

INSTITUTE OF ENVIRONMENTAL SCIENCES AND TECHNOLOGY

Design, Test, and Evaluation Division Recommended Practice 026.1

IENT-RP-DTE026.1

Using MIL-STD-810(F), 519 Gunfire

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1 SCOPE AND LIMITATIONS

1.1 Scope

This Recommended Practice (RP) is intended to provide guidelines for component and structure testing for significant response to exposure to gunfire. It is organized to supplement guidelines provided in MIL-STD-810F and to provide for realistic testing practices for gunfire environments. A substantial portion of this RP assumes that the gunfire response environment has been measured and that representative time history traces are available.

The first three procedures representing recommended practices, under “The Pulse Method,” have no prediction parameters and in general are not considered parameterizable procedures. These procedures are based upon the laboratory replication of measured equipment response to gunfire.

The fourth procedure, under “The Random Vibration Method,” assumes the prediction method of MIL-STD-810E is applicable in cases in which 1) measured data are not available, and 2) the response to gunfire would not represent a significant environment (i.e., the equipment is far from the pressure pulse emanating from the gun and isolated from the structure-borne vibration caused by the gun). This procedure attempts to specify the environment for the many complex situations whereby multiple guns are firing at several rates, and the contributions for precise analysis are difficult to categorize. In this case, equipment response may be considered, for practical purposes, to be high-level random vibration. Through use of certain signal processing tech-

niques, such as synchronous sampling, information on response from individual guns may be detected, provided the gunfiring rate is known and deterministic. Data in this area are currently unavailable, and this processing goes beyond that discussed in this RP. Finally, this RP, along with the procedures, may apply to other pulse form response environments, such as propeller-oriented environments, that are not addressed here.

1.2 Limitations

MIL-STD-810B through MIL-STD-810E are built upon a parameterization of gunfire vibration based on gun parameters and configurational geometry. The first three procedures described here are non-parametric in nature. Because of the high degree of response pulse repeatability, these procedures provide for very accurate laboratory replication of response for a particular configuration, but provide no method for modifying parameters of a model for the response for other configurations.

In cases where multiple guns are firing at different rates in a complex configuration, the response is likely to be very random in nature at a high level. In this case, The Pulse Method viewed as a transient vibration is recommended upon examination of the general spectral character of the vibration.

This RP is limited to “ordinary” cases of gunfire and exposure of components to gunfire. Cases in which the response to the pressure pulse environment may exceed electrodynamic shaker or electrohydraulic shaker limitations have not been addressed and require specially designed tests. Cases where large components are exposed to gunfire, and spatial

correlation of response becomes important, are not addressed here and again require specially designed tests. Secondary effects such as temperature and acoustic response above the response frequency range (generally DC to 2,500 Hz) are not considered in this RP.

This RP was developed from limited gunfire environment measurement data sets that have been assumed to be generally representative of response to most gunfire environments. It recognizes the inadequacy of the MIL-STD-810E "Vibration Method" and the inadequate definition of the MIL-STD-810E "Pulse Method." This RP represents a first attempt, with a limited nature, to provide guidelines for the replication of response to gunfire from measured data in laboratory testing.

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2 REFERENCES AND APPLICABLE DOCUMENTS

2.1 Institute of Environmental Sciences and Technology (IEST)

IEST-RP-DTE012.1: Handbook for Dynamic Data Acquisition and Analysis.

2.2 Military document

MIL-STD-810F: Environmental Test Methods and Engineering Guidelines. 01 January 2000.

2.3 Other references

- a) Bendat, J.S., and A. G. Piersol. *Random Data Analysis and Measurement Procedures, 2nd Edition.* New York: John Wiley and Sons, Inc., 1986.
- b) Merritt, R.G. "A Stochastic Model for the Pulse Method Part 1: Large Deterministic Component." In *1995 Proceedings. Vol. 2 Product Reliability and Design, Test, and Evaluation.* Mount Prospect, IL: Institute of Environmental Sciences, 1995.
- c) Merritt, R.G. "An Example of Pre- and Post-Filtering of Zero Memory Polynomial Models." In *Proceedings of the 68th Shock and Vibration*

Symposium. Arlington, VA: Shock and Vibration Information Analysis Center, 1997.

- d) Merritt, R.G. "Simulation of Ensemble Oriented Nonstationary Processes: Part 2." In *1994 Proceedings. Vol. 2, Product Reliability and Design, Test, and Evaluation.* Mount Prospect, IL: Institute of Environmental Sciences, 1994.
- e) Merritt, R. G., and S. R. Hertz. *Naval Weapons Center, Aspects of Gunfire, Part 1 Analysis.* China Lake, CA: Naval Weapons Center, 1990. (NWC TM 6648, Part 1, publication Unclassified.)
- f) Merritt, R. G., and S. R. Hertz. *Naval Weapons Center, Aspects of Gunfire, Part 2 Analysis.* China Lake, CA: Naval Weapons Center, 1990. (NWC TM 6648, Part 2, publication Unclassified.)
- g) Rabiner, L. R., and B. Gold. *Theory and Application of Digital Signal Processing.* Englewood Cliffs, NJ: Prentice-Hall, 1975.
- h) Sevy, R. W., and J. Clark. *AFFDL-TR-70-131: Aircraft Gunfire Vibration: The Development of Prediction Methods and the Synthesis of Equipment Vibration Techniques.* Wright-Patterson Air Force Base, OH: Air Force Flight Dynamic Laboratory, 1970.
- i) Sevy, R. W., and E. E. Ruddell. *AFFDL-TR-74-123: Low and High Frequency Aircraft Gunfire Vibration: Prediction and Laboratory Simulation.* Wright-Patterson Air Force Base, OH: Air Force Flight Dynamic Laboratory, 1975.
- j) Smallwood, D. O. "Generation of Partially Coherent Stationary Time Histories with Non-Gaussian Distributions." In *Proceedings of the 67th Shock and Vibration Symposium.* Arlington, VA: Shock and Vibration Information Analysis Center, 1996.
- k) Smallwood, D. O., "Gunfire Characterization and Simulation Using Temporal Moments." In *Proceedings of the 65th Shock and Vibration Symposium.* Arlington, VA: Shock and Vibration Information Analysis Center, 1994.

2.4 Sources of Documents

IEST

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3 TERMS AND DEFINITIONS

autospectral density

For a stationary (ergodic) random process $\{x(t)\}$ for which the finite Fourier transform of $x(t)$ is given by

$$X(f, T) = \int_0^T x(t) e^{-j2\pi ft} dt \quad (3.1)$$

the two-sided autospectral density of $x(t)$ is defined by

$$S_{xx}(f) = \lim_{T \rightarrow \infty} \frac{1}{T} E[|X(f, T)|^2] \quad (3.2)$$

An estimate of the one-sided autospectral density of $x(t)$ is given by

$$\hat{G}_{xx}(f) = \frac{2}{n_d T} \sum_{i=1}^{n_d} |X_i(f, T)|^2 \quad (3.3)$$

where T is the length of the record and n_d the number of distinct records.

Note: In actual processing, the records of length T may be windowed in the time domain, and the processing may be "overlapped" (see reference 2.3a for details).

cross-spectral density

For stationary (ergodic) random processes $\{x(t)\}$ and $\{y(t)\}$ for which finite Fourier transforms of $x(t)$ and $y(t)$ are, respectively

$$X(f, T) = \int_0^T x(t) e^{-j2\pi ft} dt \quad (3.4)$$

$$Y(f, T) = \int_0^T y(t) e^{-j2\pi ft} dt \quad (3.5)$$

the two-sided cross-spectral density function of $x(t)$ and $y(t)$ is defined by

$$S_{xy}(f) = \lim_{T \rightarrow \infty} \frac{1}{T} E[X^*(f, T) Y(f, T)] \quad (3.6)$$

An estimate of the one-sided cross-spectral density function of $x(t)$ and $y(t)$ is given by

$$\hat{G}_{xy}(f) = \frac{2}{n_d T} \sum_{i=1}^{n_d} X_i^*(f, T) Y_i(f, T) \quad (3.7)$$

where T is the length of the record and n_d the number of disjoint records (see reference 2.3a for details).

energy autospectral density function

For a time and band-limited time history $x(t)$ defined for $0 \leq t \leq T$ with finite Fourier transform

$$X(f, T) = \int_0^T x(t) e^{-j2\pi ft} dt \quad (3.8)$$

the two-sided energy autospectral density function of $x(t)$ is given by

$$L_{xx}(f, T) = E[|X(f, T)|^2] \quad (3.9)$$

a one-sided estimate of this function for an ensemble of transient records is given by

$$\hat{L}_{xx}(f, T) = \frac{2}{n_d} \sum_{i=1}^{n_d} |X_i(f, T)|^2 \quad (3.10)$$

where n_d is the number of distinct transient records.

energy cross-spectral density function

For time and band-limited time histories $x(t)$ and $y(t)$ defined for $0 \leq t \leq T$ with finite Fourier transforms

$$X(f, T) = \int_0^T x(t) e^{-j2\pi ft} dt \quad (3.11)$$

$$Y(f, T) = \int_0^T y(t) e^{-j2\pi ft} dt \quad (3.12)$$

The two-sided energy cross-spectral density function of $x(t)$ and $y(t)$ is given by

$$L_{xy}(f, T) = E[X^*(f, T) Y(f, T)] \quad (3.13)$$

A one-sided estimate of this function for an ensemble of transient records is given by

$$\hat{L}_{xy}(f, T) = \frac{2}{n_d} \sum_{i=1}^{n_d} X_i^*(f, T) Y_i(f, T) \quad (3.14)$$

where n_d is the number of distinct transient records.

energy transfer function

For time and band limited time histories $x(t)$ and $y(t)$ defined for $0 \leq t \leq T$ with energy cross-spectral density function $L_{xy}(f, T)$ and energy autospectral density function $L_{xx}(f, T)$, the energy transfer function

tion is defined as

$$H_{xy}(f, T) = \frac{L_{xy}(f, T)}{L_{xx}(f, T)} \quad (3.15)$$

An estimate of this function is given by

$$\hat{H}_{xy}(f, T) = \frac{\hat{L}_{xy}(f, T)}{\hat{L}_{xx}(f, T)} \quad (3.16)$$

ensemble

A sample collection of time history records from a single random process where each of the time history records is defined over the same time interval.

ergodic

A random process is ergodic if a single sample time history from the process has statistics representative of the entire process. That is to say, time averaged statistics of a single sample record of the process are theoretically the same as ensemble averaged statistics over the entire process. An ergodic process is always a stationary random process. Generally, a stationary random process is ergodic; however, there can be exceptions.

finite Fourier transform

For a time history $x(t)$ defined for $0 \leq t \leq T$, the finite Fourier transform (FT) is given by

$$X(f, T) = \int_0^T x(t) e^{-j2\pi ft} dt \quad (3.17)$$

Gaussian (nonGaussian)

For $x(t)$ a time history that obeys the following probability function at time t , with μ_x and σ_x constants

$$p(x) = (\sigma_x \sqrt{2\pi})^{-1} \exp \left[-\frac{(x - \mu_x)^2}{2\sigma_x^2} \right] \quad (3.18)$$

$x(t)$ will be considered to be Gaussian. Conversely, for $x(t)$ a time history that does not obey the probability function in Equation 3.18 at time t , $x(t)$ will be considered to be nonGaussian.

inverse finite Fourier transform

For the finite Fourier transform $X(f, T)$ defined over a frequency band of $0 \leq f \leq F$, the finite inverse Fourier transform (IFT) of $X(f, T)$ is given by

$$x(t) = \frac{1}{2\pi} \int_0^F X(f, T) e^{j2\pi ft} df \quad (3.19)$$

materiel

For purposes of this RP, materiel is a hardware component (e.g., section of a missile, etc.) that has

a well-defined geometry and which responds to gunfire blast energy impinging directly on it or transmitted to it via a structural path.

mean (ensemble)

For an ensemble $\{x_i(t)\}$ $0 \leq t \leq T$, $i = 1, \dots, N$, of N time history records with a mean $\mu(t)$, $0 \leq t \leq T$, an unbiased estimate of the mean of the ensemble at time t is given by

$$\hat{m}(t) = \frac{1}{N} \sum_{i=1}^N x_i(t) \quad 0 \leq t \leq T \quad (3.20)$$

mean-square (ensemble)

For an ensemble $\{x_i(t)\}$ $0 \leq t \leq T$, $i = 1, \dots, N$, of N time history records with a mean square $p(t)$, $0 \leq t \leq T$, an unbiased estimate of the mean-square for the ensemble at time t is given by

$$\hat{p}(t) = \frac{1}{N} \sum_{i=1}^N x_i^2(t) \quad (3.21)$$

nonstationary spatial cross-correlation function

For an ensemble $\{x_i(t)\}$ $0 \leq t \leq T$, $i = 1, \dots, N$, of N time history records, the nonstationary spatial cross-correlation function at time t between all pairs of records $x_i(t)$ and $x_j(t)$ such that $k = j - i$ is defined as

$$R_{xx}(k, t) = E[x_i(t) x_j(t)] \quad \begin{matrix} 0 \leq t \leq T \\ k = j - i \end{matrix} \quad (3.22)$$

nonstationary

A time history record is termed nonstationary if its statistical properties vary in time in a statistically significant way over the length of the time history record. In particular, if one or more of the first moment, second moment, or higher order moments of the random process vary in time, the random process is termed nonstationary. In this RP, random processes that are identified by time-varying first and second moments with no attention given to higher order moments will be of most concern.

parameter

Any quantity that represents a descriptive generalization of a certain characteristic of a system (e.g., the gun blast energy is a quantity that helps define the "power" of the gun and is considered a parameter).

pulse

For purposes of this RP, a brief duration high amplitude time history segment that may be used to characterize response to gunfire from a single firing

of a projectile. The duration of the pulse in seconds generally correlates with the inverse of the firing rate of the gun given in rounds per second. The amplitude of the pulse is a function of the gunfiring overpressure, experiment geometrical and physical configuration, and the materiel response.

random process

A random process is represented by a collection or ensemble of time history records with certain statistical properties defined over the process ensemble. In the case of this RP, it will be assumed that one or more sample records from the random process are related to a repeatable experiment, and that the random process completely describes the phenomenon under consideration.

root-mean-square (ensemble)

For an ensemble $\{x_i(t)\}$ $0 \leq t \leq T$, $i = 1, \dots, N$, of N time history records with a mean square $p(t)$, $0 \leq t \leq T$, (estimated by $\hat{p}(t)$), an estimate of the root-mean-square for the ensemble at time t is given by

$$\hat{r}(t) = \sqrt{\hat{p}(t)} = \sqrt{\frac{1}{N} \sum_{i=1}^N x_i^2(t)} \quad (3.23)$$

sample function

One particular realization of a random process that is a member of an ensemble representation for the random process.

standard deviation (ensemble)

For an ensemble $\{x_i(t)\}$ $0 \leq t \leq T$, $i = 1, \dots, N$, of N time history records with a standard deviation $\sigma(t)$, and mean $\mu(t)$, $0 \leq t \leq T$, an unbiased estimate of the standard deviation of the ensemble at time t with unbiased mean estimate $\hat{m}(t)$, is given by

$$\hat{s}(t) = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i(t) - \hat{m}(t))^2} \quad 0 \leq t \leq T \quad (3.24)$$

stationary

A time history record is termed stationary if its statistical properties (e.g., mean and standard deviation), over short periods of time, do not vary significantly over the length of the time history record. Statistical tests are available to quantify acceptable sampling variation over time for stationarity testing (see reference 2.3a for details).

transient vibration

A form of stationary random vibration time history that has a positive time-varying envelope that begins at zero and ends at zero over a certain period of time, T .

variance (ensemble)

For an ensemble $\{x_i(t)\}$ $0 \leq t \leq T$, $i = 1, \dots, N$, of N time history records with a variance $\sigma^2(t)$ and mean $\mu(t)$, $0 \leq t \leq T$, an unbiased estimate of the variance of the ensemble at time t with unbiased mean estimate $\hat{m}(t)$, is given by

$$\hat{v}(t) = \frac{1}{N-1} \sum_{i=1}^N (x_i(t) - \hat{m}(t))^2 \quad 0 \leq t \leq T \quad (3.25)$$

waveform control

A vibration control system executes waveform control when it replicates a properly compensated time history, $x(t)$, in an open loop mode of control. In this RP, waveform control will refer to the replication of measured equipment response in laboratory testing based upon determining the input voltage time history to the vibration system that will nearly exactly reproduce the measured equipment response when applied to the vibration system.

4 BACKGROUND AND INTRODUCTION

4.1 Background

This RP has been developed from an impression that early guidelines for testing gunfire response environments (e.g., MIL-STD-810E) are without means for substantial tailoring to more realistic environments and thus are inadequate. Moreover, vibration test control manufacturers, in general, lack the ability to provide vibration/shock reproduction systems that allow for convenient reproduction of extended time-varying response environments such as gunfire. This RP, through use of guidelines and procedures, is designed to provide two basic sets of options in testing for gunfire environments.

The first set of options is unconventional but provides for accurate and realistic simulation of gunfire environment materiel response in the laboratory based on field measured materiel response data. The second set of options follows the guidelines of MIL-STD-810E for special cases of gunfire. These special cases include the very complex multiple gun and multiple firing rate configuration for which pure harmonic response is not apparent,