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Aerospace Systems Pyrotechnic Shock Data

(Ground Test and Flight)

Final Report

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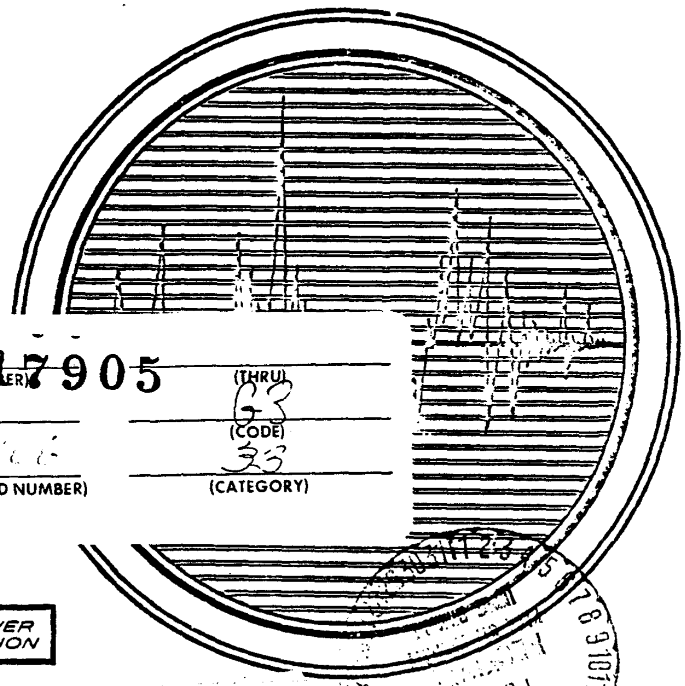
Volume VI

Pyrotechnic Shock Design Guidelines Manual



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FINAL REPORT

For

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ABSTRACT

The purpose of this document is to present a set of guidelines defining design information applicable to structure and/or equipment for designing to a pyrotechnic shock environment. These guidelines include a description of various pyrotechnic devices and associated shock levels near the source (in terms of a shock spectrum which is defined and discussed in section 1.0). Attenuation curves for a variety of structures are included and methods of isolating equipment from a shock environment are discussed. Section 5.0 lists sources of information and data on many subjects associated with pyrotechnic shock.

These guidelines are the result of the study performed under Contract NAS5-15208, "Aerospace Systems Pyrotechnic Shock Data (Ground Test and Flight)." The results of this study are contained in six volumes. The guidelines represent the first step in an attempt to present the designer with reliable information for designing to a pyrotechnic shock environment. Since analytical prediction of shock levels is presently beyond the state-of-the-art of this technology, these empirical curves must be used with discretion. A better understanding of the complex problems associated with pyrotechnic shock can be obtained by referring to the complete results of this study.

CONTENTS

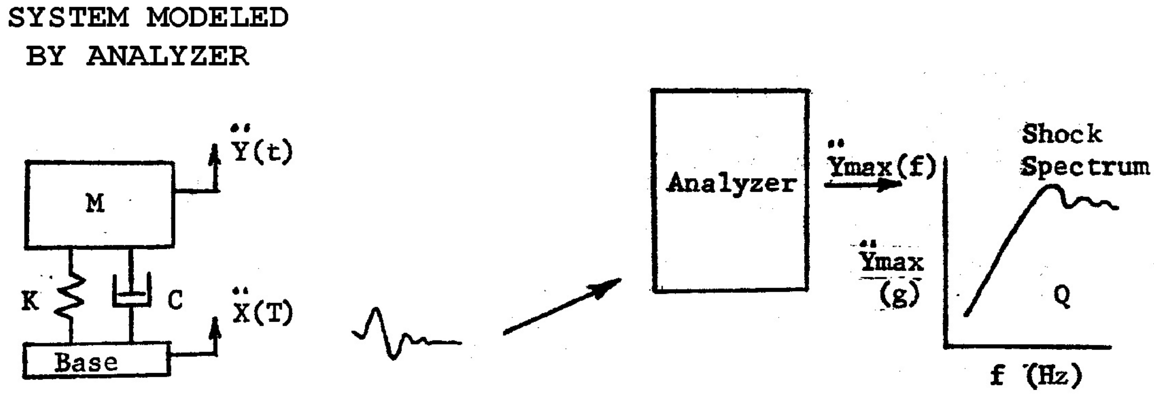
LIST OF FIGURES AND TABLES

1.0 INTRODUCTION

In recent years, pyrotechnic devices have been used extensively in the aerospace industry. These devices include linear explosive, explosive bolts, separation nuts and bolts, cartridge actuated devices (pin-puller and bolt cutters) to name a few. The environment caused by these pyrotechnics can cause damage and/or failure to equipment and structure. As a result, a technology to evaluate them is being developed. The state-of-the-art of this technology is limited mainly to testing techniques, both to predict the environment and to qualify equipment to the predicted environment.

In general, in a test program, the acceleration time histories of a number of locations are measured and recorded. Since the signature of the time history is quite complex, due to the nature of shock and intervening structure, the frequency content is not immediately obvious. To obtain the frequency information a spectral analysis is performed and results in a shock spectrum, which is the basic analytical tool for the field of pyrotechnic shock. A shock spectrum is a plot of the maximum response acceleration amplitude of a single-degree-of-freedom system versus the resonant frequency of the system and results from the application of the acceleration time history to its base.

The shock spectrum curve will vary with the amount of damping (Q) assigned to the oscillator system. The value of damping used in the analysis is noted on the spectrum. The process of obtaining a shock in the following block diagram.



$\ddot{X}(t)$ input acceleration

$\ddot{Y}(t)$ output acceleration

K = spring constant

C/C_c = ζ ratio of actual damping to critical damping

Q = $1/2\zeta$ amplification factor

f = $1/2\pi \sqrt{K/M}$, natural frequency of system

M = mass

A shock spectrum displays amplitude and frequency information characteristics of the time history and is used extensively in the aerospace industry to specify a shock environment.

A shock spectrum for specifying equipment qualification levels is best determined from full-scale test data. When this is not possible, a preliminary design spectrum can be estimated from the expected level at the source in conjunction with empirical attenuation curves. The information for using this method for a few devices and structures is contained in the following sections. This information is strictly empirical and can be in considerable error for many applications. However, this effort represents an initial attempt to classify data and to provide the designer with a starting point.

2.1 DESIGN GUIDLINES CONCERNING THE PYROTECHNIC DEVICE

2.2 Suggested Shock Environments

The aerospace industry is known to employ four general types of pyrotechnic devices to affect flight events:

a) Linear charges (MDF and FLSC);

b) Separation nuts and explosive bolts;

c) Pin-pullers and pin-pushers;

d) Bolt-cutters, pin-cutters and cable-cutters.

The estimated order of severity of the above devices is the order in which they are listed.

Near the explosive source the acceleration shock spectrum is characterized by a high amplitude curve that peaks in the high frequency range, usually well above 1000 Hz. In the low frequency range the spectrum can be approximated by a constant velocity line, which on a logarithmic plot of an acceleration shock spectrum has a numerical slope of one. Figure 2.1 shows these characteristics. Not all spectra show a definite constant velocity line but the low frequency range can be enveloped by such a line.

As the shock pulse propagates through the structure, the acceleration amplitude is attenuated. This attenuation is proportional to the distance from the source as measured along the shock paths. However, the amplitude attenuation is a function of frequency, and the high frequency range attenuates more rapidly than the low, as shown in figure 2.1, where the satellite was located approximately 100 inches from the source. The high frequency amplitude can attenuate from one to two orders of magnitude in 100 inches, while the low frequency amplitude usually attenuates less than an order of magnitude.

Suggested shock environments for these four types of devices are discussed below and presented in Figures 2.2 through 2.5. It should be remembered that these environments are only suggested; they may be in error by as much as an order of magnitude for particular cases. The suggested environments are based on data measured within 10 inches of the source and also based on a shock spectrum analysis at Q=10. These curves represent an envelope of a few measurements and cannot be considered a statistical estimate.

2.1.1 Linear Explosives

Linear explosive pyrotechnic devices are usually employed in separation joints. The level of the environments produced by such a joint is dependent upon the thickness of the material cut and the size of the explosive charge used. Figure 2.2 presents the suggested environments produced by separation joints for several combinations of joint thickness and charge size.

The acceleration time histories characteristic of linear explosive devices have an effective duration of approximately 3 milliseconds.

2.1.2 Separation Nuts and Explosive Bolts

Figure 2.3 presents the suggested shock environments produced by detonation of separation nuts and explosive bolts. Levels are shown for the environment near the source and for the use of a V-band assembly employing separation nuts.

The acceleration time histories near the shock source characteristically decay in approximately 3 milliseconds due to the high frequency signal present.

2.1.3 Pin-Pullers and Pin-Pushers

Figure 2.4 presents the suggested shock environments produced by detonation of pin-pulling and pin-pushing pyrotechnic devices.

The acceleration-time histories characteristic of pin-pullers have an effective duration of 5-15 milliseconds, while the pin-pusher is a softer, lower frequency device that may have an effective duration of up to 50 milliseconds.

2.1.4 Bolt, Pin, and Cable-Cutters

Figure 2.5 presents the suggested shock environment for bolt, pin, and cable cutting devices. This spectrum represents an envelope of data taken from these three types of devices.

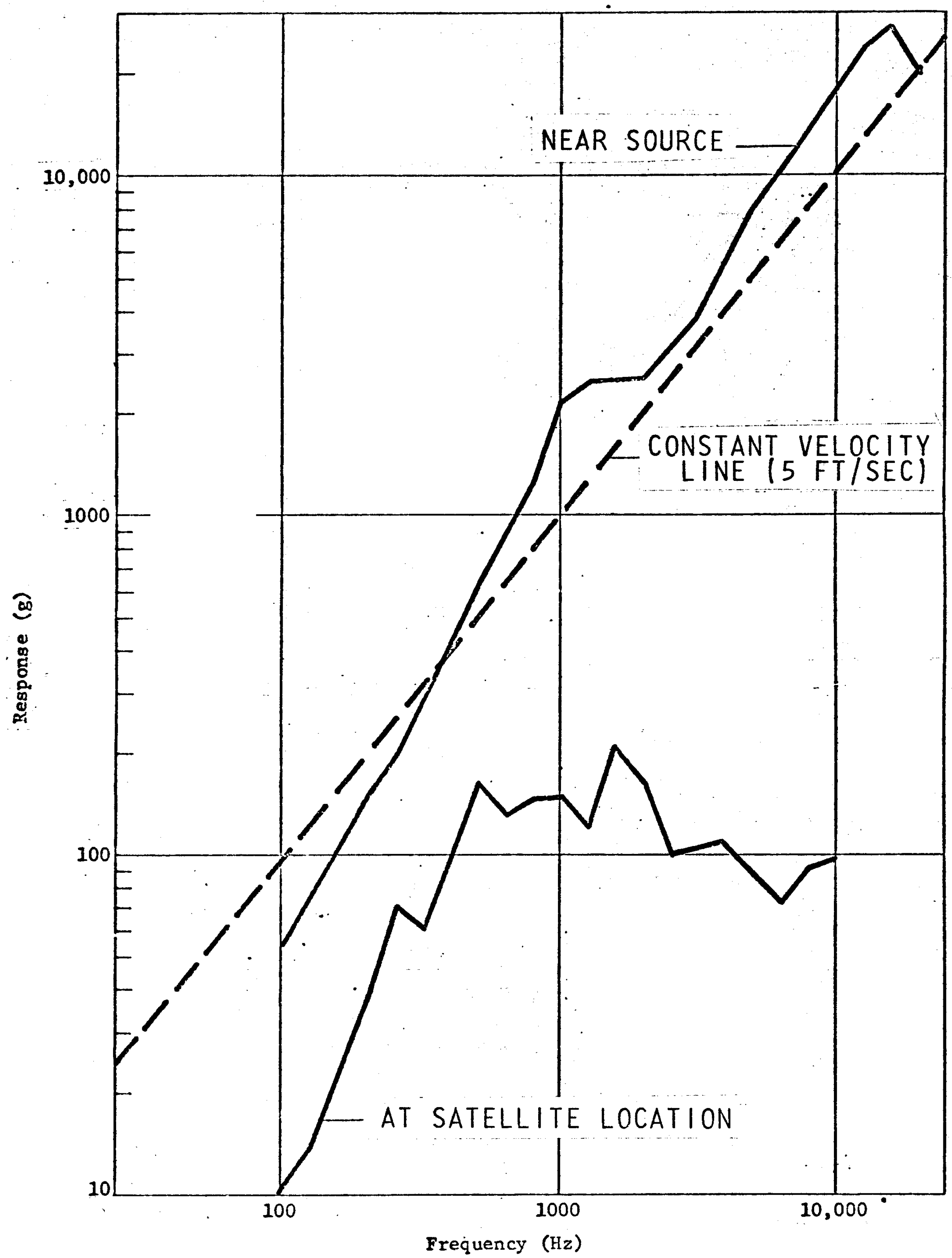


Figure 2.1 Shock Spectra

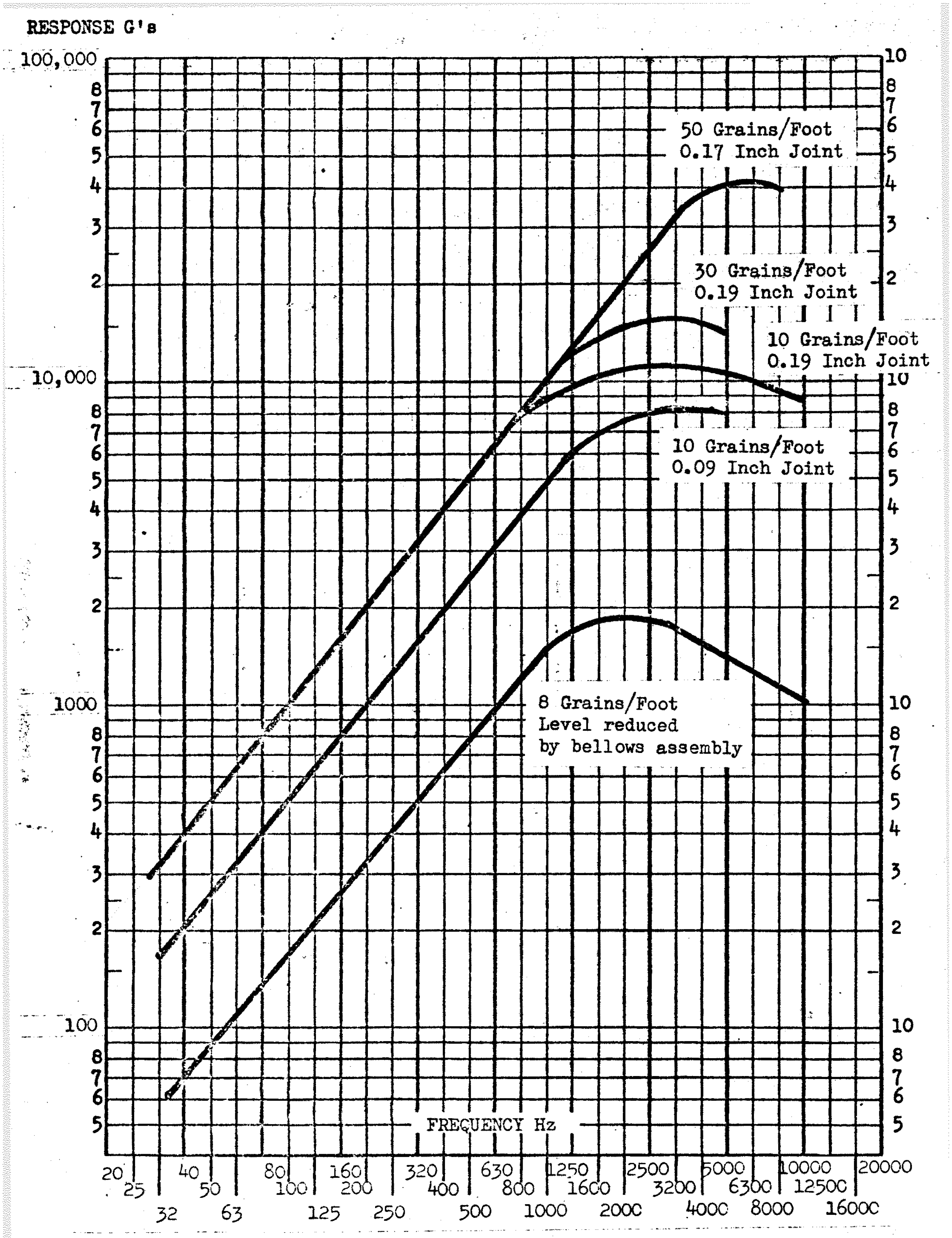


Figure 2.2 Suggested Environment Produced by Linear Pyrotechnic Devices

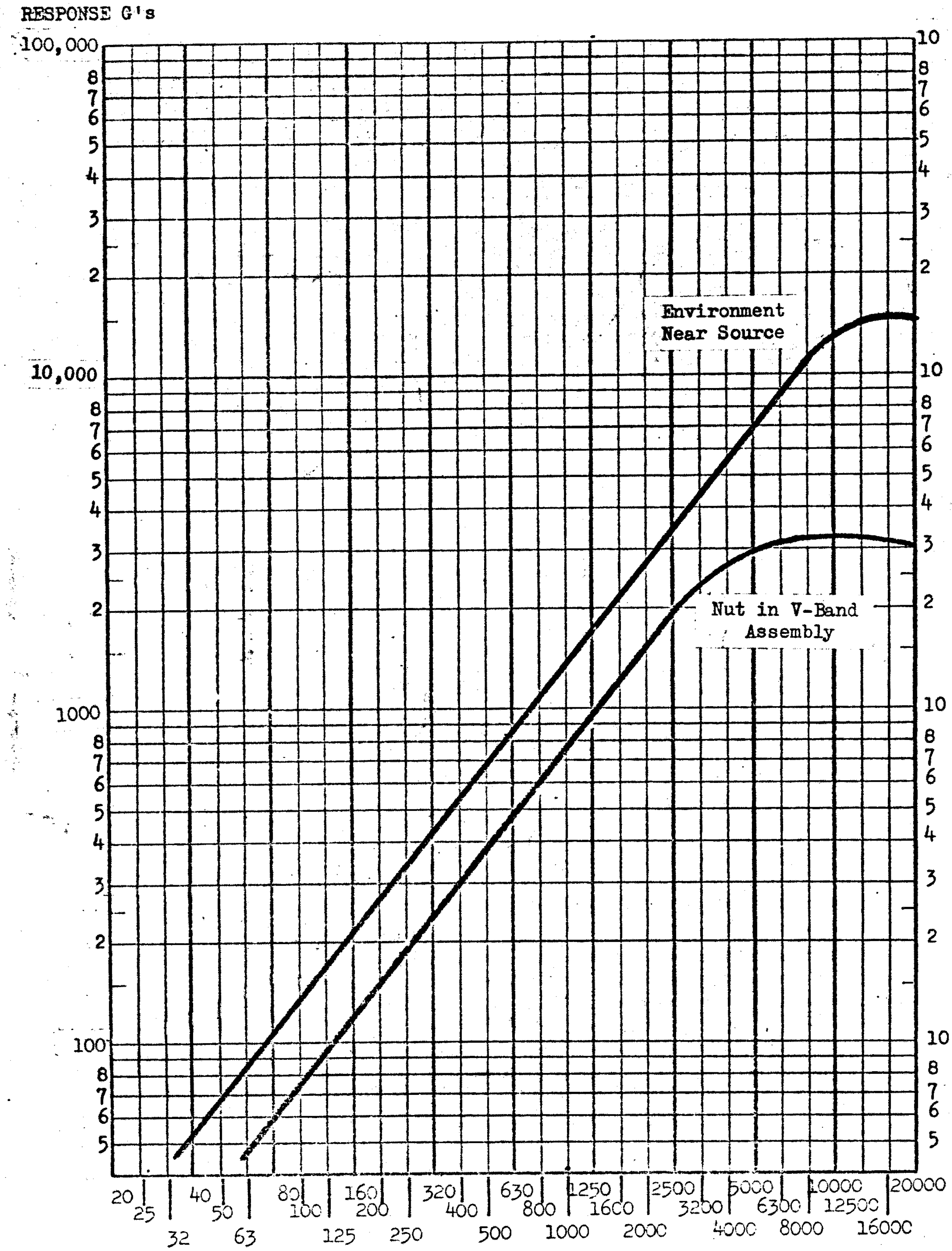


Figure 2.3 Suggested Environment Produced by Explosive Bolts and Separation Nuts

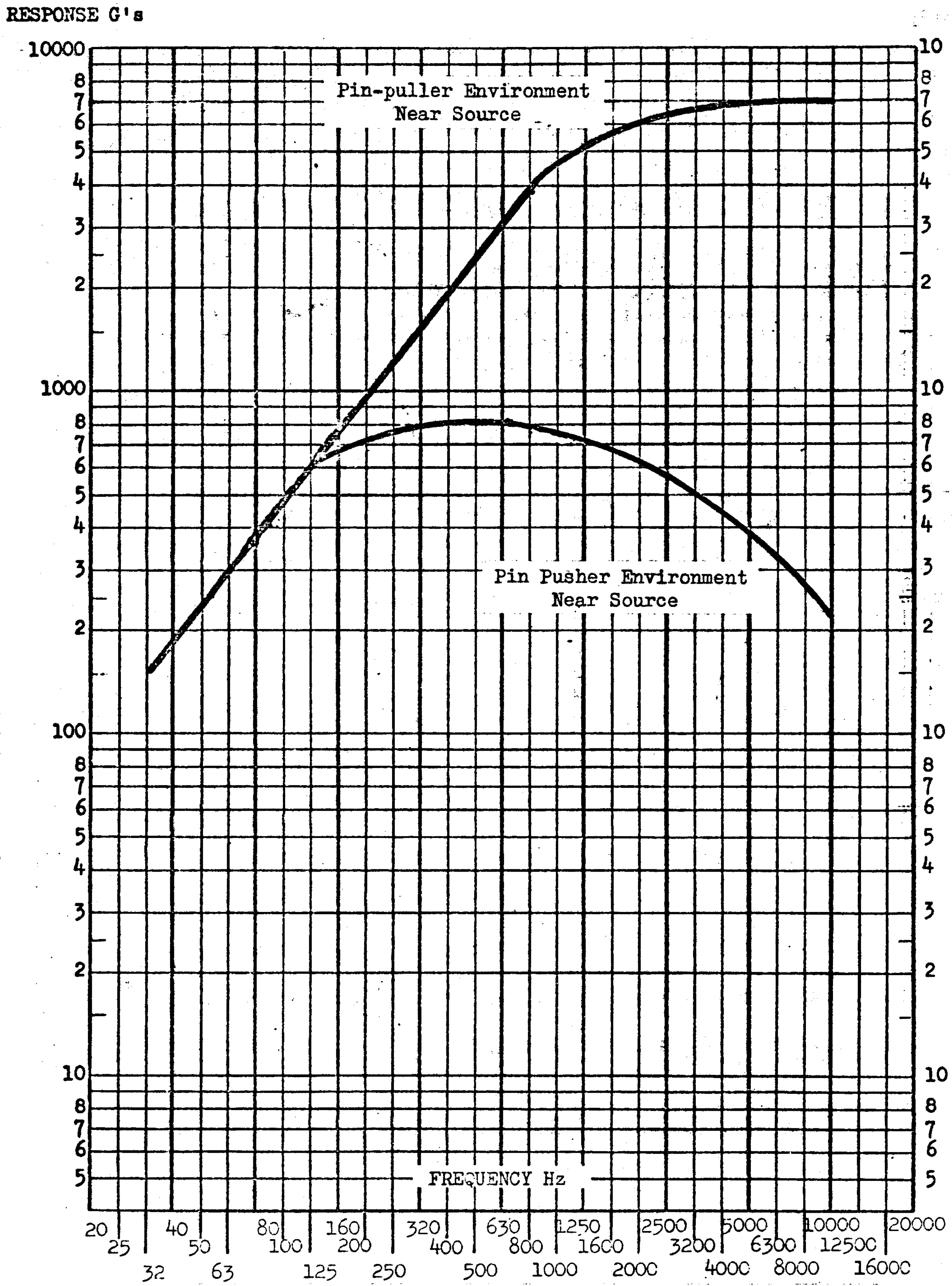


Figure 2.4. Suggested Environments Produced by Pin-Pullers and Pin Pushers

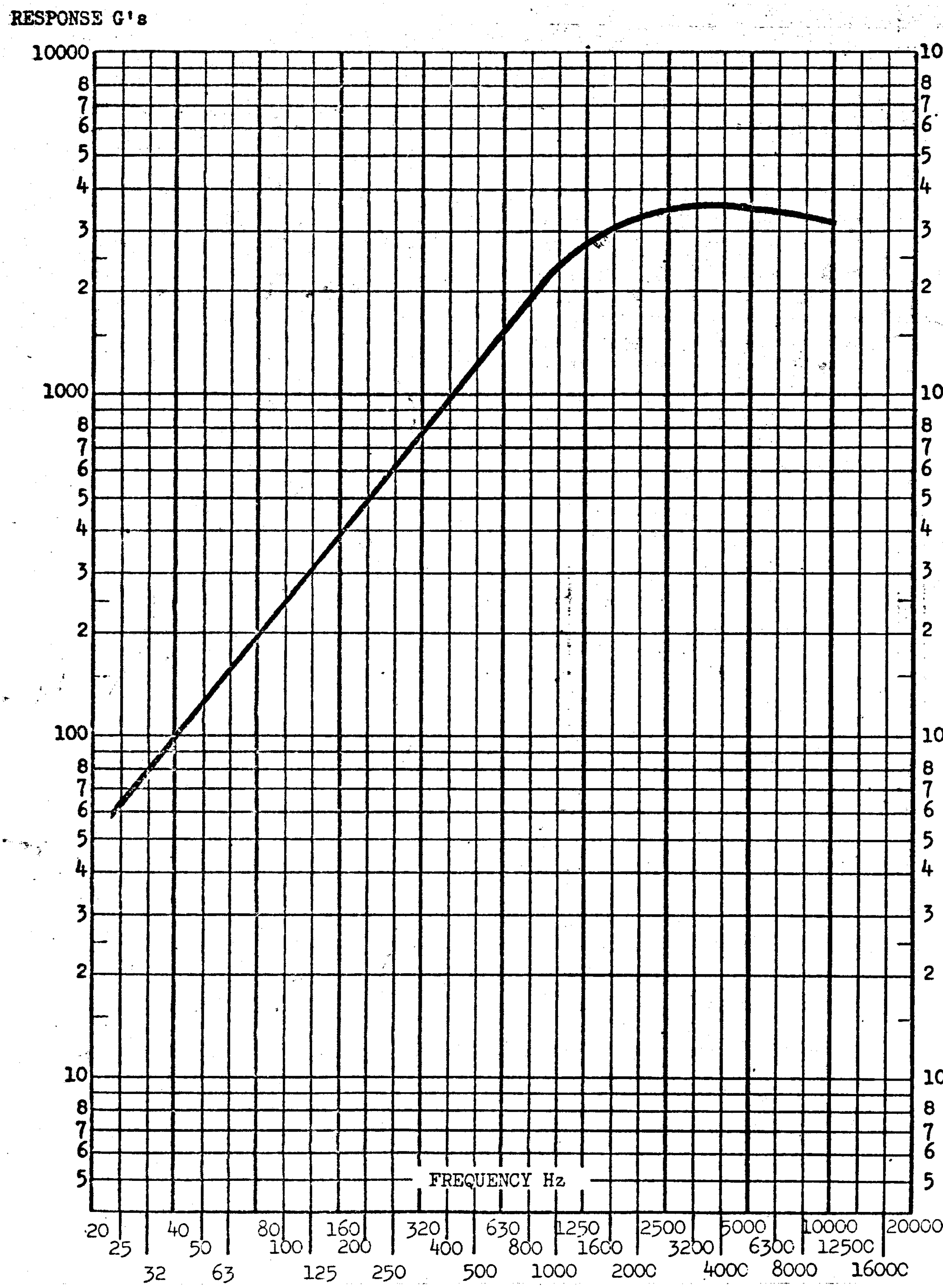


Figure 2.5. Suggested Environment Produced by Bolt -, Pin -, and Cable - Cutters

3.0 EFFECTS OF STRUCTURE

3.1 Attenuation

To empirically predict the shock environment in terms of a spectrum for a location remote from the shock source requires knowing two factors: 1) The spectrum to be expected at the source for a specific pyrotechnic device and 2) The attenuation of the spectrum with distance from the sources Source spectra for a variety of pyrotechnic devices are given in Section 2.1.

The second factor is more difficult to specify however, due to the different attenuation rates with frequency, A simple method to account for this complex situation is to specify two attenuation parameters: 1) attenuation of the peak of the spectrum and 2) attenuation of the constant velocity line. These two attenuation parameters will provide an upper bound for the predicted spectrum.

3.1.1 Attenuation of the Spectrum Peak

This section contains a number of attenuation curves for the spectrum peak for various types of structures listed in Table 3.1. The information for these curves was obtained from the data in the four data volumes of this study. The sections from which the data were taken are shown in Table 3.1.

These curves are normalized to a factor of one at the source and are to be used with the information in Section 2.0 on the shock levels of different devices, The majority of measurements are made approximately 5 inches from the source. The curves below are arbitrarily set to a value of one at 5 inches from the source. One curve is presented in each case and represents an envelope of the attenuation curves for three directions.

It must be recognized that these curves are generated from limited data for each type of structure and are to be used with discretion. Since structures vary so greatly, the levels predicted by these curves can be in considerable error. Consequently, it is recommended that the shock values be confirmed by measured data on the full scale flight configured hardware, i.e., verification tests.

TABLE 3.1. LIST OF STRUCTURES FOR ATTENUATION CURVES

STRUCTURE	DESCRIPTION OF STRUCTURE	DATA SOURCE	FIGURE
Cylindrical Shell	Without stringers or ring/frame	I.B.1 I.B.2 I.B.3	3.1
Skin/ring frame	Longeron or stringer of skin/ring frame	II.B.1	3.2
Ring/frame	Circumferential ring frame of skin/ring frame with longerons	II.B.1	3.3
Primary Truss	Truss members including the effects of joints	II.B.1	3.4
Complex Airframe	Airframe structure including skin such as the Prime vehicle	IV.A	3.5
Complex Equipment	Equipment mounting such as a payload truss network	II.B.1 II.B.2 II.B.3	3.6
Honeycomb	Honeycomb used as load carrying Structure	I.C.2	3.7

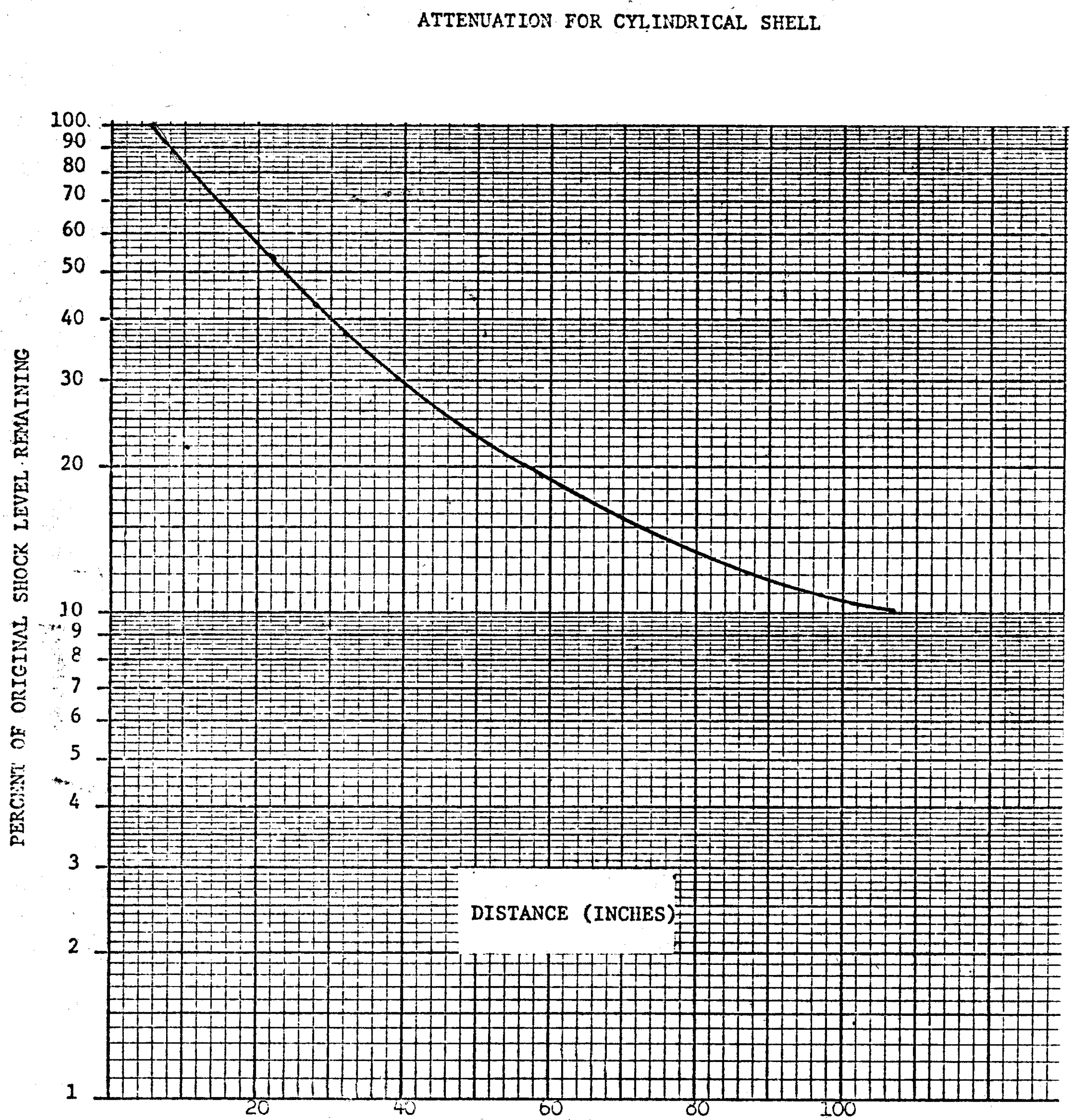


Figure 3.1 Attenuation for Cylindrical Shell

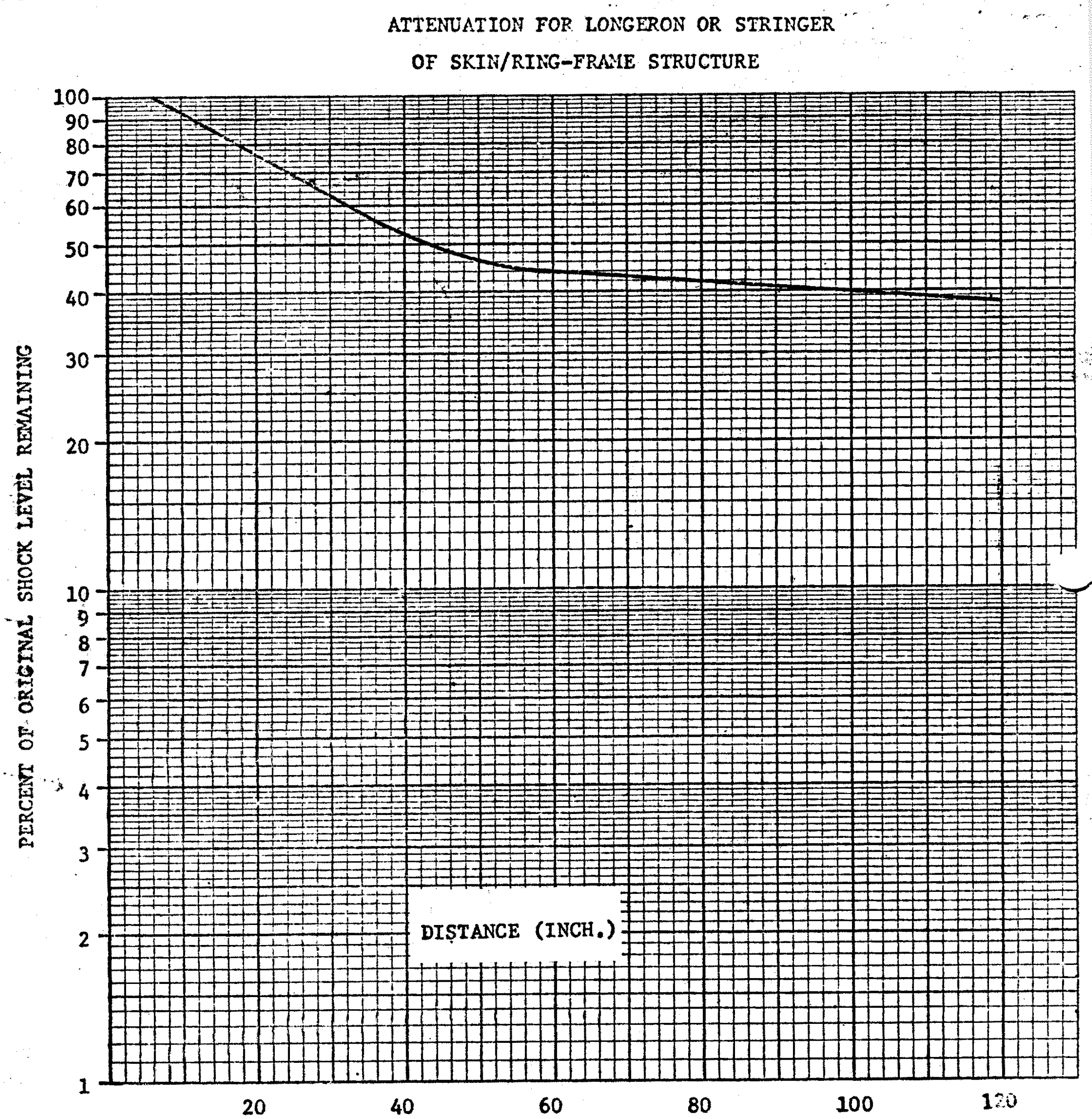


Figure 3.2 Attenuation for Longeron or Stringer

ATTENUATION FOR RING FRAME OF
SKIN/RING-FRAME STRUCTURE

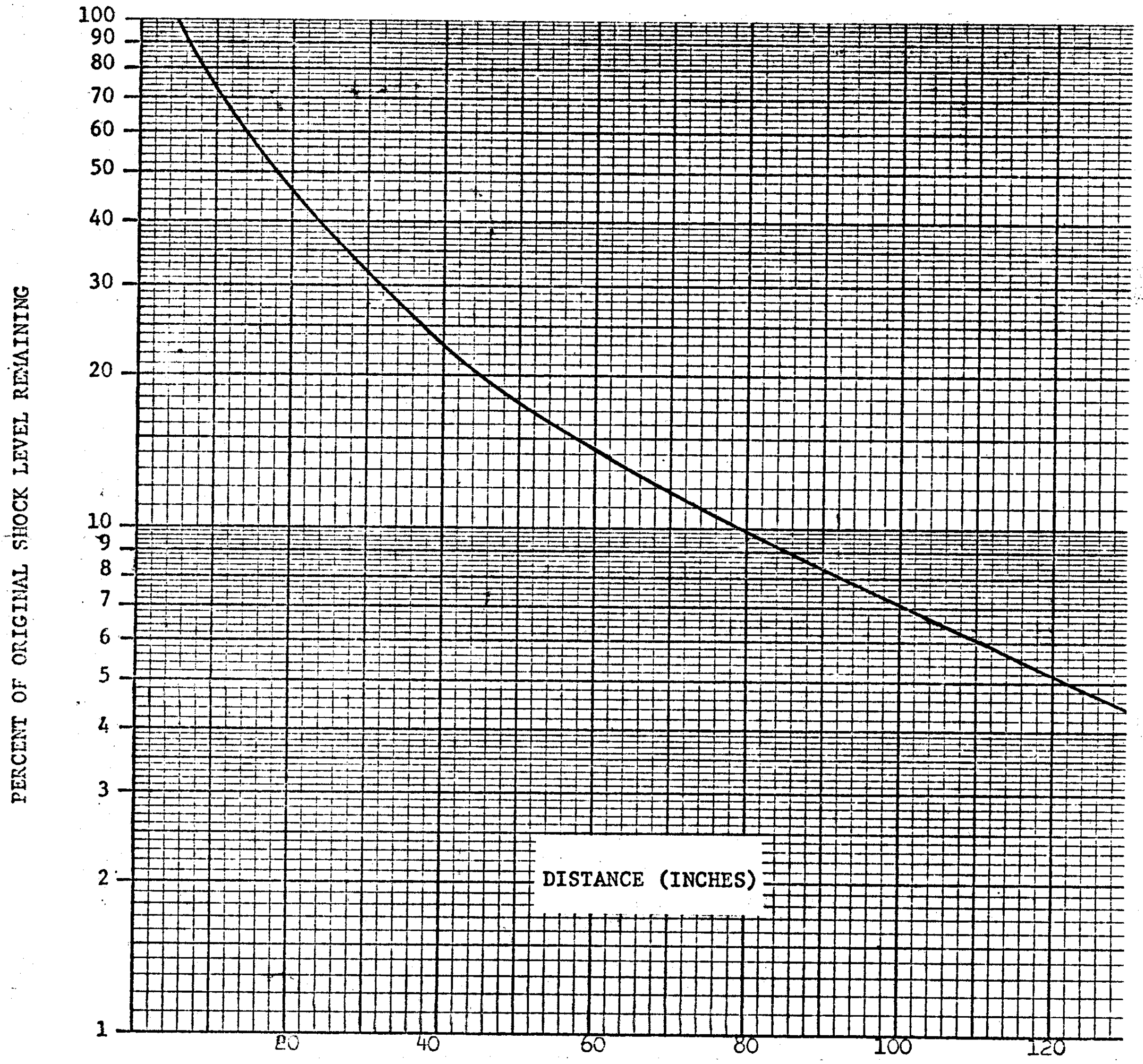


Figure 3.3 Attenuation for Ring Frame

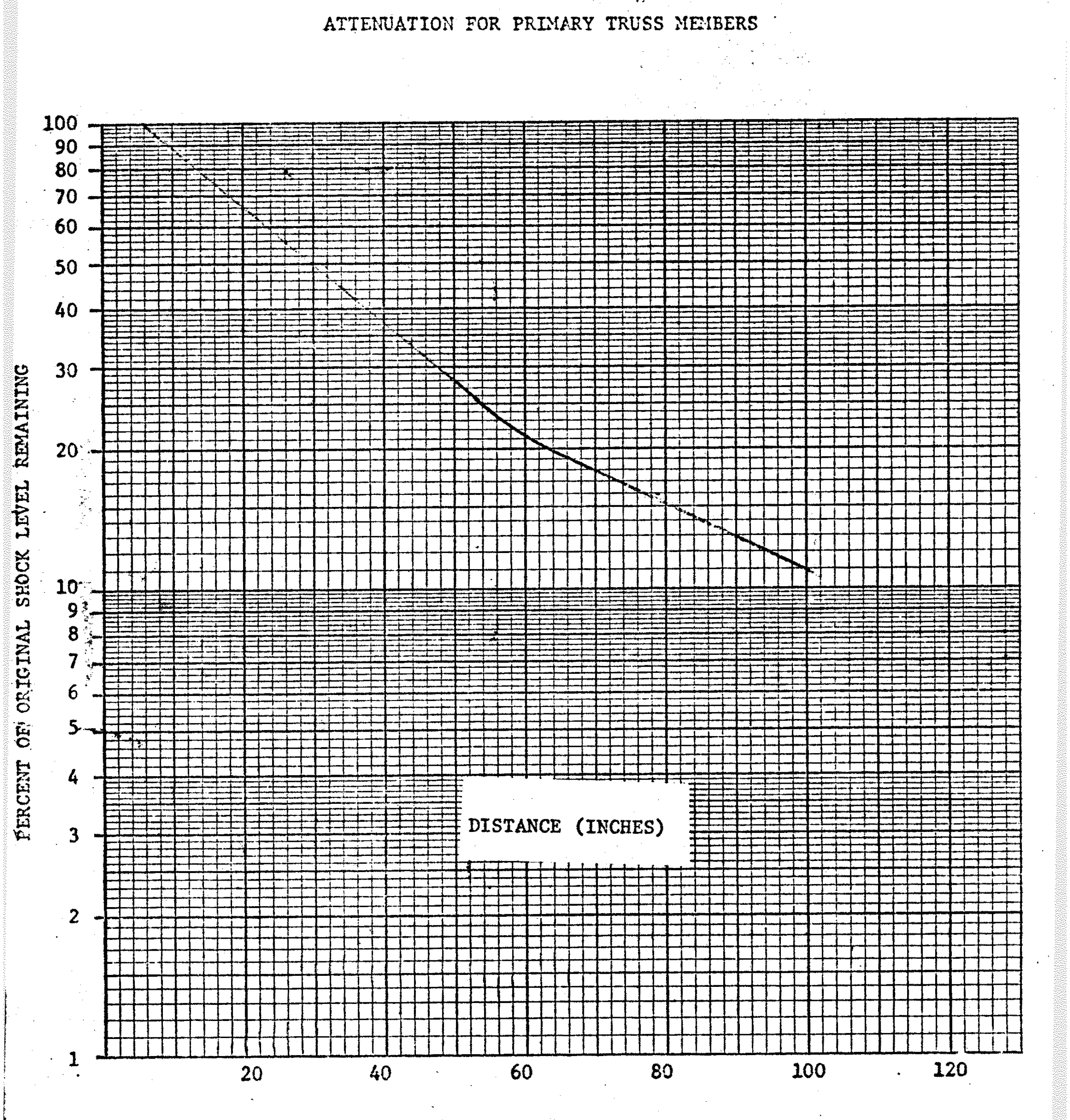


Figure 3.4 Attenuation for Primary Truss

ATTENUATION FOR COMPLEX AIRFRAME

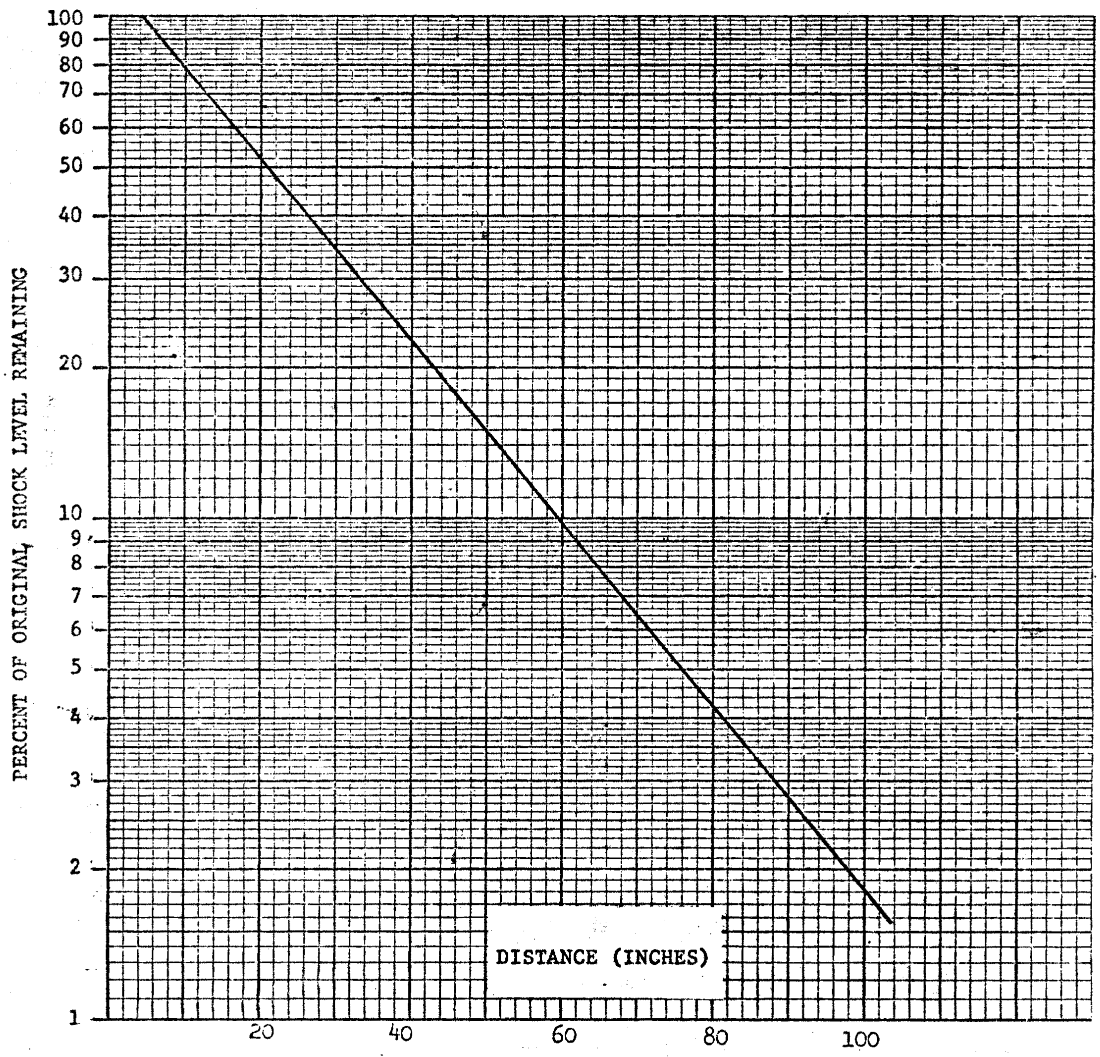


Figure 3.5 Attenuation for Complex Airframe

ATTENUATION FOR COMPLEX EQUIPMENT MOUNTING STRUCTURE

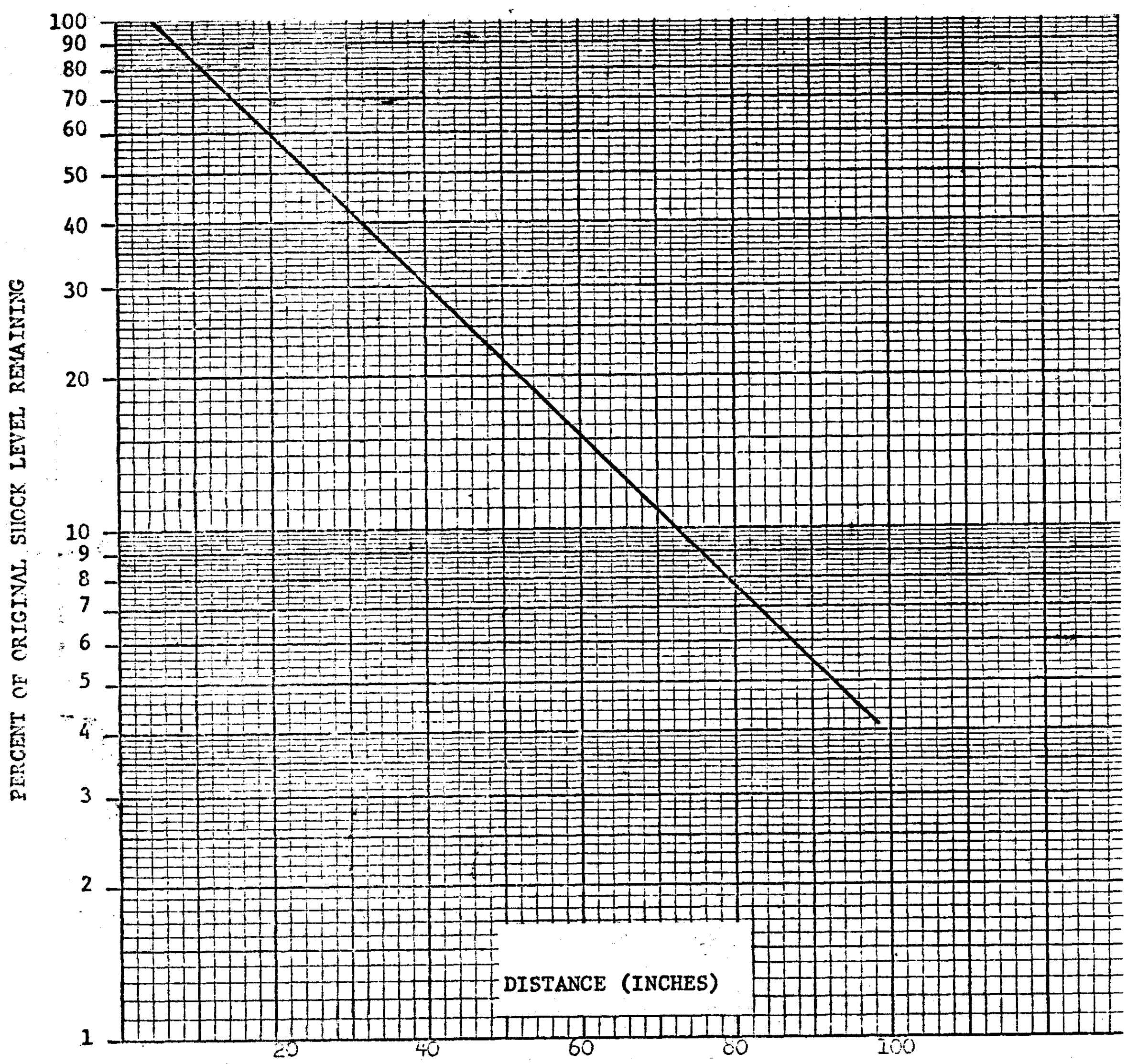


Figure 3.6 Attenuation for Equipment Mounting Structure

ATTENUATION FOR HONEYCOMB STRUCTURE

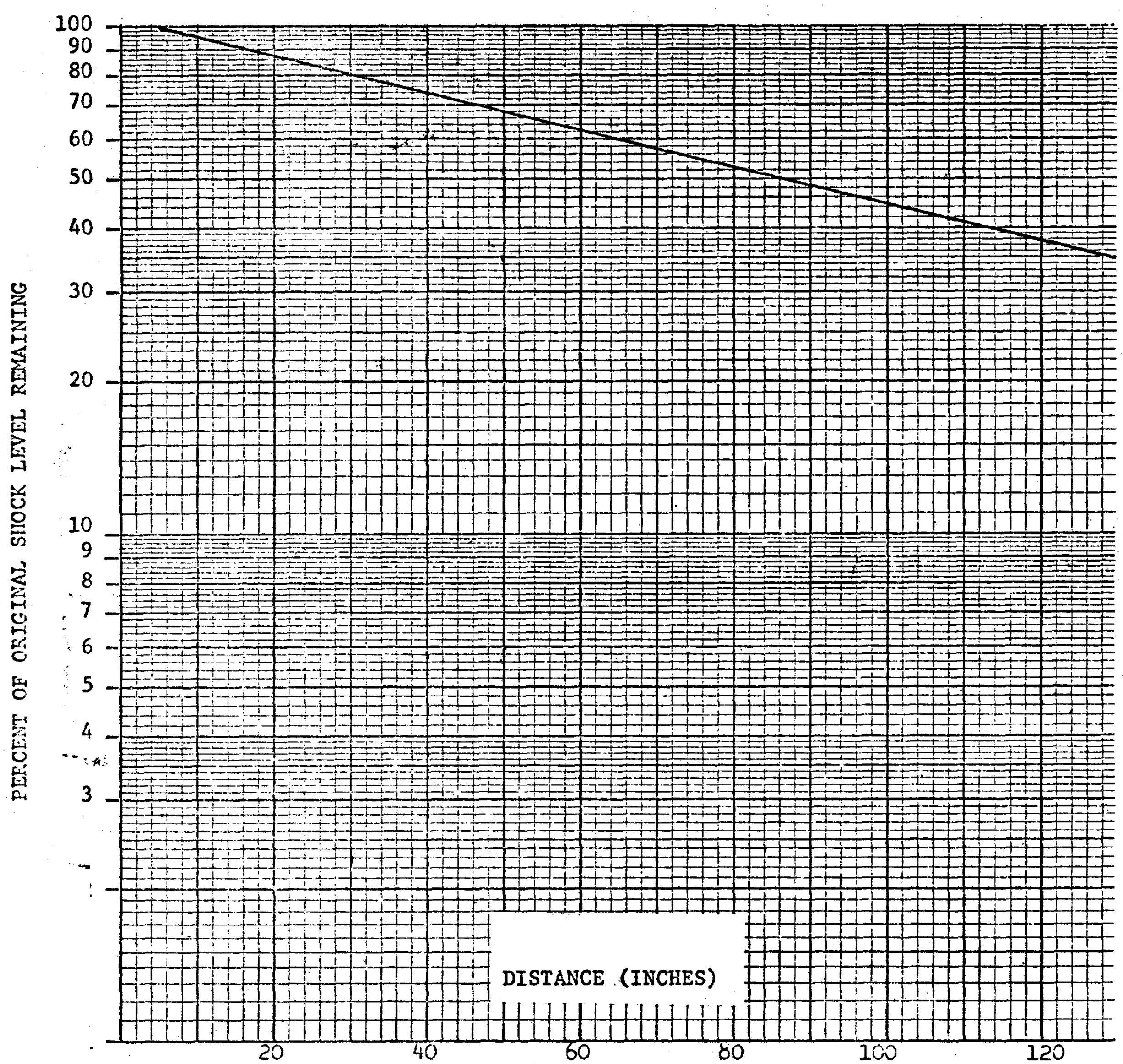


Figure 3.7 Attenuation for Honeycomb

3.1.2 Attenuation of the Constant Velocity Line

Figure 3.8 gives the attenuation curve for the constant velocity line. The curve is normalized such that the vertical axis is in terns of percentage of original velocity level remaining. Notice that this curve approaches approximately the 15 percent level. Notice the constant velocity line never attenuates more than an order of magnitude. This curve was obtained from data on a truss structure and is discussed in volume I of this report. Experience with other data indicates that this curve is representative for many types of structures. The constant velocity line represents an envelope of the shock spectrum in the low frequency range and is one method of accounting for the variation in attenuation with frequency.

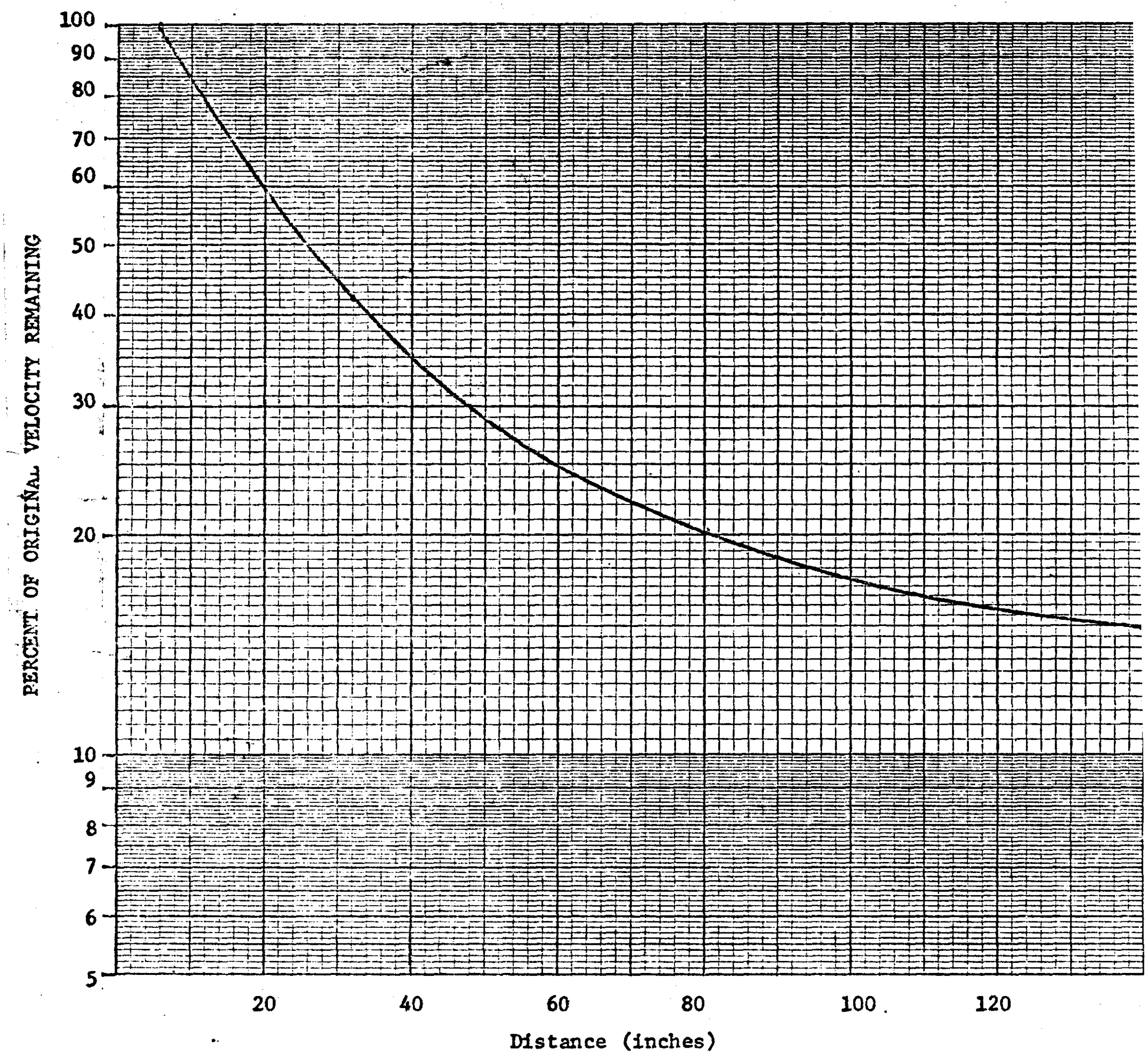


Figure 3.8 Attenuation for Constant Velocity Line

3.1.3 An Example

As an example of using the guidelines in this volume, suppose that the pyrotechnic device to be used is an explosive bolt (See Volume III for data on explosive bolts). Figure 2.3 gives the expected environment near the source as -a spectrum that peaks at 15,000 g's at 15,000 Hz and with a constant velocity line of 15 ft/sec. Figure 3.9 shows the source spectrum, Suppose further that an instrument was located 100 inches from the source measured along the shock path) and the environment for this instrument was desired. Assume the structure could be described as complex airframe (see Table 3.1). Then from Figure 3.5 the peak of the spectrum would be attenuated .to 1.8 percent of its original level or to 280 g's. A line at 280 g's is shown on Figure 3.8. From Figure 3.8 the velocity line would be attenuated to 17.5 percent of its original value or to 1.2 ft/sec. This line is shown on Figure 3.9. The region below these two lines establishes the predicted region for the expected environment.

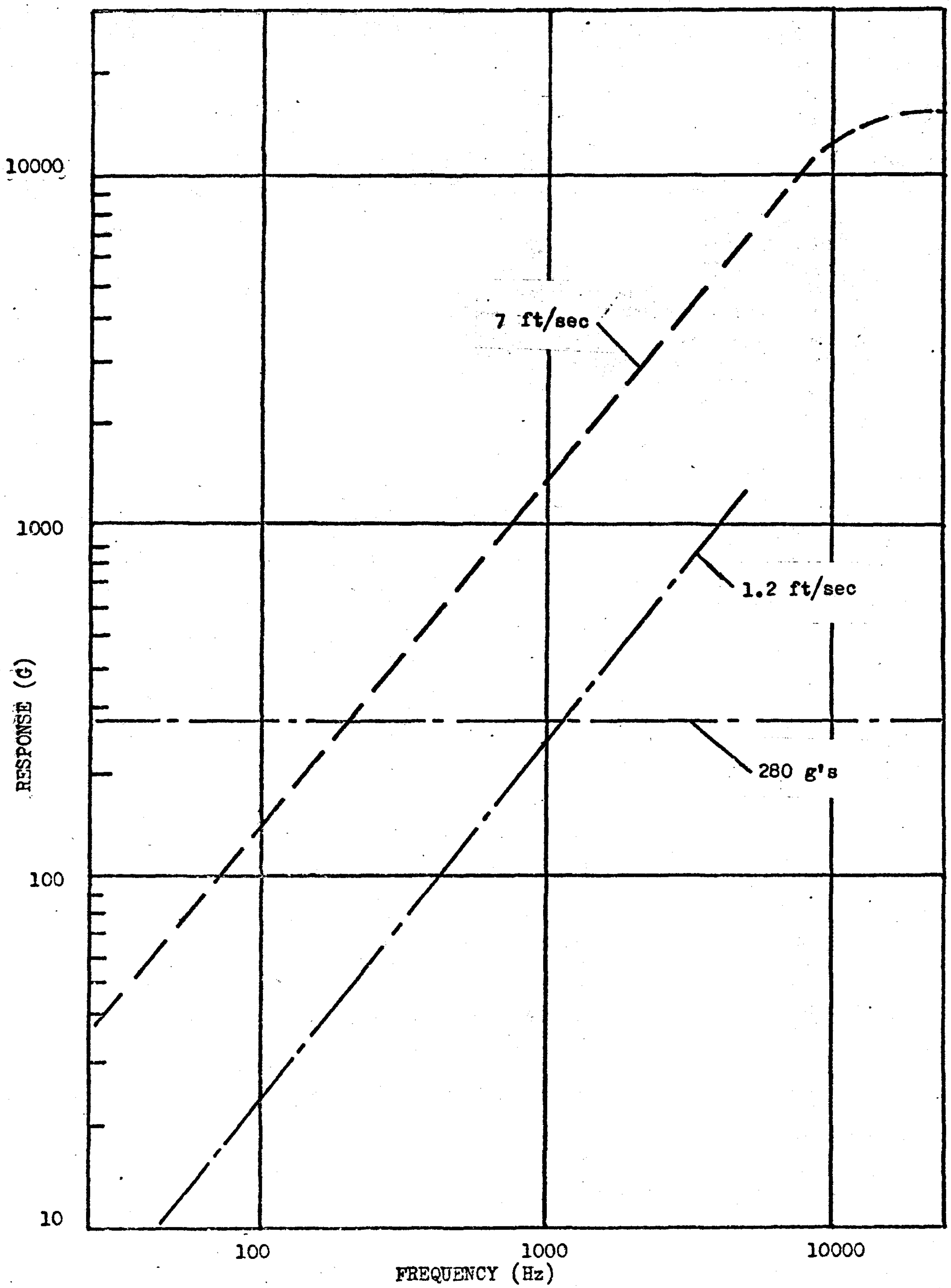


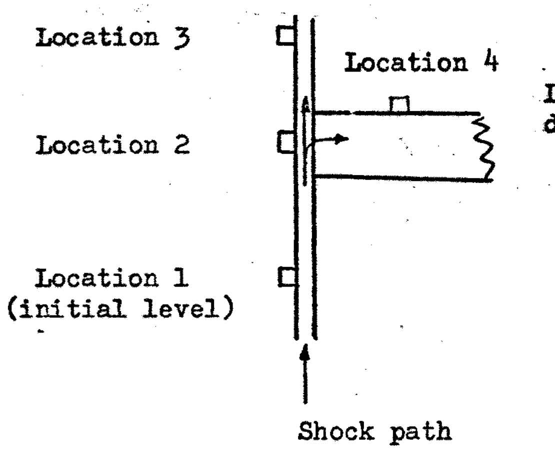
Figure 3.9 Attenuation Example

3.2 Effects of Structural Interfaces

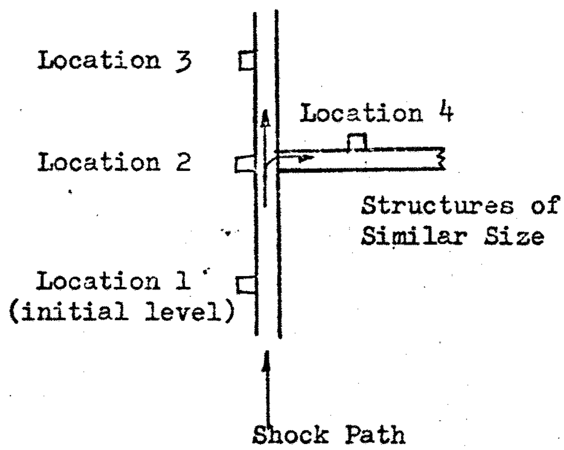
Certain structural interfaces will attenuate a shock pulse.
From general information and Reference 54, the following table has been compiled.

Interface	Percent Reduction
1. Solid Joint	0
2. Riveted butt joint	0
3. Matched angle joint	30 - 60
4. Solid Joint with layer of different material in Joint	0 - 30

Some reduction in shock levels can be expected from intervening structure in a shell type structure. The levels of reduction for a certain type of structure is shown in Figure 3.10 (see Sections I.A.1, I.A.2, II.B.2, and I.C.1 of the data volumes).



Location	Reduction of Level
2	0%
3	75%
4	30%



Location	Reduction of Level
2	0%
3	20%
4	70%

Figure 3.10 EFFECTS OF STRUCTURAL INTERFACES

4.0 EQUIPMENT DESIGN AND MOUNTING

When the shock level to sensitive equipment is too high, three methods of reducing the environment are available; isolate or redesign the pyrotechnic device, redesign or modify equipment, and isolate the equipment. The following discussion offers some basic information and references for more data on these three areas.

4.1 Isolation of Devices

Table 5.1 lists a number of data sources that discuss methods of reducing the shock leve1 of a pyrotechnic device by redesign of the device under the subject of "pyrotechnic design for shock reduction." A successful means of reducing the shock environment of a linear explosive was achieved by enclosing the charge in a bellows assembly and reducing the amount of material severed. This is discussed in Section I.B.1, I.B.2, and I.B.3 of Volume II.

The Prime vehicle (Section IV.A of Volume III) involved the use of crushable isolators to absorb some energy and isolate the effect of explosive nuts and bolts from the structure. The percent reduction in shock levels are given in Table VIII of Volume I.

Section II.C.2 of the Lockheed data (Volume V) discusses the means of isolating a pin-puller from the structure. The levels near the shock source were reduced by 30% to 60%. This was accomplished by inserting the isolation device inside the cylinder of the pressure cartridge to keep the piston from striking the end of the cylinder and by mounting the pin-puller on shock mounts.

4. 2 Modify Equipment

Some typical equipment modifications used successfully are:

1. Place relay circuits in an energized rather than de-energized state during shock to decrease the tendency toward relay-chatter or transfer.

2. Increase command-circuit time constants to prevent activation from control circuits that display short duration chatter and transfer characteristics.

3. Use timers to unlatch relays suspected of accidental latching during the shock event. Equipment modifications add considerable flight confidence, although this is not considered as a method of equipment qualification :unless the modified equipment is subsequently shock-tested.

4. 3 Equipment Isolation

An isolation scheme which has proved to be an effective method of improving equipment performance during a shock event is shock isolation by means of shock mounting. It is, however, only a means of improving equipment confidence unless the mount is shock-tested in combination with the equipment. Commercially available shock mounts generally will do an excellent job of isolating equipment, There are several considerations, however, in addition to shock isolation itself. Among these are the following:

Installation frequency;
Installation spaces;
Weight;
Heat dissipation or absorption;
Equipment alignment;
Universal application;
Electrical grounding.

4. 3. 1 Installation Frequency

In general, installation of equipment is governed by environments other than pyrotechnic shock. Support bracketry capable of carrying the steady state acceleration, plus random vibration loading are adequate for the shock environment.

4.3.2 Installation Space

Discovery of a shock-sensitive component often entails the installation of a shock mount where adequate space is not available. Where practical, sufficient "sway-space" should be considered where the addition of shock motions are anticipated.

4.3.3 Weight

One of the objections to the extensive use of shock mounts is the resulting increase in spacecraft weight. Where possible, therefore, equipment should be qualified for flight without shock mounts.

4.3.4 Heat Dissipation or Absorption

In some cases, the amount of heat dissipated or absorbed by equipment must be controlled so that operating temperature limits do not exceed qualification levels. A shock mount, when .used on high-heat-producing equipment, may add to the thermal problem by acting as insulator. Shock mounts, therefore, are undesirable in these cases except where equipment is scheduled to operate for short periods only. A moderate amount of equipment-produced heat may be dissipated by the use of flexible conduction straps between the equipment and the vehicle structure. Such straps are feasible, however, only for equipment that produces a limited amount of heat.

4. 3. 5 Equipment Alignment

Alignment of equipment which contain optical or tracking systems is difficult when combined with a requirement for shock mounting. This equipment usually is costly, often one of a kind, and requires maximum shock protection without being subject to the abuse of testing. The shock mount must maintain accurate dimensional stability once aligned and simultaneously provide the maximum possible shock reduction.

4.3.6 Universal Application

Although less important than performance, universal application is of considerable importance from a cost reduction standpoint. Each installation should, therefore, require a minimum of modification to equipment and to the vehicle, as well as a minimum of analysis and testing prior to use.

One type of shock-mount technique generally used for equipment protection is sown in Figure 4.1.

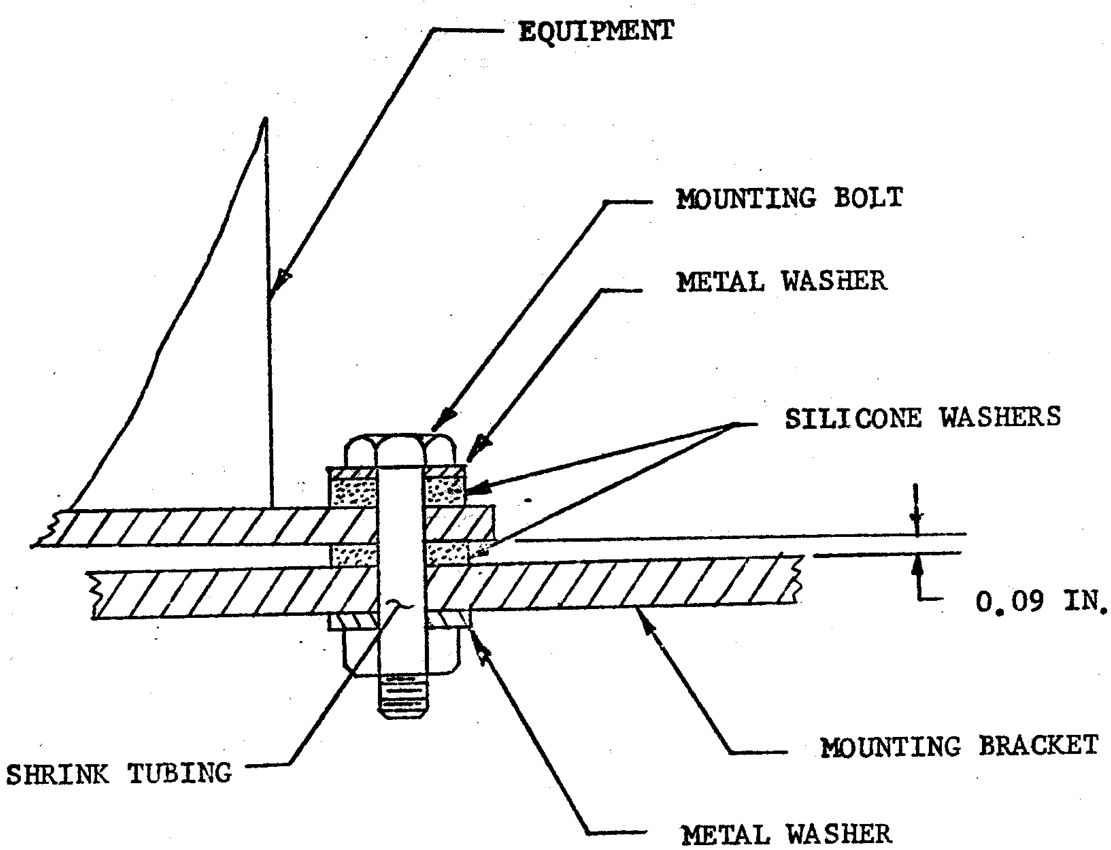


Figure 4.1 TYPICAL SHOCK MOUNT

The mount configuration consists of two silicone rubber washers and a length of plastic shrink tubing, The washers isolate the equipment package mounting flange from the vehicle structure. The shrink tubing placed around the mounting bolt completes the isolation of the equipment from the vehicle structure. The washers are semi rigid, and are in the 50 to 60 durometer range. The installation is completed by use of a gage to control the compression of the washers from an initial 0.125 inch to a 0.090 inch thickness.

This configuration, in addition to providing good shock isolation, usually satisfies requirements relative to structural vibrations, space limitations, weight, equipment alignment, and universal application.

5.0 SOURCES OF INFORMATION

The information for this design manual was obtained from many sources which have been summarized in four data volumes, II through V. Further data and insight on a number of subjects can be gained from these data volumes. Table 5.11 contains a list of subjects important to the shock engineer and gives the locations within the four volumes of data pertaining to these subjects. In addition to this table, the individual tables of contents in the data volumes list the data sections as to types of structures and pyrotechnic devices.

TABLE 5.1 SUGGESTED SOURCES OF DATA PROVIDING INFORMATION ON VARIOUS PYROTECHNIC SHOCK TOPICS

Pyrotechnic Shock Topic	Applicable Sections of Volumes II and III		Applicable Sections of Volumes IV and V	
Repeatability	I.A.4	II.B.3	II.A.2	II.E.1
	I.A.5	III.B.1	II.A.6	II.E.2
	I.A.6	III.B.2	II.A.7	II.E.3
	I.A.7	IV.A	II.B.2	II.E.5
	I.B.1	IV.B	II.D.1	II.E.6
	II.B.1	IV.C	II.D.2	II.F.2
	II.B.2	V.1		
Attenuation	I.A.2	I.B.1	II.A.2	
	I.A.6	I.B.2	II.A.5	
	I.A.7	I.B.3	II.A.7	
	I.C.1	III.B.2		
	I.C.2	IV.A		
Isolation	IV.A		II.A.3	II.C.2
			II.B.1	II.E.2
Pyrotechnic Design for Shock Reduction	I.B.1	III.B.3	II.A.3	II.B.2
	I.B.2		II.A.4	II.B.3
	I.B.3		II.B.1	II.C.1
Simulation of Structure	I.A.1	I.A.4	II.F.2	
	I.A.2	II.B.1		
	I.A.3			
Simulation of Pyrotechnic Device	II.B.2		II.F.1	
			II.F.2	
Effect of Intervening Structure	I.A.1	II.B.1	II.E.1	
	I.A.2			
	I.A.3			

TABLE 5.1 SUGGESTED SOURCES OF DATA PROVIDING INFORMATION ON VARIOUS PYROTECHNIC SHOCK TOPICS

(CONTINUED)

Pyrotechnic Shock Topic	Applicable Sections of Volumes II and III		Applicable Sections of Volumes IV and V	
Mass Effects	I.A.1 I.A.2 I.A.3	I.A.4 II.B.1	-----	
Comparison of Devices on the Same Structure	I.A.5 I.B.3 II.B.2 IV.A	IV.B IV.C V.2 V.4	II.E.4	
Effect of Multiple Charges	II.B.3 III.B.2		II.B.3	
Effect of Q	-----		II.A.1	II.A.5
Failure of Bonded Joints	-----		II.E.3	