SECTION 2.5 - EMC

Page



Tables

Table



FIGURES

Figure

Page

1.7.2 Deep Space Network (DSN) Simulation - The Deep Space Network/Flight Project Interface Design Handbook, 8l0-5, Jet Propulsion Laboratory, California Institute of Technology, Vol. I, Module TSS-10, describes existing payload (spacecraft) telemetry and command simulation capability. Vol. II describes proposed DSN capability.

1.7.3 NASA Standards – The following standards provide supporting information:

a. NASA-STD 7002, Payload Test Requirements

b. NASA-STD-7001, Payload Vibroacoustic Test Criteria

c. NASA-STD-7003, Pyroshock Test Criteria

d. NASA-HDBK-7004, Force Limited Vibration Testing

e. NASA-HDBK-7005, Dynamic Environmental Criteria

f. NASA-STD-5001, Structural Design and Test Factors of Safety for Space Flight Hardware

g. NASA-STD-5002, Load Analyses of Spacecraft and Payloads

h. NASA-STD-5009, Nondestructive Evaluation Requirements for Fracture Critical Metallic Components

i. NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware

1.7.4 Military Standards for EMI Testing - Pertinent sections of the following standards are needed to conduct the EMI tests:

a. MIL-STD-461F, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 10 December 2007

Additional documentation is specified in Section 2.5.

1.7.5 Military Standards for Non-Destructive Evaluation

a. MIL-HDBK-6870, Inspection Program Requirements, Non-Destructive Testing for Aircraft and Missile Materials and Parts.

b. NAS-410, Certification and Qualification of Nondestructive Test Personnel.

c. MSFC-STD-1249, Standard NDE Guidelines and Requirements for Fracture Control Programs.

d. MIL-HDBK-728, Nondestructive Testing.

## 1.8 DEFINITIONS

The following definitions apply within the context of this specification:

Acceptance Tests: The verification process that demonstrates that hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies and, normally, to provide the basis for delivery of an item under terms of a contract.

| | | | |
|---|---|---|---|
| Electromagnetic Compatibility | Voltage Magnitude: | ± 5% of the peak value | |
| | Current Magnitude: | ± 5% of the peak value | |
| | RF Amplitudes: | ± 2 dB | |
| | Frequency: | ± 2 % | |
| | Distance: | ± 5% of specified distance or ± 5 cm, whichever is greater | |
| Humidity | | ± 5% RH | |
| Loads | Steady-State (Acceleration): | ± 5% | |
| | Sine Burst Amplitude: | ± 5% | |
| | Static: | ± 5% | |
| Magnetic Properties | | | |
| | Mapping Distance Measurement: | | ± 1 cm |
| | Displacement of assembly center of gravity (cg) from rotation axis: | | ± 5 cm |
| | Vertical displacement of single probe centerline from cg of assembly: | | ± 5 cm |
| | Mapping turntable angular displacement: | | ± 3 degrees |
| | Magnetic Field Strength: | | ± 1 nT |
| | Repeatability of magnetic measurements (short term): | | ± 5% or ± 2 nT, whichever is greater |
| | Demagnetizing and Magnetizing Field Level: | | ±5% of nominal |
| Mass Properties | Weight: | | ± 0.2% |
| | Center of Gravity: | | ± 0.15 cm (± 0.06 in.) |
| | Moments of Inertia: | | ± 1.5% |
| Mechanical Shock | Response Spectrum: | Frequency (Hz) | Tolerance (dB) |
| | Simulated | $F_n \leq 3$ kHz | ± 6 |
| | | $F_n \geq 3$kHz | +9/-6 |

satisfies the intent of the required verification program while taking into consideration the specific characteristics of the mission and the hardware. For example:

- A spacecraft subsystem, or instrument, may be a functional subdivision of the spacecraft, but it may be distributed throughout the spacecraft rather than being a physical entity. In this case, the environmental tests, and associated functional tests, must be performed at physical levels of assembly (component, section, module, system or instrument [refer to Appendix A - hardware level of assembly]) that are appropriate for the specific hardware. Performance tests and calibrations may still be performed on the functional subsystem or instrument.

- The physical size of the system may necessitate testing at other levels of assembly. Facility limitations may not allow certain environmental tests to be performed at the system level. In this case, testing should be performed at the highest practicable level. Also, for very large systems or subsystems/instruments, tests at additional levels of assembly may be added in order to adequately verify the hardware design, workmanship and/or performance.

- For small payloads, the subsystem level environmental tests may be skipped in favor of testing at the component and system/spacecraft levels. Similarly, for very small instruments the GSFC project may elect to not test all components in favor of testing at the instrument level. These decisions must be made carefully, especially regarding bypassing lower level testing for instruments, because of the increased risk to the program (schedule, cost, etc.) of finding problems late in the planned schedule.

- In some cases, because of the hardware configuration it may be reasonable to test more than one component at a time. The components may be stacked in their flight configuration, and may therefore be tested as a "section". Part of the decision process must consider the physical size and mass of the hardware. The test configuration must allow for adequate dynamic or thermal stress inputs to the hardware to uncover design errors and workmanship flaws.

- Some test requirements stated as subsystem/instrument requirements may be satisfied at a higher level of assembly if approved by the GSFC project. For example, externally induced mechanical shock test requirements may be satisfied at the system level by firing the environment-producing pyro. A simulation of this environment is difficult, especially for large subsystems or instruments.

- Aspects of the design and/or mission may negate certain test conditions to be imposed. For example, if the on-orbit temperature variations are small, less than 5°C, then consideration should be given to waiving the thermal-vacuum cycling at the system, or instrument, level of assembly in favor of increasing the hot and cold dwell times.

The same process must be applied when developing the test plan for an instrument. While testing is required at the instrument component and all-up instrument levels of assembly, additional test levels may be called for because of hardware complexity or physical size.

Table 2.2-1
Flight System Hardware
Levels of Assembly

Table 2.2-2
Test Factors/Durations

| Test | Prototype Qualification | Protoflight Qualification | Acceptance |
|---|---|---|---|
| Structural Loads[1]<br>Level<br><br>Duration<br>Centrifuge/Static Load[6]<br>Sine Burst | <br>1.25 x Limit Load<br><br><br>1 minute<br>5 cycles @ full level per axis | <br>1.25 x Limit Load<br><br><br>30 seconds<br>5 cycles @ full level per axis | <br>1.0 x Limit Load<br><br><br>30 seconds<br>5 cycles @ full level per axis |
| Acoustics<br>Level[2]<br>Duration | Limit Level + 3dB<br>2 minutes | Limit Level + 3dB<br>1 minute | Limit Level<br>1 minute |
| Random Vibration<br>Level[2]<br>Duration | Limit Level + 3dB<br>2 minutes/axis | Limit Level + 3dB<br>1 minute/axis | Limit Level<br>1 minute/axis |
| Sine Vibration[3]<br>Level<br>Sweep Rate | 1.25 x Limit Level<br>2 oct/min | 1.25 x Limit Level<br>4 oct/min | Limit Level<br>4 oct/min |
| Mechanical Shock<br>Actual Device<br>Simulated | <br>2 actuations<br>1.4 x Limit Level<br>2 x Each Axis | <br>2 actuations<br>1.4 x Limit Level<br>1 x Each Axis | <br>1 actuations<br>Limit Level<br>1 x Each Axis |
| Thermal-Vacuum | Max./min. predict.<br>± 10°C | Max./min. predict.<br>± 10°C | Max./min. predict.<br>± 5°C |
| Thermal Cycling[4,5] | Max./min. predict.<br>± 25°C | Max./min. predict.<br>± 25°C | Max./min. predict.<br>± 20°C |
| EMC & Magnetics | As Specified for Mission | Same | Same |

1 - If qualified by analysis only, positive margins must be shown for factors of safety of 2.0 on yield and 2.6 on ultimate. Beryllium and composite materials cannot be qualified by analysis alone.

Note: Test levels for beryllium and composite structure, including metal matrix, are 1.25 x Limit Level for both qualification and acceptance testing.

2 - As a minimum, the test level shall be equal to or greater than the workmanship level.

3 - The sweep direction should be evaluated and chosen to minimize the risk of damage to the hardware. If a sine sweep is used to satisfy the loads or other requirements, rather than to simulate an oscillatory mission environment, a faster sweep rate may be considered, e.g., 6-8 oct/min to reduce the potential for over stress.

4 - It is recommended that the number of thermal cycles and dwell times be increased by 50% for thermal cycle (ambient pressure) testing.

5 - Thermal cycling testing performed as a screen for mechanical hardware with no heat generating devices may be tested to Thermal-Vacuum Test factors (See Section 2.6.2.4)

## 2.4 STRUCTURAL AND MECHANICAL VERIFICATION REQUIREMENTS

A series of tests and analyses shall be conducted to demonstrate that the flight hardware is qualified for the expected mission environments and that the design of the hardware complies with the specified verification requirements such as factors of safety, interface compatibility, structural reliability, workmanship, and associated elements of system safety.

Table 2.4-1 specifies the structural and mechanical verification activities. When the tests and analyses are planned, consideration must be given to the expected environments of structural loads, vibroacoustics, sine vibration, mechanical shock, and pressure profiles induced during all phases of the mission; for example, during launch, insertion into final orbit, preparation for orbital operations, and entry, descent, and landing. Verification must also be accomplished to ensure that the transportation and handling environments are enveloped by the expected mission environments. Mass properties and proper mechanical functioning shall also be verified.

Of equal importance with qualifying the hardware for expected mission environments are the testing for workmanship and structural reliability, which are intended to provide a high probability of proper operation during the mission. In some cases, the expected mission environment is rather benign and produces test levels insufficient to expose workmanship defects. The verification test must envelope the expected mission levels, with appropriate margins added for qualification, and impose sufficient stress to detect workmanship faults. Flight load and dynamic environment levels are probabilistic quantities. Selection of probability levels for flight limit level loads/environments to be used for payload design and testing is the responsibility of the payload project manager, but in no event shall the probability levels be less than the minimum levels in Table 2.4-2. Specific structural reliability requirements regarding fracture control for ELV payloads, beryllium structure, composite structure, bonded structural joints, and glass structural elements are given in 2.4.1.4.

The program outlined in Table 2.4-1 assumes that the payload is sufficiently modularized to permit realistic environmental exposures at the subsystem level. When that is not possible, or at the project's discretion, compliance with the subsystem requirements must be accomplished at a higher or lower level of assembly. For example, structural load tests of some components may be necessary if they cannot be properly applied during testing at higher levels of assembly.

Ground handling, transportation and test fixtures shall be analyzed and tested for proper strength as required by safety, and shall be verified for stability for applicable configurations as appropriate.

### 2.4.1 Structural Loads Qualification

Qualification of the payload for the structural loads environment requires a combination of test and analysis. A test-verified finite element model of the payload must be developed and a coupled loads analysis of the payload/launch vehicle performed.

The analytical results define the limit loads for the payload (subsystems and components) and show compatibility with the launch vehicle for all critical phases of the mission.

TABLE 2.4-1
Structural and Mechanical Verification Test Requirements

| Requirement | Payload/ Spacecraft | Subsystem/ Instrument | Unit (Component) Including Instrument Units (Components) |
|---|---|---|---|
| Structural Loads | | | |
| Modal Survey | * | $T^2$ | * |
| Design Qualification | * | $A,T/A^1$ | * |
| Structural Reliability Primary & Secondary Structure | * | $(A,T)^1$ | * |
| Vibroacoustics | | | |
| Acoustics | T | $T^2$ | $T^2$ |
| Random Vibration | $T^2$ | $T^2$ | T |
| Sine Vibration | $T^3,T^4$ | $T^3$ | $T^3$ |
| Mechanical Shock | T | $T^5$ | $T^5$ |
| Mechanical Function | A,T | A,T | - |
| Pressure Profile | - | $A,T^2$ | A |
| Mass Properties | A/T | $A,T^2$ | * |

* = May be performed at payload or component level of assembly if appropriate.

A = Analysis required.

T = Test required.

A/T = Analysis and/or test.

$A, T/A^1$ = Analysis and Test or analysis only if no-test factors of safety given in 2.4.1.1.1 are used.

$(A, T)^1$ = Combination of fracture analysis and proof tests on selected elements, with special attention given to beryllium, composites, bonded joints and weldments.

$T^2$ = Test must be performed unless assessment justifies deletion.

$T^3$ = Test performed to simulate low frequency transient vibration and any sustained periodic mission environment, or to satisfy other requirement such as strength qualification.

$T^4$ = Test must be performed for ELV payloads, if practicable, to simulate transient and any sustained periodic vibration mission environment.

$T^5$ = Test required for self-induced shocks, but may be performed at payload level of assembly for externally induced shocks.

TABLE 2.4-2
Minimum Probability-Level Requirements
for Flight Limit (maximum expected) Level

| Requirement | Minimum Probability Level |
|---|---|
| | ELV Payloads |
| Structural Loads | 97.72/50 (1),(2) |
| Vibroacoustics<br>Acoustics<br>Random Vibration | 95/50 |
| Sine Vibration | 97.72/50 (1) |
| Mechanical Shock | 95/50 |

Notes:

(1) When parametric statistical methods are used to determine the limit level, the data should be tested to show a satisfactory fit to the assumed underlying distribution.

(2) 97.72% probability of not exceeding level, estimated with 50% confidence. Equal to the mean plus two-sigma level for normal distributions.

A modal survey shall be performed for each payload (at the subsystem/instrument or other appropriate level of assembly) to verify that the analytical model adequately represents the dynamic behavior of the hardware. The test-verified model shall then be used to predict the maximum expected load for each critical loading condition, including handling and transportation, vibroacoustic effects during lift-off, insertion into final orbit, orbital operations, thermal effects during landing, etc., as appropriate for the particular mission. If the payload configuration is different for various phases of the mission, the structural loads qualification program, including the modal survey, must consider the different configurations. The maximum loads resulting from the analysis define the limit loads.

The launch loads environment is made up of a combination of steady-state, low-frequency transient, and higher-frequency vibroacoustic loads. To determine the combined loads for any phase of the launch, the root-sum-square (RSS) of the low- and high-frequency dynamic components are superimposed upon the steady-state component if appropriate.

$$N_i = S_i \pm [(L_i)^2 + (R_i)^2]^{1/2}$$

2.4.2.7 Retest of Reflight Hardware - For reflight hardware, the amount of retest that is needed is determined by considering the amount of rework done after flight and by comparing the stresses of the upcoming flight with those of the previous flight. The principal objective is to verify the workmanship. If no disassembly and rework was done, the test may not be necessary. The effects of storage, elapsed time since last exposure, etc. shall be considered in determining the need for retest. Subsystems that have been taken apart and reassembled shall, as a minimum, be subjected to an acoustic test (levels shall be equal to the limit levels) and a random vibration test in at least one axis. More comprehensive exposures shall be considered if the rework has been extensive.

2.4.2.8 Retest of Reworked Hardware – In many cases it is necessary to make modifications to hardware after a unit has been through a complete mechanical verification program. For example, replacing a capacitor on a circuit board in a electronics box that has already been through protoflight vibration testing. For this type of reworked hardware, the amount of additional mechanical testing required depends on the amount of rework done and the amount of disassembly performed as part of the rework. The primary objective of post-rework testing is to ensure proper workmanship has been achieved in performing the rework and in reassembling the component. As a minimum, the reworked component shall be subjected to a single axis workmanship random vibration test to the levels specified in Table 2.4-4. The determination of axis shall be made based on the direction necessary to provide the highest excitation of the reworked area. Testing may be required in more than one axis if a single axis test cannot be shown to adequately test all of the reworked area. If the amount of rework or disassembly required is significant, then 3-axis testing to acceptance levels may be necessary if they are higher than workmanship levels.

2.4.3 Sinusoidal Sweep Vibration Qualification

Sine sweep vibration tests are performed to qualify prototype/protoflight hardware for the low-frequency transient or sustained sine environments when they are present in flight, and to provide a workmanship test for all payload hardware which is exposed to such environments and normally does not respond significantly to the vibroacoustic environment, such as wiring harnesses and stowed appendages.

For a payload level test, the payload shall be in a configuration representative of the time the stress occurs during flight, with appropriate flight type hardware used for attachment. For example, if the test is intended to simulate the vibration environment produced by the firing of retro/apogee motors, the vibration source shall be attached at the retro/apogee motor adapter, and the payload shall be in a configuration representative of the retro/apogee motor burning mode of operation.

In addition, all ELV payloads shall be subjected to swept sine vibration testing to simulate low-frequency sine transient vibration and sustained, pogo-like sine vibration (if expected) induced by the launch vehicle. Qualification for these environments requires swept sine vibration tests at the payload, instrument, and component levels of assembly.

It is understood that, for some payload projects, the sinusoidal sweep vibration qualification program may have to be modified. For example, for very large ELV payloads (with very large masses, extreme lengths, or large c.g. offsets) it may be impracticable because of test facility limitations to perform a swept sine vibration test at the payload level of assembly. In that case, testing at the highest level of assembly practicable is required.

For the sinusoidal vibration environment, limit levels shall be used which are consistent with the minimum probability level given in Table 2.4-2. The qualification level is then defined as the limit level times 1.25. The test input frequency range shall start be limited to the frequency range in which coupled loads results are applicable and may be used for notching test responses. The typical frequency range of the sine test is 5 to 50 Hz but the range of the test may be extended depending on the specific launch vehicle and the frequency content of the coupled loads analysis. The fatigue life considerations of 2.4.2.1 apply where hardware reliability goals demand the demonstration of a specific hardware lifetime. The sine sweep environmental test program shall be included in the environmental verification plan and environmental verification specification.

2.4.3.1 ELV Payload Sine Sweep Vibration Tests - At the payload level of assembly, ELV prototype/protoflight hardware shall, when practicable, be subjected to a sine sweep vibration design qualification test to verify its ability to survive the low-frequency launch environment. The test also provides a workmanship vibration test for payload hardware which normally does not respond significantly to the vibroacoustic environment, but can experience significant responses from the ELV low-frequency sine transient vibration and any sustained, pogo-like sine vibration. Guidelines for developing mission-specific test levels are given in 2.4.3.1.b.

a. Vibration Test Requirements - Protoflight hardware shall be subjected to a sine sweep vibration test to verify flightworthiness and workmanship. The test shall represent the qualification level (flight limit level times 1.25).

The test is intended for all ELV payloads (spacecraft) except those with very large masses, extreme lengths and/or large c.g. offsets, where it is impracticable because of test facility limitations.

If the sine sweep vibration test is not performed at the payload level of assembly, it shall be performed at the next lowest practicable level of assembly.

The payload in its launch configuration shall be attached to a vibration fixture by use of a flight-type launch-vehicle attach fitting (adapter) and attachment (separation system) hardware. Sine sweep vibration shall be applied at the base of the adapter in each of three orthogonal axes, one of which is parallel to the thrust axis. The test sweep rate shall be 4 octaves per minute to simulate the flight sine transient vibration; lower sweep rates shall be used in the appropriate frequency bands as required to match the duration and rate of change of frequency of any flight sustained, pogo-like vibration. The frequency range of the sine test shall be consistent with the frequency content of the launch vehicle coupled loads analysis. Mission-specific sine sweep test levels shall be developed for each ELV payload. Guidelines for developing the test levels are given in 2.4.3.1.b.

Prior to the payload test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics, the proposed choice of control accelerometer locations, and the control strategy. The evaluation shall include consideration of cross-axis responses. If a mechanical test model of the payload is available it should be included in the survey to evaluate the need for limiting (or notching).

During the protoflight hardware sine sweep vibration test to the specified test levels, loads induced in the payload and/or adapter structure while sweeping through resonance shall not exceed 1.25 times flight limit loads. If required, test levels shall be reduced ("notched") at critical frequencies. Acceleration responses of specific critical items may also be limited to 1.25 times flight limit levels if required to preclude unrealistic levels, provided that the spacecraft model used for the coupled loads analysis has sufficient detail and that the specific responses are recovered (using the acceleration transformation matrix) from the coupled loads analysis results.

A low-level sine sweep shall be performed prior to the protoflight-level sine sweep test in each test axis. Data from the low-level sweeps measured at locations identified by a notching analysis shall be examined to determine if there are any significant test response deviations from analytical predictions. The data utilized shall include cross-axis response levels. Based on the results of the low-level tests, the predetermined notch levels shall be verified prior to the protoflight-level test. The flight limit loads used for notching analysis shall be based on the final verification cycle coupled loads analysis (including a test-verified payload model).

b. Mission-Specific Test Level Development - Sinusoidal vibration test levels required to simulate the flight environment for ELV spacecraft vary with the payload attach fitting (adapter) and spacecraft configuration, including overall weight and length, mass and stiffness distributions, and axial-to-lateral coupling. It therefore is impracticable to specify generalized sine sweep vibration test levels applicable to all spacecraft, and mission-specific test levels must be developed for each ELV spacecraft based on the coupled loads analysis.

Coupled loads analysis results should be utilized to develop mission specific sinusoidal vibration test levels based on acceleration-response time histories or processed shock response spectra (SRS) data at the interface of the test article for all significant flight event loading conditions. Equivalent sine sweep vibration test input levels can be developed by processing the interface time history data using SRS techniques and then dividing the resulting SRS by the assumed Q (where $Q=C_c/2C$). It should be noted that, in developing equivalent test input levels by dividing the SRS by Q, the assumption of a lower Q is more conservative. In the absence of test data, typical assumed values of Q are from 10 to 20. For pogo-like flight events, the use of SRS techniques is not generally required.

Prior to the availability of coupled loads analysis results, preliminary sine test levels may be estimated by using the ELV "user manual" sine vibration levels for spacecraft base drive analysis, with notching levels based on net loads equivalent to the user manual c.g. load factor loads. The base-drive analysis shall be truncated to a frequency range consistent with the launch vehicle coupled loads analysis. Alternatively, spacecraft interface dynamic response data from flight measurements or coupled loads analysis for similar spacecraft may be used for the base drive input in conjunction with a suitable uncertainty factor.

c. Performance - Before and after each vibration test, the payload shall be examined and functionally tested. During the tests, performance shall be monitored in accordance with the verification specification.

2.4.3.2 ELV Payload Subsystem (including Instruments) and Component Sine Sweep Vibration Tests - As a screen for design and workmanship defects, these items (per Table 2.4-1) shall be subjected to a sine sweep vibration test along each of three mutually perpendicular axes. For the sinusoidal vibration environment, limit levels shall be defined to be consistent with the minimum probability level of Table 2.4-2. The protoflight qualification level is then defined as the limit level times 1.25. The test input frequency range shall be consistent with the launch vehicle coupled loads analysis and shall be the same as the frequency range defined for payload testing.. The fatigue life considerations of 2.4.2.1 apply where hardware reliability goals demand the demonstration of a specific hardware lifetime.

a. Vibration Test Requirements - The test item in its launch configuration shall be attached to the test equipment by a rigid fixture. The mounting shall simulate, insofar as practicable, the actual mounting of the item in the payload, with particular attention given to duplicating the mounting interface. All connections to the item (connectors and harnesses, plumbing, etc.) should be simulated with lengths at least to the first tie-down point. In mating the test item to the fixture, a flight-type mounting (including vibration isolators or kinematic mounts, if part of the design) and fasteners, including torque levels and locking features, shall be used. Normally-sealed items shall be pressurized during test to their prelaunch pressure.

In cases where significant changes in strength, stiffness, or applied load result from variations in internal and external pressure during the launch phase, a special test shall be considered to cover those effects.

Sine sweep vibration shall be applied at the base of the test item in each of three mutually perpendicular axes. The test sweep rate shall be consistent with the payload-level sweep rate, i.e., 4 octaves per minute to simulate the flight sine transient vibration, and (if required) lower sweep rates in the appropriate frequency bands to match the duration and rate of change of frequency of any flight sustained, pogo-like vibration. The test shall be performed by sweeping the applied vibration once through the specified frequency range in each test axis.

Spacecraft subsystem, including instrument, and component levels depend on the type of structure to which the item is attached, the local attachment stiffness, the distance from the spacecraft separation plane, and the item's mass, size, and stiffness. It therefore is impracticable to specify generalized sine sweep vibration test levels applicable to all subsystems/instruments, and components, and mission-specific test levels shall be developed for each payload. Guidelines for developing the specific test levels are given in 2.4.3.2.b.

Prior to the test, a survey of the test fixture/exciter combination shall be performed to evaluate the fixture dynamics, the proposed choice of control accelerometer locations, and the control strategy. The evaluation shall include consideration of cross-axis responses. If a mechanical test or engineering model of the test article is available it should be included in the survey.

A low-level sine sweep shall be performed prior to the protoflight level sine sweep test in each test axis (with particular emphasis on cross-axis responses) to verify the control strategy and check test fixture dynamics.

b. Mission Specific Test Level Development - The mission-specific sine sweep test levels for spacecraft subsystems/components should be based on test data from structural model spacecraft sine sweep tests if available. If not available, the test levels should be based on an envelope of two sets of responses:

(1) Coupled loads analysis dynamic responses should be utilized if acceleration-response time histories or processed shock response spectra (SRS) data are available at the test article location for all significant flight event loading conditions. Equivalent sine sweep vibration test input levels should be developed using (SRS) techniques for transient flight events using the methods defined in 2.4.3.1.b.

(2) Subsystem/component responses from a base drive analysis of the spacecraft and adapter, using the spacecraft sine sweep test levels as input (in three axes),

should be included in the test level envelope. The base drive responses of the test article should be corrected for effects of the spacecraft test sweep rates if the sweep rates are not included in the base drive analysis input. Subsystem/component test sweep rates should match spacecraft test sweep rates.

Since most shakers can only apply translational (but not rotational) accelerations, for test articles with predicted large rotational responses it may be necessary to increase the test levels based on analysis to assure adequate response levels.

Also, for certain cases such as large items mounted on kinematic mount flexures, which experience both significant rotations and translations, it may be necessary to use the test article c.g. rotational and translational acceleration response levels as not-to-exceed test levels in conjunction with appropriate notching or limiting.

c. Performance - Before and after test exposure, the test item shall be examined and functionally tested. During the test, performance shall be monitored in accordance with the verification specification.

2.4.3.3 Acceptance Requirements - Sine sweep vibration testing for the acceptance of previously qualified hardware shall be conducted at the flight limit levels using the same sweep rates as used for protoflight hardware.

2.4.4 Mechanical Shock Qualification

Both self-induced and externally induced shocks shall be considered in defining the mechanical shock environment.

2.4.4.1 Subsystem Mechanical Shock Tests - All subsystems, including instruments, shall be qualified for the mechanical shock environment.

a. Self-Induced Shock - The subsystem shall be exposed to self-induced shocks by actuation of all shock-producing devices. Self-induced shocks occur principally when pyrotechnic and pneumatic devices are actuated to release booms, solar arrays, protective covers, etc. Also the impact on deployable devices as they reach their operational position at the "end of travel" is a likely source of significant shock. When hardware contains such devices, it shall be exposed to each shock source twice to account for the scatter associated with the actuation of the same device. The internal spacecraft flight firing circuits should be used to trigger the event rather than external test firing circuits. At the project's discretion, this testing may be deferred to the payload level of assembly.

b. Externally Induced Shock - Mechanical shocks originating from other subsystems, payloads, or launch vehicle operations must be assessed. When the most severe shock is externally induced, a suitable simulation of that shock shall be applied at the subsystem interface. When it is feasible to apply this shock with a controllable shock-generating device, the qualification level shall be 1.4 times the maximum expected value at the subsystem interface, applied once in each of the three axes. A pulse or complex transient with a duration comparable to the actual shock pulse shall be applied at the test item interface along each of the three axes. The shock spectrum of the generated waveform (positive and negative) shall match the desired spectrum within the tolerances specified for mechanical shock in Section 1.13. Equalization of the shock spectrum is performed at a maximum resolution of one-sixth octave. The fraction of critical damping ($c/c_C$) used in the shock spectral analysis of the test pulse should equal the fraction of critical damping used in the analysis of the data from which the test specification was derived. In the absence of a strong rationale for some other value, a fraction of critical damping equivalent to a Q of 10 shall be used for shock spectrum analysis.

If the project so chooses or if it is not feasible to apply the shock with a controllable shock-generating device (e.g. the subsystem is too large for the device), the test may be conducted at the payload level by actuating the devices in the payload that produce the shocks external to the subsystem to be tested. The shock-producing device(s) must be actuated a minimum of two times for this test.

The decision to perform component shock testing to is typically based on an assessment of the shock susceptibility of the component and the expected shock levels. If the component is not considered shock sensitive and if there is low potential for damage due to the shock environment, then the project may choose to defer shock testing to the payload level of assembly. The potential for damage due to shock can be quantified based on Figure 2.4-1. Two curves are shown in the figure; one for standard aerospace electronics and one for all other hardware. If the flight shock environment as shown on an SRS plot (Q=10) is enveloped by the appropriate curve shown in Figure 2.4-1, then the shock environment can be considered benign and there is low risk in deferring the shock test. For the case in which the shock levels are above the curve, then component level shock testing should be considered as the shock level may be high enough to cause damage. The curve provided in Figure 2.4-1 is intended as a guideline for determining whether component level shock testing should be performed. Each component should be evaluated individually to determine its susceptibility for damage due to the predicted shock environment.

It will not be necessary to conduct a test for externally induced shocks if it can be demonstrated that the shock spectrum of the self-induced environment is greater at all frequencies than the envelope of the spectra created by the external events at all locations within the subsystem.

c. Test Setup - During test, the test item should be in the electrical and mechanical operational modes appropriate to the phase of mission operations when the shock will occur.

d. Performance - Before and after the mechanical shock test, the test item shall be examined and functionally tested. During the tests, performance shall be monitored in accordance with the verification specification.

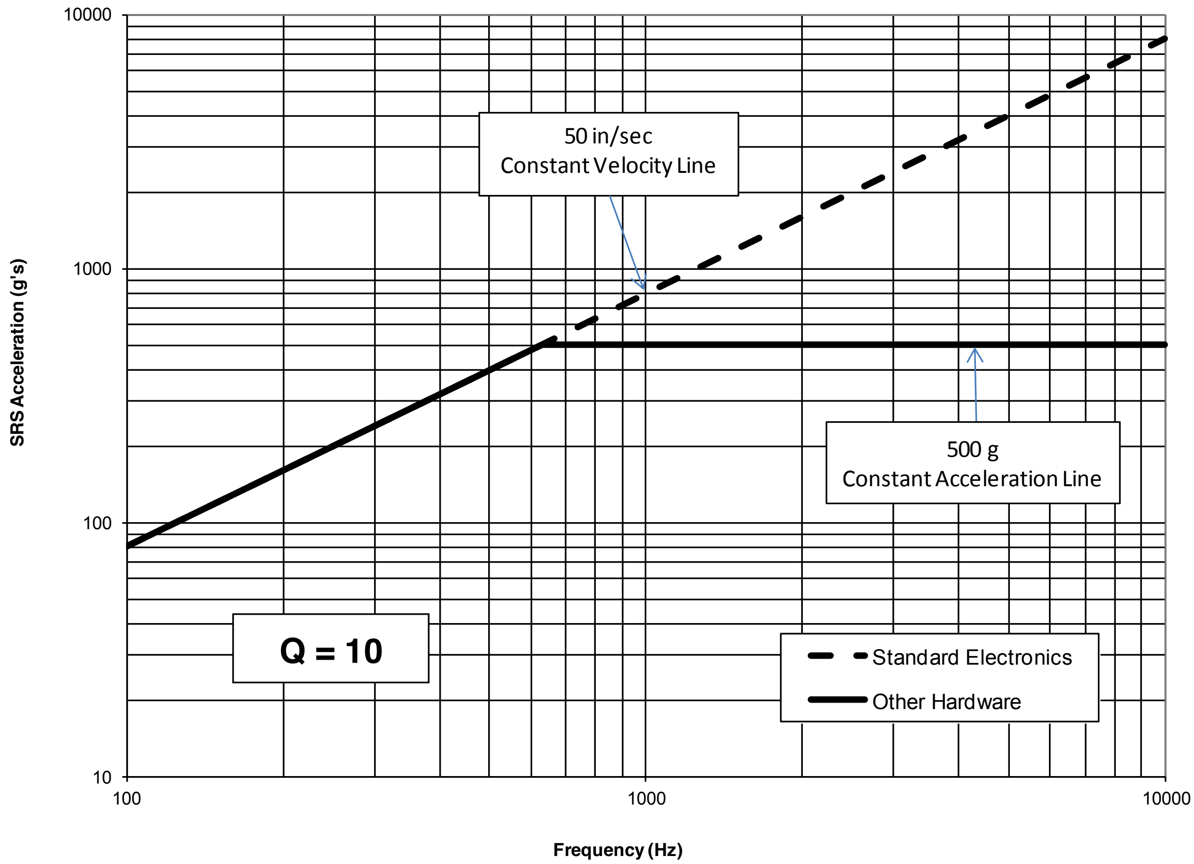



Figure 2.4-1 Shock Response Spectrum (SRS) for assessing Component Test Requirements

2.4.4.2 Payload (Spacecraft) Mechanical Shock Tests - The payload must be qualified for the shock induced during payload separation (when applicable) and for any other externally induced shocks whose levels are not enveloped at the payload interface by the separation shock level. The payload separation shock is usually higher than other launch vehicle-induced shocks; however that is not always the case. For instance, the shocks induced at the payload interface during inertial upper stage (IUS) actuation can be greater. In addition, mechanical shock testing may be performed at the payload level of assembly to satisfy the subsystem mechanical shock requirements of 2.4.4.1.

a. Other Payload (Spacecraft) Shocks - If launch vehicle induced shocks or shocks from other sources are not enveloped by the separation test, the spacecraft must be subjected to a test designed to simulate the greater environment. If a controllable source is used, the qualification level shall be 1.4 x the maximum expected level at the payload interface applied in each of the three axes. The simulated shock spectrum (positive and negative) shall match the desired test spectrum within the tolerances for mechanical shock specified in Section 1.13. The analysis should be performed with a fraction of critical damping corresponding to a Q of 10 or, if other than 10, with the Q for which the shock being simulated was analyzed.

The subsystem mechanical shock requirements may be satisfied by testing at the payload level of assembly as described above.

b. Performance - Before and after the mechanical shock test, the test item shall be examined and functionally tested. During the tests, performance shall be monitored in accordance with the verification test plan and specification.

2.4.4.3 Acceptance Requirements - The need to perform mechanical shock tests for the acceptance of previously qualified hardware shall be considered on a case-by-case basis. Testing should be given careful consideration evaluating mission reliability goals, shock severity, hardware susceptibility, design changes from the previous qualification configuration including proximity to the shock source, and previous history.

### 2.4.5 Mechanical Function Verification

A kinematic analysis of all payload mechanical operations is required (a) to ensure that each mechanism can perform satisfactorily and has adequate margins under worst-case conditions, (b) to ensure that satisfactory clearances exist for both the stowed and operational configurations as well as during any mechanical operation, and (c) to ensure that all mechanical elements are capable of withstanding the worst-case loads that may be encountered. Payload qualification tests are required to demonstrate that the installation of each mechanical device is correct and that no problems exist that will prevent proper operation of the mechanism during mission life.

Subsystem qualification tests are required for each mechanical operation at nominal-, low-, and high-energy levels. To establish that functioning is proper for normal operations, the nominal test shall be conducted under the most probable conditions expected during normal flight. A high-energy test and a low-energy test shall also be conducted to prove positive margins of strength and function. The levels of these tests shall demonstrate margins beyond the nominal conditions by considering adverse interaction of potential extremes of parameters such as temperature, friction, spring forces, stiffness of electrical cabling or thermal insulation, and, when applicable, spin rate. Parameters to be varied during the high- and low-energy tests shall include, to the maximum extent practicable, all those that could substantively affect the operation of the mechanism as determined by the results of analytic predictions or development tests. As a minimum, successful operation at temperature extremes 10°C beyond the range of expected flight temperatures shall be demonstrated.

Lubricants susceptible to adverse effects from humidity, such as MoS2 shall be given protection. Testing in a humid environment shall, where practicable, either be avoided or minimized.

#### 2.4.5.1 Life Testing

A life test program shall be implemented for mechanical elements that move repetitively as part of their normal function and whose useful life must be determined in order to verify their adequacy for the mission. The verification plan and the verification specification shall address the life test program, identifying the mechanical elements that require such testing, describing the test hardware that will be used, and the test methods that will be employed.

Mechanical Shock

The maximum shock producing event for payloads is generally the actuation of separation devices. The expected shock environment should be assessed for the device to be used, and a spacecraft separation test shall be performed if pyrotechnic devices are to be used for the separation.

A pyrotechnic shock environment is characterized as a high intensity, high frequency, and very short duration acceleration time history that resembles a summation of decaying sinusoids with very rapid rise times. In addition, it is characterized most realistically as a traveling wave response phenomenon rather than as a classical standing wave response of vibration modes. Typically, at or very near the source, the acceleration time history can have levels in the thousands of g's, have a primary frequency content from 1 kHz to 10 kHz, and decay within 3-15 milliseconds. When assessing the source pyro shock environment descriptor as given in the GEVS, the following three factors must be considered:

a. Because of the very complex waveform and very short duration of the time history, there is no accepted way for giving a unique, "explicit" description of the environment for test specification purposes. The accepted standard non-unique, "implicit" description is a "damage potential" measure produced by computing the Shock Response Spectrum (SRS) of the actual environment time history. A SRS is defined as the maximum absolute acceleration response, to the environment time history, of a series of damped, single-degree-of-freedom oscillators that have a specified range of resonant frequencies and a constant value of viscous damping (e.g., Q=10). This type of descriptor is contained in the GEVS. The resulting fundamental objective of the verification test is to create a test environment forcing time history that has nearly the same SRS as the test specification and thereby give some assurance that the test environment has approximately the same "damage potential" as the actual environment.

b. Because of the high frequency, traveling wave response like nature of the subject environment, the acceleration level will be rapidly attenuated as a function of distance from the source and as the response wave traverses discontinuities produced by joints and interfaces.

c. Because of the high frequency, short duration nature of the pyro-shock environment, "potential for damage" is essentially restricted to portions of the payload, or instrument that, for example, have very high frequency resonances (i.e., electrical/electronic elements such as relays, circuit boards, computer memory, etc.) and have high frequency sensitive electromechanical elements such as gyros, etc.

An Aerospace Systems Pyrotechnic Shock study was performed for GSFC and a report was generated in 1970 entitled Aerospace Systems Pyrotechnic Shock Data, NASA Contractor Report-116437, -116450, -116401, -116402, -116403, -116406, and -116019, Vol. I-VII. (Additional information and references can be found in Pyroshock Test Criteria NASA Technical Standard NASA-STD-7003). The following information, extracted from the 1970 final report of this study, is provided to aid in assessing expected shock levels. The results are empirical and based on a limited amount of data, but provide insight into the characteristics of the shock response spectrum (SRS) produced by various sources, and the attenuation of the shock through various structural elements.

The study evaluated the shock produced by four general types of pyrotechnic devices

- Linear charges (MDF and FLSC);
- Separation nuts and explosive bolts;
- Pin-puller and pin-pushers;
- Bolt-cutters, pin-cutters and cable-cutters

Empirically derived expected SRS's for these four categories are given in Tables A-4 through A-7. It was found that the low-frequency region could be represented, or enveloped, by a constant velocity curve. All shock response curves are for a Q=10.

The attenuation, as a function of frequency and distance was evaluated for the following general types of structure:

- Cylindrical shell;
- Longeron or stringer of skin/ring- frame structure;
- Ring frame of skin/ring- frame structure;
- Primary truss member;
- Complex airframe;
- Complex equipment mounting structure;
- Honeycomb structure.

It was found that the attenuation of the Shock, as a function of distance from the source, could be separated into two parts; the attenuation of the low-frequency constant velocity curve, and the attenuation of the high-frequency peak levels. The attenuation of the constant velocity curve was roughly the same for all types of structure; whereas the attenuation of the higher frequency peak shock response was different for the various categories of structure. Figure A-8 gives the attenuation of the constant velocity portion of the SRS as a function of distance, and Figure A-9 gives the attenuation of the peak SRS level as a function of distance for the various general categories of structure. It must be emphasized that this information was derived empirically from a limited set of shock data.

As an example of the use of these attenuation curves, assume that the source spectrum is that for an explosive bolt given in Figure A-5, and that an estimate of the shock levels 80 inches from the source is being evaluated for complex equipment mounting structure. From Figure A-8, the constant velocity, low-frequency envelope will be attenuated to approximately 20% of the original level. From Figure A-9, the peak level will be attenuated to approximately 7.8% of the original level. The assumed source spectrum and new estimate of the SRS envelope is shown in Figure A-10.

Structural interfaces can attenuate a shock pulse; guideline levels of reduction are as follows:

| Interface | Percent Reduction |
|---|---|
| Solid Joint | 0 |
| Riveted butt joint | 0 |
| Matched angle joint | 30-60 |
| Solid joint with layer of different material in joint | 0-30 |

The attenuation due to joints and interfaces is assumed for the first three joints.

A reduction of shock levels can also be expected from intervening structure in a shell type structure. An example is shown in Figure A-11.

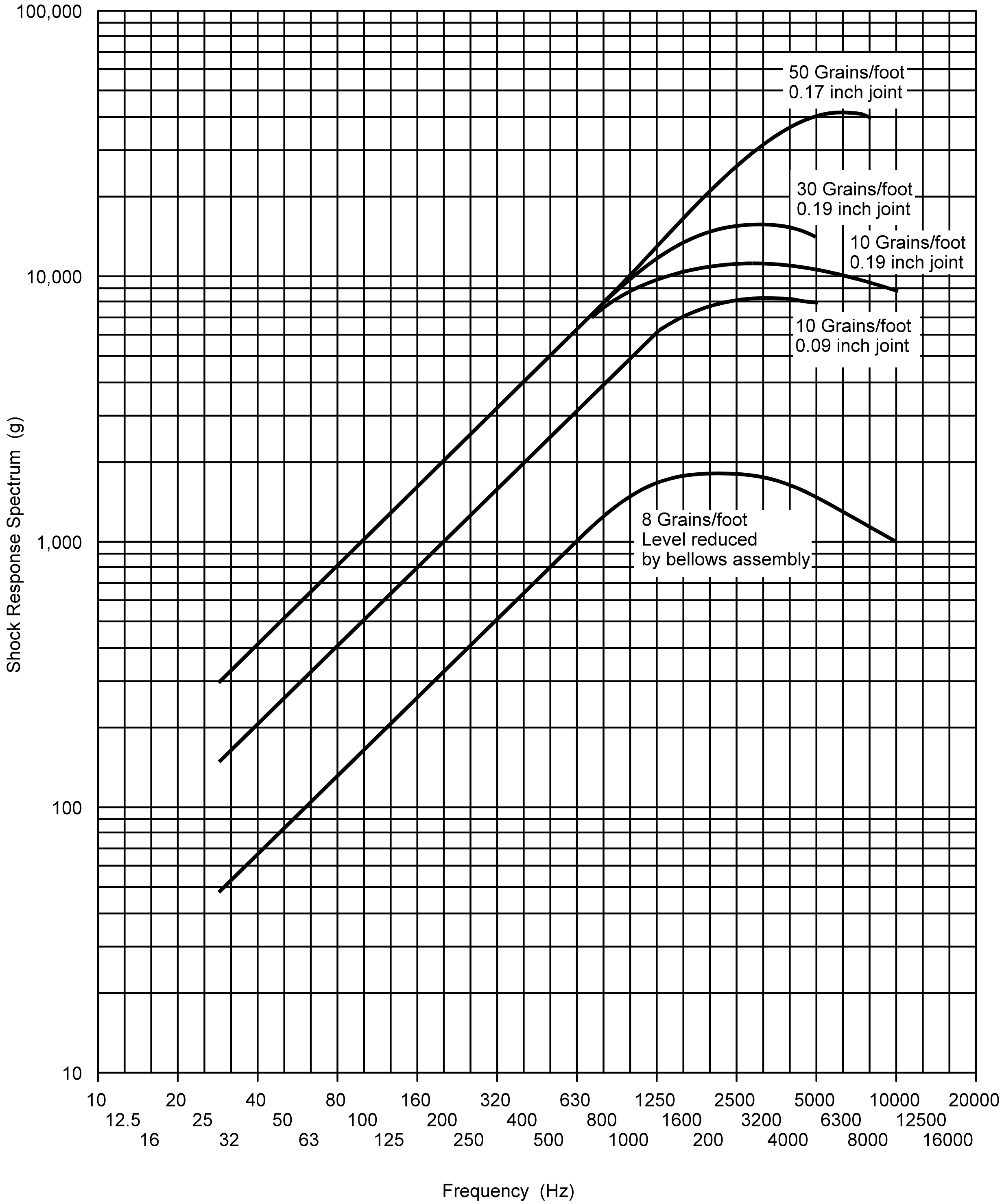



Figure A-4 - Shock Environment Produced by Linear Pyrotechnic Devices

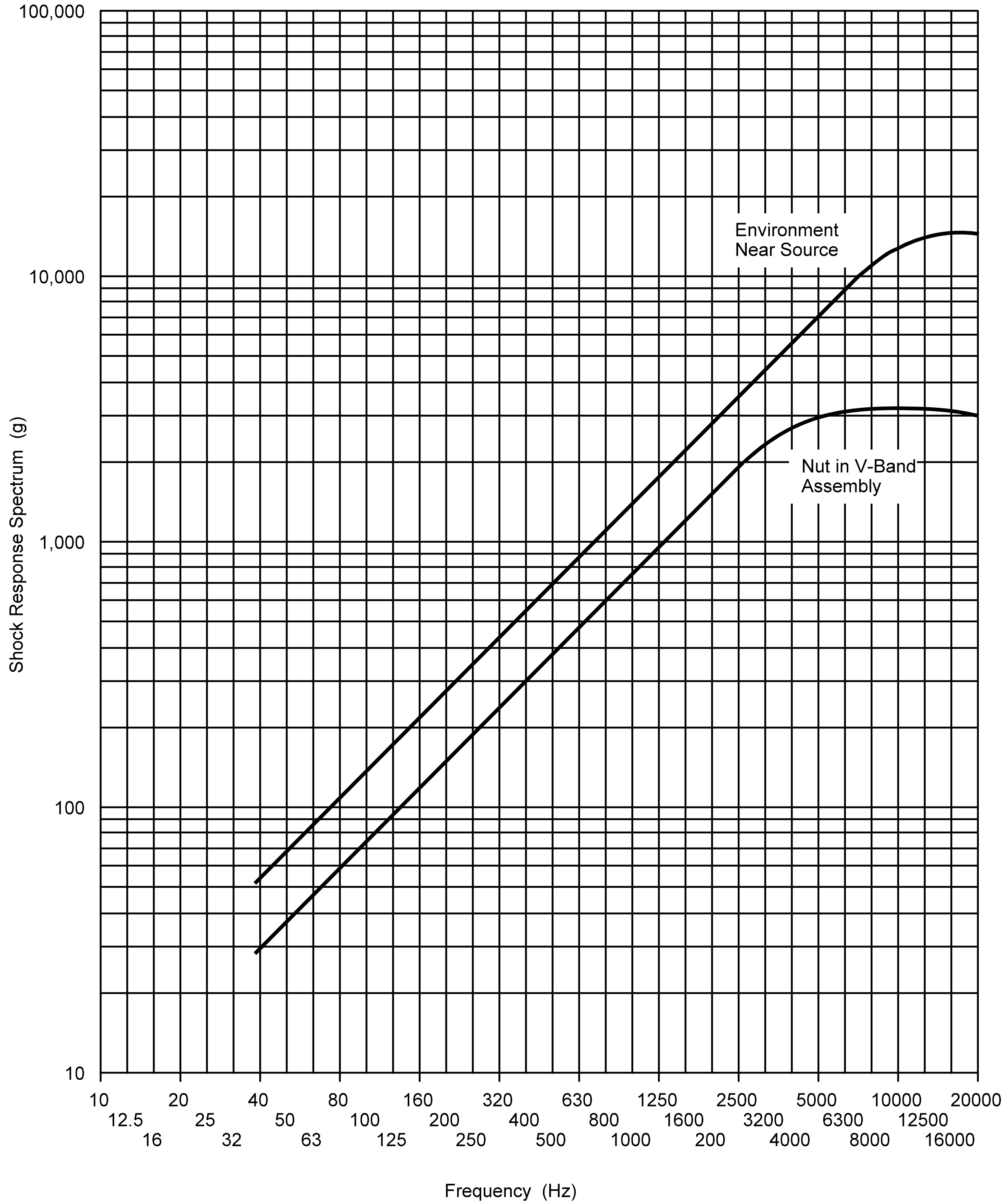



Figure A-5 - Shock Environment Produced by Separation Nuts and Explosive Bolts

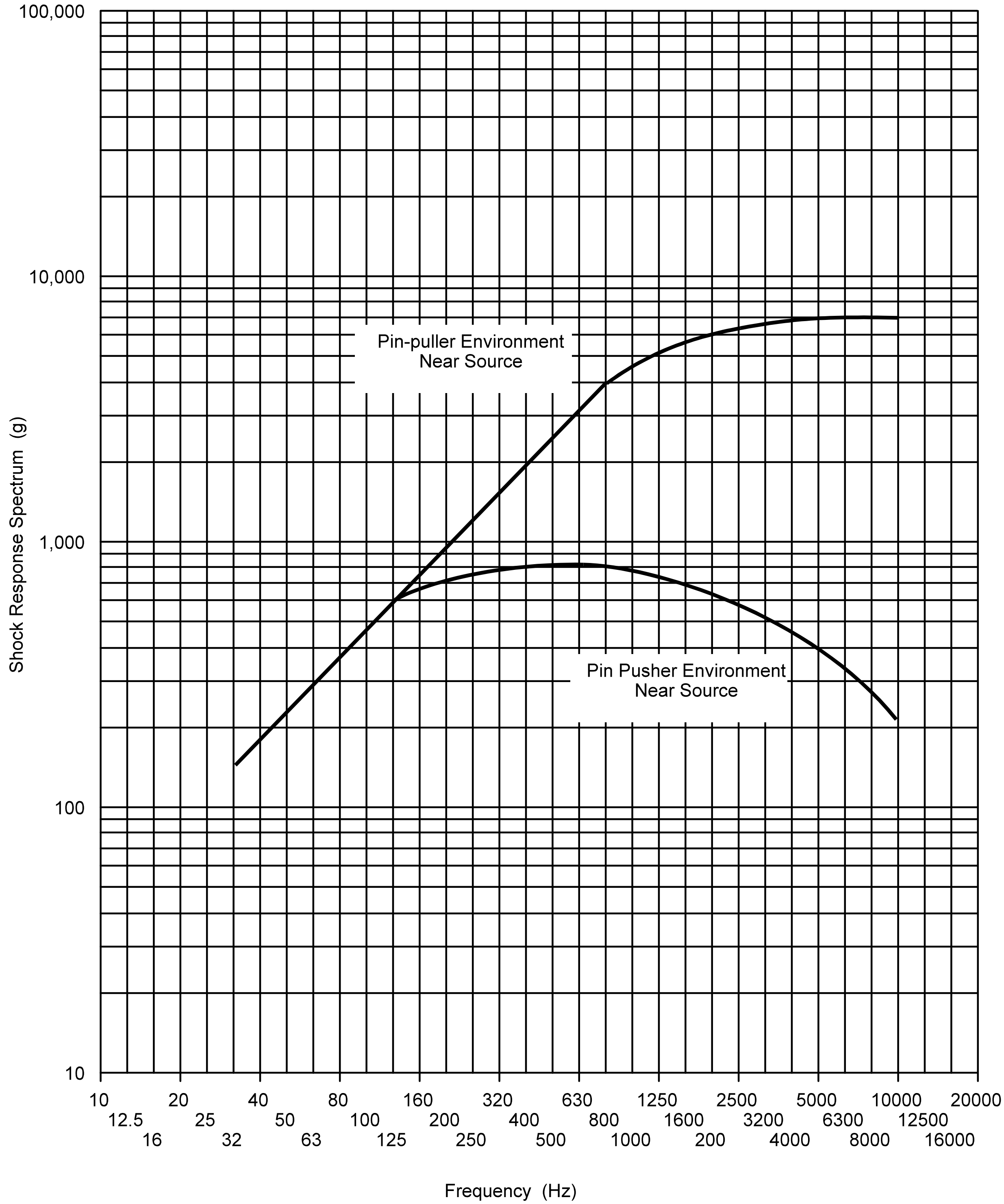



Figure A-6 - Shock Environment Produced by Pin-Pullers and Pin-Pushers

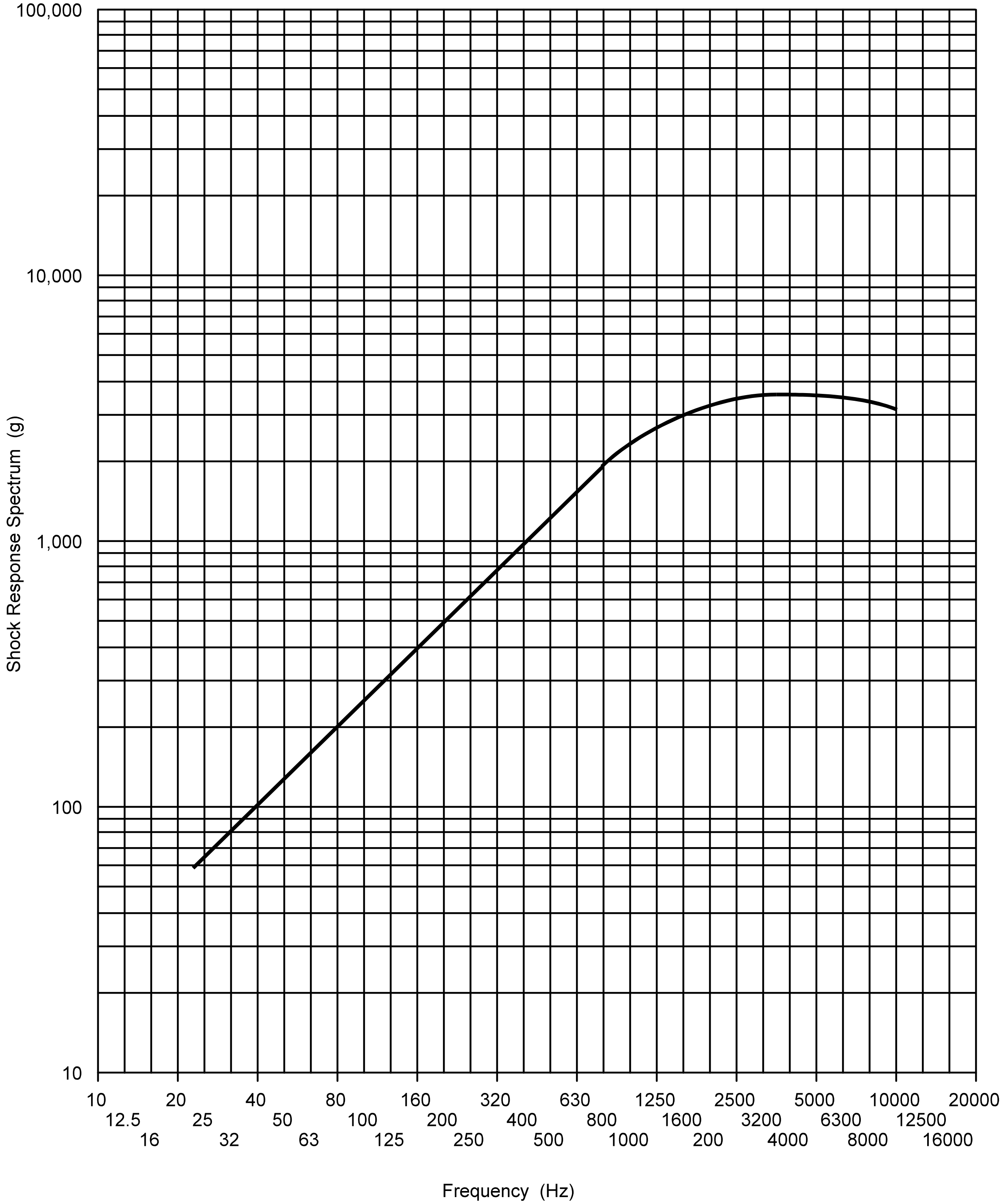



Figure A-7 - Shock Environment Produced by Bolt-Cutters, Pin-Cutters, and Cable-Cutters

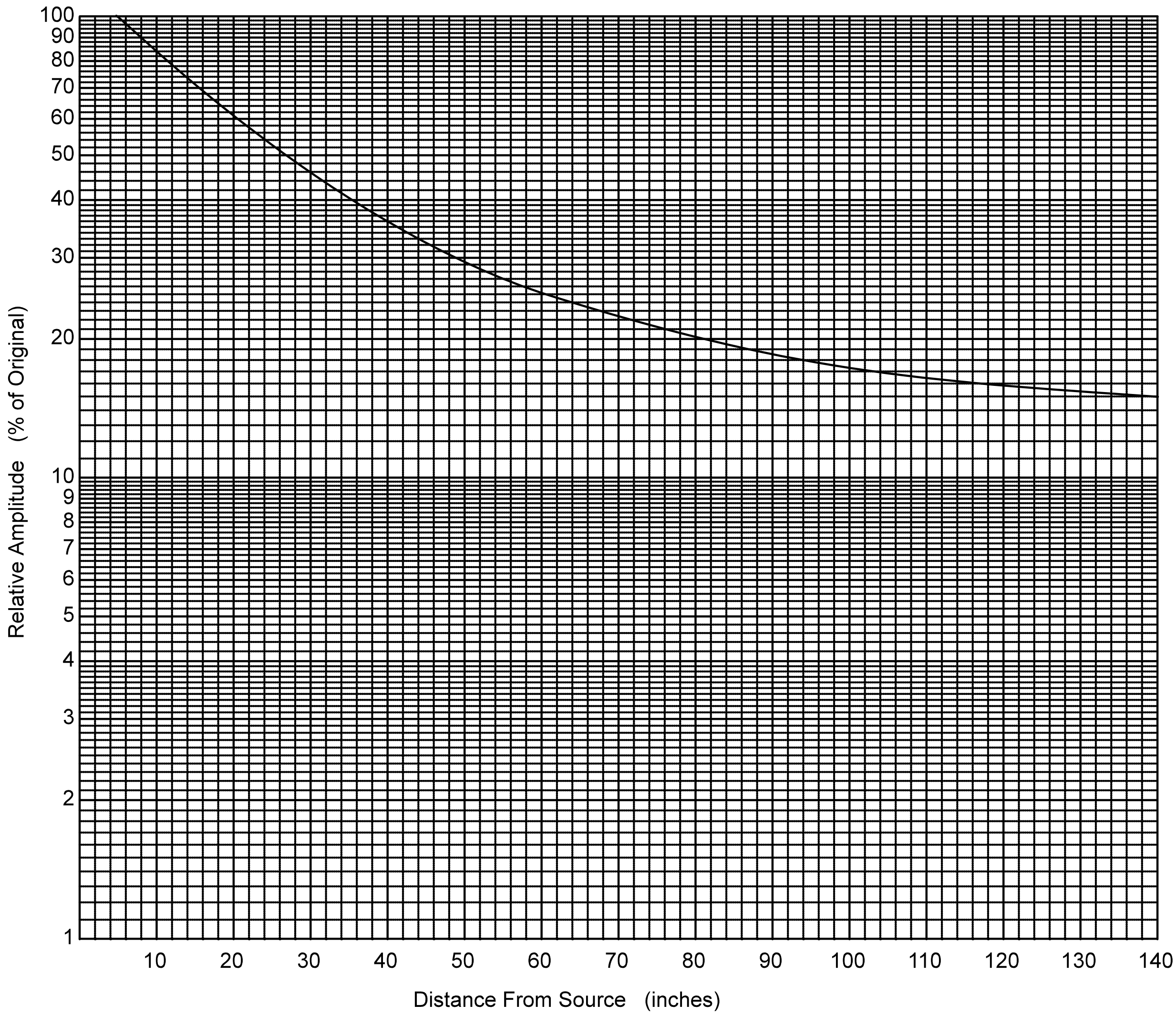
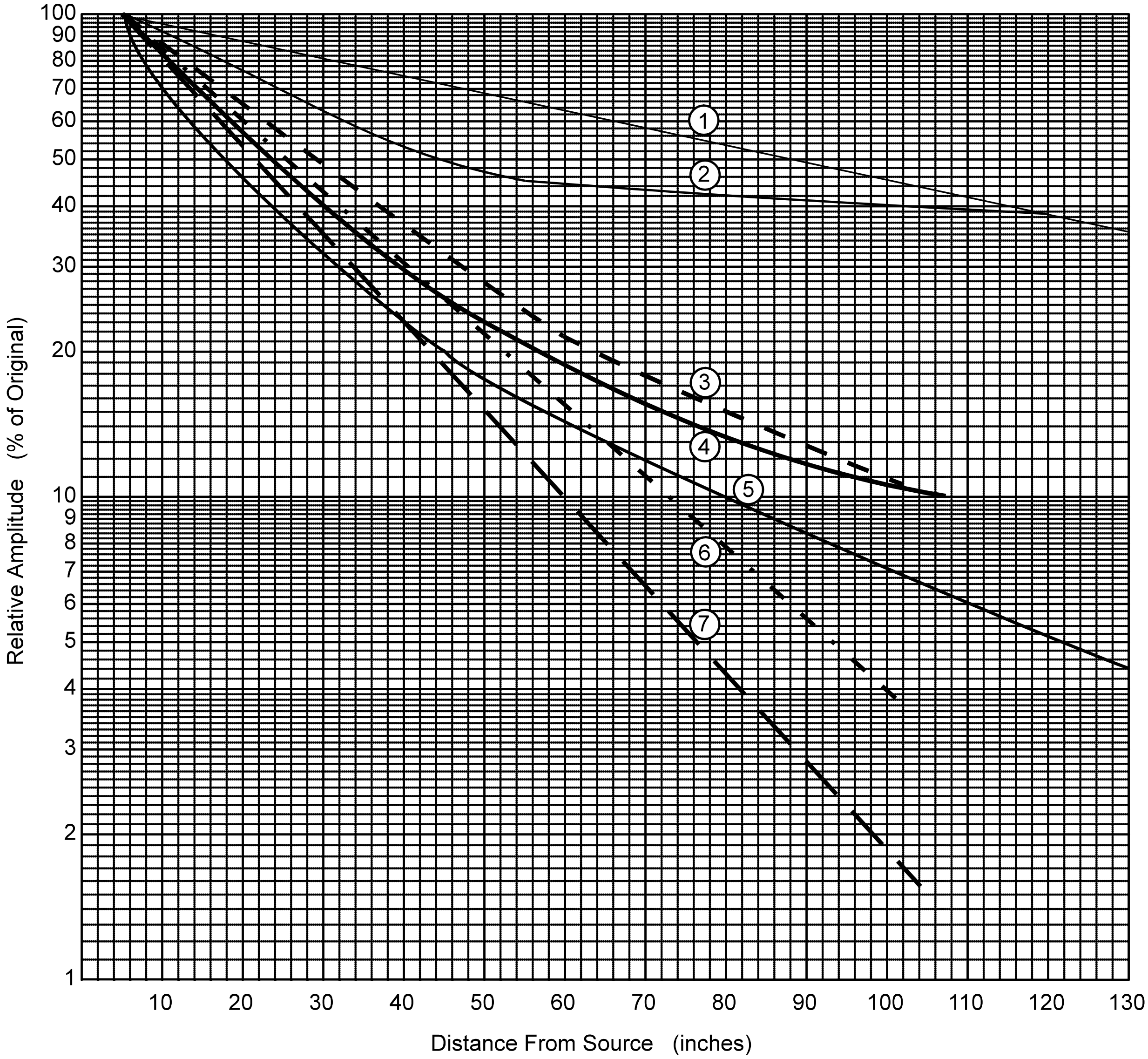



Figure A-8 - Attenuation of Constant Velocity Line




1. Honeycomb structure
2. Longeron or stringer of skin/ring-frame structure
3. Primary truss members
4. Cylindrical shell
5. Ring frame of skin/ring-frame structure
6. Complex equipment mounting structure
7. Complex airframe

Figure A-9 - Peak Pyrotechnic Shock Response vs Distance

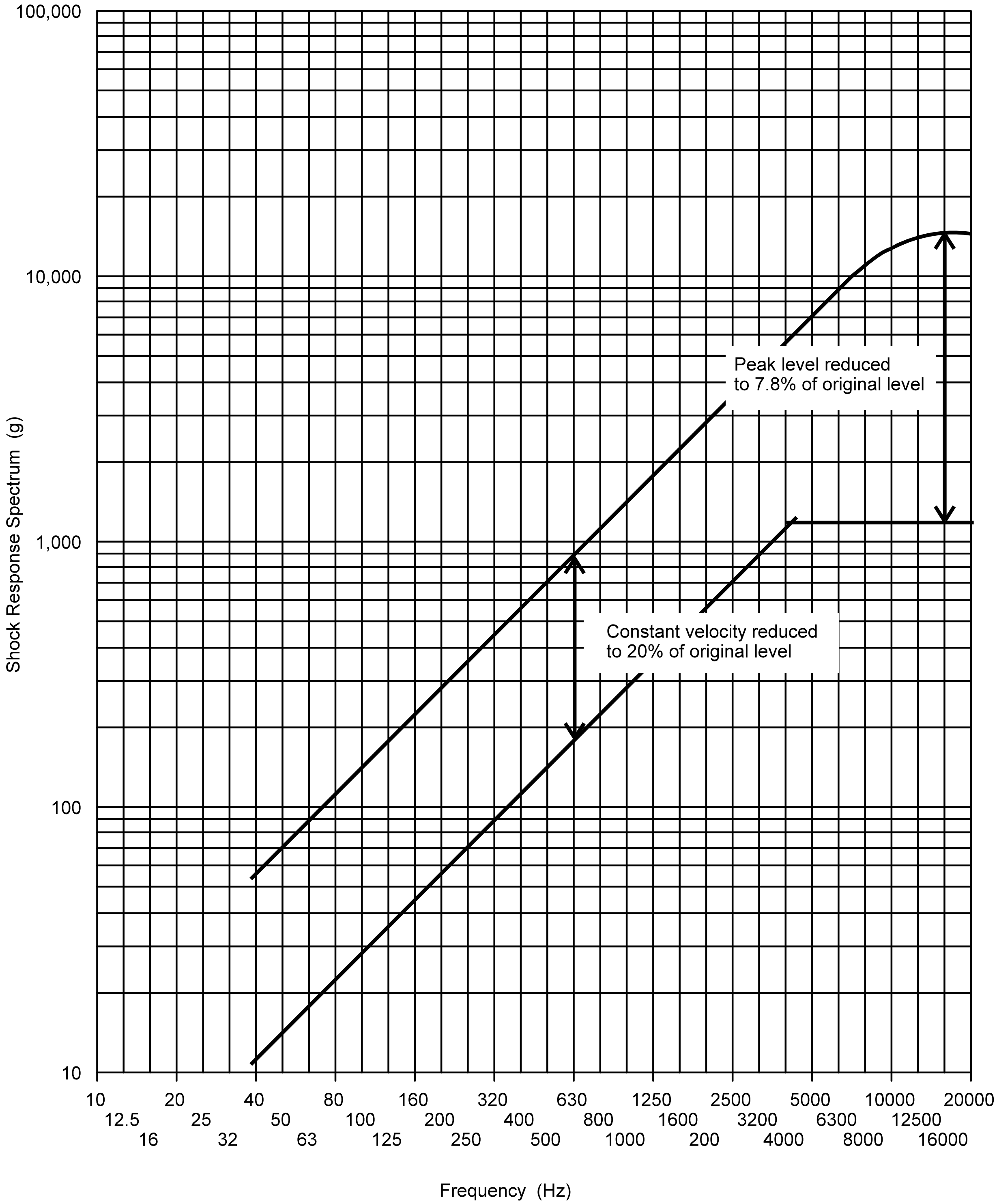



Figure A-10 - Shock Attenuation Example

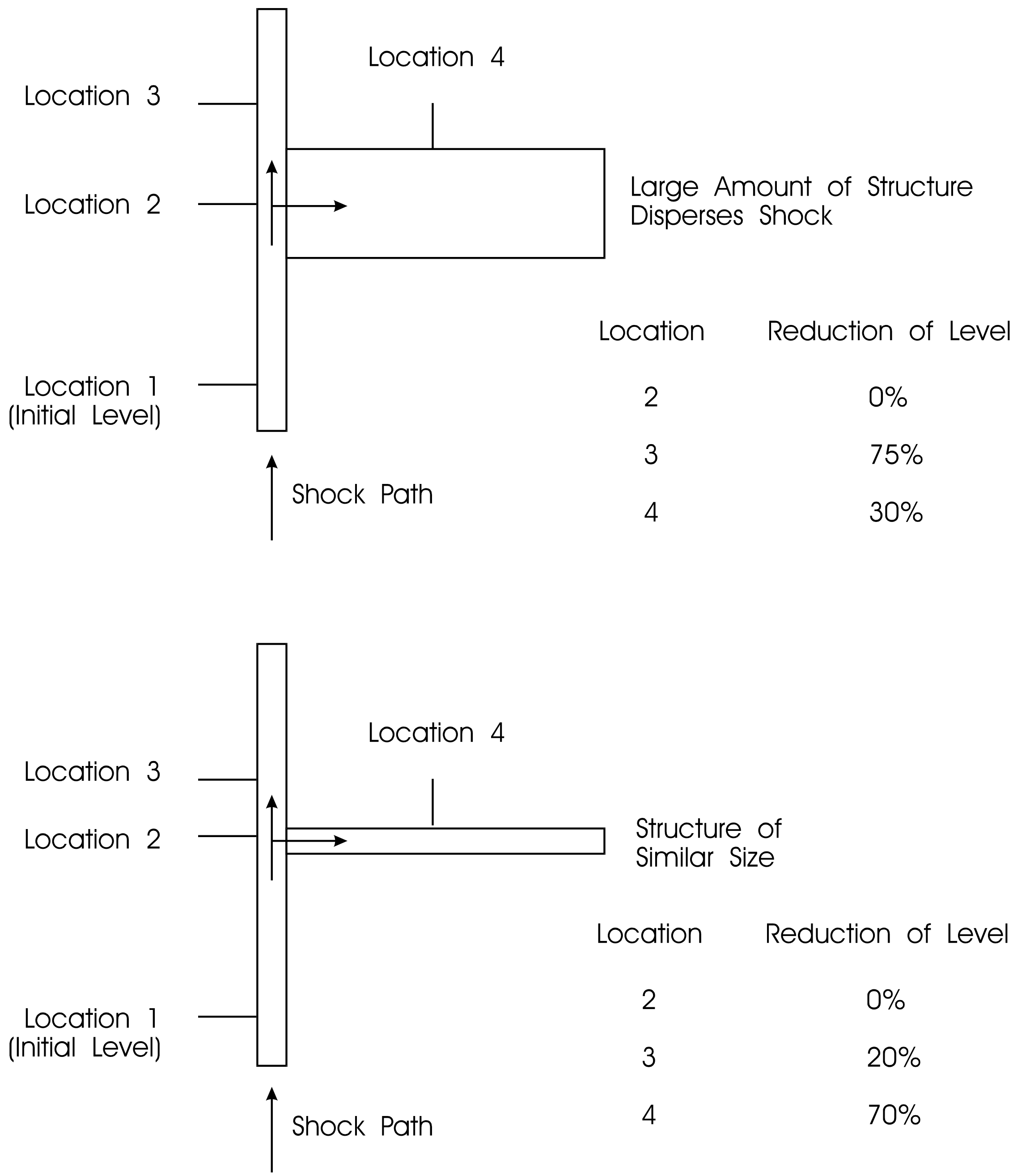



Figure A-11 - Reduction of Pyrotechnic Shock Response due to Intervening Structure