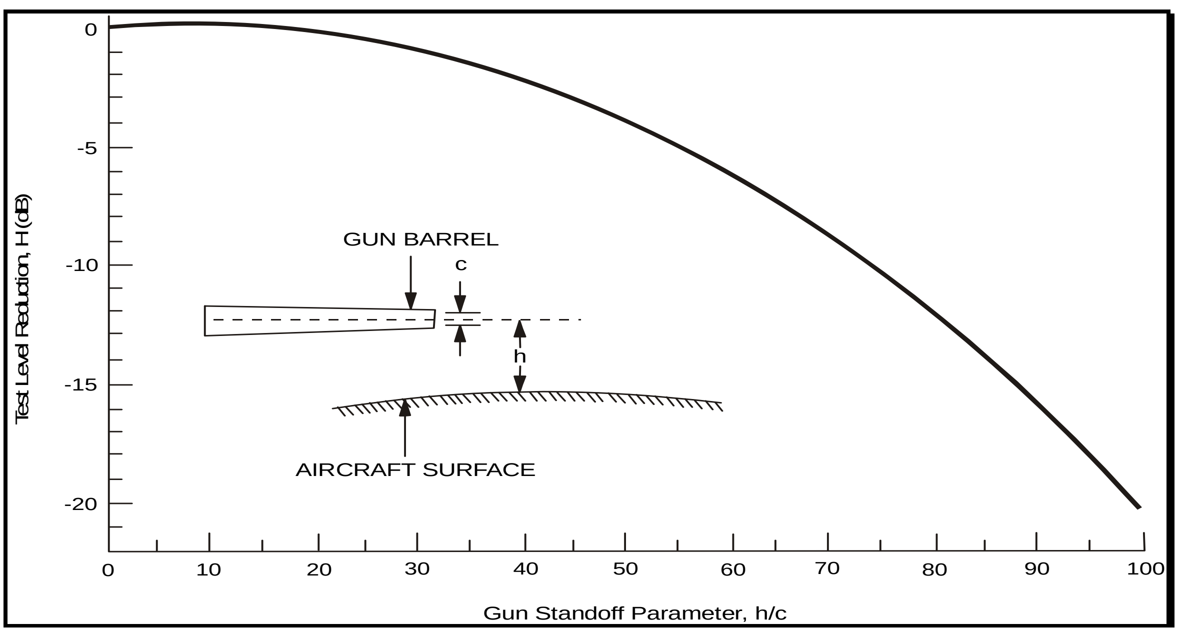

FIGURE 519.6D-4. Test level reduction due to gun standoff parameter.

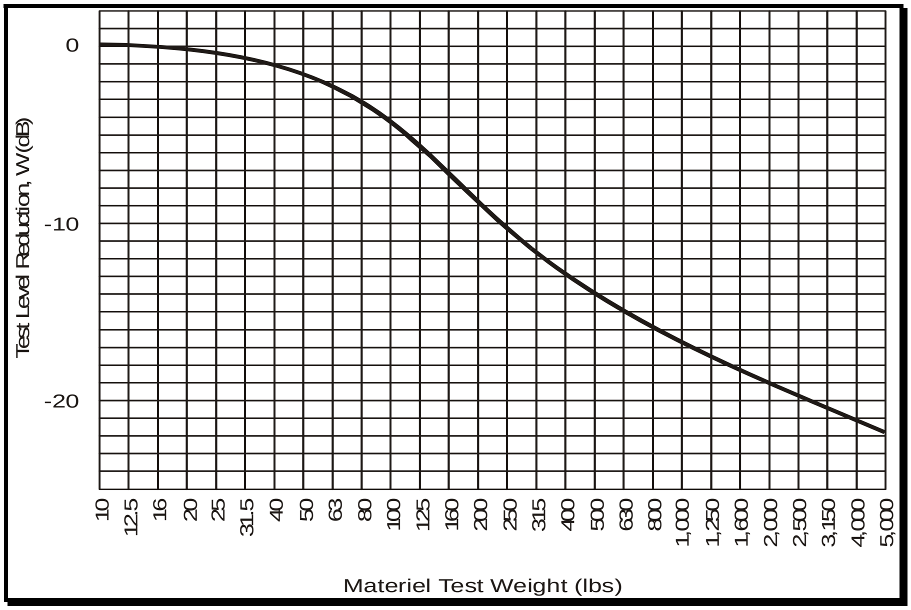

FIGURE 519.6D-5. Test level reduction due to materiel mass loading.

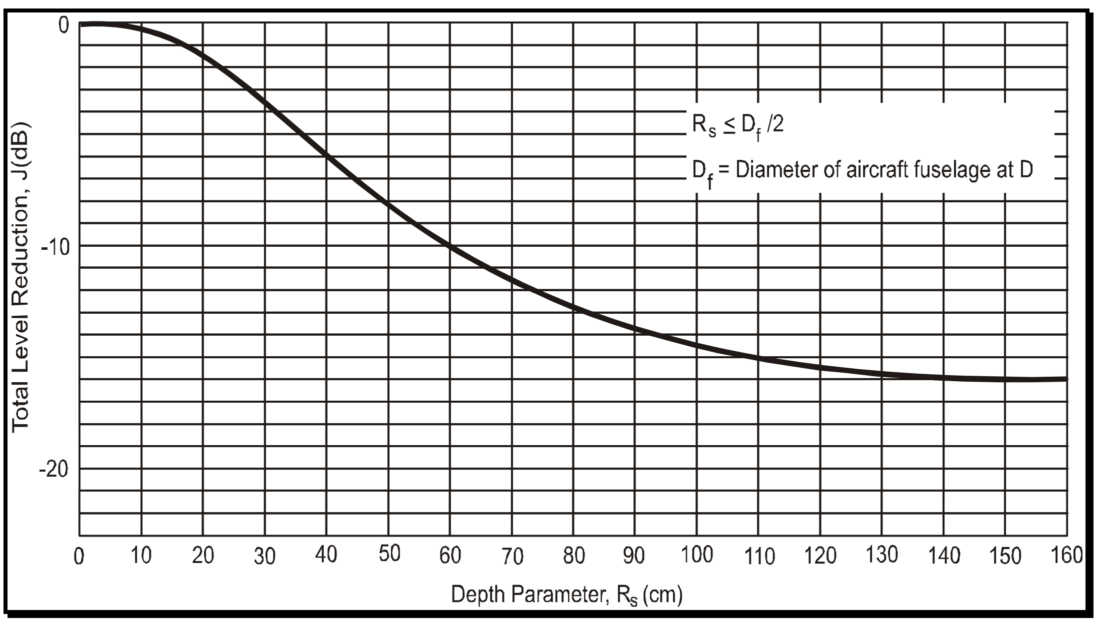

FIGURE 519.6D-6. Test level reduction due to depth parameter.

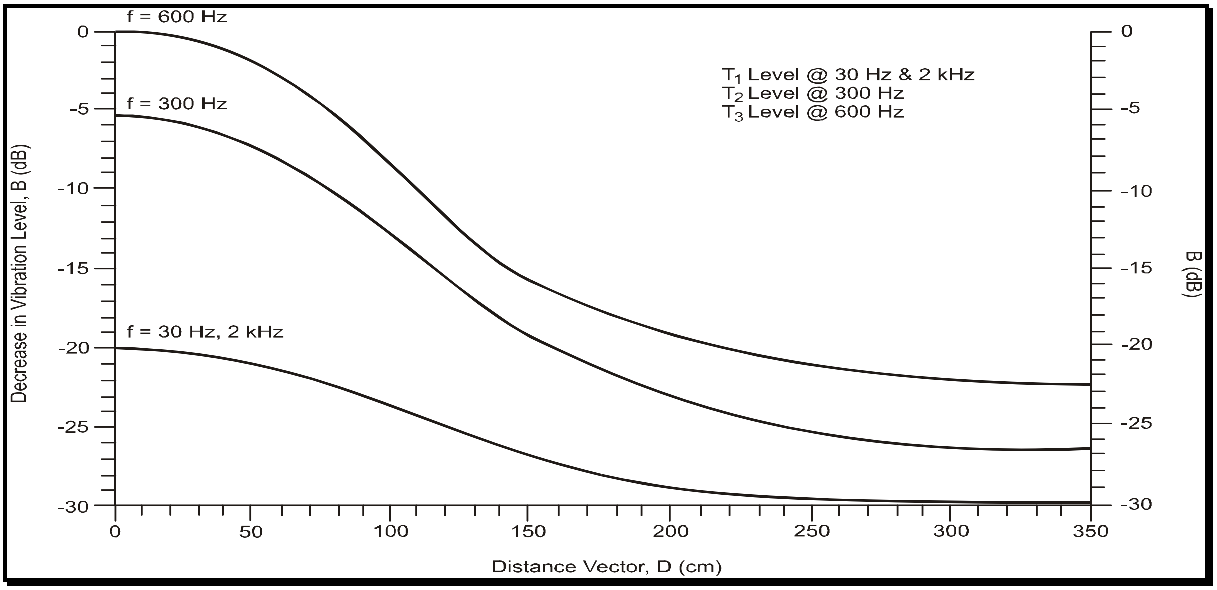

FIGURE 519.6D-7. Decrease in vibration level with vector distance from gun muzzle.

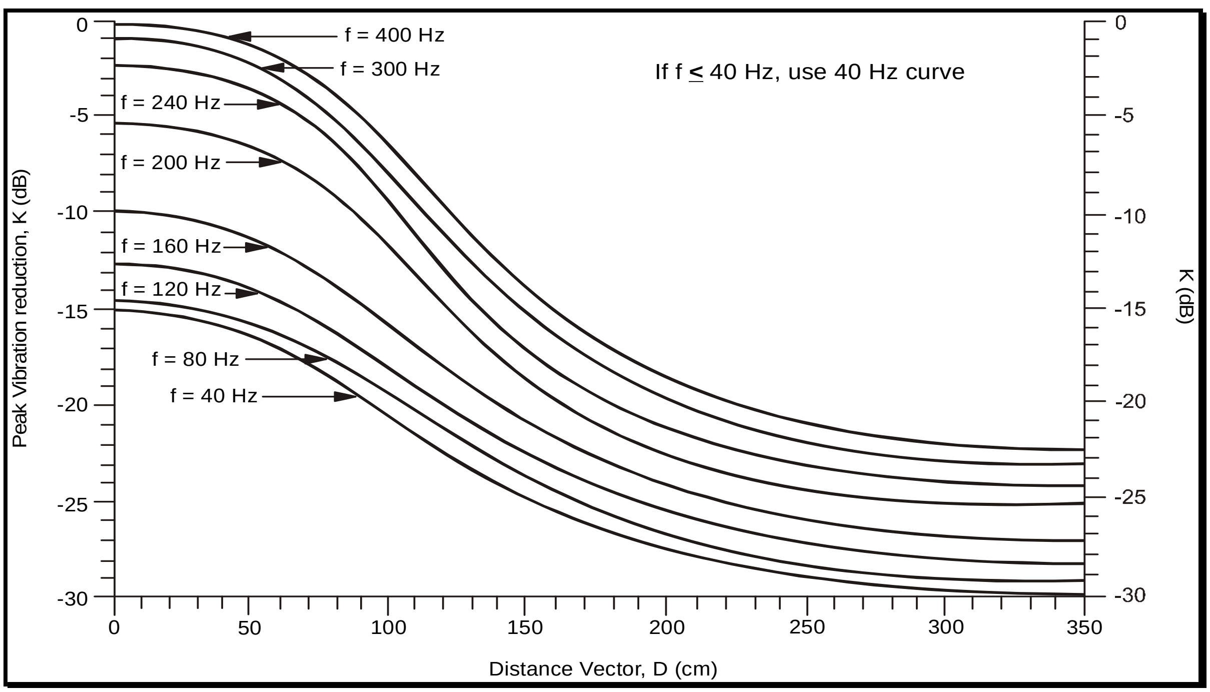

FIGURE 519.6D-8. Gunfire peak vibration reduction with distance.

METHOD 519.6 ANNEX E

GUIDELINES FOR GUNFIRE SHOCK TEST SCALING

1. BASIC CONSIDERATIONS FOR SCALING.

1.1 Background.

For purposes of discussion a ***"characteristic measured environment"*** is defined to be an environment that can be repeated an unlimited number of times providing ***"statistically consistent"*** sample functions for an underlying unknown random process. The phrase ***"statistically consistent"*** means that as the number of sample functions accumulates, it is possible to compute a mean sample function (random process deterministic component), and a random process random component consisting of an ensemble of sample function members obtained by subtracting the deterministic component from each sample function. Moreover, it is assumed that the error in estimation of the random process deterministic component approaches zero as the number of sample functions increases. The following note provides some background on these definitions.

Note:

When more than one measurement time trace is available from a given physical phenomena a decision needs to be made as to:

a. the measured time traces come from the same unknown underlying random process (they are "close enough" to be considered sample functions from a single random process). In this case the time traces may be pooled to provide a single deterministic component (time-varying mean), and a random component defined by zero mean and a time-varying standard deviation.

b. the measured time traces come from possibly more than one underlying random process (they are not "close enough" to be pooled into a single time trace representing the deterministic part of the unknown underlying random process). In this case, the time traces may be viewed correctly as coming from more than one underlying random processes that are related but stochastic processing and testing proceeds individually on each time trace.

Generally, pooling of information is risky because of the possibility of distorting the deterministic estimate of the random process. In these cases, there must be substantial reliance upon pulse ensemble correlation information between the measurement time traces.

To better understand these two cases the following aside is provided that gives insight into overall scaling issues. The situation is analogous to One-Way Analysis of Variance whereby intrinsic error is termed the ***"error within,"*** *and the very important extrinsic error is termed* ***"error among."*** *Simulation of a single measured time trace only contains knowledge of the "error within," and the unknown random process "error among" is the unknown random process variance. Pooling of information at distinctly different levels (from potentially different random processes) will inflate the extrinsic error to the point that it cannot be used for stochastic simulation of the random process and, more importantly, result in a deterministic part that is misleading.*

Generally, for more than one measured time trace and the requirement for a stochastic laboratory test, stochastically generating each measured time trace individually and applying each in proportion to the definition in the LCEP is considered optimal over and above time trace pooling.

An "optimum" Time Waveform Replication (TWR) laboratory test scenario can be defined by testing to a concatenation of a large number of sample functions over one or more materiel lifetimes as defined in the LCEP. Sub-optimum TWR laboratory testing would be defined in one of four alternative ways:

(1) repeated testing to a single selected sample function

(2) decomposition of one or more sample functions to form an ensemble of time traces that estimate the deterministic component and random component of the unknown underlying random process and

 (a) simulating the ensemble or sample function time trace as in Procedure II (no scaling)

 (b) scaling the deterministic and random components independently and

 (c) scaling the overall time trace by a single factor

Against these definitions and test scenarios the following discussion will be useful in indicating the pitfalls of time trace scaling.

Consistent with the discussion and recommendations provided in Method 525 for Time Waveform Replication, Method 519.6, considers measured time trace information to have a time-varying probability density structure with an ensemble representation. For measured gunfire shock time trace information, this is reasonable since generally the highly repetitive nature of gunfire at the firing rate of the gun lends itself to decomposing the time trace into an ensemble of individual pulses. Computation of the statistics of this ensemble at each time increment, t, usually leads to a nonzero deterministic component, $\mu(t)$, and a random component with a time-varying standard deviation, i.e., $\sigma(t)$. If for times t_1 and t_2 for $t_1 \neq t_2$ then $\mu(t_1) \neq \mu(t_2)$ or $\sigma(t_1) \neq \sigma(t_2)$ or both, then the probability structure of the ensemble is not stationary. It is a basic premise of Method 525 and Method 519.6 that any scaling of basic measured time trace information must consider scaling of the deterministic and random components separately. From basic physical considerations for gunfire, if the materiel is moved close to the gun mechanism, it is expected that the deterministic component will increase in level, whereas there is no basis for assuming that the random component will increase in level to the same proportion. If the materiel is moved further from the gun mechanism, the opposite effect should take place. Scaling that scales the deterministic and random components separately seems consistent with physical considerations, and a probabilistic approach to random process theory. The fact that generally a time-varying time trace has a time-varying variance is another consideration for scaling deterministic and random components separately.

The application of a single factor to a measured time trace based upon some form of time trace characteristic assessment is termed “ad hoc” scaling for two reasons. First, there is generally no consistent measure of the “severity” of one time trace over another time trace. For example, for an ensemble of pulses the peak of each ensemble member ordered may not reflect the order of the energy in each pulse. Enveloping individual SRS estimates for the pulses and then selecting an average scale factor by which the scaled ensemble represents a 95/50 Normal Tolerance Limit on the original ensemble may be inconsistent with both peak and energy assessments. The deeper philosophical issue that scaling correlates directly with damage probability and test conservativeness seems to be dependent upon the form of time trace. Scaling tends to negate the reason and philosophy behind Time Waveform Replication i.e., reproduction of field environment in the laboratory. Finally, the benefits of collection of substantial measurement data and concatenating the measurement data such that the requirements of the LCEP are exceeded seems like a potentially sound TWR test philosophy. This is testing to the collection of true measured time traces to the extent that several materiel lifetimes have been experienced. The question of “ad hoc” scaling has some common ground with accelerated testing for zero mean stationary random vibration and testing to the statistical envelope of a collection of zero mean stationary random vibration estimates.

It is noted here that if the random process approach is not taken i.e., it is not possible to collect more than one measurement in the field under the same experimental conditions, then a deterministic and a random component in effect cannot be reliably established. In this case scaling the time trace is an open issue and can be left to the discretion of the analyst, even though time trace scaling is not recommended practice.

1.2 Time-Varying Probability Structure.

Taking advantage of the ensemble structure the cumulative probability distribution function estimate can be computed for each time increment. Display of the ensemble time-varying mean then estimates the mean of the probability density function estimate at any time increment and the residual ensemble time-varying standard deviation estimates the standard deviation of the probability density function estimate at the time increment. Crude estimates of the skew and kurtosis can be made at any time increment and for a near zero skew and a kurtosis of three a Gaussian probability density function could be assumed at the time increment. Figure 519.6E-1 displays a composite cumulative probability distribution estimate at each time increment of the ensemble and residual for the 2000 rnd/min. Scaling the entire time trace or residual by a factor greater than one would imply stretching the horizontal axis by the scale factor. For the ensemble the contrasting shaped curves reflects the sign of the least and greatest values for the ordering. It is noted that the residual is by definition zero mean.

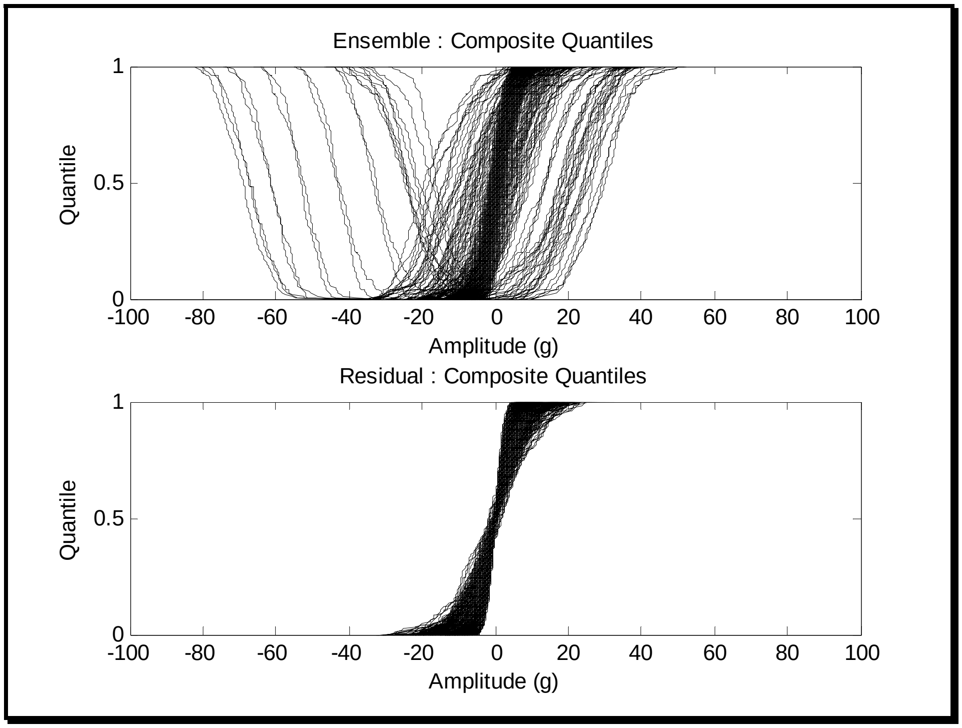

Figure 519.6E-1. Time increment composite cumulative probability distribution function for ensemble and residual.

Based upon this information it is possible to extract the 50th (mean), 80th, 95th and 99th quantiles (or percentage points) for the ensemble as displayed in Figure 519.6E-2 (the ensembles had 164 members).

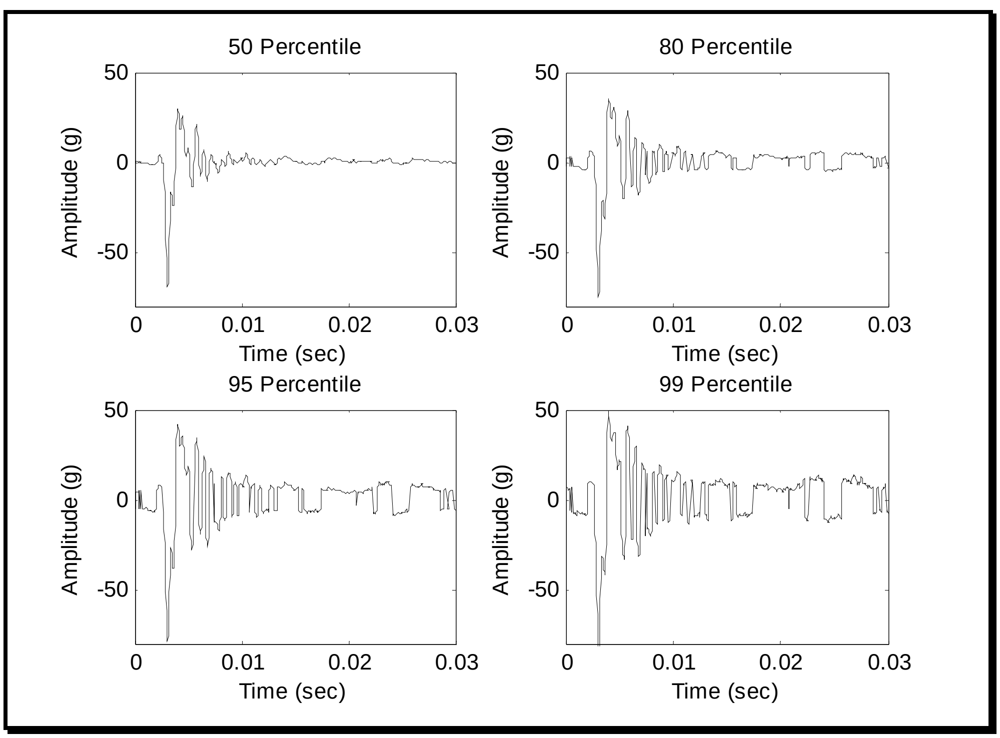

Figure 519.6E-2. Ensemble quantile (percentage point) plot.

To provide additional insight assume that the 95th quantile is selected over the ensemble and residual then the ratio of the 95th quantile value to the time-varying standard deviation at the time increment is provided in Figures 519.6E-3a and -3b.

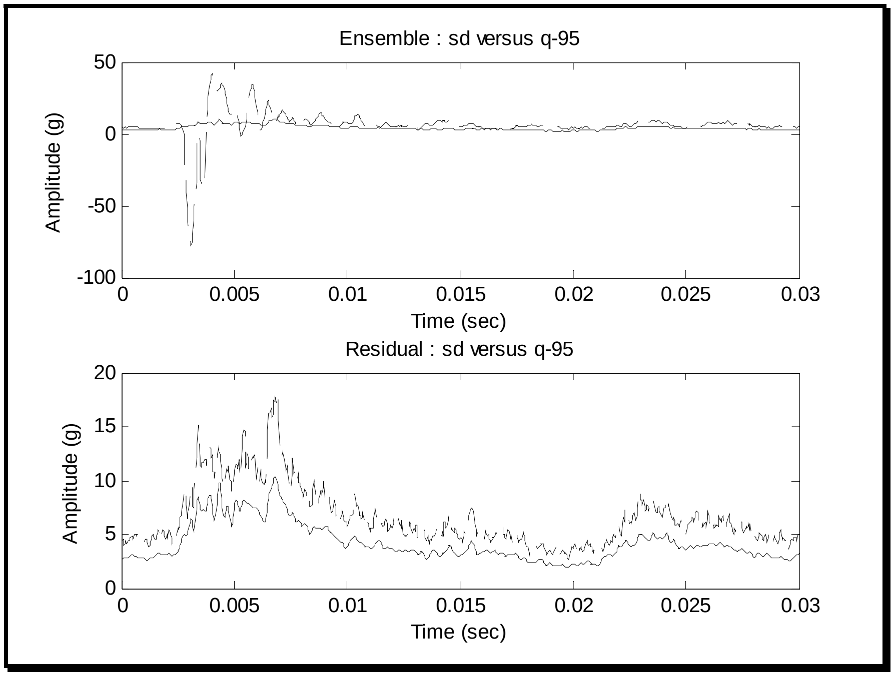

Figure 519.6E-3a. Time-varying standard deviation versus the 95th quantile to time-varying standard deviation.

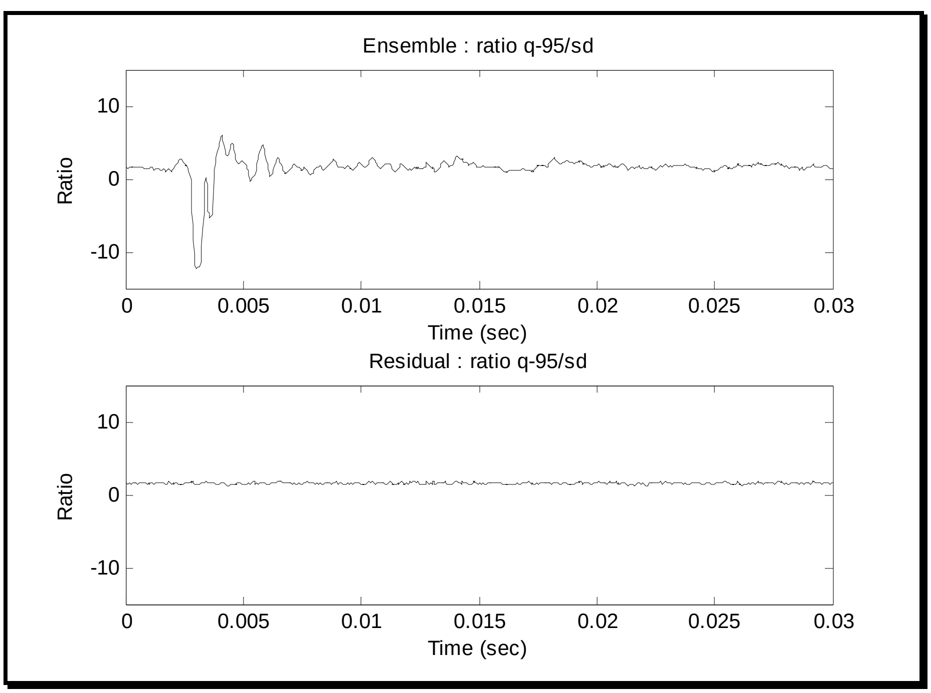

Figure 519.6E-3b. Ratio of the the 95th quantile to time-varying standard deviation.

For a time invariant standard deviation this should yield a nearly constant line that could be taken as the appropriate time trace scale for providing the " 95th quantile time trace." This is approximated by the zero mean residual but for the entire ensemble the 95th quantile may be substantially greater that the time-varying standard deviation at the time increment.

As a further display of scaling the deterministic component versus the random component energy was used as the criterion. Initially the time trace was scaled by a factor of 1.2 and the energy computed. Scaling the deterministic component by 1.251 adding the residual; adding the deterministic component and scaling the residual by 1.727; provided the same energy. This indicates that for energy criterion the ratio between the scale factors for the components to get the same energy is 1.381 and that it is possible energy wise to scale the deterministic component to a lesser degree that the random component (this is related to the substantially greater amplitudes in the deterministic component and sensitivity of energy to large values). Figure 519.6E-4 displays the scaled time traces with common energy along with the original time trace. Figure 519.6E-5 displays the cross-plots relative to scaling. The plot in the upper right corner illustrates the effect of a single factor scaling of the plot in the upper left corner. The remaining two plots demonstrate the effect of individual component scaling according to the figure caption.

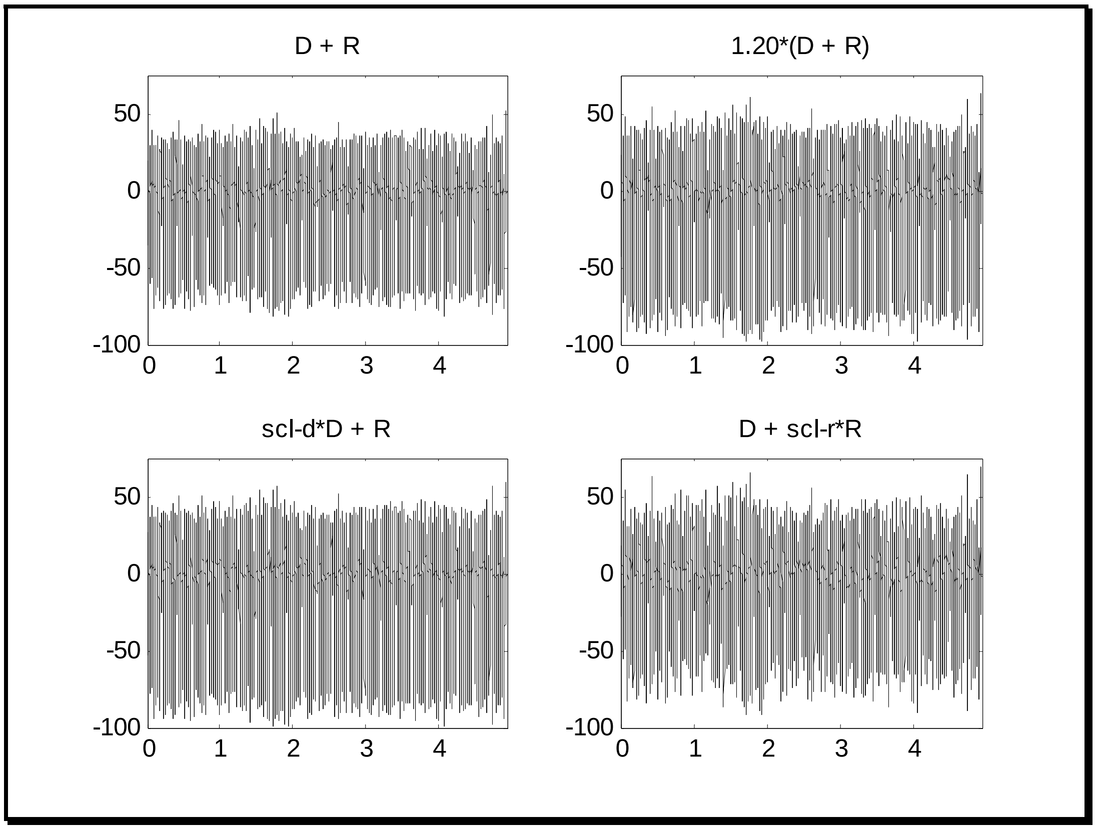

Figure 519.6E-4. Scale time traces based on energy equivalence.

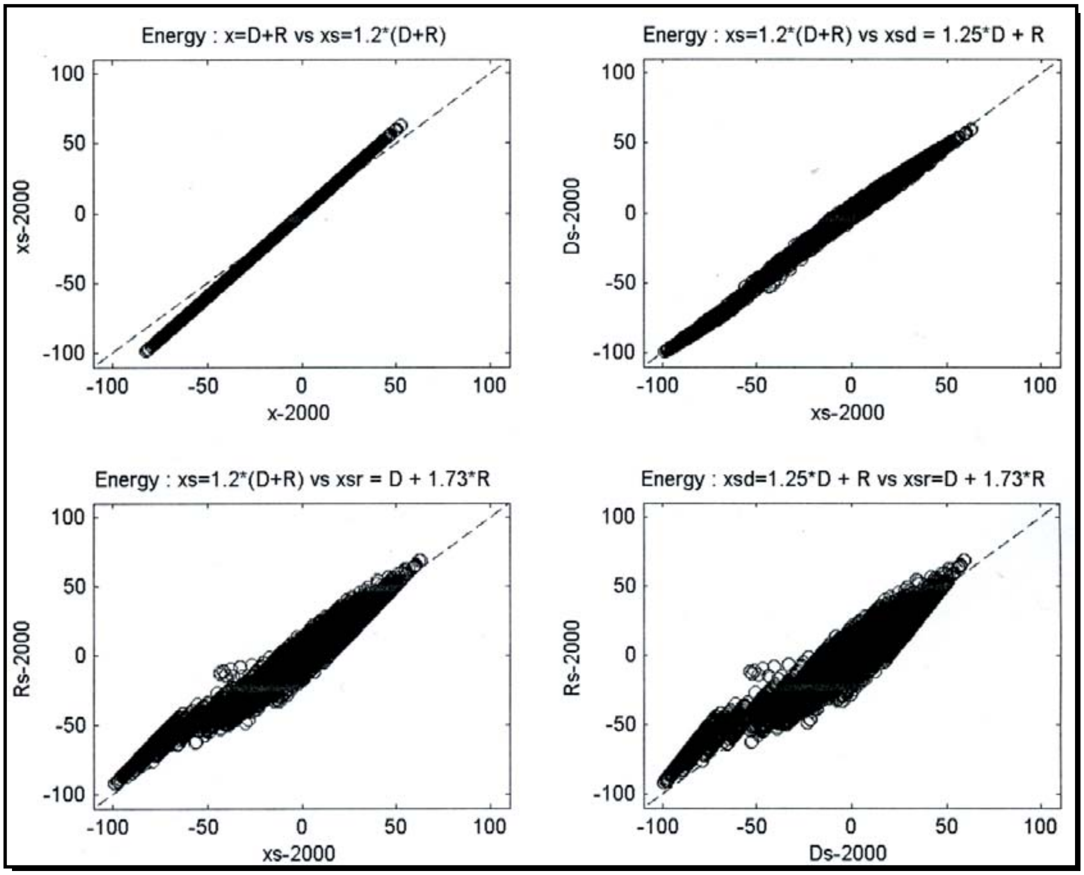

Figure 519.6E-5. Cross-plot representation for scale time traces based on energy equivalence.

This demonstration is not conclusive relative to not recommending ad hoc time trace scaling. Single time trace scaling where the random process deterministic and random components cannot be determined is generally against the philosophy of Method 525, however if it can be justified by a competent analyst such scaling may be acceptable. The case of gunfire shock where an ensemble representation is possible and components estimated, seems to limit ad hoc time trace scaling applied to the entire time trace. However based upon ensemble representation and component estimation scaling of individual components may be justified under the guidance of a competent analyst.

2. CONCLUSIONS WITH IMPLICATIONS FOR TEST TOLERANCES.

2.1 General Conclusions.

It is desirable that both stochastic generation and scaling be consistent with the probabilistic structure of a random process and take account of the model (if only an empirical model) for the random process. For significant gunfire shock, the deterministic and random parts need to be scaled separately. Application of a single scale factor in the time domain is generally unacceptable if the random process has a time-varying variance and only marginally acceptable if the variance is time invariant. Ad hoc methods that scale the measured or stochastically simulated time trace by a single factor based upon peak distribution, SRS, energy estimates should generally not be used.

If a limited number of measurements are available but levels vary and the test strategy is designed to ensure functional and operational capability according to the LCEP, at the discretion of the analyst, selected time traces may be scaled and used to build up a test ensemble for testing under TWR. This is generally creation of an artificial environment outside of the guidelines in Method 525. With proper justification, this ad hoc technique of test tailoring could be applied.

At this stage, in the relationship between gunfire shock measurement and Method 525, it is recommended that for multiple measurements the measurements be concatenated and used statistically to form a gunfire schedule or pulse train according to the LCEP description.

2.2 TWR Test Tolerances.
TWR test tolerances are to be in accordance with guidelines provided in paragraph 4 above or Method 525 TWR. If scaling is implemented then test tolerances must be consistent with the scaling prescribed.