AECTP 400

MECHANICAL ENVIRONMENTAL TESTS

(January 2006)

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NORTH ATLANTIC TREATY ORGANIZATION

NATO STANDARDISATION AGENCY (NSA)

NATO LETTER OF PROMULGATION

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ALLIED ENVIRONMENTAL CONDITIONS AND TEST PUBLICATIONS

AECTP 400

MECHANICAL ENVIRONMENTAL TESTS

AECTP 400 is one of five documents included in STANAG 4370. It is important for users to note that the content of AECTP 400 is not intended to be used in isolation, but is developed to be used in conjunction with the other four AECTP to apply the Environmental Project Tailoring process. This process ensures that materiel is designed, developed and tested to requirements that are directly derived from the anticipated service use conditions. It is particularly important that AECTP 400 is used in conjunction with AECTP 100 which addresses strategy, planning and implementation of environmental tasks, and AECTP 200 which provides information on the characteristics of environments and guidelines on the selection of test methods.

The test methods contained herein together with associated assessments are believed to provide the basis for a reasonable verification of the materiel's resistance to the effects of the specific mechanical environments. However, it should be noted that the test methods are intended to reproduce the effects of relevant environments and do not necessarily duplicate the actual environmental conditions. Where possible, guidance on the limitations of the intended applications is provided. The use of measured data for the generation of test severities is recommended if available.

AECTP 400 Test Methods address mechanical environments, both individually and when combined with other environments, such as climatic environments included in AECTP 300. The application of combined environments is relevant and often necessary where failures could be expected from potential synergistic effects.

In developing a test programme, consideration is to be given to the anticipated life cycle of the materiel and to the changes in resistance of the materiel caused by the long term exposure to the various mechanical environments. The environmental conditions included by the appropriate materiel platforms are also to be accommodated. Guidance on these aspects and information on the characteristics of environments is provided in AECTP 200. Guidelines for the planning and implementation of environmental tasks are given in AECTP 100.

AECTP 400 was not developed specifically to cover the following applications, but in some cases they may be applied :

a. Weapon effects, other than EMP,
b. Munitions safety tests covering abnormal environments,
c. Packaging testing,
d. Suitability of clothing or fabric items intended for military use,
e. Environmental stress screening (ESS) methods and procedures.

The enclosed list of AECTP 400 Test Methods reflects those currently developed and completed. It is not comprehensive in that it will be revised as other methods are developed. The methods listed are not to be applied indiscriminately, but rather selected for application as required.

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METHOD 401

VIBRATION

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of the vibration environments incurred by systems, subsystems and units, hereafter called materiel, during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified vibration environment without unacceptable degradation of its functional and/or structural performance.

AECTP 100 and 200 provide additional guidance on the selection of a test procedure for a specific vibration environment.

1.3 Limitations

It may not be possible to simulate some actual operational service vibration environments because fixture limitations or physical constraints may prevent the satisfactory application of the vibration excitation to the test item.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to a vibration environment.

a. Wire chafing.
b. Loosening of fasteners.
c. Intermittent electrical contacts.
d. Mutual contact and short circuiting of electrical components.
e. Seal deformation.
f. Structural and component fatigue.
g. Optical misalignment.
h. Cracking and rupturing.
i. Loosening of particles or parts that may become lodged in circuits or mechanisms.
j. Excessive electrical noise.

2.2 Use of Measured Data

Where practical, measured field vibration data should be used to develop test levels. It is particularly important to use field data where a precise simulation is the goal. Sufficient data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel in each LCEP phase. The sample size of measured data should as a minimum be sufficient to account for the data variances due to the distribution of the transport platform condition and age, payload capacity, operational personnel, and the environmental operating conditions.

2.3 Sequence

The effects of vibration may affect performance when materiel is tested under other environmental conditions, such as temperature, humidity, pressure, electromagnetism, etc.

Also, it should be noted that it is essential that materiel which is likely to be sensitive to a combination of environments is tested to the relevant combinations simultaneously.

Where it is considered that a combined test is not essential or impractical to configure, and where there is a requirement to evaluate the effects of vibration together with other environments, a single test item should be exposed to all relevant environmental conditions in turn.

The order of application of tests should be considered and made compatible with the Service Life Environmental Profiles. If any doubt remains as to the order of testing, then any vibration testing should be undertaken first.

2.4 Choice of Test Procedures

The choice of test procedure is governed by many factors including the in-service vibration environment and materiel type. These and other factors are dealt within the General Requirements - AECTP 100 and in the Definition of Environments - AECTP 200

This test method contains four procedures :

Procedure I	Swept Frequency Sinusoidal Vibration
Procedure II	Fixed Frequency Sinusoidal Vibration
Procedure III	Random Vibration
Procedure IV	Random Vibration (Stores)

Table 1 provides a test procedure selection matrix as a function of platform and type of environment.

Materiel may be exposed to more than one vibration environment. For example, materiel installed in aircraft will be subjected to both the transportation environment as well as the aircraft induced environment. In such cases the materiel may be required to be tested to more than one procedure.

2.5 Types of Vibration

A brief description of each type of vibration that can be used in procedures I to IV is given in the following paragraphs.

2.5.1 Swept Frequency Sinusoidal Vibration

Swept frequency sinusoidal vibration consists of sinusoidal motion whose frequency is varied at a specified sweep rate, over a specified frequency range. The amplitude of the motion may also vary over the frequency range. This type of vibration has application in the representation of environments where the materiel experiences vibration primarily of a periodic nature. It may also have applications where fatigue is to be assessed.

A swept frequency sinusoidal vibration severity is defined by the following parameters:

- The amplitude/frequency profile;
- The sweep rate and type of sweep;
- The time duration of the test.

2.5.2 Fixed Frequency Sinusoidal Vibration

Fixed frequency sinusoidal vibration has application to a range of materiel subjected to fixed and known frequencies. It may also have application to the rapid accumulation of stress reversals in order to assess the effects of fatigue.

A fixed frequency sinusoidal vibration severity is defined by the following parameters :

- The amplitude(s) of vibration;
- The frequency of the sinusoid(s);
- The time duration of the test.

2.5.3 Wideband Random Vibration

Wideband random vibration exhibits instantaneous acceleration levels with a nominally Gaussian distribution in the time domain. The spectrum levels may be constant or shaped over a wide frequency range. These conditions are likely to be experienced by most materiel at some time in their service life.

A wideband random vibration severity is defined by the following parameters :

- The Acceleration Spectral Density (ASD) spectrum profile;
- The test frequency range;
- The total root mean square, Grms, level over the test frequency range;
- The time duration of test.

2.5.4 Fixed Frequency Narrowband Random Vibration

Fixed frequency narrowband random vibration has its spectral amplitude constrained within a narrow frequency range. It may be used to represent vibration that is periodic but not necessarily sinusoidal.

A narrowband random vibration severity is defined by the following parameters :

- The ASD spectrum profile;
- The test frequency range;
- The total root mean square, Grms, level over the frequency range;
- The time duration of the test,

2.5.5 Swept Narrowband Random Vibration

Swept narrowband random vibration is defined as a narrowband of random vibration that is swept over a specified frequency range.

A swept narrowband random vibration severity is defined by the following parameters:

- The ASD spectrum profile of the narrowband;
- The swept frequency range;
- The total root mean square (Grms) level of the narrowband(s);
- The sweep rate and type of sweep;
- The time duration of the test.

2.5.6 Fixed Frequency Sinusoidal Vibration on Wideband Random Vibration

Fixed frequency sinusoidal vibration on wideband random vibration is defined as one or more fixed frequency sinusoids superimposed on wideband random vibration. Where several host platforms are specified, swept frequency sinusoidal vibration, or swept frequency narrowband random vibration on wideband vibration may be more representative.

A composite vibration severity consisting of fixed frequency sinusoidal component(s) on a wideband random vibration background is defined by the following parameters :

- The ASD spectrum profile of the wideband random vibration;
- The test frequency range of wideband random vibration;
- The total Grms level of the wide band random spectrum over the test frequency range;
- The amplitude(s) of the sinusoid(s);
- The frequency of the sinusoid(s);
- The time duration of the test.

2.5.7 Swept Frequency Sinusoidal Vibration on Wideband Random Vibration

Swept frequency sinusoidal vibration on wideband random vibration is defined as one or more sinusoids swept over a frequency range, and superimposed on random vibration.

A composite vibration severity, consisting of a swept frequency sinusoidal component(s) on a random vibration background, is defined by the following parameters :

- The ASD spectrum profile of the wideband random vibration;
- The test frequency range of the wideband random vibration;
- The total Grms level of the wideband random vibration over the test frequency range;
- The amplitude(s)/frequency profile(s) of the sinusoids;
- The sweep rate and type of sweep
- The time duration of the test.

Table 1 Vibration Test Procedure Selection

Environment	**Platform**	**Category**	**Materiel Description**	**401 Test Procedure**	**Annex Figure or Table**
Transportation	Vehicle	Truck, Wheeled	Materiel as restrained cargo	III	A-1
		Wheeled Transport	Materiel as loose cargo	See Method 406	---
		Truck with Large Assembly Cargo	Restrained large assemblies, shelters	See Method 408	---
	Aircraft	Jet	Materiel on aircraft as restrained cargo	I, II, III	C-2, C-3
		Propeller		I, II, III	C-1
		Helicopter		I, II, III	D-1
	Ship	Surface Ship	Materiel on ships as restrained cargo	I, II, III	Table E-1
		Subsurface Ship		I, II, III	Table E-1
	Railroad	Train	Materiel as cargo	I, II, III	E-1
Mission Induced	Vehicle	Tactical Wheeled	Materiel on vehicles as restrained cargo	III	A-2
		Two Wheel Trailer		III	A-3
		Tracked		III	B-1 to B-4
	Aircraft	Jet	Materiel installed in and cargo on aircraft	I, II, III	C-2 to C-4
		Propeller		I, II, III	C-1
		Helicopter		I, II, III	D-1
	Aircraft Stores	Jet	Assembled stores	I, II, III	C-5
		Jet	Installed in stores	I, II, III	C-6
		Propeller	Assembled / installed in stores	I, II, III	C-1
		Helicopter	Assembled / installed in stores	I, II, III	D-2
	Missiles	Tactical Missiles	Assembled / installed in missiles(free flight)	I, II, III, IV	---
	Engines	Turbine Engines	Installed On	I, II, III	C-7
Integrity	All	Minimum Requirement	Materiel off isolators	I, II, III	---
Development	All	Design Tool	Initial prototype or design test	I, II, III, IV	---

AECTP 401 Vibration Test Procedures :

Procedure I	Swept Frequency Sinusodial Vibration
Procedure II	Fixed Frequency Sinusodial Vibration
Procedure III	Random Vibration (Complex Vibration)
Procedure IV	Random Vibration (Stores)

2.5.8 Fixed Frequency Narrowband Random Vibration on Wideband Random Vibration

Fixed frequency narrowband random vibration on wideband random vibration is defined as one or more narrowbands of random vibration superimposed on wideband random vibration. This type of vibration is essentially the same as the wideband random vibration application described earlier.

A composite vibration severity of a fixed center frequency narrowband random component(s) superimposed on a wideband random vibration background is defined by the following parameters :

- The ASD spectrum profile of the wideband random vibration;
- The test frequency range;
- The ASD spectrum profile, of the narrowband random vibration;
- The Grms level over the test frequency range;
- The time duration of the test.

2.5.9 Swept Frequency Narrowband Random Vibration on Wideband Random Vibration

Swept frequency narrowband random vibration on wideband random vibration is defined as one or more narrowbands of random vibration swept over a frequency range and superimposed on a background of wideband random vibration.

A composite vibration severity of a swept narrowband random vibration superimposed on a wideband random vibration background is defined by the following parameters :

- The ASD spectrum profile on the wideband random vibration;
- The test frequency range;
- The ASD spectrum profile(s) of the narrowband random vibration;
- The swept frequency range;
- The sweep rate and type of sweep;
- The Grms level over the test frequency range;
- The time duration of the test.

2.6 Control Strategy and Options

2.6.1 Strategy

The vibration excitation is controlled to within specified bounds by sampling the vibratory motion of the test item at specific locations. These locations may be at, or in close proximity to, the test item fixing points (controlled input) or at defined points on the test item (controlled response). The vibratory motions may be sampled at a single point (single point control), or at several locations (multi-point control).

The control strategy will be specified in the Test Instructions. However, it should be noted that it could be influenced by :

- The results of preliminary vibration surveys carried out on materiel and fixtures;
- Meeting the test specifications within the tolerances of paragraph 5.1 ;
- The capability of the test facility.

In view of the possibility of frequency drift, it is essential when conducting fixed frequency sinusoidal "resonance dwell" tests that the frequency be constantly adjusted to ensure a maximum response. Two method are available :

- Search for the maximum dynamic response;
- Maintain the phase between the control and monitoring points.

2.6.2 Single Point Control Option

This option can be used when the preliminary vibration survey shows that inputs to the test item are normally equal at each fixing point or when one control accelerometer accurately represents an average of the inputs at each fixing point. A single control point is selected :

- Either from among the fixing points;
- Or, from among the significant points of the test items response;
- Or, in such a way that it provides the best possible solution for achieving the tolerances at the fixing points.

2.6.3 Multiple Point Control (average) Option

The option can be used when the preliminary vibration survey shows that inputs to the test item vary significantly between fixing points. The control points, usually two or three, will be selected using the same criteria listed in paragraph 2.6.2 for the single control point option. However, the control for :

- Random, will be based on the average of the ASD of the control points selected.
- Sine, will be based on the average of the peak response values at the control points selected.

2.6.4 Multiple Point Control (maximum) Option

This option can be used when responses are not to exceed given values, but care is needed to avoid an undertest. Preliminary vibration survey results are used to aid the definition of the control points on the test item at which maximum response motions occur. The control points, usually two or three, will be selected using the same criteria listed in paragraph 2.6.2 for the single point option. However, the control for:

- Random, will be based on the maximum spectrum response at any of the selected control points.

- Sine, will be based on the maximum peak response at any of the selected control points.

2.7 Materiel Operation

The test should be performed with the materiel in the operational mode specified in the Test Instruction or relevant test specification. Test specifications may require operation, performance monitoring, and documentation of electrical, mechanical, hydraulic, or other systems during vibration testing.

3. SEVERITIES

3.1General

When practical, test levels and durations will be established using projected service use profiles and other relevant available data. When data are not available, initial test severities are to be found in Annex A ; these severities should be used in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data are obtained. Where necessary these severities can be supplemented at a later stage by data acquired directly from an environmental measurement program.

3.2 Supporting Assessment

Note that the test selected may not be an adequate simulation of the complete environment and, consequently a supporting assessment may be necessary to complement the test results.

3.3 Isolation System

Materiel intended for use with vibration isolation systems should normally be tested with isolators in position. If it is not practical to carry out the vibration test with the appropriate isolators, or if the dynamic characteristics of the materiel installation are very variable, for example temperature dependent, the test should be performed without isolators at a modified severity specified in the Test Instruction. In the case where a continuous vibration test can cause unrealistic heating of the test item and/or isolators, the excitation should be interrupted by periods of rest of a duration time specified in the Test Instruction.

3.4 Subsystems

When identified, in the test plan, subsystems of the materiel may be tested separately. The subsystems can be subjected to different vibration levels. In this case, the Test Instruction should stipulate the test levels specific to each subsystem.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item;

b. The definition of the test item;

c. The type of test (development, qualification, etc.);
d. The orientation of the test item in relation to the test axes;
e. If and when operational checks are to be performed;
f. For initial and final checks, specify whether they are to be performed with the test item installed on the test facility;
g. Other relevant data required to perform the test and operating checks;
h. The vibration control strategy;
i. The monitor and control points or a procedure to select these points;
j. The pre-conditioning time;
k. The use of isolator mounts or otherwise;
l. The definition of the test severity;
m. The indication of the failure criteria;
n. In the case of a large test item or complex fixture, the considerations for control tolerance excess;
o. Any other environmental conditions at which testing is to be carried out if other than standard laboratory conditions.

4.2 If Required

a. The specific features of the test assembly (vibrator, fixture, interface connections, etc.);
b. The effect of gravity and the consequential precautions;
c. The value of the tolerable spurious magnetic field;
d. Tolerances, if different from paragraph 5.1.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances and Related Characteristics

5.1.1 Sinusoidal Vibration

The test facility should be able to excite the materiel in the method specified in the Test Instruction. The motion should be sinusoidal and such that the fixing points of the test item move substantially in phase with and parallel to the excitation axis.

The sinusoidal tolerances and related characteristics defined in Table 2 below (sinusoidal tolerances) should be used and checked with the test item installed. Only under exceptional circumstances should a Test Instruction need to specify different tolerances.

The complete test control system should not produce uncertainties exceeding one third of the tolerances listed in Table 2.

The tolerances associated with the test severity parameters are not to be used to overtest or undertest the test item.

If tolerances are not met, the difference observed should be noted in the test report.

Table 2 Sinusodial Vibration Test Tolerances

Parameter	Tolerance
Critical frequencies	+/- 0.05 Hz from zero to 0.5 Hz +/- 10% from 0.5 Hz to 5 Hz +/- 0.5 Hz from 5 Hz to 100 Hz +/- 0.5% above 100 Hz
Characteristic frequencies of the test profile (see note 2)	+/- 0.05 Hz from zero to 0.25 Hz +/- 20% from 0.25 Hz to 5 Hz +/- 1 Hz from 5 Hz to 50 Hz +/- 2% above 50 Hz
Sweep rate (see note 3)	+/- 10%
Fundamental amplitude of the vibration (displacement, velocity, acceleration)	+/- 15% at the control signal +/- 25% at the fixing points up to 500 Hz +/- 50% at the fixing points above 500 Hz
Difference between the unfiltered signal and filtered acceleration signal (see note 4)	+/- 5% on the Grms values
Transverse movement on the fixing points	< 50% of the movement for the specified axis up to 500 Hz < 100% above 500 Hz (in special cases, eg. small equipment, transverse movement may be limited to 25% and 50% respectively
Test time duration	+/- 5%

Notes :

1. Critical frequencies are frequencies at which
   - Test items malfunction and/or detrimental performance is exhibited due to the effects of vibration;
   - Mechanical resonances and other response effects, such as chatter, occur.
2. Characteristic frequencies are :
   - The frequency limits of the sweeping frequency range;
   - The transition frequencies of the test profile.
3. Unless otherwise specified, the vibration should be continuous and change exponentially with time at one octave per minute.

4. A signal tolerance of 5% corresponds to a distortion of 32% by utilization of the formula :

$$d = \frac{\sqrt{a_{tot}^2 - a_1^2}}{a_1} x\, 100$$

where: a_1 = Grms value of acceleration at the driving frequency;

a_{tot} = total Grms of the applied acceleration (including the value of a_1).

5.1.2 Random Vibration

The test facility should be capable of exciting the test item to the random vibration conditions specified in the Test Instruction. The motion induced by the random vibration should be such that the fixing points of the test item move substantially parallel to the axis of excitation. In these conditions the amplitudes of motion should exhibit a normal distribution. The tolerances defined in table 3 below should be used and checked with the test item installed.

Since the control loop time depends on the number of degrees of freedom and on the analysis and overall bandwidths, it is important to select these parameters so that test tolerances and control accuracy can be achieved. When possible, an identical analysis bandwidth should be used for both control and monitoring. When this is not possible, adequate allowance should be made to the results of the monitoring analysis.

For swept narrow band random tests, the tolerances on the swept components of the test requirement should, wherever possible, be the same as for a wide band random component. However, at some sweep rates, these tolerances may not be achievable. Therefore, the tolerance requirements for these components shall be stated in the Test Instruction. The complete test control system including checking, servoing, recording, etc., should not produce uncertainties exceeding one third of the tolerances listed in Table 3.

The tolerances associated with the test severity parameters are not to be used to overtest or undertest the test item.

If tolerances are not met, the difference observed should be noted in the test report.

Table 3 Random Vibration Test Tolerances

Parameter	Tolerance
Number (n) of independent statistical degrees of freedom (DOF) for control of the specified ASD	n > 100
Grms value of amplitude measured at the control point in the test axis	+/- 10% of the preset RMS value
Maximum local amplitude deviation of the control ASD in relation to the specified ASD (see note 1)	+/- 3 dB below 500 Hz +/- 6 dB above 500 Hz
Maximum variation of the Grms value at the fixing points in the test axis	+/- 25% of the preset RMS value
ASD measured with the same number of DOF as in the test axis, along the two transverse directions.	Less than 100% of the specified ASD of the control point.
Amplitude distribution of the instantaneous values of the random vibration measured at the control point (see note 2)	Nominally Gaussian
Frequency sweep rate (see note 2)	+/- 10%
Test time duration	+/- 5%

Notes :

1. The sum of the individual out of tolerance bandwidths shall be a maximum of 5 % of the total test control bandwidth.
2. The distribution should contain all occurrences up to 2.7 standard deviations while occurrences greater than 3 standard deviations should be kept to a minimum. Only under exceptional circumstances should a Test Instruction need to specify different tolerances.
3. Unless otherwise specified, the vibration should be continuous and change exponentially with time at one octave per minute.

5.1.3 Complex Vibration

Control system difficulties may be encountered when exciting the test item to complex vibration types such as described in paragraphs 2.5.6, 2.5.7, and 2.5.8 . With some control systems it may be possible to specify incompatible sweep rates and control strategies (statistical degrees of freedom and number of control points). In such cases, the control system may, without warning, perform the test incorrectly, in that sweeps may not be completed or that tolerances may be exceeded.

Additionally, control and performance problems may be encountered for narrowband random on random (NBROR) tests on electrodynamic vibration test systems that prevent the full rated output force capacity of the system from being obtained. The vibration amplifier current and voltage limitations during NBROR tests can prevent the full exciter force capacity from being obtained. A reduction in test system force capacity of one-third to one-half of the manufacturer Grms ratings is possible depending on the test equipment, test load size, and load resonance characteristics.

The capability of the vibraton test equipment and control system to conduct the test as specified in the Test Instruction should be verified prior to undertaking the test. Any deviation from the Test Instruction must be noted in the test report.

5.2 Installation Conditions of Test Item

5.2.1 General

Test items can vary from materiel components to structural assemblies containing several different subassemblies. Consequently, the installation procedures need to take into account the following:

- The test item attachment should simulate actual in-service mounting attachments (including vibration isolators, and fastener torque, if appropriate);
- All the connections (cables, pipes, etc.) should be installed to impose stresses and strains on the test item similar to those encountered in service.

The following should also be considered:

- The possibility of exciting the test item simultaneously along several axes using more than one vibration generator;
- Materiel resonances;
- The direction of gravity or the load factor (mechanisms, vibration isolators, etc.) must be taken into account by compensation or by suitable simulation.

5.2.2 Test set-up

Unless otherwise specified, testing should be accomplished in three mutually perpendicular axes in turn with the test item oriented as during normal operation. The test item should be hard mounted directly to the vibrator using its normal mounting method and a suitable fixture. The stiffness of the mounting fixture should be such that its induced natural frequencies are as high as possible, and do not interfere with test item response.

Alternatively for large complex materiel, the test item may be suspended from a structural frame. In this case, the test set up shall be such that its rigid body modes (translation and rotation) are lower than the lowest test frequencies. Vibration shall be applied by means of a rod or suitable mounting device running from the vibrator to a relatively hard, structurally supported point on the surface of the test item.

Control instrumentation should be mounted as specified in the Test Instruction, or its location and mounting determined according to a procedure included in the Test Instruction.

The fixture should apply the excitation to the test item so as to simulate, as accurately as possible, the vibration transmitted in service.

5.2.3 Specific platform

The following instructions are also applicable:

a. Materiel transported as secured cargo:

   - Mount the test item securely in its transport configuration on the vibration fixture/table using restraints and tie-downs typical of those to be used during actual transport. Testing should be conducted using representative stacking configurations. The excitation should be applied through all representative axes. Materiel is not normally operated in this mode.

b. Materiel carried externally on aircraft:

   - Where practical, testing should be accomplished with the mounting lugs in the normal carriage position. Suspend the store from a structural frame by means of its normal mounting lugs, hooks, and sway braces that simulate the operational mounting apparatus.
   - Alternatively, the store may be hard-mounted directly to the exciter, using its normal mounting lugs and a suitable fixture.
   - For both methods, where applicable, launcher rails shall be used as part of the test set-up.
   - Instrumentation to monitor the vibratory response of the store should be mounted on at least two relatively hard points or rings within the store such as the nose section and in the aft section. For stores such as bombs with non-integral tail cones, the aft-section mounting point should be in the aft most section of the main body of the store. At each location, two accelerometers should be mounted, one in the vertical and one in the lateral plane. The longitudinal direction is along the axis of the store, the vertical direction is defined as perpendicular to the longitudinal axis, and contained in a plane passing through the mounting lugs.

c. Materiel installed in ships.

   - Materiel should be mounted in its normal configuration with normal shock/vibration isolation mounts used throughout the test.

5.3 Test Preparation

5.3.1 Pre-conditioning

The test item should be stabilized to its initial climatic and other conditions as stipulated in the Test Instruction. The total materiel temperature conditioning exposure duration time for the test program should be less than the life expectancy time of any component material. The total exposure time must be determined from the sum of the pre-conditioning time, plus any standby time, plus actual laboratory testing time. A total exposure duration greater than the materiel life limit can create an accelerated material failure mode or materiel degradation that is unrelated to the simulated environmental test condition. In particular, caution should be used during testing of energetic or chemically reactive materials that degrade under elevated temperature conditions.

To determine the total exposure time, consideration by the test program engineer is needed for each phase of evironmental testing, mechanical climatic and electrical, and any additional standby time prior to final operational or performance tests. Standby or pre-conditioning time, such as maintaining the item at conditioned temperature over a weekend, can have a significant impact. The actual test conditions concern the duration for high temperature storage and operational tests, high temperature soaks during vibration, and possibly solar radiation tests. AECTP 200 and STANAG 4570 provide further guidance on accelerated aging.

5.3.2 Operational Checks

All operational checks including all examinations should be undertaken as stipulated in the Test Instruction.

The final operational checks should be made after the materiel has been returned to rest under pre-conditioning conditions and thermal stability has been obtained.

5.4 Procedures

5.4.1 General

Conduct the following relevant procedure in accordance with the Test Instruction.

5.4.2 Procedure I - Swept Frequency Sinusoidal Vibration

Pre-condition (paragraph 5.3.1)

Step 1. Implement control strategy, including control and monitoring points (paragraph 2.6)

Step 2. Undertake initial operational checks (paragraph 5.3.2)

Step 3. Apply sinusoidal vibration, and carry out specified operation and functional checks (paragraph 5.3.2)

Undertake the final operational checks (paragraph 5.3.2)

Repeat steps 1 to 5 for the other specified axes

Record the information required

5.4.3 Procedure II - Fixed Frequency Sinusoidal Vibration

Step 1. Precondition (paragraph 5.3.1)

Step 2. Implement control strategy, including control and monitoring point (paragraph 2.6)

Step 3. Undertake initial operational checks (paragraph 5.3.2)

Step 4. Determine the fixed frequencies. These are either specified in the Test Instruction or obtained from the preliminary vibration survey procedure contained in the Test Instruction

Step 5. Apply the sinusoidal vibration to the test item and carry out the specified operational and functional checks (paragraph 5.3.2.)

Step 6. Undertake the final operational checks

Step 7. Repeat steps 3, 5, and 6 for other specified frequencies.

Step 8. Repeat steps 1 to 6 for other specified axes.

Step 9. Record the information required.

5.4.4 Procedure III - Random Vibration or Complex Vibration

Step 1. Pre-condition (paragraph 5.3.1)

Step 2. Implement control strategy including control and monitoring points (paragraph 2.6). This step is conducted at a low vibration level, or with a dynamically representative model of the test item.

Step 3 Undertake the initial checks (paragraph 5.3.2). The initial checks may include establishing the location of any critical frequencies.

Step 4 Subject the test item to the test severity specified, and conduct operational and functional checks specified (paragraph 5.3.2)

Step 5 Undertake the final checks (paragraph 5.3.2).

Step 6 Repeat Steps 1 to 5 for the other specified test axes.

Step 7 Record the information required.

5.4.5 Procedure IV - Random Vibration (Stores)

Step 1. Pre-condition (paragraph 5.3.1)

Step 2. Implement control strategy including control and monitoring points (paragraph 2.6). This step is first conducted at a low vibration level, or with a dynamically representative model of the store.

Step 3. Undertake initial checks (paragraph 5.3.2.). The initial checks may include establishing the location of any critical frequencies.

Step 4. Apply broadband vibration to the store using an input spectrum shape of the forward control accelerometer response spectrum. The input level shall be at least 6dB down from the calculated response level of the forward accelerometer. Identify those frequencies at which the response monitoring acceleration exceed the applied input, in the direction of applied vibration, by 6dB or greater. There may be different frequencies for the forward and aft accelerometers.

Peak or notch the applied input spectrum until both the forward and aft-mounted accelerometers in the directi

It may be necessary to move the points of attachment between the vibration exciter and the store until locations are found where both ends of the store are simultaneously excited to their respective test levels.

The off-axis accelerometer response (those accelerometers 90 degrees to the applied vibration) should be examined. For each frequency where the response of an off-axis accelerometer is above in-axis response level, the following actions are suggested. For each of these frequencies, calculate the ratio of required to observed levels for each accelerometer that is in the direction of vibration (in-axis) and those that are perpendicular (off-axis) accelerometers which have excessive levels.

Average these ratios for each frequency. The input vibration spectrum may then be adjusted so that, at each of these frequencies, the respective average value is equal to unity.

The method described above provides for single excitation. If the desired vibratory response cannot be achieved, multiple excitation may be applied.

Step 5 Undertake the final checks (para 5.3.2).

Step 6 Repeat Steps 1 to 5 for each test axis.

Step 7 Record the information required.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of vibration.

7. REFERENCES AND RELATED DOCUMENTS

a. International Test Operation Procedure (ITOP) 1-2-601, Laboratory Vibration Schedules, 23 April 1998.

b. International Test Operation Procedure (ITOP) 1-1-050, Development of Laboratory Vibration Schedules, 6 June 1997.

ANNEX A

WHEELED VEHICLE VIBRATION - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Wheeled Vehicle Test	Figure/Table	Page
Ground Wheeled Common Carrier	Figure A-1	25
Tactical Wheeled Vehicle – All Terrain	Figure A-2	27
Two Wheel Trailer	Figure A-3	30

Wheeled Vehicle Vibration Environment

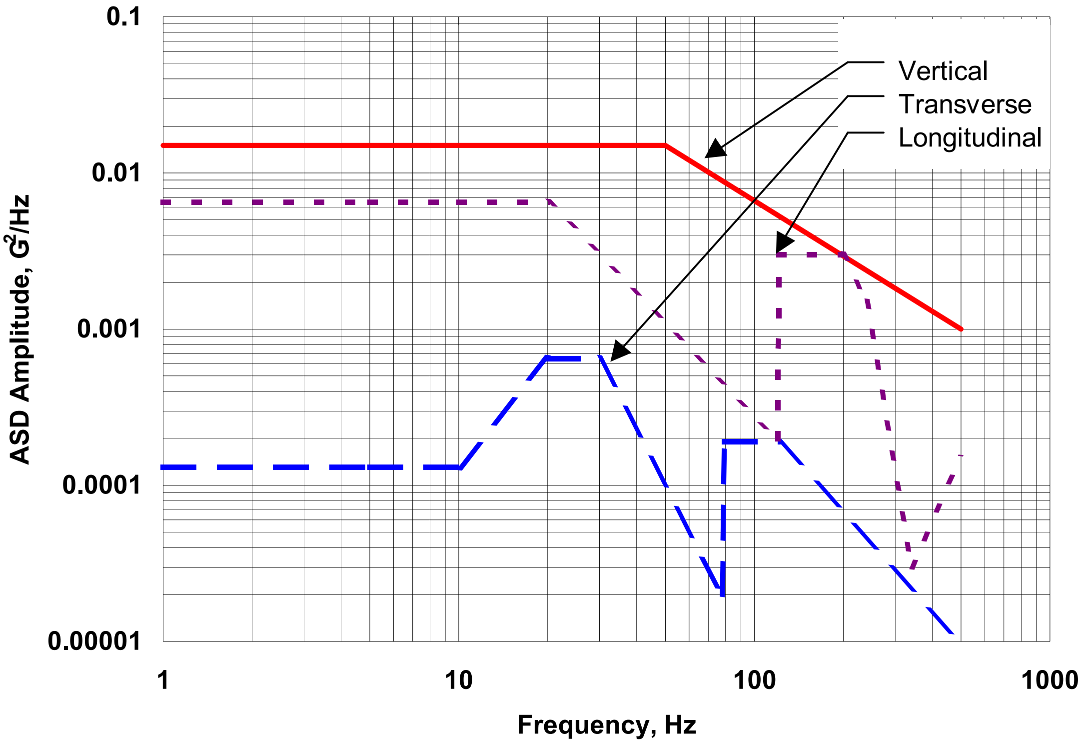
The wheeled vehicle environment is generally characterized by broadband random vibration resulting from the interaction of the vehicle suspension and structures with the road and surface discontinuities. A fully tailored vibration test is desirable that uses a vibration schedule based on current measured data from the specific vehicle and material. The wheeled vehicle and two-wheeled trailer vibration spectrum are predominantly a random spectrum with peaks and notches at discrete frequencies across the total spectrum. The environment can be simulated by a broadband random test. Annex A provides generic vibration test schedules for the common carrier, tactical wheeled, and two-wheel trailer vehicles. These schedules attempt to account for the wide statistical distribution in measured data due to conditions such as the road surface, vehicle condition, speed, and the driver. Modification of the vibration schedule exaggeration factor or test time is not recommended to account for test equipment or test scheduling time limitations. Further details of each Annex A vibration schedule is provided with the individual schedule.

The vibration simulation requires environments for ground transport regions from the point of equipment manufacture to the end use. For military applications this ground environment may be divided into two phases: common carrier transportation, and mission/field transportation. In the development of a specifc vibration test, the test plan must be developed from a typical mission/field transportation scenario to obtain a representative combination of transportation platforms and mileage requirements. It must be determined if materiel will experience the common carrier and/or mission/field transportation environments. Common carrier transportation is movement from the commercial manufacturer's plant to any storage or user installation on paved highway. Mission/field transportation is the movement of materiel from the common carrier termination point to the end-use location. The misssion/field transportation platform may consist of two wheeled trailers, 2-1/2 ton to 10-ton trucks, semi-trailers, and/or tracked vehicles. The nature of the terrain, vehicle speed, vehicle dynamic characteristics, and suspension loading affect the vibration response. In addition to paved roads or highways, the vehicles may traverse secondary unimproved roads and off-road unprepared terrain under combat conditions. The Annex A test schedules are representative of installed or secured cargo only where the material does not decouple from the transportation platform. For loosely restrained or unrestrained cargo transportation use AECTP 400 Method 406 Loose Cargo, Method 403 Classical Shock Restrained Cargo Shock procedure, or Method 408 for large assembly cargo transportation. The AECTP 200 Mechanical Conditions sections provide information to classify the vibration environment and determine an appropriate vibration test. Table A-1 summarizes the Annex A wheeled vehicle test schedules.

<u>Table A-1 Summary of Wheeled Vehicle Test Schedules</u>

Vehicle Type	Figure	Test Time, min.	Axis, Grms		
			V	T	L
Ground Wheeled Common Carrier	A-1	75	1.45	---	---
Ground Wheeled Common Carrier	A-1	180	---	0.21	0.76
Tactical Wheeled Vehicle – All Terrain	A-2	40	2.20	1.62	2.05
Two Wheeled Trailer	A-3	32	3.99	1.29	2.73

FIGURE A-1 GROUND WHEELED COMMON CARRIER



Common Carrier Schedule Breakpoints					
Vertical		**Transverse**		**Longitudinal**	
Hz	G^2/Hz	Hz	G^2/Hz	Hz	G^2/Hz
5	0.015	5	0.00013	5	0.00650
50	0.015	10	0.00013	20	0.00650
500	0.001	20	0.00065	120	0.00020
		30	0.00065	121	0.00300
		78	0.00002	200	0.00300
		79	0.00019	240	0.00150
		120	0.00019	340	0.00003
		500	0.00001	500	0.00015
Grms = 1.45		Grms = 0.21		Grms = 0.76	

Figure A-1 Ground Wheeled Common Carrier Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Vertical axis, 75 min. Transverse and Longitudinal Axis, 3 hours / axis
Equivalence Factor :	Vertical , 60 minutes / axis represents a 4000 km. (2486 mi.) distance Trans./ Long., 60 minutes / axis represents a 1609 km. (1000 mi.) distance
Vibration Spectrum :	Broadband (500 Hz) random vibration
Control Strategy :	Single or multi-point input control

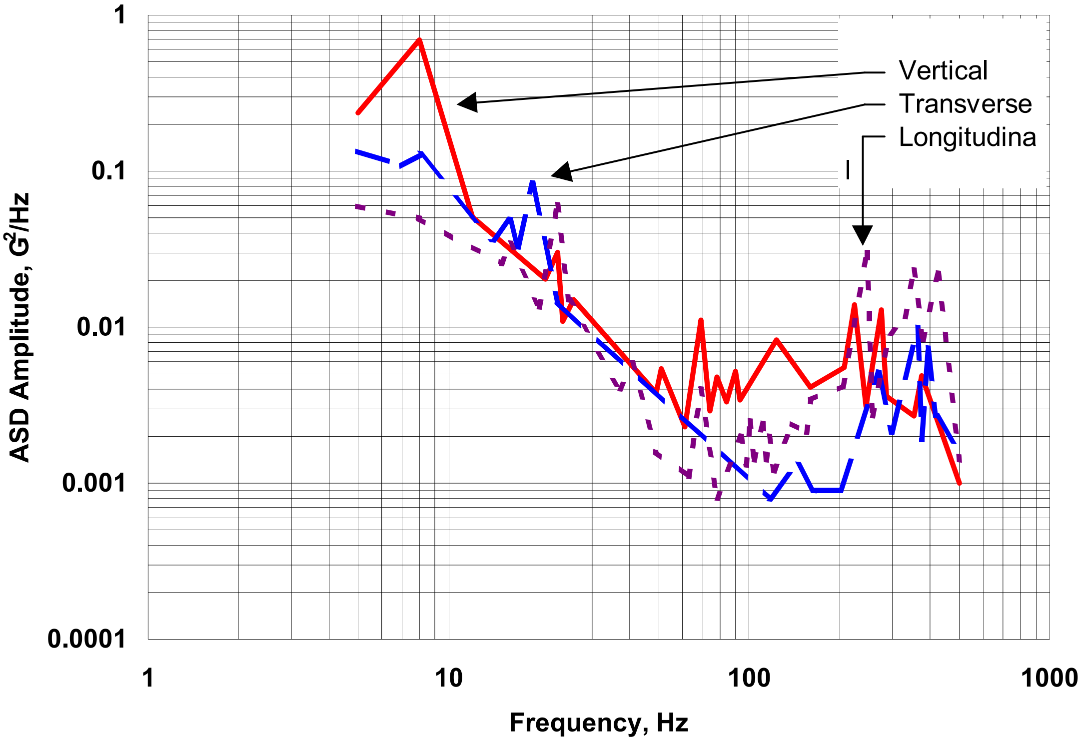
Control Notes :

1. Use the maximum control system roll-off rate at the 5 and 500 Hz breakpoints.
2. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.
3. The standard test bandwidth, 5 to 500 Hz, is indicated in the breakpoint table. For vehicles or test items with known vibration environments or resonances below 5 Hz, extend the low frequency breakpoint below 5 Hz at a flat ASD level.

Schedule Description

The Figure A-1 test schedules depict the test severity at the cargo bed of a composite of wheeled common carrier vehicles. Transportation of secured cargo on the bed area of a truck during cross country highway transportation is the typical environment. The vertical axis is up from the ground (truck cargo bed), transverse is perpendicular across the roadway, and longitudinal is parallel to the roadway. These curves are based upon data measured at the cargo bed of different configurations of single and multiple axle trucks and tractor-trailer combinations. Both conventional leaf-spring suspensions and air-cushioned suspensions are represented. The data were collected from typical highways with rough highway sections as part of the database. The vehicle data also includes variation in vibration amplitude levels due to the truck load capacity percentage. The test schedules are a worst case envelope of the measured data. An exaggeration factor has been applied to the measured data to increase the ASD amplitude and decrease the laboratory simulation test duration. In general, as illustrated in the figure, the vertical axis vibration is highest at low frequencies due to sprung and unsprung mass vibration. The longitudinal and transverse are respectively lower amplitude, in the low frequency band and higher amplitude at higher frequency where structural frame member resonance and harmonics occurs. The specific cargo area with the most severe vibration is a function of several factors. Figure A-1 is developed from the Def Stan 0035 and MIL-STD 810.

FIGURE A-2 TACTICAL WHEELED VEHICLE - ALL TERRAIN



See Schedule Breakpoints on the Reverse Side of the Page

Figure A-2 Tactical Wheeled Vehicle Schedule Breakpoints

Vertical		Transverse		Longitudinal	
Hz	G^2/Hz	Hz	G^2/Hz	Hz	G^2/Hz
5	0.2366	5	0.1344	5	0.0593
8	0.6889	7	0.1075	8	0.0499
12	0.0507	8	0.1279	15	0.0255
21	0.0202	14	0.0366	16	0.0344
23	0.0301	16	0.0485	20	0.0134
24	0.0109	17	0.0326	23	0.0608
26	0.0150	19	0.0836	25	0.0148
49	0.0038	23	0.0147	37	0.0040
51	0.0054	116	0.0008	41	0.0059
61	0.0023	145	0.0013	49	0.0016
69	0.0111	164	0.0009	63	0.0011
74	0.0029	201	0.0009	69	0.0040
78	0.0048	270	0.0051	78	0.0008
84	0.0033	298	0.0021	94	0.0020
90	0.0052	364	0.0099	98	0.0013
93	0.0034	375	0.0019	101	0.0025
123	0.0083	394	0.0073	104	0.0014
160	0.0041	418	0.0027	111	0.0024
207	0.0055	500	0.0016	114	0.0014
224	0.0139			117	0.0020
245	0.0031			121	0.0012
276	0.0129			139	0.0024
287	0.0036			155	0.0021
353	0.0027			161	0.0034
375	0.0049			205	0.0042
500	0.0010			247	0.0303
				257	0.0027
				293	0.0092
				330	0.0116
				353	0.0231
				379	0.0083
				427	0.0220
				500	0.0014
Grms = 2.20		Grms = 1.62		Grms = 2.05	

Figure A-2 Tactical Wheeled Vehicle – All Terrain Test Description

Test Parameters :

Test Axis : Vertical, Transverse, and Longitudinal

Test Duration : 40 minutes / axis

Equivalence Factor : 40 minutes / axis represents a 500 mi. (805 km.) distance

Vibration Spectrum : Broadband (500 Hz) random vibration

Control Strategy : Single or multi-point input control

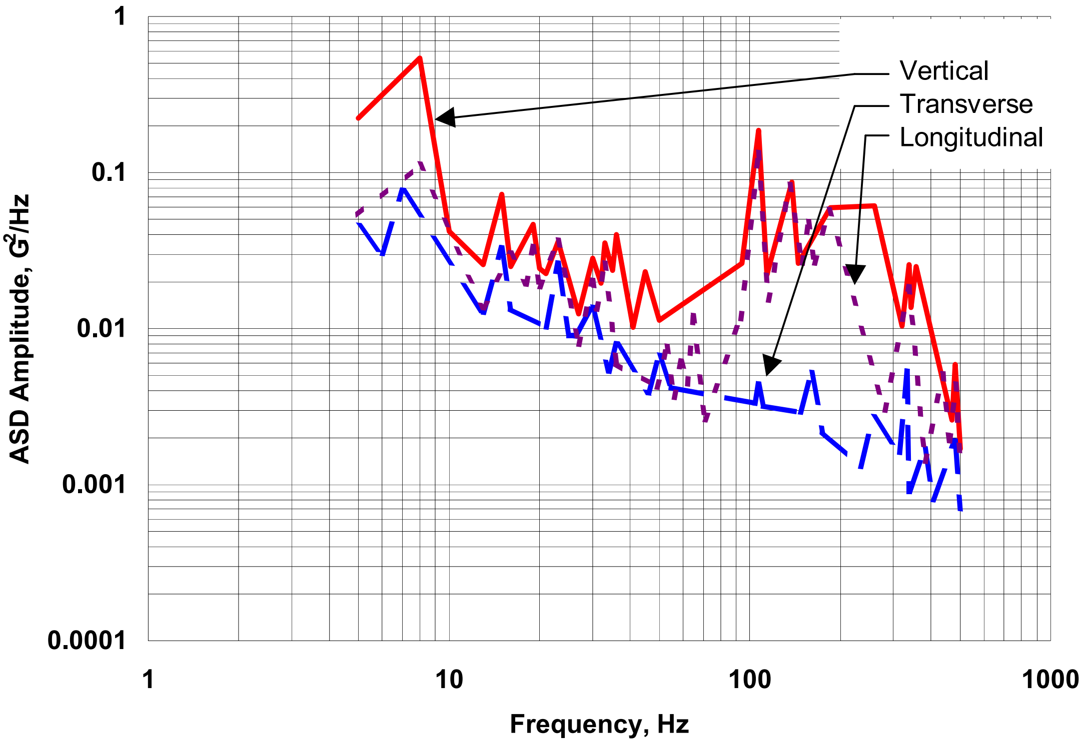
Control Notes :

1. Use the maximum control system roll-off rate at the 5 and 500 Hz breakpoints.
2. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure A-2 schedules represent the test severity at the cargo bed of a composite of tactical wheeled military vehicles. Transportation of secured cargo on the vehicle bed area over cross-country unimproved roads is the typical environment. The vertical axis is up from the ground (vehicle cargo bed), transverse is perpendicular across the road, and longitudinal is parallel to the road. The test schedules are based upon data measured at multiple locations of the cargo bed of different configurations of single and multiple axle trucks and tractor-trailer combinations. The test vehicle load capacity ratings ranged from 1-1/2 to 12 tons. The data were collected from vehicle operation over terrain representative of military operations. These road terrains include cobblestone, sinusoidal washboard, and spaced bump road surface irregularities. Data measurements were conducted at multiple speeds up to the maximum safe vehicle operational speed, and with the cargo area loaded to 75% of rated capacity for cross-country conditions. To obtain the final test schedule the data were processed by combination of terrain types and measurement locations in each axis to provide a conservative estimate of the expected environment vibration amplitude. An exaggeration factor has been applied to the measured data to increase the ASD amplitude and decrease the laboratory simulation test duration. Because cross-country operation is the most severe military wheeled vehicle operational environment, these schedules are an envelope of the worst case in-service field vibration. The test schedules are not representative of the lower amplitude vibration for vehicle operation limited to paved and/or secondary roads. The test may also not accurately represent the installed equipment vibration for material mounted in locations other than the cargo area. See ITOP 1-2-601 for additional wheeled vehicle vibration test schedules. Figure A-2 is developed from ITOP 1-2-601 and other data sources.

FIGURE A-3 TWO WHEEL TRAILER



See Schedule Breakpoints on the Reverse Side of the Page

Figure A-3 Two Wheel Trailer Schedule Breakpoints

Vertical		**Transverse**		**Longitudinal**	
Hz	G^2/Hz	Hz	G^2/Hz	Hz	G^2/Hz
5	0.2221	5	0.0451	5	0.0536
8	0.5432	6	0.0303	8	0.1129
10	0.0420	7	0.0761	13	0.0137
13	0.0256	13	0.0127	16	0.0303
15	0.0726	15	0.0327	18	0.0193
16	0.0249	16	0.0134	19	0.0334
19	0.0464	21	0.0102	20	0.0184
20	0.0243	23	0.0261	23	0.0369
21	0.0226	25	0.0090	27	0.0079
23	0.0362	26	0.0090	30	0.0203
27	0.0124	30	0.0137	31	0.0133
30	0.0282	34	0.0053	33	0.0261
32	0.0195	36	0.0079	36	0.0060
33	0.0353	46	0.0039	49	0.0042
35	0.0237	50	0.0067	53	0.0077
36	0.0400	55	0.0042	56	0.0036
41	0.0102	104	0.0033	59	0.0062
45	0.0232	107	0.0044	62	0.0044
50	0.0113	111	0.0032	65	0.0121
94	0.0262	147	0.0029	71	0.0026
107	0.1866	161	0.0052	93	0.0115
114	0.0220	175	0.0022	107	0.1344
138	0.0864	233	0.0013	115	0.0151
145	0.0262	257	0.0027	136	0.0836
185	0.0595	314	0.0016	149	0.0261
260	0.0610	333	0.0053	157	0.0485
320	0.0104	339	0.0009	164	0.0261
339	0.0256	382	0.0017	183	0.0577
343	0.0137	406	0.0008	281	0.0030
357	0.0249	482	0.0019	339	0.0184
471	0.0026	500	0.0007	382	0.0014
481	0.0059			439	0.0051
500	0.0017			462	0.0019
				485	0.0044
				500	0.0014
Grms = 3.99		Grms = 1.29		Grms = 2.73	

Figure A-3 Two Wheel Trailer Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	32 minutes / axis
Equivalence Factor :	32 minutes / axis represents a 32 mi. (52 km.) distance
Vibration Spectrum :	Broadband (500 Hz) random vibration
Control Strategy :	Single or multi-point input control

Control Notes :

1. Use the maximum control system roll-off rate at the 5 and 500 Hz breakpoints.
2. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.
3. The acceleration amplitude of the vertical axis vibration requires a high displacement exciter capability, approximately 2.6 inch pk-pk displacement. If an servo-hydraulic test system is used that is not capable of adequate high frequency simulation, then the test may be performed in two steps by using two exciters with adjacent frequency ranges. The test duration for each axis shall be used on each test systems. Alternatively, performance of the test on test systems with inadequate displacement by attenuation of the low frequency ASD amplitude requires an authorization from the test requesting agency to perform the vibration test.

Schedule Description

The Figure A-3 schedules represent the test severity at the cargo bed of a composite of two-wheeled vehicle towed trailers. Transportation of secured cargo on the trailer bed area over cross-country unimproved roads is the typical environment. The vertical axis is up from the ground (trailer cargo bed), transverse is perpendicular across the road, and longitudinal is parallel to the road. These curves are based upon data measured at multiple locations of the cargo bed of different configurations of single axle two-wheel trailers. The test trailer load capacity ratings ranged from 1/4 to 1-1/2 ton. The data were collected from trailer operation over terrain representative of military operations. These road terrains include cobblestone, sinusoidal washboard, and spaced bump road surface irregularities. Data measurements were conducted at multiple speeds up to the maximum safe vehicle operational speed, and with the cargo area loaded to 75% of rated capacity for cross-country conditions. To obtain the final test schedule the data were processed by combination of terrain types and measurement locations in each axis to provide a conservative estimate of the expected environment vibration amplitude. An exaggeration factor has not been applied to the measured data. Because cross-country operation is the most severe military wheeled trailer operational environment, these schedules are an envelope of the worst case in-service field vibration. The test schedules are not representative of the lower amplitude vibration for trailer operation limited to paved and/or secondary roads. Figure A-2 is developed from ITOP 1-2-601

ANNEX B

TRACKED VEHICLE VIBRATION - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Tracked Vehicle Vibration Environment

The tracked vehicle environment is a complex random vibration environment that is a broadband random background with a strong influence of higher energy narrowband random vibration created by the interaction of the track with the ground surface, roadwheels, and the vehicle drive sprockets. A swept frequency narrow band random on wide band random vibration can best simulate this environment. The measurement of field data is a requirement to accurately represent the swept narrow band characteristics of a specific vehicle, track type, and road surface. Annex A provides generic vibration test schedules for general vehicle locations and heavy or lightweight tracked vehicles. The most severe operational environment for tracked vehicles is hard paved road, thus these schedules are an envelope of the worst case in-service field vibration. The test schedules are not representative of lower amplitude vibration for vehicle operation limited to resilient roadway surfaces. These schedules attempt to account for the wide statistical distribution in measured data due to conditions such as the road surface, vehicle condition, speed, and the driver. Modification of the vibration schedule exaggeration factor or test time is not recommended to account for test equipment or test scheduling time limitations. The field test data reduction assumes a Gaussian random vibration environment that may not be applicable for all tracked vehicles or equipment locations. Further details of each Annex A vibration schedule is provided with the individual schedule.

The vibration simulation requires environments for ground transport regions from the point of equipment manufacture to the end use. For military applications this ground environment may be divided into two phases: common carrier transportation, and mission/field transportation. In the development of a specifc vibration test, the test plan must be developed from a typical mission/field transportation scenario to obtain a representative combination of transportation platforms and mileage requirements. It must be determined if materiel will experience the common carrier and/or mission/field transportation environments. Common carrier transportation is movement from the commercial manufacturer's plant to any storage or user installation on paved highway. Mission/field transportation is the movement of materiel from the common carrier termination point to the end-use location. The misssion/field transportation platform may consist of two wheeled trailers, 2-1/2 ton to 10-ton trucks, semi-trailers, and/or tracked vehicles. The nature of the terrain, vehicle speed, vehicle dynamic characteristics, and suspension loading affect the vibration response. In addition to paved roads or highways, the vehicles may traverse secondary unimproved roads and off-road unprepared terrain under combat conditions. The Annex B test schedules are representative of installed or secured cargo only where the material does not decouple from the transportation platform. For loosely restrained or unrestrained cargo transportation use AECTP 400 Method 406 Loose Cargo, Method 403 Classical Shock Restrained Cargo Shock procedure, or Method 408 for large assembly cargo transportation. The AECTP 200 Mechanical Conditions sections provide information to classify the vibration environment and determine an appropriate vibration test. Table B-1 summarizes the Annex B tracked vehicle test schedules.

Table B-1 Summary of Tracked Vehicle Test Schedules

Vehicle Type and Materiel Location	Figure	Test Time, hr	Axis, Grms		
			V	T	L
Material Transported as Secured Cargo	B-1	2	4.65	3.70	3.70
Materiel in Turret Bustle Rack or Installed in Turret	B-2	4	4.20	3.42	3.42
Heavy Vehicle – Materiel on Sponson or Installed in Hull	B-3	4	4.65	3.70	3.70
Light Vehicle – Materiel on Sponson or Installed in Hull	B-4	4	5.93	4.79	4.79

FIGURE B-1 MATERIEL TRANSPORTED AS SECURED CARGO

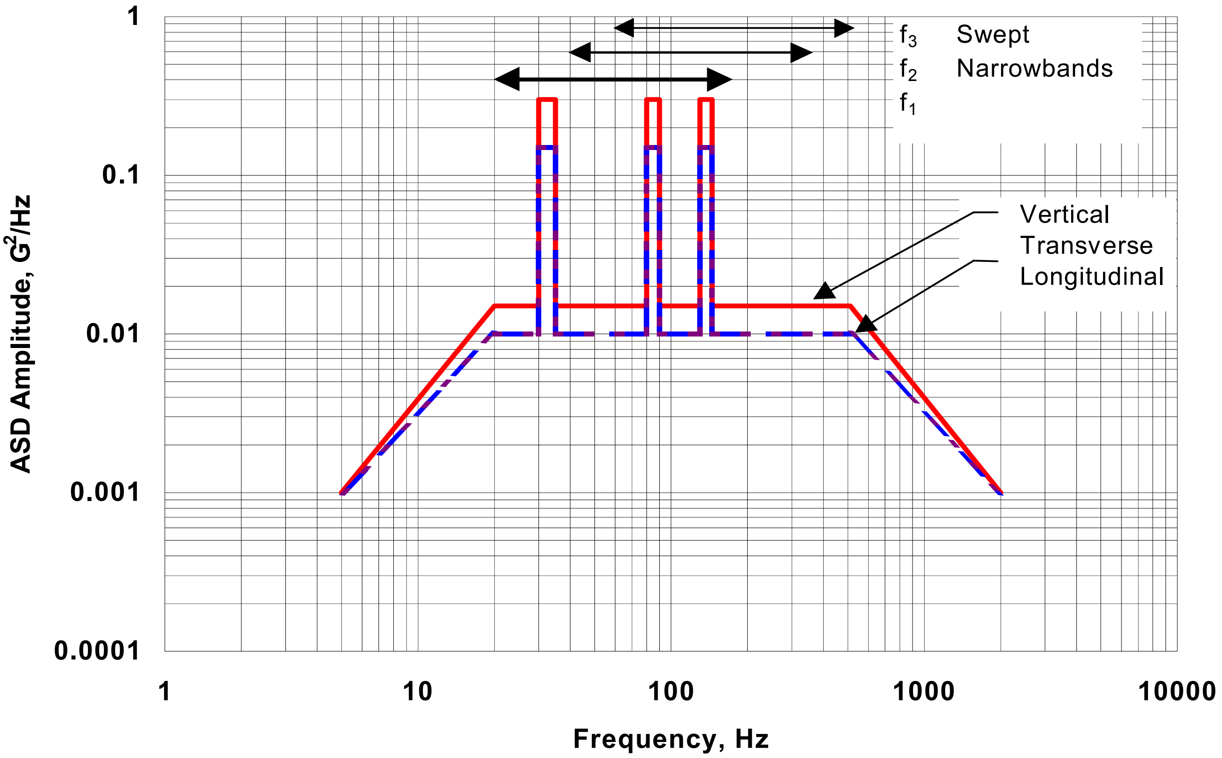


Figure B-1 Tracked Vehicle Schedule Breakpoints

Wideband Random Spectrum			
Frequency, Hz	Axis, ASD Amplitude G^2/Hz		
	V	T	L
5	0.001	0.001	0.001
20	0.015	0.010	0.010
510	0.015	0.010	0.010
2000	0.001	0.001	0.001
Wideband Grms	3.56	3.03	3.03
Total Grms	4.65	3.70	3.70

Harmonic Swept Narrowbands			
Narrowband	f_1	f_2	f_3
Bandwidth, Hz	5	10	15
Swept BW, Hz	20 - 170	40 - 340	60 – 510
# Sweeps	2	2	2
Axis	ASD Amplitude, G^2/Hz		
Vertical	0.30	0.30	0.30
Transverse	0.15	0.15	0.15
Longitudinal	0.15	0.15	0.15

Figure B-1 Materiel Transported as Secured Cargo Test Description

Test Parameters :

Test Axis : Vertical, Transverse, and Longitudinal

Test Duration : 2 hours / axis

Equivalence Factor : 45 minutes / axis represents a 160 km. (99 mi.) distance

Vibration Spectrum : Swept narrowband random on broadband random vibration(NBROR)

Control Strategy : Single or multi-point input control

Control Notes :

1. The sweep rate should be within the range of one-half to one octave per minute. The minimum 2 sweeps is one sweep up the bandwidth, followed by one sweep down the bandwidth. When the center frequency of the first narrowband, f_1, is at its lowest frequency, the lower frequency band edge of this narrowband, and the lower band edge of the wideband 0.015 g^2/Hz level (for the vertical axis) coincide at 20 Hz. When the center frequency of the third narrowband, $f_{3,}$ is at its highest frequency, the upper band edge of this narrowband, and the upper band edge of the wideband 0.015 g^2/Hz level (for the vertical axis), coincide at 510 Hz
2. The f_1 narrowband amplitude may be ramped up from 0.08 G^2/Hz at 20 Hz to the full amplitude at 40 Hz when sweeping up the bandwidth if required due to vibration test system displacement limitations. The reverse is allowable when sweeping down the bandwidth.
3. Use the maximum control system roll-off rate at the 5 and 2000 Hz breakpoints.
4. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure B-1 schedule represents the test severity for secured cargo transported in a composite of military tracked vehicles. Transportation of secured cargo directly in the hull, or crew compartments over paved roads roads is the typical environment. The vertical axis is up from the ground, transverse is perpendicular across the roadway, and longitudinal is parallel to the roadway. These curves are based upon data measured at multiple locations of the vehicle for multiple tracked vehicles. The tracked vehicle loaded weights ranged from 20 to 60 tons. The data were collected from vehicle operation over terrain representative of military operations. These road terrains include paved road, cobblestone, sinusoidal washboard, and spaced bump road surface irregularities. Data measurements were conducted at multiple speeds up to the maximum safe vehicle operational speed, and with the cargo area loaded to 75% of rated capacity. To obtain the final test schedule the data were processed by combination of terrain types and measurement locations in each axis to provide a conservative estimate of the expected environment vibration amplitude. An exaggeration factor has been applied to the measured data to increase the ASD amplitude and decrease the laboratory simulation test duration. See ITOP 1-2-601 for additional tracked vehicle vibration test schedules. Figure B-1 is developed from STANAG 4242 .

FIGURE B-2 MATERIEL IN TURRET BUSTLE RACK OR INSTALLED IN TURRET

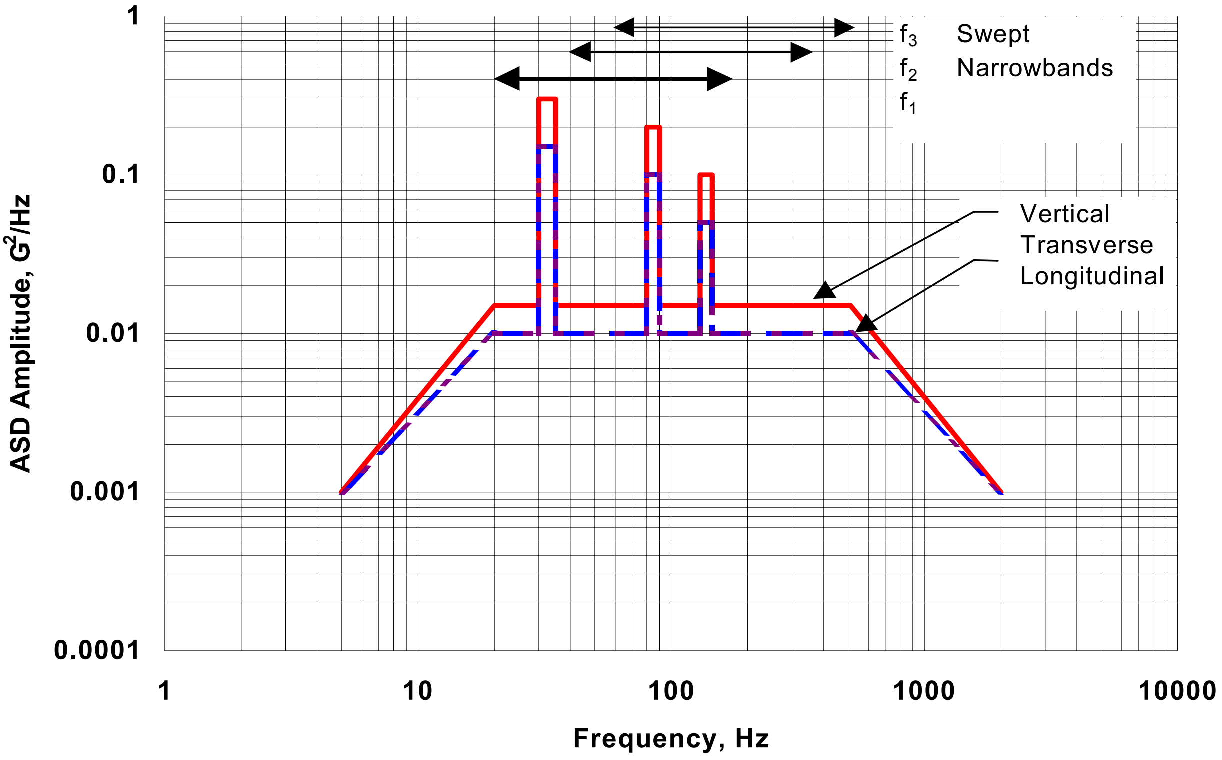


Figure B-2 Tracked Vehicle Schedule Breakpoints

Wideband Random Spectrum			
Frequency, Hz	Axis, ASD Amplitude G^2/Hz		
	V	T	L
5	0.001	0.001	0.001
20	0.015	0.010	0.010
510	0.015	0.010	0.010
2000	0.001	0.001	0.001
Wideband Grms	3.56	3.03	3.03
Total Grms	4.20	3.42	3.42

Harmonic Swept Narrowbands			
Narrowband	f_1	f_2	f_3
Bandwidth, Hz	5	10	15
Swept BW, Hz	20 - 170	40 - 340	60 – 510
# Sweeps	2	2	2
Axis	ASD Amplitude, G^2/Hz		
Vertical	0.30	0.20	0.10
Transverse	0.15	0.10	0.05
Longitudinal	0.15	0.10	0.05

Figure B-2 Materiel in Turret Bustle Rack or Installed in Turret Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	4 hours / axis
Equivalence Factor :	45 minutes / axis represents a 1600 km. (994 mi.) distance
Vibration Spectrum :	Swept narrowband random on broadband random vibration(NBROR)
Control Strategy :	Single or multi-point input control

Control Notes :

1. The sweep rate should be within the range of one-half to one octave per minute. The minimum 2 sweeps is one sweep up the bandwidth, followed by one sweep down the bandwidth. When the center frequency of the first narrowband, f_1, is at its lowest frequency, the lower frequency band edge of this narrowband, and the lower band edge of the wideband 0.015 g^2/Hz level (for the vertical axis) coincide at 20 Hz. When the center frequency of the third narrowband, $f_{3,}$ is at its highest frequency, the upper band edge of this narrowband, and the upper band edge of the wideband 0.015 g^2/Hz level (for the vertical axis), coincide at 510 Hz
2. The f_1 narrowband amplitude may be ramped up from 0.08 G^2/Hz at 20 Hz to the full amplitude at 40 Hz when sweeping up the bandwidth if required due to vibration test system displacement limitations. The reverse is allowable when sweeping down the bandwidth.
3. Use the maximum control system roll-off rate at the 5 and 2000 Hz breakpoints.
4. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure B-2 schedules represent the test severity for materiel transported or installed in the turret of a composite of military tracked vehicles. Transportation of materiel, equipment, or ammunition in the vehicle turret over paved roads roads is the typical environment. The vertical axis is up from the ground, transverse is perpendicular across the roadway, and longitudinal is parallel to the roadway. These curves are based upon data measured at multiple locations of the vehicle hull, and cargo compartments for multiple tracked vehicles. The tracked vehicle loaded weights ranged from 20 to 60 tons. The data were collected from vehicle operation over terrain representative of military operations. These road terrains include paved road, cobblestone, sinusoidal washboard, and spaced bump road surface irregularities. Data measurements were conducted at multiple speeds up to the maximum safe vehicle operational speed, and with the cargo area loaded to 75% of rated capacity. To obtain the final test schedule the data were processed by combination of terrain types and measurement locations in each axis to provide a conservative estimate of the expected environment vibration amplitude. An exaggeration factor has been applied to the measured data to increase the ASD amplitude and decrease the laboratory simulation test duration. See ITOP 1-2-601 for additional tracked vehicle vibration test schedules. Figure B-2 is developed from STANAG 4242 .

FIGURE B-3 HEAVY VEHICLE – MATERIEL ON SPONSON OR INSTALLED IN HULL

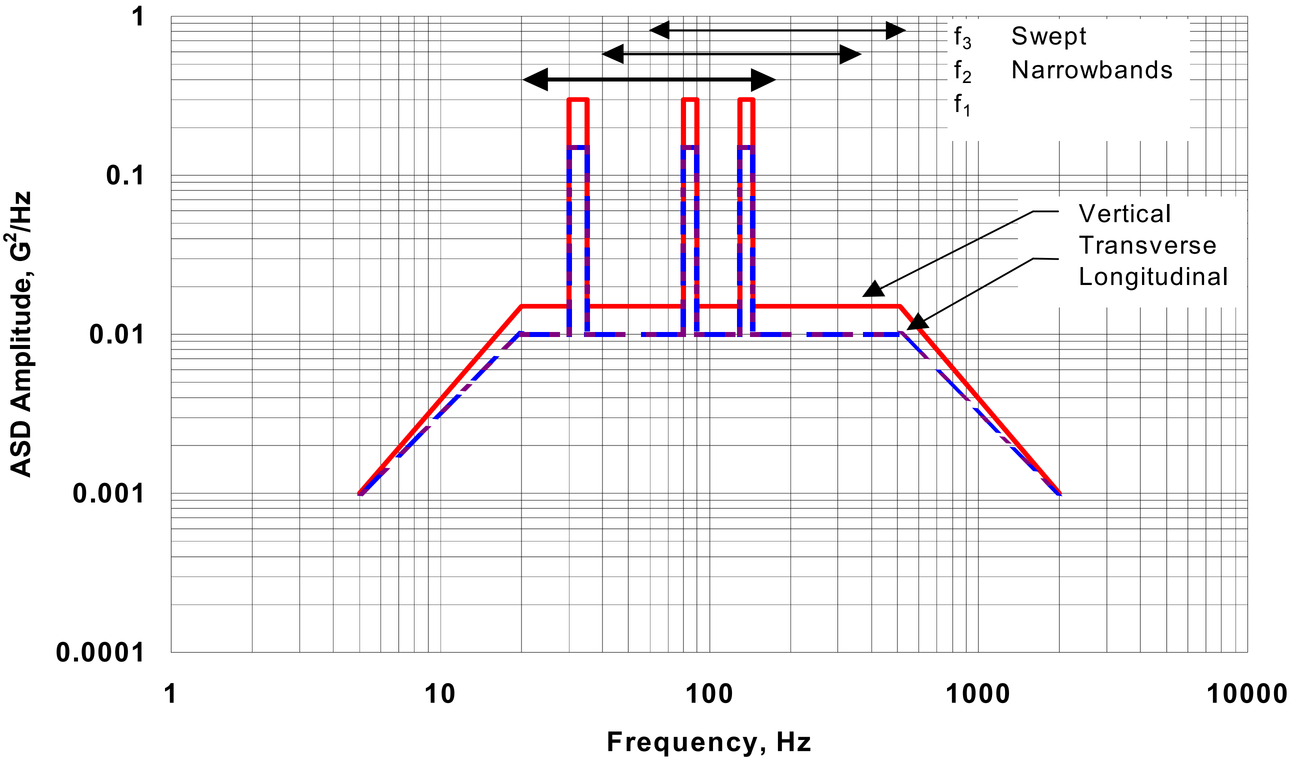


Figure B-3 Tracked Vehicle Schedule Breakpoints							
Wideband Random Spectrum				**Harmonic Swept Narrowbands**			
Frequency, Hz	Axis, ASD Amplitude G^2/Hz			Narrowband	f_1	f_2	f_3
	V	T	L	Bandwidth, Hz	5	10	15
5	0.001	0.001	0.001	Swept BW, Hz	20 - 170	40 - 340	60 – 510
20	0.015	0.010	0.010	# Sweeps	2	2	2
510	0.015	0.010	0.010				
2000	0.001	0.001	0.001	Axis	ASD Amplitude, G^2/Hz		
				Vertical	0.30	0.30	0.30
Wideband Grms	3.56	3.03	3.03	Transverse	0.15	0.15	0.15
Total Grms	4.65	3.70	3.70	Longitudinal	0.15	0.15	0.15

Figure B-3 Heavy Vehicle- Materiel on Sponson or Installed in Hull Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	4 hours / axis
Equivalence Factor :	45 minutes / axis represents a 1600 km. (994 mi.) distance
Vibration Spectrum :	Swept narrowband random on broadband random vibration(NBROR)
Control Strategy :	Single or multi-point input control

Control Notes :

1. The sweep rate should be within the range of one-half to one octave per minute. The minimum 2 sweeps is one sweep up the bandwidth, followed by one sweep down the bandwidth. When the center frequency of the first narrowband, f_1, is at its lowest frequency, the lower frequency band edge of this narrowband, and the lower band edge of the wideband 0.015 g^2/Hz level (for the vertical axis) coincide at 20 Hz. When the center frequency of the third narrowband, $f_{3,}$ is at its highest frequency, the upper band edge of this narrowband, and the upper band edge of the wideband 0.015 g^2/Hz level (for the vertical axis), coincide at 510 Hz
2. The f_1 narrowband amplitude may be ramped up from 0.08 G^2/Hz at 20 Hz to the full amplitude at 40 Hz when sweeping up the bandwidth if required due to vibration test system displacement limitations. The reverse is allowable when sweeping down the bandwidth.
3. Use the maximum control system roll-off rate at the 5 and 2000 Hz breakpoints.
4. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure B-3 schedules represent the test severity for materiel transported in the hull compartment or on sponsons of a composite of heavy military tracked vehicles. Transportation of materiel installed or restrained in racks directly in the hull, hull racks, or in the vehicle sponson racks over paved roads roads is the typical environment. The vertical axis is up from the ground, transverse is perpendicular across the roadway, and longitudinal is parallel to the roadway. These curves are based upon data measured at multiple locations of the vehicle hull, and cargo compartments for multiple tracked vehicles. The typical representative tracked vehicle loaded weight is 60 tons such as for Leclerc, Challenger2, Leo2, and M1A2 tracked vehicles. The data were collected from vehicle operation over terrain representative of military operations. These road terrains include paved road, cobblestone, sinusoidal washboard, and spaced bump road surface irregularities. Data measurements were conducted at multiple speeds up to the maximum safe vehicle operational speed, and with the cargo area loaded to 75% of rated capacity. To obtain the final test schedule the data were processed by combination of terrain types and measurement locations in each axis to provide a conservative estimate of the expected environment vibration amplitude. An exaggeration factor has been applied to the measured data to increase the ASD amplitude and decrease the laboratory simulation test duration. See ITOP 1-2-601 for additional tracked vehicle vibration test schedules. Figure B-3 is developed from STANAG 4242 .

FIGURE B-4 LIGHT VEHICLE – MATERIEL ON SPONSON OR INSTALLED IN HULL

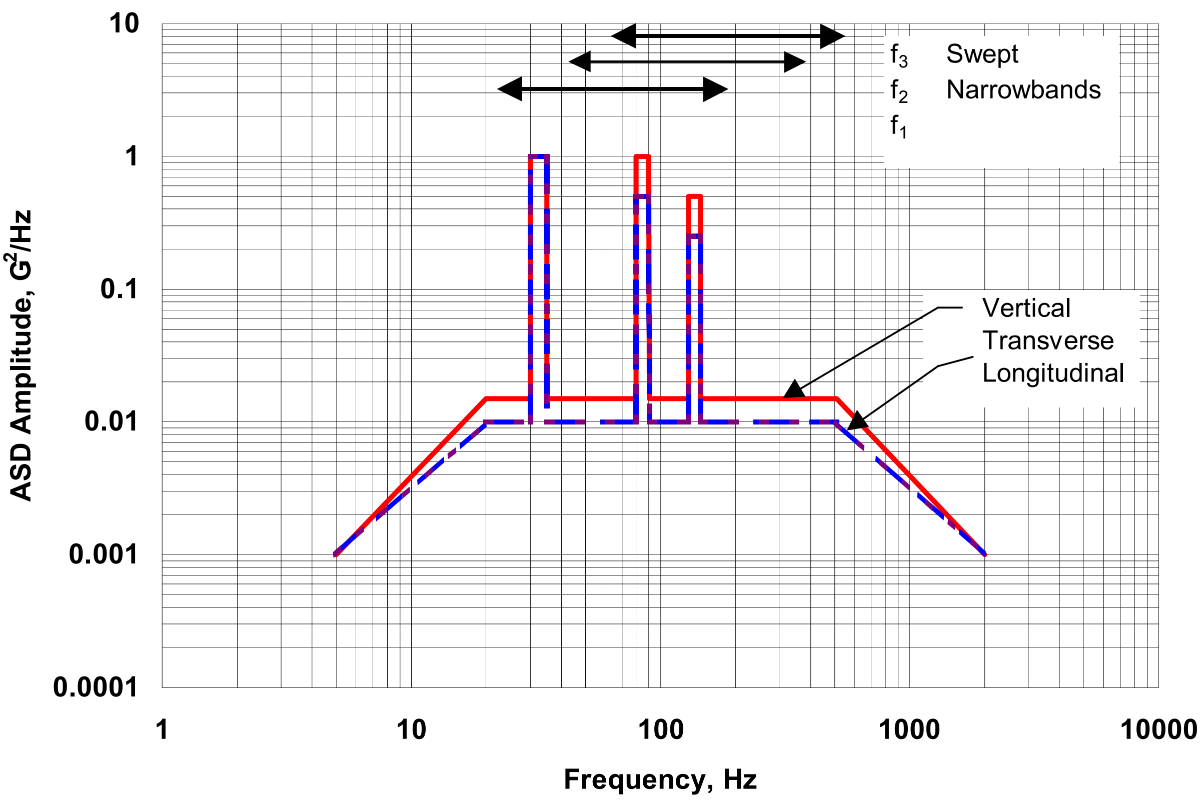


Figure B-4 Tracked Vehicle Schedule Breakpoints							
Wideband Random Spectrum				**Harmonic Swept Narrowbands**			
Frequency, Hz	Axis, ASD Amplitude G^2/Hz			Narrowband	f_1	f_2	f_3
	V	T	L	Bandwidth, Hz	5	10	15
5	0.001	0.001	0.001	Swept BW, Hz	20 - 170	40 - 340	60 – 510
20	0.015	0.010	0.010	# Sweeps	2	2	2
510	0.015	0.010	0.010				
2000	0.001	0.001	0.001	Axis	ASD Amplitude, G^2/Hz		
				Vertical	1.00	1.00	0.50
Wideband Grms	3.56	3.03	3.03	Transverse	1.00	0.50	0.25
Total Grms	5.93	4.79	4.79	Longitudinal	1.00	0.50	0.25

Figure B-4 Light Vehicle- Materiel on Sponson or Installed in Hull Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	4 hours / axis
Equivalence Factor :	45 minutes / axis represents a 1600 km. (994 mi.) distance
Vibration Spectrum :	Swept narrowband random on broadband random vibration(NBROR)
Control Strategy :	Single or multi-point input control

Control Notes :

1. The sweep rate should be within the range of one-half to one octave per minute. The minimum 2 sweeps is one sweep up the bandwidth, followed by one sweep down the bandwidth. When the center frequency of the first narrowband, f_1, is at its lowest frequency, the lower frequency band edge of this narrowband, and the lower band edge of the wideband 0.015 g^2/Hz level (for the vertical axis) coincide at 20 Hz. When the center frequency of the third narrowband, $f_{3,}$ is at its highest frequency, the upper band edge of this narrowband, and the upper band edge of the wideband 0.015 g^2/Hz level (for the vertical axis), coincide at 510 Hz

2. The f_1 narrowband amplitude may be ramped up from 0.08 G^2/Hz at 20 Hz to the full amplitude at 40 Hz when sweeping up the bandwidth if required due to vibration test system displacement limitations. The reverse is allowable when sweeping down the bandwidth.

3. Use the maximum control system roll-off rate at the 5 and 2000 Hz breakpoints.

4. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure B-4 schedules represent the test severity for materiel transported in the hull compartment or on sponsons of a composite of “lightweight” military tracked vehicles. Transportation of materiel installed or restrained in racks directly in the hull, hull racks, or in the vehicle sponson racks over paved roads roads is the typical environment. The vertical axis is up from the ground, transverse is perpendicular across the roadway, and longitudinal is parallel to the roadway. These curves are based upon data measured at multiple locations of the vehicle hull, and cargo compartments for multiple tracked vehicles. The typical representative tracked vehicle loaded weight is 25 tons such as for AMX30, Warrier, Marder, and M2A3 tracked vehicles. The data were collected from vehicle operation over terrain representative of military operations. These road terrains include paved road, cobblestone, sinusoidal washboard, and spaced bump road surface irregularities. Data measurements were conducted at multiple speeds up to the maximum safe vehicle operational speed, and with the cargo area loaded to 75% of rated capacity. To obtain the final test schedule the data were processed by combination of terrain types and measurement locations in each axis to provide a conservative estimate of the expected environment vibration amplitude. An exaggeration factor has been applied to the measured data to increase the ASD amplitude and decrease the laboratory simulation test duration. See ITOP 1-2-601 for additional tracked vehicle vibration test schedules. Figure B-4 is developed from STANAG 4242 .

ANNEX C

FIXED WING AIRCRAFT VIBRATION

GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Fixed Wing Aircraft Vibration Environment

Annex C provides general guidelines for the dynamic environment of fixed wing propeller and jet aircraft. Material exposed to aircraft gunfire is addressed separately in Method 405, and aircraft Buffet Vibration is included in AECTP 400 Method 420. The in-service vibration frequency spectra for materiel installed in propeller aircraft consists of a wideband random background with superimposed narrowband peaks. The wideband random spectrum results from various sources including aerodynamic flow, periodic, not pure sinusoidal, components, rotating elements, such as engines, gearboxes, and shafts associated with turbo-props. The main narrrowband peaks are produced by the passage of pressure fields rotating with the propeller blades. The narrowbands are centered on the propeller passage frequency (RPM x number of blades x 1/60) and the harmonics. Turbo-prop aircraft engines commonly have relatively constant-speed engines. The RPM is held constant and power changes are made through fuel flow changes and variable-pitch blades, vanes, and propellers. The narrowband peaks have an associated bandwidth because there is minor RPM drift and the vibration is not pure sinusoidal. Vibration simulation of this environment is typically accomplished with narrowband random on wideband random vibration methods.

The vibration environment for installed material and secured cargo on jet aircraft is a broadband random, typically 2000 Hz bandwidth, where the random amplitude is a function of several factors including airframe location, Mach number, and engine configuration. The vibration environment for materiel installed in jet aircraft originates from four principal mechanisms. These sources are :

a. Engine noise impinging on aircraft structures.

b. Turbulent aerodynamic flow over external aircraft structures.

c. Turbulent aerodynamic flow and acoustic resonance phenomena within cavities open to the external airflow, particularly open weapon bays.

d. Airframe structural motions due to maneuvers, aerodynamic buffet, landing, taxi, etc.

Similarly, the aircraft captive carried external store vibration is a broadband random vibration from a combination of mechanical vibration and acoustic excitation. The external store configuration is directly exposed to the ambient airflow during flight. Annex C does not address internal captive carriage vibration or internal bay cavity resonance excitation. Aircraft captive carried external store vibration originate from primarily four sources :

a. Engine noise

b. Aerodynamic boundary layer turbulence

c. Aircraft induced vibration

d. Buffet vibration excitation

For a single store the vibration is relatively independent of the carrying aircraft and mounting location on the aircraft, and is induced along the entire length of the store. For multiple stores, the consideration of aerodynamic flow and store configuration becomes more important. Annex C also provides guidance for the vibration environment of material mounted internal to an aircraft carried external store, and items mounted directly on aircraft engines. Further details of each Annex C vibration schedule is provided with the individual schedule.

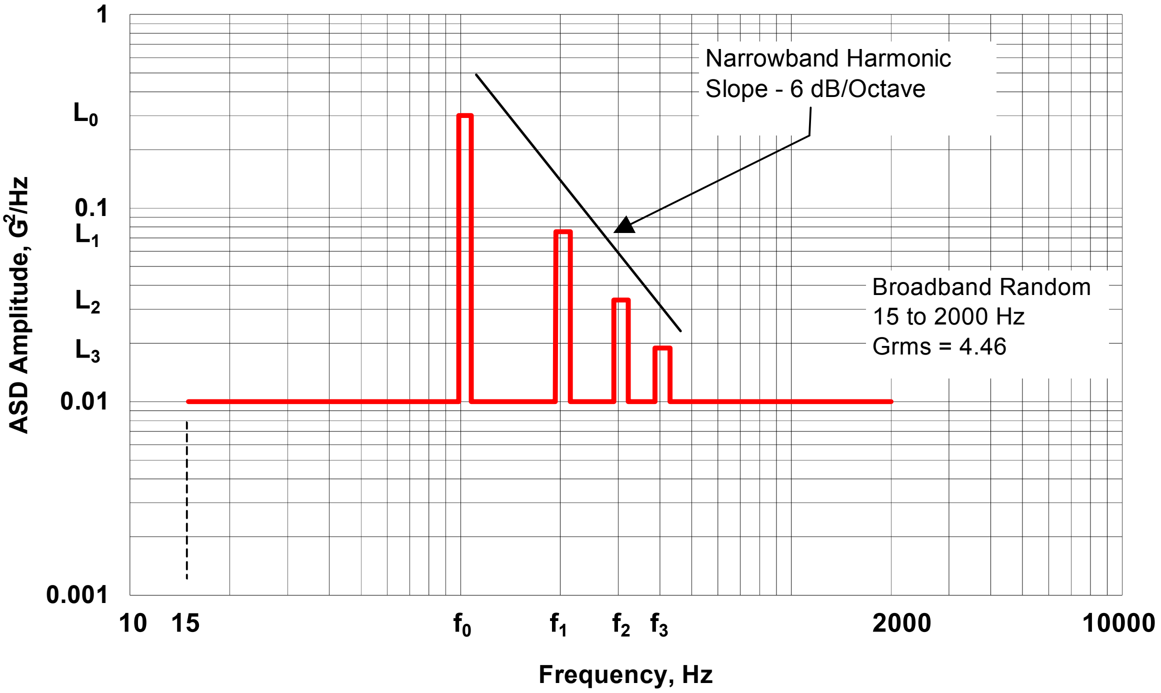


FIGURE C-1 PROPELLER AIRCRAFT

Propeller Aircraft Location and Narrowband Random Amplitudes	
Materiel Location	**Narrowband ASD, L_0 at f_0, G^2/Hz**
In fuselage or wing, forward of the propeller	0.10
In fuselage or wing, within one propeller blade radius of the propeller passage plane.	1.20
In fuselage or wing, aft of the propeller	0.30
In engine compartment, empennage, or pylons	0.60

Narrowband Notes :

1. Fundamental frequency = f_0, Hz (propeller RPM x number of blades x 1/60), Harmonic frequencies : $f_1 = 2f_0$, $f_2 = 3f_0$, $f_3 = 4f_0$.
2. For materiel mounted to the airframe external skin, increase the levels by + 3dB.

3. The narrowband random bandwidth is 10% of each f_i for constant speed excitation. When excitation is not constant speed, the bandwidth will encompass the operating speeds for cruise and high power operation.
4. C130 Aircraft : 3 blade, f_0 = 51 Hz, 4 blade, f_0 = 68 Hz, 5 Blade, f_0 = 102.Hz

Figure C-1 Propeller Aircraft Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	1 hour / axis
Equivalence Factor :	None
Vibration Spectrum :	Narrowband random on broadband random vibration (NBROR)
Control Strategy :	Single or multi-point input control

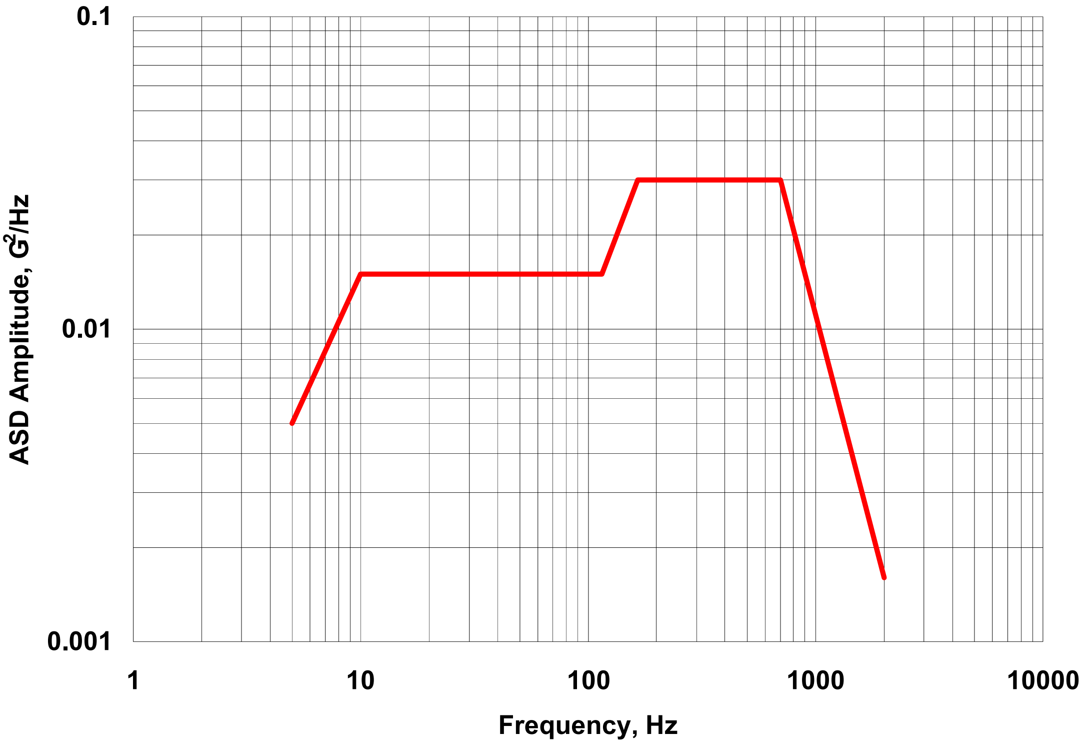
Control Notes :

1. Use the maximum control system roll-off rate at the 15 and 2000 Hz breakpoints.
2. The test schedule is derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure C-1 test schedule depicts the test severity for material installed in, or secured cargo located on, fixed wing propeller aircraft during normal flight operations. The figure provided is a general representation of the vibration environment due to structural and acoustic excitation from the engine, propeller, and the aerodynamic flow over the external aircraft. The location specific fundamental, propeller blade passage frequency, and harmonic narrowband amplitudes and frequencies are determined from the accompanying table. The test schedule is an envelope applicable for all three test axes (vertical, transverse, longitudinal) and was derived from vibration measurements on various C-130 and P-3 aircraft. The vibration spectrum presented is applicable for both a constant and variable propeller speed; however, tailoring of the narrowband amplitude, bandwidth, and sweep bandwidth based on measured data is desirable for variable speed propellers. The use of several NBROR spectrum, or swept bandwidths, to represent multiple engine operating conditions or speeds may be necessary. Typically the narrowband amplitude and swept bandwidth will be a function of the engine power output and the associated engine RPM for each operating condition such as take-off, maximum power, cruise, and engine idle. Figure C-1 is not representative of severe vibration due to aircraft combat maneuvers. The narrowband amplitudes provided may not be applicable for all locations on C-130J aircraft; some C-130J aircraft locations have narrowband harmonic amplitudes that are approximately flat; the harmonics do not roll off at 6 dB/Octave. Use measured C130J aircraft data for this requirement. Figure C-1 may not be applicable for all material carried as secured cargo on the floor of the aircraft. The vibration spectrum for this environment is similar to that presented; however measurement of flight data is suggested to tailor the low frequency response and package to airframe coupling characteristics. Figure C-1 is developed from MIL-STD 810.

FIGURE C-2 JET AIRCRAFT CARGO - TAKEOFF



Jet Aircraft Cargo - Takeoff Schedule, All Axes	
Frequency, Hz	ASD, G^2/Hz
5	0.005
10	0.015
115	0.015
165	0.030
700	0.030
2000	0.0016
Total Grms = 5.36	

Figure C-2 Jet Aircraft Cargo - Takeoff Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	1 minute / axis represents one jet aircraft takeoff
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point input control

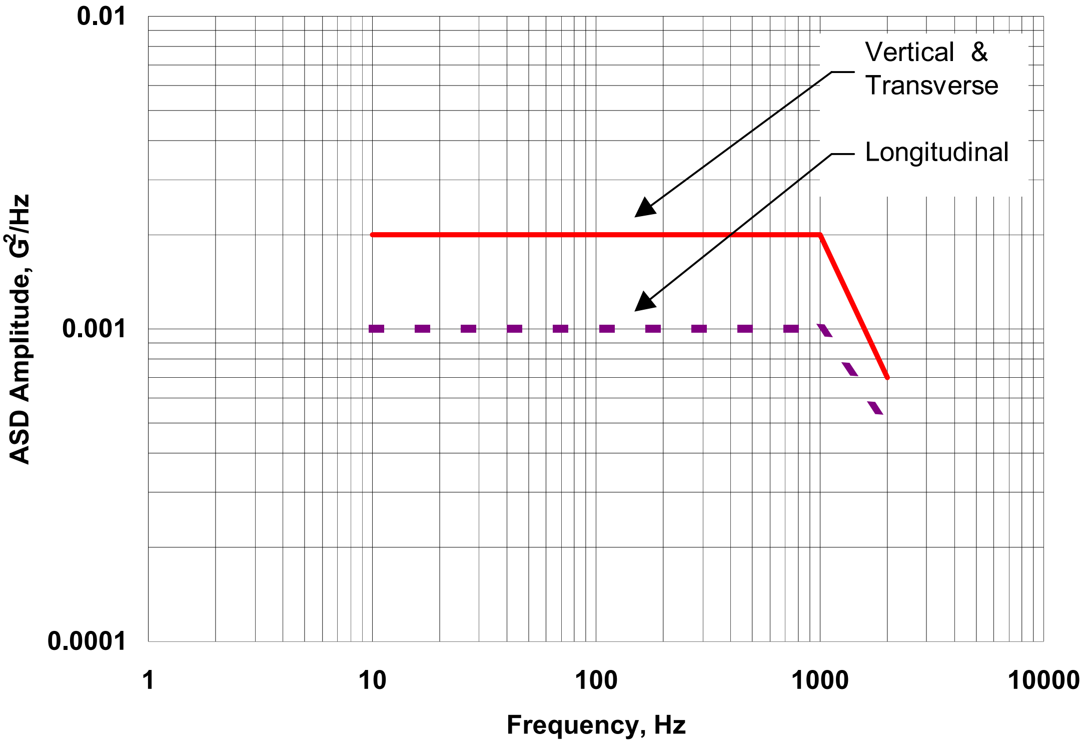
Control Notes :

1. If LCEP information is not available, the default test duration is one minute / axis or a maximum total test time of five minutes / axis.
2. Use the maximum control system roll-off rate at the 5 and 2000 Hz breakpoints.
3. The test schedule is derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure C-2 test schedule depicts the vibration severity for secured cargo located on a fixed wing jet aircraft cargo deck during typical flight takeoff. The figure represents the vibration environment due to structural and acoustic excitation from the engine, engine exhaust, and airframe structure. The test schedule is an envelope applicable for all three test axes (vertical, transverse, longitudinal) and was derived from vibration measurements on C-5, KC-10, C-17, C/KC-135, E/KE-3, C-141, and T-43 jet aircraft. The vibration spectrum presented is intended to represent the worst case vibration environment for most gas turbine engines and engine installation configurations. The test schedule is not representative of the lower amplitude vibration for other aircraft flight operations during gradual climb, decent, or constant velocity cruise. Figure C-2 is developed from MIL-STD 810.

FIGURE C-3 JET AIRCRAFT CARGO - CRUISE



Jet Aircraft Cargo - Cruise Schedule Breakpoints		
Frequency, Hz	ASD, G^2/Hz	
	Vertical & Transverse	Longitudinal
10	0.0020	0.0010
1000	0.0020	0.0010
2000	0.0007	0.0005
Total Grms	1.77	1.30

Figure C-3 Jet Aircraft Cargo - Cruise Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	1 hour / axis represents 6 hours flight time
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point input control

Control Notes :

1. If LCEP information is not available, the default test duration is two hours / axis .
2. Use the maximum control system roll-off rate at the 10 and 2000 Hz breakpoints
3. The test schedule is derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure C-3 test schedule depicts the vibration severity for secured cargo located on a fixed wing jet aircraft cargo deck during typical level subsonic flight conditions. The figure represents the vibration environment due to structural and acoustic excitation from the engine, engine exhaust, and airframe structure. The test schedule is an envelope applicable for the specified test axis and was derived from vibration measurements on several jet aircraft. The vibration spectrum presented is intended to represent the worst case vibration environment for most gas turbine engines and engine installation configurations. Figure C-3 is developed from Def Stan 0035.

FIGURE C-4 JET AIRCRAFT INSTALLED MATERIEL

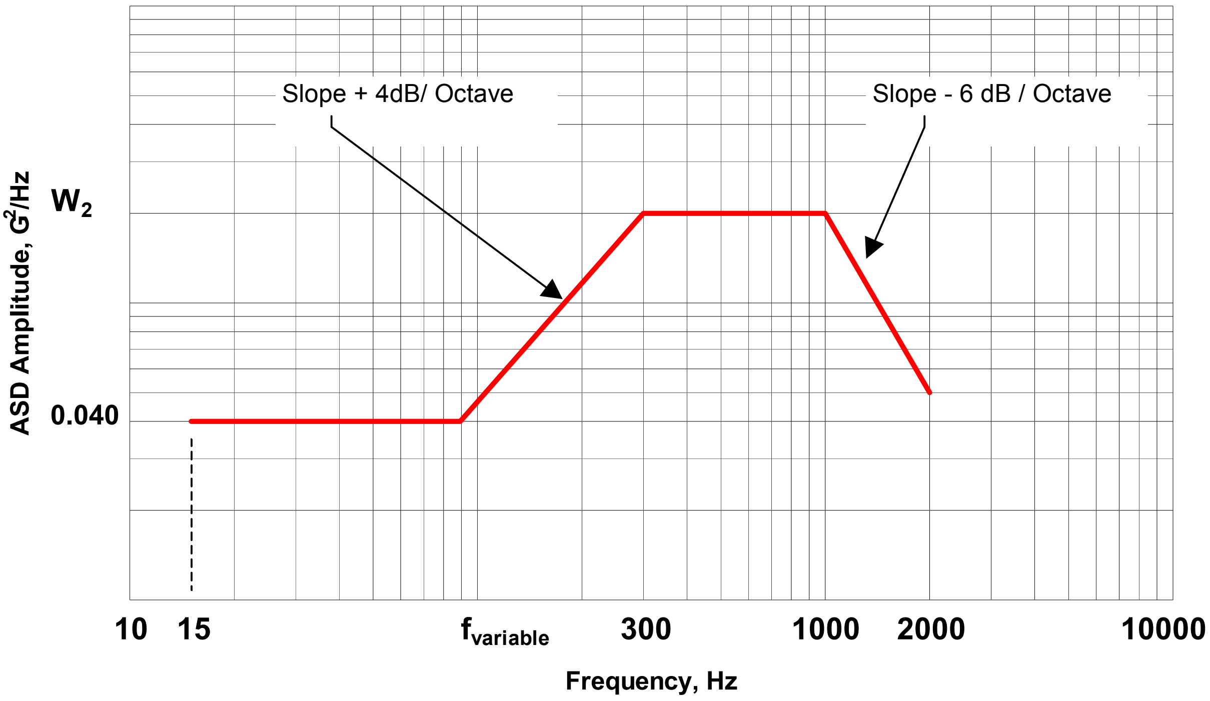


Figure C-4 Jet Aircraft Installed Materiel Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	1 hour / axis
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point input control

Control Notes :

1. The W_2 ASD level is calculated in Table C-1 . The $f_{variable}$ frequency is defined by the + 4 dB/Octave slope.
2. Use the maximum control system roll-off rate at the 15 and 2000 Hz breakpoints.
3. The test schedule is derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure C-4 test schedule depicts the vibration severity for material installed on a fixed wing jet aircraft during a typical flight condition. In the absence of measured flight data or test program supplied information the vibration severity can be estimated for the desired flight conditions. The figure represents the vibration environment induced from aerodynamic flow across airframe structures and acoustic excitation due the engine exhaust. The test schedule determined from Figure C-4 and Table C-1 is a composite of the two sources and represents the expected worst case vibration environment for most gas turbine engines and engine installation configurations. Jet noise induced vibration is usually dominant in aircraft that operate at lower dynamic pressures, such as limited to subsonic speeds at lower altitudes and transonic speeds at high altitudes. Aerodynamically induced vibration usually predominates in aircraft that operate at transonic speeds at lower altitudes or supersonic speeds at any altitude. The schedule is applicable for all three test axes (vertical, transverse, longitudinal). The equation parameters apply to materiel that is small and lightweight relative to the supporting structure. As materiel mass increases, dynamic interaction with supporting structure increases. For typical full-scale manned aircraft, this effect is usually ignored for materiel weighing less than 36 kg (80 lb). A mass loading factor is included in Table C-1 for heavier materiel. However, evaluate the installation of materiel weighing more than roughly 72 kg (160 lb.) for dynamic interaction. Materiel mounted on vibration isolation or shock mounts is dynamically uncoupled from the supporting structure. Unless the item’s mass is very large relative to the support structure, its influence on vibration of the support structure will be minimal and the mass loading factor discussed above does not apply; use the above exposure level as an input to the vibration isolators. The Figure C-4 amplitude is not representative of transient vibrations due to movable airframe structures, vortex excitation airflows, or gunfire. Table C-1 does not include vibration excitation due to local mechanical equipment such as a gearbox, pump, or motor. Figure C-4 is developed from MIL-STD 810.

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TABLE C-1 JET AIRCRAFT INSTALLED MATERIEL RANDOM AMPLITUDE

Aerodynamic Induced Vibration, W_A	$W_A = a \times b \times c \times (q)^2$ G^2/Hz
Jet Engine Noise Induced Vibration, W_J $W_J = \{ [(0.48/R) \times a \times d \times \cos^2(\theta)] \times [D_c \times (V_c / V_r)^3 + D_f \times (V_f / V_r)^3] \}$ G^2/Hz Total jet noise vibration contribution is the sum (Σ_1^n) of the W_J values for each engine.	
Random Spectrum Test Level, W_2	$W_2 = W_A + \Sigma_1^n (W_J)$ G^2/Hz

Calculation Parameters

a Platform and Materiel Mass Interaction Factor
= 1.0 for materiel mounted on vibration isolation (shock mounts) and materiel weighing less than 36 kg.(80 lb)
= $1.0 \times 10^{(0.60 - W/60)}$ for materiel weighing between 36 and 72.12 kg. (w = weight in kg)
$1.0 \times 10^{(0.60 - 0.0075 W)}$ for materiel weighing between 80 and 160 lb. (w = weight in lb)
= 0.25 for materiel weighing 72.12 kg (160 lb.) or more.

Aerodynamic Parameters	**Engine Noise Parameters**
b Vibration Level and Dynamic Pressure Proportionality Factor = 2.96×10^{-6} (SI) (6.78×10^{-9} ft lb units) for materiel mounted on cockpit instrument panels.	d Afterburner Factor = 1.0 for conditions where afterburner is not used or is not present. = 4.0 for conditions where afterburner is used.
= 1.17×10^{-5} (SI) (2.70×10^{-8} ft lb units) for materiel in cockpit and materiel in compartments adjacent to external surfaces that are smooth and free from discontinuities.	R Engine Location Distance Factor Vector distance from center of engine exhaust plane to materiel center of gravity , m (ft).
= 6.11×10^{-5} (SI) (1.40×10^{-7} ft lb units) for materiel in compartments adjacent to or immediately aft of external surface discontinuities (such as cavities, chines, blade antennae, speed brakes, etc.), or in fuselage aft of wing trailing edge, wing, empennage, and pylons.	θ Engine Location Angle Angle between R vector and engine exhaust vector (aft along engine exhaust centerline), degrees For $70° < \theta \leq 180°$ use $\theta = 70°$. D_c Engine Core Exhaust Diameter, m (ft). D_f Engine Fan Exhaust Diameter, m (ft). V_r Reference Exhaust Velocity = 564 m/sec, (1850 ft/sec)
c Mach Number (M) Correction = 1.0 for $0 \leq M \leq 0.9$ = 5.32 - 4.8M for $0.9 \leq M \leq 1.0$ = 0.52 for $M \geq 1.0$	V_c Engine Core Exhaust Velocity Engine core exhaust velocity without afterburner, m/sec (ft/sec).
q Flight Dynamic Pressure kN/m^2 (lb/ft^2) See Table C-2	V_f Engine Fan Exhaust Velocity without the afterburner, m/sec (ft/sec).

Notes

1. The a and b factors only apply to the W_2 ASD level, not the 0.04 G^2/Hz level from 15 Hz to the variable frequency breakpoint of Figure C-4.
2. Use the numerical values in parenthesis for calculations in English ft lb units.

TABLE C-2 JET AIRCRAFT DYNAMIC PRESSURE

Dynamic Pressure Equations

$$q = 2.5\ \rho_o \sigma V_a^2 \left[\left(1/\delta \left\{ \left[1 + 0.2 \left(V_{cas} / V_{ao} \right)^2 \right]^{3.5} - 1 \right\} + 1 \right)^{2/7} - 1 \right]$$

$$q = {}^1/_2\ \rho_o \sigma V_a^2 M^2 \qquad q = {}^1/_2\ \rho_o V_{eas}^2 \qquad q = {}^1/_2\ \rho_o \sigma V_{tas}^2$$

	SI units m, kg, sec		English units ft, lb, sec	
	$h \le 11000$ m	$11000 \le h \le 20056$ m	$h \le 36089$ ft	$36089 \le h \le 65800$ ft
θ	$1 - 2.2556 \times 10^{-5} \times h$	0.75189	$1 - 6.8750 \times 10^{-6} \times h$	0.75189
δ	$\theta^{5.2561}$	$0.2234\ e^{\phi}$	$\theta^{5.2561}$	$0.2234\ e^{\phi}$
σ	$\theta^{4.2561}$	$0.2971\ e^{\phi}$	$\theta^{4.2561}$	$0.2971\ e^{\phi}$
V_a	$V_{ao} \times \theta^{1/2}$	295.06	$V_{ao} \times \theta^{1/2}$	968.03
ϕ	-------	$(11000 - h) / 6342.0$	------	$(36089 - h) / 20807$
ρ_o	1.2251×10^{-3}	1.2251×10^{-3}	2.377×10^{-3}	2.377×10^{-3}
V_{ao}	340.28	------	1116.4	------
T_o	288.16 °K	------	518.69 °R	------

Equation Parameters

V_{cas} - Calibrated airspeed, m/sec (ft/sec)
V_{ias} - Indicated airspeed, m/sec (ft/sec)
V_{eas} - Equivalent airspeed, m/sec (ft/sec)
V_{tas} - True airspeed, m/sec (ft/sec)
V_a - Local speed of sound, m/sec (ft/sec)
V_{ao} - Sea level speed of sound, m/sec (ft/sec)
M - Mach number
q - Dynamic pressure, kN/m^2 (lb/ft^2)
h - Pressure altitude,m (ft), (standard atmosphere)
T_o - Sea level atmospheric temperature °K (°R)

ρ_o - Sea level atmospheric density kg/m^3 ($slugs/ft^3$ or $lb\ sec^2/ft^4$)
δ - Ratio of local atmospheric pressure to sea level atmospheric pressure
σ - Ratio of local atmospheric density to sea level atmospheric density (standard atmosphere)
θ - Ratio of temperature at altitude to sea level temperature (standard atmosphere)
ϕ - Stratospheric altitude variable

Knot Airspeed Conversion, for all air speeds below :

V_{kcas} - knots calibrated air speed (K_{kcas})
V_{kias} - knots indicated air speed (K_{kias})
V_{keas} - knots equivalent air speed (K_{keas})
V_{ktas} - knots true air speed (K_{ktas})

knot = nautical miles per hour
V, m/sec = V, knots x 0.51478
V, ft/sec = V, knots x 1.6889

Dynamic Pressure Calculation Check Cases

Airspeed	h = 3048 m	h = 10000 ft	h = 15240 m	h = 50000 ft
$V_{kcas} = 500$	$q = 38.5\ kN/m^2$	$q = 804\ lb/ft^2$	$q = 23.8\ kN/m^2$	$q = 497\ lb/ft^2$
$V_{ktas} = 500$	$q = 30.0\ kN/m^2$	$q = 626\ lb/ft^2$	$q = 6.18\ kN/m^2$	$q = 129\ lb/ft^2$
M = 0.8	$q = 31.2\ kN/m^2$	$q = 652\ lb/ft^2$	$q = 5.20\ kN/m^2$	$q = 109\ lb/ft^2$
$V_{keas} = 500$	$q = 40.6\ kN/m^2$	$q = 848\ lb/ft^2$	at all altitudes	

Notes

1. Choose the appropriate equations based on the given parameters, units, and altitude.
2. At sea level $V_{tas} = V_{eas} = V_{cas} = V_{ias}$
3. Mach number may be used at any airspeed, or for M < 1 the airspeed may be used.
4. Unless specifically stated otherwise, assume airspeeds to be in calibrated airspeed (V_{cas}).
5. When airspeed values are given as indicated airspeed (V_{ias}), assume V_{ias} equal V_{cas}.
6. Altitude (h) is pressure altitude and not height above terrain.

FIGURE C-5 JET AIRCRAFT EXTERNAL STORE VIBRATION RESPONSE

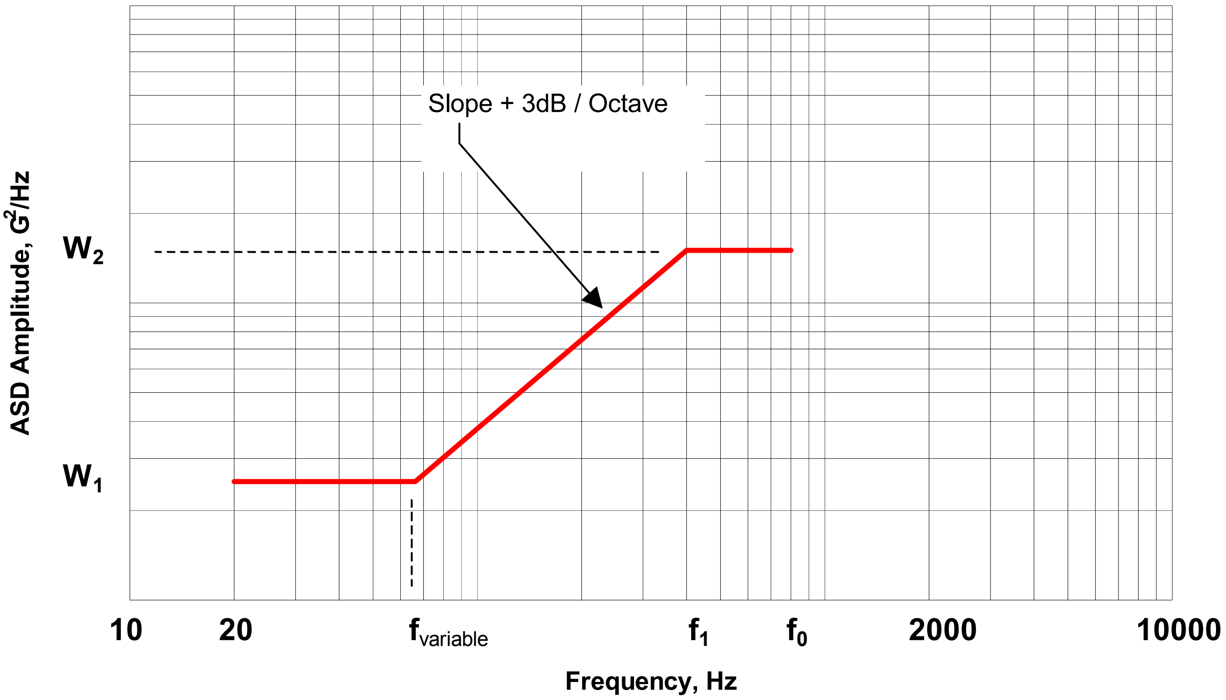


Figure C- 5 Jet Aircraft External Store Vibration Response Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point response control and/or acoustic excitation

Control Notes :

1. The W_1 and W_2 ASD levels and the frequencies f_1 and f_0 are calculated in Table C-3 . The $f_{variable}$ frequency is defined by the + 3 dB/Octave slope.
2. Use the maximum control system roll-off rate at the 20 and 2000 Hz breakpoints.
3. Jet aircraft external store high frequency vibration, approximately 1000 Hz and greater, may not be accurately transmitted to a store through only mechanical vibration test methods. Combined store mechanical and acoustic excitation, Method 413, may be required to obtain acceptable accuracy and a realistic environment simulation.

4. The test schedule is derived for a response control accelerometer(s) located at the store mounting location.

Schedule Description

The Figure C-5 test schedule depicts the vibration severity for a captive carried external wing store on a fixed wing jet aircraft during typical flight conditions, non-buffet, due to aircraft engine noise, aerodynamic turbulence, and aircraft vibration. In the absence of measured flight data or test program supplied information, the vibration severity can be estimated for the desired flight conditions. The Figure C-5 and Table C-3 are representative of store configuration, location, mass density, flight dynamic pressure, and aircraft low frequency vibration input. The test severity determined from the parametric equations is an expected worst case vibration condition during flight. The schedule is applicable for all three test axes (vertical, transverse, longitudinal). The low and medium frequency airframe structure induced portion of this environment is best simulated by mechanical excitation. The high frequency noise and aerodynamic induced portion of the resulting vibration is best represented by a combination of mechanical vibration and the acoustic noise exposures. Typical simulation practices accomplish this by a response control methodology. Evaluation of individual cases is necessary to determine appropriate laboratory simulation methods.

For limited cases the Figure C-5 test severity is applicable to estimate free flight store vibration due to aerodynamic boundary layer turbulence. The free flight store vibration mode frequencies may shift, flight dynamic pressures may be different, and turbulence from the carrier aircraft and nearby stores will be absent. The figure is not representative of an internal airframe captive carriage environment in which the store is protected from airflow turbulence excitation, or exposed to cavity resonance with the bay doors open. The worst case open aircraft bay captive carriage store vibration may be better simulated with buffet maneuver vibration methods for high angle of attack aircraft. Figure C-5 is not applicable for propeller aircraft store vibration; use Annex C Figure C-1 for a preliminary store vibration estimate. The test severity does not include vibration sources internal to the store such as engines, turbines, and motors. Figure C-5 is developed from MIL-STD 810.

FIGURE C-6 MATERIEL IN JET AIRCRAFT EXTERNAL STORES

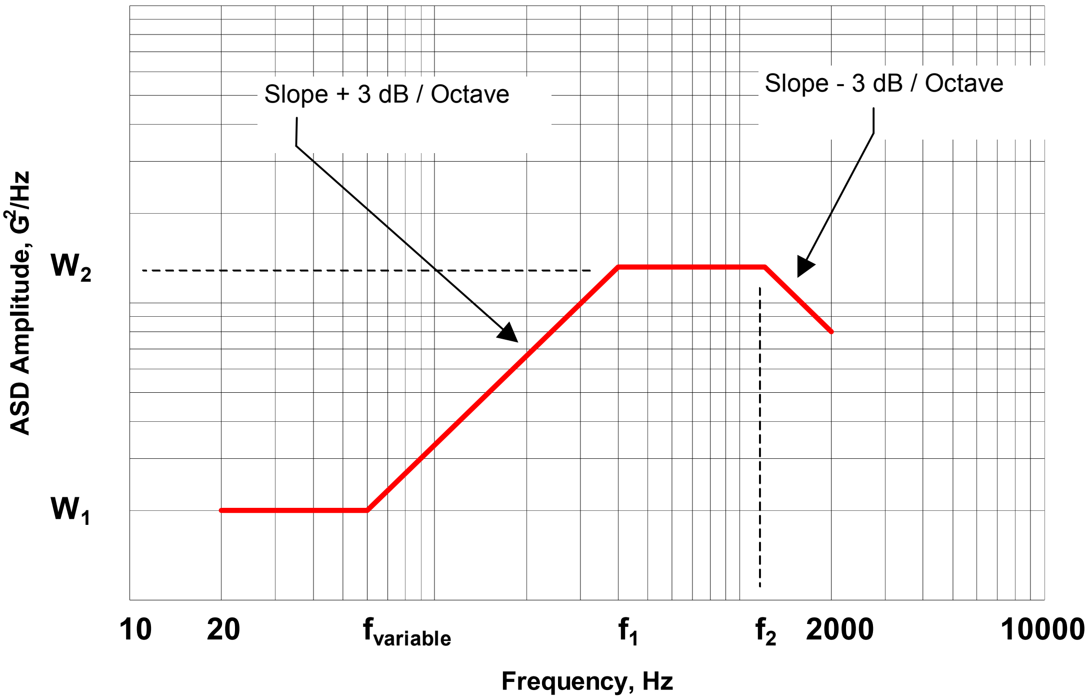


Figure C-6 Materiel In Jet Aircraft External Stores Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point input control and/or acoustic excitation

Control Notes :

1. The W_1 and W_2 ASD levels and the frequencies f_1 and f_2 are calculated in Table C-3 . The $f_{variable}$ frequency is defined by the + 3 dB/Octave slope.
2. Use the maximum control system roll-off rate at the 20 and 2000 Hz breakpoints.
3. The test schedule is derived for a control accelerometer(s) located at the material and store interface.

Schedule Description

The Figure C-6 test schedule depicts the vibration severity for material located internal to a captive carried external wing store on a fixed wing jet aircraft during typical flight conditions due to aircraft engine noise, aerodynamic turbulence, and aircraft vibration; same conditions as Figure C-5. The input exposure levels for materiel within the store are essentially the same as response levels of the store. If gunfire, cavity resonance, buffet-maneuver, and free-flight conditions occur for the store, the internal materiel will also be exposed to these conditions. In the absence of measured flight data or test program supplied information, the vibration severity can be estimated for the desired flight conditions. The Figure C-6 and Table C-3 are representative of store configuration, location, mass density, flight dynamic pressure, and aircraft low frequency vibration input. The test severity determined from the parametric equations is an expected worst case vibration condition during flight. The schedule is applicable for all three test axes (vertical, transverse, longitudinal). Typical simulation practices accomplish this test by an input control methodology. Combined store mechanical and acoustic excitation, Method 413, may be required to obtain acceptable accuracy and a realistic environment simulation. Evaluation of individual cases is necessary to determine appropriate laboratory simulation methods. See the application limitations for the Figure C-6 and Table C-3 parametric model in the Figure C-5 schedule description. Figure C-6 is developed from MIL-STD 810.

TABLE C-3 VIBRATION CRITERIA FOR JET AIRCRAFT EXTERNAL STORES

$\mathbf{W_1} = 5 \times 10^{-3} \times K \times A_1 \times B_1 \times C_1 \times D_1 \times E_1$ G²/Hz *(1)*

$\mathbf{W_2} = (H)(q/\rho)^2 \times K \times A_2 \times B_2 \times C_2 \times D_2 \times E_2$ G²/Hz *(1)*

for $M \leq 0.90$, $K = 1.0$ for $0.90 \leq M \leq 1.0$, $K = -4.8 \times M + 5.32$ for $M \geq 1.0$, $K = 0.52$ *(2)*

$f_1 = Cx10^5 \times (t / R^2)$, Hz *(3), (4), (5)* | $f_2 = f_1 + 1000$, Hz *(3)* | $f_o = f_1 + 100$, Hz *(6), (7)*

Configuration	Factors		Configuration	Factors	
Aerodynamically clean	A_1	A_2		B_1	B_2
▪ Single store	1	1	▪ Powered missile, aft half	1	4
▪ Side by side stores	1	2	▪ Other stores, aft half	1	2
▪ Behind other store(s)	2	4	▪ All stores, forward half	1	1
Aerodynamically dirty (8)	C_1	C_2		D_1	D_2
▪ Single and side by side	2	4	Field assembled sheet metal		
▪ Behind other store(s)	1	2	▪ Fin / tailcone unit	8	16
▪ Other stores	1	1	▪ Powered missile	1	1
			Other stores	4	4
	E_1	E_2			
▪ Jelly filled firebombs	½	¼			
▪ Other stores	1	1			

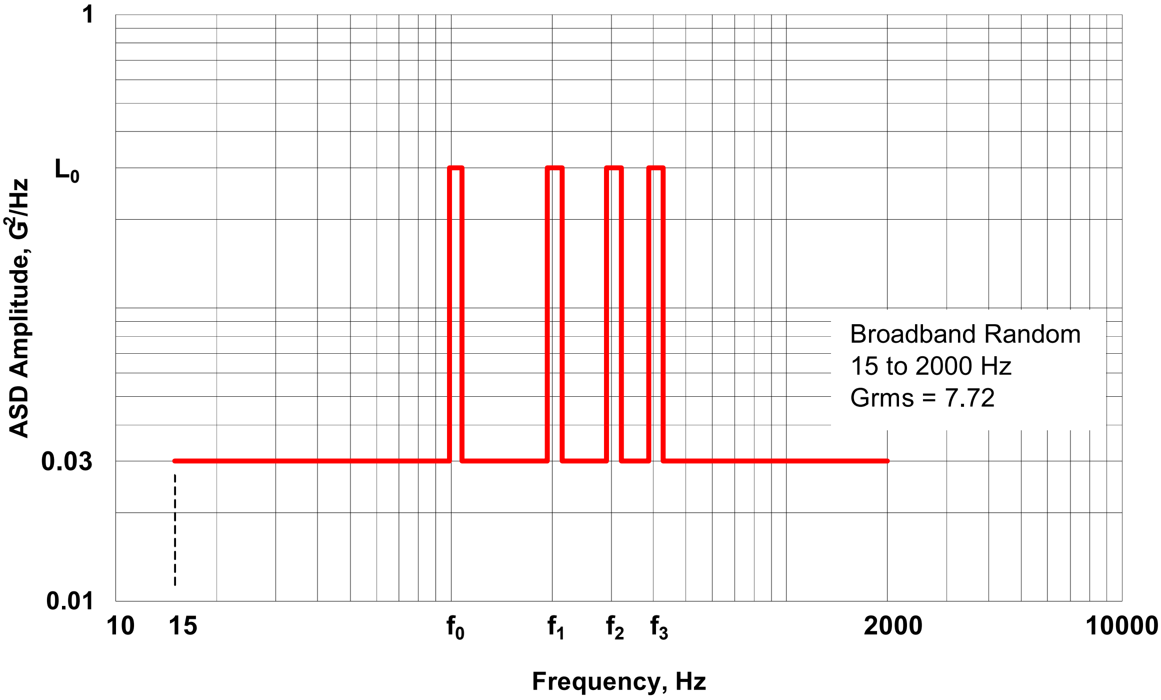
M - Mach number
H - Constant = 5.59 (metric units) (= 5×10^{-5} English units)
C - Constant = 2.54×10^{-2} (metric units, t and R in meters), or C=1.0 (English units, t and R in inches)
q - Flight dynamic pressure kN/m² (lb/ft²). Define q from Mach number and altitude.
ρ - Store weight density (weight/volume) kg/m³ (lb/ft³)
Limit values of ρ to $641 \leq \rho \leq 2403$ kg/m³ ($40 \leq \rho \leq 150$ lb/ft³)
t - Average thickness of structural (load carrying) skin – m (in)
R - Store characteristic (structural) radius m (in) (Average over store length)
= Store radius for circular cross section
= Half of major and minor diameters for elliptical cross section
= Half or longest inscribed chord for irregular cross sections

Notes :

(1) - When store parameters fall outside limits given, consult references
(2) - Mach number correction
(3) - Limit f_1 to $100 \leq f_1 \leq 2000$ Hz
(4) - Free fall stores with tail fins, $f_1 = 125$ Hz
(5) - Limit $C(t/R^2)$ to : $0.0010 \leq C(t/R^2) \leq 0.020$
(6) - $f_0 = 500$ Hz for cross sections not circular or elliptical
(7) - If $f_0 > 1200$ Hz, then use $f_0 = 2000$ Hz
(8) - Configurations with separated aerodynamic flow within the first ¼ of the store length. Blunt noses, optical flats, sharp corners, and open cavities are some potential sources of separation. Any nose other than smooth, rounded, and gently tapered is suspect. Aerodynamics engineers should make this judgement.

StoreType	**Representative Parameter Values**					
	Max q		**ρ**		**f_1**	**f_2**
	kN / m²	(lb / ft²)	kg / m³	(lb / ft³)	Hz	Hz
Missile, air to ground	76.61	(1600)	1602	(100)	500	1500
Missile, air to air	76.61	(1600)	1602	(100)	500	1500
Instrument pod	86.19	(1800)	801	(50)	500	1500
Dispenser (reusable)	57.46	(1200)	801	(50)	200	1200
Demolition bomb	57.46	(1200)	1922	(120)	125	1100
Fire bomb	57.46	(1200)	641	(40)	100	1100

FIGURE C-7 AIRCRAFT ENGINE



Schedule Notes :

1. Fundamental Frequency, f_0 Hz = Engine RPM x 1 minute / 60 seconds
2. Harmonic Frequency $f_1 = 2f_0$, $f_2 = 3f_0$, $f_3 = 4f_0$
3. Narrowband Amplitude L_0 is defined by measured data. For cases with unknown equipment configuration, the default narrowband random amplitude for all frequencies is 1.00 G^2/Hz
4. The default narrowband random frequency bandwidth is 10% of each f_I.

Figure C-7 Aircraft Engine Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	1 hour / axis
Equivalence Factor :	None
Vibration Spectrum :	Narrowband random on broadband random vibration (NBROR)
Control Strategy :	Single or multi-point input control

Control Notes :

1. Use the maximum control system roll-off rate at the 15 and 2000 Hz breakpoints.
2. The test schedule is derived for a control accelerometer(s) located at the material and engine interface.

Schedule Description

The Figure C-7 test schedule depicts the test severity for material installed directly on an aircraft gas turbine engine during normal engine operation. The figure provided is a general representation of the random vibration environment due to engine airflow turbulence and narrowband random due to engine main rotor(s) rotation. The test schedule is applicable for all three test axes (vertical, transverse, longitudinal). The test severity was derived from vibration measurements on various aircraft engines. The vibration spectrum presented is applicable for both a constant and variable engine speed; however, tailoring of the narrowband amplitude, bandwidth, and sweep bandwidth based on measured data is desirable for variable speed engines. The use of several NBROR spectrums, or swept bandwidths, to represent multiple engine operating conditions or speeds may be necessary. Typically the narrowband amplitude and swept bandwidth will be a function of the engine power output and the associated engine RPM for each operating condition such as take-off, maximum power, cruise, and engine idle. Several fundamental rotor frequencies, f_0, and associated harmonics f_1, f_2 f_3 .. may be present in the spectrum in multiple rotor engines The vibration spectrum should be tailored to include all known engine rotor frequencies. Additional rotational fundamental and harmonic frequencies may be present in the vibration spectrum from gear reduction drives to engine or aircraft shaft driven components. The test spectrum amplitude is not applicable for vibration isolation mounted material. Figure C-7 is developed from MIL-STD 810.

ANNEX D

HELICOPTER (ROTARY WING AIRCRAFT) VIBRATION

GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

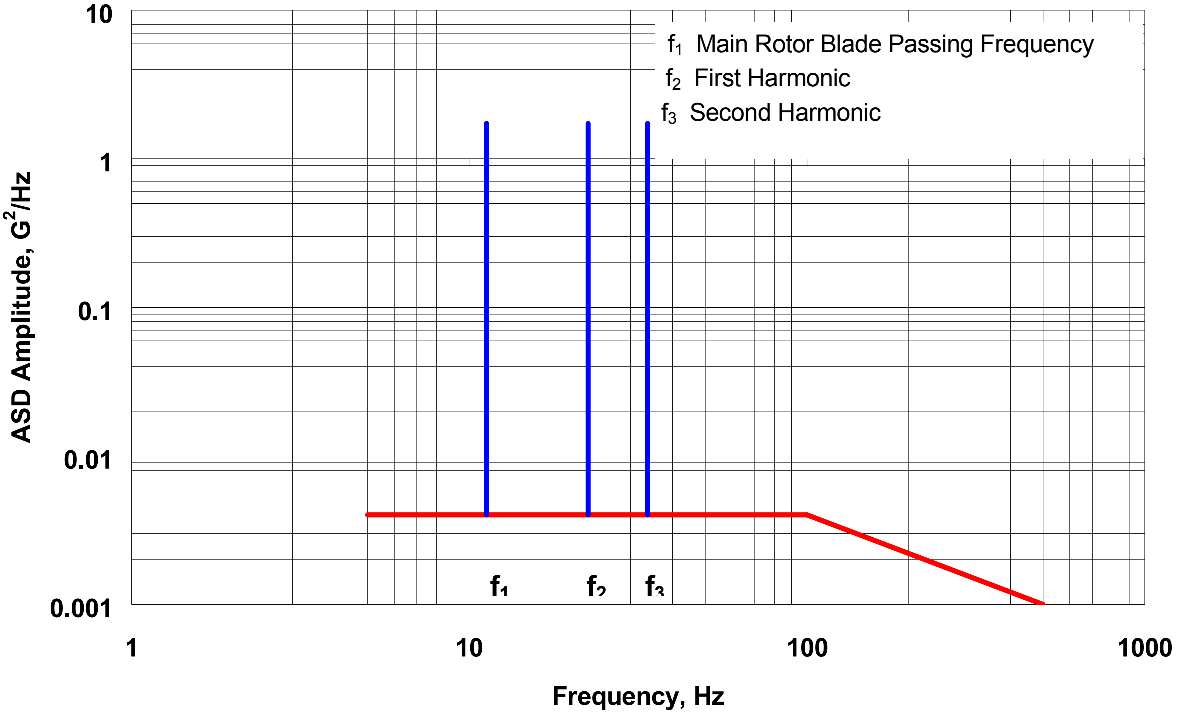
The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Helicopter Vibration Environment

Helicopter vibration is a complex environment that may consist of several classes of vibration due to the flight and main rotor aerodynamic excitation, and the engine and shaft driven component mechanical vibration excitation. In general, a broadband random vibration with superimposed higher amplitude vibration peaks characterizes the helicopter vibration environment. The peaks are generated by the rotational components in the helicopter such as the main and/or tail rotor, engine, and gear meshing. The operating speeds of the rotational components under flight conditions are essentially constant, varying by about two to five percent. The relative levels of these peaks differ throughout the helicopter depending on the proximity of the sources, geometry of the aircraft, and location of the material. Airframe structural bending modes may also contribute to the vibration spectrum. Thus, the need for measured data is especially important for accurate laboratory test simulations. The major peaks in the helicopter vibration spectrum are usually associated with the main rotor, blade passage frequency, and the harmonics. However, each type of helicopter will have different sources specific to areas of the aircraft. Since discrete frequency peaks generally dominate the vibration environment, it is logical to use these frequencies for exposure in the laboratory test. Annex D provides generic sine on wideband random test severities that are typical of a helicopter. The wing store vibration is predominately transmitted through the store mounting rack, however in some cases the use of acoustic or muli-exciter vibration could be necessary to represent a measured wing store environment. The vibration for material located directly on the engine or rotational components may be better represented by the aircraft engine test schedule.

Evaluation of the helicopter in-service operational modes is also important to accurately represent the appropriate combination of flight maneuvers. The test plan needs to consider an appropriate combination of individual tests or an enveloped spectrum representing worst case flight conditions. The helicopter vibration amplitude can change several magnitudes during hover and maximum velocity conditions. The operation of small caliber guns, missile and rockets, and other weapon systems create transient accelerations that are better simulated with AECTP 400 Method 417 SRS Shock or Method 405 Gunfire simulation methods. The AECTP 200 Mechanical Conditions sections provide information to classify the vibration environment and determine an appropriate vibration test. Further details of each Annex D vibration schedule is provided with the individual schedule.

FIGURE D-1 HELICOPTER CARGO



Helicopter Cargo Schedule Breakpoints						
Random Breakpoints, all axes		Fixed Sine Harmonic Amplitudes, G_{peak}				
Frequency Hz	ASD, G^2/Hz	Sine Peak	Vertical	Transverse	Longitudinal
5	0.004	f_1	1.73	1.73	1.0
100	0.004	f_2	1.73	1.73	1.0
500	0.001	f_3	1.73	1.73	1.0
Random Grms = 1.05					

For the Sine Harmonic Frequencies, See the Helicopter Rotor Parameters in Table D-1

Table D-1 Helicopter Main and Tail Rotor Parameters

Helicopter	Main Rotor			Tail Rotor		
	Rotation Speed, Hz	Number of Blades	f_1, Hz	Rotation Speed, Hz	Number of Blades	f_1, Hz
AH-1 (Cobra)	5.40	2	10.80	27.70	2	55.40
AH-6J (Little Bird)	7.95	5	39.75	47.30	2	94.60
AH-64 (early Apache)	4.82	4	19.28	23.40	4	93.60
AH-64 (late Apache)	4.86	4	19.44	23.60	4	94.40
CH-47D (Chinook)	3.75	3	11.25	na	na	na
EH101 (Merlin)	3.57	5	17.85	16.18	4	64.72
Gazelle	6.30	3	18.90	96.20	39	3751.80
Lynx Mk 1, Mk 2 Mk 3	5.51	4	22.04	31.90	4	127.60
Lynx 3	5.51	4	22.04	27.80	4	111.20
MH-6H	7.80	5	39.00	47.50	2	95.00
OH-6A (Cayuse)	8.10	4	32.40	51.80	2	103.60
OH-58A/C (Kiowa)	5.90	2	11.80	43.80	2	87.60
OH-58D (K. Warrior)	6.60	4	26.40	39.70	2	79.40
Puma	4.42	4	17.68	21.30	5	106.50
Sea King / Commando	3.48	5	17.40	21.30	6	127.80
UH-1(Huey)	5.40	2	10.80	27.70	2	55.40
UH-60 (Black Hawk)	4.30	4	17.20	19.80	4	79.20

Notes

a. Most helicopters have variants of the above configuration, verify that the correct parameters are applied for the required test.

b. The fundamental blade passing freequency.is f_1 . f_1 = Rotation Speed x Number of Blades

c. The harmonic frequencies are, $f_2 = 2f_1$, $f_3 = 3f_1$.

d. The CH-47 helicopter has two main rotors, no tail rotor.

e. The Gazelle helicopter has a fan tail rotor configuration.

Figure D-1 Helicopter Cargo Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	1 hour / axis represents 6 hours flight time
Vibration Spectrum :	Fixed Sine on broadband random vibration
Control Strategy :	Single or multi-point input control

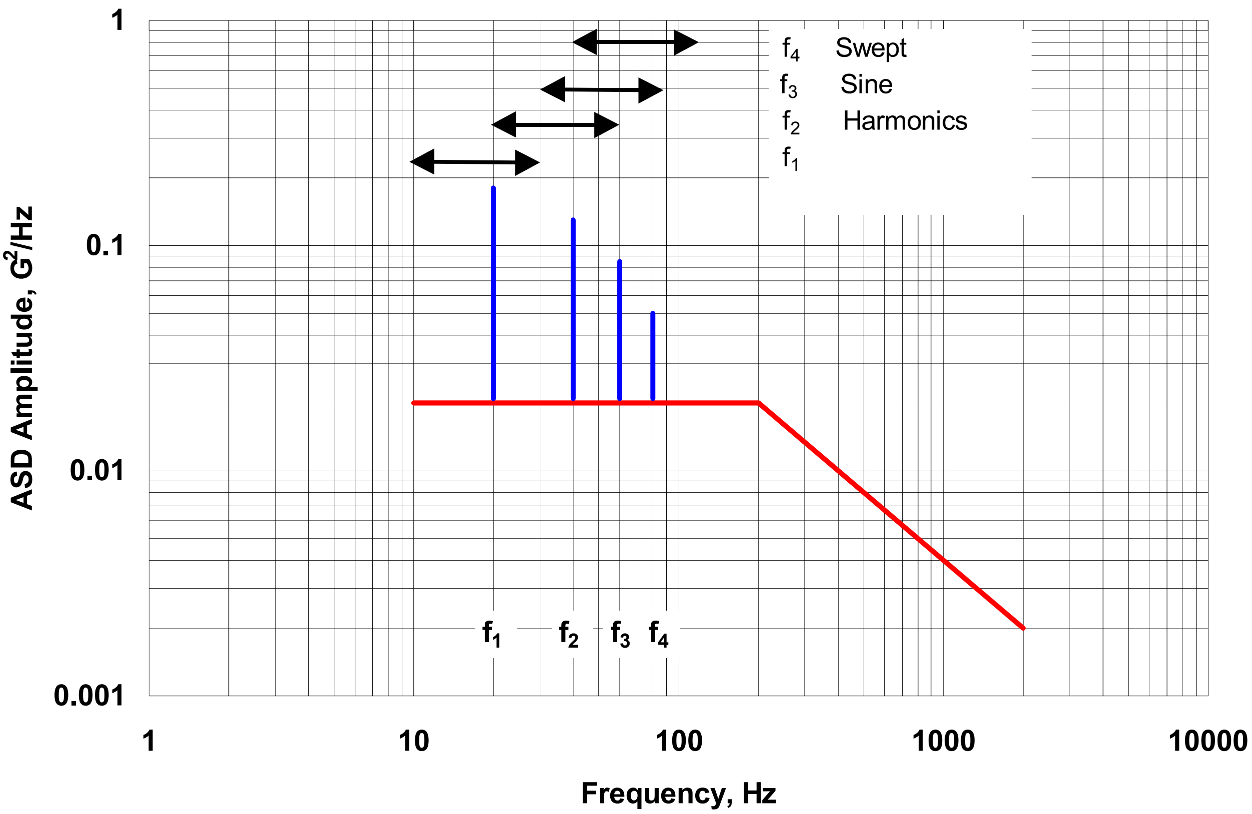
Control Notes :

1. If LCEP information is not available, the default test duration is two hours / axis .
2. Use the maximum control system roll-off rate at the 5 and 500 Hz breakpoints.
3. The Figure D-1 schedule requires only the main rotor fundamental and first two harmonics.

Schedule Description

The Figure D-1 test schedule depicts the test severity for material transported as secured cargo on the floor of a helicopter during normal flight operations. The figure provided is a general representation of the vibration environment due to structural and acoustic excitation from the engine, main rotor, and the aerodynamic flow over the external airframe. The fixed sine amplitudes and frequencies are determined from the main rotor fundamental frequency inTable D-1. The test schedule is an envelope applicable to the specified test axes (vertical, transverse, longitudinal) and was derived from vibration measurements on various helicopters. Tailoring of the fixed sine amplitude and bandwidth based on measured data is desirable to represent the required helicopter. The test schedule utilized must include fixed sine components at the fundamental main rotor blade passage frequency and the harmonics of the simulated helicopter. The use of several sine on random spectra, or bandwidths, to represent multiple engine operating conditions or shaft harmonics may be necessary. The measurement of flight data is also suggested to tailor the low frequency response and package to airframe coupling characteristics. Figure D-1 is not representative of severe vibration due to aircraft combat maneuvers. Figure D-1 is developed from multiple data sources.

FIGURE D-2 HELICOPTER INSTALLED MATERIEL AND STORES



Random Floor Breakpoints	
Frequency, Hz	ASD, G^2/Hz
10	0.02
200	0.02
2000	0.002
Random Grms = 3.61	

Swept Sine Harmonics						
Sine Peak	Sweep Bandwidth, Hz	Number of Sweeps	Helicopter Location and Sine Amplitude, G_{peak}			
			General	Instrument Panel	Engine	Stores
f_1	10 to 30	2	2.5	1.7	5.0	3.75
f_2	20 to 60	2	2.0	1.4	5.0	3.00
f_3	30 to 90	2	1.5	1.0	5.0	2.25
f_4	40 to 120	2	1.0	0.7	5.0	1.50

Figure D-2 Helicopter Installed Material and Stores Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Swept Sine on broadband random vibration
Control Strategy :	Single or multi-point input and/or response control

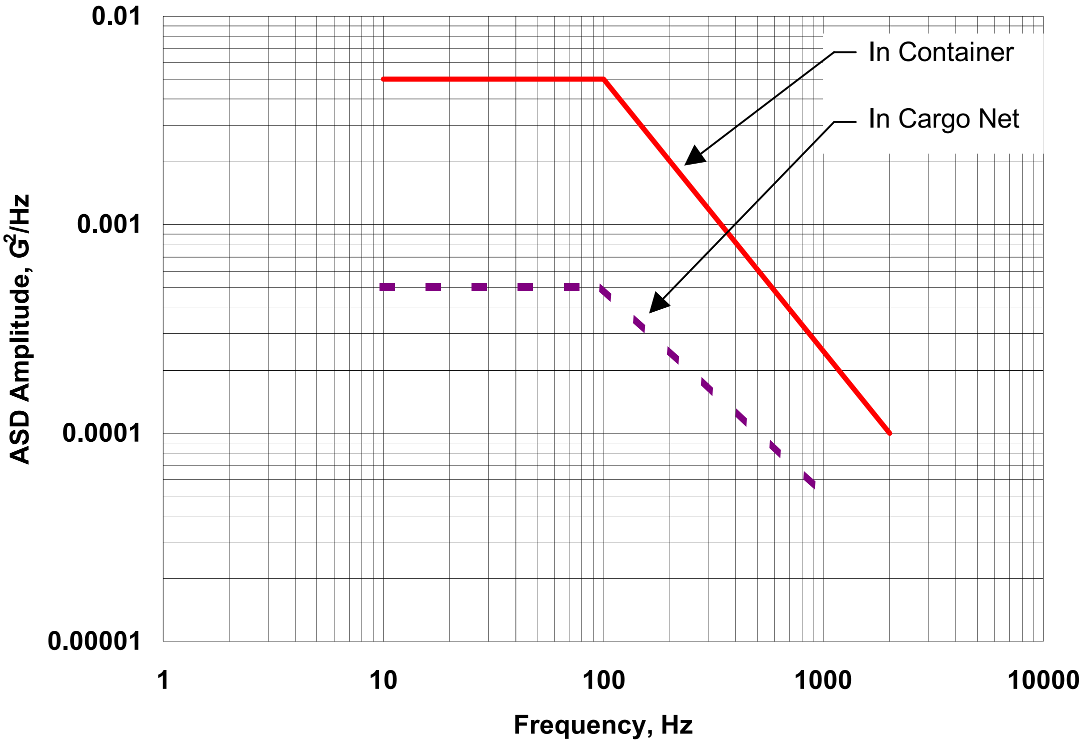
Control Notes :

1. If LCEP information is not available, the default test duration is two hours / axis.
2. The sine harmonic sweep rate (octave/minute) should be adjusted to provide 2 sweeps during the total test duration; all harmonics are swept simultaneously across the respective bandwidths. The minimum 2 sweeps is one sweep up the bandwidth, followed by one sweep down the bandwidth.
3. Use the maximum control system roll-off rate at the 10 and 2000 Hz breakpoints.

Schedule Description :

The Figure D-2 test schedule depicts the test severity for material transported in installed equipment, instrument panel, engine, and store locations on a helicopter during normal flight operations. The figure provided is a general representation of the vibration environment due to structural and acoustic excitation from the engine, main rotor, and the aerodynamic flow over the external airframe. The swept sine amplitudes and frequencies are determined from the accompanying table. The test schedule is an envelope applicable for all three test axes (vertical, transverse, longitudinal) and was derived from vibration measurements on various helicopters. Tailoring of the swept sine amplitude and sweep bandwidth based on measured data is desirable to represent specific material locations and helicopters. The test schedule utilized must include swept sine components at the fundamental main rotor blade passage frequency and the first three harmonics of the simulated helicopter. The use of several sine on random spectra, or swept bandwidths, to represent multiple engine operating conditions or shaft harmonics may be necessary. Figure D-2 is not representative of severe vibration due to aircraft combat maneuvers. Figure D-2 is derived from multiple data sources.

FIGURE D-3 HELICOPTER UNDERSLUNG LOAD



Helicopter Underslung Load Schedule Breakpoints			
Load In Container		**Load In Cargo Net**	
Frequency, Hz	ASD, G^2/Hz	Frequency, Hz	ASD, G^2/Hz
10	0.0050	10	0.00050
100	0.0050	100	0.00050
2000	0.0001	1000	0.00005
Total Grms	1.20	Total Grms	0.40

Figure D-3 Helicopter Underslung Load Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	1 hour / axis represents 6 hours flight time
Vibration Spectrum :	Wideband random vibration
Control Strategy :	Single or multi-point input control

Control Notes :

1. If LCEP information is not available, the default test duration is two hours / axis .
2. Use the maximum control system roll-off rate at the 10 and end (1000 or 2000 Hz) breakpoints
3. The test schedule is derived for a control accelerometer(s) located at the material and vibration test system interface.

Schedule Description

The Figure D-3 test schedules depict the vibration severity for a materiel load that is suspended under a helicopter for short duration transportation at a moderate speed for flight and hover. The schedules are applicable for a load carried with an elastic suspension system directly in a cargo net or inside a container. The suspension system isolates the load, thus the vibration is predominately the result of rotor or flight aerodynamic excitation. The test schedule is an envelope for all axes and was derived from vibration measurements on several helicopters. Higher level vibration and rigid body acceleration responses are possible if the helicopter and suspension system response become coupled. The vibration spectrums are not representative of rigid suspension systems, high amplitude resonant responses, or materiel load transport shock transients. Figure D-3 is developed from Def Stan 0035.

ANNEX E

GENERAL VIBRATION - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

TABLE E-1 SHIPBORNE VIBRATION

Type of ship	Region	Standard test level peak values and frequency range
Surface Ships, minesweeper size and above	Mast heads	1 mm from 2 to 14 Hz 0.8 g from 14 to 100 Hz
	Upper deck, Protected compartments, Hull	0.25 mm from 2 to 14 Hz 0.2 g from 14 to 100 Hz
Surface ships, smaller than minesweepers	Mast heads, Upper decks, Protected compartments, Hull, General test	0.5 mm from 2 to 14 Hz 0.4 g from 14 to 100 Hz
	Aft end of ship (see note 1)	0.5 mm from 2 to 14 Hz 0.4 g from 14 To 100 Hz
Nuclear and conventional submarines	All	0.125 mm from 2 to 20 Hz 0.2 g from 20 to 200 Hz

Table Notes :

1. The Aft region is 1/8th of the ship's overall length.

Table E-1 Shipborne Vibration Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	1 hour / axis, all ships and regions
Equivalence Factor :	None
Vibration Spectrum :	Swept sine vibration, fixed displacement and/or peak acceleration
Control Strategy :	Single or multi-point input control

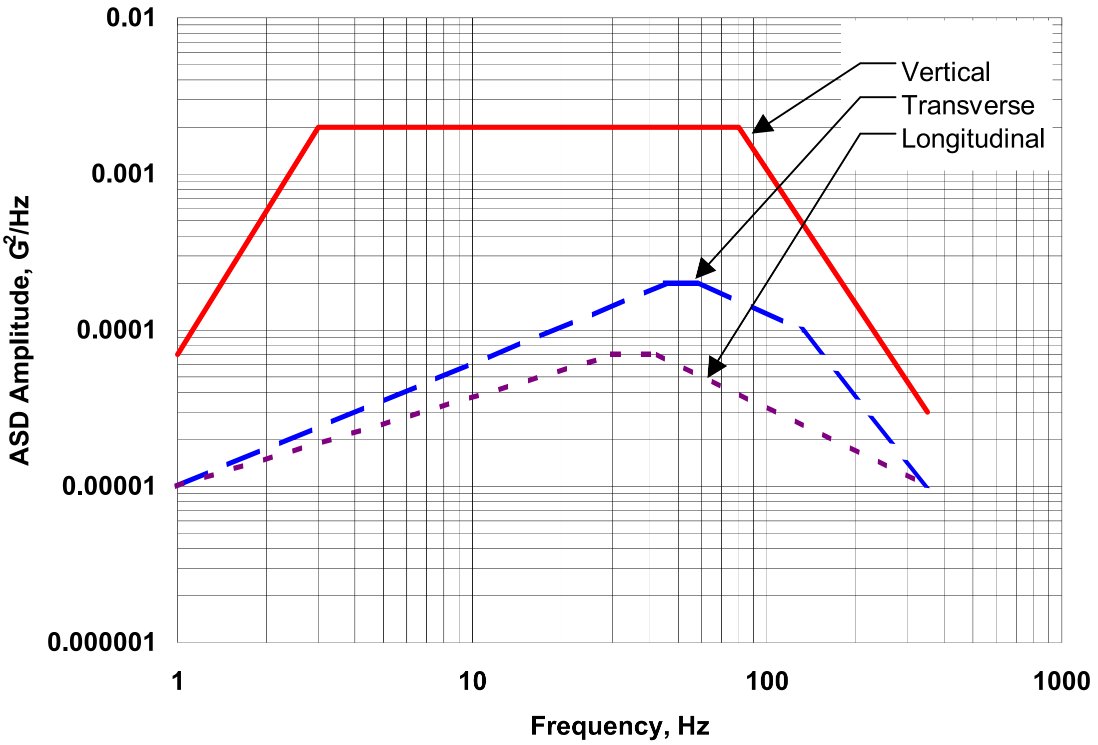
Control Notes :

1. Sine sweep rate for all tests is 1 octave / minute.
2. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

Table E-1 provides general guidelines for the severity of vibration at locations on surface ships or, underwater submarines and missiles. Shipborne vibration includes a large class of operating sea states and platform configurations that influence the vibration severity. The material mounting method and location within the ship must also be considered when establishing vibration levels. Thus, the use of measured data or platform tailored specifications is desirable to generic test levels. Materiel carried on ships generally experience an environment consisting of sinusoidal excitation from the main propeller(s) (screw) blade passage frequency of the shaft RPM x number of blades x 1/60. Random excitation occurs from water flow around the hull, and equipment operation. The vibration may consist of only sine or random spectrums, or a composite of both. Table E-1 presents only the platform sine vibration. Table E-1 is an envelope of data applicable for all three test axes (vertical, transverse, longitudinal) and was derived from vibration measurements on various platforms. Table E-1 is not applicable for evaluation of equipment resistance to ship transient shock. Table E-1 is derived from multiple NATO data sources.

FIGURE E-1 RAILROAD CARGO



Railroad Cargo Schedule Breakpoints					
Vertical		Transverse		Longitudinal	
Hz	G^2/Hz	Hz	G^2/Hz	Hz	G^2/Hz
1	0.00007	1	0.00001	1	0.00001
3	0.00200	45	0.00020	30	0.00007
80	0.00200	60	0.00020	43	0.00007
350	0.00003	130	0.00010	350	0.00001
		350	0.00001		
Grms = 0.49		Grms = 0.16		Grms = 0.10	

Figure E-1 Railroad Cargo Test Description

Test Parameters :

Test Axis :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband (350 Hz) random vibration
Control Strategy :	Single or multi-point input control

Control Notes :

1. If LCEP information is not available, the default test duration is 10 hours / axis.
2. Use the maximum control system roll-off rate at the 1 and 350 Hz breakpoints.
3. The test schedules are derived for a control accelerometer(s) located at the material and transportation platform interface.

Schedule Description

The Figure E-1 test schedules depict the test severity at the cargo bed of a composite of railcars. Transportation of secured cargo, non-isolated, on the railcar bed during cross country rail transportation is the typical environment. The vertical axis is up from the ground (railcar bed), transverse is perpendicular across the rail tracks, and longitudinal is parallel to the rail tracks. These curves are based upon data measured at the cargo bed of different configurations of railcars including flat cars, box cars, and refrigerated cars. The data were collected from typical rail lines with tracks sections across switch yards, bridges, and track crossings. The data includes varying percentage cargo load from an empty railcar to maximum capacity, and a range of railcar speeds. The typical average train speed for the measurements is 50 to 60 MPH. The test schedules are a worst case envelope of the measured data. In general, the vertical axis vibration is highest followed by the transverse and longitudinal. The vibration amplitude may be lower for items internal to suspension equipped material that is secured to the railcar bed, such as wheeled vehicles, trailers, etc. The test schedule is not representative of transient shock excitation resulting from severe track misalignment or longitudinal impact between adjacent decoupled railcars. The test schedule is also not representative of railcars equipped with high-speed magnetic levitation or air-ride suspension systems. Figure E-1 is developed from the UK Def-Stan 0035, MIL-STD 810, and other data sources.

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METHOD 402

ACOUSTIC NOISE

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ANNEX A ACOUSTIC NOISE - GUIDANCE FOR INITIAL TEST SEVERITY

ANNEX B ACOUSTIC TESTING TECHNICAL GUIDANCE

METHOD 402

ACOUSTIC NOISE

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the acoustic environment incurred by systems, subsystems and units, hereafter called materiel, during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified acoustic environment without unacceptable degradation of its functional and/or structural performance. It is also applicable for materiel where acoustic noise excitation is used in preference to mechanical vibrator excitation for the simulation of aerodynamic turbulence.

AECTP 100 and 200 provide additional guidance on the selection of a test procedure for a specific acoustic environment.

1.3 Limitations

Where a diffuse field acoustic noise test is used for the simulation of aerodynamic turbulence, it is not necessarily suitable for proving thin shell structures interfacing directly with the acoustic noise.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to an acoustic environment.

a. Wire chafing
b. Component fatigue
c. Component connecting wire fracture
d. Cracking of printed circuit boards
e. Failure of waveguide components
f. Intermittent operation of electrical contacts
g. Cracking of small panel areas and structural elements
h. Optical misalignment
i. Loosening of small particles that may become lodged in circuits and mechanisms
j. Excessive electrical noise

2.2 Use of Measured Data

Where practical, measured field data should be used to develop test levels. It is particulary important to use field data where a precise simulation is the goal. Sufficient field data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel. The measured data should accurately represent the type of acoustic excitation, frequency range, intensity, and other parameters necessary for laboratory simulation.

2.3 Sequence

Similar to vibration, the effects of acoustically induced stresses may affect material performance under other environmental conditions such as temperature, humidity, pressure, electromagnetism, etc. When it is required to evaluate the effects of acoustic noise together with other environments, and when a combined test is impractical, a single test item should be exposed to all relevant environmental conditions in turn. The order of application of the tests should be considered and should be compatible with the Life Cycle Environmental Profile.

2.4 Choice of Test Procedures

The choice of test procedure is governed by the in-service acoustic environments and test purpose. These environments should be identified from consideration of the Life Cycle Environmental Profile as described in AECTP 100.

Three procedures are presented as follows:

Procedure I	Diffuse Field Acoustic Noise
Procedure II	Grazing Incidence Acoustic Noise
Procedure III	Cavity Resonance Acoustic Noise

2.5 Types of Acoustic Excitation

2.5 1 Procedure I - Diffuse Field Acoustic Noise

A diffuse field is generated in a reverberation chamber. Normally, a wideband random excitation is provided and the spectrum is shaped. This test is applicable to materiel or structures that are required to function or survive in an acoustic noise field such as that produced by aerospace vehicles, power plants, and other sources of high intensity acoustic noise. Since this test provides an efficient means of inducing vibration above 100 Hz, the test may also be used to complement a mechanical vibration test, using acoustic energy to induce mechanical responses in internally mounted materiel. In this role the test is applicable to items such as installed materiel in airborne stores carried externally on high performance aircraft. However, because the excitation induced by a diffuse acoustic field is different from that of aerodynamic turbulence excitation, the test procedure is not necessarily suitable for testing thin shell structures interfacing directly with acoustic noise.

A practical guideline is that acoustic tests are not required if materiel is exposed to wideband random noise at a sound pressure level less than 130 dB (ref 20 μPa) overall, and if its exposure in every one-Hertz band is less than 100 dB (ref 20 μPa). A diffuse field acoustic test is usually defined by the following parameters.

- The spectrum levels.
- The frequency range.
- The overall sound pressure level.
- The duration of the test.

2.5.2 Procedure II - Grazing Incidence Acoustic Noise

Grazing incidence acoustic noise is generated in a duct, commonly known as a progressive wave tube. Normally, wideband random noise with a shaped spectrum is directed along the duct.

This test is applicable to assembled systems that have to operate or survive in a service environment of convected pressure fluctuations over the surface, such as exist in aerodynamic turbulence. These conditions are particularly relevant to aircraft panels, where aerodynamic turbulence will exist on one side only, and to externally carried stores subjected to aerodynamic turbulence excitation over their total external exposed surface.

In the case of a panel, the test item will be mounted in the wall of the duct so that grazing incidence excitation is applied to one side only. An aircraft-carried store such as a missile will be mounted co-axially within the duct such that the excitation is applied over the whole of the external surface.

A grazing incidence acoustic noise test is usually defined by the following parameters :

- The spectrum levels.
- The frequency range.
- The overall sound pressure level.
- The duration of the test.

2.5.3 Procedure III - Cavity Resonance

A resonance condition is generated when a cavity is excited by the airflow over it, such as that presented by an open bomb bay on an aircraft. This causes oscillation of the air within the cavity at a frequency dependant upon the cavity dimensions. In turn the acoustic excitation can induce mechanical vibration into the structure and components within the cavity. The resonance condition can be induced by the application of a sinusoidal acoustic source, tuned to the correct frequency, to the open cavity. The resonance condition will occur when the control microphone response reaches a maximum in a sound field held at a constant sound pressure level over the frequency range. A cavity resonance test is defined by the following parameters:

- The excitation noise frequency.
- The overall sound pressure level within the cavity.
- The duration of the test.

2.6 Materiel Operation

Where relevant, the test item should be functioned and the performance measured and noted during each test phase and/or each acoustic level applied.

3. SEVERITIES

Test levels and durations should be established using projected Life Cycle Environmental Profiles, available data, or data acquired directly from an environmental data gathering programme.

When these data are not available, guidance on developing initial test severities are to be found in Annex A. These overall sound pressure levels (OASPL) should be considered as initial values until measured data are obtained.

It should be noted that the test selected may not necessarily be an adequate simulation of the complete environment and, consequently, a supporting assessment may be necessary to complement the test results.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item.
b. The definition of the test item.
c. The type of test: development, worthiness, qualification.
d. Whether the test item is required to operate or not during the test.
e. The operating checks required: initial, during the test, final.
f. For the initial and final checks, specify whether they are performed with the test item installed in the test facility.
g. The details required to perform the test, including method of attachment or suspension of the test item.
h. The control and monitor points or a procedure to select these points.
i. The pre-conditioning time and conditions
j. The definition of the test severity.
k. The control strategy.
l. The indication of the failure criteria.
m. The method of taking into account tolerance excesses in the case of large materiel.
n. Any other environmental conditions at which testing is to be carried out, if other than standard laboratory conditions.

4.2 If Required

a. The effect of gravity and the consequent precautions.
b. The number of simultaneous test items for Procedure I

c. Tolerances, if different from paragraph 5.1.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

The test tolerances are given below in Table 1

5.2 Control

The control strategy depends upon the type of test and the size of the materiel.

5.2.1 Control Options

5.2.1.1 Single Point Noise Control

The single point should be defined to provide an optimum control position in the chamber or progressive wave tube.

5.2.1.2 Multiple Point Noise Control

The control points should be selected to define a controlled volume within the reverberation chamber. Control should be based upon the average of the sound pressure levels at each microphone. Where the range of measurements at the monitoring positions does not exceed 5 dB (OASPL), a simple arithmetic average of the sound pressure levels may be used. For a range of 5 dB or greater, a logarithmic average of the sound pressure levels should be used.

Table 1 – Acoustic Test Tolerances

Parameter	Tolerance
Overall sound pressure level averaged over all control microphones, ref specified overall sound pressure level	+ 3dB - 1dB
Overall sound pressure level at each control microphone, ref specified overall sound pressure level	+ 4dB - 2dB
Averaged test spectrum from all control microphones at levels above -15dB (1) in 1/3 octave bands, ref specified 1/3 octave band sound pressure levels.	+ 4dB - 4dB
Averaged test spectrum from all control microphones at levels below -15dB (1) and above -25dB (1) in 1/3 octave bands, ref specified 1/3 octave band sound pressure levels.	+ 6dB - 6dB
Averaged test spectrum from all control microphones at levels -25dB (1) and below in 1/3 octave bands, ref specified 1/3 octave band sound pressure levels.	+ 10dB - 10dB
Test time duration	+/- 5% or +/- 1 min whichever is lesser

Notes

(1) n octave band, level of -15dB becomes -10dB, and level of -25dB becomes –20dB

5.2.1.3 Vibration Response Control

Where it is necessary to achieve a given vibration acceleration response on the test item, the test spectrum should be adjusted to achieve the required response which may be monitored at either a single point or as the average from multiple monitoring points.

5.2.2 Control Methods

Control can be by either open or closed loop. Open loop control is adequate for progressive wave tubes and for small chambers having a single noise source. Closed loop control is more effective for large chambers having multiple noise sources that cover different bands in the test frequency range.

5.2.3 Overall Accuracy of Control

The uncertainty of measurement of the total measurement system, including statistical errors, should not exceed one third of the specified tolerance for the overall sound pressure level.

5.3 Installation Conditions of Test Item

5.3.1 Procedure I - Diffuse Field Acoustic Noise

The test item should be suspended or otherwise mounted in a reverberation chamber on an elastic system in such a manner that all appropriate external surfaces are exposed to the acoustic field and no surface is parallel to a chamber surface. The resonance frequency of the mounting system with the specimen should be less than 25 Hertz, or 1/4 of the minimum test frequency, whichever is the lesser. If cables, pipes etc., are required to be connected to the test item during the test, these should be arranged so as to add similar restraint and mass as in-service.

A microphone should be located in proximity to each different major face of the test item at a distance of 0.5 meter from the face, or midway between the center of the face and the chamber wall, whichever is the lesser. The outputs from these microphones should be averaged to provide a single control signal. Where the chamber is limited to a single noise injection point, one microphone should be placed between the test item and the chamber wall furthest from the noise source. The orientation of the microphones in such a facility is not critical, although the microphone axes should not be set normal to any flat surface. The microphones should be calibrated for random incidence.

5.3.2 Procedure II - Grazing Incidence Acoustic Noise

System test items such as panels should be mounted in the wall of the duct such that the required test surface is exposed to the acoustic excitation. This surface shall be flush with the inner surface of the duct so as to prevent the introduction of cavity resonance or local turbulence effects. System test items such as stores should be suspended or otherwise mounted centrally within the duct on an elastic support such that all external surfaces are subjected to the progressive wave. The rigid body modes of the system should be lower than 25 Hertz or 1/4 of the lowest test frequency, whichever is the lesser. Care must be exercised to ensure that no spurious acoustic or vibratory inputs are introduced by the test support system or any ancillary structure.

The microphone(s) for control and monitoring of test conditions should preferably be mounted in the duct wall opposite to the test panel. Other positions within the duct may be selected provided that the microphone is positioned so that it responds to only grazing incidence waves, and that the necessary corrections are applied to the measured level. The microphones should be calibrated for grazing incidence.

5.3.3 Procedure III - Cavity Resonance Acoustic Noise

The test item should be suspended or otherwise mounted in a reverberation chamber such that only that part of the specimen to be tested is exposed to the direct application of acoustic energy. All other surfaces should be protected so that their level of acoustic excitation is reduced by 20 dB. Protective coverings should not provide any additional vibration damping to the structure. The microphone for control of the test should not be located within the cavity to be tested.

5.3.4 Effects of Gravity

Tests will normally be carried out with the materiel mounted in the correct spatial orientation, unless it is shown that the performance of the materiel is not affected by gravity.

5.4 Preparation for Test

5.4.1Pre-conditioning

Unless otherwise specified in the Test Instruction the test item should be allowed to stabilise at laboratory ambient conditions.

5.4.2 Inspection and Performance Checks

Inspection and performance checks may be carried out before and after testing. The requirements for these checks should be defined in the Test Instruction. If these checks are required during the test sequence, the time intervals at which they are required should also be specified.

5.5 Procedures

The Test Instruction should stipulate whether the test item is or is not to be operating during the test.

5.5.1 Procedure I - Diffuse Field Acoustic Noise Testing

Step 1 Install the test item into the reverberation chamber in accordance with paragraph 5.3.1.

Step 2	Select microphone positions for control, monitoring and control strategy in accordance with paragraph 5.2.
Step 3	When using open loop control, remove the test item and confirm that the specified overall sound pressure level and spectrum can be achieved in an empty chamber, then replace the test item in the chamber.
Step 4	Pre-condition in accordance with paragraph 5.4.1.
Step 5	Conduct initial checks in accordance with pararaph 5.4.2
Step 6	Apply the test spectrum for the specified time. If required, carry out inspections and performance checks in accordance with paragraph 5.4.2.
Step 7	Carry out the final inspection.
Step 8	Remove the test item from the chamber.
Step 9	In all cases record the information required.

5.5.2 Procedure II - Grazing Incidence Acoustic Noise Testing

Step 1	Install the test item in accordance with paragraph 5.3.2.
Step 2	Select microphone positions for control, monitoring and control strategy in accordance with paragraph 5.2
Step 3	Pre-condition in accordance with paragraph 5.4.1.
Step 4	Conduct initial checks in accordance with paragraph 5.4.2.
Step 5	Apply the test spectrum for the specified time. If required, carry out inspections and performance checks in accordance with paragraph 5.4.2.
Step 6	Carry out the final inspection.
Step 7	Remove the test item from the duct.
Step 8	In all cases record the information required.

5.5.3 Procedure III - Cavity Resonance Acoustic Noise Testing

Step 1	Install the test item into the chamber in accordance with paragraph 5.3.3.

Step 2 Locate the control microphone in accordance with paragraph 5.3.3.

Step 3 Pre-condition in accordance with paragraph 5.4.1.

Step 4 Conduct initial checks in accordance with paragraph 5.4.2.

Step 5 Apply the sinusoidal acoustic test level and adjust its frequency to achieve the resonance condition as indicated by the response from the control microphone, adjust to the Test Instruction level, and apply for the specified time. If required, carry out inspections and performance checks in accordance with paragraph 5.4.2.

Step 6 Carry out the final inspection.

Step 7 Remove the test item from the chamber.

Step 8 In all cases record the information required.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of the acoustic test conditions.

7. REFERENCES AND RELATED DOCUMENTS

a. ISO 266, Acoustics – Preferred Frequencies, International Organization for Standardization, 1997

b. IEST RP-DTE040.1, High-Intensity Acoustics Testing, Institute of Environmental Sciences and Technology, USA, January 2003

c. NASA-STD-7001, Payload Vibroacoustic Test Criteria, National Aeronautics and Space Agency, USA, 21 June 1996

d. Piersol, Allan G., Vibration and Acoustic Test Criteria for Captive Flight of Externally Carried Stores, AFFDL-TR-71-158, December 1971

e. Burkhard, Alan H., Captive Flight Acoustic Test Criteria for Aircraft Stores, Shock and Vibration Bulletin 43, Part 3, January 1973

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ANNEX A

ACOUSTIC NOISE - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

1. WIDEBAND RANDOM AND INCIDENCE NOISE TESTING

1.1 Overall Sound Pressure Level (OASPL)

From the in-service operation for the materiel the test overall sound pressure level and duration may be obtained from Table A-1. The values have been developed from those in MIL-STD 810.

1.2 Test Spectrum

The applied test spectrum associated with these levels is shown in Figure A-1. The test spectrum should be achieved while maintaining the test parameters within the tolerances given in paragraph 5.1

1.3 Simulation of Aerodynamic Turbulence

Where a wideband noise test is required for the simulation of aerodynamic turbulence, the test levels and durations should be derived in conjunction with those for the complementary mechanical test; see Method 401, Annex A.

Table A-1 Overall Sound Pressure Test Levels and Duration

Typical Application	Test Level (OASPL) dB	Duration (minutes)
Transport aircraft, at locations not close to jet exhausts	130	30
Transport aircraft, in internal material bays close to jet exhausts	140	30
High performance aircraft at locations not close to jet exhausts	140	30
High performance aircraft in internal materiel bays close to jet exhausts	150	30
Air-to-air missiles on medium performance aircraft(q< 57456 Pa)	150	30
Air-to-ground missiles on medium performance aircraft (q< 57456 Pa)	150	15
Ground materiel in enclosed engine runup areas	150	30
High performance aircraft, in internal materiel bays close to reheat exhaust and gun muzzles or in nose cones	160	30
Airborne rocket, most locations, but excluding booster or engine bays	160	8
Air-to-air missiles on high performance aircraft (q< 86184 Pa)	165	30
Air-to-ground missiles on high performance aircraft (q< 86184 Pa)	165	15
Airborne rocket boosters or engine bays	165	8
Ground materiel on rocket launchers	165	8

2. CAVITY RESONANCE TESTING

2.1 Test Parameters

For cavity resonance testing the sound pressure level B_o, frequencies f_N and duration T will be as calculated or defined in Table A-2. The values have been developed from those in MIL-STD 810.

Table A-2 Cavity Resonance Test Conditions

Test level

$$B_0 = 20\ \log(q) + 76.4\,\text{dB}\ \ (\text{ref } 20\ \mu\,\text{Pa})$$

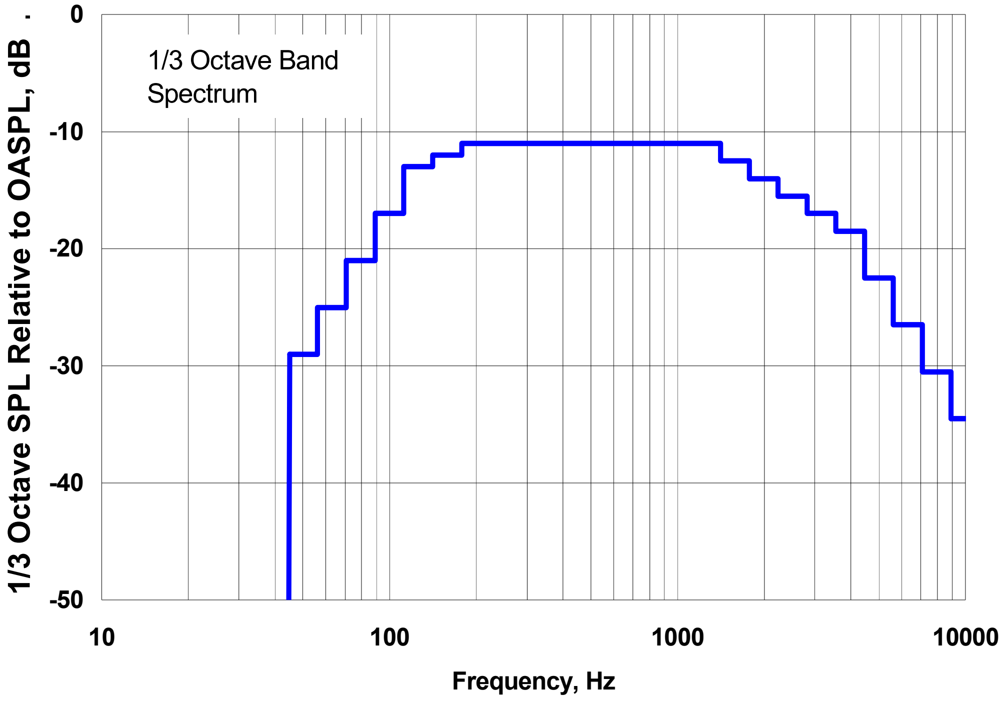
$$f_n = \frac{6.13(N-0.25)\left(2.4-\frac{M^2}{2}\right)^{0.5}}{0.57(L)(C)\underset{\mathbf{2}}{+}\left(2.4-\frac{M^2}{2}\right)^{0.5}}Hz$$

Definitions

B_o = Sound Presssure Level, dB
f_N = Resonance frequency for the N^{th} mode (where N =1, 2, 3,..) up to 500 Hz
(where the first mode f_1 > 500 Hz , use only this mode)
N = Mode number
C = Speed of sound at altitude of flight (m/s)
L = Length or radius of opening exposed to the air stream (m).
M = Mach number
q = Flight dynamic pressure when cavity is open (Pa)

Notes :

1. Test duration: T = 1 hour for each resonance frequency.
2. A second set of resonance frequencies should be identified by using the distance parameter, L, as the depth of the cavity.



1/3 Octave Band Center Frequency, Hz	Nominal SPL, dB		1/3 Octave Band Center Frequency, Hz	Nominal SPL, dB
50	- 29.0		800	-11.0
63	- 25.0		1000	-11.0
80	- 21.0		1250	-11.0
100	-17.0		1600	-12.5
125	-13.0		2000	-14.0
160	-12.0		2500	-15.5
200	-11.0		3150	-17.0
250	-11.0		4000	-18.5
315	-11.0		5000	-22.5
400	-11.0		6300	-26.5
500	-11.0		8000	-30.5
630	-11.0		10000	-34.5

Figure A-1 Applied Test Spectrum

Note: Overall test levels are given in Table A-1

ANNEX B

ACOUSTIC TESTING TECHNICAL GUIDANCE

1. REVERBERATION CHAMBERS

A reverberation chamber is basically a cell with hard, acoustically reflective walls. When noise is generated in this room, the multiple reflections within the main volume of the room cause a uniform diffuse noise field to be set up. The uniformity of this field is disturbed by three main effects.

a. At low frequencies, standing modes are set up between parallel walls. The frequency below which these modes become significant is related to the chamber dimensions. Small chambers, below about 100 cubic metres in volume, are usually constructed so that no wall surfaces are parallel to each other in order to minimise this effect.

b. Reflections from the walls produce higher levels at the surface. The uniform noise field therefore, only applies at positions within the central volume of the chamber, and test items should not be positioned within about 0.5 metre of the walls.

c. The size of the test item can distort the noise field if the item is large relative to the volume of the chamber. It is normally recommended that the volume of the test item should not exceed 10% of the chamber volume.

Noise is normally generated with an air modulator and is injected into the chamber via a coupling horn. Provision is made in the chamber design to exhaust the air from the modulator through an acoustic attenuator in order to prevent the direct transmission of high intensity noise to areas outside the test chamber.

2. PROGRESSIVE WAVE TUBES

A parallel sided duct usually forms the working section of such a progressive noise facility. This may be circular or rectangular in section to suit the test requirements. For testing panels, a rectangular section may be more suitable, while an aircraft carried store may be more conveniently tested in a duct of circular section.

An air modulator coupled into one end of the working section by a suitable horn generates noise. From the opposite end of the plain duct, another horn couples the noise into an absorbing termination. Maximum absorption over the operating frequency range is required in order to minimise standing wave effects in the duct. Noise then progresses along the duct and is applied with grazing incidence over the surface of the test item.

The test item itself may be mounted within the duct, in which case the grazing incidence wave will be applied over the whole of its external surface. Alternatively the test item may be mounted in the wall of the duct when the noise will be applied to only that surface within the duct, e.g. on one side of a panel. The method used will depend upon the test item and its in-service application.

3. ACOUSTIC NOISE CHARACTERISTICS

Radiated high intensity noise is subjected to distortion due to adiabatic heating. Thus, due to heating of the high pressure peaks and cooling of the rarefaction troughs, the local speed of propagation of these pressures is modified. This causes the peaks to travel faster and the troughs to travel slower than the local speed of propagation such that, at a distance from the source, a sinusoidal wave becomes triangular with a leading shock front.

This waveform is rich in harmonics, and therefore the energy content is extended into a higher frequency range. It can be seen from this that it is not possible to produce a pure sinusoidal tone at high noise intensities.

The same effect takes place with high intensity random noise that is commonly produced by modulating airflow with a valve driven by a dynamic actuator. This may be either electrodynamic or hydraulic in operation. Due to velocity and/or acceleration restraints on the actuator, it is not possible to modulate the airflow at frequencies greater than about 1 KHz. Acoustic energy above this frequency, extending to 20 kHz or more, therefore results from a combination of cold air jet noise and harmonic distortion from this lower frequency modulation.

4. CONTROL STRATEGIES

Microphones are normally used to monitor and control the test condition. When testing stores and missiles, it is recommended that not less than three microphones be used to control the test. Some test items may be more effectively monitored on their vibration response, in which case the monitoring requirements of Method 401 should be followed as appropriate.

The monitoring system should be capable of measuring random noise with a peak to rms ratio of up to 3.0. Pressure calibrated microphones used in reverberation chambers should be corrected for random incidence noise, while those used in progressive wave tubes should be corrected for free field grazing (90°) incidence noise, and both should have a linear pressure response. Provision should be made for averaging the outputs of the microphones to provide the spatial average of the noise for control purposes.

5. DEFINITIONS

5.1 Sound Pressure Level:

The sound pressure level is the logarithmic ratio of the sound pressures expressed as:

$$L_p = 10\log\left(\frac{I}{I_0}\right) = 20\log\left(\frac{P}{P_o}\right)$$

where L_p = sound pressure level, dB

I = measured intensity, W/m^2

I_o = reference intensity = 10^{-12} W/m^2

P = measured P_{RMS} pressure, Pa

P_o = reference pressure = 20×10^{-6} Pa

5.2 Third Octave Filters:

A third octave filter has an upper to lower passband frequency ratio of $2^{1/3}$ or approximately 1.26. The effective filter bandwidth between the filter upper and lower frequency –3dB points is approximately 23 % of the center frequency. The relationships between the filter center frequency and upper or lower -3dB filter points are defined below. Standard third octave frequency bands are defined in International Specification ISO 266, reference b. For other definitions relevant to random vibration and data analysis refer to Method 401.

Third Octave Filter Equations

$$f_0 = \sqrt{(f_1 \times f_2)}$$

$$f_1 = \frac{f_0}{\sqrt[3]{2}}$$

$$f_2 = f_1\sqrt[3]{2}$$

$$\frac{(f_2 - f_1)}{f_0} \approx 0.23 \qquad \text{approximate equation}$$

where :

f_0 = filter center frequency, Hz

f_1 = filter lower -3dB frequency, Hz

f_2 = filter upper -3dB frequency, Hz

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METHOD 403

CLASSICAL WAVEFORM SHOCK

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METHOD 403

CLASSICAL WAVEFORM SHOCK

1. SCOPE

1.1 Purpose

The purpose of this test method is to induce responses in systems, subsystems and units, hereafter called materiel, that are comparable with those likely to be experienced in-service during the specified operational conditions, and that can be readily reproduced in the laboratory using appropriate shock test equipment. The basic intention is not necessarily to replicate the in-service environment.

1.2 Application

This test method is primarily designed to undertake shock testing involving the classical time history acceleration waveforms, such as the half-sine pulse, the terminal peak sawtooth pulse and the trapezoidal pulse. Descriptions of the shock response spectra (SRS) for these classical waveforms are available in Method 417, SRS Shock, Annex C. Other time domain pulses can be accommodated by this test method, provided that they are within the capabilities of the shock test facility. To provide adequate test repeatability and control, an electrodynamic or servohydraulic test system is preferred for the test procedures, but the test method does not exclude the use of drop or impact type test equipment. For more accurate simulation of complex shock environments with many zero crossings, and whenever possible for measured transient time domain field shock data, the procedures defined in Method 417 are recommended. Moreover, if the test specification is in an SRS format, then Method 417 is recommended. For pyrotechnic shock environment testing, Method 415, Pyroshock, is recommended.

1.3 Limitations

This test method does not cover complex shock responses, or shocks described in an SRS format. Specifically, this test method does not accommodate environments arising from gun blast, nuclear blast, pyrotechnic shock, underwater explosion, and safety drops.

The classical waveform shock pulses in Method 403 do not necessarily replicate the shock environment experienced in-service. Also, it may not be possible to simulate actual operational in-service shock environments because test machine and/or fixture limitations may preclude the satisfactory application of the specified pulse to the test item.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all-inclusive but provides examples of problems that could occur when materiel responds to transient shock environments.

a. Materiel electronic circuit card malfunction, electronic circuit card damage, electronic connector failure

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

c. Permanent mechanical/structural deformation of the material 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 component being exceeded

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

f. Fatiguing of materiel (low cycle fatigue)

g. Intermittent electrical contacts

h. Cracking and rupturing of material

2.2 Use of Measured Data

The use of measured data is not generally applicable for the Classical Waveform Shock method; however field data may be beneficial for the characterization of the amplitude, duration, and required number of the laboratory test shock pulse(s). If sufficient measured acceleration time history data are available, Method 417 should be used wherever practical.

2.3 Sequence

The effect of shock induced stress may affect materiel performance under other environmental conditions such as vibration, temperature, altitude, humidity, leakage or EMI/EMC. Also, it is essential that materiel which is likely to be sensitive to a combination of environments be tested to the relevant combinations simultaneously.

Where it is considered that a combined environment test is not essential or not practical to configure, and where it is required to evaluate the combined environment effects, a single test item should be exposed to all relevant environmental conditions. The order of application of environmental tests should be compatible with the Life Cycle Environmental Profile.

2.4 Choice of Test Procedure

There is only one procedure for Classical Waveform shock testing. The selection of the test method is governed by several factors including the in-service shock environment and materiel type. These and other factors are dealt with in the General Requirements, AECTP 100, and in the Environmental Conditions, AECTP 200, documents.

2.5 Types of Shock Simulation

The three classical shock pulses specified in this test method are :

- Half-sine
- Terminal peak sawtooth
- Trapezoidal

These transient time domain pulses are defined in the Test Procedure section Figures 1, 2, and 3 respectively. Several methodologies exist to perform the acceleration contol within the specified tolerence limits depending on the shock amplitude, required velocity, duration, and test equipment available. Test fixturing to replicate the in-service environment and control structural resonances is required for all methods because the shock severity and equipment damage potential is strongly a function of the mounting configuration.

2.6 Velocity Change

Specifying the severity of the test by pulse shape, peak acceleration, and duration is an adequate definition for many purposes. Consequently, the velocity change need not be specified except where it is necessary either to achieve a high degree of reproducibility, or where there is a need to supplement or replace one of the normal parameters used to define the shock pulse. For example, high reproducibility is applicable to repeat tests on production batches of equipment. Specification of the velocity change may also be preferred to duration for shocks of high intensity and of extremely short duration. The Test Instruction should, in these instances, invoke the velocity change requirement and specify the method of measurement.

Velocity change may be determined from the measured data by any of the following :

a. From the impact velocity for shock pulses not involving rebound motion.
b. By the drop and rebound height as appropriate, where free fall facilities are used.
c. By integrating the acceleration pulse with respect to time between the limits of 0.4D before the start of the pulse, to 0.1D beyond the pulse, where D is the duration of the ideal pulse.

2.7 Materiel Operation

The test item should be operated and its performance measured and noted as specified in the Test Instruction or relevant specification.

3. SEVERITIES

3.1 General

Annex A provides an initial test severity for a classical shock and a restrained cargo environment. This test severity should be used in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data are obtained, at which time consideration should be given to undertaking any further tests using Method 417.

3.2 Supporting Assessment

The test pulse selected is unlikely to be an adequate simulation of the in-service environment and consequently, a supporting assessment is usually necessary to complement the test results and justify the selected test rationale.

3.3 Isolation System

Materiel intended for use with shock isolation systems should be tested with its isolators in position. If it is not practical to carry out the shock test with the appropriate isolators, or if the dynamic characteristics of the materiel installation are highly variable, the test item should be tested without isolators at a modified test severity specified in the Test Instruction.

3.4 Sub-System Testing

When identified in the Test Instruction, sub-systems of the materiel may be tested separately and can be subjected to a different shock severity. In this case the Test Instruction should stipulate the shock severity specific to each sub-system.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item
b. The definition of the test item
c. The definition of the test severity including axes, duration and number of pulses to be applied
d. The type of test: development, qualification etc.
e. The method of mounting, including isolators if applicable
f. The operation or non-operation of test item during test
g. The packaging conditions, if applicable
h. The requirements for operating checks if applicable
i. The control strategy, pulse shape or velocity change
j. The details required to perform the test
k. The definition of the failure criteria if applicable

4.2 If Required

a. The climatic conditions, if other than standard laboratory conditions
b. The effect of gravity and the consequent precautions
c. The value of the tolerable spurious magnetic field
d. The tolerances, if different or additional to these in Paragraph 5.1

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

Tolerances for the classical waveforms are given in Figures 1, 2 and 3 respectively. The Figure 1 half-sine shock tolerance also applies to the restrained cargo test procedures.

5.2 Installation Conditions of Test Item

Unless otherwise stated in the Test Instruction for the materiel, the following will apply :

a. The test item shall be mechanically fastened to the shock machine, directly by its normal means of attachment, or by means of a fixture. The mounting configuration shall enable the test item to be subjected to shocks along the various axes and directions as specified. External connections necessary for measuring purposes should add minimum restraint and mass.

b. Any additional stays or straps should be avoided. If cables, pipes, or other connections are required during the test, these should be arranged so as to add similar restraint and mass as in the in-service installation.

c. Materiel intended for use with isolators shall be tested with its isolators installed, see paragraph 3.3. .

d. The direction of gravity or any additional mass loading factors must be taken into account by compensation or by suitable simulation.

5.3 Adjustment

a. The test apparatus should be adjusted to ensure that the required test parameters can be produced during the actual test. A dynamic representation of the test item should be used for this purpose. An actual test item can be used if low amplitude shocks are acceptable for this task, but only as a last resort due to the potential for materiel damage.

b. Unless otherwise specified, the shock measurement instrumentation system shall conform with the Figure 4 frequency bandwidth requirements.

5.4 Test Preparation

5.4.1 Pre-conditioning

The test item should be stabilised to its initial climatic and other conditions as stipulated in the Test Instruction.

5.4.2 Operational Checks

All operational checks including all examinations should be undertaken as stipulated in the Test Instruction.

The final operational checks should be made after the materiel has been returned to rest under pre-conditioning conditions, and thermal stability has been obtained.

5.5 Procedures

Step 1	Select the test pulse or velocity change strategy, adhering to the tolerances defined in paragraph 5.1.
Step 2	Adjust the shock generator in accordance with paragraph 5.3. The installation of a dynamic representation shall be in accordance with paragraph 5.2. Make the test equipment adjustments necessary to obtain three consecutive shocks which meet the severity specified. Replace the dynamic representation with the real test item.

Step 3 Make the initial operational checks as defined in paragraph 5.4.2.

Step 4 Apply the shock and record the data required to prove the validity of the test. For assemblies mounted on isolators, any bottoming or impact with the structure or adjacent assemblies should be noted.

Step 5 Make the final operating checks as defined in paragraph 5.4.2.

Step 6 Repeat steps 1 to 5 as stipulated in the Test Instruction.

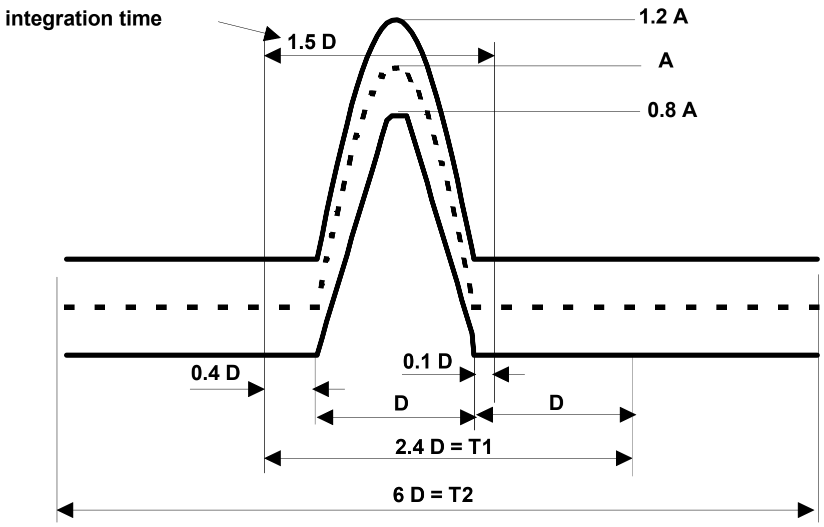


Figure 1 Half-sine Pulse
(Refer to key under Figure 3)

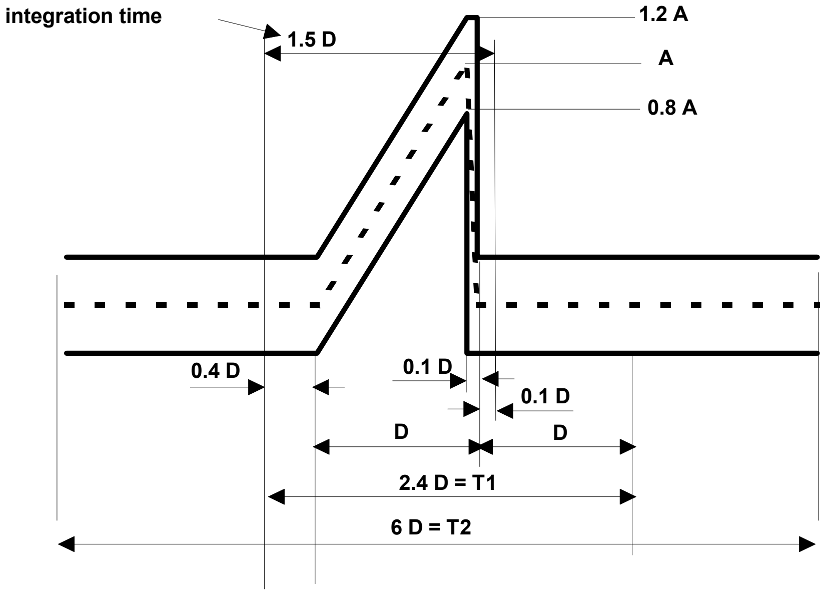


Figure 2 Terminal Peak Sawtooth Pulse
(Refer to key under Figure 3)

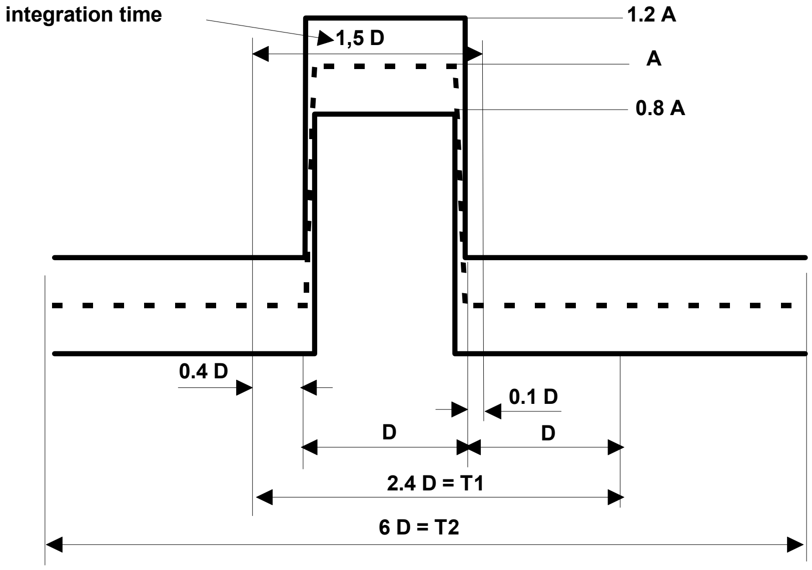
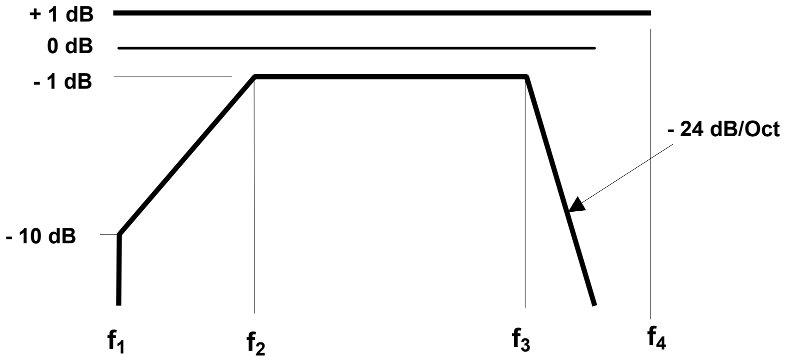


Figure 3 Trapezoidal Pulse

Key to Figure 1, 2, and 3 :

▬ ▬ ▬ ▬	nominal pulse
▬▬▬▬	limits of tolerances
D	duration of nominal pulse
A	peak acceleration of nominal pulse
T_1	minimum time during which the pulse shall be monitored for shocks produced using a conventional shock testing machine
T_2	minimum time during which the pulse shall be monitored for shocks produced using a vibration generator



Duration of Pulse (ms)	Low frequency Cut off (Hz)		High frequency Cut Off (kHz)	Frequency at which response may rise above +1 dB (kHz)
	f_1	f_2	f_3	f_4
25	0.2	1	1	2
11	0.5	1	1	2
6	1	4	2	4
3	4	16	5	25
<3	4	16	15	25

Notes :

a. For shocks of duration less than 3 milliseconds, the high frequency cut-off and +1dB response frequencies indicated may be inadequate if accurate measurement of the pulse shape is required. In such instances, the Test Instruction shall state the required frequencies of cut-off and the +1dB response.

b. There should be no significant phase shift over the frequency range of the measuring system

Figure 4 Required Frequency Response of Measurement Instrumentation System, Shock Test

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the completion of the shock test series.

7. REFERENCES AND RELATED DOCUMENTS

a. Smallwood, David, O., Shock Testing on Shakers Using Digital Control, Institute of Environmental Sciences and Technology, Technology Monograph, 1985

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ANNEX A

CLASSICAL WAVEFORM SHOCK - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

1. SCOPE

This Annex provides information for selecting a classical pulse shape, peak acceleration, duration, and laboratory test parameters. A Classical Waveform Shock and Restrained Cargo Shock initial test severity are provided in the Annex. Determination of the appropriate test requires consideration of the dynamic environment and possible test item orientation(s) during the in-service conditions. The shocks transmitted to materiel through its environment vary in both shape and amplitude and differ from classical pulse shapes. These classical pulses do not exist in a real environment but are intended to approximate the typical shocks encountered in-service and create materiel responses similar to those from the actual shock. The response of an item with multiple degrees of freedom depends upon both the shock input shape and amplitude, and the resonant frequency, damping, non-linearity, and transmissibility characteristics of the materiel being tested. Further information on the relationship of the time history shock waveform to the shock response spectrum, and details of shock testing is provided in Method 417, SRS Shock, Annex B and C.

2. CLASSICAL WAVEFORM SHOCK

2.1 Background

For general purposes, the terminal peak sawtooth has the advantage over the half-sine pulse shape of having a more uniform residual shock response spectrum This increases the likelihood that the test item resonances will be excited and that the test can be reproduced. The half-sine pulse has application where the test is representing a shock resulting from impact with, or retardation by, a predominantly linear elastic system. Other test conditions may require control to a different classical waveform, such as the initial peak sawtooth or trapezodial pulse. The Classical Shock test procedure will not be required along any axis for which a sufficiently severe random vibration test procedure is required in the test program, provided that materiel operational requirements during testing are comparable.

2.2 Test Severity

The classical shock waveforms and amplitudes defined in Table A-1 are applicable to evaluate materiel integrity for cases where measured shock data are unavailable. Tailoring of the specified wafeforms and amplitudes is acceptable to the extent defined in the Test Instruction. The Minimum Integrity test is a low level shock intended to expose design flaws in non-ruggidized materiel that are likely to result in failure of the materiel. The Vehicle Transport test represents a range of vehicle transpotation environments for typical installed materiel. The Crash test represents the shock occurring during a low speed vehicle accident. The test is intended to evaluate the failure potential of the in-service shock isolation or mounting hardware. The High Intensity shock is representative of impact or collision. The Rail Impact-Standard Car test is representative of a severe impact for large shipping containers mounted on standard railcars or trucks; see reference a. The Rail Impact-Cushioned Coupler Car is representative of rail impacts for materiel mounted directly on cushioned coupler cars or equipment in cases secured to the railcar ; see reference b.

2.3 Number of Shocks

For test items with a known in-service environment, the shock test pulse shall be applied three times in each orthogonal positive and negative axis of the test item in which the shock occurs during the in-service environment. For test items with an undefined in-service orientation, the default number of shock pulses applied shall be a minimum of three, in both the positive and negative polarity directions, along each of the three orthogonal axes, a total of 18 shocks.

Table A-1 Classical Shock Initial Test Severity

Test Category	Axis	Waveform Shape	Amplitude, Gs	Duration, ms
Minimum Integrity	All	Terminal Peak Sawtooth	15	11
Transportation	All	Terminal Peak Sawtooth	30	18
Crash Shock	All	Terminal Peak Sawtooth	40	11
High Intensity Shock	All	Terminal Peak Sawtooth	100	6
Rail Impact- Standard Car	Vertical	Half-sine	26	9
	Longitudinal	Half-sine	39	18
Rail Impact-Cushioned Coupler Car	Vertical & Transverse	Half-sine	3.1	30
	Longitudinal	Half-sine	5.1	30

3. RESTRAINED CARGO SHOCK

3.1 Background

The Restrained Cargo Shock test severity is representative of the repetitive shocks materiel receives during transportation as restrained cargo in commercial and military vehicles on paved roads and off-road conditions. The payload shock arises from a vehicle traversing pot-holes, curbs and general irregularities in the road surface. The amplitude and waveform of the shock is dependent upon the topography of the irregularity and the vehicle's suspension system, mass and speed. The characteristic of a typical shock is an initial pulse followed by a rapid exponential sinusoidal decay. Even for severe shocks, the vehicle's suspension damping ensures that the amplitude of the response decays within a few cycles.

The dominant frequency component of the payload shock in most cases is that of the vehicle's heave and pitch suspension modes. However, the majority of the energy transmission could be below the effective frequency range of the vehicle or materiel shock isolation. Consequently, the materiel may experience these shocks without any effective protection. Restrained Cargo Shock testing is undertaken to reproduce structurally transmitted shocks. It is not usually necessary to conduct both the shock and loose cargo testing for these conditions. The testing program selection depends upon the tie-down configuration and the characteristics of the materiel/package assembly. For example, Restrained Cargo Shock testing is applicable for large and/or heavy payloads when the payload is sufficiently constrained to prevent payload bounce and jostle from occurring. Method 406, Loose Cargo, is applicable for materiel that is not restrained during transport.

3.2 Test Severity

Restrained Cargo Shock is performed using the Figure A-1 classical shock half-sine waveform with an 11 millisecond duration. Waveform control tolerances are defined in Method 403 Figure 1. The applicable test waveform amplitude and shock distribution depends on the transportation environment. For materiel transportation on primarily paved road, the test severity provided in Table A-2 is applicable. For materiel transportation in a mission/field role in on and off road conditions, the severity is provided in Table A-3. These test severities and shock amplitude distributions are not intended to correlate with specific transport vehicles or represent a defined Life Cycle Environmental Profile.

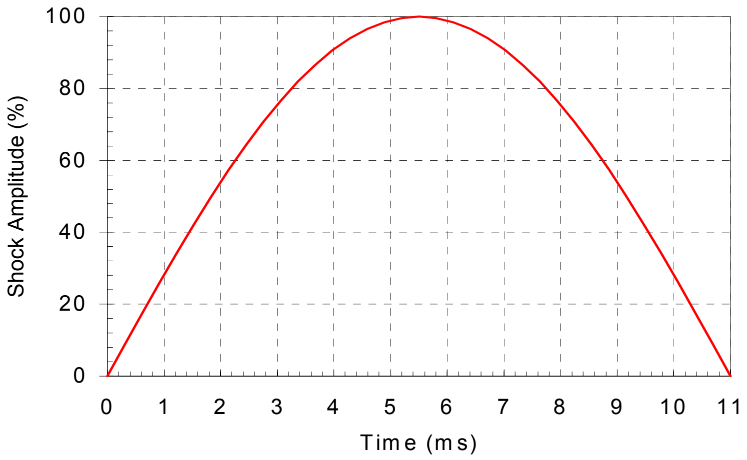

Figure A-1 Restrained Cargo Shock Half-sine Shock Waveform

Table A-2 Restrained Cargo Road Transportation Shock Test Severity

Peak Amplitude, Gs	Total Number of Shocks
1.5	150
2.0	84
3.0	42
3.5	24
4.0	3

Table A-3 Restrained Cargo Mission/Field Shock Test Severity

Peak Amplitude, Gs	Total Number of Shocks
3.0	402
4.5	204
6.0	84
7.5	42
8.0	3

3.3 Orientation of Shock

Where the materiel under test has a known in-service orientation, the restrained cargo shock waveform shall be applied in the positive direction of the primary axis of motion of the platform. For example, horizontally mounted materiel would be tested using a positive polarity waveform in the vertical axis. For test items with an undefined in-service orientation, the specified number of shock pulses shall be equally divided between both the positive and negative polarity direction of each orthogonal axis. In either case, the three maximum amplitude shock waveforms shall be applied in the most critical structural axis or direction specified in the Test Instruction.

4. REFERENCES

a. Magnuson, C.F. and Wilson L.T, Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks, Sandia Laboratories, Report SAND76-0427, July 1977.

b. Random Vibration and Shock Testing of Equipment for Use on Railway Vehicles, IEC TC9 WG 21, Draft 12th revision, 1996 (9/1371).

METHOD 404

CONSTANT ACCELERATION

METHOD 404

CONSTANT ACCELERATION

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the acceleration environment incurred by systems, subsystems and units, hereafter called materiel, during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified acceleration environment without unacceptable degradation of its functional and/or structural performance. It is applicable to materiel that is installed in aircraft, helicopter, air carried stores, surface launched missiles, and missiles in free flight.

1.3 Limitations

This test method takes no account of the rate of change of acceleration. The test method also does not include procedures for combined static acceleration and vibration testing; see reference a.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to an acceleration environment.

a. Deflections that interfere with materiel operation.
b. Permanent deformations and fractures that disable or destroy the materiel.
c. Breakage of fasteners involving safety.
d. Short and open circuits.
e. Variations in inductance and capacitance values.
f. Malfunctions of relays.
g. Jamming or bending of mechanisms or servo controls.
h. Joint seal leaks.
i. Variation in pressure and flow regulation.
j. Cavitation of pumps.
k. Modification of the dynamics characteristics of dampers and isolators.

2.2 Use of Measured Data

Where practical, measured field data should be used to develop test levels. It is particularly important to use field data where a precise simulation is the goal. Sufficient field data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel. As a minimum, information on the in-service acceleration level, duration, and orientation should be obtained.

2.3 Sequence

The acceleration can be potentially destructive. The Test Instructions should determine its place in the test sequence.

2.4 Choice of Test Procedure

There are two acceleration procedures. A rotary centrifuge, or a trolley, rail guided sled, are the most common test facility techniques to achieve a desired constant acceleration. These two procedures do not necessarily give the same acceleration input because the centrifuge is rotary motion and the trolley is a linear acceleration. It is for the Responsible Authority to choose the appropriate test facility according to the test items and effects to be simulated.

2.4.1 Procedure I - Centrifuge

The centrifuge generates acceleration loads by rotation about a fixed axis. The direction of acceleration is always radially towards the centre of rotation of the centrifuge, whereas the direction of the load induced by acceleration is always radially away from the centre of rotation. When mounted directly on the test arm, the test item experiences both rotational and translational motion. The direction of the acceleration and the load induced is constant with respect to the test item for a given rotational speed, but the test item rotates 360 degrees for each revolution of the arm.

Certain centrifuges have counter-rotary fixtures mounted on the test arm to correct for rotation of the test item. With this arrangement, the test item maintains a fixed direction with respect to space, but the direction of the acceleration and the induced load rotates 360 degrees around the test item for each revolution of the arm.

2.4.2 Procedure II - Trolley (Sled)

A trolley (sled) arrangement on a track generates linear acceleration in the direction of the sled motion. The test item mounted on the sled is uniformly subjected to the same acceleration level as the sled experiences. The acceleration test level and the time duration at the test level is dependent upon the length of the track, and the sled propulsion system.

This arrangement can produce a significant vibration environment. This vibration may be more severe that the normal service use environment. Careful attention to the attachment design may be needed to isolate the test item from this vibration environment. Telemetry and/or ruggedized instrumentation is required to measure the performance of the test item during the test.

2.5 Controls

2.5.1 Procedure I - Centrifuge

Where necessary during test, the acceleration shall be checked using suitable sensors. Variations of acceleration shall be controlled within the tolerance requirements of paragraph 5.1.1.

The speed rise and descent times should be such that the transverse accelerations are lower than the accelerations specified along the test axis.

2.5.2 Procedure II - Trolley (Sled)

Where necessary during the test, the acceleration shall be checked using suitable sensors. Variation of acceleration shall be controlled within the tolerance requirement of paragraph 5.1.2.

3. SEVERITIES

3.1 General

When practical, test levels and durations will be established using projected service use profiles and other relevant available data. When data are not available, initial test severities are to be found in annex A. These severities should be used in conjunction with the appropriate information given in AECTP 200. These severities should be considered as initial values until measured data are obtained. Where necessary, these severities can be supplemented at a later stage by data acquired directly from an environmental measurement programme.

3.2 Supporting Assessment

It should be noted that the test selected may not necessarily be an adequate simulation of the complete environment, and consequently a supporting assessment may be necessary to complement the test results.

3.3 Test Levels

Generally, the test includes two severities :

Severity 1 : Performance at limit acceleration – materiel in operation.

The purpose is to check the correct operation of materiel while it is subjected to the limit accelerations to be encountered in service and to check that there is no residual deformation.

(Limit acceleration is the maximum acceleration that the structure of the materiel should withstand without residual deformation.)

Severity 2 : Performance in extreme acceleration – materiel not necessarily in operation.

The purpose is to check the resistance of materiel to extreme acceleration.

Extreme acceleration is the maximum acceleration that the structure of the materiel should withstand without breaking, but may have residual deformation. It is the limit acceleration times a factor of 1.5.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The location of the control accelerometer
b. The definition of the test item
c. The orthogonal reference associated with the test item and its origin.
d. The pre-conditioning time.
e. The operation or non operation of the test item during the test
f. The operation checks to be scheduled : initial, during the test, and final ; in particular, for the initial and final checks, specify whether they are to be made with the test item installed on the test apparatus.
g. The necessary reference dimensional checks, initial and final.
h. The definition of the test severity.

4.2 If Required

a. The special features in assembling the test item.
b. The effect of gravity and consequent precautions.
c. Details relating to radial acceleration gradient.
d. Details necessary concerning the speed rise and descent times.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

5.1.1 Procedure I - Centrifuge

The acceleration obtained should be the acceleration required, within ±10 %, at all points of the test item, by setting the rotation speed and distance r. The acceleration due to gravity is not taken into account.

When the size of the materiel is large in relation to the length of the arm, the Test Instruction may require that only certain sensitive points should be subjected to the acceleration required ± 10 %.

5.1.2 Procedure II – Trolley (Sled)

The acceleration obtained should be the acceleration required within ±10 % at all points on the test item.

5.2 Installation Conditions of Test Item

The test item should be mounted on the test facility as installed in-service.

For safety reasons, take care to ensure the test item is not ejected from the test machine if the attachment points break. Any safety device used should not induce any additional stress during the test. A stress calculation should be made on the test set-up before the test.

When using a centrifuge, the wires and pipes between the slip ring and the test item should be rigidly fixed on the arm of the centrifuge. The terms, front side, upper side, left and right hand side designate the sides of the test item referenced in relation to the orthogonal axes pertaining to the carrier.

5.2.1 Procedure I - Centrifuge

The orientation of the test item on the centrifuge shall be as follows :

1. Forward acceleration: front side of the test item facing the centre of the centrifuge.
2. Backward acceleration: 180° from the position above.
3. Upward acceleration: upper side of the test item facing the centre of the centrifuge.
4. Downward acceleration: 180° from the position above.
5. Acceleration to the left: left hand side of the test item facing the centre of the centrifuge.
6. Acceleration to the right: right hand side of the test item facing the centre of the centrifuge.

5.2.2 Procedure II – Trolley (Sled)

The orientation of the test item on the trolley shall be as follows:

1. Backward acceleration: front side of test item facing the beginning of the track.
2. Forward acceleration: 180° from the position above.
3. Upward acceleration: upper side of the test item facing the end of the track.
4. Downward acceleration: 180° to the position above.
5. Acceleration to the left: left side of the test item facing the end of the track.
6. Acceleration to the right : right side of the test item facing the end of the track.

5.3 Sub System Testing

The sub systems of the materiel may be subjected to different severities. In this case, the Test Instruction should stipulate the severity specific to each sub system.

5.4 Effects of Gravity and Load Factor

Where the performance of the materiel is likely to be affected by the direction of gravity or the load factor (mechanisms, isolators, etc.) these must be taken into account by compensation or by suitable simulation.

5.5 Test Preparation

5.5.1 Pre-conditioning

Unless otherwise specified, the test item should be stabilised to its initial conditions as stipulated in the Test Instruction.

5.5.2 Initial Checks, During the Test and Final

These checks include the controls and examinations stipulated in the Test Instruction. The final checks are made after the materiel has been returned to rest in normal controlled atmospheric conditions, and thermal stability is obtained.

5.6 Procedure

The procedure steps apply to both the sled and trolley acceleration configurations.

Step 1 Install the test item so that the direction of the acceleration is parallel to the axis defined by the Test Instruction.

Step 2. Make the initial checks.

Step 3. Apply the required acceleration for the specified time. The test item is to be operated when required in the Test Instruction.

Step 4. Make the final checks

Step 5. Unless otherwise specified, apply the constant acceleration in each of the other five remaining directions. The order of application is not mandatory, but it is advisable to begin with the lowest acceleration level.

Step 6. In all cases, record the information required by the Test Instruction.

6. EVALUATION OF TEST RESULTS

The test item performances shall meet all appropriate Test Instruction requirements during and following the constant acceleration test.

7. REFERENCES AND RELATED DOCUMENTS

a. Rogers J.D. et al., VIBRAFUGE – Combined Vibration and Centrifuge Testing, 60th Shock and Vibration Symposium Proceedings, SAVIAC, 1989, volume III, page 63.

ANNEX A

CONSTANT ACCELERATION - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

TABLE A-1 TEST SEVERITY 1 (LIMIT) ACELERATION (Gs)

Carrier	Forward	Backward	Up	Down	Left	Right
Light Aircraft	3	5	5	3	5	5
Propeller Aircraft	1	1.5	10	8.5	5	5
Jet Transport	1.5	2	8	5	3	3
Combat Aircraft	10	15	15	15	15	15
External Stores						
wing	15	20	20	20	20	20
fuselage	10	15	15	15	15	15
Helicopter	2	2	7	3	4	4
External Stores	2	2	7	3	4	4
Missiles (free flight)						
Anti aircraft	30	10	50	50	50	50
Anti missile	50	10	100	100	100	100
Surface target	10	10	20	20	20	20

Notes
1. Duration : unless otherwise specified, the duration shall be sufficient to conduct checks as detailed in the Test Instruction.
2. Table acceleration data derived from multiple sources.

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METHOD 405

GUNFIRE

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ANNEX A PROCEDURE I - DIRECT REPRODUCTION OF MEASURED MATERIEL RESPONSE DATA

ANNEX B PROCEDURE II - STATISTICALLY GENERATED REPETITIVE PULSE

ANNEX C PROCEDURE III - REPETITIVE PULSE SHOCK RESPONSE SPECTRUM (SRS)

ANNEX D PROCEDURE IV - HIGH LEVEL RANDOM VIBRATION, SOR, NBROR, VIBRATION AND GUIDANCE FOR INITIAL TEST SEVERITIY

METHOD 405

GUNFIRE

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the gunfire environment response incurred by systems, subsystems, components and units, hereafter called materiel, during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the repetitive gunfire environment without unacceptable degradation of its functional and/or structural performance.

1.3 Limitations

It may not be possible to simulate the actual operational in-service gunfire environment response because of fixture limitations or physical constraints that may prevent the satisfactory application of the gunfire excitation to the test item. This test method is not intended to simulate temperature or blast pressure effects due to gunfire.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel are exposed to a gunfire environment.

a. Wire chafing
b. Loosening of fasteners
c. Intermittent electrical contacts
d. Touching and shorting of electrical parts
e. Seal deformation
f. Structural deformation
g. Structural and component fatigue
h. Optical misalignment
i. Cracking and rupturing
j. Loosening of particles or parts that may become lodged in circuits or mechanisms.
k. Excessive electrical noise.

2.2 Use of Measured Data

Measured data from field gun firing should be used to develop test levels for Procedures I, II, III, and IV. It is particularly important to use field-measured data where a precise response simulation is the goal. Sufficient field measured data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel. The quality of field measured gunfire data should be verified in accordance with reference c prior to developing laboratory test levels.

2.3 Sequence

The response to gunfire may affect materiel performance when materiel is tested under other environmental conditions such as vibration, shock, temperature, humidity, pressure, electromagnetics, etc. It is essential that materiel which is likely to be sensitive to a combination of environments be tested to the relevant combinations simultaneously.

Where it is considered that a combined test is not essential, or impractical to configure, and where it is required to evaluate the effects of gunfire together with other environments, a single test item should be exposed to all relevant environmental conditions sequentially.

The order of application of tests should be considered and made compatible with the Life Cycle Environmental Profile. If any doubt remains as to the order of testing, then gunfire testing should be undertaken immediately after completing vibration tests.

2.4 Rationale for Procedures and Parameters

Response to gunfire is characterized by a high level non-stationary, time-varying, vibration or repetitive shock that in general is superimposed upon an ambient vibration environment. Gunfire response has principal frequency components at the firing rate of the gun and it’s harmonics. Ambient vibration is comparatively low level energy, distributed fairly uniformly at frequencies other than the principal frequency components throughout the band of measurement. The response materiel to gunfire is dependent upon the dynamic characteristics of the materiel itself. The gunfire environment is considered to be time-varying because it usually has a time-varying root-mean-square (rms) level that is substantially above the ambient or aircraft induced environmental vibration level for a comparatively short period of time. One option is to consider the environment response data to be a series of well defined pulses at a particular repetition rate. With this assumption, the data analysis is usually not easily performed in terms of a stationary analysis, such as an auto-spectral density estimate, or as a transient analysis of the environment in terms of a shock response spectrum. If the analysis of the measured data concludes that the gunfire induced environment is only a slight increase in the ambient vibration level with no readily distinguishable pulse time characteristics, stationary random vibration analysis techniques, or Procedure IV, may be used to specify the test.

2.5 Choice of Test Procedures

The procedures are given in order of preference based on the ability of the test facility to replicate the gunfire environment. Improper test procedure selection may result in a severe under test or over test.

Nonstationary, time-varying, Vibration

Procedure I	Direct Reproduction of Measured Materiel Response Data
Procedure II	Statistically Generated Repetitive Pulse - Mean (deterministic) plus Residual (stochastic) Pulse
Procedure III	Repetitive Pulse Shock Response Spectrum (SRS)
	Stationary Vibration
Procedure IV	High Level Random, Sine-on-Random (SOR), Narrowband Random on Random (NBROR) Vibration

These procedures can be expected to cover the entire range of testing for materiel exposed to a gunfire environment. For example, in cases of severe materiel response to a gunfire environment with highly sensitive components, only Procedures I and II are appropriate. The use of these procedures requires that the materiel response data be measured at hard points on the materiel. Materiel test fixturing is also required such that the input environment excitation configuration is very similar for the measured in-service and laboratory conditions.

Procedure I is recommended as the most suitable test procedure because it provides the most accurate replication of the dynamic response of the materiel.

Procedure II is recommended as the second most suitable procedure because it provides good accuracy of replicating materiel dynamic response in addition to providing flexibility with regard to pulse randomization and gunfire burst length.

Procedure III is inferior to Procedures I and II because materiel time domain gunfire response characteristics cannot be simulated as precisely using SRS techniques, such as complex transient waveform generation. But, Procedure III can be used where test facility limitations preclude the use of Procedures I and II.

Procedure IV is applicable when the materiel is distant from the gunfire excitation, and measured data at appropriate hard points of the materiel indicate a random vibration gunfire environment only slightly above the most severe measured random vibration level. Procedure IV is also appropriate for aircraft gunfire in the absence of measured data. Annex D provides guidance for an initial predicted aircraft gunfire environment and test severity where no measured data are available.

In applying these procedures it is assumed that the dynamics of the materiel are well known, in particular, the resonance's of the materiel and the relationship of these resonances to the gun firing rate and its harmonics. It is recommended that the materiel dynamic response information be used in selecting a procedure and designing a test using this test method.

2.6 Types of Gunfire Materiel Response Simulation

A brief description of each type of gunfire simulation procedure is given in the following paragraphs.

Procedure I - Direct Reproduction of Measured Materiel Response Data

In-Service gunfire materiel response is duplicated to achieve a near exact simulated reproduction of the measured gunfire response acceleration time history. Guidelines are provided in Annex A.

Procedure II - Statistically Generated Repetitive Pulse – Mean (deterministic) plus Residual (stochastic) Pulse

Characteristics of the in-service gunfire materiel response are statistically modeled by typically creating a “pulse ensemble” and obtaining a time varying mean “pulse” and associated residuals using nonstationary data processing. The statistical model of the gunfire response is simulated to achieve a very good reproduction of the measured gunfire acceleration time history. Guidelines are provided in Annex B.

Procedure III - Repetitive Pulse Shock Response Spectrum (SRS)

The measured gunfire acceleration time history is broken into individual pulses for analysis. Maximax shock response spectra are computed of the individual pulses to characterize the gunfire environment with a unique SRS. An acceleration time history is created that has a duration equivalent to an individual measured gunfire pulse, and that exhibits the characteristic gunfire SRS. The characteristic SRS gunfire pulse is repeated at the gun-firing rate. Guidelines are provided in Annex C.

Procedure IV - High Level Random, SOR, NBROR Vibration

If no pulse form is indicated by the measured in-service gunfire response or the materiel is distant from the gun and only high level random vibration is exhibited, guidelines provided in Method 401 shall be used. Typically for Procedure IV, the firing rate of the gun cannot be determined from an examination of the field measured response time history. In the absence of measured response data, Annex D provides guidance for an initial test severity.

2.7 Control

2.7.1 Control Strategy

The dynamic excitation is controlled to within specified bounds by sampling the dynamic response motions of the test item at specific locations. These locations may be at, or in close proximity, to the materiel attachment points, for controlled input tests, or at defined points on the materiel, for controlled response tests. The dynamic response motions may be sampled at a single point, for single point control, or at several locations, for multi-point control.

The control strategy depends on:

- The results of preliminary vibration or resonance search surveys carried out on the tet item and fixtures,
- Meeting the test specifications within the tolerances of paragraph 5.1,
- The capabilities of the test facility.

2.7.2 Control Options

2.7.2.1 Single Point Control

Single point control is required for Procedures I through III, and optional for Procedure IV. A single response point shall be selected to represent the materiel hard point from which the in-service response data were obtained, or upon which predictions were based.

2.7.2.2 Multiple Point Control

In cases where the materiel is distant from the gunfire excitation, and the measured data at appropriate hard points indicate no more than a random vibration environment slightly above ambient conditions, multiple point control may be desirable for Procedure IV. Multiple point control will be based on the control strategy and on the average of the ASD's of the control points selected.

2.7.3 Control Methods

2.7.3.1 Open Loop Vibration Control

Application of the techniques for Procedures I through III will generally involve a computer with a digital-to-analog interface and analog-to-digital interface with the analog output going directly to drive the exciter. Signal processing is performed off-line or open loop where the resulting exciter drive signal will be stored as a digital signal. During testing, feedback response will be monitored only for abort conditions.

2.7.3.2 Closed Loop Vibration Control

For Procedure IV closed loop vibration control is to be used. Because the loop time depends on the number of degrees of freedom and on the analysis and overall bandwidths, it is important to select these parameters so that the test tolerances and control accuracy can be maintained during the test. The feedback response points will be monitored and used for both control conditions and abort conditions.

3. SEVERITIES

3.1 General

The test severities will be established using available data or data acquired directly from an environmental data acquisition program. When these data are not available, initial test severities and guidance may be found in Annex D. Test guidance is provided in Annexes A through C for cases in which data have been collected and a precise simulation is desired. It should be noted that the test selected might not necessarily be an adequate simulation of the complete environment; thus, a supporting assessment may be necessary to complement the test results.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTIONS

4.1 Compulsory

a. The identification of the test item
b. The definition of the test item
c. The orientation of the test item in relation to test axes
d. Operating or non-operating condition of the test item during test
e. The operational checks: initial, during the test, and final
f. Initial and final test item checks required and test conditions
g. The details required to perform the test
h. The pre-conditioning time and conditions
i. The use of isolator mounts and their characteristics
j. The definition of the test severity
k. The failure criteria
l. The control strategy
m. Environmental conditions at which testing is to be conducted
n. The specific features of the test assembly (exciter, fixture, interface connections, etc.)

4.2 If Required

a. The effect of gravity and the consequent precautions
b. Tolerances, if different from paragraph 5.1.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

Unless otherwise specified in the Test Instruction, the tolerances applied to the single gun-firing rate, swept or unswept, are ± 2.5 %. The complete test parameter control system, checking, servoing, recording, etc., should not produce uncertainties exceeding one third of the tolerance values specified in paragraph 5.1.1 through 5.1.4.

5.1.1 Procedure I - Direct Reproduction of Measured Materiel Response Data

a. Time Domain: Ensure the duration of one pulse is within ± 2.5 % of the measured gunfire duration.
b. Amplitude Domain: Ensure the test item time history response peaks are within ±10 % of the measured gunfire time history peaks.

c. Frequency Domain: Compute an average energy spectral density (ESD) estimate over the ensemble created from the materiel time history response that is within ± 3 dB of the average ESD estimate based on the measured gunfire response time history. In cases in which an ensemble from the data cannot be created, compute an autospectral density (ASD) estimate of the time history records for comparison, provided the data is appropriately windowed to reduce spectral leakage. The tolerances for the ASD analysis are ± 3 dB.

5.1.2 Procedure II - Statistically Generated Repetitive Pulse

a. Time Domain: Ensure the duration of one pulse is within ± 2.5 % duration of the measured gunfire rate.

b. Amplitude Domain: Ensure materiel time history response peaks are within ±10 % of the measured gunfire time history peaks.

c. Frequency Domain: Compute an average energy spectral density (ESD) estimate over the ensemble created from the materiel time history response that is within ± 3 dB of the average ESD estimate based on the measured gunfire time history response.

5.1.3 Procedure III - Repetitive Pulse Shock Response Spectrum (SRS)

a. Time Domain: Ensure the duration of one pulse is within ± 5 % duration of the measured gunfiring rate.

b. Amplitude Domain: Ensure materiel time history response peaks are within ± 10 % of the measured gunfire time history response peaks.

c. Frequency Domain: Ensure the maximax SRS computed over the materiel time history response from one simulated gunfire pulse is within + 3 dB and –1 dB from the mean SRS computed over the ensemble of field measured materiel response data. Use an SRS analysis with at least 1/6 octave frequency spacing.

5.1.4 Procedure IV - High Level Random, SOR, NBROR Vibration

a. Time Domain. Ensure the root-mean-square (RMS) value of the amplitude measured at the control point in the test axis is within ± 5 % of the preset RMS value. Likewise, ensure the maximum variation of the RMS value at the attachment points in the test axis is ± 10 % of the preset RMS value.

b. Amplitude Domain. Ensure the amplitude distribution of the instantaneous values of the random vibration at the control point is nominally Gaussian. Use an amplitude distribution that contains all occurrences up to 2.7 standard deviations. Keep occurrences greater than 3.5 standard deviations to a minimum.

c. Frequency Domain. Ensure an autospectral density analysis (ASD) of the test item time history response is within ± 3 dB of an ASD computed of the field measured gunfire data or the predicted gunfire environment. Allow exceedances up to ± 6 dB above 500 Hz, but limit the accumulation of all local exceedances to 5 % of the overall test frequency bandwidth. Use a maximum analysis filter bandwidth of 5 Hz, and attempt to have the number of independent control statistical degrees of freedom (DOF) greater than 100. Ensure the ASD measured along the two transverse orthogonal axes, using the same number of DOF as that used for the control, is less than 25 % of the specified ASD of the control point over 90 % of the overall bandwidth.

5.2 Installation Conditions of Test Item

Test items can vary from individual materiel items to structural assemblies containing several items of materiel of different types. The test procedures should take into account the following:

- Fixturing should simulate actual in-service use mounting attachments, including vibration isolators, and fastener torque's, if appropriate.
- All the connections, cables, pipes, etc., should be installed in such a way that they impose stresses and strains on the test item similar to those encountered in-service use.
- The possibility of exciting the test item simultaneously along several axes using more than one vibration exciter.
- Suspension of the test item at low frequency to avoid complex test fixture resonance's and utilization of a force entry frame.
- The direction of gravity or the load factor may be taken into account by compensation or by suitable simulation. For high g aircraft maneuvers, the effects of gravity may be substantial and require separate acceleration testing of the test item.

5.2.1 Test set-up

5.2.1.1 General

Unless otherwise specified in the Test Instruction, the test item shall be attached to the vibration exciter by means of a rigid fixture capable of transmitting the vibration conditions specified. The fixture should input vibration to racks, panels, and/or vibration isolators to simulate as accurately as possible the vibration transmitted to the materiel during in-service use. When required, materiel protected from vibration by these means should also pass the appropriate test requirements with the test item hard-mounted to the fixture.

5.2.1.2 Stores

When the materiel is a store, use the following guidelines:

Where practical, testing shall be accomplished in three mutually perpendicular axes with the mounting lugs in the normal carriage position. Suspend the store from a structural frame by means of its normal mounting lugs, hooks, and sway braces that simulate the operational mounting apparatus. The test set-up shall be such that the rigid body modes of translation, rotation, or vibration for the combined structure are between 5 and 20 Hz. Vibration shall be applied to the store by means of a rod or other suitable mounting device running from a vibration exciter to a relatively hard, structurally supported point on the surface of the store. Alternatively, the store may be hard-mounted directly to the exciter using its normal mounting lugs and a suitable fixture. The stiffness of the mounting fixture shall be such that its induced resonant frequencies are as high as possible and do not interfere with the store response. For all methods, launcher rails shall be used as part of the test setup where applicable. The response to be simulated may be difficult to accomplish for a store.in this testing configuration, except for Procedure IV.

5.3 Subsystem Testing

When identified in the Test Instruction, subsystems of the materiel may be tested separately. The subsystems can be subjected to different gunfire levels. In this case, the Test Instruction should stipulate the gunfire levels specific to each subsystem.

5.4 Test Preparation

5.4.1 Pre-conditioning

Test materiel should be stabilized to its initial climatic and other conditions as stipulated in the Test Instruction.

5.4.2 Operational Checks

All operational checks and examinations should be undertaken as stipulated in the Test Instruction. The final operational checks should be made after the test item has been returned to rest under pre-conditioning conditions and thermal stability has been obtained.

5.5 Procedures

The Test Instruction should stipulate whether the test item is in operation during the test. Continuous gunfire vibration testing can cause unrealistic damage of material, such as unrealistic heating of vibration isolators. The excitations should be interrupted by periods of rest, defined by the Test Instruction. For additional details on each of the procedures in paragraphs 5.5.1 through 5.5.4, refer to Annexes A, B, C, and D respectively.

5.5.1 Procedure I - Direct Reproduction of Measured Materiel Response Data

Step 1 Obtain a digital representation of the field measured response data. In general this will involve the digitalization of a full measured materiel acceleration response for input to the vibration control system.

Step 2 Pre-condition the test item in accordance with paragraph 5.4.1.

Step 3	Choose the control strategy and control points and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, and 2.7.3.1.
Step 4	Perform operational checks in accordance with paragraph 5.4.2.
Step 5	Mount the test item on the vibration exciter in accordance with paragraph 5.2.
Step 6	Determine the time history representation of the vibration exciter drive signal required to provide the desired gunfire acceleration response.
Step 7	Apply the drive signal as an input voltage and measure the test item acceleration response at the selected control and monitoring points.
Step 8	Verify that the test item response is within the allowable tolerances specified in paragraph 5.1 and 5.1.1.
Step 9	Apply the gunfire simulation for on and off periods and the total test duration in accordance with the Test Instruction. Perform operationaland functional checks in accordance with the Test Instruction.
Step 10	Repeat the previous steps in each other axis specified in the Test Instruction.
Step 11	In all cases, record the information required.

5.5.2. Procedure II - Statistically Generated Repetitive Pulse

Step 1	Generate a statistical representation of the field measured data as a mean (deterministic) plus Residual (stochastic) pulse. 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 control system.
Step 2	Pre-condition the test item in accordance with paragraph 5.4.1.
Step 3	Choose the control strategy and control or monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, and 2.7.3.1.
Step 4	Perform the operational checks in accordance with paragraph a 5.4.2.
Step 5	Mount the test item on the vibration exciter in accordance with paragraph 5.2.
Step 6	Determine the time history representation of the vibration exciter drive signal required to provide the desired gunfire acceleration response.
Step 7	Apply the drive signal as an input voltage and measure the test item acceleration response at the selected control and monitoring points.

Step 8 Verify that the test item response is within the allowable tolerances specified in paragraph 5.1 and 5.1.2.

Step 9 Apply the gunfire simulation for on and off periods and the total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10 Repeat the previous steps in each other axis specified in the Test instruction.

Step 11 In all cases, record the information required.

5.5.3 Procedure III – Repetitive Pulse Shock Response Spectrum (SRS)

Step 1 Separate the measured field data into individual pulses and compute the SRS over the individual pulses using damping factors of 5%, 2%, 1%, and 0.5% , or a Q = 10, 25, 50, and 100.

- Compute the statistical mean SRS for each of the respective damping factors used.
- Compare the mean SRS for each of the damping factors to determine the predominant frequencies and to obtain an estimate of the duration or “half cycle content” comprising the individual predominant frequencies. An individual selected pulse, as the result of separation of the measured field data into individual pulses, may be used instead of the mean shock spectrum for each of the damping factors.
- Characterize the SRS time history using the estimate of the duration or “half cycle content” for specification of “wavelet” duration, and choose either the mean SRS or an individual pulse for amplitude characterization. This procedure assumes the complex SRS waveform generation is based upon wavelets, amplitude modulated sine functions.

Step 2 Pre-condition the test item in accordance with paragraph 5.4.1.

Step 3 Choose the control strategy and control and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, and 2.7.3.1.

Step 4 Perform operational checks in accordance with paragraph 5.4.2.

Step 5 Mount the test materiel on the vibration exciter in accordance with paragraph 5.2.

Step 6 Compensate the exciter drive signal.

Step 7 Input the SRS transient drive signal through the exciter control system at the firing rate of the gun, and measure the test item acceleration response at the selected control and monitoring points.

Step 8 Verify that the test item response is within the allowable tolerances specified in paragraphs 5.1 and 5.1.3.

Step 9 Apply the gunfire simulation on and off periods and the total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10 Repeat the previous steps in each other axis specified in the Test Instruction.

Step 11 In all cases, record the information required.

5.5.4 Procedure IV - High Level Random, SOR, NBROR Vibration.

Step 1 Calculate the ASD test level.

- Compute an autospectral density estimate of the measured gunfire materiel response data using an a 2000 Hz analysis bandwidth with a maximum 5 Hz analysis bandwidth resolution, or compute a 2000 Hz autospectral density prediction.
- Generate a random vibration test spectrum from the measured data, or from the prediction generate a test spectrum consisting of a broadband random base with four superimposed discrete frequency peaks that occur at the fundamental firing rate of the gun and the first three harmonics of the firing rate.

Step 2 Pre-condition the test item in accordance with paragraph 5.4.1.

Step 3 Choose the control strategy and control and monitoring points in accordance with paragraphs 2.7.1, 2.7.2.1, 2.7.2.2, and 2.7.3.2.

Step 4 Perform the operational checks in accordance with paragraph 5.4.2.

Step 5 Mount the test item on the vibration exciter in accordance with paragraph 5.2.

Step 6 Input the vibration test spectrum in the appropriate vibration exciter control system support software.

Step 7 Apply the drive signal as input and measure the test item acceleration response at the selected control and monitoring points.

Step 8 Verify that the test item response is within the allowable tolerances specified in paragraphs 5.1 and 5.1.4.

Step 9 Apply the gunfire simulation on and off periods and total test duration in accordance with the Test Instruction. Perform operational and functional checks in accordance with the Test Instruction.

Step 10 Repeat the previous steps in each other axis specified in the Test Instruction.

Step 11 In all cases, record the information required.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of gunfire simulation. In general, the operational and structural integrity of the test item shall be maintained during testing. Any compromise of either operational and/or structural integrity of the test item shall constitute failure of the item in testing.

7. REFERENCES AND RELATED DOCUMENTS

a. IEST RP-DTE026.1, Using MIL-STD 810(F), 519 Gunfire, Institute of Environmental Sciences and Technology, USA, January 2002

b. 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.

c. IES-RP-DTE012.1, Handbook for Dynamic Data Acquisition and Analysis, Institute of Environmental Sciences and Technology, USA, January 1995

d. Bendat, J.S. and A.G. Piersol, Random Data : Analysis and Measurement Procedures, John Wiley and Sons Inc, NY, 1986

ANNEX A

PROCEDURE I - DIRECT REPRODUCTION OF MEASURED MATERIEL RESPONSE DATA

1. SCOPE

1.1 Purpose

This Annex provides guidance and a basis for direct reproduction of measured materiel response data in a laboratory test on an electrodynamic vibration exciter under waveform control in an open loop mode.

1.2 Application

This technique is useful for the reproduction of single point materiel response that may be characterized as nonstationary or as a transient vibration. Acceleration is considered the variable of measurement in the discussion to follow, although other variables could be used, provided the dynamic range of the measured materiel response is consistent with the dynamic range of the electrodynamic system used as an input device to reproduce the materiel response.

2. DEVELOPMENT

2.1 Basic Consideration for Environment Determination

It is assumed that an in-service environmental measurement test is performed with properly instrumented materiel where the measurements are made at preselected points on the materiel. 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 making an in-service test by examination of random vibration data on the materiel using various accelerometer mounting locations and fixturing configurations, the same points as those to be used in the laboratory testing. Ensure the field measured data is DC coupled, not high pass filtered, and sampled at ten times the highest frequency of interest. Examine the measured data time history traces for any indication of clipping, or any accelerometer performance peculiarities such as zero shifting which may be the case for any potential high level form of mechanical shock. If there is an indication of accelerometer measurement anomalies, examine a potentially corrupted acceleration time history carefully according to the procedures used in qualifying pyrotechnic shock data. Perform processing such as time history integration to examine velocity and displacement characteristics, sample ASDs computed, etc. See reference a for further details. If there is no indication of accelerometer anomalies, the in-service measured data is AC coupled, high pass filtered at a very low frequency, 1 Hz, and sampled at ten times the highest frequency of interest and placed in a digital file for manipulation. The upper frequency limit is determined by the anti-alias filter upper cutoff limit, which is generally around 2000 Hz. An example of gunfire simulation using the Procedure I techniques is discussed below. This procedure is performed on a personal computer with signal processing capability and analog-to-digital and digital-to-analog interfaces.

2.2 Test Configuration

An instrumented test item is installed in a laboratory vibration fixture and mounted to the armature of an electrodynamic exciter. The test item employed during the laboratory simulation is the same materiel configuration used to collect the captive-carry gunfire vibration materiel response data during an in-service test. A piezoelectric accelerometer is installed internal to the test item for purposes of acceleration response input control.

2.3 Creating a Digital File of the Gunfire Vibration Response

The first step in this simulation process is to digitize the measured flight data to obtain an amplitude time history, see Figure A-1. Digital processing of the analog data was performed using a 2,000 Hz, 48dB/octave anti-alias filter and a sample rate of 20,480 samples per second for good time history amplitude resolution. The anti-alias filter should have linear phase characteristics.

2.4 Characterization of Exciter Drive Signal/Test Item Inverse Frequency Response Function

Definition of the inverse frequency response function between the exciter drive signal and the acceleration response of the test item installed on the exciter is achieved by subjecting the test item to a low level of swept sine excitation. The swept sine excitation is generated on the PC using a sample rate of 20,480 samples per second and a block size of 2,048 points for a duration of approximately 0.1 seconds. The swept sine input uses a start and stop frequency 10 Hz and 2,000Hz. The swept sine excitation is input through the power amplifier using the digital-to-analog interface of the PC. Figure A-2 presents the swept sine exciter input along with the resulting test item response, Figure A-2b. The swept sine exciter input and the test item response were digitized utilizing the PC analog-to-digital interface using a sample rate of 20,480 samples per second and a block size of 2,048 points. The inverse frequency response function, IH (f), is estimated as follows.

$$IH\,(f) = E_{dd}(f) \,/\, E_{dx}(f)$$

where

E_{dd} = the input energy spectral density of the swept sine exciter drive signal d(t)

E_{dx} = the energy spectral density cross spectrum between the acceleration response of the test item x(t), and the swept sine exciter drive signal, d(t)

Figure A-3 presents the modulus and phase of the inverse frequency response function. To reduce the noise in IH(f), three or more IH(f) estimates may be averaged. Under laboratory conditions, usually the signal-to-noise ratio is so high that averaging to reduce noise levels in the estimate is unnecessary, see reference b and c.

2.5 Tapering the Inverse Frequency Response Function

Because the signal processing software computes the inverse frequency response function out to the sampling rate Nyquist frequency, which is far above the frequency range of interest, a tapering function is applied to the inverse frequency response function. The tapering function removes the unwanted frequency content, noise, beyond the frequency band of interest, 10 to 2,000 Hz. The modulus is reduced to zero from 2,000 Hz over a bandwidth of approximately 200 Hz; whereas, the phase remains constant beyond 2,000 Hz. The modulus and phase of the tapered inverse frequency response function is presented in Figure A-4. Some experimentation with the tapering configuration may be needed at this point on behalf of the tester to optimize the information preserved in the 10 – 2000 Hz frequency domain.

2.6 Computing the Impulse Response Function

The impulse response function is generated by computing the inverse Fourier transform of the tapered inverse frequency response function and is displayed in Figure A-5.

2.7 Computing the Compensated Exciter Drive Signal

The compensated exciter drive signal is generated by convolution of the impulse response function, Figure A-5, in units of (volts/g) with the measured gunfire materiel response, Figure A-1 in units of (g). This could also be accomplished in the frequency domain by multiplying transforms i.e., IH(f) by the transform of an unwindowed block of time history using either overlap-and-save or overlap-and-add procedures. The compensated exciter drive signal is illustrated in the top portion of Figure A-6

2.8 Reproducing the Gunfire Materiel response

Utilizing the digital-to-analog interface capability of the PC, the compensated exciter drive signal is input through the power amplifier to obtain the desired gunfire materiel response from the test item. The exciter is under waveform control in an open loop mode of operation. For the short duration of the nonstationary record or transient vibration, this is an adequate mode of exciter control. Figure A-6 presents the compensated exciter drive signal along with the resulting materiel response. Figure A-7 is a comparison of the overall in-service measured gunfire materiel response with the laboratory simulated gunfire test item response.

2.9 Conclusion

For single point materiel response measurements on comparatively simple dynamic materiel, the method of direct reproduction of in-service measured materiel response is near optimal. The main advantage of this technique is that it permits reproduction of materiel responses, nonstationary or transient vibration, that are difficult if not impossible to completely specify and synthesize for input to a vibration control system. The main disadvantage of this technique is that there is no obvious way to statistically manipulate the measured materiel response data to ensure a conservative test. However, conservativeness could be introduced into the testing by performing the manipulation at a reduced level of exciter power amplifier gain, and then testing at the higher gain. The assumption behind this technique is that the test item response resulting from the exciter input is a linear function of the power amplifier gain. This linearity assumption would need to be independently verified before testing.

2.10 Reference and Related Documents

a. IES-RP-DTE012.1, Handbook for Dynamic Data Acquisition and Analysis, Institute of Environmental Sciences and Technology, USA, January 1995

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

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

3. RECOMMENDED PROCEDURES

3.1 Recommended Procedures

For single materiel response measurements, on comparatively simple dynamic materiel, use Procedure I. This procedure is to be used in cases which laboratory replication of the response environment is absolutely essential to establish materiel operational and structural integrity under gunfire environment.

3.2 Uncertainty Factors

The only significant uncertainty in this procedure results in the degree to which the measured environment differs from the actual in-service environment. It is usually not possible to obtain the measured environment under every conceivable in-service condition.

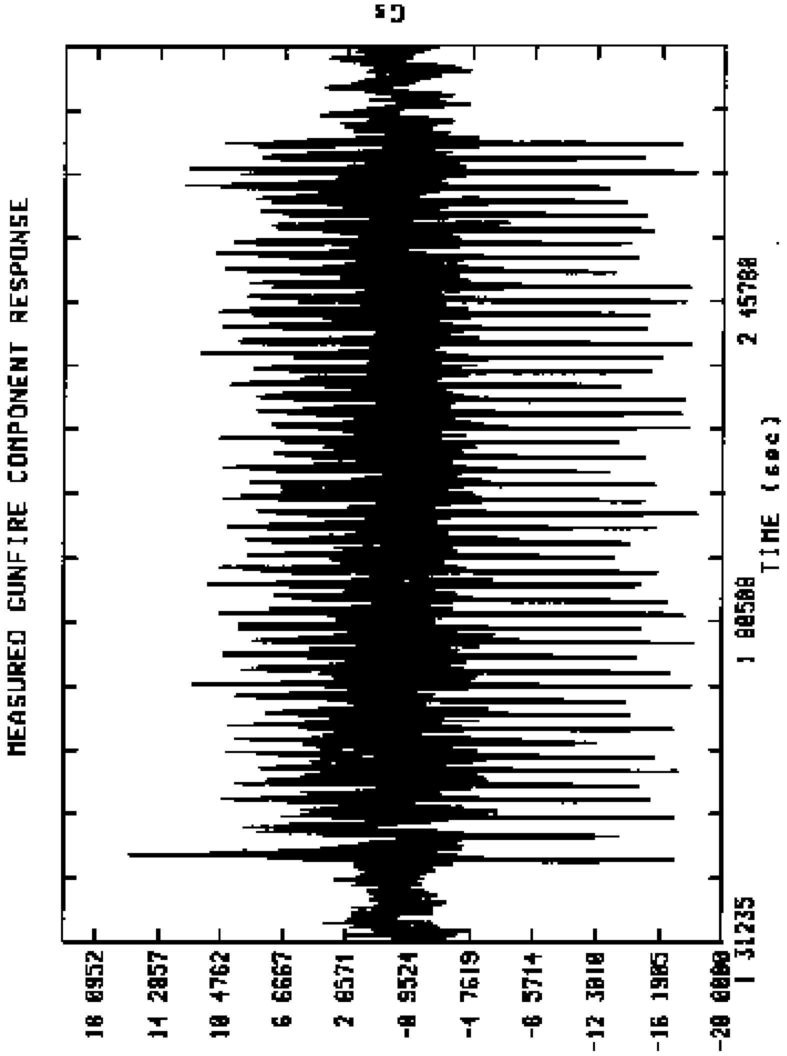
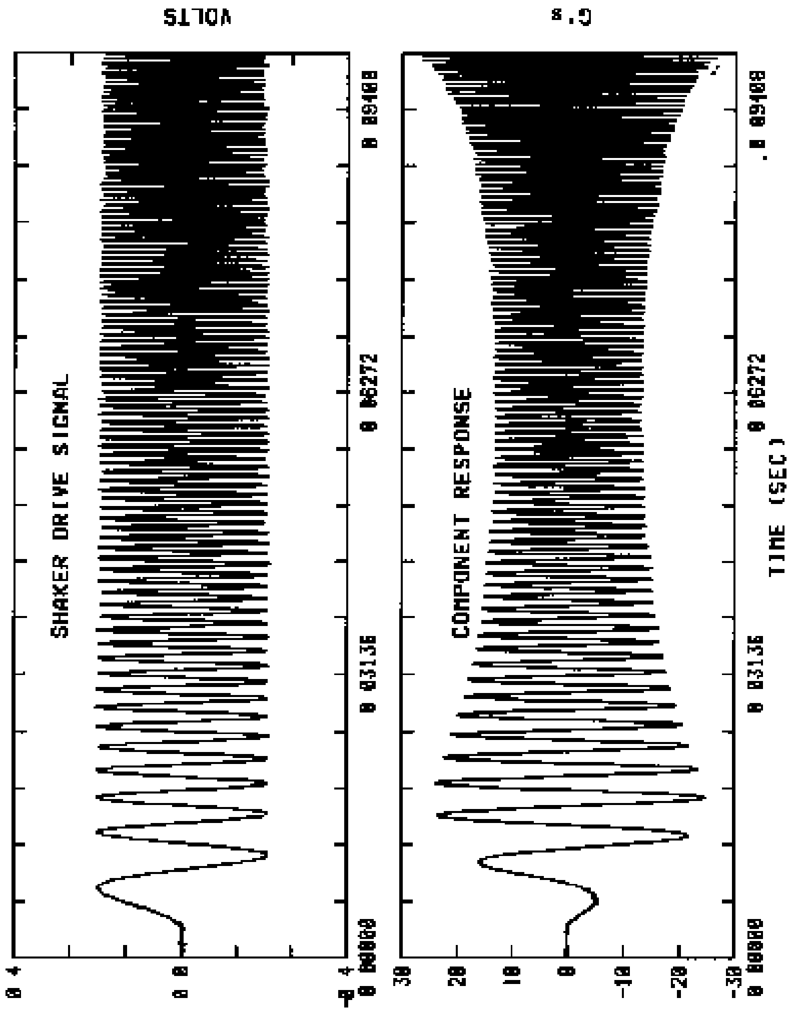
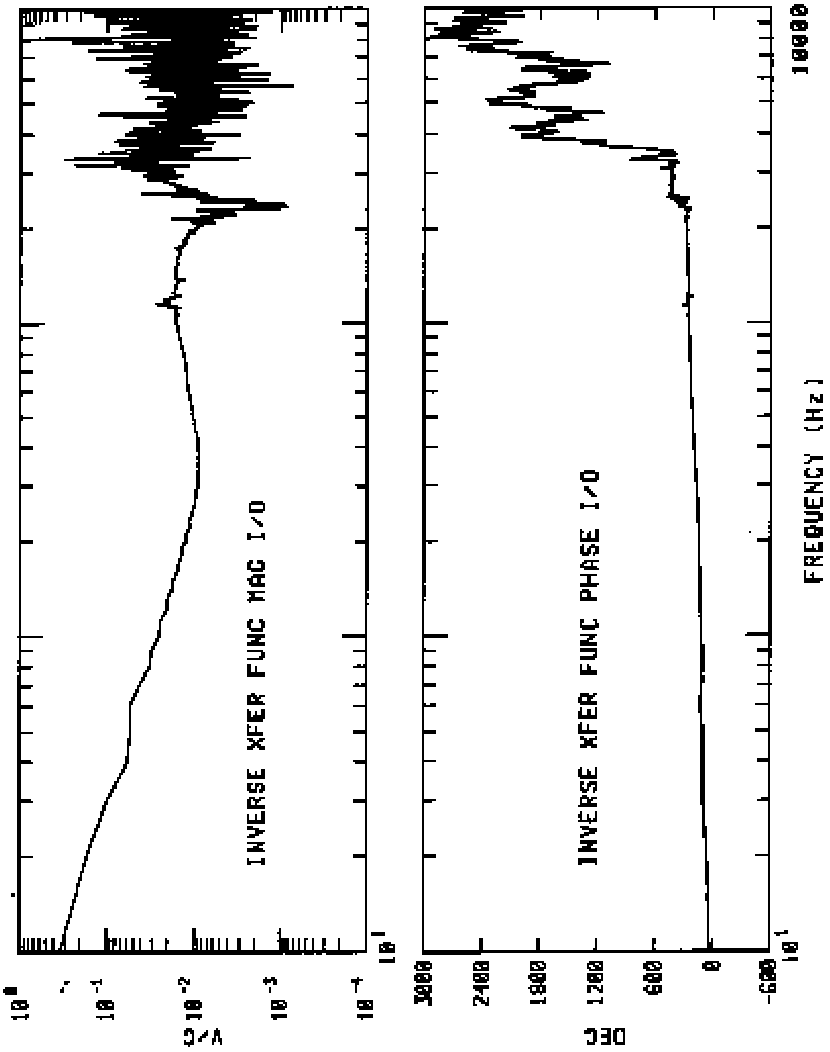


FIGURE A-1 Digital Flight Data



a. Input b. Response

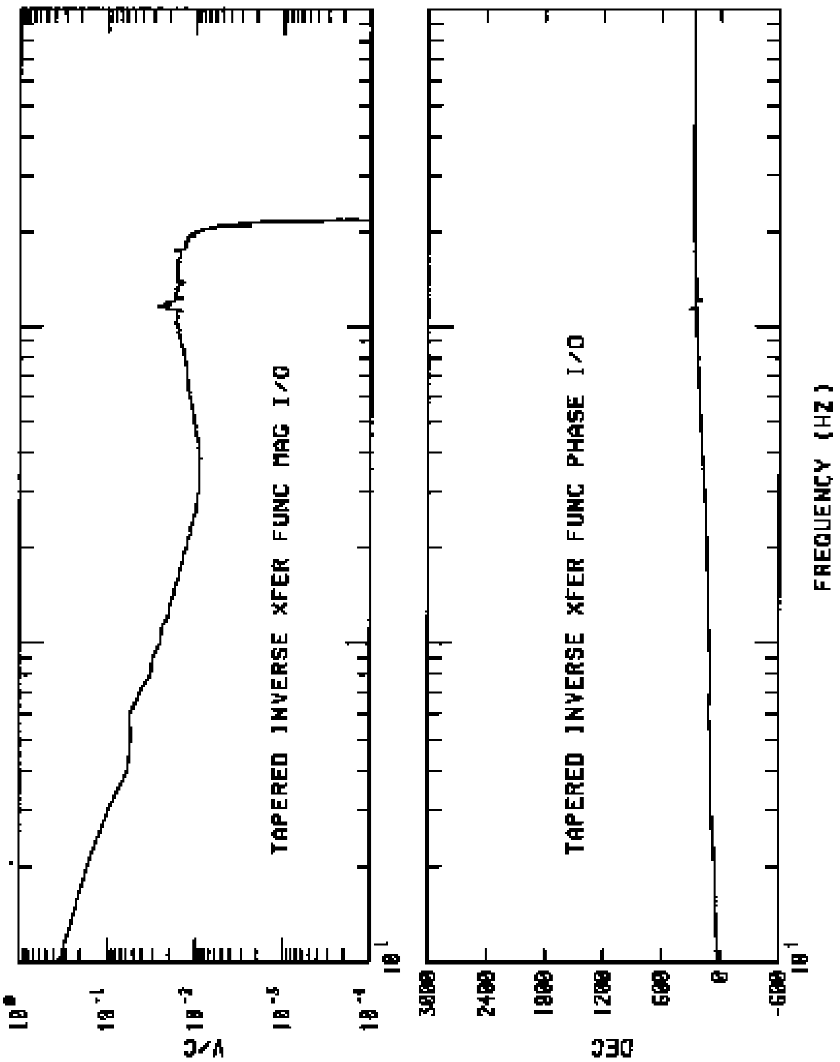
FIGURE A-2 Swept Sine Exciter Input with Resulting Test Item Response



a. Modulus

b. Phase

FIGURE A-3 Modulus and Phase of Inverse Frequency Response Function



a. Modulus b. Phase

FIGURE A-4 Modulus and Phase of Tapered Inverse Frequency Response Function

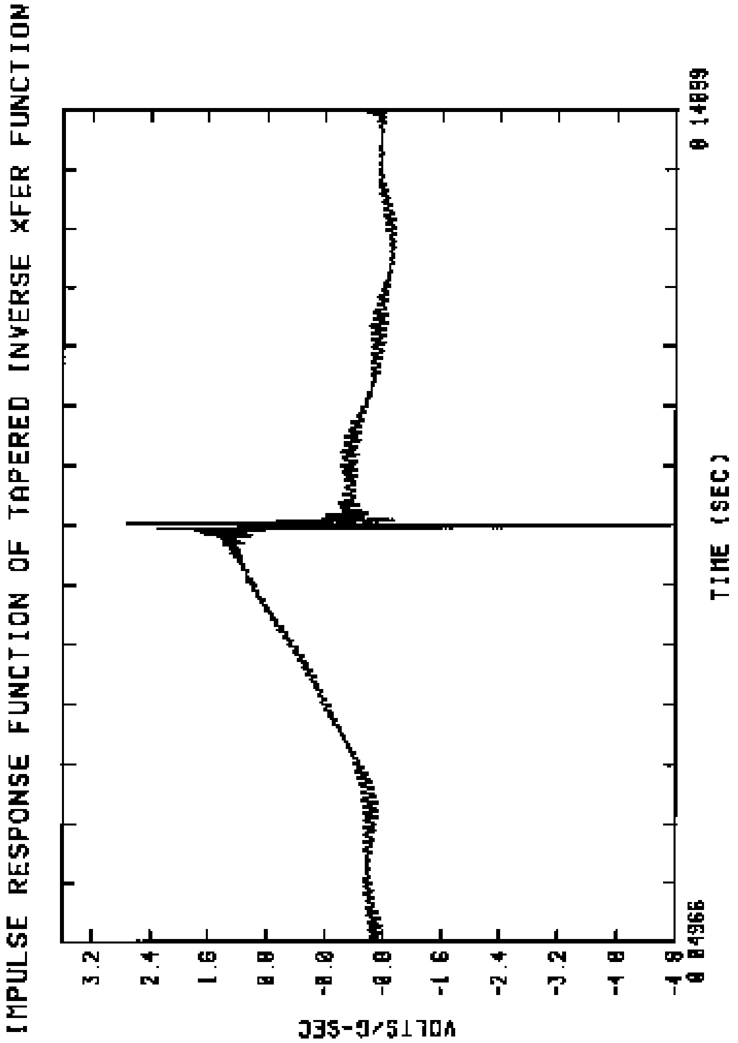
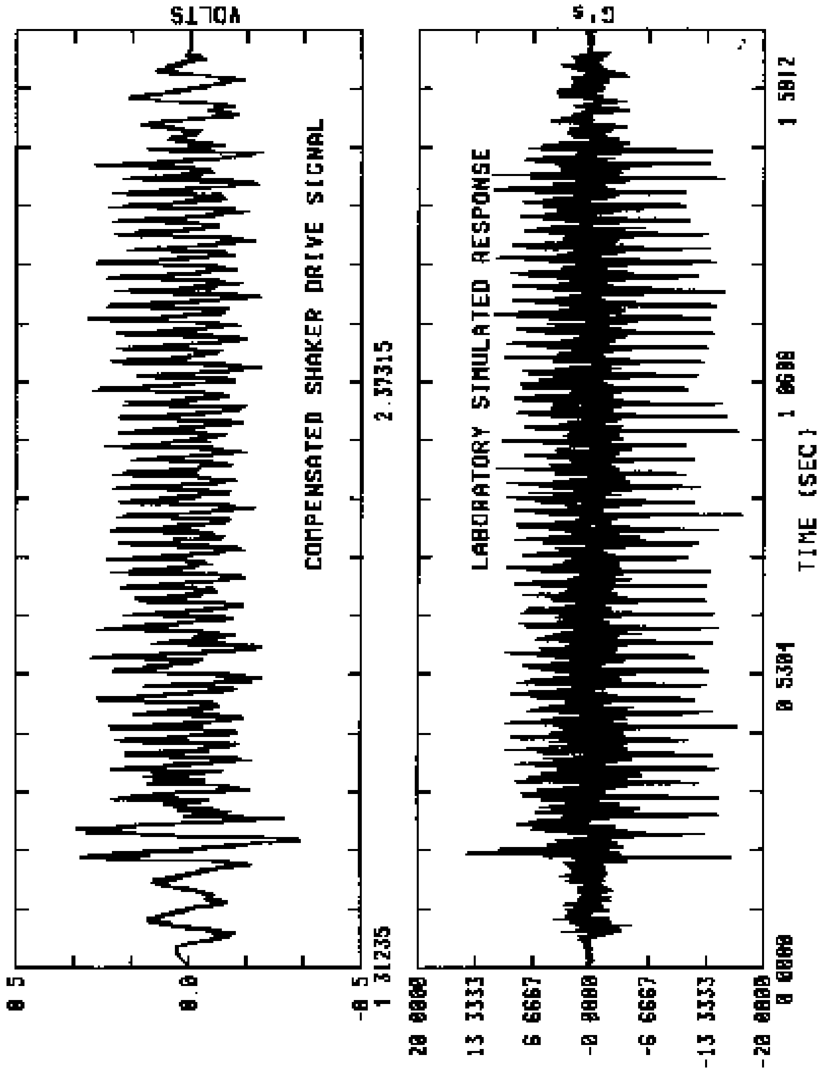


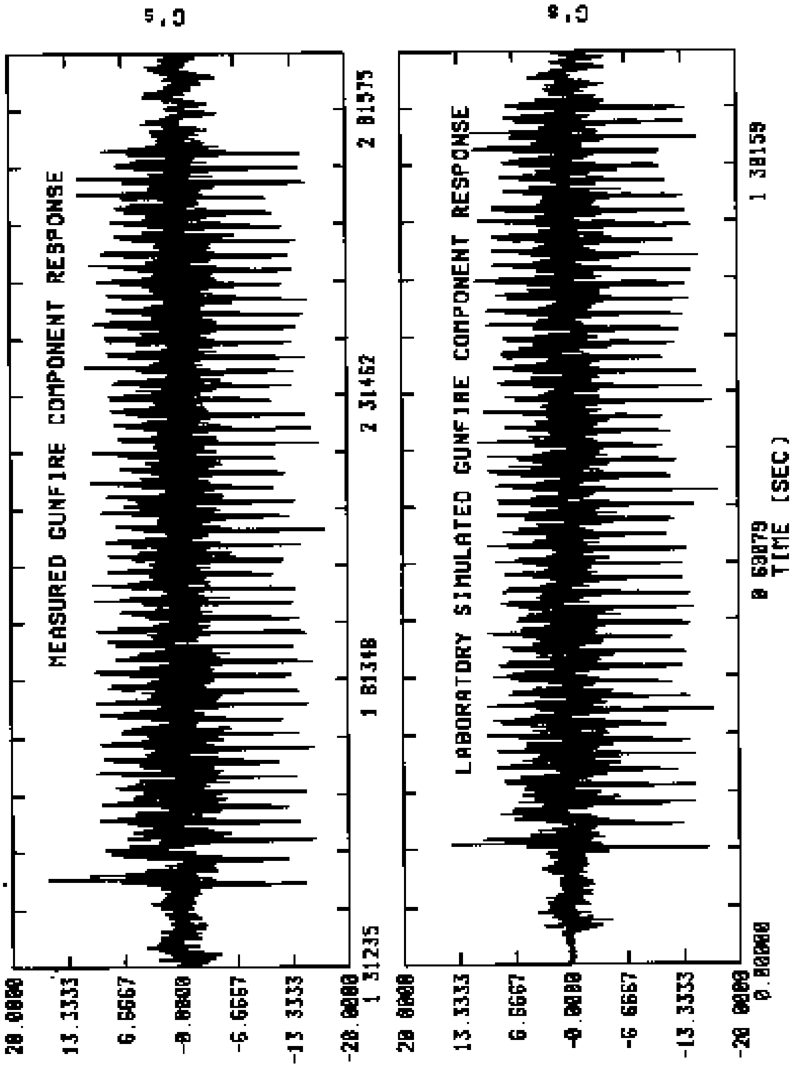
FIGURE A-5 Impulse Response Function



a. Drive Signal

b. Materiel Response

FIGURE A-6 Compensated Exciter Drive Signal Along with Resulting Test Item Response



a. Measured b. Simulated

FIGURE A-7 Comparison of Measured Gunfire Materiel Response with Laboratory Simulated Gunfire Test Item Response

ANNEX B

PROCEDURE II - STATISTICALLY GENERATED REPETITIVE PULSE

MEAN (DETERMINISTIC) PLUS RESIDUAL (STOCHASTIC) PULSE

1. SCOPE

1.1 Purpose

This Annex provides an overview of Procedure II techniques for simulation of a time-varying random process given a sample function for the process that can be used to generate ensemble statistics describing the time varying character of the process.

1.2 Application

Details for the technique are found in reference c. Other aspects of the technique are found in references d and e. More recent developments are found in references f and g. The stochastic simulation technique described here for a single unknown time-varying random process for which a single sample function from the process is available. The single sample function is representative of a single gunfire physical configuration for which extrapolation to other configurations is undetermined. Benefits of Procedure II are defined below. The following paragraphs provide a description of Procedure II and some of its limitations.

a. Is convenient to implement on a personal computer used to control a vibration system,

b. Has many features analogous to that of traditional stationary time history exciter simulation based on autospectral density estimate specification,

c. Is very flexible in terms of the length of statistically equivalent records it can generate for laboratory replication of a in-service measured response environment,

d. Has statistics that are easy to interpret and that approximate the true statistical variation in the unknown underlying random process,

e. Can be generalized to other forms of time-varying random processes with ensemble representation easily,

f. Abandons a minimal number of higher order features of the measured response ensemble not considered essential to conservative in-service measured data replication by way of laboratory test item response simulation testing.

2. DEVELOPMENT

2.1 Nomenclature

E { }	expected value of the quantity within the braces
N, N_p	number of pulses in an ensemble

N_s	number of simulated pulses
N_t	number of time points in an ensemble member
$P(x,t)$	probability distribution function for a nonstationary random process
$R_{xx}(\tau,t)$	nonstationary auto-correlation function
V[ ]	variance of the quantity within the brackets
$\{x_i(t)\}$	random process
$x_i(t)$	ith sample function for a random process, $\{x_i(t)\}$
$X_T(f)$	Finite Fourier Transform of x(t) over an interval of time T
$\mu_x(t)$	true time-varying mean
$\hat{\mu}_x(t)$	time-varying mean estimate
$\sigma_x(t)$	true time-varying standard deviation
$\hat{\sigma}_x(t)$	time-varying standard deviation estimate
$\Psi_x^2(t)$	true time-varying mean square
$\hat{\Psi}_x^2(t)$	time-varying mean square estimate
T_p	period in seconds of a stationary sample record
$f_1=1/Tp$	fundamental frequency of a stationary sample record in Hertz
T	sampling time interval
$f_c=1/(2T)$	Nyquist cutoff frequency

2.2 Introduction

The term "ensemble" is taken to mean a collection of sample time history records defined over a specific time interval. In the case of a nonstationary environment, the only complete description of the environment is given through:

a. Statistical estimates of all the probabilistic moments of the process as a function of amplitude and time from the specification of P(x,t), or

b. A statistical estimate of the time-varying auto-correlation function $R(\tau,t)$. Generally P(x,t) and $R(\tau,t)$ are not available either directly in an analytic form or through an accurate estimate based on the limited in-service measured response data.

For practical purposes, for an in-service measured environment, estimation of the (1) time-varying mean, (2) time-varying standard deviation, (3) time-varying root mean square, (4) overall average energy spectral density, and (5) time-varying autocorrelation assist in characterizing the nonstationary random process from which the sample ensemble is created. Replication of some or all of these measured ensemble estimates in the simulation process will, in general, provide a satisfactory nonstationary test simulation of the in-service environment.

2.3 Assumptions

It is assumed that acceleration is the materiel response measurement variable, however, other measurement variables, e.g., strain, may be just as useful, provided, they are capable of capturing the characteristic amplitude or frequency range of interest.

To assist the practitioner in deciding if the procedures described in this annex are applicable to a particular measurement and test objectives, the following basic assumptions are made.

a. The in-service measured materiel response is obtained from measurements at "hard points" on the materiel to be tested. The term "hard point" implies that :

   (1) Local materiel response peculiar to the location of the measurement instrumentation, including structural nonlinearity, is not dominant in the materiel response measurement, and

   (2) Measured materiel response at the selected point is representative of the overall materiel response.

b. A sample time history of the measured in-service materiel response shows a distinct time-varying quality that repeats in a time interval correlated with the firing rate of the gun.

c. A sample time history of the measured in-service materiel response can be decomposed into an ensemble of shorter time history records, or pulses. The pulses have similar time-varying characteristics at equal time intervals from the beginning of each pulse. The decomposition method of the sample time history record is left to the discretion of the analyst; this usually can be accomplished by examining the measured "timing" or "firing" pulse for a repeated event, or by cross-correlation methods applied to the sample time history.

d. Information is available about the configuration of the test item relative to the materiel configuration for which the measured in-service response data was measured.

e. The frequency response function for the electrodynamic or servohydraulic test system exciter can be characterized by the techniques outlined for Procedure I in Annex A.

f. Application of the test frequency response function to the simulated amplitude time history can be accomplished through :

   (1) An energy spectral density function where each pulse is individually compensated by way of the convolution of the pulse time history with the system impulse response function. The pulses are concatenated into a long output voltage time history for input to the digital-to-analog interface. or,

   (2) A long time history convolution, whereby the uncompensated long output time history is first generated, and then convolved with the system impulse response function to

provide the compensated voltage drive signal for input to the digital-to-analog interface.

Both of these techniques assume generation of a long compensated voltage waveform to be run in an open loop form on a vibration system. For this open loop configuration, it is suggested that the length of the compensated waveform not exceed five seconds, and the appropriate abort limits are active on the vibration system. Closed loop control will become the norm for operation with improvements in vibration control system to increase the energy spectral density formulation with waveform compensation on individual pulses. At this time, practicality of this procedure is limited by the processor speed in input and output to the vibration system. In addition development is required for : (1) a rationale to quantitatively judge the "adequacy" of the simulation in "real time," based on the time-varying statistical estimates, and (2) a means of "real time" compensation of "inadequate" simulation "in real time".

g. The adequacy of the simulation in meeting the specification on the difference, or error, between the measured in-service materiel response statistics and the measured test item response from the laboratory test simulation is based upon utilizing equivalent sample sizes or correcting the error measure based on sample size differences.

In summary, at the time of this writing, the test simulation of a measured in-service materiel response is based on:

- Pretest generation of the uncompensated test sample time history,
- Compensation of the test sample time history,
- Open loop control for the vibration system,
- Off line processing of the test item response sample time history for direct comparison with measured in-service materiel response sample time history.

2.4 Modeling and Statistics for Description of a Materiel Response Time-Varying Random Process

A very general model for a time-varying random process is the "product model", which assumes in its most basic form, that the time-varying characteristics of a random process can be separated from the frequency characteristics of the random process, see reference b. For materiel response to gunfire a form of product model can be used to adequately describe this response. The procedures used in constructing the model require some experience. Unfortunately, this modeling does not provide for parameterized predictions of materiel response in other measured data configurations. The basic statistics to be used to characterize a measured response environment with an ensemble representation are the defined below. The error statistics for the simulation may be based on the error expressions for a. to d.

a. The time-varying mean,

b. Time-varying standard deviation,

c. Time-varying root mean square,

d. Average energy spectral density function, may be time dependent.

The following is a definition of the product model used in this development. Taking t as the continuous time variable, for discrete processing; each ensemble member consists of N_t time samples in the time interval $0 \leq t \leq T_p$. Consideration is given to the time-varying frequency character over discrete time intervals, which can be explored in more detail through the nonstationary auto-correlation function. References c, d, and e consider the issue in more detail. Using the reference b notation and terminology for u(t), a sample time history from a stationary random process, {u(t)}; and both $a_1(t)$ and $a_2(t)$ deterministic time histories, then a general time-varying random process {x(t)} can be modeled as

$$x(t) = a_1(t) + [a_2(t)\ \ u(t)]_f \qquad \text{(B-1)}$$

$a_1(t)$ is a deterministic time history in terms of the in-service time-varying ensemble mean estimate. $a_2(t)$ is a deterministic time history in terms of the in-service time-varying ensemble standard deviation estimate. The function $a_2(t)$ shapes, in the time domain, the root mean square level of the residuals from the in-service ensemble after $a_1(t)$ has been removed from the in-service ensemble. The “f” following the bracket indicates that the residual information is a function of frequency content and in the description below, f, represents the time-varying frequency content in four discrete and equal length time intervals. For this model $a_1(t)$, the time-varying mean of the ensemble, will be referred to as the "signal" and $[a_2(t)\ (u(t))]_f$, as the shaped residual or "noise". If the time-varying random process is heavily dominated by the deterministic time-varying mean or "signal", i.e., the amplitude of $a_1(t)$ is large in comparison with the residual $[a_2(t)\ (u(t))]_f$, then one should expect comparatively small time domain errors in the time-varying mean, standard deviation and root mean square. The frequency content should also be easily replicated. The residual ensemble constructed by subtracting the time-varying mean from each sample time history of the original ensemble is defined in terms of the in-service measured ensemble as follows:

$$\{r(t)\} = \{x(t) - \hat{\mu}_x(t)\} \qquad \text{(B-2)}$$

This residual ensemble has the following two properties:

- Time-varying mean of {r(t)} is zero
- Time-varying root mean square of {r(t)} is the time-varying standard deviation of the original ensemble {x(t)}

Time domain criterion for testing the validity of the simulation is given as the variance of the time domain estimators of the time-varying mean, time-varying standard deviation and the time-varying root mean square. Expressions for these estimators and their variance are provided in equations (B-3) through (B-9). The unbiased time-varying mean estimate for an ensemble {x(t)} of N time history samples is given by

$$\hat{\mu}_x(t) = \frac{1}{N} \sum_{i=1}^{N} x_i(t) \quad 0 \leq t \leq T_p \qquad \text{(B-3)}$$

and the variance of this estimator is given as

$$V[\hat{\mu}_x(t)] = E\left[(\hat{\mu}_x(t) - \mu_x(t))^2\right] \qquad 0 \leq t \leq T_p \qquad \text{(B-4)}$$

where $\mu_x(t)$ is the true nonstationary time-varying mean of the process.

The time-varying standard deviation estimate for this ensemble {x(t)} is given by

$$\hat{\sigma}_x(t) = \sqrt{\frac{\sum_{i=1}^{N}[x_i(t) - \hat{\mu}_x(t)]^2}{N-1}} \qquad 0 \le t \le T_p \qquad \text{(B-5)}$$

and the variance of this estimator can be given in its theoretical form as

$$V[\hat{\sigma}_x] = E\left[\{\hat{\sigma}_x(t) - \sigma_x(t)\}^2\right] \quad 0 \le t \le T_p \qquad \text{(B-6)}$$

where $\sigma_x(t)$ is the true nonstationary time-varying standard deviation of the process.

The unbiased time-varying mean square estimate for an ensemble {x(t)} is given by

$$\hat{\psi}_x^2(t) = \frac{1}{N}\sum_{i=1}^{N} x_i^2(t) \quad 0 \le t \le T_p \qquad \text{(B-7)}$$

and the variance of this estimator is given as

$$V[\hat{\psi}_x(t)] = E\left[\{\hat{\psi}_x^2(t) - \psi_x^2(t)\}^2\right] \qquad 0 \le t \le T_p \qquad \text{(B-8)}$$

where $\psi_x^2(t)$ is the true nonstationary time-varying mean square of the process.

In the frequency domain, the average energy spectral density function for an ensemble {x(t)} is

$$E_{xx}(f) = 2E\left[\left|X_{T_p}(f)\right|^2\right] \qquad 0 \langle f \langle f_c \qquad \text{(B-9)}$$

and the variance of this estimator is given in theoretical form as

$$V[\hat{E}_{xx}(f)] = E[\{\hat{E}_{xx}(f) - E_{xx}(f)\}^2] \qquad 0 \langle f \langle f_c \qquad \text{(B-10)}$$

In computing these estimates of error, or quantitatively measuring how "close" the laboratory simulation test item response is to in-service materiel response, the "true" quantities are unknown but can be taken as the processed in-service measured materiel response.

2.5 Specific Application of the Model to the Measured Materiel Response

This portion of the Annex provides a brief overview of the actual processing necessary to perform a successful stochastic materiel response simulation to a measured in-service materiel response environment. The in-service measured materiel response to be modeled is a fifty pulse, N_p=50, round 30 mm gunfire event depicted in Figure B-1a. The gun-firing rate is approximately 40 rounds per second and the event lasts for about 1.25 seconds. This record is digitized at 20,480 samples per second with an anti-alias filter set at 2 kHz. It is clear from visual inspection of the amplitude time history that the record has periodic time-varying characteristics. This record is decomposed into an ensemble of 50 pulses each of about 25 milliseconds length for which classical time-varying statistical techniques are applied. Figure B-2a contains the plot of a typical pulse, pulse 37, of the ensemble and figure

B-3a contains its residual. Figure B-4a contains a plot of the mean estimate for this ensemble defined in equation B-3. The standard deviation estimate of the ensemble of N records defined in equation B-5 is shown in figure B-5a. This is also the root mean square of the residual ensemble. Figure B-6a contains a plot of the root mean square for the ensemble. By subtracting the mean from each member of the ensemble, a residual ensemble is obtained. This residual ensemble has zero mean and a non-zero time-varying root mean square the same as the standard deviation of the original ensemble.

It is very important to understand the characteristics of this residual ensemble. It should be clear from the above figures that the measured ensemble has a time-varying mean, a time-varying mean square and a time-varying frequency with higher frequencies in the initial portion of the record. An energy spectral density computed on the original measured ensemble and the measured residual ensemble reveals the effect of removal of the time-varying mean from the original ensemble and the differing frequency characteristics of the two ensembles. Figure B-7a provides a superposition of both of the energy spectral density estimates. The filter bandwidth for the ESD estimates is 5 Hz. An even more dramatic depiction of the time frequency character of the original ensemble is given in Figure B-8a, T1 through T4. In this analysis the pulse length is divided into four equal time segments of 6.25 ms each and the average ESD computed for each segment retaining a 20 Hz filter bandwidth. The estimates are averaged over the ensemble with no time domain tapering applied. When all four spectra are superimposed upon one another, it is clear that the variation of frequency with time is substantial both for the original ensemble and for the residual ensemble in figure B-9. The residual ensemble is studied for its second order or correlation properties in references c, d and e. The actual steps used to perform the simulation according to the model outlined in Figure B-1 and to estimate the error in the time-varying mean, standard deviation, root mean square, and the partial and overall energy spectrum estimate are contained in Reference c.

Figures B-10a and 10b depict the deterministic function $a_1(t)$ and the estimate function $a_2(t)$, respectively. Figure B-11a displays the residual information before the residual is filtered and Figure B-11b the residual after filtering is applied. Using information from references a and b only, Fourier based FFT and inverse FFT are used to determine the simulated test ensemble. Segmentation in time in order to simulate the time-varying frequency characteristics of the ensemble did provide for some minor discontinuities at the time interval boundaries in the simulation. From reference e it can be noted that it is also possible to segment the time-varying characteristics in the frequency domain which also results in some minor discontinuities in the frequency domain.

The results of the simulation are displayed in the figures below in order to allow the practitioner to note the general fidelity in the simulation. Figure B-1b represents a simulated ensemble with N_p pulses to give an overall qualitative assessment of the simulation. Figure B-2b and figure B-3b provide plots of a typical pulse, number 37, and its residual from this simulated ensemble, respectively. Figure B-4b is the mean for the ensemble with Figure B-5b the standard deviation, and Figure B-6b the root mean square. Figures B-7 through B-9 display measured information with corresponding simulated information. Figure B-12 contains the maximum, the median time-varying root variance estimates for the time-varying mean for sample sizes of 10, 25 and 50 pulses. This represents the error that might be expected at each time point as a result of the simulation of the three sizes of the ensembles.

Corresponding information is provided in Figure B-13 for the time-varying standard deviation and in Figure B-14 for the time-varying root mean square. In general for an ensemble with N_p sample time histories the maximum root variance is less than 2.5g's with the median being below 0.75g's. These plots for the most part display some degree of uniformity over the time interval.

2.6 Implementation

The technique outlined above may be implemented by pre-processing the data and generating the simulated materiel response ensemble on a mainframe computer or a PC. In either case, the simulated digital waveform must be appropriately compensated by the procedure described in Annex A before the analog voltage signal to the exciter is output. This technique of stochastic simulation is quite elaborate in detail but does provide for a true stochastic time-varying laboratory simulation of materiel response based on measured in-service materiel response. The technique is flexible, in that it can produce an unlimited number of "pulses" all slightly different with testing limited only by the length of time a vibration controller can provide an adequate simulation in an open loop mode of control. If it is assumed that exciter output and test item response scale linearly with exciter master gain, degrees of test conservativeness in the stochastic simulation may be introduced.

2.7 References and Related Documentation

a. Lanczos C., Discourse on Fourier Series, Hafner Publishing Company, New York, 1966.

b. Bendat J. S. and Piersol A. G., Random Data: Analysis and Measurement Procedures, 2nd edition, John Wiley & Sons Inc., New York, 1986.

c. Merritt R. G., Simulation of Ensemble Oriented Nonstationary Processes, Part 2, Proceedings of 1994 IES 40th Annual Technical Meeting, Chicago, IL, May 1994.

d. Merritt R. G., An Example of the Analysis of a Sample Nonstationary Time History,Proceedings of 1994 IES 40th Annual Technical Meeting, Chicago, IL, May 1994.

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

f. Smallwood D.O., Characterization and Simulation of Gunfire With Wavelets, Proceedings of the 69th Shock and Vibration Symposium, Volume 1, Minneapolis, MN, October 1998.

g. Merritt R. G., A Note on Prediction of Gunfire Environment Using the Pulse Method,Proceedings of 1999 IEST 45th Annual Technical Meeting, Ontario, California, May 1999.

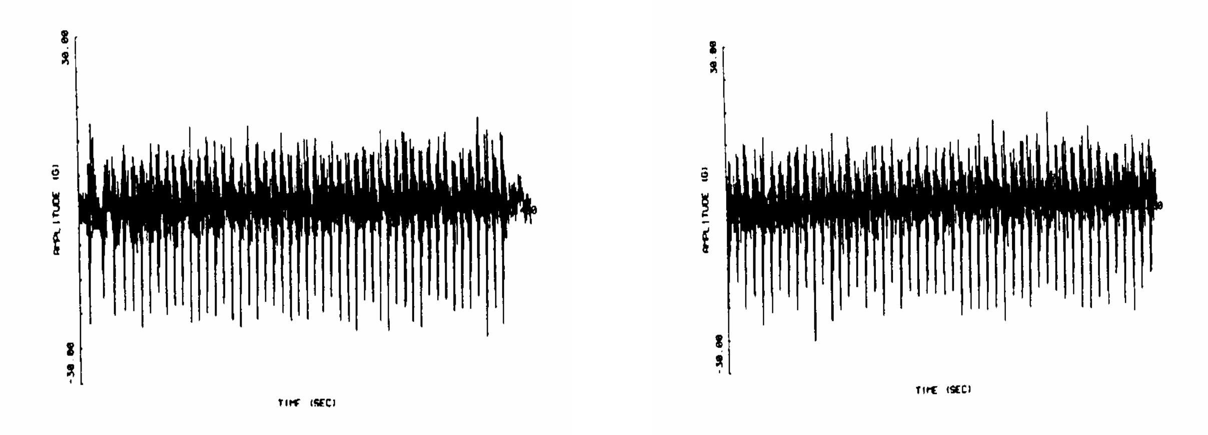
3. RECOMMENDED PROCEDURES

3.1 Recommended Procedures

Use Procedure II for single materiel response measurements, on comparatively simple dynamic materiel. This procedure is to be used in cases in which a statistically correct laboratory replication of the response environment is absolutely essential to establish materiel operational and structural integrity under the gunfire environment.

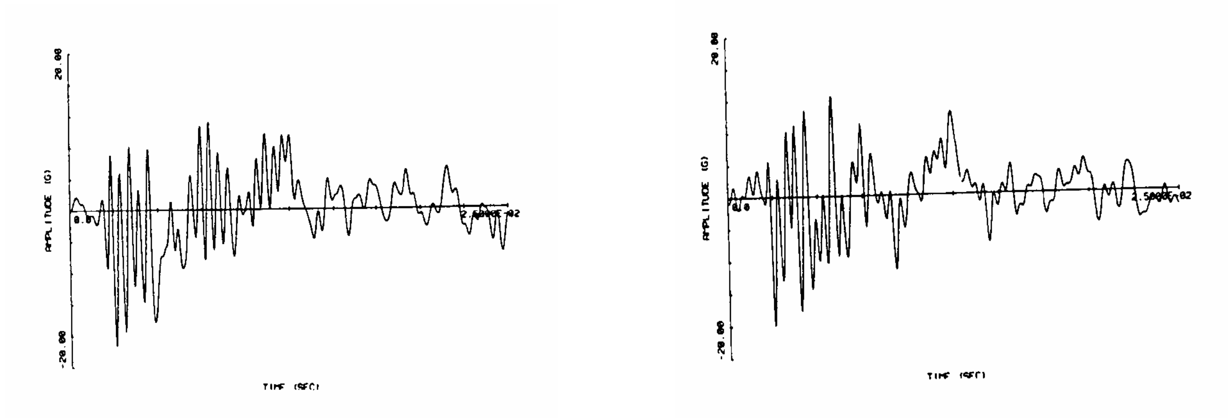
3.2 Uncertainty Factors

The only significant uncertainty in this procedure results in the degree to which the measured environment differs from the actual in-service environment. It is usually not possible to obtain the measured environment under every conceivable in-service condition. The errors in the simulation are independent of the variability of the in-service environment.



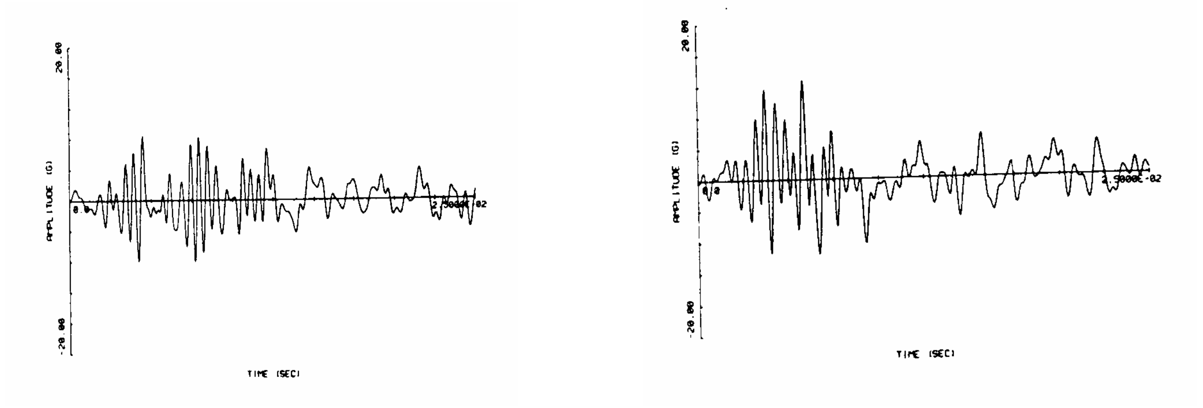
(a) Measured Data (b) Simulated Data

FIGURE B-1 Fifty Round 30 mm Gunfire Event



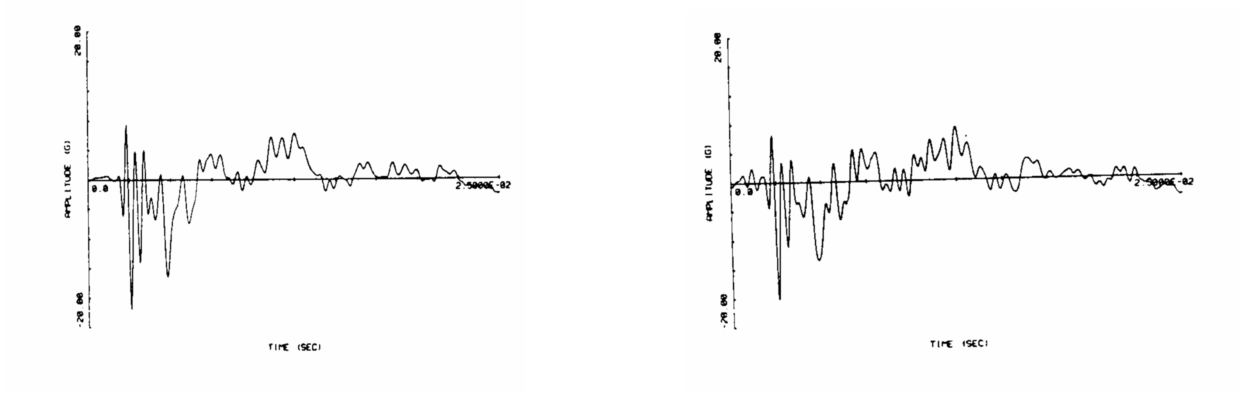
(a) Measured Data (b) Simulated Data

FIGURE B-2 Ensemble Sample Time History Pulse (Pulse 37)



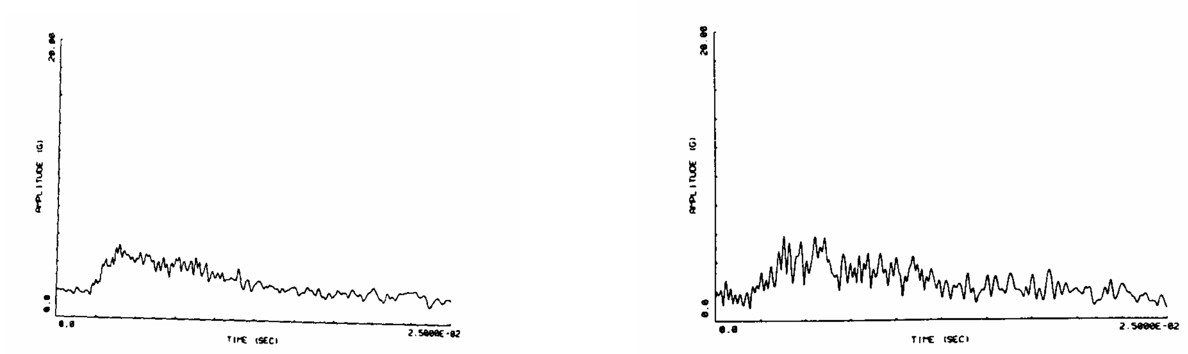
(a) Measured Data (b) Simulated Data

FIGURE B-3 Ensemble Residual Sample Time History Pulse (Pulse 37)



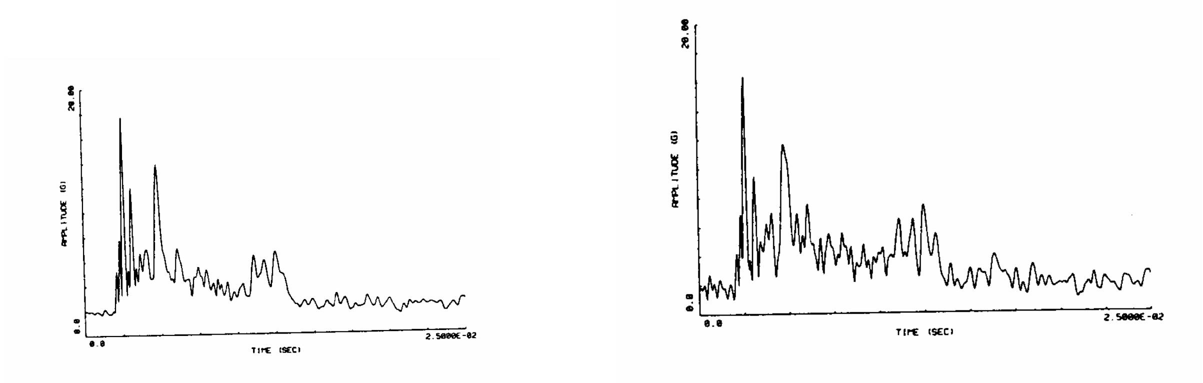
(a) Measured Data (b) Simulated Data

FIGURE B-4 Ensemble Time - Varying Mean Estimate



(a) Measured Data (b) Simulated Data

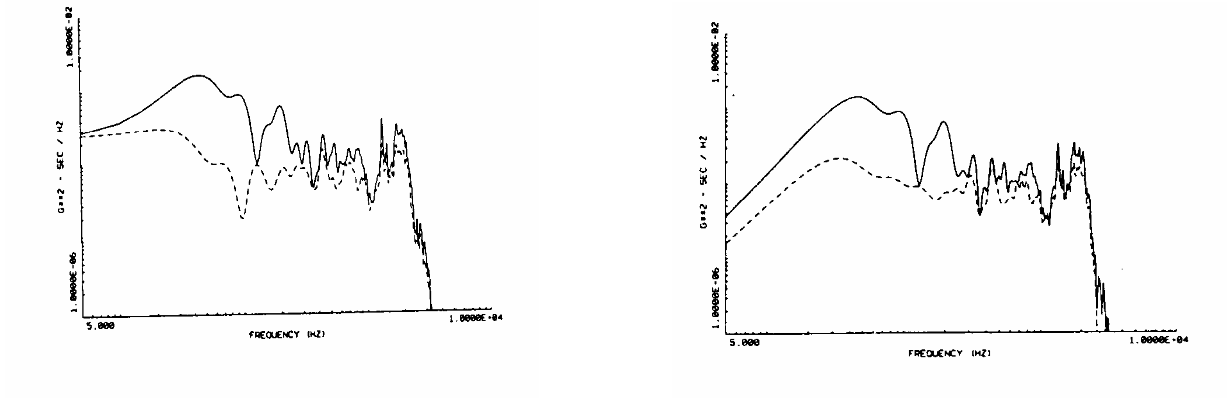
FIGURE B-5 Ensemble Time - Varying Standard Deviation



(a) Measured Data

(b) Simulated Data

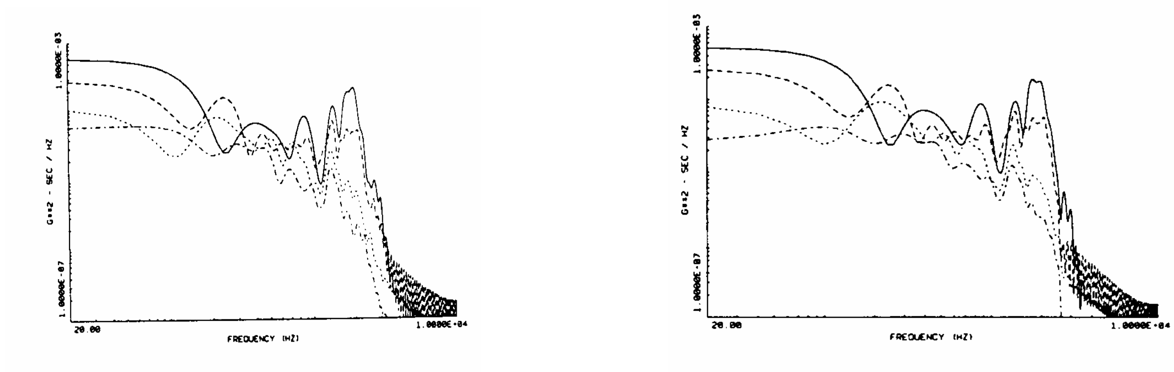
FIGURE B-6 Ensemble Time - Varying Root Mean Square Estimate



(a) Measured Data Ensemble

(b) Simulated Data Ensemble

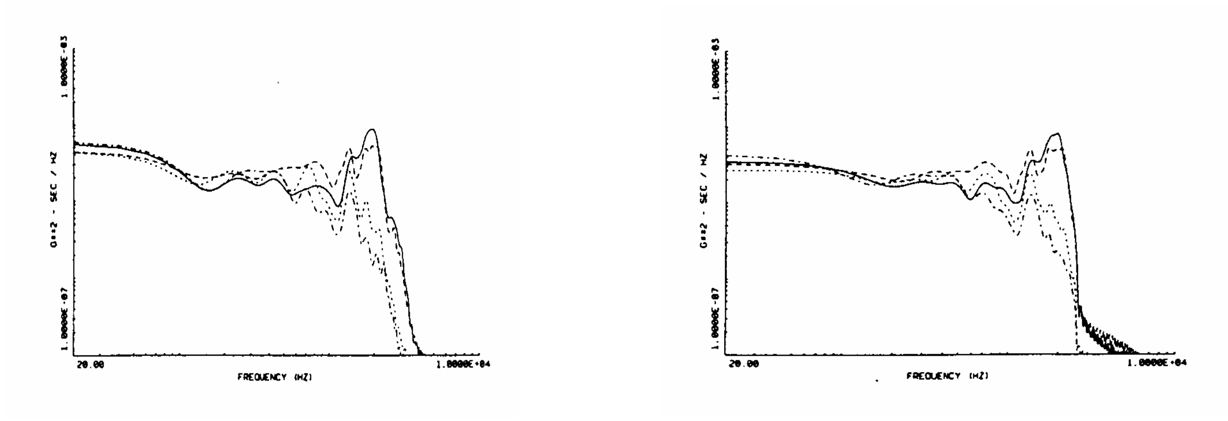
FIGURE B-7 Energy Spectral Density Function Estimate



(a) Measured Data Ensemble

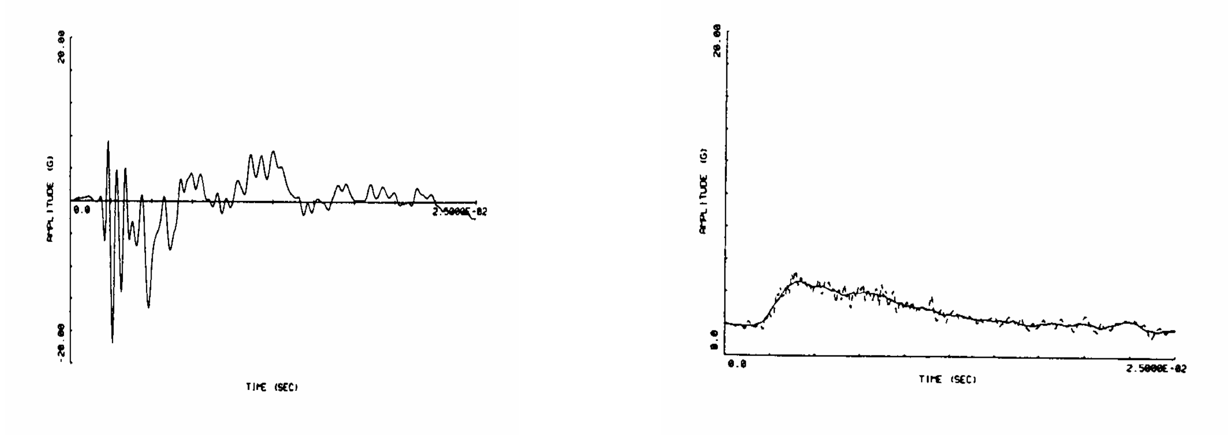
(b) Simulated Data Ensemble

FIGURE B-8 Short Time Energy Spectral Density Function Estimate



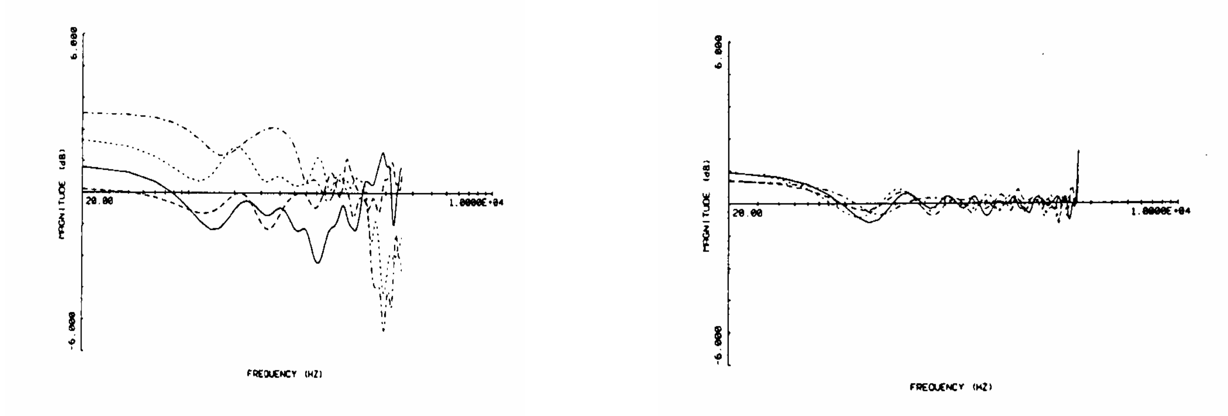
(a) Measured Residual Ensemble (b) Simulated Data Ensemble

FIGURE B-9 Short Time Energy Spectral Density Function Estimate



(a) $a_1(t)$ - Deterministic Signal (b) $a_2(t)$ - Estimate Smoothed Residual window

FIGURE B-10 Nonstationary Model Deterministic Functions



(a) Before Residual Filtering (b) After Residual Filtering

FIGURE B-11 Segmented ESD Ratio

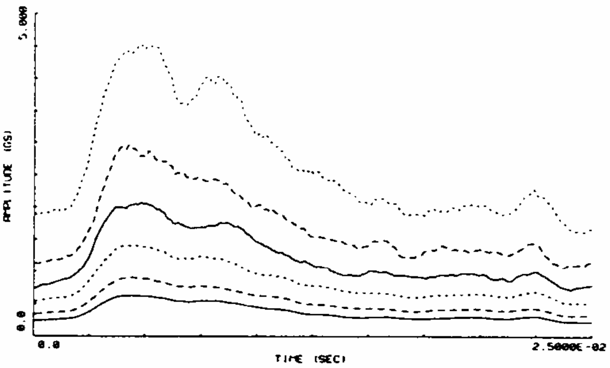


FIGURE B-12 Smoothed Simulation Root Variance Estimate for the Time-Varying Mean for Simulated Ensemble Sample Sizes of 10, 25, and 50, Sample Time Histories of Maximum and Median

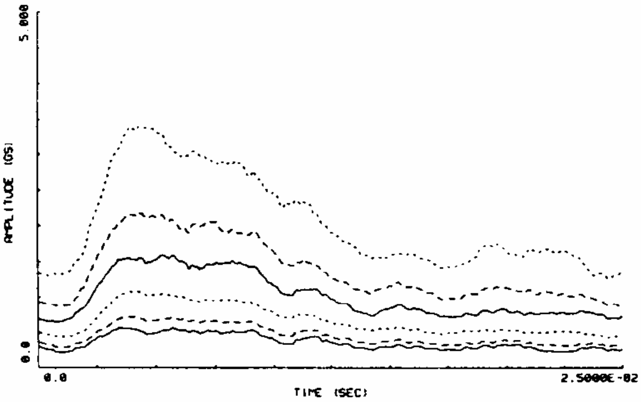


Figure B-13 Smoothed Simulation Root Variance Estimates for the Time-Varying Standard Deviation for Simulated Ensemble Sample Size of 10, 25, and 50 Sample Time Histories of Maximum and Median

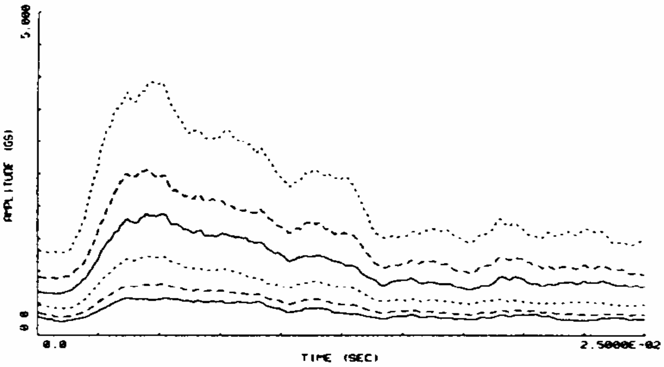


Figure B-14 Smoothed Simulation Root Variance Estimate for the Time-Varying Root Mean Square for Simulated Ensemble Sample Size of 10, 25, and 50 Sample Time Histories of Maximum and Median

ANNEX C

PROCEDURE III - REPETITIVE PULSE SHOCK RESPONSE SPECTRUM (SRS)

1. SCOPE

1.1 Purpose

This annex provides an overview of a technique for laboratory simulation of a gunfire environment based upon a form of the “pulse method”.

1.2 Application

The stochastic simulation technique to be described here for a single unknown time-varying random process for which a single sample function from the process is available. The sample function is representative of a single gunfire physical configuration for which extrapolation to other configurations is undetermined. Benefits of Procedure III are defined below. The following paragraphs present an overview of the Procedure III methodology and its limitations.

a. Is convenient to implement on a vibration control system with shock response spectra (SRS) capability,

b. Has many features analogous to that of traditional SRS exciter shock simulation based on SRS estimate specification,

c. Is very flexible in terms of the length of statistically equivalent records it can generate for laboratory test replication of an in-service measured response environment ,

d. Is not restricted to one form of pulse and,

e. Abandons a minimal number of higher order features of the measured response ensemble not considered essential to conservative in-service measured response data replication by way of laboratory test item response simulation testing.

2. DEVELOPMENT

2.1 Introduction

The SRS method assumes that the measured materiel response time history can be decomposed into an ensemble of individual pulses. Maximax SRS are computed over the ensemble of pulses using various damping factors to assist in characterizing the frequency content of the individual pulses. The SRS mean is also computed over the ensemble of pulses for each damping factor to further characterize the materiel response pulses. Using the information from the SRS, an acceleration time history is synthesized using amplitude modulated sine components, wavelets or damped sinusoids. The SRS based acceleration response time history is then used as the characteristic gunfire materiel response pulse, and input to the test item at the firing rate of the gun, see references b and c.

2.1.1 Procedure Advantages

a. It makes use of standard laboratory shock test equipment,

b. The method reproduces the frequency characteristics of the measured materiel response data,

c. The SRS can easily be specified in documents and reproduced at various test facilities.

2.1.2 Procedure Disadvantages :

a. The character of the time history generated by the wavelets or damped sinusoids is not well controlled and may not appear similar in form to the measured materiel response pulses,

b. Little or no statistical variation can be easily introduced into the simulation, and

c. Reproducing the series of pulses at the firing rate of the gun may present a problem for vibration control systems not designed for this mode of operation.

A particular example of gunfire materiel response simulation using Procedure III is discussed below. This procedure is performed using a digital vibration control system with SRS testing capability, see references b and c.

2.2 Test Configuration

An instrumented test item is installed in a laboratory vibration fixture and mounted to the armature of an electrodynamic exciter. The test item employed during the laboratory simulation is of the same configuration as the materiel used to collect the in-service measured response data. A piezoelectric accelerometer is installed internal to the test item for purposes of acceleration response measurement.

2.3 Creating a Digital File of the Gunfire Vibration Response

The first step in this simulation process is to digitize the measured in-service materiel response data to obtain an acceleration time history, see Figure C-1. Digital processing of the analog data is performed using a 2kHz, 48dB/octave low pass anti-alias filter. The digital file is DC coupled, not high pass filtered, at a sample rate of 20,480 samples per second for good time history peak resolution. The anti-alias filter should have linear phase characteristics.

2.4 Computing the Shock Response Spectra

If examination of the individual measured response pulses indicates similar character between the pulses, a representative pulse is chosen for analysis. The SRS is then computed over the representative pulse using a specified analysis Q of 10, 25, 50, and 100. To increase the statistical confidence in the results, the pulse sequence may be ensemble averaged in time. The "mean" of the ensemble is taken as the representative pulse, and the procedure above applied. The SRS used in the procedure may also be taken to be the mean SRS of the entire pulse individual SRSs. If the pulse characteristics are very dissimilar, then it may be necessary to run several tests depending upon the judgement of an experienced analyst.

2.5 Estimating Equivalent Half-cycle Content of Representative Gunfire Materiel Response Pulse

Figure C-2 shows that the representative gunfire materiel response pulse contains seven predominant frequencies at approximately 80, 280, 440, 600, 760, 1360, and 1800 Hz. A 2Q half-cycles for a constant amplitude sine wave provides approximately 95% of the maximum SRS amplitude for a given SRS Q value. An estimate of the equivalent half-cycle content that makes up the predominant frequencies contained in the measured gunfire response can be determined by identifying the Q at which the peak acceleration for a particular frequency of the SRS begins to level off. A Q of 10 in Figure C-2 characterizes the half-cycle content of the 80 Hz component. The half-cycle content of the other predominant frequencies, except at 1800 Hz, is represented by a Q of 25. A Q of 50 quantifies the half-cycle content of the 1800 Hz component.

2.6 SRS Transient Generation For Gunfire Materiel Response Pulse Representative

After estimating the frequency content of the representative gunfire materiel response pulse, a SRS transient time history pulse is generated using a digital vibration control system, by means of a proprietary wave synthesis algorithm. The SRS transient time history pulse is composed of 1/12 octave wavelets, with the majority of the 1/12 octave components limited to three half-cycles, the minimum allowed for the vibration control system. The seven predominant frequencies are restricted for half-cycle content by either the 25-millisecond duration of the gunfire response pulse, 40-Hz gun firing rate, or by the half-cycle estimation technique discussed in Annex C, paragraph 2.5. A Q of 10 is identified for the 80 Hz component; a Q of 25 for the 280, 440, 600, 760, and 1360 Hz components; and a Q of 50 for the 1800 Hz component. The SRS mean is computed over the ensemble of pulses for each damping factor, Q = 10, 25, 50, and 100, to characterize the SRS amplitudes. The mean SRS that is computed using an analysis Q of 50 is then selected to define the SRS amplitude for each frequency component of the simulated materiel response pulse. Zero time delay is specified for each of the 1/12 octave wavelets. Table C-1 provides the wavelet definition for making up the complex transient pulse, and Figure C-3 displays the SRS gunfire materiel response complex transient pulse produced from the wavelet definition.

2.7 Simulating the Gunfire Component Response

The final step in the gunfire materiel response simulation is to repeat the SRS gunfire transient at the gun firing rate of 40 Hz. Because of output pulse rate limitations of the vibration control system being used, the 40 Hz firing rate could not be achieved. Figure C-4 is an acceleration time history that illustrates the repetitive character of the SRS gunfire simulation method without vibration controller output pulse rate limitations.

Figure C-4 is generated for illustrative purposes by digitally appending the Figure C-3 SRS materiel response transient pulse at the gun firing rate. If the vibration control system does not allow for such rapid repetition, the Annex A waveform control procedure could be used on a digitally simulated and exciter compensated series of materiel response pulses.

2.8 Reference and Related Documents

a. IES-RP-DTE012.1, Handbook for Dynamic Data Acquisition and Analysis, Institute of Environmental Sciences and Technology, USA, January 1995

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

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

3. Recommended Procedures

3.1 Recommended Procedures

For single point materiel response measurements on comparatively simple dynamic materiel, use Procedure III. This procedure is to be used in cases in which laboratory replication of the response environment is essential to establish materiel operational and structural integrity under gunfire environment and for which the test facility is incapable of using Procedure I and II.

3.2 Uncertainty Factors

This procedure includes no statistical uncertainty in addition to any uncertainty in the degree to which the measured environment compares with the in-service environment.

TABLE C-1 Wavelet Definition for SRS Gunfire Pulse

Frequency Hz	Amplitude g	Half-cycles	Frequency Hz	Amplitude g	Half-cycles
78.75	11.995	3	445.45	34.995	21
83.43	11.803	3	471.94	26.455	3
88.39	11.628	3	500.00	19.999	3
93.64	11.455	3	529.73	21.232	3
99.21	11.285	3	561.23	22.568	3
105.11	11.117	3	594.60	23.988	29
111.36	10.952	3	629.96	18.323	3
117.98	10.777	3	667.42	13.996	3
125.00	10.617	3	707.11	20.448	3
132.43	10.459	3	749.15	29.992	37
140.31	10.304	3	793.70	31.225	3
148.65	10.151	3	840.90	32.509	3
157.49	10.000	3	890.90	33.845	3
166.86	10.814	3	943.87	35.237	3
176.78	11.708	3	1,000.00	36.728	3
187.29	12.662	3	1,059.46	38.238	3
198.43	13.709	3	1,122.46	39.811	3
210.22	14.825	3	1,189.21	41.448	3
222.72	16.051	3	1,259.91	43.152	3
235.97	17.358	3	1,334.84	44.975	49
250.00	18.793	3	1,414.21	37.325	3
264.87	20.324	3	1,498.31	31.010	3
280.62	22.004	13	1,587.40	50.003	3
297.30	18.275	3	1,681.79	80.631	3
314.98	16.901	3	1,781.80	130.017	89
333.71	14.825	3	1,887.75	124.882	3
353.55	13.002	3	2,000.00	119.950	3
374.58	16.653	3			
396.85	21.330	3			
420.45	27.321	3			

Notes :

a. Wavelet definition is based upon form of wavelet in proprietary SRS waveform synthesis software, see reference b.

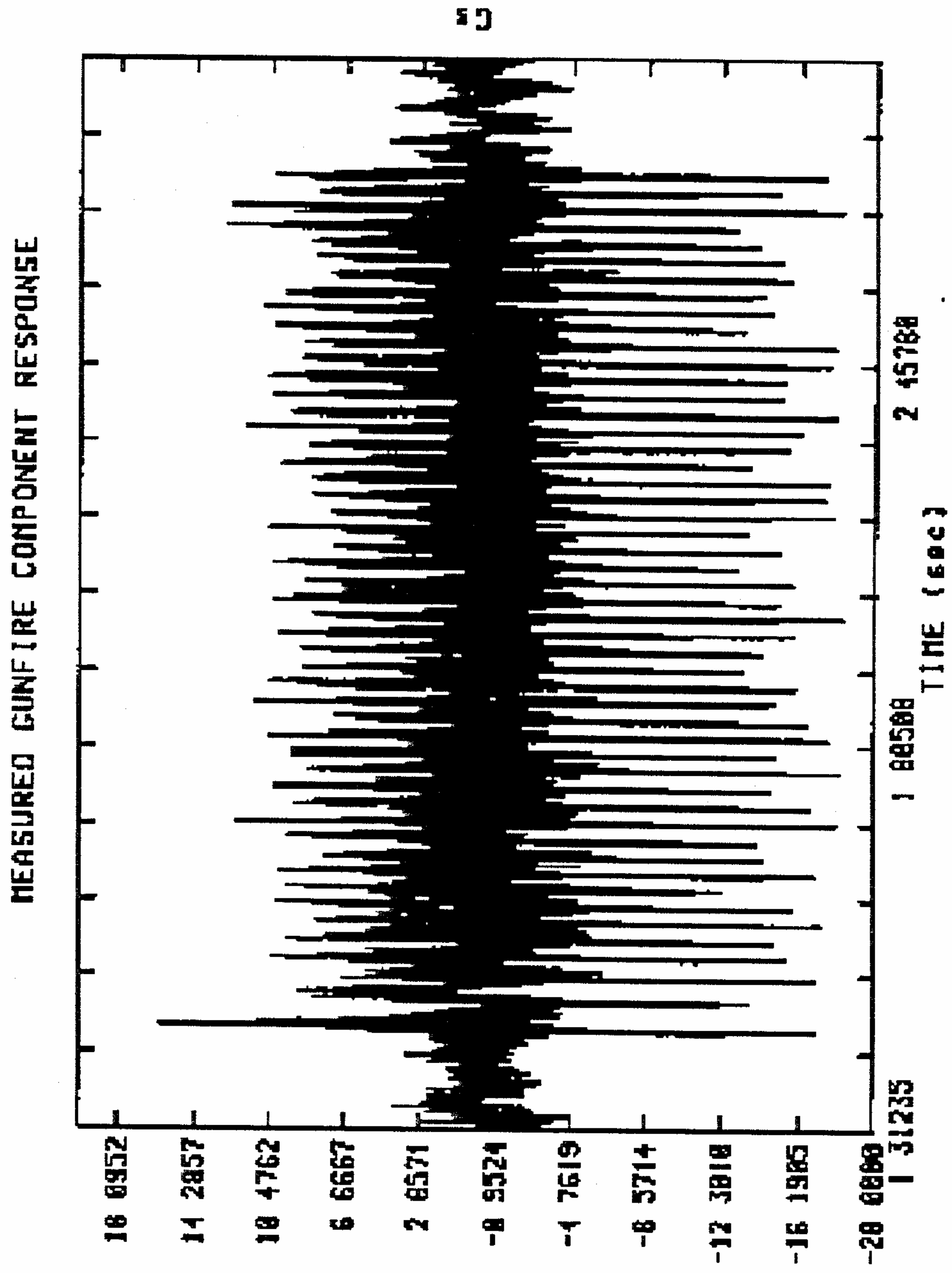
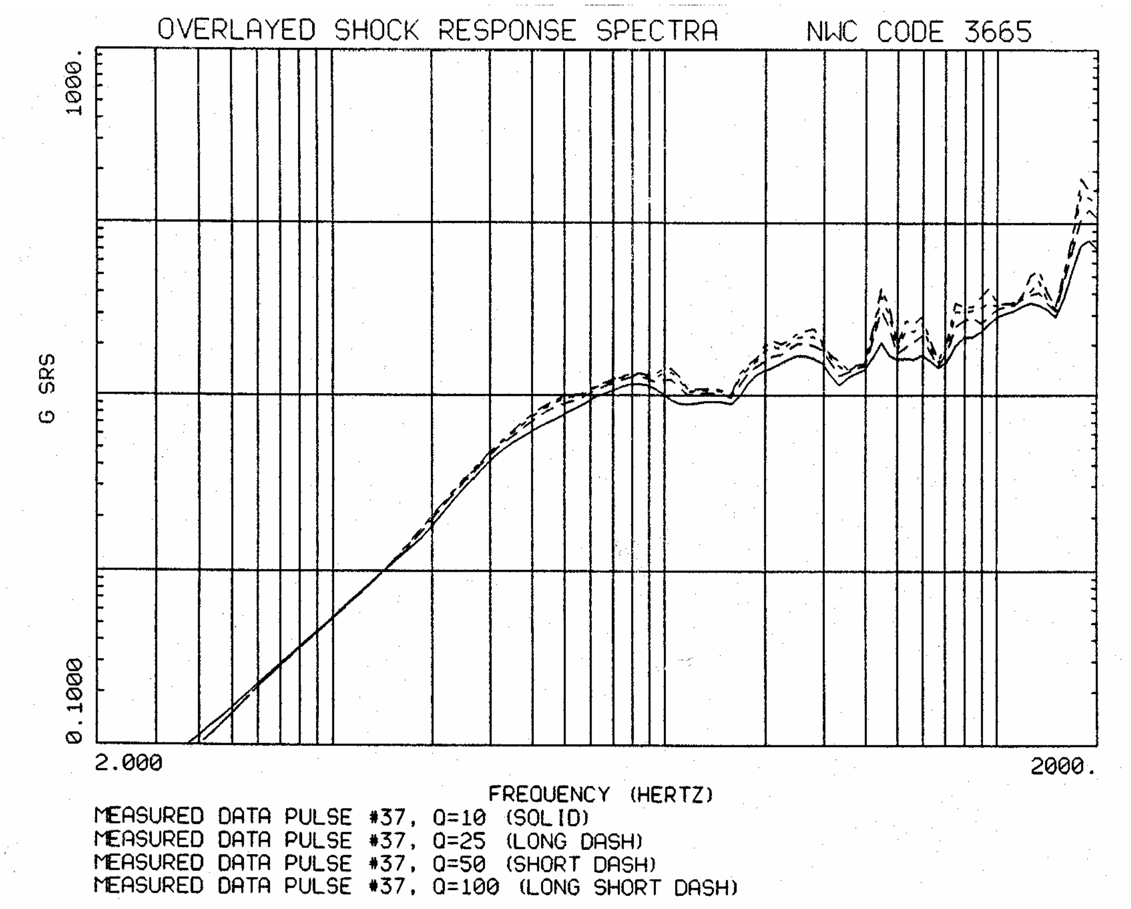


Figure C-1 Digitised Flight Data



<u>**Figure C-2 Comparison of Representative Gunfire Pulse Using a Q of 10, 25, 50 and 100**</u>

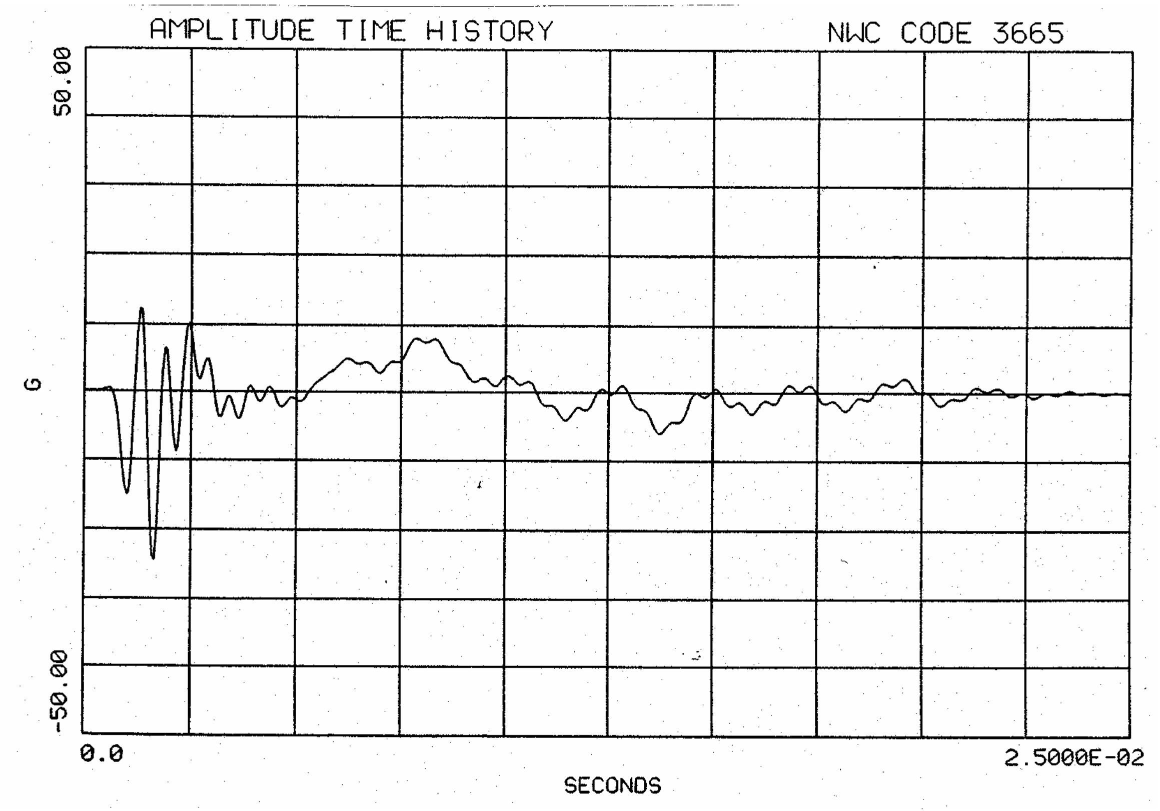


Figure C-3   SRS Gunfire Pulse Generated Using a Digital Controller

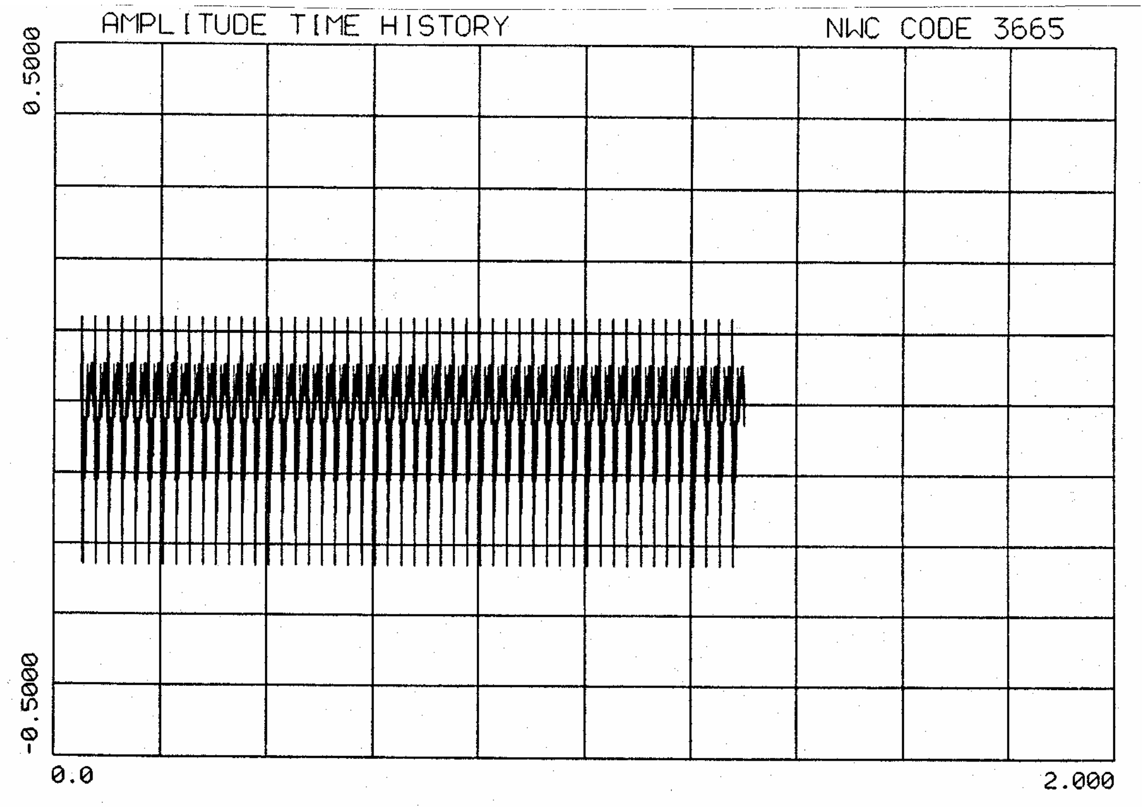


Figure C-4 SRS Pulse Gunfire Simulation

ANNEX D

PROCEDURE IV - HIGH LEVEL RANDOM, SOR, NBROR VIBRATION AND GUIDANCE FOR INITIAL TEST SEVERITY

1. SCOPE

1.1 Purpose

This Annex provides the option of utilizing predicted gunfire vibration data, when no measured data are available, to ensure that materiel mounted in an aircraft with onboard guns can withstand the vibration levels caused by:

- Pulse overpressures emitting from the muzzle of the gun impinging upon the materiel support structure and,
- Structure-borne vibration.

This Annex also provides the option for utilizing high level random vibration when the measured data spectrum displays no outstanding discrete harmonic contents.

1.2 Application

This Annex is applicable only for aircraft gunfire and materiel mounted in an aircraft with onboard guns. Guidance in this Annex is to be used only if in-service measured materiel response data are not available or will not be available in the early stages of a development program. This Annex is not intended to justify the use of sine-on-random (SOR) or narrowband random-on-random (NBROR) for cases in which measured data displays broadband spectra along with components at discrete frequencies. The information in this Annex should be used 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, the severity's developed using the information in this Annex should be supplanted with the severity's estimated from the materiel response under in-service measurement 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:

- Apply Procedure I in the form of transient vibration, or,
- Submit the materiel to a specified level of high level broadband 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 Instruction, see method 401, Vibration.

2. DEVELOPMENT

2.1 Introduction

This Annex is essentially additional guidance based on reference a. The “Pulse Method” in reference a I-4.4.1 of has not been included, but is covered in reference b, which provides insight into the use of the “Pulse Method” in conjunction with a predictive rationale. References c, d and e provide information relative to the origin of gunfire vibration for aircraft in reference a. 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 or materiel configuration, the levels of materiel response to gunfire are generally subject to a large degree of uncertainty. This uncertainty increases substantially in gunfire configurations where the gun is less than a meter from the materiel, and the materiel is excited by the gun blast pressure wave.

2.2 Predicting Gunfire Vibration Spectra.

Gunfire prediction spectra consist of a broadband spectrum representative of an ASD estimate from stationary random vibration along with four harmonically related sine waves. Figure D-1 provides a generalized vibration spectrum for gunfire-induced vibration that defines the predicted response of materiel to the gunfire environment. Four single frequency, harmonically related, sine vibration peaks superimposed on a broadband random vibration spectrum characterize the spectrum. The vibration peaks are the frequencies that correspond to the nominal gunfire rate and the first three harmonics of the gun-firing rate. The specific values for each of the parameters shown in Figure D-1 can be determined from Table D-1, Table D-2 and Table D-3, and Figures D-2 to D-8. The suggested generalized parametric equation for the three levels of broadband random vibration defining the spectrum in Figure D-1 is given in dB for g²/Hz, with reference to 1 g²/Hz as:

$$10 \log_{10} T_j = 10 \log_{10} (NF_1E) + H + M + W + J + Bj - 53 \text{ dB} \qquad j = 1, 2, 3 \qquad \text{(D-1)}$$

where the parameters are defined in Table D-1. The suggested generalized parametric equation for the four levels of single frequency, sine, vibration defining the spectrum in Figure D-1 is given in dB for g²/Hz, with reference to 1 g²/Hz as:

$$10 \text{ LOG}_{10} P_i = 10 \text{ LOG}_{10} T_3 + K_i + 17 \text{ db} \qquad i = 1, 2, 3 \qquad \text{(D-2)}$$

where the parameters are defined in table D-1.

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 in Figure D-2. For configurations involving multiple guns, the origin of vector D is determined from the centroidal point of the gun muzzles as shown in Figure D-3. Figure D-7 and Figure D-8 provide for spectra reduction factors related to the distance D for the random spectra and the discrete frequency spectra, respectively.

- Gun standoff distance, h. The distance normal to the aircraft's surface in Figure D-4
- Depth parameter, Rs. The distance normal to the aircraft's skin to the materiel location inside the aircraft. If Rs is unknown, use Rs = three inches (76 mm) ; See Figure D-2. Figure D-6 provides spectra reduction factors related to Rs.
- The gun caliber parameter, c, in millimeters, or inches

The vibration peak bandwidths, consistent with windowed Fourier processing, should be based 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:

$$\mathrm{BW}_{3\mathrm{db}} = \frac{\pi\sqrt{\mathrm{F}}}{4}$$

for:

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

F = the fundamental frequency, Fi, 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

a. Perform sinusoidal sweeps within the proposed bandwidth for the fundamental and each harmonic or

b. 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 response becomes 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 test, in each of the three axes, equivalent to the expected total time the materiel will experience the environment in-service. This duration may be conservatively estimated by multiplying the expected number of aircraft sorties in which the 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 gunfire time of gunfire per sortie can be determined from Table D-2 by dividing the 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 Instruction. For example, vibration could be applied for two-seconds followed by an eight 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 :

a. The interruption of the exciter input signal.

b. Use of the Annex A waveform replication strategy for transient vibration.

2.4 Spectrum Generation Techniques

Gunfire materiel response 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. Most vibration control system software packages contain a provision for performing a gunfire vibration test based on this form of predicted SOR 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 method of solving this problem is to enter into the vibration controller the broadband random spectrum with its strong vibration peaks. At those frequencies that have the intense vibration peaks, sine waves can be electronically added to the input of the vibration amplifier. Ensure the amplitude of these sine waves is such that the vibration level 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 Gs. Care must be exercised in specifying the amplitude of the sine waves in G or equivalent input voltage corresponding to a G level. This means of environment replication allows the gunfire test to be done closed loop with commonly available laboratory test equipment and control system software.

2.5 Reference and Related Documents

a. Merritt, R.G., A Note on Prediction of Gunfire Environment Using the Pulse Method, IEST, 40th ATM, Ontario, CA, May 1999.

b. Sevy, R. W., and E. E. Ruddell, Low and High Frequency Aircraft Gunfire Vibration and Prediction and Laboratory Simulation, AFFDL-TR-74-123, December 1975, DTIC number AD-A023-619.

c. Sevy, R. W., and J. Clark, Aircraft Gunfire Vibration, AFFDL-TR-70-131, November 1970, DTICnumber AD-881-879.

d. Smith, L.G., Vibration Qualification of Equipment Mounted in Turboprop Aircraft, Shock and Vibration Bulletin, Part 2, May 1981.

3. RECOMMENDED PROCEDURES

3.1 Recommended Procedure

For aircraft vibration for equipment mounted in the aircraft with no available measured data use Procedure IV with the prediction methodology.

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. Changes in the levels, durations, or both for the sake of increasing test conservativeness must be supported by rationale and environment 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 level, i. e. testing with this procedure may be quite unconservative.

TABLE D-1 Suggested Generalized Parametric Equations for Gunfire-Induced Vibration.

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

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

For

N = Maximum number of closely spaced guns firing together. For guns that are dispersed on the host aircraft, such as in wing roots and in gun pods, separate gunfire vibration 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 D-3).

H = Effect of gun standoff distance, h (see Figure D-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 the weight of the equipment to be tested (use Figure D-5). If weight of materiel is unknown, use W = 4.5 kilograms.

J = Effect of equipment's location relative to air vehicle’s skin

(use Figures D-2 and D-6).

Bj = Effect of vector distance from gun muzzle to materiel location (see Figure D-7).

Fi = Gunfiring rate where F_1 = fundamental frequency from Table D-2.

$(F_2 = 2F_1, \quad F_3 = 3F_1, \quad F_4 = 4F_1)$

T_j = Test level in G^2/Hz. j = 1, 2, 3

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 D-8) .

Notes :

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

TABLE D-2 Typical Gun Configurations Associated with Aircraft Classes.

Aircraft/Pod	Gun (Quantity)	Location	Firing Rate		Rounds Capacity
			Rounds/Min	Rounds/Sec	
A-4	**MK 12(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-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
MIRAGE	DEFA 554		1200 & 1800	20 & 30	
RAFALE	DEFA 791B		2520	42	
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 D-3 Gun Specifications.

GUN	**GUN CALIBER**		**BLAST ENERGY, E** Joules, 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
DEFA 554	30	1.18	125.000
DEFA 791B	30	1.18	245.000

Notes :

a. joules (J) x 0.7376 = foot-pounds

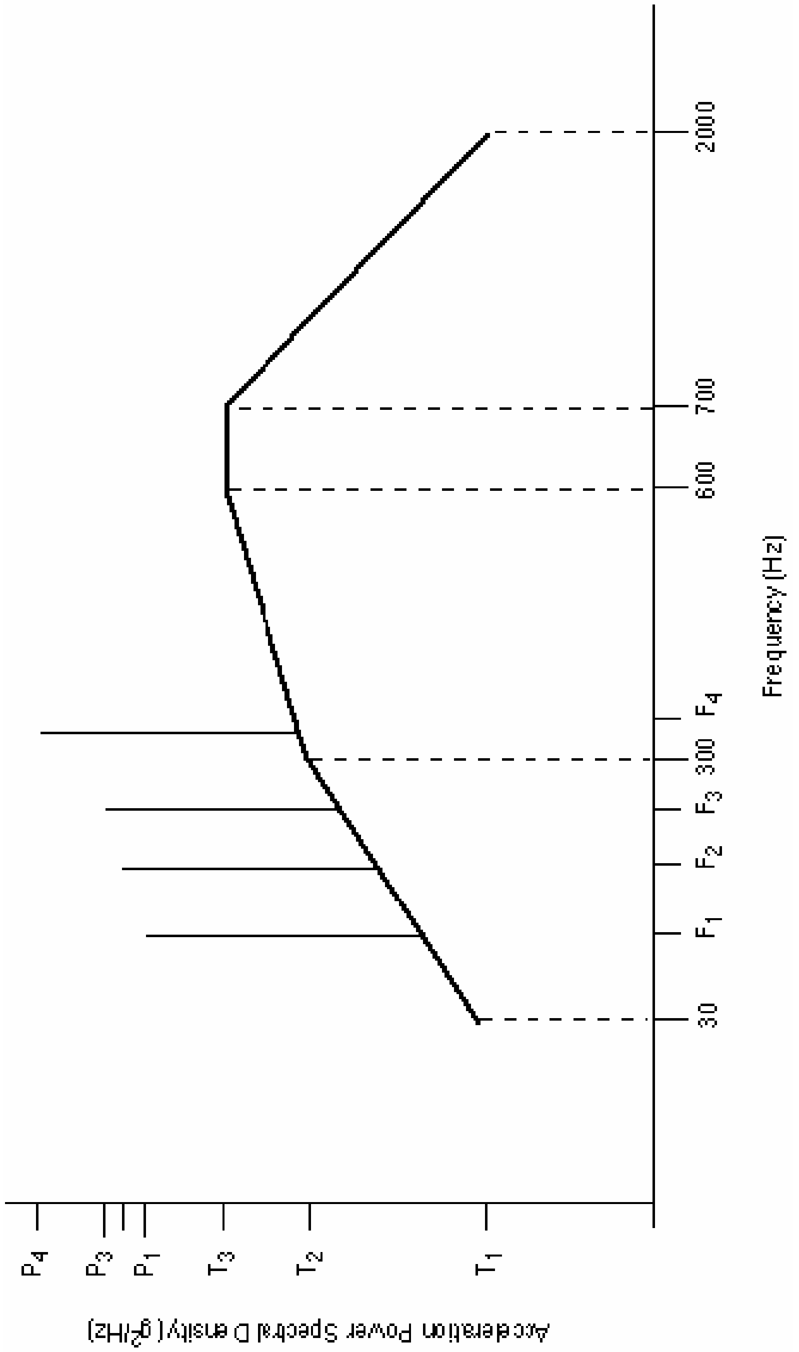


Figure D-1 Generalised Gunfire Induced Vibration Spectrum Shape

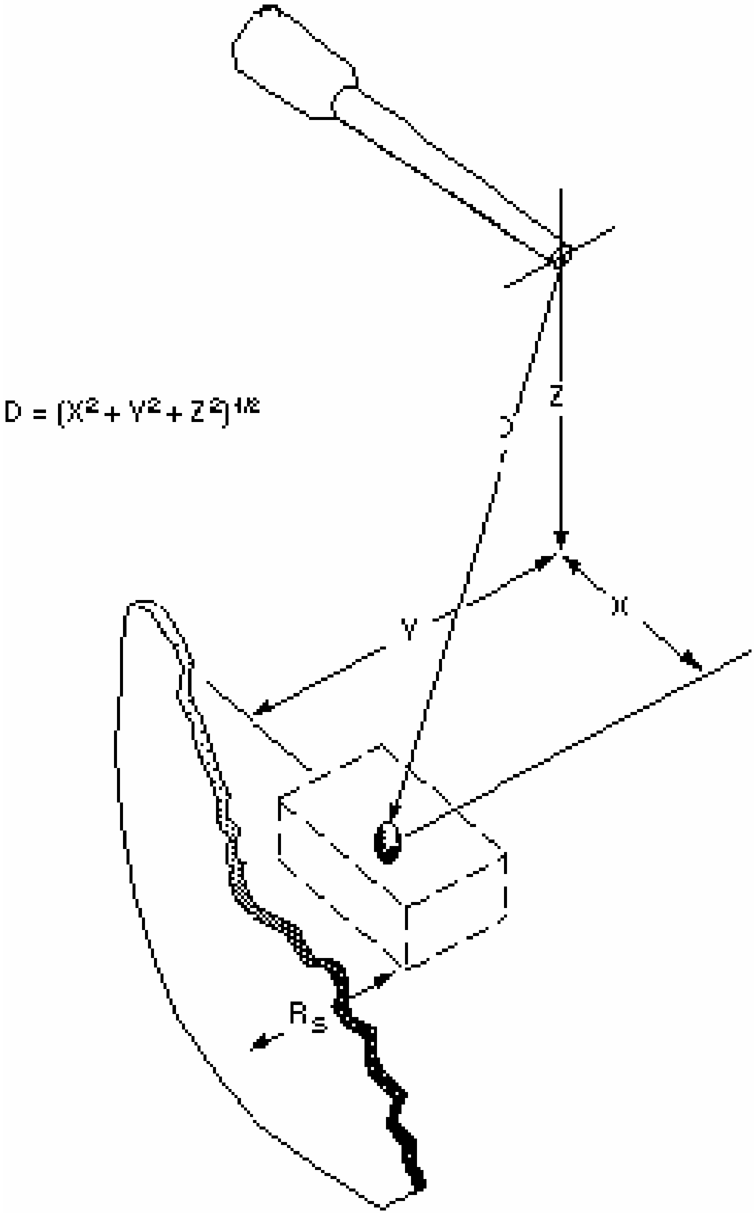


Figure D-2 The Distance Parameter (D) and the Depth Parameter (R_S)

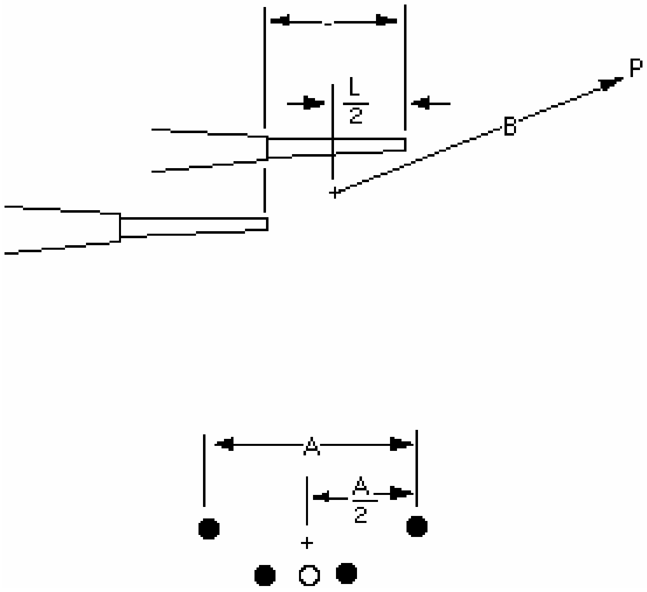


Figure D-3   Multiple Guns, Closely Grouped

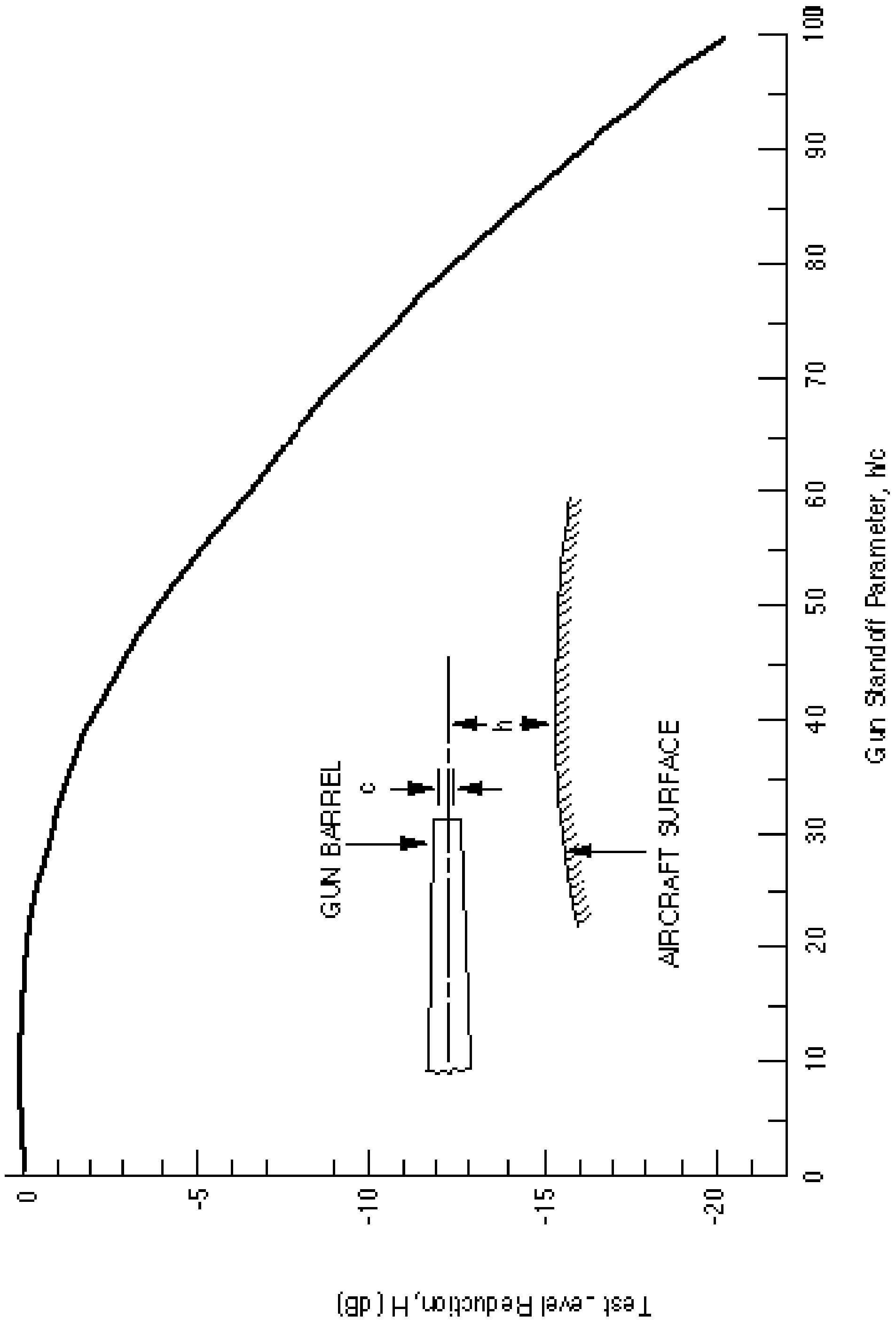


Figure D-4   Test Level Reduction Due to Gun Standoff Parameter

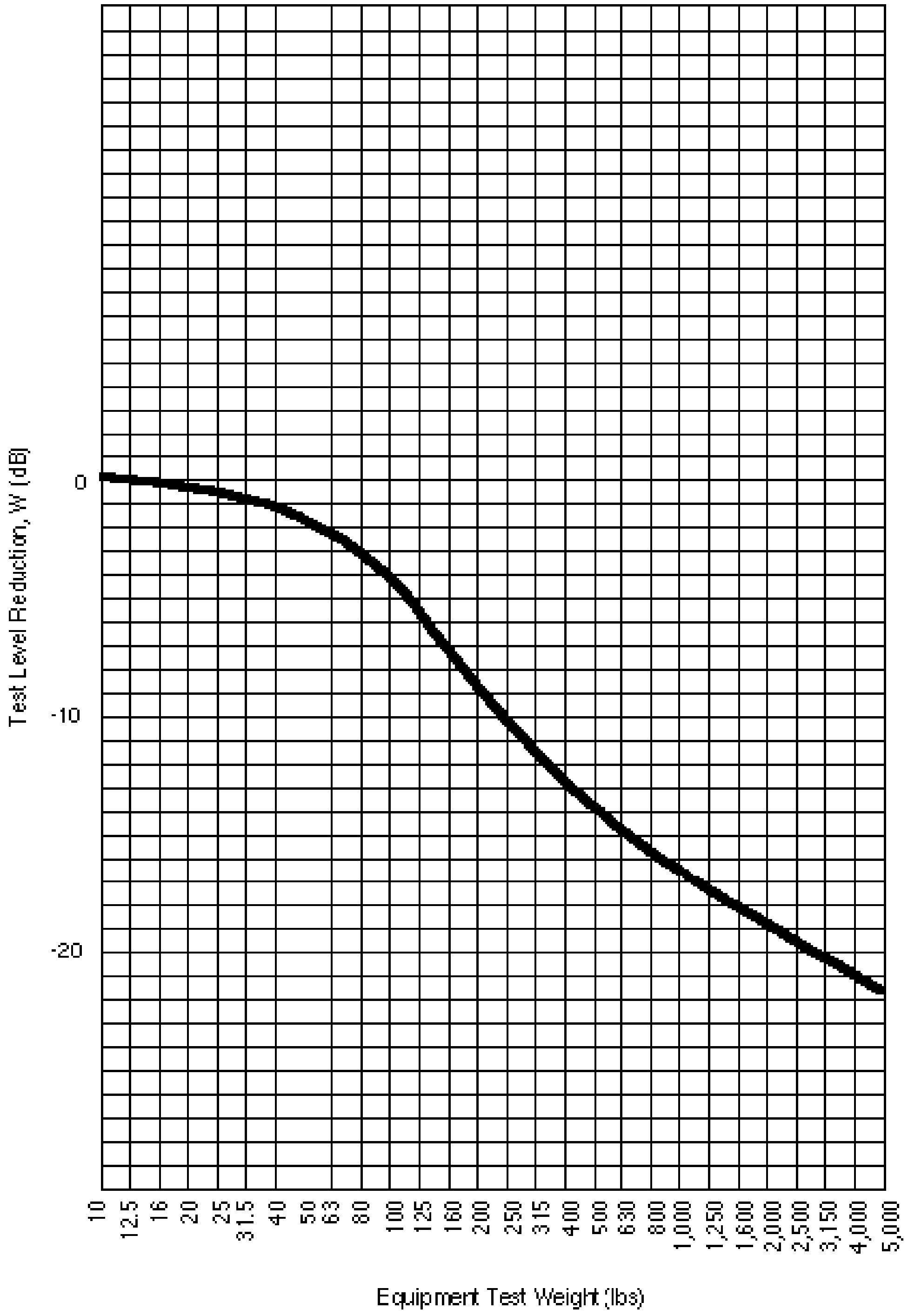


Figure D-5   Test Level Reduction Due to Materiel Mass Loading

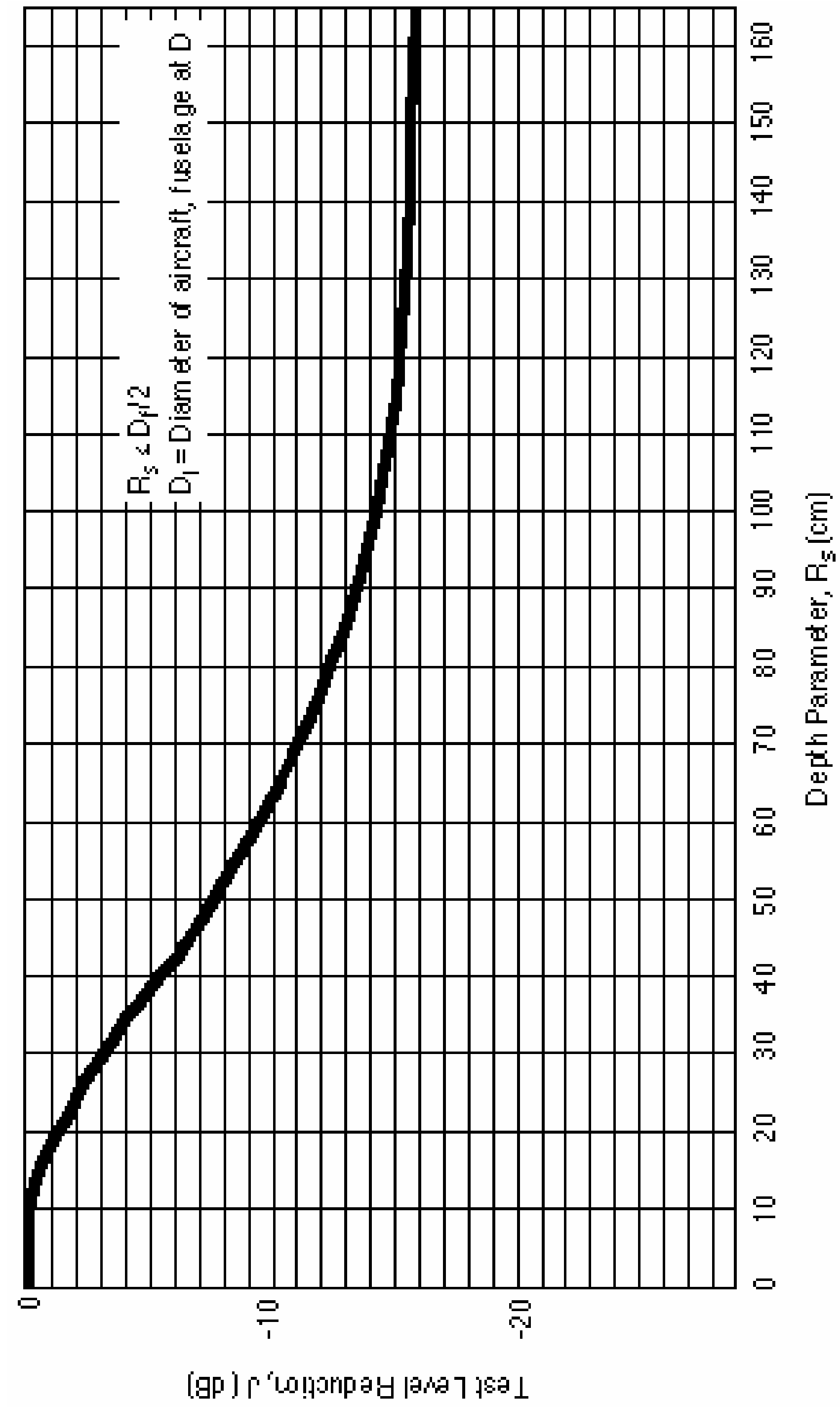


Figure D-6 Test Level Reduction Due to Depth Parameter

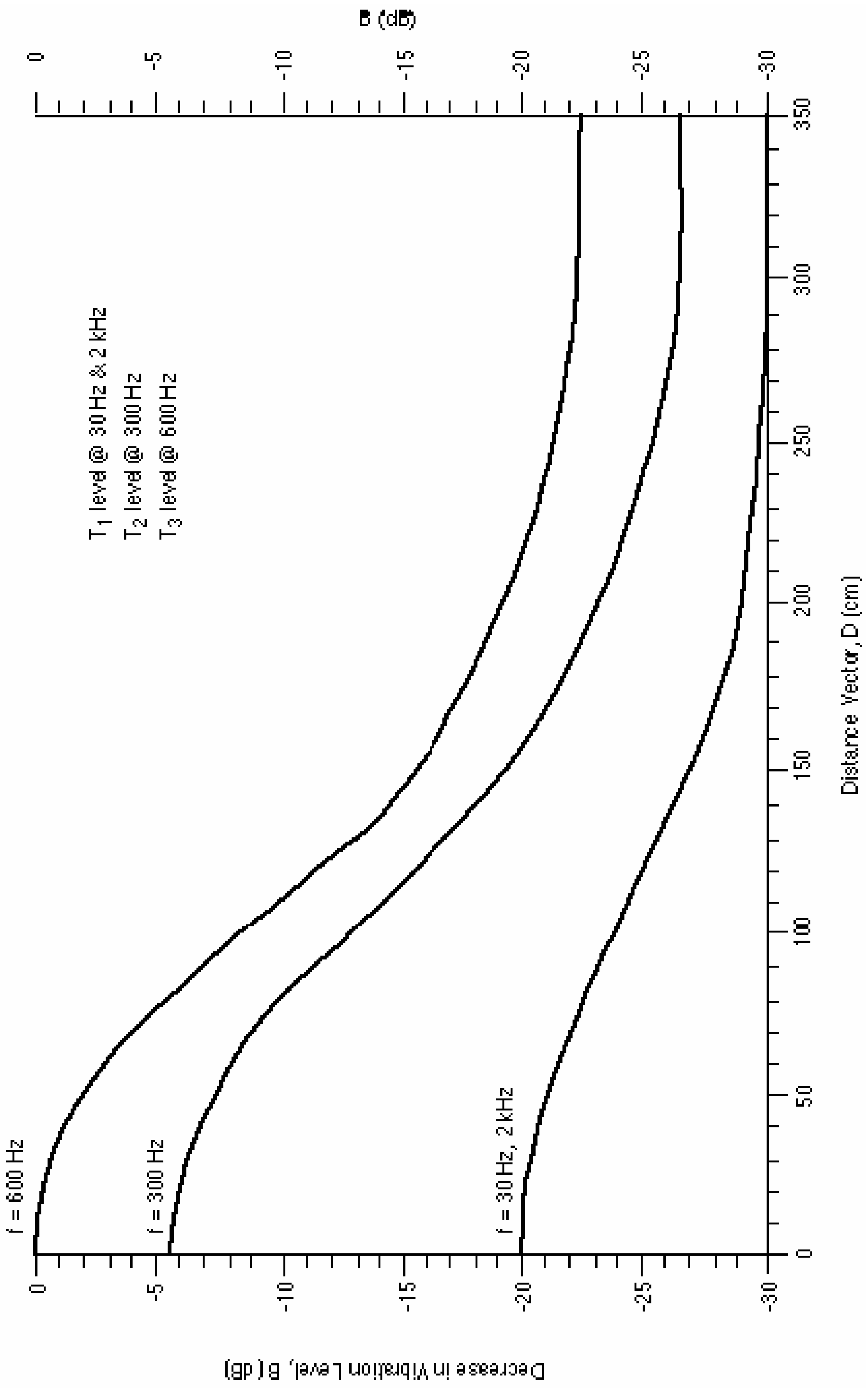


Figure D-7 Decrease in Vibration Level with Vector Distance from Gun Muzzle

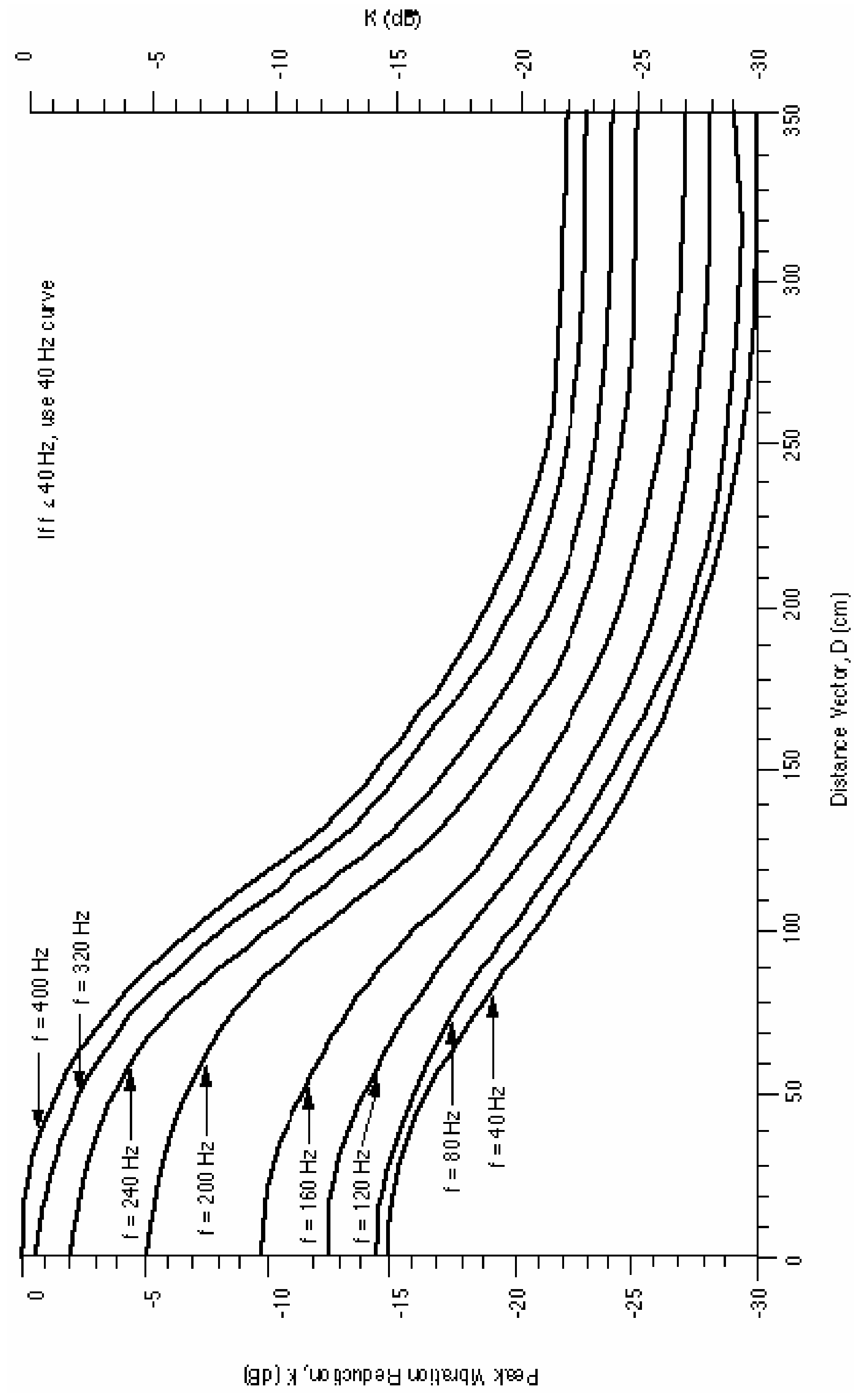


Figure D-8 Gunfire Peak Vibration Reduction with Distance

METHOD 406

LOOSE CARGO

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METHOD 406

LOOSE CARGO

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of the transportation shock environment incurred by systems, subsystems and units, hereafter called materiel, during transportation as loose cargo in vehicles. In particular, this test method accommodates the unrestrained collision of materiel with the floor and sides of the cargo load bed and with other cargo.

1.2 Application

The test method is applicable where materiel is required to demonstrate its adequacy to resist the loose cargo environment without unacceptable degradation of its functional and/or structural performance. AECTP 100 and 200 provide additional guidance on the selection of a test procedure for related vibration and shock environments during transportation.

1.3 Limitations

This method does not address vibrations as induced by secured cargo transportation or transportation of installed materiel, nor individual shocks or impacts inflicted during handling or accidents.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to the loose cargo environment.

a. Fatigue, cracking, rupture,
b. Deformation, specially of protruding parts,
c. Loosening of connections and seals,
d. Displacement of components,
e. Chafing of surfaces.

2.2 Use of Measured Data

Measured data and in-service information should be obtained to tailor the duration of the loose cargo test based on LCEP information. The loose cargo table amplitude control parameters are generally not modified to match a specific vehicle or transport platform.

2.3 Sequence

In a test sequence, loose cargo tests will be scheduled in order to reflect as closely as possible the projected service use profiles. However, if it is considered that this test would probably generate critical materiel failures, the position within the sequence could be changed.

2.4 Choice of Test Procedure

The choice of test procedures is governed by the test item configuration.

Two procedures are proposed. These two types differ from one another only in the installation of the test item. Circular synchronous motion is to be used for both types of tests.

These two types of tests are :

Procedure I :	Equipment likely to slide (e.g., rectangular cross section items)
Procedure II :	Equipment likely to roll (e.g., circular cross section items)

2.5 Materiel Operation

Unless specified in the Test Instruction, the materiel is not operated during this test.

3. SEVERITIES

The test levels result from the rotational speed of the package tester table in the test facility and may be dependent on the individual apparatus and the test item configuration. The test time will be established using the projected service use profiles. Test severities are to be found in Annex A.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item,
b. The definition of the test item,
c. The orientation of the test item in relation to the axis of throw of the test table,
d. The operating checks: initial, final,
e. The details required to perform the test,
f. The monitor points on the test item (if any),
g. The pre-conditioning conditions and time (if any)
h. The definition of the test severity including test time,
i. The indication of the failure criteria,
j. The fencing configuration of the package tester,

4.2 If Required

a. Tolerances, if different from paragraph 5.1.,

5. TEST CONDITIONS AND PROCEDURES

5.1Tolerances

The tolerance of the speed of rotation is +/- 2 rpm

5.2 Installation Conditions of Test Item

Procedure I: Using suitable fixturing as described in Annex B, the test item will be placed on the steel covered package tester bed (see Annex B). The wooden impact walls and sideboards shall be positioned so as to allow impacting on only one end wall (no rebounding) and to prevent rotation of the test item through 90 degrees about the vertical axis. Multiple test items will not be separated by sideboards. The test item will be positioned in its most likely shipping orientation. In the event the most likely shipping orientation cannot be determined, the test item will be placed on the bed with the longest axis of the test item parallel to the long axis of the table (throw axis).

Procedure II: Using suitable fixturing as described in Annex B, the test item will be placed on the steel covered bed of the package tester (see Annex B). The wooden impact walls and sideboards shall be placed so as to form a square test area (see Annex B for the formula to compute the area dimensions). The test item will be placed on the package tester in a random manner. Because part of the damage incurred during testing of these items is due to the items impacting each other, the number of test items should be greater than three.

5.3 Test Preparation

No test will be started on an area of the steel plate which is severely damaged or worn through.

5.3.1 Pre-conditioning

Unless otherwise specified, the test item should be stabilized to its initial conditions stipulated in the Test Instruction.

5.4 Initial and Final Checks

These checks include the controls and examinations stipulated in the Test Instruction.

5.5 Procedure

5.5.1 Procedure

Step 1 Make the pre-conditioning checks in accordance with para. 5.3.1.

Step 2 Make the initial checks in accordance with para. 5.4.

Step 3	Place the test item on the bed of the package tester as specified in para. 5.2.
Step 4	Operate the table for the time specified in the Test Instructions. After half the total designated test time, the test shall be stopped, the test item shall be rotated 90 degrees about the test item's vertical axis (using the same test area constraints described above), and the test continued.
Step 5	Make the final checks in accordance with para. 5.4.
Step 6	In all cases, record the information required

5.5.2 Procedure II

Step 1	Make the pre-conditioning checks in accordance with para. 5.3.1.
Step 2	Make the initial checks in accordance with para. 5.4.
Step 3	Place the test item on the bed of the package tester as specified in para. 5.2.
Step 4	Operate the table for the time specified in the Test Instructions. After half of the total designated test time the test shall be stopped, the test items once again placed in a random manner, and the test continued.
Step 5	Make the final checks in accordance with para. 5.4.
Step 6	In all cases, record the information required

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the loose cargo test.

7. REFERENCES AND RELATED DOCUMENTS

a. Connon, W.H., Ground Vehicle Loose Cargo Vibration Schedules, Report USACSTA-6277, AD Number B114819, January 1987

b. Charles, D. and Neale, M., Loose Cargo Test Options, 65th Shock and Vibration Symposium Proceedings, SAVIAC, volume I, page 233, 1994.

c. White, G.O., TECOM Package Tester Characterization, US Army Aberdeen Test Center, Report ATC-7883, AD Number B217688, September 1996

ANNEX A

LOOSE CARGO - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

The severity contained in this annex is based on measured data on items likely to slide and items likely to roll and is applicable to both Procedure I and Procedure II. This severity represents 240 km of loose cargo transport in tactical wheeled vehicles over rough terrain.

- Package tester rotation speed, circular synchronous motion: 300 rpm ± 2
- Test time: 20 minutes

For munitions safety certification testing, the test item shall be tested in the horizontal and/or vertical orientation as applicable. For a sequential test program, the test item shall be oriented horizontally for 10 minutes of the test followed by 10 minutes in the vertical orientation. For a non-sequential test program, one-half of the sample test items shall be tested in the horizontal orientation for 20 minutes and the remaining half shall be tested in the vertical orientation.

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ANNEX B

TECHNICAL GUIDANCE - TEST FACILITY DESCRIPTION

Simulation of this environment requires use of a package tester or equal hydraulic test system which imparts a 25.4 mm (one inch) peak to peak circular motion to the table at a frequency of 5 Hz. This motion takes place in a vertical plane. The term multiple test items refers to identical test items and not a mixture of unrelated items.

(1) Typical test equipment is depicted in Figure B-1. This equipment is commonly referred to as a package tester. The fixturing required is as shown and will not secure the item to the bed of the package tester. The fence opposite the vertical impact wall is not intended as an impact surface, but is used to restrain the test item from leaving the tester. The distance to this restraining fence should be sufficient to prevent constant impact, but still prevent one or more of multiple test items from "walking" away from the others. The height of the test enclosure (sideboards, impact wall and restraining fence) should be at least 5 cm higher than the height of the test item to prevent unrealistic impacting of the test item on the top of the enclosure.

(2) The test bed of the test system shall be covered with a cold rolled steel plate, 5 to 10 mm thick. The metal plate shall be secured with bolts, with the tops of the heads slightly below the surface. The bolts shall be at sufficient interval around the four edges and through the centre area to prevent diaphragming of the steel plate.

(3) For the circular cross section items, the impact walls and sideboards shall be placed so as to form a square test area. The size of the test area is determined by a series of equations presented below. Derivation of these equations is presented in Annex C. SW and SB are chosen based on test item geometry to provide realistic impacting with the test bed impact walls and between test items. Typical value for both SW and SB is 25 mm. The following formula shall be used to determine the test area dimensions :

For values of the number of test items, N > 3, the required slenderness ratio, R_r, is computed from equation 1 :

$$R_r = \frac{N\ L}{0.767\,L\,N^{1/2} - 2S_W - (N-1)S_B} \qquad \text{equation 1}$$

R_r = required slenderness ratio

L = length of the test item, cm

D = diameter of the test item, cm

N = number of test items

S_W = space between test item and wall, cm

S_B = space between each test item, cm

The test item actual slenderness ratio, R_a, is computed from:

$$R_a = L/D \qquad \text{equation 2}$$

and is independent of the number of test items, N.

If the actual test item slenderness ratio, R_a, is greater than the required ratio, R_r, computed in equation 1, then :

$$X = 0.767\ L\ N^{1/2} \qquad \text{equation 3}$$

X = length of each side of the square test area

If the actual test item slenderness ratio, R_a, is less than the required ratio, R_r, computed in equation 1, then :

$$X = ND + 2S_W + (N-1)S_B \qquad \text{equation 4}$$

For values of N $\leq$ 3, the required slenderness ratio, R_r, is computed from equation 5 :

$$R_r = \frac{N\ L}{1.5L - 2S_W - (N-1)S_B} \qquad \text{equation 5}$$

If the actual test item slenderness ratio, R_a, is greater than the required ratio, R_r, computed in equation 5, then :

$$X \geq 1.5L \qquad \text{equation 6}$$

Otherwise :

X is computed from equation 3.

Generally, if the actual slenderness ratio, L/D, is greater than 4, equations 3 or 6 (depending upon the number of test items) are applicable.

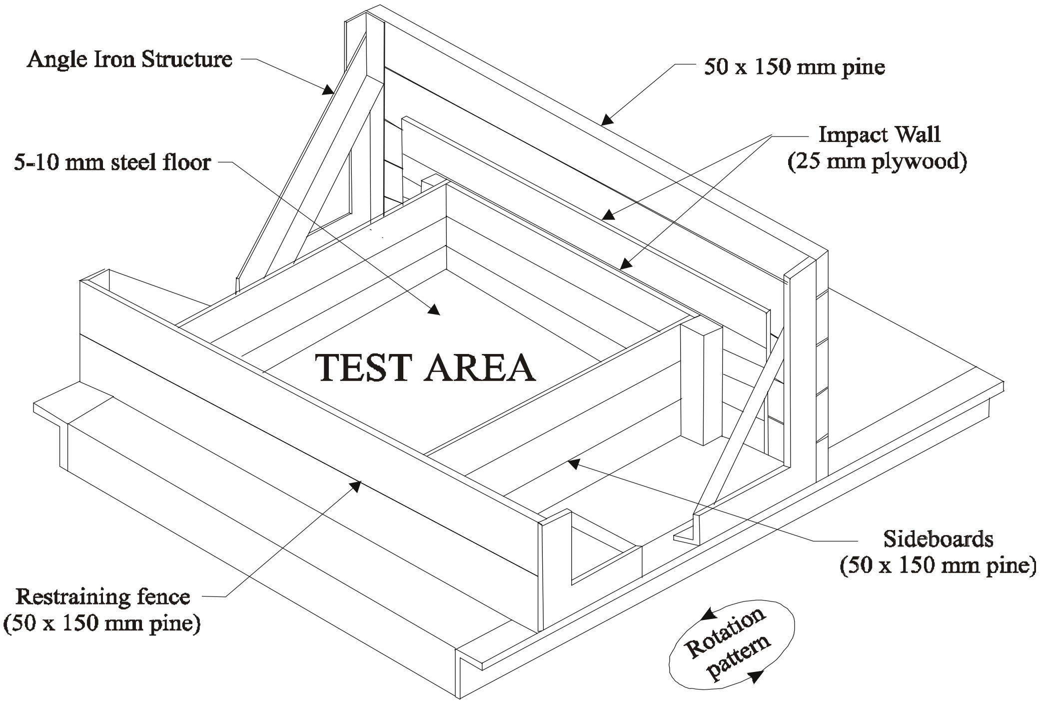

Figure B-1 Typical Package Tester

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ANNEX C

DERIVATION OF TEST AREA COMPUTATION EQUATIONS

Originally, the computation of the size of the test area for multiple (N > 3) circular cross section test items was computed from:

$$X = 0.767\ L\ N^{1/2} \qquad \text{equation 1}$$

X = length of each side of the square test area, cm

L = length of the test item, cm

N = number of test items

This was derived originally for testing slender items (e.g., rounds of ammunition) and is not applicable for items with a low slenderness ratio where the actual test item slenderness, R_a, is defined by:

$$R_a = L/D \qquad \text{equation 2}$$

R_a = actual test item slenderness ratio

L = length of the test item, cm

D = diameter of the test item, cm

The actual slenderness ratio is independent of the number of test items, N.

For any test item, the test area width may be defined as:

$$W = N\ D + 2S_w + (N-1)S_B \qquad \text{equation 3}$$

W = required width of square test area, cm

D = diameter of the test item, cm

N = number of test items

S_W = space between test item and wall, cm

S_B = space between each test item, cm

It is possible to compute a slenderness ratio required to determine if the test area is dependent upon the length or width of the test item by using the definition of R from equation 2 and calling this required value R_r.

$$R_r = L/D \qquad \text{equation 4}$$

Thus:

$$D = L/R_r \qquad \text{equation 5}$$

Substituting into equation 3:

$$W = (N\ L/R_r) + 2S_w + (N-1)S_B \qquad \text{equation 6}$$

Solving for R_r:

$$R_r = \frac{N\ L}{W - 2S_W - (N-1)S_B} \qquad \text{equation 7}$$

The diameter of the test item becomes the critical factor whenever the value W is equal to or greater than the value X. Since the value R_r is inversely proportional to W, it will reach a maximum value when W reaches a minimum value relative to X, or when W equals X. Combining equation 1 with equation 7:

$$R_r = \frac{N\ L}{0.767\,L\,N^{1/2} - 2S_W - (N-1)S_B} \qquad \text{equation 8}$$

If the test item has an actual slenderness ratio, R_a, greater than the required ratio, R_r, equation 1 is used to determine the test area. Otherwise, the test area is determined by equation 3.

The derivation can also be performed when the number of test items, N, $\leq$ 3. For this case, the original test area computation was based on:

$$X \geq 1.5\,L \qquad \text{equation 9}$$

The requirement for W may still be defined by equation 3. The critical value for R_r can be calculated by inserting the value of X from equation 9 as the value for W in equation 7. This yields:

$$R_r = \frac{N\ L}{1.5\,L - 2S_W - (N-1)S_B} \qquad \text{equation 10}$$

If the test item has an actual slenderness ratio, R_a, greater than the required ratio, R_r, equation 9 is used to determine the test area. Otherwise, the test area is determined by equation 3.

METHOD 407

MATERIEL TIEDOWN

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METHOD 407

MATERIEL TIEDOWN

1. SCOPE

1.1 Purpose

The purpose of this test method is to represent the loads incurred by materiel, including containers, during specified tiedown conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist, during tiedown, the specified loads without unacceptable degradation of its structural and/or functional performance. It is particularly applicable to materiel having integral attachments such handles, eye bolts and shackles.

1.3 Limitations

This test does not address materiel performance while it is tied down.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel and its tiedown arrangements are subjected to tiedown loads.

a. Failure of tiedown attachments.

b. Failure or displacement of materiel structural or load spreading elements.

c. Loosening of screws, rivets, etc.

2.2 Use of Measured Data

Where practical, in-service measured data should be acquired to tailor the materiel tiedown test. As a minimum the exposure duration and frequency information based on the LCEP are needed. In addition, information on specific load tiedown configurations, tiedown materials, and the restraint tension are needed.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel, they should be included in this test. Representative climatic data may be found in AECTP 200, Leaflet 2311 if measured data are not available.

2.4 Climatic Conditioning

This test should be conducted at the prevailing air temperature, unless it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature or humidity, then appropriate climatic conditions should be used.

3. SEVERITIES

This test should be performed in accordance with the severities of Annex A.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

The Test Instruction should include the following:

4.1 Compulsory

a. The identification of the test item
b. The definition of the test item
c. The gross weight of the test item
d. The type of test: development, qualification
e. The visual or other examinations required, and the phase of the test in which they are to be conducted
f. The definition of the failure criteria
g. The loading and environmental conditions at which testing is to be carried out
h. Tolerances

4.2 If Required

a. Any permitted deviations from this test method

5. TEST CONDITIONS AND PROCEDURES

5.1 Preparation for Test

5.1.1 Loading Devices

Each loading device used for these tests should have suitable safe working load carrying capacity.

5.1.2 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilized, whichever is the shorter period. (See AECTP 300, Method 301).

5.1.3Checks

Initial, during testing, and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedure

Unless otherwise specified in the Test Instruction, position the test item on a hard and level test surface and secure it sufficiently to prevent movement.

Apply the test load(s) in the direction(s) specified in the Test Instruction. The test load(s) should be applied statically to each attachment, one at a time. (If the test load(s) are derived from Annex A, the load(s) should be applied orthogonally, as indicated, to each attachment, one at a time).

Apply the load(s) for the time period specified.

6. EVALUATION OF TEST RESULTS

Unless otherwise specified in the Test Instruction the tiedown attachments are expected to survive the test without degradation and should be fit-for-purpose on completion of the test.

7. REFERENCES AND RELATED DOCUMENTS

a. MIL-STD 209J, Interface Standard for Lifting and Tiedown Provisions, USA Department of Defense, 28 Jan 1998

ANNEX A

MATERIEL TIEDOWN - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

DIRECTION	LOAD	MINIMUM TEST DURATION (Minutes)	CLIMATIC CONDITIONS
Forward/aft (Longitudinal axis of equipment)	$\frac{4 \text{ x MSW}^*}{\text{N}}$	5	Prevailing Site Conditions
Downward	$\frac{2 \text{ x MSW}}{\text{N}}$	5	
Lateral (in each direction)	$\frac{1.5 \text{ x MSW}}{\text{N}}$	5	

Notes

a. MSW = Maximum weight of item (including payload in the case of container test).
b. N = Number of attachments effectively resisting motion in that axis.
c. Table developed from MIL-STD-209

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METHOD 408

LARGE ASSEMBLY TRANSPORT

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METHOD 408

LARGE ASSEMBLY TRANSPORT

1. SCOPE

1.1 Purpose

The purpose of this method is to replicate the vibration and shock environment incurred by large assemblies of materiel installed or transported in wheeled or tracked vehicles. In this test method, the specified vehicle type is used to provide the mechanical excitation to the installed or transported assembly.

1.2 Application

This test is applicable to:

- Materiel comprising a large assembly,
- Materiel forming a high proportion of the vehicle gross mass,
- Materiel forming an integral part of the vehicle.

which is required to demonstrate its adequacy to resist the specified ground mobility conditions without unacceptable degradation of its functional and/or structural performance.

This test method is also applicable where a laboratory test such as Test Method 401 - Vibration, or Test Method 406 - Loose Cargo, may not be practical or cost effective.

AECTP 100 and 200 provide additional guidance on the selection of test procedure for ground mobility conditions.

1.3 Limitations

None specified.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to ground mobility conditions.

a. Wire chafing.
b. Loosening of fasteners.
c. Intermittent electrical contacts.
d. Mutual contact and short circuiting of electrical components.
e. Seal deformation.
f. Structural and component fatigue.

g. Optical misalignment.

h. Loosening of components.

i. Excessive electrical noise.

2.2 Use of Measured data

Where practical, measured field operational information should be used to tailor the test levels. Sufficient data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel in each LCEP phase. The measured data and information acquired should as a minimum be sufficient to account for the data variances due to the distribution of the transport platform condition and age, payload capacity and restraint system, operational personnel, and the environmental operating conditions.

2.3 Sequence

The test will comprise several parts involving different road surfaces, distances and vehicle speeds, and in some cases different vehicles. The order of application of each part should be considered and made compatible with the Life Cycle Environment Profile.

2.4 Test Facility

When setting up the test, consideration must be given to the test surfaces available at the particular test location selected to undertake the test. Also, the selection of the test surfaces and related test distances must be appropriate for the specified type of vehicles and their anticipated use.

2.5 Strapping Arrangements

During the test it is important to reproduce the more adverse arrangements that could arise in normal use. For example, during transportation excessive tightening of webbing straps could prevent movement of the test item(s) during the test and thereby limit the damaging effects; whereas relaxation of strap tension during service use could produce repeated shock conditions.

2.6 Large Assembly Installation

The test item should be installed in or on the vehicle in its design configuration. If the assembly is to be contained within a shelter, or if other units are attached to the materiel assembly in its in-service configuration, then these items should also be installed in their design configuration.

3. SEVERITIES

Military vehicles fall into the following broad groups:

a. Medium mobility wheeled land vehicles spending a high proportion of their life on normal paved roads.

b. High mobility wheeled land vehicles spending time on both roads and cross-country conditions.

c. Tracked vehicles.

Distances and speeds, together with any restrictions on weather conditions, shall be formulated for each vehicle type and shall cover all relevant surface types, such as smooth roads, rough roads and cross country.

All such selections and formulations for the test shall be agreed with the authority responsible for compliance with the environmental requirements.

A typical set of test conditions is given in Annex A.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the item(s) to be tested,

b. The type of test: development, qualification, etc,

c. If operating checks are to be performed and when,

d. The type(s) of vehicle(s) to be tested and the associated load state(s),

e. The test conditions for each vehicle and the associated tolerances for distance and vehicle speed,

f. The configuration of the materiel during the test,

g. The climatic conditions under which the test is to be conducted if other than ambient,

h. Other relevant data required to perform the test and operating checks,

i. A statement of the failure criteria.

4.2 If Required

None identified.

5. TEST CONDITIONS AND PROCEDURES

5.1 Installation Conditions of Test Item

The test item shall be mounted in or on the vehicle as stated in the Test Instruction.

5.2 Procedure

Examine the test item and carry out any required performance checks.

The vehicle containing the test item shall be subjected to the specified test conditions.

Any required performance checks shall be undertaken as specified.

Test item shall be examined as specified for any detrimental effects.

In all cases, record the information required.

6. EVALUATION OF TEST RESULTS

The performance of the test item shall meet all appropriate Test Instruction requirements during and following the application of the Large Assembly Transport test conditions.

7. REFERENCES AND RELATED DOCUMENTS

a. Test Operations Procedure (TOP) 1-1-011, Vehicle Test Facilities At Aberdeen Proving Ground, AD No. A103325, 6 July 1981

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ANNEX A

LARGE ASSEMBLY TRANSPORT - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Typical test courses for the Large Assembly Transport test are indicated below. The vehicle containing the installed test item shall be driven over the required test course(s) at the speed and total duration, or distance, defined in the Test Instruction. Ensure that the test duration on each test course and the vehicle operational speed are in accordance with the scenario(s) of the Life Cycle Environment Profile. If the LCEP in-service road information is not available, the specified default test severity may be used. Reference a provides a description of applicable test courses. If the test course speed tolerance is undefined in the Test Instruction, the typical course speed tolerance is +/- 10 % of the specified vehicle speed.

Default Test Severity - The default minimum test severity is defined by operation of the test vehicle over each of the five test courses below at the defined speed and total course distance. The vehicle speed(s) used for the tests will be as specified below unless the speed exceeds the safe driving conditions, in which case the maximum safe operating speed will be used with agreement from the test requesting organization. The total distance requirement can be completed with repetitive runs across a shorter distance of test course. However, the individual courses must be of a sufficient length to excite the full length of the vehicle and simulate a typical continuous road surface driving condition. Repetitive vehicle runs across an excessively short test course section is not acceptable. The total cumulative distance for all five courses is approximately 10 km (6 miles). Unless defined in the Test Instruction, a sequential order for testing on the different courses is not a requirement.

Test Course	Vehicle Speed MPH	(km/hr)	Course Length feet	(m)
Coarse Washboard (150 mm waves, 2 m apart)	5	(8)	3950	(1204)
Two Inch Washboard (50 mm)	10	(16)	4100	(1250)
Radial Washboard (50 mm to 100 mm waves)	15	(24)	1200	(366)
Three Inch Spaced Bump (75 mm)	20	(32)	3800	(1158)
Belgian Block	20	(32)	19700	(6005)

METHOD 409

MATERIEL LIFTING

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METHOD 409

MATERIEL LIFTING

1. SCOPE

1.1 Purpose

The purpose of this test method is to represent the loads incurred by materiel, including containers, during specified lifting conditions.

1.2 Application

This test is applicable when materiel is required to demonstrate its adequacy to resist the specified loads during lifting without unacceptable degradation of the structural and/or functional performance. The method is applicable to lifting attachments on materiel such as handles, eye-bolts and their attachments to the materiel, fork lift attachments, provision for grabs, as well as materiel which is not provided with any specific lifting device.

1.3 Limitations

This test method is not applicable to snatch loading conditions and is only applicable to individual items of materiel. When several items are to be handled as a single load, the Test Instruction must state the test requirements.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel and its lifting arrangements are subjected to lifting loads.

a. Failure of lifting attachments.
b. Failure or displacement of local structural or load spreading elements.
c. Loosening of screws, rivets, etc.
d. Unsecure furniture and fittings.
e. Deterioration of climatic protection.
f. Damage to protective coatings.

2.2 Use of Measured Data

Where practical in-service measured data should be acquired to tailor the materiel lifting test. As a minimum the exposure duration and frequency information based on the LCEP are needed. In addition information on specific load lifting configurations, lift materials or equipment, and lift height should be obtained.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel they should be included in this test. Representative climatic data may be found in AECTP 200, Leaflet 2311 if measured data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions during the test.

2.5 Choice of Test Procedures

The choice of test procedures is governed by the configuration of the materiel lifting arrangements. Five procedures are presented as follows:-

Procedure I	Materiel Fitted with Handles
Procedure II	Materiel Fitted with Lifting Attachments
Procedure III	Materiel Fitted with Forklift Facilities
Procedure IV	Materiel Provided for the Use of Grabs
Procedure V	Materiel with no Lifting Devices

3. SEVERITIES

This test should be performed in accordance with the severities of Annex A which presents values that have been derived based on common equipment information. When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature or humidity, appropriate climatic conditions should be used.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item,

b. The definition of the test item,

c. The gross weight of the test item,

d. The type of test: development, qualification,

e. The visual or other examinations required, and the phase of the test in which they are to be conducted,

f. The definition of the failure criteria,

g. The loading of environmental conditions at which testing is to be carried out,

h. The test tolerances.

4.2 If Required

a. Any permitted deviations from this test method.

5. TEST CONDITIONS AND PROCEDURES

5.1 Preparation for Test

5.1.1 Lifting Devices

Each lifting device used for these tests should have suitable safe working load carrying capacity.

5.1.2 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shorter period. See AECTP 300, Method 301.

5.1.3 Initial, During test, and Final Checks

Checks are to be conducted as specified in the Test Instruction.

5.2 Procedures

5.2.1 Procedure I - Materiel Fitted with Handles

Step 1 Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2 Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3 Sequentially lift the test item and freely suspend it from each handle for the period specified in the Test Instruction. Return the item to rest between each lift. If testing outside a climatic conditioned environment, re-stabilise the test item at the required climatic conditions between lifts.

5.2.2 Procedure II - Materiel Fitted with Lifting Attachments

Step 1 Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2 Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3 Sequentially lift the test item and fully suspend it from each lifting attachment for the period specified in the Test Instruction. Return the item to rest between each lift. If testing outside a climatic conditioned environment, re-stabilise the test item at the required climatic conditions between lifts.

Step 4 Lift the test item and load using slings attached to the lifting points and maintain the freely suspended test item in this position for the period specified in the Test Instruction. The angles between the legs of a two legged sling and the diagonal opposite legs of a four legged sling should not be more than 90 degrees and not less than 60 degrees. The test load shall not interfere with the attachment and alignment of the slings.

5.2.3 Procedure III - Materiel Fitted with Fork Lifting Facilities

Step 1 Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2 Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3 Lift the test item clear of the ground using a fork lift truck with the forks extended to at least two thirds of the underside dimensions of the base of the specimen across which the forks are carrying out the lift. Maintain this position for the period specified in the Test Instruction. Return the item to rest on the floor.

5.2.4 Procedure IV - Materiel Providing for the Use of Grabs

Step 1 Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.

Step 2 Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.

Step 3 Lift the test item with grabs applied at the designated grab points and suspend the test item clear of the ground for the period specified in the Test Instruction. Return the item to rest on the floor.

5.2.5 Procedure V - Materiel with No Lifting Devices

Step 1	Unless otherwise specified in the Test Instruction position the pre-conditioned test item on a hard and level test surface.
Step 2	Apply the test load as specified in the Test Instruction. The test load should be distributed to maintain the normal centre of gravity as far as possible.
Step 3	Lift the test item by two slings positioned at approximately one sixth of the length of the container from each end and held clear of the ground for the period stipulated in the Test Instruction. The angle between the diagonally opposite legs of the slings should not be more than 90 degrees and not less than 60 degrees. Return the item to rest on the floor.

6. EVALUATION OF TEST RESULTS

The test item performance should meet all appropriate Test Instruction requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction lifting arrangements are expected to survive the test without degradation and the materiel should remain safe and fit-for-purpose on completion of the test.

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ANNEX A

MATERIEL LIFTING - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

The default test severity for Materiel Lifting tests is defined in Table A-1.

TABLE A-1 - Materiel Lifting Load Factors and Duration

Test Procedure	Load Factor	Test Duration, minutes	Climatic Condition
I – Materiel Fitted with Handles	3	5	Prevailing Test Site Conditions
II - Materiel Fitted with Lifting Attachments	2	5	
III – Materiel Fitted with Fork Lifting Facilities	1.25	5	
IV – Materiel Providing for the Use of Grabs	2	5	
V – Materiel with No Lifting Devices	3	5	

Notes :

a. The test load is the gross weight of the materiel (materiel weight plus the weight of the contents in the case of a container test) multiplied by the load factor.

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METHOD 410

MATERIEL STACKING

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METHOD 410

MATERIEL STACKING

1. SCOPE

1.1 Purpose

The purpose of this test method is to represent the compression loads incurred by materiel, including containers, during specified stacking conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified compression loads during stacking without unacceptable degradation of the structural and/or functional performance. The method is applicable to materiel structural elements that may be subjected to the compressive loads applied to materiel on the bottom of a stack of identical materiel. It is also applicable to materiel that may be subjected to side compression loads that are applied while materiel is being lifted by a net.

1.3 Limitations

This test is not applicable for the simulation of rapidly applied loads that may occur during drop conditions that could arise during the handling and stacking of materiel.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is subjected to compressive loads arising from stacking.

a. Failure or displacement of local structural or load spreading elements.

b. Loosening of screws, rivets, fastenings, etc.

c. Unsecured furniture and fittings.

d. Deterioration of climatic protection.

e. Damage to protective coatings.

Some types of materiel can, over prolonged periods, buckle or partially collapse when stored in conditions of high relative humidity, or when wet from exposure to the weather.

2.2 Use of Measured Data

Where practical in-service measured data should be acquired to tailor the materiel stacking test. As a minimum the exposure duration and frequency information based on the LCEP are needed. In addition information on specific stacking configuration(s), stacking materials or equipment, and height should be obtained.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on materiel, they should be included in this test. Representative climatic data may be found in AECTP 200, Leaflet 2311 if measured data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions during the test.

2.5 Load Distribution

Where it is important to simulate the load distribution at the interface between the materiel bottom and the next lower height materiel, a minimum of two test items should be used for the test.

Where materiel is stacked as palletized loads so that the lowest height materiel is supported by a pallet, this pallet may need to be included in the test, or the effect simulated.

Where uneven compressive loads could arise from stacking materiel on uneven surfaces during shipping, these conditions should be simulated in the test.

When staggered stacking could arise during in-service conditions, such arrangements should be simulated in the test.

Where materiel can be expected to be stacked in more than one orientation, all materiel sides relevant to these orientations should be subjected to this stacking test.

3. SEVERITIES

This test should be normally performed in accordance with the severities of Annex A . When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature or humidity, appropriate climatic conditions should be used.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item,
b. The definition of the test item,
c. The gross weight of the test item,
d. The type of test: development, qualification,

e. The visual or other examinations required, and the phase of the test in which they are to be conducted,

f. The loading and environmental conditions at which testing is to be carried out and the associated durations,

g. The test item faces to which the test is to be applied,

h. The definition of the failure criteria,

i. Test tolerances.

4.2 If Required

a. The test surface, if other than a hard level surface,

b. The load distributions, if adverse conditions need to be tested,

c. Any permitted deviations from this test method.

5. TEST CONDITIONS AND PROCEDURES

5.1 Preparation for Test

5.1.1 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shortest period See AECTP 300, Method 301.

5.1.2 Checks

Initial, during testing, and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedures

5.2.1 Procedure I - Vertical Loading (Simulating Stacking Loadings)

Step 1	Unless otherwise specified in the Test Instruction, position the pre-conditioned test item on a hard and level test surface.
Step 2	Conduct the appropriate compression test on the uppermost surface of the test item using the load and duration specified in the Test Instruction.
Step 3	If testing outside a climatic conditioned environment, re-stabilise the test item at the required climatic conditions.
Step 4	Repeat the test of Step 2 for the next appropriate test item orientation.
Step 5	Repeat Steps 3 and 4 for all remaining orientations.

5.2.2 Procedure II -Side or End Loading (Simulating Net Loadings)

Step 1 This test procedure is not applicable for materiel that has a gross mass of 120kg or more, or a volume of 0.28m^3 or more.

Step 2 Unless otherwise specified in the Test Instruction, position the pre-conditioned test item on a hard and level test surface.

Step 3 Subject the side or end faces of the test item to the test load and test duration specified in the Test Instruction. A suitable horizontal loading device should be used if the test item is sensitive to equipment orientation or to gravitational effects.

6. EVALUATION OF TEST RESULTS

The test item performance should meet all appropriate Test Instruction requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction the materiel is expected to survive the test without degradation, and the materiel should remain safe and fit-for-purpose on completion of the test.

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ANNEX A

MATERIEL STACKING - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Unless defined in the Test Instruction, the default test severity for the Materiel Stacking tests is defined below.

Load

A static load should be applied that will produce an equivalent condition on the materiel equal to the number of similar materiel items stacked to a total height not exceeding 2 m (6.6 ft), for containers up to 15 kg (33 lb) gross weight each, or 6 m (19.7 ft) for materiel over 15 kg (33 lb) gross weight each.

Duration

The load should be applied for a period of 8 days.

Climatic Conditions

Prevailing test site conditions.

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METHOD 411

MATERIEL BENDING

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METHOD 411

MATERIEL BENDING

1. SCOPE

1.1 Purpose

The purpose of this test is to represent the bending loads incurred by materiel, including containers, during specified transit conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified bending loads during transit without unacceptable degradation of it's structural and/or functional performance. The method is applicable to materiel structural elements that may be subjected to the bending loads caused by it's own mass and/or by top loading with other materiel of different mass and proportions.

1.3 Limitations

The use of this test is normally limited only to materiel whose length exceeds four times the smallest cross sectional dimension.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive, but provides examples of problems that could occur when materiel is subjected to bending loads. Some types of materiel, over prolonged periods, can buckle or partially collapse when stored in conditions of high relative humidity, or when wet due to weather exposure.

a. Failure or displacement of structural elements.
b. Loosening of screws, rivets, fastenings, etc.
c. Unsecured furniture and fittings.
d. Deterioration of climatic protection.
e. Damage to protective coatings.

2.2 Use of Measured Data

Where practical, in-service measured data should be acquired to tailor the materiel bending test. As a minimum the exposure duration and frequency information based on the LCEP are needed. In addition, information on specific bending configuration(s), point loads, and storage or handling should be obtained.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel, they should be included in this test. Representative climatic data may be found in AECTP 200, Leaflet 2311 if measured climatic data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible and the room ambient conditions recorded. Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions during the test.

2.5 Load Distribution

Where the materiel normally rests on supports and/or is positioned in a particular orientation during transit, these conditions should be simulated in the test.

The test item should be supported at each end, and a static load applied over a centre span area of the test item. The centre span area shall extend the full transverse width of the test item and the area shall be equal to the cross sectional area of the test item. Each end of the test item should be supported over an area equal to half the cross sectional area of the test item.

For a materiel item in a long rectangular box, with a rectangular cross section, and dimensions of Length x Width x Height (L x W x H) the centre span area is W x H. The end support area shall each be one half the W x H area.

3. SEVERITIES

This test should be normally performed in accordance with the severities of Annex A. When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature, appropriate climatic conditions should be used.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

The Test Instruction should include the following:

4.1 Compulsory

a. The identification of the test item,

b. The definition of the test item,

c. The gross weight of the test item,

d. The type of test: development, qualification,

e. The visual or other examinations required, and the phase of the test in which they are to be conducted,

f. The loading and environmental conditions at which testing is to be carried out and the associated durations,

g. The test item faces to which the test is to be applied,

h. The definition of the failure criteria,

i. The test tolerances.

4.2 If Required

a. The test support, if other than hard and level supports,

b. The load distributions, if adverse conditions need to be tested,

c. Any permitted deviations from this test method.

5. TEST CONDITIONS AND PROCEDURES

5.1 Preparation for Test

5.1.1 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shorter period. See AECTP 300, Method 301.

5.1.2 Checks

Initial, during testing, and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedure

Unless otherwise specified in the Test Instruction, position the pre-conditioned test item on end supports or the in-service condition, placed on a hard and level test surface. The geometry of the supports is defined in paragraph 2.5.

Apply the test load, distributed as described in paragraph 2.5, to the upper surface of the test item using the load and duration specified in the Test Instruction.

If testing outside the climatic conditioning facility, re-stabilise the test item at the required temperature.

Repeat the test of Step 2 for the next appropriate test item orientation.

Repeat Steps 3 and 4 for all remaining orientations.

6. EVALUATION OF TEST RESULTS

The test item performance should meet all appropriate Test Instruction requirements during and following the application of the test loading and environmental conditions. Unless otherwise specified in the Test Instruction the materiel structure is expected to survive the test without degradation and the materiel should remain safe and fit-for-purpose on completion of the test.

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ANNEX A

MATERIEL BENDING - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Unless defined in the Test Instruction, the default test severity for the Materiel Bending test is defined below.

Load

A static load of three times the gross weight of the materiel should be applied over the centre span of the materiel; see paragraph 2.5 for the load distribution.

Duration

The load should be applied for a period of not less than five minutes.

Climatic Conditions

Prevailing test site conditions.

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METHOD 412

MATERIEL RACKING

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METHOD 412

MATERIEL RACKING

1. SCOPE

1.1 Purpose

The purpose of this test method is to represent the existing loads incurred by materiel, including containers, during specified racking conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified twisting loads during racking without unacceptable degradation of its structural and/or functional performance.

1.3 Limitations

The use of this test is normally limited only to materiel in excess of 225 kg (496 lb) gross weight

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive, but provides examples of problems that could occur when materiel is subjected to twisting loads arising from racking. Some types of materiel, over prolonged periods, can buckle or partially collapse when stored in conditions of high relative humidity, or when wet due to weather exposure.

a. Failure or displacement of structural elements.
b. Loosening of screws, rivets, fastenings, etc.
c. Unsecured furniture and fittings.
d. Deterioration of climatic protection.
e. Damage to protective coatings.

2.2 Use of Measured Data

Where practical, in-service measured data should be acquired to tailor the materiel racking test. As a minimum the exposure duration and frequency information based on the LCEP are needed. In addition, information on specific racking configuration(s), material handling procedures, and a potential lift height should be obtained.

2.3 Sequence

The order of application of this test should be compatible with the Life Cycle Environmental Profile. When combined environments are identified and considered to have a potential effect on the materiel they should be included in this test. Representative climatic data may be found in AECTP 200, Leaflet 2311 if measured climatic data are not available.

2.4 Climatic Conditioning

This test should, wherever practical, be conducted in a chamber with the test item stabilised at the required climatic conditions. If size limitations or safety hazards prevent this, the stabilised test item should be removed from the chamber, the test conducted as quickly as possible, and the room ambient conditions recorded. . Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions during the test.

2.5 Load Distribution

Where the materiel normally rests on supports and/or is positioned in a particular orientation during transit, these conditions should be simulated in the test.

3. SEVERITIES

This test should be normally performed in accordance with the severities of Annex A. When it is known that materials used in the construction of the materiel are sensitive to wide ranges of temperature, appropriate climatic conditions should be used.

4. INFORMATION TO BE SPECIFIED IN THE TEST INSTRUCTIONS

4.1 Compulsory

a. The identification of the test item,
b. The definition of the test item,
c. The gross weight of the test item,
d. The type of test: development, qualification,
e. The visual or other examinations required, and the phase of the test in which they are to be conducted,
f. The loading and environmental conditions at which testing is to be carried out and the associated durations,
g. The face on which the test is to be carried out if there is no designated test item base,
h. The definition of the failure criteria,
i. The test tolerances.

4.2 If Required

a. The test supports, if other than hard and level supports;

b. The load distributions, if adverse conditions need to be tested;

c. Any permitted deviations from this test method.

5. TEST CONDITIONS AND PROCEDURES

5.1 Preparation for Test

5.1.1 Climatic Conditioning

If climatic conditioning is required, the test item should be conditioned to the required conditions for 16 hours, or until the temperature of the test item has stabilised, whichever is the shorter period. See AECTP 300, Method 301.

5.1.2 Checks

Initial, during testing, and final checks are to be conducted as specified in the Test Instruction.

5.2 Procedure

Step 1	Unless otherwise specified in the Test Instruction, position the pre-conditioned test item on a hard and level test surface.
Step 2	Apply the test load specified in the Test Instruction in accordance with the loading conditions defined in Annex A.
Step 3	If testing outside the temperature conditioning facility, re-stabilise the test item at the required temperature.
Step 4.	Repeat the test of step 2 for the next appropriate test item orientation.
Step 5.	Repeat steps 3 and 4 for all remaining orientations.

6. EVALUATION OF TEST RESULTS

The test item performance should meet all appropriate Test Instruction requirements during and following the application of the test loading and environmental conditions.

Unless otherwise specified in the Test Instruction, the test item structure is expected to survive the test without degradation and the materiel should remain safe and fit-for-purpose on completion of the test.

ANNEX A

MATERIEL RACKING - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Unless defined in the Test Instruction, the default test severity for the Materiel Racking test is defined below.

Loading Conditions and Duration

With the test item standing upon its face on a hard, level surface, a base corner shall be lifted and supported at a height of 300 mm (12 inches) for a period of not less than 5 minutes.

The test item shall then be lowered and the operation repeated on the diagonally opposite corner.

The two remaining corners shall then be similarly treated.

Climatic Conditions

Prevailing test site conditions.

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METHOD 413

ACOUSTIC NOISE COMBINED WITH TEMPERATURE AND VIBRATION

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ANNEX A DERIVATION OF TEST PARAMETERS

ANNEX B TEST FACILTY REQUIREMENTS

METHOD 413

ACOUSTIC NOISE COMBINED WITH TEMPERATURE AND VIBRATION

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the environment induced in the internal equipment, hereafter called materiel, of stores and missiles when carried externally on high performance aircraft during the specified operational conditions.

To achieve an accurate simulation, this test method combines acoustic noise excitation with mechanical vibration and conditioned airflow to produce the required mechanical and thermal responses in the internal units of the test item. The test method is also capable of reproducing the changes in the vibration and temperature responses that arise during specific aircraft mission profiles.

1.2 Application

This test is applicable where materiel is required to demonstrate its adequacy to resist the specified environment without unacceptable degradation of its functional and/or structural performance.

The principles of this test method may also be applicable to the simulation of other vibration environments, such as those induced during missile flight conditions.

AECTP 100 and 200 provide additional guidance on the selection of a test procedure for a specific environment.

1.3 Limitations

Where this test is used for the simulation of aerodynamic turbulence, it is not necessarily suitable for proving thin shell structures interfacing directly with the acoustic noise.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive, but provides examples of problems that could occur when materiel is exposed to this combined environment.

a. Wire chafing
b. Component fatigue
c. Component connecting wire fracture
d. Cracking of printed circuit boards

e. Failure of waveguide components

f. High cycle fatigue failure of small panel areas

g. High cycle fatigue failure of small structural elements

h. Optical misalignment

i. Loosening of small particles that may become lodged in circuits and mechanisms

j. Excessive electrical noise

2.2 Use of Measured Data

Where practical, field data should be used to develop test levels. It is particularly important to use field data where a precise simulation is the goal. The parameters and profiles are influenced by store type, aircraft installation, aircraft performance and mission conditions. Profile derivation information is given in Annex A. When measured flight data are not available, sufficient information is presented in Annex A to determine test profiles and levels.

2.3 Sequence

This test is designed for the simulation of the primary environmental effects that are induced in complete assembled stores during external carriage on fixed wing aircraft. However, should a test item need to be exposed to any additional environmental tests, then the order of application of the tests should be compatible with the Life Cycle Environmental Profile.

2.4 Rationale for Procedure and Parameters

2.4.1 Test Rationale

In particular this test is designed to reproduce the main responses measured in flight at the internal units of complete assembled stores, and to provide a realistic simulation of relevant flight mission conditions through the use of acoustic noise, vibration, and temperature conditioning.

The test equipment configuration for this test method is shown in Figure 1. Acoustic noise is applied using the acoustic field of a reverberation chamber, while low frequency excitation of the store will be induced by a mechanical vibration exciter. This broadly represents the operational environment in that low frequency excitation, below about 100 Hertz, normally results from mechanical input through the attachment points. At higher frequencies the major in-service excitation source results from aerodynamic flow over the exterior skin surface of the store, and is simulated in the test method by the acoustic noise field. A more detailed description of the facility requirements is given in Annex B

2.4.2 Test Parameters

All environmental parameters are controlled from the responses of the test item. Thus the vibration and acoustic noise excitation should be controlled to give the required internal unit vibration responses. Temperature control should normally be achieved at an external thin skin section since time constants and power dissipation during power on periods will significantly affect the internal component temperatures.

Therefore, the parameters required to fully define the test conditions are:

a. The temperature profile in terms of constant temperatures, rates of temperature change during transition periods, and the time duration for each element of the mission.

b. The vibration response in terms of spectrum, rms acceleration level, and location(s), and the time duration for each element of the mission.

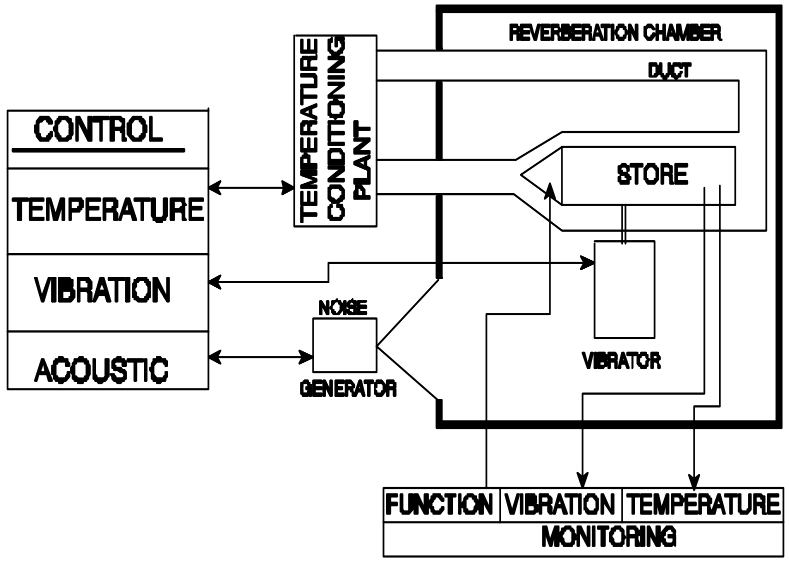

Figure 1 Typical Test Facility Layout

2.4.3 Precursor Trials

Control of the test conditions is derived from store responses. Therefore, a representative store should be made available for precursor trials in order to establish the required excitation conditions. It may be necessary to control the vibration response of the store from external locations such as at strong points of the structure. In this case it is required that the external control characteristics be established after setting up the reference condition at the internal location(s). The precursor trial should be carried out in accordance with paragraph 5.6.1.

2.5 Materiel Operation

When specified, during in-service simulations, the test item should be functioning and its performance should be measured and recorded.

3. SEVERITIES

Test levels and durations should be established using data acquired directly from the project environmental data acquisition programme, from the International Standard Atmosphere (ISA) tables or equivalent, other appropriate flight measured data, or critical design conditions derived from projected Life Cycle Environmental Profiles. These test profiles should be derived in accordance with the procedure given in Annex A.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item.

b. The definition of the test item.

c. The type of test: development, reliability, etc.

d. The times at which the test item is to be operating during the test.

e. The operating checks required: initial, during the test final.

f. The details required to perform the test including the method of installation of the test item.

g. The monitor and control points or a procedure to select these points.

h. The indication of the failure criteria.

i. The initial climatic conditions, from AECTP 300 or from measured data

j. The initial climatic conditions as derived from AECTP 300 or from measured data.

4.2 If Required

a. The effect of gravity and the consequent precautions.

b. The tolerances, if different from paragraph 5.1

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

Tolerances should be specified for all relevant vibration, acoustic, temperature, and duration control parameters. If tolerances are not met, the difference observed shall be noted in the test report.

5.1.1 Vibration

For wideband random elements of the test, the tolerances should be in accordance with those in Method 401 Vibration.

5.1.2 Acoustic

For reverberant acoustic field elements of the test, tolerances should be in accordance with those in Method 402 Acoustic Noise.

5.1.3 Temperature

For non-transitional temperature elements of the test, the tolerances should be in accordance with those in Method 301. For temperature transitions, the tolerances should be defined in the Test Instructions.

5.1.4 Duration

The test duration shall be within +/- 2 % or one minute of the specified requirement, whichever is the lesser.

5.2 Control

The environmental parameters required to control the test conditions are stated in paragraph 2.4.2. The derivation of these parameters is given in Annex A.

5.3 Installation Conditions

The installation conditions are included in paragraph 5.6 and supported by further detail in Annex B.

5.4 Effects of Gravity

If the performance of the materiel is affected by gravitational effects, then the in-service mounting orientation should be used during the tests.

5.5 Preparation for Test

5.5.1 Pre-conditioning

Unless otherwise specified, the test item should be stabilized to the initial conditions stipulated in the Test Instruction. See also AECTP 300, Method 301.

5.5.2 Inspection and Performance Checks

Inspection may be carried out before and after testing. The requirements of these inspections should be defined in the Test Instruction. If these checks are required during the test sequence, then the time intervals at which the inspections are required should also be specified.

5.6 Procedures

5.6.1 Precursor Test

A precursor trial shall be carried out on a representative test item, as follows, in order to establish the control parameters:

Step 1	Use AECTP 300 as appropriate. This will determine the response temperature of the test item to be used at the initiation of this test.
Step 2	Install instrumentation on or in the representative test item similar to measurement trials used to establish the service environment.
Step 3	Install the representative test item in the reverberation chamber, as detailed in paragraph 5.6.2, Steps 1, 2., and 4.
Step 4	In the event that internal access within the representative item is not possible, externally instrument the representative item as specified in the Test Instruction. The spectral data from these external locations may need to be used as a basis for vibration control for the actual operational test item.
Step 5	Apply acoustic noise with mechanical vibration, to fill in the low frequency excitation, until the required vibration spectra are obtained at the internal instrumentation locations.
Step 6	Record the acoustic sound pressure levels and vibration spectra necessary to achieve the required internal vibration responses.
Step 7	In all cases, record and analyse the data as specified.
Step 8	Remove the representative item from the chamber.

5.6.2 Operational Test

The test item shall be subjected to the following procedure:

Step 1	Install the test item in the chamber using the in-service attachment points as specified in the Test Instruction.
Step 2	Arrange connections to the test item, such as cables, hoses, etc., so that they impose similar dynamic restraint and mass to the test item as when the materiel is mounted in the in-service condition.
Step 3	Install accelerometers and temperature sensors on the test item at the specified locations.

Step 4 Install the temperature duct over the test item and ensure that a uniform gap is provided, and that connections to the test item do not unduly obstruct this gap. The duct should not provide any additional restraint to the test item.

Step 5 Connect the temperature conditioning duct to the supply duct.

Step 6 Close the chamber, initiate the temperature conditioning system, and stabilise the test item at the required temperature.

Step 7 Perform the test using the parameters determined in paragraph 5.6.1, Step 5 and with the required temperature profiles as specified in the Test Instruction.

Step 8 Record all the information as specified in the Test Instruction

Step 9 Remove the test item from the chamber and perform the post test inspections stipulated in the Test Instruction.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of the test conditions.

7. REFERENCES AND RELATED DOCUMENTS

a. IEST RP-DTE040.1, High-Intensity Acoustics Testing, Institute of Environmental Sciences and Technology, USA, January 2003

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ANNEX A

DERIVATION OF TEST PARAMETERS

1. SCOPE

1.1 This annex defines procedures by which acoustic, vibration, and thermal test cycle severities can be established. The main application of the procedure is to derive test severities and test cycles for testing of stores, missiles and other airborne weapons. The procedure may also be applicable to aircraft materiel provided the environments of prime concern are vibration or kinetic heating induced by aerodynamic flow. The severities derived using this annex procedure could also be adopted for mechanical vibration, Method 401, when combined with thermal testing.

2. DATA REQUIREMENTS

2.1 The data required to determine vibration and thermal test cycle severities are the installation details for the aircraft platform, the sortie profiles, the number of each type of sortie, and information on altitude or temperature conditions.

2.2 The sortie profiles need to be defined in terms of airspeed, altitude and time. Illustrative profiles are shown in Figure A-1. Representative sortie profiles are frequently set out in the technical requirements specification for stores, missiles, and other airborne weapons. Another source of

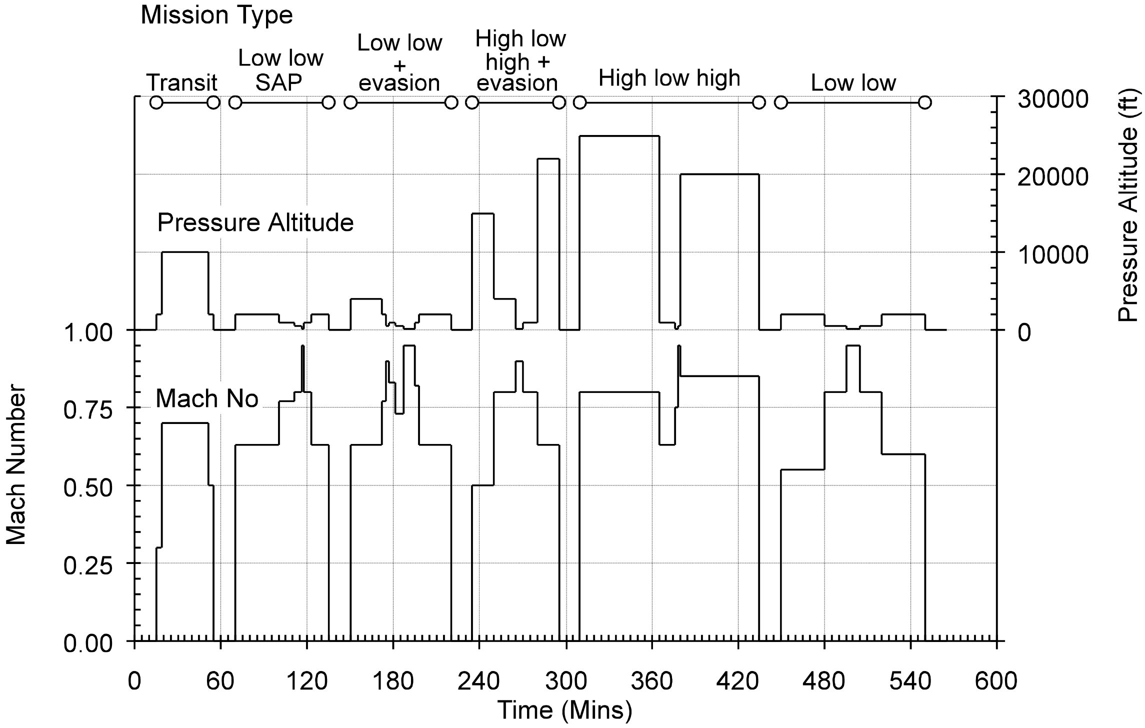

Figure A-1 Flight Profiles for Six Illustrative Missions

suitable information is the aircraft manufacturer. Additionally, a number of representative sortie profiles suitable for reliability testing are defined in MIL-HDBK 781, reference a. Whatever the source conditions, they should not exceed the capability of the carriage aircraft with the required weapons configuration.

Table A-1 Illustrative Store Use

Flight Manoeuvre	Number of missions per year	Duration of longest mission, minutes	Duration of shortest mission, minutes	Average mission duration, minutes	Percentage of total missions, %	Percentage of total duration, %
High level transit	1	40	40	40	3	2
Low level ground attack following standing air patrol	7	85	65	74	19	18
Low ground attack with evasion	7	85	60	69	19	17
Low ground attack	8	100	60	74	21	21
High low high strike with evasion	4	100	60	84	11	12
High low high strike	10	125	45	83	27	30

2.3 The proportion of each type of sortie within the operational life of the materiel must be established in order that this distribution can be reflected in the test conditions. Illustrative store use is presented in Table A-1. This information has been derived from UK data supplied by RAF Logistics Command. Such information is normally included in the technical requirements specification for stores, missiles, and other airborne weapons.

2.4 Information on nominal altitude-temperature conditions can be obtained from International Standard Atmosphere (ISA) tables. For extreme altitude-temperature conditions, reference should be made to AECTP 200, Leaflet 2311. This leaflet also indicates the range of sea level temperature conditions likely to be experienced in world-wide weapon deployment.

3. TEMPERATURE PROFILE

3.1 For each phase of the sortie profile, the altitude condition will enable the ambient temperature to be determined. Using the aircraft speed at each altitude, it is possible to calculate the skin recovery temperature from the following expressions:

$$Tr = Ta\left[1+\frac{r(\gamma-1)M^2}{2}\right]$$

Where :

T_r = adiabatic thin skin temperature, degrees K or R
T_a = ambient air temperature as a function of altitude, degrees K or R
r = Recovery factor
γ = Ratio of specific heats, 1.4 for air, standard conditions
M = Mach number

In the absence of other information, a recovery factor of 0.9 can usually be assumed. This reduces the above expression to :

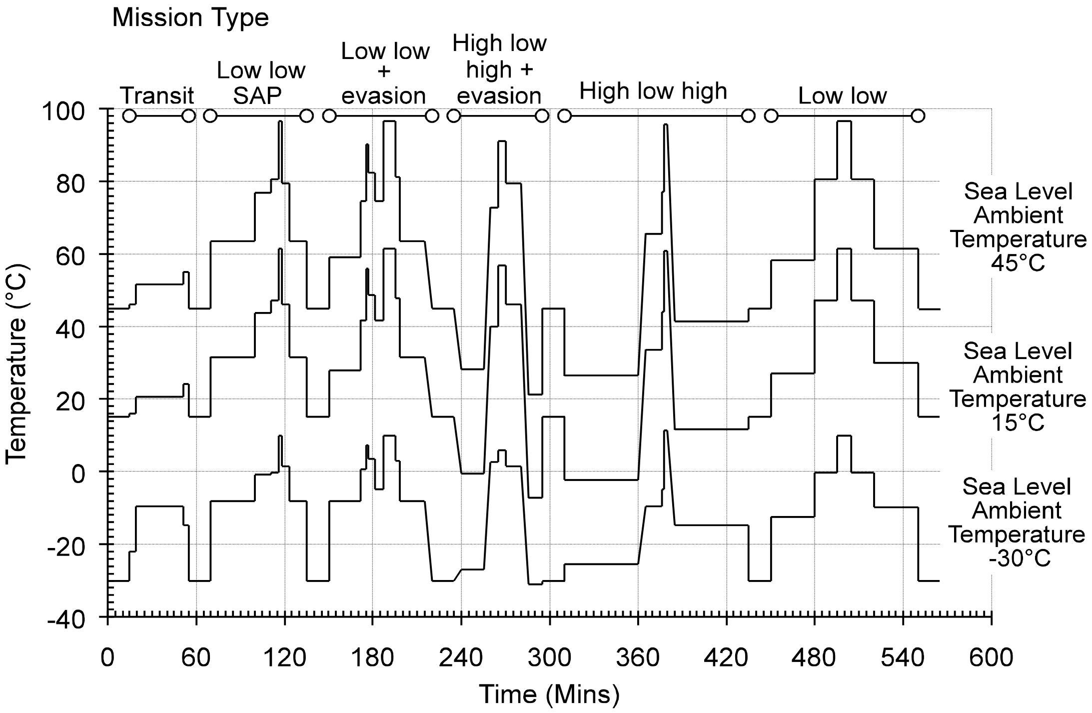

Figure A-2 Temperature Profiles for Six Illustrative Mission Types

$$T_r = T_a (1 + 0.18 M^2)$$

3.2 Having established the temperature condition for each phase of the sortie, it is possible to plot the temperature profile of the materiel skin for the complete sortie. Temperature profiles for six illustrative sorties are shown in Figure A-2. Since small variations in skin temperature may not be directly reflected in internal component temperatures, it is possible to combine temperature conditions to produce a composite temperature sortie that will include both stable temperature conditions and associated rates of change of temperature at each stage.

3.3 Where it is required to cover world-wide operating conditions, the temperature cycle can be enhanced by the introduction of cycle deviations to represent various sea level temperatures as shown in Figure A-2.

3.4 To maintain representative conditions, particularly for reliability testing purposes, the basic temperature cycle will normally not comprise only the extreme positive and negative sea level temperatures. The probability of operation away from sea level ambient temperature should be established to determine the number of cycles at each condition. Cycles based on hot and cold level temperatures should be interspersed with the ambient cycles such that each condition is evenly distributed over the life cycle of the store.

4. VIBRATION PROFILE

4.1 For each phase of the sortie profile, the aircraft pressure, altitude, and airspeed can be used to proportion flight vibration data into an appropriate profile. The vibration severities generated are intended to represent store responses occurring in flight. For the purpose of the laboratory test, combined acoustic and mechanical excitations are used to generate the required vibration response profile. The exact proportion of acoustic and mechanical excitations required will depend upon the facilities available.

4.2 The vibration severities experienced by a store vary throughout a sortie with changes in flight dynamic pressure, which may follow the profiles of Figure A-3, for example. Vibration severities are also dependent upon a number of non-sortie dependent criteria such as store geometry and construction, measurement location, and axis. Hence, appropriate flight measured vibration data are required for the store when subjected to specific flight conditions. The measured severities can then be scaled according to the sortie profiles required for test purposes, such as those shown in Figure A-4. Figure A-5 shows a typical vibration spectrum that may be established from the illustrative vibration data.

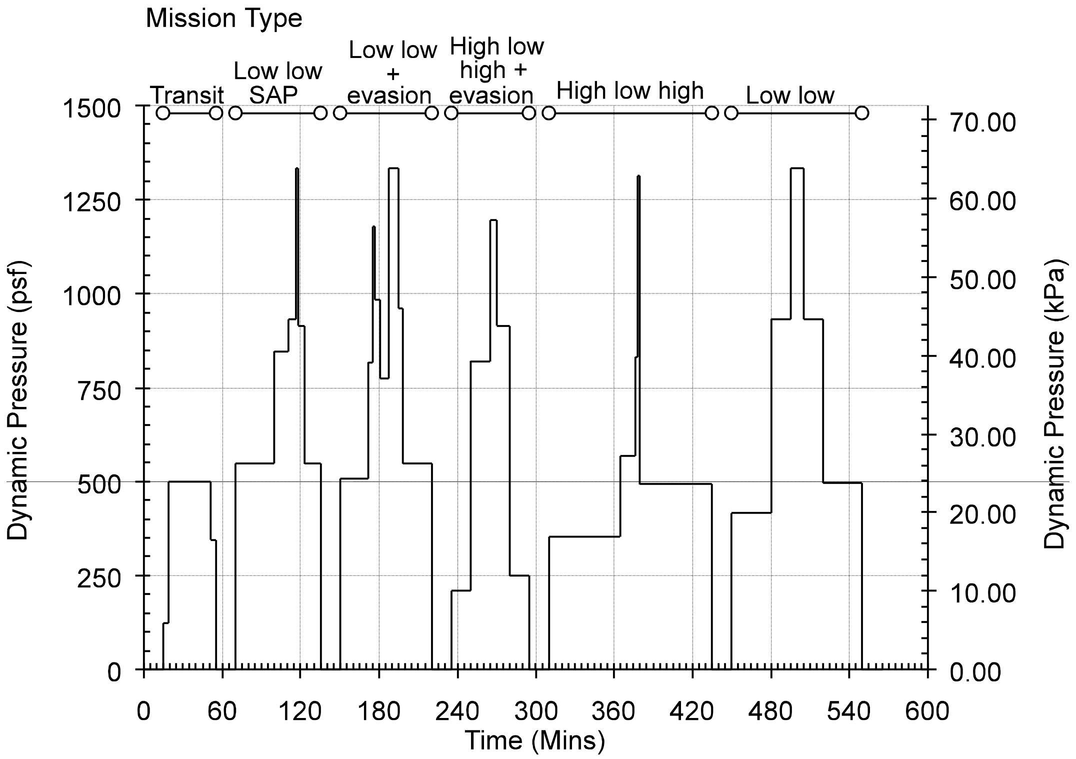

Figure A-3 Equivalent Free Stream Dynamic Pressure Illustrative Missions

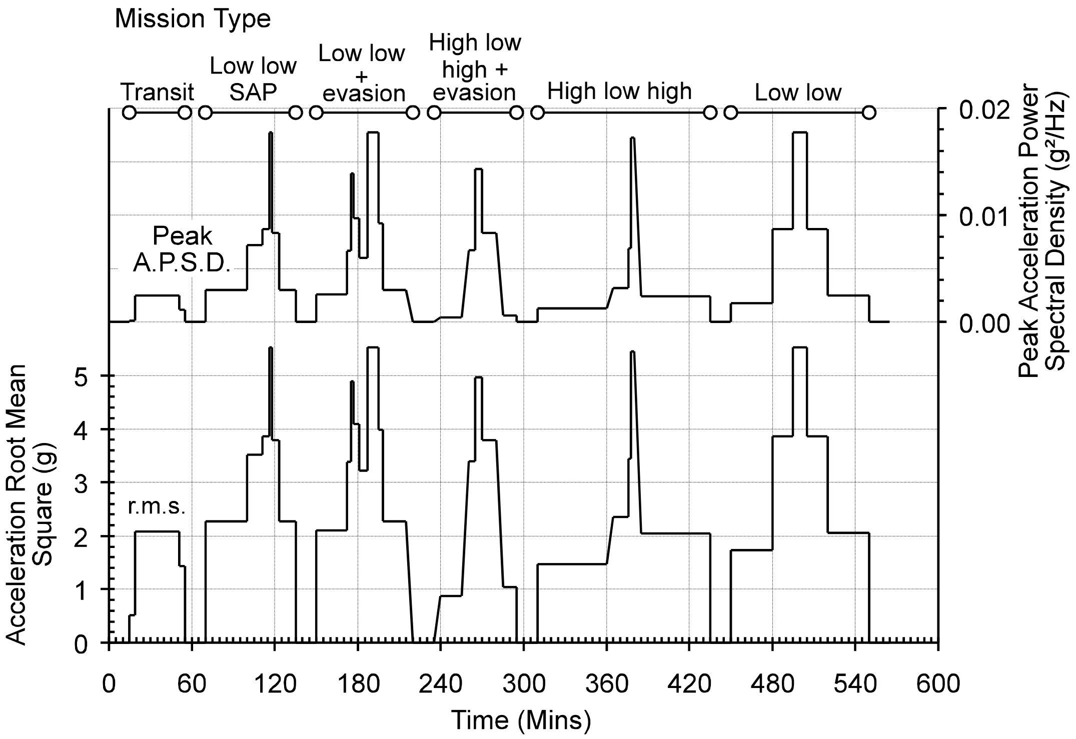

Figure A-4 Illustrative Vibration Test Severity Profiles

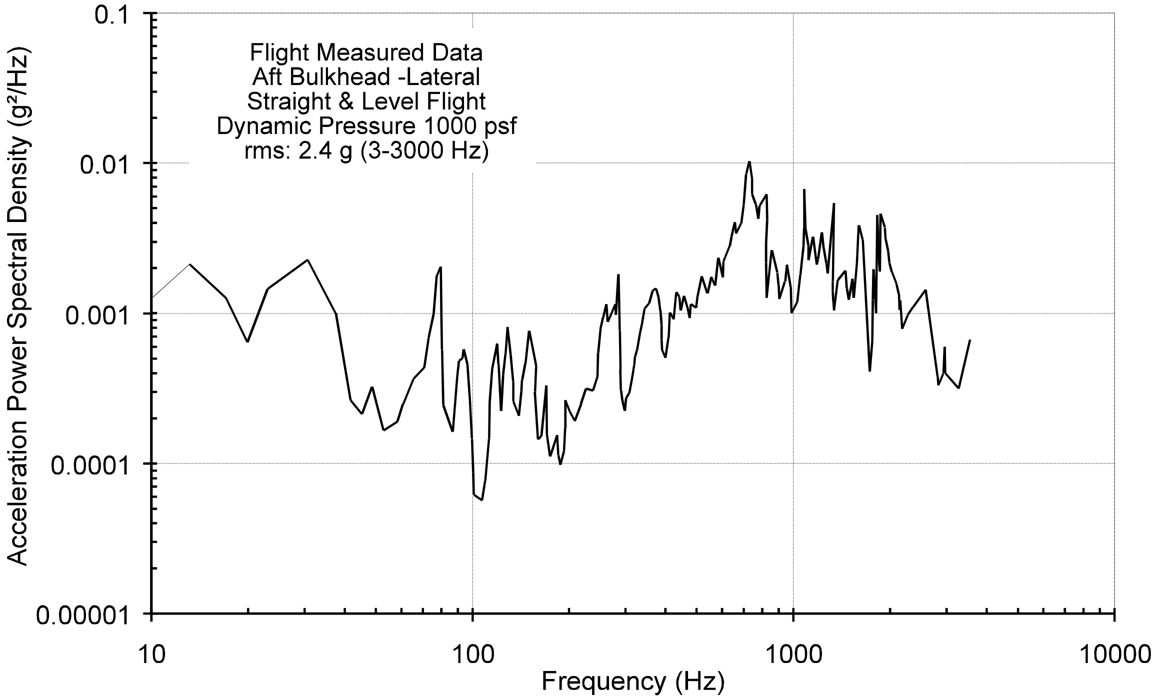

Figure A-5 Illustrative Vibration Test Severity Spectrum

4.3 The approximate relationships between flight dynamic pressure and vibration severities are given below

$$\text{Acceleration, rms} = B\,q$$

$$\text{Acceleration, ASD} = C\,q^{2}$$

Where B and C = Constants for a given aircraft or store configuration
q = Flight dynamic pressure

4.4 The relationship between flight dynamic pressure, q with aircraft velocity and altitude is given by:

Dynamic pressure $$q = \frac{1}{2}\rho_0 V^2 = \frac{1}{2}\gamma P M^2$$

Where ρ_0 = atmospheric density at sea level, kg/m^3

V = equivalent air speed, m/s

P = air pressure at specified altitude, Pa

M = true Mach number of aircraft

γ = ratio of specific heats, 1.4 for air, standard conditions

For ISA conditions:

$$q = 70.9\,M^2 (1 - 2.256 \times 10^{-5} h)^{5.2561}$$ kPa, h = altitude in meters

or

$$q = 1480\,M^2 (1 - 6.875 \times 10^{-6} h)^{5.2561}$$ lb/ft^2, h = altitude in feet

4.5 In the absence of suitable measured flight vibration data, alternative information can be derived from AECTP 200, Leaflet 246/2.

5. REFERENCES

a. MIL-HDBK 781A, Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification and Production, USA Department of Defense, 1 April 1996.

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ANNEX B

TEST FACILITY REQUIREMENTS

1. INTRODUCTION

This test method is designed to provide a close approximation to the flight vibration and temperature environment seen by the internal components of assembled materiel carried externally on fixed wing aircraft.

2. VIBRATION CONDITIONS

The main source of vibration in-service is the aerodynamic flow excitation acting over the total exposed surface of the materiel. Under laboratory test conditions the acoustic field of a reverberation chamber simulates this vibration.

Acoustic excitation at low frequencies in a reverberation chamber is normally limited by the size of the chamber, the low frequency cut off of the noise generation system, and the power availability. Additionally, the very low frequencies, that result from the wing and pylon bending and torsional modes for example, are mechanically coupled through the store attachment interface. Low frequency energy should be applied to the test item by means of a mechanical exciter operating in the nominal frequency range of 5 to 100 Hertz.

Mechanical vibration is applied via a light coupling connected to a strong point on the test item. This single point coupling should be rigid in the axis of vibration but should allow lateral motion of the test item.

The acoustic and mechanical stimuli are adjusted to achieve the required composite vibration response at the specified internal location(s).

3. TEMPERATURE CONDITIONS

The normal method of generating high intensity noise in a reverberation chamber involves the use of a relatively high airflow through the chamber. In order to achieve the required temperature conditions at the test item skin, it is necessary to enclose the test item and to control the temperature within that enclosure. This enclosure must be effectively transparent to the acoustic noise.

To achieve rapid temperature changes at the test item skin and to reduce losses of conditioned airflow, it is preferred that the acoustically transparent enclosure be connected into a closed loop with the heat exchanger(s).

Temperature control will normally be established with a temperature sensor attached to a section of the external skin of the test item. The capacity of the facility temperature conditioning equipment should be sufficient to ensure that the thermal response of this skin section follows the highest temperature change rate within the tolerance specified.

4. FACILITY DESIGN CONSIDERATIONS

The reverberation chamber construction must include sufficient structural mass and damping such that the noise spectrum is not unduly influenced by vibration of the chamber interior surfaces. This can be achieved by ensuring that the chamber wall fundamental resonance frequencies are less than the lowest acoustic test frequency required.

Low frequency excitation is applied mechanically; hence the low frequency response of the chamber is not as critical as for a standard acoustic test. The minimum chamber size for a given vibration response spectrum may be selected for a cut-off frequency at or below the crossover between mechanical and acoustic excitation. Chamber dimensions required to accommodate the test item may be the limiting factor, and the ratio of the major dimensions of the chamber must provide for adequate modal density at the lowest acoustic noise frequency.

The section of temperature conditioning air ducting within the chamber should be constructed to survive long periods of exposure to the acoustic noise conditions. Additionally, it may be desirable to incorporate noise attenuation within the external ducting to minimize the noise transmission to areas outside the chamber.

METHOD 414

HANDLING

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ANNEX A HANDLING - GUIDANCE FOR INITIAL TEST SEVERITY

METHOD 414

HANDLING

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the environment incurred by systems, subsystems and units, hereafter called materiel, during loading, unloading and handling.

1.2 Application

This test is applicable where materiel is required to demonstrate its adequacy to resist the specified handling environment without unacceptable degradation of its functional and/or structural performance.

1.3 Limitations

This method is not intended to simulate basic shock, blast environments, transportation, or safety drop conditions. The drop tests in this method are uncontrolled except for the drop height and orientations. Controlled tolerance shock test procedures are provided in Methods 403, 415, and 417. Safety drop tests for munitions are covered by STANAG 4375.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive, but provides examples of problems encountered during handling and dropping of materiel.

a. Structural deformation

b. Cracking and rupturing

c. Loosening of fasteners

d. Loosening of parts or components

2.2 Use of Measured Data

Where practical, in-service measured data should be acquired to tailor the materiel handling test. As a minimum the exposure duration and frequency information based on the LCEP are needed. In addition, information on specific handling configuration(s) and procedures, potential lift heights, and type of handing equipment should be obtained.

2.3 Sequence

The drop and handling test may be performed anytime in the test program. The requesting organization will determine its place in the test sequence.

2.4 Test Procedures

The choice of test procedure is governed by the test purpose. The tailoring process described in AECTP 100 should identify the test purpose. Different test procedures are used to simulate the in-service environments such as loading, unloading and handling of materiel.

2.4.1 Procedure I - Transit Drop

This procedure is intended to determine if the test item is capable of withstanding shocks normally induced by loading and unloading of materiel from a transportation platform, or other elevated surface. The procedure is not representative of shocks induced during transportation.

2.4.2 Procedure II - Horizontal Impact

This procedure is intended to determine the ability of materiel to withstand horizontal impacts encountered during loading and unloading of materiel, such as an impact collision when materiel is swinging on a crane. The procedure is not intended to simulate the materiel transportation environment.

2.4.3 Procedure III - Bench Handling

This procedure shall be used to determine the ability of materiel to withstand shock encountered during operations such as maintenance, calibration and servicing. This procedure is not required if it can be demonstrated that the structural response of the materiel from the Procedure I drop test included in a test programme are of a higher level.

3. SEVERITIES

Initial test severities are provided in Annex A.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. Identification of test item
b. Definition of test item
c. Definition of test severity
d. Test type(s) bench handling, impact or drop
e. Packaging conditions, if applicable
f. Axes and direction(s) in which impact is applied
g. Operating checks: initial, final
h. Orientation relative to gravity
i. Details required to perform test
j. Failure criteria

4.2 If Required

a. Climatic conditions during the test

b. Tailored shock or impact conditions

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

The tolerances on the drop height, impact velocity, and test item inclination angle are ± 3%, unless otherwise specified in the Test Instruction.

5.2 Procedure I – Transit Drop

The transit drop test facility should include an instantaneous release device, such as an electrical solenoid operated hook or wire release, from which the test item is suspended. Unless specified in the Test Instruction, the impact-surface for weights of up to 500 kg should be constructed of a 5 cm thick pinewood layer bearing directly on a minimum 10 cm thick concrete base surface. For greater weight test items a suitably thick concrete base surface should be used. Thin wood or concrete floors that deflect or deform under the impact force loading are not acceptable.

If the test item is to be packaged during in-service use, the item shall be within the package container during testing. If the materiel can be transported with or without a container, the transit drop test shall be conducted for both the packaged and unpackaged configurations.

Step 1 Perform the initial checks of the test item in accordance with the Test Instruction.

Step 2 If required, pre-condition the test item to the required climatic conditions. Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions between drops.

Step 3 Install the test item in the orientation required by the type of test: in the container, casing, on a frame, or unequipped.

Step 4 Perform the drops in accordance with Annex A , paragraph 2.

Step 5 After each drop, perform the final checks in accordance with Test Instruction and record the condition of the test item.

5.3 Procedure II - Horizontal Impact

The horizontal impact test equipment shall be capable of simulating the horizontal motion and impact conditions of the test item with a surface orientated as required in the Test Instruction. Unless specified in the Test Instruction, the impact surface shall be of a similar stiffness as defined in Procedure I. When the orientation of the test item with respect to gravity is not important, the transit drop test procedure may be used.

Step 1 Perform the initial checks of the test item in accordance with the Test Instruction.

Step 2 If required, pre-condition the test item to the required climatic conditions. Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions between impacts.

Step 3 Install the test item in the orientation required by the Test Instruction.

Step 4 The test item shall strike the test surface in accordance with the conditions of Annex A , paragraph 3.

Step 5 After each impact, perform the final checks in accordance with the Test Instructions and record the condition of the test item.

5.4 Procedure III - Bench Handling

The bench handling test shall be performed on a horizontal, solid wood, bench top at least 4 cm thick. The thickness of the bench top is specified for standardization purposes. The test item shall not be packaged or within a container.

Step 1 Perform the initial checks of the test item in accordance with the Test Instruction.

Step 2 If required, pre-condition the test item to the required climatic conditions. Subsequent pre-conditioning of the test item may again be required if the climatic conditions of the test item exceed the tolerances in the Test Instructions between impacts

Step 3 Using one edge as a pivot, lift the opposite edge of the test item until one of the following conditions occurs, whichever occurs first.

a. The test item forms an angle of 45 degrees with the horizontal bench top.

or

b. The raised edge of the test item is 10 cm above the horizontal bench top. Ten centimetres is an average height one corner of materiel in the field will be raised during servicing and is used for standardization purposes.

Step 4 Let the test item drop back freely to the horizontal bench top. Repeat using the other edges of the same horizontal face as pivot points, for a total of four drops.

Step 5 Repeat steps 1 through 4 with the test item resting on the other faces until it has been dropped for a total of four times on each face on which the test item could be realistically placed during servicing.

Step 6 After each impact perform final checks in accordance with the Test Instruction and record the condition of the test item.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of the test conditions.

7. REFERENCES AND RELATED DOCUMENTS

a. Accidental Drops, Their Range of Heights and Probable Frequencies of Occurrence, Sandia Labs report EDB # 341, 31 March, 1952.

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ANNEX A

HANDLING - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

1. SCOPE

This annex is intended to provide the rationale behind the information contained in the preceding procedures, and provides guidance for selecting the test and test severity.

2. PROCEDURE I - TRANSIT DROP TEST

The standard shock test for packaged materiel is a transit drop test in which the test item is dropped from a predetermined height onto a rigid surface. The type of handling the materiel may receive during in-service shipment determines the height of the drop. For example, packages weighing up to 23 Kg may be considered to be within the "one man throwing limit". Materiel of such weight may be thrown easily onto piles, or in other ways severely mishandled due to the light weight. Packages weighing between 23 and 45 Kg may be considered to be within a "one man carrying limit". These packages are somewhat heavy to be thrown, but can be carried and dropped from a height as great as shoulder height. A "two man dropping limit" may apply to a weight range between 45 to 90 Kg. The corresponding drop height for this mode of handling may be waist height. A further weight range is from 90 to 450 Kg. Packages in this range would be handled with light cranes or lift trucks, and may be subjected to impacts from excessive lifting or lowering actions. Finally, very heavy packages weighing over 450 Kg would be handled by heavier transport equipment with correspondingly more skill. Drops for this materiel would be from very small heights. Similarly, the size of the package classifies the type of handling into one man, two men, light materiel, or heavy materiel with corresponding drop heights. Thus, the drop heights for these tests are derived from the type of handling to which the package is more likely to be subjected during a shipping cycle. The type of handling is dependent on the size and weight of the package.

In addition to drop heights that vary with package size and weight, another factor in handling testing is the orientation of the package at impact. For example, small, lightweight packages are likely to be subjected to free fall drops onto sides, edges, and corners of the package. Larger, heavier packages handled by light or heavy materiel are likely to encounter drops of the type where one end rests on the floor and the other end is dropped, a bottom rotational drop. The applicable drop heights based on materiel weight and dimension are summarized in Table A-1.

Table A-1 Transit Drop Handling Tests

Weight of Test Item and Case, kg (lb)	Largest Dimension, cm (inches)	See Notes	Drop Height, cm, (inches)	Number of Drops
Under 45 (100) Manpacked or transportable	< 91 (36)	a, d	122 (48)	Drop on each face, edge, and corner. Total of 26 Drops
	≥ 91 (36)	a, d	76 (30)	
45 to 90 (100 to 200) Inclusive	< 91 (36)	a	76 (30)	Drop on each corner. Total of 8 Drops
	≥ 91 (36)	a	61 (24)	
90 to 450 (200 to 1000) Inclusive	< 91 (36)	a	61 (24)	
	91 to 152 (36 to 60)	b	61 (24)	
	> 152 (60)	b	61 (24)	
Greater than 450 (1000)	No limit	c	46 (18)	Drop on each bottom edge and bottom face or skids. Total of 5 Drops.

Notes :

a. The test item shall be oriented so that upon impact a line from the centre of gravity of the test item to the point of impact is perpendicular to the impact surface.

b. The longest dimension of the test item shall be parallel to the floor. The test item shall be supported at the corner of one end by a block 0.125 m in height, and at the other corner along the same edge by a block 0.30 m in height. The lowest opposite end of the test item shall be raised to the specific height at the lowest unsupported corner and allowed to fall freely.

c. While in the normal position, the test item shall be subjected to the edgewise drop test as follows If the normal transit position is unknown, the test item shall be so oriented that the two longest dimensions are parallel to the floor. One edge of the base of the test item shall be supported on a block 0.15 m in height. The opposite edge shall be raised to the specific height and allowed to fall freely.

d. The 26 drops may be divided among no more than five test items.

3. PROCEDURE II - HORIZONTAL IMPACT

The horizontal impact test is based on measurements of impact force and velocity for materiel swinging from an overhead crane. Materiel with requirements for Procedure II is typically heavier weight, and may be packaged or unpackaged. Impact of the packaged item could occur during unloading at a supply point or warehouse. Similarly, the unpackaged item could be exposed to a horizontal impart during unloading, shipment, or installation. The Test Instruction should define the required impact velocity, angle, surface, and any specific laboratory simulation conditions. Lacking any test programme specific information, use an impact velocity of 2.5 m/s . Conduct two 90 degree, orthogonal, impacts on each materiel face that could be impacted during in-service use. A drop height of 32 cm. (13 inches) can be used for cases where a transit drop test is a suitable alternative.

4. PROCEDURE III - BENCH HANDLING

The test method procedure paragraph 5.4 defines the typical test severity for bench handling of materiel. The maximum expected angle for maintenance and service is 45 degree or a 10 cm height of the materiel edge. These criteria are applicable for the test unless defined otherwise in the Test Instruction.

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METHOD 415

PYROSHOCK

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METHOD 415

PYROSHOCK

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of complex high amplitude and high frequency transient responses which are incurred by systems, subsystems and units, hereafter called materiel, during the specified operational conditions under exposure to pyroshock from pyrotechnic explosive or propellant-activated devices.

1.2 Application

This method is applicable where materiel is required to demonstrate its adequacy to resist the pyroshock environment without unacceptable degradation of its functional and/or structural performance. Supplemental technical guidance is contained in references a, b, and Annex A.. AECTP 100 and 200 provide guidance on the selection of a test procedure for the pyroshock environment.

1.3 Limitations

Because of the highly specialised nature of pyroshock, apply it only after giving careful consideration to information contained in the paragraphs below. In general, it may not be possible to simulate some of the actual in-service pyroshock environments because fixture limitations or physical constraints can prevent the satisfactory application of the pyroshock to the test item.

a. This method does not include the shock effects experienced by materiel as a result of any mechanical shock, transient vibration, shipboard shock, or EMI. For these types of shocks see the appropriate method in AECTP 400.

b. This method does not include the effects experienced by fuse systems that are sensitive to shock from pyrotechnic devices. Shock tests for safety and operation of fuses and fuse components may be performed in accordance with other applicable national and international standards specifically addressing fuse system environmental testing.

c. This method does not include special provisions for performing pyroshock tests at high or low temperatures.

d. This method is not intended to be applied to manned space vehicle testing, see reference b and Annex A reference l.

e. This method does not address secondary effects such as induced blast, EMI, and thermal effects.

f. This method does not address effects of ballistic shock on materiel.

2. TEST GUIDANCE

2.1 Introduction

Because of the highly unique form of the environment, introductory discussion is provided to characterise the environment.

2.1.1 Rationale for Pyroshock Testing

Pyroshock tests involving pyrotechnic, explosive- or propellant-activated devices are performed to :

a. Provide a degree of confidence that materiel can structurally and functionally withstand the infrequent shock effects caused by the detonation of a pyrotechnic device on a structural configuration to which the materiel is mounted.

b. Experimentally estimate the materiel's fragility level relative to pyroshock in order that shock mitigation procedures may be employed to protect the materiel structural and functional integrity.

2.1.2 Definition of Pyroshock

Pyroshock is often referred to as "pyrotechnic shock." For purposes of this document, initiation of a pyrotechnic device will result in an effect that is referred to as a pyroshock Pyroshock refers to the localised intense mechanical transient response caused by the detonation of a pyrotechnic device on adjacent structure.

A number of devices are capable of transmitting intense transients to a materiel. In general, a pyroshock is caused by : (1) an explosive device, or (2) a propellant activated device, releasing stored strain energy, coupled directly into the structure. For clarification, a propellant activated device includes items such as a clamp that releases strain energy causing a structural response greater than that obtained from the propellant explosion alone. The excitation source can be described in terms of their spatial distribution as : point sources, line sources and combined point and line sources, see Annex A reference I. Point sources include explosive bolts, separation nuts, pin pullers and pushers, bolt and cable cutters, and pyro-activated operational hardware. Line sources include flexible linear shaped charges (FLSC), mild detonating fuses (MDF), and explosive transfer lines. Combined point and line sources include V-band (Marmon) clamps. The loading from the pyrotechnic device may be accompanied by the release of structural strain energy from structure preload or impact amongst structural elements as a result of the activation of the pyrotechnic device. The test method is used to evaluate materiel likely to be exposed to one or more pyroshocks in its lifetime.

Pyroshocks are generally limited to a frequency range between 100 Hz and 1,000,000 Hz, and a time duration from 50 microseconds to not more than 20 milliseconds. Acceleration response amplitudes to pyroshock may range from 300g to 300,000g. The acceleration response time history to pyroshock will, in general, be very oscillatory and have a substantial rise time, approaching 10 microseconds. In general, the pyroshocks generate material stress waves that will excite materiel to respond to very high frequencies with wavelengths on the order of sizes of micro electronic chip configurations. Because of the limited velocity change in the structure resulting from the firing of the pyrotechnic device, and the localised nature of the pyrotechnic device, the structural resonances of the materiel below 500 Hz will normally not be excited. The materiel system will undergo very small displacements with small overall structural damage. The pyroshock acceleration environment in the vicinity of the materiel will usually be highly dependent upon the configuration of the materiel. The materiel or its parts may be in the near-field or far-field of the pyrotechnic device with the pyroshock environment in the near-field being the most severe, and that in the far-field the least severe.

2.1.3 Pyroshock Characteristics

Pyroshock is a physical phenomenon characterised by the overall material and mechanical response at a structure point. The pyrotechnic device produces extreme local pressure, with perhaps heat and electromagnetic emission, at a point or along a line. This extreme local pressure provides a near instantaneous generation of local high-magnitude non-linear material strain rates accompanied by the transmission of high-magnitude and high frequency material stress waves that produce a high acceleration and low velocity, short duration response at distances from the point or line source. The characteristics of pyroshock are:

a. Near the source stress waves in the structure caused by high material strain rates, non-linear material region, that propagate into the near-field and beyond;

b. High frequency, 100 Hz - 1,000,000 Hz, and very broadband frequency input;

c. High acceleration, 300 g - 300,000 g, with low structural velocity and displacement response;

d. Short-time duration, typically < 20 milliseconds;

e. High residual structure acceleration response, after the pyrotechnic event;

f. Point source or line source input, the input is highly localised;

g. Very high structural driving point impedance, P/v. Where P is the large explosive force or pressure, and v is the small structural velocity. At the source the impedance could be substantially less if the material particle velocity is high;

h. Response time histories away from the source that are highly random in nature, i.e., little repeatability and very dependent on the configuration details;

i. Response at points on the structure greatly affected by structural discontinuities;

j. Substantial heat and electromagnetic emission may accompany the structural response from ionisation of gases during the pyrotechnic event.

2.1.4 Pyroshock Intensity Classification

The nature of the response to pyroshock suggests that the materiel or its components may be classified as being in the “near-field” or “far-field” of the pyrotechnic device. The terms near-field and far-field relate to the shock intensity at the response point and the intensity is a function, in general unknown, of the distance from the source and the structural configuration between the source and the response point.

a. Near-Field. In the near-field of the pyrotechnic device, the response is governed by the structure material stress wave propagation effects. Materiel, or any portion of the materiel, is in the near-field of an intense pyrotechnic device if within a distance of 15 cm (6 in) of the point of detonation of the device, or a portion of it in the case of a line charge. If there are no intervening structural discontinuities, the materiel may be expected to experience peak accelerations in excess of 5000 g, and substantial spectral content above 100,000 Hz. The near-field of a less intense pyrotechnic device can be considered to be within 7.5 cm (3 in) of the point of detonation of the device, or a portion of it, with subsequent reduction in the peak acceleration levels and spectral levels.

b. Far-Field. In the far-field of the pyrotechnic device the pyroshock response is governed by a combination of material stress wave propagation effects and structural resonance response effects. Materiel, or any portion of the materiel, is in the far-field of an intense pyrotechnic device, if at a distance of beyond 15 cm (6 in) of the point of detonation of the device or a portion of it, in the case of a line charge. If there are no intervening structural discontinuities, the materiel may be expected to experience peak accelerations between 1000g and 5000 g and substantial spectral content above 10,000 Hz. The far-field of a less intense pyrotechnic device can be considered to be beyond 7.5 cm (3 in) of the point of detonation of the device, or a portion of it, with subsequent reduction in the peak acceleration levels and spectral levels. On occasion, the far-field of a pyrotechnic device is characterised by the mechanical structural resonance response effects above. If there are no intervening structural discontinuities, the materiel may be expected to experience peak accelerations below 1000g and most spectral content below 10,000 Hz.

2.1.5 Effects of the Environment

The following discussion is not intended to be all inclusive, but provides examples of problems that could occur when materiel is exposed to pyroshock.

In general, pyroshock has the potential for producing adverse effects on all electronic materiel. The level of adverse effects increases with the level and duration of the pyroshock, and decreases with the distance from the pyrotechnic device. Durations for pyroshock that produce material stress waves with wavelengths that correspond with the natural frequency wavelengths of micro-electronic components within materiel will enhance adverse effects. In general, the structural configuration transmits the elastic waves and is unaffected by the pyroshock. Examples of problems associated with pyroshock include:

a. Materiel failure as a result of destruction of the structural integrity of micro-electronic components,

b. Materiel failure as a result of relay chatter;

c. Materiel failure as a result of circuit card malfunction, circuit card damage and electronic connector failure. On occasion, circuit card contaminants having the potential to cause short circuits may be dislodged under pyroshock.

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

2.2 Use of Measured Data

This section provides background and guidance on the use of measured data in pyroshock testing, and comment for cases in which measured data are not available. For pyroshock, pyro-devices are “designed into” the overall materiel configuration and must perform for a specific purpose. In this case, it is easier to obtain measured data during such times as laboratory development. On occasion measured pyroshock data may be readily available, and should be processed and utilised to the greatest extent possible in the Test Instruction development.

2.2.1 Measured Pyroshock Data Available

a. If measured data are available, the data may be processed using the Shock Response Spectra (SRS), Fourier Spectra (FS) or the Energy Spectral Density (ESD). For engineering and historical purposes, the SRS has become the standard for measured data processing. In the discussion to follow it will be assumed that the SRS is the processing tool. In general, the maximax SRS spectrum, absolute acceleration or pseudo-velocity, is the main quantity of interest. Determine the SRS required for the test from analysis of the measured environmental acceleration time history. After carefully qualifying the data, to make certain there are no anomalies in the amplitude time histories, compute the SRS. Annex A reference f provides information regarding the qualifying of pyroshock data. The analyses will be performed for a Q = 10 at a sequence of natural frequencies at intervals of at least 1/6 octave and not greater resolution than 1/12th octave spacing to span at least 100 to 20,000 Hz, and not to exceed 100,000 Hz. When a sufficient number of representative shock spectra are available, employ an appropriate statistical technique, in general enveloping, to determine the required test spectrum. Method 417 Annex D describes the statistical techniques. Parametric statistics can be employed if the data can be shown to satisfactorily fit an assumed underlying probability distribution. For example, the test level can be based on a maximum predicted environment defined to be equal to or greater than the 95th percentile value at least 50 percent of the time, this is a tolerance interval approach. When a normal or log-normal distribution can be justified, Method 417 Annex D, derived from Annex A reference g, provides a method for estimating the test level.

b. Use an increase over the maximum of the available spectral data to account for variability of the environment, and establish the test spectrum when insufficient data are available for statistical analysis. The increase is based upon engineering judgement and should be supported by rationale for the judgement. It is often convenient to envelop the SRS by computing the maximax spectra over the sample spectra, and add a + 6 dB increase margin to the SRS maximax envelope.

c. When employing the pyroshock test, determine the effective transient time duration, T_e , from the time history. For all procedures, the pyroshock shock amplitude time history used for the SRS analysis will be T_e in duration. In addition, measurement data will be collected for a duration T_e prior to the pyroshock, and duration T_e after the pyroshock for subsequent analysis. In general, each individual axis of the three orthogonal axes will have approximately the same shock test SRS and the average effective duration as a result of the omni-directional properties of a pyroshock in Procedure I and Procedure II. For Procedure III, the form of shock test SRS may vary with axes. An SRS exciter shock technique, complex transient, must be employed when using Procedure IV. Classical shock pulse forms of shock are not acceptable substitutes for an SRS based test procedure.

2.2.2 Measured Pyroshock Data not Available

If a database is not available for a particular configuration, the tester must rely upon configuration similarity and any associated measured data for prescribing a pyroshock test. Because of the sensitivity of both the pyroshock to the system configuration, and the wide variability inherent in pyrotechnic shock measurements, the tester must proceed with caution. As a basic guide for pyroshock testing, Figure A-10 provides SRS estimates for four typical aerospace application pyrotechnic point source devices. Figure A-11 provides information on the attenuation of the SRS peaks and the SRS ramp with distance from the source for the Figure A-10 point sources. Information in Figure A-10 and Figure A-11 came from Annex A reference n. Reference n also recommends that the attenuation of the peak SRS across joints be taken to be 40% for each joint, up to three joints, and that there be no attenuation of the SRS ramp. Figure A-12 provides the degree of attenuation of the peak time history response as a function of the shock path distance from the source for seven aerospace structural configurations. This information is summarised from Annex A reference o. The SES scaling law or the RLDS scaling law may provide guidance, see paragraph 3.2.2.

In most cases, either Procedure II or Procedure III are the optimum procedures for testing with the smallest risk of either substantial undertest or gross overtest. If Procedure I is not an option, the tester must proceed with caution with Procedure II or Procedure III according to the guidelines within this method. Other helpful information concerning test procedures is contained in reference a. In reality, a test transient is deemed suitable if the SRS equals or exceeds the given SRS requirement over the minimum frequency range of 100 to 20,000 Hz and the duration of the test transient is within 20% of that of the normal pyroshock response duration for other configurations.

2.3 Sequence

Pyroshock is normally experienced near the end of the life cycle, except otherwise noted in the life cycle profile. Normally, schedule pyroshock tests late in the test sequence, unless the materiel must be designed to survive extraordinarily high levels of pyroshock for which vibration and other shock environments are considered nominal. Pyroshock tests can be considered independent of the other tests because of their unique specialised nature, and consideration of combination environment tests will be rare. It is good practice to expose a single test item to all relevant environmental conditions in turn if independence of other tests cannot be confidently substantiated.

In addition, perform tests at room ambient temperature unless otherwise specified or there is reason to believe either operational high temperature or low temperature may enhance the pyroshock environment.

This method does not include sequence-related guidance for unplanned test interruption as a result of pyroshock device or mechanical test equipment malfunction for cases in which the pyroshock is being mechanically simulated. Generally, if the pyroshock device malfunctions or interruption occurs during a mechanical shock pulse, repeat that shock pulse. Care must be taken to ensure stresses induced by the interrupted shock pulse do not invalidate subsequent test results. In particular, check materiel functionality and inspect the overall integrity of the materiel to ensure pre-shock test materiel integrity. Record and analyse data from such interruptions before continuing with the test sequence.

2.4 Choice of Test Procedures

The choice of test procedure is governed by many factors including the in-service environment and materiel type. These and other factors are dealt with in the general requirements of AECTP 100, and in the definition of environments in AECTP 200. This test method includes four test procedures.

2.4.1 Procedure I - Near-Field with Actual Configuration

Replication of pyroshock for the near field environment using the actual materiel and associated pyrotechnic device in the in-service configuration Procedure I is intended to test materiel, including mechanical, electrical, hydraulic, and electronics, in the in-service mode and actual configuration. The test item and pyrotechnic device physical relationship are maintained in the laboratory test. In Procedure I the materiel, or a portion, is located in the near-field of the pyrotechnic device(s).

2.4.2 Procedure II - Near-Field with Simulated Configuration

Replication of pyroshock for the near-field environment using the actual materiel, but with the associated pyrotechnic device isolated from the test item Procedure II is intended to test materiel, including mechanical, electrical, hydraulic, and electronics, in the in-service mode but with a simulated structural configuration. Normally this will minimise testing costs because less materiel configurations and/or platforms associated with the test item will be damaged. The test setup can be used for repeated tests at varying levels. Every attempt should be made to use this procedure to duplicate the actual platform or materiel structural configuration by way of a full-scale test. If this is too costly or impractical, employ scaled tests with consideration for configuration details in the scaling process. In particular, only the structure portion directly influencing the materiel is needed in the test, provided it can be assumed that the remainder of the structure will not influence materiel response. On occasion, a special pyrotechnic device may be employed for testing the materiel, such as a flat steel plate to which the materiel is mounted and the pyrotechnic charge is attached. In Procedure II it is assumed that the materiel, or some part, lies within the near-field of a pyrotechnic device(s).

2.4.3 Procedure III - Far-Field with Mechanical Test Device

Procedure III is replication of pyroshock for the far-field environment with a mechanical device that simulates the pyroshock peak acceleration amplitudes and frequency content. Pyroshock can be applied using conventional high acceleration amplitude or frequency excitation devices. Reference a provides a description of shock input devices, their advantages and limitations. Procedure III typically excludes an electrodynamic exciter because of exciter frequency range limitations. In Procedure III it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device(s).

2.4.4 Procedure IV - Far-Field with Electrodynamic Exciter

Procedure IV is replication of pyroshock for the far-field environment using an electrodynamic exciter to simulate the comparatively low frequency structural resonant response to the pyrotechnic device. In all cases, it is necessary to verify, using in-service measurements, that the simulation using an exciter is representative of the platform resonant response alone. In Procedure IV it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device(s). The materiel is subject to the structure platform resonant response alone.

2.5 Procedure Selection Considerations

Based on the test data requirements, determine which test procedure is applicable. Note any structural discontinuities that may serve to mitigate the effects of the pyroshock on the materiel, and select the procedure based on the actual materiel in-service configuration. In some cases, the selection of the procedure will be driven by test practicality. Consider all pyroshock environments anticipated for the materiel during its life cycle, both in its logistic and operational modes. In any case, one test will be considered sufficient for testing over the entire amplitude and frequency range of exposure of the materiel. Do not break up measured or predicted response to pyroshock into separate amplitude or frequency ranges, and apply different techniques in testing in each separate amplitude or frequency range. When selecting the procedure consider the following :

a. The Operational Purpose of the Materiel From the requirement documents, determine the functions to be performed by the materiel either during or after exposure to the pyroshock environment.

b. The Location Relative to the Pyrotechnic Device Determine if the materiel or a portion of the materiel lies within the near-field or far-field of the pyrotechnic device, see the definition in paragraph 2.1.4.

   If the materiel, or a portion, is located within the near-field of the pyrotechnic device, without isolation of the materiel, and if there are no measured field data, apply only Procedure I or II.

   If the materiel is located within the near-field of the pyrotechnic device, and measured field data exist, apply Procedure III if the processed data supports the amplitude and frequency range capabilities of the test devices.

If the materiel is located within the far-field, and is subject to structural response only, apply Procedure IV if the processed data supports the velocity, displacement, and frequency range of an electrodynamic exciter. If the data does not support the electrodynamic exciter limitations, apply Procedure III.

c. Operational Purpose. The test data required to determine whether the operational purpose of the materiel has been met.

3. SEVERITIES

3.1 General

When practical, test levels and durations will be tailored or established using projected in-service use profiles and other relevant data. Pyroshock events are "designed into" the overall materiel configuration with a well defined sequence of occurrence. When measured data are not available consult Annex A or the references provided. All information should be used in conjunction with the appropriate information given in AECTP 200. Having selected one of the four pyroshock procedures based on the materiel's requirements documents and the tailoring process; complete the tailoring process by identifying appropriate parameter levels, applicable test conditions and applicable test techniques for the procedure. For pyrotechnic testing, exercise extreme care in consideration of the details in the tailoring process. Base these selections on the requirements documents, the Life Cycle Environmental Profile, the Operational Environment Documentation, and information provided with this procedure. Consider the following when selecting test levels.

3.2 Test Conditions - Shock Spectrum Transient Duration and Scaling

Derive the SRS and the effective transient duration, T_e, from measurements of the materiel's functional environment or, if available, from dynamically scaled measurements of a similar environment. Because of the inherent very high degree of randomness associated with the response to a pyroshock, extreme care must be exercised in dynamically scaling a similar event. For pyroshocks there are two known scaling laws for use with response from pyroshocks that may be helpful if used with care, see reference b and Annex A reference l.

3.2.1 Pyroshock Source Energy Scaling (SES)

The first scaling law is the Source Energy Scaling (SES) where the SRS is scaled at all frequencies by the ratio of the total energy release of two different devices. For E_r and E_n the total energy in two pyrotechnic shock devices the relationship between the SRS processed levels at a given natural frequency, $f_{n,}$ and distance, $D_{1,}$ is given by the following expression :

$$SRS_n\,(f_n\,|\,E_n, D_1) \;=\; SRS_r\,(f_n\,|\,E_r, D_1)\sqrt{\frac{E_n}{E_r}}$$

In using this relationship, it is assumed that either an increase or decrease in the total energy of the pyrotechnic shock devices will be coupled into the structure in exactly the same way. Excessive energy from one device will go into the structure as opposed to being dissipated in some other way, e.g., through the air.

3.2.2 Pyroshock Response Location Distance Scaling (RLDS)

The second scaling law is the Response Location Distance Scaling (RLDS) where the SRS is scaled at all frequencies by an empirically derived function of the distance between two sources. For D_1 and D_2, the distances from a pyrotechnic shock device the relationship between the SRS processed levels at a given natural frequency, f_n, is given by the following expression:

$$\mathrm{SRS}\left(f_n \middle| D_2\right) = \mathrm{SRS}\left(f_n \middle| D_1\right)\exp\left\{\left[-8\times10^{-4}\, f_n^{\left(2.4 f_n^{-0.105}\right)}\right]\left(D_2 - D_1\right)\right\}$$

In using this relationship it is assumed that D_1 and D_2 can be easily defined as in the case of a pyrotechnic point source device. Figure A-9 from reference b displays the ratio of SRS(f_n|D_2) to SRS(f_n|D_1) as a function of the natural frequency, f_n, for selected values of the term (D_2 - D_1). It is clear from this plot that as the natural frequency increases there is a marked decrease in the ratio for a fixed (D_2 - D_1) > 0 , and as (D_2 - D_1) increases, the attenuation becomes substantial. This scaling relationship when used for prediction between two configurations relies very heavily upon (1) similarity of configuration, and (2) similarity of type of pyrotechnic device. Annex A reference l and the example provided in this reference should be consulted before applying this scaling relationship.

3.3 Specific Procedures - Test Axes, Duration, and Number of Shock Events

3.3.1 Procedure I - Near-Field with Actual Configuration

For Procedure I, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event, and there is little available data to substantiate the number of pyroshocks, apply three or more shocks at each environmental condition based on the anticipated service use. A suitable test shock for each axis is one that yields an SRS that equals or exceeds the required test SRS over the specified frequency range when using a duration specified T_e value for the test shock time history and when the effective duration of the shock is within twenty percent of the specified T_e value. Determine the SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test is to test the physical and functional integrity of the materiel under the actual pyroshock configuration in the near-field of the pyroshock device.

3.3.2 Procedure II - Near-Field with Simulated Configuration

For Procedure II, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event, and there is little available data to substantiate the number of pyroshocks, apply three or more shocks at each environmental condition based on the anticipated service use. A suitable test shock for each axis is one that yields an SRS that equals or exceeds the required test spectrum over the specified frequency range when using a duration specified T_e value for the test shock time history and when the effective duration of the shock is within twenty percent of the specified T_e value. Determine the maximax SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test is to test the structural and functional integrity of the materiel under a simulated pyroshock configuration in the near-field of the pyroshock device.

3.3.3 Procedure III - Far-Field with Mechanical Test Device

For Procedure III, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event, and there is little available data to substantiate the number of pyroshocks, apply three or more at each environmental condition based on the anticipated service use. The measured response test requirements may be satisfied along more than one axis with a single test shock configuration. Consequently, it is conceivable that a minimum of three test shock repetitions will satisfy the requirements for all directions of all three orthogonal axes. At the other extreme, a total of nine shocks are required if each shock only satisfies the test requirements in one direction of one axis. If the required test spectrum can be satisfied simultaneously in all directions, three shock repetitions will satisfy the requirement for the test. If the requirement can only be satisfied in one direction, it is permissible to change the test set-up and impose three additional shocks to satisfy the spectrum requirement in the other direction. A suitable test shock is one that yields an SRS that equals or exceeds the required test SRS over the specified frequency range. Determine the maximax SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test should be to test the structural and functional integrity of the system under pyroshock in the far-field of the pyroshock device.

3.3.4 Procedure IV - Far-Field with Electrodynamic Exciter

For Procedure IV, subject the test item to a sufficient number of suitable shocks to meet the specified test conditions. The following guidelines may be applied. For materiel that is likely to be exposed only rarely to a given pyroshock event, perform one shock for each appropriate environmental condition. For materiel that is likely to be exposed more frequently to a given pyroshock event, and there is little available data to substantiate the number of pyroshocks, apply three or more shocks at each environmental condition based on the anticipated service use. The measured response will not be omni-directional. For Procedure IV it may be permissible, but highly unlikely, to simultaneously meet the test requirements along more than one axis with a single test shock configuration. Consequently, it is conceivable that a minimum of three test shock repetitions will satisfy the requirements for all directions of all three orthogonal axes. At the other extreme, a total of nine shocks are required if each shock only satisfies the test requirements in one direction of one axis. If the required test SRS can be satisfied simultaneously in all directions, three shock repetitions will satisfy the requirement for the test. If the requirement can only be satisfied in one direction, it is permissible to change the test set-up and impose three additional shocks to satisfy the SRS requirement in the other direction. A suitable test shock is one that yields an SRS that equals or exceeds the required test spectrum over the specified frequency range. Determine the maximax SRS for Q = 10, and at least 1/6-octave frequency intervals. The objective of the test should be to test the structural and functional integrity of the system under pyroshock where the low frequency structural response of the platform is the primary input to the materiel.

3.4 Supporting Assessment

It should be noted that the selected test procedure may not provide an adequate simulation of the complete environment and, consequently, a supporting assessment may be necessary to compliment the test results. In the case of pyroshock this may be difficult since prediction methodology for this environment is in its infancy. What prediction methodology exists is based primarily on empirical test results with few adequate analytical models.

3.5 Isolation System

Materiel intended for use with shock isolation systems, or special structural isolation configurations, should normally be tested with its isolators or shock attenuation devices in position, or under the special structural isolation configuration. The test item should be tested without isolators if it is not practical to carry out the pyroshock test with the appropriate isolators, or if the high frequency dynamic characteristics of the materiel installation are highly variable. Or, test the item in a structural configuration at a modified severity specified in the Test Instruction. Determining the modified severity is a questionable practice, unless the materiel configuration is very basic and the scaling laws can be applied.

3.6 Sub-System Testing

When identified in the Test Instruction, sub-systems of the materiel may be tested separately and can be subject to different pyroshock severities. If this course of action is elected, extreme care must be exercised to properly define the sub-system boundary conditions because of the sensitivity of pyroshock levels to attachment points at sub-system boundaries.

3.7 Materiel Configuration

Configure the test item for pyroshock as would be anticipated during in-service conditions including particular attention to the details of the mounting of the materiel to the platform. Pyroshock response variation is particularly sensitive to the details of the materiel and platform configuration.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

4.1.1 Pretest

The following information is required to conduct a pyroshock test adequately.

General. Information.

(1) The identification of the test materiel

(2) The definition of the test materiel

(3) The type of test : development, qualification, etc.,

(4) The operation or non-operation of the test materiel during the test

(5) The packaging conditions, if applicable

(6) The operating checks to be performed and when, if applicable

(7) The control strategy

(8) The indication of the failure criteria

Specific to this Method.

(1) Test system (test item/platform configuration) detailed configuration including

  (a.)Location of the pyrotechnic device

  (b.)Location of the materiel with respect to the pyrotechnic device

  (c.)The structural path between the pyrotechnic device and the materiel; and any general coupling configuration of the pyrotechnic device to the platform and the platform to the materiel including the identification of structural joints

  (d.)Distance of the closest part of the materiel to the pyrotechnic device

(2) Pyroshock environment, including

  (a.)Type of pyrotechnic device

  (b.)If charge related - size of pyrotechnic device charge

  (c.)If charge effect - stored strain energy in primary device

  (d.)Means of initiation of the pyrotechnic device

  (e.)Anticipated EMI or thermal effects

(3) Duration of pyroshock if Procedure III or Procedure IV is used, or the size and distribution of the pyrotechnic device charge if Procedure I or Procedure II is used.

(4) General materiel configuration including measurement points on or near the materiel.

4.1.2 During Test

For test validation purposes, record deviations from planned or pre-test procedures or parameter levels, including any procedural anomalies that may occur.

4.1.3 Post-test

Record the following post-test information.

General

Information listed previously.

Specific to this method.

(1) Previous test methods to which the specific test item has been exposed.

(2) Duration of each exposure or number of specific exposures.

(3) Any data measurement anomalies, e.g., instrumentation high noise levels, etc.

(4) Status of the test item for each visual examination.

(5) Test levels with supporting measurement analysis.

(6) Results of operational checks.

4.2 If Required

The number of simultaneous test materiel tolerances, if different from paragraph 5.1.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances and Test Level Estimation

Following are guidelines for test tolerances for pyroshock for the four procedures. All tolerances are specified on the maximax acceleration SRS. Any tolerances specified on the pseudo-velocity SRS must be derived from the tolerances on the maximax acceleration SRS and be consistent with those tolerances. The test tolerances are stated in terms of single measurement tolerance. For an array of measurements defined in terms of a “zone” , see Annex A reference g, a tolerance may be specified in terms of an average of the measurements within a “zone”. It should be noted, however, this is in effect a relaxation of the single measurement tolerance and that individual measurements may be substantially out of tolerance while the average is within tolerance. In general, when specifying test tolerances based on averaging for more than two measurements within a zone the tolerance band should not exceed the 95/50 one-sided normal tolerance upper limit computed for the logarithmically transformed SRS estimates nor be less than the mean minus 1.5 dB. Any use of zone tolerances and averaging must have support documentation prepared by a trained analyst. It should be noted from reference b, current aerospace practice for tolerance on the maximax SRS is given as + 6 and -6 dB for $f_n < 3$ kHz and +9 and - 6 dB for $f_n > 3$ kHz with at least 50% of the SRS magnitudes shall exceed the nominal test specification.

5.1.1 Procedure I - Near-Field with Actual Configuration

If prior measured data are available or a series of pyroshocks are performed, all acceleration maximax SRS computed with a one-tweleveth octave frequency resolution are to be within –3 dB and + 6dB over a minimum of 80 % of the overall frequency bandwidth from 100 Hz to 20 kHz. For the remaining 20 % part of the frequency band, all SRS are to be within – 6 dB and + 9 dB.

5.1.2 Procedure II - Near-Field with Simulated Configuration

If prior measured data are available or a series of pyroshocks are performed, all acceleration maximax SRS computed with a one-tweleveth octave frequency resolution are to be within –3 dB and + 6 dB over a minimum of 80 % of the overall frequency bandwidth from 100 Hz to 20 kHz. For the remaining 20% part of the frequency band, all SRS are to be within – 6 dB and + 9 dB.

5.1.3 Procedure III - Far-Field with Mechanical Test Device

If prior measured data are available or a series of pyroshocks are performed, all acceleration maximax SRS computed with a one-twelveth octave frequency resolution are to be within –1.5 dB and + 3dB over a minimum of 80 % of the overall frequency bandwidth from 100 Hz to 10 kHz. For the remaining 20 % part of the frequency band, all SRS are to be within – 3 dB and + 6 dB.

5.1.4 Procedure IV - Far-Field with Electrodynamic Exciter

If prior measured data are available or a series of pyroshocks are performed, all acceleration maximax SRS computed with a one-twelveth octave frequency resolution are to be within –1.5 dB and + 3 dB over a minimum of 90 % of the overall frequency bandwidth from 10 Hz to 2 kHz. For the remaining 10 % part of the frequency band, all SRS are to be within – 3 dB and + 6 dB.

5.1.5 Sufficient Data for Test Level Estimation

When a sufficient number of representative shock spectra are available, employ an appropriate statistical technique (in general an enveloping technique) to determine the required test spectrum. Method 417 Annex D describes the appropriate statistical techniques. In general, parametric statistics can be employed if the data can be shown to satisfactorily fit an assumed underlying probability distribution. For example, in certain standards the test levels are based upon a maximum predicted environment defined to be equal to or greater than the 95th percentile value with a confidence coefficient of at least 0.50 . This is an upper tolerance level approach. When a normal or lognormal distribution can be justified, Annex A reference g provides a method for estimating such a test level.

5.1.6 Insufficient Data for Test Level Estimation

When insufficient data are available for statistical analysis, use an increase over the maximum of the available spectral data to establish the required test spectrum to account for variability of the environment. The degree of increase is based upon engineering judgement and should be supported by rationale for that judgement. In these cases it is often convenient to envelope the SRS by computing the maximax spectra over the sample spectra and proceed to add a + 6dB margin to the SRS maximax envelope.

5.2 Control

The control strategy is dependent upon the type of test and the configuration of the materiel. In general the testing is open-loop from pre-configured tests used to calibrate the test severity.

5.3 Installation Conditions of Test Materiel

5.3.1 Test Facility

Pyroshock can be applied using actual pyrotechnic devices in the design or a simulated configuration, conventional high acceleration amplitude/frequency test input devices, or an electrodynamic exciter. The pyroshock apparatus may incorporate a compressed gas shock tube, metal-on-metal contact, ordnance-generated pyroshock simulator, electrodynamic exciter, actual pyrotechnic device on a scale model, actual pyrotechnic device on a full scale model, or other activating types of apparatus. For Procedure I or Procedure II, references related to ordnance devices must be consulted. For Procedure III the guidelines in the method must be followed. Reference a provides a source of alternative test input devices, their advantages and limitations. In this procedure it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device. Utilise the guidelines in this method; reference a provides supplemental information for consideration for such testing. For Procedure IV, it is assumed that all parts of the materiel lie in the far-field of the pyrotechnic device and the measured or predicted data are consistent with the 2000 Hz frequency limitations of the electrodynamic exciter in addition to the acceleration amplitude limitations. It is also important to note that for large materiel, the velocity input of the exciter may exceed the velocity of the materiel under the actual pyroshock environment. For velocity sensitive materiel, this may constitute an over test. In the ensuing paragraphs the portion of the test facility responsible for delivering the pyroshock to the materiel will be termed the shock apparatus. Such shock apparatus includes the pyrotechnic shock device and the fixturing configuration in Procedure I and Procedure II, the mechanical exciter and the fixturing configuration in Procedure III, and the electrodynamic exciter and the fixturing configuration in Procedure IV.

5.3.2 Calibration

Ensure the shock apparatus is calibrated for conformance with the specified test requirement from the selected procedure. Procedure I may be used without pre-shock calibration in cases in which the configuration details are in accordance with the test plan. However, Procedure I should be used with a pre-shock calibration in cases in which the hardware is expendable and added test costs are not exorbitant, to ensure accurate test simulation for the materiel. For Procedure II, before the test item is attached to the resonating plate, it will be necessary to attach a simulated test item and obtain measured data under test conditions to be compared with the desired test response. Caution must be exercised so that the pre-test shocks do not degrade the resonating plate configuration. For Procedure III, calibration is crucial. Before the test item is attached to the shock apparatus it will be necessary to attach a simulated test item and obtain measured data under test conditions to be compared with the desired test response. For Procedure IV, utilising the SRS method with proper constraints on the effective duration of the transient, calibration is necessary. Before the test item is attached to the shock apparatus, it will be necessary to attach a simulated test item and obtain measured data under test conditions to be compared with the desired test response. For Procedure II, Procedure III and Procedure IV, remove the calibration load and then perform the shock test on the actual test item.

5.3.3 Instrumentation

In general for pyroshock, acceleration will be the quantity measured to meet specification with care taken to ensure acceleration measurements can be made that provide meaningful data i.e., the measured data are well qualified, Annex A reference f. On occasion more sophisticated devices may be employed, e.g., laser velocimeter. In these cases give special consideration to the instrument amplitude and frequency range specifications in order to satisfy the measurement and analysis requirements.

5.3.3.1 Accelerometer

a. Transverse sensitivity of less than or equal to 5%.

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

c. For all pyroshock procedures a flat frequency response within ±10% across the frequency range 10 - 20,000 Hz. The devices may be of the piezoelectric type or the piezoresistive type. (Experience has shown that valid pyroshock measurements within the near-field of the pyroshock device are very difficult to make.)

d. Use measurement devices compatible with the requirements and guidelines provided in the paragraphs above.

5.3.3.2 Signal conditioning

Use signal conditioning compatible with the instrumentation requirements for the materiel. In particular, filtering will be consistent with the response time history requirements. Use signal conditioning requirements compatible with the requirements and guidelines provided in the paragraphs above. In particular use extreme care in filtering the acceleration signals either (1) directly at the attachment point, i.e., mechanical filtering to reduce the very high frequencies associated with the pyroshock, or (2) at the amplifier output. The signal into the amplifier should never be filtered for fear of filtering bad measurement data and the inability to detect the bad measurement data. The signal from the signal conditioning must be anti-alias filtered before digitising.

5.3.4 Data Analysis

5.3.4.1 Digitising the analog voltage signal will not alias more than a 5 percent measurement error into the frequency band of interest (100 Hz to 20 kHz).

5.3.4.2 Filters that are used to satisfy the data digitisation requirement shall have linear phase-shift characteristics.

5.3.4.3 Filters that are used to satisfy the data digitisation requirement shall have a pass band flatness within one dB across the frequency range specified for the accelerometer (see paragraph 5.3.3).

5.3.4.5 Analysis procedures will be in accordance with those requirements and guidelines provided in the paragraphs of this method; supplemental information can be found in Annex A reference f . In particular, the pyroshock acceleration amplitude time histories will be qualified according to the procedures provided in the paragraphs of this method. Each amplitude time history will be integrated to detect any anomalies in the measurement system. e.g., cable breakage, slew rate of amplifier exceeded, data clipped, unexplained accelerometer offset, etc. The integrated amplitude time histories will be compared with criteria given in the paragraphs of this method. For Procedure I and Procedure II to detect emission from extraneous sources, configure an accelerometer without sensing element and process its response in the same manner as for the other accelerometer measurement responses. If this accelerometer exhibits any character other than very low level noise, consider the acceleration measurements to be contaminated by an unknown noise source.

5.3.5 Test Set-up

5.3.5.1 Procedure I - Near-Field with Actual Configuration

In this procedure the materiel is tested on the actual overall configuration. For installation ensure the in-service mounting conditions are maintained.

5.3.5.2 Procedure II - Near-Field with Simulated Configuration

In this procedure mount the materiel on the flat plate (or other suitable simulation device) in either an isolated or an un-isolated configuration dependent upon the in-Service condition.

5.3.5.3 Procedure III - Far-Field with Mechanical Test Device

In this procedure follow test instruction procedures for installing materiel for a shock test. Details of the installation procedures will depend upon the test device configuration.

5.3.5.4 Procedure IV - Far-Field with Electrodynamic Exciter

In this procedure follow test instruction procedures for installing materiel for a shock test on an electrodynamic exciter.

5.4 Effects of Gravity

Because of the potentially high acceleration levels for pyroshock, gravity has no effect on the test configuration or analysis of the test data. Only in cases in which the materiel itself is sensitive to gravity and the operation of the materiel depends upon the direction of gravity relative to the materiel orientation should the effects of gravity be considered.

5.5 Preparation for Test

5.5.1 Preliminary Steps

Prior to initiating any testing, review pre-test information in the test instruction to determine test details (e.g., procedures, test item configuration, pyroshock levels, number of pyroshocks):

a. Choose the appropriate test procedure.

b. Determine the appropriate pyroshock levels for the test prior to calibration for Procedure II, Procedure III and Procedure IV from previously processed data (if available).

c. Ensure the pyroshock signal conditioning and recording device has adequate amplitude range and frequency bandwidth. It may be difficult to estimate a peak signal and range the instrumentation appropriately. In general, there is no data recovery from a clipped signal, however for overranged signal conditioning, it is usually possible to get out meaningful results for a signal 20 dB above the noise floor of the measurement system. In some cases, redundant measurements may be appropriate, one measurement being overranged and one measurement ranged at the best estimate for the peak signal. The frequency bandwidth of most recording devices is usually readily available, but one must make sure that device input filtering does not limit the signal frequency bandwidth.

5.5.2 Pre-test Checkout

All items require a pre-test checkout at standard ambient conditions to provide baseline data. Conduct the checkout as follows:

Conduct a complete visual examination of the test item with special attention to any micro electronic circuitry areas. Pay particular attention to its platform mounting configuration and potential stress wave transmission paths.

Document the results for compliance with General Requirements.

Where applicable, install the test item in its test fixture.

Conduct an operational checkout in accordance with the approved test plan along with simple tests for ensuring the measurement system is responding properly.

Document the results for compliance with General Requirements.

If the test item operates satisfactorily, proceed to the first test. If not, resolve the problem and restart at Step 1.

Remove the test item and proceed with the calibration (except in the case of Procedure I for no pre-shock calibration).

5.6 Procedures

The following procedures provide the basis for collecting the necessary information concerning the platform and test item under pyroshock.

5.6.1 Procedure I - Near-Field with Actual Configuration.

Step 5. Follow the guidance of this test method to select test conditions. Mount (1) the test item if there will be no calibration for actual materiel configuration used in this procedure or (2) a dynamically similar test item if there is to be calibration prior to testing. Select accelerometers and analysis techniques, that meet the criteria, outlined in previous paragraphs of this method; supplemental information is contained in Annex A reference f .

Step 6. Perform a functional check on the test item.

Step 7. Subject the test item (in its operational mode) to the test transient by way of the pyrotechnic device.

Step 8. Record necessary data that show the shock transients met or exceeded desired test levels. This includes test set-up photos, test logs, and plots of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure these assemblies did attenuate the pyroshock.

Perform the functional check on the test item. Record performance data.

If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4, and 5, a minimum of three times for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4, and 5, as specified in the Test instruction.

Document the test series.

5.6.2 Procedure II - Near-Field with Simulated Configuration

Step 9. Following the guidance provided in this method; supplemental information is in reference a, select test conditions and calibrate the shock apparatus as follows:

a. Select accelerometers and analysis techniques, that meet the criteria, outlined in previous paragraphs of this method; supplemental information is contained in Annex A reference f .

b. Mount the calibration load (the actual test item, a rejected test item, or a rigid dummy mass) to the test apparatus in a manner similar to that of the actual test item. If the test item is normally mounted on shock isolators to attenuate the pyroshock, ensure the isolators are functional during the test.

c. Perform calibration shocks until two consecutive shock applications to the calibration load produce waveforms that, when processed with SRS algorithm meet or exceed the desired test conditions, for at least one direction of one axis.

d. Remove the calibrating load and install the actual test item on the shock apparatus, paying close attention to mounting details.

Step 10. Perform a functional check of the test item.

Step 11. Subject the test item, in its operational mode, to the test pyroshock.

Step 12. Record necessary data that show the shock transients met or exceeded desired test levels. If requirements are given in terms of more than one axis, examine responses in the other axes to ensure the test specification has been met. Include test set-up photos, test logs, and photos of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure the isolators attenuated the pyroshock.

Step 13. Perform the functional check on the test item. Record performance data.

Step 14. If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4, and 5, a minimum of three times (for each of the three axis) for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4, and 5, (for each of the three axis) as specified in the Test instruction.

Step 15. Document the test series.

5.6.3 Procedure III - Far-Field with Mechanical Test Device.

Step 16. Following the guidance provided in this method; supplemental information is in reference a. Select test conditions and calibrate the shock apparatus as follows:

a. Select accelerometers and analysis techniques, that meet the criteria, outlined in previous paragraphs of this method; supplemental information is contained in Annex A reference f .

b. Mount the calibration load (the actual test item, a rejected item, or a rigid dummy mass) to the test apparatus in a manner similar to that of the actual materiel. If the materiel is normally mounted on shock isolators to attenuate the pyroshock, ensure the isolators are functional during the test.

c. Perform calibration shocks until two consecutive shock applications to the calibration load produce waveforms that, when processed with an SRS algorithm meet or exceed derived test conditions for at least one direction of one axis.

d. Remove the calibrating load and install the actual test item on the shock apparatus paying close attention to mounting details.

Perform a functional check of the test item.

Subject the test item (in its operational mode) to the test pyroshock.

Record necessary data that show the shock transients met or exceeded desired test levels. If requirements are given in terms of more than one axis, examine responses in the other axes to ensure the test specification has been met. Include test set-up photos, test logs, and photos of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure the isolators attenuated the pyroshock.

Perform the functional check on the test item. Record performance data.

If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4, and 5, a minimum of three times for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4, and 5, as specified in the Test instruction.

Document the test series.

5.6.4 Procedure IV - Far-Field with Electrodynamic Exciter.

Step 17. Following the guidance provided in this method; supplemental information is in Annex A references. Select test conditions and calibrate the shock apparatus as follows:

a. Select accelerometers and analysis techniques, that meet the criteria, outlined in previous paragraphs of this method; supplemental information is contained in Annex A reference f .

b. Mount the calibration load (the actual test item, a rejected item, or a rigid dummy mass) to the electrodynamic exciter in a manner similar to that of the actual materiel. If the materiel is normally mounted on shock isolators to attenuate the pyroshock, ensure the isolators are functional during the test.

c. Develop the SRS wavelet or damped sine compensated amplitude time history based on the required test SRS.

d. Perform calibration shocks until two consecutive shock applications to the calibration load produce waveforms that, when processed with SRS algorithm meet or exceed derived test conditions for at least one direction of one axis.

e. Remove the calibrating load and install the actual test item on the electrodynamic exciter paying close attention to mounting details.

Perform a functional check of the test item.

Subject the test item, in its operational mode, to the test electrodynamic pyroshock simulation.

Record necessary data that show the shock transients met or exceeded desired test levels. If requirements are given in terms of more than one axis, examine responses in the other axes to ensure the test specification has been met. Include test set-up photos, test logs, and photos of actual shock transients. For shock isolated assemblies within the test item, make measurements and/or inspections to assure the isolators attenuated the pyroshock.

Perform the functional check on the test item. Record performance data.

If a dynamically similar test item is used to calibrate the test set-up, repeat steps 3, 4, and 5, a minimum of three times for statistical confidence. If the required test tolerances have been met, replace the substitute test item with the actual test item and repeat steps 3, 4, and 5, as specified in the Test instruction.

Document the test series.

6. EVALUATION OF TEST RESULTS

In addition to the guidance provided above, the following information is provided to assist in the evaluation of the test results. Analyse any failure of a test item to meet the requirements of the system specifications, and consider related information such as follows.

6.1 Procedure I - Near-Field with Actual Configuration

Carefully evaluate any failure in the structural configuration of the test item, e.g., mounts or tiedowns, that may not directly impact failure of the functioning of the materiel, but that would lead to failure in its service environment conditions. Carefully examine any failures as a result of EMI emission.

6.2 Procedure II - Near-Field with Simulated Configuration

Carefully evaluate any failure in the structural configuration of the test item, e.g., mounts or tiedowns, that may not directly impact failure of the functioning of the materiel, but that would lead to failure in its service environment conditions. Carefully examine any failures as a result of EMI emission.

6.3 Procedure III - Far-Field with Mechanical Test Device

The mechanical shock simulation will, in general, provide a more severe low frequency environment, comparatively large velocity and displacement, than the actual pyroshock event and, hence, any structural failures may be more related to those found in the SRS prescribed shock tests described in Method 417. Clearly identify structural failures that may be due solely to over test in the low frequency environment.

6.4 Procedure IV - Far-Field with Electrodynamic Exciter

The electrodynamic shock simulation will, in general, provide a more severe low frequency environment, comparatively large velocity, than the actual pyroshock event and, hence, any structural failures may be more related to those found in the SRS prescribed shock tests described in Method 417. Clearly identify structural failures that may be due solely to overtest in the low frequency environment.

7. REFERENCES AND RELATED DOCUMENTS

a. IES-RP-DTE032.1, Pyroshock Testing Techniques, Institute of Environmental Sciences and Technology, USA, 1 September 2002

b. NASA-STD-7003, Pyroshock Test Criteria, USA National Aerospace and Space Administration, 18 May 2003.

ANNEX A

PYROSHOCK TECHNICAL GUIDANCE

1. SCOPE

This annex is designed to provide technical guidance on the general considerations and terminology given to pyroshock testing within the last few years that is supported by the references in this annex.

1.1 General Considerations - Terminology

1.1.1 Single Measured Environments

In general, response acceleration will be the experimental variable of measurement for pyroshock. This choice of measurement variable does not preclude other variables of measurement such as velocity, displacement, or strain from being measured and processed in an analogous manner, as long as the interpretation, capabilities, and limitations of the measurement variable are clear. Particular attention must be given to the high frequency environment generated by the pyrotechnic device, and the capabilities of the measurement system to faithfully record the materiel responses. Annex A reference f details the trade-off between pyroshock measurement procedures and should be implemented.

The terms that follow will be helpful in the discussion relative to analysis of response measurements from pyroshock testing. To facilitate the definition of the terms, each of the terms is illustrated for a typical pyroshock measurement. Figure A-1 provides an acceleration amplitude time history plot of a measured far-field pyroshock with the instrumentation noise floor displayed before the pyroshock, the pyroshock, and the subsequent post-pyroshock noise floor. It is important to provide measurement data including both the pre-pyroshock noise measurement and the post-pyroshock combined noise and low level residual structure response. The first and last vertical lines represent the equal duration pre-pyroshock, pyroshock, and post-pyroshock time intervals selected for analysis. The pre-pyroshock time interval contains the instrumentation system noise floor, and serves as a measurement signal reference level. The pyroshock time interval includes all the significant response energy of the event. The post-pyroshock time interval is of equal duration to the pre-pyroshock time interval, and contains the measurement system noise in addition to some of the pyroshock residual noise inconsequential to the response energy in the pyroshock. In some cases where the pre-pyroshock and post-pyroshock amplitude levels are substantial compared to the pyroshock, the pyroshock has been mitigated and/or the measurement system noise is high, the identification of the pyroshock may need critical engineering judgement relative to the start and the termination of the pyroshock event. In any case, analysis of pre-pyroshock and post-pyroshock measurement information in conjunction with the pyroshock measurement information is essential. Validate all data collected from a pyroshock. Annex A reference f provides guidelines. One of the simplest, and most sensitive, criteria for validation is an integration of the signal time history after removing any small residual offset. If the resulting integrated signal has zero crossings and does not appear to go unbounded, the pyroshock has passed the first validation test. Figure A-2 provides the velocity plot for the pyroshock in Figure A-1.

a. Effective Transient Duration For a pyroshock, the "effective transient duration", $T_{e,}$ is the minimum length of time that contains all significant amplitude time history magnitudes. T_e begins at the noise floor of the instrumentation system, just prior to the initial most significant measurement, and proceeds to the point that the amplitude time history is a combination of measurement noise and substantially decayed structural response. An experienced analyst is required to determine the pertinent measurement information to define the pyroshock event. The longer the duration of the pyroshock, the more low frequency information is preserved that may be important for far-field test considerations. For near-field test considerations, the effective transient duration will be much shorter because of the higher ranging of the measurement system. The amplitude criterion requires that the amplitude of the post-pyroshock amplitude time history envelope be no more than 12 dB above the noise floor of the measurement system depicted in the pre-pyroshock amplitude time history. Method 417 Annex E provides further description of $T_{e.}$

   From Figure A-1 there appears to be at least two logical times at which the pyroshock might be terminated. The first time is immediately after the end of the high frequency information, the second vertical dashed line in Figure A-1 at approximately 3.5 milliseconds after the beginning of the pyroshock. The second time is given by the third vertical line in Figure A-1, some 6.6 milliseconds after the beginning of the pyroshock and after some of the apparent low frequency structural response has been attenuated. These judgements, based on examination of the amplitude time history, use an amplitude criterion and a frequency criterion. Figure A-3 contains a plot of amplitude of the absolute value of the pyroshock, in dB versus time. This figure illustrates the difficulty in coming up with precise criteria for determining the effective duration of a pyroshock. The initial noise floor level is never obtained in the record. Figure A-1 illustrates the difference between processing the two different pyroshocks in Figure A-1, with the SRS, i.e., the short duration pyroshock and the long duration pyroshock. It is clear that the only significant difference is near 100 Hz. The magnitude of the SRS at lower natural frequencies can be quite sensitive to the effective transient duration, whereas the SRS at higher natural frequencies is generally insensitive to the effective transient duration.

b. Shock Response Spectrum Analysis Annex A reference k defines the absolute acceleration maximax Shock Response Spectrum (SRS) and provides examples of the SRS computed for classical pulses. The SRS value at a given undamped natural oscillator frequency, fn, is defined to be the absolute value of the maximum of the positive and negative acceleration responses of a mass for a given base input to a damped single degree of freedom system. The base input is the measured shock over a specified duration (the specified duration should be the effective duration). For processing of pyroshock shock response data, the absolute acceleration maximax SRS has become the primary analysis descriptor. In this measurement description of the pyroshock, the maximax absolute acceleration values are plotted on the ordinate, with the undamped natural frequency of the single degree of freedom system with base input plotted along the abscissa.

A more complete description of the pyroshock, and potentially more useful for pyroshock damage comparison in the far-field, can be obtained by determining the pseudo-velocity response spectrum. This spectrum is plotted on four-coordinate paper where, in pairs of orthogonal axes, the pseudo-velocity response spectrum is represented by the ordinate with the undamped natural frequency being the abscissa and the maximax absolute acceleration along with the pseudo-displacement plotted in a pair of orthogonal axes. All plots have the same abscissa, see Annex A reference k. The pseudo-velocity at a particular oscillator undamped natural frequency is thought to be more representative of the damage potential for a shock since it correlates with stress and strain in the elements of a single degree of freedom system, Annex A reference b. The pseudo-velocity response spectrum can be computed either by (1) dividing the maximax absolute acceleration response spectrum by the undamped natural frequency of the single degree of freedom system, or (2) multiplying the relative displacement by the undamped natural frequency of the single degree of freedom system. Both these means of computation provide essentially the same spectra except possibly in the lower frequency region, in which case the second method of computation is more basic to the definition of the pseudo-velocity response spectrum.

Figure A-5 provides the estimate of the maximax absolute acceleration SRS for the record pyroshock record in Figure A-1, and Figure A-6 provides the estimate of the pseudo-velocity, pseudo-displacement and maximax absolute acceleration for this record on four-coordinate paper. In general, compute the SRS over the pyroshock event duration, and over the duration measurement for the pre-pyroshock and the post-pyroshock events with twelfth octave spacing and a Q = 10 (Q=10 corresponds to a single degree of freedom system with 5% critical damping). Figure A-5 also provides estimates of the maximax absolute acceleration SRS for the pre-pyroshock and the post-pyroshock. Figure A-6 provides estimates of the pseudo-velocity response spectrum for the pre-pyroshock and the post-pyroshock. If the testing is to be used for laboratory simulation, use a second Q value of 50 (Q=50 corresponds to a single degree of freedom system with 1% critical damping) in the processing. It is recommended that the maximax absolute acceleration SRS be the primary method of display for the pyroshock, with the pseudo-velocity response spectrum as the secondary method of display and useful in cases in which it is desirable to be able to correlate damage of simple systems with the pyroshock.

c. Energy Spectral Density Annex A reference l defines the Energy Spectral Density (ESD) estimate for a pyroshock of duration T. In this description, the properly scaled magnitude of the Fourier Transform of the total pyroshock is computed at a uniform set of frequencies and displayed as a two-dimensional plot of amplitude versus frequency. The amplitude units are (units^2-sec)/Hertz. In determining the ESD estimate, it is important that, if the Fast Fourier Transform is used, the block size is selected such that all of the pyroshock event is contained within the block but excessive noise beyond the duration of the transient is removed by zero-padding the Fourier Transform block. The ESD description is useful for comparing the distribution of energy within the frequency band amongst several pyroshocks. However, if adjacent frequency components are not averaged, the percentage of normalised random error in the ordinate is 100%. By averaging n adjacent ordinates, the percentage of normalised random error decreases as $1/\sqrt{n}$ with a decreased frequency resolution. Computation of the ESD estimates for the pre-pyroshock and the post-pyroshock provide useful information relative to the distinct frequency character of the pyroshock as compared to the frequency character of the pre-pyroshock noise and the post-pyroshock combination noise and structural response. Figure A-7 provides ESD estimates for the pyroshock and the pre-pyroshock and post-pyroshock events in Figure A-1, respectively.

d. Fourier Spectra Annex A reference I defines the Fourier Spectra (FS) estimate for a pyroshock of duration T. In this description, the properly scaled square root of the magnitude of the Fourier Transform of the total pyroshock is computed at a uniform set of frequencies and displayed as a two-dimensional plot of amplitude versus frequency. The amplitude units are (units-sec). In determining the FS estimate, as in the case of the ESD estimate, it is important that if the Fast Fourier Transform is used, that the block size is picked such that all of the transient is contained within the block but excessive noise beyond the duration of the transient is removed by zero-padding the Fourier Transform block. This description is useful for noting outstanding frequency components within the overall frequency band amongst pyroshocks. If adjacent frequency components are not averaged, the percentage normalised random error in the ordinate is 100%. By averaging n adjacent ordinates, the percentage of normalised random error decreases as $1/\sqrt{(n)}$ with a decreased frequency resolution. Computation of the FS estimates for the pre-pyroshock and the post-pyroshock provide useful information relative to the distinct frequency character of the pyroshock as compared to the frequency character of the pre-pyroshock noise and the post-pyroshock combination noise and structural response. Figure A-8 provides FS estimates for the pyroshock and the pre-pyroshock and post-pyroshock events in Figure A-1, respectively.

e. Other Methods Over the past few years, at least two other techniques potentially useful in processing pyroshock data have been suggested. Annex A reference h describes the utilisation of time domain or temporal moments for comparing the characteristics of the pyroshock over different frequency bands. The usefulness of this technique resides in the fact that if the pyroshock can be represented by a simple nonstationary product model, the time domain moments must be constant over selected filter bandwidths. Thus the pyroshock can be characterised by a model with potential usefulness for stochastic simulation. Annex A reference i explores this reasoning for mechanical shock. It has been suggested, Annex A reference j, that "wavelet" processing may be useful for pyroshock description, particularly if a pyroshock contains information at intervals of time over the duration of the shock at different time scales, i.e., different frequencies. It is likely that this form of processing may become more prevalent in the future as the level of examination of transients becomes more sophisticated and if “wavelet” processing is shown to be more useful for description of phenomenon with substantial randomness.

1.1.2 Combination of Measurements

In general, for pyroshock tests a single response record is obtained. At times it may be convenient or even necessary to combine equivalent processed responses in some appropriate statistical manner. Annex A reference g and Method 417 Annex D of this standard discuss some options in statistically summarising processed results from a series of tests. In general, processed results, either from the SRS, ESD or FS are logarithmically transformed in order to provide estimates that are more normally distributed. This is important since often very little data are available from a test series, and the probability distribution of the untransformed estimates cannot be considered to be normally distributed. In all cases, the combination of processed results will fall under the category of small sample statistics and needs to be considered with care utilising parametric or less powerful nonparametric methods of statistical analysis. Method 417 Annex D addresses some appropriate techniques for the statistical combination of processed test results from a limited number of tests.

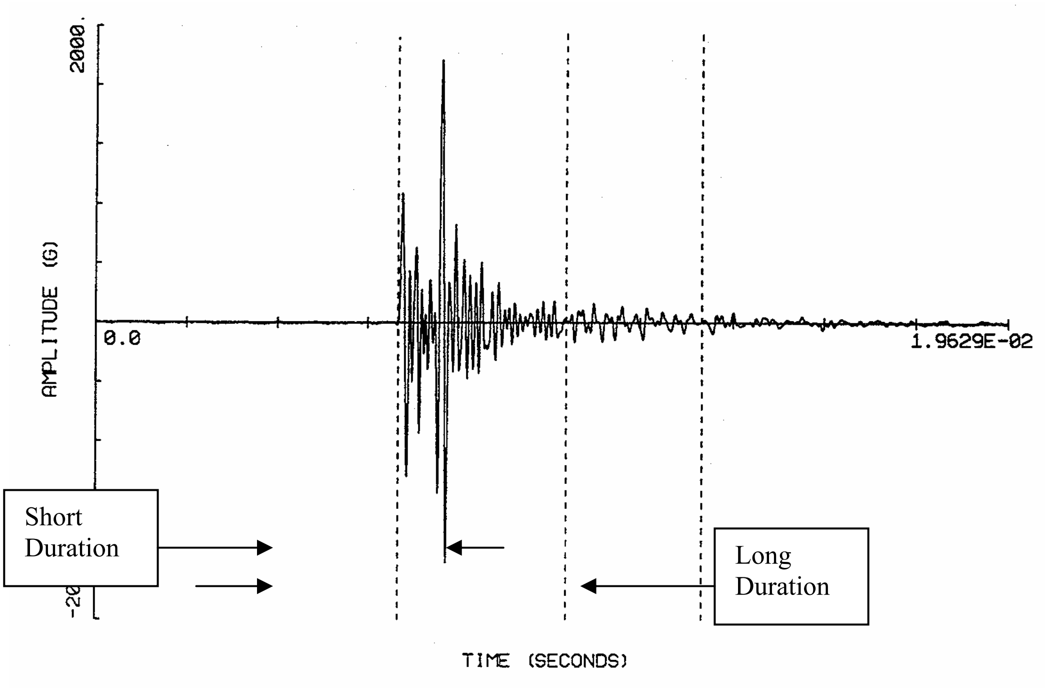

Figure A-1 Total Event Pyroshock Amplitude Time History

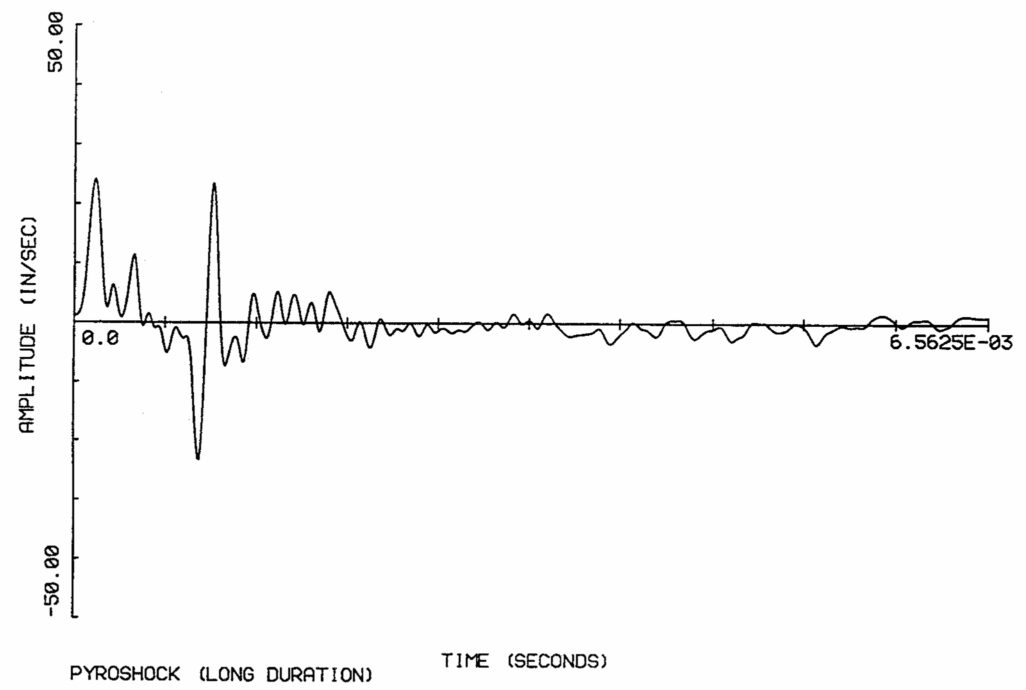

Figure A-2 Pyroshock Velocity Amplitude Time History

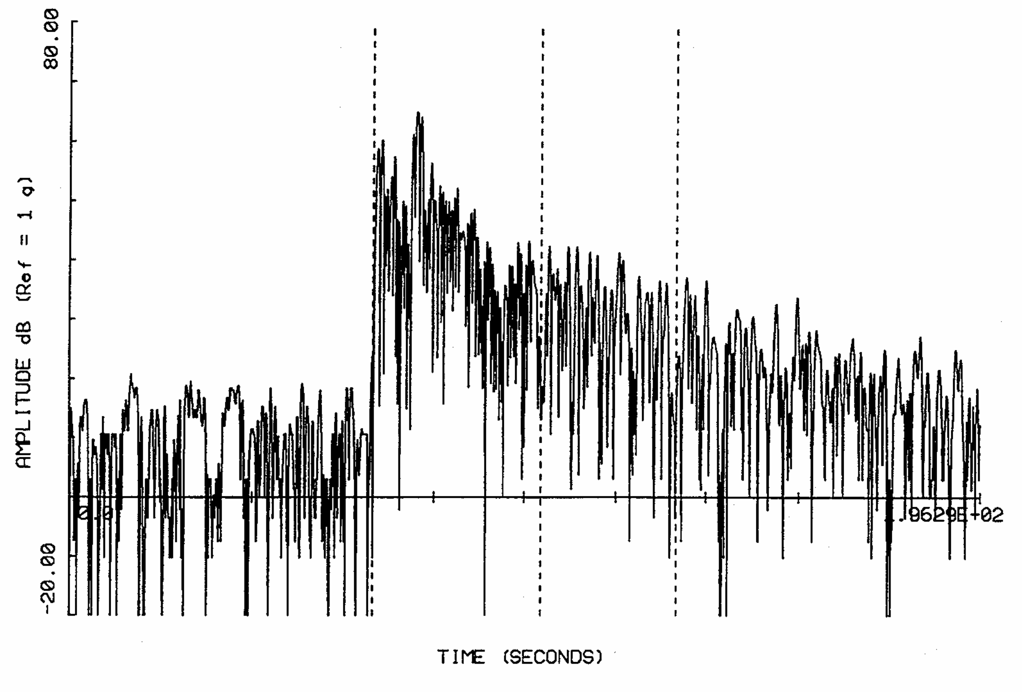

Figure A-3 Magnitude Amplitude Time History

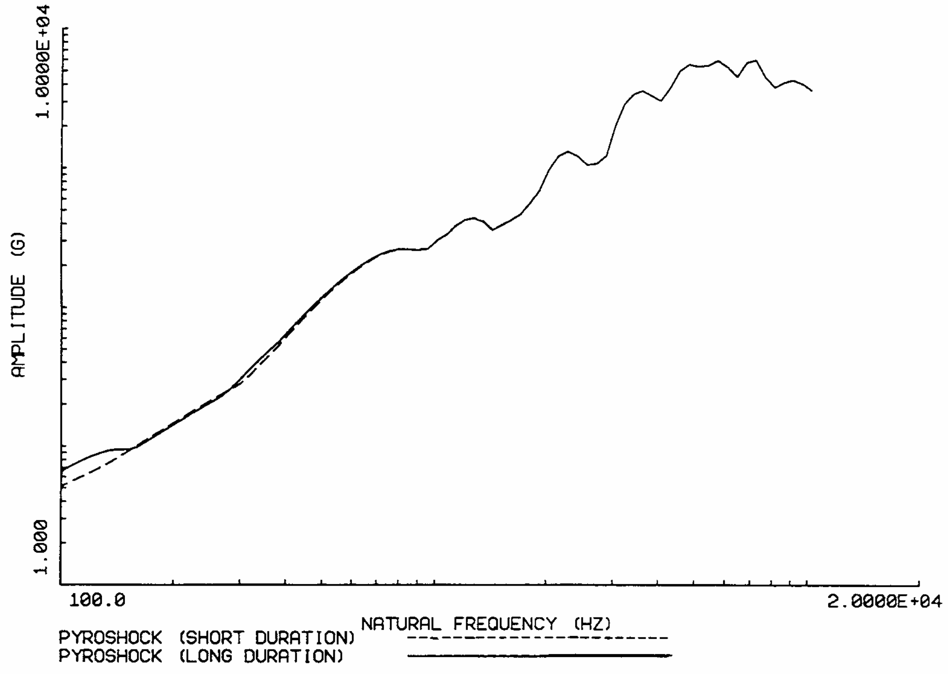

Figure A-4 Acceleration Maximax SRS

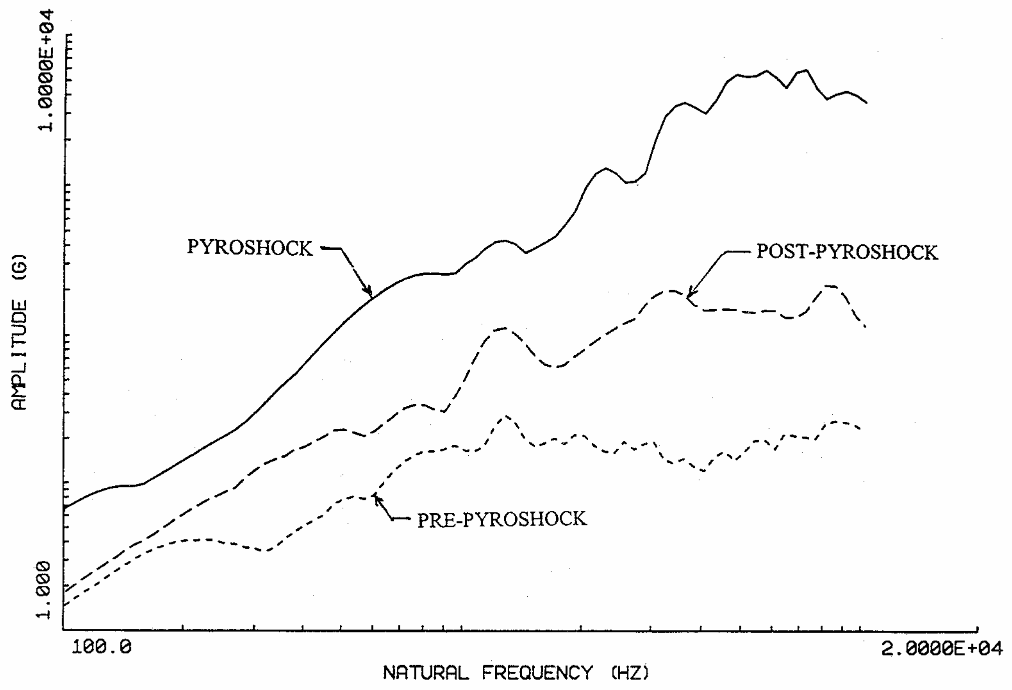

Figure A-5 Acceleration Maximax SRS - Total Shock Event

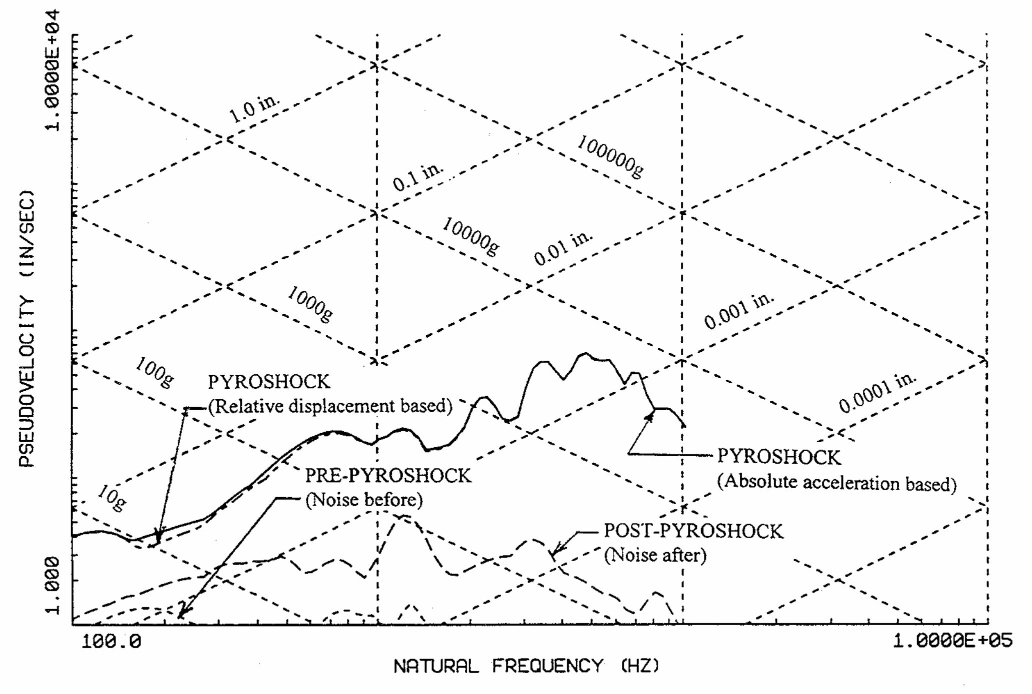

Figure A-6 Pseudovelocity Response Spectrum

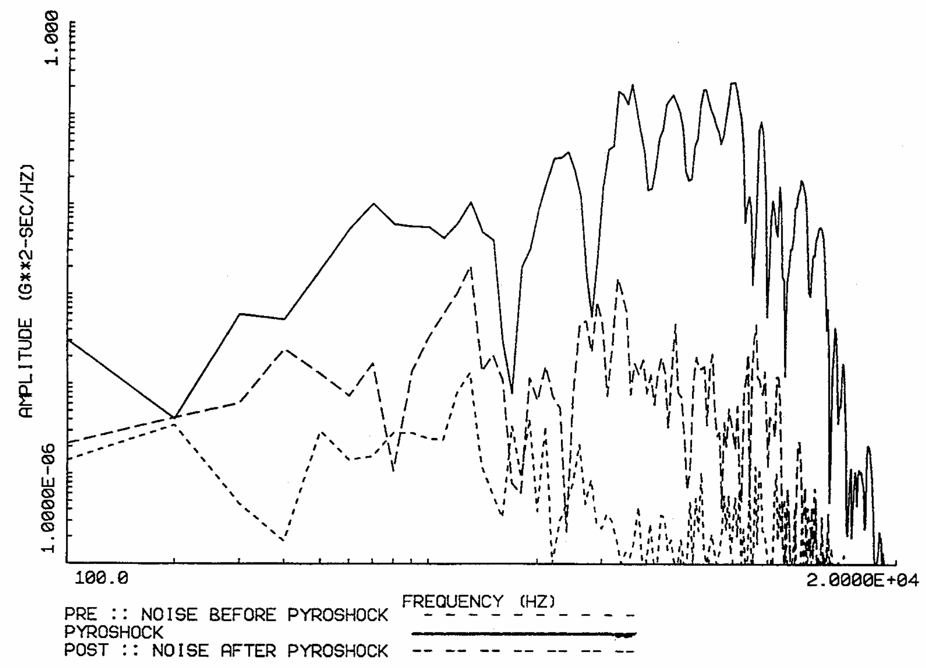

Figure A-7 Acceleration Energy Spectral Density Estimate

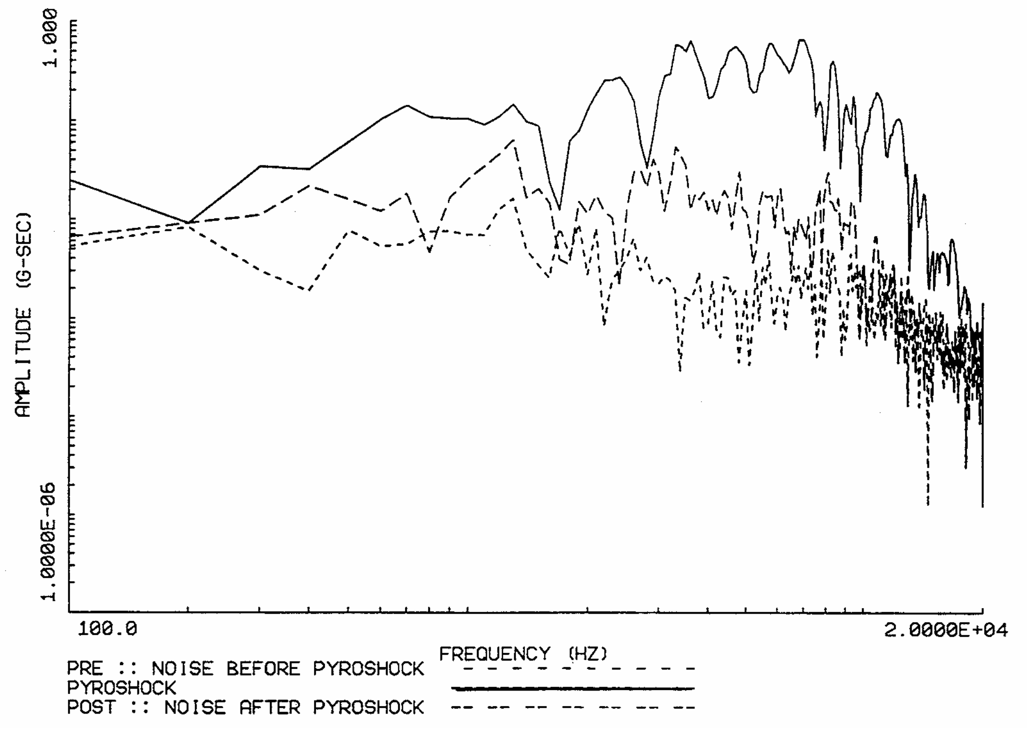

Figure A-8 Acceleration Fourier Transform Estimate

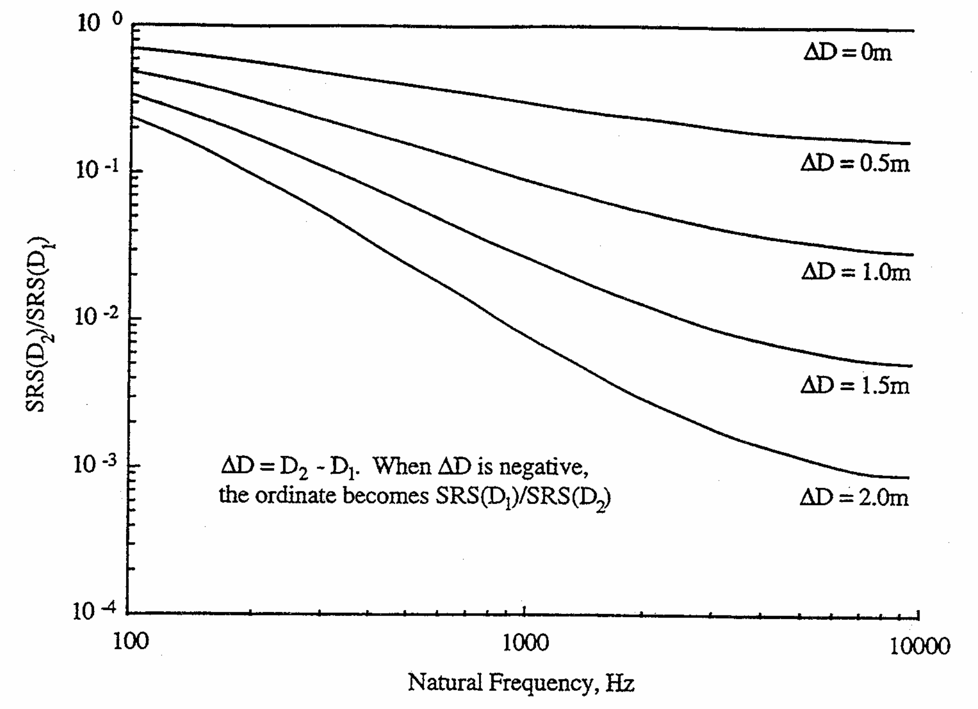

Figure A-9 Correction of Shock Response Spectrum for Distance From Pyrotechnic Source

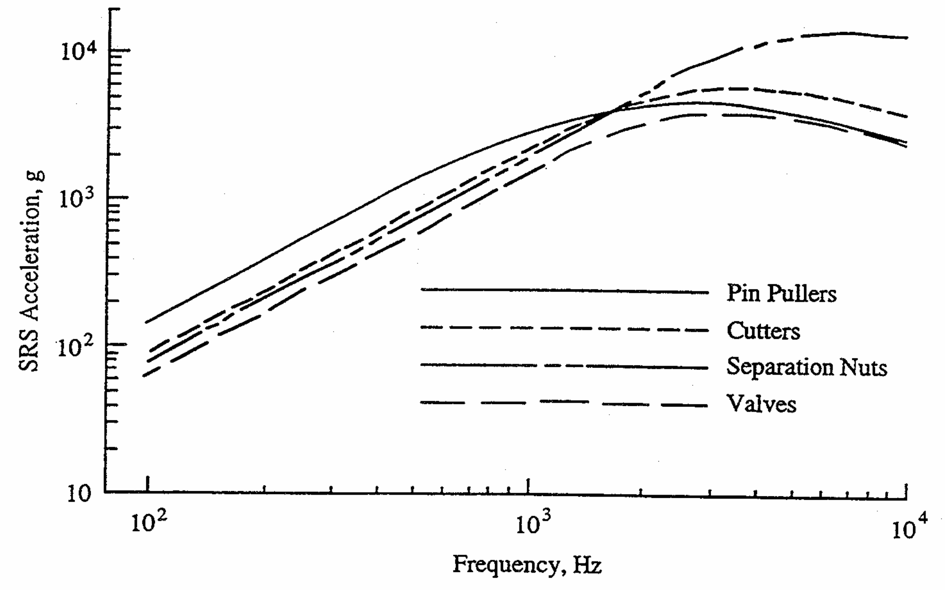

Figure A-10 Shock Response Spectra for Various Point Source Pyrotechnic Devices

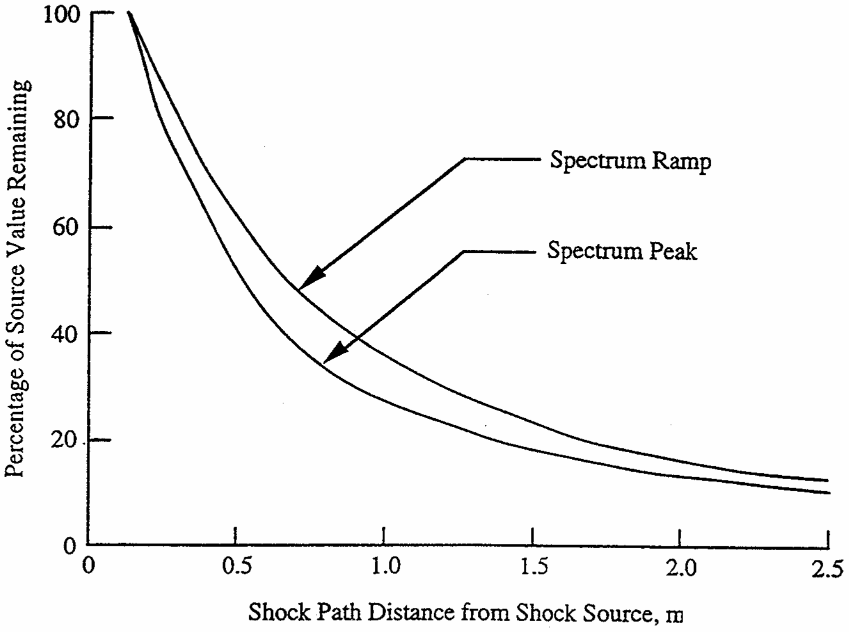

Figure A-11 Shock Response Spectrum vs Distance From Pyrotechnic Source

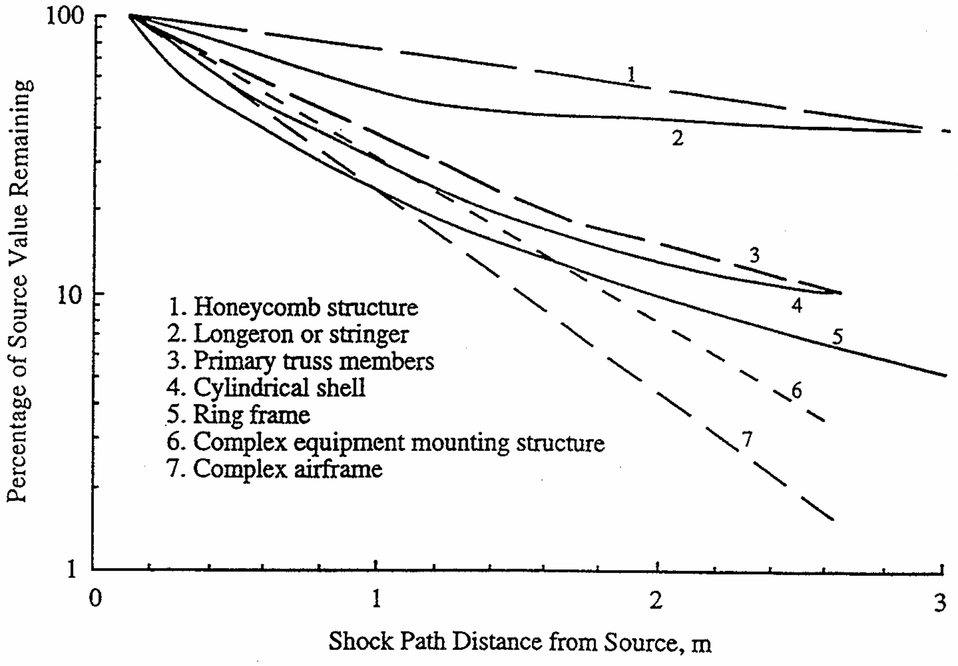

Figure A-12 Peak Pyroshock Time History Response vs Distance From Pyrotechnic Source

REFERENCES AND RELATED DOCUMENTS

Included below are references used in the text to define terminology and provide information on techniques used in pyroshock testing.

a. Harris, Cyril M., ed. Shock and Vibration Handbook, 3rd Edition, NY, McGraw-Hill, 1988.

b. Gaberson, H. A. and R. H. Chalmers. Model Velocity as a Criterion of Shock Severity, Shock and Vibration Bulletin 40, Pt. 2, (1969) 31-49.

c. ANSI/ASTM D3332-77, Standard Methods for Fragility of Products Using Machines. 1977.

d. Gaberson, H. A. and R. H. Chalmers. Reasons for Presenting Shock Spectra with Velocity as the Ordinate, Proc. 66th Shock and Vibration Symp., Vol. II, pp 181-191, Oct/Nov. 1995.

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.

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k. Kelly, Ronald D. and George Richman, Principles and Techniques of Shock Data Analysis, The Shock and Vibration Information Center, SVM-5, United States Department of Defense.

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n. Barrett, S., The Development of Pyro Shock Test Requirements for Viking Lander Capsule Components, Proceedings of the 21st ATM, Instutite of Environmentatal. Sciences., pages 5-10, Apr. 1975

o. Kacena, W. J., McGrath, M. B., and Rader, W. P., Aerospace Systems Pyrotechnic Shock Data, NASA CR-116437, -116450, -116401, -116402, -116403, -116406, and -116019, Vol. I-VII, 1970.

METHOD 416

RAIL IMPACT

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METHOD 416

RAIL IMPACT

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the railroad car impact conditions that occur during rail shipment of systems, subsystems and units, hereafter called materiel, and their tiedown arrangements during the specified logistic conditions. Rail impacts tests are also conducted to subject large materiel to specified longitudinal and/or transverse shocks to demonstrate material strength.

1.2 Application

AECTP 200 provides guidance on the selection of a test procedure for a specific rail impact environment. Further description of procedures for railcar loading and transportation are provided in reference d.

Test Procedure I (US Cushioned Coupler Car) is applicable where materiel is required to demonstrate its adequacy to resist the specified railroad car impact environment without unacceptable degradation of its functional and/or structural performance. This test is mandatory for materiel to be transported by rail in the US.

Test Procedure II (European Railway) is applicable for the generation of a low-level, long duration shock on large test items, and is a requirement of the European Railway Administration.

Test Procedure III (Laboratory Simulation) is a laboratory simulation applicable to items fitted onto or transported by railway vehicles.

1.3 Limitations

This method is not intended for railcar crash conditions or small individual packages that would normally be shipped mounted on a pallet.

2. TEST GUIDANCE

2.1 Effect of the Environment

The following list is not intended to be all inclusive, but provides examples of problems that could occur when materiel is exposed to the rail impact environment.

a. Loosening of tiedown straps.
b. Failure of attachments, creating a safety hazard.
c. Shifting of materiel on the railcar.
d. Failure of materiel.

2.2 Use of Measured Data

For Procedures I and II, measured field shock data is generally useful only as a baseline reference during testing. Measured data can be used to tailor the classical shock waveform amplitude in Procedure III, or provide a shock time history waveform for laboratory simulation tests.

2.3 Choice of Test Procedures

Procedure I - US Cushioned Coupler Car is mandatory for test items shipped by rail within the US. Procedure I is derived from MIL-STD 810 and reference e. Procedures II and III are not acceptable substitutes for Procedure I. In addition, analytical computer model based simulation, such as finite element methods, do not eliminate the requirement to perform the Procedure I laboratory testing

Procedure II - European Railway is for shock test purposes only and is a requirement of the European Railway Administration. Procedure II is derived from reference c.

Procedure III - Laboratory Simulation is a laboratory shock test used to simulate the rail impact environment, and is based on acceleration levels from references a and b.

2.4 Sequence

The order of the rail impact testing will be determined by the requesting organization and specific sequential test requirements should be stated in the Test Instruction.

3. SEVERITIES

Test conditions are specified in paragraph 5.3.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item
b. The definition of the test item
c. The definition of test severity
d. Tiedown conditions
e. Axis and direction in which the impact is applied to the test item
f. Details required to perform the test
g. Speed measurement
h. The indication of the failure criteria

4.2 If Required

a. Railcar speed tolerances, if different from paragraph 5.1.,
b. Tolerances on acceleration amplitude and pulse width (Procedure II)

c. Tiedown chain or cable tension and instrumentation or load measurement requirements

d. Instrumentation requirements for test item acceleration or railcar coupler force.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

The procedure I railcar impact speed tolerance is + 0.8, - 0.0 km/hr for all railcar impact speeds and successive impacts.

5.2 Installation Conditions of Test Item

Test Procedure I requires that the test item be mounted on the railcar in direct contact with the floor, and secured using the approved or Test Instruction specified tiedown method.

Test Procedure II requires that the test item be secured to the railcar in a manner such that the test item suspension is rendered mostly ineffective.

Test Procedure III requires that the test item be secured to the shock machine as described in Method 403, paragraph 5.2 .

5.3 Test Conditions

Several techniques exist to calibrate a section of rail track and monitor the railcar speed for testing, such as radar, timing, or track marking. Tests are typically performed on a level section of track with a minimum 61 m (200 ft.) length test section. A locomotive car is used to initiate the motion of the moving railcar(s). Use of an incline track section to initiate railcar motion is also possible. To insure test repeatability, the measurement of tiedown forces and railcar coupler force in Procedure I and II is desirable. In addition, the use of empty railcars for the stationary, or moving, impact mass railcars will improve test repeatability by eliminating the amount of shock impact energy transferred into kinetic energy motion of the mass located on these railcars. Increasing the mass of impact railcars with dummy weight is permissible; however the mass must be securely attached to the railcar to prevent relative motion during testing.

5.3.1 Test Procedure I - US Cushioned Coupler Car

The test item shall be mounted on a cushioned coupler car. The railcar containing the item to be tested should travel at the specified speed and collide with a stationary railcar(s) having a minimum total gross weight of 250,000 lbs (114,000 kg). One to five stationary railcars are allowable to meet the 250,000 lbs. Prior to impact the airbrakes of the non-moving railcar(s) shall be set in the emergency position, and the couplers shall be compressed. If the test item can be shipped in only one orientation, the railcar shall be impacted once at speeds of 4, 6, and 8 mph (6.4, 9.7, and 13.0 km/hr) in one direction and 8 mph (13.0 km/hr) in the opposite direction (a total of 4 impacts). The tiedown hardware shall not be re-tensioned during the successive speed tests. If the test item can be shipped in more than one orientation, the test shall be repeated for each transportation orientation. The specified speeds are mandatory for equipment to be transported by rail in the USA.

Blockings, tiedowns, and the test item shall be inspected after each impact. The blockings and tiedowns shall be repaired if damaged, and the test performed again starting with the lowest impact speed. Failure of tiedown attachments considered built in parts of the equipment shall constitute a failure. Repair and retesting will be required.

5.3.2 Test Procedure II - European Railway

The test item is positioned on a stationary test car, and is impacted by another railcar (impact car) which is set in motion by a locomotive at an initial speed of 5.0 km/h (3 mph). The impact speed is gradually increased until the required acceleration amplitude and pulse width are achieved. The maximum permissible speed is 10.0 km/h (6 mph). If the specified acceleration cannot be achieved at an impact speed of 10.0 km/h, the mass of the impact car must be increased. The required Procedure II measured test item acceleration levels are defined in Table 416-1 .

Table 416-1 Procedure II Measured Test Item Shock Acceleration Amplitude

Axis	Peak Acceleration, g	Pulse Width, ms
Longitudinal	4.0	50
Lateral	0.5	50
Vertical	0.3	50

It is unlikely that the acceleration and pulse width for the lateral and vertical axes will be met simultaneously with those in the longitudinal axis. Therefore, the tolerances specified in the Test Instruction should take into account of this uncertainty.

5.3.3 Test Procedure III - Laboratory Simulation

Test Procedure III is a laboratory shock simulation applicable to items fitted onto or transported by railway vehicles. See Method 403, Classical Waveform Shock, Annex A for test severities. Test procedures defined in Method 417, SRS Shock, may also be applicable for laboratory simulation tests if adequate field data is available for the simulation requirements.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of the rail impact test.

7. REFERENCES AND RELATED DOCUMENTS

a. Random Vibration and Shock Testing of Equipment for Use on Railway Vehicles, IEC TC9 WG 21, Draft 12th revision 1996 (9/1371).

b. Magnuson, C.F. and Wilson L.T, Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks, Sandia Laboratories, Report SAND76- 0427, July 1977.

c. RIV Anlg II Verladevorschriften Band I und II (taken from the Guidelines/Requirement of the European Railway Administration)

d. TM 55-2200-001-12, Transportability Guidance, Application of Blocking, Bracing, and Tiedown Materials for Rail Transport, US Department of Army, 18 November 1992

e. Test Operation Procedure (TOP) 1-2-501, Rail Impact Testing, AD Number A295441, 10 October 2001

METHOD 417

SRS SHOCK

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METHOD 417

SRS SHOCK

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the effects of complex transient responses that are incurred by systems, subsystems, and units, hereafter called materiel, during the specified operational shock conditions. The test method centers on the use of the shock response spectrum (SRS) and techniques associated with the SRS.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified complex transient responses without unacceptable degradation of its functional and/or structural performance. It is particularly useful for tailoring shock responses where measured time history data are available for the operational environment, and when used for this purpose, this test method is the preferred alternative to classical waveform shock testing. The test method is based primarily on the use of an electrodynamic or an servohydraulic vibration test system, with an associated control system used as a shock test machine. This method precludes the use of more traditional shock test machines such as the shock drop table. If it can be demonstrated that the materiel exposure shock is more of a classical form e.g., half-sine, terminal peak sawtooth, or trapezoidal, Method 403 Classical Waveform Shock is recommended. AECTP 200 provides additional guidance on the selection of a test procedure for a specific shock environment.

1.3 Limitations

This test method is not intended to cover close proximity gun blast, nuclear blast, underwater explosion, or safety drop environments. Pyrotechnic shocks are addressed in Method 415 Pyroshock.

It may not be possible to simulate some in-service operational high amplitude, high frequency responses because vibration test system power constraints or fixture limitations may prevent the satisfactory application of the SRS shock pulse to the test item.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel responds to complex shock environments.

a) Materiel electronic circuit card malfunction, electronic circuit card damage, electronic connector failure ;

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

c) Permanent mechanical/structural 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 component being exceeded ;

e) Materiel failure as a result of increased or decreased friction between parts, or general interference between parts ;

f) Fatiguing of materiel (low cycle fatigue) ;

g) Intermittent electrical contacts ;

h) Cracking and rupturing of materiel.

2.2 Use of Measured Data

Measured time history data from a specific operational environment should be used to develop the test severity levels. It is essential to use measured data where a precise materiel response simulation is required. Sufficient measured data should be obtained to adequately describe the environmental conditions that the materiel will experience. If possible, the measured data should be used to construct a statistical description of the environment against which the statistics of the materiel response from testing may be compared; also see AECTP 200, leaflet 2410. In any case, use of measured data for specifying test severity levels must follow guidelines for rational processing of the data to provide environmental envelopes, etc.

2.3 Sequence

The effect of shock induced stress in the materiel may affect the materiel performance under other environmental conditions such as vibration, temperature, altitude, humidity, pressure, leakage, EMI/EMC, etc. or any combination of these environmental conditions. If the materiel is likely to be sensitive to a combination of environments, it is essential that the materiel be tested to the relevant environmental combinations simultaneously.

Where it is considered that a test with combined environments is not essential, or impractical to conduct, and it is required to evaluate the effects of materiel response to shock with the materiel response to other environments, then a single test item should be exposed to all relevant environmental conditions. The order of application of the environmental test should be compatible with the Service Life Environmental Profile.

2.4 Choice of Test Procedure

There is only one procedure for SRS shock testing.

2.5 General Information for SRS Shock Simulation

2.5.1 General Guidance

Recommended procedures for developing test waveforms from SRS are provided in Annexes B through E. It should be noted that there is no unique amplitude time history pulse associated with a given SRS, and selection of an artificially generated time history pulse from a given SRS must (1) resemble the measured materiel response in amplitude and general shape, and (2) have a duration corresponding closely with the duration of the measured materiel response.

The test requesting organization has the responsibility to verify that the time history used to generate the SRS in the test laboratory is compatible, in terms of amplitude and duration, with the time history measured during an operational condition. In all cases, it is essential that any test waveform developed from an SRS be agreed to by the requesting organization. If the test laboratory does not have access to this operational time domain data, a statement to this effect shall be included in the test report.

2.5.2 Classical Shock Waveforms

Many operational shock environments produce materiel response of a complex nature. To assess the structural integrity and the functional performance, it is necessary to subject the materiel to a close representation of the materiel's expected in-service environment. Only in some very special cases will the materiel response be adequately replicated by the use of classical pulses, e.g. half-sine, terminal peak sawtooth, trapezoidal, etc., on traditional shock test machines. Realistic replication of measured or predicted materiel response shock environments on vibration test systems is possible with computer-based vibration control systems. Test methods can be implemented that allow the tailored use of such equipment to reproduce the materiel response to operational shock environments. With the advent of a modern vibration test systems capable of reproducing most field measured or predicted complex amplitude time history waveforms, the use of classical shock tests has become a less desirable mode of testing because of the potential for over or under testing in certain frequency ranges and the effort needed to properly calibrate the traditional shock machines. The general information in this section is primarily directed towards the test replication of complex materiel response on a modern vibration test system.

2.5.3 Equipment Limitations

The ability of exciter systems to apply shock or transient waveforms to a test item is limited by the force, acceleration, velocity, and displacement capabilities of the vibration test system used. Configuring tests such that the velocity and displacement capabilities of the vibration test system are not exceeded is important. It is often necessary to adjust the amplitude or phase of low frequency components of the complex waveform to ensure that the velocity and displacement requirements for the test remain within acceptable limits. There are several methodologies for time history pulse compensation to limit the exciter displacement and velocity. Also, there are substantial differences in response variable ranges in different frequency regions between electrodynamic and servohydraulic vibration test systems. In general, electrodynamic vibration systems are capable of testing to 2000 Hz with reduced low frequency displacement capability. Servohydraulic vibration systems are capable of test to perhaps 1000 Hz, but with substantial low frequency displacement capability. Annex C provides further information on SRS test equipment.

2.5.4 Preliminary Testing

Since shock tests are performed in an open-loop mode on vibration control systems, it is essential that the input signal in the form of voltage be adjusted before the test. It is also important to recognize that the goal of the test is the precise replication of the predicted or measured materiel response. To permit the vibration control system to achieve the required test waveform, it is almost always necessary to apply several precursor pulses to the test item at a greatly reduced amplitude. The relationship between the vibration control system voltage and the measured response under these precursor pulses is then used to adjust the input voltage signal to achieve the desired materiel response waveform. In order to avoid unnecessary stress to the test item, it is recommended that a dynamic representation of the test item be used to compensate the vibration control system output waveform. However, the dynamic response characteristics of the representation must be very similar to those of the actual test item to which the full amplitude waveform is to be applied. If a dynamic representation is not available, the Test Instruction must state the number of precursor pulses to be applied without producing unacceptable fatigue, and the maximum test amplitude level not to be exceeded. If response averaging of the system transfer function is used in the compensation process, usually three precursor pulses will be adequate to ensure a minimum deviation from the full level response requirements. For cases where the test item responds nonlinearly as a function of response level, waveform compensation may not be possible and initial testing must be performed at full test levels using a dynamic representation of the test item, or an actual test item.

2.6 Derivation of Test Waveform

Guidance on deriving a test waveform from measured time domain data is provided in Annexes B through E.

2.7 Control and Tolerancing Strategies

2.7.1 General Techniques

For the control system to replicate the required materiel response waveform at the test item reference point, the drive waveform applied to the vibration test system is adjusted automatically by use of Fourier processing methods. For verification of the proper application of the waveform to the materiel, the following comparisons should be made:

a. Compare the time history measured at the materiel response reference point with the actual time history, see paragraph 2.7.4. In general, this is a visual inspection of the waveform amplitude peak levels and the general waveform shape.

b. Compare the SRS measured at the materiel response reference point with the SRS specified by the Test Instruction.

The general method used for the control of the test conditions using both time domain inspection and SRS comparison is illustrated in Figure 1.

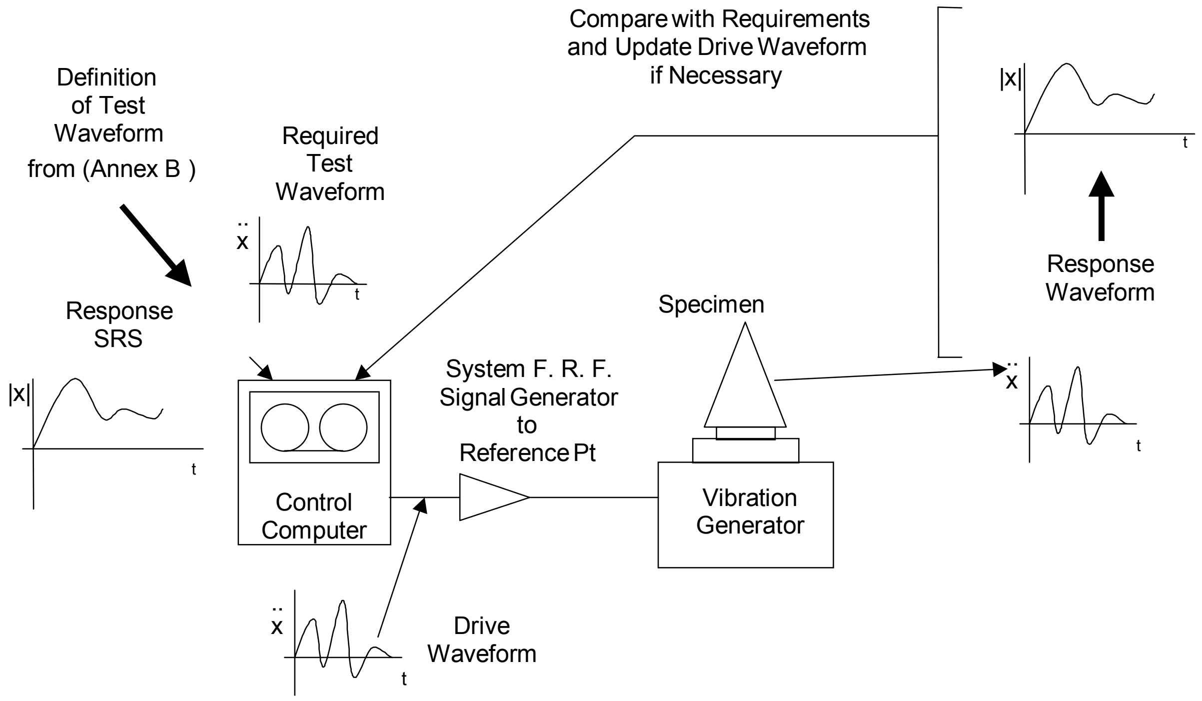

Figure 1 General Methodology of the SRS Shock Test

2.7.2 Simple Waveforms

For relatively simple measured waveforms, few zero crossings, the direct comparison of waveform shapes in the time domain is the most suitable approach. The tolerancing of such simple waveforms as found in classical shock is essentially the same as that for half-sine, terminal peak sawtooth, and trapezoidal pulses as defined in Method 403. The tolerance boundary is placed above and below the required waveform. The test item response waveform as measured at the reference point should be within these boundaries. In cases in which relatively simple waveforms are used in conjunction with a vibration control system, the methodology of such a test control and verification is illustrated in Figure 2.

2.7.3 Complex Waveforms

For complex waveforms, many zero crossings, the use of the SRS as the basis for materiel response comparison and verification is more applicable. An example of a typical complex waveform is shown in Figure 6 of AECTP 200, Leaflet 249/1.

Tolerances are achieved by placing boundaries above and below the required SRS. The upper boundary is often the required, and not to be exceeded, materiel SRS level that is generally a conservative estimate of the in-service environment SRS. The SRS derived from the waveform sampled at the materiel response reference point should be within the upper and lower boundary tolerances. The methodology for a test controlled in this manner is illustrated in Figure 3.

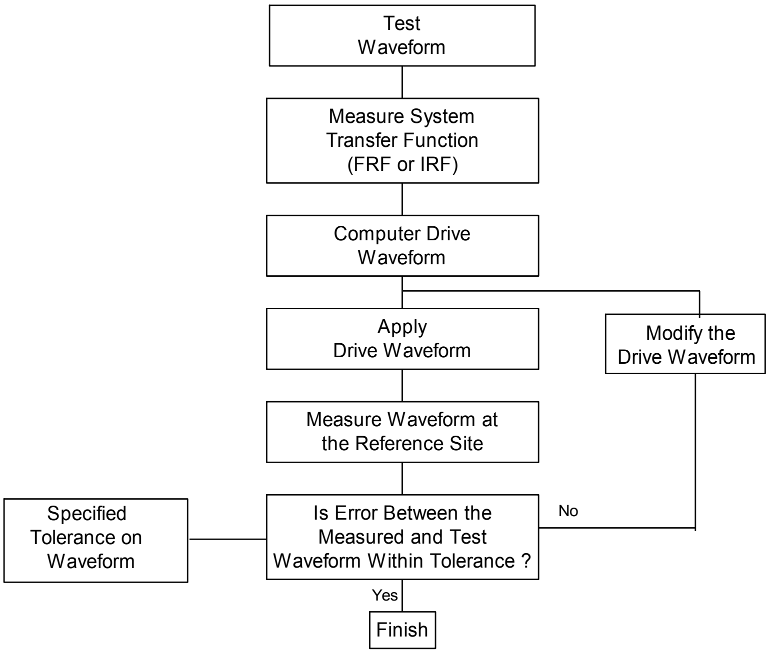

Figure 2 Methodology for the SRS Shock Test When Controlled on Time Domain Parameters

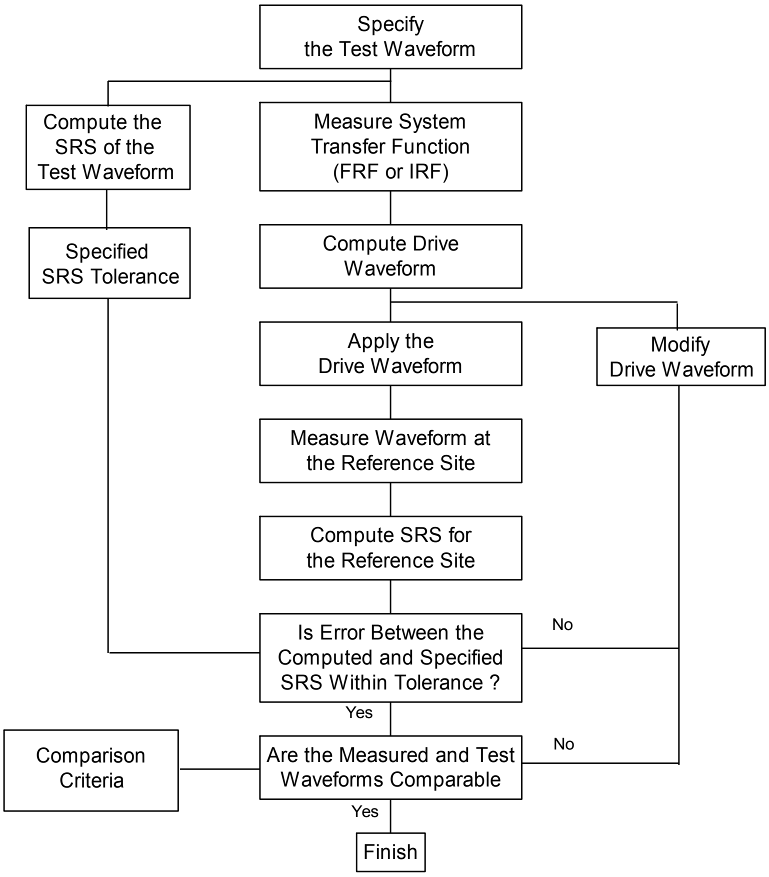

Figure 3 Methodology for SRS Shock Test When Controlled on SRS

2.7.4 Waveform Duration

As mentioned in paragraphs 2.5.1 and 2.7, when an SRS is used for control and tolerance purposes, additional constraint criteria may need to be applied to the time domain parameters. The need for additional constraints is a result of the fact that a single SRS may be replicated by many forms of time history pulses. Failure to accurately reproduce the original time history can result in variation in failure modes produced. When selecting these additional constraints, consider the characteristics of the original materiel response waveform. The two most common constraints applied are a peak amplitude distribution and/or effective pulse duration. In general, a peak amplitude constraint is applicable when failure of the test item could occur as a result of overstress. An effective pulse duration is applicable when low cycle fatigue is of concern. In either case, the duration of the test waveform pulse should not exceed, nor be shorter, than the measured materiel response waveform by more than 15% of total duration. Annex E provides further guidance on definition an appropriate effective duration. When in doubt, peak amplitude should be used as the primary constraint with the peak amplitude of the replicated waveform within 25% of the peak amplitudes of the measured or predicted test waveforms. These two constraint criteria do not preclude the use of alternative methods to ensure that the characteristics of the test pulse are representative of the predicted or measured materiel response characteristics. More complex alternative constraints may use either Fourier spectra, energy spectral density, or time domain/frequency domain energy measures. When such alternative constraint criteria are used, the approach should be clearly stated in the Test Instruction along with supporting documentation and rationale for use of the alternative criteria.

2.8 Control, Monitor, Attachment, Reference Points

For the purpose of this test, the definitions of the fixing, monitor, control and reference points are as follows:

a. An attachment point is defined as a part of the test item in contact with the mounting fixture or vibration table at a point where it is usually fastened in-service.

b. A control point is a position at which measurements are made to allow the transient excitation to be controlled to within specific bounds. In general, the control point on the test item is chosen such that local resonances of the materiel are at a minimum, but the overall response of the test item is well described. If local resonances are not kept to a minimum, there may be difficulty in compensation of the test waveform.

c. A monitor point is a position at which measurements are made in order to establish knowledge of the response behaviour of the test item.

d. The reference point is the point at which the materiel response measurements are measured, or derived, to confirm that the requirements of the Test Instruction are satisfied. The reference point should be stated in the Test Instruction. It may be a monitor point, a control point or a “conceptual point” created by manual or automatic processing of the signals from several control points.

2.9 Materiel Operation

The test item should be operated and its performances measured and noted as specified in the Test Instruction or relevant specification.

3. SEVERITIES

3.1 General

When practical test severities will be established using predicted or measured data acquired with consideration of the projected in-service life profiles and other relevant available data. In general, for complex pulses there are no initial test severities covering specific operational environments for this test method. Further information on response characteristics for specific operational environments is given in AECTP 200.

3.2 Supporting Assessment

The test selected may not be an adequate simulation of the complete environment and consequently, a supporting assessment may be necessary to complement the test results and justify the selected test rationale.

3.3 Isolation System

Materiel identified for use with shock isolation systems should normally be tested with its isolators installed. If it is not practical to carry out the shock test with the appropriate isolators, or if the dynamic characteristics of the materiel are variable, the test item should be tested without isolators at a modified severity specified in the Test Instruction.

3.4 Subsystem Testing

When identified in the Test Instruction, sub systems of the materiel may be tested separately and can be subjected to different shock severities. In this case, the Test Instruction should stipulate the shock severities specific to each subsystem.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item;
b. The definition of the test item;
c. The test severities, including each axes and direction;
d. The specific SRS;
e. The associated time history;
f. The number of pulses to be applied;
g. The type of test : development, qualification, etc.;
h. The method of mounting, including isolators if applicable;
i. The operation or non-operation of the test item during test;
j. The packaging conditions, if applicable;
k. The limits for cross axis motions, if applicable;
l. The requirements for operational checks, if applicable;
m. The reference, control, and monitor points to be used;
n. The tolerances to be applied;
o. The details required to perform the test;
p. The definition of the failure criteria, if applicable;

4.2 If Required

a. The climatic conditions, if other than standard laboratory conditions;
b. The effects of gravity and the subsequent precautions;
c. The value of the tolerable magnetic field during the test;
d. The tolerances, if different or additional to those in paragraph 5.1.

5. TEST CONDITIONS AND PROCEDURES

5.1 Tolerances

Unless otherwise stated in the Test Instruction, the waveform or SRS measured at the reference point(s) shall not deviate from the tolerance requirements by more than the values defined.

5.1.1 Simple Transient Waveforms

For simple transient test waveforms controlled in the time domain, 90 % of the waveform peak and valley amplitudes are to be within ± 10 % amplitude of the specified peaks and valleys respectively. In addition, the controlled waveform peak and valley sequence shall be in sequence of the original waveform, and the transient duration within ± 20 % of the effective duration of the waveform.

5.1.2 Complex Transient Waveforms

For tests controlled on the waveform SRS parameters, the maximax SRS amplitude computed with a one-twelfth octave frequency resolution shall be within -1.5 dB to + 3 dB over 90 % of the specified test control bandwidth, and – 3 dB to + 6 dB over the remaining 10 % of the frequency bandwidth. The minimum test control bandwith for electrodynamic and servohydraulic test systems is 10 Hz to 2000 Hz. Additional constraints on time domain parameters, peak amplitude and/or effective duration, are usually necessary to ensure that an adequate simulation is achieved. These additional constraints are described in paragraphs 2.5.1 and 2.7.4, and those adopted shall be stated in the Test Instruction. The default time duration tolerance of the complex transient control is ± 20 % of the effective duration of the waveform.

The following guidance is provided for application with pseudo-velocity response spectra or multiple point measurement control to specify a shock environment. All tolerances are specified on the maximax acceleration SRS. Tolerances specified on the pseudo-velocity response spectra must be derived from the tolerances on the maximax SRS and be consistent with those tolerances, including a waveform duration tolerance. The test tolerances are stated in terms of single measurement tolerance. For an array of measurements defined in terms of a "zone", the amplitude tolerance may be specified in terms of an average of the measurements within the zone. This is in effect a relaxation of the single measurement tolerance and the individual measurements may be substantially out of tolerance while the average is within tolerance. In general, when specifying test tolerances based on averaging for more than two measurements within a zone, the tolerance band should not exceed the 95/50 one-sided normal tolerance upper limit computed for the logarithmically transformed SRS estimates, nor be less than the mean minus 1.5 dB, see Annex D. Any allowable use of "zone" tolerances and averaging must be specified in the Test Instruction. A tolerance on the duration of the pulse shall also apply to the input pulse duration to the measurement array.

5.2 Installation Conditions of the Test Item

Unless otherwise stated in the Test Instruction for the materiel, the following will apply :

a. Using the normal means of attachment, the test item shall be mechanically fastened to the vibration/shock test system by means of a fixture. Any additional stays or straps should be avoided.

b. The mounting configuration shall enable the test item to be subjected to the specified SRS. The fixing points of the test item should move, as far as practical, in phase and in straight lines parallel with the line of motion. It may be necessary to use different test fixtures for each test axis.

c. Any connections to the test item, such as cables, pipes, or wires, shall be arranged so that they impose similar dynamic restraint and mass to its in-service configuration. Any external connections for measuring purposes shall add minimum restraint and mass.

d. Where gravitational force is important, or when in doubt, the test item shall be mounted so that the gravitational force acts in the same direction as it would in the in-service use.

e. Subject to the guidance given in paragraph 3.3, materiel intended for use with isolators shall normally be tested with the isolators on the test item installed.

5.3 Test Preparation and Pre-conditioning

If required, any structural dynamic characterization tests shall be undertaken and recorded as stipulated in the Test Instruction.

A number of trial applications of the test shock pulse is usually necessary before the control equipment is able to achieve an acceptable response at the reference point. This is a precursor activity usually performed on a dynamically representative test item, see paragraph 2.5.4. If required, the test item shall be stabilized to its initial climatic and other conditions as stipulated in the Test Instruction.

5.4 Operational Checks

All operational checks, including visual examinations, shall be undertaken in accordance with the Test Instruction. The final operational checks should be made when the materiel is at rest, and pre-conditioning conditions including thermal stability, have been obtained.

5.5 Procedure

Undertake the preliminary tasks and test item pre-conditioning as stated in paragraphs. 5.2. and 5.3.

Implement the control strategy, including reference, control, and monitoring points, as defined in the Test Instruction and guidance given in paragraphs 2.5, 2.6, and 2.7.

Undertake the initial operating checks as stated in paragraph 5.4.

Apply the full level transient pulse to the test item in the axes and directions stated in the Test Instruction.

Undertake the final operating checks.

Note : Where the test program requires a number of different SRS test spectrums for the different types of shock or vibration environments, it may be possible to complete the entire sequence of tests for one axis, provided prior agreement is defined in the Test Instruction.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the completion of the SRS shock test.

7. REFERENCES AND RELATED DOCUMENTS

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e. Handbook for Dynamic Data Acquisition and Analysis, IEST-RP-DTE012.1, Institute of Environmental Sciences and Technology, Mount Prospect, IL., 1995.

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

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

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ANNEX A

SRS SHOCK - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Presently initial test severities for Shock Response Spectrum (SRS) controlled tests are not defined. For guidance on the development of tailored test severities, refer to Annexes B, C, and D.

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ANNEX B

TECHNICAL GUIDANCE ON THE DERIVATION OF NON-CONVENTIONAL TEST WAVEFORMS

1 DEFINITION OF THE TEST WAVEFORM

1.1 General

Current facilities and techniques allow the derivation of test waveforms from measured and environmental data by several different methods. The most common approaches include the derivation of test waveforms from:

a. Direct capture of measured in-service data;
b. A shock response spectrum (SRS);
c. Fitting of an analytically described waveform.

1.2 Test Waveforms Derived from Analog Capture

The transient capture facility available on most computer-based control systems may be used to acquire a transient waveform directly. However, the use of waveforms acquired by this approach may be limited by the following:

a. The requirements of the test waveform may be beyond the physical limitations of the vibration test system in terms of either thrust, velocity, or displacement.
b. The statistical uncertainty associated with a single measured event.

The first limitation can sometimes be resolved by modifying the test waveform to ensure that the test system velocity and displacement constraints are met. This is usually achieved by modulating the measured in-service data with a low frequency waveform to ensure the final velocity and displacement are zero. The second limitation can be overcome if sufficient confidence can be achieved in the test data.

1.3 Test Waveforms Derived from a SRS

Where measured data exist which relate to a particular shock environment, but due to data complexity are not suitable as test criteria, the derivation of a test waveform from an SRS may be appropriate. Unfortunately many test time history waveforms can be derived from a single specific SRS. As such, due cognizance should be taken of the nature of the original time history. In these circumstances the derived waveform should always be agreed with the test requesting organization.

A suitable method of deriving a test waveform from a SRS is discussed below under paragraph 2, Generation of Test Waveforms from SRS. The procedure is used to create a test waveform described as an analytical function. The derivation of SRS from field data is addressed in paragraph 3, Determination of SRS from Field Data.

1.4 Test Waveforms Described by Analytical Functions

Where measured data exhibit a repeatable form in the time domain, or are of a simplistic nature, it may be possible to fit a mathematical or analytical function to define the shock time history waveform. It may be necessary when using this approach to modulate the required waveform to ensure that the test control waveform is within the physical capabilities of the vibration test system.

2 GENERATION OF TEST WAVEFORMS FROM SRS

The use of summations of oscillatory type pulses has been recognized as a possible method for representing certain types of shock environments. With the development of digital control techniques it is possible to reproduce complex time histories.

Two types of oscillatory pulse have attained fairly widespread use. These are the decaying sinusoid, which has the form :

$$A = A_o e^{-\zeta \omega t} \sin(\omega t) \quad \text{Equation 1}$$

and the wavelet type pulse which has the form :

$$A = A_o \sin(\omega t) \sin(\psi t)$$

Equation 2

A, ω, ψ,ζ are the amplitude, cyclic frequencies, and the fraction of critical damping (decay rate) of the oscillatory pulses.

Acceptable results may be obtained by using either of these pulses. The approach considered here is the application of decaying sinusoids. However, the comments are largely applicable to both types of oscillatory pulses.

The basic procedure for deriving a suitable waveform from a specified SRS, illustrated in Figure B-1, is as follows:

a. First, an initial estimate is made of the characteristics of the required waveform.

b. Second, this estimate is improved using an iterative procedure.

Obtaining initial estimates of the test waveform may be considered to have three aspects, namely the identification of the frequencies of the important sinusoidal components, the determination of the decay rate for each component, and the determination of the amplitude of each decaying sinusoid.

For those SRS that exhibit clearly identifiable peaks, the initial choice of frequency components is relatively straight forward. However, where no obvious peaks exist, reference to the Fourier spectrum or Energy Spectral Density of the field data may provide an insight into a suitable choice of starting frequencies.

The decay rate of each sinusoidal component may be determined from either inspection of the time history response, or its associated SRS. Decay rates can be obtained from the time history response using techniques such as a logarithmic decrement. The shape of the SRS, as shown in Figure B-2 can also aid the choice of decay rates.

The amplitudes of the sinusoids can be estimated from Figure B-3. Figure B-3 represents the normalized maximum response of a single degree of freedom system to a decaying sinusoidal input as a function of the decay rate of the sinusoid. The plot is for various levels of damping in the single degree of freedom system. Figure B-4 is a plot of the inverse of Figure B-3, that is, the input level for a unit maximum response of a single degree of freedom system with damping. The amplitude of the sinusoidal component may therefore be determined by multiplying the value of the test SRS at the frequency of the decaying sinusoid by the input level corresponding to the appropriate decay rate from Figure B-4.

The sign of the amplitude of the sinusoidal components may be either positive or negative. The choice of sign does not have an effect on the absolute maximax SRS of the composite waveform. If the spectrum contains discrete peaks, then a superposition of in-phase waveforms will accentuate the peaks and valleys in the spectrum. If however, the spectrum is without marked peaks, the synthesis of component waveforms combined alternatively in and out of phase will tend to smooth the spectrum.

An important point to note is that the final velocity and displacement of the derived waveform may not be zero. In order to overcome potential problems with the vibrator exciter control, a compensation pulse is normally added to the synthesized time history. In some proprietary shock synthesis programs this compensation pulse is added without user intervention. However, in other programs the compensation pulse frequency and decay rate must be selected. Generally, a compensation pulse should be applied with a frequency of approximately one-half to one-third the minimum frequency in the SRS with a decay rate approaching 100% of critical damping. Using suitable values of compensation pulse frequency (ω_m) and decay rate (ζ_m), the compensation pulse amplitude (A_m) and

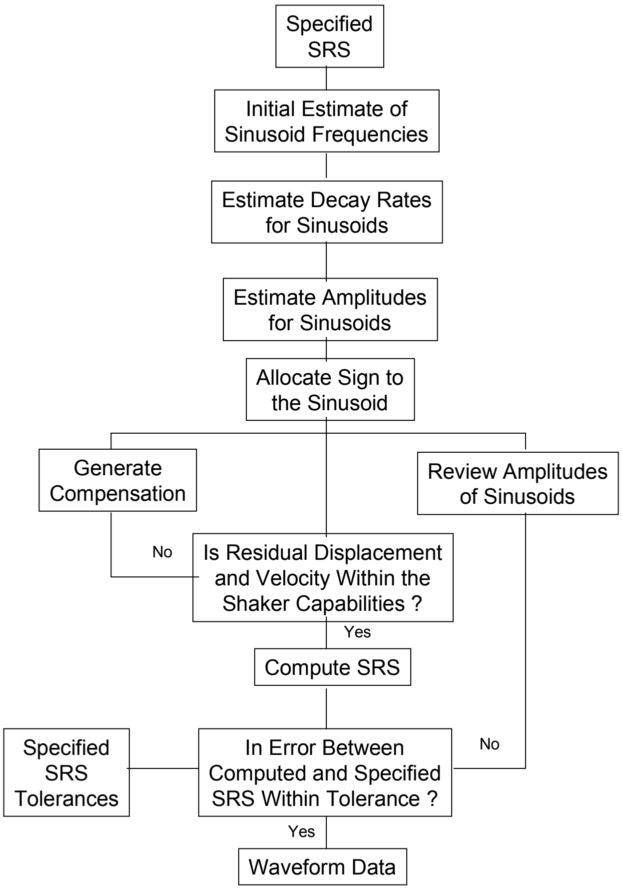

Figure B-1 Generation of a Test Waveform From a SRS

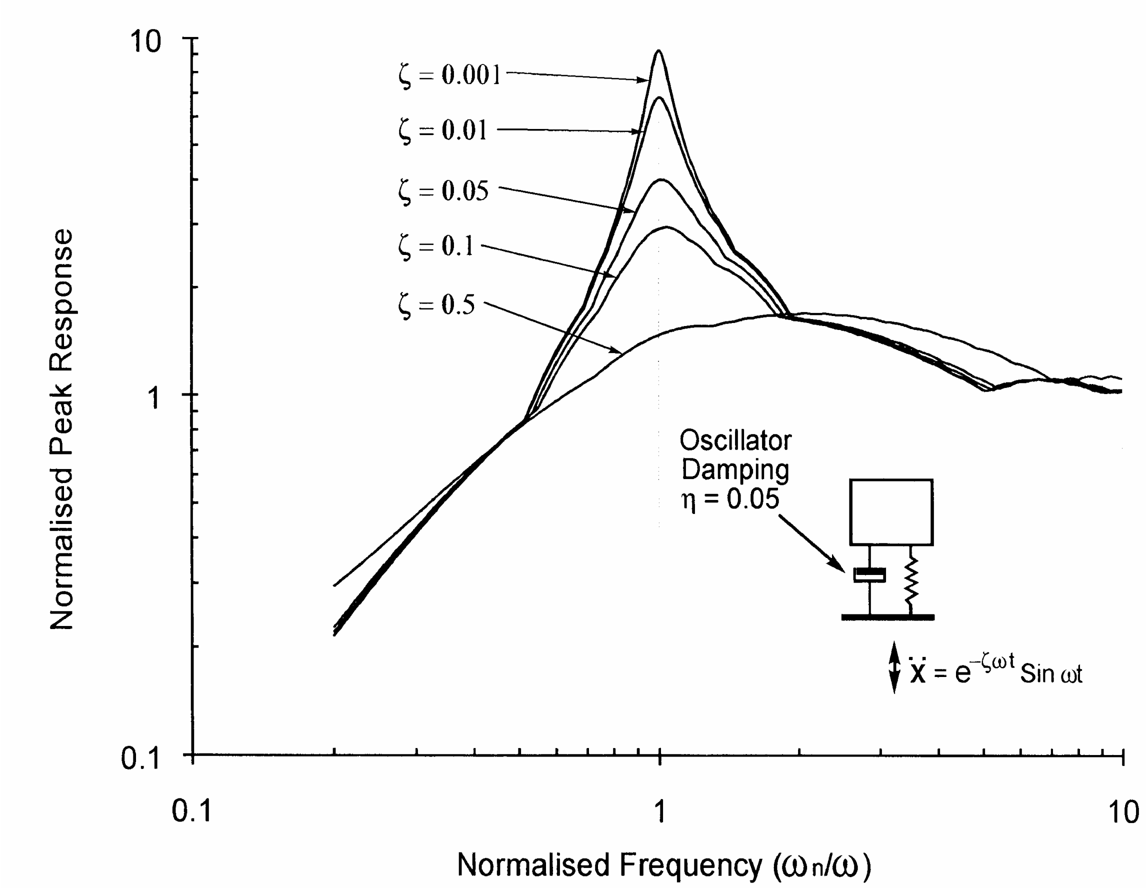

Figure B-2 Normalized Maximum Response

delay time (τ), can be computed (using Equations 3 and 4) to control residual velocity and displacement respectively. In this case the delay time is the time between initiation of the compensation pulse and the subsequent start of the decaying sinusoids.

$$\frac{A_m}{\omega_m\left(\zeta_m^2+1\right)} = -\sum_{i=1}^{n}\frac{A_i}{\omega_i\left(\zeta_i^2+1\right)} \qquad \text{Equation 3}$$

$$\frac{A_m\pi}{\omega_m\left(\zeta_m^2+1\right)} = \frac{2\zeta_m A_m}{\omega_m^2\left(\zeta_m^2+1\right)^2} + \sum_{i=1}^{n}\frac{2\zeta_m A_m}{\omega_i^2\left(\zeta_i^2+1\right)^2} \qquad \text{Equation 4}$$

A_i, ω_i, ζ_i are the amplitude, cyclic frequency, and decay rate of the i^{th} sinusoidal component.

It is important to note that the above procedure will develop a SRS based on the assumption that the individual sinusoidal components act independently. An iteration process is then required whereby component amplitudes and decay rates are varied to obtain a better fit to the SRS. This procedure is, in general, built into proprietary shock synthesis computer programs.

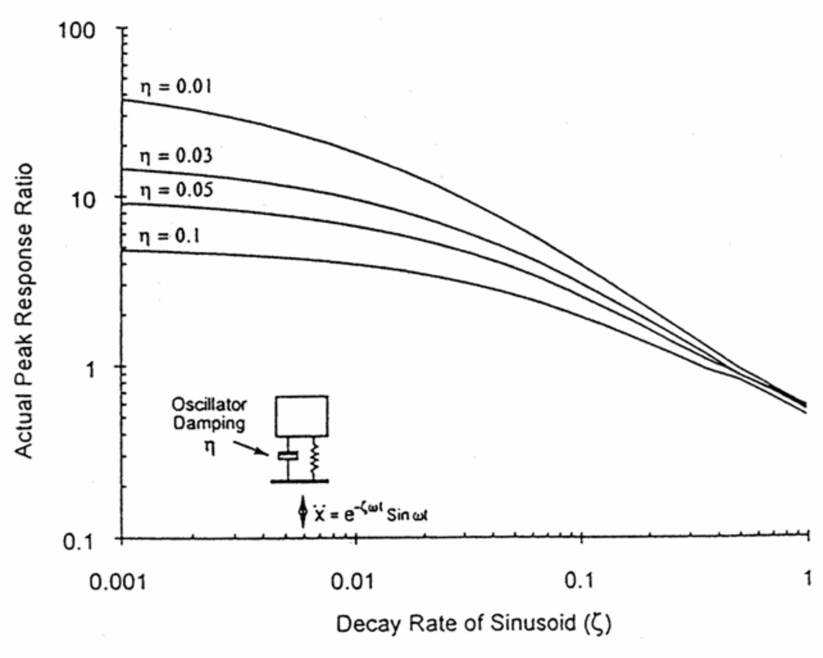

Figure B-3 Response per Unit Input

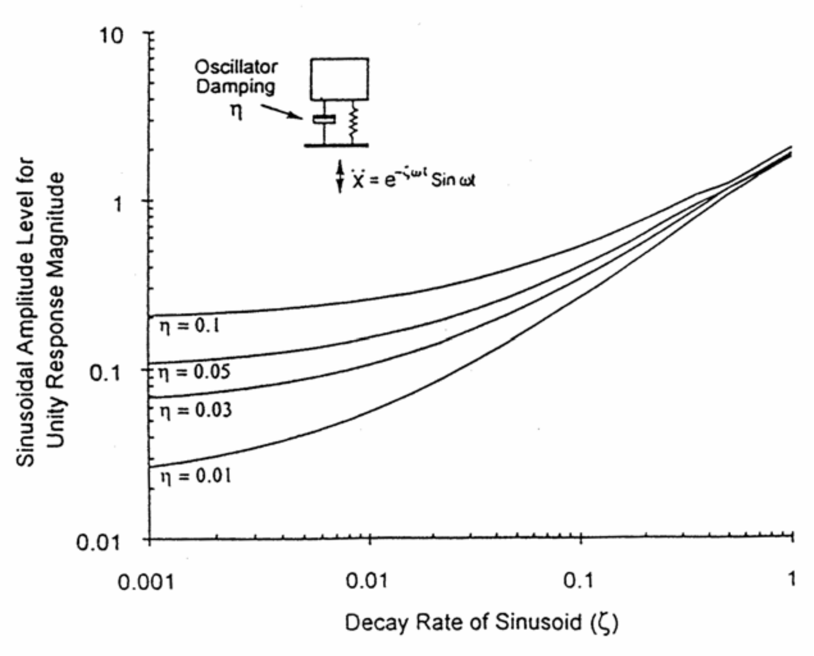

Figure B-4 Input per Unit Response

3 THE DETERMINATION OF SRS FROM FIELD DATA

This section provides guidelines for the generation of a test control SRS from measured transient acceleration time history field data. In general, each axis of the field data for a specific location will have a different SRS.The SRS required for the determination of the test control SRS will be obtained from reduction of the measured time histories of the transient event.The duration of the shock input time history used for the response spectrum calculation should be twice the effective pulse duration starting at a time to include the most significant data prior to and/or following the effective duration.

The SRS analysis parameters, damping, frequency interval, and frequency range should be selected from consideration of the shock waveform and the materiel to be tested. However, useful starting values are a damping ratio of 5% of critical damping (Q = 10) at a sequence of resonant frequencies at intervals of 1/6th octave, or smaller, to span at least 5 Hz to 2000 Hz.

The spectrum used to define the test control SRS should be a composite of positive and negative directions commonly called the maximax spectrum. It should be the maximum value obtained from both the primary and residual responses. When a sufficient number of spectra is available, an appropriate statistical basis should be employed to determine the required test SRS. Guidance for a statistical analysis is found in Annex D.

As a general guide for the classical waveform shock type of test, use of 95.5% population limits is usually applicable for most applications. However, for certain types of tests (notably function and reliability assessment), the use of smaller population limits (typically 68.3%) may be more appropriate. For some safety demonstration testing, population limits of 99.7% or greater may be required. For some materiel, the design requirements may specify alternative values to be adopted. Selection of these population limits must be consistent with the statistical procedures employed in Annex D.

When insufficient data are available for statistical analysis (the use of the above guidance becomes suspect for less than five samples), an increased envelope of the maximum available spectral data should be used to establish the required test spectrum in order to account for variability of the environment.

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ANNEX C

TECHNICAL GUIDANCE ON THE PERFORMANCE OF SHOCK TESTS

1 SCOPE

This annex is intended to provide guidance and definitions that are useful to set up and perform shock tests. It is not intended to be a textbook on SRS shock.

2 LIMITATIONS

Shock testing can be performed on test apparatus designed specifically for this purpose, such as test systems with mechanically or explosively generated shock transients. Alternatively, it may be possible to use a vibration test system within the mechanical and electrical limitations of the equipment. The Annex C descriptions are primarily related to SRS simulation on electrodynamic and servohydraulic exciter systems.

2.1 Displacement

The test specification defines, either through the time history transient waveform or through the SRS, the maximum acceleration to be reached in a given time. This results in a transient displacement whose instantaneous value should remain within the limits of the test system. Generally speaking, simulation of a transient time history waveform requires a larger displacement than an SRS simulated by oscillatory transients.

2.1.1 Electrodynamic Exciter

These exciters are normal vibration test exciters, usually with either a maximum peak to peak displacement stroke of 25 mm (1 inch) or, with some later machines, 50 mm (2 inches). Some shock testing is possible within these equipment limitations, and the pre and post pulse deviations permitted by the Test Instruction. The neutral position of the exciter armature can be set to take into account possible dissymetries in the transient displacement. Overtravel of the armature at shock test energy levels can severely damage the exciter.

2.1.2 Servohydraulic Exciters

The use of suitable servohydraulic exciters for classical pulse shock testing circumvents the displacement limitation of electrodynamic exciters. The major servohydraulic exciter limitation is the lower high frequency response bandwidth, although, advanced systems are capable of operation to 1 kHz bandwidth. The servohydraulic system load, therefore acceleration, capability often exceeds that of the electrodynamic systems available.

2.2 Velocity

2.2.1 Electrodynamic Exciter Velocity Limitations

The maximum velocity of these exciters is limited by the acceleration and displacement limits imposed by system electrical and mechanical design parameters. Maximum velocities of 70 to 100 inches/second are typical operational limits.

2.2.2 Servohydraulic Exciter Velocity Limitations

Velocity limitations are a result of hydraulic flow restrictions and vary from system to system. Systems designed for shock testing may have parallel servo valves and hydraulic accumulators which give wider limits on velocity and frequency bandwidth.

2.3 Acceleration

2.3.1 Electrodynamic Exciter Acceleration Limitations

Acceleration is limited by the amount of electrical power that can be fed through the armature, the mechanical strength of the armature and table assembly, the total load including self mass and internal losses, and the mechanical and electrical impedances of the test system and load. The test system mechanical impedance term, above, includes anti-resonance effects in the frequency domain which can absorb a disproportionate amount of the available power. The armature mechanical strength typically limits the maximum acceleration level to 100g.

2.3.2 Servohydraulic Exciter Acceleration Limitations

Since, within other limitations of these exciters, tests can be controlled by a displacement/time or force/time method, the effects of test item anti-resonance play a much less important role within the test. Since these exciters are self stopping when the servo valves close, there is less chance of system over-run damage and, therefore, higher accelerations can be safely achieved.

2.4 Frequency Range

2.4.1 Electrodynamic Exciter Frequency Range

The useful frequency range of these exciters is limited at low frequencies by their displacement amplitude limitation, and at high frequencies by modal density. Modal density of the test item, its support assembly and the exciter head and armature dictate that energy absorbent anti-resonances will be present in sufficient magnitude to account for any reasonable available power when driving from a frequency response function oriented pulse shaping controller, as most current exciter shock controllers are. Performance capabilities of electrodynamic systems typically extend to 2000 Hz, however additional considerations of fixture resonances may be needed above 500 Hz.

2.4.2 Servohydraulic Exciter Frequency Range

There is little limitation at the low frequency end of the spectrum other than dictated by the pressure and flow characteristics of the system hydraulic components, the available stroke, and the hardware mechanical strength. At high frequencies there is a finite operational limit related to the mass/stiffness of both the hydraulic medium and the servo valve operating speed. The effects of this are minimized in high performance systems by using parallel accumulators and servo valves with short hydraulic column lengths between the accumulator and ram.

2.4.3 Electrodynamic Exciter Power Amplifier

The combination of instantaneous voltage and output current available for electrodynamic test systems is limited by the power amplifier and field/armature components, and depends on the construction of the amplifier (tube or solid circuit type), amplifier class, exciter field and armature power capacity.

2.4.4 Servohydraulic Exciter Power System

This type of exciter does not draw its power directly from a hydraulic line, it only requires an adequate pressure and flowrate to recharge the accumulators to the required pressure in a sufficiently short time, commensurate with being ready to perform the next required shock. Where the exciter runs from a hydraulic main pressure system serving a whole test facility, it is necessary to use local accumulators when shock testing to minimize the line pressure fluctuations.

3 WAVEFORM SHOCK GENERATION

3.1 Generalities

During a shock simulation test, the test item is stationary before and after the total shock time history transient, therefore the change in total velocity is zero. This fact dictates the need to precede and/or follow the specified transient waveform with additional pulses. These pre-and post pulses must be chosen such that, without changing the result of the test, they accumulate and/or dissipate energy in such a way as to zero both the initial and final velocity.

For example, in the case of a half-sine, the initial and final velocity is non-zero :
Parameters a(t), t, D, v(t), A are the acceleration , time, shock duration, velocity, and shock amplitude.

$$0 \le t \le D$$

$$a(t) = A \sin\left(\frac{\pi t}{D}\right)$$

$$v(t) = -\frac{DA}{\pi} \cos\left(\frac{\pi t}{D}\right)$$

when t = 0,

$$v(t) = -\frac{D\ A}{\pi} \neq 0$$

when t = D,

$$v(t) = \frac{D\ A}{\pi} \neq 0$$

3.2 Case of Half-Sine

In practice, the half-sine may be one of three different types :

- Impulse (half sine with post-pulse)
- Impact with perfect rebound (half sine with pre- and post-pulse)
- Impact without rebound (half sine with pre-pulse)

In the following examples, the first two most widely used cases will be presented.

The computation below is made for a semi-sinusoidal shock. The same method can be applied for other waveforms.

3.2.1 Impulse (half sine with post-pulse)

Parameters a(t), V(t), d, t, D, A, p are the acceleration , velocity, displacement, time, shock duration, shock amplitude, and pre/post pulse constant.

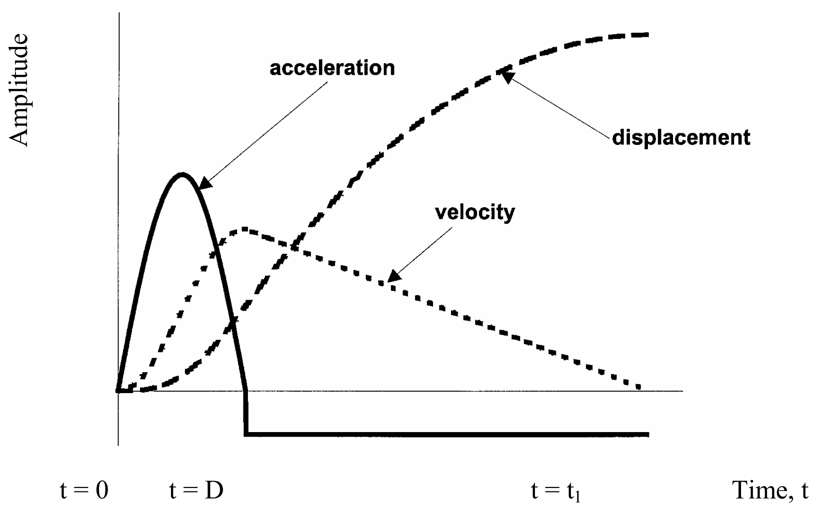


Figure C-3.1 Impulse (Half-sine with Post-pulse)

From 0 to D, we obtain:

$$a(t) = A \sin(\omega t) \qquad \text{for } \omega = \frac{\pi}{D}$$

$$v(t) = -\frac{A}{\omega}(\cos(\omega t) - 1) \quad \text{for initial condition} : v(0) = 0$$

$$d(t) = \frac{A}{\omega}\left(t - \frac{\sin(\omega t)}{\omega}\right) \qquad \text{for} \quad t = 0, \quad d(t) = 0$$

From D to t_1, we obtain:

$$a(t) = -pA$$

the total duration is :

$$t_1 = D\left(1+\frac{2}{\pi p}\right)$$

$$v(t) = -pA(t-D) + 2\frac{A}{\omega}, \quad \text{for initial condition } v(t_1) = 0$$

From continuity for the displacement to t = D, then:

$$d(t) = -pA\,\frac{t^2}{2} + At\left(D\,p + \frac{2}{\omega}\right) - AD\left(\frac{1}{\omega} + D\,\frac{p}{2}\right)$$

Maximum displacement is for $t = t_1$

$$d_{max} = p\frac{A}{2}\left(\left(\frac{2}{p\omega}\right)^2 - D^2\right)$$

If the relative masses of the moving part (M_m) and of the body (M_c) of the exciter are taken into account, the value of the acceleration becomes :

$$G = \frac{A}{g_n + \left(1+\frac{M_m}{M_c}\right)}$$

(Applies only if M_m is an inert mass without dampers)

3.2.2 Impact With Rebound (half sine with pre- and post-pulse)

Parameters a(t), V(t), d, t, D, A, p are the acceleration , velocity, displacement, time, shock duration, shock amplitude, and pre/post pulse constant.

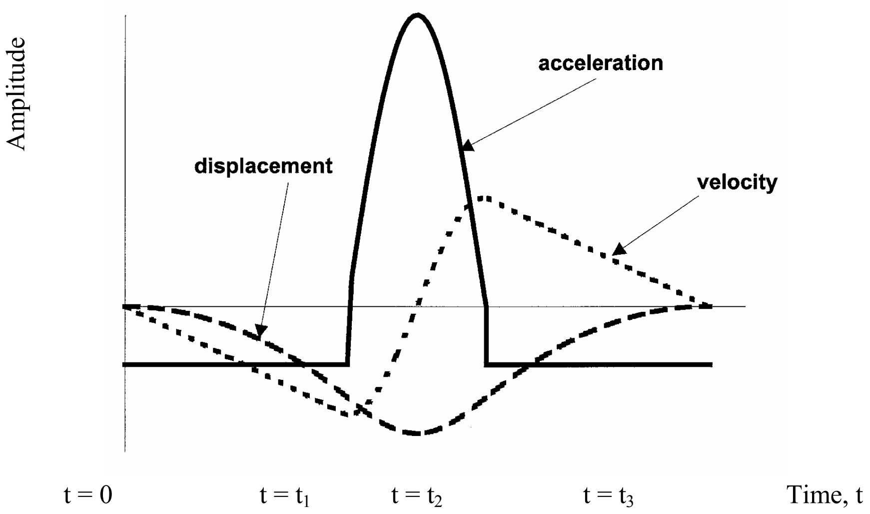


Figure C-3.2 Impact with Rebound (Half-sine with Pre- and Post-pulse)

From 0 to t_1

$$a(t) = -pA$$

$v(t) = -pAt$ when $t = 0$, $v(t) = 0$

$d(t) = -pAt^2/2$ when $t = 0$, $d(t) = 0$

Between t_1 and t_2

$a(t) = A \sin \omega(t - t_1)$ with $t_2 - t_1 = D$, and $\omega = \pi/ D$

the equality of the acceleration curve area produces:

$$t_1 p = 1 / \omega$$

$$v(t) = -A / \omega \cos \omega(t - t_1) + cte$$

the velocity should be zero with: $\omega t = \pi/ 2$

then,

$$v(t) = -\frac{A}{\omega}\cos \omega (t - t_1)$$

$$d(t) = -\frac{A}{\omega^2}\sin \omega (t - t_2) + cte$$

for $t = t_1$

$$d(t) = -\frac{A}{\omega^2}\left(\sin \omega (t - t_2) + \frac{1}{2p}\right)$$

the displacement becomes maximum when $\omega t = \pi/ 2$

$$d_{max} = \frac{A}{\omega^2}\left(1 + \frac{1}{2p}\right)$$

From t_2 to t_3

$$t_3 = t_1 + t_2 = D\left(1 + \frac{2}{\pi p}\right)$$, the total duration is t_3, $D = t_2 - t_1$

$$a(t) = -pA$$

$v(t) = -pA(t - t_2) + cte$, $v(t_3) = 0$

then

$$v(t) = A\left(p(D - t) + \frac{2}{\omega}\right)$$

$$d(t) = At\left(p\left(D - \frac{t}{2}\right) + \frac{2}{\omega}\right) + cte$$

when $t = t_3$, $d(t) = 0$

then:

$$d(t) = At\left(p\left(D - \frac{t}{2}\right) + \frac{2}{\omega}\right) - \frac{Ap}{2}\left(D + \frac{2}{p\omega}\right)^2$$

If the relative masses of the moving part (M_m) and of the body (M_c) of the exciter are taken into account, the value of the acceleration becomes:

$$G = \frac{A}{g_n + \left(1 + \frac{M_m}{M_c}\right)}$$

(Applies only, if M_m is an inert mass without dampers)

3.2.3 Conclusion

The maximum displacement during a shock simulation compared with the rest position before the shock is at least four times less for an impact with rebound than for an impulse shock. This ratio is two times less for the velocity. Thus, half-sine shock tests are usually applied using the method of impact with rebound. This is of particular advantage when a shock test is performed on a vibration test system. Adjustment of the test system to deliver the specified pulse should be performed with a dynamic representation of the test item. The response of the test item will affect the pulse delivered by the test system. The ratio of the mass of the test item to that of the test table should be sufficiently small to ensure that waveform distortion does not exceed the tolerance limits. When testing with the SRS method, and especially when testing with methods which add pre-and/or post-pulses to the specified pulse, if the test item incorporates shock isolators, the validity of the relative motion within the isolators should be confirmed during pre-test setup of the test system.

4 CHARACTERISTICS OF THE SRS

4.1 Definitions

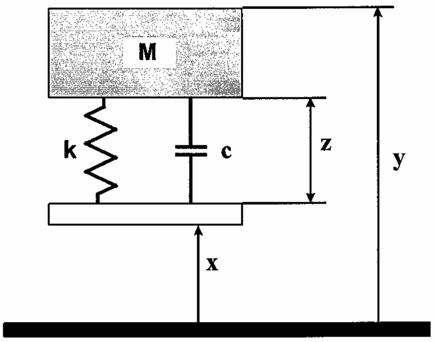
The shock response spectrum (SRS) is an envelope of the response of a linear single degree of freedom system (SDOF) to a transient input as a function of the SDOF system natural frequency, f_n. The system is generally considered to be undamped, or lightly damped as defined by the damping quality factor, Q. See the SDOF system defined in Figure C-4.

The SRS response parameter can be defined in several forms :

- either the maximum relative displacement of the mass in relation to the base (maximum of z) ;
- or the absolute maximum velocity of the mass (maximum of $\dot{y}$) ;
- or the absolute maximum acceleration of the mass (maximum of $\ddot{y}$).

$$\omega_n = 2\pi f_n = \sqrt{\frac{k}{m}} \qquad \zeta = \frac{c}{2\sqrt{km}}$$

$$Q = \frac{1}{2\zeta_n} = \frac{\sqrt{km}}{c}$$



f_n = natural frequency
ω_n = cylical frequency
c = damping coefficient
k = spring constant
m = mass
ξ = fraction of critical damping
Q = quality (Q) factor

x = displacement relative to base
y = absolute displacement
z = relative displacement

Figure C-4 Single Degree of Freedom Linear System

The relative displacement is more correctly linked to the constraints (damage potential), the velocity to the energy, the absolute acceleration to the forces (destructive potential) due to the shock. The balance of forces applied to the system with one degree of freedom in Figure C-4 provides the differential equation of motion.

$$m\ddot{y} + c(\dot{y} - \dot{x}) + k(y - x) = 0 \qquad \text{Equation 1}$$

By differentiating this equation once, twice, and reducing it to the relative displacement, the following equations are obtained :

$$\frac{d^2\dot{y}}{dt^2} + 2\xi_n\omega_n\frac{d\dot{y}}{dt} + \omega_n^2\dot{y} = 2\xi_n\omega_n\frac{d\dot{x}}{dt} + \omega_n^2\dot{x} = 2\xi_n\omega_n\ddot{x} + \omega_n^2\dot{x} \qquad \text{Equation 2}$$

$$\frac{d^2\ddot{y}}{dt^2} + 2\xi_n\omega_n\frac{d\ddot{y}}{dt} + \omega_n^2\ddot{y} = 2\xi_n\omega_n\frac{d\ddot{x}}{dt} + \omega_n^2\ddot{x} \qquad \text{Equation 3}$$

$$\ddot{z} + 2\xi_n\omega_n\dot{z} + \omega_n^2 z = -\ddot{x} \qquad \text{Equation 4}$$

The comparison of Equations 3 and 4 show that, if a system with one degree of freedom is undamped ($\xi_n = 0$), the SRS of the absolute acceleration is obtained by multiplying the SRS of the relative displacements by $-\omega_n^2$.

The spectra are thus identical when they are made dimensions by dividing by the factors :

- the absolute maximum acceleration of the mess $\ddot{y}_m$, divided by the maximum acceleration $\ddot{x}_m$ of the base, $\ddot{y}_m/\ddot{x}_m$
- the relative maximum displacement of the mass z_m , divided by the relative maximum static displacement.

For a lightly damped system, Q > 10, the standardized spectra of absolute accelerations and relative displacements can be considered as identical.

$$z_s = -\frac{m}{k}\ddot{x}_m = \frac{\ddot{x}_m}{\omega_n^2};\frac{z_m}{z_s} = -\omega_n^2\frac{z_m}{\ddot{x}_m}$$ Equation 5

Conversely, comparing Equations 2 and 4 shows that in the case of an undamped system, the velocity response to the shock spectrum cannot be simply deduced from the relative displacement response to the shock spectrum given that if $|\omega_n^2 \dot{x}| = |\omega_n \ddot{x}|$ there is a phase shift of □/ 2 between the velocity and acceleration.

The velocity obtained by writing $\omega_n^2 \dot{x} = -\omega_n \ddot{x}$ in Equation 2 is referred to as the "pseudo-velocity" (Z). The pseudo-velocity is equal to the relative velocity, $\dot{z}$, in an undamped system.

These considerations involve defining:

- the SRS of the relative displacements, S_d
- the SRS of the relative velocities or "pseudo-velocities", $S_v = \omega_n S_d$
- the SRS of the absolute accelerations $S_\gamma = -\omega_n^2 S_d$

These three spectra are identical when they are standardized respectively by the relative displacement, the maximum pseudo-velocity, and maximum acceleration, $z_s, \ddot{x}_m/\omega_n, \ddot{x}_m$, and when the system is lightly damped, Q > 10.

Generally, the shock is known from the time domain absolute acceleration signal, $\ddot{x}(t)$, of the fasteners of the materiel to its in-service platform. Thus, the exciter simulation control is made practical by use of accelerometers for absolute acceleration control. The main purpose of the simulation is to test the robustness of the materiel with the destructive potential of the shock. Excluding special cases, the SRS is therefore that of the absolute acceleration. In the case in which the mechanical system cannot be modeled by second order differential equations with constant coefficients, the concept of the SRS is not applicable (e.g., when the wavelength of the shock is not large in relation to the dimensions of the materiel involved).

4.2 Primary, Residual, and Maximax Response Spectrum

The SRS consists of four spectra :

- a primary response with positive and negative spectrum that are points of maximum positive and negative response occuring during the primary peak of the shock transient (the, positive direction is that of the positive polarity acceleration $\ddot{x}(t)$ of the shock).
- a residual response with positive and negative spectrum that are points of maximum positive and negative response occuring after the primary peak of the shock transient. For a lightly damped system, Q > 10, the amplitude of the two residual spectra points are generally equal in absolute value.

The maximax SRS is the envelope of the maximum absolute values of these four SRS spectra. In general, the materiel is not symmetrical, and the shock response depends on the direction of application of the shock. A shock corresponding to actual data is not simple and both negative and positive values contribute to the absolute maximum SRS response. For this reason, the shock with the maximax response spectrum is applied along each positive and negative axis. The control SRS specified is therefore the maximax spectrum of the absolute acceleration.

The residual SRS of acceleration $A_R(\omega_n)$ is linked to the absolute value of the Fourier spectra of the shock $|F(\omega_n)|$, when the damping of the systems with one degree of freedom is zero. If $|F(\omega_n)|$ is the Fourier transform modulus of the shock's acceleration time signal, Equation 6

$$\left|F(\omega_n)\right| = \frac{A_R(\omega_n)}{\omega_n} \qquad \text{Equation 6}$$

relates the quantities. In this relation, $|F(\omega_n)|$ has the dimensions of a velocity, i.e., of an acceleration by rad/s.

The spectra of all the shocks with the same pulse form can be standardized in relation to the peak amplitude of the acceleration, A, and the duration, D, of the pulse. The coordinate scales would be as follows.

- ordinate a_{max} / A
- abscissa f_nD or $2\pi f_nD$

4.3 Description of SRS of Classical Shock Pulses

Figure C-5 shows the positive SRS for three classical shock pulses, terminal peak sawtooth, half-sine, and a trapezoidal pulse for the case of low damping, $Q_n > 10$. In the low frequency range, up to $f_nD = 0.4$, the SRS envelope is dominated by the residual spectra and the response is in proportion to the velocity change of the pulse. The maximum response approaches that of an impulse and is approximately the same as that due to a Dirac pulse function whose velocity change is that of the area of the time domain acceleration shock.

In the range of intermediate frequencies, $0.4 < f_nD < 1$, the primary spectra offer differences in amplitude which depend on the pulse rise time. The terminal peak sawtooth, with the longest rise time, has the lowest response for a given pulse peak amplitude. The trapezoidal pulse has the highest response due to the very short rise time and the peak plateau. For higher frequencies, $f_nD > 5/2$, the response remains approximately constant.

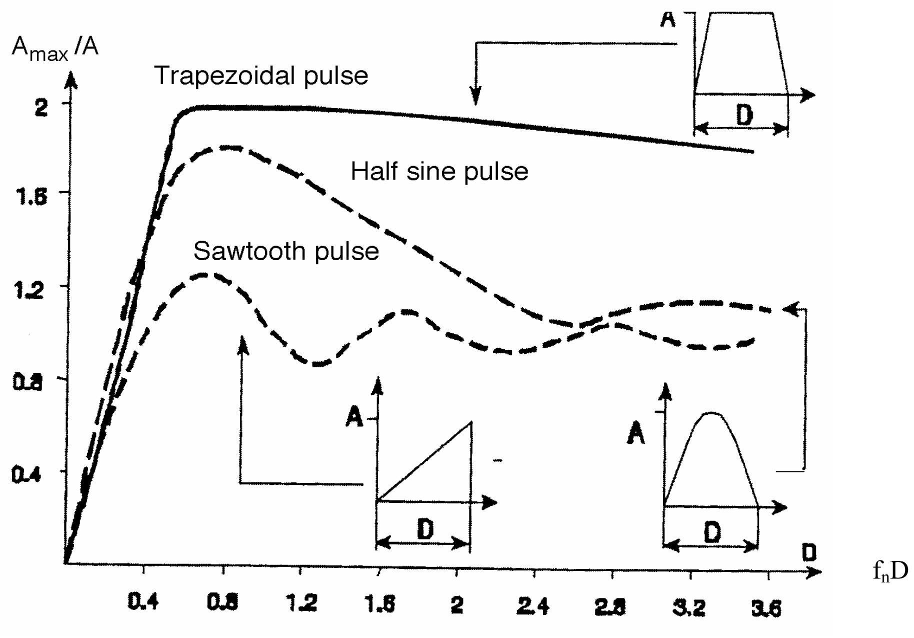


Figure C-5 Classical Waveform Positive SRS

Figure C-6 shows the primary (solid lines) and positive residual (dashed lines) SRS of the three classical pulse waveforms. The negative primary spectrum for these pulses is nearly zero, due to the positive polarity of the waveform, and is not shown. The half-sine and trapezoidal pulse spectra have periodic zero values due to the symmetry of the pulse waveform. The terminal peak sawtooth primary and positive residual spectrum amplitudes are similar across a wider range of the lower frequency bandwidth than the sine and trapezoidal waveforms. The decent time from the terminal peak maximum to zero amplitude influences the SRS spectrum characteristics. For a zero descent time, the negative residual spectrum is equal in absolute value with the positive residual spectrum. The effect of a non-zero descent time decreases the residual spectrum amplitude in the higher frequency bandwidth range with alternating zero values. The SRS spectrum is also strongly a function of the damping coefficient.

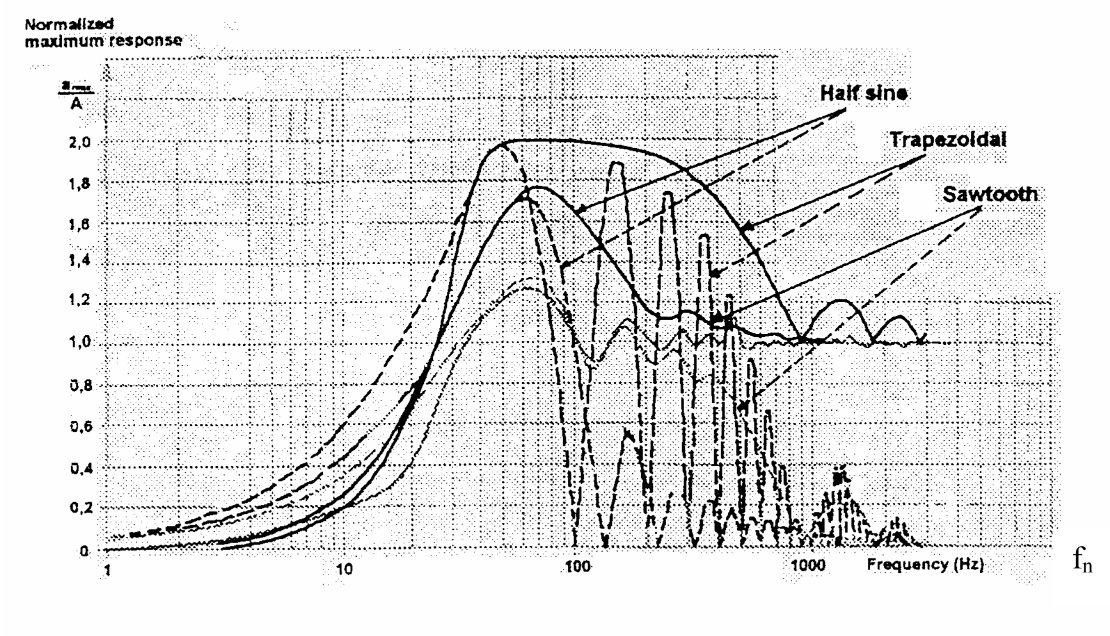


Figure C-6 Primary (solid line) and Residual (dashed line) SRS

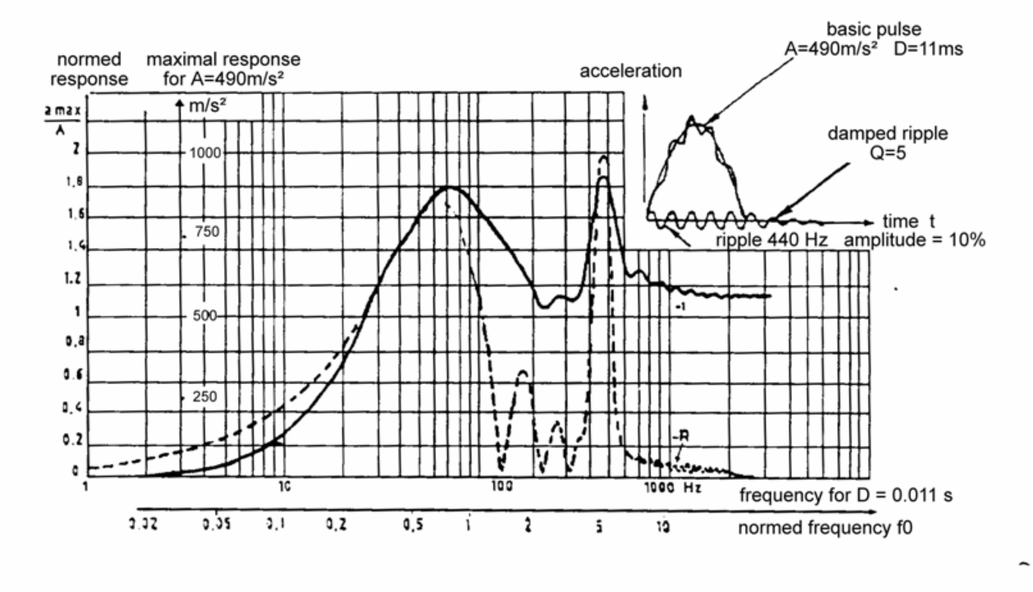


Figure C-7 Primary (solid line) and Residual (dashed line) SRS for Half-sine with Ripple

4.4 Effect of Waveform Ripple

Oscillatory systems with light damping are highly sensitive to ripple superimposed on the shock waveform. For example, the effects produced on a half-sine SRS are indicated in Figure C-7. A ripple with an amplitude of 10 percent of that of the half-sine amplitude, and frequency of 440 Hz is superimposed on the waveform. In comparision to Figure C-6, the waveform ripple creates a considerable diffference in the SRS spectrum ; in particular near the ripple frequency of 440 Hz. Generally, it is necessary to eliminate ripple to maintain the reproducibility of the test.

4.5 Advantages of the SRS Method in Comparison to the Classical Shock Method

a. Accurate representation of the real environment is easier.

b. SRS methods aid assessment of the risk of damage to the main modes.

c. An accurate SRS test is easier to define.

d. Reproducibility of a complex transient is possible.

e. The SRS allows comparison of the relative severities of different shocks and synthesis of an envelope of shocks is possible.

f. SRS control tolerances easier to apply than temporal signal tolerances.

4.6 Limits of the Use of the SRS Method in Comparison to the Classical Shock Method

a. The SRS is independent of the temporal signal.

b. An infinite number of temporal signals can be defined for an individual SRS.

c. Phase information and response mode recombination are lost.

d. Only with the temporal signal can the shock amplitude limits be specified and adequately analyzed.

e. If the temporal shock is not adequately specified, significant errors are possible.

f. In real systems, which are more complex than simple models, there are coupling, nonlinearities, n degrees of freedom, and divergence in comparison with the single DOF system.

4.7 Cautionary Notes on the Use of the SRS Method

a. It can be difficult to determine the most suitable form of pre and/or post waveform compensation.

b. Excessive distortion of the control system waveform is possible when generating a transient which is not of the impulsive type.

4.8 Systems With Multiple Degrees of Freedom

In order to compute the SRS of a system with multiple degrees of freedom it is necessary to represent the action of the shock by a matrix of generalized forces linked to the system's degrees of freedom. This process can be accomplished by applying the equations of motion for the forces in the form of acceleration at the materiel's fastening points to the carrier ; for example, in paragraph 4.1, Equations 1 and 3, written in a matrix form with n degrees of freedom.

In the case in which the materiel mass is large and entails considerable coupling with the support structure, the system to be analyzed should include a part of the support structure.

To undertake these computations, the vibration test program should develop, or have available, the frequency transfer function of the system from suitable excitation forces. In most cases the specific modes of the system can be superimposed, decoupled, and several SRS computed for the damping values of the modes. With this procedure it is possible to define the specification of the test shock to not overtest, when the real damping coefficient is less than the theoretical one employed, nor undertest in the opposite case.

5 GENERATION OF A SPECIFIED SHOCK

5.1 Shock Specified by Waveform

5.1.1 Mechanical Shock Machine

A specified waveform is obtained by the use of a shock programmer material to control the motion of the test item and the shock machine table. This is an iterative procedure that depends on the type of machine used, and is done experimentally with a dynamically representative mock-up of the test item.

5.1.2 Vibration Test System

5.1.2.1 Analog Control

The test analog control process is illustrated in Figure C-8.

The control chain includes:

- a programmable electrical pulse generator, with variable gain and adjustable pulse time, producing a pulse e(t) described by a set of time values
- a transfer function compensator; this (H_1) is adjustable by gain compensation devices in several frequency ranges and axial resonance frequency compensation devices

The transfer function (H_2) of the amplifier-vibration-test item assembly and control chain is measured by applying either sinusoidal sweeping, a pulse, or white noise with a sufficient number of statistical degrees of freedom.The compensator is set using progressive amplitudes in order for the output signal s(t) to be defined for Equation 7.

$s(t) = H_1 \cdot H_2\, e(t) = ke(t)$ where $k = H_1 \cdot H_2$

$$H_1 = \frac{k}{H_2} \qquad \text{Equation 7}$$

Analog control becomes difficult to use when the transfer function H_2 can no longer be simulated by that of a decoupled system ; digital control is then desirable.

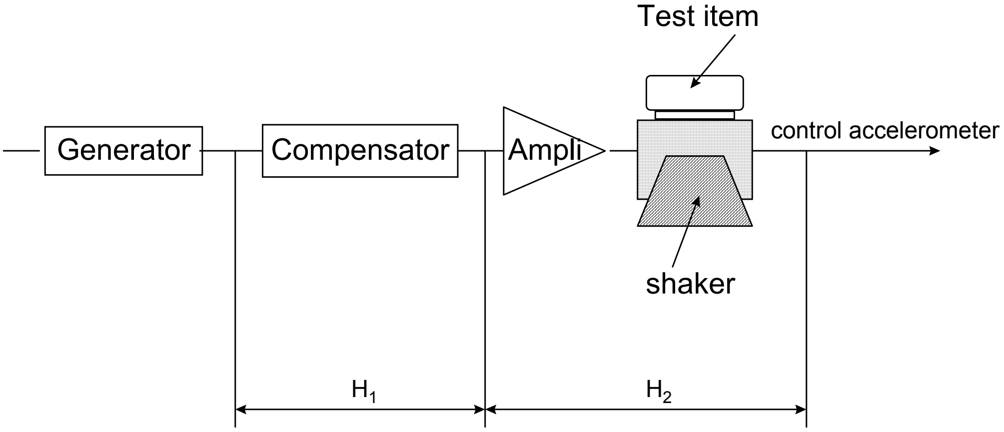


Figure C-8 Analog Control Setup for the Waveform Method

5.1.2.2 Digital Control

The setup includes a control system programmed to adapt the reference input shock to the transfer function. that may be symbolically written as $H_2(f) = s(f)/e(f)$. The H_2 transfer function validity should be controlled by the coherence function, μ(f), between the output signal, s(t), and the input signal, e(t), averaged over a ensemble of trial shocks, otherwise the coherence function for one set of pulses is 1.0.

If:

$\overline{G_{11}(f)}$	Direct Fourier transform of e(t)
$\overline{G_{22}(f)}$	Direct Fourier transform of s(t)
$\overline{G_{12}(f)}$	Cross Fourier transform between s(t) and e(t)
$\overline{G^*_{12}(f)}$	Conjugate transform of $G_{12}(f)$
$H_2(f) = \dfrac{\overline{G_{22}(f)}}{\overline{G_{11}(f)}}$	Transfer Function
$\mu(f) = \dfrac{\overline{G^*_{12}(f)} \cdot \overline{G_{12}(f)}}{\overline{G_{11}(f)} \cdot \overline{G_{22}(f)}}$	Coherence Function

where $\tilde{\tilde{G}}_{ij}$ represents an estimated average over several pulses.

The input drive signal is corrected by a reverse Fourier transform at progressive amplitudes.The correction loop can contain optimization algorithms dependent on the specified waveform and the prepulse and post-pulse compensation necessary to reduce the power required of the vibration system while remaining within the specified tolerances of the waveform.

5.2 Shock Specified in the Form of an SRS

5.2.1 Mechanical Shock Machine

A time history waveform is generated having an SRS that envelopes, as closely as possible over the specified frequency range, the defined test control SRS. Rules based on the characteristics of the SRS are applied:

- The “static”' amplitude of the SRS at high frequencies provides the maximum acceleration of the waveform
- The pulse time of the waveform is provided by the abscissa value of the first point which reaches the maximum acceleration of the waveform

The waveform obtainable closest to the one thus determined is adopted, preferably the terminal point sawtooth, whose SRS is best "filled" in each direction.

5.2.2 Vibration Test System

5.2.2.1 Analog Control

The principle of analog shock generation and control is shown in Figure C-9.

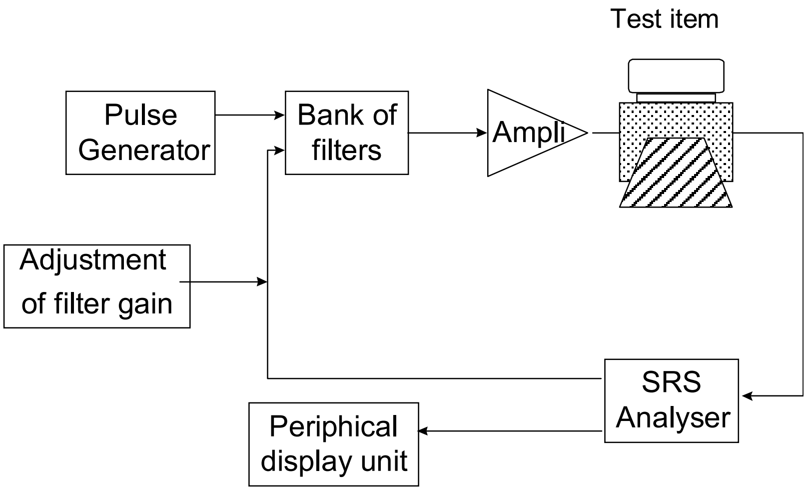


Figure C-9 Analog Setup for SRS Generation

5.2.2.2 Digital Control

Digital control system software can synthesize a given SRS. The control system generates a set of transients, generally damped sinusoids of frequency f_n, logarithmic decrement n, and delay n, so that the SRS of each sinusoid coincides with that of the SRS specified at frequency f_n. The various parameters are adjusted contingent on the response spectrum obtained from the vibration system, test item, and control accelerometer chain. Figure C-10 shows a general flowchart of procedures required to generate and control either a time history waveform or SRS specified shock test. For either case, the procedure requires several trial tests with a dummy or representative test item, and the process is bounded by the operational voltage e(t), current i(t), and structural limits of the vibration test equipment.

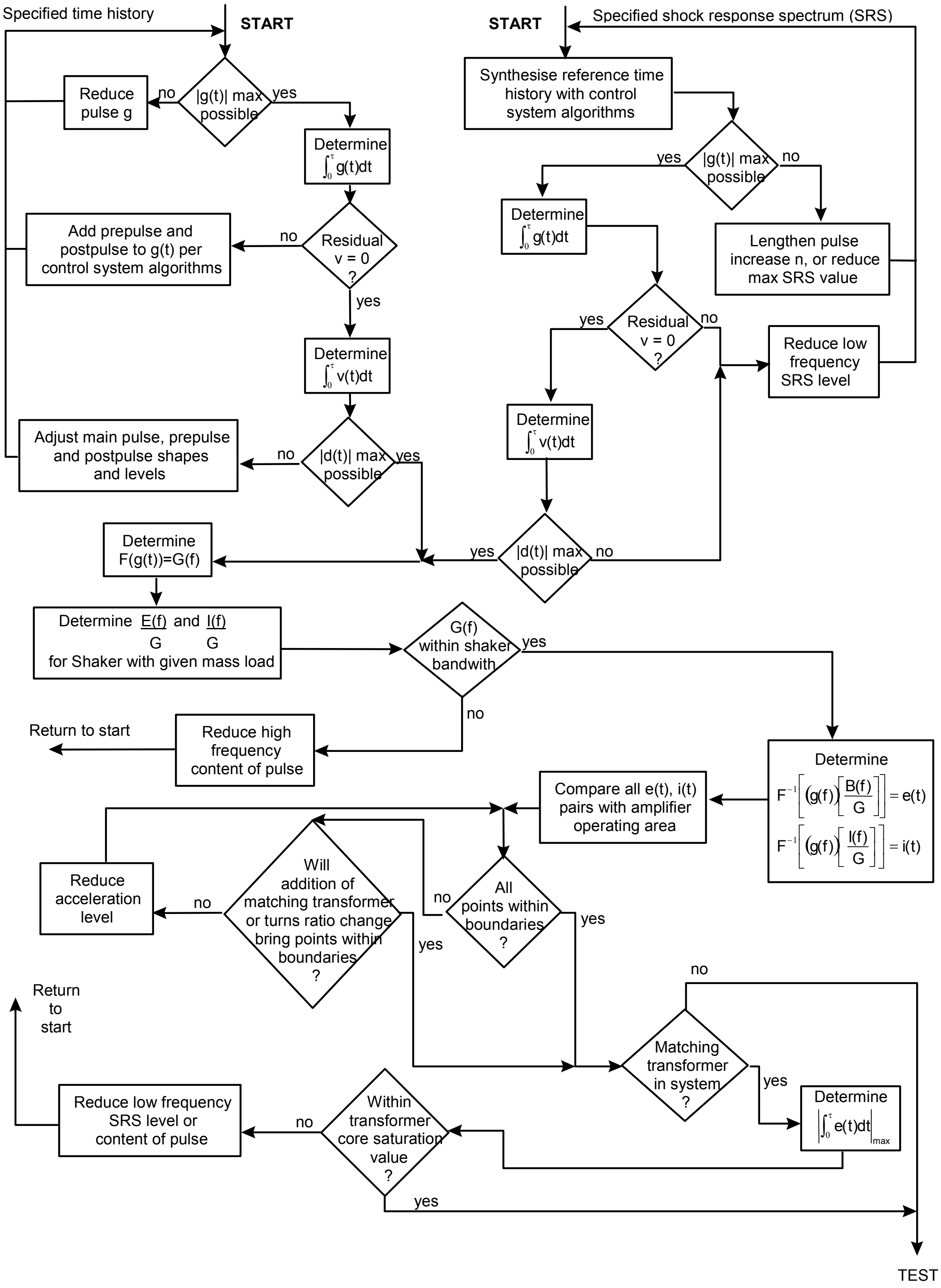


Figure C-10 General Shock Test Procedure

ANNEX D
STATISTICAL CONSIDERATIONS FOR DEVELOPING LIMITS ON PREDICTED AND PROCESSED DATA

1 SCOPE

1.1 Purpose

This Annex provides information relative to the statistical characterization of a set of data for the purpose of defining an envelope, or upper and lower limit, of the data set.

1.2 Application

The Annex information is generally applicable to frequency domain spectrum that are either predictions based on given information, or processed time domain measurement data. Appropriate processing of the time domain data provides a frequency spectrum that may be in the form of Acceleration Spectral Density (ASD), Shock Respons Spectrum (SRS), Energy Spectral Density (ESD), or Fourier Spectrum (FS). For example, a set of ASD is created for stationary random vibration, or a set of SRS, ESD, FS for a very short duration transient. Given the set of frequency domain spectrum, information in this Annex allows the establishment of data envelopes by statistical methods. The frequency spectra and envelope are in statistical terms, “estimates” of the true dynamic environment and required for analysis or testing purposes.

2 DEVELOPMENT

2.1 Basic Assumptions

Prediction or measurement spectrum, and mixed combinations, may be considered in the same manner. It is assumed that the uncertainty in individual measurements (processing errors) do not affect the enveloping considerations. For measured field data digitally processed such that the SRS, ESD, FS, or ASD are obtained for single sample records, it is useful to examine and summarize the overall statistics of “similar” spectrum selected in a manner to not bias the summary statistics. To ensure an unbiased envelope spectrum, the measurement locations might be chosen randomly, consistent with the measurement objectives. A set of similar frequency spectrum are generally obtained in the following manner :

a. spectra at a single location on the materiel that have been obtained from repeated testing under essentially identical experimental conditions ;

b. spectra that have been obtained from one test, where the measurements are taken (1) at several neighbouring locations displaying a degree of response homogeneity, or (2) in “zones” or points of similar response at varying locations,

c. or, some combination of a. and b above.

It is assumed that there is a certain degree of homogeneity among the spectra across the frequency band of interest. This latter assumption generally requires that first, the spectra for a given frequency contain no significant "outliers" that can cause a large variance, and second, a larger input stimulus to the system from which the measurements are taken implies larger magnitude response spectra values.

2.2 Basic Summary Pre-processing

There are two methods in which a summary envelope may be obtained. The first method is to utilize an “enveloping” scheme on the basic spectra to arrive at a conservative estimate of the environment, and some qualitative estimate of the spectra distribution relative to this envelope. This procedure is dependent upon the judgement of the analyst, and can produce inconsistent results among analysts. The second method is to combine the individual spectrum by a statistically appropriate technique and infer the statistical significance of the data based upon statistical distribution theory. Reference a summarizes the current state of knowledge relative to this approach and its relationship to enveloping. In general, the spectra referred to and their statistics are related to the same frequency band over which the processing takes place. Unfortunately, for a given frequency band, the statistics behind the ensemble of spectrum are not easily accessible because of the unknown distribution function of amplitudes for the frequency band of interest. In most cases, the distribution function can be assumed to be normal if the individual spectra are transformed to a "normalizing" form by computing the logarithm to the base 10 of the spectrum. For an ESD and FS, the averaging of adjacent components (assumed to be statistically independent) increases the number of degrees of freedom in the spectra while decreasing the frequency resolution with the possible introduction of statistical bias in the spectra. For an ASD, this is also the case provided the bias error in the spectrum is small, i.e., the resolution filter bandwidth is a very small fraction of the overall spectrum bandwidth.

Because SRS spectrum are based on maximum response of a single degree of freedom system as its natural frequency is varied, the adjacent spectrum tend to be statistically dependent and, therefore, not well smoothed with averaging filters unless the SRS is computed for very narrow frequency spacings. In such cases, smoothing of SRS spectra is better accomplished by reprocessing the original time history data at a broader natural frequency spacing, e.g., 1/6th octave as opposed to 1/12th octave. There is no apparent way to smooth dependent SRS spectra mathematically when reprocessing cannot be performed, and the acceptable alternative is some form of enveloping of the spectra. In any case, the larger the sample size, the closer the logarithm transform of the spectra is to the normal distribution unless there is a measurement selection bias error in the experiment. Finally, the upper limit envelopes obtained in the paragraphs to follow are generally smoothed by straight line segments intersecting at spectrum "breakpoints" before final use of the enveloped data. No guidance is provided in this Annex on the final "smoothing" procedure, e.g., whether spectrum peaks should be clipped or enveloped, and the relationship of the bandwidth of the data to the degree of clipping, etc.. Such smoothing should be performed only by an experienced analyst; reference a discusses this further.

2.3 Parametric Upper Limit Statistical Estimate Considerations.

In all the formulas for the estimate of the statistical upper limit of a set of N predictions or measurements, the individual spectrum are denoted as x_i, creating a set from 1 to N .

$$\{ x_i \} = \{ x_1, x_2, \ldots\ldots x_N \} \qquad i = 1, 2, \ldots\ldots, N$$

It is assumed that the spectra will be logarithm transformed to bring the overall set of measurements closer to those sampled of a normal distribution, and that the measurement selection bias error is negligible. Since the normal and "Student t" distributions are symmetric, the formulas below apply for the lower bound by changing the sign between the mean and the standard deviation quantity to minus. It is assumed that all spectrum are at a single frequency, or for a single bandwidth, and that spectra among bandwidths are independent such that each bandwidth under consideration may be processed individually, and the results summarized on one plot over the entire bandwidth as a function of frequency. The logarithm transform is given by Equation 1.

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

The mean estimate, m_y, for true mean, μ_y is given by Equation 2.

$$m_y = \frac{1}{N} \sum_{i=1}^{N} y_i \qquad \text{Equation 2}$$

The unbiased estimate of the standard deviation, s_y , for the true standard deviation σ_y is given by Equation 3.

$$s_y = \sqrt{\frac{\sum_{i=1}^{N} \left(y_i - m_y\right)^2}{N-1}} \qquad \text{Equation 3}$$

2.3.1 Upper Normal Confidence Limit (NCL)

The upper confidence interval limit on the true mean μ_y with a confidence coefficient of $1 - \alpha$ (or confidence of $100\ (1 - \alpha)$ percent) is given by Equation 4, where ($t_{N-1}; \alpha$) is the α

$$\mathrm{NCL}(N,\alpha) = 10^{m_y + \frac{S_y t_{N-1;\alpha}}{\sqrt{N}}} \qquad \text{Equation 4}$$

percentage point of the Student t distribution with N-1 degrees of freedom. NCL is termed the upper $100(1-\alpha)$ percent confidence limit on the true mean of the population from which the sample $\{ X_1, X_2, \ldots, X_N \}$ was taken. NCL is included here for reference purposes and generally is not useful for establishing upper limits unless $N > 50$.

2.3.2 Upper Normal One-sided Tolerance Limit (NTL)

The upper normal one-sided tolerance limit on the proportion β of the population values that will be exceeded with a confidence coefficient (γ.is given in Equation 5 for the NTL(N, β, γ) ,

$$\mathrm{NTL}(N, \beta, \gamma) = 10^{\left(m_y + s_y k_{N,\beta,\gamma}\right)} \qquad \text{Equation 5}$$

where $k_{N,\beta,\gamma}$ is the one-sided normal tolerance factor given in Table D-1 for selected values of N, β and γ. NTL is termed the upper one-sided normal tolerance interval for which (100 β percent of the values will lie below the limit with (100 γ percent confidence. For $\beta = 0.95$ and $\gamma = 0.50$, this is referred to as the 95/50 limit.

In general, the NTL estimation should not be used for small N with values of β and γ close to 1 since it is likely the assumption of the normality of the logarithm transform of the spectra will be violated. For large N > 50, the NCL (N) = NTL (N, β, γ) for $\alpha = (1 - \beta)$ and $\gamma = 0.50$.

2.3.3 Upper Normal Prediction Limit.(NPL)

The upper normal prediction limit is the value of x, for the original data set, that will exceed the next predicted or measured value with confidence coefficient γ, and is given by Equation 6,

$$\mathrm{NPL}(N,\gamma) = 10^{m_y + s_y\sqrt{1+\frac{1}{N}}\; t_{N-1;\alpha}} \qquad \text{Equation 6}$$

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

TABLE D-1 Normal Tolerance Factors for Upper Tolerance Limit

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

2.4 Non-parametric Upper Limit Statistical Estimate Assumptions.

If there is reason to believe that the logarithm transformed spectra will not be sufficiently normally distributed to apply the parametric limits defined above, then consideration must be given to non-parametric bounds i.e., bounds that are not dependent upon assumptions concerning the distribution of spectra values. In this case, the individual spectra are not logarithm transformed. All of the assumptions concerning the selection of spectra are applicable for non-parametric estimates. With additional manipulation, lower limits may be computed using the information in paragraphs 2.3.1., 2.3.2., and 2.3.3.

2.4.1 Upper Limit. (ENV)

The maximum envelope limit is determined by selecting the maximum estimate value in the data set, Equation 7. The main disadvantage of this procedure is that the statistical

$$\text{ENV (N)} = \max\{ x_1, x_2, \ldots\ldots x_N \} \qquad \text{Equation 7}$$

distribution properties of the spectra are neglected so that no probability of exceedance of this maximum value is specified. In the case of outliers in the spectra, ENV (N) may be far too conservative. ENV (N) is also sensitive to the bandwidth of the spectra.

2.4.2 Upper Distribution-free Tolerance Limit (DFL)

The distribution-free tolerance limit that utilizes the original untransformed sample values is defined to be the upper limit for which the fraction β of all sample values will be less than the maximum predicted or measured value with a confidence coefficient of γ. This is based on order statistic considerations, where in Equation 8, x_{max} is the maximum value of the set of

$$\text{DFL}(\text{N}, \beta, \gamma) = x_{\max}; \quad \gamma = 1 - \beta^{\text{N}} \qquad \text{Equation 8}$$

data, β is the fractional proportion below x_{max}, and γ is the confidence coefficient. Given N, β and γ are not independently selectable ; that is:

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

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

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

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

2.4.3 Upper Empirical Tolerance Limit (ETL)

The empirical tolerance limit uses the original untransformed sample values and assumes the predicted or measured estimate set is composed of N measurement points over M frequency resolution bandwidths for a total of NM estimate values. That is a set of points, $x_{ij,}$ where M is the average at the j^{th} frequency bandwidth over all N measurement points.

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

$$m_j = \frac{1}{N}\sum_{i=1}^{N} x_{ij} \qquad j = 1, 2, \ldots, M. \qquad \text{Equation 9}$$

Equation 9 for m_j is used to construct an estimate set normalized over individual frequency resolution bandwith, for the points :

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

where : $$u_{ij} = \frac{x_{ij}}{m_j} \qquad i = 1, 2, \ldots, N; \qquad j = 1, 2, \ldots, M \qquad \text{Equation 10}$$

The normalized estimate set {u} is ordered from smallest to largest and $u_\beta = u_{(k)}$ where $u_{(k)}$ is the k^{th} ordered element of set {u} for $0 < \beta = \frac{k}{MN} \leq 1$ is defined. For each frequency or frequency band, ETL is given by Equation 11.

$$ETL(\beta) = u_\beta m_j = x_{\beta j} \qquad j = 1, 2, \ldots, M \qquad \text{Equation 11}$$

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

3 RECOMMENDED PROCEDURES

3.1 Recommended Statistical Procedures for Upper Limit Estimates.

Reference a provides a discussion of the advantages and disadvantages of estimate upper limits. The guidelines in this reference are recommended here. In all cases, the data should be carefully plotted with a clear indication of the method of establishing the upper limit and the assumptions behind the method utilized.

a. When N is sufficiently large, N > 6, establish the upper limit by using the expression for the DFL for a selected $\beta \geq 0.90$ such that $\gamma \geq 0.50$.

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

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

3.2 Uncertainty Factors

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

4 REFERENCES

a. 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.

b. Conover, W.J., Practical Nonparametric Statistics. New York; Wiley, 1971, Chapter 3.

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ANNEX E

EFFECTIVE SHOCK DURATION

1 SCOPE

1.1 Purpose

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

1.2 Application

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

2 DEVELOPMENT

2.1 Shock Envelope Development Assumptions

The shock duration is determined by the form of the envelope over the absolute value of the measured peaks in the shock time history. This assumes that for a shock time history, the distribution of the positive and negative peaks are essentially the same; the shock time history is symmetrical with respect to polarity about the time axis. It should be clear that the envelope of these peaks in general is a complex piecewise continuous function that has no simple analytical description. Figure E-1 displays a typical shock time history along with its envelope and two sets of vertical lines. One line indicates the effective shock duration, $T_{e,}$ and the other line the alternate duration of T_{E} . T_E is a shorter duration defined as the duration with all data magnitudes exceeding 1/3 of the peak magnitude. Figure E-2 displays the short time average RMS along with one set of vertical lines indicating the duration of T_e. In the development to follow it is assumed that the measured shock transient peak distribution in time has an initial segment characterized by a rise time, t_r , and a following segment characterized by a decay time, t_d , where in general $t_d > t_r$. It is assumed that the envelope of the initial peak amplitude distribution normalized to the absolute value of the maximum peak acceleration, Ap, is of a third order polynomial in the form of Equation 1.

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

for $0 \le t \le t_r$ and $(a_1 + a_2 + a_3) = 1$

It is assumed that the envelope of the trailing segment is characterized by a simple exponentially decaying function normalized to Ap as in Equation 2.

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

Equation 2

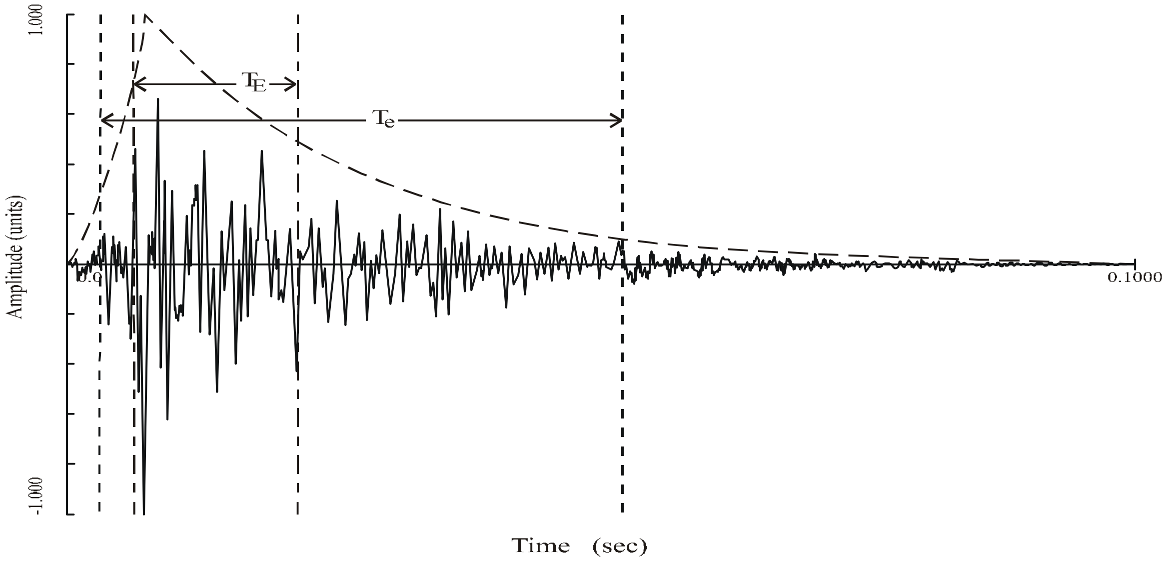

Figure E-1 Typical Shock Time History with Envelope, T_E and T_e

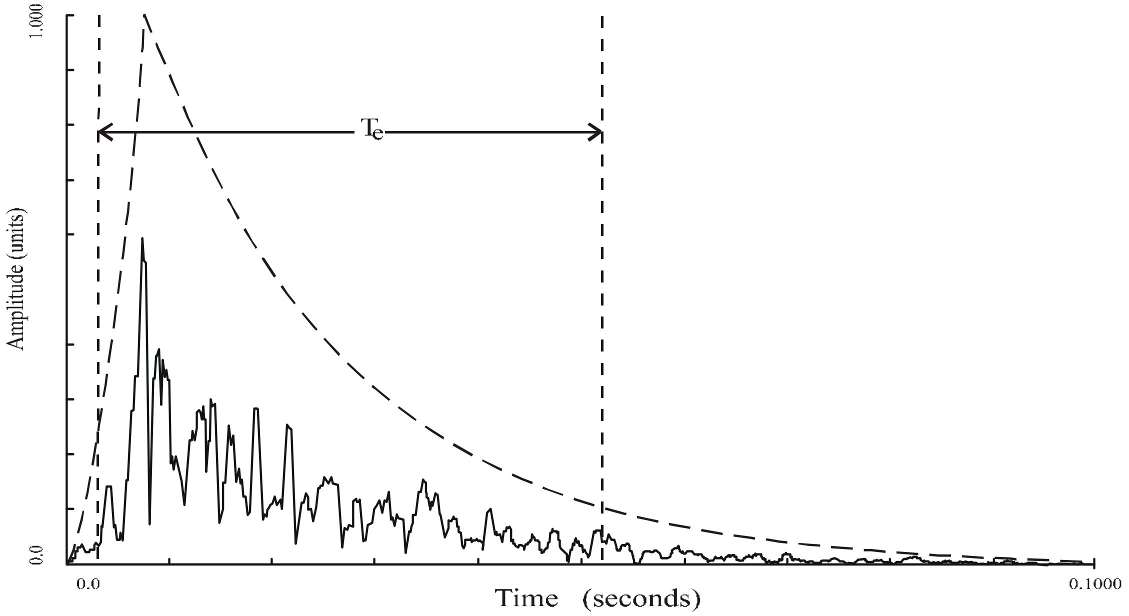

Figure E-2 Typical Shock Time History RMS with Envelope and T_e

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

2.2 Comparison of T_e and T_E

The T_E duration was originally defined, in MIL-STD-810E, to be “the minimum length of time that contains all data magnitudes exceeding 1/3 of the peak magnitude associated with the shock event.” In this document, T_e is revised to be defined as the minimum length of time that contains at least 90% of the root-mean-square (RMS) time history amplitudes exceeding in value 10% of the peak RMS magnitude associated with the shock event. Figure E-3 provides a scatter plot of T_E versus T_e for shocks simulated according to the envelope forms above and provides a visual correlation between the two durations. From this statistical simulation, on this particular simple form of pulse, it can be concluded that the median ratio of T_e to T_E is 2.62 with 95% of the ratios lying between 1.71 and 5.43. In general T_e may be considered to be approximately 2.5 T_E.

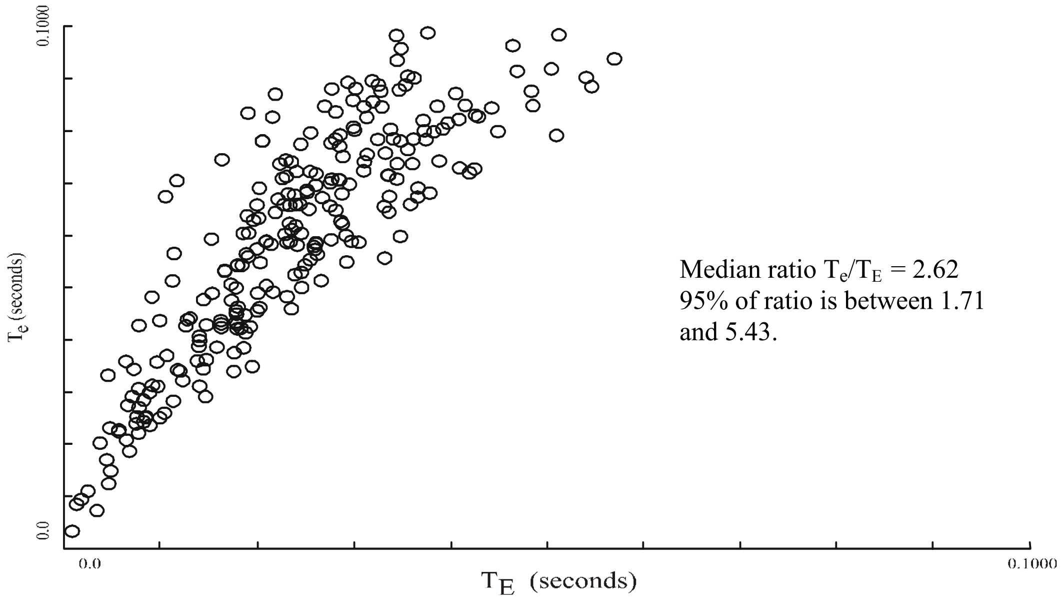

Figure E-3 Scatter Plot T_E versus T_e

3 RECOMMENDED ANALYSIS PROCEDURE

3.1 SRS Calculation Time Duration

When measured time histories are available, the SRS calculation or synthesis for the laboratory test should be based on an appropriate length time duration transient. The duration length, T_e , required should be determined by examining representative time history measurements. The duration T_e should extend from the first significant response time history point to an analytically derived T_e , or to the noise floor of the instrumentation system, whichever is shortest. A maximum duration, T_{max} , can be defined from the minimum SRS calculation frequency , f_{min} , for the simulation requirement.

$$T_{max} = \frac{1}{2f_{min}}$$

If the T_e duration based on measured data is less than T_{max} , $T_e < T_{max}$, the duration for the laboratory SRS simulation may be extended to T_{max}. Or similarly, the laboratory SRS simulation should be based on the maximum duration of T_e or T_{max} . If required, the measured data can be windowed to taper the shock event to zero amplitude, and meet the above duration time for the SRS computation. The window must be chosen to maintain the initial peak amplitude of the transient. When a sufficient number of representative shock spectra are available, an appropriate statistical enveloping technique should be employed to determine the required SRS test spectrum with a statistical basis, see Annex D. Statistical techniques should be applied to envelope the available measured data if insufficient measured data are available.

METHOD 418

MOTION PLATFORM

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METHOD 418

MOTION PLATFORM

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the motion platform conditions incurred by systems, subsystems and units, hereafter called materiel, during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified motion platform environment without unacceptable degradation of functional and/or structural performance. The most common environment for induced platform motion is a large ship during a rough sea state condition. For combined axis, multi-degree of freedom motion, see Method 421.

1.3 Limitations

This test is not intended to represent any motion of the materiel mounting platform other than rigid body motion.

2. TEST GUIDANCE

2.1 Effects of the Environment

The following list is not intended to be all-inclusive but provides examples of problems encountered when materiel is exposed to motion platform :

a. Structural deformation,

b. Cracking and rupturing,

c. Loosening of fasteners,

d. Loosening of parts or components.

2.2 Use of Measured Data

Where practical, measured field operational informatioin should be used to tailor the test levels. Sufficient data should be obtained to adequately describe the conditions being evaluated and experienced by the materiel in each LCEP phase. The measured data and information acquired should as a minimum be sufficient to account for the data variances due to the distribution of the transport platform condition and age, payload capacity and restraint system, operational personnel, and the environmental operating conditions.

2.3 Sequence

The order of application of the test should be considered relative to other tests and made compatible with the Life Cycle Environmental Profile.

2.4 Choice of Test Procedures

There is only one test procedure, see paragraph 5.4

2.5 Types of Motion

Unless otherwise specified, the motion should be sinusoidal. Measured in-service data can be used for laboratory sinusodial simulation testing, time waveform replication, or other similar techniques.

2.6 Control Strategy

This motion can be controlled with an angular sensor, or it is possible to use a linear sensor fixed to the table. In the latter case, it is necessary to make a correction between linear and angular motion.

3. SEVERITIES

When practical, test levels and durations will be established using projected in-service use profiles and other relevant available data. When data are not available, initial test severities are provided in Annex A. These severities should be used in conjunction with the appropriate information given in AECTP 200.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of test item,
b. The definition of test item,
c. The definition of test severity,
d. The orientation of the test item in relation of the test axes,
e. Operation checks : initial, final,
f. Details required to perform the test,
g. The indication of failure criteria.
h. Climatic conditions for the test.

4.2 If Required

a. Tolerances, if different from paragraph 5.3,
b. The specific features of the test assembly.

5. TEST CONDITIONS AND PROCEDURES

5.1 Types of Motion

Four motions are defined for a ship with vertical, transverse, and longitudinal axes of v, t, and l respectively. Vertical is normal to the ground plane. Transverse is across the short dimension of the ship and perpendicular to the v and l axis. Longitudinal is parallel to the long ship dimension, and is perpendicular to the v and t axis.

- Roll is the oscillatory rotational motion of a ship about the longitudinal axis.
- Pitch is the oscillatory rotational motion of a ship about the transverse axis.
- Yaw is the oscillatory rotational motion of a ship about the vertical axis.
- Heave is the oscillatory translation motion of a ship in the vertical axis.

5.2 Test Facility

The test facility is typically a large table which can oscillate about a horizontal axis.Two types of test machines are common.

- A horizontal table coupled, at each end, with two or more vertical hydraulic actuators. The control system generates actuator motion to simulate roll or pitch motion by control of the table rotation about a horizontal axis. Alternatively, by controlling the vertical motion of the table, heave motion can be simulated.
- A horizontal table with bearings forming a fixed horizontal hinge line. The table oscillates by use of one or several hydraulic actuators. This table configuration does not simulate heave motion.

5.3 Tolerances

Tolerances for the test equipment frequency and angular displacement are indicated below. These values shall be applied for laboratory testing if a test tolerance value(s) is not defined in the Test Instruction.

a. Frequency :

(1) ± 0.05 Hz	from	0 Hz to 0.5 Hz
(2) ± 10 %	from	0.5 Hz to 5 Hz

b. Angular Displacement :

(1) ± 15 % at the control signal

5.4 Procedure

If the test item in-service orientation is unknown onboard the transportation platform, and undefined in the Test Instruction, the test item will be tested in all three major axes. The Test Instruction shall specify if the test item must be operating during the test.

Step 18. If applicable, pre-condition the test item.

Step 19. Implement the control strategy, including control and monitoring points.

Step 20. Perform the initial operational checks.

Step 21. Apply the specified motion, and conduct the required operational and functional checks.

Step 22. Perform the final operational checks.

Step 23. Repeat Steps 1 to 5 for the other required axes.

Step 24. Record the information required in the Test Instruction

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the completion of the motion platform test.

ANNEX A

MOTION PLATFORM - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

The test item will be subjected to controlled roll and pitch motion defined on the appropriate in-service platform in Table A-1 for the test duration specified. A test severity is not stated for yaw and heave axis motion because in-service levels are usually low. Table A-1 provides a test severity for a sea state 5/6 and is derived from multiple NATO sources.

Table A-1 Motion Platform Initial Test Severity

Platform	**Roll**		**Pitch**		**Test Duration**
	Frequency Hz	**Angle** Degrees	**Frequency** Hz	**Angle** Degrees	
Aircraft Carrier	0.065	+/- 20.0	0.143	+/- 5.0	30 min./axis
Frigate	0.091	+/- 30.0	0.196	+/- 10.0	
Submarine	0.143	+/- 30.0	0.100	+/- 10.0	

METHOD 419

UNDEX ASSESSMENT AND TEST

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ANNEX B UNDEX ASSESSMENT AND TEST CONSIDERATIONS

ANNEX C UNDEX TESTING USING SRS METHODS

ANNEX D UNDEX TEST EQUIPMENT

METHOD 419

UNDEX ASSESSMENT AND TEST

1. SCOPE

1.1 Purpose

The test method procedures are applicable to systems, subsystems, and units, hereafter called materiel, which must function or survive a non-contact underwater explosion (UNDEX) event. The purpose of this test method is to provide an UNDEX assessment method, which uses a multi-discipline approach to the production of a materiel safety and suitability for service statement. The method combines both analytical analysis and physical testing to ensure that materiel deployed or transported at sea can withstand the UNDEX environment. The principle objectives of the test method are the following:

a. Derive an assessment process for materiel such that the safety and suitability for service criteria can be demonstrated with an acceptable and appropriate margin of safety balanced against the risk consequences of failure.

b. Define safety as the prime requirement of an assessment, and provide guidance for serviceability compared with current custom and practice regarding ship design criteria.

c. Integrate UNDEX assessment with the current procedures for assessing the dynamic behaviour of materiel.

d. Provide a materiel UNDEX assessment strategy to enable appropriate questions to be asked and assessment routes identified for independent assessment.

e. Enable existing vibration and shock test facilities to be used for live UNDEX testing of materiel.

1.2 Application

Transportation by sea is likely at some stage during the life cycle of most materiel. This is particularly the case in times of increased tension or hostility when large quantities of materiel to support services require shipment to front line bases and theatre. Naval weapons are a special case in that they are also deployed on-board naval vessels and often have different packaging or storage arrangements. As a consequence, there is a need to assess the effects of UNDEX events when materiel are stored, deployed or transported on a seagoing vessel. The issues are wider than materiel serviceability in that any compromise of safety has wider implications for the safety of the complete vessel and crew.

The increasing structural complexity of materiel and the trend to purchase commercial off the shelf (COTS) hardware from third party sources also requires improvements in assessment methods and data for the provision of relevant safety and suitability for service arguments. Integrated and tailored assessment using modelling and historical databases in support of tests provide the opportunity to optimise the assessment process. This is particularly relevant to the assessment of materiel subject to UNDEX events. At present, assessment of materiel subject to the UNDEX environment is commonly tested using a Shock Grade Curve Scheme, and where necessary by specialised one-time assessment. Since the Grade Curve Scheme is not entirely applicable to materiel that exhibit complex dynamic response behaviour, a tailored multi-disciplinary assessment approach using modelling, test and correlation from historical data is required. Therefore, the need exists to formalise the tailored assessment process to compliment the Shock Grade Curve Scheme.

Grade Curves are empirical and represent structures subjected to a range of underwater explosions both in the near and far field. They can be directly applied to materiel, which may be considered to be a rigid body, a severe limitation for complex munitions. Shock Grade Curves assume a representative structure, which is sub-divided into shock environments or grades. This is an attempt to subdivide, albeit coarsely, the ship into areas of differing dynamic character of the shock input where the different positions will see significantly different dynamic input conditions for the same UNDEX event. Furthermore, the transmission path will be different between the stowage and operational deployment positions resulting in modified dynamic input levels. For example, at deck level lower frequency excitation, 10's of Hz, will be present whilst within the hull the frequency content will be in the range of hundreds of Hz. In essence a Shock Grade Curve Scheme provides a prescriptive procedure for determining the response of a rigid body, firmly attached to a seating within a vessel. This rigid body can readily be considered as a simple lump mass model. However, the weakness of the lump mass approach and simple use of the fundamental natural frequency is that the shock input to individual components and their response, modified by the equipment structure, cannot be considered.

This test method defines a tailored UNDEX assessment process that builds on the Shock Grade Curve Scheme, and extends the capability to cover dynamically complex materiel. It describes a rationale and assessment process applicable to a wide range of materiel using a comprehensive and tailored assessment strategy designed to be used in support of safety and suitability for service UNDEX assessments. Where Shock Response Spectrum (SRS) testing forms a part of the assessment process, the AECTP 400 Method 417 methodology should be applied; and Method 403 when classical shocks are specified.

1.2.1 UNDEX Environment

Throughout this document the term UNDEX is used to describe the dynamic loads ensuing from underwater explosive detonation. Historically the descriptions, 'underwater shock' and 'shock loading' have been used incorrectly as general terms. Shock is just one effect that occurs from an UNDEX event, and therefore forms one part of the total UNDEX induced loading as described below. A short review of the physics and characteristics of an UNDEX event is provided below. Figure 1 illustrates the event.

The UNDEX event consists of the early time shock and oscillating gas bubble effects. Following detonation of a submerged explosive charge, or warhead, approximately one third of the explosive energy is propagated into the surrounding fluid in the form of an acoustic pressure pulse. The peak pressure and the decay rate are functions of the charge size, explosive type, and the distance from the point of detonation. Similarly, quantities such as impulse and energy flux density, which are derived from pressure time data, are dependent upon these quantities. The pressure pulse is typically characterised by a very fast rise time, a few milliseconds, pressure peak followed by a slower pressure decay. The decay is generally modelled as exponential, with the peak pressure being inversely proportional to the distance from the detonation point, P ~ 1 / distance. Near the detonation point, the pulse shock wave propagation velocity is typically three to five times the 1500 m/s (4921 ft/s) speed of sound in water. The pressure peak, for a nominal distance from the detonation, is in the range of 5 to 25 MPa (725 to 3626 PSI), with an effective duration of 1 millisecond.

At the point of detonation the explosive event also introduces a volume of high pressure and temperature gas into the fluid. This gas expands against the ambient hydrostatic pressure. The bubble expansion attains considerable outward momentum, which overshoots the equilibrium condition, and an oscillating gas bubble thus ensues. The principle effects from the gas bubble are considerable incompressible flows of water radially out from the point of detonation, a flow which alternates direction as the bubble oscillations develop. Each time the bubble reaches a minimum condition, a rebound phenomenon occurs whereby a pressure pulse is propagated into the fluid. The action of migration of the buoyant bubble and energy dissipation of each cycle ensures that the bubble rarely oscillates beyond two or three cycles.

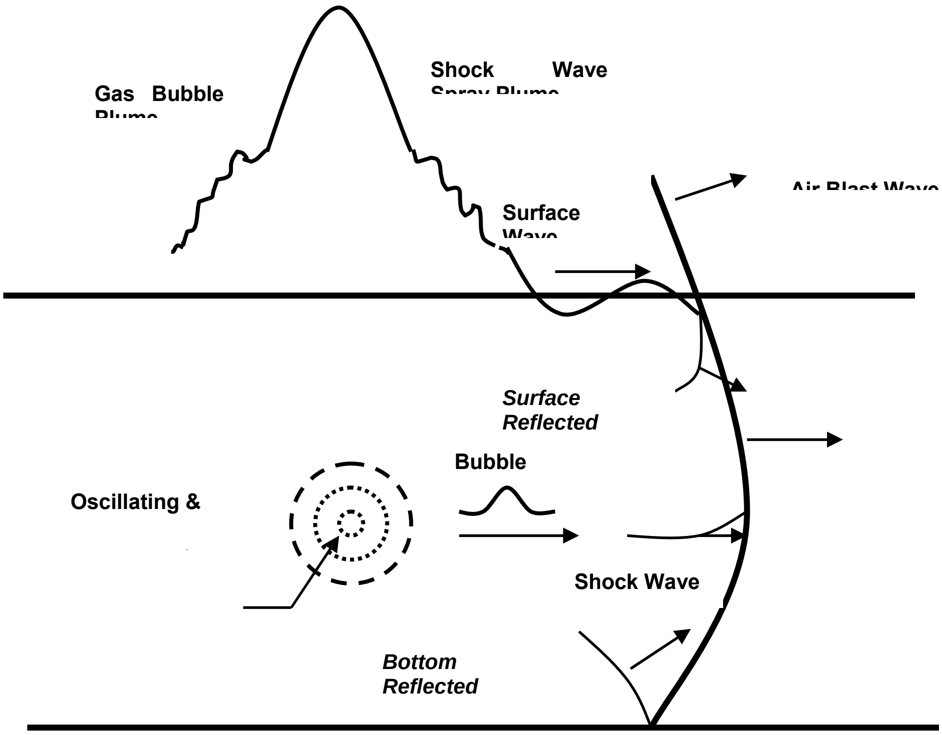


Figure 1 UNDEX Shock Wave Characteristics

1.2.2 Outline of UNDEX Assessment Process

UNDEX assessment in the context of shipborne materiel is a multi-disciplinary activity in the assessment of safety and suitability for service of a materiel when subject to the effects of an UNDEX event. There should be a minimum of three scenarios considered in the UNDEX assessment.

- Transit
- Magazine Storage
- Operational Deployment (e.g. in the launcher)

The transit scenario occurs where a sea vessel transports the materiel. Transportation could potentially be by naval vessel, naval transport, or a commercially chartered transport vessel. Transportation by sea potentially applies to materiel for all three services. The casing or packaging of materiel may differ considerably from the operationally stored configurations. For materiel, which is identified for use by the navy, assessment of the magazine stowage condition is necessary. However, materiel with commonality to other services may also be stowed in naval warship magazines. These naval warship conditions should have the same level of assessment as naval ordnance since they are equally likely to be exposed to the full exigencies of the UNDEX loading. Operational deployment of materiel will see the materiel removed from the magazine environment and placed in a launcher, or deployment system, where the materiel may spend a significant part, or perhaps all, of its time at sea.

There are three levels of survivability considered for materiel carried in naval warships; the three levels of function are summarised below. The vessel itself, and all equipment, has been designed to well established shock resistant design guidelines. Therefore, the requirement exists to rationalise the UNDEX design levels of the vessel with those for the materiel. Typically a warship is designed to fulfil a level of function at a specific severity of attack. This is engendered in the concept of the Shock Factor. The function may be the ability to remain a viable weapons platform, or could merely be the ability to maintain propulsion and steerage. Overriding this severity of attack criteria is the most demanding level which defines the point where uncontrollable flooding occurs in the vessel, commonly referred to as “to float”.

Level	I	To fight -	The ability to maintain a particular operational function.
Level	II	To move or mobility -	Ability to fight has been lost, but a capability to move and steer is maintained sufficient to return to port.
Level	III	To float -	Watertight integrity, or the point where uncontrollable flooding occurs.

For each of the assessment scenarios and ship design criteria it is necessary to determine if the materiel is safe and serviceable and determine what constitutes unacceptable failure. At Level III it is necessary for the materiel to remain safe and not pose a threat to the watertight integrity of the vessel by the initiation of a significant detonation or burning event. Premature ignition or detonation is considered to be a worst-case condition and is clearly unacceptable. All materiel must be able to meet this failure criterion and be capable of safe disposal following exposure to an event below the level III design criterion.

Serviceable can be subjective and difficult to relate to the ship design levels. For example, a single materiel item such as a shell could be questionable in terms of serviceability but other shells and the system for launching them, the gun, may remain operable and able to fight. However, a self-defence air weapon when launched must be guaranteed to be serviceable. Typically serviceability levels need to be assessed on a case-by-case basis.

A further requirement may be imposed relating to the Level I ship design criteria. It should be confirmed that a stowed or deployed materiel, at the level at which the fighting capability of the vessel is to be maintained, will not impact upon the overall fighting capability of the vessel. For example, while the post-shock state of the materiel may itself be safe, the materiel location on a stowage rack may impede the handling of other weapons, thus compromising the fighting function of the platform in which it is stored. The safe and serviceable criteria are shown in Figure 2. The safety requirement must be maintained for all of the three ship design criteria levels including safe disposal. The serviceability criteria vary with the requirement. It is often difficult to define when serviceability is lost since it could be a gradual process, rapid, or catastrophic loss of function. In practice, it is necessary to define zones where serviceability may be questioned, but in general serviceability should as a minimum be maintained at Level I.

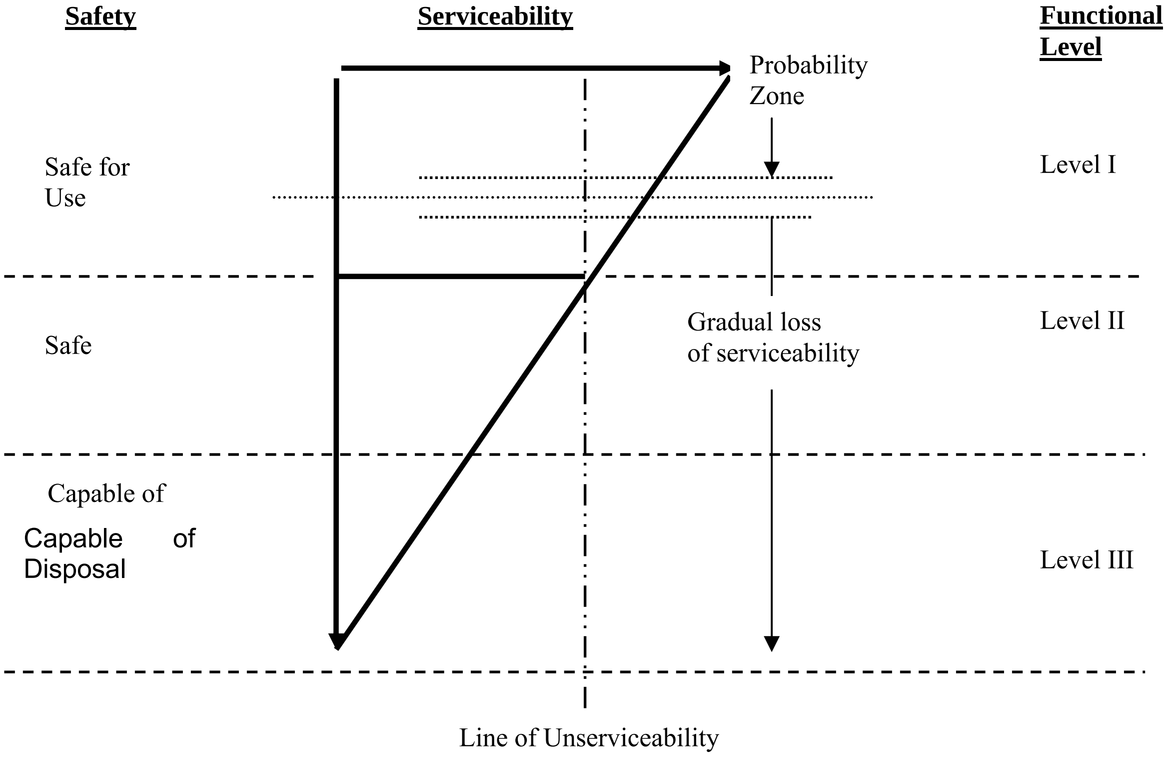


Figure 2 Materiel Safety and Suitability Diagram

1.2.3 Assessment Complexity

Several criteria provide a basis to differentiate the need for a simplistic or more complex UNDEX assessment. Annex B also provides a summary of general considerations for UNDEX planning. The main areas for consideration are:

a. Structural Flexibility - This is characterised by multi-modal behaviour. In general, generic empirical models or data can only be applied to rigid bodies and those represented by simple lump mass models where only the first mode is of interest. Where the degree of structural flexibility, packaging, or support cannot be adequately represented by lump masses, or where a multi-modal response is required, then a tailored approach to the UNDEX assessment should be considered.

b. Distributed Systems – The materiel, it's housing, or the structure in which it is stored, may occupy a significant volume of the vessel structure. Generally, materiel which are long and slender, fall into this category and therefore require individual assessment. Long and slender materiel, such as a torpedo located on flexible mounts or arranged over a number of ships or submarine frames, requires a tailored assessment. In this case the structure will exhibit multi-modal behaviour and be subjected to UNDEX loading which will invariably differ in phase along the materiel length. This response results in complex dynamic behaviour of the materiel or container which must also be adequately represented in the UNDEX assessment. The materiel dynamic behaviour can also be influenced by the proximity of other materiel in the stowage location. This situation can change as materiel are expended and illustrate the need to consider a range of payload configurations in the UNDEX assessment.

c. Shock Isolation Mounts - Materiel shock isolation mounts are generally highly non-linear, allowing large deformations to occur which represents a difficult modelling problem to achieve the desired degree of accuracy. Even so, the support structure and mounts should be considered to be integral to the materiel and modelled or tested accordingly. Materiel mountings offer a degree of protection from an UNDEX event and are therefore an essential element in the load path. Complex dynamically responsive materiel and supports will require a tailored UNDEX assessment.

d. Packaging - The packaging becomes an integral part of the materiel structure, which can have a marked influence on the materiel dynamic behaviour and will need to be included in the dynamic model and UNDEX assessment. Different packaging and environments may need to be considered relating to the materiel in the transit, magazine, and operational conditions.

e. Cost - UNDEX testing, analysis and assessment can be costly. This dictates that a cost benefit analysis be performed to aid the decision-making process relating to the requirement to undertake a tailored UNDEX assessment. This is in contrast to simply testing materiel by applying the generic empirical model or data. However, the cost of the UNDEX assessment should be considered in terms of optimising the overall assessment process by reducing the number of scenarios requiring laboratory testing to demonstrate safety and suitability for service requirements.

1.2.4 UNDEX Assessment Scheduling in the Test Programme

UNDEX assessment is not generally considered to be a design driver for materiel and occurs at the end of the design process prior to acceptance, after design of a suitable stowage, encapsulation, racking and mounting. It is most applicable during the qualification stage, since it requires an advanced design and a prototype or fully engineered materiel to be meaningful. This does not preclude inclusion of UNDEX information in the functional design process, providing that the limitations are understood and acceptable. The UNDEX assessment will be specific to the deployed platform and remain valid through service life. However, if there are any life cycle design changes, which influence the UNDEX environment i.e. new platform, launcher or stowage etc. then a further assessment may be required. Where an UNDEX assessment has not been considered at the qualification stage it is recommended that a retrospective assessment be carried out. This is particularly relevant when considering extension of service life where the UNDEX assessment should play an important role and as a minimum, if one already exists, be reviewed. In general UNDEX assessments should be performed where benefit or gain can be shown to add confidence to the service life safety case. The safety case brings together all safety arguments into a single structured, comprehensive and auditable document.

For the UNDEX assessment to be meaningful it critically depends upon the quality, quantity and timely availability of relevant information. The sponsor of the assessment must be aggressively proactive in obtaining this information at the appropriate time in the project or procurement cycle. When considering COTS procurement the requirement for data relating to the UNDEX assessment should be identified at the earliest time and included in the procurement contract to ensure availability when required.

Examples of data required are:

- Structural profile of the materiel
- Mass distribution and or mass of component parts.
- Method of stowage
- Materials and method of construction.
- Details of warhead, explosive fill, propellant and pyrotechnics.
- Environment in which to be assessed i.e. ship class, launcher Vs magazine etc.
- Existing vibration or static structural test results.
- Existing live drop test data.

The materiel life cycle UNDEX assessment and equivalent elements for the design certification process is shown in Figure 3. The materiel life cycle stages range from the Staff or Service Requirement, through design, manufacture and certification, operational use, life extension and safe disposal. For many materiel development programmes the UNDEX assessment and documentation may simply form part of the design certification documentation. For COTS materiel information relating to the design manufacture, qualification and certification for use and release to service will be necessary and should be specified at the procurement contract stage. Clearly life cycle condition monitoring and operational records form an important requirement to assess changing operational conditions and requirements and for assessing life extension and safe disposal.

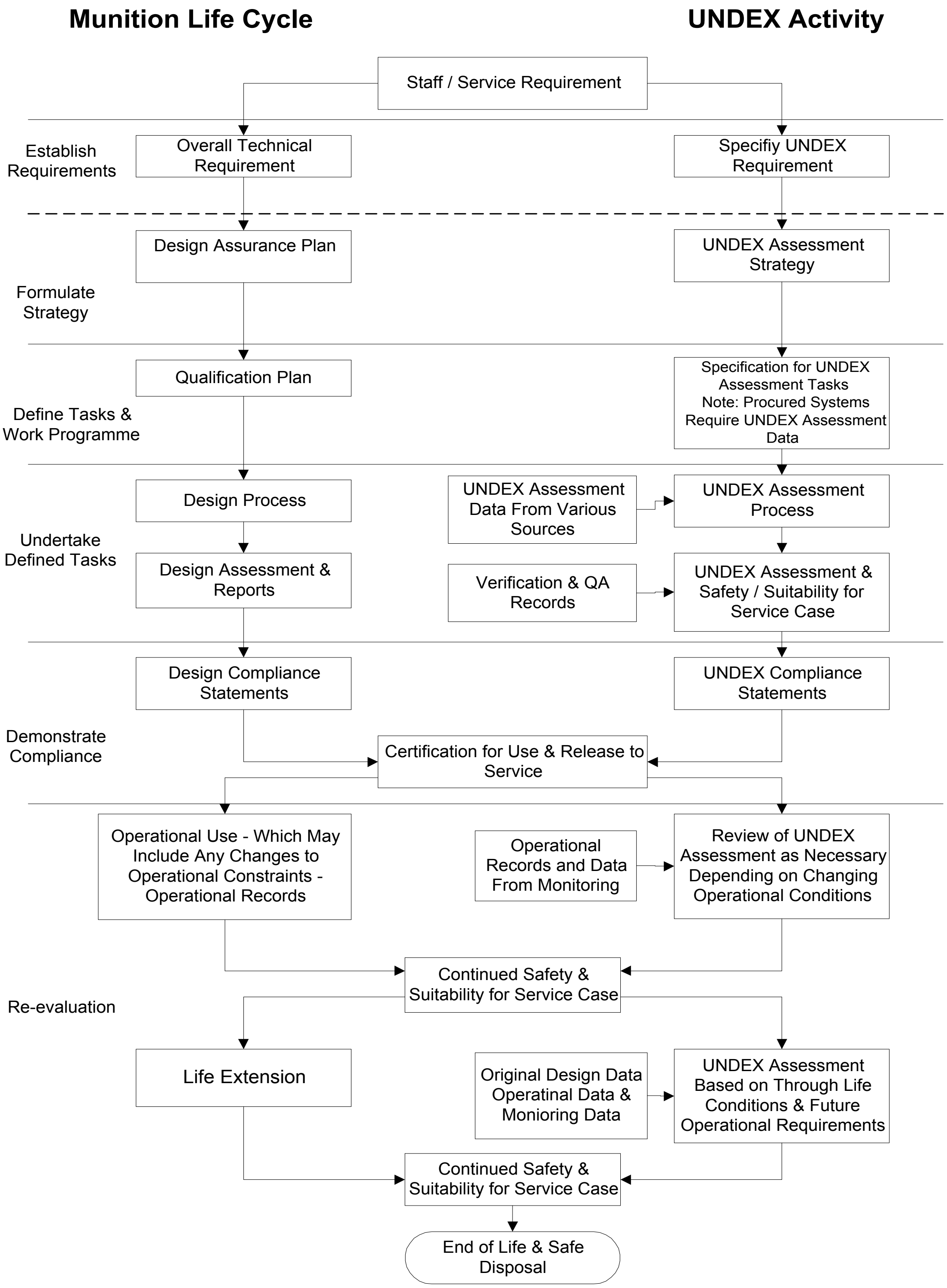


Figure 3 UNDEX Assessment and Materiel Life Cycle Relationship

1.2.5 UNDEX Assessment Application

The results of an UNDEX assessment form a key component to a multi-discipline safety case as shown in Figure 4. In general, a safety case considers various inputs from each technical discipline to form the argument conclusion where the case is judged on the basis of the strengths and weaknesses of each contributing discipline. Typically the theory of a safety case can be provided from a combination of laboratory testing, tailored assessment, modelling techniques, generic standards, and historical database input. These information sources combine to give strength and depth to the safety case.

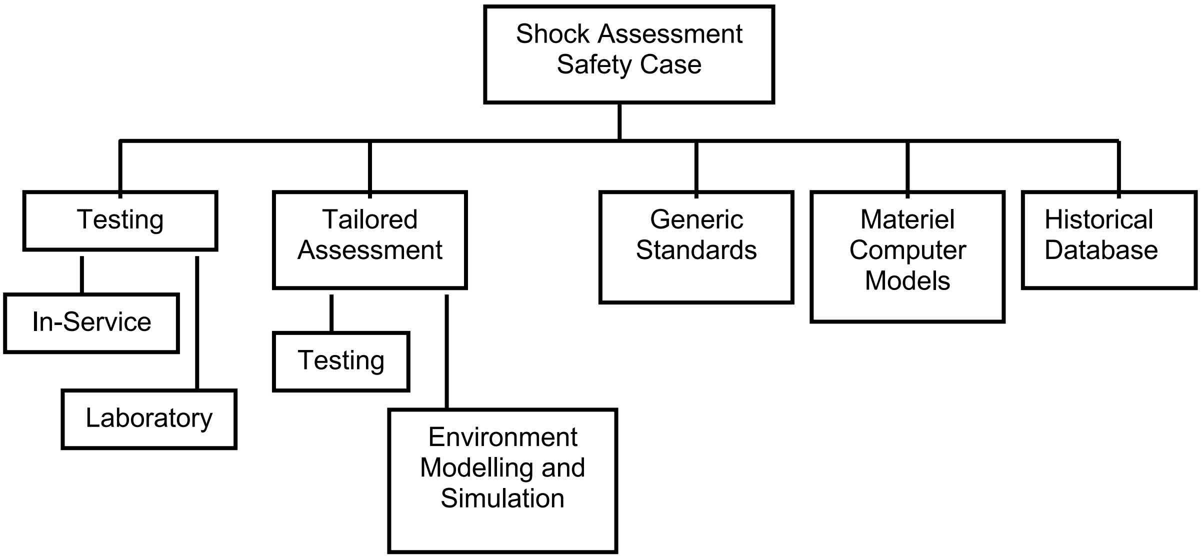


Figure 4 Multi-Discipline Shock Safety UNDEX Assessment

The combination of techniques employed to reach a conclusion will depend upon the complexity of the materiel, the consequences of failure, and suitability for service requirements. Furthermore, where analytical techniques are employed, the verification and validation of basic theory will need to be demonstrated. For example, artillery shells would require basic shock qualification testing in conjunction with generic empirical models, or data, to determine the level of test and demonstrate safety and suitability for service. A packaged, semi-flexible, materiel on elastomeric mounts would require lump mass modelling and application of the generic empirical models, or data, and testing. A more complex, flexible materiel may justify the use of a non-linear finite element model, and where feasible, full-scale shock trials using equipment specific failure criteria. When considering a general UNDEX assessment, the principles of a graded escalation, fitness for purpose, approach using a multi-discipline safety case consistent with the perceived risk, due to failure modes and consequences, required confidence level, and cost should be applied.

1.3 Limitations

Laboratory or field simulation, and in-service measurement, of UNDEX environments is a complex task. The UNDEX event is a function of the stand-off distance from the ship to explosive charge varies from low frequency, high displacement and acceleration, excitation to near pyroshock high frequency excitation conditions. Laboratory simulation equipment generally cannot encompass the entire range of requirements. A range of equipment is needed to simulate the possible excitation modes. Further guidance on appropriate test procedures and equipment is provided in the following sections and Annex D. The analytical modelling approach also has limitations due to non-linear response and multiple UNDEX excitation paths. The choice of the model, and boundary conditions should be carefully chosen to match the failure mode under consideration. The limitations are summarized below.

- Laboratory simulation tests and equipment may only have the capability to evaluate one portion of the UNDEX environment or expected failure mode.
- UNDEX analytical models should be used to validate testing and the expected dynamic response.
- The use of measured in-service is critical to the accuracy of UNDEX assessment and testing.

2. TEST GUIDANCE

Presently the assessment of materiel subjected to the UNDEX environment is usually performed using impact techniques based upon either generic empirical model data, or where necessary by a one-time specialized assessment. The generic empirical equations are based upon vessel type, storage location within the vessel, and serviceability, or safety requirements of the materiel in question. However, these methods are extremely limited where the materiel is dynamically flexible, or is stowed in a manner or location where the empirical equations do not apply. These cases require the tailored UNDEX assessment procedures to be considered.

2.1 Effect of the Environment

Traditional methods of considering UNDEX focus on the direct shock wave effects, and established design methods have developed for considering this phase of the loading. While it is true that the shock wave is a potentially severe damage loading, it is a relatively local phenomenon and only contains one third of the total explosive energy. The remainder of the energy is dispersed with the secondary oscillating gas bubble effects, which may provide more severe loading than the initial shock wave excitation. The oscillating gas bubble can promote excitation of the fundamental flexural modes of the ship or submarine hull girder. Additional structural loading occurs from the interaction of the gas bubble with the ship hull. Where the underwater explosion is in close proximity to the hull structure, it subjects the hull structure, internal equipment, and materiel to an extremely high intensity transient loading. This occurs from focusing the gas bubble energy into a shape charge effect, generating a jet, which interacts with the hull. The consequence is localised impulsive loading, which can be extremely severe. In contrast to the initial fast transient of the shock wave, the flexural behaviour, commonly referred to as whipping, is global in nature, occurs over several seconds, generates large displacements, and can represent a worst case loading condition.

The process identified in this method advocates a balanced approach to considering UNDEX excitation, which include the secondary bubble effects where applicable. In this respect, it is considered more appropriate to term any assessment of this kind an 'UNDEX assessment' as opposed to a 'shock assessment' description. There is little point in ensuring safety and suitability for service for the early time shock loading when some seconds later a whipping or jet excitation compromises the materiel. The object of the assessment is the materiel, thus the important issue is the interaction of the various UNDEX loads with the materiel. This loading is dependent upon the following factors:

- The low and high frequency interaction of the shock wave and the gas bubble with the vessel hull.

- For the shock loading, the transfer function between the hull and the materiel stowage position. The primary transmission path through the hull, bulkheads, decks, and stowage structure will progressively modify the dynamic input from the explosive event.

- For whipping loads, the materiel survivability, which is driven by the gross flexural characteristics of the vessel hull girder, the structural mass and stiffness distribution.

- The material and construction of the vessel.

- The inclusion of any shock or vibration isolation materials or devices.

- The materiel stowage configuration.

2.1.1 Failure Mechanisms

UNDEX is considered to be a single load phenomenon consisting of shock and whipping components. Mechanical failure generally occurs through high inertia loading particularly where there is an inertia mismatch, such as a rocket booster attached to a missile. Shock loading can cause local plasticity, plastic collapse, and or buckling. In addition whipping could result in high strain, low cycle fatigue. A list of common UNDEX failure mechanisms is provided below.

a. Break or deform seals.
b. Component cracking.
c. Induction of fissures in the explosive.
d. Formation of powder from the energetic material.
e. Shaking of loose energetic material into cracks or screw threads.
f. Local heating by shaking the particles against one another or by friction with package furniture or mountings.
g. Distortion, thus compressing explosives either in bulk, cracks, or screw threads.

h. Break or damage mechanical parts of arming mechanisms, thus producing an armed blind store.
i. Make or break electrical circuits by damaging wiring or components
j. Cause damage which is undetectable until an attempt is made to use the store, or until further damage is incurred and a low-level event results in the failure being observed or catastrophic failure.
k. Loosening of fasteners.
l. Intermittent electrical contacts.
m. Mutual contact and short circuit of electrical components.
n. Structural or component failure or fracture.
o. Optical misalignment.
p. Cracking and rupture.
q. Loosening of parts that may become lodged in circuits or mechanisms.

2.1.2 Failure Modes

The failure modes must be linked to the input excitation and to positively validate the cause of potential failures. The list below is not exhaustive, but it illustrates the variety of conditions in which failure can arise and the close interaction between the mechanical damage mechanisms. In general failures will fall into the following categories.

a. Detonation - This form of failure is considered to be unacceptable under any circumstances and is a principal concern of the UNDEX assessment.

b. Deflagration, slow burn - This form of failure is considered to be unacceptable under any circumstances and is a principal concern of the UNDEX assessment.

c. Fatigue, particularly at welds or parent metal - Under the action of cyclic loading, defects that have been initiated by the UNDEX event or a pre-existing condition can grow until a pre-defined crack size is reached. This can threaten the integrity of the materiel or its component parts and may onset another failure mechanism.

d. Brittle fracture - Brittle materials should be avoided for use where the materiel will be subject to severe shock loading. However, for completeness brittle fracture occurs when the crack driving force at the tip of the crack becomes greater than the material toughness value. Failure is characterised by rapid crack extension and complete failure of the component due to a single peak load condition. In some cases depending upon the design and the material properties the crack will arrest.

e. Fracture - Fracture can be quantified using linear elastic fracture mechanics, elastic-plastic fracture mechanics, and combined methods. Fracture toughness properties are determined from experimental measurement and should reflect the material, temperature, and loading (strain rate) to which the materiel or structure under investigation is to be subjected. For shock loading the materiel is subject to transient dynamic forces, which should involve the determination of dynamic material toughness properties. Plastic collapse and strength requires the material tensile properties.

f. Plastic Failure - Can be localised plasticity such as deformation, or gross plastic failure such as the formation of plastic hinges.

g. Leakage - Describes a failure condition for a containment vessel where the fitness for purpose of the vessel is compromised by providing a path from the interior to the exterior.

h. Instability (buckling) - At any cross section, the total aggregate area and position of any defects should be such that the buckling strength of the component is not reduced to, or below, the maximum applied loading conditions.

i. Failure from initial imperfections - Initial geometric imperfections can cause stress concentrations resulting in an accelerated or enhanced likelihood of failure from defects located within these regions. UNDEX assessment for other modes of failure should therefore consider these higher stresses.

j. Control or functional limits (displacement limits) - Shock induced failure of electronic components and control systems result in the materiel failing to meet the serviceability criteria and in some cases can compromise safety.

k. Combined failure modes - These are combinations of the above failure modes in which complex interactions can occur. Typical examples include: combined fracture and plastic collapse, crack initiation followed by fatigue and fracture, or plastic collapse, buckling followed by fracture.

l. Collision and adequate space envelope - The space envelope surrounding the stowed materiel should be adequate to prevent collision during the UNDEX event. Collision with other materiel or support structural members can represent a significant cause of shock or impulsive input and subsequent damage to the materiel or support structure.

2.2 Use of Measured Data

The application and need to use measured in-service data is discussed throughout this test method. The UNDEX test method relies on measured data because the measurements are costly, difficult to obtain accurately, needed as a basis for laboratory simulation testing, and required for model validation. Investigation of the existing historical databases of measured and expected scale and full-scale responses for both the platform and test item should be a defined task in the UNDEX assessment process.

2.3 Choice of Test Procedures

UNDEX assessment and testing relies on both laboratory experiments and analytical or modelling methods. The choice of the equipment and analytical methods clearly depends on the type of materiel and simulation or failure mode investigation. Choices of equipment and modelling vary from full-scale experimental tests to scale laboratory response measurements.

For the laboratory testing approach, the required equipment depends primarily on the required displacement, acceleration, velocity, and combined environments needed for a test. The Laboratory Test Methods paragraph below and Annex C and D provide information on equipment applications. Annex C provides information on the use of SRS techniques for above or below shock mount laboratory shock simulation. Annex D provides more detailed information on the various types of test equipment. Where appropriate, other test methods and procedures in AECTP 400 should be applied.

For the analytical, assessment, or modelling approach the Analysis Methods paragraph below and Annex A and B provide further information. Annex A provides a guide to the UNDEX assessment process. Annex B provides a question and answer format to determine requirements and procedures.

2.3.1 Laboratory Test Methods

Other than impact testing, and in specific cases electrodynamic exciter shock testing, there are currently limited facilities available for laboratory shock testing of live materiel. Inert materiel laboratory testing can be performed using shock machines, barges, and underwater rigs. UNDEX trials using representative platform sections and existing purpose built barges can be undertaken using large charges, such as 450 kg TNT equivalent of explosive. Qualification testing is currently mostly conducted by comparing the predicted or measured UNDEX response of an inert materiel with drop testing results. This approach leaves considerable scope for uncertainty, since it is a common belief that the comparison can be made on the basis of peak acceleration. For a more rigorous comparison, though not ideal, the two tests must be compared in temporal and spectral domains using a common mechanism, such as the SRS. However, a way forward is to further develop the above mount SRS method employing modelling techniques used in conjunction with currently deployed vibration test systems. It is considered that a significant proportion of UNDEX testing for dynamically complex materiel could be conducted in this manner. A summary of common laboratory test methods is provided below.

- Barge testing of inert materiel.
- Shock table testing of inert materiel (Deck Shock Machine & Two Tonne Machine).
- Pendulum hammer type devices on live and inert materiel.
- Electrodynamic or hydraulic exciter shock testing of inert and live materiel. Where the above mount SRS is known, the shock input time history can be experimentally determined provided the materiel weight and dynamic response characteristics remain within the exciter thrust limit.
- Free fall programmable classical shock pulses. Generally applicable to the testing of live materiel, up to 1350 kg and 3000 Gs, at low pulse widths used for ‘Safe and Suitable’ shocks. The correlation to UNDEX assessment is debatable.

- Drop testing of both inert and live stores. Generally applicable to the testing of live stores but correlation to UNDEX assessment is debatable.

- Whipping - currently no whipping test is defined other than scale model facilities and access to historical data from previous whole ship trials. Barge testing does not take account of whipping.

The deck and two tonne shock machines are commonly used for inert materiel. The pendulum hammer type shock machines are applicable to testing of equipment to MIL-STD-901D, reference e. Where the above mount shock response spectrum is known, and the shock levels fall within defined limits of shock simulation on vibration test systems, the SRS offers a more appropriate and realistic shock testing method for live and inert materiel. Free fall programmable shock machines provide an additional form of drop testing, typically where classical shock pulses are required. This method is particularly applicable to structurally simple materiel and where live testing is essential. Drop testing is used as a compromise in conjunction with an assessment of the UNDEX behaviour. The test equipment and techniques are described further in Annex D.

2.3.2 Analysis Methods

A validated theoretical model offers the potential to reduce the amount of qualification testing. Validation using experimental test results either from specific tailored testing or a historical shock database is essential. The veracity of the numerical modelling and validation effort is proportional to the depth and accuracy of the information on which it is based. A well-validated model offers the scope to perform many load case assessments and thereby identify the worst cases that can form the basis of a testing programme. Also modelling can provide the above mount input information necessary to allow shock testing using electrodynamic exciters which in many cases can offer a more appropriate alternative to drop testing. However, modelling does not replace the need for qualification testing as a proof of safety and suitability for service.

Analysis methods can range from simple lump mass analytical methods to complex non-linear numerical methods such as Finite Element (FE) and Boundary Element (BE). A wide-ranging modelling capability is necessary to perform a tailored UNDEX assessment; some of the methodologies include:

- Non-linear Structural Dynamic Modelling. Using commercial codes, including ABAQUS, NASTRAN, ASAS, DYNA etc.

- Fluid and Shock Loading Model. Using either a BE interface or some Eulerian fluid models.

- Fluid and Structural Interaction Modelling. Using either an approximate method, DAA2, or more advanced methods such as Hydrocodes with full Arbitrary LaGrange - Euler (ALE) coupling.

- Transient Response Analysis. Where a finite element method is used with the dynamic UNDEX input applied as a loading function either from directly measured

UNDEX data, or using an approximate input derived from a generic empirical equation.

Modelling is compared against a realistic series of load cases and extensive transient or vibration validation is performed which typically includes static, modal, frequency response, full shock transient, frequency, time domain, and acceleration spectral density (ASD) validation with experimental results. The key to achieving analysis results in which confidence can be gained is based upon the following points.

- Rigorous verification and validation using experimental data and use of national shock testing archive and databases.
- A commensurate level of complexity applied to the analysis, defined on a case-by-case basis. There is constantly the need to avoid using a ‘sledge hammer to crack a walnut’ while ensuring that oversimplification does not occur and debase the assessment. This is particularly the case where examples of complex finite element models have been used with a generic empirical response model pulse as a dynamic input. Given the assumptions inherent in the empirical equation, the level of approximation of the input does not do justice to the level of complexity of the model. This situation should be avoided and a more accurate loading defined from experimental data directly or using a fluid structure interaction technique.
- Ensure that test programmes include input from the analysis to optimise applicability.
- UNDEX assessment is a specialist area requiring technical specialists who are familiar with test, analysis, the platform and the application of rigorous QA procedures.
- Utilisation of a national historical UNDEX database.

2.4 Sequence

The effect of UNDEX induced shock may affect materiel performance under other environmental conditions, such as vibration, temperature, altitude, humidity, leakage or EMI/EMC. Also, it is essential that materiel which is likely to be sensitive to a combination of environments be tested to the relevant combinations simultaneously.

Where it is considered that a combined environmental test is not essential or not practical to configure, and where it is required to evaluate the effects of UNDEX with other environments, a single test item should be exposed to all relevant environmental conditions. The order of application of environmental tests should be compatible with the Life Cycle Environmental Profile.

3. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

General information requirements are specified below. The requirements need to be tailored to the laboratory or analytical techniques used for the UNDEX assessments or test programme.

3.1 Compulsory

a. The identification of the test item

b. The definition of the test item

c. The definition of the test severity including amplitude, duration and number of pulses to be applied.

d. The type of test: development, qualification etc.

e. The method of mounting, including isolators if applicable, and below or above isolation mount.

f. The operation or non-operation of the test item during test.

g. The packaging conditions, if applicable.

h. The requirements for operating checks if applicable.

i. The control strategy (Pulse shape, time history etc.)

j. The tolerances and control limits.

k. The details required to perform the test.

l. The definition of the failure criteria if applicable

3.2 If Required

a. The climatic conditions if required if other than standard laboratory conditions.

b. The effect of gravity and the consequential precautions.

c. The value of the tolerable spurious magnetic field.

4. TEST CONDITIONS AND PROCEDURES

The UNDEX assessment and test partially relies on other AECTP 400 test methods and test standards to define detailed test procedures because of the multiple materiel excitation paths. The AECTP 400 methods for Classical Shock (Method 403), Pyroshock (Method 415), SRS Shock (Method 417), Motion Platform (Method 418), and Multi-Exciter Shock and Vibration (Method 421) all collectively support simulation of portions of the UNDEX environment. The procedures in these test methods should be applied as appropriate to the specific test programme. The Test Instruction must define the hierarchy of documents and standards to satisfy the compliance requirements. This test method provides the additional considerations necessary for the UNDEX environment to the appropriate test. In cases of analytical assessment, similar validation procedures should be applied.

4.1 Tolerances

Where classical shocks are a test requirement, tolerances are given in Method 403. Where complex waveforms are specified, unless stated in the Test Instruction the shock response measured at the reference point shall not deviate from the specified requirements by more than the values defined below:

For tests controlled on the SRS parameters the tolerance on the SRS amplitude should be ±1.5 dB over the specified frequency range. Over a limited frequency range, a tolerance of ± 3 dB is permissible. Additional constraints on the time domain parameters, peak amplitude, and /or effective duration, are usually necessary to ensure that an adequate simulation is achieved. These additional constraints are described in Method 417, Annex D and E. The tolerances used shall be stated in the Test Instruction.

4.2 Installation Conditions of the Test Item

The following will apply where UNDEX testing forms part of the assessment, unless otherwise stated in the Test Instruction. The direction of gravity or any loading factor due to mechanisms, or shock isolation, must be taken into account by compensation or by suitable simulation.

- The test item shall be mechanically attached to the shock machine or exciter, directly by its normal means of in-service attachment, or by means of a fixture. The mounting configuration shall enable the test item to be subject to the UNDEX loads along the various axes and directions specified. External connections necessary for measuring purposes should add minimum restraint and mass.
- Any additional restraints or straps should be avoided. If cables, pipes, or other connections are required during the test, these should be arranged so as to add similar restraint and mass as the in-service installation.
- Materiel intended for use with isolators shall be tested with the isolators installed unless the above mount UNDEX input shock has been specified.
- Shock isolators may require instrumentation and monitoring to verify that temperature induced failures are created due to the dynamic excitation. Sequential periods of testing and stationary should be used if isolator heating is observed.

4.3 Test Conditions

Generally precursor testing will be a requirement for an UNDEX test programme. Any structural characterization tests shall be undertaken and recorded as stipulated in the Test Instruction.

- A number of applications of the test pulse is usually required before the control equipment is able to achieve an acceptable response at the reference point. This is precursor activity usually performed on a dynamic representation of the test item.

- The test item should be stabilized to its initial climatic and other conditions as stipulated in the Test Instruction.

4.4 Calibration

The test equipment should be calibrated and adjusted to ensure that the required test parameters can be reproduced during the actual test. This is best achieved using a dynamically representative test item.

5. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate Test Instruction requirements during and following the application of the UNDEX environment test.

6. REFERENCES AND RELATED DOCUMENTS

General References

a. NATO STANAG 4137, Standard Underwater Explosion Test for Surface Ships and Underwater Craft, 17 Feb 1976.

b. NATO STANAG 4141, Shock Testing of Equipment for Surface Ships, 15 December 1976.

c. NATO STANAG 4142, Shock Resistance Analysis of Equipment for Surface Ships, 8 March 1977.

d. NATO STANAG 4150, Shock Testing of Heavyweight Ship Equipment in Floating Shock Vehicles, 24 April 1979.

e. MIL-S-901D, Shock Tests H.I. (High Impact) Shipboard Machinery, Equipment, and Systems, Requirements For, USA Department of the Navy, 17 March 1989.

f. SVM-17 - Naval Shock Analysis and Design, Scavuzzo, Rudolph J. and Pusey, Henry C., ISBN 0-9646940-4-2, Shock And Vibration Information Analysis Center (SAVIAC), 2000.

UK UNDEX Environment References

a. BR 8541: Explosive Safety Requirements For Armament Stores For Naval Use, September 1996, 3rd Edition.

b. BR 8472: Naval Standard Range Mounts For Equipment Installation (To Attenuate Mechanical Shock or Vibration)

c. BR 3021: Shock Manual (Metric), March 1975

d. BR8470: Shock and Vibration Manual

e. CB 5012: Shock Manual (Metric), December 1974

ANNEX A

UNDEX ASSESSMENT PROCESS

1 ASSESSMENT OUTLINE

This Annex provides a detailed overview of how individual technical functions, or disciplines, associated with UNDEX assessments may be combined to produce a unified methodology for performing an UNDEX assessment of materiel. The framework for an UNDEX assessment process and the common steps necessary to satisfy the requirements are defined. The process is directed specifically at the qualification of materiel to meet the safe and suitable for service criterion, but can include service life extension and disposal as described in STANAG 4570. The main document for this test method also provides introductory information on the UNDEX environment and considerations for testing. There are three distinct phases to the UNDEX assessment process shown in Figure A-1. These three phases, can combine in an iterative way to refine the process, as more information becomes available.

Phase 1 – Definition of Scope An overview combined with definition of acceptance criteria and tasks, including the identification of appropriate technical information and disciplines. This effectively defines the assessment requirement and strategy. Phase 1 concludes with documentation of the reviewed and approved UNDEX assessment plan.

Phase 2 – Assessment Evaluation A suitable assessment route is adopted according to the definition of the task. A detailed analytical or experimental analysis is then performed based upon that assessment route. The results are interpreted and compared with the selected acceptance criteria defined previously.

Phase 3 – Assessment Conclusions On the basis of the detailed assessment results, a decision is made with respect to safety and suitability for service.

2 ASSESSMENT PHASES IN DETAIL

2.1 Phase 1 – Definition of Scope

This is the specification of the assessment requirement from a consideration of existing and required information. It is essential to have well defined objectives for the UNDEX assessment as a starting point, along with the desired level of confidence in the assessment. Four steps may be identified in this phase of the work:

- Task Overview
- Acceptance Criteria Definition
- Task Definition
- UNDEX Assessment Plan Documentation

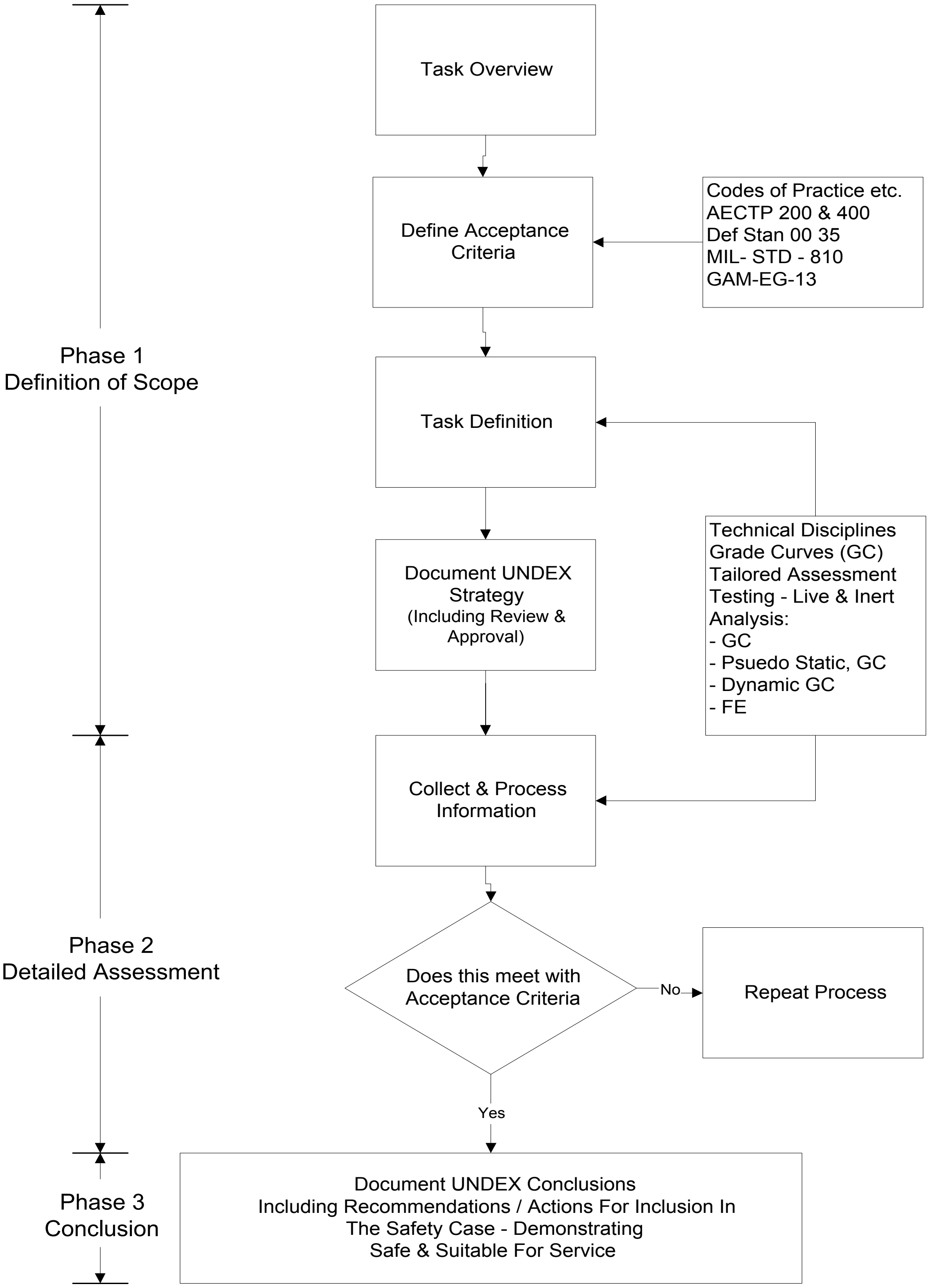


Figure A-1 General Phases of the UNDEX Assessment

How these steps interact is shown in Figure A-2. Annex B provides a comprehensive list of questions and guidance notes to assist in the UNDEX assessment scope definition. The scope should assess and include the availability of all relevant information. For example, commercial off the shelf (COTS) materiel may not be supported by sufficient technical information to allow an UNDEX assessment; the availability of representative test specimens may be restricted. Using the questions in conjunction with the plan shown in Figure A-6 permits the scope of the assessment to be well defined.

2.1.1 Task Overview

The aim of this step is to provide an overview of the objectives and requirements of the UNDEX assessment using the ability to fight, move and float as guidance. Decisions taken on the objectives will affect the direction and emphasis of the assessment performed in the later phases. For example, when safety is the prime objective then failure conditions could be limited to those, which cause potential injury or loss of life. Overall financial constraints, time limits, or lack of information may also influence objectives and UNDEX assessment procedures.

2.1.2 Acceptance Criteria Definition

Three main elements indicated below make up the acceptance criteria. Failure criteria are part of the overall acceptance criteria. However, failure criteria are particularly important since they govern the choice of assessment route, as described later in this Annex. Where it is difficult to define acceptance or failure criteria, environmental testing may prove necessary as part of the evaluation process. To avoid final conclusions of an assessment being qualified by arbitrarily chosen degrees of confidence, the required confidence in the assessment should be chosen at the start. This choice depends on the consequences of failure and level of criticality.

- Define the required function of the materiel.
- Define the failure criteria.
- Define the required confidence

2.1.3 Task Definition

The Figure A-2 flowchart illustrates the procedure to be followed in the task definition step. The objective of this step is to provide adequate planning and ensure that the assessment commences with a comprehensive consideration of the work involved. Responses to the list of questions in Annex B allow the following:

- Systematic reduction of the problem to a size that can be completed.
- Selection of the most appropriate method of assessment.
- Identification of critical items or components.
- Identification of failure modes that are possible given the excitation mechanisms.

It may not immediately be obvious which components are critical to achieving and maintaining safety and suitability for service. Techniques such as Failure Modes and Effects Analysis (FMEA) or Redundancy Analysis may be required to identify the critical regions. The components may further be reduced in number by consideration of possible failure modes associated with the UNDEX excitation mechanisms Each component will have its own margin of safety, and it is desirable to consider the range to further reduce the assessment to the most critical components. Furthermore, there may be components, which have an overriding influence on the safety of the system as a whole. For example, a warhead booster may be more critical than other components, and will thus drive the safety assessment. Any assumptions made which will reduce the problem size will ultimately need to be justified to the safety case officer and documented.

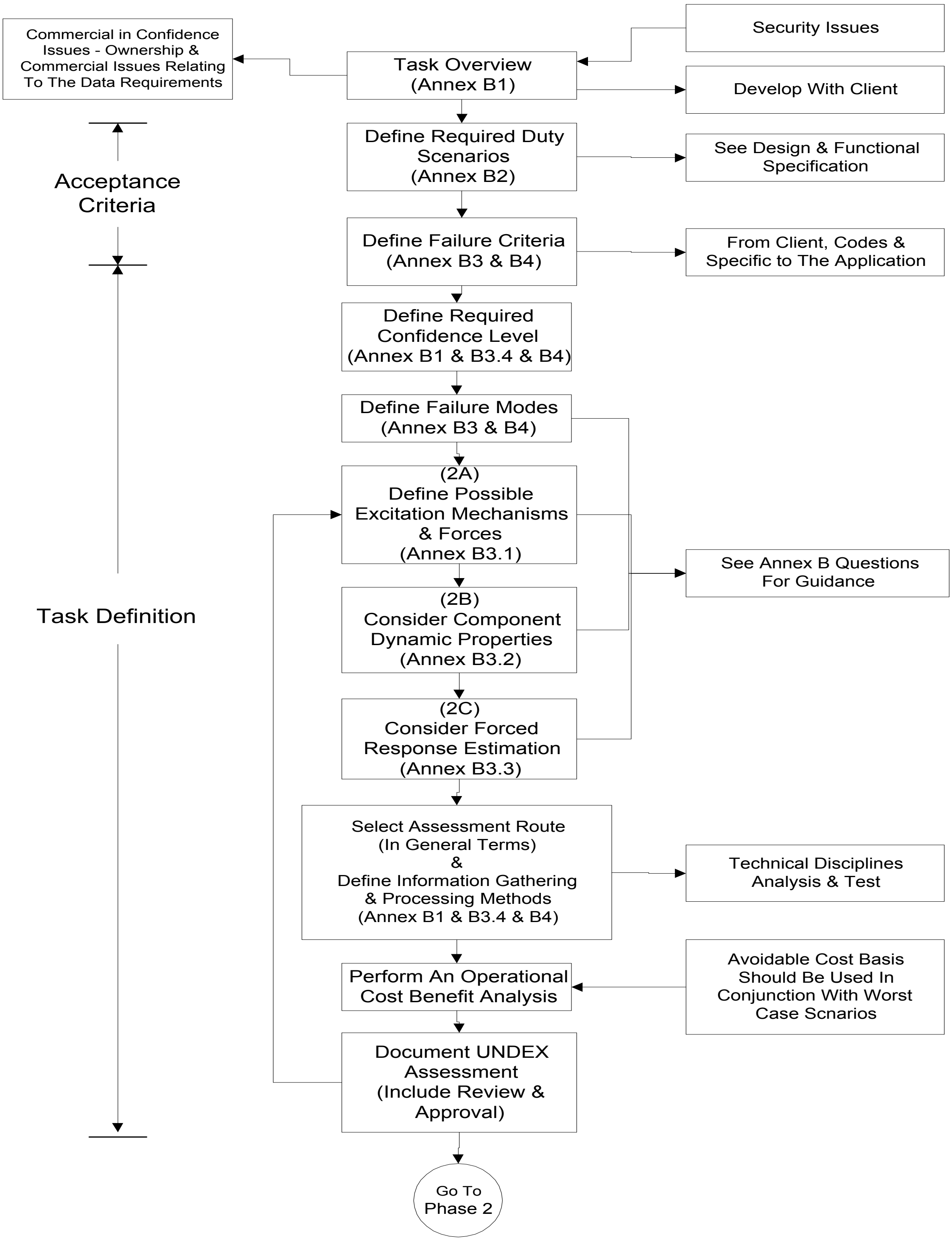


Figure A-2 Phase 1 - Definition of Scope UNDEX Assessment Plan Documentation

The final step in Phase 1 is to fully document the task overview, acceptance criteria, and task definition, including appropriate review and approval. Information on materiel components, excitation mechanisms, and likely failure modes identified during this stage should be documented. If several assessment cases have been identified for detailed assessment, then each should be considered individually. For example, a materiel may be stowed differently in various vessel classes.

2.2 Phase 2 - Evaluation

The definition of tasks, with a cost benefit assessment, will enable selection of an appropriate route to satisfy the objectives of the UNDEX assessment. The chosen assessment route may require refinement, as further information becomes available, to complete the analysis in the definition of scope. The detailed assessment leading to the decision on safety and suitability for service has four steps as shown below and in Figures A-3 and A-4.

- Step 2A - Excitation Mechanisms and External Forces
- Step 2B - Materiel Properties Definition
- Step 2C - Structural Response Estimation
- Step 2D - UNDEX assessment.

The input requirements and output results from steps 2A to 2D are determined by the objectives of the UNDEX assessment and are described below. These steps can be accomplished through the required combination of laboratory testing and analytical, or modelling, analysis. Discussion is presented below on four methods to complete steps 2A through 2D, followed by information on the individual Phase 2 steps.

a Method I - Testing Only

Full scale testing of inert materiel can readily be accomplished at several test facilities using mechanical simulation test equipment or a floating test platform. Inert materiel structural testing can be undertaken in accordance with BR 8541 and consistent with the guidelines for general Naval equipment in BR 8470 and CB 5012 or using specific tailored testing. However, live energetic materiel testing is limited to the use of mechanical simulation equipment such as shock, vibration, or drop test systems. Shock response spectra, or waveform replication techniques using electrodynamic or servo-hydraulic test systems offer the most accurately controlled test procedure. Either equipment type requires a defined input acceleration time history within the limits of the exciter thrust, displacement and frequency bandwidth capability. Pyroshock excitation, Method 415, may also be applicable. The equipment performance limitations can restrict test capabilities for large low frequency displacements and high frequency excitation requirements. The use of acceleration dynamic responses above the materiel isolation mount as the input control specification may be desirable for the UNDEX test. Drop also tests provide a measure of general ruggedness, but the induced loading, duration, and magnitude can be significantly different from measured shipborne UNDEX loading. This limits the correlation of drop test data to predicted UNDEX performance, particularly for dynamically complex materiel. If the tests are definitive, the qualification test can form the basis of the UNDEX safety case directly.

Full scale testing avoids using unproven scaling techniques, but unique test fixturing may be necessary, which are costly and physically large. The fixturing and equipment may itself suffer significant damage and be unusable for further tests. Procedures II, III, and IV may be necessary to extrapolate testing data to inaccessible regions of the structure or materiel. Also testing may not be practical when considering the combination of load cases necessary to establish the safety and suitability for service case. Annex D provides further information on laboratory or experimental test equipment.

b Method II - Tailored Test and Validated Analysis

This method provides a balance between test and theoretical analysis. This ensures the most cost-effective use of testing, combined with measured data to validate any analysis. The analysis allows extreme environment cases to be considered which may not be feasible to investigate through laboratory testing. The existence of measured data provides the safety case officer with improved confidence, in a cost-effective manner; the number of test cases can generally be reduced. Testing may include modal as well as qualification testing. Modal tests will require application of theoretical or empirical scaling laws if scale models have been used.

c Method III - Validated Analysis

Given the databases of UNDEX transient acceleration responses already existing, it is often possible to use measured data from previous tests or experiments. Procedure III is similar to II, but uses historical data to correlate with an existing model or data set. However, caution is required in the use of inadequately documented measured test data. The validity of the historical data needs to be justified to the safety case officer.

d Method IV - Unvalidated Analysis

This option is the least desirable, but is the only possible course of action when tailored testing is not possible and no relevant historical data exists. This procedure is only to be used as a last resort. Theoretical developments and new computer simulations not requiring validation by future experiments are included. The obvious increased level of uncertainty will attract increased scrutiny. The safety case officer will require evidence of the validity of the approach, competence of the UNDEX assessment team, and a proven track record in this type of analysis. The use of reliability error bands is a useful method of improving confidence.

The more complex assessment methods should be aimed at reducing the uncertainties in the UNDEX assessment procedure where higher risk situations are encountered. A combination of cost limitations and acceptable degree of uncertainty will determine the UNDEX assessment procedure. Assessment of uncertainties is often made on a subjective basis and an experienced engineer is required to make these judgements aided where appropriate by suitable techniques. The detailed assessment has three possible outcomes:

- The assessment is acceptable, the materiel may have passed or failed, and the output from step 2D forms the response in Phase 3.
- The assessment is unacceptable because of an insufficient level of confidence in the UNDEX assessment, and the decision is made to improve the assessment by repeating steps 2A to 2D until the required degree confidence level is achieved.

- The assessment is unacceptable due to a high degree of uncertainty, and the decision is made to redefine the materiel stowage, or recommend alterations to the materiel. This will require redefining the scope and repeating steps 2A to 2D.

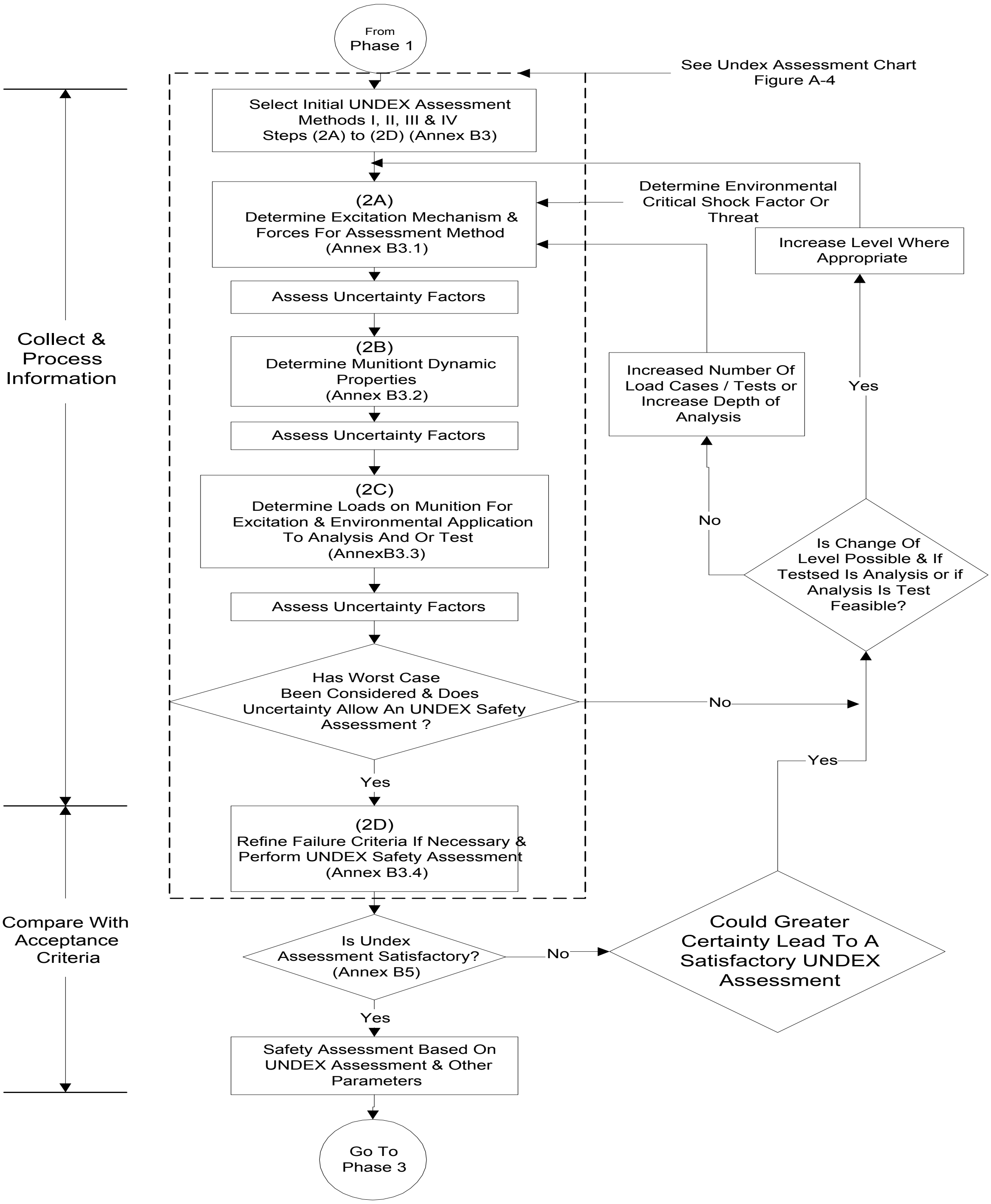


Figure A-3 Phase 2 - Assessment Evaluation

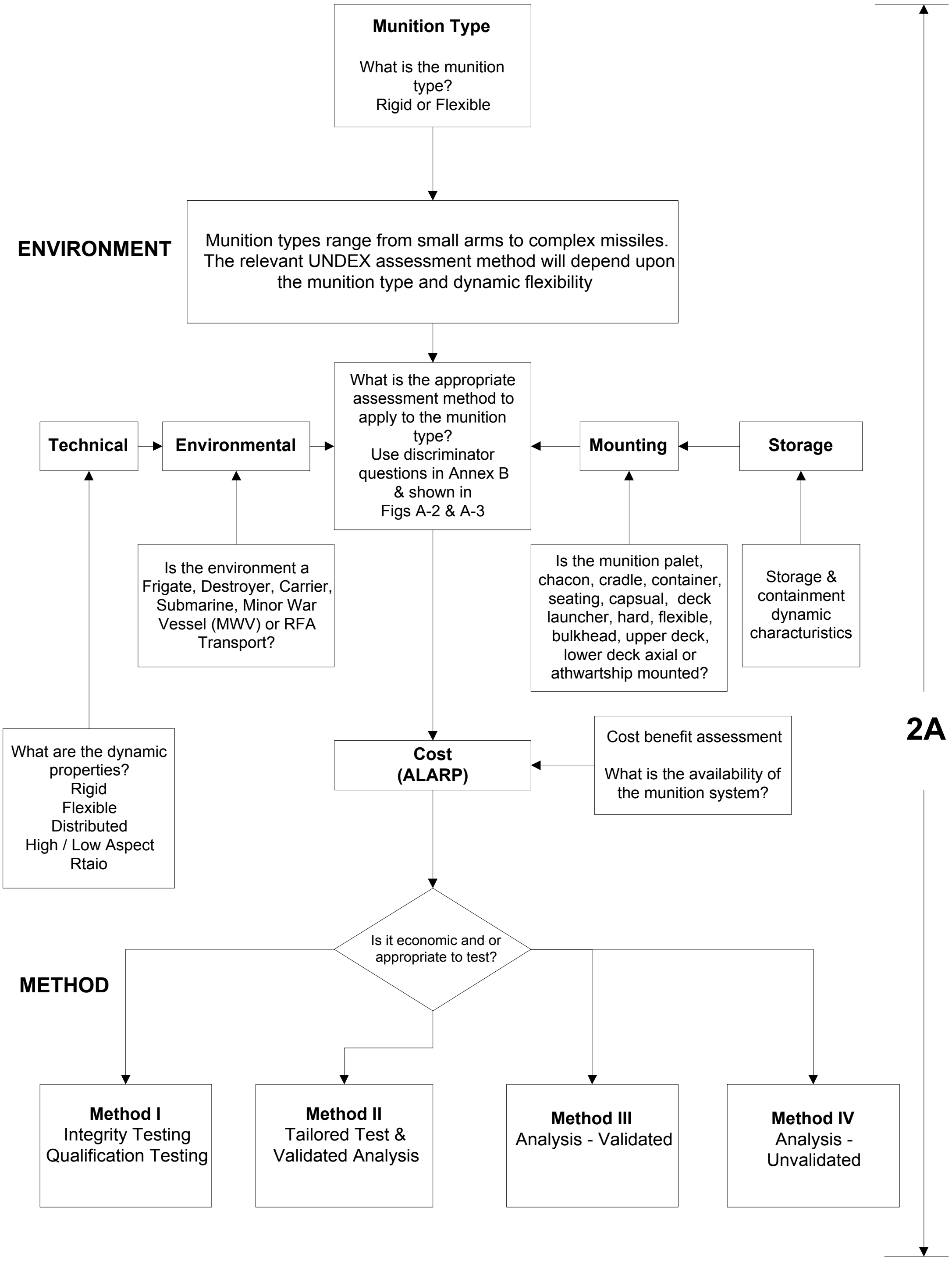


Figure A-4 UNDEX Assessment Flow Diagram

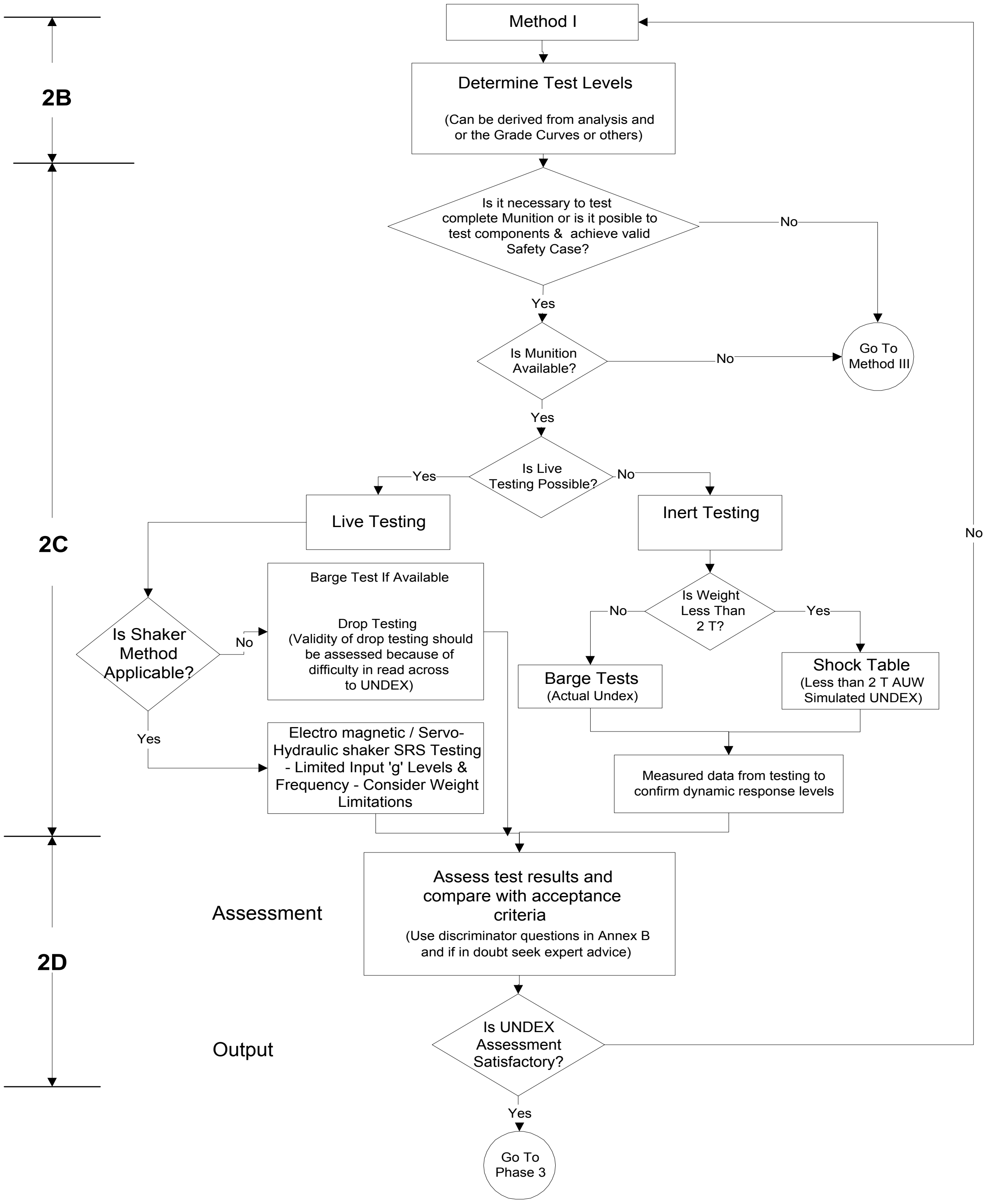


Figure A-4 Continued UNDEX Assessment Flow Diagram

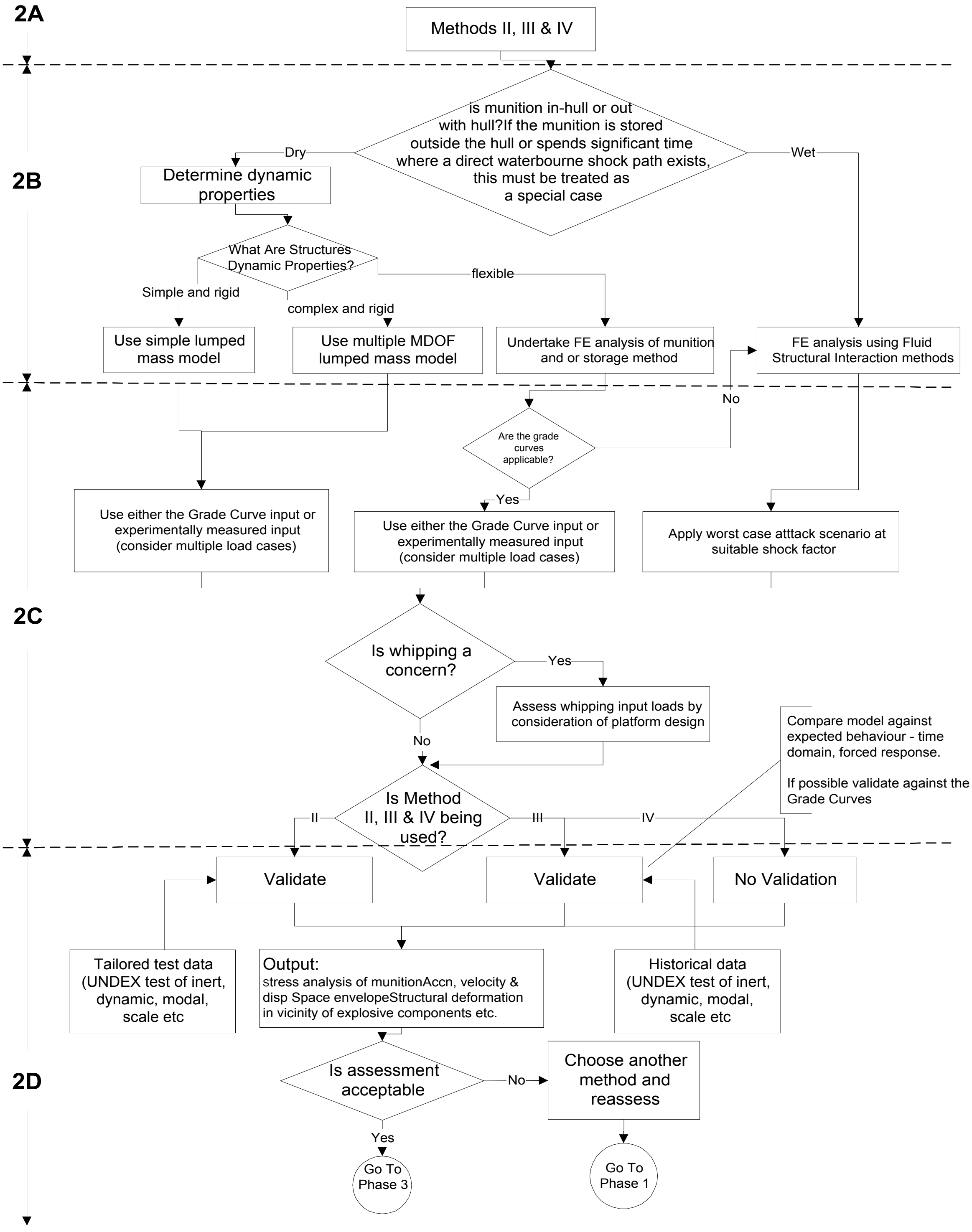


Figure A-4 Continued UNDEX Assessment Flow Diagram

The accuracy of the four assessment steps should be increased until a satisfactory cumulative level of confidence in the assessment procedure can be demonstrated. It is not essential to increase the level of accuracy in all of the assessment steps simultaneously, only where a weakness is identified. The UNDEX assessment flow diagram shown in Figure A-4 comprises the generalised steps 2A to 2D, encompassing specific requirements. These steps are the same for generalised vibration assessment, which allow integration of the two procedures. The following sections consider each key step.

Step 2A - Excitation Mechanism and External Forces

The main excitation mechanisms are direct structure-borne shock and bubble induced whipping. Where the materiel is stored or deployed with the vessel or is in a position where a direct fluid path exists, then this is a special case. In such circumstances structure borne shock plus the direct shock wave loading need consideration. It should be ascertained what combination of these excitation mechanisms is required to be included in the UNDEX assessment. For example whipping would not be included for a fast patrol craft. In general all ships need to be considered for shock but only high aspect ratio vessels are susceptible to whipping. The levels associated with the excitation mechanisms can be taken from the Shock Grade Curve Scheme, measured from experiment or derived from theoretical evaluation. The ‘worst case’ stowage configuration and a range of ‘worst case’ UNDEX scenarios will generally require to be considered, although these will vary on a case-by-case basis.

Procedure I - Analytical Methods

In an UNDEX assessment analytical methods can be used to relate the response of a materiel to a given dynamic input excitation and define test-input data. This will often require a non-linear analysis accomplished using finite elements and / or boundary element methods. These analytical methods are complex and require sophisticated specialist software used by personnel with appropriate direct experience. Personnel competency and associated QA should be specified and will depend upon the type of analysis and assessment required. Validation and verification of the analysis techniques and UNDEX assessment is essential and employ experimental data, Grade Curves, non-linear material properties and the extensive historical shock database etc.

Procedure II - Experimental Methods

Experimental methods reduce the uncertainty associated with the UNDEX assessment and analytical methods by the use of full scale and model trials. They deal with the real physical system, which encompass non-linearity and the interaction effects. However, experimental testing and full-scale trials can be expensive. They should be considered in terms of

- Qualification testing.
- The requirement for verification and validation of the analysis.
- Assessment of the potential cost benefit.
- The number of scenarios, which need to be considered to evaluate the operational safety and suitability for service requirement.

Considerable specialist knowledge, expertise and experience are required to specify, install, operate and monitor equipment and interpret the data correctly.

Step 2B - Materiel Properties Definition

A necessary prerequisite of an UNDEX assessment is the need to assess the dynamic properties of the materiel, stowage support, and the ships structure (such as stiffness, mass, damping, frequency, mode shape, etc.). This can be achieved by analytical and /or experimental methods.

Procedure I - Analytical Methods for Dynamic Properties

For materiel and stowage which can be approximated to one or two degrees of freedom, simple hand calculations using lump mass parameters are acceptable for determining the dynamic behaviour of the materiel and its stowage support, provided that the material properties are known. This approach is included in the UK UNDEX reference a.

For multi-degree of freedom and more complex systems, finite element and modal analysis is necessary. This requires the generation of a computer model, which represents accurately the geometric and material properties of the materiel and its supports. Experience in finite element modelling and analysis will reduce the uncertainties caused by an incorrect representation of the actual physical system. This applies in particular to aspects, which are difficult or unnecessary to model accurately such as damping, junctions at structural elements and non-linear behaviour of supports etc.

Procedure II -- Experimental Methods for Dynamic Properties

Dynamic properties can be determined by modal testing techniques. In brief this involves the excitation of the component at low levels of vibration and the measurement of the response. The signal usually measured by transducers placed on the component or by non-contact methods is analysed to provide the modal frequencies, shapes and the damping characteristics. Modal testing techniques generally provide much more accurate dynamic characteristics than analytical methods. However, since low vibrations are used to determine modal characteristics they are essentially linear. The validity of using a linear representation will need justification because of the high excitation levels associated with an UNDEX event.

Step 2C – Structural Response Estimation

The external dynamic forces in conjunction with the dynamic properties will cause a dynamic response of the materiel and its support. This response will be in the form of internal stresses and strains and these parameters are essential for the UNDEX structural integrity assessment. Methods of evaluating dynamic response may be either theoretical or experimental.

Procedure I - Analytical Methods for Structural Response

Dynamic response can be computed using the finite element technique. The computer model generated to provide the dynamic characteristics can be utilised to calculate the dynamic responses. Damping cannot be defined by an analytical method but can be estimated and included in the model. Damping must always be included in the analysis and if no accurate damping levels are available it should be estimated as the result of experience or measurement. For linear structural systems analysis techniques such as modal superposition are adequate. However, for non-linear behaviour, non-linear finite element methods and the use of direct time-integration techniques are required. Whereas non-linear approaches are not necessarily required for all UNDEX analyses, those considering safety criteria are likely to be at high shock factors, near or at hull lethality levels. These will invariably drive mounting structures, packaging, and casings into plastic behaviour.

In the case of materiel, which can be represented as lump masses the Shock Grade Curves Scheme can be applied directly, to obtain the forced response levels associated with shock and latterly a crude representation of whipping effects.

Procedure II - Experimental Methods for Structural Response

Two uses of experimental testing are possible to monitor the structural response in an UNDEX assessment: Full-scale testing and model testing.

Full scale testing is usually expensive but produces the most accurate results since all the physical conditions are representative. UNDEX testing of inert materiel is possible but in the UK live testing has historically largely been restricted to drop testing. With the improvement of vibration / shock controllers and availability of high thrust electro-magnetic shakers it is now feasible to consider applying SRS methods for live materiel testing. The size of materiel capable of being tested using this method is governed by the above mount shock level / time history, its weight and dynamic behaviour. Currently UNDEX testing using this method has successfully been completed on materiel up to 900 kg. SRS testing applies equally to inert materiel and provides realistic input shocks consistent with operational response time histories. A further advantage of this method is that currently deployed dynamic test facilities can be utilised without costly capital expenditure. However, both drop testing and SRS testing rely upon an understanding of the operational input shock time history, which can only be derived from barge tests, full scale tests of inert materiel or from theoretical models and the historical database.

With inert testing, where there are a number of support configurations or attack scenarios full scale testing can be impractical. The usual form of testing is to use the actual materiel or a dynamically equivalent replica supported in a representative manner. This is then tested at the pre-defined UNDEX severity and strains and dynamic responses are recorded. Scale models may be used, but normal static scaling procedures may be inappropriate. When considering the dynamic behaviour scaling factors are difficult to determine, especially for complex components. A review of UNDEX test techniques applicable to materiel is given in ANNEX C.

Step 2D - UNDEX Assessment

Potential Damage Mechanisms

The dynamic and strain information obtained is generally for a fully operational materiel, which is defect free. The values are used in combination with the requirements of the assessment and the chosen failure modes, to select a suitable UNDEX assessment technique. Common failure mechanisms and modes are listed in Section 2.1.1 & 2.1.2 of Method 419 and it is possible for them to be present either singly or combined.

UNDEX Methods of Assessment

UNDEX assessment is an integrated multi-disciplinary activity combining experiment, test and theoretical analysis.

The failure modes can be assessed using experimental testing, fracture mechanics based analytical techniques, non-fracture mechanics based techniques, or semi-empirical treatments such as the Shock Grade Curve Schemes.

Procedure I Experimental Testing

An UNDEX assessment implies that if the materiel is able to sustain the stresses and strains imposed during an UNDEX event, then it passes safety requirement at the ‘to float’ level and if it remains functional at the ‘to fight’ level then it is considered serviceable. Testing full-scale prototypes either to service loads or to destruction will give an indication of the likely failure modes and the factors of safety. Correlation with small-scale tests is possible but uncertainty may be introduced due to scaling effects. Small scale testing is generally used to obtain mechanical toughness properties for materials and is impracticable for live materiel. Testing may take the form of simulated shock using test machines or barge tests.

Procedure II Analytical Assessment Techniques

Procedure II can range from the application of simple analytical formulae to full-blown Hydrocode treatment of the fluid structure interaction problem. The key is choosing a method of complexity consistent with the level of detail required in the assessment. At the simple level direct solution of the equations of motion for simple rigid systems can suffice. Where flexible equipment and / or supports are included then the direct choice is the use of finite element techniques whereby the load is provided from a Shock Grade Curve Scheme or an experimentally measured input. Where the assessment necessarily needs to consider fluid structure interaction it is possible to consider estimated hull inputs using Taylor plate theory. In reality fluid structural interaction is considered with the more sophisticated yet still approximate techniques. These include the cylindrical wave approximation, virtual mass approximation and the improved approximation inherent in the doubly asymptotic approximation (DAA) family. The DAA approach is essentially a boundary element approach, which considers the fluid field as a boundary wrap over a structural finite element model. For scenarios where fluid volumes and cavities are significant increasing complexity is required and the only acceptable choice in this instance is the use of a Hydrocode. Hydrocodes are specialist codes and are currently 'state-of-the-art'. Their use requires significant investment in expertise and hardware and depending upon the maturity of the fluid structure coupling contained within, the results may not be any more accurate than those of an approximate method.

Procedure III Codes of Practice and Guidance Documents for UNDEX Assessment.

There are currently no guidance documents or codes of practice applicable to tailored UNDEX assessment of complex materiel. A range of documents are available which provide guidance and procedures applicable to simple materiel and these include: AECTP 200 & 400, Def Stan 00 35, MIL STD 810, GAM-EG-13, BR 8470, BR 8472, BR 3021, CB 5021, NES 814, NES 1004.

2.3 Phase 3 – Assessment Conclusions

An UNDEX assessment is deemed to be complete when a definitive statement can be made that the integrity of the materiel can or cannot be proven for required duty and meet the safety and suitability for service criteria within an acceptable margin, Figure 4.8. This statement should be qualified with an assigned level of confidence determined by the uncertainty factors associated with the particular steps taken in the UNDEX assessment. Comparison with any target probability or confidence requirements defined in Phase 1 will also influence the final statement. A clearly drawn, concise and unambiguous conclusion should be recorded. The MOD safety case assessor will require well defined audit trails from the assessment start to conclusion. Any conclusions drawn may be qualified by comparison with pre-determined, quantifiable criteria.

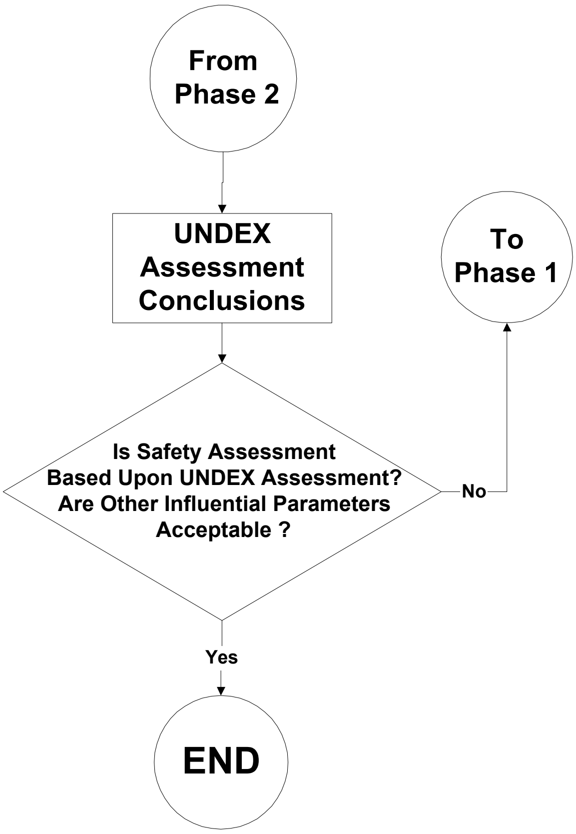


Figure A-5 Phase 3 - UNDEX Assessment Conclusion

3 DOCUMENTATION EXAMPLE

An example of a single-page summary record of an UNDEX assessment is shown in Figure A-6.

PHASE 1: DEFINITION OF SCOPE **NUMBER:**

Structure	
Component	
Objective of Assessment	
Failure Mode(s) Considered	
Excitation Mechanism(s)	
Brief Description	

PHASE 2: DETAILED UNDEX ASSESSMENT

Step	Method			
	Method I Testing Only	Method II Tailored Testing & Validated Analysis	Method III Validated Analysis	Method IV Unvalidated Analysis
Step 2A Excitation Mechanisms & Forces				
Step 2B Materiel & Component Dynamic Properties				
Step 2C Dynamic Response Determination				
Step 2D UNDEX Assessment				

PHASE 3: CONCLUSIONS

ADDITIONAL INFORMATION

Key References	

Figure A-6 Example of Single Page UNDEX Assessment Summary

ANNEX B

UNDEX ASSESSMENT AND TEST CONSIDERATIONS

1. INTRODUCTION

This Annex reviews the general considerations needed to determine an appropriate UNDEX assessment process or test programme. Consideration of a range of in-service conditions and analysis approaches will provide the necessary information to allow completion of the required documentation or experimental tests. The questions specified are only guidelines, and additional topics may need to be evaluated for individual UNDEX test programme or Test Instruction requirements. Fundamental questions to start the process are defined below:

a. What is the required function of the materiel or components?
b. What constitutes an unacceptable failure?
c. Is there an acceptable failure scenario?
d. What is the required confidence in the conclusions of the assessment?
e. Is a safety case required, if so what category?
f. Is personnel safety involved?
g. If the consequences of failure are economic, how large is the potential loss?
h. What are the results of a fault consequence assessment?
i. Is post shock disposal of the materiel to be considered?
j. What level of serviceability is required?
k. Is the UNDEX assessment associated with new materiel, or a life extension case?

The most pertinent question is perhaps the definition of an acceptable and unacceptable failure. The simplest condition for which materiel can compromise operations is by detachment from the mounting point(s) during the UNDEX event, and becoming a “projectile” on the ship. Environmental simulation tests for this condition are generally referred to as “crash hazard” tests. Therefore, captivity of the materiel, or shock isolation hardware failure, is an important issue.

There are generally no circumstances where premature ignition or detonation of energetic material can be tolerated for safety considerations. Explosive failure is self evident from a safety viewpoint, and can only meet the watertight integrity requirement. However, safety could be compromised by a second order event, such as fuel leakage, fuse instability, radioactive leakage, or any event which could impact upon the efficient capability of the ship to meet it’s shock design criteria.

Furthermore, following an UNDEX event, the capability for safe handling, servicing, or disposal of the materiel must exist. Increasing shock levels can be associated with a decrease in serviceability and reliability. This introduces the concept of “safety levels” associated with the failure mechanism(s), and is directly related to the safety case category required from the UNDEX assessment. The key criteria which must be defined by the

UNDEX assessment process, is determination if the materiel is safe or serviceable at the required level (I, I, or III), to fight, move, or float respectively.

2. ENVIRONMENTAL CONSIDERATIONS

Does the UNDEX assessment include transit by commercial ships?

a. How is the materiel packaged?
b. How is the materiel protected?
c. How is the materiel slung and loaded?
d. What events will the materiel be exposed to during loading and storage?
e. Where is the materiel stored?
f. Is the materiel stored above or below deck?
g. Is the materiel in a container?
h. Is there any form of dynamic isolation? (Elastomeric mounts, yielding constant force devices, crushable materials, compliant structures etc.)
i. Can the materiel become a mechanical projectile?
j. Can the materiel create a personnel, equipment, or operational hazard?
k. What is the free travel and sway space?
l. What is the space envelope associated with the materiel storage position?
m. Can external mechanical bodies, as a result of UNDEX, affect the materiel?

Does the UNDEX assessment include stowage in naval ships magazines?

a. What are the stowage arrangements and configuration?
b. Where and how will the materiel be stowed?
c. Where will the materiel be stored? - (Close to the hull, on deck, seating, above or below the waterline etc.).
d. What structure is between the wetted hull and the storage position?
e. What is the shock loading path?
f. What is the free travel and sway space? i.e. what is the space envelope associated with the materiel storage position?
g. Is there any form of dynamic isolation? (Elastomeric mounts, yielding constant force devices, crushable materials, compliant structures etc.)
h. Can the materiel become a mechanical projectile? If not, how is the materiel restrained?
i. If the materiel is restrained can the restraint itself impose damage under high deceleration?
j. Can the materiel hazard other materiel, itself or personnel? Either by impact, leakage and electrical hazard initiated by failure.
k. Is the UNDEX assessment to include operational deployment- Naval ships (ready for use launcher environment)?
l. Is the materiel located on the hull, deck, upper or lower deck?
m. Is there any isolation between the launcher and the ship structure?
n. At what axial position is the materiel located on the ship?
o. What are the boundary conditions in terms of the launcher structural dynamics?
p. Can any part of the launcher structure impinge on the space envelope of the materiel boundary (crushing etc.)?

q. How is the materiel restrained? Is it merely gravity, interference or other physical restraint?
r. Does the materiel need to be judged on a case-by-case basis?

3. POTENTIAL FAILURE MODES

What are the potential failure modes of the materiel?

a. Detonation
b. Deflagration, slow burn
c. Fatigue, in particular at welds to parent metal
d. Fracture
e. Plastic collapse
f. Leakage
g. Instability and buckling
h. Failure from initial imperfections
i. Control or functional limits such as displacement limits
j. Combined failure modes
k. Collision and adequate space envelope

3.1 Step 2A EXCITATION MECHANISMS AND FORCES

What excitation mechanisms are conceivable?

It is important to consider that any combination of the perceived excitation mechanisms, while potentially damaging in themselves, will also have the potential to make the materiel a projectile. Captivity of the materiel is an overriding requirement.

Derived from any of the excitation mechanisms and external forces the materiel could become, or suffer impact from other detached materiel. Also, the materiel may still remain attached to the elastomeric mounts but could exceed its allowable sway space and collide with other structures or materiel.

Whipping is dependent upon the attack geometry and the geometric and dynamic characteristics of the target. A long slender ship would generally be subject to whipping; a short landing craft would be subject to severe sinusoidal rigid body motion. There are generally more instances where whipping motion excitation is a concern than non-existent.

Hydrostatic pressure pre-load may be an important issue for submarine assessment cases. General UNDEX dynamic excitations are below.

a. Shock
b. Whipping
c. Acoustic, fluid-acoustic coupling, acoustic shock waves.
d. Fluid phenomena - Bubble flow loading (incompressible fluid flow), cavitation
e. Mechanical transmission
f. Differential hydrostatic pressure
g. Impact from drops, energetic missiles, collision, loss of captivity etc.
h. Transient pressures

What are the characteristics of these possible excitation mechanisms?

a. Steady state, transient or random
b. Transient - acoustic
c. Transient bubble
d. Frequency range, broadband, narrow band.
e. Amplitude distribution and time distribution, i.e. maximum pulse magnitude & phasing.
f. Spatial correlation, uniform distribution, point loads.

When considering the characteristics of the possible excitation mechanisms the following should be addressed.

- The explosive type, depth and warhead size and attack angle.
- The shock factor for the attack weapon.
- The peak overpressure, impulse duration, and amplitude.

The shock factor, which may be expressed as a direct hull shock factor, keel shock factor or an angle shock factor, is related to the energy flux density. From these considerations the input shock loading can be defined.

Shock Factor →	Parameter Fraction →	Shock Grade Curve Scheme
An explosive parameter related to the energy flux density from an UNDEX explosive event	The Shock Grade Curves Scheme relate to a given position and known input level. The parameter fraction is a scaling constant to relate information at other shock factors	The Shock Grade Curves Scheme can supply: Acceleration Velocity Displacement

How does the excitation change with operational variables?

- Depth
- Time
- Attitude of impact: component or target of excitation.
- Angle of attack

What is the likely accuracy of the above estimates of excitation forces?
Estimation of the forces is based upon well established and validated techniques, and upon either empirical equations, or from the Shock Grade Curve Scheme. The Shock Grade Curve Scheme is a distillation of a very large database of ship and submarine dynamic responses to UNDEX events.

- Are they based on direct measurement local to the structure or component?
- If so, were the measurements made under worst-case conditions for each possible excitation?

- If based on empirical formulae, can the use of the formulae be justified?
- If theoretical, how has the theoretical model used been validated?

3.2 Step 2B COMPONENT DYNAMIC PROPERTIES

Are dynamic material properties for materiel, packaging, and support structure, available?

- Aerospace alloys, elastomeric mounts, seals etc.
- If the information is not available where can it be found?
- Is testing necessary - modal, shock, and static properties, UTS, Charpy etc.?
- Is information available on the inter-connection of components?
- Will the inter-connections effect the dynamic behaviour of the materiel or equipment i.e. friction across bolted joints?
- What test information is available to allow verification of FE or other models?

Are in-service measurements available covering the range of possible variables?

- Force, time, acceleration, and amplitude
- Frequency
- Variation in properties between nominally identical components (elastomeric mounts and interconnections)

What are the boundary conditions of the component under assessment?

- Isolated from other structures (free, rigidly fixed or damped)
- Strongly coupled to other structures, which are not significantly dynamically influenced by the component.
- Strongly coupled to other structures, mutually interacting with them
- Does the materiel occupy a significant axial length? (since shock loading of a distributed system will be phased) This is important both axially and athwartships.

Is it reasonable to assume linear behaviour in the excitation force range?

- For low shock loads a linear system can be utilised. However, above a threshold shock factor a non-linear assessment will be required.
- For Non-linear mounting systems treatment of the mounts as linear isolators is not adequate.

Could the materiel have resonant frequencies in the excitation frequency band?

- Higher frequency modes of the materiel may be excited depending upon the resonance characteristics.
- Low frequency mounting systems may be susceptible to low frequency whipping inputs.

Is the modal density sufficiently high that the statistical analysis is applicable or are individual modal properties required?
In general it is the first ten modes of the materiel structure, which will be significant. This limitation can be considered to be a benefit in terms of the FE model and its validation since it is difficult to accurately validate high order modes.

Are the component resonant frequencies high compared to the impact duration for transient excitations so that pseudo-static calculations are sufficient and no modal properties arerequired?

- If a Shock Grade Curve Scheme approach is adopted, only rigid body behaviour with no high frequency components is considered. However, for flexible structures high frequency modes could be excited. The interaction between components would then need to be evaluated. This is an important factor when defining the need for tailored testing.
- The pseudo static approach tends to lead to structural forces, which are conservative resulting in a degree of pessimism. Therefore, pseudo static analysis should be treated with caution. However, this approach is often used in the absence of a dynamic analysis and can result in unrepresentative responses. Tailored assessment using modelling and test should be used where possible.

What are the mode shapes, relevant modes and the estimated (modal or averaged) damping values?

- Fundamental response mode
- Impulse response
- Mechanical damping
- Fluid damping
- Acoustic radiation damping
- Are the damping sources lumped or distributed?

How will the above dynamic parameters be altered by environmental factors associated with operation? Including:
Shock assessment is primarily involved with gross movement where subtleties such as temperature are second order. However, pre-load can have a significant effect when considering elastomeric isolators.

- Temperature
- Pre-load changes at supports

Variations in the characteristics between nominally identical components are likely. Can the possible spread be estimated?
In most cases it is not possible to estimate the spread of dynamic response characteristics. The nominal design and build standard is generally consistent and is adopted. There are far more influential approximations made in the assessment than considering a nominal spread in the materiel dynamic properties characteristics e.g. the fluid / hull and structural load path can only be approximated.

What is the estimated accuracy of the frequencies, damping values and mode shapes?

- Are they based on relevant measurements on a real component?
- If theoretical, how has confidence in the relevance of the model been obtained?
- If empirical, are the data / formulae applicable to those components in this environment?

3.3 Step 2C DYNAMIC RESPONSE DETERMINATION

Are the measurements of the response under the correct environmental conditions available?

- Do they cover all excitations identified above?
- Are they made under the most onerous of conditions?
- Coincidence of structural and excitation frequencies for most lightly damped modes
- Highest coupling in terms of spatial match.
- Conditions needed to promote onset of instabilities.
- Impact conditions associated with highest forces.

Can responses be estimated by extrapolating limited measurements from similar structures or Materiel?

- How has the extrapolation been justified?
- What are the main parameters to which the response is sensitive?
- What is the likely accuracy of the estimated response?

This is the basis of the Shock Grade Curve Scheme, which is limited to compact, rigid materiel. The following questions will help in identifying if the materiel can be considered as rigid.

- What is the aspect ratio of the materiel or collective materiel?
- Are materiel supported individually or collectively?
- Could individual materiel be removed for use?
- Is the materiel or collection of materiel a flexible, multi-modal structure or is it rigid and compact?
- Examples of a typical materiel or collection of materiel, which are rigid and compact, are shells, depth charges, case of racked shells, Blow Pipe, Sea Wolf. Those, which can be considered to be flexible and or distributed, include Tomahawk, torpedoes and air weapons.

If no direct measurements of the response are available, what theoretical estimates can be made for each relevant excitation force?
This only applies to tailored assessments of flexible materiel described above. There are established, validated and verified techniques for estimating the UNDEX loading on marine structures. The Shock Grade Curve Scheme can be used for limited lump mass structural

models or as inputs where it is deemed that fluid structure interaction calculation is not required.

How sensitive is the response to known mechanical and excitation variables?
The Shock Grade Curve Scheme is relatively insensitive to mechanical changes, principally because of the crude modelling capability. Tailored assessment may take account of the materiel structural geometry thereby providing a more sensitive assessment.

3.4 Step 2D MECHANICAL INTEGRITY ASSESSMENT

3.4.1 Simple Materiel - Shock Grade Curve Scheme or Test Approach

For a simple materiel a testing programme would be appropriated which covers the most onerous conditions.

Are component endurance or failure data available under the most onerous conditions?

- Are the results statistically meaningful?
- Do all the parameters, which significantly affect the dynamic response or failure resistance, have pessimistic values?

In calculating the endurance or likelihood of failure, how sensitive is the result to the dynamic strength parameter used?

- What is the safety margin on the allowable dynamic response?

The Shock Grade Curve Scheme is insensitive to the dynamic and strength parameters used and therefore it is difficult to scope the range of parameters.

It is very difficult to adequately define a safety margin using the Shock Grade Curve Scheme. An approximation for whipping is included in the 1987 Shock Grade Curve Scheme but their accuracy can be questioned since whipping is approximated simply by the inclusion of a low frequency sine residual component in the tail of the specified impulse. In practice whipping response will be platform specific.

Are the results of this assessment acceptable in terms of the ability of the component to meet the duty specified?

- If not, is this because parts of the assessment are overly conservative? If so, initiate a detailed analysis of these in Phase 2 of the analysis.
- If not, what are the main options for improving the integrity as identified by the assessment and sensitivity study?
- Evaluate most likely options for improvement starting at question 1 again.

Both the Shock Grade Curve Scheme and tailored assessment using complex numerical methods will not define if the materiel failure criteria. If the failure criteria are based upon structural damage these methods are well placed to provide this, where the simple analysis will not. The Grade Curves are sufficient to determine acceleration levels and the gross dynamic response for simple materiel. This can then be related to survival or damage test levels (i.e. 30g over 10 ms can be predicted) and historical data associated with weapon survival or failure used for comparative purposes. The tailored assessment and testing approach can give the inertial load and structural behaviour in and around the materiel from which assessment of the failure modes and likelihood of detonation may be assessed.

3.4.2 Complex Materiel - Shock Grade Curve Scheme or Test Approach

The added complexity of analysis methods to investigate the dynamic behaviour of complex materiel allows the sensitivity of the result to dynamic and strength parameters to be assessed. This allows a range of ‘what if’ questions to be investigated. However, this approach can be costly and a cost benefit analysis will be required.

Are component endurance or failure data available under the most onerous conditions?

- Are the results statistically meaningful?
- Do all the parameters, which significantly affect the dynamic response or failure resistance, have pessimistic values?

In calculating the endurance or likelihood of failure, how sensitive is the result to the dynamic strength parameter used?
What is the safety margin on the allowable dynamic response?

Are the results of this assessment acceptable in terms of the ability of the component to meet the duty specified?

- If not, is this because parts of the assessment are overly conservative? If so initiate a detailed analysis in Phase 2 of the process.
- If not, what are the main options for improving the integrity as identified by the assessment and sensitivity study?
- Evaluate most likely options for improvement starting at question 1 again.

4. FAILURE CRITERIA

What data are required to derive failure criteria?

- Materials data
- Geometry data
- Environmental data
- Fastenings

What failure criteria can be derived from available data, including component in-service experience?

- What is the estimated probability of failure associated with these criteria?
- Are there uncertainties that could make the failure criteria optimistic?

Shock assessment attempts to model the dynamic behaviour of a large section of the ship and predict its dynamic response to complex transient inputs. The materiel, structure if flexible, will also require to be modelled in some detail. The level of knowledge to achieve the desired objective is high and the analyses are complex, non-trivial and should not be confused with static modelling. The level of controls, which must be in place to manage the analysis and minimise the potential for error and the uncertainties, are high. The objective of an UNDEX assessment must therefore be to refine the scope to the worst-case behaviour in terms of safety assessment, suitability for service and influence the qualification testing programme.

5. UNDEX ASSESSMENT VERIFICATION AND VALIDATION

- Is it economically viable to get test data?
- Is it politically acceptable to get test data?
- Is a materiel available to risk destruction?
- Can a testing programme be influenced by modelling; thereby, only providing the minimum data to allow validated results? Maximum load cases can be explored.
- Is data derived from live materiel available or is only dummy materiel data available?
- In which case, what method and criteria are to be used to determine if detonation is possible?

ANNEX C

UNDEX TESTING USING SRS METHODS

1. BACKGROUND AND HISTORICAL PERSPECTIVE

Laboratory UNDEX Testing has traditionally been performed using mechanical shock test machines in conjunction with test standards such as UK BR 8740 or USA MIL-S-901. This procedure relies on the application of below mount shock levels to relatively dynamically inactive equipment. UNDEX testing of live explosive materiel commonly uses various drop test shock simulation methods. The advent of improved complex shock control systems, in conjunction with long stroke, high thrust, exciters for vibration test systems make it possible to consider the use of shock response spectrum (SRS) techniques for inert and live UNDEX testing. This shock test method is most effective where dynamically complex materiel is concerned, and the above shock isolation mount input time history data are available or can be derived. Generally, SRS methodologies rely upon definition of an SRS test severity from an in-service measured acceleration time history. Where necessary it may require a dynamic finite element model to establish the above mount time history and the associated SRS. The defined input SRS is then applied with a suitable fixture and high thrust vibration system to the test item.

Where the materiel is a low to medium mass, direct use of SRS techniques can sometimes be performed with the below mount measurements because the input peak acceleration levels can be increased significantly up to those specified in the Grade Curves. However, for higher mass materiel it is necessary to establish the above mount dynamic response of the materiel before proceeding. The use of modelling in conjunction with the SRS methodology is an advantage since it potentially reduces the overall testing requirements by identifying worst cases, and providing a more appropriate and technically superior shock test method that closely simulates the actual predicted in service conditions.

2. APPLICATION OF SRS TECHNIQUES TO UNDEX TESTING

The key steps in the application of SRS techniques to UNDEX testing of materiel are shown in Figure C-1. The defined process assumes that the test item characteristics, in-service LCEP, test equipment performance envelope, and data analysis capabilities are known.

Definition of Material Properties and Test Parameters

1. Determine the mass of the materiel, and physical characteristics.
2. Determine the type of support structure, mount, and the stowage configuration.
3. Determine the materiel and its container dynamic properties if applicable.
4. Define the level of UNDEX survivability.
5. Determine the below mount shock input time history.
6. Determine if an electrodynamic exciter has adequate thrust to apply the specified below mount shock time history without recourse to the above mount FE modelling. If yes, go to step 7, then skip to step 12. If no, go to step 7, and implement intermediate steps.

Above Isolation Mount Response and Modelling Considerations

7. Determine the above mount materiel shock response time history. By laboratory test if the exciter is capable. Or, by modelling in the steps below.
8. Model the support structure, mount, container and materiel using a non-linear finite element model and determine the system dynamic behaviour.
9. Model the shock input to the support structure
10. Calculate the worst case above mount dynamic response of the materiel for various UNDEX scenarios.
11. Calculate the worst-case SRS at the point of interest.

Definition and Verification of Laboratory Testing

12. Develop a representative shock test fixture taking into account the mass, inertia, thrust and performance limitations of the test laboratory electrodynamic exciter.
13. Develop an UNDEX test specification. Use the calculated SRS to derive an equivalent shock input time history comprising a series of damped sinusoids. This includes converting the shock time history into a SRS, which is split into multiple, phased damped sinusoids. The exciter to test item transfer function is then defined. Apply the specified shock pulse in terms of damped sinusoids to the test system exciter and materiel to achieve the in-service shock. The materiel shock response time history is then compared to the in-service shock time history for validation purposes.
14. Perform preliminary tests to evaluate the dynamic behaviour of the test setup and the test item; identify the optimum test control point(s) and confirm that the test specification can be adequately met. Compare the test shock response time history with the in-service shock response time history as well as the SRS.
15. Undertake live materiel UNDEX testing.

3. INFORMATION REQUIREMENTS FOR SRS TESTING

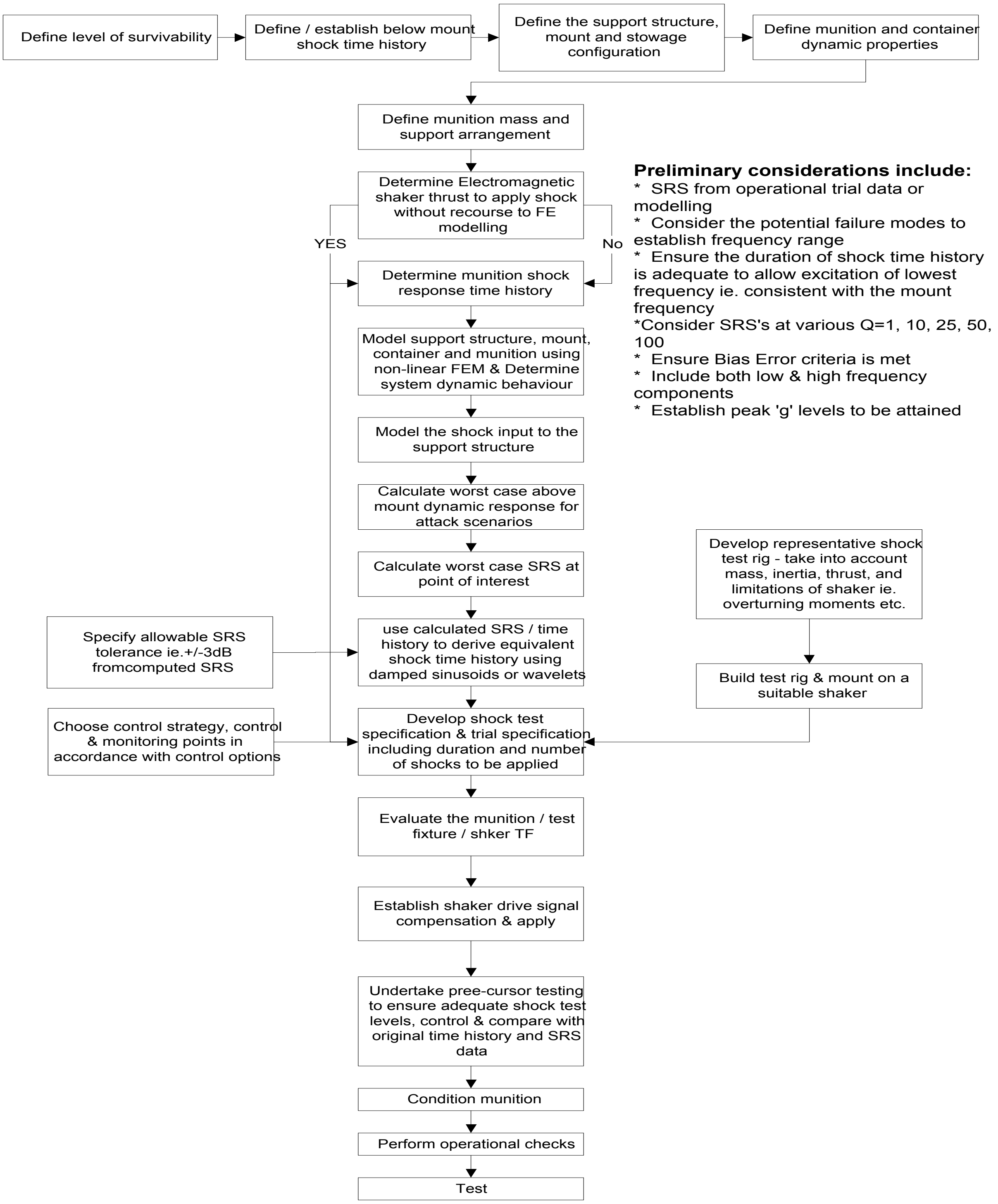
3.1 Preliminary Considerations

- The shock response time history and its SRS obtained from either in-service measurement data or modelling is used as the basis of the shock test specification. The test specification will be developed for the frequency range that potentially affects the failure modes of interest.

- The duration of the shock response time history should be assessed as adequate to allow specification of the low frequency SRS, nominally 5Hz to 10Hz. This low frequency limit needs to be consistent with mount resonances and the test system exciter thrust and control requirement.

- SRS's at various damping levels appropriate to the materiel to be shock tested should be considered, such as Q = 1%, 5%, 10%, and 15% as required.

- Ensure that both low and high frequency components are included in the test specification SRS. Low pass filtered data may be used to interpret the time history, but should not generally be used when analysing the SRS without fully understanding the consequences in terms of potential damage.



Preliminary considerations include:
* SRS from operational trial data or modelling
* Consider the potential failure modes to establish frequency range
* Ensure the duration of shock time history is adequate to allow excitation of lowest frequency ie. consistent with the mount frequency
*Consider SRS's at various Q=1, 10, 25, 50, 100
* Ensure Bias Error criteria is met
* Include both low & high frequency components
* Establish peak 'g' levels to be attained

Fig C-1 Key Steps In Materiel UNDEX SRS Testing

- It is necessary to ensure bias error criteria has been met

- The peak acceleration level to be simulated during the laboratory test, the mass of the materiel and test equipment exciter must be established. This information will be used to establish that the test system is capable of adequately performing the shock test to the full acceleration test level.

- It is necessary to establish the test specification SRS control limits at the 3dB level.

- The number and level of pre-cursor shocks to achieve adequate control must be established and taken into account in the SRS test specification.

3.2 Shock Test Specification

- The shock test specification will be in the form of a shock pulse time history consisting of a series of damped sinusoids (frequency, acceleration amplitude, damping %, delay % and polarity). This time history will be derived from the specified SRS and shock response time history using a specified damping and frequency range.

3.3 Fixturing Design

- Where possible in-service materiel components should be used in the test fixturing design. Where a container is used, the container must be mounted to the exciter head expander and support plate structure using the in-service configuration.

- Where possible, it is necessary to avoid non-linear joints and interfaces. The non-linear effects may only become apparent during the application of the full level shock pulse and not be included during evaluation of the system transfer function.

- Where possible, fixturing symmetry about the shaker centreline should be maintained to avoid overturning moments, significant structural overhang, and unwanted rotational inertia effects.

- The introduction of lateral shock components should be avoided.

3.4 Shock Test Control Instrumentation

- It is necessary to use accelerometers mounted in the direction of the shock for control purposes.

- Where possible triaxial accelerometers should be used to establish any lateral shock components.

- Where possible triaxial accelerometers should be used to monitor the materiel's structural response at key positions of interest.

- Where a container is used, it is necessary to instrument the materiel and the container to establish any dynamic magnification across the mounts throughout the frequency range of interest.

3.5 Precursor Testing

During precursor testing it is necessary to:

- Establish the structural integrity of the fixturing and the test setup.

- Determine the optimum control parameters and strategy.

- Evaluate the fixturing dynamic behaviour.

- Establish if the specified shock input at full test level can be achieved.

- Establish if the test system and controller is capable of control at full test level.

- Demonstrate that the test specification SRS can be achieved with the ± 3 dB limits.

- Demonstrate instrumentation calibration and integrity.

- Select control point(s) on the shaker base plate or materiel structure.

- Determine the test fixturing and control system dynamic response characteristics, in terms of the system transfer function. This is achieved by exciting the structure with random excitation, measuring the response at the control point and analysing over the frequency range of the SRS. The resulting transfer function is then used to shape the exciter drive signal to achieve the required shock pulse. Note the low-level random excitation will not generally detect non-linear effects exhibited by the fixturing and materiel.

- Apply the shock pulse to the structure at a reduced level, nominally – 12 dB, and repeat at least three times to achieve an average. Repeat this process at – 9 dB, -6 dB, and – 3 dB before going to full level. The number of averages will depend on the fixturing, structure and SRS being applied. The gradual approach to full test level is necessary to establish optimum control parameters and take account of non-linear effects.

- Confirm optimum location of the control point(s).

- Compare both the response time history and the SRS with those specified at the control point and at relevant points on the materiel structure. This will validate the shock input test specification.

- If the results show that the specified shock pulse is not being adequately achieved it may be necessary to consider the following:

  - Alternative test control positions.
  - Reduction or redistribution of fixturing and test load mass.
  - Application of other damping levels used to calculate the SRS.
  - Phasing and damping of the damped sinusoids used to construct the input shock pulse.
  - Use of a test system with a higher thrust capability.
  - Improvement in the control system capabilities.
  - Multiple shock strategy.
  - Relaxation of the control tolerance limits.

3.6 Live Test Programme

When undertaking the live test it is necessary to consider the following:

- Confirm the control transfer function derived during the precursor test.

- Validate the precursor test results, the shock response time histories and SRS, at low levels using live materiel prior to undertaking the full live test programme.

- Confirm similarity between the input time history and the operational UNDEX event time history.

- Include in the live test programme strategy the need to apply multiple shocks at reduced level to establish the control parameters.

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ANNEX D

UNDEX TEST EQUIPMENT

1. EQUIPMENT CHARACTERISTICS

The objective of an UNDEX shock test is to induce a response in the test item, which as closely as possible, corresponds to the expected response of in-service materiel during a non-contact underwater explosion for a specified threat event. A shock test of individual inert materiel can be performed using an operational ship, barge platform, vibration test system, free fall drop, or shock machine as appropriate within the equipment displacement, amplitude, and frequency limits. Shock testing of live explosive materiel is currently often restricted from full-scale ocean or barge testing due to environmental concerns. The choice of equipment depends on the test item dimensions, mass, shock excitation level, and Test Instruction requirements. Large or heavy test items may require component or sub-assembly testing. In some cases, full scale operational ship testing may be the only option due to the physical characteristics of the test item or the installation configuration.

1.1 Operational Ship Shock

The use of a full-scale, or partial-scale, operational ship test is typically the most realistic test method; however the tests are also expensive to conduct. One benefit of operational ship testing is that simultaneous testing of several test items in actual in-service configuration can be conducted. The tests also permit acquisition of measured engineering data for subsequent laboratory or experimental testing, and model validation. In general, operational ship tests require a higher level of considerations and funding, but the benefits can be justified based on the test program requirements. These full or scale ship tests can only be performed if the ship is beyond the manufacturing phase, which can adversely affect the timeliness of the project.

1.2 Shock Barge

A shock barge is a floating platform into or on which an inert materiel is installed for detonation of an explosive charge in the water. The test item installation can be a full-scale in-service configuration, or a scaled model. Similarly, the body of water can be natural open-ocean, an isolated pond, or a water tank suitable for the scale of the test. The charge is positioned relative to the barge to simulate an UNDEX scenario corresponding to the particular Shock Factor. For all floating platform tests, a number of considerations are necessary to account for the shock wave direct and reflected transmission path to the barge, installation of the test item, water properties, and the explosive charge characteristics. Two common types of floating barges are flat or keel shaped barges (Type 1) and round bottomed barges (Type 2) to simulate ocean surface ships and submarines respectively. Type 1 barges vary in size and are used for equipment tests ranging from components to full-scale generators, pumps, and gun systems. Type 2 barges have a semi-cylindrical cross section of a submarine hull with ballasting and buoyancy provided by bow and stern structures. The test section of the barge is semi-cylindrical with scantlings similar to those of a submarine pressure hull from the keel to just above the horizontal centreline. The frames are continued to a deep coaming of similar scantlings at the weather deck.

1.3 Mechanical Shock Machines

A shock machine is equipment that induces a shock response in the test item by a rapid displacement of the machine table or an impact projectile. The transfer function associated with the operation of the machine determines the displacement and acceleration profile. The severity of the response that can be induced in a test item depends upon the machine capacity and combined mass of the test item plus fixturing. The shock pulse from these machines is typically generated by hydraulic, pneumatic, or gravity control. A closed loop control system may not be present on some machines, and shock pulse is created by default control parameters. The characteristics of several types of shock machines are presented below.

1.3.1 Deck Shock Machine

The deck shock machine is designed to induce a lightly damped oscillatory shock response. Such a response is experienced by materiel directly fastened to a vessel in locations remote from the hull during an UNDEX excitation. The deck shock machine consists of a horizontal shock table, to which the test item is attached. Linkages to four transverse torsion bars connect the table. The torsion bars are located in journal bearing pedestals, which are directly attached to the machine foundation. The inner end of each torsion bar is fitted with a crank arm. Energy to operate the machine is provided by two hydraulic rams that apply torque to the torsion bars using the crank arms before the machine is actuated. The outer end of each torsion bar is fitted with a dog and pawl arrangement. The pawls are held into the dogs by means of cams connected to two pneumatic rams that are a firing rod and firing cylinder.

Once the required torque is achieved in the torsion bars, the machine is actuated by way of the pneumatic rams. The linkages to the shock table thus transmit the energy stored in the torsion bars. The linkage between the torsion bars and the shock table may be set to induce either vertical or horizontal motion of the shock table. Response characteristics of a typical deck shock machine are shown in Table D-1.

TABLE D-1 Deck Shock Machine Characteristics

Parameter	Capability
Table dimensions	2740 mm x 1070 mm (9 ft x 3.5 ft)
Maximum test mass	680 kg (1499 lb)
Maximum displacement	64 mm (2.5 in)
Maximum velocity	Small mass: 6.1 m/s (240 in/s) Maximum mass: 4.3 m/s (169 in/s)
Maximum acceleration	Small mass: 1000 m/s^2 (102 g) Maximum mass: 700 m/s^2 (71 g)

1.3.2 Two Tonne Shock Machine

The two tonne shock machine is designed to induce the heavily damped oscillations, which would be experienced by materiel in locations close to the hull of a vessel due to a UNDEX event. The machine operates on the same principle as a compressed air gun; a projectile is propelled by compressed air to impact on a target. To prevent the direct transmission of reaction forces to the surrounding floor, the machine is secured to a reaction mass of approximately two hundred tonnes in mass below the floor level. This reaction mass bottom surface is supported by oil springs and is free to move vertically in roller guides. The inner cylinder, orientated vertically, has within it a projectile, which is free to slide in the cylinder bore. Surrounding the inner cylinder, and concentric with it, is the outer cylinder. The annulus space between the two cylinders, stores the compressed air, which provides the energy to propel the projectile. Connecting the annulus and the cylinder bore are ports, which are closed by the projectile when it is at the bottom of the inner cylinder, prior to commencement of the working stroke. Projectile cylinder seals prevent the unwanted escape of air from the annulus to the spaces above and below the projectile.

The cavity below the projectile is connected to the annulus through a valve, which is operated remotely. The operation of the shock machine is initiated by opening this valve and allowing pressure to build up below the projectile, slowly moving the projectile upwards. The projectile eventually uncovers all the compressed air ports, which causes the projectile to move quickly up the inner cylinder towards the shock table.

Integral with the projectile is an acceleration damper, which operates on an oleopneumatic principle. When the projectile impacts with the shock table, relative displacement between the damper piston and the projectile body occurs. While this takes place, hydraulic fluid is transferred from the damper chamber through an orifice plate to a second chamber in which a separator, backed by nitrogen pressure, is free to slide. As the stroke of the damper piston proceeds, a shaped restrictor moves into the orifice varying the effective area of the orifice, and hence also the damping.

The deceleration of the shock table is controlled by eight oil pneumatic dampers operating on a similar principle to that of the accelerating damper. The shock imparted to the shock table can be varied as indicated below. Typical two tonne shock machine characteristics are shown in Table D-2.

a. Adjusting the table height;
b. Varying the pressure of air in the annulus;
c. Varying the initial relative positions of the orifice and restrictor in the acceleration dampers;
d. Varying the initial relative positions of the orifice and restrictor in the deceleration dampers;
e. Acceleration, varying the nitrogen pressure behind the separator in the acceleration dampers;
f. Deceleration, varying the nitrogen pressure behind the separator in the deceleration dampers.

TABLE D-2 Two Tonne Shock Machine Characteristics

Parameter	500 Kg Test Mass		1900 Kg Test Mass	
Maximum displacement	46 mm	(1.8 in)	38 mm	(1.5 in)
Maximum velocity	9 m/s	(354 in/s)	6 m/s	(236 in/s)
Maximum acceleration	5500 m/s^2	(561 g)	3000 m/s^2	(306 g)
Maximum deceleration	2750 m/s^2	(280 g)	1500 m/s^2	(153 g)

This shock machine is capable of inducing vertical motion of the shock table. Shock tests in other directions may be conducted by attaching the test item to the shock table in an appropriate relative position, using appropriately designed rigid fixturing.

1.3.3 Lightweight and Medium Weight Pendulum Hammer Shock Machine

The Lightweight (LWSM) and Medium Weight (MWSM) shock machines are the equipment specified in the MIL-S-901 test specification. The machine consists of a gravity accelerated pendulum hammer that impacts an anvil plate to excite the attached test item. The severity of the impact is tailored by the drop height of the hammer. Table D-3 provides typical characteristics for the LWSM and MWSM machines. Reference e also provides further information on the test machines.

TABLE D-3 Lightweight and Medium Weight Shock Machine Characteristics

Parameter	Lightweight Shock Machine		Medium Weight Shock Machine	
Hammer Weight	400 lb	(181 Kg)	3000 lb	(1361 Kg)
Maximum Test Weight	550 lb	(250 Kg)	7400 lb	(3357 Kg)
Maximum displacement	1.5 inches	(38 mm)	3.0 inches	(76 mm)

1.4 Vibration Test Systems

Vibration test systems, electrodynamic or servo-hydraulic, can be used to apply a measured or synthesised input time history, for the associated shock response spectrum (SRS), to either an inert or live test item. The use of vibration systems for UNDEX testing is restricted principally by the availability of the input time history, low frequency displacement, peak acceleration, frequency range, and the mass and geometry of the combined materiel plus fixturing. However, where these criteria can be met, this equipment is effective and more appropriate than drop testing.

Traditionally electrodynamic or servo-hydraulic exciters have been used for a variety of shock simulation testing. However, they have been ignored for UNDEX testing for anything other than small components because of their limited dynamic range (displacement, velocity, acceleration and frequency response). Test systems in common use have acceleration, displacement and frequency limits of 100 G, 2 inches, and 200 Hz respectively. With the advent of improved shock control systems and long stroke high thrust shakers, these limitations has been largely overcome for moderate weight materiel, typically up to 800 kg (1764 lb), and the test limitation depends on the required materiel dynamic response.

The limitations can be further reduced by using the above shock mount isolation response as a control point instead of the below mount SRS dynamic excitation as an input. The peak G and excitation frequency range are greatly reduced at the materiel by mechanical isolation mounts, which act as mechanical filters, and the current generation of exciters can approach the peak G levels defined in the Grade Curves. To be able to use vibration test systems for UNDEX testing materiel it is necessary to calculate the above mount dynamic response using realistic below mount input data and a representative model of the mount and materiel. This process can be complex; however, the reward is the definition of shock input levels generally within the range of the modern exciters. Specification of the above mount materiel dynamic response allows an SRS to be derived. The SRS in the form of a matched acceleration time pulse can then be applied to the test item using an exciter with a suitable fixture. Currently it is considered that this technique offers a solution to UNDEX testing of materiel that are installed on mechanical mounts, or packaged materiel where the package can be considered as the mount.

For applications where materiel test severity levels fall within the useable envelope of vibration test systems, this equipment offers a more suitable, technically superior, alternative to conventional methods of UNDEX testing of inert and live materiel. Furthermore, this method of UNDEX testing can be accomplished using existing live materiel test facilities, and therefore represents the only fully representative method currently available. Where force limitations are encountered for large items, multi-exciter test systems can be used to meet the test specification. Further description of vibration test system equipment and application to shock and SRS testing is provided in Methods 403 and 417. Information on multi-exciter test methods for physically large or heavy test items is provided in Method 421.

1.5 Drop Test Machines

Drop testing can either be performed simply by dropping the test item onto various materials used to shape the input transient shock event or using a free fall machine which is configurable to simulate simple transient shock events. A drop test is free fall, or mechanically accelerated, and induces a short duration transient event, which simulates the rise time of the initial shock pulse, a few milliseconds. The longer time duration associated with the actual UNDEX event is ignored. Dropping the materiel onto various materials or a configurable platform can shape the input pulse by programming the shock event. This can be effective where classical shock pulses are required, but drop testing is severely limited on the grounds of realism and should only be considered as a ruggedness test. It is often a technique, which is difficult to justify, since half-sine components are chosen almost at random from the in-service complex oscillatory dynamic response time history records. Furthermore, the Fourier spectrum of the approximate half-sine pulse is completely different from the operational SRS, which has a marked effect on excitation of potential failure mechanisms.

METHOD 420

BUFFET VIBRATION

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METHOD 420

BUFFET VIBRATION

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the short duration vibration environment for wing or fuselage mounted materiel on aircraft during flight induced buffet vibration. The materiel, hereafter referred to as stores, is typically electro-mechanical systems, subsystems, bombs, missiles, Electronic Countermeasure (ECM) pods, and fuel tanks. Buffet vibration is a high amplitude vibration occurring during limited flight manoeuvres due to aerodynamic flow and structural vibration modes. The test considerations are different from Method 401 (Vibration) because of the short duration of the event.

1.2 Application

The test method includes discussion of the buffet phenomenon, the causes, and aggravating factors. The flight manoeuvres that generate buffet are identified and the relative effects due to store type, aspect ratio, mass, and location are discussed. Interaction between the host aircraft wing or fuselage and the store vibration modes are also addressed. This test method is applicable where stores are required to demonstrate adequacy to resist buffet vibration safely without unacceptable degradation of the store performance and/or structure.

Buffet vibration occurs as a result of unsteady aerodynamic pressure acting on aircraft structures, including the externally carried fuselage or wing stores. Another possible source of store vibration in buffet is the excitation of the store skin panels and store fins if equipped. Such responses are highly dependent upon the structural details of the particular store, and not suitable for generalized test methods. The extent of the induced vibration on the store depends primarily upon the following factors.

a. Flight Condition. The angle of attack of the host aircraft is a key parameter influencing the response of the store in buffet. During straight and level flight, stores will be excited by aerodynamic flow over exposed surfaces. A boundary layer will form at the store nose that becomes turbulent and thicker downstream, thus imparting vibration energy to the store. The nature of the turbulent airflow is predominantly low frequency excitation. Short duration aircraft combat or high speed manoeuvres result in loading from centrifugal, gravitational, and aerodynamic forces that induces additional vibration excitation in the store.

b. Aircraft Configuration. The location the store is mounted on the aircraft and number of other stores present in the airflow around the store will influence the susceptibility to buffet. Wing mounted stores generally experience more buffet excitation than under-fuselage stores. The total combined mass of a particular weapon load installed on the aircraft will influence its agility in manoeuvring and also influence the overall dynamic response behaviour and the magnitude of buffet induced responses.

c. Aircraft and Store Dynamic Characteristics. The modal response characteristics of the aircraft and of the installed store will influence the amplitude of vibration response. Buffet can be problematic for flexible high aspect ratio stores because either the store, or their installation, can possess low frequency modes less than 100 Hz. These modes can be associated with
  - Store bending.
  - Rigid body motion of the store arising from the flexibility of its carriage equipment.
  - Rigid body motion arising from aircraft wing bending and torsion.

1.3 Limitations

Accurate laboratory simulation of buffet vibration requires adequate fixturing for the airframe, store mounting, and matching of test equipment and test item impedance to the actual in-service conditions. Common limitations of the laboratory simulation procedures are below.

a. Simulation of the actual in-service buffet environment may not be possible because fixture limitations or test equipment physical constraints prevent the satisfactory uniform application of the vibration excitation to the test item at all locations

b. Current vibration control equipment may not be able to simulate the measured vibration due to a non-Gaussian or transient vibration environment.

c. The test method initial test severities may not be applicable to high aspect ratio stores with a variable diameter along the store length.

d. The test method initial test severities do not include internal store generated vibration excitation.

2. TEST GUIDANCE

2.1 Effects of the Environment

A large number of parameters influence the maximum dynamic response of a wing or fuselage mounted store. Accurate prediction and characterization of the response to eliminate problems also has several approaches. In general, the measurement of flight data for required mission flight profiles, modal analysis, and analytical modelling can adequately predict the potential for failures on specific airframes and stores. The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to the buffet vibration environment.

a. Structural or fatigue induced failure of the store mounting points on the airframe or store.

b. Failure of internal store components.

c. Reduction of the store in-service life due to severe dynamic environment.

d. Aircraft flight manoeuvre limitations due to coupling of airframe and store motions.

2.2 Choice of Test Procedures

The test method procedures are designed to reproduce the primary low frequency dynamic responses measured in flight of complete assembled stores and to provide realistic laboratory simulation of relevant mission flight conditions through the use of vibration and temperature conditioning. For the test method, aircraft stores are divided into two classes, low and high aspect ratio (AR). These two classes also each contain separate wing and fuselage mounted stores. The cases indicated in Table 1 are covered in the test method. The dimensionless aspect ratio is defined in Equation 1 as the ratio of the store length to diameter.

In general, stores can be categorized as low aspect ratio (AR< 7, stiff structure) or high aspect ratio (AR >15, flexible structure). The low AR materiel, generally bombs or heavy structure, has a higher fundamental first bending mode than high AR stores, generally missiles or rockets. Consequently, the first bending modes for low and high AR stores are approximately 200 Hz and 60 Hz respectively. There is not a clear division between high and low AR stores. Any store with a first bending mode frequency of approximately 200 Hz or greater can be treated as a low AR store, regardless of the specific AR.

Table 1 – General Store AR and Fundamental Frequency

Aspect Ratio	**Store Fundamental Frequency, F_n (typical), Hz**
Low, AR < 7, stiff store	$F_n > 200$ Hz
AR between 7 to 15	Dependent on F_n
High, AR > 15, flexible store	$F_n \sim 60$ Hz

$$\text{Aspect Ratio (AR)} = \text{Store Length / Store Diameter} \qquad [1]$$

The dominant vibration response for the low AR store during buffet will generally be in a rigid body mode of the mounting platform. An important exception to this is when the store does not have a uniform cross-section, such as laser guided bombs with slender front guidance unit sections compared to the warhead sections. Such cases demand special attention to determine the lowest bending mode frequency, which may be that of the entire guidance unit bending on the warhead section. For other store types, the most significant mode may be bending of the store's tail on the centre section.

The induced buffet vibration for a high AR store is coupled between the platform modes and the store modes. Thus, flexible stores are more prone than stiff stores to the induced buffet excitation amplification because of the low frequency excitation characteristics of buffet vibration. The above categories of modal response are not mutually exclusive. In particular, a high AR store bending mode may be close to wing torsion or bending modes, giving rise to a severe buffet vibration environment.

Interaction between the modes of vibration, the dynamic excitation, and other factors can combine to create situations where buffet becomes a major consideration for the store design. A worst-case installation could involve a high AR store at an outboard wing station of an agile aircraft. Or, a least problematic installation could be a low AR store carried on a fuselage station of a not very agile aircraft.

Store vibration responses arising from buffet vibration are usually confined to frequencies from 5 to 400 Hz. The vibratory energy will be imparted by aerodynamic excitation encountered in–service over the surface area of the store. For practical purposes the effects of buffet vibration can be simulated with mechanical excitation alone; the higher frequency acoustic driven excitation is excluded for the low frequency motion simulation.

2.3 Use of Measured Data

Where practical, air carriage data should be used to develop buffet test levels. It is particularly important to use air carriage data where precise simulation is the goal. Sufficient air carriage data should be obtained to adequately describe the conditions being evaluated and experienced by the store. Examples of measured store buffet vibration response for high and low aspect ratio, and wing or fuselage mounted stores are given in Annex B.

2.3.1 Measured Store Buffet Vibration Data Available

Several considerations exist for a store or airframe test program with scheduled data acquisition. When defining the aircraft flight profile for data acquisition, it is important to ensure that flight manoeuvres expected to generate buffet are included, wind-up-turns, steady heading sideslips, vectored thrust in flight, etc. It is also important that instrumentation transducer locations are selected for buffet vibration laboratory simulation. In particular, it is important that any relevant store, pylon and aircraft structural modes are identified that could be expected to respond to buffet vibration, so that accelerometers or other transducers can be positioned accordingly. In most cases, measurements at the extremities of the store should be given a high priority for this purpose. Through knowledge of the structural dynamics of the store, pylon and aircraft are of great value when interpreting the measured flight responses. Such knowledge would be gained from either an analytical finite element analysis or preferably experimental modal analysis of the store in its carriage configuration on the aircraft.

Typical signal processing techniques currently used for identifying flight events can be deficient for identifying and quantifying critical buffet vibration conditions. Two particular issues arise with buffet, which are problematic in terms of signal processing. The first is the short duration of the event. The second is the limited bandwidth over which the buffet vibration takes place. It is recommended that the Grms time history be used for identifying buffet vibration events within the complete measured time history should employ a restricted frequency bandwidth covering only the modes likely to be excited during buffet excitation, typically 5 to 500 Hz. It is also essential that the time history record lengths are adequate to meet the appropriate data processing error criteria. When quantifying the effect of buffet in an ASD format, the data should be analysed up to 500 Hz. However, because data are likely to be non-stationary, appropriate care must be taken when computing and interpreting ASD data.

When developing a test severity from measured data an acceptable approach is to construct a random spectrum test with a tailored severity. For each buffet manoeuvre condition, obtain the ASD that best describes the vibration responses, taking into account the possible non-stationary properties of the data. Use the ASDs generated to assemble a credible worst-case ASD by overlaying the individual ASDs and enveloping by a number of straight-line segments.

For each mission only a short time will be spent in buffet vibration. Similarly, during the entire life of the store only a short period (minutes) may be spent in actual buffet. Therefore, the worst-case ASD should be used for each buffet excursion and aggregated over the total number of missions. It should be noted that the spectrum of random vibration commonly generated in test facilities is Gaussian, the software control algorithms are based on Gaussian excitation. It is recommended that buffet vibration data be checked to conform to a Gaussian distribution and if found not to be so the PSD amplitude should be corrected. Techniques for time domain replication may provide better laboratory simulation accuracy but require extraordinary management manipulation for test equipment procurement funding.

For high aspect ratio stores not only can buffet generate high vibration responses, but the buffet environment exposure times can be significant in terms of the total air carriage life of several hundred hours during multiple mission deployment. Additionally, high aspect ratio stores are more likely to be exposed to severe manoeuvres because of the mission flight profile for high performance aircraft. For stiff stores, however, buffet vibration amplitudes are likely to be lower than flexible stores, but the exposure times in terms of total air carriage life are also likely to be lower, such as several hours air carriage.

High and low aspect ratio store vibration amplitudes arising from the effects of buffet vary over a wide range on a given aircraft as well as between aircraft. Therefore, buffet vibration test severities should be based upon in-service flight vibration measurements. The worst case high aspect ratio store on the wing of high performance aircraft necessitates the tailored testing approach. Nevertheless, for initial design and other purposes the use of generic severities may be necessary for preliminary design.

2.3.2 Measured Store Buffet Vibration Data Not Available

Annex A provides generic ASD spectra based upon measured data for each of the four store types described in this test method. As a minimum, tailoring of the fundamental vibration mode frequencies is desired for a specific aircraft and store. The test specifications permit the use of initial estimates of wing, structural, and store modal frequencies, but these estimates are suggested only for design formulation; the final test should be based upon experimental data or analytical modelling, for example finite element analysis. In the absence of any measured data the Annex A initial severity may be used for preliminary evaluation.

2.4 Sequence

The buffet vibration test is designed for the simulation of the primary environmental effects that are induced in complete assembled stores during external carriage on fixed wing aircraft.

However, should a store need to be exposed to any additional environmental tests, then the order of application of the tests should be compatible with the life cycle environmental profile.

The effects of buffet may affect performance when the store is tested under other environmental conditions, such as temperature. Stores that are likely to be sensitive to a combination of environments should be tested to the relevant combinations simultaneously. If the simultaneous environment test is considered non-essential, or impractical to configure, a single store should be exposed to all relevant environmental conditions sequentially.

The order of application of tests should be considered and made compatible with the store Life Cycle Environmental Profile. If doubts concerning the sequence of testing, buffet vibration testing should be undertaken first, or in conjunction with air carriage vibration testing.

3. SEVERITIES

Test conditions are specified in paragraph 5.3.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The technical identification of the store

b. The definition of the store

c. The type of test: development, qualification, or other

d. The method of store mounting

e. The orientation of the store in relation to the laboratory test axis

f. If store operating checks are to be performed and when

g. The initial and final checks, specify whether they are to be performed with the store installed on the test facility

h. Other relevant data required to perform the test and operating checks

i. The vibration control strategy, and test reporting requirements

j. The monitor and control points or a procedure to select these points

k. The definition of test severity

l. The indication of failure criteria

m. The method to account for tolerance excess in the case of large stores and a complex fixture

n. Any other environmental conditions at which testing is to be carried out if other than standard laboratory conditions

o. The pre-conditioning time

p. The operation or non-operation of the store during testing.

q. The requirements for operating checks if applicable

r. The tolerances and control limits

s. Other details required to perform the test

4.2 If Required

a. The specific features of the test assembly (vibrator, fixture, interface connections etc.)

b. The climatic conditions if required if other than standard laboratory conditions

c. The effect of gravity and the consequential precautions

d. The value of the tolerable spurious magnetic field

e. Tolerances if different to those specified in paragraph 5.3

5. TEST CONDITIONS AND PROCEDURES

5.1 Test Controls

5.1.1 Precursor Trials

Control of the test conditions is derived from the store dynamic response. Therefore, a dynamically representative store should be made available for precursor trials in order to establish the required excitation conditions. Precursor testing is essential to assess the dynamic behaviour of the store and test equipment. The maximum response experienced at the store extremities should be limit controlled and it is essential that the vibration control position corresponds to measured air carriage data. Buffet vibration testing should be undertaken in the vertical, transverse, and longitudinal directions. In some cases cross coupling will ensure that adequate vibration amplitudes are generated in the transverse or longitudinal axis.

5.1.2 Control Strategy & Options

It is recommended to test for the effects of buffet separately from tests designed to represent the effects of straight and level flight. The test control strategy should recognise that the maximum vibration responses usually occur at the extremities of the store and that limit control will be necessary. Buffet testing should be performed as a controlled response at a position, which corresponds to, measured air carriage data, preferably adjacent to the fixture. The vibration control strategy should be in accordance with AECTP 400 Method 401 Vibration Section 2.6.

5.2 Store Operation

When specified in the Test Instruction or relevant specification, during in-service simulations, the store should be operated and its performance measured and noted.

5.3 Tolerances

The test tolerances and related characteristics associated with buffet vibration testing should be in accordance with AECTP 400 Method 401 Section 5.1.

5.4 Installation Conditions of Test Item

The installation conditions of the test item associated with buffet testing should be in accordance with AECTP 400 Method 401 Section 5.2.

5.5 Test Preparation

The test preparation of the test item associated with buffet testing (pre-conditioning and operational checks) should be in accordance with AECTP 400 Method 401 Section 5.3.

6. EVALUATION OF TEST RESULTS

The test item performance shall meet all appropriate specification requirements during and following the application of the buffet vibration.

7. REFERENCES AND RELATED DOCUMENTS

a. Piersol, Allan G., Vibration and Acoustic Test Criteria for Captive Flight of Externally Carried Aircraft Stores, AFFDL - TR-71-158, December 1971.

b. Heaton, P.W., and Czuchna, J.S., Prediction of Dynamic Environments for Airborne External Stores During Aircraft Straight and Level Flight, IES, 41st Annual Technical Meeting, May 1995.

c. Heaton, P.W., and White, G.P., Airborne Store Captive Cruise Vibration Spectral Variations Scaling, Proceedings of the 65th Shock & Vibration Symposium, November. 1994.

d. Czuchna, J.S., L.E. Pado, R.M. Hauch, and G.P. White, Comparison of Prediction Techniques Airborne Store Captive Cruise Vibration, Proceedings of the 65th Shock & Vibration Symposium, November 1994.

e. Richards, David P., The Derivation of Procedures to Estimate Vibration Severities of Airborne Stores, Proceedings of the Institute of Environmental Sciences, May 1990.

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ANNEX A

BUFFET VIBRATION - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

The Annex A vibration test schedules are designed to simulate vibration test amplitudes for stores located at an under-wing or under-fuselage aircraft position. Both high and low aspect ratio stores are considered. In general, the procedures described are suitable for all new requirements where in-service data exists. Figures A-1 to A-4 provide generalized vibration spectra for buffet induced vibration. The spectral envelope is a characteristic shape, which varies depending on the store aspect ratio and carriage position.

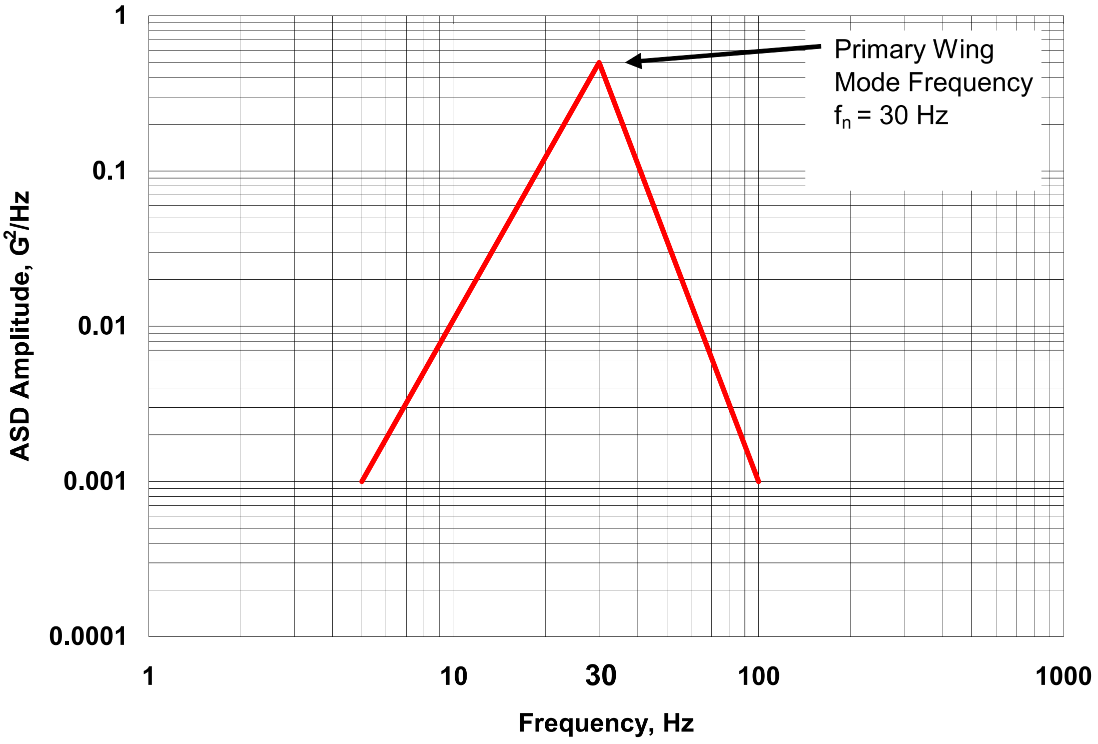
Development of generic buffet vibration test levels is a complicated process because of the potential for complex interactions between the store and the aircraft. As a result, there is the potential for extreme dynamic response levels, which can be inappropriate as default test levels for all stores and airframes. For example, stores of non-uniform cross section are outside the scope of the default severity. The non-uniform mass may create, or interact with other modes, and induce a resonance condition that is not included in the default test schedules. In compiling the default test severities, consideration has been given to aircraft wing modes and store rigid body or bending modes. Consequently, the following default severities should not be considered all embracing, but are offered as a way forward for initial design and development purposes. When available, measured data or analytical models should be used to define the primary mode frequency and/or the ASD amplitude peak level.

Annex B provides comparisons of in-service measure buffet conditions. AECTP 200 also provides guidance on factors influencing aircraft vibration. Table A-1 below provides a summary of the Annex A buffet vibration default tests. As shown, the induced vibration energy is a function of both the store type and location. A rigid, low aspect ratio, store on an aircraft fuselage location is the least severe. A flexible, high aspect ratio, store on a flexible wing location is the most severe. This comparison is based only on the Annex A initial test severity schedules and may not apply for the actual aircraft or store under consideration.

Table A-1 Summary of Buffet Vibration Test Schedules

Store Configuration	Figure	Test Time, maximum, min.	Grms V, T, L
Low Aspect Ratio Wing Store	A-1	15	2.63
Low Aspect Ratio Fuselage Store	A-2	15	1.46
High Aspect Ratio Wing Store	A-3	15	5.06
High Aspect Ratio Fuselage Store	A-4	15	3.35

FIGURE A-1 LOW ASPECT RATIO WING STORE



Random Spectrum Breakpoints	
Frequency, Hz	ASD, G^2/Hz
5	0.001
30	0.500
100	0.001
Random Grms = 2.63	

Figure A-1 Low Aspect Ratio Wing Store Test Description

Test Parameters :

Test Axes :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point response control

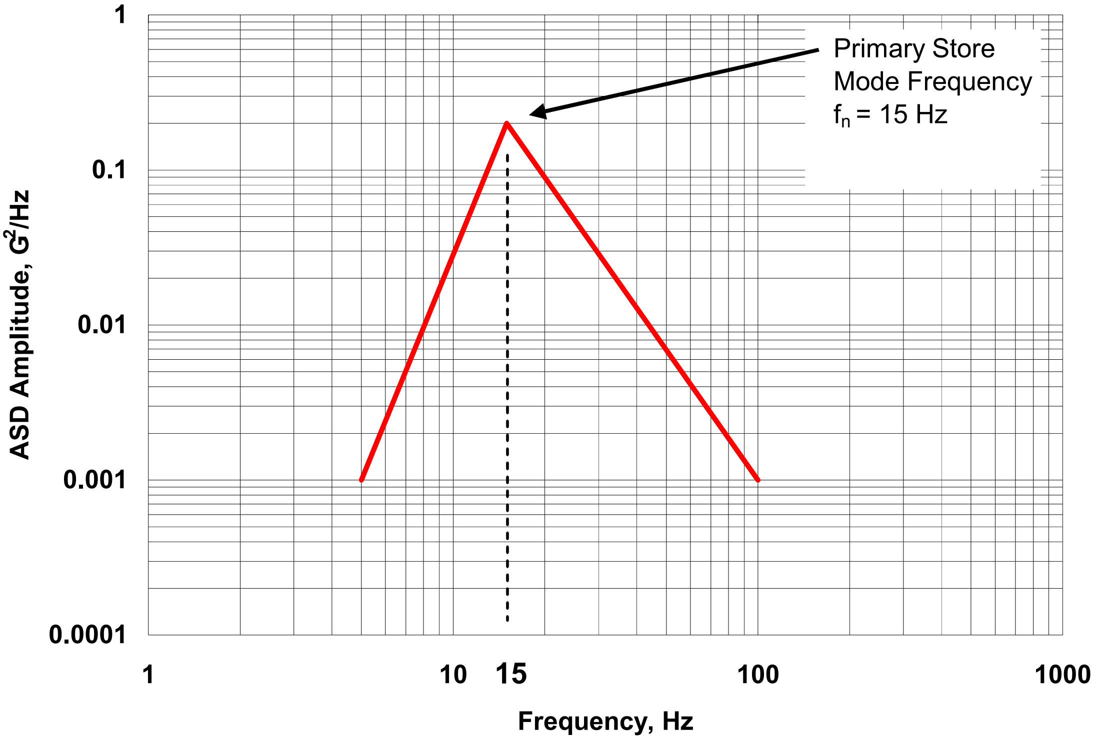
Control Notes :

1. When the test duration cannot be defined from the LCEP, the default duration for each axis is 6 seconds for each buffet vibration event or a maximum of 15 minutes total in each axis.
2. Cross coupling effects may be utilized to satisfy the transverse and/or longitudinal axis vibration requirements. When cross coupling is less than the longitudinal requirement, testing should be conducted in the longitudinal axis to in-flight levels or where this data is not available at half the amplitude used for the maximum experienced in the vertical or lateral axes.
3. Use the maximum control system roll-off rate at the 5 and 100 Hz breakpoints.
4. The test schedule is derived for a response control accelerometer(s) located at the store mounting location.

Schedule Description

The default severity for low aspect ratio wing stores under is shown in Figure A-1 and should be applied in each axis. This figure shows a single spectral peak at the dominant wing mode associated with either bending or torsion. If the actual dominant natural frequency mode is known, the mode frequency should be used to centre the peak. However, in the absence of known dominant modal frequencies, a default value of 30 Hz should be used.

FIGURE A-2 LOW ASPECT RATIO FUSELAGE STORE



Random Spectrum Breakpoints	
Frequency, Hz	ASD, G^2/Hz
5	0.001
15	0.200
100	0.001
Random Grms = 1.46	

Figure A- 2 Low Aspect Ratio Wing Store Test Description

Test Parameters :

Test Axes :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point response control

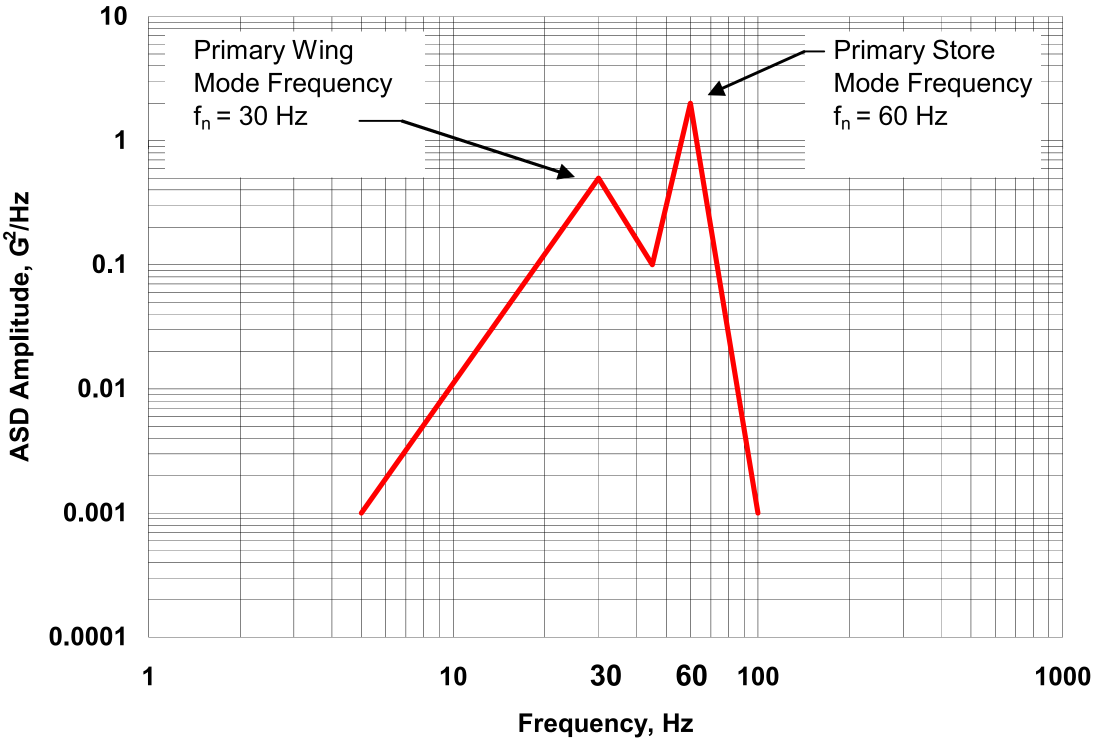
Control Notes :

1. When the test duration cannot be defined from the LCEP, the default duration for each axis is 6 seconds for each buffet vibration event or a maximum of 15 minutes total in each axis.
2. Cross coupling effects may be utilized to satisfy the transverse and/or longitudinal axis vibration requirements. When cross coupling is less than the longitudinal requirement, testing should be conducted in the longitudinal axis to in-flight levels or where this data is not available at half the amplitude used for the maximum experienced in the vertical or lateral axes.
3. Use the maximum control system roll-off rate at the 5 and 100 Hz breakpoints.
4. The test schedule is derived for a response control accelerometer(s) located at the store mounting location.

Schedule Description

The default severity for low aspect ratio stores carried under fuselage is shown in Figure A-2 and should be applied in each axis. This figure shows a single spectral peak at the rigid body natural frequency of the installed store. If the rigid body natural frequency is known, the frequency should be used to centre the peak. However, in the absence of this information, a default value of 15 Hz should be used.

FIGURE A-3 HIGH ASPECT RATIO WING STORE



Random Spectrum Breakpoints	
Frequency, Hz	ASD, G^2/Hz
5	0.001
30	0.500
45	0.100
60	2.000
100	0.001
Random Grms = 5.06	

Figure A- 3 High Aspect Ratio Wing Store Test Description

Test Parameters :

Test Axes :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point response control

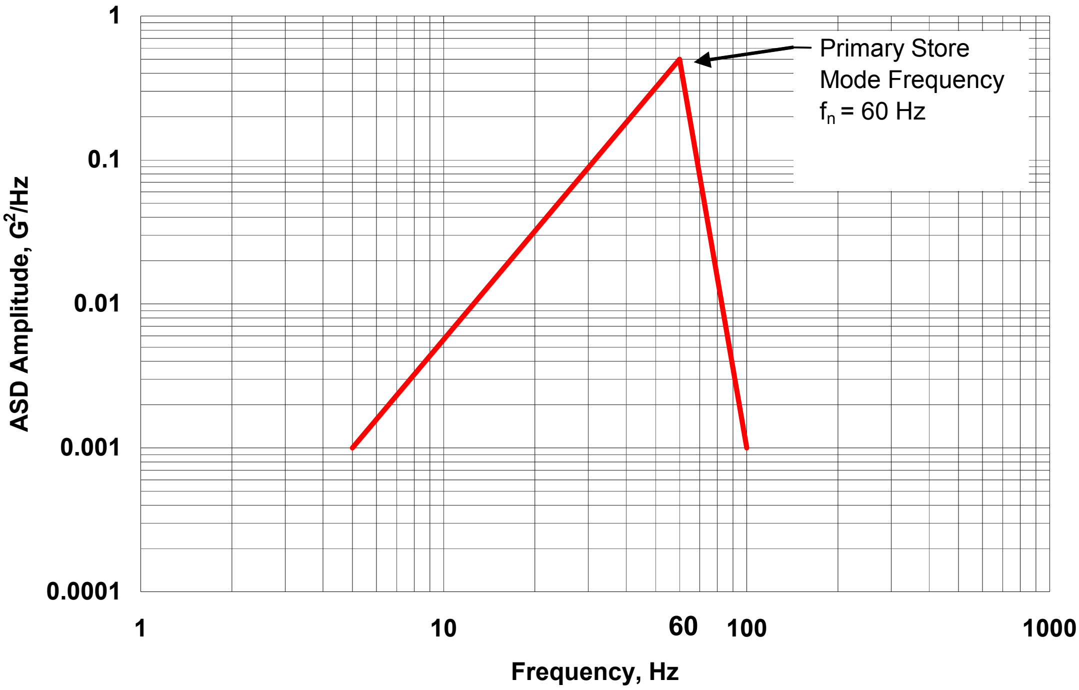
Control Notes :

1. When the test duration cannot be defined from the LCEP, the default duration for each axis is 6 seconds for each buffet vibration event or a maximum of 15 minutes total in each axis.
2. Cross coupling effects may be utilized to satisfy the transverse and/or longitudinal axis vibration requirements. When cross coupling is less than the longitudinal requirement, testing should be conducted in the longitudinal axis to in-flight levels or where this data is not available at half the amplitude used for the maximum experienced in the vertical or lateral axes.
3. Use the maximum control system roll-off rate at the 5 and 100 Hz breakpoints.
4. The test schedule is derived for a response control accelerometer(s) located at the store mounting location.

Schedule Description

The default severity of high aspect ratio stores carried under wing is shown in Figure A-3 and should be applied in each axis. This figure shows two peaks associated with the dominant wing mode and the store first bending mode. If the two modal natural frequencies are known, then they should be used to centre the peaks. If the two natural frequencies are closer than 10 Hz then a tailored approach must be followed. In the absence of the two modal frequencies then a wing mode of 30 Hz and store bending mode of 60 Hz should be used. The spectral minima between the two modes should be set to 45 Hz or half the frequency difference between the two modes if the frequencies are known.

FIGURE A-4 HIGH ASPECT RATIO FUSELAGE STORE



Random Spectrum Breakpoints	
Frequency, Hz	ASD, G^2/Hz
5	0.001
60	0.500
100	0.001
Random Grms = 3.35	

Figure A- 4 High Aspect Ratio Fuselage Store Test Description

Test Parameters :

Test Axes :	Vertical, Transverse, and Longitudinal
Test Duration :	Use the duration defined by the Life Cycle Environmental Profile
Equivalence Factor :	None
Vibration Spectrum :	Broadband random vibration
Control Strategy :	Single or multi-point response control

Control Notes :

1. When the test duration cannot be defined from the LCEP, the default duration for each axis is 6 seconds for each buffet vibration event or a maximum of 15 minutes total in each axis.
2. Cross coupling effects may be utilized to satisfy the transverse and/or longitudinal axis vibration requirements. When cross coupling is less than the longitudinal requirement, testing should be conducted in the longitudinal axis to in-flight levels or where this data is not available at half the amplitude used for the maximum experienced in the vertical or lateral axes.
3. Use the maximum control system roll-off rate at the 5 and 100 Hz breakpoints.
4. The test schedule is derived for a response control accelerometer(s) located at the store mounting location.

Schedule Description

The default severity of a low aspect ratio store carried under an aircraft fuselage is shown in Figure A-4 and should be applied in each axis. This figure shows a single peak associated with the store first bending mode. If the actual dominant bending mode frequency is known, the mode frequency should be used to centre the peak. If the first bending modal frequency is unknown then a default frequency of 60 Hz should be used.

ANNEX B - MEASURED BUFFET VIBRATION SPECTRUMS

Annex B contains several examples of measured store flight vibration data to illustrate the amplitude and spectral differences in store vibration during buffet conditions. The primary spectral peak in these plots is shown to be in the 10 to 100 Hz bandwidth region addressed by this test method. There are in some cases additional higher frequency resonance peaks; however the amplitude of these secondary peaks is typically a factor of at least 10 times lower in amplitude than the primary peak. If required, a full bandwidth simulation may be possible with combined mechanical and acoustical simulation equipment. The main objective for the buffet vibration test method is the simulation of the low frequency regions in which the buffet vibration amplification occurs.

The data also illustrates the possible problems in the use of the Annex A initial test severity as design criteria without actual in-service measurement data. The generic test spectrums may fail to simulate an additional vibration mode, such as wing torsion. The amplitude ratio between the store and wing modes also may not be representative of the in-service buffet conditions.

Figure B-1 and B-2 are vibration data for a low aspect ratio (AR ≈ 5) wing store. Figure B-1 shows vibration spectra from the instrumented store during straight and level flight (S&L) and also when undertaking a wind-up-turn (WUT). Both data sets are for a 420 psf dynamic pressure flight manoeuvre. In this case the store response in the vertical axis at the store centre of gravity can be seen to increase by more than three orders of magnitude at low frequency. In this case, the store is being driven by vibration of the aircraft's wing in buffet; the response near 25 Hz is due to a wing torsion mode. Further data from this particular airframe and store combination indicate that the vibration response of the store is also related to the aircraft angle attack and flight dynamic pressure as shown in Figure B-2.

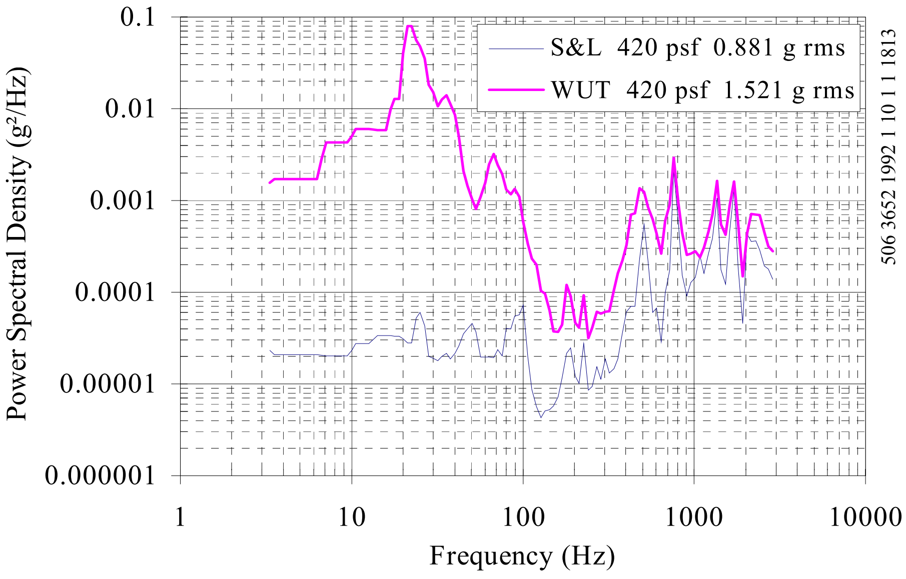
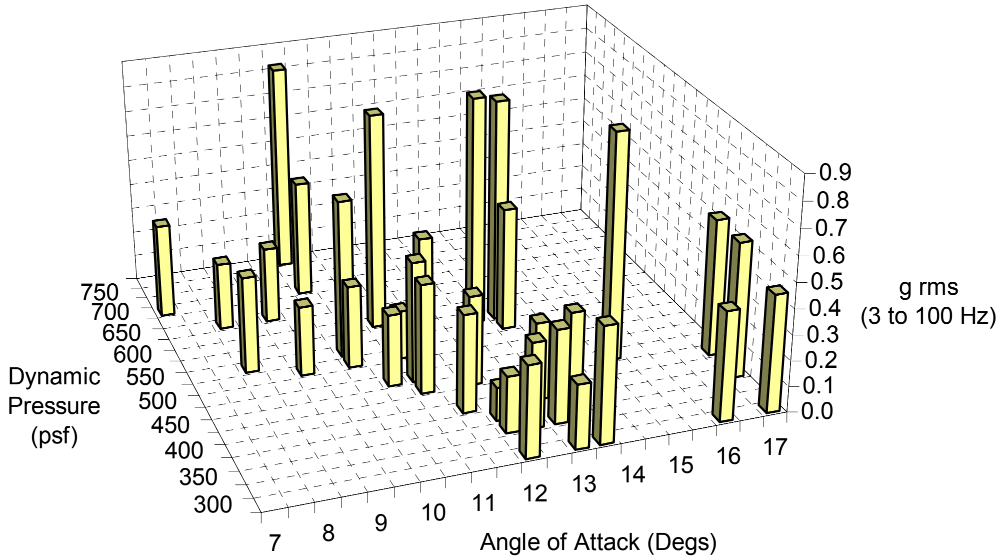


Figure B-1 Low Aspect Ratio (AR ≈ 5) Wing Store, Straight-Level Flight and Buffet



Notes

1. Aspect Ratio approximately 5, stiff store.
2. Data acquired over the 3 to 100 Hz frequency range where store buffet was known to occur.
3. Data acquired under stationary buffet conditions.

Figure B-2 Store Vibration as a Function of Angle of Attack and Flight Dynamic Pressure

Figure B-3 is vibration data for a high aspect ratio wing store. Vibration responses from straight and level flight (S&L) and buffet conditions are shown in Figure B-3. The store fundamental bending modes in the vertical and lateral axes are near 60 Hz, and these modes dominate the ASD for buffet conditions. Specifically, the figure shows data from the store nose, where it can be seen that the difference in amplitude at 60 Hz is about 20. Aircraft wing modes are not as prevalent in this data as in Figure B-1. The lack of wing modes could be due to the limited range of flight conditions included in these flights, and/or the significant differences in the two aircraft's wing construction and dynamic behaviour. The vibration peak centred near 8 Hz is believed to be a wing bending and/or store pitching motion.

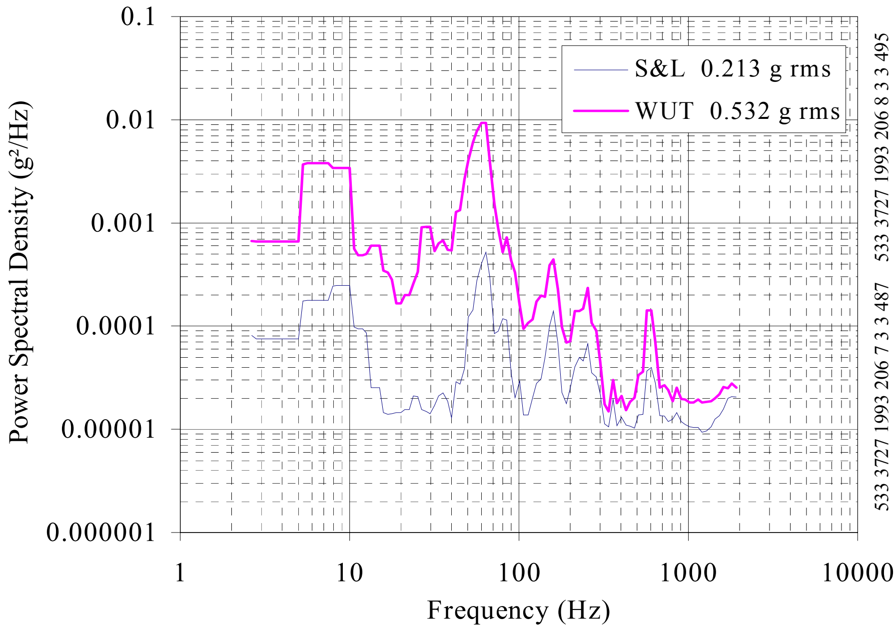


Figure B-3 High Aspect Ratio Wing Store, Straight-Level Flight and Buffet

Figure B-4 is flight vibration data for a high aspect ratio (AR ≈ 17) wing store. Store vibration data from straight and level flight (S&L) and a wind-up-turn (WUT) are presented in the figure. The main spectrum difference is the store response amplification at the store first bending mode, 50 Hz, which is approximately 60 times higher than straight and level flight; 0.3 G^2/Hz in buffet compared to 0.005 G^2/Hz during level flight.

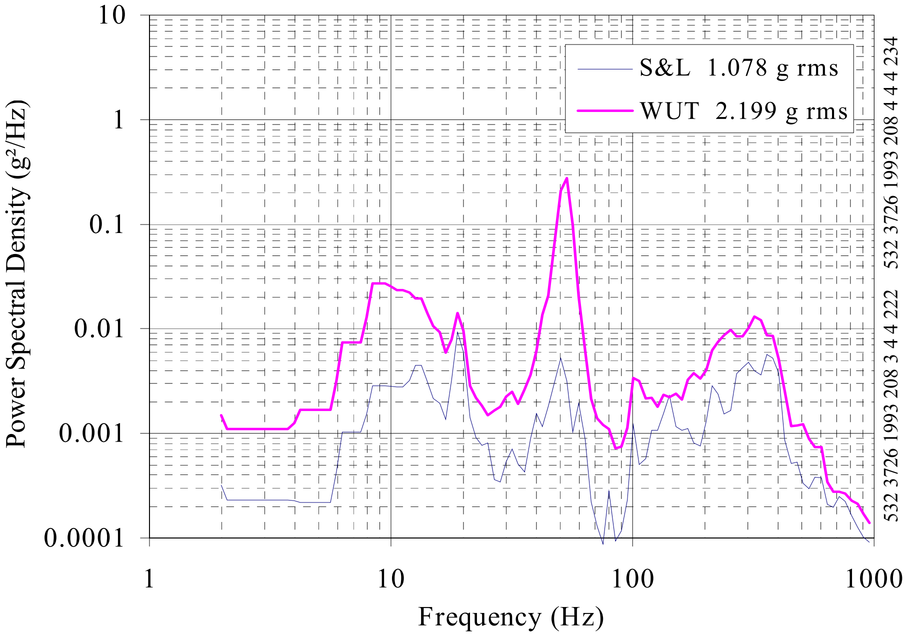


Figure B-4 High Aspect Ratio (AR ≈ 17) Wing Store, Straight-Level Flight and Buffet

Figure B-5 and B-6 are vibration data for a high aspect ratio (AR ≈ 18) store during straight and level flight (S&L), a wind-up-turn (WUT), and carried under-wing and under-fuselage. When carried under the aircraft wing, the Figure B-5 store vibration data indicate that the dominant response in buffet is at the store fundamental bending mode of approximately 33 Hz. No major wing or pylon modes appear to be excited by either of the two manoeuvres. As expected, the buffet vibration responses of the store carried on a fuselage station in Figure B-6 are much lower than when the store is mounted under-wing.

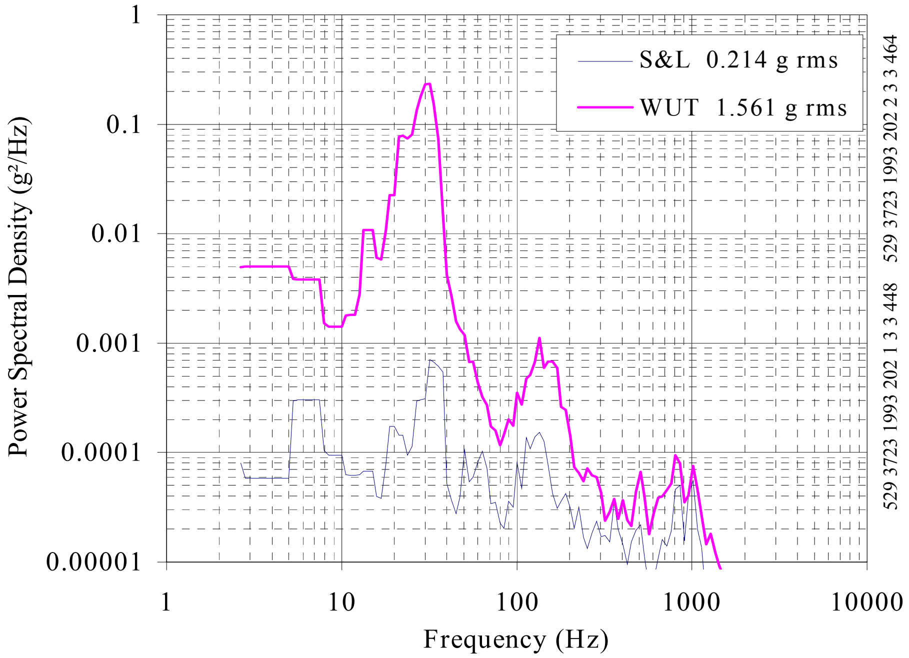


Figure B-5 High Aspect Ratio (AR ≈ 18) Wing Store, Straight-Level Flight and Buffet

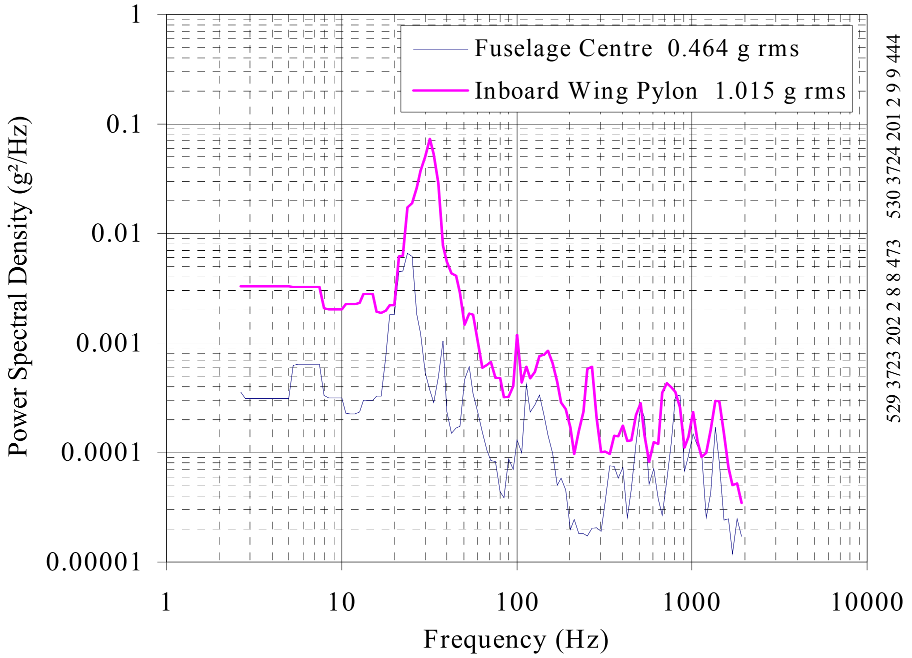


Figure B-6 High Aspect Ratio (AR ≈ 18) Wing and Fuselage Store During Buffet

METHOD 421

MULTI - EXCITER VIBRATION AND SHOCK TESTING

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METHOD 421

MULTI - EXCITER VIBRATION AND SHOCK TESTING

1. SCOPE

1.1 Purpose

The purpose of this test method is to replicate the vibration and shock environments incurred by systems, subsystems and units, hereafter called materiel, during the specified operational conditions.

1.2 Application

This test method is applicable where materiel is required to demonstrate its adequacy to resist the specified dynamic environment without unacceptable degradation, of its functional and/or structural performance. AECTP 100 and 200 provide additional guidance on the selection of a test procedure for a specific vibration environment. The test method is applicable to either electrodynamic or servohydraulic test equipment.

Frequently a test item's weight, physical dimensions, complex dynamic response, or specific in-service environment require the use of multi-exciter methods for laboratory simulation of a dynamic environment. A common multi-exciter application is testing of long slender materiel with a high length to diameter ratio, such as a missile system.

Multi-exciter test methods permit a balance of energy distribution on the materiel structure, and typically a higher thrust capability than single exciter systems. When a large force capacity is required, equipment is operated in multi-exciter single axis (MESA) mode for vibration and shock testing. Two or more exciters may also be coupled in phase, or inverted phase, to a horizontal slip table for testing.

Tests requirements for simultaneous control of multiple vibration spectrums or multi degree of freedom (DOF) motion are also applicable to multi-exciter testing. The test control is based on multiple exciter drive and response data channels, commonly referred to as multiple input and multiple output (MIMO) control. The most general case is multi-exciter multi-axis (MEMA) control for complete or partial 6 DOF translation and rotation motion control. The control methodology can be either a single frequency spectrum amplitude and phase control or multiple ASD spectrum control. A summary of the most common test equipment configurations is defined below. The configurations are also applicable to multi-axis shock testing, and with some additional considerations, waveform replication testing.

a. Two exciters in phase, or 180 degree inverted phase; a simple MESA configuration

b. Multiple exciters and single axis motion (MESA) with a single vibration spectrum.

c. Multiple exciters with one or multiple vibration spectrums (MIMO).

d. Multiple exciters and multi-axis motion (MEMA).

1.3 Limitations

Fixturing design limitations or physical constraints may prevent the satisfactory application of the in-service dynamic excitation to the test item.

Test data acquired for typical single axis laboratory dynamic simulations may not be applicable to multi-exciter tests if proper phase and correlation between the data channels is not obtained during the data acquisition process. Similarly, laboratory simulation tests may not fully duplicate in-service failure modes if the test is based on insufficient data acquisition and test documentation methods.

2. TEST GUIDANCE

When using multi-exciter test systems, the information presented in AECTP methods 401, 403, and 417 should also be used as general guidance for the test setup, procedures, and test severity.

2.1 Effects of the Environment

The following list is not intended to be all inclusive, but provides examples of problems that could occur when materiel is exposed to a multi-axis dynamic environment. These environmental effects can also occur in single axis environments, but damage may be unique to the multi-axis environment, such as a rotational induced failure.

a Optical misalignment,

b Fatigue, cracking, rupture,

c Deformation, specially of protruding parts,

d Loosening of connections and seals,

e Displacement of components,

f Chafing of surfaces,

g Contact, short circuiting, or degradation of electrical components.

2.2 Choice of Test Procedure

Multi-exciter testing applies to many applications and different equipment configurations. The basic options for test procedures are summarized below. The list of procedures is not intended to cover all equipment or testing configurations, but provides information on the most common test procedures. A general description of considerations for all three types of procedures is in paragraph 5.

2.2.1 Procedure I – Multi-exciter – Single axis (MESA)

2.2.2 Procedure II – Multi-exciter – Multi-output (MIMO)

2.2.3 Procedure III – Multi-exciter – Multi-axis (MEMA)

2.3 Use of Measured Data

Where practical, in-service field data should be used to develop test levels. It is particularly important to use field data for multi-exciter tests because of the requirements for phase correlation. Sufficient field data should be obtained to adequately describe the conditions and perform a laboratory simulation.

2.3.1 Measured Data Available

When conducting a vibration or shock test using multiple exciters the normal test parameters as well as those specific to this form of testing will be required. A fundamental understanding of the specific parameters applicable to multi-exciter testing is essential. Some important dynamic parameters include:

- Frequency bandwidth
- Sampling rate
- Random error

- PSD (shape & frequency content)
- Cross coupling and error minimization
- Partial Coherence
- Phase

Important static parameters include:

- Temperature
- Ambient and induced pressure
- Humidity

Other important issues include:

- Fixture design
- Impedance mismatches
- Modal data
- Rigid body modes
- Discrepancies between operational and laboratory test data

Precursor testing is essential when considering the use of multiple exciters. During this test program stage it will be necessary to iterate to an acceptable control solution in order to optimise the control spectra within the prescribed limits. This will require a fundamental understanding of the materiel and fixture structural response, which can be obtained from a modal analysis. It is considered essential to perform on-line modal analysis in the test setup because it allows evaluation of the non-linear effects caused by the specified vibration and shock operational levels. Thus, an accurate assessment of the materiel or fixture dynamic behaviour can be made.

Normal Mode Analysis employs sine sweeps, resonance dwell, linearity checks and use of the Modal Indicator Function (MIF). From this information, dynamic mass and stiffness can be evaluated allowing assessment of the materiel and fixture design. It is also important to decouple close modes to improve fixture design.

2.3.2 Measured Data Not Available

If adequate measurement of the in-service dynamic environment is not possible, a pseudo spectral domain multi-exciter test can possibly be developed from a combination of generic test severity data, modal analysis, and experimental laboratory tests of the materiel installed in the test fixture. Laboratory testing will need to be used to estimate the phase, and correlation relationships between the materiel response channels. Modal tests should verify similar dynamic response between the in-service platform installed materiel and the fixture installed materiel. For multi-axis time waveform replication control the need for actual measured in-service data is a requirement. Without measured data the correlation between the field measurements and laboratory control is not possible.

2.4 Sequence

The effects of vibration may affect performance when materiel is tested under other environmental conditions, such as temperature, humidity, pressure, electromagnetic, etc.

Also, it should be noted that it is essential that materiel, which is likely to be sensitive to a combination of environments, is tested to the relevant combinations simultaneously.

Where it is considered that a combined test is not essential or is impractical to configure, and where it is required to evaluate the effects of vibration together with other environments, a single test item should be exposed to all relevant environmental conditions in turn.

The order of application of tests should be considered and made compatible with the Life Cycle Environmental Profile. If any doubts remain as to the order of testing, then any vibration testing should be undertaken last.

2.5 Materiel Operation

Unless specified in the Test Instruction, the materiel is not operated during this test.

3. SEVERITIES

The test levels should be defined from the Test Instruction requirements and based on measured in-service data. The test time will be established from the Test Instruction or based on the in-service LCEP information. Specific multi-axis test severities are currently not defined in this test method due to the dependence of the test on the measured environment. The initial test severity defined in other AECTP 400 test methods can be used as a preliminary test level. However, the use of single axis test specifications lack the phase and correlation information required for accurate multi-axis testing.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

a. The identification of the test item,

b. The definition of the test item,

c. The type of test : development, qualification, reliability,

d. The orientation of the test item in relation to the test axes,

e. If operating checks are to be performed and when,

f. For initial and final checks, specify whether they are to be performed with the test item installed in the test facility,

g. Other relevant data required to perform the test and operating checks,

h. The vibration control strategy,

i. The monitor and control points, or a procedure to select these points,

j. The temperature pre-conditioning time,

k. The use of isolator mounts or otherwise,

l. The definition of the test severity (test level and duration),

m. The indication of the failure criteria,

n. In the case of large test items and complex fixtures, a method of accounting for tolerance excess,

o. Environmental conditions at which testing is to be carried out if other than standard laboratory conditions.

4.2 If Required

a. The specific features of the test assembly (exciter, fixture, interface connections, etc.),

b. The effect of gravity and the consequent precautions,

c. The value of the tolerable spurious magnetic field,

d. Test tolerances, if different from paragraph 5.1.

5. TEST CONDITIONS AND PROCEDURES

5.1 Test Facility

The multi-exciter system primarily consists of three elements: the exciter, fixtures, and a control system. The exciters operate together in the same plane, or independently, as required and provide adequate thrust to permit testing with the full test item mass and acceleration level. As a minimum, the range of vibration and shock tests currently specified in STANAG 4370, AECTP 400 must be met. Additional small lower thrust exciters can be used in conjunction with the primary exciters to allow localised vibration and shock inputs to the material.

An important consideration in the use of multi-exciter systems is the use of one master gain control for each exciter. This limits divergence in the control loop, resulting in improved control within the defined limits. A further requirement is minimizing the control loop update time constant. The longer the record length (i.e. slower the update time), the more statistically accurate the control capability.

Statistical accuracy in terms of the number of degrees of freedom used in the calculations is essential. The number of DOF is dependent upon the pre-test levels used to attain full power (0 dB, -3 dB, -6 db etc.). With each level approaching full level the number of degrees of freedom increase. The number of DOF should be characterised at the 99% confidence level to achieve a result within 5% of the defined value, or 95% at the –3 dB level. With real time closed loop control the statistical accuracy will continue to be updated as the test progresses.

5.1.1 Test Fixture

Consideration of fixture design is essential at the earliest stage of defining the multi-exciter test requirement. It is essential that the fixture match as closely as possible the in-service structural support to replicate the materiel operational dynamic loading and structural dynamic response characteristics.

Fixtures come in various shapes and sizes depending upon the materiel and test under consideration. Fixtures can be considered with fixed and flexible attachments, namely:

a. Direct attachment with yokes or attached directly into the structure.
b. Direct attachment with flexible drive rods and hinges / knife edges.
c. Direct attachment with pivots, ball joints etc. depending upon the number of degrees of freedom to be constrained.
d. Slip tables employing elements of the above.

To assist in fixture and control strategy assessment the different dynamic responses of following materiel should be considered. The appropriate vibration test fixture, test spectra, and control strategy depend upon the dynamic complexity and size of the materiel under test.

a. Dynamically flexible symmetric structures with varying L / D ratios, such as air to air missile and torpedoes..

b. Dynamically stiff structures with flexible extremities, such as laser guided bombs.
c. Dynamically & geometrically complex asymmetric structures, such as cruise missiles.
d. Large stiff materiel where sufficient thrust is an issue, such as iron bombs
e. Above materiel categories in shipping or storage containers.

Consideration must be given to the primary support arrangement for the materiel under test. In principle the fixture design should allow adequate support for the materiel, while minimising the cross coupling effects and exciter off axis effects. It is essential that unwanted cross-axis motions be minimised. Rigid body modes are of particular concern in fixture design, but with the application of improved control algorithms this problem can be minimised. Also it is necessary to consider effects such as differential displacements across the materiel and how this affects the exciter. The control system may not, in all cases, be able to accommodate poor fixture design.

5.2 Test Controls

Real time, or active, closed loop control will generally be used. This control approach modifies the drive signal during the test to improve test accuracy on a continual basis. Generally the vibration and shock testing controller will allow a range of applications from single exciter to multi-exciter testing. The multi-exciter system will allow control of independent exciters in a single plane and control additional exciters in multiple axes applying different spectra. The control hardware must be capable of simultaneous parallel control and analysis and should incorporate a fully integrated modal analysis capability. Further essential multi-exciter control requirements can be broadly considered under the following headings:

a. Pre characterisation testing, where adaptive characterisation techniques help to deal with non-linear effects.

b. Definition and suppression of unwanted cross coupling motions; these include cross coupling compensation methods, either physical or within the control algorithms.

c. Phase, Coherence, Cross Spectral Density (CSD) and other relevant control parameter definitions derived from either the test setup and materiel under test or from operational data.

d. Shock and waveform replication capability where the test is accomplished using replication of the time history including closed loop control with cross coupling compensation, phase and coherence control.

5.2.1 Control Strategy

The vibration test spectra and control strategy will depend upon the vibration test data available, in conjunction with the vibration test objectives. Where practical tailored test spectra will be used. Where tailored vibration and shock test data are not available standard test data defined in the relevant standards STANAG 4370, AECTP 400 will be used. Also it may simply be a requirement that the vibration test is undertaken using a single spectrum control strategy to balance the energy between the front and rear of the materiel or provide adequate thrust to meet the materiel weight limitations. Where operational data is available in the form of independent ASDs, Partial Coherence, Phase, CSDs etc. it will be possible to adopt a fully specified multi-exciter control strategy. Under some circumstances it may be necessary to apply limit control in orthogonal axes to protect the exciter. Limit control could also require use of a spectral envelope. Examples of typical test and control strategies include:

a. Single Spectrum – Specified from operational data or specification.

b. Multiple ASDs – Specified from operational data or relevant specification.

c. Multiple ASDs and Partial Coherence – Specified from in-service or lab test setup data.

d. Multiple ASDs and Phase – Specified from operation or lab test setup data.

e. Multiple ASDs, Partial Coherence and Phase - Specified from operation or lab test setup data.

f. Multiple ASDs, Partial Coherence, Phase and intermediate position ASD – Specification from operation or lab test setup data.

g. Multiple ASDs, CSDs and other relevant parameters – Specified from operation or lab test setup data.

h. Time History Replication – Specification from in-service test data.

i. It is also necessary to consider shock inputs either in the form of classical shock pulses, SRS and time waveforms.

j. Control limits both in terms of level and envelope based on in-service data.

5.2.2 Control Functions

The choice of test procedure is governed by many factors including the in-service vibration environment and materiel type. These and other factors are addressed in AECTP 100, AECTP 200, and AECTP 400. Multi-exciter test and control strategies include:

a. Random - Multi-exciter, single axis, single control spectrum. Multi-exciter, multi-axis, and multiple control spectra.

b. Swept Sine - Identical sine and level. Multiple sine components and phase, levels and phase in variable directions.

c. Mixed Mode - Sine or narrow band random on random, and sine on random - Multi-exciter, single axis, single control spectrum. Multi-exciter, multi axis, multiple control spectra.

d. Classical Shock - Different input shocks at each exciter.

e. SRS Shock Synthesis – Tailored using wavelets, damped sinusoids or both. Different input shocks on each exciter.

f. Time Waveform Replication - Replication of time history.

g. Transient Capture – Multiple shock domain.

Control of a multi-exciter system is generally achieved by specifying either ASDs or ASDs and phase, partial coherence and CSDs in the form of a control matrix. This matrix is populated on the leading diagonal by the ASDs at the drive points and the off diagonal by the cross-spectral components. The control system uses either pre-stored cross-spectral data, should it be available from operational test, or cross-spectral data derived from the laboratory test setup.

5.2.3 Control Locations

Multi-exciter vibration or shock test control will generally be achieved either at the attachment yokes or some other structural position(s) where important components are located, where in-service test data is available, at the extremities where limits need to be applied, or at structural hard points. Spectral shape and limit control at intermediate positions will generally be required. The control strategy will be dictated by the information available at the time of the test specification to meet the test objectives. However, the preferred strategy will be dictated by the in-service vibration data available or to be collected in support of the test programme. The test and control strategies, control points and the need for cross-coupling information will influence in-service data acquisition requirements.

5.2.4 Control Limits

Vibration control limits will be set in terms of spectral shape, amplitude, partial coherence, phase, or CSD. Vibration control can be achieved using standard spectral shape and amplitude control limits. Shock limits will be set in terms of classical pulses, SRS and time history replication. Static limits will be set in terms of temperature, pressure and humidity etc.

Standard control limit advice for random, narrow band random, sinusoidal vibration and shock is given in AECTP 401.

Orthogonal control limits may be a requirement in addition to those specified in-plane. Where partial coherence, phase and CSD are specified it will be necessary to determine the optimum control limits from experiment. This also applies to shock tests and the implementation of time waveform replication methods.

5.2.5 Cross Spectral Data

Specification of phase, partial coherence, and CSD have significant implications for in-service testing and analysis. Cross correlation coefficients must be derived from the laboratory structure under test if in-service data is not available. Differences between the cross coupling coefficients derived from in-service and lab test data result if the in-service data is not available. This makes a comparison of the two data sets a requirement of the test specification. When the differences are large, a detailed analysis by the test specification authority in conjunction with the test facility personnel will be required.

A suggested way forward is to compare the coherence, phase and CSD between the two structural configurations and then make a judgement whether or not to specify partial coherence and phase, or to define the terms to 1 and 0 respectively. Clearly this calls for in-service data and vibration precursor test data for the comparison. A further way forward would be to utilise the partial coherence, phase and CSD derived from the laboratory test configuration, which again emphasises the importance of precursor testing.

During the inversion of the cross coupling matrix there is generally some form of optimisation undertaken. If this capability is available to the test engineer it significantly enhances the ability to make judgements in specifying the important parameters and optimising the control strategy to be adopted.

5.3 Installation Conditions of Test Item

Test items can vary from materiel components to structural assemblies containing several different subassemblies. Consequently, the installation procedures need to take in account the following:

a. The test item attachment should simulate as close as possible actual in-service mounting attachments including vibration isolators, fasteners, torques, if appropriate.

b. All the connections, cables, pipes, etc., should be installed by a method that they impose stresses and strains on the test item similar to those encountered in-service.

c. Suspension of the test item using low frequency supports avoids complex test fixture resonances.

d. The direction of gravity or the load factor influence on mechanisms, vibration isolators, etc. must be taken into account by compensation or by suitable simulation.

5.3.1 Test Set-Up

Unless otherwise specified, testing should be accomplished with simultaneous excitation in as many axes or degrees of freedom as the measured data and test equipment permit. Field ASD data collected in only three orthogonal axes, without phase, typically limits triaxial laboratory simulation capability and rotational motion control. The test item should be mounted directly to the exciters using in-service mounting hardware and a suitable fixture. The mounting fixture should have sufficient stiffness such that the fixture's natural frequencies are as high as possible and do not interfere with test item response in the test control bandwidth. The fixture should apply the excitation to the test item so as to simulate as accurately as possible the vibration transmitted in-service.

Alternatively for large complex materiel, the test item may be suspended from a structural frame. In this case, the test setup shall be such that the suspension rigid body translation and rotation modes are lower than the lowest test frequencies. Vibration shall be applied by means of a rod or suitable mounting device running from the exciters to a hard, structurally supported point(s) on the surface of the test item as determined during precursor testing.

Control instrumentation should be mounted as determined by precursor testing and as specified in the Test Instruction, or its location and mounting determined according to a procedure included in the Test Instruction.

Testing must as closely as possible replicate the postulated failure modes in terms of test specification and mounting. Materiel intended for use with vibration isolation systems should normally be tested with isolators in position. If it is not practical to conduct the vibration test with the appropriate isolators, or if the dynamic characteristics of the materiel installation are extremely variable, for example temperature dependent, then the test item should be tested without isolators at a modified severity specified in the Test Instruction. In the case where a continuous vibration test can cause unrealistic heating of the test item and/or isolators, the excitation should be interrupted by periods of rest, consistent with the in-service environment, which should be specified in the Test Instruction.

When identified in the test plan, subsystems of the materiel may be tested separately. The subsystems can be subjected to different vibration levels. In this case, the Test Instruction should define the test levels appropriate for each subsystem.

5.4 Platform Specific Considerations

The following instructions are also applicable. Further guidance on the transport environment considerations is given in AECTP 200.

a. Materiel transported as secured cargo:

Mount the test item securely in its transport configuration on the vibration fixture or table using restraints and tie-downs typical of those to be used during actual transport. Testing should be conducted using representative stacking configurations. The excitation should be applied through all representative axes. Materiel is not normally operated in this mode.

b. Materiel carried externally on aircraft:

Where practical, testing should be accomplished with the mounting lugs in the normal carriage position. Suspend the materiel from a structural frame by means of its normal mounting lugs, hooks and sway braces which simulate the operational mounting apparatus.

Alternatively, the materiel may be mounted directly to the exciter via suitable fixtures.

For both methods, where applicable, launcher rails should where possible be used as part of the test setup.

Instrumentation to monitor the vibratory response of the materiel should be mounted as appropriate to meet the test objectives and to limit unrepresentative damage.

c. Materiel installed in ships.

Where possible materiel should be mounted in its normal configuration with normal shock or vibration isolation mounts used throughout the test.

5.5 Test Tolerances

The test conditions specified in AECTP 401 paragraph 5.1 shall apply to vibration testing. The test conditions specified in AECTP 403 paragraph 5, where applicable, shall apply to classical shock testing. The conditions specified in AECTP 417 paragraph 5, where applicable shall apply to SRS shock testing.

5.6 Pre-conditioning

Unless otherwise specified, the test item should be stabilized to its initial conditions defined in the Test Instruction.

5.7 Test Procedure

The following test sequence using a multi-exciter system is a general guide. The procedure requires additional modification for the specific test program, control methodology and as more information on the test becomes available.

Step 1 Define the Control Strategy.

Step 2 Define the Type of Test and Test Specification.

a. Specify multi-exciter testing with or without cross coupling

b. For each input define ASD breakpoints, narrowband random and sine; If shock testing is a requirement, define the classical chock pulse, SRS or the time history.

c. Define start and end frequencies.

d. Define the resolution to meet bias error criteria.

e. For classical shock, specify the amplitude of the pulse in dB relative to the reference profile, number of pulses to be input, polarity of shock pulse and time between pulses. For SRS shock use shock response synthesis.

f. Define partial coherence and phase from operational data if this information is available Otherwise allow these parameters to float, coherence = 1 and phase = 0 and/or preferably define CSDs.

g. Set control limits, alarms and aborts such as control on range, RMS, rate of change etc.

h. Set abort limits ±3dB up to 500 Hz, ±6dB above 500 Hz

Step 3 Define Control Points

a. The yokes.

b. The attachment point(s)

c. Define other important structural positions to be monitored or used for control purposes.

d. Specify spectral shape and limit control at intermediate positions

Step 4 Pre-Test Checkout
Run a precursor test to determine transfer functions and cross coupling terms. Pre-test may include a modal analysis. This will also identify any undue cross axis excitation affecting the exciter.

Step 5 Update Test Control Parameters
Re-specify partial coherence and/or phase or CSD etc. Use values from precursor tests or allow each to float.

Step 6 Conduct Loop Check.
Assess both the loop integrity and transfer functions. This is achieved using increasing, constant level, or burst random excitation. For multi-exciter operation the burst random can be replaced by a user defined profile. This allows the system to output different levels to each exciter and if necessary profile levels across the frequency bandwidth.

a. Loop integrity – each channel is checked for signal to noise ratio and feedback integrity using output signals with the system automatically increasing the level. This accounts for non-linear effects.

b. Transfer Functions – This mode measures the system transfer function matrix between the drive signals and all the response channels. When the test is started the control algorithm uses the transfer function information to ensure that the first transition is as near pre-equalisation as possible.

- Determine noise limits and check loop parameters
- Calculate the impedance matrix at low level
- Compute the equalisation of the two input spectra, i.e. up to –3dB
- Determine statistical parameters
- Compare test spectra with specification

Step 7 Full Test Level

Bring the system up to full level by increments and undertake the full level vibration or shock test. The test progresses with multiple stages. Each stage represents either a level, bringing the test to full level smoothly, or different test strategies in a mission profile. Each stage should be defined with different conditions for the following parameters.

a. Duration : Each stage to be set for a maximum or minimum duration time.
b. Level : Set in + dB up or – dB down with respect to the full test level reference.
c. Correction Strategy : Each stage can be defined to use a different correction strategy and control averaging strategy.
d. Saved and Measured Data : Each stage can be defined as active for measurement acquisition storage, or inactive.
e. Dwell : Test may include dwell periods for hold and evaluate during the test sequence.

Control Strategies – The control system measures the control error using a mixture of linear and exponential averages to form the basis of making a transfer function measurement between the Desired Response Profile (DRP) and the Actual Response Profile (ARP). Once the error is known it can be corrected.

Multi Coherence Function (MCF) - The MCF is calculated and a minimum value is assigned to this function for each drive signal. If the MCF is less than the assigned value, there is no correction. This avoids unwanted correction and divergence problems due to abnormal behaviour in the response.

Control Channels - One control channel per exciter is used for multi-exciter control. The other channels are used for analysis. Measurement data can be taken at time intervals during the test, at the completion of the test, or at the end of each stage.

Step 8 Post Processing

During the test, data is saved according to the automatic schedule defined and any manual requirements. The following basic signal processing capabilities should be available in the control software.

a. Transfer Functions
b. ASDs
c. Autospectra
d. Partial Coherence
e. Cross Spectra
f. Phase

It may be necessary to employ a post processing toolbox for additional data analysis. Also, during the precursor and live test programme modal analysis can be performed online to provide information relating non-linearity and the materiel dynamic response behaviour.

6. EVALUATION OF TEST RESULTS

The test item performances shall meet all appropriate specification requirements during and following the application of the multi-exciter test requirements.

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METHOD 422

BALLISTIC SHOCK

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METHOD 422

BALLISTIC SHOCK

1. SCOPE

1.1 Purpose

This method includes a set of ballistic shock tests generally involving momentum exchange between two or more bodies or momentum exchange between a liquid or gas and a solid. The test is performed to:

a. Provide a degree of confidence that materiel can structurally and functionally withstand the infrequent shock effects caused by high levels of momentum exchange on a structural configuration to which the materiel is mounted.

b. Experimentally estimate the materiel's fragility level relative to ballistic shock in order that shock mitigation procedures may be employed to protect the materiel's structural and functional integrity.

1.2 Application

The Ballistic shock test method simulates a high-level transient shock that generally results from the impact of projectiles or ordnance on armoured combat vehicles, hardened targets, or other structures. The transient event can be considered as a specific application of transient or pyrotechnic shock. The physical phenomenon is characterized by the overall material and mechanical response at a structure point from elastic or inelastic impact. Such impact may produce a very high rate of momentum exchange at a point, over a small finite area or over a large area. The high rate of momentum exchange may be caused by collision of two elastic bodies or a pressure wave applied over a surface.

1.2.1 Ballistic Shock Definition

Ballistic shock is a high-level transient shock that generally results from the impact of projectiles or ordnance on armoured combat vehicles. Armoured combat vehicles must survive the shocks resulting from large calibre non-perforating projectile impacts, mine blasts, and overhead artillery attacks, while still retaining their combat mission capabilities. Reference d discusses the relationship between various shock environments (ballistic shock, transportation shock, rail impact shock, etc.) for armoured combat vehicles. Actual shock levels vary with the type of vehicle, the specific munition used, the impact location or proximity, and where on the vehicle the shock is measured. There is no intent in this test method to define the actual shock environment for specific vehicles. Furthermore, it should be noted that the ballistic shock technology is still limited in its ability to define and quantify the actual shock phenomenon. Even though considerable progress has been made in the development of measurement techniques, current instrumentation, such as the shock sensing gages, are bulky and cumbersome to use. The development of analytical (computational) methods to determine shock levels, shock propagation, and mitigation is lagging the measurement technology. The analytical methods under development and in use to date have not evolved to the level where analytical results can be relied upon to the degree that the need for testing is eliminated. That is, the prediction of ballistic shock response is, in general, not possible except in the simplest configurations. When an armoured vehicle is subjected to a non-perforating large calibre munition impact or blast, the structure locally experiences a force loading of very high intensity and of relatively short duration. The force loading is localized, however the entire vehicle is subjected to stress waves travelling over the surface and through the structure. In certain cases, pyrotechnic shocks have been used in ballistic shock simulations. There are several caveats in such testing. The characteristics of ballistic shock are outlined in the following paragraphs.

1.2.2 Ballistic Shock Momentum Exchange

Ballistic shock usually exhibits momentum exchange between two bodies or between a fluid and a solid. It commonly results in velocity change in the support materiel. Ballistic shock has a portion of its characterization below 100 Hz, and the magnitude of the ballistic shock response at a given point reasonably far from the ballistic shock source is a function of the size of the momentum exchange. Ballistic shock will contain material wave propagation characteristics (perhaps substantially nonlinear) but, in general the material is deformed and accompanied by structural damping other than damping natural to the material. For ballistic shock, structural connections do not necessarily display great attenuation since low frequency structural response is generally easily transmitted over joints. In processing ballistic shock data, it is important to be able to detect anomalies. With regard to measurement technology, accelerometers, strain gages, and shock sensing gages are applicable measurement transducers; see reference a. In laboratory situations, laser velocimeters are useful. Ballistic shock resistance is not, in general, “designed” into the materiel. The occurrence of a ballistic shock and its general nature can only be determined empirically from past experience based on well-defined scenarios. Ballistic shock response of materiel in the field is, in general, very unpredictable and not repeatable among materiel.

1.2.3 Ballistic Shock Physical Phenomenon

Ballistic shock is a physical phenomenon characterized by the overall material and mechanical response at a structure point from elastic or inelastic impact. Such impact may produce a very high rate of momentum exchange at a point, over a small finite area or over a large area. The high rate of momentum exchange may be caused by collision of two elastic bodies or a pressure wave applied over a surface. General characteristics of ballistic shock environments are as follows:

a. Near-the-source stress waves in the structure caused by high material strain rates (nonlinear material region) that propagate into the near field and beyond;

b. Combined low and high frequency (10 Hz to 1,000,000 Hz) and very broadband frequency input;

c. High acceleration (300 G to 1,000,000 G) with comparatively high structural velocity and displacement response;

d. Short-time duration, less than 180 milliseconds;

e. High residual structure displacement, velocity, and acceleration response (after the event);

f. Caused by (1) an inelastic collision of two elastic bodies, or (2) an extremely high fluid pressure applied for a short period of time to an elastic body surface coupled directly into the structure, and with point source input. The input is either highly localized as in the case of collision or area source input, or widely dispersed as in the case of a pressure wave;

g. Comparatively high structural driving point impedance (P/v, where P is the collision force or pressure, and v the structural velocity). At the source, the impedance could be substantially less if the material particle velocity is high;

h. Measurement response time histories that are very highly random in nature. The response has little repeatability and very dependent on the configuration details;

i. Shock response at points on the structure is somewhat affected by structural discontinuities;

j. Structural response may be accompanied by heat generated by the inelastic impact or the fluid blast wave;

k. The nature of the structural response to ballistic shock does not suggest that the materiel or its components may be easily classified as being in the “near field” or “far field” of the ballistic shock device. In general, materiel close to the source experiences high accelerations at high frequencies, whereas materiel far from the source will, in general, experience high acceleration at low frequencies as a result of the filtering of the intervening structural configuration.

1.3 Limitations

Because of the highly specialized nature of ballistic shock and the substantial sensitivity of ballistic shock to the configuration, apply the test method only after giving careful consideration to information contained in references c and d.

a. This method does not include provisions for performing ballistic shock tests at high or low temperatures. Perform tests at room ambient temperature unless otherwise specified or if there is reason to believe either operational high temperature or low temperature may enhance the ballistic shock environment.

b. This method does not address blast, EMI, and thermal secondary effects

2. TEST GUIDANCE

After examining requirements documents and applying the test tailoring process to determine where ballistic shock effects occur in the life cycle of the materiel, use the following to confirm the need for this test method and to place it in sequence with other methods.

2.1 Effects of the Environment

In general, ballistic shock has the potential for producing adverse effects on all electronic, mechanical, and electro-mechanical materiel. In general, the level of adverse effects increases with the level and duration of the ballistic shock and decreases with the distance from the source (point or points of impact) of the ballistic shock. Durations for ballistic shock that produce material stress waves with wavelengths that correspond with the natural frequency wavelengths of micro-electronic components within the materiel will enhance adverse effects. Durations for ballistic shock that produce structure response movement that correspond with the low frequency resonances of mechanical and electro-mechanical materiel will enhance the adverse effects. The following list is not intended to be all inclusive but provides examples of problems that could occur when materiel is exposed to the ballistic shock environment.

a. Materiel failure as a result of destruction of the structural integrity of micro-electronic chips including their mounting configuration;

b. Materiel failure as a result of relay chatter;

c. Materiel failure as a result of circuit card malfunction, circuit card damage, and electronic connector failure. On occasion, circuit card contaminants having the potential to cause short circuits may be dislodged under ballistic shock. Circuit card mounts may be subject to damage from substantial velocity changes and large displacements;

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

e. Materiel failure as a result of sudden velocity change of the structural support of the materiel or the internal structural configuration of the mechanical or electro-mechanical materiel.

2.2 Choice of Test Procedure

This test method includes five ballistic shock test procedures. Table 1 provides a summary of the typical parameters for each test procedure. Annex A provides a default SRS test level and associated acceleration amplitudes for Procedures II through IV if measured field ballistic shock data is not available. Based on the test instruction requirements, determine which test procedure is applicable. In most cases, the selection of the procedure will be dictated by the actual materiel configuration; carefully consider any gross structural discontinuities that may serve to mitigate the effects of the ballistic shock on the materiel. In some cases, the selection of the procedure will be driven by test practicality. Consider all ballistic shock environments anticipated for the materiel during its life cycle, both in its logistic and operational modes. When selecting test procedures, consider the following :

a. The operational purpose of the materiel. From the requirements documents, determine the functions to be performed by the materiel either during or after exposure to the ballistic shock environment.

b. The natural exposure circumstances for ballistic shock. The natural exposure circumstances for ballistic shock are based on well-selected scenarios from past experience and the chances of the occurrence of such scenarios. For example, if an armoured vehicle is subject to a mine blast, a number of assumptions must be made in order to select an appropriate test for the ballistic shock procedure. In particular, the size of the mine, the location of major pressure wave impact, the location of the materiel relative to the impact "point," etc. If the armoured vehicle is subject to non-penetrating projectile impact, the energy input configuration will be different from that of the mine, as will be the effects of the ballistic shock on the materiel within the armoured vehicle. In any case, condition each scenario to estimate the materiel response as a function of amplitude level and frequency content. It will then be necessary to decide to which scenarios to test and which testing is most critical. Some scenario responses may "envelope" others, which may reduce the need for certain testing such as road, rail, gunfiring, etc. In test planning, do not break up any measured or predicted response to ballistic shock into separate amplitude and/or frequency ranges utilizing different tests to satisfy one procedure.

Table 1 – Typical Ballistic Shock Simulation Procedure Parameters

Test Procedure	Maximum Test Item Weight	Test Bandwidth, Hz
I Ballistic Hull & Turret, BH & T	Unlimited	Full Spectrum
II Large Scale Ballistic Shock Simulator, LSBSS	500 Kg (1100 lb)	10 – 100K
III Light Weight Shock Machine, LWSM	114Kg (250 lb)	10 – 3K
IV Medium Weight Shock Machine, MWSM	2273 Kg (5000 lb)	10 – 1K
V Drop Table	18 Kg (40 lb)	1 - 500

2.2.1 Procedure I – Ballistic Hull and Turret (BH&T)

Replication of the full frequency spectrum shock associated with ballistic impacts on armoured vehicles is accomplished by firing projectiles (live fire tests) at a "Ballistic Hull and Turret" (BH&T) with the materiel under test mounted on the BH&T structure. This procedure is very expensive and requires that an actual vehicle or prototype be available, as well as appropriate threat munitions. Because of these limitations, a variety of other approaches is often pursued.

Test items are mounted in the BH&T that replicates the full-size vehicle in its "as designed" configuration and location. If required, the vehicle mass is adjusted to achieve proper dynamic response. Appropriate threats (type, distance, and orientation) are successively fired at the hull and/or turret. This procedure is used to evaluate the operation of actual components, or the interaction between various components during actual ballistic impacts. This procedure is also used to determine actual shock levels for one particular engagement, which may be above or below the 'default' shock level specified in Annex A.

Procedure I is different from the other ballistic shock methods in that the shock levels are unknown until each particular shot (threat munition, attack angle, impact point, armour configuration, etc.) has been fired and measurements have been made. The shock levels are determined by the interaction of the threat munition and the armour as well as by the structure of the vehicle. Although the levels cannot be specified in advance, this technique produces the most realistic shock levels.

2.2.2 Procedure II – Large Scale Ballistic Shock Simulator (LSBSS)

Ballistic shock testing of complete components over the 10 Hz to 100 KHz spectrum can be accomplished using devices such as the Large Scale Ballistic Shock Simulator (LSBSS). This approach is used for components weighing up to 500 Kg (1100 lbs), and is considerably less expensive than the BH&T approach of Procedure I. This procedure is used primarily to test large, hard mounted components at the 'default' shock level specified in Annex A. The procedure is useful for evaluating components of unknown shock sensitivity.

2.2.3 Procedure III - Light Weight Shock Machine (LWSM)

Components weighing less than 113.6 kg (250 lbs) and shock mounted to eliminate sensitivity to frequencies above 3 kHz can be tested over the default Annex A 10 Hz to 3 kHz spectrum using a MIL-S-901 Light Weight Shock Machine (LWSM). The LWSM is adjusted for 15 mm (0.59 inch) displacement limits. Use of the LWSM is less expensive than full spectrum simulation, and may be appropriate if the specific test item does not respond to high frequency shock and cannot withstand the excessive low frequency response of the drop table (Procedure V).

The ballistic shock is simulated using a hammer impact. The test item is mounted on an anvil table of the shock machine using the test item's tactical mount. The anvil table receives the direct hammer impact, which replicates the lower frequencies of general threats to a hull or turret. This procedure produces 'partial spectrum' testing (up to 3,000 Hz) at the default test levels specified in Annex A.

2.2.4 Procedure IV - Medium Weight Shock Machine (MWSM)

Components weighing less than 2273 kg (5000 lbs) and not sensitive to frequencies above 1 kHz can be tested over the default Annex A 10 Hz to 1 kHz spectrum using a MIL-S-901 Medium Weight Shock Machine (MWSM). The MWSM is adjusted for 15 mm (0.59 inch) displacement limits. Use of the MWSM may be appropriate for heavy components and subsystems that are shock mounted and/or are not sensitive to high frequencies.

The ballistic shock is simulated using a hammer impact. The test item is mounted on the anvil table of the shock machine using the test item's tactical mount. The anvil table receives the direct hammer impact, which replicates the lower frequencies of general threats to a hull or turret. This procedure produces 'partial spectrum' testing (up to 1,000 Hz.) at the default test levels specified in Annex A.

2.2.5 Procedure V - Drop Table

Lightweight components, typically less than 18 kg (40 lbs), which are shock mounted can often be evaluated for ballistic shock sensitivity at frequencies up to 500 Hz using a drop table. This technique often results in an overtest at the low frequencies. The vast majority of components that need shock protection on an armoured vehicle can be readily shock mounted. The commonly available drop test machine is the least expensive and most accessible test technique. The shock table produces a half-sine acceleration pulse that differs significantly from ballistic shock. The response of materiel on shock mounts can be enveloped quite well with a half-sine acceleration pulse if an overtest at low frequencies and an undertest at high frequencies is acceptable. Historically, these shortcomings have been acceptable for the majority of ballistic shock qualification testing.

Ballistic shock is simulated by the impact resulting from a drop. The test item is mounted on the table of a commercial drop machine using the test item's tactical mounts. The table and test item are dropped from a calculated height. The table receives the direct blow at the impact surface, which approximates the lower frequencies of general threat to a hull or turret. This procedure is used for 'partial spectrum' testing of shock mounted components that can withstand an overtest at low frequencies.

2.3 General Considerations and Terminology

Having selected one of the five ballistic shock procedures, based on the materiel's requirements documents and the tailoring process, complete the tailoring process by identifying appropriate parameter levels, applicable test conditions and applicable test techniques for that procedure. Exercise extreme care in consideration of the details in the tailoring process. Base these selections on the requirements documents, the Life Cycle Environmental Profile, the Operational Environment Documentation and information provided with this method. Consider the following information when selecting test levels.

In general, response acceleration will be the experimental variable of measurement for ballistic shock. However, this does not preclude other variables of measurement such as velocity, displacement, or strain from being measured and processed in an analogous manner, as long as the interpretation, capabilities, and limitations of the measurement variable are clear. Pay particular attention to the high frequency environment generated by the ballistic attack, as well as the capabilities of the measurement system to accurately record the materiel's responses. For the purpose of this method, the terms that follow will be helpful in the discussion relative to analysis of response measurements from ballistic shock testing.

Effective Transient Duration - The "effective transient duration" is the minimum length of time which contains all significant amplitude time history magnitudes beginning at the noise floor of the instrumentation system just prior to the initial pulse, and proceeding to the point that the amplitude time history is a combination of measurement noise and substantially decayed structural response. In general, an experienced analyst is required to determine the pertinent measurement duration to define the ballistic shock event. The longer the duration of the ballistic shock, the more low frequency information is preserved. The amplitude time history magnitude may be decomposed into several "shocks" with different effective transient durations if it appears that the overall time history trace contains several independent "shock-like" events in which there is decay to near noise floor of the instrumentation system between events. Each event may be considered a separate shock. Method 417 Annex E provides further description of the effective transient duration.

Shock Response Spectrum Analysis - Reference b defines the equivalent static acceleration maximax Shock Response Spectrum (SRS) and provides examples of SRS computed for classical pulses. The SRS value at a given undamped natural oscillator frequency, f_n, is defined to be the absolute value of the maximum of the positive and negative acceleration responses of a mass for a given base input to a damped single degree of freedom system. The base input is the measured shock amplitude time history over a specified duration; the specified duration should be the effective transient duration. To some extent, for processing of ballistic shock response data, the equivalent static acceleration maximax SRS has become the primary analysis descriptor. In this measurement description, the maximax equivalent static acceleration values are plotted on the ordinate with the undamped natural frequency of the single degree of freedom system with base input plotted along the abscissa. Interpret the phrase "equivalent static acceleration" literally only for rigid lightweight components on isolation mounts. Test Method 417 provides further description of the effective transient duration and SRS.

2.4 Use of Measured Data

Derive the SRS and the effective transient duration, T, from measurements of the materiel's response to a ballistic shock environment or, if available, from dynamically scaled measurements of a similar environment. Because of the inherent very high degree of randomness associated with the response to a ballistic shock, extreme care must be exercised in dynamically scaling a similar environment. For ballistic shock, there are no known scaling laws because of the sensitivity of the response to the size of the shock and the general configuration.

2.4.1 Measured Ballistic Shock Data Available

If measured data are available, the data may be processed utilizing the Shock Response Spectrum (SRS). The use of Fourier Spectra (FS) or the Energy Spectral Density (ESD) is not recommended, but may be of interest in special cases. For engineering and historical purposes, the SRS has become the standard for measured data processing. In the following discussion, it will be assumed that the SRS is the data processing tool. In general, the maximax SRS spectrum (equivalent static acceleration) is the main quantity of interest. With this background, determine the SRS required for the test from analysis of the measured environmental acceleration time history. After carefully qualifying the data, to make certain there are no anomalies in the amplitude time histories, according to the recommendations provided in reference a, compute the SRS. The analyses will be performed for Q = 10 at a sequence of natural frequencies at intervals of at least 1/12th octave spacing to span a frequency range consistent with the objective of the specific test procedure.

Because sufficient field data are rarely available for statistical analysis, an amplitude increase over the envelope of the available spectral data is sometimes used to establish the required test spectrum to account for variability of the environment. The degree of permissible amplitude increase is based upon engineering judgement and should be supported by rationale for that judgement. In these cases, it is often convenient to envelope the measured SRS by computing the maximax spectra over the sample spectra and adding a +6 dB margin to the SRS maximax envelope. This amplitude increase should not be applied to the default SRS test values in Annex A of this method.

2.4.2 Measured Ballistic Shock Data Not Available

If a database is not available for a particular configuration, carefully use configuration similarity and any associated measured data for prescribing a ballistic shock test. Because of the sensitivity of the ballistic shock to the system configuration and the wide variability inherent in ballistic shock measurements, use caution in determining ballistic simulation test levels. Annex A Table A-1 and Figure A-1 give 'default' values for expected ballistic shock levels when no field measurement results are available.

2.5 Sequence

Unless otherwise identified in the life cycle profile and, since ballistic shock is normally experienced in combat and potentially near the end of the life cycle, normally schedule ballistic shock tests late in the test sequence. In general, the ballistic shock tests can be considered independent of the other tests because of their unique and specialized nature.

3. SEVERITIES

Test conditions are specified in paragraph 5 and Annex A.

4. INFORMATION TO BE PROVIDED IN THE TEST INSTRUCTION

4.1 Compulsory

4.1.1 Pretest

a. Type of ballistic shock test device.

b. Means of initiation of the ballistic shock test device.

c. Duration of the ballistic shock.

d. General materiel configuration including measurement locations on or near the materiel.

e. Test system (test item/platform configuration) detailed configuration including:

   1. Location of the ballistic shock test device;

   2. Location of the materiel;

   3. The structural path between the ballistic shock device and the materiel, and any general coupling configuration of the ballistic shock device to the platform and the platform to the materiel including the identification of structural joints.

4.1.2 During Test

a. For test validation purposes, record deviations from planned or pre-test procedures or parameter levels, including any procedural anomalies that may occur.

b. Damage to the test device or test fixture that may result in a variation of input test levels and preclude further testing until replaced or repaired.

4.1.3 Post Test

a. Duration of each exposure as recorded by an instrumented test fixture or test item, and the number of specific exposures.

b. Any data measurement anomalies, e.g., high instrumentation noise levels, loss of sensors or sensor mounting as a result of testing, etc.

4.2 If Required

a. The climatic conditioning conditions, if other than standard laboratory conditions;

b. Test tolerances, if different or additional to those in the test procedures.

5. TEST CONDITIONS AND PROCEDURES

5.1 Test Facility

The most common equipment is the drop table shock test machine utilized for shock testing of small items. For larger items that are sensitive to high frequency shock, higher frequency content and can only tolerate limited displacement, the Light Weight Shock Machine (LWSM) and Medium-Weight Shock Machine (MWSM) specified in MIL-S-901 can be useful tools for ballistic shock simulation. For large items, the Large Scale Ballistic Shock Simulator (LSBSS) utilizes an explosive charge to drive a plate to which the materiel is mounted. Reference d further describes test equipment for ballistic shock testing.

a. Procedure I - A BH&T device is the armour shell of a vehicle. It must contain the actual, fully functional, vehicle armour, but may not have an operational engine, suspension, gun, tracks, etc. The number of functional components and total weight of the BH&T device are adjusted to meet the requirements of each individual test effort.

b. Procedure II - The LSBSS is a 22,700 kg (25-ton) structure that uses high explosives and hydraulic pressure to simulate the shock experienced by armoured vehicle components and materiel (up to 500 kg (1100 lbs)) caused by the impact of enemy projectiles. Reference g provides further information related to LSBSS equipment.

c. Procedure III - The MIL-S-901 Lightweight Shock Machine uses a 182 kg (400-lb) hammer to impact an anvil plate containing the test item. Hammer drops of 1 foot, 3 feet, and 5 feet are used from two directions in three axes if the worst case axis is unknown. If the worst case axis is known and agreed, it is only necessary to test in the worst case axis.

d. Procedure IV - The MIL-S-901 Medium-Weight Shock Machine uses a 1360 kg (3000-lb) hammer to impact an anvil table containing the test item. Hammer height is a function of the weight on the anvil table (test item and all fixturing), and is specified in Table 1 of reference f, MIL-S-901.

e. Procedure V - Drop tables typically have a mounting surface for the test item on an anvil that is dropped from a known height. In some machines, the anvil is accelerated by an elastic rope, hydraulic, or pneumatic pressure to reach the desired impact velocity. The duration and shape (half-sine or saw tooth) of the impact acceleration pulse are determined by a ‘programmer’ (elastic pad or hydro-pneumatic device), which in turn determines the frequency content of the simulated shock. Test method 403 provides further guidance on classical shock waveforms.

5.2 Test Controls

a. For shock-mounted components, it is often necessary to determine the transfer function of the shock mounting system. Typically, a ‘dummy weight’ of the appropriate mass and centre of gravity is mounted in place of the test item and subjected to full level shocks. The input shock and test item responses are measured to verify performance of the shock mounts. Once shock mount performance has been verified, evaluation of an operational test item can begin.

b. Prior to subjecting the test item to the full level shock, a variety of ‘preparation’ shocks are typically performed. For Procedure I (BH&T), a low level ‘instrumentation check’ round is normally fired prior to shooting actual threat ammunition. A typical ‘instrumentation check’ round would be 4 to 16 oz. of explosive detonated 1 to 18 inches from the outer armour surface, and would usually produce no more than 10% of the shock expected from threat munition. For Procedure II (LSBSS), a low-level instrumentation check shot is usually fired prior to full level testing. For Procedure III (MIL-S-901 LWSM), the 1 foot hammer blow is normally used to check instrumentation, and any measurement problems are resolved prior to 3-foot and 5-foot hammer drops. For Procedure IV (MIL-S-901 MWSM), use the ‘Group 1’ hammer height for the instrumentation check. A similar approach is used on Procedure V Drop Table, where a low-level drop is used to check instrumentation before conducting the full level shock.

5.3 Instrumentation

Acceleration or velocity measurement techniques that have been validated in shock environments containing the high level, high frequency shock that characterize ballistic shock must be used. In general, ballistic shock measurements require the use of at least two different measurement technologies to cross check each other for validity. In addition, the frequency spectrum of ballistic shock content is generally so wide (10 Hz to more than 100,000 Hz) that no single transducer can make valid measurements over the entire spectrum. The broad time frequency environment provides a challenge for calibration of measurement sensors and any tolerances provided in the Test Instruction. The physical dimension of the ballistic measurement transducer, severe environment, and cost may limit the ability to measure more then one axis. Reference e and h provides further details on instrumentation and measurement techniques.

5.4 Installation Conditions of Test Item

Configure the test item for ballistic shock as would be anticipated during in-service use. In particular, attention is needed to the details of the mounting of the materiel to the testing platform.

5.5 Preparation for Test

5.5.1 Preliminary Planning

Prior to initiating any testing, review pretest information in the test instruction to determine test details such as procedures, test item configuration, ballistic shock levels, number of ballistic shocks. Typical planning requirements are indicated below :

a. Choose the appropriate test procedure.

b. If the ballistic shock is a calibrated test, determine the appropriate ballistic shock levels for the test prior to calibration.

c. Ensure the ballistic shock signal conditioning and recording devices have adequate amplitude range and frequency bandwidth. It may be difficult to estimate a peak signal and range the instrumentation appropriately. In general there is no data recovery from a clipped signal. However, if signal conditioning is over-ranged, it is usually possible to acquire meaningful results for a signal 20 dB above the noise floor of the measurement system. In some cases, redundant measurements may be appropriate - one measurement being over-ranged and one measurement ranged at the best estimate for the peak signal. The frequency bandwidth of most recording devices is usually readily available, but ensure that the recording device input filtering does not limit the signal frequency bandwidth.

5.5.2 Pretest Checkout

All items require a pretest checkout 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 any micro-electronic circuitry areas. Pay particular attention to the item's platform mounting configuration and potential stress wave transmission paths.
Step 2. Document the results.
Step 3. Where applicable, install the test item in its test fixture.
Step 4. Conduct an operational checkout in accordance with the approved test instruction along with simple tests to ensure the measurement system is responding properly.
Step 5. Document the results for comparison with test data.
Step 6. If the test item operates satisfactorily, proceed to the first test. If not, resolve the problem and restart at Step 1.

Step 7.Remove the test item and proceed with the calibration.

5.6 Test Procedures

The following procedures provide the basis for collecting the necessary information concerning the platform and test item under ballistic shock. Since one of four or more ballistic shock devices may be employed, the instructions below must be consistent with the ballistic shock device selected. General requirements applicable for Procedures II through IV are provided below, followed by detailed procedures for each ballistic shock test Procedure I to V. The detailed test descriptions for Procedures II through V below assume the default test amplitudes in Annex A will be applied for the test procedures. If measured data is available for the test, the data is substituted for the Annex A test severity.

For Ballistic Shock Procedures II to IV, subject the test item to the appropriate ballistic shock level a minimum of three times in the axis of orientation of greatest shock sensitivity (i.e., the worst case direction). Perform a functional verification of the component during/after each test. For frequencies above 1 kHz, many ballistic shock events produce similar shock levels in all three axes. If the shock levels are known from previous measurements, the shock testing can be tailored appropriately. If shock measurements are not available, use steps a through g outlined below.

a. Ensure the test item remains in place and that it continues to function during and following shocks that are at or below the average shock level specified in Annex A Table A-1. The test item must also remain in place and continue to function following shocks that are at or below the worst case shock level specified in Annex A Table A-1. Ensure materiel critical to crew survival (e.g., fire suppression systems) continues to function during and following the worst case shock.

b. Mount the transducer(s) used to measure the shock on the structure as near as possible to the structure mount. Take triaxial measurements at this location. If triaxial measurements are not practical, make as many uniaxial measurements as is practical.

c. Analyze the shock measurements in the time domain, as well as the frequency domain. Calculate the SRS using a damping ratio of 5 percent of critical damping (Q = 10); calculate the SRS using at least 12 frequencies per octave, proportionally spaced in the region from 10 Hz to 10 kHz (e.g., 120 frequencies spaced at approximately 10, 10.59, 11.22, 11.89, 12.59, ….8414, 8913, 9441, 10,000 Hz).

d. For a test shock to be considered an acceptable simulation of the requirement, 90 percent of the points in the region from 10 Hz to 10 kHz must fall within the bounds listed in Annex A Table A-2.

e. If more than 10 percent of the SRS points in the 10 Hz to 10 kHz region are above the upper bound, an overtest has occurred. If more than 90 percent of the SRS points lie between the upper and lower bounds, the desired qualification test has occurred. If none of the above occurs, and more than 10 percent of the points are below the lower bound, an undertest has occurred. Averaging of the time history or SRS from multiple measurement transducers for the same axis is not acceptable to meet the qualification requirements.

f. If the test item or its mount fails during an acceptable test or an undertest, redesign the materiel and/or its mount to correct the deficiency.

g. Retest the redesigned materiel and/or its mount following the above procedure.

5.6.1 Procedure I – Ballistic Hull and Turret (BH&T)

Step 1. Select the test conditions and mount the test item in a Ballistic Hull and Turret (BH&T), that may require 'upweighting' to achieve the proper dynamic response. In general, there will be no calibration when actual hardware is used in this procedure. Select measurement techniques that have been validated in ballistic shock environments.
Step 2. Perform a functional check on the test item.
Step 3. Fire the threat munitions at the BH&T and verify that the test item functions as required. Typically, make shock measurements at the mounting location ('input shock') and on the test item ('test item response').
Step 4. Record necessary data for comparison with pretest data.
Step 5. Photograph the test item as necessary to document damage.
Step 6. Perform a functional check on the test item. Record performance data.

5.6.2 Procedure II - Large Scale Ballistic Shock Simulator (LSBSS)

Step 1. Mount the test item to the LSBSS using the same mounting hardware as would be used in the actual armoured vehicle. Select the orientation of the test item with the intent of producing the largest shock in the 'worst case' axis.
Step 2. A dummy test item is typically mounted until measurements confirm that the proper explosive 'recipe' (i.e., combination of explosive weight, stand-off distance, and hydraulic displacement) has been determined to obtain the shock levels specified in Annex A Table A-1 and on Figure A-1. Following the dummy checkout, mount an operational test item to the LSBSS.
Step 3. Fire the LSBSS and verify the test item is functioning as required before, during, and after the shot.
Step 4. Record initial data for comparison with post test data.
Step 5. Fire three test shots at the shock level specified in Annex A Table A-1.
Step 6. Inspect the test item; photograph any noted damage, and record data for comparison with pretest data.

5.6.3.Procedure III – Light Weight Shock Machine (LWSM)

Step 1. Modify the mounting for the anvil plate , by shimming the four table lifts, to restrict total travel, including dynamic plate deformation, to 15 mm (0.59 inch). Mount the test item to the LWSM using the same mounting hardware as would be used in an actual armoured vehicle. Choose the orientation of the test item with the intent of producing the largest shock in the 'worst case' axis.

Step 3.Perform a pretest checkout and record data for comparison with post test data.

Step 4.Typically, make shock measurements at the 'input' location to ensure that the low frequency shock levels specified in Annex A Table A-1 and on Figure A-1 have been attained on the 5-foot drop.

Step 5.Perform a 1 foot hammer drop followed by a performance check; record data.

Step 6.Perform a 3-foot hammer drop followed by a performance check; record data.

Step 7.Perform a 5-foot hammer drop followed by a performance check; record data.

Step 8.Repeat Step 5 two more times.

Step 9.If the worst case axis is unknown, see paragraph 5.1c, repeat steps 2 to 6 for each direction of each axis for a total of 18 five-foot hammer drops.

5.6.4 Procedure IV - Medium Weight Shock Machine (MWSM)

Step 1.Modify the supports for the anvil table, by shimming the four table lifts, to restrict table total travel, including dynamic plate deformation, to 15 mm (0.59) inch.

Step 2.Mount the test item to the MWSM using the same mounting hardware as would be used in an actual combat vehicle. Choose the orientation of the test item with the intent of producing the largest shock in the 'worst case' axis, see Step 7 below.

Step 3.Perform a pretest checkout and record data for comparison with post test data.

Step 4.Typically, make shock measurements at the 'input' location to ensure that the low-frequency shock levels specified in Annex A Table A-1 and on Figure A-1 have been attained on the Group III drop. See Table 2, Group III below; the table is derived from MIL-S-901.

Step 5.Perform a Group I height hammer drop followed by a performance check; record data.

Step 6.Perform a Group III height hammer drop followed by a performance check; record data.

Step 7.Repeat Step 6 two more times.

Step 8.If the worst case axis is unknown, see paragraph 5.1c, repeat steps 2 to 6 for each direction of each axis for a total of 18 hammer drops at the Group III height.

5.6.5 Procedure V – Drop Table

Step 1.Analytically calculate the expected response of an in-service shock mounted test item, and calculate a shock response spectrum (SRS). Or, based on measured field test data, calculate an in-service SRS level. Choose a half-sine acceleration pulse whose SRS 'envelopes' the expected response of the shock mounted item. This envelope approach typically results in an overtest at the lowest frequencies.

Step 2. Hard mount the test item to the drop table.

Step 3. Conduct a performance check and record transient shock data for comparison with post test data.

Step 4. Test using the appropriate half sine acceleration pulse three times in each direction of all three axes, both positive and negative, for a total of 18 drops.

Step 5. Conduct a performance check and record data for comparison with pretest data.

Table 2 – Procedure IV MIL-S-901 MWSM Hammer Drop Heights

Total Weight on Anvil Table		Group I		Group II		Group III	
lb	Kg	ft	cm	ft	cm	ft	cm
Under 1000	Under 454	0.75	23	1.75	53	1.75	53
1000 to 2000	454 to 907	1.00	30	2.0	61	2.0	61
2000 to 3000	907 to 1361	1.25	38	2.25	69	2.25	69
3000 to 3500	1361 to 1588	1.50	46	2.5	76	2.5	76
3500 to 4000	1588 to 1814	1.75	53	2.75	84	2.75	84
4000 to 4200	1814 to 1905	2.0	61	3.0	91	3.0	91
4200 to 4400	1905 to 1996	2.0	61	3.25	99	3.25	99
4400 to 4600	1996 to 2087	2.0	61	3.5	107	3.5	107
4600 to 4800	2087 to 2177	2.25	69	3.75	114	3.75	114
4800 to 5000	2177 to 2268	2.25	69	4.0	122	4.0	122
5000 to 5200	2268 to 2359	2.5	76	4.5	137	4.5	137
5200 to 5400	2359 to 2449	2.5	76	5.0	152	5.0	152
5400 to 5600	2449 to 2540	2.5	76	5.5	168	5.5	168
5600 to 6200	2540 to 2814	2.75	84	5.5	168	5.5	168
6200 to 6800	2812 to 3084	3.0	91	5.5	168	5.5	168
6800 to 7400	3084 to 3357	3.25	99	5.5	168	5.5	168

6. EVALUATION OF TEST RESULTS

Analyze any failure of a test item to meet the requirements of the system specifications, and consider related information. Carefully evaluate any failure in the structural configuration of the test item, such as mounts, that may not directly impact failure of the functioning of the materiel but that would lead to failure during in-service environment conditions.

7. REFERENCES AND RELATED DOCUMENTS

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g. Hollburg, Uwe, “On the Simulation of Ballistic Shock Loads”, Proceedings of the 58th Shock and Vibration Symposium, Volume 1, pp. 119-135, October 1987.

h. International Test Operation Procedure (ITOP) 4-2-828, Ballistic Shock Testing, 5 January 2000.

ANNEX A

BALLISTIC SHOCK - GUIDANCE FOR INITIAL TEST SEVERITY

This annex is to be used only if measured data will not be available in the early stages of a program, and the information is vital to the design of the materiel. If there is the possibility of obtaining measurement data on the materiel platform, the severities developed using the information in this annex should be considered as preliminary.

The data contained in this annex for developing the prediction of the test levels are based on an envelope of measured data, and may be more or less severe than the environment being simulated. Further description of actual measured environments of specific platforms and operating conditions is contained in AECTP 200. The initial test severities provided in the following sections should be tempered with engineering judgement when used.

Annex A provides characteristics of a default Shock Response Spectrum (SRS) for use with the ballistic shock Procedures II through IV. The Annex is not applicable for Procedures I and V. Procedure I (BH&T) is a live fire test rather than a laboratory simulation. Procedure V is based on an analytical or measured SRS level for the drop test. Table A-1 provides typical characteristics for a measured ballistic shock and the representative maximax SRS peak. The representative average, worst, and minimum case SRS spectra are shown in Figure A-1 for a 10 to 100 KHz bandwidth. The amplitudes defined in Table A-1, or alternatively Figure A-1, are the laboratory simulation requirements and do not require an envelope or exaggeration factor. These test levels are based on measured ballistic shock data for various vehicles, threat munitions, and impact configurations.

TABLE A-1 Ballistic Shock Characteristics

Maximum [2] Resonant Frequency, Hz	Average Shock			Worst Case Shock		
	Peak Displacement, mm	Peak Velocity, m/s	Peak [1] Value of SRS, Gs	Peak Displacement, mm	Peak Velocity, m/s	Peak [1] Value of SRS, Gs
10	15	1.0	6.0	42	2.8	17
29.5	15	3.0	52.5	42	8.5	148
100	15	3.0	178	42	8.5	502
1,000	15	3.0	1,780	42	8.5	5,020
10,000	15	3.0	17,800	42	8.5	50,200
100,000	15	3.0	178,000	42	8.5	502,000

Notes

1. The SRS, or Equivalent Static Acceleration, values are calculated for a damping ratio equal to 5 percent of critical, Q = 10 .
2. Tests involving all frequencies from 10 Hz to the maximum frequency are indicated.

TABLE A-2 SRS Tolerance Functions for Default Ballistic Shock

SRS Tolerance Boundary	Resonant Frequency, f_n	
	From 10 to 29.5 Hz	From 29.5 to 10 KHz
Upper Limit (+ 9 dB) Lower Limit (- 6 dB)	SRS = (0.1702) $f_n^{\ 2}$ SRS = (0.03026) $f_n^{\ 2}$	SRS = (5.020) f_n SRS = (0.89272) f_n

The test tolerances are defined in Table A-2 and are the minimum and worst case SRS. The upper tolerance SRS is the average plus 9 dB, and the lower tolerance is the average minus 6 dB. The tolerance limits apply for the bandwidth limits of the required test procedure, or as defined in the Test Instruction. The tolerance limit is not applicable above 10 KHz. The test method defines the specific procedures, numbers of shocks applied, and any applicable exclusions for available measured test data or other Test Instruction requirements.

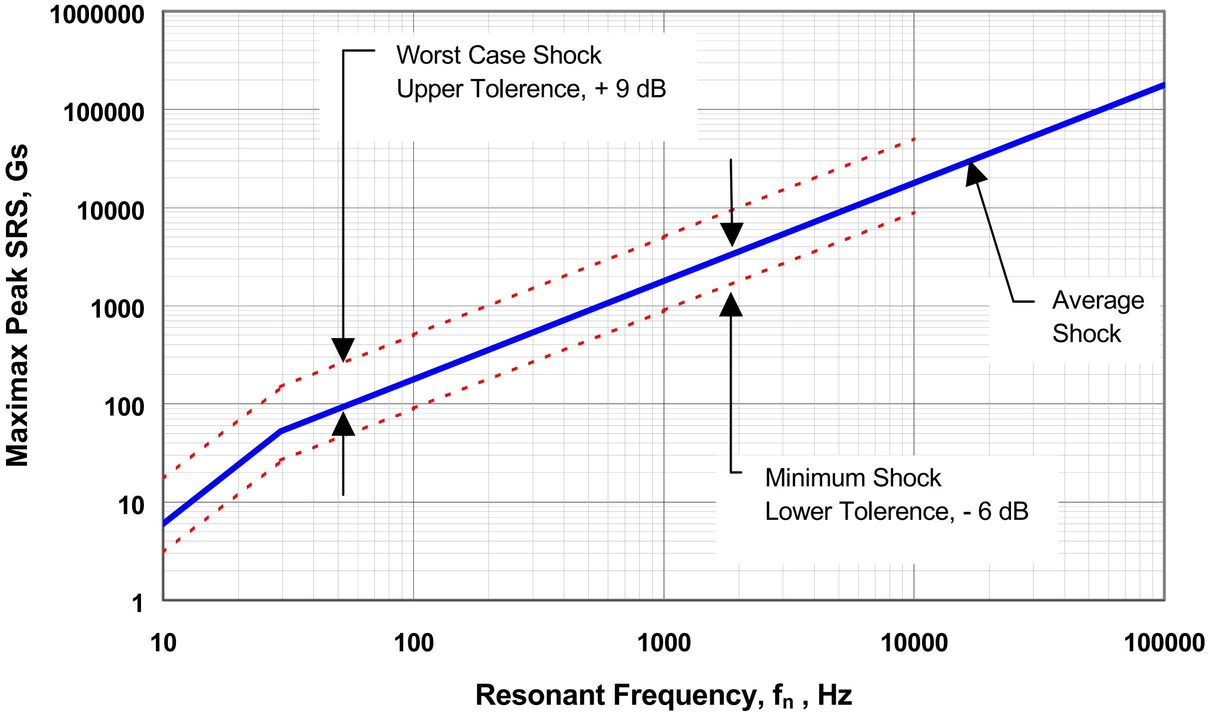

FIGURE A-1 Default Ballistic Shock SRS Test Level and Tolerances

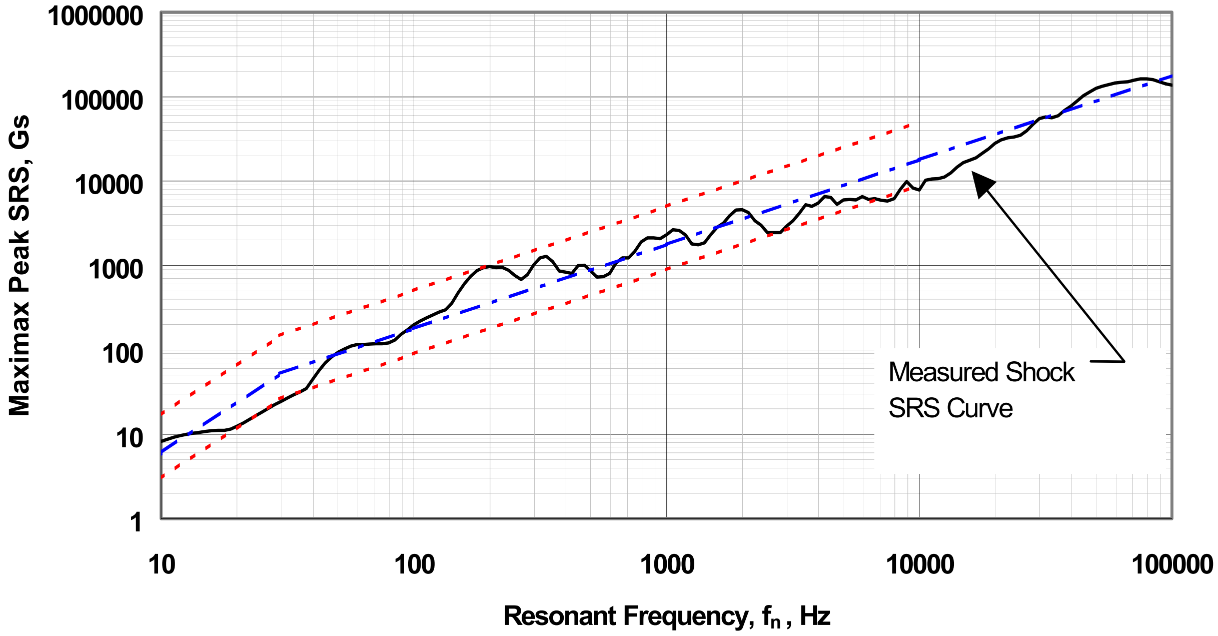

FIGURE A-2 Measured Ballistic Shock SRS

Figure A-2 illustrates a laboratory ballistic shock simulation measured SRS, default average, tolerance limits, and the pass–fail test criteria described in the test procedure. For the required test bandwidth, 10 to 10 KHz, the measured SRS is slightly outside both the upper and lower tolerance limits for several frequencies. From the SRS calculations, the primary out of tolerance bands are approximately 20 to 30 Hz, 7 to 8 KHz, and 9.5 to 10 KHz. In this case, the sum of the out of tolerance SRS values, 14 points below the lower tolerance limit, exceeds the maximum of 10 % or 12 points. The test is not acceptable, the measured SRS is an undertest of the test item.