MIL-HDBK-304B
31 OCTOBER 1978
SUPERSEDING
MIL-HDBK-304A
25 SEPTEMBER 1974

MILITARY STANDARDIZATION HANDBOOK

PACKAGE CUSHIONING DESIGN

AREA PACK

MIL-HDBK-304B
PACKAGE CUSHIONING DESIGN

31 October 1978

DEPARTMENT OF DEFENSE
Washington DC 20301

1. The first edition of this standardization handbook was developed by the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, under contractual agreement with the assistance of the cushioning industry in accordance with established procedures.

2. This publication, which is the second revision, was revised and approved on 31 October 1978 for printing and inclusion in the military standardization handbook series.

3. Beneficial comments (recommendations, additions> deletions) and any pertinent data which may be of use in improving this document should be addressed to Air Force Packaging Evaluation Agency (AFALD/PTPT), Wright-Patterson APB OH 45433 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

SCOPE.

This document provides basic and fundamental information on cushioning materials and their uses. It will provide valuable information and guidance to engineering and technical personnel concerned with designing cushioning systems and specifying required cushioning for protecting fragile equipment. This handbook is not intended to be referenced in purchase specifications except for informational purposes, nor shall it supersede any specification requirements.

Every effort has been made to reflect the latest information on the use of cushioning materials and designing cushioning systems for fragile equipment. It is the intent to review this handbook periodically to insure its completeness and currency.

REFERENDED DOCUMENTS: not applicable

DEFINITIONS: not applicable (See Appendix III for Glossary of Terms)

GENERAL REQUIREMENTS: General requirements, illustrations, examples problems, cushioning techniques and testing procedures are presented in Chapters 1-6.

DETAILED REQUIREMENTS: Detailed data is presented in Appendix IV (Stress-Strain Curves), Appendix V (Peak-Acceleration - Static Stress Curves) Appendix VI (Transmissibility - Frequency Curves) and Appendix VII (Transmissibility Tables)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

APPENDIX IV

STRESS-STRAIN CURVES

APPENDIX V

PEAK ACCELERATION-STATIC STRESS CURVES

APPENDIX VI

TRANSMISSIBILITY CURVES

APPENDIX VII

TRANSMISSIBILITY TABLES

CHAPTER 1. INTRODUCTION

Properly cushioning the vast quantity of equipment and material, packaged by all branches of the Department of Defense and Industry under Government contracts, is an almost insurmountable task. The challenge to designers of military packaging is to protect items that range from small, fragile electronic instruments to bulky aircraft structures from the conditions that the package will encounter in worldwide shipment--and do it economically.

The objective of this handbook is to provide an orderly, concise cushioning design procedure for the solution of cushioning problems applicable to all areas of packaging design and application. Liberal use is made of illustrations to depict key points, and a considerable amount of information is presented in the form of graphs.

In the past, the minimum package cushioning requirements for protecting fragile equipment from shock and vibration during shipment have been determined basically by "cut and try" methods. However, progress by numerous researchers has now produced sufficient information to enable the packaging designer to estimate cushioning requirements in most problems with fair precision. Nevertheless, some aspects of cushioning design still are too intangible for practical solution by analytical methods. Therefore, efficient cushioning design requires a blend of both scientific design principles and data together with a liberal amount of sound judgement.

To facilitate cushioning design on both a scientific and a practical basis, this document presents discussion of the analytical design methods and practical considerations that must be understood and used by the package designer in solving cushioning problems.

The information in this handbook, which is based largely upon research at the U.S. Forest Products Laboratory, Department of Agriculture, and the Air Force Packaging Evaluation Agency, applies chiefly to conventional cushioning materials, such as polyurethane foam, foamed polystyrene, foamed polyethylene, cellulose wadding, and rubberized hair. Cushioning devices, such as are shown in Figure 1-1, are considered to be beyond the scope of this document. Also, this document does not contain data on the creep characteristics of the cushioning materials. Although desirable, only fragmentary information of this nature was available at the time of preparation of the document. Transmissibility data, however, have been developed since the previous revision and have been included in this revision.

In the preparation of this document considerable effort was devoted toward simplifying the various ramifications of cushioning design. However, some aspects, such as fragility testing, are inherently complex and might be difficult to handle for personnel without considerable engineering training. Nevertheless, it seems probable that much of the material will be useful to individuals who take the time to study these procedures and recommendations.

Frequently, for brevity, detailed background information concerning particular topics was excluded from the handbook but listed in separate references. Firm comprehension of the complexities of individual problems is a requirement for the designer who must make approximations in the absence of specific quantitative information in order to solve problems, Therefore, the designer should review the information in the literature cited in Appendix II in addition to that presented in this document.

Most thorough knowledge of the handbook can be gained by reviewing the material in the order presented. However, comprehension of the cushioning design principles recommended herein might be gained more quickly by beginning with Chapter 3, “Selection and Application of the Proper Cushioning Material,” and referring to the referenced sections as they occur.

Organization of Chapter 3 thus deserves particular mention. Naturally, detailed discussion of the different aspects of cushioning design results in this information being dispersed throughout many chapters. Many of these facets are brought together in Chapter 3, In the first section of the chapter; a general procedure is given to present an understanding of the required steps in design of cushioning. The second section deals with design according to the various cushioning characteristics. The third section contains comprehensive example problems that constitute, in effect, a general review of design principles and procedures. The fourth section outlines a method by which package cushion design may be programmed and processed by computer.

Parenthetical notations, such as (2:1), beginning in section 2.2 pertain to the numbering of equations and formulae.

Parenthetical numbering, such as (3), (27), etc., placed throughout the text will be used to reference literature in Appendix II, pages 183-186.

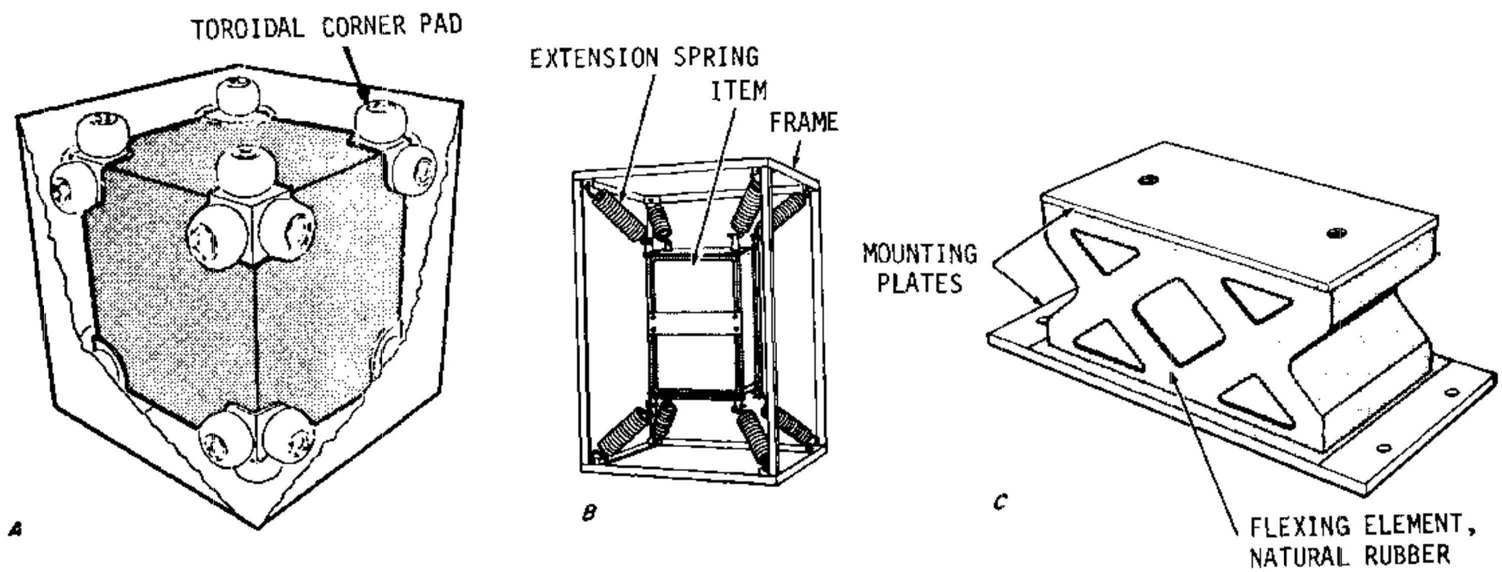


FIGURE 1-1. Cushioning devices. A, plastic toroidal corner pads; B, tension spring cushioning system; C, natural rubber shock mount.

CHAPTER 2. FUNDAMENTAL CONSIDERATIONS

Every package cushioning problem involves three fundamental considerations:

(1) The natural and induced environments that the packaged item and its package must withstand.

(2) The characteristics of the item, such as fragility, material and finish, and particulars of design.

(3) The capability of the packaging system to protect the item from transportation, handling, and storage conditions.

Restated, in each cushioning problem a particular combination of interior and exterior packaging materials with definite performance characteristics is used to protect an item having a particular resistance to damage from some degree of exposure to environmental hazards. Generally, all other aspects of package cushioning design can be considered as refinements of these three basic considerations.

A closely related corollary is that the packaging engineer must strive to achieve the greatest possible economy in design obtainable without reducing the protection to a level where intolerable shipping damage claims will result. Of course, the value, number, and logistical importance of items to be protected will greatly affect the required degree of cushioning protection.

2.1 ROUGH-HANDLING CONSIDERATIONS ASSOCIATED WITH SHIPPING.

The nature and amount of rough handling that is received by packages during shipment varies widely with a number of factors. However, the two principal elements of rough handling are shock and vibration. The field of shock and vibration analysis is a highly complex branch of engineering science, and detailed discussion of this subject is beyond the scope of this document. See references (6), (7), (9), (13), (17), (24), and (34). The information given herein is a very brief summary considered to be most applicable to package cushioning design problems.

2.1.1 Shock. A shock is a sudden, severe, nonperiodic excitation of an object or system.* Shock pulses may either be simple or complex in nature and shocks of varied nature are produced during shipment by rough-handling practices (Figure 2-l). When simple, these shock pulses are classified as half-sine, saw-tooth, or rectangular types (Figure 2-2). A complex shock pulse is characterized by the irregularity evident on the acceleration-time pulse shown in Figure 2-3. The intensity of simple shock pulses can be expressed in terms of pulse shape, peak amplitude, duration, and rise time (Figure 2-4). Rise time is the interval of time required for the leading edge of a pulse to rise from some specified small fraction to some specified larger fraction (e.g., from 1/10 to 9/10) of the maximum value.

* A complete glossary of terms is given in Appendix III, page 187

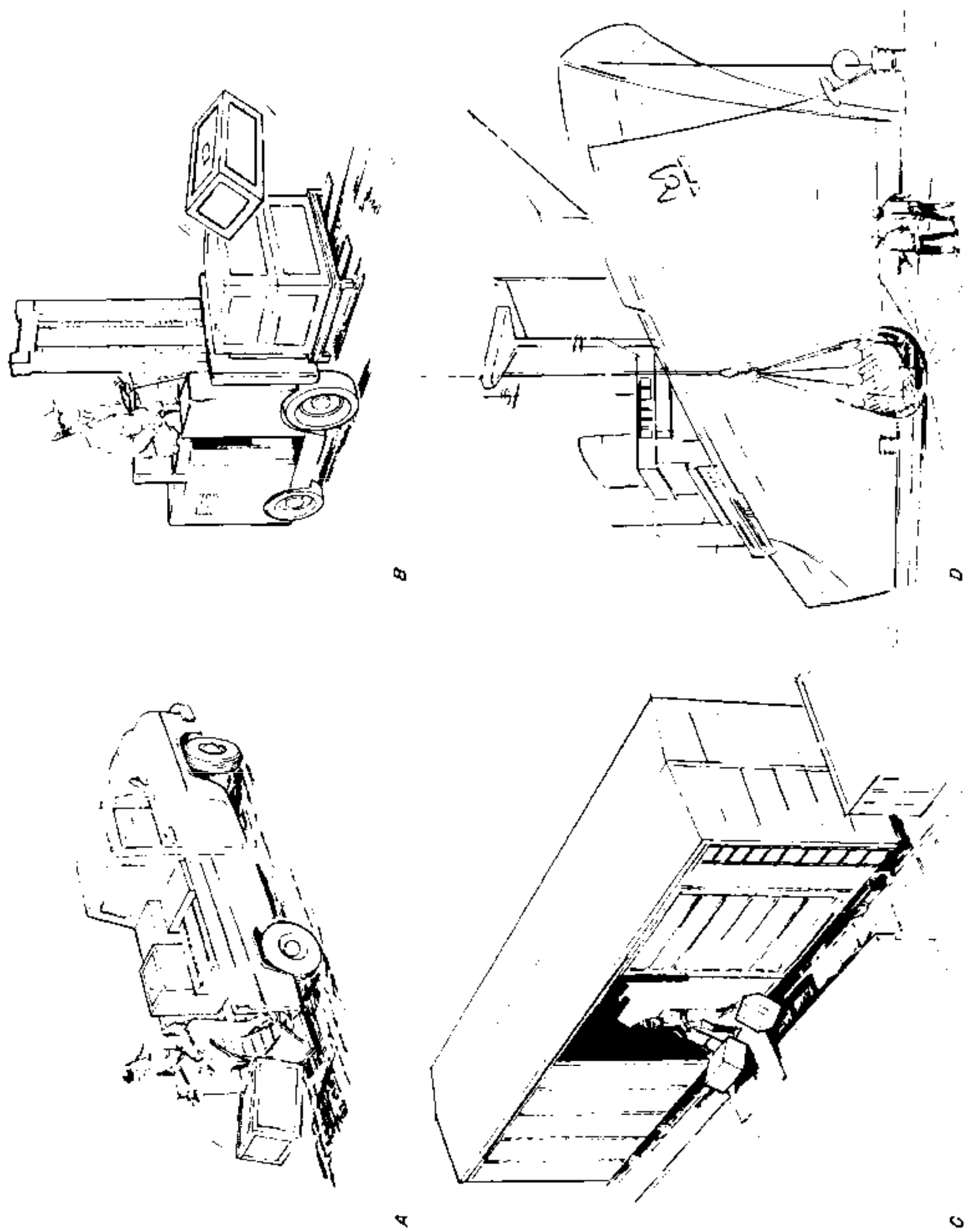


FIGURE 2-1. Some shock-producing shipping practices.

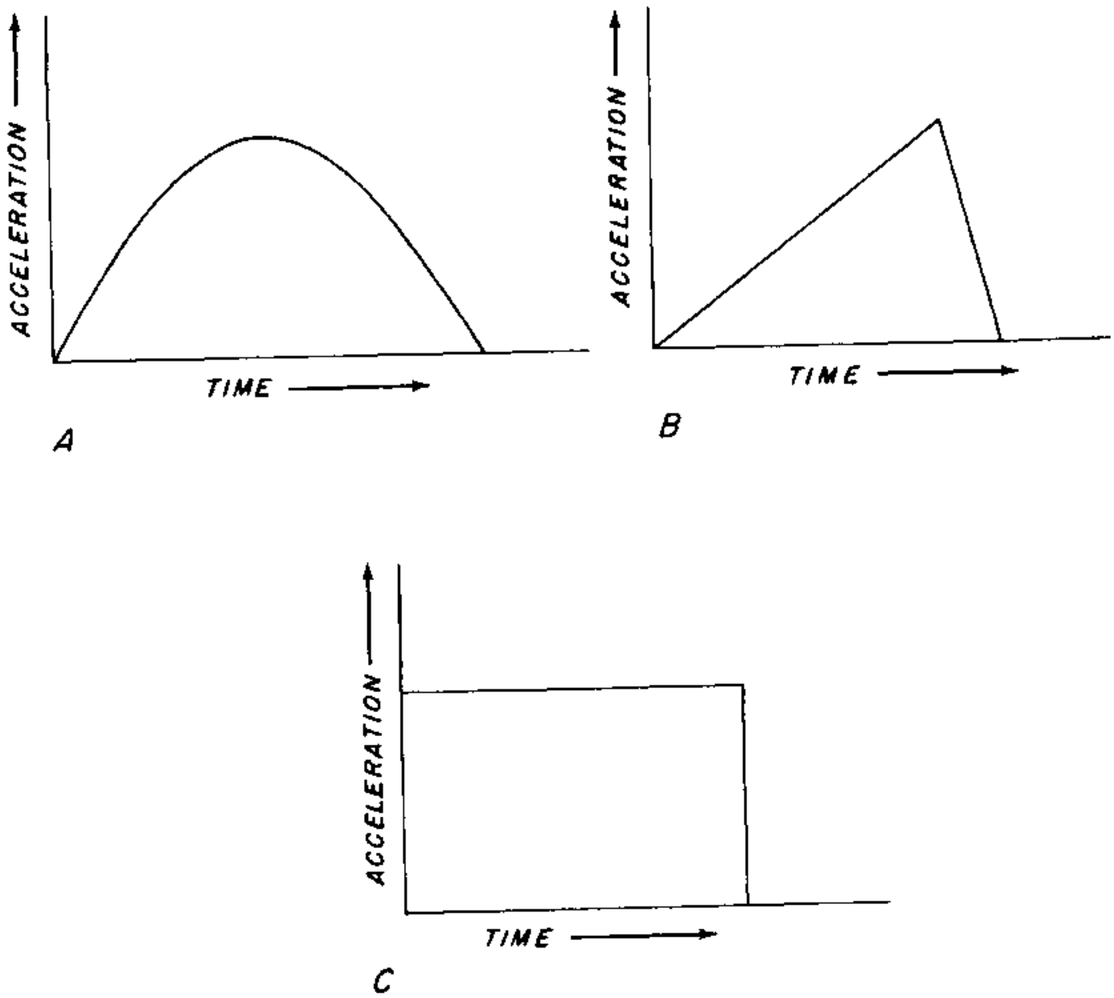


FIGURE 2-2. Simple shock pulses. A, half-sine; B, triangular (“saw tooth"); and C, rectangular.

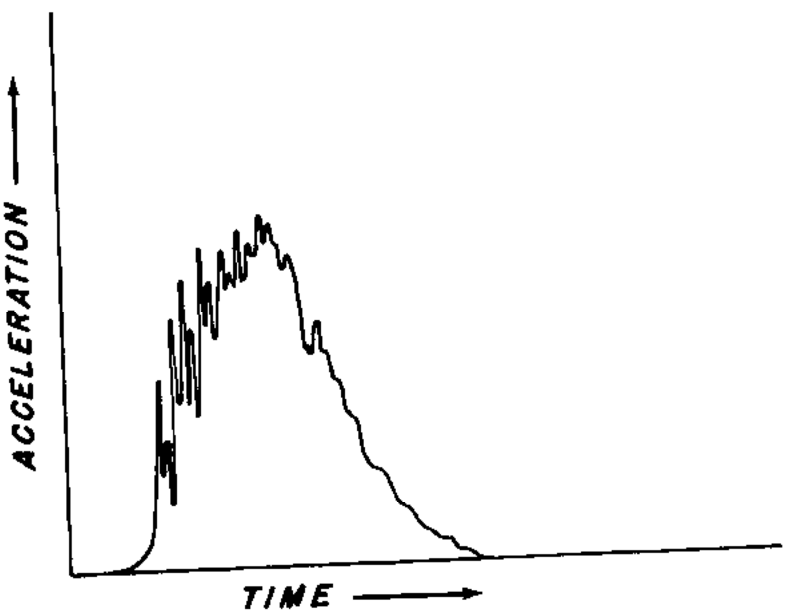


FIGURE 2-3. A complex acceleration-time pulse.

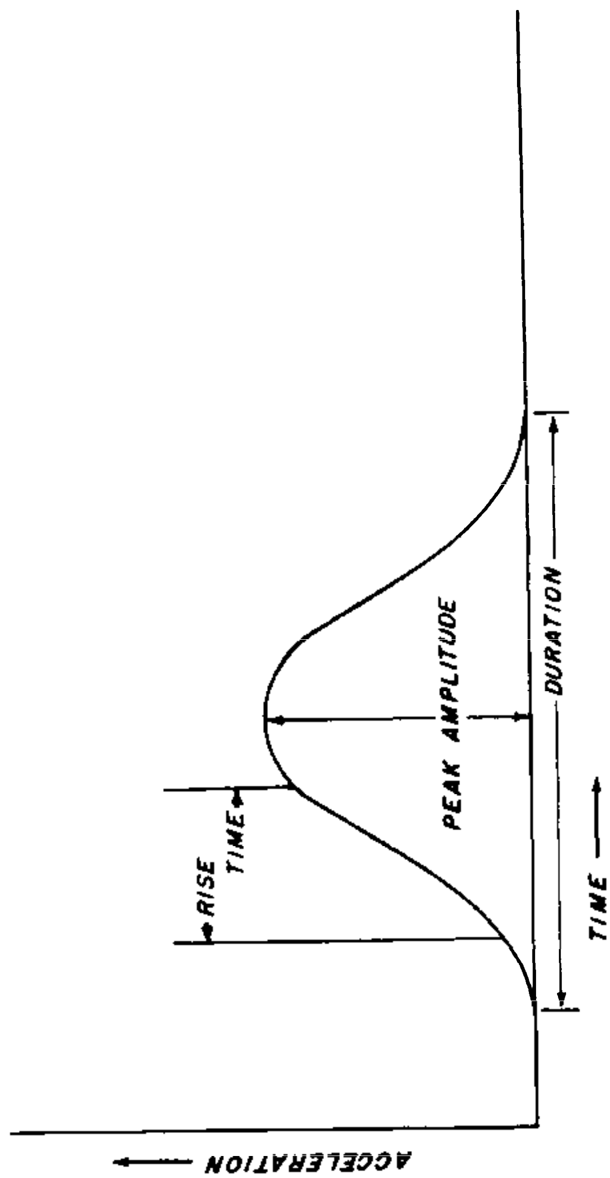


FIGURE 2-4. Basic parameters of a shock pulse.

Adequate description of the intensity of more complex shock pulses necessitates graphical representation. Because the description of complex shock pulses by graphs is often considered unwieldly, the “shock spectrum” method has been used as an alternative.

pulses involving very sudden changes of velocity, i.e., extremely short rise times, are sometimes expressed as velocity shock.

2.1.1.1 Intensity of shocks received by cushioned items. Certain factors that cause shocks to packaged items are common to all modes of shipment. For example, transfer or storage of lading usually involves human handling with or without the aid of mechanical equipment. Mishandling during these operations, as exemplified by Figure 2-1, produces severe impacts to the packages that might exceed all others received during shipment.

Packaging designers have achieved reasonable success in preventing shipping losses due to shock by designing their packages and cushioning systems according to the presumption that shocks received by the packages during handling operations will be the most severe received during the entire shipment. Generally, the intensity of shocks applied during laboratory testing of military packages is controlled by the impact velocities and surfaces required by various performance tests in procurement specifications (e.g. , the latest revisions of MIL-STD-794, MIL-P-116, MIL-STD-1186, MIL-E-5272, and MIL-STD-810).

2.1.1.2 Shock spectrum. Any item, regardless of its rigidity, has elements capable of oscillation relative to a fixed reference. When shock excited, these elements vibrate at their natural frequencies until damping stops the motion. In the meantime, damage or malfunction of one or more of the elements might have occurred. The peak accelerations and peak relative displacements of the elements are particularly significant in describing the response of the item to the applied shock.

For any particular acceleration-time pulse, the distribution of the maximum acceleration responses of a series of single-degree-of-freedom systems (damped or undamped) plotted as a function of the frequencies of the system is called the “shock spectrum” for the pulse. The systems are assumed to be undamped, unless otherwise specified. Shock spectra do not describe shock pulses but are, in effect, indicators of the damage potential of shock pulses. As an example of typical shock spectra, Figure 2-5 shows the shock spectra corresponding to the inset terminal peak saw-tooth acceleration pulse. The spectra designated as “positive during” represent the acceleration response of the systems during the application period of the pulse; the “positive after” and “negative after” spectra represent the response during the time interval immediately after application of the pulse.

The shock spectrum concept has not been employed directly in package cushioning design because of its indirect nature. However, it is used extensively in conjunction with specification of shock pulses that are delivered by shock testing machines to equipment in order to insure their operational serviceability. It is also useful for specification of input

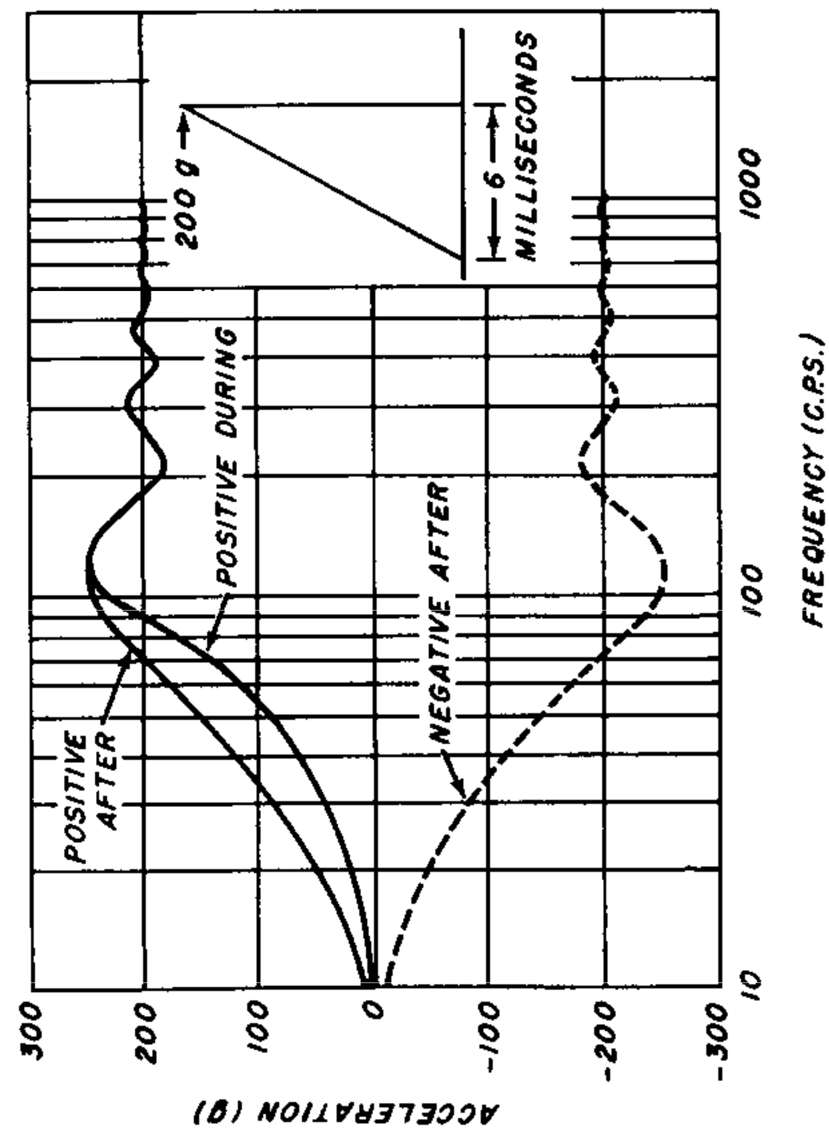


FIGURE 2-5. Shock spectra for the inset acceleration-time pulse.

wave forms in fragility rating tests (see 6.4). For a detailed discussion of this concept refer to (4), (16), (17), (25), (26), (30).

2.1.2 Vibration Caused by Shipment. The nature of Vibration is often categorized as being either random or periodic. Random vibration is defined as an oscillation whose amplitude can be specified only on a probability basis. Periodic vibration is the repetition of a particular wave form at equal time intervals. Vibration that is transmitted to packages while being shipped by a particular mode of transportation is generally considered to be quasi-periodic at discrete frequencies, together with a random noise background.

In the field of package cushioning design, a knowledge of shipping vibration conditions is a prerequisite for design of a cushioning system that will not resonate within the package and thereby produce damage. Conditions of resonance can result in large amplification of input forces and displacements thereby significantly increasing the probability of damage to the container and/or item contained therein. Generally, vertically applied vibration is considered to be more important than laterally or longitudinally applied vibration. Consequently, pertinent information for vertically applied vibration is given in the succeeding paragraphs. It is important to note that although the data presented may imply that steady state vibration occurs at various frequencies, such data frequently represent transient vibration at such frequencies. Therefore, the data given should be regarded merely as indications of shipping vibration conditions, since more research on the nature of the entire shipping environment is needed.

2.1.2.1 Railway. The principal source of both vertical and lateral vibration of lading during shipment by railway is the movement of the car wheels along the rails. The forcing lateral vibrations are caused primarily by “hunting” of the wheel treads on the rails. Vertical forcing vibrations are caused by elasticity of the rails, irregularities in their surfaces, gaps between adjacent rails, flat spots on the wheels and wheel imbalance. The resultant vibrations, which obviously vary with the speed of the car, are applied through the trucks and spring suspension systems of the car to the car beds. The combined weight of the car body plus lading constitute the mass of the mass-spring system with the truck spring suspension system. Depending upon the weight of the car body and lading, the natural frequency of this system may vary from 2.5 to 7.5 cps (cycles per second).

According to Guins, Figure 2-6 represents the ranges of predominant frequencies and corresponding acceleration amplitudes of vertical vibration in railroad freight car beds. The diagonally cross-hatched areas refer to values for cars equipped with truck springs of the year 1915, while the blank and vertically cross-hatched areas refer to values for modern trucks with snubbers. As indicated by Figure 2-6, the principal forcing frequencies related to rail shipment of concern to the cushioning designer range from 2.5 to 7.5 cps and from 50 to 70 cps (12). He should only be concerned with the modern snubbed trucks.

Vibration environment measurements on railroad flat cars (27) are presented in Figure 2-7. Recorded events included switching, stopping, crossing

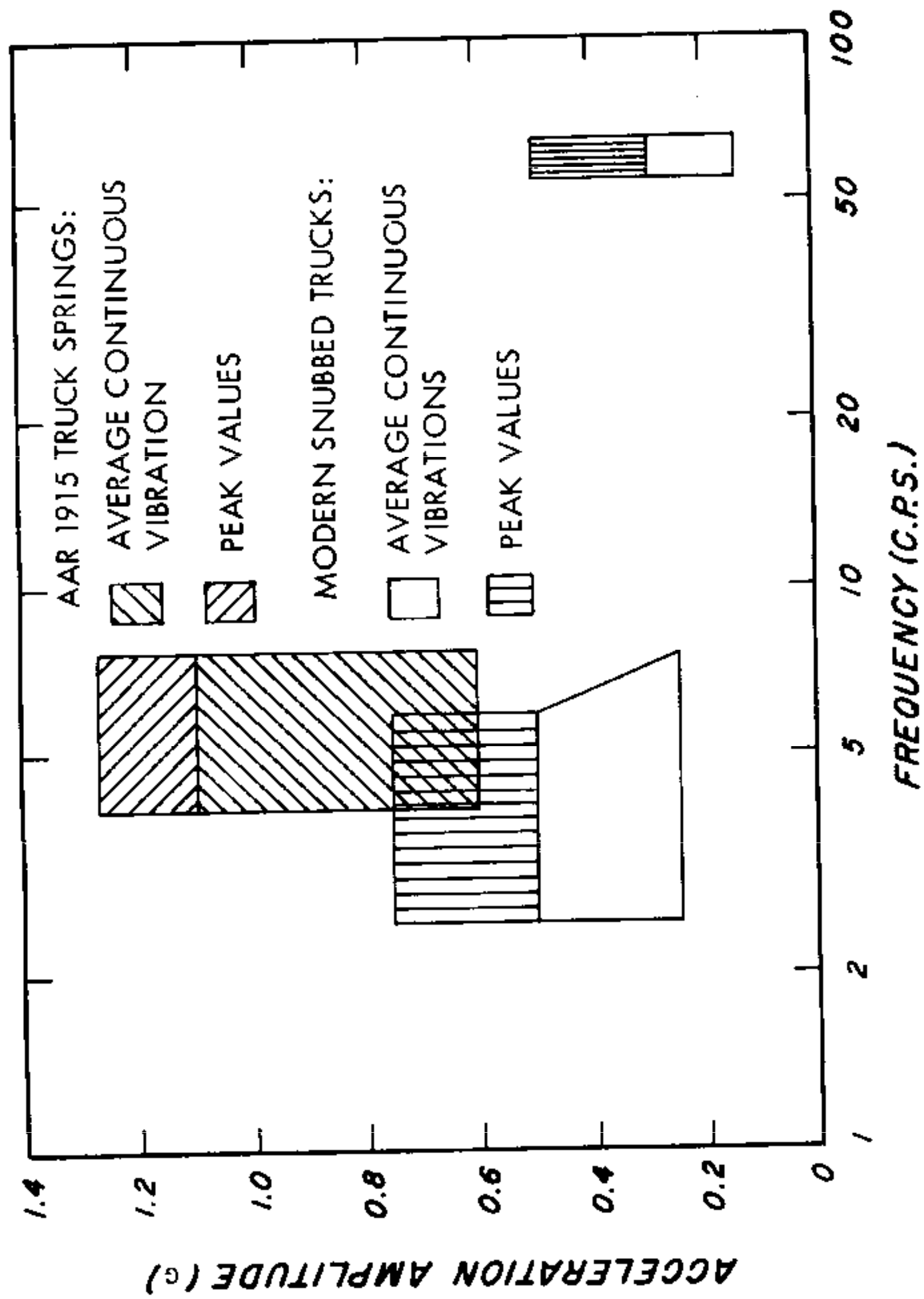


FIGURE 2-6. Ranges of predominant frequencies and corresponding acceleration amplitudes in railroad cars.

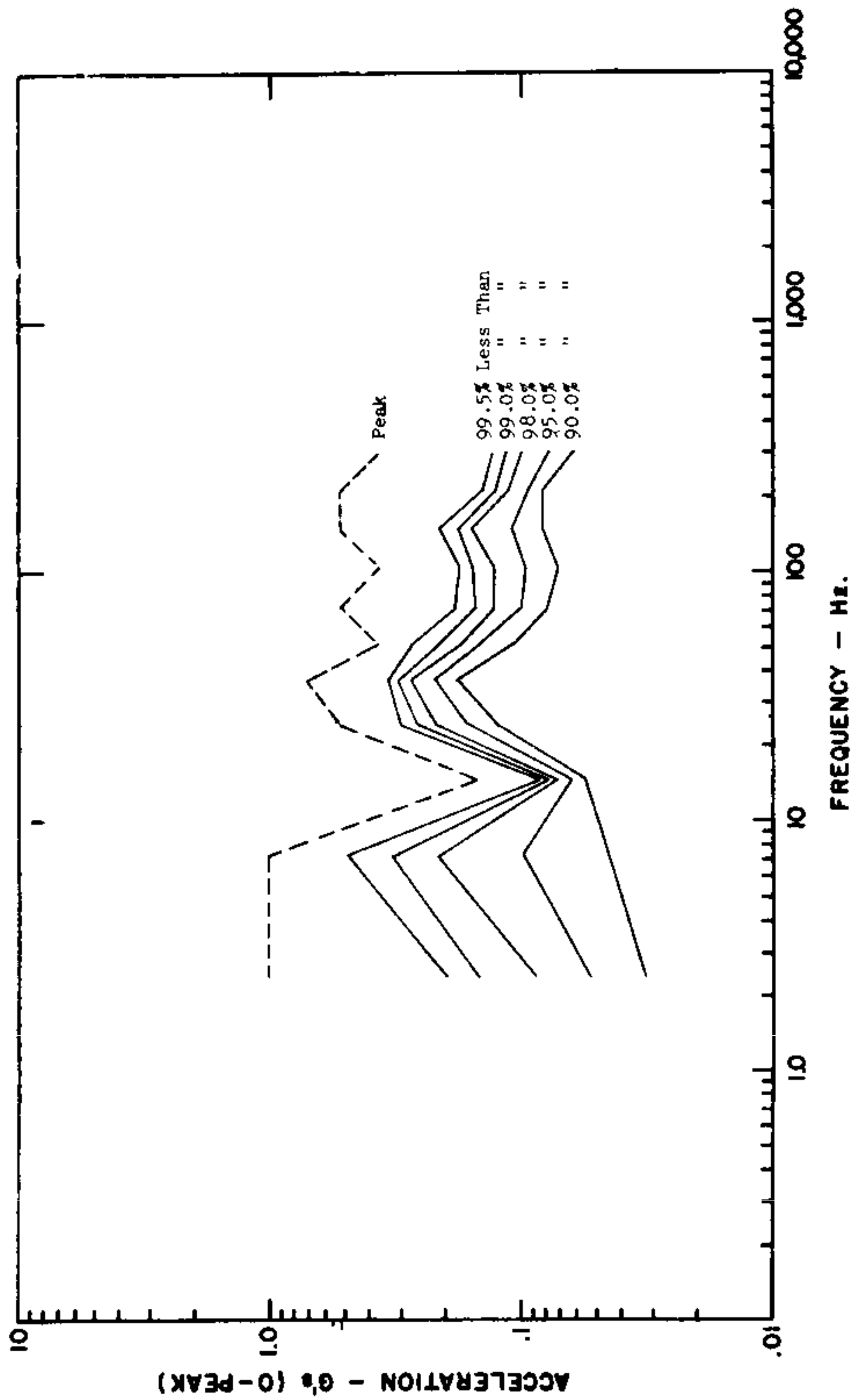


Figure 2-7 FREQUENCY SPECTRA, RAILROAD, VERTICAL DIRECTION, COMPOSITE OF VARIOUS CONDITIONS.

intersecting tracks, level runs at 40 mph, hill ascents and descents, bridge crossings, rough tracks, curves and tunnels. In recognition of the fact that many recorded inputs are the result of transient impulses rather than steady state vibration, the data in Figure 2-7 has been presented in the form of probability curves, each curve indicating the percent probability that the amplitude of a recorded vibration input will lie below the envelop of the curve.

2.1.2.2 Truck. Vibration transmitted to packages during shipment by truck may be caused by a variety of conditions. Some of the most common are impacts of the wheels at various speeds against irregularities in the road, wheel shimmy, engine vibration, and suspension imbalance.

Under normal highway conditions some of the more significant vibration inputs may occur in the 5-7 Hz ranges which are representative of the truck suspension system and tire natural frequencies, respectively. The vibration environment (vertical direction) for a flatbed semi-trailer (27) loaded with 15 tons of cargo is presented in Figure 2-8. Measurements were made at various locations on the trailer floor. The plotted data represents a composite of sixteen different road conditions traversed at speeds varying from 10 to 60 mph. The probability curves indicate the percent probability that the amplitude of a recorded vibration input will be below the envelop of the curve. Vibration measurements (vertical direction) made on the floor of an air-ride trailer van (27) are presented in Figure 2-9. Acceleration levels are expressed in G's (rms). One conclusion drawn from the study which produced this data was that the amplitudes measured on the van floor rarely exceed one G peak.

2.1.2.3 Aircraft. The principal aircraft used for transportation of cargo are powered either by propellers (with turbine engines) or by jet engines. Vibration transmitted to cargo as a result of the operation of these aircraft is traceable to a number of causes, such as propeller imbalance, flexural vibrations of propeller blades and other aircraft members due to aerodynamic distrubances, and engine vibrations. Additionally, impact of the tires with irregularities of the ground surface produces vibration in the aircraft during taxiing operations and during takeoff and landing.

During taxi operations, maximum vertical accelerations of 0.2 to 0.5 G may be expected in the frequency range of 1 to 3 cps. As indicated by Figure 2-10, packages resting on the cargo decks of various types of cargo aircraft in flight may be expected to experience maximum accelerations of less than 4 G in the range of 8 to 500 cps (22).

Separate vibration data on propeller, jet and helicopter aircraft (27) operating under a variety of conditions are presented in Figure 2-11. Specific vibration data (vertical direction) for the C-130 cargo aircraft during take-off (27) are illustrated in Figure 2-12. This operation produced the maximum vibration environment.

2.1.2.4 Ship. Cargo transports can be considered to be complicated freely floating beams with many natural modes of vibration. The principal

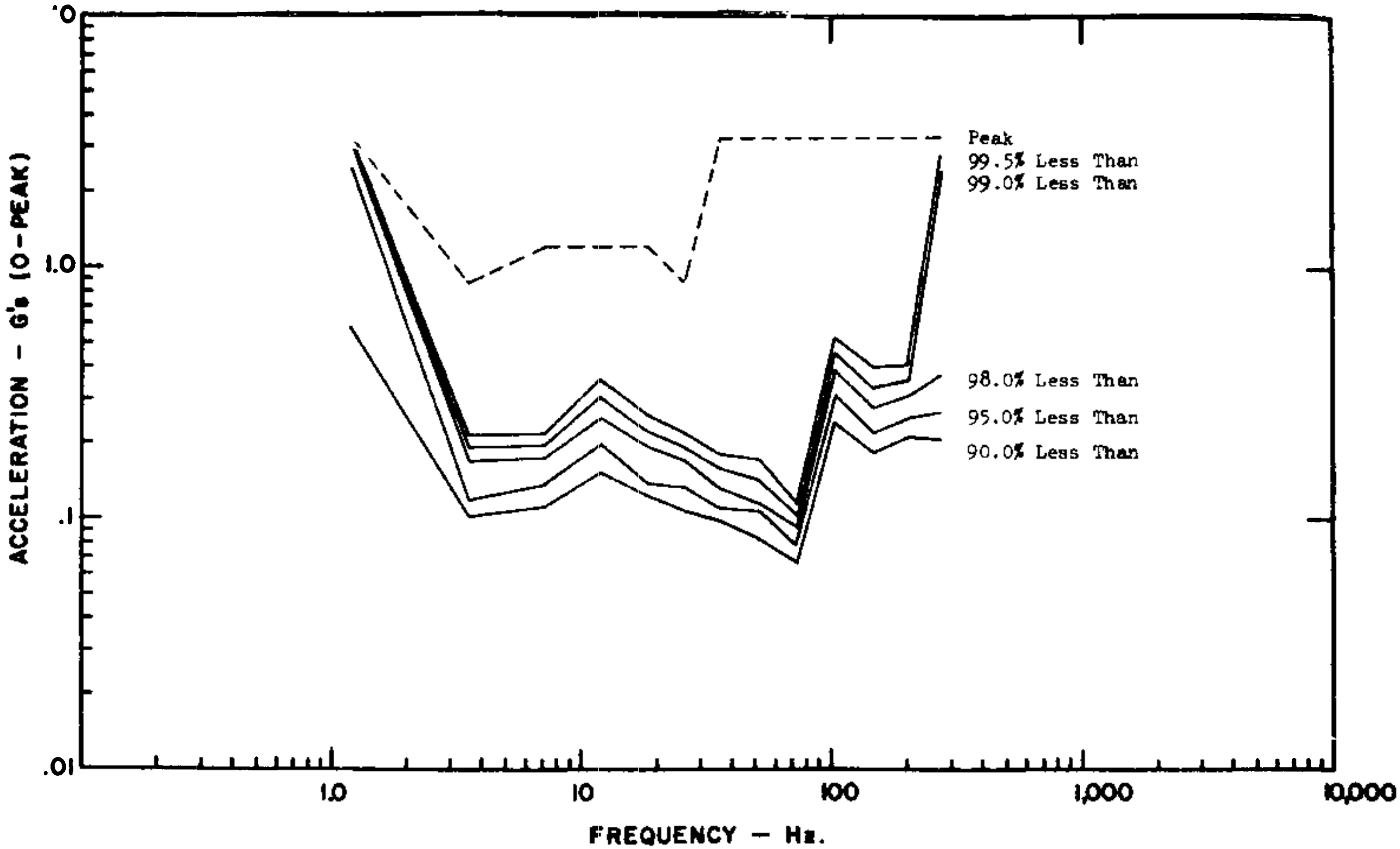


Figure 2-8 FREQUENCY SPECTRA, TRACTOR - SEMI-TRAILER, LOADED VERTICAL DIRECTION (FRONT, CENTER, AFT) COMPOSITE OF VARIOUS ROAD TYPES AND ROAD SPEEDS

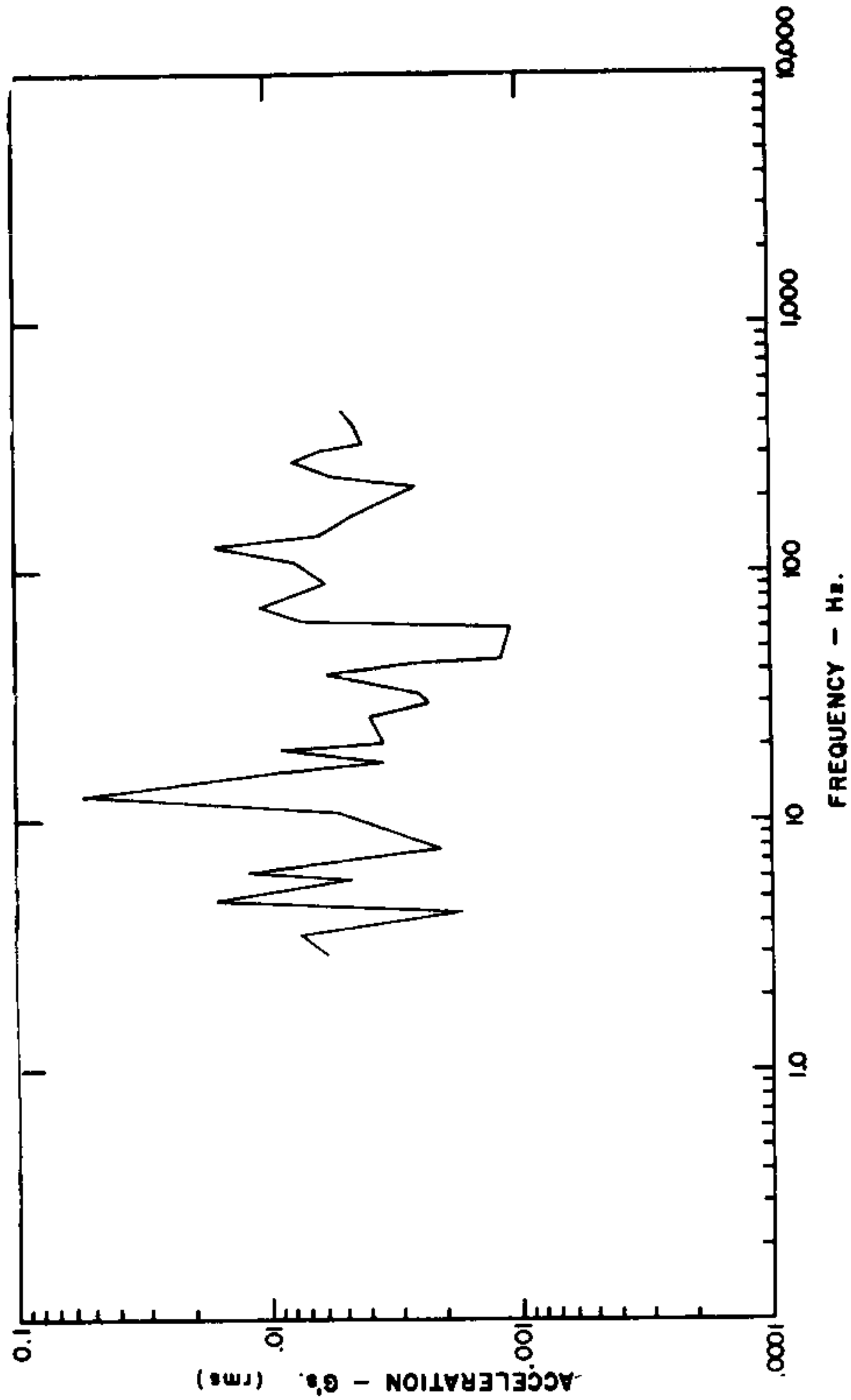


Figure 2-9 FREQUENCY SPECTRA, TRACTOR - TRAILER VAN - AIR-RIDE SUSPENSION, VERTICAL DIRECTION

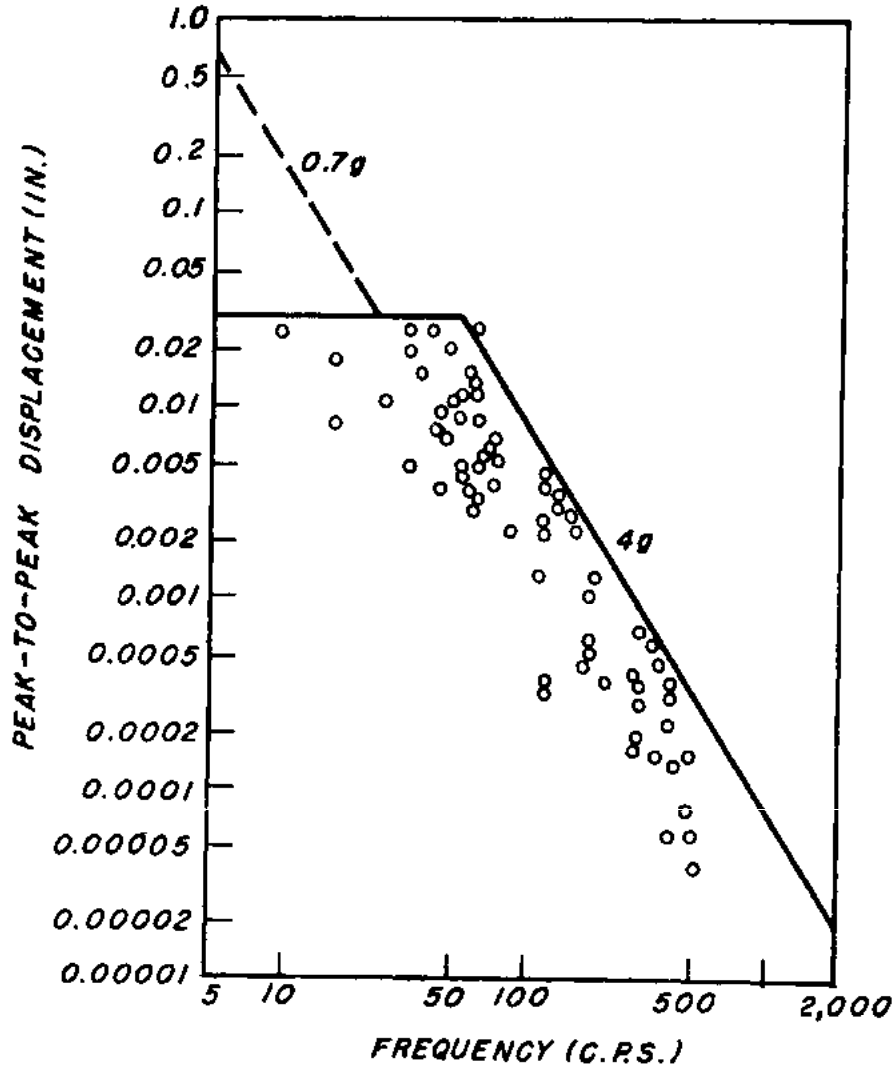


FIGURE 2-10. Displacement and frequency data for vibration on cargo decks of cargo aircraft.

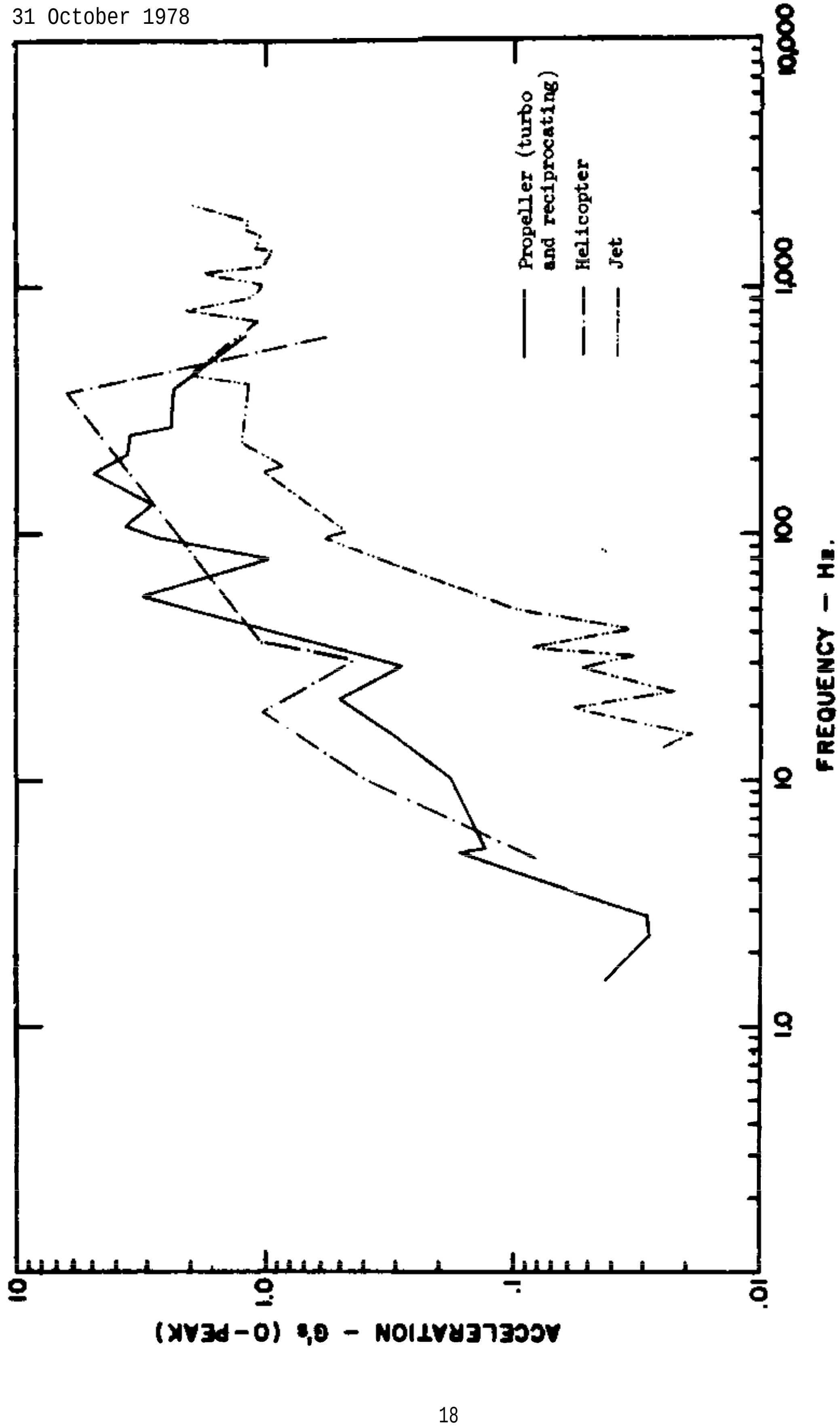


Figure 2-11 AIRCRAFT ACCELERATION ENVELOPE - COMPOSITE (PROPELLER, HELICOPTER, JET)

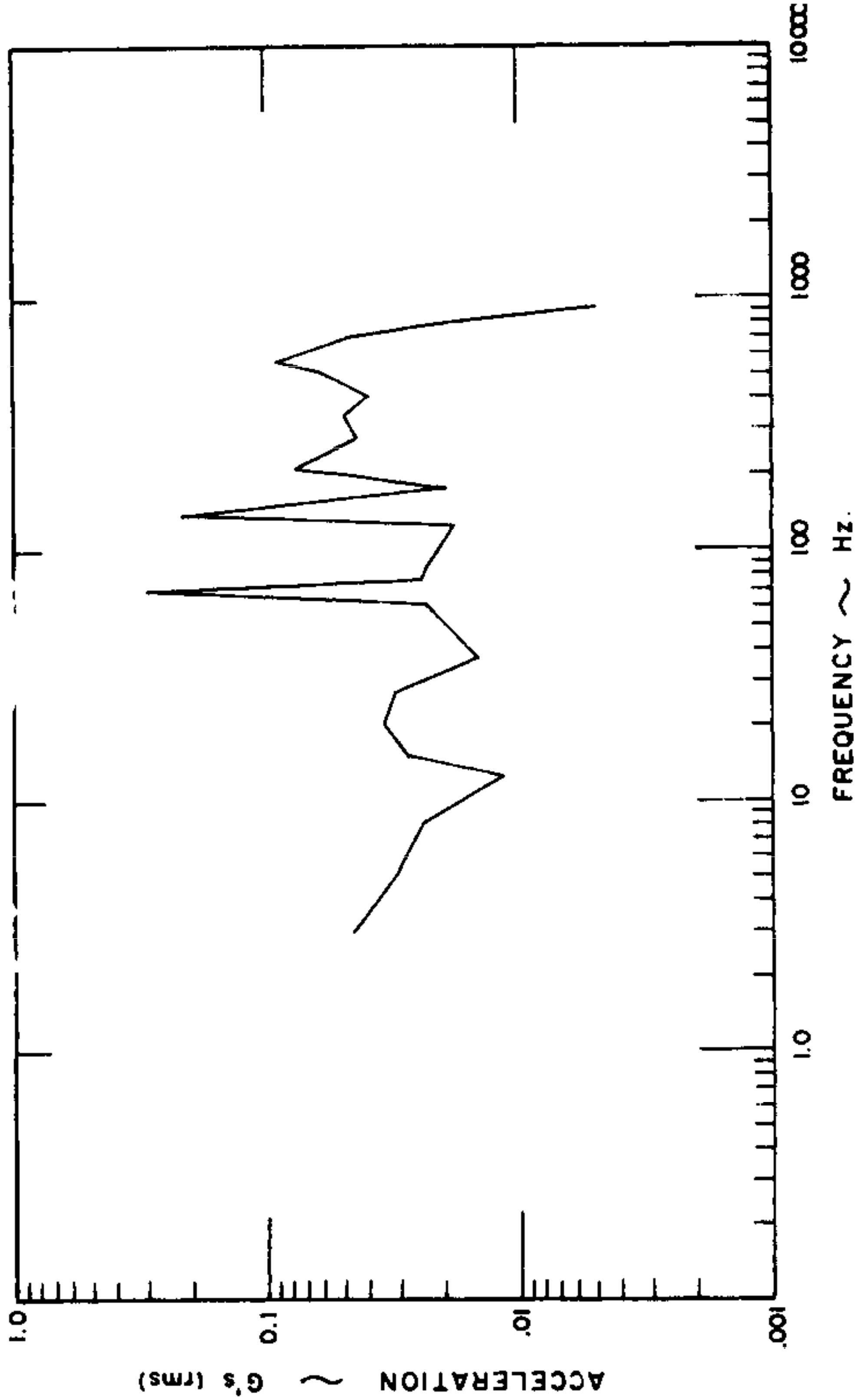


Figure 2-12 FREQUENCY SPECTRA, C-130 AIRCRAFT, TAKEOFF
VERTICAL DIRECTION.

sources of vibration excitation of cargo ships while underway are the beating against the hull of the pressure fields generated by the propeller blades, propeller drive shaft unbalance, and hydrodynamic buffeting of the hull. Because the nature of vibration transmitted to cargo is largely dependent upon the flexural response of the decks to the input vibration, it is obvious that the specific location of the cargo is important.

A summary of vibration data produced under various operating conditions is presented for many sizes and types of ships (27) in Figure 2-13. The plots include measurements in all directions and locations.

2.2 FRAGILITY OF ITEM.

The index of fragility of packaged items customarily used by packaging engineers is the maximum acceleration that any specific item can withstand in any direction before breakage or malfunction occurs. However, it is most essential that the packaging engineer recognize that amplification phenomena can produce drastically different peak accelerations of different parts of an item as a result of a single impact. Consequently, the part of the item to which the fragility rating is referred is most important.

For example, in Figure 2-14A, a hypothetical packaged item is depicted diagrammatically. Figure 2-14B shows that the acceleration of the fragile element m_1 might, depending upon the physical characteristics of the systems, differ greatly from that of the basic structure m_2.

(NOTE: The amplification factor is equal to the ratio of the maximum acceleration experienced by m_1 to the maximum acceleration experienced by m_2; B_1 and B_2 are the damping coefficients across springs k_1 and k_2, and w_1^2 and w_2^2 equal k_1/m_1 and k_2/m_2, respectively.) (24), (29).

Therefore, in order to effect a standard fragility rating procedure, all fragility assessment, cushioning design methods, and test procedures to determine shock transmission to packaged items considered herein are based upon peak acceleration rating of the basic rigid structures of items. In those instances where none of the accessible portions of items are relatively rigid, the item should be enclosed or blocked in position inside a relatively rigid interior container; acceleration measurements should be based upon the peak acceleration of the substituted case corresponding to damage or malfunction of the enclosed item. Techniques for "rigidizing" items are discussed in 4.3.2 and 6.4.3.1.

Expressed in terms of the acceleration due to gravity (g), the fragility factor (G_m) is:

$$G_m = \frac{a_m}{g} \tag{2:1}$$

where a_m is the maximum acceleration that an item can withstand without damage or malfunction.

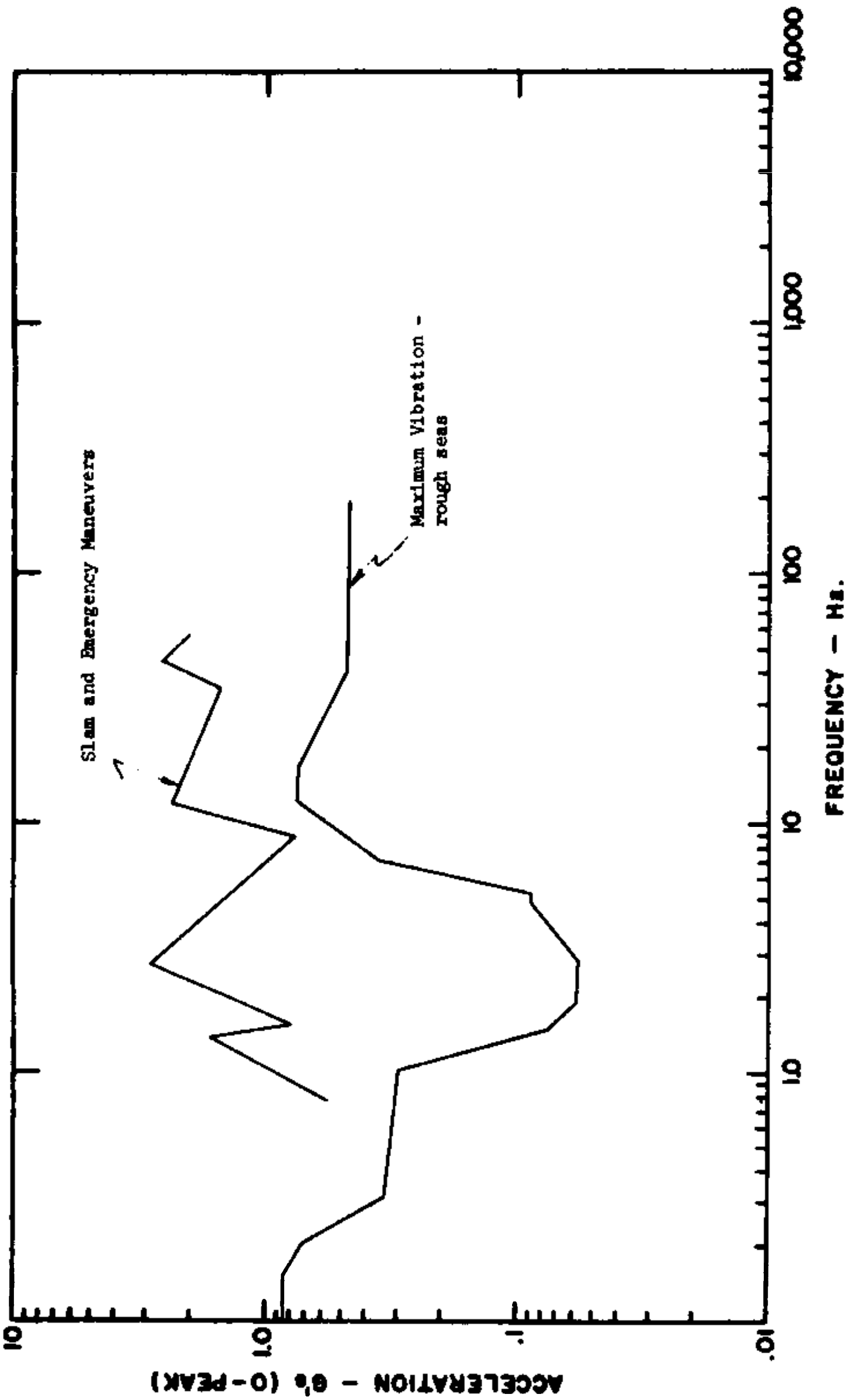


Figure 2-13 SHIP ACCELERATION ENVELOPE - COMPOSITES (Slam and Emergency Maneuvers; Maximum Vibration)

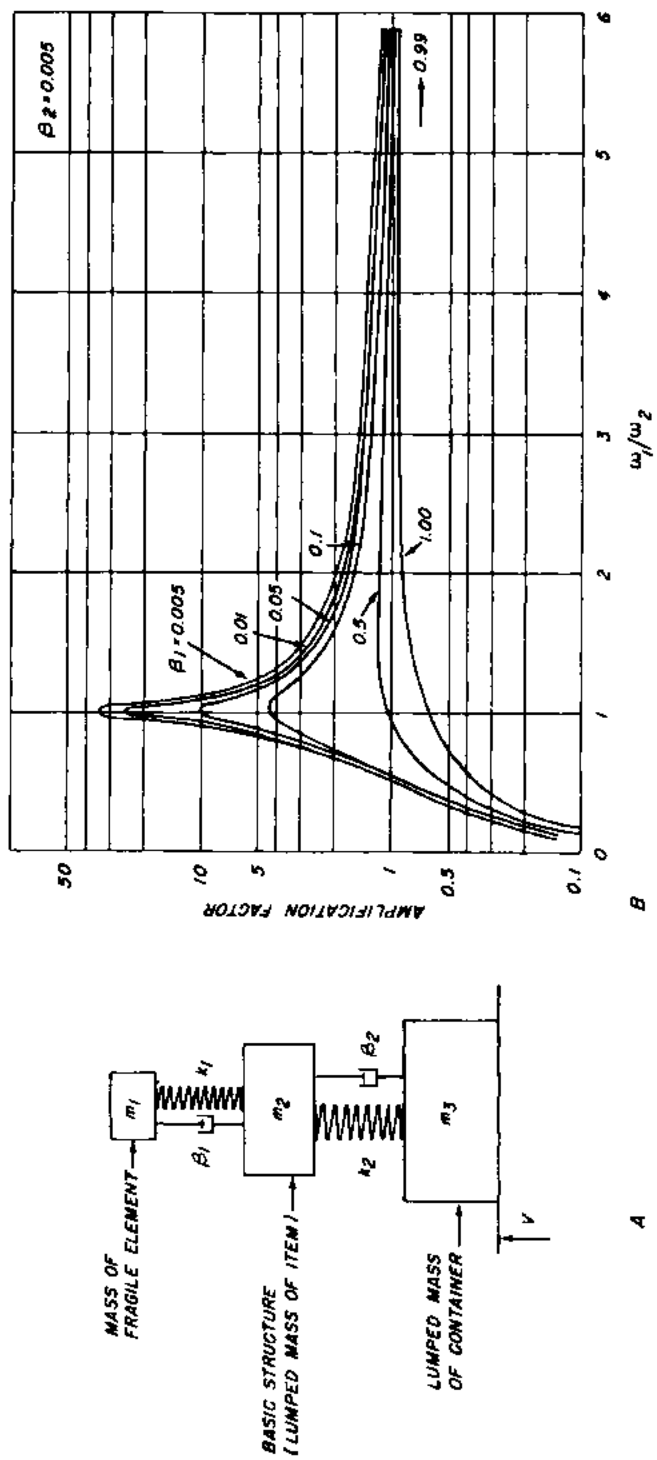


FIGURE 2-14. Amplification factors for linear damped systems for a step velocity change of $\underline{m_3}$.

In many instances, the specification of peak acceleration, exclusive of duration and rise time (Figure 2-4), as a criterion of item fragility appears warranted because the shock pulses received by cushioned items during shipment tend to be relatively simple and of long duration (about 5 to 25 milliseconds). The fragility rating method advocated herein involves application of similar or equivalent wave forms. In practice, the use of peak acceleration as an index of fragility has produced simple, reasonably successful and rational cushioning design procedures. However, recent investigations have indicated that velocity change as well as peak acceleration may play an important part in defining item fragility. For an in-depth discussion of this "Damage Boundary" technique of fragility assessment, see 6.4.3 and 6.4.4.

Some typical fragility ratings are presented below:

15 - 24 Gs	-	Missile guidance systems, precision aligned test equipment, gyros, inertial guidance platforms.
25 - 39 Gs	-	Mechanically shock-mounted instruments (shock mounts secured prior to packaging provided for in-service use only), vacuum tube electronics equipment, altimeters, airborn radar antennas.
40 - 59 Gs	-	Aircraft accessories, electric typewriters, most solid-state electronics equipment, oscilloscopes, computer components.
60 - 84 Gs	-	TV receivers, aircraft accessories, some solid-state electronics equipment.
85 - 110 Gs	-	Refrigerators, appliances, electromechanical equipment.
110+ Gs	-	Machinery, aircraft structural parts such as landing gear, control surfaces, hydraulic equipment.

2.2.1 Fragility Assessment.

2.2.1.1 By testing. The most accurate method for fragility assessment is by testing the item until damage occurs. Although various valid objections apply to any fragility assessment test method, the test procedures that are considered to be most appropriate herein are discussed in detail in Section 6.4.

2.2.1.2 By estimation. While testing of items to determine equitable fragility ratings is desirable for cushioning design, on many occasions such testing is unfeasible. Some common reasons for this are: (1) sufficiently accurate testing and recording equipment is not available, (2) only a few expensive items are to be shipped and, therefore, the potential savings to be realized by accurate cushioning design are insignificant compared to the expense of fragility testing, and (3) records from previously conducted fragility tests of similar items are available for estimation of the fragility ratings.

CAUTION: Beware of estimating item fragility values without accurate knowledge of actual fragility values for types of equipment as a basis for inference. Such estimates frequently are grossly conservative and incompatible with economical cushioning design.

It is important that the packaging designer interpret clearly the implications of the results of environmental shock tests, such as those specified in MIL-STD-810. The shock levels required by such environmental performance tests are intended to simulate operational conditions, but not necessarily the shipping environment--which is oftentimes more severe. Unfortunately, many items are never given actual fragility tests and, as an alternative, the package designers merely use the operational environmental test shock input values as the fragility ratings for the items for cushioning design purposes. The operational environmental shock test values for some items are sometimes only about 20 percent of actual fragility ratings. It is obvious, therefore, that the packaging engineer must differentiate between operational environmental test conditions and actual fragility values, since the accuracy of his cushioning design will vary with the accuracy of his assessment of actual design parameters.

In some instances, a particular kind of item is shipped in successive lots. Once shipping records (including damage claims) have been obtained, redesign of the packaging for greater efficiency is possible for subsequent shipments. To accomplish this it is necessary, first, to estimate the fragility of the item on the basis of the known performance of the cushioning used in previous shipments and then to compute the most economical cushioning system according to the methods discussed in 3.2.3. The following example will illustrate how shipping records might be used to estimate the fragility rating of an item.

PROBLEM: A rigid 8-inch cubical item that weighs 12 pounds has been shipped successfully in a package utilizing 8X8X4-inch rubberized hair pads. During a subsequent shipment involving the same kind of items and containers but 8X8X3-inch rubberized hair pads, some items were damaged by impact. The maximum drop height is unknown. Estimate the fragility rating of the items.

SOLUTION: Since both the maximum height of drop and item fragility rating are unknown, it is necessary to assume a fixed value for one of these parameters in order to calculate the other. Accordingly, a flat drop from 30 inches is assumed. (For purposes of illustration in this problem, assume that a check of cushioning performance data indicates that, for the loading condition involved, an 8X8X3-inch rubberized hair pad will produce a peak acceleration of 97 G; a 4-inch pad would produce a peak acceleration of 53 C. Therefore, the mean fragility rating of this kind of item probably lies between 53 and 97 G. Cushioning redesign, if desirable, should be based upon a fragility rating of about 50 G and a 30-inch flat drone

NOTE: The design methods involving the use of peak acceleration-static-stress curves are described in 3.2.1.

2.3 SHOCK AND VIBRATION ISOLATION CAPABILITY OF THE CUSHIONING SYSTEM.

2.3.1 Shock Isolation.

The shock isolation capability of cushioning materials is dependent upon such factors as their dynamic force-displacement characteristics, damping qualities, loading rates, and item weights. However, for purposes of cushioning design against shock, this handbook advocates methods involving "peak acceleration–static stress" curves, which are described in detail in 3.2.1.1. While these curves serve as indicators of the shock isolation capability of cushioning materials, a better understanding of this cushioning property can be gained by considering additionally the basic physical phenomena involved in shock cushioning (2.3.1.1) and the shock absorption capability of cushioning materials as indicated by compressive force-displacement (stress-strain) curves (2.3.1.2).

2.3.1.1 Basic phenomena. To allow analysis of the effects of shock upon a cushioned package by the use of relatively simple laws, it is advantageous to consider the cushioned item within a container as a simple, damped, single-degree-of-freedom mass-spring system (Figure 2-15). Additionally, the item is considered to be homogeneous. The cushioning is considered to be visco–elastic, to have linear elasticity and to be of insignificant mass relative to the item. Furthermore, the item, container and impacting surface are con–sidered to be rigid, and it is assumed that the container will not rebound.

If the described system is dropped without rotation from height h (Figure 2–15A), it is accelerated constantly until it strikes the impacting surface squarely after a time interval τ of:

$$\tau = \sqrt{\frac{2h}{g}} \qquad (2:2)$$

The velocity of the package at impact vf is equivalent to:

$$v_f = \sqrt{2gh} \qquad (2:3)$$

Following impact, the kinetic energy of the item is stored and dissipated by the compression of the cushion.

Depending upon the fraction of critical damping of the cushioning material B_2, the maximum force $\underline{F_m}$ will occur at some time prior to the instant when maximum displacement $\underline{x_m}$ is reached (Figure 2-15B). (NOTE: For an undamped

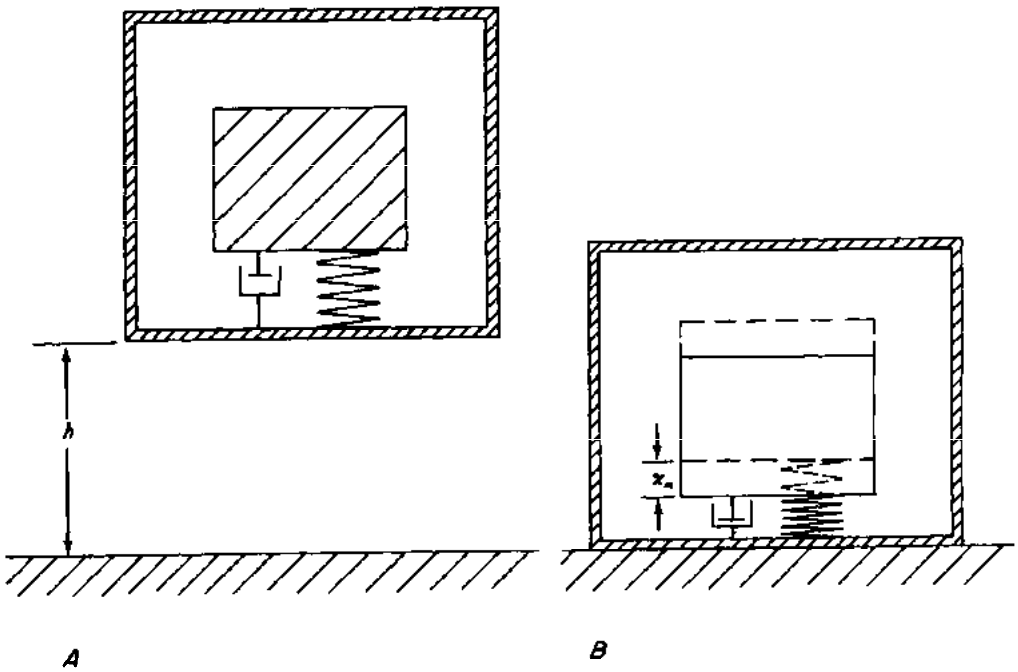


FIGURE 2-15. Idealized mechanical system representing a falling package that contains a cushioned item. A, at the instant of release; B, at the instant of maximum cushioning displacement.

cushioning system, F_m would occur at the same time as x_m.) Since Newton's second law of motion states:

$$F_m = ma_m = W\ G_m \qquad (2{:}4)$$

the maximum acceleration am of the item corresponds to F_m (24).

The kinetic energy of the item at the instant of impact is absorbed or dissipated by the cushioning while being deflected to X_m according to:

$$W\ (h + x_m) = \int_0^{x_m} F\,dx \qquad (2{:}5)$$

The hysteresis loop for energy absorbed by the cushioning system is represented by the shaded area in Figure 2-16. As shown, the force exerted against the item during rebound will be lower than on the initial compressive downstroke.

2.3.1.2 Compressive force–displacement and stress-strain curves as indicators of cushioning performance. Because of the ease with which they can be derived, static compressive force-displacement curves (or their converted form, stress–strain curves) are generally made available for practically all kinds of cushioning materials by their manufacturers. While the methods for derivation might vary slightly, usually they are similar to those given in 6.1.2.5.

Generally, materials having little inherent damping (rubberized hair and expanded resilient polystyrene) will produce compressive stress-strain curves that are essentially unchanged by loading rate. However, data derived from tests of highly damped material, such as urethane foam, produce quite variable curves with different loading rates. Because shock loading in service is of a variable dynamic nature and because the designer usually is not safe in making assumptions about the quantitative accuracy of static compressive force-displacement or stress-strain curves, their use for solving shock cushioning problems is discouraged. Rather, as mentioned in 2.3.1 and 3.2.1.1, peak acceleration-static stress curves are recommended for solution of shock cushioning problems. Nevertheless, static compressive force-displacement and stress-strain curves are helpful to the designer for gaining a rudimentary understanding about how efficiently cushioning materials can be expected to perform as shock isolators as well as calculating the amount of initial set that can be expected when the item to be protected is placed in its cushioned pad.

From equation (2:4), it is evident that during compression of the cushion by the item, the maximum acceleration varies directly with the resistive force exerted by the cushion. The ideal compressive force-displacement curve for a cushioning material is that shown in Figure 2-17, providing the constant force level is below that which will cause damage. In reality, no existing cushioning materials exhibit ideal compressive force-displacement curves. However, the performance of the more efficient cushioning materials, such as urethane

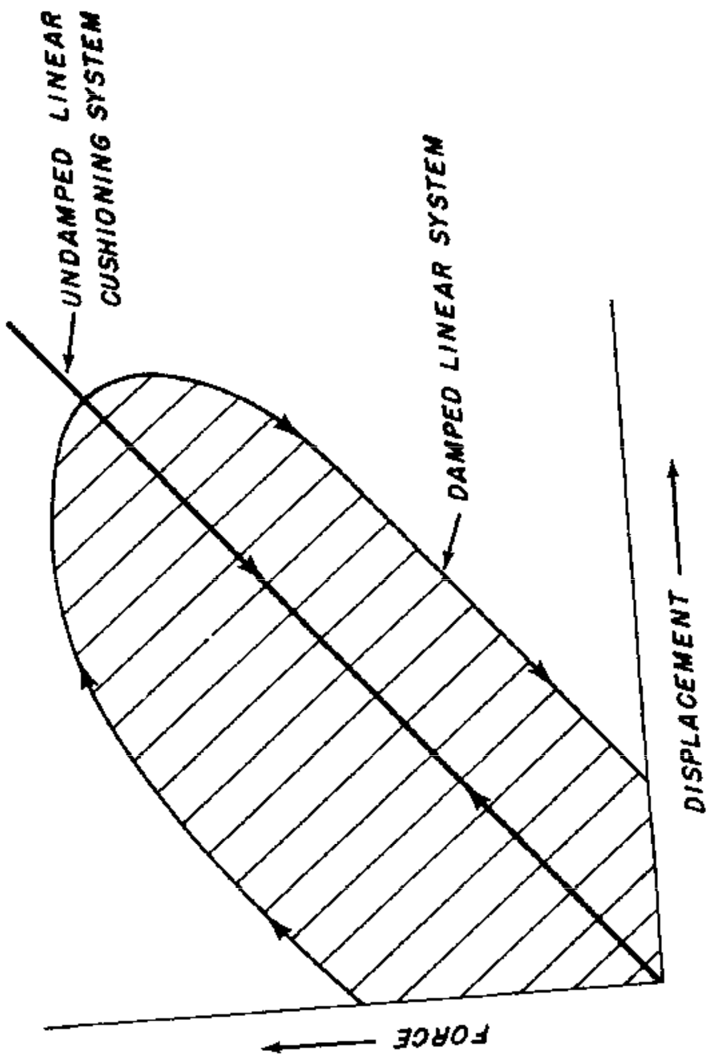


FIGURE 2-16. Force-displacement curves for damped and undamped linear cushioning systems.

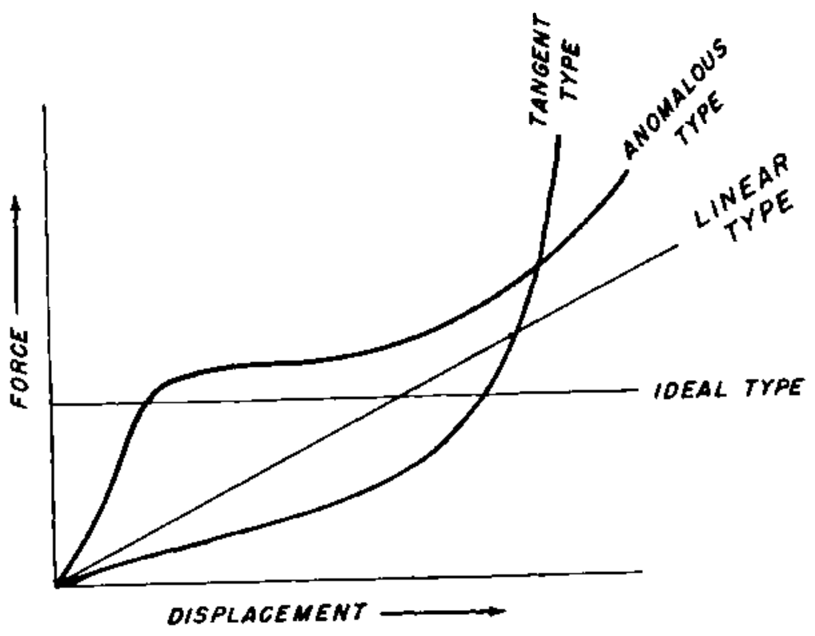


FIGURE 2-17. Force-displacement curves for various types of cushions.

foam, foamed polyethylene, and rubberized hair (loaded on edge) do include a range of displacement through which they apply a nearly constant force. Two common phenomena responsible for this type of curve (anomalous type, Figure 2-17) are viscous damping and columnar buckling.

Other common cushioning materials, such as cellulose" wadding, expanded resilient polystyrene, and rubberized hair (loaded flatwise) are said to be tangent-type materials because of the shape of their force-displacement curves (Figure 2-17).

2.3.2 Vibration Isolation. Although principal emphasis in package cushioning design is placed upon achieving protection of items from shock, the cushioning system must also protect items from vibration received during shipment. As indicated by the 90% probability curves for the acceleration-frequency graphs presented in Figures 2-7 and 2-8, steady state transportation vibration amplitudes can generally be expected to be at or below the 0.1 G level. Transient shock inputs of this magnitude could not be expected to cause item damage. However, steady state vibration inputs at these relatively low levels can cause damage if their frequencies match or approach the natural frequencies of secondary elements or components of the item. In a situation such as this the resultant resonant conditions can amplify component acceleration and displacements to the failure level.

Vibration input conditions can also contribute to damage indirectly if they cause the item-cushioning system itself to vibrate at its natural frequency. Continuous "working" of the cushioning material under this condition could result in degradation of the cushioning to the extent that subsequent shock inputs might reach damaging levels. A practical analytical method for solving packaging vibration isolation problems is complicated by the fact that most common package cushioning materials exhibit non–linear load-displacement characteristics. The mathematical functions representing non-linear systems are not amenable to direct solution. Despite these difficulties a rational design method is available for the solution of vibration problems using a combined analytical and experimental approach as described in the following text.

2.3.2.1 Linear Systems. A linear system is one whose response is directly proportional to the excitation force. Although most package cushioning materials exhibit non-linear characteristics, a brief discussion of linear systems will aid in understanding some of the fundamental aspects of vibration as related to packaging considerations. A rigid item cushioned in a package can be idealized as the linear viscoelastic single-degree-of-freedom system represented by Figure 2-18. The forcing vibrations caused by shipment are applied to the outer container and transmitted to the contents.

2.3.2.1.1 Transmissibility. The vibration transmissibility for a linear cushioning system is indicated by the function T_r, which is defined as the ratio of the force or motion transmitted to the mass through an isolation system to the force or motion exerted or described by the foundation (vehicle bed).

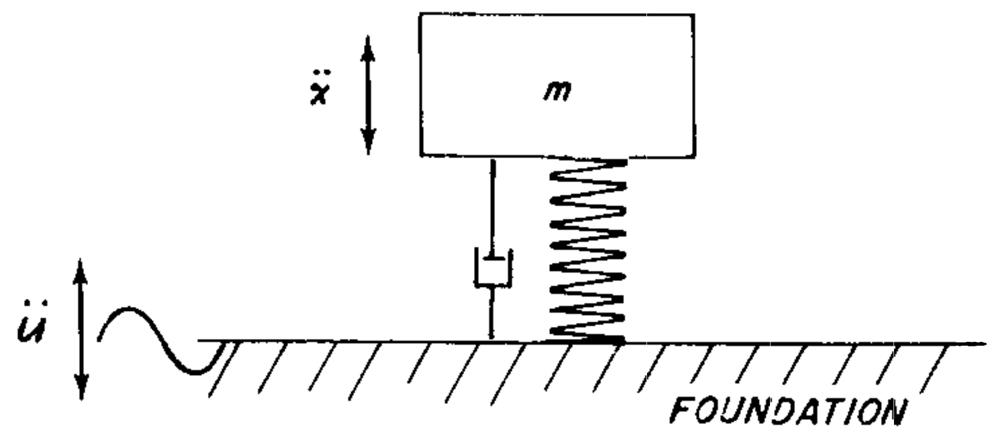


FIGURE 2-18. Idealized item-cushioning system bearing on a vibrating foundation.

The equation representing T_r is

$$T_r = \sqrt{\frac{1 + \left[2\beta_2 \frac{f_f}{f_n}\right]^2}{\left[1 - \left(\frac{f_f}{f_n}\right)^2\right]^2 + \left[2\beta_2 \frac{f_f}{f_n}\right]^2}} \qquad (2:6)$$

where f_f is the forcing frequency of the foundation, f_n is the undamped natural frequency of the item-cushioning system and β_2 is the fraction of critical damping of the cushioning material (7).

The relationship between T_r, β_2, and forcing frequency f_f for a viscous-damped linear system such as depicted by Figure 2-18 is illustrated in Figure 2-19. As shown, the transmissibility of such a system increases' from unity to a maximum as $\frac{f_f}{f_n}$ approaches 1.0 (resonance). Theoretically, for $\beta_2 = 0$, T_r is an infinite value. However, since all systems possess some damping, T_r is reduced accordingly. Since the maximum acceleration $\ddot{x}$ experienced by the item during vibration is: $\ddot{x} = T_r \ddot{u}$ (2:7)
where u is the maximum acceleration of the foundation, it is clear that the greatest danger of damage to the item of a vibrating cushioned system occurs at resonance. Figure 2-19 also indicates that vibration isolation of a viscous-damped linear system only begins when $\frac{f_f}{f_n} > \sqrt{2}$

The foregoing discussion indicates that appreciable daming in the cushioning material is desirable. Similarly, the $\frac{f_f}{f_n}$ ratio should be larger than $\sqrt{2}$. A practical limit on the desirability of high damping inherent in the cushioning is the adverse effect (increase of transmitted shock) caused by fractions of critical damping above 0.5 (24).

At resonance, the transmissibility of a viscous-damped system is a function solely of the damping fraction β. For systems where $\beta < 0.1$:

$$T_r = \frac{1}{2\beta} \qquad (2:8)$$

2.3.2.1.2 Calculation of natural frequency of a linear cushioned system. The undamped natural frequency (f_n) of the linear system illustrated in Figure 2-18 can be determined from the following equation:

$$f_n = \frac{1}{2\pi} \sqrt{\frac{kg}{W}} \qquad (2:9)$$

where: k = the linear stiffness of the spring.
w = the weight of the item.
g = the gravitational constant.

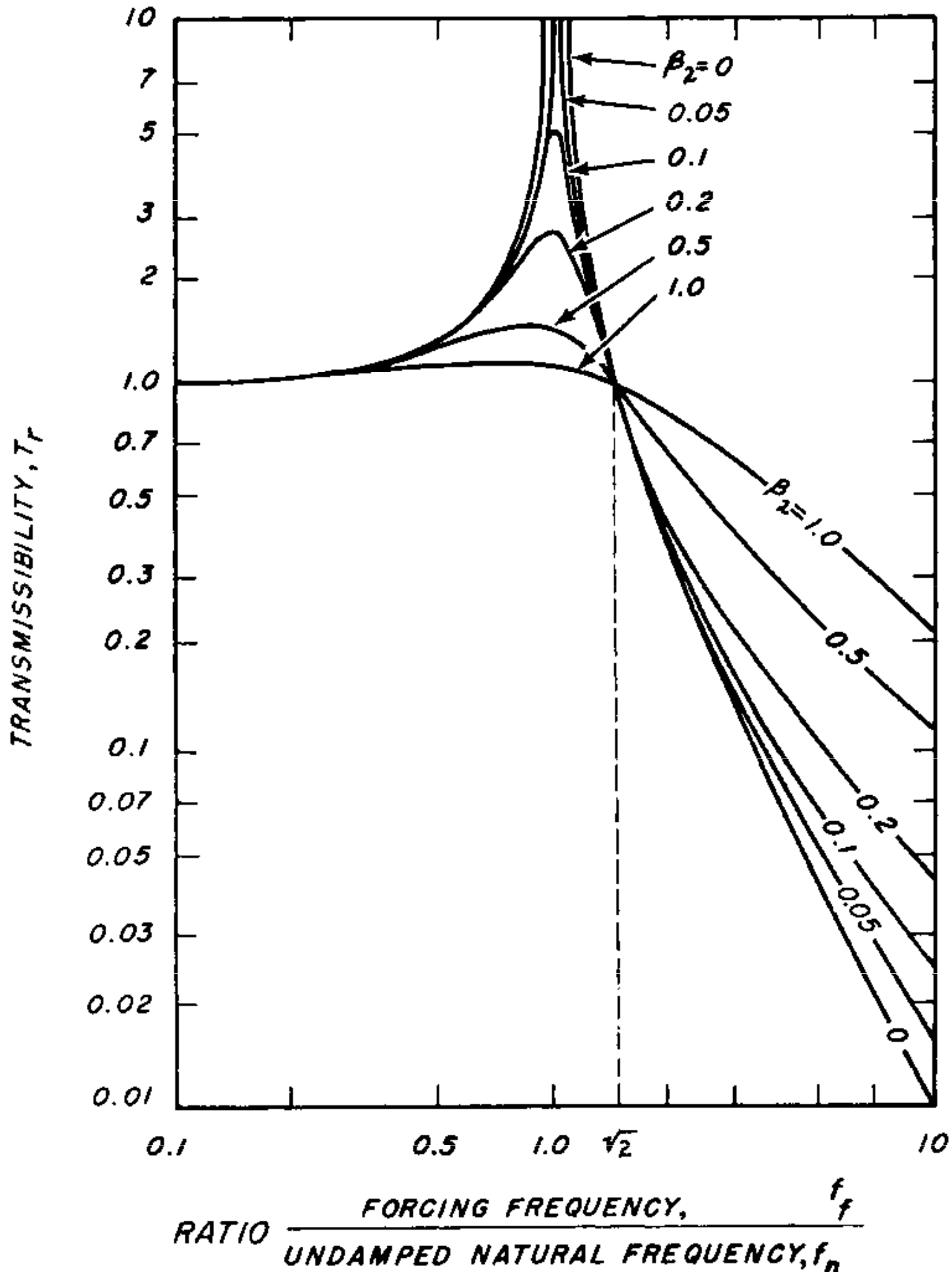


FIGURE 2-19. Effects of damping upon the transmissibility curve for the viscous-damped linear cushioning system depicted in figure 2-18.

2.3.2.2 Non-linear Systems. A non-linear system is one whose response is not directly proportional to the excitation force. The slope of the force-displacement curve for non-linear materials is continuously changing with displacement as represented by the tangent and anomalous type materials in Figure 2-17.

2.3.2.2.1 Experimentally derived transmissibility curves. Because of non-linear elasticity and a lack of quantitative data for the damping characteristics of most package cushioning materials, it is necessary to derive transmissibility curves by empirical testing. The transmissibility curve presented in Figure 2-20 is typical of the curves presented in Appendix VI for the 22 materials considered in this Handbook. To facilitate some of the cushion design procedures described in 3.2.2.2, significant points from these transmissibility curves are also presented in a tabular format in Appendix VII. Because the transmissibility of non-linear cushioning will vary with cushion thickness and static stress loading it was necessary to develop separate curves for material thickness ranging from one to six inches in one inch increments and also at six to ten static stress points distributed over the "useable" static stress range for the material in question. Unlike linear systems, the transmissibility of a non-linear material can vary significantly with the magnitude of the input vibration. Therefore, the curves in Appendix VI were developed using a constant vibration acceleration amplitude of 0.5 G. This acceleration magnitude was selected because it was considered to be representative of the acceleration levels experienced during shipment for the frequency range used in performing the vibration transmissibility tests (1 to 150 Hz). It has also been observed during transmissibility testing of many cushioning materials that maximum acceleration response occurs as the input acceleration approaches the 0.5 G level. Above this level, for some cushioning materials, the test load momentarily loses contact with the cushion pads at certain input frequencies.

2.3.2.2.2 Determination of natural frequency of a non-linear system. Because of the variation in the stiffness (k) of non-linear cushioning materials as they are deformed, the natural frequency (f_n) of package cushioning systems employing these materials cannot be calculated directly from equation (2:9) presented in 2.3.2.1.2. To estimate the natural frequency of a non-linear cushioning system, a static compressive stress-strain curve, such as shown in Figure 2-21, is required for the cushioning material. This curve is then used in conjunction with the following modified form of equation (2:9) for natural frequency:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{df/ds}{WT/gA}} \qquad (2:10)$$

where: f = unit stress (exerted by the item against the cushion)
s = strain
W = the weight of the item
T = the original thickness of the cushion
A = the bearing area of the cushion

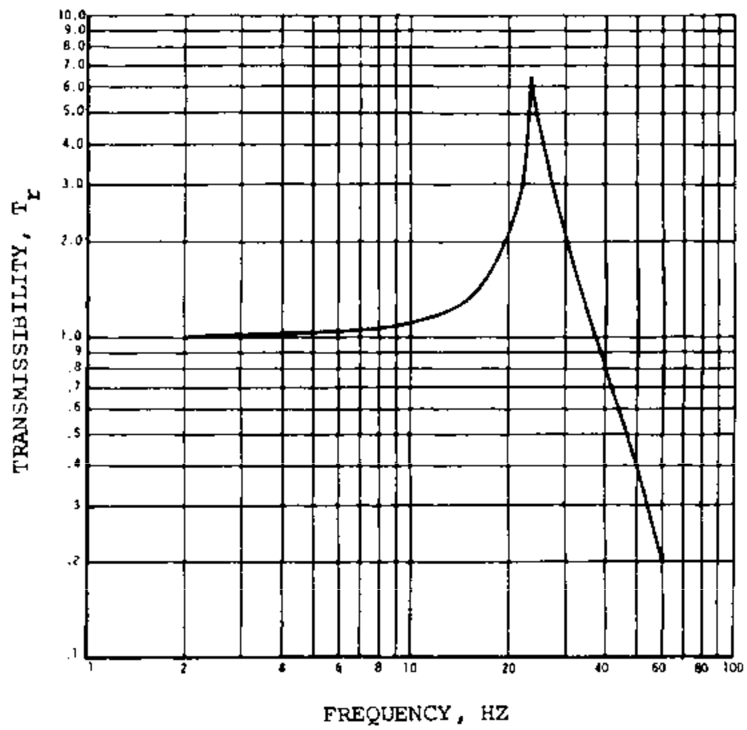


FIGURE 2-20. Polyurethane Foam (Ether), 2 Pcf, 4 Inch Material Thickness, .18 psi Static Stress

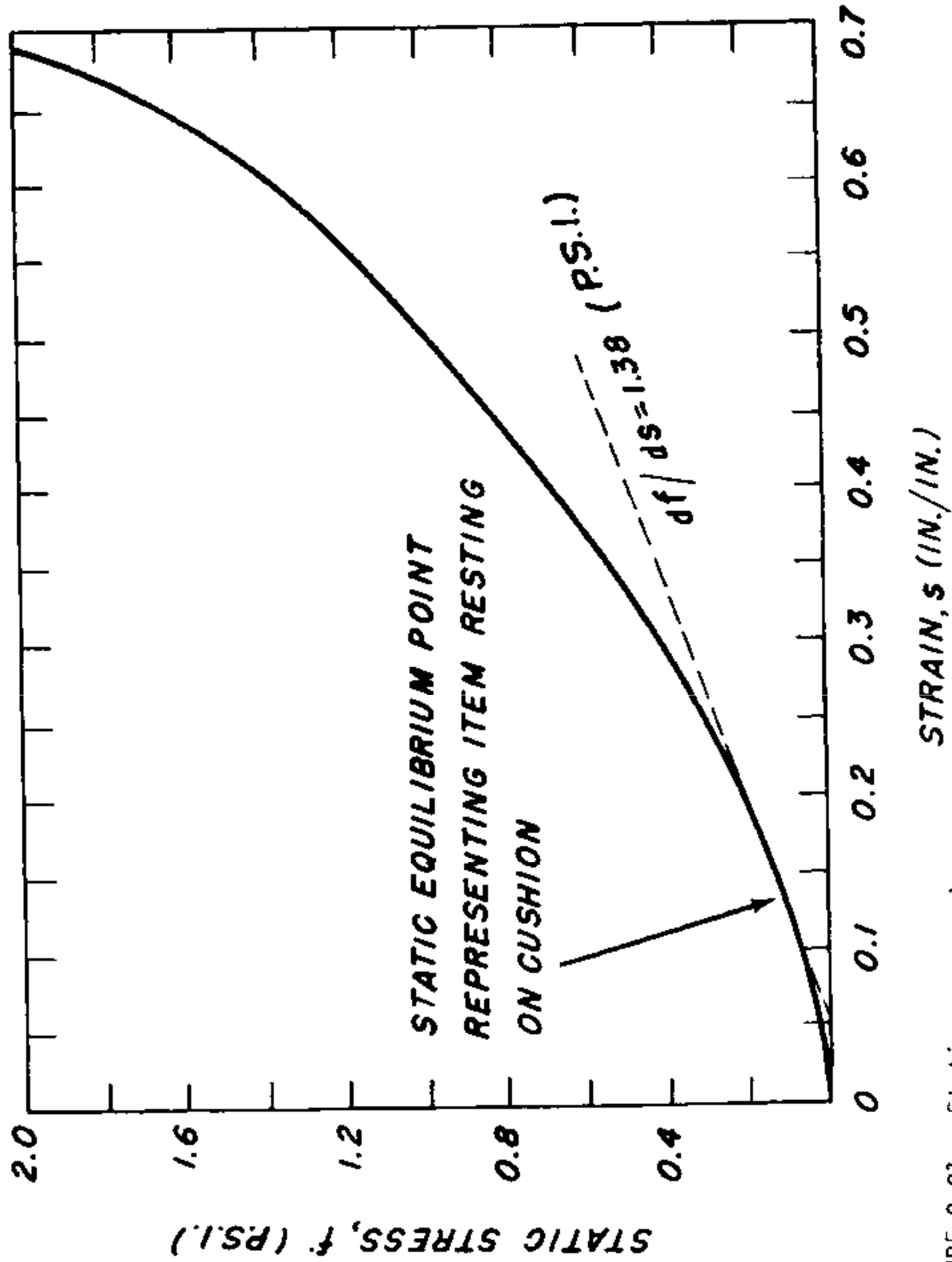


FIGURE 2-21. Static compressive stress-strain curve for a hypothetical cushioning material.

This formula serves as an approximation of the natural frequency of the cushioning system if the displacement of the item during vibration is small and if the stress-strain behavior of the cushion is not abruptly non-linear in the range of interest. The natural frequency (f_n) of a cushioning system may be calculated by determining the slope (df/ds) of a static compressive stress-strain curve for the cushioning material (see Figure 2-21) at the static stress point representative of the cushion bearing load and then substituting the value for (df/ds) in equation 2:10. Static stress-strain curves may be derived from tests according to the procedure described in 6.1.2.5. Curves for the cushioning material considered in this handbook are presented in Appendix IV. The natural frequency of systems utilizing the cushioning materials considered in this handbook can be more accurately determined by referring directly to the transmissibility curves or tables in Appendices VI and VII. The frequency at which the peak amplitude occurs is the natural frequency of the cushioning system. Alternatively, the natural frequency can be obtained from the tables of transmissibility data. The values in the frequency column with the heading Q = MAX represent the natural frequency of a cushioning system having the thickness and static loading specified.

CHAPTER 3. SELECTION AND APPLICATION OF THE PROPER CUSHIONING MATERIAL

3.1 CUSHIONING DESIGN PROCEDURE.

Rational cushioning design requires consideration of many factors. Detailed information, because of its volume, its necessarily distributed throughout this handbook. Therefore, the following procedures are given to provide an immediate resume of the steps required in the design procedure. Typical comprehensive cushioning problems are given in 3.3.

Step (l). Determine all pertinent elements of the problem. These include the item characteristics, its weight, fragility rating (2.2), dimensions, and any particular features (such as projections or non-supportive surfaces) that will require special consideration; the number of items; and anticipated shipping environmental conditions (especially drop height, container orientation during impact, atmospheric conditions, number of shipments, and transportation mode) from which the cushioned item must be protected (2.1.1.1).

Step (2). Determine the most economical cushioning material and method for protection of the item. This will involve:

(a) Determining which cushioning materials and application methods will furnish adequate protection (3.2.1.2, 3.2.2, 3.2.6, and Chapter 4).

(b) Eliminating the obviously less desirable cushioning materials and making certain that the materials remaining under consideration will meet the minimum requirements for characteristics, such as recovery ability, dusting resistance, tensile strength, hydrothermal stability, etc. (refer to 3.2.4 through 3.2.13 and to MIL-C-26861 (36).

(c) Computing the most economical cushioning material and application method (3.2.3).

Step (3). Calculate or estimate the allowance in thickness of cushioning pads that is required to offset creep (3.2.7).

Step (4). Calculate the exterior container dimensions according to 3.2.6, if this calculation has not already been made under step 2(c).

Step (5). Make instrumented impact and/or vibration tests of the complete package with an actual item or dummy item (3.2.1.2.5 and 6.3). If an actual item is used, conduct functional tests of the item before and after testing to insure the adequacy of the packaging.

3.2 DESIGN ACCORDING TO THE VARIOUS CUSHIONING CHARACTERISTICS.

Generally, each cushioning material has a combination of features that makes it ideal for certain applications but not for others. Consequently, rational selection of a specific material for use in any particular application should include consideration of all of the characteristics of the cushioning material that relate to its function as a packaging material. Package cushioning design based upon the pertinent characteristics of cushioning materials is discussed in 3.2.1 through 3.2.13.

3.2.1 Shock Absorption Capability.

3.2.1.1 Peak acceleration-static stress curves as indicators. In general, peak acceleration-static stress (Gin-W/A) curves have proved to be the most practical basis for indicating the shock absorption capability of cushioning materials and for solving problems of this nature. G_m-W/A curves are derived from dynamic compression test data according to the test procedure and computations given in 6.1.2.1. Essentially, this procedure involves impact tests with relatively rigid loading devices that strike the cushioning specimens squarely (thereby simulating flat drops). The specimens are mounted on a rigid impact base.

A typical set of G_m-W/A curves representing the different thicknesses of a polyethylene foam (2.0 pcf) for a 30-inch drop height at 73°F is shown in Figure 3-1. Additionally, sets of Gin-W/A curves for various cushioning materials and design parameters are shown Appendix V, graphs 1.12 through 22.48.

Since G_m- W/A curves indicate directly the relationship between G_m and W/A, their shapes also indicate the versatility and efficiency of the materials. The lower its curve swings (toward G_m = 0), the better protection a material will provide. Also, materials charaterized by curves that occur through a broad W/A range are more versatile than those that extend through a more limited range.

To determine approximately how much of a particular kind of cushioning material is required to protect a specific item, two steps are necessary: first, determine the bearing area of the item; second, select from a set of Gin-W/A curves for the cushioning material the minimum thickness that will apply a G_m that is less than the fragility rating for the item.

The bearing area of the sides of regularly shaped rectangular items against the cushioning materials during flat drops can be determined by a simple calculation of the area of the sides. However, calculation of the effective bearing area of the same items for cornerwise impacts is more complicated (3.2.1.2.4.1).

Also troublesome is the calculation of the effective bearing area of irregularly shaped items. However, for such items, it may be simpler to measure the effective bearing areas for flat and cornerwise impacts by light projection methods.

This can be accomplished simply by holding the item on the floor in the proper impact attitude directly below an illuminated light bulb. The effective bearing area is the area within the shadow cast by the item. The bulb should be located a sufficient distance away to minimize the error caused by parallax.

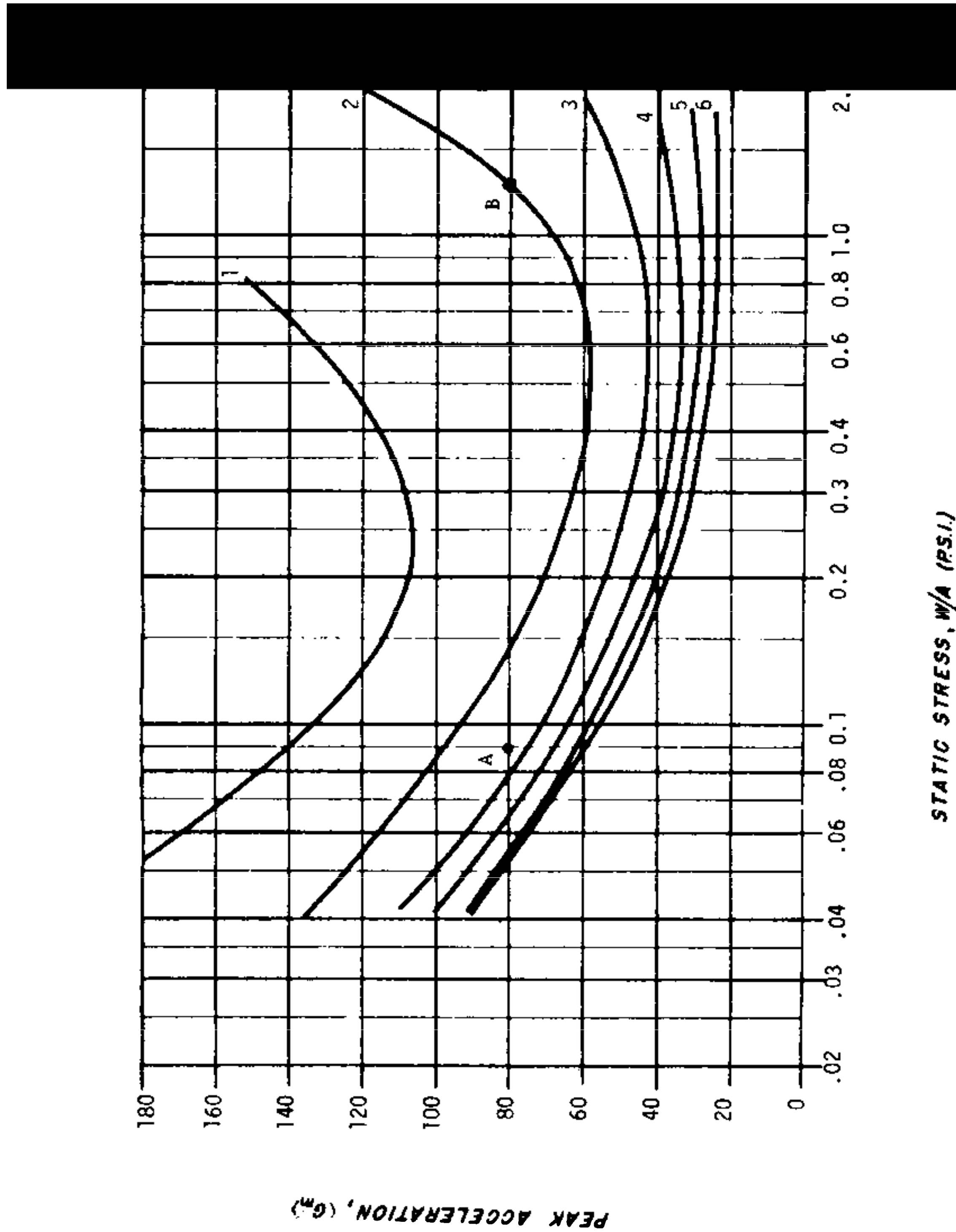


Figure 3-1. A Typical Set of Peak Acceleration - Static Stress Curves (Polyethylene, 2 pcf, 30" drop height)

The described light projection method for determining effective bearing area of items is suitable when the cushioning material is to be applied by complete encapsulation (4.1.1), but it is unsuitable for application by corner pads (4.1.2) and side pads (4.2.2).

3.2.1.1.1 Effects of variable temperature and humidity upon G_m-W/A curves. The compression characteristics of different kinds of cushioning material when exposed to high humidity or temperature extremes are highly variable. For example, materials such as resilient expanded polystyrene are nearly non-hydroscopic and their cushioning performance characteristics are little affected by temperature extremes. In contrast, the performance of thermoplastic materials, such as urethane foam and polyethylene foam, is affected by temperature. Consequently, if packages containing cushioning material are expected to be exposed to temperature extremes or high humidity during shipment or storage, the packaging designer must recognize the danger in designing by data that indicate material performance only at moderate atmospheric conditions.

More research about the effects of variable temperature and humidity upon cushioning performance is needed. In general, high temperature can soften certain cushioning materials significantly and alter the performance characteristics accordingly. Low temperature exposure is considered to be the worst of the extreme exposure conditions because of the possibility that the cushioning will stiffen drastically or break down and thereby become ineffective. Obviously, no relatively wet cushioning materials should be used in packages that will be exposed to low temperature.

Limited data are currently available in the form of G_m-W/A curves to show the effects of exposure to humidity and temperature extremes (all G_m-W/A curves shown in this handbook were derived from tests conducted at 73 F and 50 percent relative humidity). Nevertheless, some data has been developed (Letchford (19)) on the probable minimum safe temperatures at which representative kinds of cushioning material might be expected to perform satisfactorily. For example, as the temperature of different kinds of cushioning material is reduced during preconditioning and flat drop testing, the peak acceleration values increase only slightly until some critical temperature is reached. At this temperature, the peak acceleration values sharply increase. This particular point is called the “probable minimum ‘safe’ temperature”, and it differs for each kind of material. Occasionally, as some material stiffen, the peak acceleration values actually decrease (probably because of increased cushioning efficiency). However, all of the materials deflect less as they stiffen with reduced temperature.

Therefore, cushioning design for stock isolation based upon data derived at 73 F and 50 percent relative humidity appears to be reasonably accurate to the minimum temperature shown in the following:

Material	Probable Minimum "Safe" Temperature
Urethane foam (polyester type)	-10°F
Urethane foam (polyether type)	-20°F
Rubberized hair	below -60°F
Expanded polystyrene	-20°F
Polyethylene	below -60°F

Obviously, cushioning materials that might change performance drastically during the same shipment due to temperature fluctuations cannot be expected to perform satisfactorily at all times during the shipment. Therefore, until more complete knowledge about the low temperature performance characteristics of all kinds of materials is gained, it is recommended that the designer use cushioning materials according to the minimum "safe" temperatures listed (38).

3.2.1.2 Shock isolation design procedure. Cushioning design for shock protection primarily involves reference to Gin-W/A curves. However, rational cushioning design also requires various supplemental considerations. These considerations are discussed in order.

3.2.1.2.1 Make initial estimate. To obtain an initial estimate of the type of cushioning and its dimensions needed to protect a particular item, the designer will refer to the G_m- W/A curves given in Appendix V .

He determines, first, the static stress of the item against the cushioning He then refers to sets of G_m-W/A curves for the anticipated impact conditions and determines directly the kind and thickness of material required to protect the item. (For convenience in referring to subsequent discussions to the various materials for which Gin-W/A curves are presented in Appendix V, the identification numbers given in 2.1.2.l.l will be used.) To illustrate the method, the following example is given:

PROBLEM: A 20-pound, 15-inch cubical rigid item having a fragility rating of 80 g must be protected from a 30-inch flat drop. Determine what size of pads of the polyethylene represented by Figure 3-1 is optimum for protection of each face of the item by (a) complete encapsulation, (b) side pads, and (c) corner pads (4.1).

SOLUTION: The W/A of any side of the item is $20/15^2 = 0.09$ psi. In Figure 3-1, point "A" represents the coordinated 0.09 psi and 80 g. The curves for the various thicknesses of material indicate that at least a 3-inch thickness of material is required to protect the item. Thus, if the item is to be encapsulated in cushioning material, a 3-inch thickness of material on all faces is required.

Three-inch face pads, 15 X 15 inches, could also be used to protect the item. However, the designer should recognize that these might not be the least size that will furnish adequate protection. In checking the possibility of using smaller face pads, the fragility rating and weight of the item are fixed, but the bearing area of the item against the pad can be changed. Furthermore, the curve for the 2-inch material indicates that adequate protection could be obtained in the W/A range from about 0.14 to 1.30 psi. The maximum savings in material would result from the highest value of W/A (at point "B"), since this would involve the least bearing area (therefore, size of cushion). The required bearing area can be computed by: W/A = 1.30

$$A = \frac{20}{1.30} = 15.4 \text{ sq in} = (3.9 \text{ in})^2$$

Therefore, a set of six 2.0- X 3.9- X 3.9- inch face pads would suffice.

The use of corner pads provides four small pads for protection against flat drops perpendicular to each face. The required size of each of the three component pads comprising each corner pad would be:

$$\sqrt{\frac{15.4}{4}} \text{ by } \sqrt{\frac{15.4}{4}} \text{ by 2 inches}$$

or about 2 X 2 X 2 inches (Figure 3-2A). For added protection against bottoming during cornerwise impacts, it is usually prudent to fill the void spaces along the edges (Figure 3-2B).

3.2.1.2.1.1 Material identification numbers. For convenience, the materials for which G_m-W/A curves are presented in Appendix V are identified by the following numbers. (The thickness in inches will usually follow the number. Thus, 10-4 will indicate foamed polyethylene of 2-pound density and 4-inch thickness.)

NUMBER	MATERIAL	DENSITY (pcf)
1	Polyurethane-Ether	1.5
2	Polyurethane-Ether	2.0
3	Polyurethane-Ether	4.0
4	Polyurethane-Ester	1.5
5	Polyurethane–Ester	2.0
6	Polyurethane-Ester	4.0
7	Rubberized Hair Type II	1.1
8	Rubberized Hair Type III	1.5
9	Rubberized Hair Type IV	1.7
10	Polyethylene Foam	2.0
11	Polyethylene Foam	4.0
12	Polystyrene Foam	1.5
13	Polystyrene Foam	2.5
14	Polyethylene, Chemically Crosslinked	2.0
15	Convoluted Ether Polyurethane--l", 2", 3"	1.1
16	Convoluted Ether Polyurethane 2" ,4" ,6"	1.1

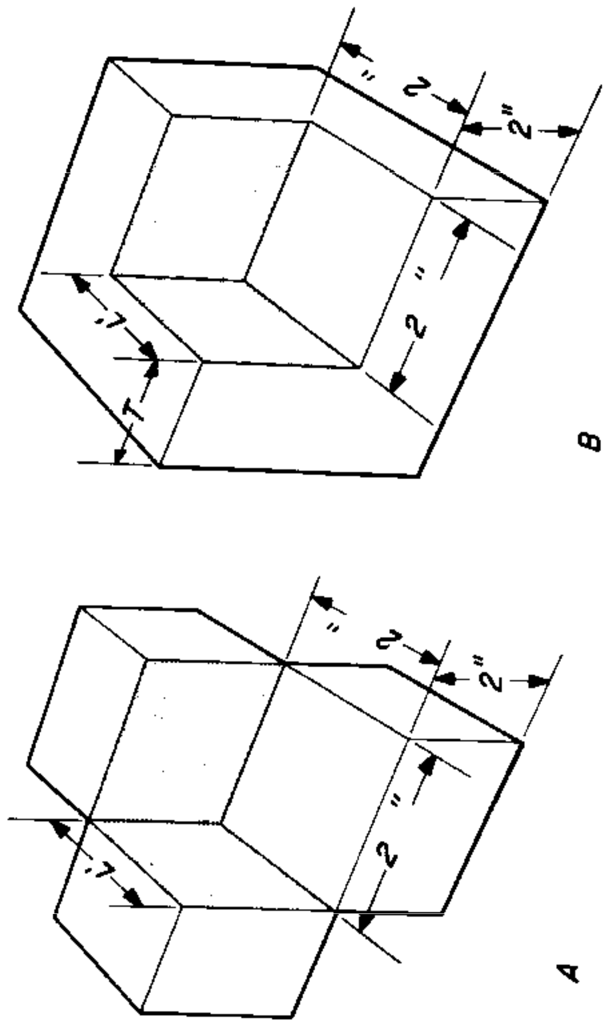


FIGURE 3-2. Corner pads according to problem 3.2.1.2.1. A, with void spaces along edges; B, without void spaces along edges.

Material identification numbers continued:

NUMBER	MATERIAL	DENSITY (pcf)
17	Convoluted Ether Polyurethane--l", 2", 3"	1.5
18	Convoluted Ether Polyurethane--2", 4", 6"	1.5
19	Cellulose Wadding	2.0
20	Air Encapsulated Film, .5" ply thickness (PPP-C-795)	.691
21	Hexagonal Film, Open Cell (PPP-C-1842A)	1.40
22	Hexagonal Film, Reinforced Cell (PPP-C-1842A)	1.8

3.2.1.2.2 Select cushioning application method. Once the designer has made an initial estimate of the amounts of different kinds of cushioning that will protect the item, his next step in the design should be to compute the cost (3.2.3) related to the use of the different materials and application methods. He can then select the most suitable material and application method. Some of the most common application techniques involve complete encapsulation, corner pads, and face pads. These and various other application techniques are discussed throughout Chapter 4.

3.2.1.2.3 Check for buckling (if pertinent). Long, slender cushions tend to buckle, instead of becoming uniformly compressed, when subjected to a compressive force applied along the lengthwise axis of the cushion. Generally, this is undesirable if face pads are used because the item might tip (Figure 3–3) and become damaged as a result of collision of the item with the container. (NOTE: Under certain circumstances, controlled buckling in cushioning can be desirable). In general, danger from buckling may be disregarded when application methods other than face pads are employed. Normally, a cushion will be relatively stable if:

$$\frac{\sqrt{\text{Area}}}{T} \geq 1.33 \qquad (3:1)$$

where T is the original thickness of the cushioning material. Restated, the minimum bearing $A_{min.}$ that will insure stability of a face pad is given by:

$$A_{min.} = (1.33T)^2 \qquad (3:2)$$

CAUTION: Although economy of cushioning design might dictate reduction of cushioning bearing area to a minimum, the

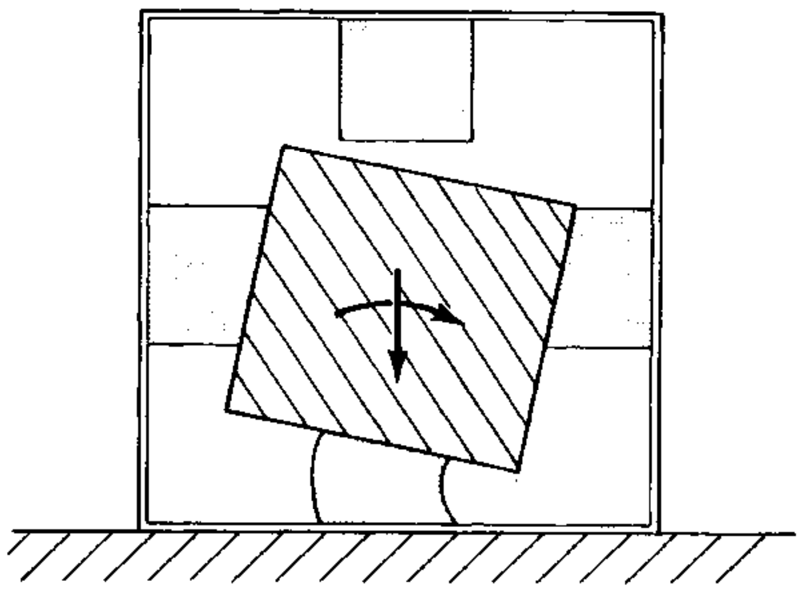


FIGURE 3-3. Columnar buckling of cushion.

designer must insure that the load–bearing portion of the item can withstand the resultant stress (15), (28).

3.2.1.2.4 Check the effectiveness of the cushioning against cornerwise impacts (if required). Flat drops of containers against their faces are generally considered to be the most severe type of rough handling that a package might encounter during shipment. Therefore, cushioning design is primarily concerned with providing ample flat drop protection. However, cornerwise impacts of packages are also quite common in service. Many complete package acceptance tests in specification involve cornerwise impacts so the designer must be certain that his design, based upon flat drop protection, will also suffice for cornerwise drops. Only limited research has been conducted to reveal the correlation between cushioning performance as determined in flat drops using a cushion testing apparatus and corner drops of complete packages.

Some indication of this relationship is given in the Gin-W/A curves shown in Figures 3–4 and 3–5. The curves represent test data collected by the U.S. Forest Products Laboratory to show the combined effects of cornerwise–impact loading with different kinds of containers upon dynamic compression test data for rubberized hair (Type IV, 3.0 inch thickness, 1.8 pcf) and urethane foam (polyester type, 3.0 inch thickness, 4.0 pcf) . These-materials were selected because they represent extremes in damping. Three samples of each material were tested in accordance with 6.1.2. Other samples were fabricated into corner pads (as in Figure 3-2B) and corner-drop tested with dummy loads and appropriate recording equipment inside single-wall corrugated fiberboard containers (RSC domestic B–flute, 225 psi Mullen strength) and paper-overlaid veneer containers (PPP-B-576, style A) according to 6.3. An equivalent drop height of 22 inches was used for all tests and W/A for the cornerwise–drop tests is based upon A_T (equation (3:5)) , (33).

As shown, at lower W/A values the paper–overlaid veneer containers, being stiffer than the corrugated fiberboard containers, produced higher G_m values than the flat drop test values obtained without containers. However at higher values of W/A the container corners became crushed and provided extra cushioning. The corrugated fiberboard containers provided safe (even additive) protection throughout the entire W/A range but like the paper–overlaid veneer containers, their greatest additive effect also occurred at the higher W/A range.

These data indicate that extra thickness of pad will be needed for corner drops involving effective bearing stresses of less than about 0.4 psi and paper-overlaid veneers (and probably cleated plywood) containers. However, additional test data are needed to establish more conclusively the relationship between flat drop test data and cornerwise–drop test data for complete packages.

The safest method to check the adequacy of the design in providing overall shock protection is by conducting instrumented complete package drop tests. After the cushioning that will protect the item from drops has been determined,

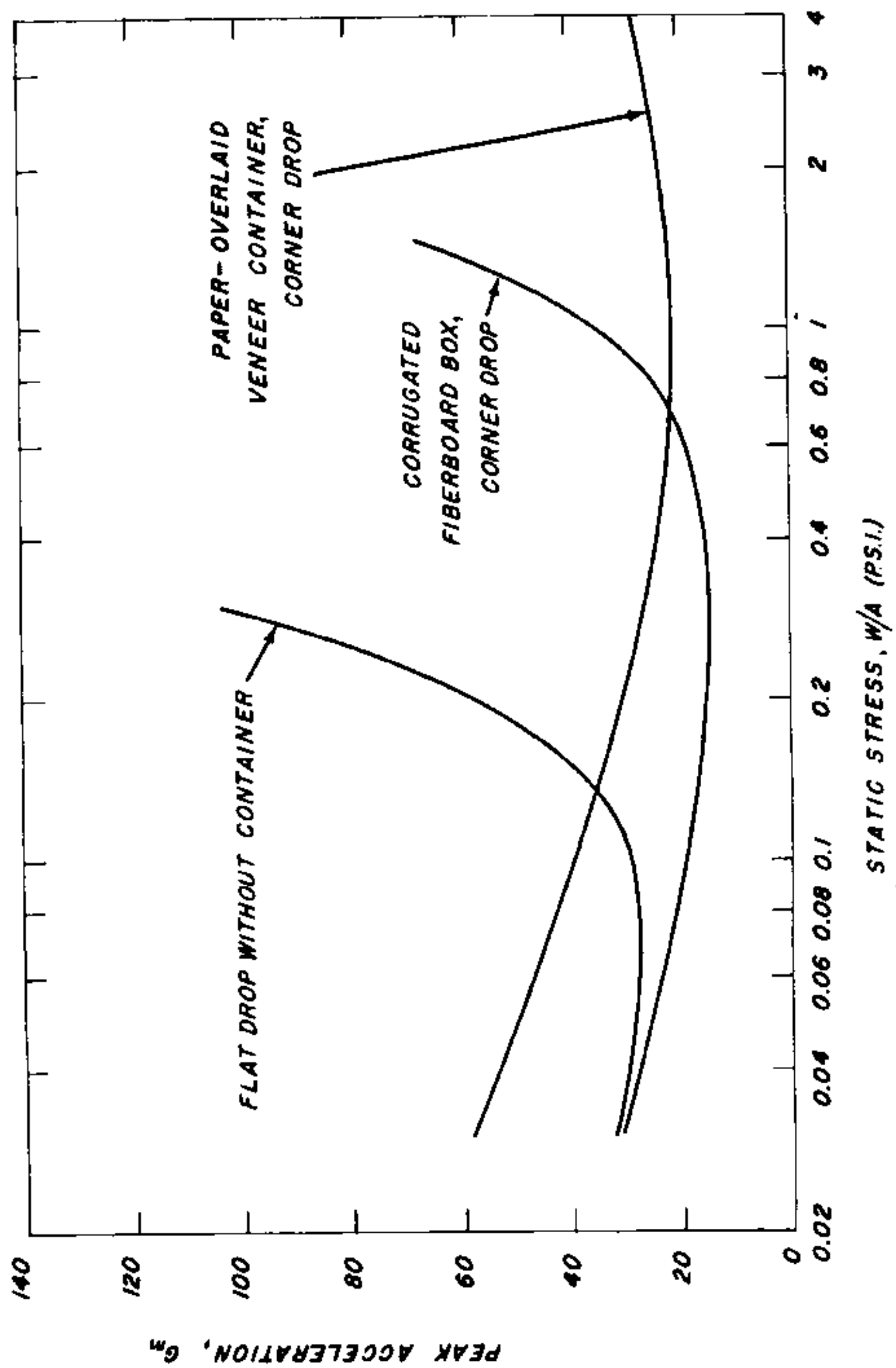


FIGURE 3-4. Combined effects of different kinds of containers and corner-wise impact loading upon dynamic compression test data for rubberized hair.

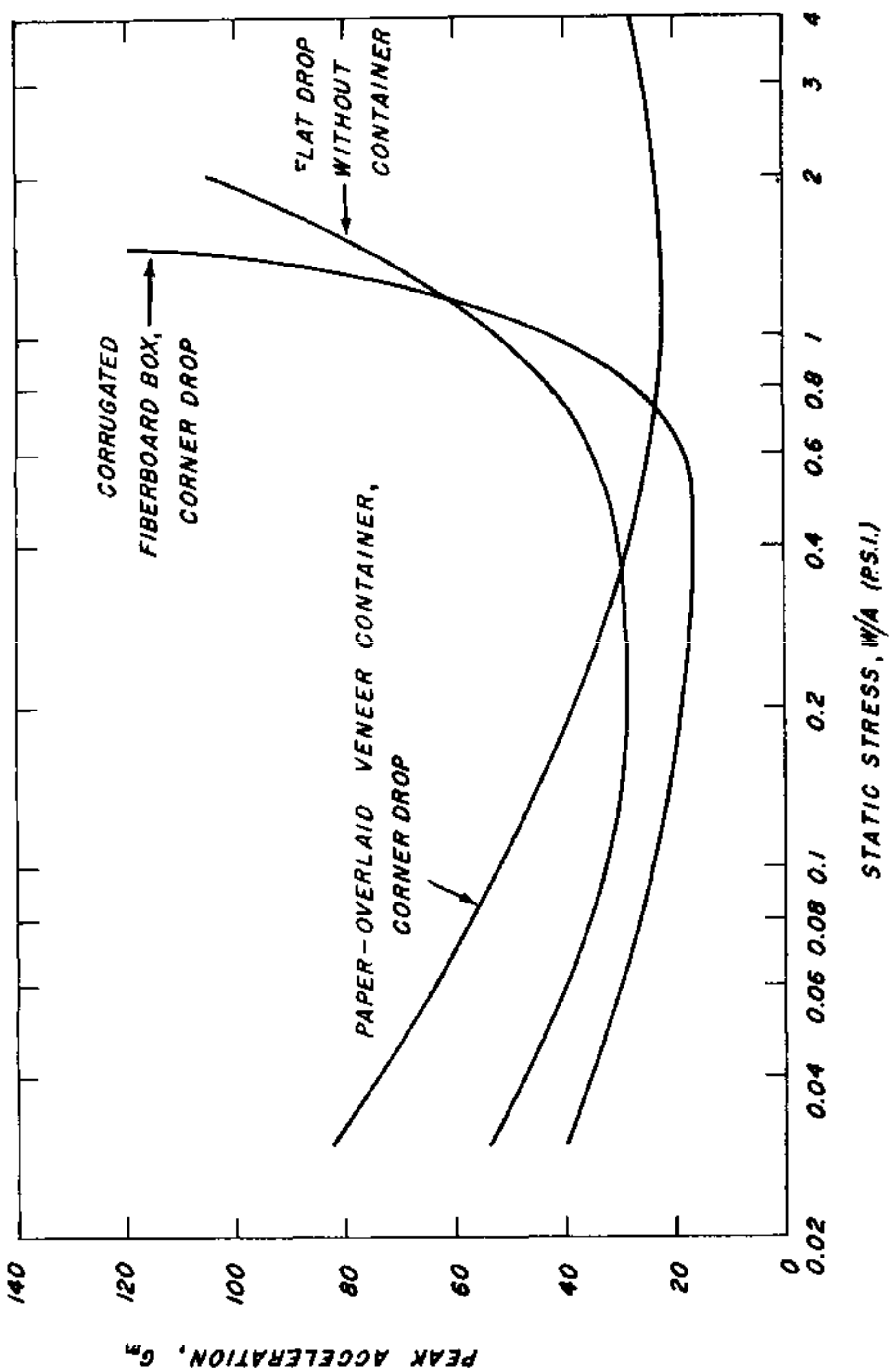


FIGURE 3-5. Combined effects of different kinds of containers and cornerwise impact loading upon dynamic compression test data for urethane foam.

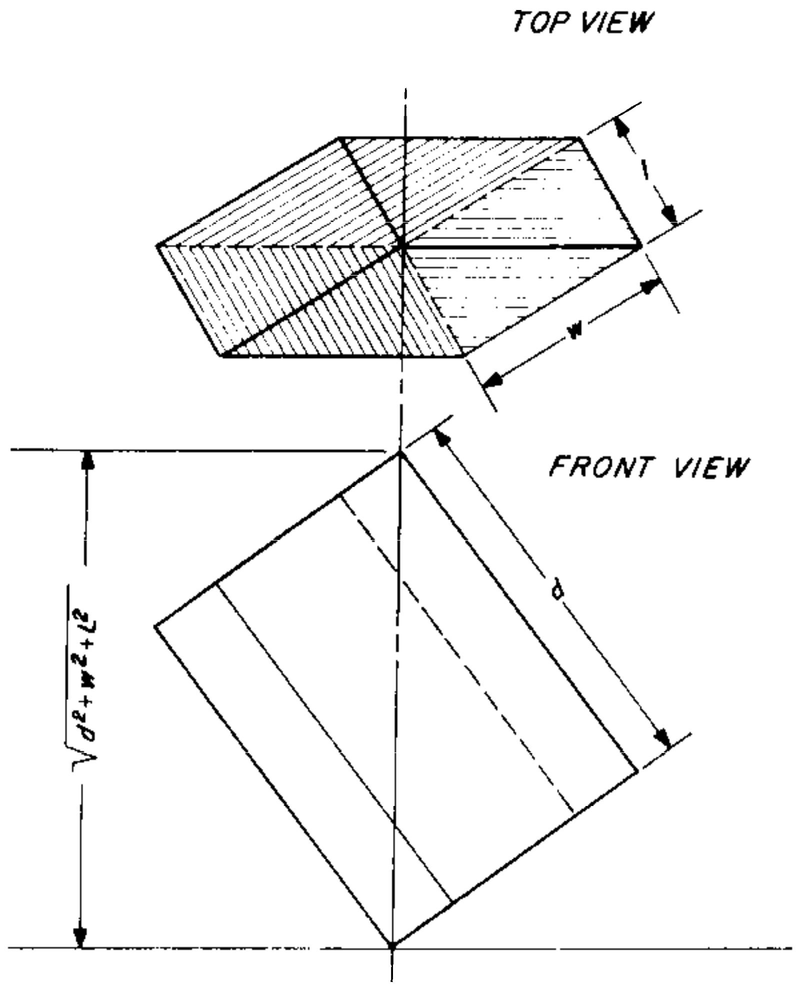


FIGURE 3-6. Hypothetical homogeneous item in cornerwise impact attitude.

an estimate of the suitability for cornerwise impacts of design based upon flat drop test data can frequently be made by the method described in 3.2.1.2.4.2.

3.2.1.2.4.1 Calculating effective bearing area for cornerwise impacts.

In cornerwise-drop tests of complete packages, specifications usually require that, when dropped, the corner to be impacted must be aligned along a vertical line through the center of gravity for the package (Figure 3-6). Upon impact the item, due to its inertia, tends to continue moving vertically downward without rotation, and the supporting cushioning (except that located in close proximity to the impacted corner) is loaded to some degree in shear. If an item was completely encapsulated in material, the effective bearing area A_T of the item for this situation is the projected bearing area in the horizontal plane of the three sides adjacent to the impacted corner of the item. For example, the effective bearing area of the hypothetical homogeneous item depicted in cornerwise-impact attitude in Figure 3-6 would be the summation of the shaded areas shown in the top view. As stated in 3.2.1.1, this area can be measured by light projection methods or it can be computed for the different conditions described in the following text.

Obviously, AT is a function of L, w, and d of the item. For any item that is a rectangular prism, the relationship between A_T and L, w, and d is:

$$A_T = \frac{3\ (L\ w\ d)}{\sqrt{L^2 + w^2 + d^2}} \qquad (3:3)$$

If the item is a cube, the equation reduces to:

$$A_T = 1.73\ L^2 \qquad (3:4)$$

The effective bearing area of corner pads cushioning items during cornerwise impacts A'_T is also a function of L, w, and d. If they are supporting cubical items and the pads are essentially composed of three portions having equal length and width dimensions, the A'_T is: $A'_T = 1.73\ L'^2$ (3:5) where L′ is the length of the side of one of the three major components of the corner pads (Figure 3-2).

If the same pads are used with items that are rectangular prisms having different dimensions of L, w, and d, the A'_T is:

$$A'_T = \frac{L'^2\ (d + w + L)}{\sqrt{d^2 + w^2 + L^2}} \qquad (3:6)$$

Because of the complexity of the phenomena involved, it is not feasible to calculate A_T when side cushioning pads are used. In such instances, the most practical recourse for the designer is simply to bypass the analytical check for cornerwise-drop protection. However, it is essential to check the effectiveness of the design for both flat and cornerwise-drop protection by conducting actual tests of the complete package (3.2.1.2.5 and 6.3).

3.2.1.2.4.2 Estimating protection for cornerwise impacts.

Once the designer has decided upon the cushioning that will adequately protect the item from flat drops, he should then check the effectiveness of the cushioning against cornerwise impacts by (1) calculating the effective bearing area by one of the pertinent equations in 3.2.1.2.4.1 and then (2) determining whether additional thickness is needed for cornerwise-drop protection by reference to the G_m-W/A curves.

To illustrate estimation of cushioning requirements for cornerwise impacts, the following example problem is given:

PROBLEM: Determine the amount of urethane foam (polyester type, 4.0 pcf) that is required to protect an item by complete encapsulation in a single-wall corrugated fiberboard box from flat and corner drops of 24 inches. The item weighs 10 pounds and is a 12-inch cube that will endure up to 50 g.

SOLUTION: Since the bearing area of each of the sides is 144 square inches, W/A = 0.07 psi. The curves in graph 6.24 (which are based upon flat drop test data) show that 2-inch thick cushioning will provide adequate protection for a flat drop.

The projected bearing area for a corner drop, calculated by equation (3:4) is:

$$A_T = (1.73)\ (144) = 249 \text{ square inches}$$

$$W/A_T = 0.04 \text{ psi}$$

The curves in graph 6.24 indicate that, for W/A_T = 0.04 psi, a 3-inch thickness of material would be required to protect the item.

3.2.1.2.4.3 Estimations involving adjacent cushions of different thickness.

Design against flat drops (especially with rectangular items) often yields different thicknesses of cushioning material against the various faces. This disparity of thickness presents a slight problem in checking the adequacy of the same design for cornerwise-drop protection. However, in such instances, it is suggested that the designer should (1) calculate the effective static stress for cornerwise impact, (2) determine from the curves the minimum required thickness, and (3) adjust the cushioning thickness of any of the sides, if necessary, to comply with the minimum required thickness.

3.2.1.2.5 Conduct instrumented complete package drop and vibration tests.

The data given in Appendices V through VII will give a first estimate of the cushioning performance requirements, but shock and/or vibration tests of the complete package should be conducted before the package design is finally accepted. Some empirical adjustment of cushioning thickness might be indicated by the test results.

The nature of the tests will be dictated by applicable specifications or other pertinent requirements. Recommended techniques for instrumenting the items (or dummy items) for testing of complete packages are given in 6.3.

The peak acceleration–static stress curves shown in Appendix V were derived according to the test procedure given in 6.1.2.1, which is based upon tests involving relatively rigid testing surfaces. The transmissibility-frequency curves shown in Appendix VI were derived according to the test procedure given in 6.1.2.2 which eliminates most of the frictional force experienced in actual applications. Therefore, the effects of container behavior are not included. The performance of cushioning materials inside complete packages under certain conditions can vary appreciably from the performance exhibited during tests of a cushion pad alone using a cushion testing apparatus (11), (14), (23), (32).

Figures 3-4 and 3–5 provide partial indications that design through the useful range of static stress with peak acceleration-static stress curves derived exclusive of container effects probably will be somewhat inaccurate, especially concerning optimum static stress values. Inconsistencies between cushion pad performance data and completed package performance serve to emphasize the need for confirmation of cushion performance through completed package testing. The nature of the inconsistencies between cushion pad and completed package tests is discussed in 3.2.1.2.5.1 through 3.2.1.2.5.3.

3.2.1.2.5.1 Rebound effects. Immediately after a flat drop, the container usually rebounds to some extent. This phenomenon (Figure 3-7) causes the container (and cushion) to move vectorially opposite to the motion of the item and increases the peak acceleration experienced by the item. The quantitative nature of effects caused by rebound have not been clearly defined but work being conducted by the U.S. Forest Products Laboratory indicates that under certain loading conditions (especially where very lightweight items and flat drops are involved) the increase in peak acceleration of the item can be large.

3.2.1.2.5.2 Corner crushing and buckling of sides. In certain instances, especially when relatively flexible containers (some kinds of corrugated fiberboard containers) containing heavy items are dropped on corners or edges, the sides tend to buckle and the corners crush as indicated in Figure 3-8. In this instance, the energy absorption capacity of the supporting cushioning material is partially bypassed, thereby, causing the corner of the item to

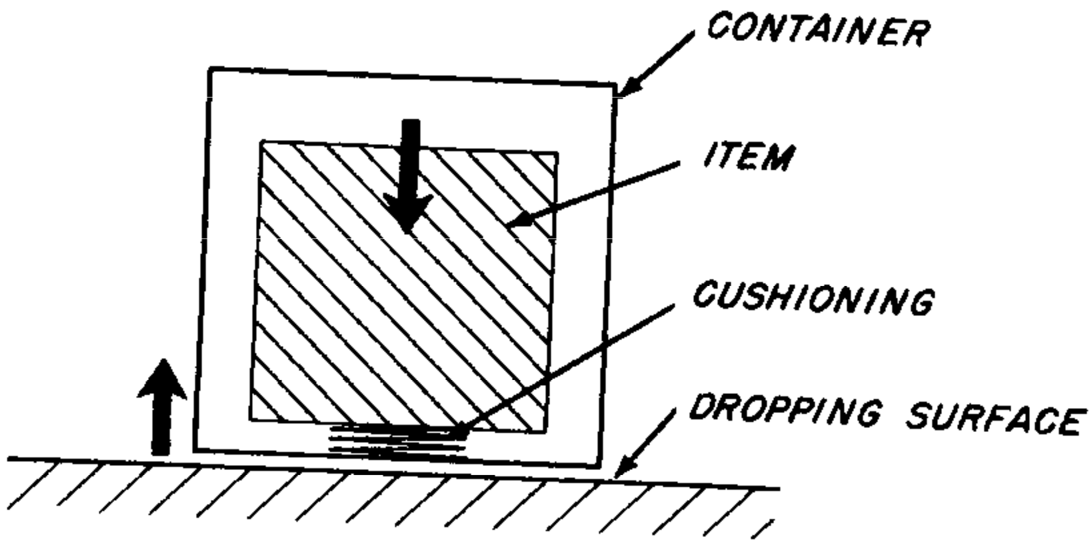


FIGURE 3-7. Container rebound immediately after collision with a rigid Surface.

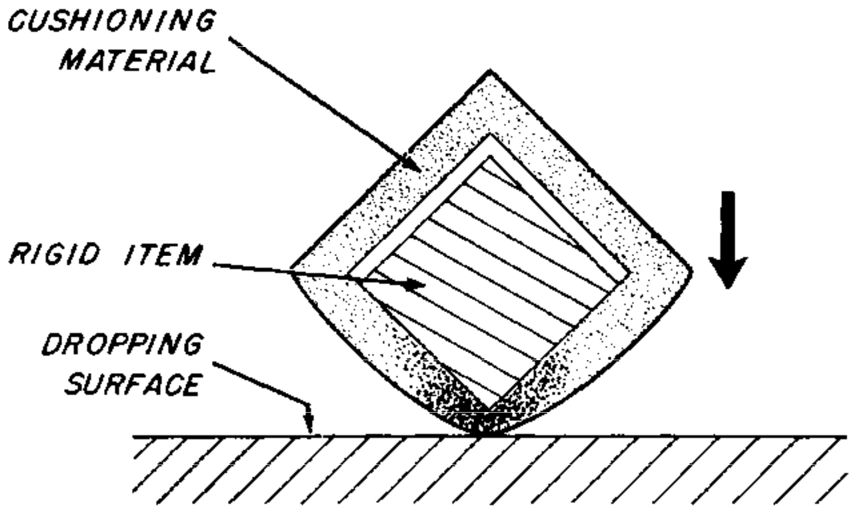


FIGURE 3-8. Buckling of sides during impact of heavily loaded flexible container.

“bottom” and be damaged.

In other instances, the peak acceleration of items during corner impacts of packages is reduced because the corners crush together with only slight flexure of the sides.

Obviously, the beneficial or deleterious nature of corner crushing and side buckling is dependent upon the stiffness of container and the amount of applied energy and can best be quantified by specific complete package testing.

3.2.1.2.5.3 Pneumatic and frictional effects. Since the dynamic compression performance of most cushioning materials is viscoelastic in nature, enclosure of such materials in a container may influence both peak acceleration and static stress loading values. Viscous damping may be increased when the cushion pads are enclosed, thus, restricting air flow within the box and increasing the effective load bearing capability of the pad under rapid loading rates. In addition, frictional (Coulomb) damping may retard movement of the item in relation to the side pads.

3.2.2 Vibration isolation capability. Generally shock isolation is considered first in the design of packaging for items of a size and weight which are susceptible to free fall drop during manual handling. After an acceptable pack has been designed with regard to shock protection it should then be evaluated with respect to its vibration response and isolation characteristics. Package vibration problems usually involve one or both the following considerations:

a. The response of the pack “as a whole” to its vibration environment.

b. The response of secondary elements of the item to the vibration environment.

3.2.2.1 Transmissibility curves for representation of vibration response.

Any linear cushioning system can be represented by the set of generalized transmissibility curves presented in Figure 2-19. The transmissibility of a cushioning system is expressed as a non-dimensional ratio of its response amplitude to the excitation amplitude. The ratio may be one of forces, displacements, velocities, or acceleration. As indicated in Figure 2-19, the shape of the curve is affected by the degree of damping in the system.

Unlike linear systems, non–linear systems, such as represented by all the cushioning materials presented in this handbook, cannot be characterized by a single set of curves. Instead, a total of 1260 curves are displayed in Appendix VI, to define the transmissibility properties of 22 types of package cushioning material. Since the natural frequency of a non-linear system is continuously changing with displacement, the frequency axis of the transmis–sibility curves for these materials represents the forcing frequency (input) rather than a ratio of the forcing frequency to the natural frequency, as is the case with linear systems. Several important points can be identified on the transmissibility curves of both linear and non-linear systems, which can be useful in the design of package cushioning systems. As previously noted in 2.3.2.2.2, the frequency value corresponding to the peak amplitude of the curve represents the resonant frequency of the cushioning system for the cushion material thickness and bearing load specified. For linear systems, the peak amplitude always corresponds with a one to one frequency ratio. The peak amplitude represents the point of maximum amplification of vibration inputs. The nearly horizontal segment of the extreme left hand portion of a transmissibility curve indicates that when the forcing frequencies are relatively low, i.e., significantly less than the natural frequency of the system, the response of a cushioned item is of approximately the same amplitude as the forcing frequency. The point at which the curve drops below a transmissibility value of one indicates the frequency or frequency ratio at which vibration isolation begins. For linear systems this point occurs when the forcing frequency is 1.414 times greater than the natural frequency of the system. For non-linear systems vibration isolation also occurs when the forcing frequency is significantly greater than the resonant frequency; however, unlike the linear system, the ratio of these frequencies is not constant at 1.414 but varies with the type of material, thickness, and static loading stress.

3.2.2.2 Vibration isolation design procedures.

3.2.2.2.1 Problem: Item/ Cushion Response. The following problem illustrates the manner in which the resonant frequency of a package can be determined as well as the magnitude of its response to vibration inputs from the environment:

Assume that an item, 10 inches cube and weighing 8 pounds, has been cushioned on all sides with 2 inch thick pads of polyurethane (ether) foam of 1.5 pound per cubic foot density to provide shock protection at a level of 30 G when the pack containing the item is dropped from a height of 24 inches. Determine the resonant frequency of the pack and the acceleration respcnse of the packaged item due to vibration inputs experienced during air transport in a turbo-prop aircraft.

Solution: The first step in the solution is to calculate the static bearing stress (σ) exerted by the item on the cushion pad upon which it rests:

$$\sigma = W/A = \frac{8\ \text{(lbs)}}{100\ \text{(sq. in.)}}$$

$$\sigma = 0.08\ \text{psi}$$

From Appendix VI select the transmissibility curve for 1.5 pcf polyurethane (ether) of 2 inches thickness developed at a static bearing stress which most closely corresponds to the calculated bearing stress value of 0.08 psi. For this case, the curve satisfying the above requirements is presented in Curve 1.2. On the graph of the 2 inch thick material, project a line from the peak value on the curve perpendicular to the frequency coordinate axis, The point of intersection with this coordinate axis identifies the resonant frequency of the pack at 46 Hz. Alternatively, the resonant frequency could have been found by referring to the Q = MAX Column of Table I, Appendix VII.

A horizontal line projected from the peak (resonant) point on the curve to the transmissibility coordinate axis indicates that the pack has a transmissibility of 6 at its resonant frequency,

The probable overall maximum response of the pack to its transportation environment can be determined by referring to the aircraft acceleration envelop for propeller driven aircraft in Figure 2-11. Project a perpendicular line upward from the frequency coordinate axis at the point representing the resonant frequency of the pack (46 Hz) to the point at which it intersects the envelop curve for propeller aircraft. From this point of intersection project a horizontal line to the left. The point at which this line intersects the acceleration coordinate axis identifies a peak acceleration input value of 1,7 G.

The response of the packaged item to a vibration input of 1.7 G at 46 Hz is then determined from equation (2:7) which relates input ($\ddot{\mu}$) and output (x) accelerations to transmissibility (T_r):

$$\ddot{x} = T_r \ddot{\mu}$$

$$\ddot{x} = (6)(1.7)$$

$$\ddot{x} = 10.2 \text{ G}$$

Since the vibration response acceleration of 10,2 G is below the specified required protection level of 30 G, damage to the item would not be expected,

3.2.2.2.2 Problem: Modification of item vibration response. Although the previous problem solution indicated that the item response would be less than the fragility of the item (.30 G), nevertheless, repetitive acceleration inputs of 10.2 G may be of concern because of possible fatigue type damage to the item or degradation of the cushioning material itself, Therefore, in this case, redesign of the cushion pack might be desirable to reduce the potential level of vibration response.

Solution: An alternate cushioning material is required which will reduce the vibration response of the item to the environmental frequency input of 46 Hz while continuing to provide protection at the specified shock level of 30 G.

Generally, more than one type of cushioning material is considered when designing a pack for shock protection. If more than one of these materials meet the specified design criteria, then cost effectiveness usually becomes the determining factor in the final material selection. This was the case for the pack cited in 3.2.2.2.1 which was designed using the computer program described in Section 3.4. Although the package cushion design program identified a total of 13 different materials which would provide the required level of protection, polyurethane (ether) of 1.5 pounds per cubic foot density was selected because it was the most cost effective material. However, since vibration response has assumed primary importance, the remaining cushioning materials should be re–examined with regard to their vibration isolation characteristics. Although the transmissibility curves could be used for this purpose, the most efficient approach would be to make reference to the vibration performance data tables. Specifically, the frequency values in the column labeled "Q-1" would be examined. These frequencies represent the point at which vibration isolation begins. Therefore, those materials which would provide vibration isolation for the conditions specified in this problem would be the ones having a frequency value less than the 46 Hz environmental input vibration. In the design for shock isolation, Rubberized hair, Type III, had been identified as the second most cost effective material. The thickness of the cushioning pad of this material required to provide protection at the 30 G level was 2.5 inches. Therefore, to estimate the frequency value at Q=l, Table 8 was inspected for both 2 inch and 3 inch thicknesses at a loading of 0.076 psi. The Q=l frequencies values at the 2 and 3 inch thicknesses were 22 and 26 Hz, respectively. Therefore, by linear interpolation, the Q=l value for a 2.5 inch pad was estimated to be 24 Hz. Since this value is significantly below 46 Hz, appreciable attenuation of the input vibrations would be expected. The degree of attenuation is determined by entering the transmissibility curves (Curve 8.2) at 46 Hz for the 2 and 3 inch thicknesses of the materials. The transmissibilities are found to be 0.25 and 0.18 respectively for the 2 and 3 inch pad thicknesses. Again, by linear interpolation the transmissibility for a 2.5 inch thick pad is estimated at 0.22. By means of equation (2:7), the vibration response of a pack utilizing rubberized hair, Type III, is then calculated as follows:

$$\ddot{\chi} = T_r \ddot{\mu}$$

$$\ddot{\chi} = (0.22)\ (1.7)$$

$$\ddot{\chi} = 0.374 \text{ G}$$

As indicated above, the substitution of rubberized hair for polyurethane (ether) resulted in nearly a 30 fold reduction in the vibration response of the packaged item at 46 Hz. However, the maximum vibration response of the item must be checked at the resonant frequency of rubberized hair, Type III. By referring to Table 8 it is determined, by interpolation, that 2.5 inches of rubberized hair has a resonant frequency of 13 Hz at a loading of 0.076 psi. It is seen from the transmissibility curve 8.2, that for 2 and 3 inches of rubberized hair, the maximum transmissibility of 5 occurs at approximately 13 Hz. At this frequency the input peak acceleration of the propeller type aircraft (Figure 2-11) is approximately 0.3. From equation (2:7) $\ddot{\chi} = T_r \ddot{\mu}$, the maximum acceleration experienced by the item is (5) x (0.3) = 1.5 G. This is still considerably below the possible 10.2 G response using the polyurethane ether.

3.2.2.2.3 Problem: Vibration isolation of multi-resonant systems. In addition to the overall vibration response of the system represented by the packaged item and its cushioning, consideration must also be given to the fragile elements of which an item may be comprised. Generally, in a problem of this type, the fragile element can be characterized as a linear system. Assume that a cubical shaped item having a single fragile element is to be shipped by rail and will experience vibration inputs represented by the peak vibration envelop curve presented in Figure 2–7. The item weighs 64.8 pounds and is 12 inches in cube. The fragile element has a natural frequency of 25 cps, a damping coefficient of .02 and can withstand up to 45 G. Also, assume that it has been determined previously that adequate shock protection can be obtained by using a 12 x 12 x 4 inch pad of polyurethane (ester), 4 pound per cubic foot density. Neglecting fatigue effects, determine whether this same cushioning pad will furnish adequate vibration isolation to the item.

Solution: The item resting on the cushion can be represented by the two degree of freedom system shown in Figure 2-14. The first step in the solution is to determine the natural frequency of the item/cushioning system by referring to the appropriate transmissibility curve for polyurethane (ester), 4 lb/cu ft density. The static bearing stress exerted by the item on the cushion pad is calculated by dividing the weight of the item by the area of that item resting on the cushioning material.

$$\sigma = W/A = \frac{64.8 \text{ lbs}}{144 \text{ sq in}}$$

$$\sigma = 0.45 \text{ psi}$$

Curve 6.10 is then selected as the representative transmissibility curve for the bearing stress of 0.45 psi and cushion pad thickness of 4 inches. The natural frequency of the item/cushioning system is the frequency corresponding to the peak value on the transmissibility curve, which in this case is 7 cps. Alternatively, the natural frequency could have been obtained by using the vibration performance data table for the material, selecting the frequency value from the Q=MAX column. Since the item is to be shipped by rail and will experience vibration inputs represented by the peak curve in Figure 2-7, then peak amplitudes of + 1 G will be encountered at the system's natural frequency of 7 cps. Therefore, it is necessary to calculate the maximum acceleration the item will experience at resonance of the system. Curve 6.10 indicates that at resonance (7 cps) the transmissibility of the cushioning material is approximately 2.5. The maximum acceleration of the item (X_2) during vibration is calculated by equation (2:7):

$$\ddot{X}_2 = T_r\ddot{\mu} = (2.5)\ (1) = 2.5 \text{ g}$$

When the natural frequency of a fragile element is much higher than the resonant frequency of the item/cushioning system, as is the case in this problem, then the fragile element receives essentially the same peak acceleration as the item proper. Therefore, since 2.5 G < 45 G, the fragile element would not be damaged because of resonance of the cushioning system.

Next, it is necessary to check the possibility of damage because of resonance of the fragile element, since its natural frequency also occurs within the expected shipping vibration environment. To determine the response of the fragile element, first determine the severity of the vibration transmitted by the cushioning to the item. Reference to Figure 2-7 indicates that at the resonant frequency of 25 Hz for the fragile element, the transmissibility of the 4 inch thickness of cushioning material will be approximately 0.25. By substituting this cushion transmissibility value and the environmental vibration amplitude value (Figure 2-7) at 25 Hz in equation (2:7), the maximum acceleration response of the item proper is determined as follows:

$$\ddot{X} = T_r \ddot{U} = (.25)(.55)$$

$$\ddot{X}_2 = .14\ G$$

Since it is assumed that the fragile element can be represented by a linear system, equation (2:8) is used to determine the transmissibility (T_r) of the element at its natural frequency:

$$T_r = \frac{1}{2\beta} = \frac{1}{(2)(.02)} = 25$$

The maximum acceleration of the element X_1, therefore, is

$$\ddot{X}_1 = (25)(.14G) = 3.5$$

Consequently, since 3.5 G < 45 G, the cushioning selected initially for shock isolation purposes should also provide adequate vibration protection.

3.2.3 Cost.

Progressive packaging design requires the designer to minimize the cost of packaging wherever possible. Unfortunately, the true total cost of cushioning in specific applications usually involves many factors, some of which are intangible. In practice, calculation of the true total cushioning cost is usually too laborious to justify the effort required for such calculations. Nevertheless, rational selection of the most inexpensive material for particular applications requires an equitable computation based upon the principal elements of cost. Accordingly, the "cushioning cost index" (C_x) is suggested herein as a reasonable basis for equitable comparison of cushioning costs. Mathematically, C_x is equivalent to:

Cushioning
cost index

Cost of
shipping

$$C_x = \left(\frac{VC_m}{n} + C_p + C_{ic} + C_{ec}\right) + \left[C_L\left(P_m + P_p + P_{ic} + P_{ec}\right)\right] + C_s \qquad (3:7)$$

where:

$\underline{V}$ is the volume of cushioning material required to protect the item.

C_m is the initial cost per unit volume of cushioning material (delivered to the package designer's plant) in dollars.

$\underline{n}$ is the expected number of trips for which a cushioning material will be used (although variable, n is often considered to be one for relatively nonresilient materials and two or more for resilient materials).

C_p is the material cost of platens or die-cut trays in dollars.

$\underline{C_{ic}}$ is the cost of the interior container in dollars.

$\underline{C_{ec}}$ is the cost of the exterior container in dollars.

CL is the cost of labor per man–minute in dollars.

Pm is the labor in man–minutes that is required to cut and apply the platens or die-cut trays.

P_p is the labor in man–minutes that is required to fabricate and apply the platens or die–cut trays.

$\underline{P_{ic}}$ is the labor in man-minutes that is required to set up, load, and close the interior container.

$\underline{p_{ec}}$ is the labor in man–minutes that is required to set up, load, and close the exterior container.

C_s is the cost of shipping the complete package to its destination.

The cost of storage of cushioning materials prior to use is excluded from this formula because it is highly intangible and usually is considered to be part of overhead.

Cost comparison by equation (3:7) considers materials according to the required thicknesses as indicated by the method given in 3.2.1.2.1 (without extra thickness allowance for expected creep of the pad as determined in 3.2.7). This exclusion is considered expedient to simplify the cost comparison without introducing large error.

To determine the most economical cushioning material for particular applications, first decide which of the materials available will protect the item, according to the methods and considerations discussed elsewhere in this chapter and Chapter 4. Once the materials and cushioning application techniques have been selected, the appropriate information can be substituted in equation (3:7) and the most economical methods and materials computed.

To illustrate further the use of equation (3:7), the following example is given:

PROBLEM: Five rigid items, each 16 x 16 x 12 inches, weighing 10 pounds, and having a fragility rating of 50 Gs, must be packed individually in corrugated fiberboard boxes to withstand flat drops from a 30-inch height. Because only five items are involved, complete encapsulation is considered to be the simplest and most economical cushioning application method (Chapter 4). By reference to the G_m-W/A curves for 30-inch drop in Appendix V, it is determined that adequate protection would be afforded by materials 1 through 9, 15 through 19, 21 and 22 (see 3.2.1.2.1.1 for decoding). Of these, only 1, 5, 9, and 19 are stocked. Therefore, determine which of the stocked materials is most economical for packaging the items separately by complete encapsulation.

SOLUTION: The format given in equation 3:7 has been developed to provide an orderly cost computation procedure. When the details are entered in the appropriate columns, the "cushioning cost index" (C_x) for each cushioning material will be the result. These values can then compared to determine the most economical cushioning material to use. In this example, since C_x is lowest for material number 1, it is the least expensive material for this application. Further, material number 19 should be eliminated since it probably will not be suitable for more than one trip.

3.2.4 Density.

Density of a cushioning material is important in affecting its cost of usage, since its weight contributes to the tare weight of a package; cost of shipment is directly related to the tare weight of the packages. Obviously, the higher the density of material, the less satisfactory it is for packaging purposes.

Density is also of some value as an indicator of cushioning performance of some materials. However, generalizations about the correlation between cushioning performance and density of material should be avoided, since many materials (especially the plastic foams) exhibit little direct correlation between performance and density.

A recommended procedure for determining density is given in 6.1.1.2.

3.2.5 Recoverability (Compression Set)

Cushioning materials have varied ability to regain original thickness in the direction of compressive deformation after removal of the load. In the field of packaging it is common to express any deviation from perfect recovery ability (100 percent of original thickness) as "set". Because most cushioning applications involve compression loading of cushioning materials, the set is usually "compression set".

Various types of loading can cause compression set. During shelf storage wherein materials are subjected to relatively long-term static compressive loads, most cushioning materials tend to acquire a certain amount of compression set. Similarly, deformation of cushioning materials caused by the dynamic compression loading, typified by shock and vibration received by packages during shipment, produces compression set. Because compression set can be caused by various forms of loading, several procedures are recommended herein for evaluation of this characteristic (6.1.2).

Compression set is undesirable in cushioning material for two principal reasons: (1) looseness (and the related increased likelihood of damage). and (2) with some cushioning materials it indicates that the compressive stress-strain behavior of the material has changed and the possibility of damage caused by "bottoming" has also increased.

Some effects of looseness in a package are depicted by Figure 3–9 wherein (A) represents a cushioned item being displaced normally from its original position during a drop against a flat rigid surface; (B) illustrates the same item in a different position due to jostling and looseness and thus receiving an impact on a point; and (C) represents a loosely packaged item moving in a direction opposite from that of the exterior container and cushioning. The instance of (C) could occur during vibration of the package as it rests on the bed of a truck or rail car; the vibration causes larger peak forces and accelerations to be developed and these, in turn, increase the likelihood of damage to the item.

Compensation for compression set is usually accomplished by: (1) designing according to data that have involved a realistic amount of preworking prior to test (6.1.2.5.6) and repetition of impacts (6.1.2.1.6), or (2) applying an excess of cushioning material in precompressed condition (usually accomplished indirectly when such compensation is made for creep as described in 3.2.7) .

3.9.6 Static Compressive Force–Displacement Characteristic.

Knowledge of this characteristic (especially in the converted form, stress-strain curves) is useful to the packaging designer for the following applications: (1) solution of vibration isolation problems (2.3.2.2.2), and (2) calculation of the amount of displacement of the cushioning material by the item while at rest.

A recommended procedure for determining the static force-displacement (and stress-strain) characteristics of cushioning materials is given in 6.1.2.5, and static stress-strain curves for various kinds of cushioning materials are given in charts 1 thrcugh 22 of Appendix IV, pages 193 to 215.

The information on displacement of cushioning material by an item at rest is required by the packaging designer to estimate the maximum W/A for which a particular cushioning material should be used. Although the maximum amount of initial static compression of the cushion cannot be prescribed by rule, it is reasonable to restrict this to within 15 percent (a strain of 0.15) of the initial cushioning thickness. In some instances, the shape of the stress–strain curve provides a rather sharp indication of the maximum usable W/A value for the material. For example, with any of the styrene foam cushions represented by the compressive stress–strain curves shown in charts 12 and 13, it is obvious that any W/A value that would load a material in the

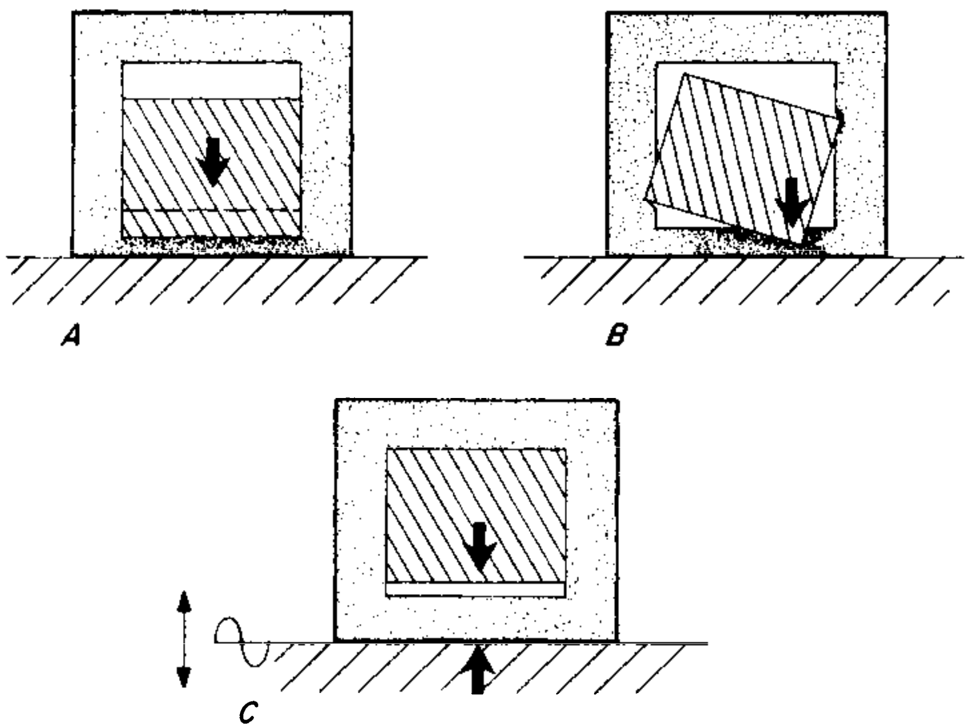


FIGURE 3-9. Effects of looseness in a package. A_, normal displacement during impact; B, nonuniform loading during impact by item disoriented because of looseness; C_, out-of-phase motion of item and container during vibration.

"plateau" region may be undesirable. Such a condition would cause the cushion to bottom quite rapidly, especially when loaded toward the part of the curve where the strain begins to increase abruptly, such as any point above the .6 in/in point on the curve in chart 12.

The amount of displacement of the cushion by the item at rest is also useful to the designer in calculation of the inside dimensions for the exterior container. To prevent looseness, the container dimensions are calculated to be the minimum that will accommodate the cushioning and item while at rest. (NOTE: Exclude creep considerations when calculating the exterior container dimensions.) Accordingly, the displaced thickness of the cushioning that supports the item while at rest is discounted in the calculations. As a practical consideration, when the calculated container height occurs between multiples of 1/4 inch, the next lower multiple of 1/4 inch should be used. The following example problem is given to illustrate further the use of static cushioning displacement data:

PROBLEM: A 25- x 8- x 8- inch item that weighs 50 pounds is to be packaged in cellulose wadding (4 inch) by complete encapsulation. Determine what size of corrugated fiberboard container is required to accommodate the item and cushioning. (Assume that the bottom of the item is 25 x 8 inches.)

SOLUTION: Bearing stress of the bottom of the item $= \frac{50}{(8)\ (25)} = 0.25$ psi.

The static compressive stress-strain curve in chart 19 indicates that for this material at a static bearing stress of 0.25 psi, the material will deflect about 0.2 inch per inch of thickness. Since the cushion is 4 inches thick, the total deflection is:

$$\text{Total deflection} = (4)\ (0.2) = 0.8 \text{ inch}$$

Therefore, the container height (inside dimensions) would be:

$$\text{Container height} = \text{full thickness of top pad} + \text{item height} + \text{compressed thickness of bottom pad}$$

$$= 4 + 8 + (4.0 - 0.8)$$

$$+ 15.2 \text{ inches}$$

Then the dimensions of the exterior container would be 33 x 16 x 15.2 inches.

3.2.7 Creep.

Virtually all cushioning materials, when subjected to a constant load for a period of time, tend to lose thickness. This phenomenon is called the creep characteristic of the material. The creep rate for all common package cushioning materials is greatest at initial loading and declines exponentially with elapsed time thereafter. After a load is removed, a cushion will regain most of its original thickness, but some permanent set will have been produced. Therefore, to prevent looseness in packages, it is desirable to apply extra thickness of cushioning material (in a precompressed state) in the package. However, because of the difficulty of closing a container after insertion of precompressed cushions, their use to offset creep is practicable only if relatively light precompression forces are required for application. In practice, it is customary to limit precompression of pads to the top-to-bottom direction in packages.

The amount of extra cushioning thickness required to offset creep can be estimated arbitrarily or, preferably, be calculated when creep-time data and knowledge of the shipment time is available. Regardless of the method of determination used, it is customary to add extra thickness to either the top or bottom cushioning--but not both.

Creep-time curves for various cushioning materials are not given herein because these data have, so far, been unavailable for the commonly used range of static stress. However, designers might be able to obtain creep-time data from the manufacturers or vendors of cushioning material.

If creep-time data are available, the extra thickness required to offset creep can be calculated by the following formula:

$$T_a = T + \frac{(\text{Creep})\ (T)}{100} \tag{3:8}$$

where T_a is the thickness of material required to protect the item, including the extra allowance to offset creep; T is the original thickness of material required to protect the item without an allowance for creep.

If the calculation of T_a indicates an unavailable thickness, it is generally advisable to use the next greater thickness of material.

A suggested method for determining the creep characteristics of cushioning materials is given in 6.1.2.4.

3.2.8 Tensile Strength and Flexibility.

Minimum tensile strength and flexibility are customarily prescribed in cushioning material specifications in order to make sure that the materials will not fail during normal handling and application, especially during wrapping operations. Suggested test procedures to evaluate minimum tensile strength and flexibility are given in 6.1.2.6 and 6.1.2.10, respectively.

3.2.9 Dusting and Fragmentation.

Despite large differences in their composition, all cushioning materials, if subjected to scuffing or miscellaneous rough handling, will release some fragments. These fragments might then become widely scattered.

Inside a package, the liberation of such particles is particularly objectionable when such items as optical equipment are being shipped because the jostling associated with shipment causes the particles to work into remote interstices and parts of the item. In addition to possible damage to the item, considerable labor in cleaning might be required before the part is usable.

Outside a package, the liberation of such particles may constitute a nuisance, both as litter and airborne particles.

Dusting and fragmentation testing procedures are discussed in 6.1.2.7.

3.1.10 Hydrogen Ion Concentration (pH).

The hydrogen ion concentration of the aqueous extract of cushioning materials has been considered traditionally to be somewhat of an indication of the inherent acidity and, therefore, the corrosiveness of the materials. Although its value for this is questionable, no better practical test of corrosiveness of cushioning materials has so far been developed. Therefore, this test is frequently specified for quality control purposes in cushioning specifications. A pH rating of 7.0 is considered to be “neutral” (neither acidic nor basic). However, the fact that a pH test indicates the aqueous extract of a material is 7.0 does not necessarily indicate that the material, when placed next to a ferrous metal in the presence of moisture or a humid atmosphere, will not cause corrosion (31).

A common pH test is described in 6.1.2.11.

3.2.11 Hydrothermal Stability.

Some cushioning materials, especially certain formulations of polyester-type urethane foam, tend to deteriorate rapidly in the presence of high humidity and temperature. Since the degradation of the material might result in substantial reduction of the stiffness of the material (and therefore cushioning ability) , a test (6.1.2.9) is included in material specifications to insure the stability of the performance characteristics of the material in the presence of high temperature and humidity.

3.2.12 Abrasive Qualities.

Two aspects of abrasion relative to cushioning materials concern the package designer: (1) the inherent abrasiveness of the component material of cushion materials themselves, and (2) the capability of cushioning materials to prevent abrasion of the item by rough surfaces or projections of other objects (staples, surfaces of crate members, impinging corners of exterior containers of nearby packages, etc.) .

Currently. no generally accepted test for the abrasion prevention capability of cushioning materials exists. One formidable obstacle deterring the development of such a test method is that little is known about the nature of the abrasion hazards of service on which such a test must be based.

Amounts of material required to prevent abrasion must be selected according to past shipping records, sound judgment, and common carrier regulations. A suggested test for the abrasiveness of cushioning materials is given in 6.1.2.3.

3.2.13 Fungus Resistance.

In some instances, cushioning materials are used in conjunction with open packages or crates that are exposed during shipment and storage to warm, humid environments for rather long periods of time. Since such environmental conditions are conducive to fungus growth and some cushioning materials are inherently susceptible to fungus attack, a fungus resistance test, such as is given in 6.1.2.8, is sometimes required in procurement documents to insure adequate performance of materials under the described conditions.

The packaging designer should use discretion, however, in specifying the use of fungus-resistant cushioning materials. While practically any cushioning material can be made fungus resistant, treatment of naturally nonresistant cushioning materials for fungus resistance usually involves impregnation with a salt. Unfortunately, the salt impregnation can introduce corrosion tendencies that cannot be detected by the pH test (3.2.10).

3.3 COMPREHENSIVE EXAMPLE PROBLEMS.

Examples are given to demonstrate the solution of normal cushioning problems that require consideration of a variety of factors. Solutions are based upon the steps listed in the design procedure of 3.1. (NOTE: Step (1) of 3.1 is omitted because the pertinent elements of the problems are given by the problem statements.)

3.3.1 Example Problem.

One thousand high value items that are destined for replacement of field equipment are to be packaged individually to withstand 30-inch flat drops. Each item is 12 x 6 x 6 inches, weighs 7.5 pounds and can withstand peak acceleration up to 40 g. Furthermore, the items are regularly shaped without projections. Determine the most economical cushioning design and exterior container size to protect the items.

SOLUTION: (by procedure of 3.1)

Step (2). As stated in 3.2.1.2.1, the cushioning materials that will provide adequate protection can be determined by reference to the G_m-W/A curves in Appendix V. The kinds and thicknesses of material that will provide adequate protection are the following:

For the 6 x 12 inch faces* Material No.	Thickness	For the 6 x 6 inch faces* Material No.	Thickness
1	2-1/2	1	4
2	2	2	3
3	2-1/2	3	3
4	4	4	3-1/2
5	3	5	2-1/2
6	2-1/2	6	2-1/2
8	3	8	5-1/2
9	3-1/2	9	5
21	4-1/2	21	5

*Decode by reference to 3.2.1.2.1.1.

Because of their higher densities, #3 (urethane foam, ether type, 4.0 pcf) and #6 (urethane foam, ester type, 4.0 pcf) can be eliminated immediately in favor of #1, 2 and 5 (urethane foams, 1.5 and 2.0 pcf).

Furthermore, since reusable cushioning materials are required for returning repairable parts, it is inadvisable to employ hexagonal film material for this use. Therefore, material number 21 can be eliminated from consideration.

This limits the selection to only urethane foams or rubberized hair. These materials will satisfy the minimum requirements for the characteristics described in 3.2.4 through 3.2.13 and prescribed in MIL-C-26861.

It is decided that the application methods most worthy of consideration are molded pads, corner pads, and complete encapsulation. Based upon the cost computations shown in Figure 3-11 for the various combination of materials and methods, the most economical cushioning design involves complete encapsulation with material number 2 (polyurethane foam, ether type, 2.0 pcf), 2 inches thick on top, bottom, and sides, and 3 inches on the ends.

Step (3). No creep data are available for this material. Nevertheless, as discussed in 3.2.7, some reasonable allowance should be made arbitrarily to offset expected compression set and creep, say by using a 2-1/2-inch pad instead of a 2-inch one as the bottom pad.

Step (4). The exterior container dimensions can be computed to allow room for the item and cushioning.

Step (5). Instrumented drop tests of a dummy item and a pilot package yield the following results: Flat drop (on bottom)--34 G, flat drop (on end--39 G.

Since the item has a fragility rating of *40* G, the cushioning as designed is proven to be adequate.

3.3.2 Example problem.

Twenty irregularly shaped electronic items of high Value are to be repackaged individually for shipment to various locations. Each package must contain sufficient cushioning to allow the item to withstand cornerwise drops of up to 30 inches. Each of the items in the initial consolidated package was immobilized inside a 5 x 5 x 11-1/4 inch interior carton. The interior carton plus the item and blocking weighs 31 pounds, and the item in place can withstand up to 60 G. Since the interior carton and blocking are already available at no extra cost, it has been decided simply to cushion the interior carton inside an exterior corrugated fiberboard container. Determine the most economical cushioning design and exterior container size.

SOLUTION: (by procedure of 3.1)

Step (2). Since only 20 items are involved, little prospect exists for appreciable savings by refining the cushioning design. Therefore, the cushioning design is held to a minimum, and only complete encapsulation is considered as an application method. As explained in 3.2.1.2.4, it is desirable first to check the materials that will furnish safe flat drop protection and secondly to check their effectiveness against cornerwise drop. Accordingly! the safe materials as determined from the appropriate Gin-W/A curves in Appendix y (for flat drop protection) are the following:

For the 5 x 11-1/4 inch faces* Material No.	- Thickness	For the 5 x 5 inch faces* Material No.	- Thickness
4	3	4	4-1/2
5	2-1/2	5	4
6	2-1/2	6	5
10	2	10	3
11	2-1/2	11	2-1/2
12	4	12	3
14	2-1/2	14	3

*Decode by reference to 3.2.1.2.1.1.

Since the interior carton containing the tube is a rectangular prism, its effective bearing area A_T during a cornerwise impact is computed by equation (3:3):

$$A_T = \frac{3(11.25)\,(5.0)\,(5.0)}{\sqrt{11.25^2 + 5.0^2 + 5.0^2}} = 63.7 \text{ square inches}$$

A recheck of the curves, using the new static stress (for the 31-Pound carton containing the item and a bearing area of 63.7 square inches) reveals that the same materials that were suitable for flat drop protection will also suffice for cornerwise drop protection.

Material #12, molded expanded polystyrene foam, may be eliminated from consideration since high volumes of production are required to amortize mold costs . The 4.0 pcf polyethylene (#n) and polyurethane (#6) may also be eliminated because of their high density. This leaves 10, 4, and 5 to analyze for least cost. Number 10 gives the least cost.

Step (3). No creep data are currently available for this material. Nevertheless, it is decided to provide an extra 1/2 inch thickness of material to the bottom pad to offset expected loss of thickness due to creep and compression set.

Step (4). It is determined that an exterior container, 17-1/4 x 9 x 9 inches, is needed.

Step (5). instrumented drop tests of a complete package containing a dummy item and cushioning, from a height of 30 inches, yield the following results: Flat drop (on bottom) --59 G; flat drop (on end)--5O G; and cornerwise drop--45 G.

Based upon the test results, it is decided to accept the design. The accepted cushioning design is not excessively conservative because some safety margin is desirable to hedge against variation in material performance and the severity of service handling conditions.

3.3.3 Example Problem. Five waveguide terminals are to be packaged for shipment to several sites in the United States. An expected volume of 5 items per month are to be shipped. Each item is 8 x 4 x 4 inches in size and weigh 1.5 pounds. The item is odd shaped with many knobs and other protrusions. It can stand 80 G in any direction without damage. Find the most economical cushion design and container size to protect this item in a 42-inch drop (flat).

SOLUTION: (by procedure in 3.1)

Step (2). The low volume shipped indicates that a simple design is needed since the expense of an elaborate design will be wasted on so few items. A light, flexible cushioning material will probably be best since the loading (W/A) is very low (.05 psi on bottom and sides and .09 psi on ends). Corner pads are eliminated from consideration due to the small item size and odd shape as well as the excessive design and fabrication costs for the low volume involved.

The following materials will provide adequate protection for complete encapsulation or wrap as determined from G_m-W/A curves in Appendix V:

For the 8 x 4-inch faces* Material No.	- Thickness	For the 4 x 4-inch faces* Material No.	- Thickness
1	1-1/2	1	2
2	1-1/2	2	2
3	1-1/2	3	2
4	2-1/2	4	2-1/2
5	2	5	2
6	2	6	2
7	3-1/2	7	5-1/2
8	2	8	3
9	2	9	3
16	2	16	4
17	2	17	3
18	2	18	4
19	3	19	3
20	2	20	2-1/2
21	3	21	3
22	4-1/2	22	4

*Decode by reference to 3.2.1.2.1.1.

Since the shape of the item is fairly complex, it will probably be easiest to consider wrap-type materials (in ply thicknesses of 1/2 inch or less) because no interior container or blocking and bracing will be required. This limitation eliminates materials 7, 8, and 9. The polyurethanes (1 through 6) are also not considered because, in this case, only two and three-inch thicknesses are stocked by the packaging activity. These thicknesses are too thick to bend easily around the protrusions on the item. cost analysis shows cellulose wadding (#19) to be most economical.

Step (3). Cellulose wadding exhibits a high percentage of creep, even when lightly loaded. Therefore, 1/2 inch is added to the thickness to assure a tight package.

Step (4). The resulting container dimensions (with 3-1/2 inches cushioning on all faces--3 inches for cushioning, 1/2 inch for creep) are 14 x 10 x 10. The container dimensions are not increased to allow for the extra material added because of creep.

Step (5). Instrumented drop tests of the packaged item show 61 G for the required 42 inch flat drop; therefore, the material selected will adequately protect the item.

3.4 CUSHION DESIGN BY COMPUTER.

3.4.1 The design procedures outlined in preceding sections of this chapter are, of necessity, detailed and often tedious. If all design possibilities are fully considered, including the many cushion materials, application techniques, container styles and materials, and comparative labor and transportation costs, the design procedure becomes very time-consuming. In fact, if this process is carried to the extreme of finding the absolute optimum design, the expense of the packaging engineer's labor may become a significant percentage of total package costs.

A means by which these calculations may be simplified is available through time-sharing computer technology. A program has been developed by the Air Force Packaging Evaluation Agency (AFPEA), Wright-patterson AFB, in cooperation with AFLC/ACDR, to find the most economical package cushion design considering all of the parameters discussed above. A program listing and/or card deck as well as other information about this program may be obtained by writing: AFALD/PTPT, Wright-Patterson AFB OH 45433. The Package Cushion Design program file name is "PACK/CUSHD.H, R." The development, capabilities and advantages of the program are outlined below.

3.4.2 AFPEA Package Cushion Design Computer Program.

The AFPEA Package Cushion Design Program is written in time-sharing Honeywell Fortran Y, (the Honeywell version of Fortran IV) which should be compatible with most time-sharing systems with minor modifications. A sample printout of the program instructions is given in Figure 3-10, showing the options and materials available.

The materials listed in the program are the same materials whose Peak Acceleration versus Static Stress curves are shown in Appendix V of this Handbook.

With two exceptions, cushion data for each material is available in thicknesses of one through six inches in one-inch increments and drop heights of 12 through 48 inches in 6-inch increments. The exceptions are convoluted polyurethane which are presented in 1, 2, 3 or 2, 4, 6-inch thicknesses because of their configurations and cellular polyethylene film (Aircap), which is shown in multiples of l-inch thicknesses .

Test data for each material, developed using the dynamic compression test procedure specified in paragraph 6.1.2.1 of this Handbook, was fed into a separate curve-fitting computer program using multiple regression analysis to generate mathematical equations of the Peak Acceleration versus Static Stress curves presented in Appendix V. These equations form the data base for the program. Costs of the materials are representative of the Industry average and are updated periodically to reflect inflationary trends and supply fluctuations.

Four types of container materials are listed with associated costs and weights. Two container styles are presently available--regular slotted container (RSC) and full telescope container (FTC).

A transportation subroutine is included to further compare various package design costs on the basis of transportation mode and distance.

FIGURE 3-10: COMPUTER PRINTOUT OF PROGRAM INSTRUCTIONS

```
INSTRUCTIONS? YES OR NO.  (LAST CHANGED 15 MAR. 74)
=YES
SEVERAL OPTIONS, OR A COMBINATICN OF OPTICNS,
  ARE AVAILABLE TO THE USER. TO SELECT THE OPTION
  TYPE IN THE OPTION NUMBER.
OPTION 1 - PEAK ACCELERATION FOR AN EXISTING CUSHION PACK.
OPTICN 2 - COMPLETE CUSHIONING ENCAPSULATION OF AN ITEM.
OPTION 3 - CORNER PAD CUSHIONING.
OPTION 4 - CUSHION WRAP.

THE FOLLOWING TABLE LISTS THE MATERIALS CONSIDERED
  BY THE PROGRAM AND THEIR USES.  THEY ARE REFERENCED
  BY THE NUMBER IN THE LEFT MOST COLUMN. AN '*' NEXT
  TO THE NUMBER INDICATES THAT THE MATERIAL IS NOT
  YET AVAILABLE.
```

MAT	MATERIAL NAME	USES ENCAP	C-PADS	WRAP	DENSITY LBS/CU FT	COST $/BD FT
1	POLYURETHANE-ETHER	X	X	X	1.500	0.0780
2	POLYURETHANE-ETHER	X	X	X	2.000	0.0940
3	POLYURETHANE-ETHER	X	X	X	4.000	0.1500
4	POLYURETHANE-ESTER	X	X	X	1.500	0.1450
5	POLYURETHANE-ESTER	X	X	X	2.000	0.1750
6	POLYURETHLANE-ESTER	X	X	X	4.000	0.3630
7	RUBBERIZED HAIR TYPE II	X	X		1.100	
8	RUBBERIZED HAIR TYPE III	X	X		1.500	
9	RUBBERIZED HAIR TYPE IV	X	X		2.000	
10	POLYETHYLENE FOAM	X	X		2.000	0.2500
11	POLYETHYLENE FOAM	X	X		4• 000	0.3400
12	POLYSTYRENE FOAM	X	X		1.500	0.1410
13	POLYSTYRENE FOAM	X	X		2.500	0.2250
14	POLYETHYLENE MINICELL L-200	X	X		2.000	
15	CONV. ETHER POLY. 1" 2" 3"	X		X	1.150	0.0938
16	CONV. ETHER POLY. 2" 4" 6"	X		X	1.150	0.1500
17	CONV. ETHER POLY. 1" 2" 3"	X		X	1.500	0.1010
18	CONV. ETHER POLY. 2" 4" 6"	X		X	1.500	0.1650
19	KIMPAK	X		X	2.000	0.0430
20#	AIRCAP TYPE SD-240	X		X	0.691	0.0940
21	HEXAGONAL FILM, OPEN CELL (PPP-C-1842A)	X		X	1.400	0.1006
22	HEXAGONAL FILM, REINFORCED CELL (PPP-C-1842A)	X		X	1.800	0.1254

\# DATA AVAILABLE FOR 1, 2, & 3 IN. THICKNESSES ONLY

COST FOR SPECIAL MATERIALS:

MAT.	1"	2"	3"	4"	5"	6"
7	0.1025	0.0775	0.0817	0.0775	0.0800	0.0775
8	0.1075	0.0837	0.0900	0.0837	0.0875	0.0837
9	0.1175	0.0912	0.1000	0.0912	0.0965	0.0912
14	0.4160	0.4050	0.4000	0.4000	0.4000	0.4000

CONTAINER MATERIAL DATA-

NUM	MATERIAL TYPE	COST/SQ. FT.	WGT./SQ.FT.
1	SINGLE WALL V3C	$ .0302	.22 LBS.
2	DOUBLE WALL V1lC	$ .0470	.39 LBS.
3	SOLID WA-L V2S	$ .0500	.32 LBS.
4	SOLID WALL V3S	$ .0450	.31 LBS.

TRANSPORTATION TABLE

MODE	TYPE	DISTANCE
1	PARCEL POST	ZONE 1-8 (0 FOR LOCAL)
2	COMMERCIAL AIR	AIR MILES
3	TRUCK	ROAD MILES
4	LOGAIR	AIR MILES

(NOTE: MATERIAL COSTS SHOWN ARE SUBJECT TO CHANGE. CURRENT PRICES SHOULD BE OBTAINED BEFORE COST ANALYSIS ARE MADE.)

FIGURE 3-10: COMPUTER PRINTOUT OF PROGRAM INSTRUCTIONS

Generally, the heavier the package (both cushion weight and container weight) the greater the transportation cost. This cost also increases with distances, such that an optimum design will show greater savings the farther it is shipped.

3.4.2.1 The Package Cushion Design Program performs two basic functions, either a performance evaluation of a known package design or the determination of the package design for a specific item under known conditions. The second function is subdivided into three options––complete encapsulation, corner pads, or cushion wrap.

The first function (peak acceleration developed in an existing package) can be used to evaluate a package which has proven to be inadequate in previous use or to verify a package which was designed by the computer, then altered to fit production or other constraints. The package engineer inputs to the computer information on the desired drop height, kind of material, weight, surface area (one fact at a time), and cushion thickness. The computer response (output) is in terms of the peak acceleration (g) that the packaged item would experience. The process can be repeated as often as necessary to evaluate all surfaces of the item (each different size face must be input separately) and for different materials and drop heights.

The other three options essentially design the total package. For each option the drop height, item dimensions, item weight, fragility, container style and material, and transportation mode and distance are the required input. The program then computes total costs for all materials available. If a particular material is not feasible for an item (i.e., the cushion characteristics show that the cushion will not protect the item), a "o" is printed. All feasible materials are printed in order of increasing cost. Complete design data can then be obtained by inputting the number of the material desired. This data includes cushion dimensions (complete encapsulation, corner pads, or cushion wrap, depending on option), container dimensions (ID), total package weight, and costs for cushioning materials, container, transportation, and labor. This step may be repeated for all materials which were considered feasible in the initial cost table. The complete data input procedure must be repeated for each additional option and for each separate material.

3.4.3 Example Problems (Computer Solutions).

The Example Problems from 3.3.1 through 3.3.3 are repeated here (Figures 3-11 thru 3-14) in the form of computer printouts of their solutions. Each design procedure was carried out in a few minutes instead of the several hours required using the manual computational techniques presented in paragraph 3.

In each Example, all three options (complete encapsulation, corner pads, and cushion wrap) were run (only the best solutions are shown here) and then expanded to complete the design data for the least–cost material. Of course, complete data may be output for other materials, if desired.

FIGURE 3-11: COMPUTER PRINTOUT OF EXAMPLE PROBLEM IN PARAGRAPH 3.3.1

OPTICN?
=2
DROP HEIGHT IN INCHES.
=30
INPUT DIMENSIONS OF ITEM IN ORDER OF LENGTH.
WIDTH, HEIGHT. ALL DIMENSIONS MUST BE IN INCHES.
=12, 6, 6
WEIGHT IN POUNDS?
=7.5
FRAGILITY RATINGS OF TOP, SIDE, AND END FACES.
=40,40,40
TYPE OF CONTAINER- INDICATE 'RSC' FOR REGULAR SLOTTED CONTAINER
OR ‘FTC’ FOR FULL TELESCOPE C0NTAINER.
=RSC
CCNTAINER MAT. NUM. (1 THRU 4 ARE STD.)
=1
TRANSPORTATICN MODE & DISTANCES
=1,0

THE FOLLOWING TABLE LISTS THE MATERIAL NUMBERS
AND THEIR RESPECTIVE TOTAL COST FIGURES.

MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST
7	0.	10.	0.	11	D.	12	0.	13	0.
14	0.	15	0.	16	0.	17	0.	18	0.
19	0.	20.	0.	21	0.	2	2.63		2.94
3	3.06	8	3.83	5	4.34	9	4.39	22	5.02
4	5.44	6	5.60.						

MAT. #?
= 2
CUSHION DIMENSIONS (COMPLETE ENCAPSULATION) FOR MAT. # 2

	LENGTH	WIDTH	THICKNESS
TOP FACE	12.00 IN.	6.00 IN.	2.00 IN.
SIDE FACE	12.00 IN.	10.00 IN.	2.00 IN.
END FACE	10.00 IN.	10.00 IN.	3.00 IN.

CONTAINER DIMENSIONS ARE AS FOLLOWS

LENGTH	WIDTH	HEIGHT
18.00 IN.	10.00 IN.	10.00 IN.

TOTAL WEIGHT 10.49 LBS

CUSHION COST	CONTAINER COST	SHIPPING COST	OTHER COSTS	TOTAL COST
$ 0.89	$ 0.49	$ 0.86	$ 0.38	$ 2.63

FIGURE 3-11

FIGURE 3-12: COMPUTER PRINTOUT OF EXAMPLE
PROBLEM IN PARAGRAPH 3.3.2

```
 OPTION?
=2
 DROP HEIGHT IN INCHES.
=30
 INPUT DIMENSIONS OF ITEM IN ORDER OF LENGTH,
WIDTH, HEIGHT.  ALL DIMENSIONS MUST BE IN INCHES.
= 11.25,5,5
WEIGHT IN POUNDS?
=31
FRAGILITY RATINGS OF TOP,SIDE, AND END FACES.
=60,60,60
TYPE OF CONTAINER- INDICATE 'RSC' FOR REGULAR SLOTTED CONTAINER
          OR 'FTC' FOR FULL TELESCOPE CONTAINER.

=RSC
CONTAINER MAT. NUM. (1 THRU 4 ARE STD.)
=1
TRANSPORTATION MODE & DISTANCE?
=1,0

THE FOLLOWING TABLE LISTS THE MATERIAL NUMBERS
AND THEIR RESPECTIVE TOTAL COST FIGURES.
```

MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST
1	0.	2	0.	3	0.	7	0.	8	0.
9	0.	13	0.	15	0.	16	0.	17	0.
18	0.	19	0.	20	0.	21	0.	22	0.
10	4.15	12	4.63	4	4.65	5	4.65	11	4.67
14	6.34	6	7.11						

```
MAT. #?.
= 10.
CUSHION DIMENSIONS (COMPLETE ENCAPSULATION) FOR MAT. #          10
               LENGTH       WIDTH      THICKNESS
TOP FACE      11.25 IN.    5.00 IN.    2.00 IN.
SIDE FACE     11.25 IN.    9.00 IN.    2.00 IN.
END FACE       9.00 IN.    9.00 IN.    3.00 IN.

 CONTAINER DIMENSIONS ARE AS FOLLOWS
             LENGTH      WIDTH       HEIGHT
             17.25 IN.    9.00 IN.    9.00 IN.

TOTAL WEIGHT             33.49 LBS.
```

CUSHION COST	CONTAINER COST	SHIPPING COST	OTHER COSTS	TOTAL COST
$ 1.94	$ 0.43	$ 1.44	$ 0.35	$ 4.15

FIGURE 3-12

FIGURE 3-13: COMPUTER PRINTOUT OF VERIFICATION OF PEAK ACCELERATION FOR MATERIAL NUMBER 10, EXAMPLE PROBLEM IN PARA 3.3.2

```
 OPTION?
=1
 DROP HEIGHT IN INCHES.
=30
INPUT NUMBER OF MATERIAL
= 10
INPUT WEIGHT (IN POUNDS) AND AREA (SQ. IN.).
= 31,25
INPUT THICKNESS OF MATERIAL.
= 3

 PEAK ACCELERATION =     50.347

 IS A NEW RUN, USING NEW DATA, DESIRED?
= YES
 OPTION?
=1
 DROP HEIGHT IN INCHES.
= 30
INPUT NUMBER OF MATERIAL
= 10
INPUT WEIGHT (IN POUNDS) AND AREA (SQ. IN.).
= 31,56.25
INPUT THICKNESS OF MATERIAL.
= 2

  PEAK ACCELERATION =   59.119

IS A NEW RUN, USING NEW DATA, DESIRED?
= YES
 OPTION?
= 1
 DROP HEIGHT IN INCHES.
= 30
INPUT NUMBER OF MATERIAL
=10
INPUT WEIGHT (IN POUNDS) AND AREA (SQ. IN.).
= 31,63.7
INPUT THICKNESS OF MATERIAL.
= 3

 PEAK ACCELERATION =    45.242

 IS A NEW RUN, USING NEW DATA, DESIRED?
= NO

PROGRAM STOP AT 8860
*BYE

CREATE OFF AT 10.510
```

FIGURE 3-13

FIGURE 3-14: COMPUTER PRINTOUT OF EXAMPLE PROBLEM IN PARAGRAPH 3.3.3

OPTION?
=2
DROP HEIGHT IN INCHES.
=42
INPUT DIMENSIONS OF ITEM IN ORDER OF LENGTH,
WIDTH, HEIGHT. ALL DIMENSIONS MUST BE IN INCHES.
=8,4,4
WEIGHT IN POUNDS?
=1.5
FRAGILITY RATINGS OF TOP,SIDE, AND END FACES.
=80,80,80
TYPE OF CONTAINER- INDICATE 'RSC' FOR REGULAR SLOTTED CONTAINER
OR 'FTC' FOR FULL TELESCOPE CONTAINER.
=RSC
CONTAINER MAT. NUM. (1 THRU 4 ARE STD.)
=1
TRANSPORTATION MODE & DISTANCE?
=1,0

THE FOLLOWING TABLE LISTS THE MATERIAL NUMBERS
AND THEIR RESPECTIVE TOTAL COST FIGURES.

MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST
10	0.	11	0.	12	0.	13	0.	14	0.
15	.0.	2	1.35	1	1.46	21	1.63	3	1.71
22	1.72	20	1.75	8	1.78	9	1.84	19	1.86
17	1.86	5	2.06	4	2.20	16	2.29	18	2.39
7	2.89	6	2.91						

MAT. #?
=19

CUSHION DIMENSIONS (COMPLETE ENCAPSULATION) FOR MAT. # 19

	LENGTH	WIDTH	THICKNESS
TOP FACE	8.00 IN.	4.00 IN.	3.00 IN.
SIDE FACE	8.00 IN.	10.00 IN.	3.00 IN.
END FACE	10.00 IN.	10.00 IN.	3.00 IN.

CONTAINER DIMENSIONS ARE AS FOLLOWS

LENGTH	WIDIH	HEIGHT
14.00 IN.	10.00 IN.	10.00 IN.

TOTAL WEIGHT 4.13 LBS.

CUSHION COST	CONTAINER COST	SHIPPING COST	OTHER COSTS	TOTAL COST
$ 0.38	$ 0.44	$ 0.70	$ 0.34	$ 1.86

OPTION?

=4
INPUT FLY THICKNESS (USED FOR ALL MATERIALS)
=15
THE FOLLOWING TABLE LISTS THE MATERIAL NUMBERS
AND THEIR RESPECTIVE TOTAL COST FIGURES.

MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST	MAT NUM	TOTAL COST
7	0.		0.	9	0.	10	0.	11	0.
12	0.	13	0.	14	0.	15	0.	21	0.
22	0.	1	1.59	2	1.65	19	1.77	20	1.85
3	1.87	17	1.89	5	1.95	4	2.11	6	2.66
16	2.78	18	2.90						

MAT. #?
=19

FIGURE 3-14: COMPUTER PRINTOUT OF EXAMPLE PROBLEM IN PARAGRAPH 3.3.3

CHAPTER 4. APPLICATION TECHNIQUES

Selection of the most advantageous cushioning application technique for any particular problem requires consideration of various factors, especially the nature of the item and the cost related to the different application techniques. In many instances, several different application methods can be employed satisfactorily. This chapter provides examples of different application techniques and supplementary information in order to (1) suggest usable methods directly, and (2) stimulate the designer to devise other satisfactory techniques.

4.1 COMMON TECHNIQUES.

4.1.1 Complete Encapsulation.

This method involves covering the entire surface of the item with cushioning material by wrapping the item in a blanket or placing pads about the item (Figure 4-1A). When individual pads are used, it is ordinarily advisable to leave some clearance (perhaps 1/8 inch) between pads to prevent binding. Since complete encapsulation usually requires no jigs and little prefabrication of materials, it is especially advantageous for cushioning small lots of items.

4.1.2 Corner Pads.

Properly designed corner pads (Figure 4–lB) can effectively protect items having square corners (or irregularly shaped items enclosed within an interior container) . However, specific sizes and kinds cf pads are required to protect particular items. Consequently, use of corner pads might be impractical if many small lots of different types of items are to be cushioned, since this will require costly fabrication labor or stocking of many different sizes of corner pads. Corner pads are most frequently used to cushion larger lots of items, wherein the effort required to procure or stock a particular kind or size of corner pad is more than offset by the suitability of the pads for the particular application.

4.2 AREA ADJUSTMENT TECHNIQUES.

Use of a cushioning material in its optimum load-bearing range often requires the use of a pad size different from the full bearing area of the adjacent side of an item. In general, this is necessary to minimize peak impact forces by allowing lightweight items to compress the cushioning material appreciably and preventing heavy items from bottoming during impact. This section deals with common techniques for achieving cushioning bearing areas either larger or smaller than the adjacent sides of the item.

4.2.1 Increasing Bearing Area.

The principal devices employed to increase the load-bearing area of an

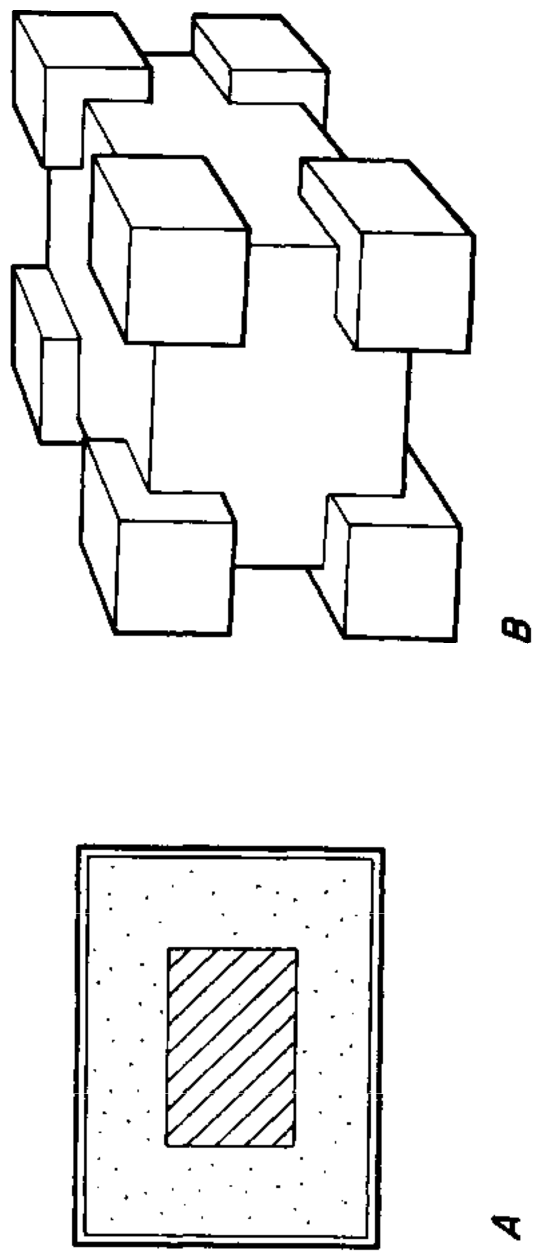


FIGURE 4-1. Common cushioning application techniques. A, complete encapsulation; B, corner pads.

item against a cushion are platens (Figure 4-2) usually made of solid and corrugated fiberboard, plywood, or paper–overlaid veneer. The designer should select platens that are stiff enough to distribute the load without flexing appreciably.

4.2.2 Reducing Bearing Area.

Reduction of the bearing area of an item against the cushioning is usually achieved simply by reducing the pads to the desired size. However, maintaining the desired position of pads thus reduced in size so that the item will not rotate during impact can be troublesome. Three possibilities for achieving these objectives include the use of (1) corner pads (Figure 4-lB), (2) face pads glued to the sides of the exterior container in the desired locations, or (3) complete encapsulation with a material in which convolutions have been cut on the cushion surface (Figure 4-3). The effect of these convolutions, usually employed with polyurethane foams, is to decrease the bearing area, since the item will rest only on the peaks of the convolutions.

4.3 CUSHIONING IRREGULARLY SHAPED ITEMS.

The cushioning of irregularly shaped items often presents special problems, particularly when fragile projections are involved. The methods given in this section can be placed into two general categories: (1) floating, or encapsulating, the item directly in cushioning material, and (2) immobilizing the item and then cushioning it in its immobilized condition. Regardless of the method used, a primary requisite is that adequate thickness of cushioning must be provided to prevent bottoming of projections. Therefore, the thickness of material to be provided must be measured from the outer container to the outermost projection--not to the item proper. Unfortunately, the effect of projections in reducing the effective thickness of cushions is often overlooked, especially in the production of molded cushions. This practice is illustrated in Figure 4–4 wherein the required thickness of material to protect all sides of the hypothetical item shown in Figure 4–4 is represented by T_x.

4.3.1 Floating Items in Cushioning Material.

Small, lightweight, irregularly shaped items can often be floated, or completely encapsulated, in cushioning material. A wide variety of materials have been used satisfactorily for applications of this nature. If an appreciable number of items of a particular kind are to be packaged, savings in labor and material might be realized by procuring precut pads from the manufacturer, instead of cutting the pads at the user's plant. A typical application involving a precut pad is shown in Figure 4-5.

4.3.1.1 Use of molded pads. Molded pads made of rubberized hair, expanded polystyrene, and other materials can be manufactured to fit and protect almost any item, regardless of shape or size. A typical example of a pack employing molded pads is shown in Figure 4-6. Such pads are usually

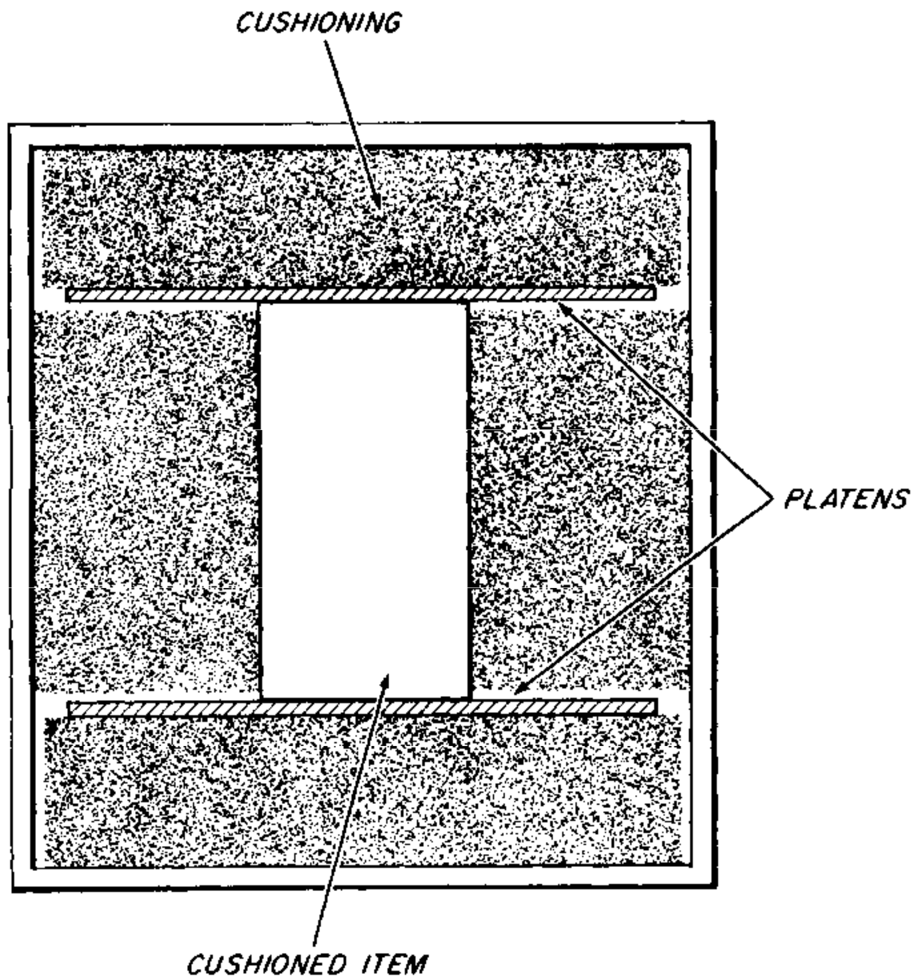


FIGURE 4-2. Load-bearing platens used to increase the bearing area of an item against cushions.

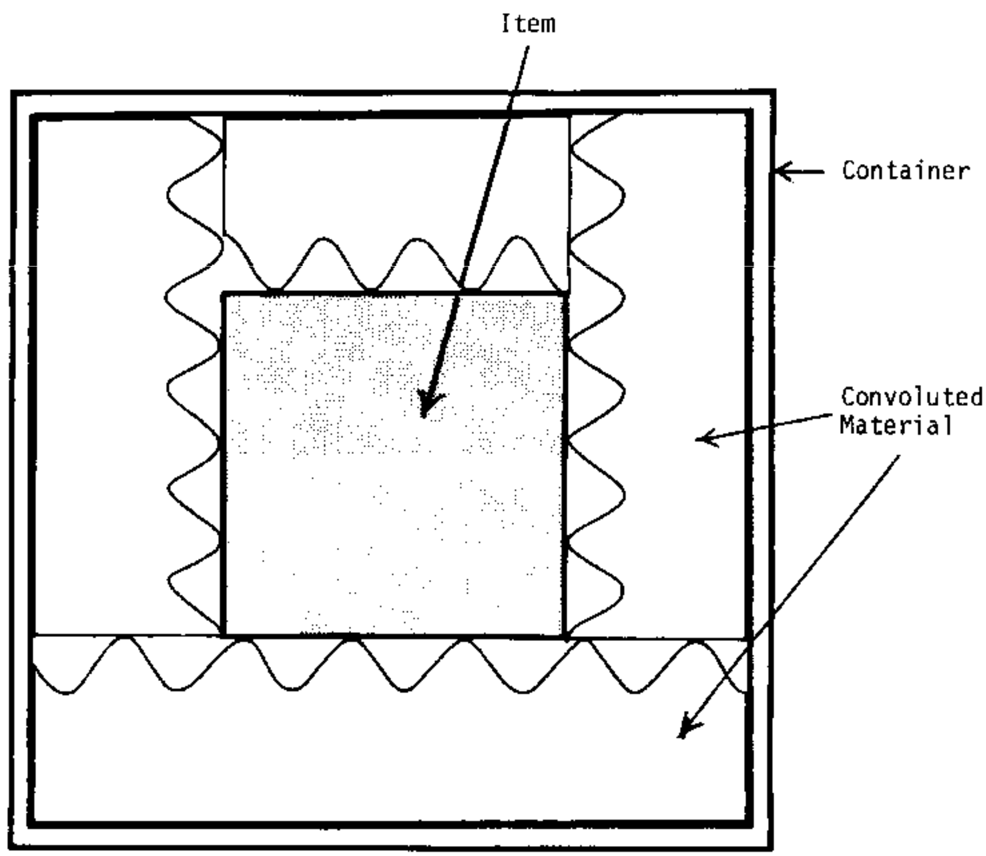


FIGURE 4-3. Convoluted material used to decrease bearing area.

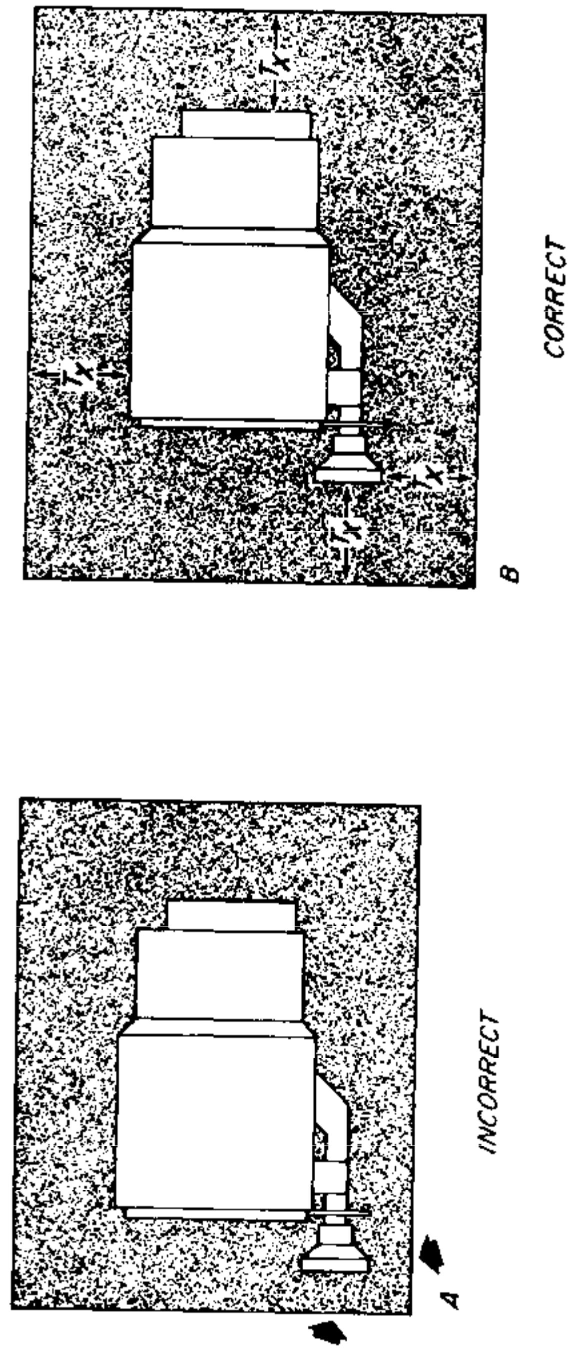


FIGURE 4-4. Cushioning of an item with projections.

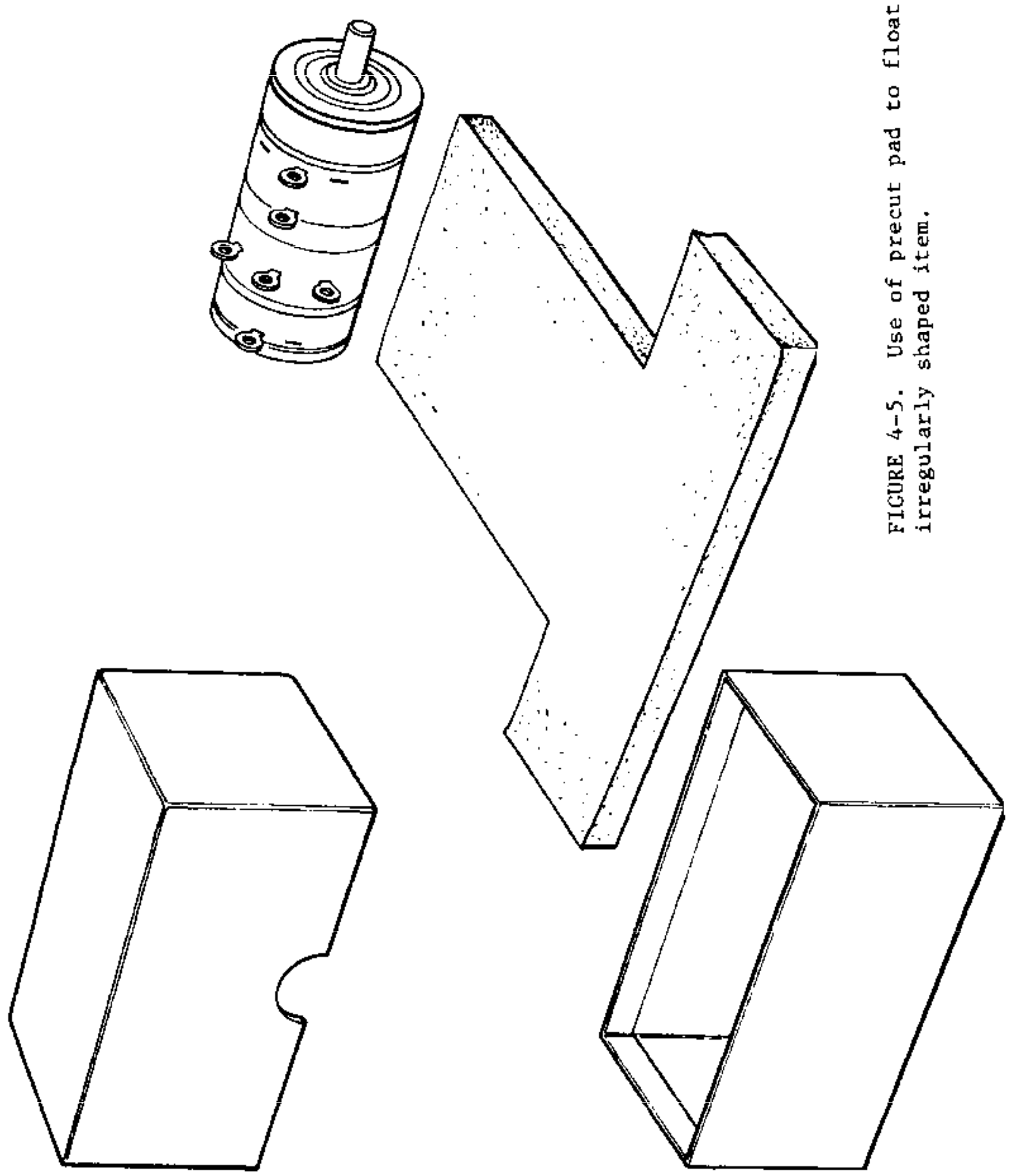


FIGURE 4-5. Use of precut pad to float irregularly shaped item.

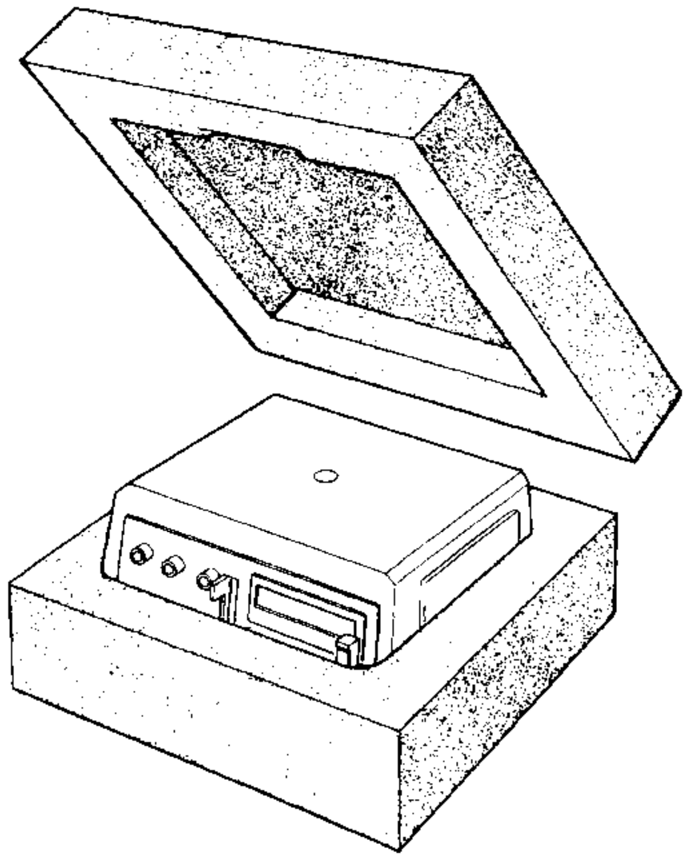


FIGURE 4-6. Use of molded pads.

custom designed and produced by the cushioning manufacturer.

In addition to being well suited to packaging of irregularly shaped items, molded pads are often reusable and require less labor for application. However, since they are produced by custom lots, individual pads cost considerably more than equal quantities of sheet stock material.

4.3.2 Immobilizing the Item in an Interior Container.

Some fragile items may be of such configuration that fragile elements protrude from the casing or basic framework of the item, such as knobs or switches on a radio, or the item may not even have a framework per se, such as the tube in Figure 4-7. In order to package such items, it is necessary to mount the item in a framework such as a plywood base or block it inside a fiberboard box. This not only protects exposed fragile elements but also provides a homogeneous shape which will provide for more uniform load distribution and will also simplify subsequent cushion design calculations.

Some of the more common techniques that have been used to immobilize items are the use of:

(1) Fiberboard pads and die-cut inserts (Figure 4-7).

(2) Molded or cut rigid materials, such as certain types of expanded polystyrene or foamed polyurethane (Figure 4-8).

(3) Corrugated or solid fiberboard blocking (Figures 4-9 and 4-10).

(4) A base to which the item may be anchored (Figure 4-10).

(5) A combination of materials. For some items, such as the delicate electronic tube depicted in Figure 4–11, it is advantageous to use a combination of materials to immobilize the item. In this instance, the item consists essentially of a large glass envelope partially housing a massive rotating anode. The most delicate portion of the item is the collar where the glass is joined to the metal shaft. Obviously, use of ordinary cushioning procedures would cause the acceleration force exerted by cushioning material during impact to be applied mainly to the glass envelope. If this force were applied laterally, it is clear that the inertia of the internal metal element would tend to cause relative movement and breakage.

The solution shown involves the use of a wood collar on the protrusion of the metal element beyond the glass in order to immobilize the element within the relatively rigid molded polystyrene form and the interior carton.

4.4 APPLICATION OF DUNNAGE.

4.4.1 Filling Voids.

It is frequently desirable to fill voids in packages with various kinds of

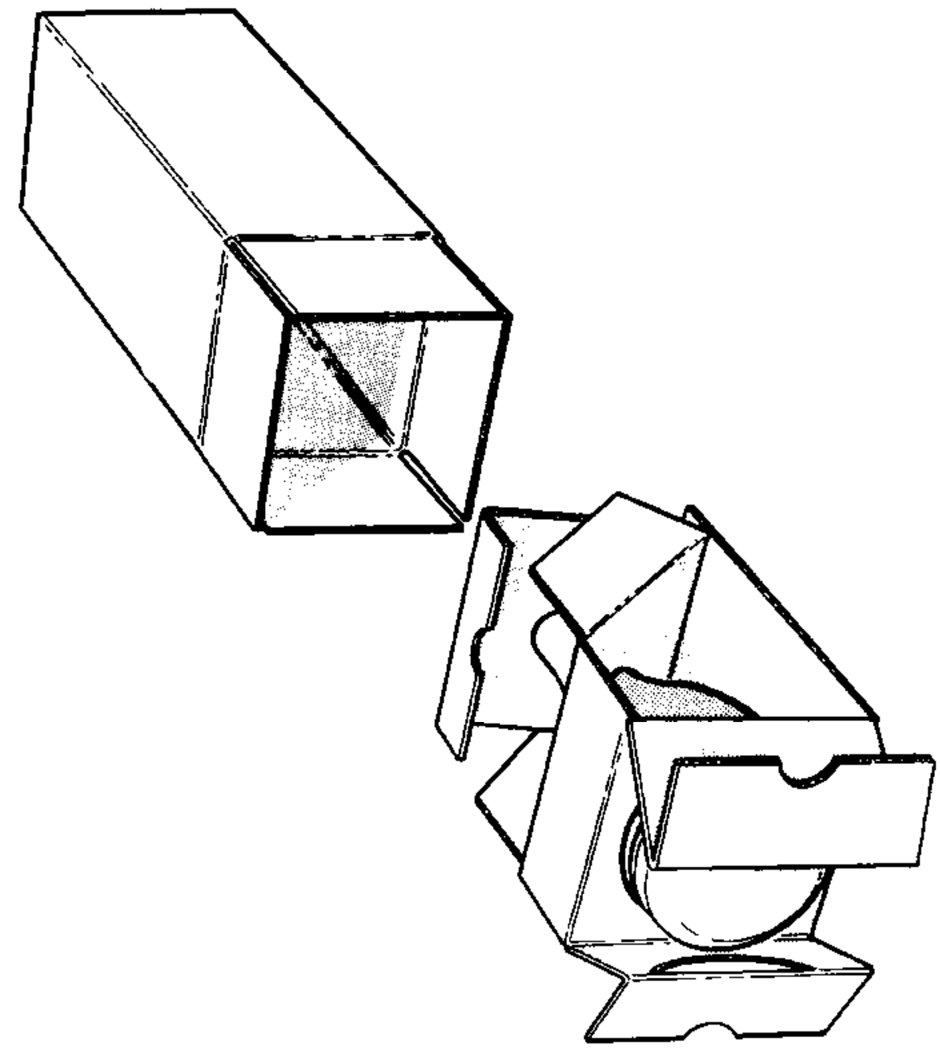


FIGURE 4-7. Use of folded die-cut corrugated fiberboard to immobilize item.

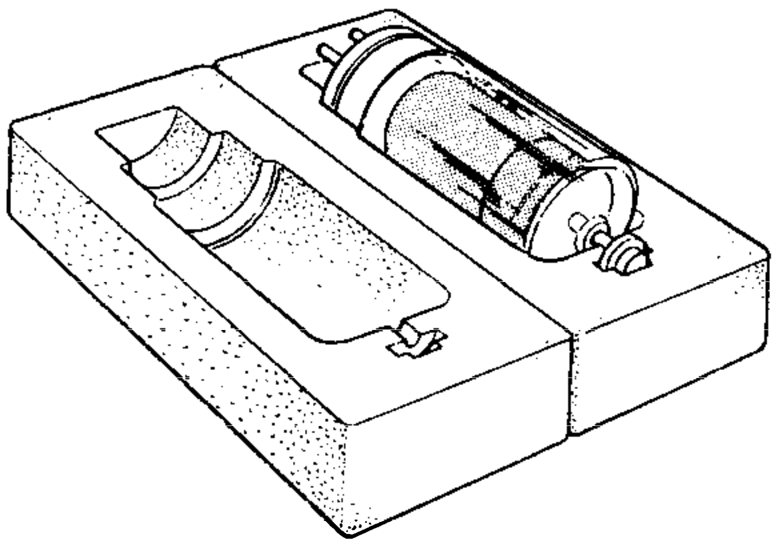


FIGURE 4-8. Use of molded or cut rigid material to immobilize item.

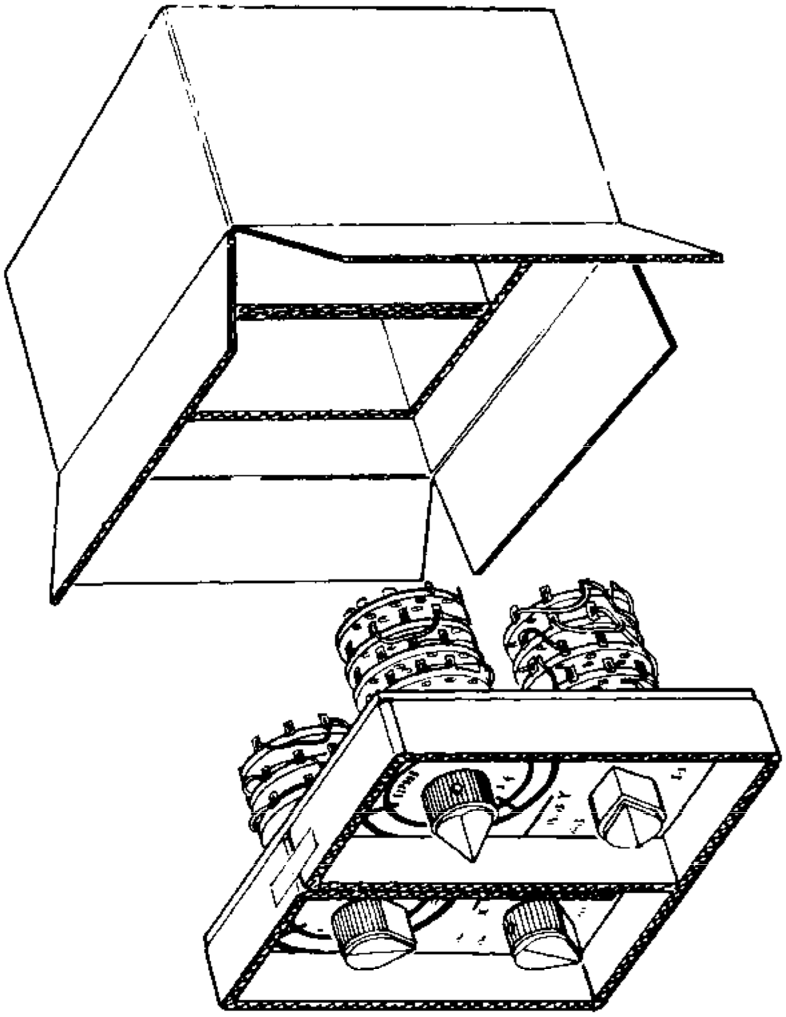


FIGURE 4-9. Use of corrugated fiber-board blocking to immobilize fragile items.

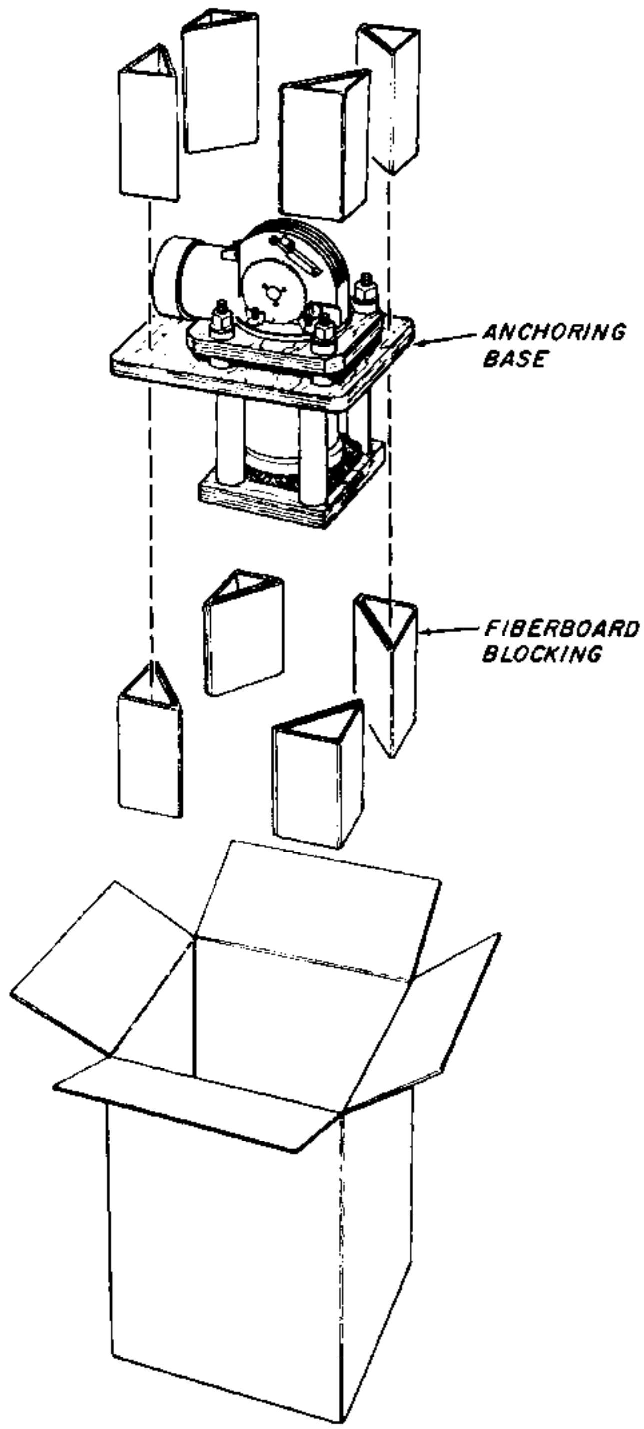


FIGURE 4-10. Use of corrugated fiberboard blocking and wood anchoring base to immobilize item.

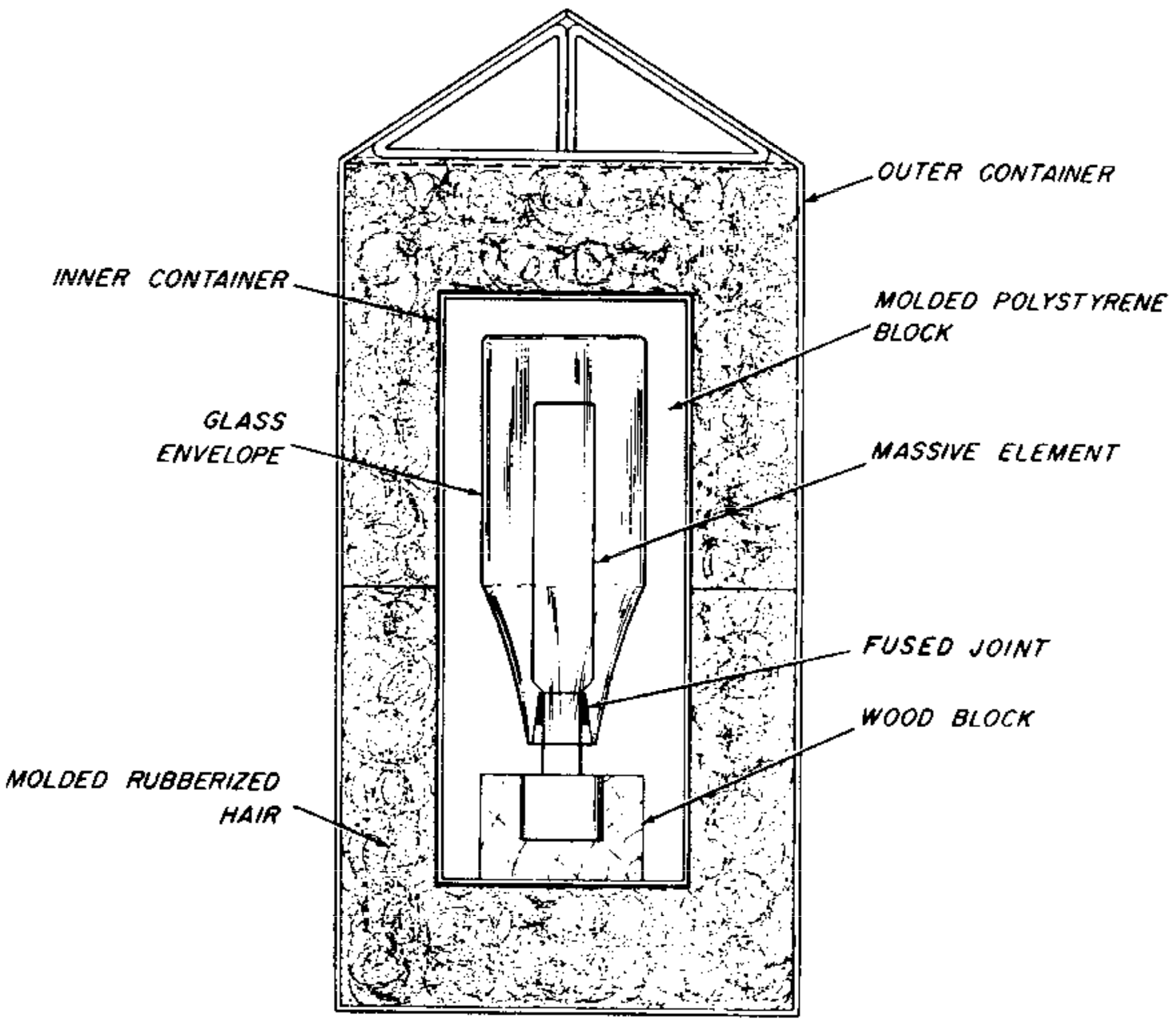


FIGURE 4-11. Use of a combination of materials to immobilize and cushion item.

dunnage to prevent reorientation of the packaged item and the related possibility of shipment damage. The primary application of this type of packaging involves low volume operations where a specifically designed package would be too expensive. Materials used for filling voids include expanded polystyrene in a variety of shapes, some looking like small potato chips, others like spaghetti strands.

Another common variety of loose-fill cushioning material is available in the form of kraft paper straws approximately one inch long and 1/4 inch in diameter.

Natural materials such as popcorn have also been used on rare occasions. However, these materials may be susceptible to moisture, insect infestation, mildew, etc.

The commonly used varieties of loose-fill dunnage materials cited above may be used as cushioning if care is taken to overfill the package, insuring that there will be some compression force added to the material when the tcp closure is made. This method of filling prevents excessive migration of the item in the package when the package is subjected to shock and vibration during shipment. Some wrap materials, such as cellulose wadding, polyurethane foams, flexible cellular plastics, and tnin-sheet polypropylene foam, are also used to fill voids in the package by simply wadding up several sheets of the material and forcing it into the void.

4.4.2 Padding Projections.

Occasionally, it is desirable to wrap items or to pad sharp projections with dunnage material. Several new materials have been made available in the past few years in addition to the cellulose wadding traditionally used for this purpose. Polypropylene foam in thicknesses ranging from l/16inch to 1/4 inch, some in expanded patterns, are used effectively as cushion wrap materials both to pad projections and to entirely wrap the item providing some degree of cushioning. Another type of wrap material consists of two layers of polyethylene foam, sealed together such that one inch or 1/4 inch bubbles of air are trapped between the film layers. These bubbles form small cushioning "pillows" which serve to isolate the item from shock when used in several layers. However, care must be taken not to to "overload" this type of material. Otherwise the air bubbles may rupture, resulting in excessively high shock values.

4.5 MISCELLANEOUS APPLICATION TECHNIQUES.

Satisfactory cushioning application techniques for certain kinds of items may involve consolidation or separation of parts and the use of a variety of materials and application techniques. Some examples of such applications are given in the following:

4.5.1 Nesting Items Between Layers of Cushioning Material.

The nesting technique (Figure 4–12) is especially suited to multiple

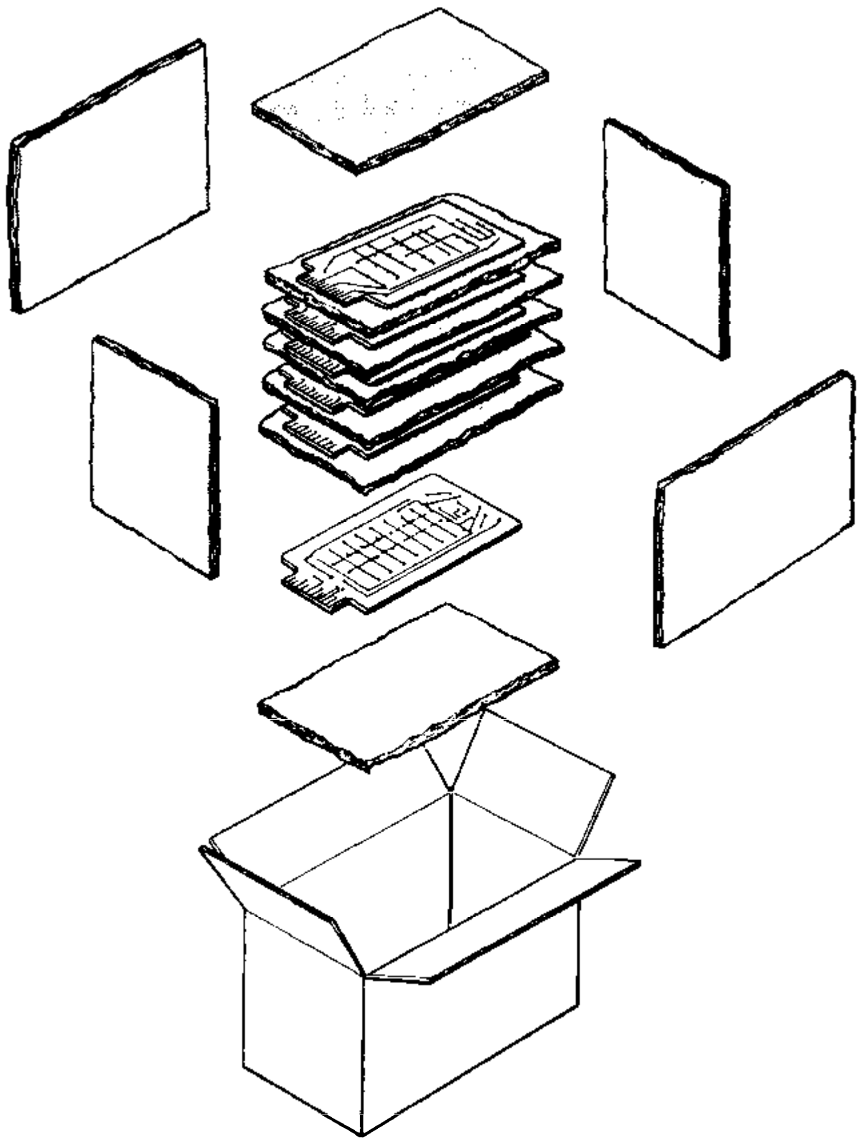


FIGURE 4-12. Nesting items in cushioning material.

packaging of series of relatively small, similarly shaped items. The kind, thickness, and type of cushioning material selected for applications of this nature should be selected in accordance with the procedures described in Chapter 3.

4.5.2 Disassembly of Large, Fragile Items.

Occasionally, fragile components of large items can be separated from the item proper and packaged individually. The principal advantage of this technique is that savings can be realized by providing extra protection only to the components that actually require such protection. However, proper authorization should be obtained before components of items are disassembled for packaging purposes and all components should be labeled clearly.

4.5.3 Use of Cushioning Materials to Prevent Abrasion.

Certain items have polished or painted surfaces that require protection from abrasion during shipment. Depending upon the particular item involved, various kinds of material may be used successfully. One example is depicted in Figure 4-13 wherein cushioning is used under the strapping in order to prevent abrasion of the surfaces of the electronic console. Adhesive-backed foamed plastics, heavily wax-coated corrugated fiberboard, or wrap materials also are often suitable for similar applications.

4.5.4 Cushioned Bases or Pallets.

Large, heavy items frequently can be attached to a cushioned base or pallet (Figure 4-13). Since these items can usually be expected to remain upright during shipment, only bottom cushioning is required. In addition to its role as a shock and vibration isolator, the cushioned base serves as an integral part of the container.

4.5.5 Foam-In-Place.

Many types of polyurethane foams, both rigid (for blocking and bracing) and flexible (similar to those discussed in Chapter 3), may now be applied in liquid form. Two foam chemicals are thoroughly mixed in a dispensing machine and poured into the container around the item or a portion of the item. Since foam–in-place application techniques are significantly different from those discussed here, the reader is referred to the U.S. Air Force's Technical Order 00-85-37, "Foam-in-Place Packaging" (40).

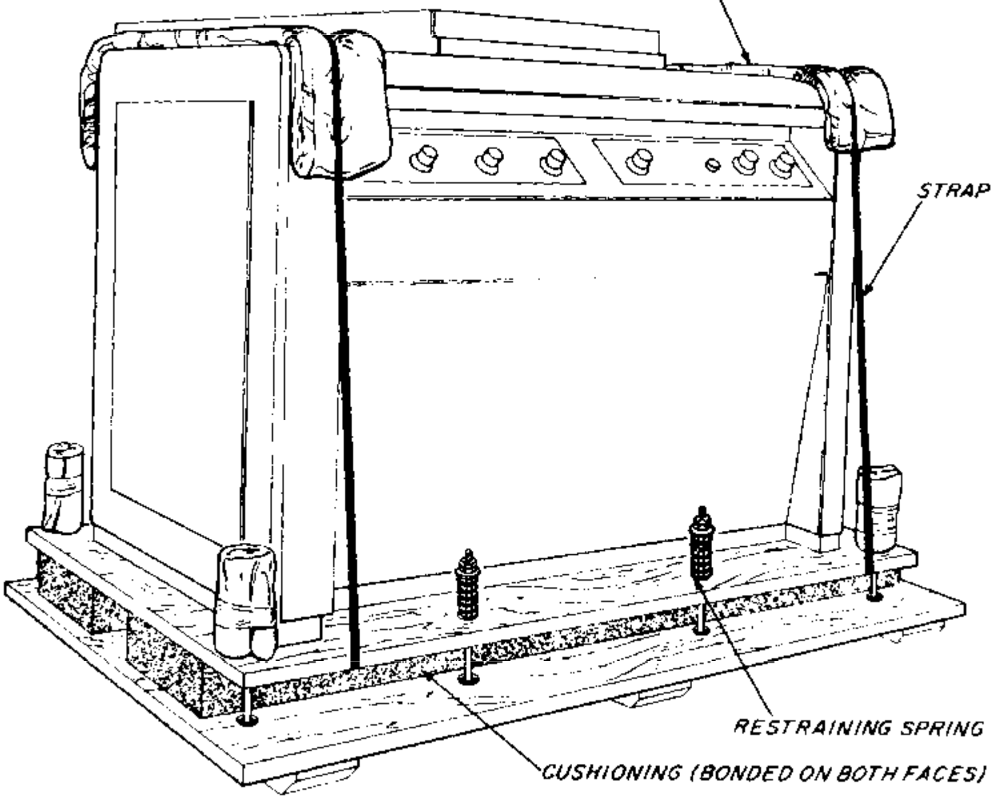


FIGURE 4-13. A cushioned base.

CHAPTER 5. MIL-C-26861--ITS RAMIFICATIONS IN CUSHIONING DESIGN

5.1 GENERAL.

Prior to the development of Military Specification MIL-C-26861, all existing cushioning specifications contained only qualitative requirements. The performance characteristics of cushioning materials, especially their shock absorption capabilities, were loosely and indirectly controlled. Therefore, considerable variation in performance between successive lots of materials was allowed. Since analytical cushioning design is based upon inference from data for previously tested material, variation in material performance produces a reduction in analytical design accuracy. MIL-C-26861 was developed primarily to enable the designer to procure cushioning materials with known performance characteristics.

It should be noted that MIL–C–26861 does not provide a complete solution to the cushioning performance stabilization and procurement problem. Its chief disadvantage is that procurement by this specification involves many classes and grades of materials and tends to be burdensome. Nevertheless, so far all research efforts devoted to development of a simplier classification method for cushioning performance without large inaccuracies have been unsuccessful. Therefore, despite its complexity, procurement by MIL-C-26861 is the most rational means available for the designer to obtain cushioning materials with known performance characteristics.

Because it contains performance-type tests and requirements and because it is desirable to reduce the number of specifications involved in procurement, MIL-C-26861 was written to include a variety of cushioning materials (urethane foam, polyethylene foam, resilient expanded polystyrene, rubberized hair, etc.).

5.2 PRINCIPAL FEATURES OF MIL-C-26861.

The most important feature of MIL-C–26861 is the classification of cushioning materials in grades and classes according to their dynamic compression characteristics. However, the specification also contains provisions for evaluation and control of other characteristics, such as creep, static compressive force-displacement, compression set, density, tensile strengths pliability (flexibility), breakdown (fragmentation), hydrogen ion concentration (pH), and hydrolytic stability (stability during hydrothermal exposure).

5.2.1 Classification of Materials According to Dynamic Compression Test Data.

To comply with the specification, the supplier must submit to the qualifying activity (the U.S. Air Force Packaging Evaluation Agency) peak acceleration–

static stress (G_m-W/A) curves* for each kind, density, and thickness of cushioning material for a constant 24-inch drop height. (NOTE: Detailed information about the nature and derivation of ~-W/A stress curves is given in 3.2.1.1.) The qualifying activity then classifies the materials according to how the curves intersect a grid composed of range limits for G_m and W/A. To be classified within a particular grade and class, the curve representing any particular material must occur completely below the boundary for the grade and through the entire W/A range represented by the class.

For example, the curve shown in Figure 5–1 represents a hypothetical material that would qualify under class 1 as grades C and D; class 2 as grades A, B, C, and D; class 3 as grades B, C, and D; and class 4 as grade D.

5.2.2 Required Dynamic Compression Testing Procedure.

MIL-C–26861 requires the use of a dynamic compression testing procedure which is essentially the same as that described in 6.1.2.1. This test proce– dure is based upon ASTM method D 1596-78 (41).

At least three specimens of each kind and thickness of material must be tested with a constant equivalent drop height of 24 inches.

5.3 RAMIFICATION IN CUSHIONING DESIGN.

As previously stated, a manufacturer wishing to have his cushioning material qualified under MIL–C-26861 must submit dynamic compression test data to the qualifying activity. This requirement will result in the derivation of cushioning performance data. This technical data will then be made available to the packaging designer. For qualification purposes, the performance tests of materials need be conducted only once by the manufacturer, providing that he certifies that the production process for subsequent lots is not altered. Qualification of new (or altered) materials under MIL-C–26861 will entail some time delay and cost (due to testing); however, it is expected that these factors will tend to standardize cushioning materials and their dynamic compression characteristics.

Obviously, packaging designers are interested in cushioning data for drop heights other than 24 inches, as required for qualification purposes (2.1.1 and 3.1). A requirement for such data was not included in the specification

---

* For information on how laboratories may become qualified to derive Gin-W/A curves according to MIL-C-26861 and for the current list of laboratories qualified, contact the Air Force Packaging Evaluation Agency (PTPT), Wright-Patterson AFB OH 45433.

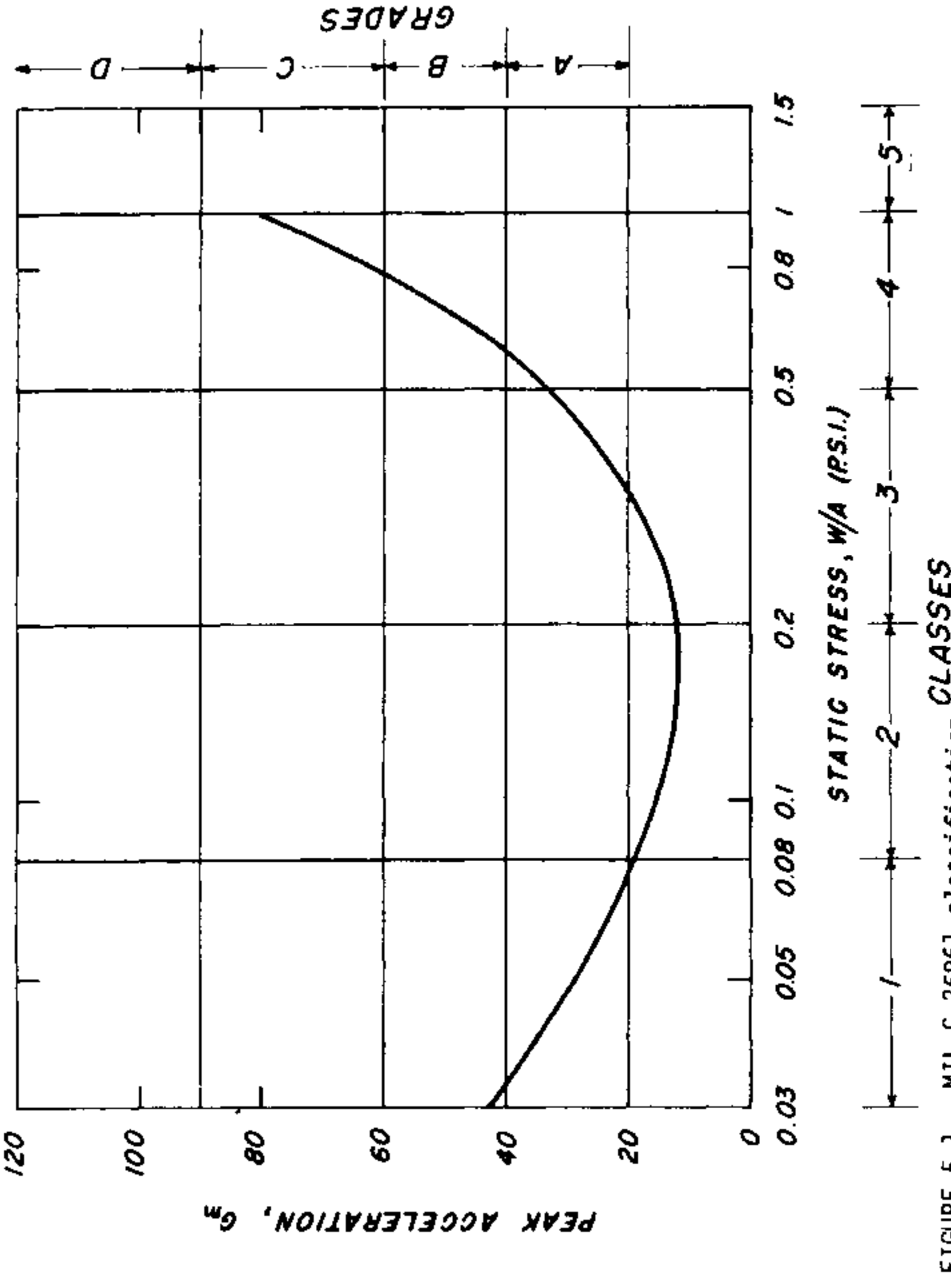


FIGURE 5-1. MIL-C-26861 classification grid superimposed upon G_m-W/A curve for urethane foam.

because this would raise the costs of qualification prohibitively. To help fill the need, dynamic compression test data for various cushioning materials are given in Appendix V. Also, dynamic compression test data are becoming more readily available from progressive manufacturers as they discover the value and conduct tests on their own initiative.

5.3.1 Material Procurement Under MIL-C-26861.

The packaging designer, having determined that he wishes to use a particular kind and thickness of cushioning material, must then determine its classification under MIL-C-26861 for procurement purposes.

It is expected that users, once they have become familiar with the different MIL-C-26861 classes and grades for cushioning materials, will stock only the few commonly required combinations.

CHAPTER 6. TESTING PROCEDURES AND APPARATUS

6.1 DETERMINATION OF INDIVIDUAL CUSHIONING CHARACTERISTICS.

Design data for the pertinent characteristics of cushioning materials are obviously a prerequisite for rational cushioning design. Generally, this information is obtained by designers (1) directly from vendors, (2) by conducting their own tests, (3) from published literature, or (4) by deduction from material specification tests. The usefulness of test data for design purposes is directly related to the accuracy of the data in reflecting the cushioning performance under service conditions. Therefore, the practical value of published test data must be assessed by a designer primarily according to his knowledge of the test procedures and apparatus used. Some knowledge about the reliability of the testing facility is also helpful.

The information in this chapter is presented to provide the designer with sufficient information about test methods, apparatus, and underlying principles to enable him to conduct his own tests of cushioning characteristics and, to assess the applicability and practical value of published design data.

6.1.1 Techniques.

6.1.1.1 Measuring dimensions.

6.1.1.1.1 Scope. This procedure is intended for use in determining the overall length, width, and thickness of a cushion specimen.

6.1.1.1.2 Apparatus. The apparatus used will be the following: A jig with one movable block (Figure 6-1) with a measuring scale graduated to 0.01 inch, plates of suitable size and weight that will provide a uniform load of 0.025 psi to the entire specimen, and a dial indicator attached to a support to measure the thickness of the specimen to the nearest thousandth of an inch (Figure 6-2).

6.1.1.1.3 Specimens. The specimens will be the cushioning materials used in the various tests. Usually their length and width dimensions will be at least 4 inches.

6.1.1.1.4 Conditioning. Unless otherwise specified, specimens preconditioned to a lower moisture content shall be conditioned to equilibrium in air uniformly maintained at 73 °F ± 3.5 ° and 50 ± 2 percent relative humidity. The specimen shall be considered at equilibrium when the change in weight during a one hour or longer period of conditioning does not exceed 0.02 percent of the specimen's weight at the end of the period.

6.1.1.1.5 Procedure. Length of specimen shall be determined in the jig (Figure 6-l). Place the movable block firmly against the end of the specimen and measure the distance between the two blocks at the midpoints of the specimen edges to the nearest hundredth of an inch. Width of the specimen will be determined in like manner.

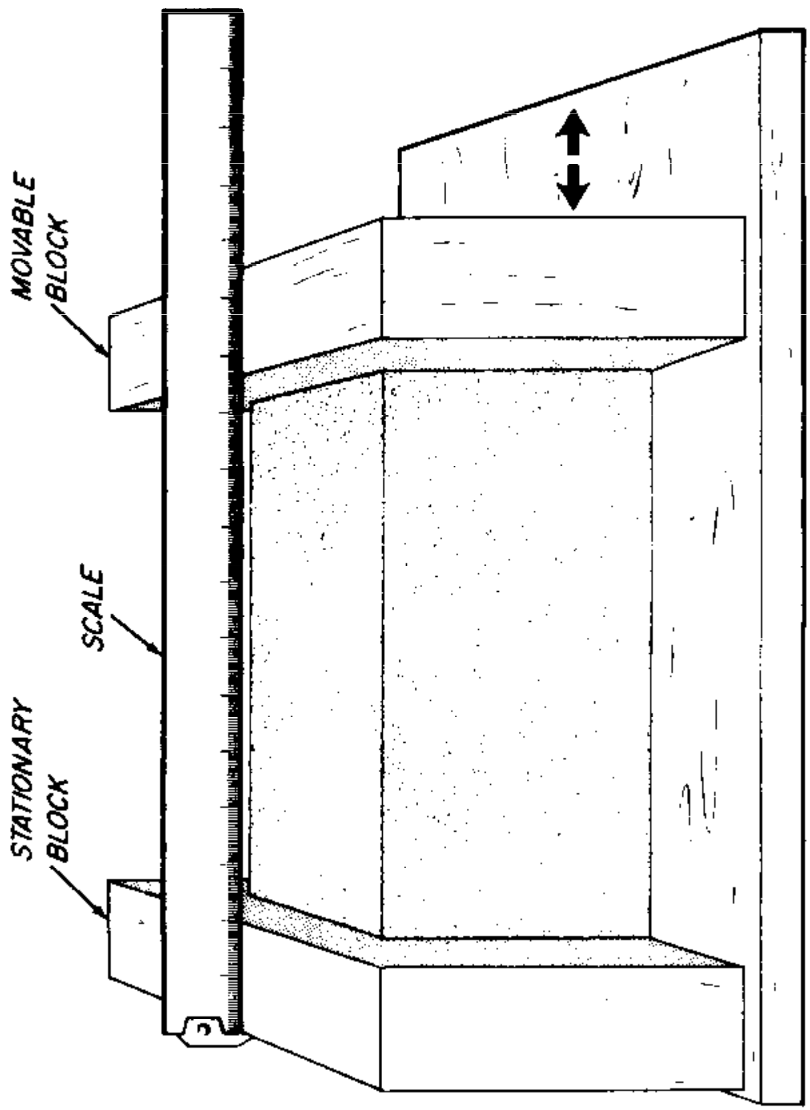


FIGURE 6-1. Apparatus for measuring the length and width of a cushion.

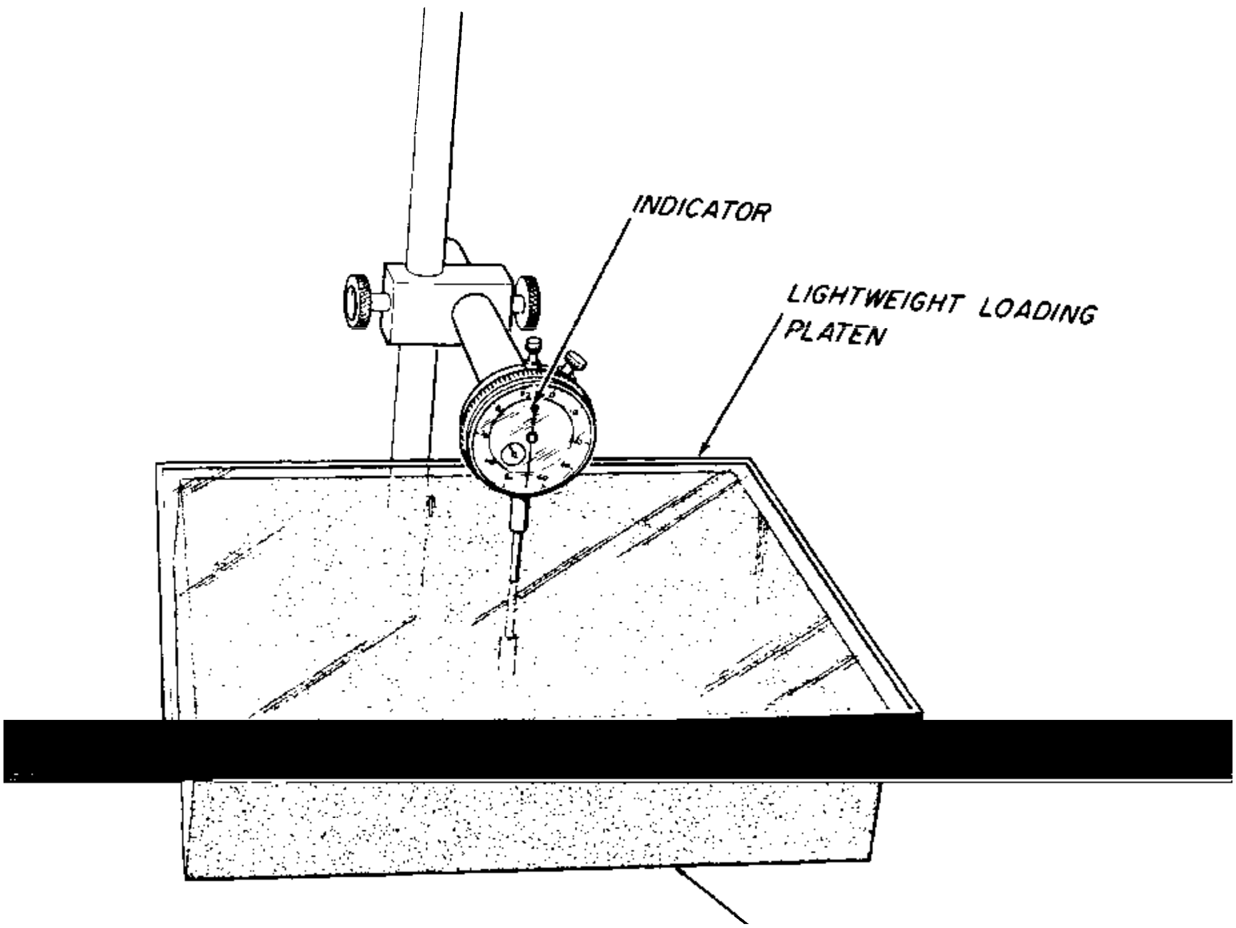


FIGURE 6-2. Equipment used to measure the thickness of a cushion.

To determine the original thickness T of the specimen, load the top surface area of the specimen with a plate to 0.025 psi. (Example: Specimen 4.00 X 4.00 inches, (4) (4) (0.025) = 0.40 pound load.) After a 30 second interval and while the specimen is still under load, either measure the thickness at the geometric center of the top surface of the specimen or average the thickness measurements taken with the scale graduated to one hundredth of an inch on the four corners.

6.1.1.1.6 Report. The report should include the following information:

a. Date of test and notation of results.

b. Description of the materials tested will include manufacturing origin, generic description (cellulose wadding, fibrous glass, polyester–type urethane foam, etc.) manufacturer's proprietary designation, and compliance of the material with material specifications, if known.

6.1.1.2 Determining density.

6.1.1.2.1 Scope. This procedure is intended for use in determining the density in pounds per cubic foot of various cushioning materials.

6.1.1.2.2 Apparatus. The apparatus will be a weighing scale or torsion balance that is capable of weighing a specimen to within 0.02 percent of its weight.

6.1.1.2.3 Specimen. The specimens will be those measured in 6.1.1.1.

6.1.1.2.4 Conditioning. Conditioning will be as in 6.1.1.1.4.

6.1.1.2.5 Procedure. The length, width, and thickness will be determined as in 6.1.1.1 and each specimen will be weighed to within 0.01 pound. The density of each specimen will be calculated according to the following formula:

$$D = \frac{(1,728)\ (W)}{L\ W\ T} \qquad (6:1)$$

where D - density in pounds per cubic foot; w - weight of specimen in pounds; L = length of specimen in inches; W = width of specimen in inches; and T = thickness of specimen in inches (minimum l-inch thickness).

6.1.1.2.6 Report. The report should include the following information:

a. Date of test and notation of procedure.

b. The number of specimens and description of the materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, and compliance of the material with material specifications, if known.

c. A tabulation of specimens and their densities.

6.1.1.3 Determining moisture content.

6.1.1.3.1 Scope. This procedure is intended for use in determining the moisture content of cushioning materials in percent of the oven-dry weight of the specimen.

6.1.1.3.2 Outline of method. The moisture content is calculated from weight values obtained before and after drying a representative specimen of cushioning material in an oven. Since a material might contain an amount of water greater than its oven-dry weight, moisture content determined by this method might exceed 100 percent. Limitations of this test are that it might be destructive and its inherent accuracy is reduced if the cushioning material contains an appreciable amount of volatile components other than water.

6.1.1.3.3 Apparatus. A drying oven that can be maintained within ± 3.6°F of any desired temperature within the range of 150° to 220° F is required to dry the specimens to a constant weight.

An accurate thermometer or thermocouple shall be used to check the temperature of the oven.

A balance is required that will weigh a specimen within an accuracy of 0.02 percent of the weight of the specimen. A torsion balance, Harvard trip balance, triple-beam balance, and automatic direct reading balance are examples of suitable equipment.

6.1.1.3.4 Specimens. Each specimen shall be not less than 10 grams in weight and cut to represent the cross section of the cushioning material as nearly as possible. A sharp bandsaw or pair of shears shall be used to cut the specimens, and all loose particles shall be removed from the section before it is weighed.

6.1.1.3.5 Test procedure. Weigh each specimen, or portion thereof, to an accuracy of ± 0.02 percent. If physical tests of the material are involved and unless otherwise specified, the specimen shall be weighed immediately following the tests. If this is impractical, the specimen shall be protected from a moisture change until weighed by placing it in a tightly closed container that is highly impervious to moisture vapor transmission. This original weight (w_o) of the specimen shall be recorded on the data sheet.

Immediately after the specimen has been weighed, it shall be placed in the oven and heated at 217 F ± 3.6 until it reaches constant weight. Lower temperature shall be maintained if the specimen tends to deteriorate at the specified temperature. The specimen shall be considered to be at constant weight when the change in weight during a one hour or longer period of drying does not exceed 0.02 percent of the specimen's weight at the end of the period.

Upon attaining constant weight, each specimen shall be removed from the oven and the oven-dry weight (w_d) shall be recorded. The weighing accuracy shall be the same as that required for the original weighing.

6.1.1.3.6 Computation of moisture content. The moisture content shall be calculated by the following formula:

$$\text{Moisture content (pet)} = \left(\frac{w_o - w_d}{w_d}\right)(100) = \left(\frac{w_o}{w_d} - 1\right)(100) \qquad (6:2)$$

6.1.1.3.7 Report. The report should include the following information:

a. Date of test and reference to the test procedure.

b. Number of specimens and description of the kind of materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), specimen dimensions, manufacturer's proprietary designation, and compliance of the material with material specifications, if known.

c. A list of the moisture content in percent for each specimen.

6.1.2 Test Methods.

6.1.2.1 Dynamic compression.

6.1.2.1.1 Scope. This section covers a method for determining the shock isolation capability of cushioning materials, especially those that exhibit a high degree of compressibility and recovery. Since the shock isolation performance of package cushioning materials inside complete packages sometimes differs from that which the same materials render outside the package, the data derived by this method do not necessarily represent the actual performante of these materials in packages. The specimen size and impact loading rate can also affect the data. However, the data obtained by this test procedure are usually sufficiently accurate for the purpose of initial design.

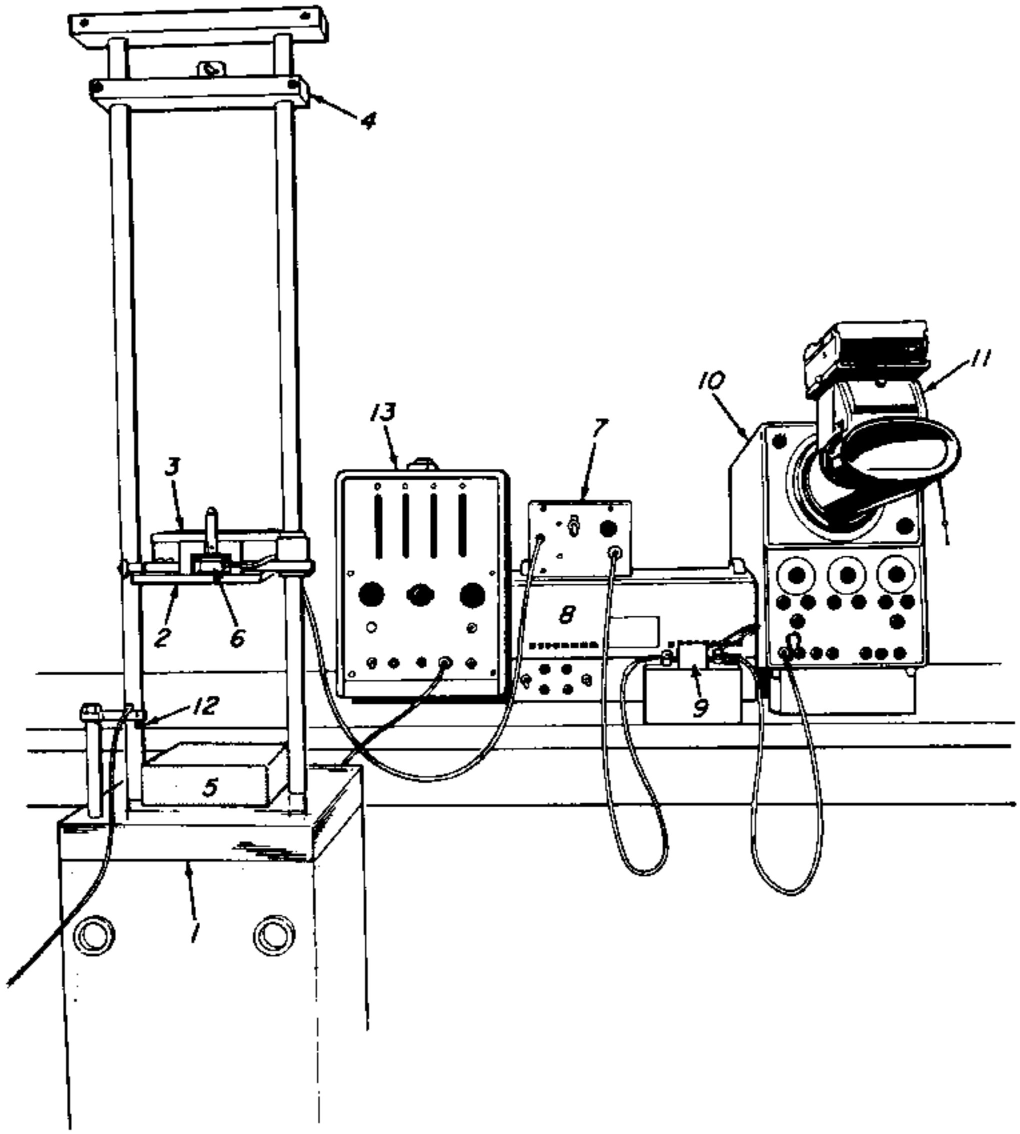
6.1.2.1.2 Outline of method. The test apparatus consists of a testing machine having a dropping head (to represent a packaged item) and impact surface for dynamic loading of a cushion to simulate impact in rough handling. The signal output from a transducer mounted on the loading head is fed into a suitable recording system which has been calibrated to read peak G's ; $(G=\frac{a}{g})$. The recorded test data can then be analyzed and expressed as peak acceleration-time curves, which are useful for solving cushioning problems involving shock isolation.

6.1.2.1.3 Testing machine. Any type of dynamic testing apparatus that will produce test conditions conforming to the requirements specified in this section is acceptable. However, the dynamic tester shall consist of a dropping head having a flat impact surface that is larger than the cushion to be tested and a massive impact base with a face parallel to the face of the dropping head. The dropping head shall be suitably guided for movement in a vertical direction with a minimum of friction. A typical dynamic compression testing apparatus and associated instrumentation are shown in Figure 0–3.

The dynamic cushion tester illustrated in Figure 6-4 was specially designed for obtaining cushion performance data at extremely low static stress values. Use of a “break away” dropping head makes possible the simulation of very light weight loads. Upon contact with the top surface of the cushion specimen during impact, the dropping head separates from the carriage and its weight alone acts on the cushion.

For any dynamic testing machine, it is important that the dropping head and the impact base of the equipment have sufficient rigidity. Insufficient rigidity can cause undesirable vibrations in the apparatus which are recorded in the acceleration-time curve. An example of shock-excited ringing of the loading device is illustrated in Figure 6-5. The possibility that distortion of the acceleration–time pulse may be caused by ringing of the loading head and not because of the behavior of the cushion can be confirmed by the existence of distortion of the trace beyond the time when the pulse returns to zero acceleration. At this instant the loading head is no longer in contact with the cushion (it has rebounded away); therefore, distortion at this time must be caused by residual vibration of the loading head.

Under certain conditions, such as tests of stiff rubberized hair with a lightweight loading head, secondary peaks on the leading edges of acceleration-time pulses may be observed. These are caused by shock wave propagation in the cushioning material, and a typical illustration of the effects of this phenomenon is shown in Figure 6-6. Shock wave effects are generally manifested by gradual peaks on the leading edge of pulses, and when observed, they seldom cause appreciable distortion of the peak acceleration value for the pulses.



Dynamic compression testing apparatus (guided vertical drop type). 1, Anvil; 2, dropping head platen; 3, adjustable weights; 4, adjustable crosshead and release mechanism; 5, test specimen; 6, crystal accelerometer; 7, charge amplifier; 8, power supply; 9, low-pass filter; 10, cathode ray oscilloscope; 11, Polaroid camera; 12, wiper contacts; and 13, electronic counter.

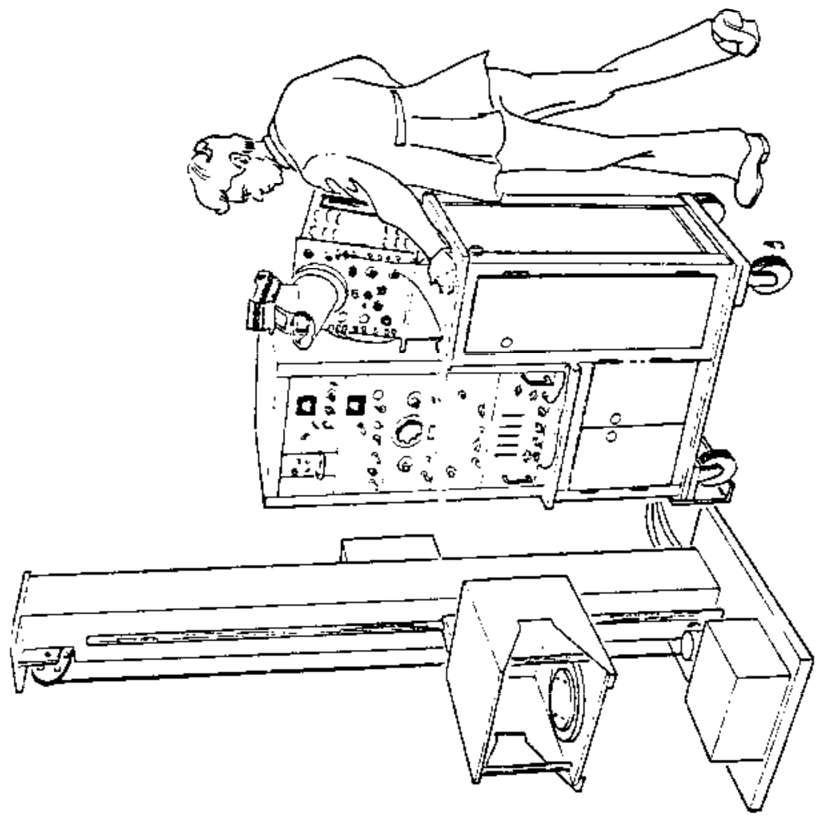


FIGURE 5-4. Dynamic cushion tester with "Break Away" drop head for low static stress testing.

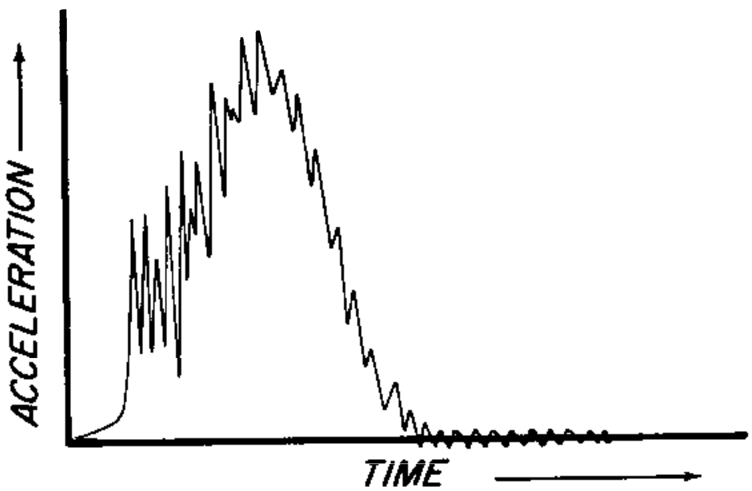


FIGURE 6-5. Acceleration-time curve showing distortion caused by shock-excited ringing of the loading head.

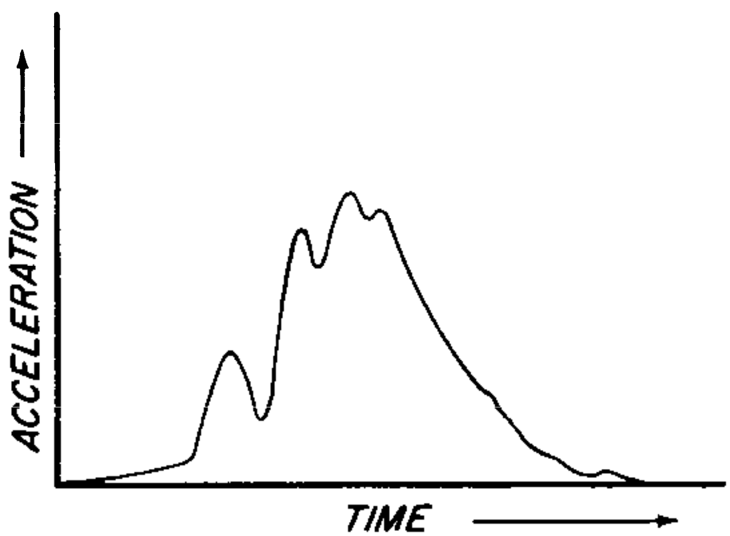


FIGURE 6-6. Acceleration-time pulse showing shock wave effects.

Another indication of the existence of undesirable flexural vibrations of loading heads and the impact bases are sharp irregularities in the curves plotted for successive recorded peak acceleration values. High-speed motion pictures sometimes are helpful in determining fundamental difficulties involving such characteristics as insufficient stiffness in loading heads or, impact bases.

One rule of thumb for the li~inimum ratio of mass of the impact base is that it must be at least 50 times the mass of the loading head.

All dynamic dropping heads are influenced by friction due to guides and air resistance. The significance of this effect varies not only with the type of apparatus but with the weights of any particular testing machine. Accordingly, the drop height is specified as equivalent free-fall height (based upon impact velocity) rather than actual drop height (a 24-inch free fall is equivalent to 136.3 inches per second). The actual impact velocity must be controlled to within t 2 percent of the desired value.

6.1.2.1.4 Recording apparatus. The selection of a specific recording system is optional. Common systems consist of cathode ray oscilloscopes with Land process cameras, storage type oscilloscopes, or galvanometer-type oscillographs. These systems allow detailed analysis of data, since complete acceleration-time pulses are recorded.

All recording systems, regardless of type (including both transducers and recorders) must have a frequency response adequate to measure the peak acceleration-time values to an accuracy of t 5 percent of the actual value. The acceleration–time pulse is generally a transient pulse that approximates a half–sinusoid at optimum cushion displacements and becomes triangular and even spire-like as a result of impacts involving low or high extremes of cushion displacement. The actual pulse duration values obtained during testing depend upon the particular combination of drop height, cushion thickness, and cushioning materials, and will usually range between 5 to 25 milliseconds.

The chief limiting factor of complete transducer-recording systems is often the inherent ability of the damped mechanical spring-mass elements (transducers) of the system to respond to applied pulses. To obtain an accuracy of better than 5 percent of the peak acceleration in measuring acceleration pulses, a transducer which is damped to between 0.4 and 0.7 of the critical value must have a natural period of about one-third or less of the duration of the acceleration pulse. Therefore, according to this rule and the pulse duration values experienced in testing, accelerometers damped between 0.4 and 0.7 of the critical value must have a natural frequency of 600 cps or higher.

For additional basic information about recording instrumentation, refer to 6.2.

6.1.2.1.5 Test specimens. Each test specimen will have length and width dimensions of 8 inches unless otherwise specified. Thicknesses of specimens shall be those of particular interest to the investigator. Dimensions shall be measured according to 6.1.1.1.5.

The weight and density of the test specimens shall be determined in accordance with 6.1.1.2.5.

6.1.2.1.6 Test procedure. Unless otherwise specified, the conditioning of test specimens shall be the same as that specified in 6.1.1.1.4. Ambient conditions during testing shall conform to those existing during conditioning.

Position the test specimen on the impact base and prepare the dropping head to strike the cushion. Then impact the specimen with a series of five drops at the predetermined dropping head weight and the impact velocity that will produce the lowest desired static stress, allowing a minimum of one minute between each drop. The acceleration-time record of the dropping head during compression of the cushion will be recorded for each drop. After a three-minute rest, the thickness of the specimen shall be measured according to Section 6.1.1.1.5 and recorded. The same test procedure will be repeated with the other two specimens. A quantity of weight will then be added to the dropping head and five consecutive drops shall be made on each of the three specimens. The dropping procedure will be repeated with several more increments cf weight, used in ascending order, until sufficient data are derived to establish the peak acceleration-static stress curve for the material. Usually five to nine points will be required. When the dynamic compression set (6.1.2.1.7) following drop tests at any weight increment exceeds 10 percent, a new set of specimens will be employed for tests at all succeeding weight increments; this fact shall be reported in the test report. The same procedure shall be employed for various heights of drop (impact velocities).

6.1.2.1.7 Calculations. The first peak acceleration reading obtained from each set of five drops will be disregarded and the remaining four will be averaged. The average values for each specimen will then be averaged to obtain one value for each loading weight increment. The average peak acceleration for all weight increments will be plotted as a function of the corresponding static stress.

Dynamic set shall be calculated as follows:

$$\text{Set (\%)} = \frac{\text{Original thickness (T)} - \text{Thickness after test } (T_2)}{\text{Original thickness (T)}} \times 100 \qquad (6:3)$$

6.1.2.1.8 Report. The report should include the following information and results:

a. Date of test and reference to the test procedure.

b. The number of specimens and description of the materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, test specimen dimensions, density (6.1.1.2.5), and compliance of the material with material specifications, if known.

c. The equivalent drop height employed.

d. The dynamic set, as calculated in 6.1.2.1.7. If specimens other than those used initially in the test were tested, give details regarding the materials and the substitutions.

The average peak acceleration values and corresponding values of dropping weight per unit area in tabular form.

The peak acceleration-static stress curve (plotted on 3-cycle semilogarithmic graph paper) derived from the test data. The logarithmic scale shall be used as the coordinate axis for the static stress values.

One representative acceleration–time record each for drop tests involving the greatest, least, and an intermediate load used in the test series, together with complete details on the test conditions used to produce the data.

6.1.2.2 Vibration transmissibility.

6.1.2.2.1 Scope. This section covers a method for determining the vibration transmissibility/isolation capability of cushioning materials, especially those that exhibit non-linear dynamic load–deflection characteristics. Since the vibration transmissibility/isolation performance of package cushioning materials inside complete packages sometime differs from that which the same materials exhibit outside the package, the data derived by this method may not necessarily represent the actual performance of these materials in packages. The specimen size and frequency sweep rate can also affect the data. However, the data obtained by this test procedure should provide useful guidance for the purposes of initial design.

6.1.2.2.2 Outline of methcd. The test apparatus consists of a vibration tester on which is mounted a test block and fixture representing a packaged item. The signal outputs from transducers located in the test block and on the platform of the vibration tester are fed into a suitable recording system. The recorded test data can then be analyzed and presented in the form of vibration transmissibility-frequency curves which are useful for solving cushioning problems involving vibration isolation.

6.1.2.2.3 Testing machine. Any type of vibration testing apparatus that will produce test conditions conforming to the requirements specified in this section is acceptable. However, the vibration tester shall consist of a test block and fixture (Figure 6-7) mounted on the platform of the vibration tester as shown in Figure 6-8. The test block is a rectangular parallelepipeds constructed to facilitate incremental changes in weight. The faces of the block bearing on the cushion test specimens shall measure 8" x 8". A cavity will be located at the geometric center of the block for mounting an accelerometer. The test fixture will be designed to restrict the test block to essentially vertical movement with a minimum of friction. A second accelerometer shall be attached to the platform of the vibration tester to monitor its vertical movement. For vibration transmissibility determinations it is important that the test block be free from friction and rotation which would reduce transmissibility and change the frequency at resonance. Also, care must be taken to avoid distortion of test data caused by the test block separating from the test material during test. The existence of a void between the test material and test block can result in shock excited ringing of the test block.

6.1.2.2.4 Recording apparatus. The selection of a specific recording system is optional. One commonly used system consists of a cathode ray Oscilloscope, tracking filter, automatic frequency sweep module and an Ii-Y recorder. A system of this type provides for detailed analysis of data and the direct plotting of vibration transmissibility–frequency curves. All recording systems, regardless of type (including transducers and recorders) must have a frequency response which is adequate to measure the peak acceleration-frequency values to an accuracy of ± 5 percent of the actual value.

6.1.2.2.5 Test specimens. Each test specimen will have length and width dimensions of 8 inches—unless otherwise specified. Thickness of specimens shall be those of particular interest to the investigator. Dimensions snail be measured according to 6.1.1.1.5. The weight and density of the test specimens shall be determined in accordance with 6.1.1.2.5.

6.1.2.2.6 Test procedure. Unless otherwise specified, the conditioning of test specimens shall be the same as that specified in 6.1.1.1.4. Ambient conditions during testing shall conform to those existing during conditioning. Two specimens of the material/thickness combination under investigation are placed in the test fixture, one below and one above the test block. The test block is weighted for the desired static stress and placed on the bottom pad. After at least one minute to allow for an initial creep, the top pad is placed on the block. The top of the fixture is then placed upon the top pad so that it preloads the pads to a static stress load of 0.1 psi. The top of the fixture is then clamped in place. Starting at a low frequency (approximately 1.5 Hz) the frequency is increased at a rate of approximately 0.4 decades per minute. The input acceleration is held constant at 0.5 G, zero to peak, by varying the vibration system displacement as the frequency changes automatically. The input acceleration is

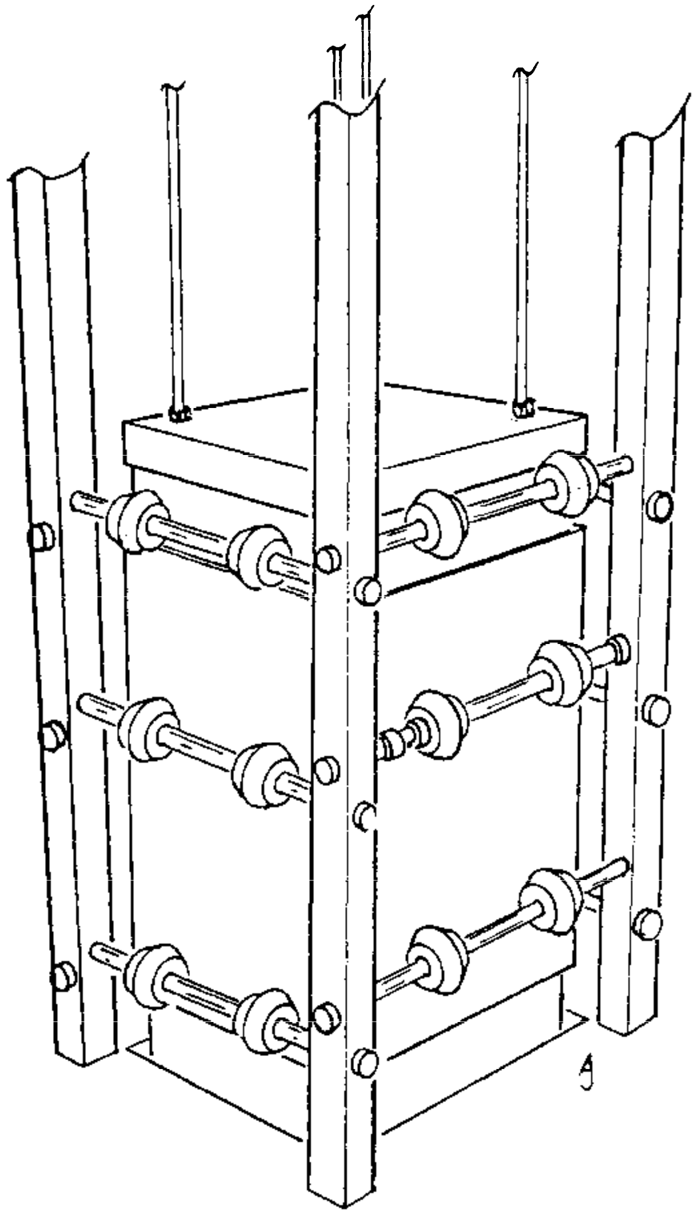


FIGURE 6-7. Test block and fixture for vibration transmissibility determinations.

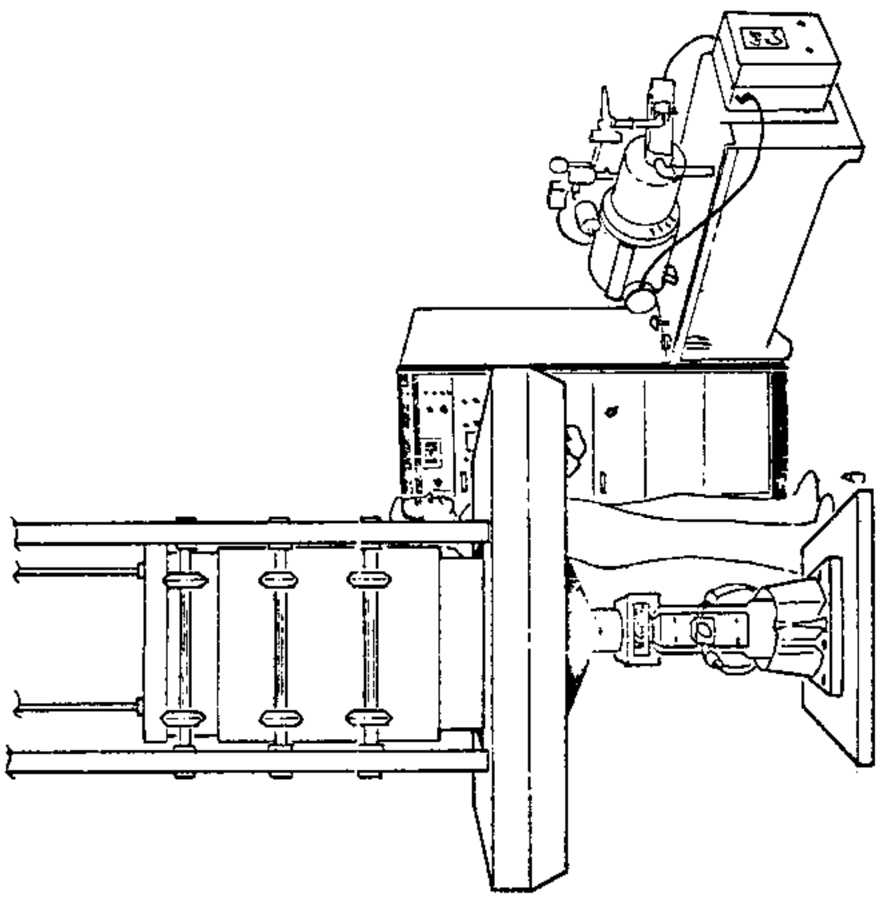


FIGURE 6-8. Vibration test system for transmissibility determination.

monitored on the oscilloscope. The frequency is increased through the resonance of the material and beyond until the response transmissibility signal from the accelerometer mounted in the test block decreases to approximately 0.2. This response signal, which passes through the tracking filter, provides an output proportional to the log of the peak amplitude and is used to drive the Y axis of the X-Y plotter. The output from the automatic frequency sweep module drives the X axis of the X-Y plotter. Since the input is held constant the X-Y plot represents transmissiblity (Y-axis) versus frequency (X-axis).

6.1.2.2.7 Report. The report should include the following information and results:

a. Date of test and reference to the test procedure.

b. Description of the material tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.). Manufacturer’s proprietary designation, test specimen dimensions, density (6.1.1.2.5), and compliance of the material with material specifications, if known.

c. Vibration transmissibility versus frequency curves for the static stress/thickness combination plotted on a log-log scale.

6.1.2.3 Abrasive qualities.

6.1.2.3.1 Scope. This procedure indicates the abrasive nature of a cushioning material.

6.1.2.3.2 Apparatus. The following apparatus will be used:

a. A flat sheet of aluminum alloy No. 1100-H25, not less than 9 inches square and having one side bright finish. The test area shall be a portion of the bright surface that is clean and free from mars.

b. A weight of 4 ± 0.02 pounds in the form of a rectangular metal block. The bottom surface of the block to which the specimen adheres shall be a 2.0 to 2-1/16-inch square and machined to a finish with roughness not greater than 16 microinches (root mean square).

6.1.2.3.3 Specimens. The cushioning specimens shall be 1-7/8 to 2 inches square with a uniform thickness not greater than 1/2 inch and shall be representative of the material as supplied by the manufacturer. Usually it will be necessary to cut the specimens to the proper thickness for this test.

6.1.2.3.4 Conditioning. Conditioning shall be as in 6.1.1.1.4. Ambient conditions during testing shall conform to those existing during conditioning.

6.1.2.3.5 Procedure. Center the cushioning specimen on the bottom of the weight and fasten it with a single layer of pressure-sensitive double-coated tape (Minnesota Mining & Manufacturing CO. tape No. 400, Mystik Adhesive Products, Inc. double-backed tape No. 6360, or other suitable products). The area of the specimen tested for abrasiveness shall correspond with the areas that normally contact items in service. Place the specimen and weight upright on the test area of the aluminum sheet, so that the specimen supports the weight. Use sufficient caution to insure that the specimen and the aluminum test surface remain clean. The specimen supporting the weight shall be rubbed back and forth on the bright side of the aluminum sheet in a direction perpendicular to the machine direction of the aluminum sheet with a stroke of approximately 6 inches and a speed of approximately one foot per second. The technique of rubbing shall not alter the pressure between the aluminum and the specimen. Continue rubbing for 30 seconds or less if scratches are clearly developed in the aluminum.

Using direct and side lighting at various angles to the plane and direction of rubbing, visually examine the aluminum sheet for any scratches or other effect resulting from the test.

Classify the effect on the rubbed surface as "scratched", "dulled", "polished", or "not affected".

If the aluminum surface appears dulled, examine with a 10-power magnifying glass and wash the area with a liquid cleaning solution to determine whether the dull appearance was caused by scratching or by deposition of fragments of the specimen on the aluminum.

6.1.2.3.6 Report. The report should include the following information:

a. Date of test and reference to the test procedure.

b. The number of specimens and a description of the materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, density (6.1.1.2), test specimen dimensions, and compliance of the material with material specifications, if known.

State the classification of the condition of the aluminum test surface following testing as being either "scratched", "dulled", "polished", or "not affected".

6.1.2.4 Creep.

6.1.2.4.1 Scope. This method of test determines the creep characteristics of cushioning materials in the bulk, sheet, or molded form. These data are useful to the packaging designer as an indication of tendencies of various package cushioning materials to produce looseness in packs during service. However, the creep rates determined by this test might differ from those actually existent in a package during shipment because of variations in specimen thickness and area, varying ambient conditions of temperature, humidity, and by shock and vibrations.

6.1.2.4.2 Outline of method. The test apparatus consists of a testing device with a base plate and a guided movable platen that can be loaded with weights. The loaded movable platen is placed on a cushion to simulate static compressive loading of a cushioning material in actual service. By measuring the change in thickness of the loaded cushion with time, the creep properties of the cushioning material can be obtained.

6.1.2.4.3 Apparatus. The apparatus shall consist of an inner and outer wood box (Figure 6-9) constructed of dressed lumber having an actual thickness of 3/4 inch.

6.1.2.4.3.1 Inner box. The inner box serves as a movable guided platen that can be loaded with suitable weights (lead shot or lead weights molded to the dimensions of the inner box). The outside dimensions of the inner floating box are 6-3/8 inches (+0, -1/32) X 6-3/8 inches (+0, -1/32) x 8 inches (+1/32). The middle of the front and back vertical panels of the inner box shall be marked (with ink) at the lowest possible point to indicate where the measurement should be made.

6.1.2.4.3.2 Outer box. The outer box serves as the base plate of the testing device. The inside dimensions of the outer box are 6-1/2 inches (+1/32, -O) X 6-1/2 inches (+1/32, -0) X 9-1/4 inches (±1/32). The area 6-1/2 X 6-1/4 inches is removed from the front and back vertical panels of the outer box as shown in Figure 6-9. The horizontal surface (base plate) of the outer box shall be marked directly below those on the inner box.

6.1.2.4.4 Test specimens. The test specimens shall be right square or right cylinders with the lateral dimensions at least as great as the original thickness. The minimum dimensions of the specimens as determined by 6.1.1.1 shall be at least 2 X 2 inches along the length and width, and 1 inch in thickness. The preferred size is 6 X 6 X 4 inches thick. If the cushioning material, as supplied, is less than 1 inch thick, the required thickness may be obtained by using two or more layers of material. Weight shall be measured in accordance with 6.1.1.2.

6.1.2.4.5 Conditioning. Conditioning of specimens shall be according to 6.1.1.1.4 unless the creep tests are to be conducted at conditions other than 73°F ± 3.5 and 50 ± 2 percent relative humidity. In such an event, the ambient conditions for conditioning shall correspond to those used in the test.

6.1.2.4.6 Preworking. For cushioning applications where a high degree of compressibility and recovery of the cushion is required, preworking of the test specimens prior to loading is desirable. A suggested preworking procedure consists of the following: Prior to testing, each specimen shall be cyclically loaded between 0 and 65 percent of the original thickness 10

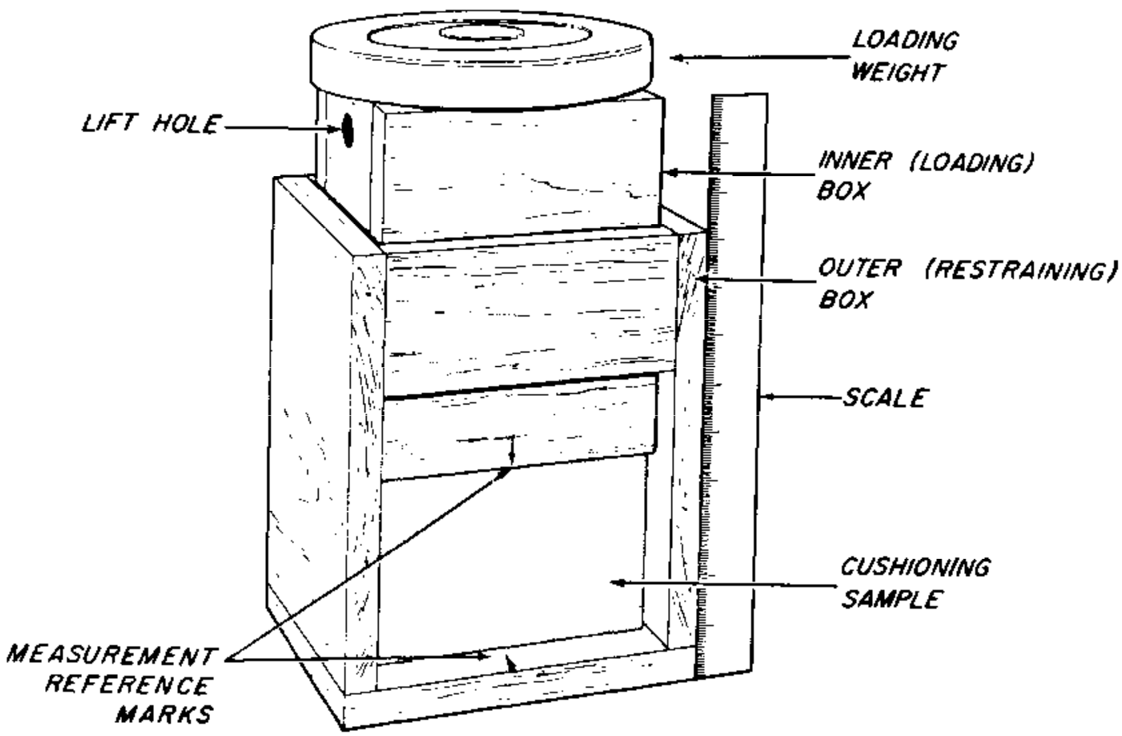


FIGURE 6-9. Creep testing apparatus.

times or until the change in unloaded thickness between the loading cycle does not exceed 2 percent of the original thickness. Preworking of specimens to be tested at environmental conditions other than 73°F ± 3.5 and 50 ± 2 percent relative humidity shall be performed at room temperatures before conditioning at the required temperature. After this preworking, the specimen shall be rested for a minimum of 1 hour. The thickness of the specimen after the rest period shall be measured according to 6.1.1.1 and recorded.

6.1.2.4.7 Test procedure. Although creep tests may be conducted with any desired environmental conditions, such tests will normally be conducted at 73 F ± 3.5 and 50 ± 2 percent relative humidity, unless otherwise specified.

Center the specimen on the base of the outer box utilizing the apparatus specified in 6.1.2.4.3, and then apply the unloaded inner box evenly and gently to the entire upper surface of the specimen. Next, apply the desired load evenly and gently to the inner box. To determine the thickness of the specimen while under load at any particular time (T_n)$_s$ measure the vertical distance between the bottom of the inner box panel and the outer box panel at the reference marks on both the front and back of the test apparatus. The average of these two measurements shall be recorded as Tn. Measure and record (T_n) at any desired time interval but at least after 60 ± 5 seconds, 6 minutes, 1 hour, 24 hours, 96 hours (4 days), and 168 hours (7 days) following application of the load. More frequent readings are recommended.

At the end of the creep loading test time, remove the test load from the specimen. At three time intervals--30 seconds, 30 minutes, and 24 hours after removal of the load--measure thickness of the specimen according to 6.1.1.1. During the time between measurements, the platen used for measuring the specimen should be removed.

> NOTE: Since creep tests in progress are affected by shock and vibration received by the apparatus, the location of the apparatus shall be selected so that a minimum of such disturbance will occur. When no ideal location is available, the test apparatus and mounting shall be isolated from shock and vibration.

6.1.2.4.8 Calculations. Calculate density according to 6.1.1.2. Calculate the static stress for each loading as follows:

$$\text{Static stress (psi)} = \frac{w}{L \times W} \qquad (6:4)$$

where w is weight of load in pounds, L is length of specimen in inches, and W is width of specimen in inches.

Calculate creep at a particular time according to the formula:

$$\text{Creep } (\%) = \left(\frac{T - T_n}{T} \right) (100) \qquad (6:5)$$

where T is the original thickness of material in inches; and T_n is the thickness in inches of the material under load after a particular time interval.

Calculate permanent set according to the following formula:

$$\text{Permanent set } (\%) = \left(\frac{T - T_{r3}}{T} \right) (100) \qquad (6:6)$$

where T_r1, T_r2, and T_r3 represent thickness measurements made with the load removed after 30 seconds, 30 minutes, and 24 hours, respectively.

6.1.2.4.9 Report. The report shall include the following information and results:

Date of test and reference to the test procedure.

The number of specimens and a description of the kind of materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, density (6.1.1.2), and compliance of the material with material specification, if known.

Original thickness of material.

The preworking procedure of the specimen, if used.

The thickness of material after preworking.

The static stress applied to each specimen.

The initial thickness of specimens under load.

The thicknesses of the specimen while under load that have been applied for the specified periods of time.

The creep, based upon original thickness or thickness after preworking (if used).

A plot of creep versus time of application of load.

Thickness after recovery period.

Permanent set, based upon the original thickness or thickness after preworking.

State whether the specimens contacted the sides of the outer boxes during the loading period.

Describe ambient atmospheric test conditions.

6.1.2.5 Static compressive force-displacement.

6.1.2.5.1 Scope. This procedure is intended to evaluate the relationship between a slowly applied compressive load and the resultant displacement of cushioning materials. The information is particularly helpful in the determination of the size of outer container required to accommodate the item and cushioning.

6.1.2.5.2 Apparatus. A universal testing machine similar to that shown in Figure 6-10 or a weight-increment type device shall be used. However, universal testing machines equipped with autograph recorders are generally best suited for this test.

When tests are to be conducted at various controlled conditions, facilities for maintaining the desired temperatures and humidities shall be provided:

One practical technique for controlling the atmospheric testing conditions involves locating the testing machine within a room capable of maintaining the desired conditions.

Another technique involves enclosing only the immediate area of the specimen inside a chamber, as in Figure 6-11. The chamber rests on the lower platen of the testing machine with the testing head extending through the top of the chamber so that the cushioning material specimen can be tested inside the chamber. Chambers of this type are usually equipped with a thermostat-controlled fan, heating coils, a dry ice receptacle, or other means of cooling the chamber. Usually the temperatures required are from -60 to 160 F. Humidity can be controlled by the use of open containers of various saturated salt solutions in the chamber (18).

A dial indicator graduated in 0.001 inch divisions over 1 inch or more travel (Figure 6-12) is used to measure the movement between the upper and lower platen during the test if the machine is not equipped with an autographic recorder. Gage blccks may be used to extend the displacement-sensing range of the dial gage.

6.1.2.5.3 Test specimens. Test specimens shall be right square prisms with minimum dimensions not less than 4 X 4 inches 1 inch thick. Larger specimens are recommended wherever possible. Materials less than 1 inch in thickness shall be laminated to make the minimum thickness.

6.1.2.5.4 Conditioning. Specimens to be tested at a particular atmosphere shall be conditioned for at least 5 hours before testing.

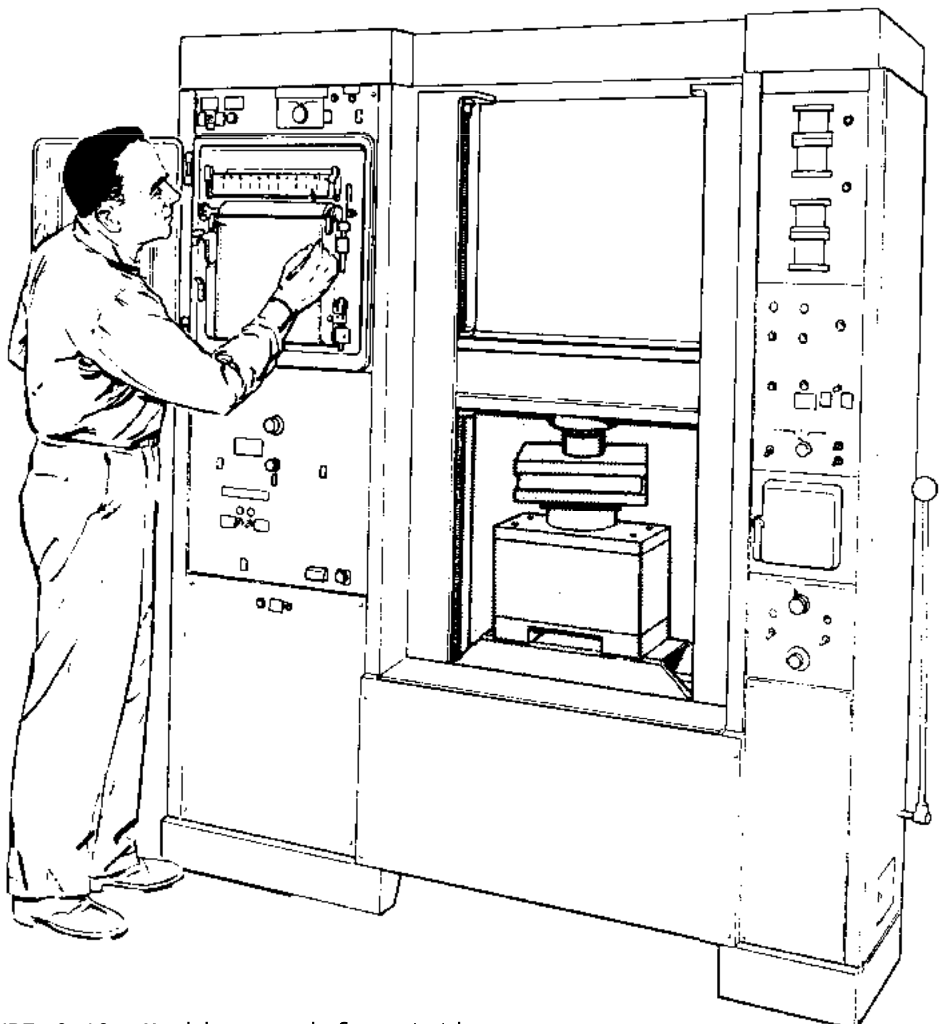


FIGURE 6-10. Machine used for static compressive force-displacement testing.

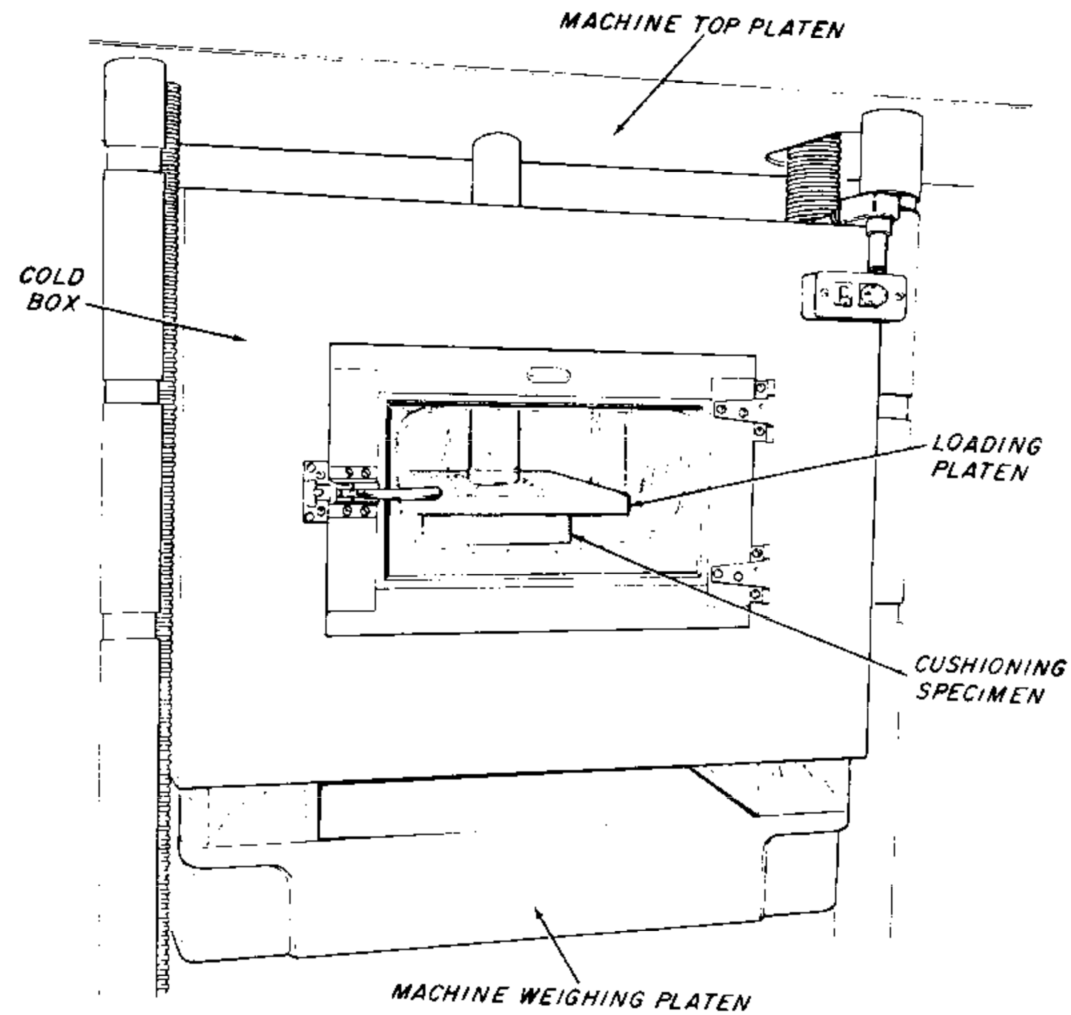


FIGURE 6-11. Insulated chamber used with a universal testing machine to conduct tests at various temperatures.

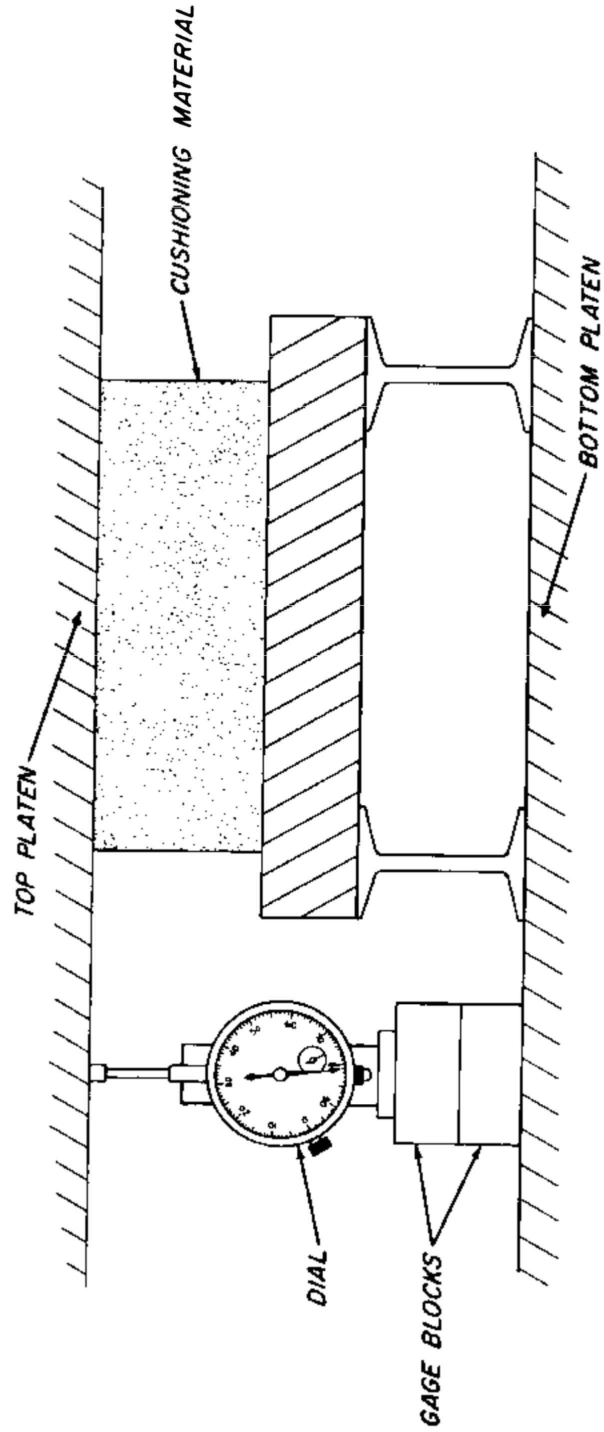


FIGURE 6-12. Preferred test setup for static-compression testing when autographic recorder is unavailable.

Room temperature test specimens shall be conditioned according to 6.1.1.1.4.

Specimens that are to be tested in atmospheres other than those around the testing machine shall be conditioned at the required testing conditions. Where relatively low or high temperatures are involved, a cabinet placed near the testing machine similar to the testing chamber described in 6.1.2.5.2 has been used satisfactorily.

6.1.2.5.5 Preworking. The original thickness, length, and width shall be measured according to 6.1.1.1. Prior to testing, each specimen shall be cyclically loaded between O and 65 percent of the original thickness 10 times or until the change in unloaded thickness between the loading cycles does not exceed 2 percent of the original thickness. Preworking of specimens to be tested at high or low temperatures shall be performed at room temperatures before conditioning at the required temperature.

One hour or more after the final preworking cycle the thickness after preworking (T) will be measured in accordance with 6.1.1.1 and then used as the zero deflection point.

6.1.2.5.6 Test procedure. The specimen shall be loaded in a compression testing machine or weight–increment type device so that the rate of strain shall be not greater than 1.0 inch per minute per inch of specimen thickness after precompression. If the testing machine is not equipped with an autographic recorder, a dial indicator shall be used so that the movement of the movable platen relative to the stationary platen is registered. The load shall be recorded at increments of deflection of not greater than 5 percent of the thickness of the specimen at the start of loading or in increments small enough to obtain about 20 readings for the curve. Continue loading the specimen until a deflection of at least 50 percent of the thickness after preworking is reached and until a 100 percent increase in load produces a change in deflection of less than 5 percent of the original thickness. Then unload the specimen. If a weight-increment device is used, the deflection of the specimen shall be determined immediately after the application of a change in load. If the testing machine has an autographic recorder, a continuous curve shall be taken while the load is being applied. A correction is sometimes necessary to compensate for the movement of the stationary platen when using machines with autograph recorders. On some machines this movement is infinitesimal but on others it presents a variable that will affect the results of the test.

Three minutes after the compressive force is relieved, measure the thickness of the specimen as in 6.1.1.1.

If the testing machine is not equipped with an autographic recorder, plot a compressive force-displacement curve using the force as the ordinate and the displacement as the abscissa.

6.1.2.5.7 Computations. For stress-strain curves, compute the compressive stress in pounds per square inch at various points along each force-displacement curve using the following formula:

$$\text{Stress, } f = \frac{F}{LW} \qquad (6:7)$$

where $\underline{F}$ = force exerted by the testing machine in pounds; $\underline{L}$ = length of specimen in inches; $\underline{W}$ = width of specimen in inches; and $\underline{f}$ = stress applied to cushion.

Compute the strain corresponding to stress by the following formula:

$$\text{Strain, } s = \frac{x}{T} \qquad (6:8)$$

where s = strain resulting from f; $\underline{x}$ = displacement of cushioning material by an object; and $\underline{T}$ = original thickness of cushion.

Plot the stress-strain curve for each specimen with stress as the ordinate and strain as the abscissa.

Compute the compression set in percent after compression testing by the following formula:

$$\text{Compression set (\%)} = \left(\frac{T - T_c}{T}\right)(100) \qquad (6:9)$$

where $\underline{T}$ = original thickness of the specimen; and T_c = thickness of the specimen after compression testing.

6.1.2.5.8 Report. The report should include the following information and results:

a. Date of test and reference to the test procedure.

b. The number of specimens and description of material. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.) , manufacturer's proprietary designation, density (6.1.1.2), test specimen dimensions, and compliance of the material with material specifications, if known.

c. Ambient testing condition and rate of loading.

d. The stress-strain curve for each specimen.

e. A tabulation of the compressive set for each specimen after pre-working.

6.1.2.6 Tensile strength.

6.1.2.6.1 Scope. This procedure is intended for use in checking compliance of the tensile strength of a cushioning material with a minimum strength requirement.

6.1.2.6.2 Apparatus. The following apparatus is used for this test:

Two clamps, as shown in Figure 6-13, having a width equal to or greater than the width of the specimen (usually 3 inches). The clamps shall be designed to exert sufficient uniform pressure to prevent slippage of the specimen during the test.

A testing machine or weights of appropriate size to facilitate application of the specified tensile stress (Figure 6–13).

6.1.2.6.3 Specimens. Unless otherwise specified, the test specimen shall be a strip 4 ± 1/8 inches long, 3 ± 1/8 inches wide, and 1 ± 1/8 inch thick. For thicker materials that cannot be readily reduced to the specified thickness, the closest thickness obtainable may be used and the width of the specimen shall be reduced to produce a cross sectional area of 3 ± 3/8 inches. For materials less than 1 inch thick, sufficient layers shall be stacked to attain the specified thickness. Thickness shall be measured according to 6.1.1.1. For materials with oriented structure or fibers, some specimens shall be cut with length parallel, and an equal number shall be cut with length perpendicular to the direction or orientation.

6.1.2.6.4 Conditioning of test specimens. Unless otherwise specified, the conditioning of test specimens shall be the same as that specified in 6.1.1.1.4. Ambient conditions during testing shall conform to those existing during conditioning.

6.1.2.6.5 Test procedure. The specimen shall be clamped across the 3-inch width of the specimen so that the clamps are at 90° to the specimen's longitudinal axis and 2 ± 1/16 inches apart. One clamp shall be suspended from a stationary support. Sufficient weight (including the weight of the lower clamp) to exert the required stress shall be suspended from the specimen. The required stress shall be based upon the cross–sectional area of the specimen prior to loading. A tensile stress of 1.5 pounds per square inch shall be applied to all cushioning materials except cellulose wadding, which will be subjected to a stress of 0.25 pound per square inch. Exercise care in placing the specimen squarely in the clamps so that the tensile stress will be applied uniformly across the entire cross section of the specimen. Similarly, the weights shall be applied so that no swinging or twisting occurs.

Alternatively, a testing machine may be used to load the specimens as shown in Figure 6-13. The platen applying the load shall move at the rate of 1/2 inch per minute.

6.1.2.6.6 Report. The report should include the following information:

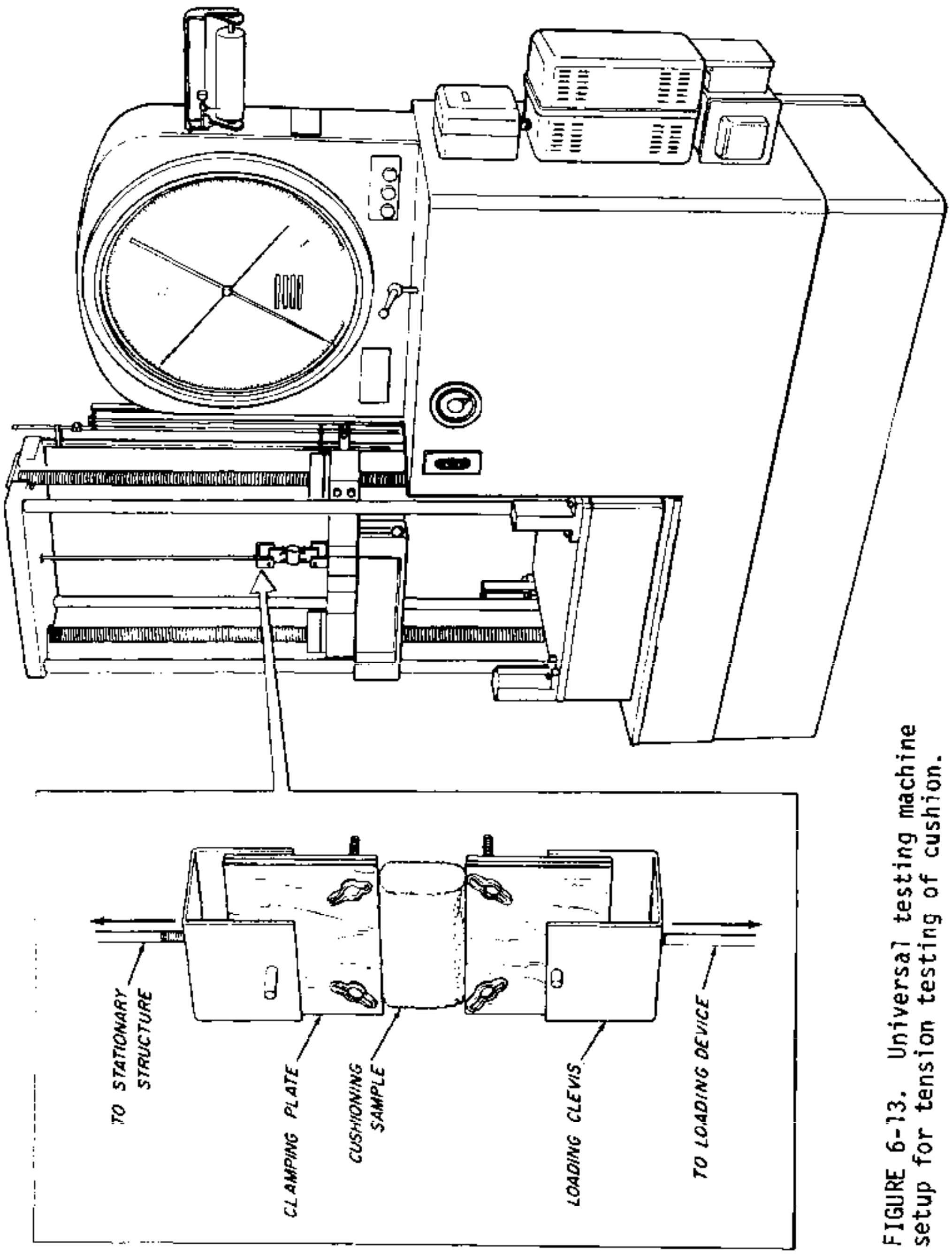


FIGURE 6-13. Universal testing machine setup for tension testing of cushion.

a. Date of test and reference to the test procedure and alternative used.

b. The number of specimens and description of the material, This will include manfacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, density (6.1.1.2), test specimen dimensions, and compliance of the material with material specifications, if known.

c. Details as to whether or not the cushioning material supported the weight. Additionally, describe separation of the plies, occurrence of cracks, or other indications of failure that have been observed.

6.1.2.7 Fragmentation (dusting and breakdown). No generally accepted testing procedure exists for fragmentation testing of cushioning materials. Nevertheless, there is a definite need for one or more suitable test procedures to evaluate the tendency of cushioning materials to liberate fragments (3.2.9). Although several dust tests have been used in various specifications, the following test is recommended because it produces more meaningful and reproducible results.

6.1.2.7.1 Scope. This procedure is intended to measure the dust-forming and fragmentation characteristics of all kinds of commonly used cushioning materials that are provided in either sheet stock or molded form.

6.1.2.7.2 Outline of method. The test consists of placing the cushioning material specimen in a wire basket, placing the basket in a paint pail, and agitating the pail in a paint shaker. A sample of the airborne dust is then withdrawn from the container and the number of dust particles within a fractional sample are counted. Fragmentation or breakdown of the specimen is determined by weighing the fragments of the specimen that fall to the bottom of the pail during agitation.

6.1.2.7.3 Test apparatus and material. The apparatus required for counting the dust particles is essentially the same as that used by the hygiene departments or industrial commissions of all States of the U.S.A. The apparatus (essentially illustrated in Figure 6-14) is as follows:

Weighing balance with sufficient capacity to weigh specimens of approximately 12 grams to the nearest 0.001 gram.

Specimen holder or basket that is 4 X 4 X 3 inches and fabricated of No. 2 mesh, 0.047 inch brass woven wire screen.

Paint pail, one-gallon capacity with a friction cover. The cover of the pail shall have a 1/4 inch diameter hole drilled in its center. The body of the pail shall have a 1/2 inch diameter hold drilled in the side wall centered one inch from the top rim of the pail.

Analytical filter paper to be used for filtering the air coming into the can and filter the distilled water.

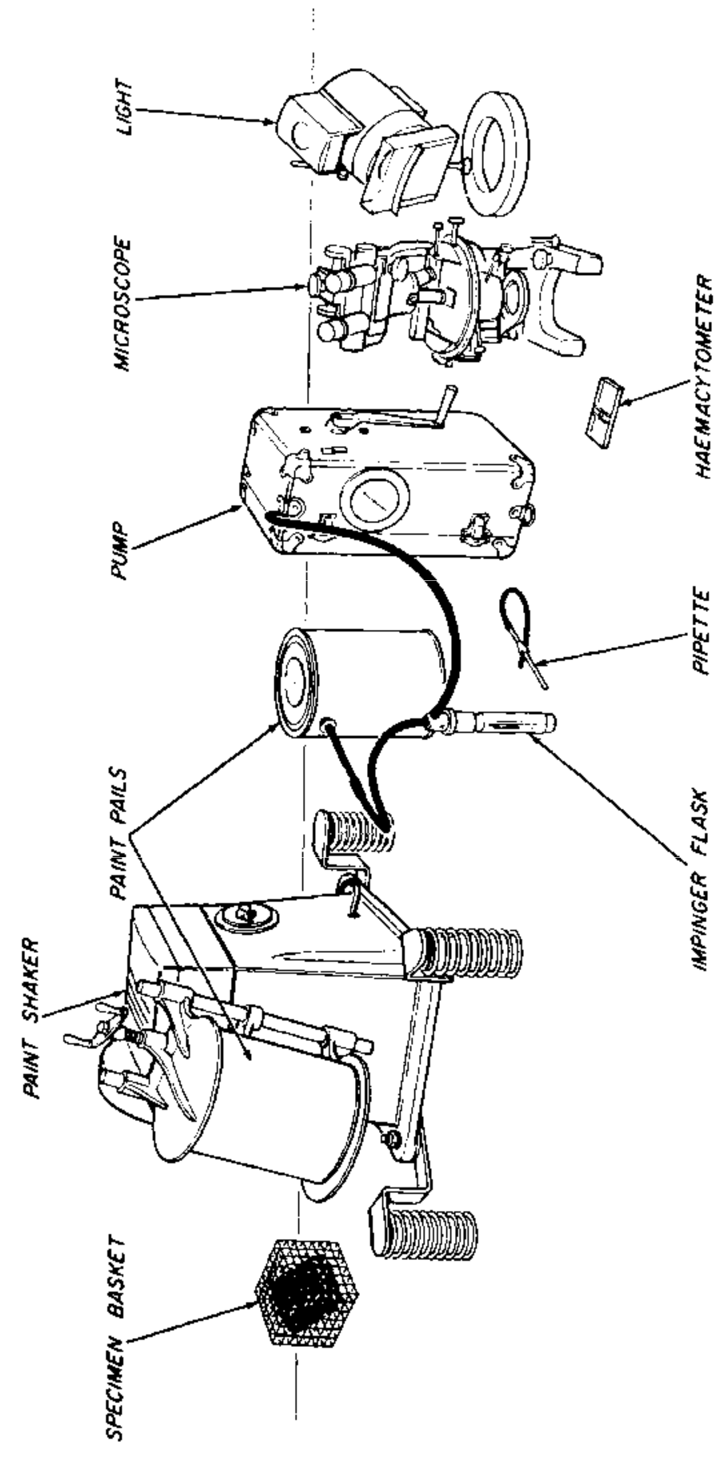


FIGURE 6-14. Apparatus for testing the fragmentation (dusting and breakdown) tendencies of cushioning materials.

Impinger apparatus including a pump, tubing, and flask to be used to collect the dust particles.

A pipette that is suitable to extract the sample of water. This pipette is similar to those used to take blood samples. (Usually such a pipette is provided as an accessory.)

A burker-type Neubauer ruled haemacytometer with cover glass to be used in counting the number of dust particles (Figure 6-15A).

A microscope and light source accessory, capable of 240 or 250 power magnification to be used to count the dust particles in the haemacytometer.

Paint shaker to be used to agitate the specimen.

A supply of distilled water is required to trap the dust particles.

A supply of nonfoaming wetting agent (detergent) to be used in the distilled water to help trap the dust particles.

A supply Of A.C.S. absolute ethanol (C_2H_5OH) or absolute propanol (C_3H_7OH) to be used to clean the parts of the apparatus.

In conducting the test, first clamp the pail in the paint shaker and agitate it for 10 minutes. Then remove the pail and place it in an upright position. Remove the tape from the hole on the pail body and insert the rubber cork with one end of the l/4-inch rubber tube through it. The tube should extend into the pail about 1/4 inch. The other end of the rubber tube shall be attached to the top of the impinger flask. Connect the impringer flask to the impinger pump with the other piece of l/4-inch rubber tubing. Two minutes after the agitation is stopped, deposit the dust in the flask by running the impinger pump for 5 minutes at a vacuum of 12 inches of water. Disconnect the rubber tubes from the flask and shake the flask vigorously for 30 seconds. Withdraw a sample of the liquid containing the dust in the flask, count the number of particles and record the data. This count will be known as the "final dust count (D_f)". Remove the basket from the pail and brush any loose fragments of cushioning material into the pail with a camel's hair brush. Turn the pail on its side with the body hole at the bottom. Brush all of the fragments through the hole onto a piece of paper of known weightThen weigh the paper and the fragments and subtract the weight of the paper to find the weight of the debris. Record the weight of the fragments.

6.1.2.7.7 Computations. Compute fragmentation of the original weight.

$$\text{Fragmentation (\%)} = \left(\frac{W_f}{W_o}\right)(100) \qquad (6:10)$$

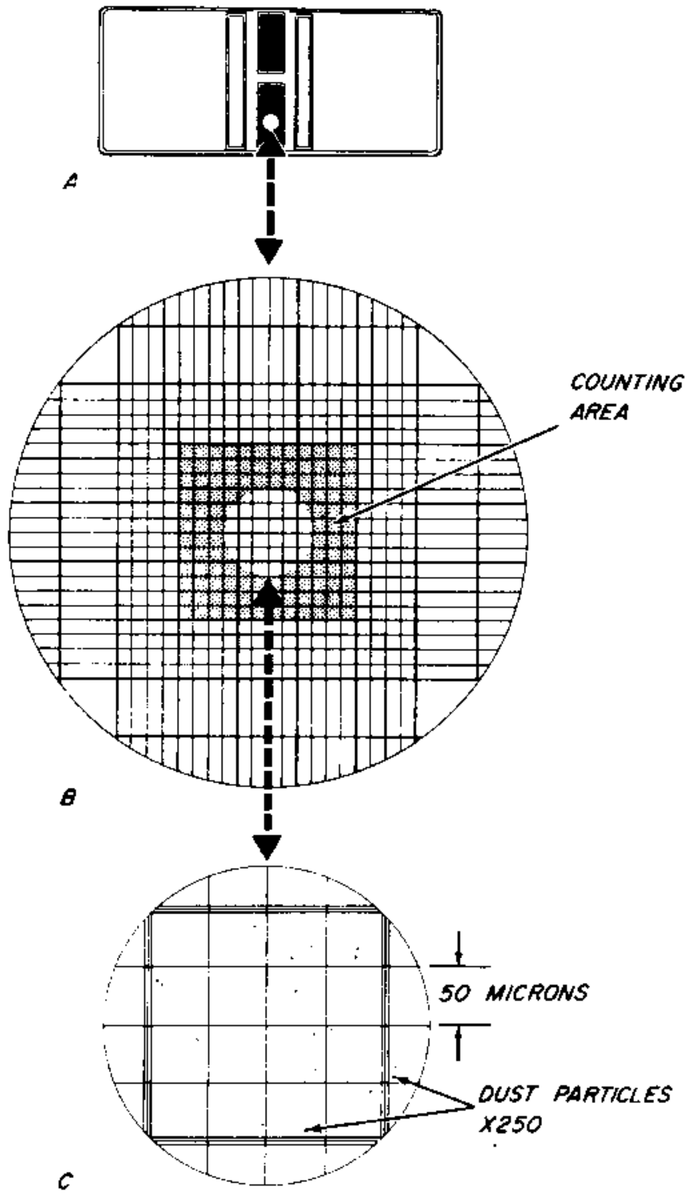


FIGURE 6-15. Operator's view of haemacytometer and portions thereof. A view without magnification; B, view with intermediate magnification: and C, view at 250-power magnification.

where W. = original weight of specimen before testing and after conditioning; W_f = weight of the fragments broken from the specimen by agitation.

Compute the number of dust particles, per area of nine center squares and subtract the original dust count.

$$N_d = D_f - D_o \qquad (6:11)$$

where Do = original dust particle count of the apparatus; Df = final dust particle count after agitation of the specimen; and N_d = number of dust particles for specification rating purposes.

6.1.2.7.8 Report. The report should include the following information and results:

a. Date of test and reference to the test procedure.

b. The number of specimens and a description of the materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, density (6.1.1.2), test specimen dimensions, compliance of the material with material specifications, if known.

c. A tabulation of the number of dust particles per test for each specimen.

d. A tabulation of the percent of fragmentation or breakdown for each specimen.

6.1.2.8 Fungus resistance.

6.1.2.8.1 Scope. This procedure is designed to show whether or not a material is subject to attack by fungi. It is necessary only where the cushioning materials are exposed to high humidities over an extended period. It is accomplished by spraying specimens of the material with a suspension of mixed spores of standard test fungi, and then watching for the presence of fungus growth on the specimens while they are stored under conditions favorable to the growth of fungi.

> CAUTION: The procedure requires all necessary precautions to insure that extraneous sources of available carbon are not permitted to contaminate specimens, inoculum or nutrient-salts agar, upon which specimens and viability controls are incubated.

6.1.2.8.2 Apparatus. The equipment needed includes:

a. Erlenmeyer flasks of 125 and 250 milliliter capacity.

b. Incubation chamber with controlled temperature and in which a relative humidity of 85 percent or more is maintained. A conventional-type research incubator with trays of water on the bottom and on one or more of the upper shelves will be adequate.

c. Autoclave capable of maintaining a steam gage pressure of 15 psi.

d. Atomizer.

e. Glass specimen dishes with covers to permit aeration. Depending on the size of specimens, the following vessels are suggested: (1) for thin specimens up to 2 X 2 inches in dimensions, 90 millimeter covered petri dishes; (2) for larger specimens, use large petri dishes, 16-ounce square bottles, beakers, fruit jars (Figure 6-16), or pyrex baking dishes covered with sheets of window glass.

6.1.2.8.3 Supplies.

The nutrient–salts solution used is a solution of CP grade chemicals in the following proportions:

KH_2PO_4. . . . . . . .0.7 gram	NaC1. . . . . . 0.005 gram
K_2HPO_4. . . . . . . 0.7 gram	$FeSO_4 . 7H_2O$. . . 0.002 gram
$MgSO_4$. . . . . . . 0.7 gram	$ZnSO_4 . 7H_2O$. . . 0.002 gram
NH_4NO_3. . . . . . . .1.0 gram	$MnSO_4 . 7H_2O$. . . 0.001 gram
Distilled water. . 1 liter	

In preparing this solution, the salts shall be added to the entire amount of water to avoid precipitation.

The nutrient-salts agar (a uniform mixture of agar-agar in the nutrient-salts solution proportioned 20 grams of agar to 1 liter of solution) shall be sterilized in the autoclave at 15 pounds steam pressure for 20 minutes. If the pH is below 6.0 or above 6.5, adjust with NaOH or HC1 so that after sterilization the pH falls within these limits.

The following test fungi, unless otherwise specified, shall be used for the mixed spore suspension:

Organism	ATCC NO.	QM NO.
Aspergillus niger	6275	458
Penicillium funiculosum	9644	391
Aspergillus flavus	9643	380
Chaetomium globosum	6205	459
Trichoderma sp.	9645	365

Cultures of the fungi may be obtained from the American Type Culture Collection, 2112 M Street, NW, Washington 7, D.C.; for Service use, fungus cultures may be obtained from the U. S. Army Natick Research and Development

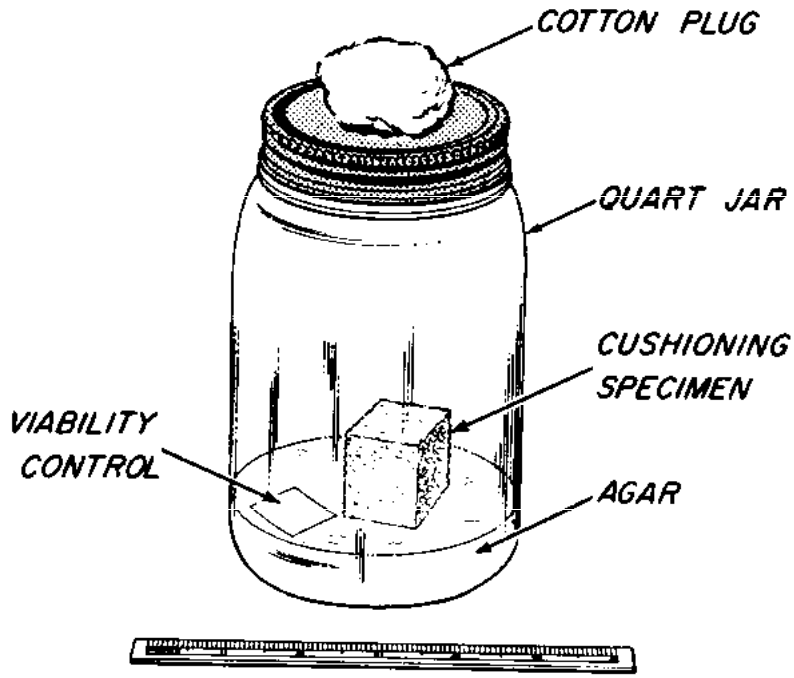


FIGURE 6-16. Fungus resistance test apparatus.

Command, Natick MA.

Cultures of all the above fungi, except *Chaetomium globosum*, shall be maintained separately on potato dextrose agar slants in 16 X 200 millimeter tubes. *Chaetomium globosum* shall be maintained on previously sterilized filter paper strips large enough to cover the surface of nutrient-salts agar slants in 16 X 200 millimeter tubes. The stock cultures may be kept for not more than 4 months at a temperature from 3 to 10°C (37.4 to 50 F).

6.1.2.8.4 *Specimens.* Cushioning specimens shall consist of not less than three representative pieces of the material, large enough to permit visual examination for mold growth. A total surface area of about 10 square inches is usually convenient. All necessary precautions shall be taken to insure that the specimens remain clean and representative of the product for test.

6.1.2.8.5 *Viability controls.* With each group of specimens, a sufficient number of viability controls (not less than three) shall be included in the test to demonstrate the viability of the inoculum. These shall be 1 inch square pieces of sterile filter paper.

6.1.2.8.6 *Conditioning of specimens.* Unless otherwise specified, the specimens require no conditioning and shall be tested without sterilization.

6.1.2.8.7 *Procedure.* Test cultures of each test fungus shall be prepared from stock cultures (6.1.2.8.3).

To prepare the inoculum, first a fungus suspension shall be prepared of each of the five fungi by pouring into each test culture 10 milliliters of a solution containing 0.05 gram of a nontoxic wetting agent, such as sodium dioctyl sulfosuccinate per liter of distilled water. A platinum or nichrome inoculating wire shall then be used to scrape the surface growth gently from the culture of the test organism. The fungus suspension thus obtained shall be combined by pouring all five into one 125 milliliter Erlenmeyer flask containing 10 to 15 solid glass beads, 5 millimeters in diameter. The flask shall be glass stoppered and then shaken vigorously to liberate the spores from the fruiting bodies and to break up spore clumps. The shaken suspension shall then be filtered through a thin layer of glass wool in a glass funnel into a flask in order to remove mycelial fragments. The filtered spore suspension shall then be centrifuged and the liquid discarded. The residue shall be resuspended in about 50 milliliters of distilled water and centrifuged. The combined spores obtained from the fungi shall be washed in this manner three times. The final washed residue shall be suspended in 100 milliliters of nutrient-salts solution (6.1.2.8.3) and used as the inoculum. This inoculum may be prepared fresh each day or may be held in the refrigerator at 3 to 10°C (37.4 to 50 F) for not more than 4 days.

Nutrient-salts agar shall be poured into specimen dishes to provide a solidified layer 1/8 to 1/4 inch in depth. After the agar is solidified, the specimens and viability controls shall be placed on the surface of the agar. Not more than one viability control shall be placed in a dish. Specimens of only one material shall be placed in the same dish and each shall be not less than 1/4 inch from any other specimen in the same dish. By means of the atomizer, the surfaces of the agar, specimens, and viability controls shall be uniformly coated with a heavy fog of the inoculum, using care to avoid wetting to such an extent that droplets run together. The covers shall then be placed promptly on the dishes, and the covered dishes shall be placed in the incubator. The apparatus completely set up is depicted by Figure 6-16.

Incubation shall be in the chamber at a temperature of 28° to 30°C (82.4° to 86°F) and a relative humidity not less than 85 percent. Viability controls shall be examined after 14 days' incubation; if copious fungus growth is not present on all viability controls, the test shall be deemed inconclusive for any specimens on which copious grown does not occur and the test of the products they represent shall be repeated. Incubation shall continue for 28 days unless profuse fungus growth covers the specimens in a shorter period of time.

At the end of the incubation period observe and record for each specimen and each viability control whether or not it nourished the growth of fungus, as indicated by the percent of the specimen's surface covered by growth and the intensity of growth (thin, moderate, or heavy).

6.1.2.8.8 Report. Immediately following each test, the report of the facts pertinent to the test shall be completed and shall include the following:

a. Date of test.

b. A statement that the test was conducted in compliance to this procedure or a description of the deviations from this procedure. Report all options selected and details of otherwise specified procedures that were followed as permitted in paragraph 6.1.2.8.3.

c. Number of specimens and a description of the kind of materials tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation.

When the test is performed to check compliance with requirements, state that the specimen did or did not meet the requirements and give the source for the requirements.

For each specimen, a statement of whether or not the product tested is subject to attack by fungi in this test. (If any portion of the surface was covered by mold growth, the product is subject to attack by fungi,)

NOTE: For determining the effects of fungus attack on cushioning properties, the appropriate tests for the properties should be performed on the specimens before and after the fungus resistance test.

6.1.2.9 Hydrothermal exposure test.

6.1.2.9.1 Scope. This procedure is intended to determine the change in resistance to compression at room temperature of cushioning specimens that are subjected to high humidity and relatively high temperatures over an extended period.

6.1.2.9.2 Apparatus. The apparatus required for this test is as follows:

a. A drying oven or cabinet is required of a suitable size to hold the specimens on the upper shelves and capable of maintaining the required temperature and humidity over an extended period. Generally, 95 ± 5 percent relative humidity can be maintained by placing open vessels of distilled water on the bottom shelf.

b. A balance or scales is required that is suitable for weighing the specimen with an accuracy of ± 0.01 pound.

c. A compression testing machine is required similar to the one in 6.1.2.5.2.

6.1.2.9.3 Specimens. The specimens shall be in accordance with those specified in 6.1.2.5.3.

6.1.2.9.4 Conditioning. Unless otherwise specified, all test specimens shall be conditioned according to 6.1.1.1.4 before testing.

6.1.2.9.5 Test procedure. Ambient atmospheric conditions during pre-working and compressive testing shall conform to those existing during the original conditioning (6.1.2.9.4).

The original thickness, length, and width shall be determined as in 6.1.1.1 and the weight shall be determined by weighing on the balance or scales.

Perform the prework on the specimen as provided in 6.1.2.5.5.

Determine the thickness after preworking as in 6.1.1.1.

Load the specimen in the compression testing machine until the thickness is equal to 50 percent of the thickness after preworking. Record the force that causes this strain and relieve the force on the specimen.

Three minutes after the load has been relieved, measure the thickness of each specimen according to 6.1.1.1.

After compression testing, store all of the specimens for 2 weeks in an oven maintained at 120° ± 2° F and 95 ± 5 percent relative humidity.

Weigh and measure each specimen as in 6.1.1.2.5 and 6.1.1.1. Immediately after removing each specimen from the oven, before weighing or measuring it, wrap it in a sheet of polyethylene or plastic of known weight. Weigh the wrapped specimen, then subtract the weight of the wrap from the total weight to determine the specimen weight.

Condition each specimen as in 6.1.1.1.4.

Load the specimen in the compression testing machine and record the load when compressed to 50 percent of the thickness after preworking and promptly relieve the load.

Remove the specimen from the testing machine and 3 minutes after the compressive force is relieved, measure the thickness of the specimen as in 6.1.1.1.

Remove all water containers that were in the drying oven and place the cushioning specimens in the oven maintained at 214 to 221 F until they come to equilibrium or until two consecutive weighings at least one hour apart do not vary more than 0.02 percent.

Weigh each ovendried specimen.

6.1.2.9.6 Computations. Compute the moisture content for each specimen, based on ovendry weight, before compression testing and after humidification.

$$\text{Moisture content (\%) before testing} = \left(\frac{W_o - W_d}{W_d}\right)(100) \quad (6:12)$$

$$\text{Moisture content (\%) after humidification} = \left(\frac{W_h - W_d}{W_d}\right)(100) \quad (6:13)$$

where W_O = original weight of the specimen after conditioning as in 6.1.1.1.4, W_d = ovendry weight of the specimen and W_h = weight of the specimen immediately after humidification.

Compute the compression set of original thickness, after preworking, after the first compression test, and after the final compression test that follows humidification.

$$\text{Compression set (\%) after preworking} = \left(\frac{T - T_p}{T}\right)(100) \quad (6:14)$$

$$\text{Compression set (\%) after first 50 pct. compression test} = \left(\frac{T - T_i}{T}\right) \quad (6:15)$$

$$\text{Compression set (\%) after final 50 pct. compression test} = \left(\frac{T - T_f}{T}\right) \quad (6:16)$$

where T = original thickness of the specimen after conditioning as in 6.1.l.1.4; T_p = thickness of the specimen after preworking; T_i = thickness of the specimen after the first compression test; and T_f = thickness of the specimen after the final compression test.

Compute the change in resistance to compression of the first compression load at 50 percent deformation.

$$\text{Loss of compression resistance} = \left(\frac{F_o - F_f}{F_o}\right)(100) \qquad (6:17)$$

where F_o = compressive load at a deformation of 50 percent of the thickness after preworking but prior to exposure; and F_f = compressive load at a deformation of 50 percent of the thickness after preworking after exposure.

6.1.2.9.7 Report. The report should include the following information and results:

a. Date of test and reference to the test procedure.

b. The number and description of the specimens and kind of material tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, density (6.1.1.2), test specimen dimensions, and compliance of the material with material specifications, if known.

c. A tabulation listing each specimen, the original moisture content, and the moisture content after humidification.

d. A tabulation listing each specimen with the compression set after preworking, after first compression test, and after the final compression test.

e. A tabulation listing each specimen with the change in resistance to compression.

6.1.2.10 Flexibility of cushioning materials.

6.1.2.10.1 Scope. This procedure is intended to insure that cushioning materials possess sufficient flexibility so that they can be wrapped around corners of items if this is desirable.

6.1.2.10.2 Apparatus. The apparatus required for this test will be a cylinder or mandrel with a diameter three times (±10 percent) of the thickness of the specimen.

6.1.2.10.3 Specimens. Each test specimen shall be a strip of the cushioning material with a length approximately 12 times its thickness and a width one-half its length.

6.1.2.10.4 Conditioning. Room temperature test specimens shall be conditioned as specified in 6.1.1.1.4.

Low temperature test specimens shall be conditioned in a cold temperature chamber of -30° ± 3°F for a period of 4 hours or more preceding the test.

The cylinder used in the test shall be conditioned for at least 1/2 hour immediately preceding the test at the conditions specified for the test specimens.

6.1.2.10.5 Test procedure. The test shall be made by bending the specimen snugly around the mandrel through a total angle of 180 . The specimen shall be-examined for failure while it is in place on the mandrel. Failures such as cracking, delamination, surface spalling, or any other failure shall be noted.

Ambient atmospheric conditions shall be the same during testing as those used during conditioning.

6.1.2.10.6 Report. The report should include the following information:

a. Date of test and reference to the test procedure.

b. The number and description of the specimens and kind of material tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer's proprietary designation, density (6.1.1.2), test specimen dimensions, and compliance of the material with material specifications, if known.

co Statements that the specimen showed "no signs of failure", "cracked", "delaminated" , or any other apparent failure that might indicate weaknesses in the structure of the cushioning material.

6.1.2.11 Hydrogen ion concentration (pH).

6.1.2.11.1 Scope. This procedure is intended for the determination of the hydrogen ion concentration (pH) of cushioning materials.

6.1.2.11.2 Apparatus. The apparatus for this test will be essentially as shown in Figure 6-17 and the following:

a. A balance accurate to 0.001 gram.

b. A 500 milliliter pyrex (or equivalent) Erlenmeyer flask with standard tapered connection.

c. A water-cooled condenser with standard tapered connection.

d. A 400 milliliter pyrex (or equivalent) beaker.

e. A hotplate.

f. A pH meter.

6.1.2.11.3 Test specimens. Five grams of the material, including the glue line if present, shall be cut or shredded so that no dimension exceeds 1/4 inch.

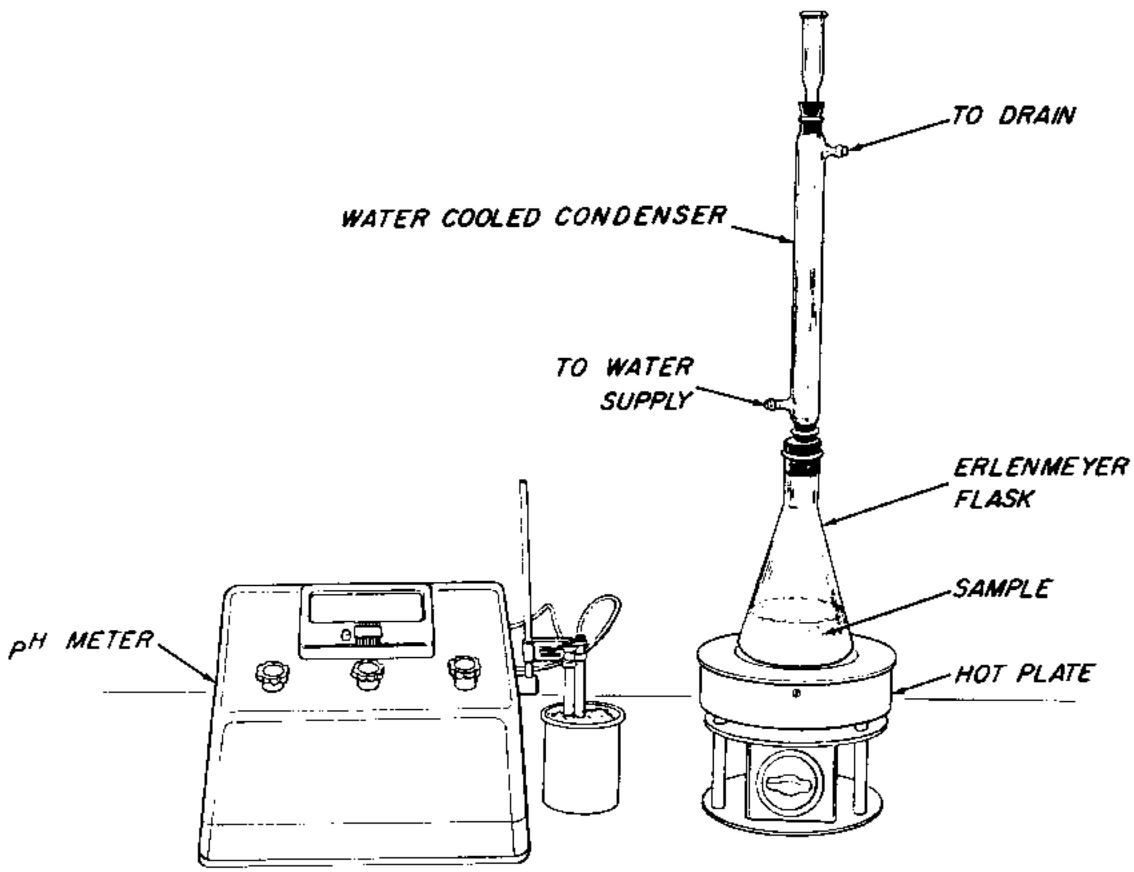


FIGURE 6-17. Hydrogen ion concentration (pH) test apparatus.

6.1.2.11.4 Test procedure. Place an accurately weighed 5 gram portion of air-dry shredded material in a 500 milliliter pyrex Erlenmeyer flask and add 250 milliliters of boiling distilled water. The distilled water shall have a pH of 6.7 to 7.1 when free of carbon dioxide. To avoid the tendency of the material to float, the water shall be added gradually and the flask should be well shaken.

Fit the flask with the water-cooled condenser.

Place the flask and contents on a hotplate and reflux gently for one hour with occasional shaking to insure that all pieces are immersed in the water.

Cool rapidly to room temperature.

Determine the pH with a calibrated pH meter.

6.1.2.11.5 Report. The report should include the following information:

a. Date of test and reference to the test procedure.

b. Description of the number of specimens and kind of material tested. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer’s proprietary designation, density (6.1.1.2), test specimen dimensions, and compliance of the material with material specifications, if known.

c. The average of three determinations of the pH to the nearest 0.1 pH unit.

6.2 GENERAL PRINCIPLES OF INSTRUMENTATION FOR SHOCK MEASUREMENT.

Measurement of shock customarily is made in terms of acceleration experienced by the item. Magnitude of shock is usually expressed in g units, multiples of acceleration due to gravity.

Detailed information on instrumentation may be found in Chapter 12 to 20 of reference (13).

Electrical and electronic instrumentation is necessary to measure impact shock accurately. Any such instrumentation system is composed of three basic elements: The transducer, the required auxiliary equipment, and the recording device. In general, the choice of auxiliary equipment is dictated by the transducer used.

6.2.1 Frequency Response Requirements of Components and Systems.

The instrumentation system must have an overall frequency response adequate to allow the accurate recording and measurement of the acceleration-time pulse. The quality of the system should be such that peak acceleration values can be measured to within ± 5 percent of their actual value. Because acceleration-time pulses are generally transients approximating half-sine, versed-sine or triangular shapes, the range of frequency response necessary for accurate measurement of these transients is greater than would be necessary for continuing sinusoidal waves of the same time period. Often the chief factor limiting frequency response of instrumentation systems is the inherent ability of the mechanical spring-mass elements of the input and output transducers (accelerometers and galvanometers) to respond to higher frequency signals.

As a guide to adequate frequency response for damped transducers, the following rule is recommended: To obtain an accuracy of better than 5 percent of the peak acceleration in measuring acceleration pulses with the general characteristics of triangular or half-sine or versed sine pulses, a transducer damped 0.4 to 0.7 of critical must have a natural period of about one-third or less of the duration of the acceleration pulse (20).

6.2.2 Transducers and Auxiliary Equipment.

A transducer that senses acceleration, called an accelerometer, converts the reaction of a seismic system to acceleration into a proportional electrical signal. Two types of accelerometers, the resistance strain gage type and the piezoelectric type, are commonly used in shock and vibration testing. They differ greatly in principle of operation, characteristics, and required auxiliary equipment, and each type has its own advantages and disadvantages. However, both types are capable of producing accurate and reliable test data.

6.2.2.1 Strain gage accelerometers. The resistance strain gage is basically a length of very fine wire that exhibits a change in resistance proportional to the mechanical strain imposed on it. The strain gage accelerometer consists of a mass so mounted as to produce strain in the gages that is proportional to the accelerating force.

The usable frequency response of strain gage accelerometers extends from zero frequency to several hundred cycles per second. Most strain gage accelerometers employ viscous damping of about 0.7 of critical damping, as this damping ratio produces linear phase shift. Furthermore, at this damping factor, frequency response is essentially linear to about 0.6 of the natural frequency of the instrument.

Since the resistance strain gage is a passive device, an external power source is needed. Either alternating or direct current power may be used, but DC sources are preferred because the use of AC excitation restricts the upper frequency limit of the accelerometer to about one-tenth of the power frequency.

The output signal level of strain gage accelerometers is low and some form of amplification is needed to raise the signal levels to that required by recording devices.

Either AC or DC amplifiers may be used but the use of DC amplifiers is recommended to preserve the zero frequency response that is one of the chief advantages of the strain gage accelerometer.

Output impedances are low and relatively long cables may be used from the accelerometer without introducing problems of signal loss or interference pickup. A typical system using a resistance strain gage accelerometer is diagrammed in Figure 6-18.

6.2.2.2 Piezoelectric accelerometers. Piezoelectric accelerometers employ small pieces of piezoelectric material, such as barium titanate or lead zirconate, as the sensing element. When subjected to mechanical stress or acceleration, this material generates an electric charge that is proportional to the applied force or acceleration.

The output signals are relatively large and the transducers can be made very small and lightweight. The natural frequency of the accelerometer may be on the order of 50 Hz with essentially linear frequency response to about one-fifth of the natural frequency.

Since the piezoelectric accelerometer is self–generating, no external power source is needed. Because of this, however, no output signal is possible at zero frequency because no energy is being supplied. The piezoelectric accelerometer has a high capacitive internal impedance. This capacitance and the input resistance of the circuit to which it is connected establishes an RC time constant that limits the low frequency response of the accelerometer. When the time constant is small and the duration of the pulse is sufficiently large, a portion of the generated charge may leak off before the pulse is completed. Therefore, the accuracy of peak acceleration measurements is dependent on the ratio of the time constant to the pulse length. A small time constant is indicated by a “negative overshoot” as shown in Figure 6-19. Therefore, as the overshoot increases, the error between the apparent peak acceleration and the actual peak acceleration increases. A more complete discussion of the response characteristics of piezoelectric accelerometer may be found in (8). Greater time constants may be obtained by the use of high impedance matching circuits, usually of the cathode follower type. The cathode follower should have an input impedance of at least 100 megohms. When this condition is met, the low frequency response should extend to between 2 and 10 Hz.

The high output impedance also makes cable length and quality of importance. The length of the cable from the accelerometer to the cathode follower usually is limited to a few feet.

One instrumentation system using a piezoelectric accelerometer is diagramed in Figure 6-20.

6.2.2.2.2 Solid State Charge Amplifiers. The development of solid state charge amplifiers has further increased the simplicity and reliability of piezoelectric accelerometer systems. The accelerometer is connected directly

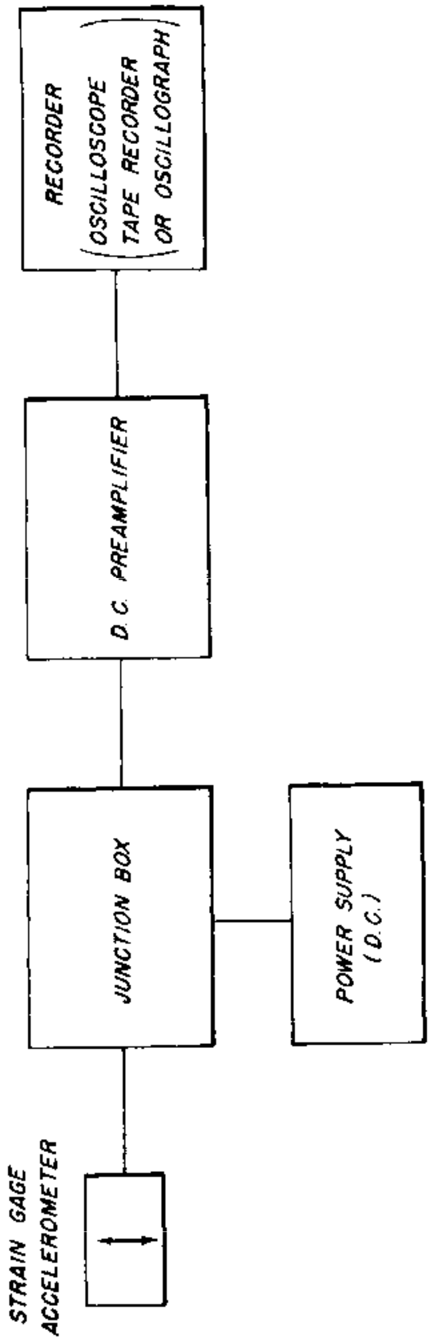


FIGURE 6-18. Typical recording system employing a strain gage accelerometer.

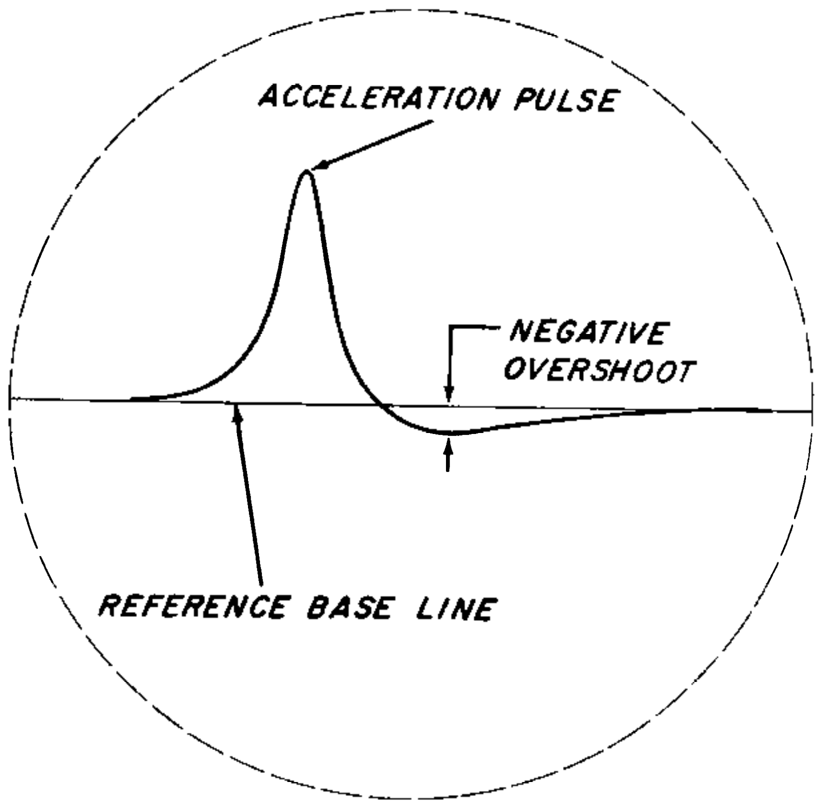


FIGURE 6-19. Negative “overshoot” on acceleration-time record obtained with piezoelectric accelerometer.

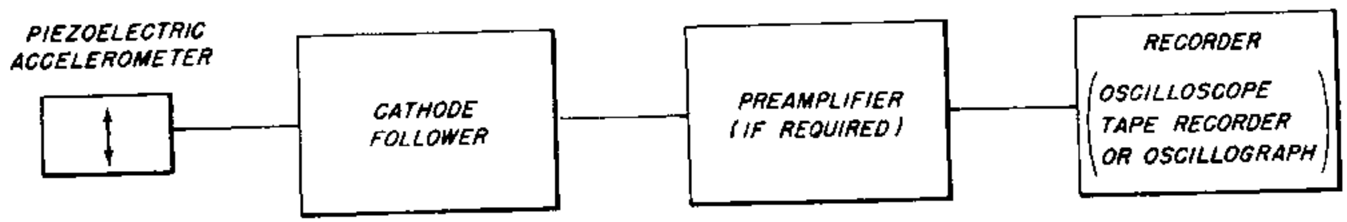


FIGURE 6-20. Typical recording system employing a piezoelectric accelerometer.

to the charge amplifier which is driven by an external power supply of approximately 30 VDC output. The input signal is applied to a field effect transistor (FET) which provides a high impedance input. The signal is then amplified and output to a recording device.

The basic difference between the charge amplifier and the cathode follower is that the charge amplifier in effect converts the input charge (from the piezoelectric accelerometer) to an output voltage which is directly proportional to the charge. The advantages of this sytem are better frequency response (2 to 1000 Hz), a range of several output sensitivities and a signal level which is essentially independent of cable length. Some models also include a variable filter system to further increase the signal-to-noise ratio.

6.2.3 Recording Devices.

Many types of recording devices are available but only a few are suitable for recording the short period transient signals encountered in shock testing. Suitable types include the cathode ray oscilloscopes, magnetic tape recorders and some galvanometer-type recorders.

6.2.3.1 Cathode Ray Oscilloscopes. The cathode ray oscilloscope is well suited for this recording. Since the only moving element is an almost massless electron beam, the frequency response of an oscilloscope is limited only by its electronic amplifier circuits and greatly exceeds the requirements. The oscilloscope may be adjusted for single sweep operation and thus a single transient event may be recorded. One particular type of oscilloscope, the storage oscilloscope, has the ability to retain a trace image for as long as desired. Permanent recording is usually desired and may be easily accomplished by photographing the trace with a Polaroid camera which presents a developed record in seconds. The oscilloscope is basically a single channel device but two or more channels may be obtained by the use of multigun cathode ray tubes or by electronic switching of a single beam.

6.2.3.2 Magnetic tape recorders. Magnetic tape recorders have many desirable features but their high cost and complexity often prohibits their use. Only this type of recorder records the data in a form that may be reproduced by electronic systems for further analysis. Frequency response is very good and many channels of information may be recorded simultaneously. Visual reproduction may be obtained by replaying the tape-recorded signal into some other type of recorder. The time base may be altered as desired by replaying at a different speed, and thus recorders with limited frequency response may be used when the tape is replayed at a slow speed.

6.2.3.3 Galvanometer-type recorders. Galvanometer-type recorders using a light beam as the moving writing element may be suitable if their frequency response characteristics are adequate. Some have good frequency response extending to 5,000 Hz.

6.2.3.4 Other types of recorders. Level recorders and pen recorders are generally deficient in frequency response characteristics due to the inertial effects of their mechanical elements and, therefore, are not generally suitable for this use.

6.2.4 Calibration.

The probable limits of accuracy of the components of an instrumentation system can be estimated from the information given here and from manufacturers' specifications and calibration data. However, empirical calibration testing is needed to establish the calibration sensitivity of the overall system initially and to assure that accurate calibration is maintained during subsequent use.

Although empirical calibration testing of complete recording systems at the test site is strongly recommended, a minimal safeguard against gross calibration error would be periodic calibration of the accelerometer by the manufacturer ((l), (10), (21)).

6.2.5 Summary of Requirements for Instrumentation.

The entire instrumentation system should be capable of accurately reproducing complex signals associated with shock. To accomplish this objective to a reasonable degree, a linear frequency response from near zero frequency to at least several hundred cycles per second is needed. Phase shift should either be zero or linear with frequency. The better the overall response characteristics of the entire system, the more accurately the input signal will be reproduced. The calibration of the recording systems should be checked periodically to prevent data recording errors.

6.3 IMPACT TESTING OF INSTRUMENTED COMPLETE PACKAGES.

6.3.1 Scope.

This section is intended to present methods of instrumentation and data analysis to be used in conjunction with the impact tests of instrumented complete packages required by various specifications. A discussion of general instrumentation principles is given in Section 6.2 and detailed information on instrumentation may be found in Chapters 12 to 20 of (13).

The purpose of this method of testing is to determine the ability of a package to protect a packaged item from shock damage and to determine the magnitude and characteristics of the shocks received by the packaged item when subjected to impact tests that simulate service conditions. A knowledge of the ability of a package to provide shock protection plus the knowledge of the fragility rating of an item will permit the packaging engineer to design or choose the proper packaging for the item.

As explained in Section 2.2, the fragility of an item is expressed in terms of the shock experienced by the base structure of the item. Ideally, a packaged item may be one which is considered to be a rigid homogeneous body having high damping and which experiences a uniform level of shock throughout its structure. In reality, most items will have a more complex response to a shock input with different portions of the item experiencing different levels of shock. Therefore, measurement of the primary shock input must be made on the rigid base structure of an item or on a rigid base attached to the item for this purpose. If this is not practicable, such shock measurements should be made on a simulated test item.

6.3.2 Outline of Test Method.

An actual or simulated test item is instrumented and packed in the test container and the test container is then subjected to the desired impact test conditions. The acceleration-time pulse received by the item is recorded by the use of accelerometers and associated electronic equipment. These data are then analyzed and the magnitude of the shock transmitted by the package to the item is determined.

6.3.3 Measurement of Displacement.

The relative displacement of an item within a package might be of significance, if the displacement is large enough to allow projections of the item to contact the outer container, as described in Section 4.3. If this occurs, the package cushioning is no longer effective and excessive shocks may be transmitted to the item. Measurement may be made with sufficient accuracy by simple mechanical methods, such as, the deformation of a small block of putty or by the penetration of a pin in a small block of soft material such as lead or balsa wood. The energy used in such methods must be kept small to avoid influencing the cushioning characteristics of the package.

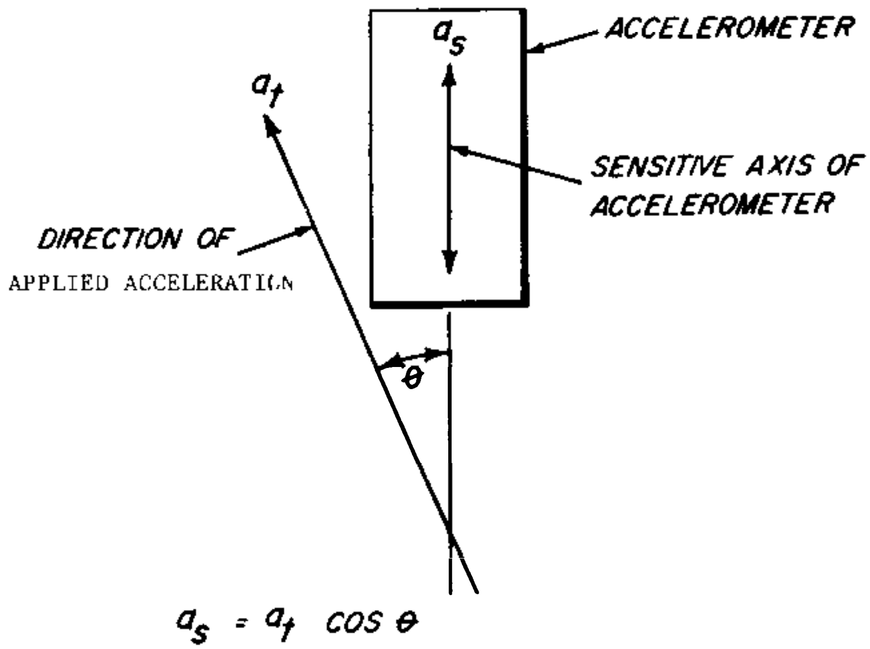
6.3.4 Transducer Mounting Considerations.

The accuracy and usefulness of the data are directly affected by the method of mounting and the positioning of the transducers on the test item. As a general rule, the accelerometer should be mounted as close to the center of gravity of the test item as possible with its sensitive axis on a plane that passes through the center of gravity and directly in line with the applied force.

6.3.4.1 Use of a single accelerometer. Acceleration is a vector quantity which has both magnitude and direction but accelerometers are uniaxial sensing devices. Therefore, a single accelerometer should be used only if the direction of the applied shock is controllable and known so that the sensitive axis of the accelerometer may be aligned in the direction of the applied shock. Some amount of misalignment is tolerable, as the errors produced by small angles of misalignment are very small. The component of acceleration sensed by the accelerometer is:

$$a_s = a_t \cos \theta \qquad (6:18)$$

where at = total acceleration; θ = angle of misalignment in degrees; and as = acceleration sensed by the accelerometer as shown in Figure 6-21. A table of cosines of angles given in Figure 6-21 shows that for small angles the



1	0.99985
2	0.99939
3	0.99863
4	0.99756
5	0.99619
6	0.99452
7	0.99255
8	0.99027
9	0.98769
10	0.98481
11	0.98163
12	0.97815

FIGURE 6-21. Vector diagram and cosine table indicating effects of accelerometer misalignment.

difference between as and at will be small.

6.3.4.2 Use of three mutually perpendicular accelerometers. In most container testing situations, the direction of the impact is not completely controllable or accurately known. When this situation exists. measurement of acceleration must be made on three mutually perpendicular axes, and the magnitude of the actual acceleration is determined by the vector summation of these three components. Further discussion of this procedure is given in 6.3.8.

The three accelerometers should be mounted on a common rigid mounting block as close together as possible with their sensitive axes on three mutually perpendicular planes which pass through a common point as shown in Figure 6-22. This mounting block should be firmly attached to the basic rigid structure of the item as close to the center of gravity of the item as possible. The farther the accelerometers are from the center of gravity of the item, the less representative the measured accelerations will be of the shock experienced by the packaged item as a unit. This is due to components of acceleration produced by rotation of the test item.

6.3.4.3 Special mounting problems. The nature of some test items might cause difficulty in mounting of transducers. Some of these mounting problems can be overcome by attaching a rigid mounting plate to the test item and mounting the transducers on this plate. At other times, the item might be blocked in a rigid inner container and transducers attached to this container. Transducer mounting techniques are discussed in more detail in (5).

6.3.5 Construction of Simulated Test Items.

Occasionally, because of prohibitive cost or unavailability of test items or because of difficulty associated with proper mounting of the transducers on the item, it may be inadvisable to test actual items. Therefore, a simulated test item must be constructed which has the same size and density characteristics as the actual item. The materials used should be stiff and rigidly fastened together so that the shocks recorded by the transducers are the same as the shocks experienced by the main structure of the actual item. Proper size and density characteristics may be obtained by using combinations of material of different densities. Wood has frequently been found to be a desirable material for use in simulated test items.

It is desirable to construct the simulated test item so that it has the same center of gravity as the actual item and to mount the transducers at this location. When a generalized test item is to be used for comparative tests of containers or cushioning materials and methods, a symmetrical form such as shown in Figure 6-23 is most desirable.

6.3.6 Orientation and Numbering of Package and Item.

The surfaces of the test container and the test item should be identified by a standard system of notation such as used in ASTM procedure D 775 (2). The position of the accelerometers and the orientation of the container with

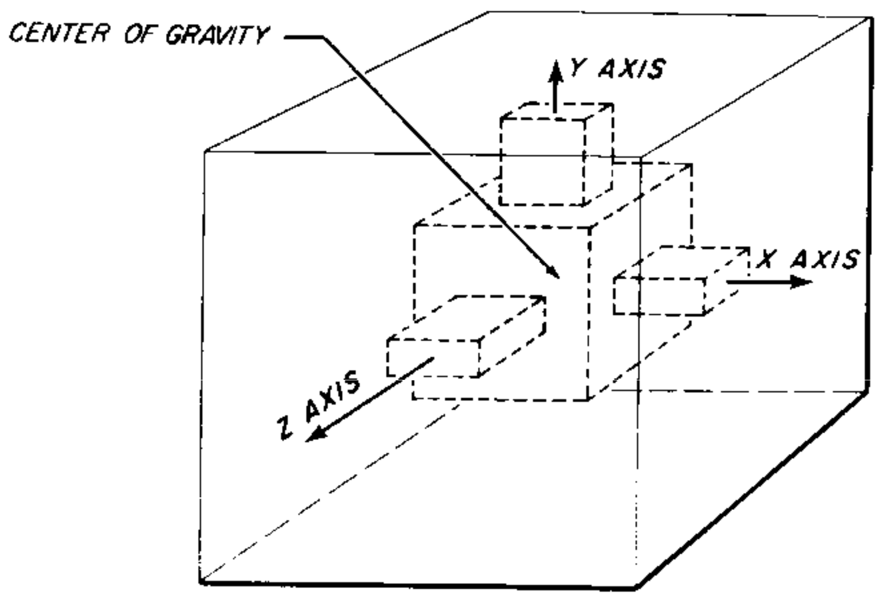


FIGURE 6-22. Recommended triaxial acceler. ometer mounting technique.

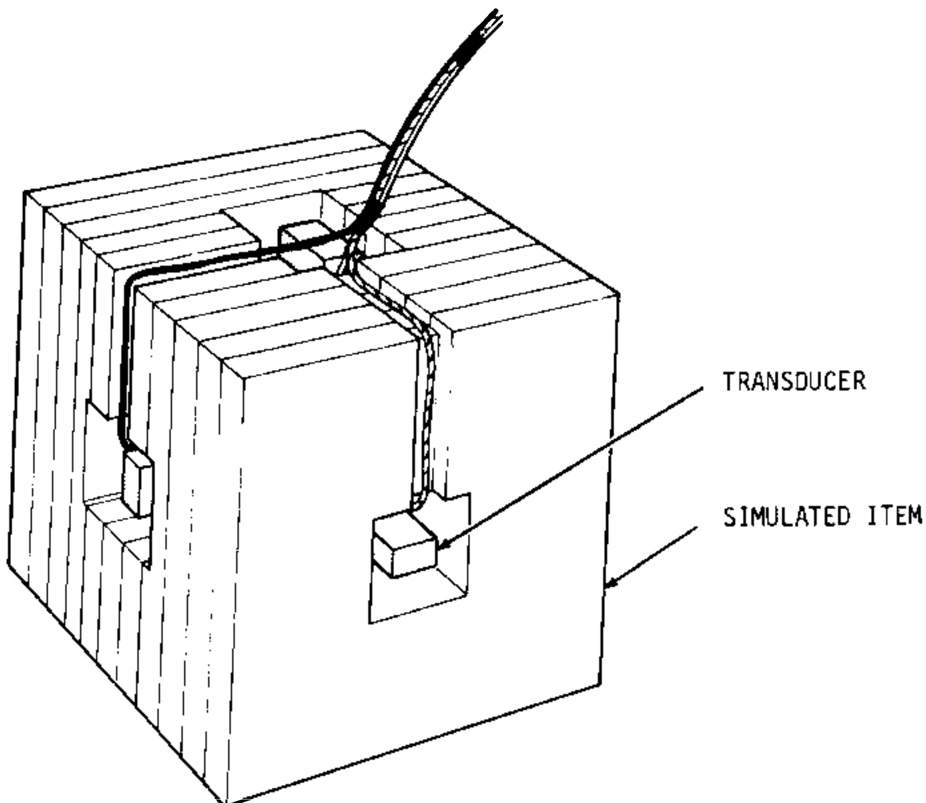


FIGURE 6-23. Accelerometer mounting technique for commonly used simulated test item.

respect to this identification system should be recorded for each test.

6.3.7 Instrumentation Requirements for Complete Package Testing. The general principles and requirements for shock measurement as discussed in Section 6.2 apply to complete package testing. In addition to these requirements, a number of special requirements must be considered.

Frequency response requirements for measurement of peak acceleration values are given in Section 6.2.1. Since in complete package testing the entire acceleration–time response must be analyzed, frequency response requirements are more stringent than for determination of peak acceleration alone. In general, the better the overall response characteristics of the instrumentation system, the more accurately the entire acceleration-time response will be reproduced.

While it is considered inadvisable to specify exact frequency response requirements here, a uniform frequency response extending from almost zero frequency to about 1,000 cycles per second is suggested as a reasonable minimum response characteristic.

Another important requirement for complete package testing is that three (or more) data recording channels must be operated simultaneously. All channels should be identical so that phase or time differences do not exist between channels. The recorder should be a multichannel type employing a common recording medium to maintain proper time relationships between channels.

A diagrammatic sketch of an instrumentation system for complete package testing depicting the relationship between channels is shown in Figure 6-24.

6.3.8 Analysis of Data.

Because acceleration is a vector quantity and since the direction of accelerations experienced in container tests are not known, the magnitudes cannot be measured directly. However, the magnitude can be determined by the vector addition of three components whose magnitudes and direction are known. These three components are measured by accelerometers whose sensitive axes are mounted 90 from each other, along axes, x, y, and z as shown in Figure 6-24. The magnitude of the vector sum of these accelerations is determined by the equation:

$$a_r = \sqrt{a_x^2 + a_y^2 + a_z^2} \qquad (6:19)$$

Peak acceleration will not necessarily occur along all axes at the same instant of time and the peak resultant acceleration may or may not coincide with peak values of any of the components. Therefore, it is necessary to analyze the data point by point along the common time base to determine resultant peak acceleration. A typical test record with the dashed lines indicating the difference in time at which peak acceleration values occur is shown in Figure 6-25.

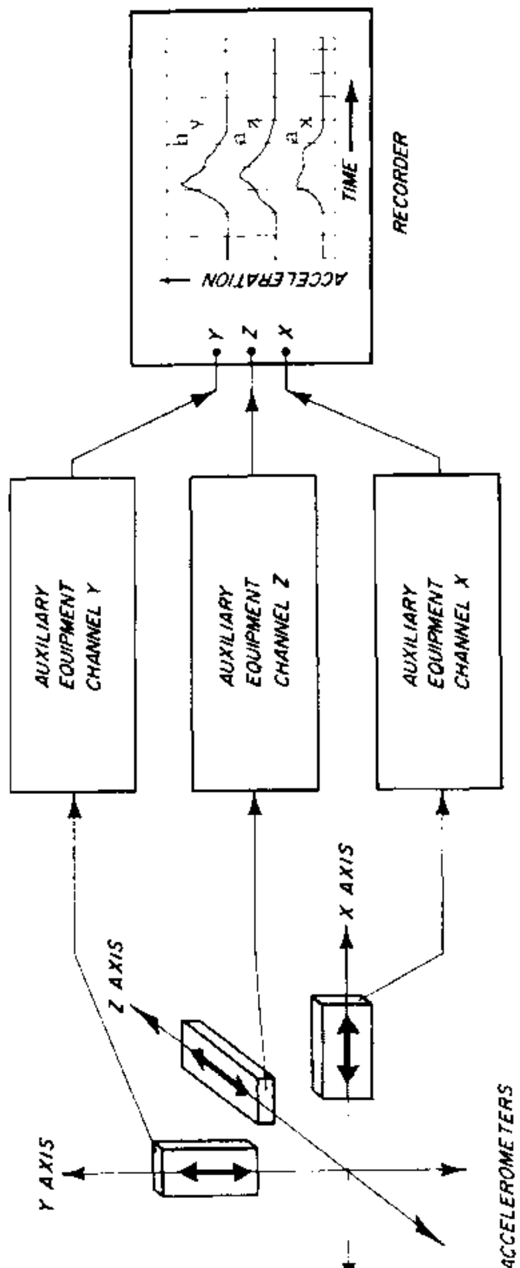


FIGURE 6-24. Diagrammatic sketch of triaxial recording system.

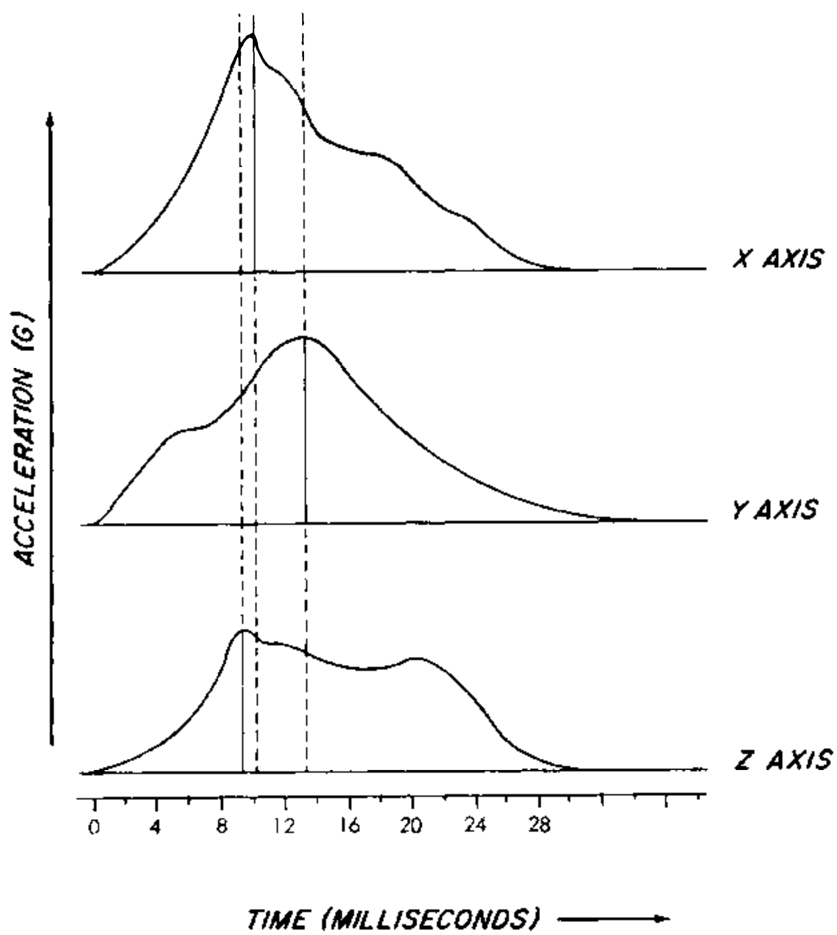


FIGURE 6-25. Typical test record for instrumented container impact test.

Test of Corrugated Fiberboard Container No. 4 Date 18 April 1974

Test Condition 24″ Corner Drop Time 2:00 PM

Package Orientation Corner 5-3-4 -Impacted By B. H. Dye

TIME (Ms)	a_x (G)	a_y (G)	a_z (G)	Resultant * a_r (G)
6	7.2	6.5	3.6	11.45
8	11.9	7.6	7.1	15.78
a_z peak	15.7	9.2	10.1	20.81
10	16.9	10.2	9.4	21.86
a_x peak	17.1	10.4	9.2	22.02
12	14.2	12.9	9.2	21.19
a_y peak	11.2	13.5	8.3	19.36
14	9.8	13.1	7.8	18.11
16	8.5	10.6	7.4	15.46
18	8.3	8.1	7.4	13.75
20	6.5	6.0	7.8	11.79

* Resultant $(a_r) = \sqrt{a_x^2 + a_y^2 + a_z^2}$

FIGURE 6-26. Sample data analysis computation sheet for one instrumented container drop test.

The acceleration along each axis at each time instant is determined by multiplying the corresponding recorded pulse height by the calibration factor of that recording channel. The resulting information may be most easily compiled in a table as shown in Figure 6-26 and from this data the maximum shock experienced by the packaged item can be determined.

6.4 FRAGILITY TESTING.

6.4.1 Scope.

At present, no single generally accepted fragility testing procedure exists. The principal cause for disagreement on this subject is that the nature of how items fail when subjected to different shock pulses is complex. Consequently, various individuals, depending upon their background and resources, advocate different concepts, equipment, and testing procedures for obtaining fragility ratings for items.

The procedures described herein are recommended for determination of item fragility ratings that are usable with the design methods for shock protection described in 3.2.1. While the two variations of the same general fragility procedure (Method A, 6.4.3, and Method B, 6.4.4) that are specified herein differ somewhat, either of the methods should produce fragility ratings that are consistent with the degree of precision obtainable in cushioning design. The principal differences between Methods A and B involve the equipment and techniques used for application of the pulses. It is probable that of the two procedures, more exact control and reproducibility of test results are obtainable by the use of Method A.

Method A requires the use of standard programmable shock testing machines. Packaging engineers who have more limited access to various kinds of testing equipment might prefer to conduct fragility rating tests according to Method B for expediency.

6.4.2 Effects of Shock Pulse Shapes.

The objective of the fragility test methods described herein is to determine by laboratory test methods the maximum acceleration that any specific item can sustain during shipment before damage will occur. Various investigators have indicated that the response of simple or complex items to shocks is dependent upon acceleration wave forms as well as the maximum amplitude (29) (38). Therefore, in order to minimize discrepancies between damaging acceleration levels received by items during shipment and fragility ratings obtained by laboratory tests, the effects of pulse shape must be considered in fragility testing procedures. Although they employ basically different methods, both Methods A and B of this procedure incorporate pulse shape effects in fragility rating.

6.4.2.1 Characteristics of shock pulse received by cushioned package items. Shocks received by items during shipment are those applied by the cushioning materials as a result of rough handling of the package. The time duration of most acceleration-time pulses that cushioned packaged items receive because of dropping from heights of 18 to 36 inches range from 10 to 40 milliseconds. Most of these pulses are asymmetrical or complex in form. However, many generally resemble simple half-sine or triangular pulses.

6.4.2.2 The Use of "Damage Boundary" Theory in Item Fragility Testing.

The Damage Boundary concept of fragility determination advanced by Newton (26) is based on a rectangular waveform shock pulse. This pulse is used to approximate the complex waveforms seen by the item during impact. A rectangular waveform consists of all frequencies, thus insuring that any resonant frequency of the item will be excited during the test impact. In this method, it is recognized that item damage is not only a function of peak acceleration but also of the velocity change (algebraic sum of the impact and rebound velocities) associated with the shock of impact. In the case of a rectangular peak acceleration versus time pulse, the velocity change is equal to the peak acceleration times the duration.

The generalized "damage boundary", depicted graphically in Figure 6-27, can be defined for any particular item through testing of the item on a programmable shock machine. A minimum of two test points are required to establish the horizontal and vertical portions of the damage boundary curve. For a rectangular wave form shock pulse the intersection of the horizontal and vertical boundary lines establish the critical velocity change value. The horizontal section of the curve in Figure 6-27 shows that for velocity change values greater than the critical value, the item will fail at some constant minimum acceleration value. At velocity change values less than the critical value, the vertical section of the curve indicates that the item will not fail, regardless of the magnitude of the acceleration. Combinations of acceleration and velocity change values falling within the shaded region of Figure 6-27 will result in damage to the item. For a more complete understanding of this method, see Newton (26) and Kipp (16). Reference (37) by Venetos describes a practical application of this method.

6.4.3 Method A.

The test procedure involves application of a series of shocks to the item beginning with relatively low peak acceleration, long duration pulses, then high peak acceleration, short duration pulse as described in 6.4.3.3.1 until the item fails. Various shock testing machines are used to apply shocks to the item. The severity and nature of shocks are expressed in terms of peak acceleration and velocity change as described by Figure 6-27.

6.4.3.1 Test items. The test items are the items to be packaged and shipped. As explained in Section 2.2, the fragility rating of any specific item must be based upon the maximum acceleration of the relatively rigid basic structure of the item as distinguished from localized acceleration of relatively flexible elements. In those instances where none of the accessible portions of items are relatively rigid, the item should be enclosed and blocked inside a rigid container and acceleration measurements should be referred to the container. However, in many instances, it will only be

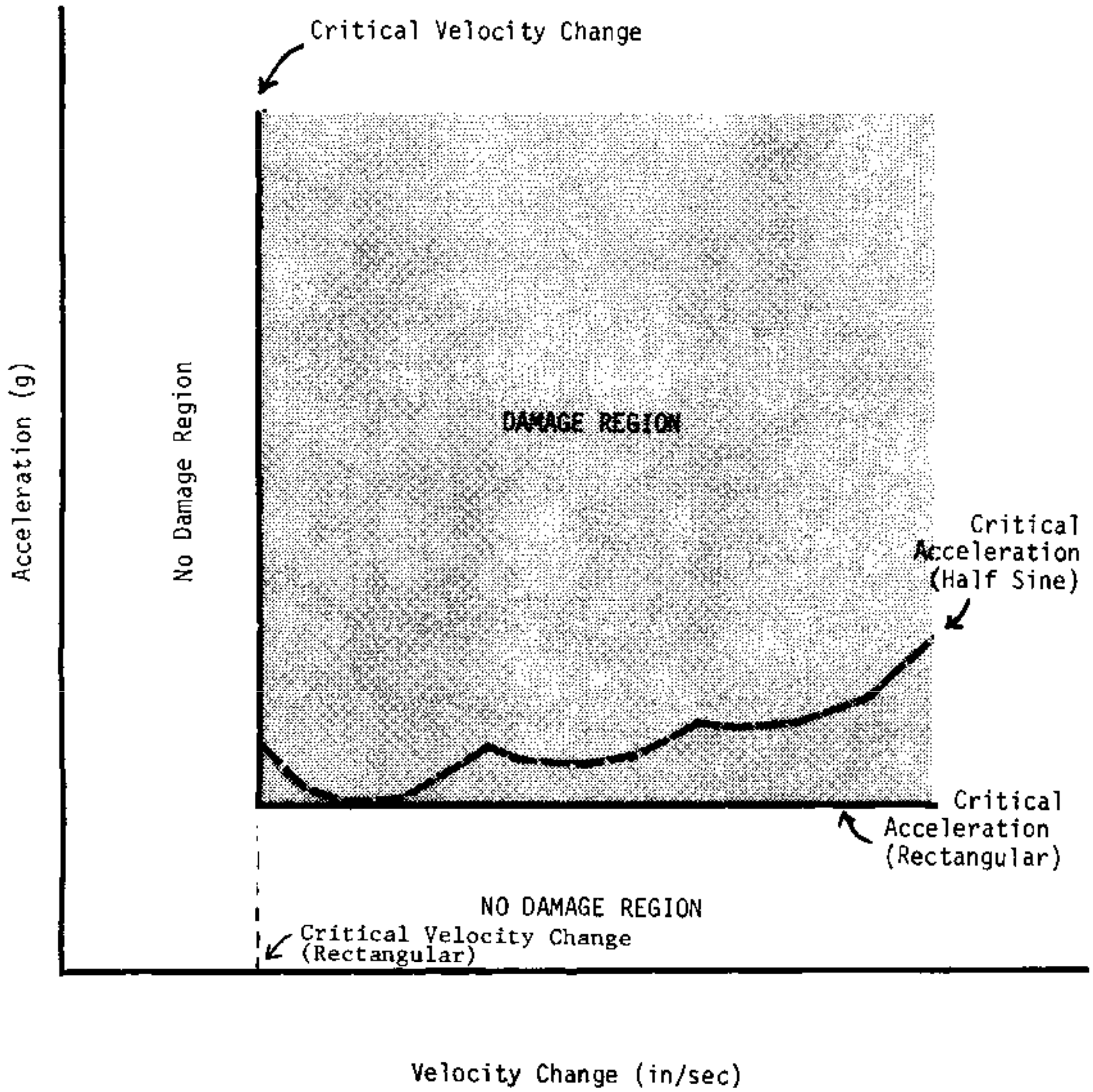


FIGURE 6-27. "Damage Boundary" curve used in fragility testing.

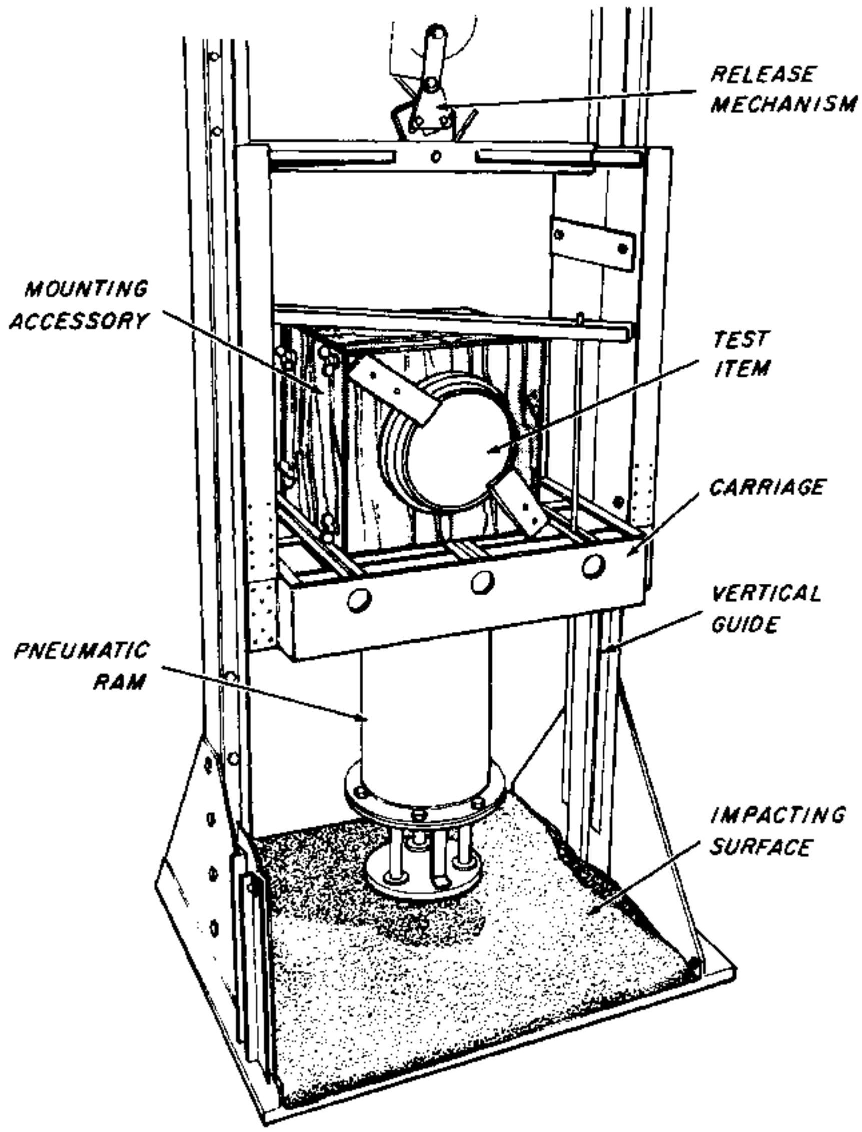


FIGURE 6-28. Shock testing machine employing pneumatic ram.

necessary to attach a rigid platen (of plywood of sufficient thickness) with provisions for mounting accelerometers along different axes of sensitivity, if necessary, to a substantial portion of the item. Accordingly, acceleration values recorded by the attached accelerometer will represent acceleration of the item proper, instead of that of localized flexible elements.

Since the construction of different kinds of items varies widely, the number of specimens that should be tested in order to obtain a valid rating for a group of items of any particular kind must vary. However, it is recognized that while repetitive testing of similar items is highly desirable, it might sometimes be too expensive. Choice of the number of items to test is left, therefore, to the discretion of the testing engineer.

6.4.3.2 Apparatus.

6.4.3.2.1 Shock testing machines. Various types of shock testing machines may be used. Some of the different types that have been used satisfactorily are discussed briefly in the following:

6.4.3.2.1.1 Pneumatic ram type. The pneumatic ram-type shock testing machine shown in Figure 6-28 consists of a metal carriage approximately 2 feet square on which the equipment or component is mounted. The table is guided during vertical motion by eight steel rollers that follow two vertical steel posts. The table is raised by hand or power-driven hoist. The wire rope which is used for raising the table passes over pulleys mounted at the top of the framework and down to the winch. A magnetically operated release connects the rope and carriage.

A pneumatic ram, mounted on the underside of the table, acts as a retardation pad or cushioning. The ram consists of a cylinder and piston. Air is exhausted from (and supplied to) the cylinder through a Schrader valve. The intensity of the shock can be varied over a wide range by controlling the amount of air within the cylinder.

This type of shock testing machine will provide peak applied acceleration in the range of 5 to 90 G with duration times in the range of 10 to 50 milliseconds with variation of drop heights from 12 to 54 inches and table loads up to 100 pounds (29).

6.4.3.2.1.2 Programmable Shock Testing Machines.

The programmable shock testing machine, as described in Figure 6-29, is a modification of the pneumatic ram-type machine previously discussed. The shock table (carriage) rides on close-tolerance bearings and includes a pneumatic braking system to prevent repeated shocks. The pulse shapes are controlled by programmers which are classified by the kind of shock they produce. In general, rectangular pulses are produced by pneumatic cylinders with elastomeric impact surfaces, while the shorter half-sine wave pulses are produced by high density plastic cylinders or rigidly mounted elastomeric pads.

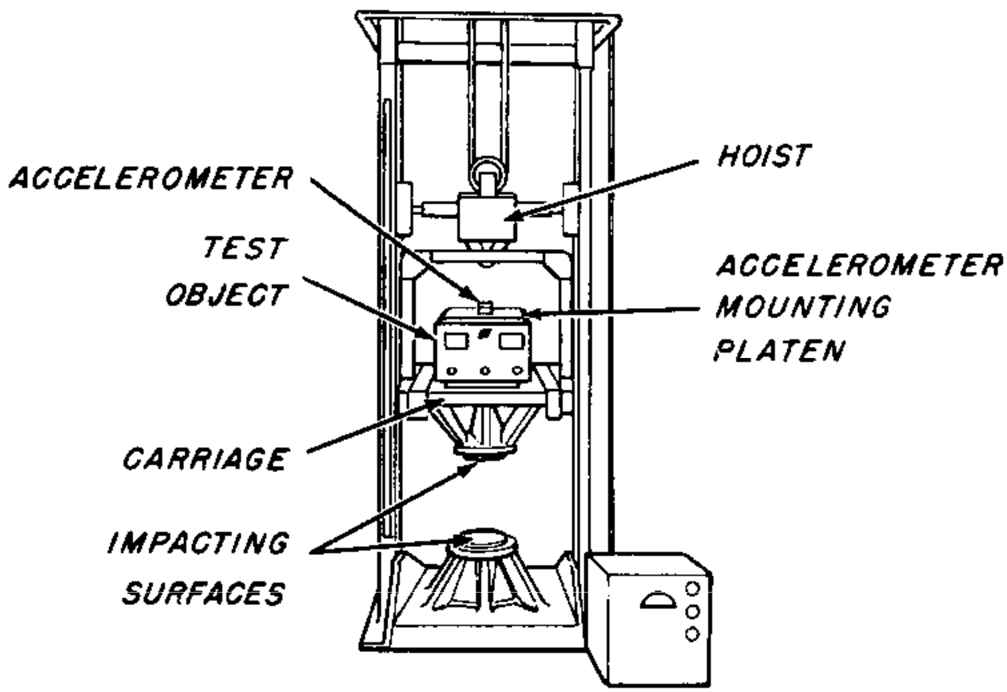


FIGURE 6-29. Shock testing machine employing programmers on the impacting surfaces to produce pulses of the desired shape.

Pulse amplitudes are determined by the pneumatic pressure in the programmer cylinders while pulse durations are controlled by changing drop height. Peak accelerations of up to 1,000 G and time durations of from one millisecond to over 60 milliseconds can be achieved.

6.4.3.2.1.3 HYGE shock tester. This type of shock testing machine (Figure 6-30) operates through the action of differential gas pressures acting on the two faces of a thrust piston in a closed cylinder. As indicated in the inset schematic drawing, the cylinder is separated into two chambers by an orifice plate. In operation, a relatively low gas pressure in the top chamber forces the thrust piston against the "O" ring seal. The entire top area of the piston is exposed to the gas pressure in the top chamber. On the underside of the piston, only the smaller area bearing on the ring seal is exposed to the gas pressure in the lower chamber. When the gas pressure in the lower cylinder is increased, the seal breaks. Suddenly the pressure in the lower cylinder is applied to the entire bottom area of the piston and the entire thrust column is accelerated upward because of the resultant imbalance of forces. The shape of the applied acceleration-time pulse is controlled principally by the orifice sizes, metering pin shapes, and reactive loads applied by the attached item.

HYGE shock testers are capable of generating reproducible half-sine, sawtooth, and nearly rectangular pulses. Furthermore, a maximum thrust of 40,000 pounds and acceleration up to 2,000 G of small masses are obtainable with the largest HYGE models.

6.4.3.2.2 Recording apparatus. Recording apparatus usually will consist of one or more recording channels, each of which shall include an acceleration transducer and accessory recording equipment. Details for selecting suitable sensing and recording equipment are given in Section 6.2.

6.4.3.3 Test procedure. The test item shall be prepared for shock testing with attached accelerometers in accordance with 6.4.3.1. The item shall be attached firmly to the carriage of the shock testing machine with a fixture that will allow orientation of the item in the various plans desired. The accelerometers shall be mounted in accordance with the principles given in 6.3.4. The carriage and attached item shall then be given an impact of sufficiently mild severity so that (in the judgment of the test engineer) damage is most improbable. A complete acceleration-time record for the impact shall be recorded. Also, the item shall be examined for damage and given a functional check, if necessary. Shock pulses of the same severity shall be applied along other possible planes of weakness with the axis of sensitivity of the accelerometer aligned with the directions of the applied forces. Generally, pulses should be applied along three mutually perpendicular axes (in both directions, if deemed advisable), one of which shall be perpendicular to the side of the item normally used as a mounting base.

6.4.3.3.1 Control of Applied Shock Pulses. Shock pulses should be applied beginning with rectangular waveform pulses of sufficiently long duration to assure testing at a velocity change value representative of the

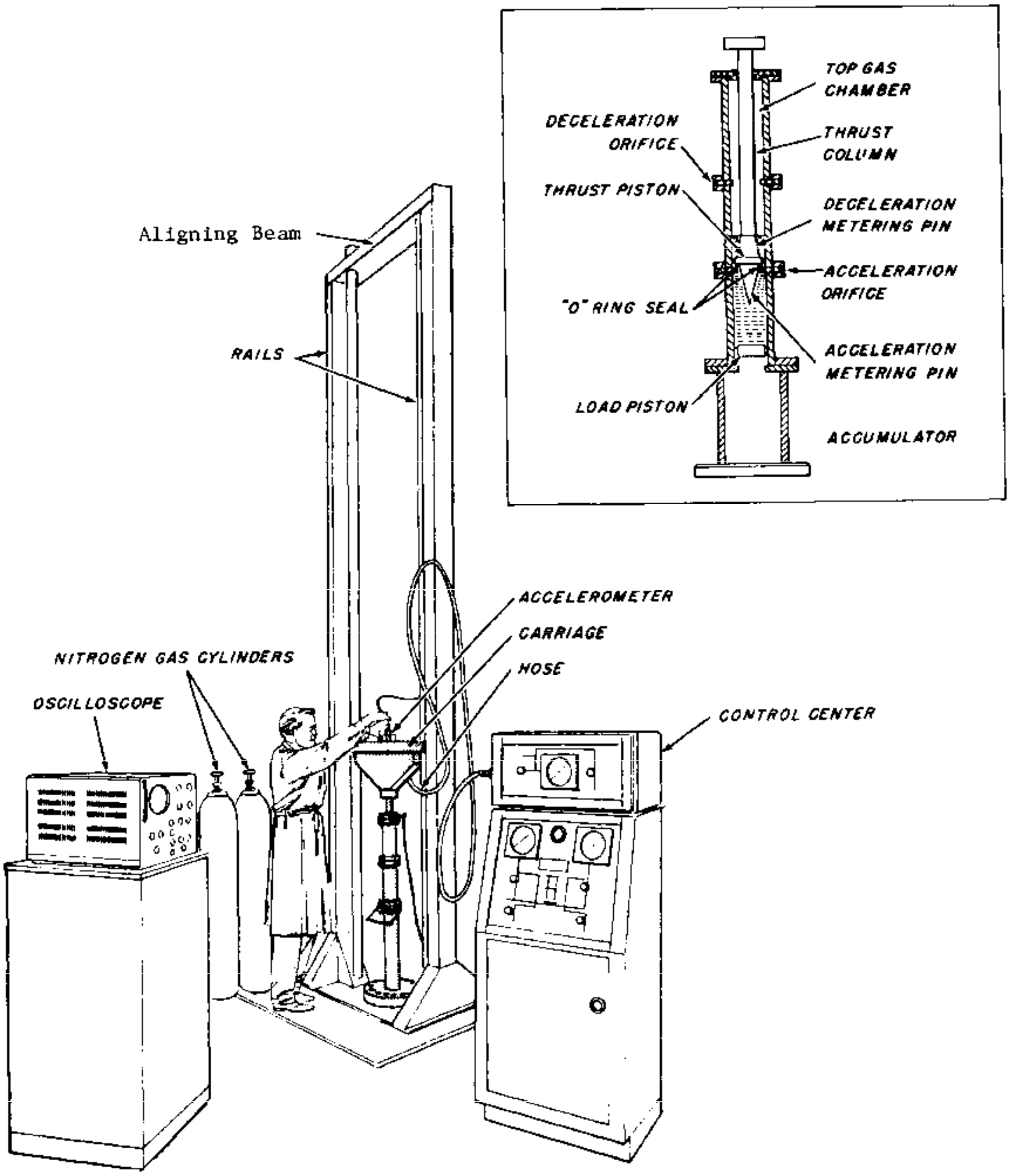


FIGURE 6-30. The HYGE shock testing machine.

constant acceleration (horizontal portion) of the damage boundary curve (Figure 6-27). The acceleration level for these pulses should be low enough to assure that the item will not be damaged by the first impact and should be increased in small enough increments to attain accurate results. (Setting of these parameters is left to the packaging engineer since they depend on the estimated fragility of the item to be tested). Typical starting points may be in the range of 10-20 G's at a duration of 20-30 milliseconds.

When the constant acceleration portion of the damage boundary curve has been determined, the shock programmers are changed to produce half sine pulses of duration short enough (low velocity change values) to assure that the item will not be damaged. Peak acceleration values should be at least twice as great as were found for the constant acceleration portion of the damage boundary curve. Velocity change is then increased, holding peak acceleration constant, until item damage occurs. The prior velocity change value (at which damage did not occur) is then used to establish the vertical position of the damage boundary curve.

6.4.3.4 Fragility Rating Determination.

The complete fragility profile may now be drawn as in Figure 6-27. In practice, the boundary of primary concern for most packaging applications will be the constant acceleration (horizontal) portion of the curve.

6.4.3.5 Report. The report should record the following information:

a. Date of test and reference to the test procedure.

b. All significant details and sketches (if desirable) about the test item, including its name, model number, size) weight configuration, accelerometer mounting techniques, etc.

c. A list of the pertinent test details including the type of shock tester and recording equipment used; input pulse shapes, peak amplitudes, and duration; and the orientation of the damaging force to the test item.

d. A list of the fragility ratings (both velocity change and acceleration) and the average obtained as a result of the tests.

6.4.4 Method B.

This test procedure involves application of a series of shocks to an item beginning with the least severe and progressively increasing in severity, until damage or malfunction of the item occurs. Instead of applying shock pulses by the use of shock testing machines, each shock is applied by simply dropping the item against a cushioning pad inside a shipping container. Appropriate recording equipment is attached or coupled to the item, and the fragility rating for the item is determined from the records.

An illustration of a typical test setup by this method is shown in Figure 6-31.

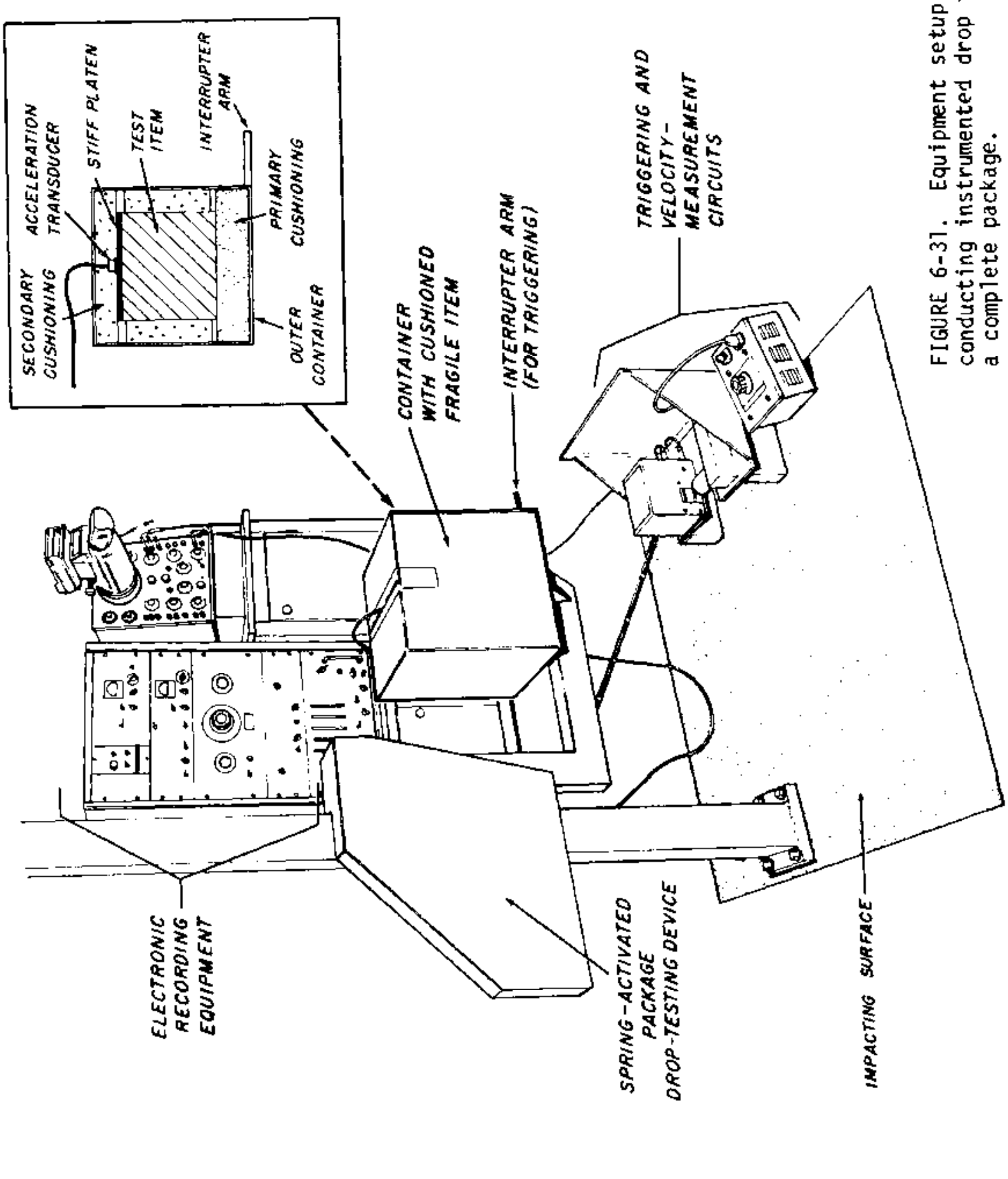


FIGURE 6-31. Equipment setup for conducting instrumented drop test of a complete package.

6.4.4.1 Test item. Same as 6.4.3.1.

6.4.4.2 Apparatus.

6.4.4.2.1 Shock testing equipment. The principal materials and apparatus required for conducting shock tests according to this procedure are discussed in the following:

6.4.4.2.1.1 Package drop testing equipment. A variety of common laboratory drop testing equipment may be used for conducting flat drop tests of the package containing the cushioned item--dropleaf tables, spring-activated cantilever arm drop testers (Figure 6-31), and pendant solenoid-activated release mechanisms. However, such apparatus must be capable of delivering the package squarely against the impacting surface.

The impact surface should be either concrete or a heavy steel plate embedded in a solid footing.

6.4.4.2.1.2 Containers. The container used shall be big enough to hold the item and cushioning. Furthermore, it should be of the same general construction and material as the container that will probably be used to ship the item, if this information is known.

For example, an activity might be shipping practically all of its items in a particular size and weight class in RSC single-wall corrugated fiberboard containers made from fiberboard of a particular combination of liners and corrugated section. Accordingly, the same kind of container should be used for fragility testing.

6.4.4.2.1.3 Cushioning materials. A variety of commonly used resilient cushioning pads (urethane foam, rubberized hair, etc.) may be used to apply shock pulses to the test item. In general, the test engineer will require a combination of sizes and thicknesses of cushions in order to conduct fragility tests of different sizes and weight of items.

The function of the secondary cushioning materials (inset, Figure 6-31) is to maintain the proper orientation of the item against the cushion during impact and to protect the item if the container should fall on a side subsequent to the planned flat drop. Cushioning materials used for this purpose should be similar to those used for primary cushioning.

6.4.4.2.2 Recording apparatus. Same as 6.4.3.2.2.

6.4.4.3 Test procedure. The test item shall be prepared for fragility testing as described in 6.4.3.1. Accelerometers shall be attached to the item in accordance with the principles described in 6.3.4. Next, the instrumented item shall be placed in the container with cushioning pads located as shown in the inset of Figure 6-31 and dropped squarely against the impact surface. The acceleration-time pulse shall be recorded and the item shall then be examined for damage and checked functionally.

As in *6.4.3.3* shock pulses of approximately equal severity should be applied along three mutually perpendicular axes (in both directions, if deemed advisable), one of which is perpendicular to the plane normally used for mounting purposes. For shapes of items other than cubical, it will be necessary to utilize different sizes of boxes for impacts along different axes. However, the test setup inside each package for each drop should conform essentially to that shown in the inset of Figure 6-31.

The same dropping and inspection procedure shall be repeated in such a manner that progressively more severe acceleration pulses shall be applied to the item until damage occurs. Complete acceleration-time histories shall be recorded for each impact.

Ordinarily, for the first drop the test engineer should select a prudent combination of drop height and cushion thickness (e.g., 5-inch thick urethane foam pad and a drop height of 18 inches) that will produce an acceleration pulse with a peak amplitude well below that likely to cause failure. In order to produce more severe pulses, greater drop height and/or less cushion thickness can be used. Drop heights employed should be between a maximum of 36 inches and the least practical amount obtainable with the particular kind of drop tester used. In selecting particular combinations of drop height and cushion thickness, the test engineer should be guided by dynamic performance data.

Although it is impractical to specify a particular rate of increase of peak amplitude of successive acceleration pulses, the test engineer should strive to strike a balance between excessively large increases (that might cause the rating process to overshoot) and an excessive number of tests.

6.4.4.4 Fragility rating determination. Same as 6.4.3.4

6.4.4.5 Report. The report should record the following information:

a. Date of test and reference to the test procedure.

b. The number of specimens and description of the material. This will include manufacturing origin, generic description (cellulose wadding, ester-type polyurethane foam, etc.), manufacturer’s proprietary designation, density (6.1.1.2), and compliance of the material with material specifications, if known.

c. A list of the pertinent test details, including a description (and sketches if desirable) of the container; arrangement, kind, and size of the cushion pads employed; and height and type of drop (cornerwise, edgewise, or flat drop).

d. A list of the fragility ratings and the average obtained as a result of the tests.

APPENDIX I. NOTATION

A Bearing area.

A_T Effective bearing area of rectangular solid during cornerwise impact.

a Acceleration.

a_m Maximum acceleration.

a_r Vector sum of acceleration components along x-, y-, and z- axes in Figure 6–26.

a_s Acceleration sensed by accelerometer in Figure 6-21.

a_t Total applied acceleration in Figure *6-21.*

a_x Acceleration sensed along x-axis in Figure 6-24.

a_y Acceleration sensed along y-axis in Figure 6-24.

a_z Acceleration sensed along z-axis in Figure 6-24.

C_L Cost of labor per unit time.

c_m Initial cost of cushioning material per unit volume.

c_p Material cost of platens or die-cut trays.

c_s Cost of shipping a package.

c_x Cushioning cost index in equation (3:7).

c_{ec} Material cost of an exterior container.

c_{ie} Material cost of an interior container.

D Density.

D_f Final dust particle count after specimen agitation.

D_o Original dust particle count (involving only the dust particles present because of atmospheric contamination).

d Depth dimension.

F Force.

F_f Final force required to compress specimen to 0.5 T_P after exposure in hydrothermal exposure test.

F_m Maximum applied force.

F_O Original force required to compress specimen to 0.5 T_P prior to exposure in hydrothermal exposure test.

f Applied stress.

f_f Forcing frequency.

f_n Undamped natural frequency of an item-cushioning system.

G Ratio of a to g.

G_m Maximum G - used to denote the fragility factor for an item; also used to express peak acceleration.

g The constant acceleration of a freely falling body due to gravity (usually considered to be 32.2 feet per second per second).

h Height of drop.

k_1 Spring rate of fragile element of packaged item represented by Figure 2-14.

k_2 Spring rate of linear cushioning in Figure 2–14.

L Length dimension.

L′ Length of one of three sides of a corner pad as shown in Figure 3-2.

m Mass of an object.

m_1 Lumped mass of fragile element of packaged article in Figure 2-14.

m_2 Lumped mass of packaged item in Figure 2-14.

m_3 Lumped mass of outer container in Figure 2-14.

N_d Number of dust particles for specification rating purposes.

n Number of trips for which a cushion may be expected to be used.

P_m Labor required to cut and apply cushioning materials.

P_P Labor required to fabricate and apply platens or die-cut trays.

P_{ec} Labor required to set up, load, and close an exterior container.

P_{ic} Labor required to set up, load, and close an interior container.

S Strain.

T Original thickness of cushioning material.

T_1 Initial cushioning thickness under load in creep test.

T_2 Cushioning thickness under load, measured next after T_1 in creep test.

T_3 Cushioning thickness under load, measured next after T_2 in creep test.

T_a Cushioning thickness required to protect an item, including a thickness allowance for expected loss from creep.

T_C Cushioning thickness after static compression testing.

'f Cushioning thickness after final compression test in *hydrothermal* exposure test.

T_i Cushioning thickness after first compression test in hydrothermal exposure test.

T_n Cushioning thickness under load after a particular time interval in creep test.

T_P Cushioning thickness after preworking.

T_r Transmissibility, the ratio of force to applied force or acceleration output to acceleration input.

T_x Cushioning thickness required to protect item in Figure 4-4.

T_{rl} Cushioning thickness after 30–second recovery period in creep test.

Tr_2 Cushioning thickness after 30-minute recovery period in creep test.

Tr_3 Cushioning thickness after 24-hour recovery period in creep test.

u Maximum acceleration of vibrating foundation.

V Volume of cushioning material.

v Velocity of foundation in Figure 2-14.

v_f Impact velocity of package.

w Weight of an object.

w_d Ovendry weight of a specimen.

w_f Weight of fragments released during fragmentation test.

w_h Specimen weight after humidification.

w_0 Original weight of specimen.

w Width dimension.

x Displacement.

x Maximum acceleration of a packaged item during vibration.

x_1 Maximum accleeration of fragile element in Figure 2-14.

x_2 Maximum acceleration of lumped mass of item in Figure 2-14.

x_m Maximum displacement.

β Fraction of critical damping of spring in any spring-mass system.

β_1 Fraction of critical damping of element of packaged item in Figure 2-14.

β_2 Fraction of critical damping of package cushioning in Figure 2–14.

τ A specific time interval.

θ Angle of accelerometer misalignment in Figure 6–21.

ω_1 Radian frequency of vibration of an element of packaged item in Figure 2-14.

ω_2 Radian frequency of vibration of package item–cushioning system in Figure 2-14.

rms Root-mean-square (0.707 x peak).

APPENDIX II. LITERATURE CITED

1. American Standards Association, "Calibration of Shock and Vibration Pickups”, ASA Publication S2.2-1959, 1959.

2. American Society for Testing and Materials. "Drop Test for Shipping Containers”, ASTM Method D 775-61, 1961.

3. American Society for Testing and Materials, “Method of Test for Dynamic Properties of Package Cushioning Materials”, ASTM Method D 1596-71, 1971.

4. Barnes, W. P., “A Spectral Analyzer for Shock Environments”, Shock, Vibration, and Associated Environments Bulletin No. 29, Office of Secretary of Defense, Research and Engineering, 1960.

5. Baxter, R. D., Beckman, J. J., and Brown, H. A., “Measurement Techniques”, Chapter 20 in Shock and Vibration Handbook, McGraw-Hill Book Co., New York, 1961.

6. Brown, K., “Package Design Engineering”, John Wiley and Sons, Inc., New York, 1959.

7. Crede, C. E., “Vibration and Shock Isolation”, John Wiley and Sons, Inc. , New York, 1951.

8. Dranetz, A. I., "Piezoelectric and Piezoresistive Pickups”, Chapter 16 in Shock and Vibration Handbook, McGraw-Hill Book Co., New York, 1961.

9. Gigliotti, M. E., “Design Criteria for Plastic Package Cushioning Materials”, Plastics Technical Evaluation Center, Picatinny Arsenal, Dover, N. J., 1962.

10. Godshall, W. D., "The FPL Linear Deadweight Accelerometer Calibrator”, U. S. Forest Products Laboratory Report No. 2239, Madison, Wisconsin, 1962.

11. Grabowski, T. J., “Design and Evaluation of Packages Containing Cushioned Items Using Peak Acceleration Versus Static Stress Data”, Shock, Vibration and Associated Environments Bulletin No, 30, part II, Office of the Secretary of Defense, Research and Engineering, Washington, D. C., 1962.

12. Guins, S. G., “Rail Vehicles”, Chapter 45 in Shock and Vibration Handbook, part II, McGraw-Hill Book Co., New York, 1961.

13. Harris, C. M., and Crede, C. E., “Shock and Vibration Handbook”, Vols. 1, 2, and 3, McGraw-Hill Book Co., New York, 1961.

14. Henny, C., and Leslie, F., “An Approach to the Solution of Shock and Vibration Isolation Problems as Applied to Package Cushioning Materials”, Shock, Vibration and Associated Environments Bulletin No. 30, part II, Office of the Secretary of Defense, Research and Engineering, Washington, D. C., 1962.

15. Kerstner, O. S., “General Principles of Package Design”, NAI-57-187, Northrop Aircraft, Inc., Hawthorne, California, 1957.

16. Kipp, W. J., “Product Fragility Assessment”, Lansmont Corp., Monterey, California, 1972.

17. Klein, E., Ayre, R. S., and Vigness, I., “Fundamentals of Guided Missile Packaging”, Naval Research Laboratory, Office of Assistant Secretary of Defense, Research and Development, 1955.

18. Lange, N. A., “Handbook of Chemistry, Tenth Edition”, McGraw-Hill Book Co., New York, 1961.

19. Letchford, A., “The Dynamic Performance of Certain Cushioning Materials at Temperatures Down to -50°C”, Proceedings of Symposium on Dynamics of Package Cushioning, Royal Radar Establishment, Ministry of Aviation, Malvern, England, 1960.

20. Levy, S., and Kroll, W. D., “Response of Accelerometers to Transient Accelerations”, Journal of Research of the National Bureau of Standards, vol. 45, 1951.

21. Levy, S., and Bickford, R. H., “Calibration of Pickups”, Chapter 18 in Shock and Vibration Handbook, McGraw-Hill Book Co., New York, 1961.

22. Magrath, H. A., Rogers, O. R., and Grimes, C. K., “Shock and Vibration in Aircraft and Missiles”, Chapter 47 in Shock and Vibration Handbook, McGraw–Hill Book Co., New York, 1961.

23. Mazzei, J. H., “Confined State Testing of Dynamic Properties of Cushioning Materials”, Technical Report FRL-TR-45, Feltman Research and Engineering Laboratories, Picatinny Arsenal, Dover, New Jersey, 1961.

24. Mindlin, R. D., “Dynamics of Package Cushioning”, Bell System Technical Journal, Vol. 24 (304), pp. 352-461, 1945.

25. Mustin, S., “Theory and Practice of Cushion Design”, Shock and Vibration Information Center, U. S. Department of Defense, Washington, D. C., 1968.

26. Newton, E., "Fragility Assessment Theory and Test Procedure", Monterey Research Laboratory, Inc., Monterey, California, 1968.

27. Ostrem, F. E., and Libovicz, B., "A Survey of Environmental Conditions Incident to the Transportation of Materials", Report PB–204 442, General American Transportation Corp., Niles, ILL., 1971.

28. Pearsons, K. S., and Ungar, E. E., "Development of Packaging Material with Constant Restoring Force", WADD TR 60–573, U. S. Air Force, Wright-Patterson AFB, Ohio, 1961.

29. Ripperger, E. A., and Fowler, W. T. "The Response of yielding Structures to Shock Loading", Shock, Vibration and Associated Environments Bulletin No. 30, part 111, Office of the Secretary of Defense, Research and Engineering, Washington, D. C., 1961.

30. Rubin, S., "Concepts in Shock Data Analysis", Chapter 23 in Shock and Vibration Handbook, Vol. 2, McGraw–Hill Book Co., New York, 1961.

31. Stambler, S., and Gordon, S., "Corrosivity of Cushioning Materials, U.S. Department of the Navy, Bureau of Supplies and Accounts, Engineering Report 2.50602, 1961.

32. Stern, R. K., "FPL Dynamic Compression Testing Equipment for Testing Package Cushioning Materials", U. S. Forest Products Laboratory Report No. 2120, Madison, Wisconsin, 1958.

33. Stern, R. K., "Trends in the Isolation of Packaged Items", Shock, Vibration and Associated Environments Bulletin No. 30, part II, Office of the Secretary of Defense, Research and Engineering, Washington, D.C., 1962.

34. Timoshenko, S., "Vibration Problems in Engineering", Third Edition, D. Van Nostrand Company, Inc., New York, 1955.

35. Unholtz, K., "Vibration Testing Machines", Chapter 25 in Shock and Vibration Handbook, McGraw-Hill Co., New York, 1961.

36. U. S. Department of Defense, "Cushioning Material, Resilient Type, General, Military Specification MIL-C-26861, 1970.

37. Venetos, M. A., "Determination of Fragility Values for the LN-12 Inertial Guidance Platform and Associated G–200 Gyroscope", Air Force Packaging Evaluation Agency (AFPEA), DSPT Report No. 73-55, Wright-Patterson AFB, Ohio, 1973.

38. Vigness, I., "Shock Testing Machines", Chapter 26, Shock and Vibration Handbook., McGraw-Hill Book Co.. New York. 1961.

39. Whiting G. W., "Effect of Outdoor Storage Environment on Cushioning Properties”, Air Force Packaging Evaluation Agency (AFPEA), DSPT Report No. 50, Wright-Patterson AFB, Ohio, 1973.

40. TO-00-85-37, "Foam-In-Place Packaging”, 1975.

41. ASTM-D 1596-64, "Shock Absorbing Characteristics of Package Cushioning Materials”.

APPENDIX III. GLOSSARY OF TERMS

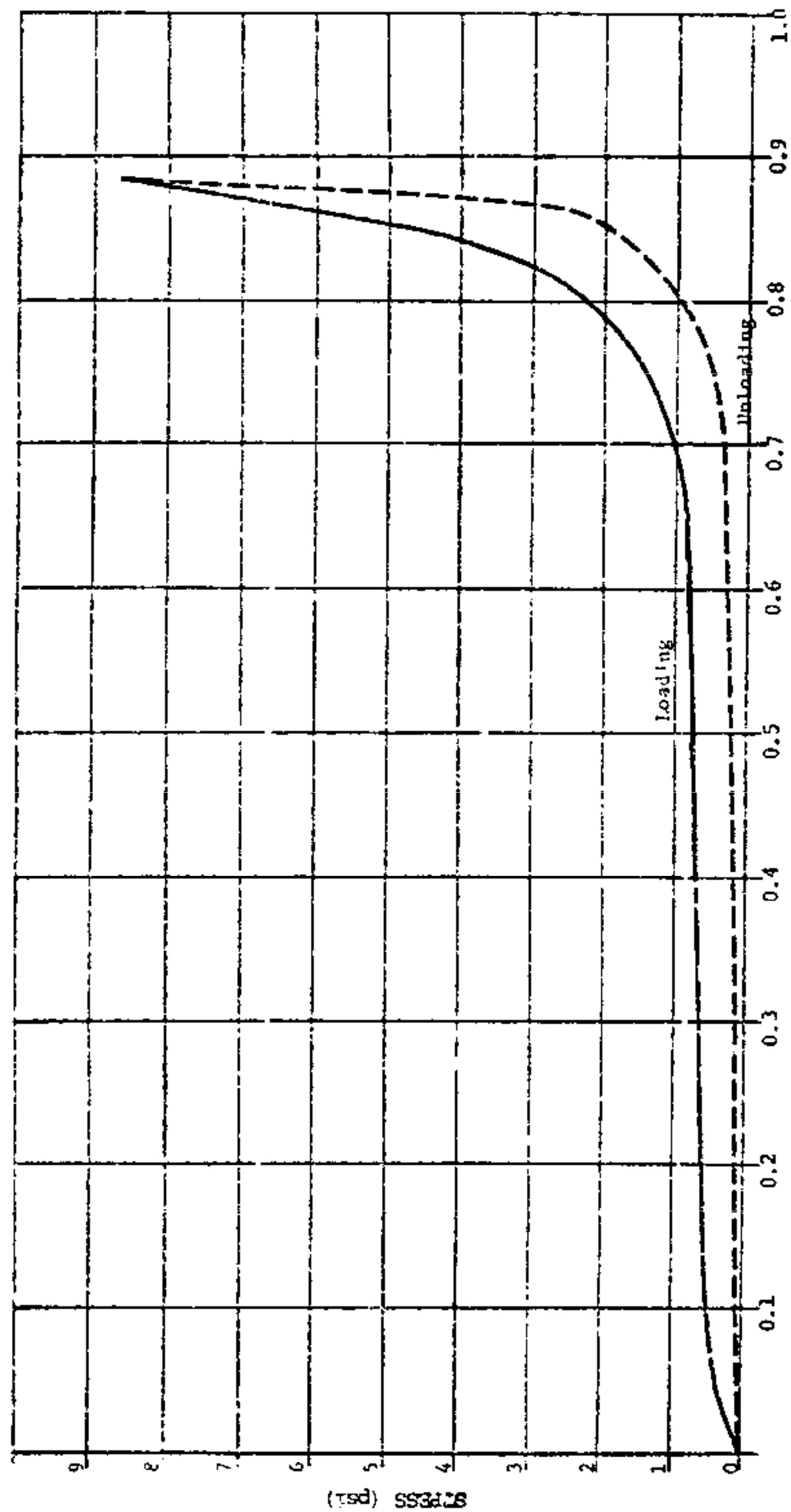
Acceleration	A vector quantity describing the time rate of change of velocity of a body in relation to a fixed reference point.
Amplification factor	As used in this document, the ratio of the peak acceleration response to the peak acceleration of an applied acceleration pulse.
Blocking	Relatively stiff materials used in packaging to immobilize items.
Car ton	As used in this document, a closed box (usually made of paperboard) used as interior packing of a unit pack.
Compression set	The loss of thickness of a cushioning specimen after a specified time interval following removal of a compression load.
Container	As used in this document, any box, crate, can, or drum that is used in unit packs to ship items.
Container, exterior	As used in this document, the outermost container of a unit pack.
Container, interior	As used in this document, a container used internally in a unit pack.
Creep	The strain–time response of a material to a constant stress.
Cushioning cost index	A relative cost factor that reflects the essential cost elements involved in application of a particular cushioning material in a specific application.
Cushioning material	A material, as distinguished from a built-up device, used as a shock and vibration isolator.
Cushioning material, anomalous type	A cushioning material characterized by a force-displacement curve that does not correspond to any general type (see Figure 2-11).
Cushioning material, ideal type	A cushioning material that exerts a constant resistive force to variable displacement (see Figure 2-11).

Cushioning material, linear type	A cushioning material having a linear force-displacement curve (see Figure 2–11).
Cushioning material, tangent type	A cushioning material having a force-displacement curve that is linear at small values of displacement, but which increases nonlinearly at higher values of displacement (see Figure 2-11).
Damping	The dissipation of energy with time or distance.
Damping, critical	The minimum viscous damping that will allow a displaced system to return to its initial position without oscillation.
Damping, fraction of critical	The fraction of critical damping (damping ratio) for a system with viscous damping is the ratio of actual damping coefficient to the critical damping coefficient.
Design, analytical	Design by calculation.
Design, empirical	Design by trial and error.
Displacement	A vector quantity describing the change of position of a body, point, or surface relative to a fixed reference point.
Dunnage	Cushioning material that is used primarily to fill void spaces or to pad projections in packages.
Dust	Fine particles that are liberated from a material as a result of agitation and which tend to remain airborne for an appreciable period of time.
Dusting test	A test to measure the propensity of a material to liberate dust.
Effective bearing area	The projected area of the item in the direction of impact.
Elasticity	The force-displacement characteristic of a material.
Encapsulation, complete	A cushioning method involving application of material continuously around the entire exterior surface of an item.

Equivalent drop height	The height of free fall required by a body in a vacuum to attain a particular instantaneous velocity.
Flotation	Completely encapsulated (see encapsulation, complete).
Fragility rating (G-factor, G-value)	The ratio of the maximum acceleration that an object can safely withstand to the acceleration of gravity.
Fragments	Small particles that are liberated from a material as a result of agitation and which tend to settle immediately after liberation.
Fragmentation test	A test to measure the propensity of a material to liberate fragments (including dust particles) during handling.
Frequency	The reciprocal of the period of periodic oscillation.
Frequency, discrete	A single, distinct frequency of sinusoidal oscillation.
Frequency of excitation	The frequency of an externally applied force or other input that causes the system to respond in some way.
Frequency, forcing	A frequency of excitation.
Frequency, natural	The frequency of free oscillation of a system.
Frequency, resonant	A frequency at which resonance exists.
Hydrothermal stability test	A test to determine the resistance of a material to a combination of elevated temperature and humidity.
Immobilize	To make the external parts of an object essentially immobile relative to each other.
Inoculum	As used in this document, a suspension of fungus spores used to inoculate a cushioning specimen and viability control material in a fungus resistance test.
Isolator	A device or material used to reduce the severity of applied shock and/or vibration to a packaged item.

Nesting	As used in this document, cushioning of a series of like items with intermediate layers of cushioning material.
Overshoot	Excessive momentary response of a recording system to an applied signal.
Pad, corner	A tri-faceted cushion used at an interior corner of a shipping container to cushion a regularly shaped item or interior container.
Pad, face	A cushion that is applied adjacent to the face of an item or interior container in a package.
pH	As applied to cushioning material, a symbol denoting the negative logarithm of the hydrogen ion concentration of the aqueous extract of a cut or shredded material. It is commonly used to express the acidity or alkalinity of a material.
Piezoelectric	The capability of some crystalline materials to generate an electric charge when stressed.
Preworking	Cyclic loading of a cushion prior to testing or use in order to produce essentially consistent compression characteristics.
Pulse rise time	The interval of time required for the leading edge of a pulse to rise from some specified small fraction to some specified larger fraction of the maximum value. (Frequently, “rise time” is taken to include the time required to increase from 1/10 to 9/10 of the maximum value.)
Recovery ability	The ability of a cushioning material to regain its original dimensions following removal of a load causing deformation.
Resilience	A material characteristic indicating an ability to withstand temporary deformation without permanent deformation or rupture.
Resonance	Resonance of a system in forced oscillation exists when any change, however small, in the frequency of excitation causes a decrease in the response of the system.
Rigidize	To immobilize (see immobilize).

Shock	A sudden, severe nonperiodic excitation of an object or system.
Shock pulse	A substantial disturbance characterized by a rise and decay of acceleration from a constant value in a short period of time. Shock pulses are normally displayed graphically as curves of acceleration as a function of time.
Shock pulse, simple	A shock pulse characterized by a smooth acceleration-time curve.
Shock pulse, complex	A shock pulse comprised of a wide range of frequency components that are not related harmonically to each other.
Shock spectrum	A plot of the maximum acceleration experienced by a single-degree-of-freedom system as a function of its own natural frequency in response to an applied shock.
Shock, velocity	A mechanical shock resulting from a non-oscillatory change in velocity of an entire system.
Single-degree-of-freedom system	A system, consisting of a rigid mass attached to a reference foundation by a massless spring, that is constrained along a straight line.
Strain	Deformation per unit length.
Stress	Force per unit area.
Transducer	An instrument that converts shock and vibration or other phenomena into a corresponding electrical or mechanical signal.
Transmissibility	The nondimensional ratio of the response amplitude of a system in steady-state forced vibration to the excitation amplitude. The ratio may represent accelerations, forces, displacements, or velocities.
Unit pack	As used in this document, the first complete or identifiable package, comprising one or more items, cushioning material, and container(s).
Velocity	A vector quantity describing the time rate of change of displacement of a body in relation to a fixed reference point.



STRAIN (IN/IN)

CHART 2. POLYURETHANE ETHER 2 PCF

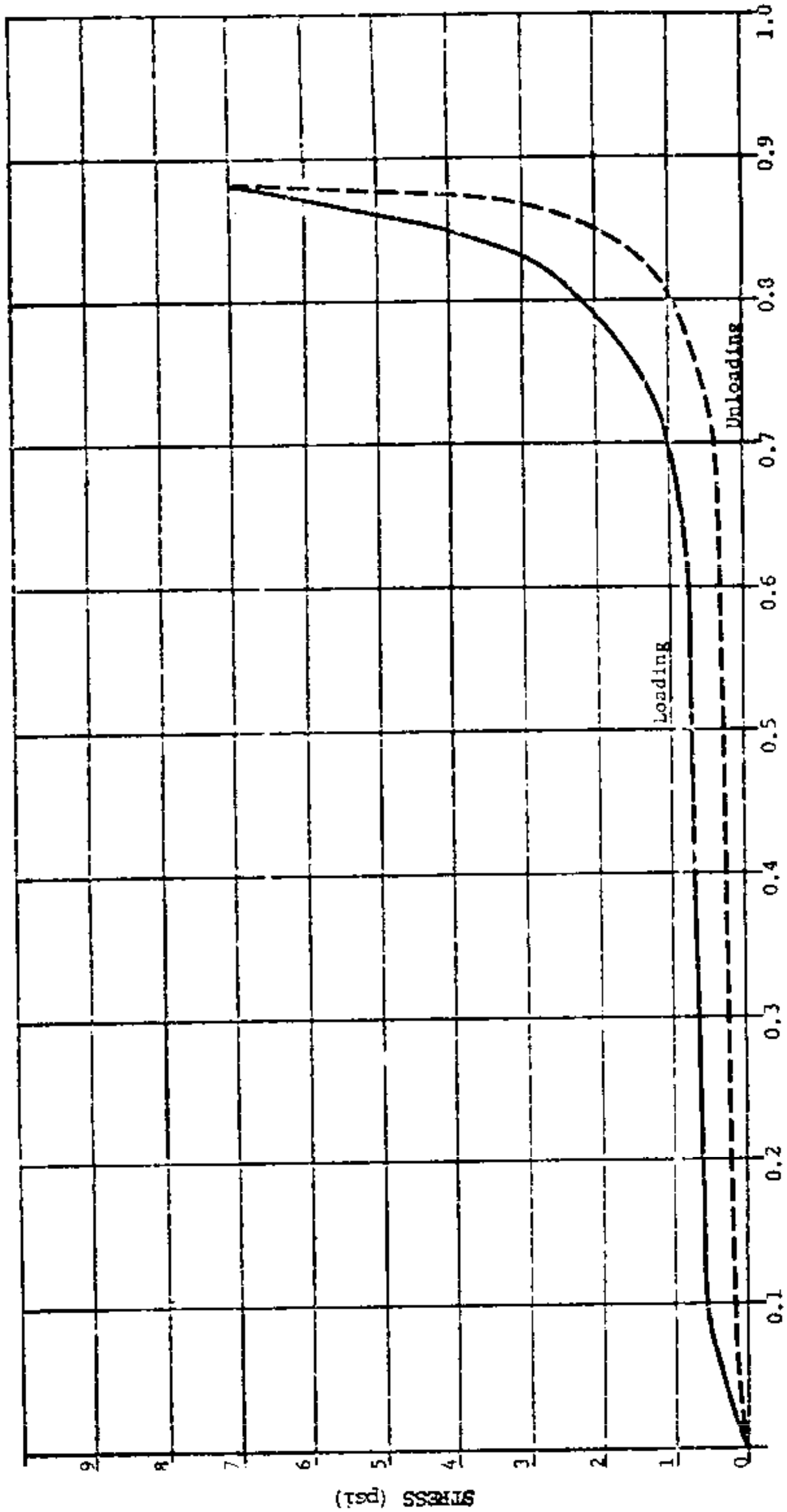
Velocity change	The difference in system velocity magnitude and direction from the start to the end of the shock pulse.
Velocity shock	Mechanical shock resulting from a rapid net change in velocity.
Viability control	Specimen(s) of pure filter paper used in fungus resistance tests to prove the viability of the inoculated fungus spores.
Vibration	The oscillation of an element of a mechanical system about a suitable reference point.
Vibration, periodic	A vibration consisting of a waveform that is repeated at equal time intervals.
Vibration, quasi-periodic	A vibration that deviates slightly from periodic vibration.
Vibration, random	An oscillation having an instantaneous amplitude that can be specified only on a probability basis.
Vibration, steady-state	A periodic vibration.
Viscoelastic	An adjective indicating that a material or system has both energy-storing and energy-dissipating capability during deformation.

APPENDIX IV. STRESS - STRAIN CURVES

Static compressive stress-strain curves are presented in this Appendix (Charts 1 thru 22).

The derivation of stress-strain curves is described in 6.1.2.5, and their use is discussed in 2.3.1.2, 2.3.2.2.2, and 3.2.6.

All data given herein were derived from empirical tests conducted under contract by AFPEA, Wright-Patterson AFB OH, under controlled atmospheric conditions of 73° F and 50 percent relative humidity and are generally representative of commercially available materials (complete listing on page xiii).



STRAIN (IN/IN)

CHART 1. POLYURETHANE ETHER 1.5 PCF

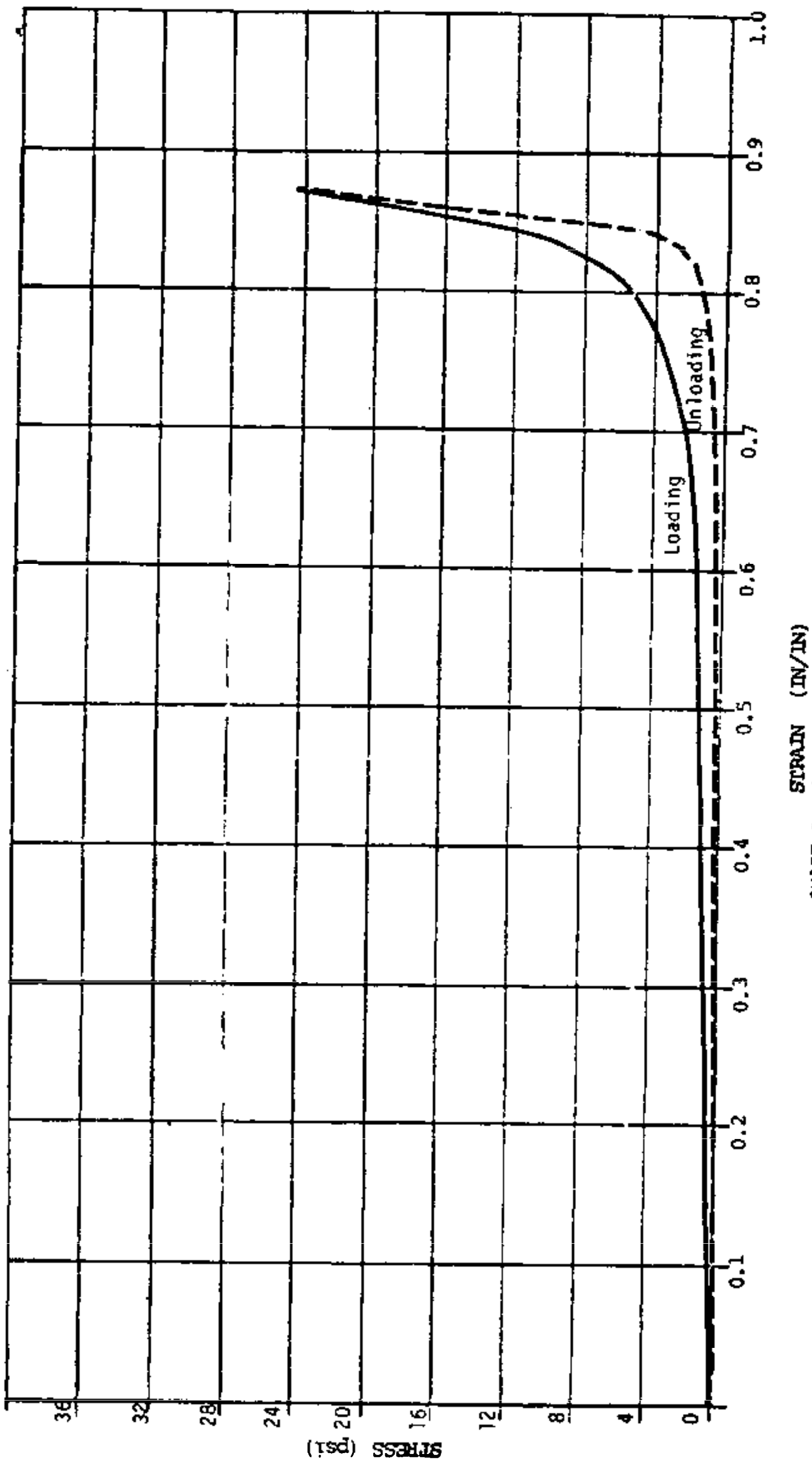


CHART 9. RUBBERIZED HAIR, TYPE IV

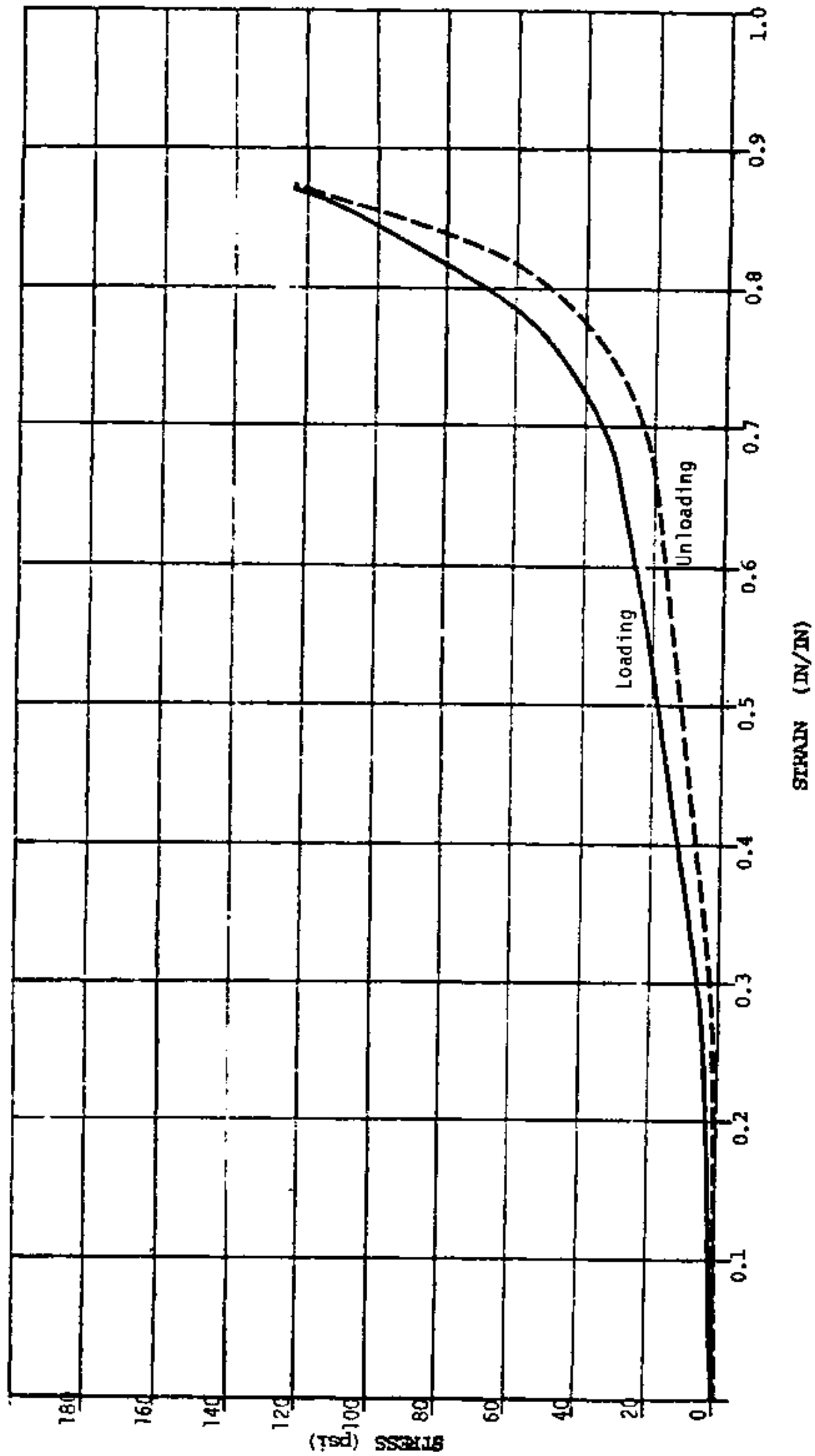


CHART 10. POLYETHYLENE 2.0 PCF

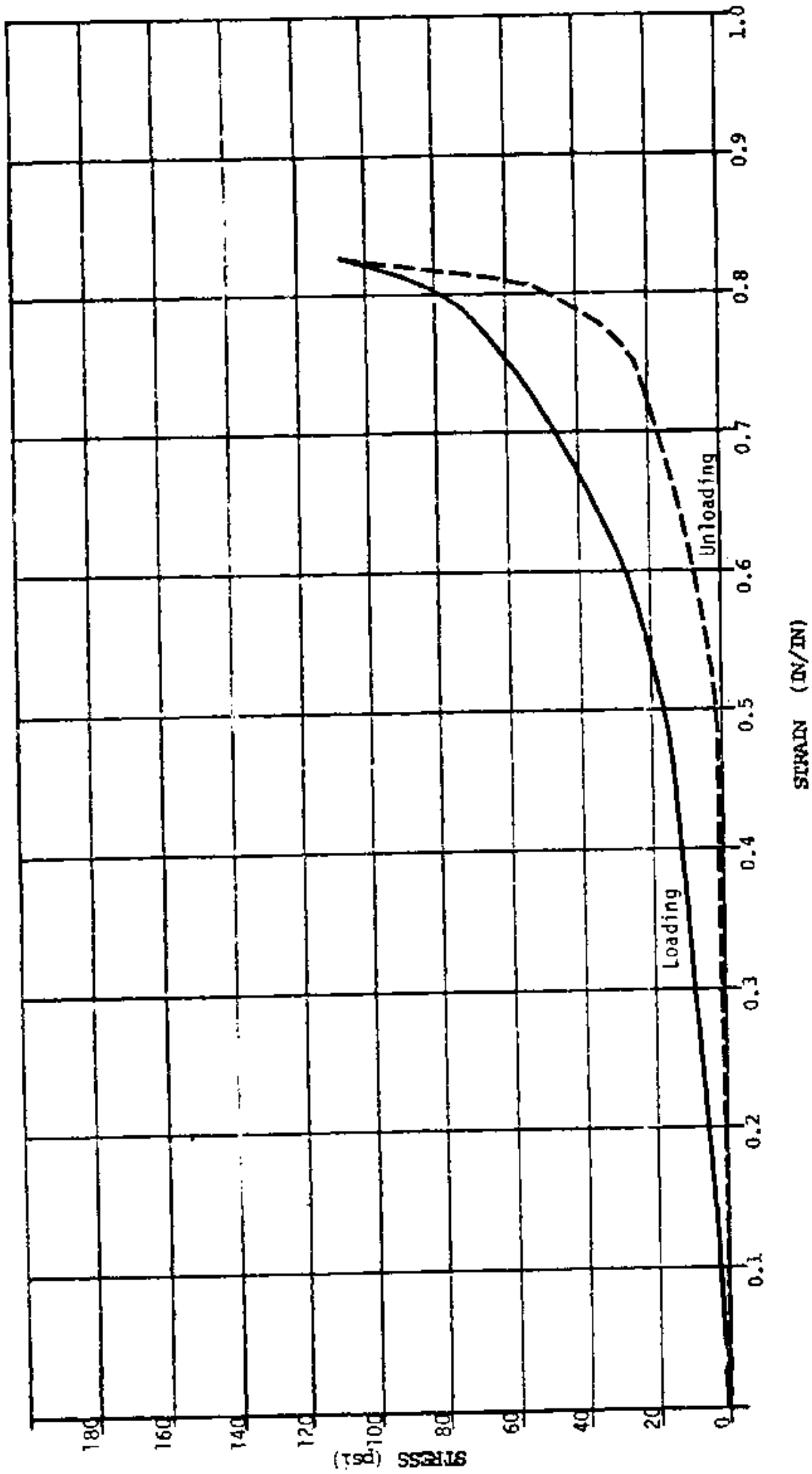


CHART 11. POLYETHLENE 4.0 PCF

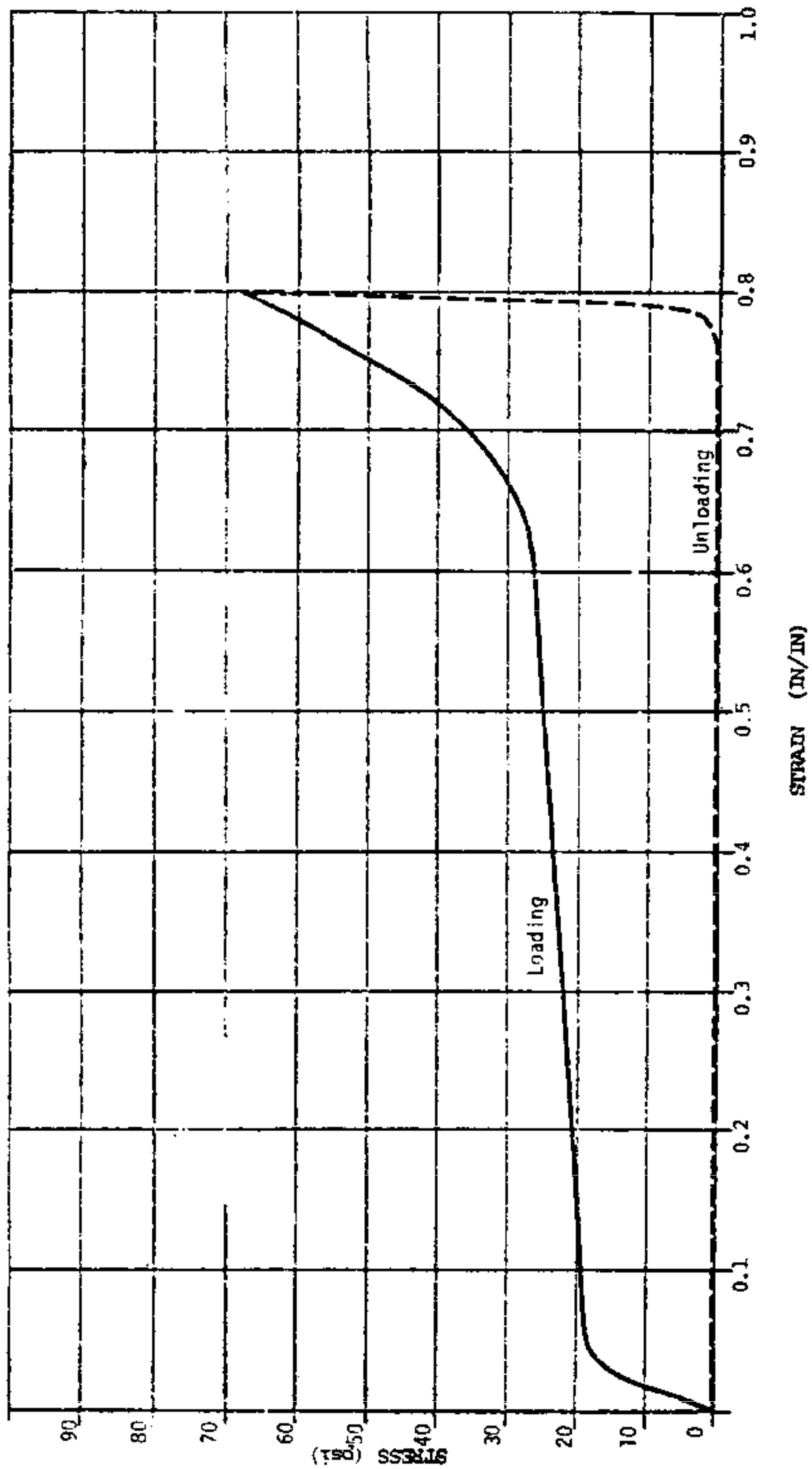


CHART 12. POLYSTYRENE 1.5 PCF

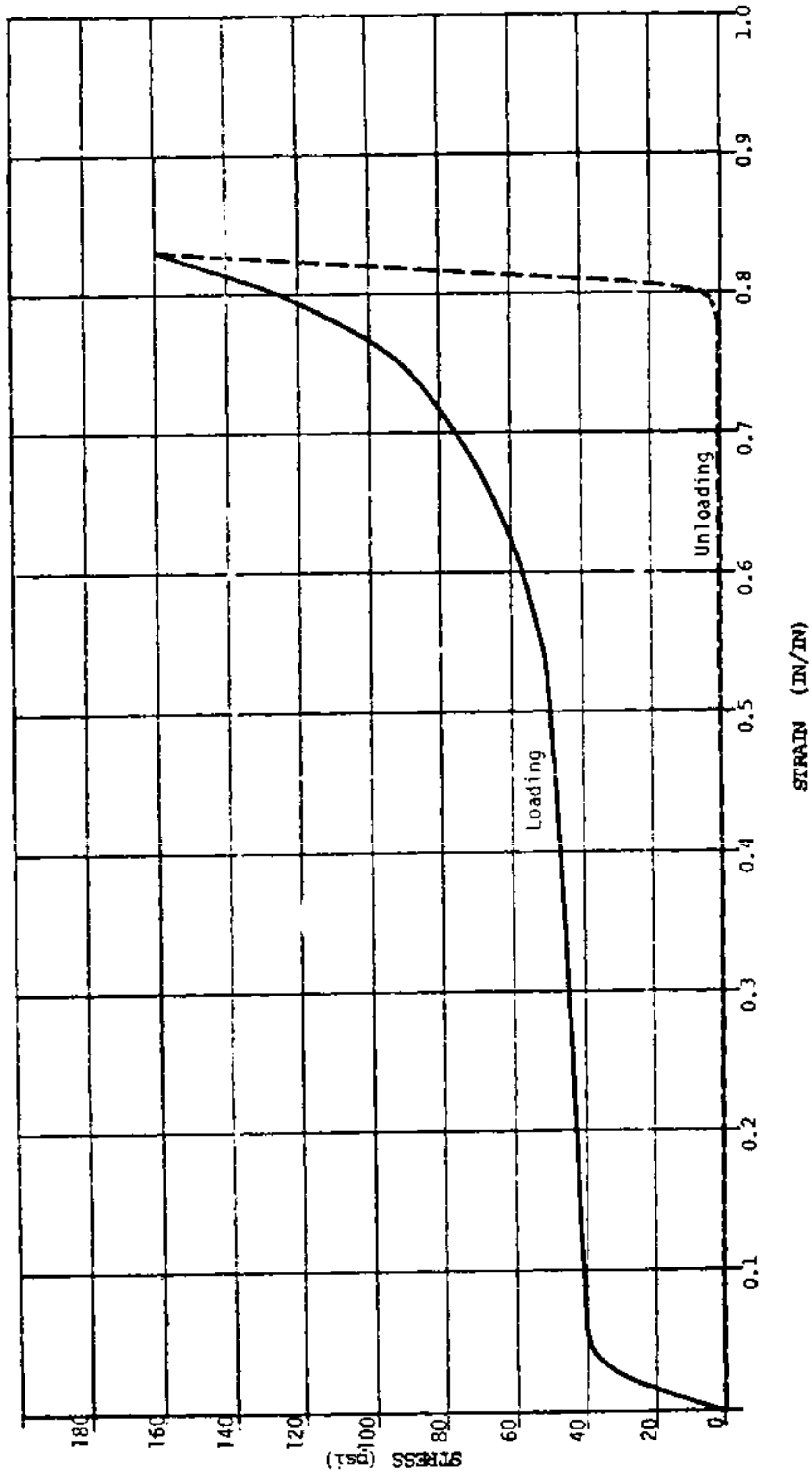


CHART 13. POLYSTYRENE 2.5 PCF

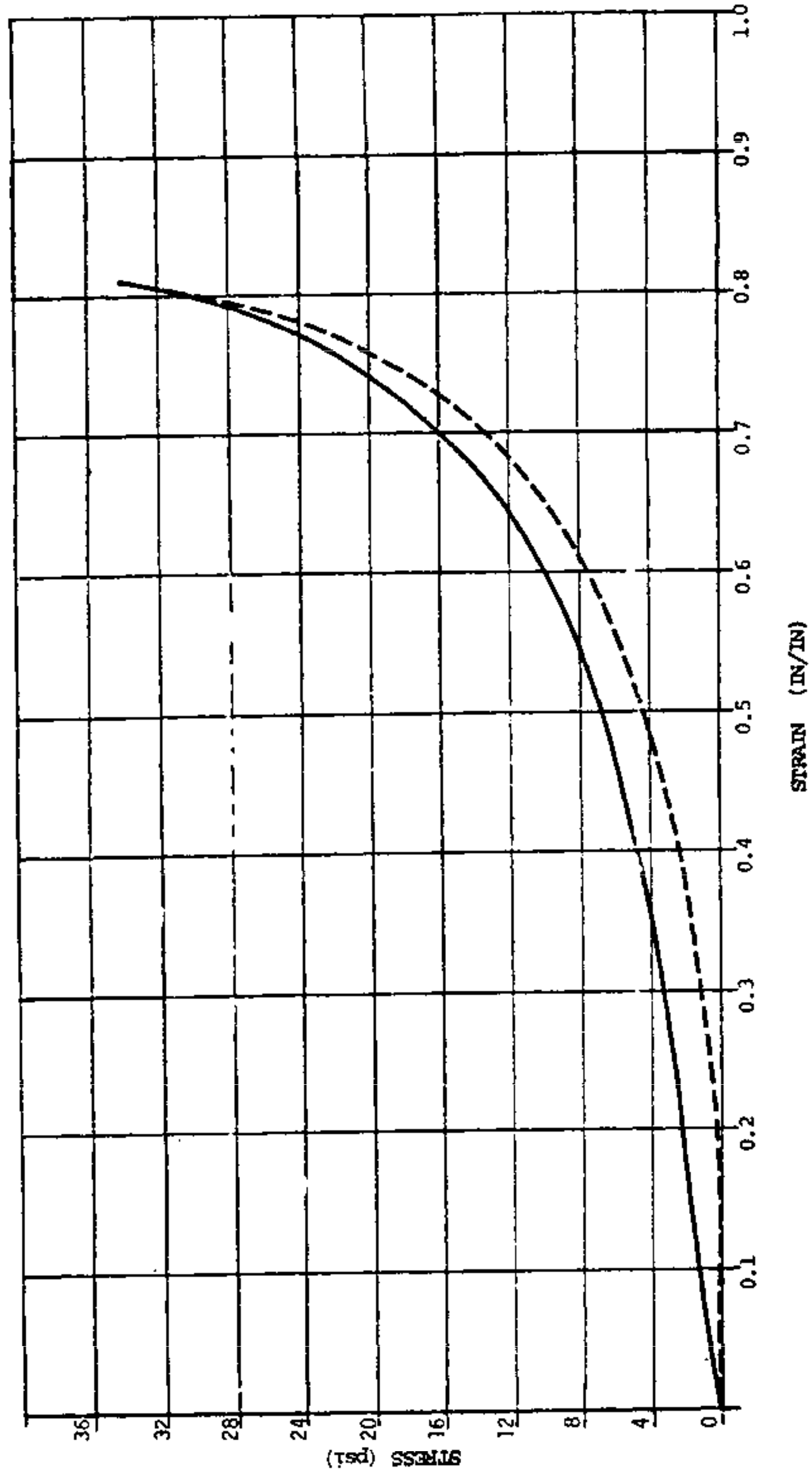


CHART 14: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf

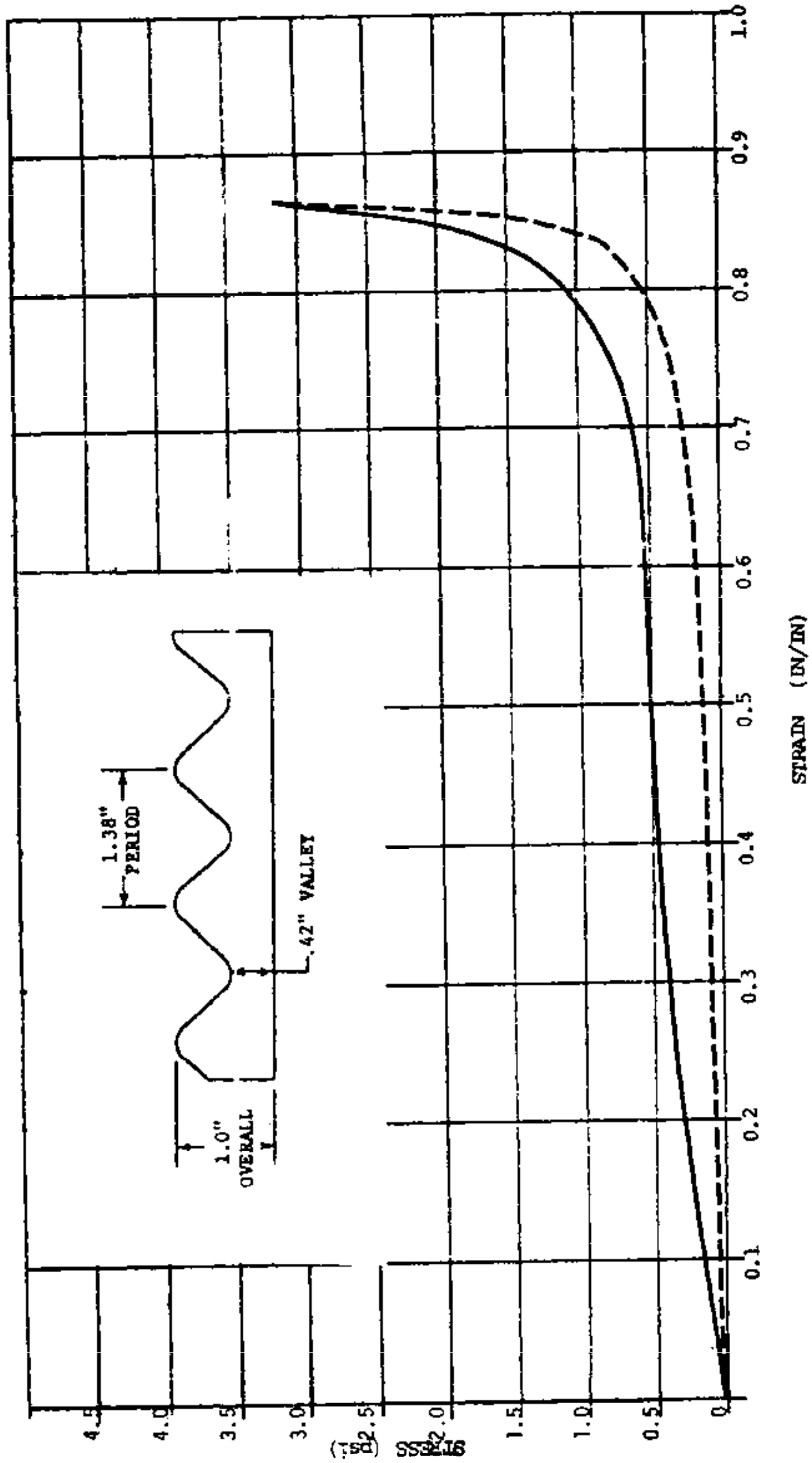


CHART 15. CONVOLUTED POLYURETHANE ETHER 1.15 PCF
(1.0" overall, 1.38" pitch, 0.42" valley)

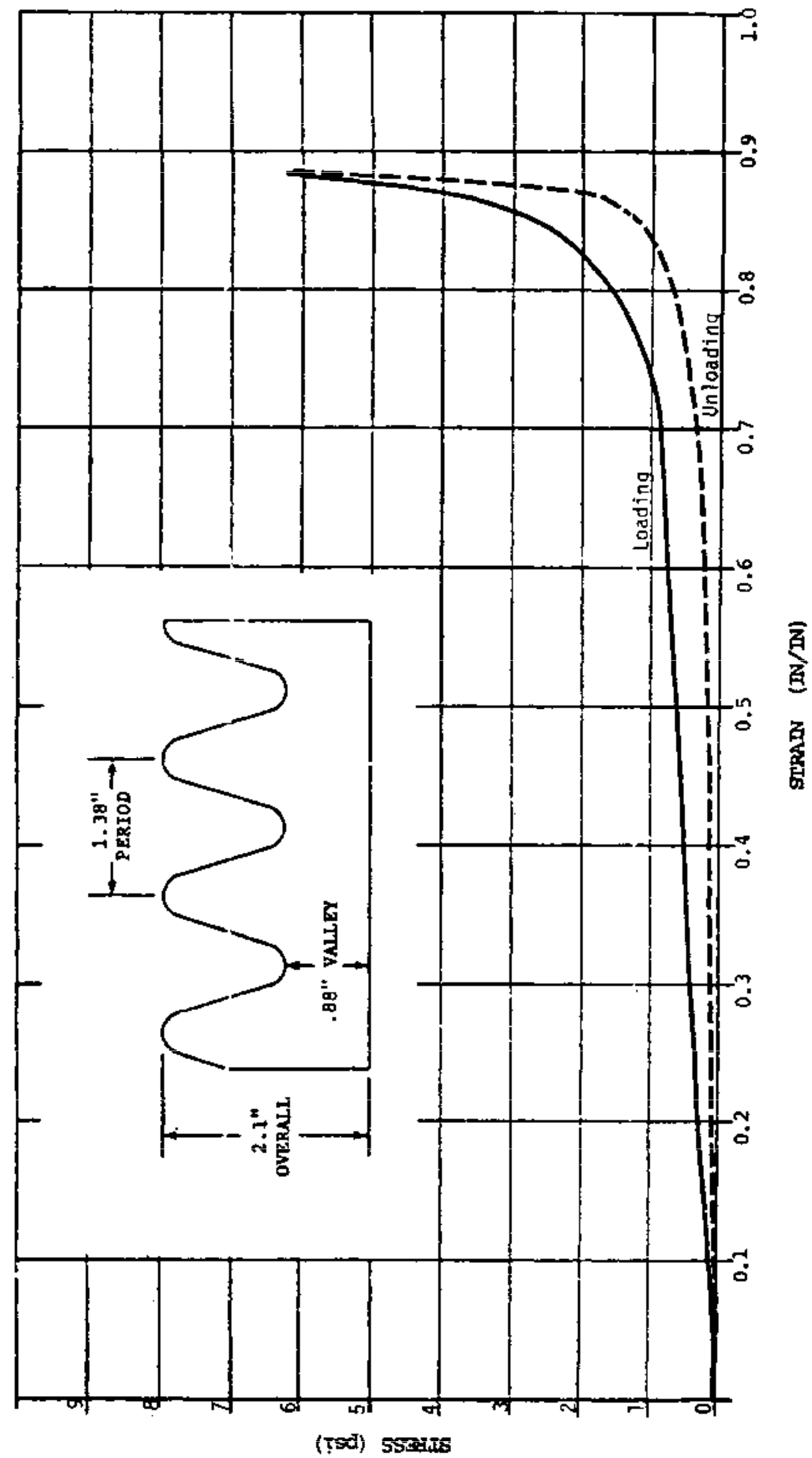
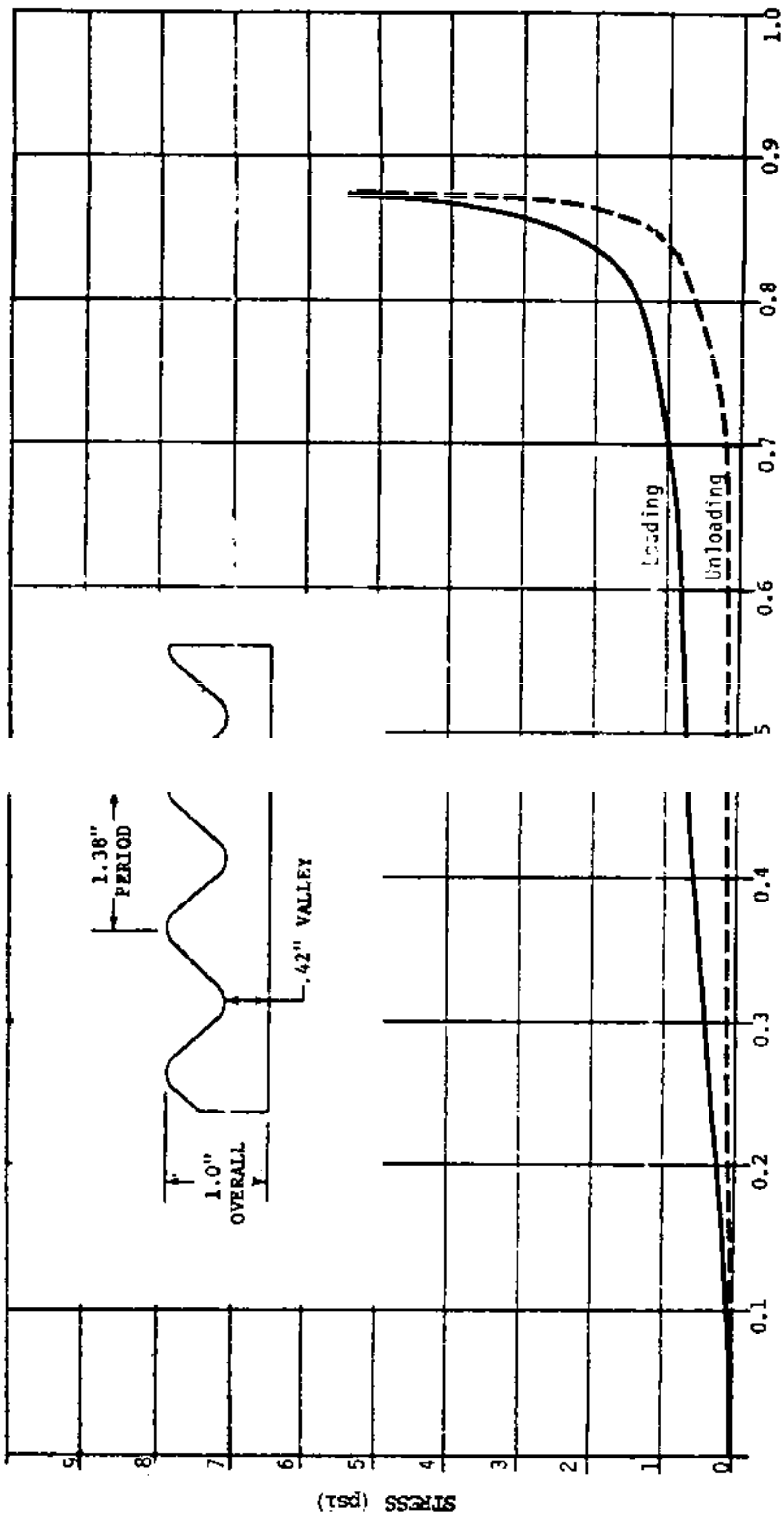


CHART 16. CONVOLUTED POLYURETHANE ETHER 1.15 PCF
(2.1" overall, 1.38" pitch, 0.88" valley)



STI (IN/IN)

CHART 17. CONVOLUT DLYURETHANE ETHER 1.5 PCF
(1.0" overall,) pitch, 0.42" valley)

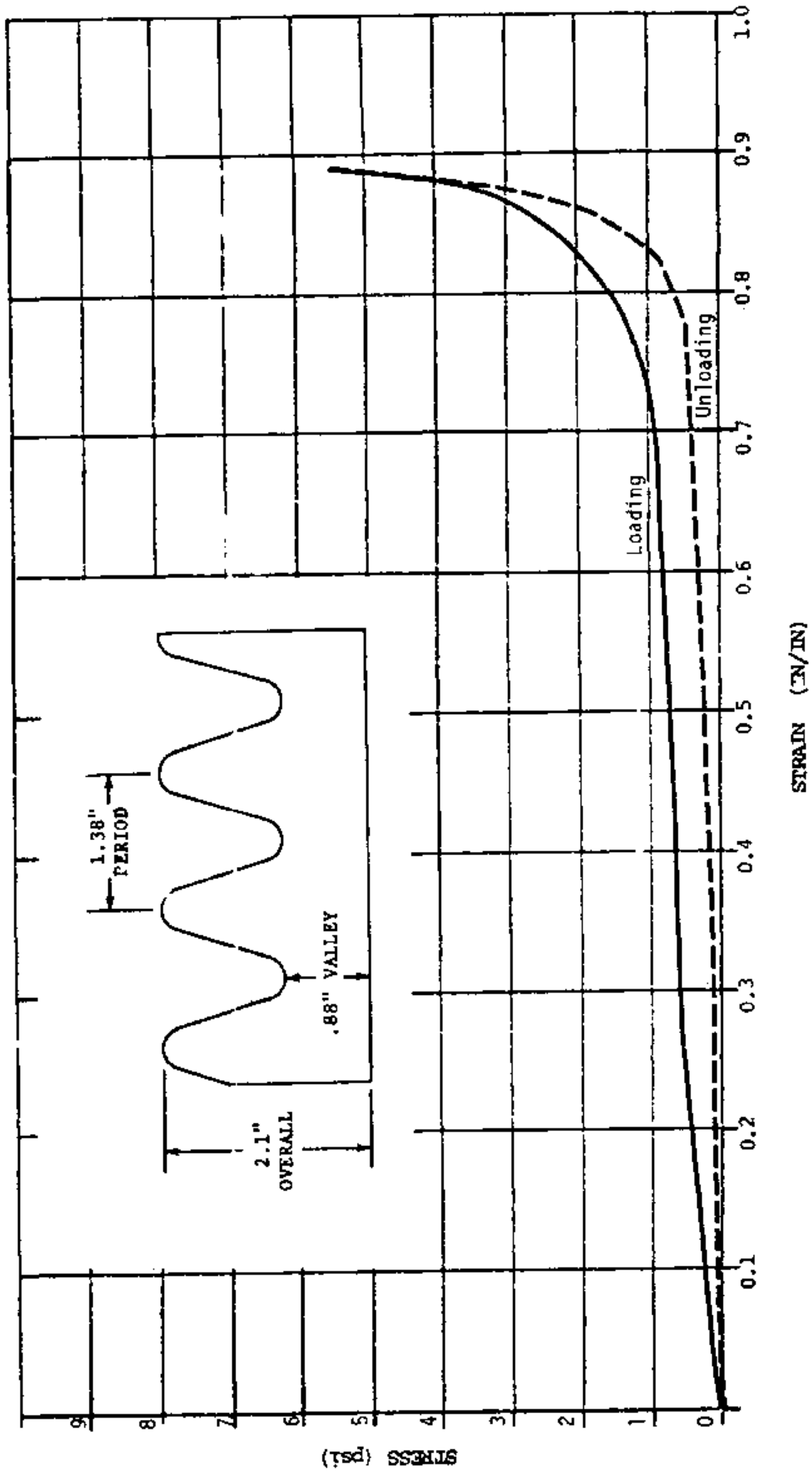


CHART 18. CONVOLUTED POLYURETHANE ETHER 1.5 PCF
(2.1" overall, 1.38" pitch, 0.88" valley)

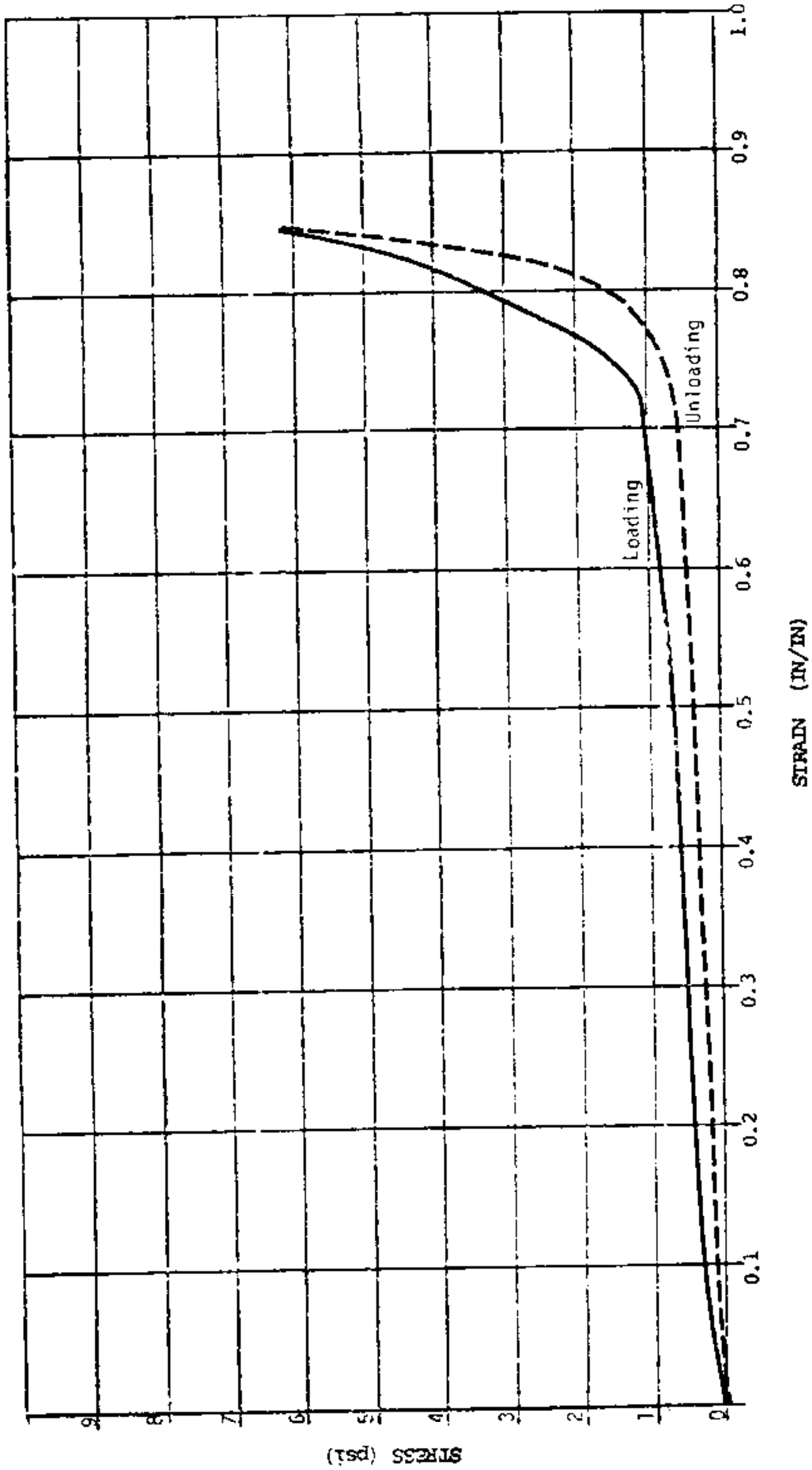


CHART 3. POLYURETHANE ETHER 4 PCF

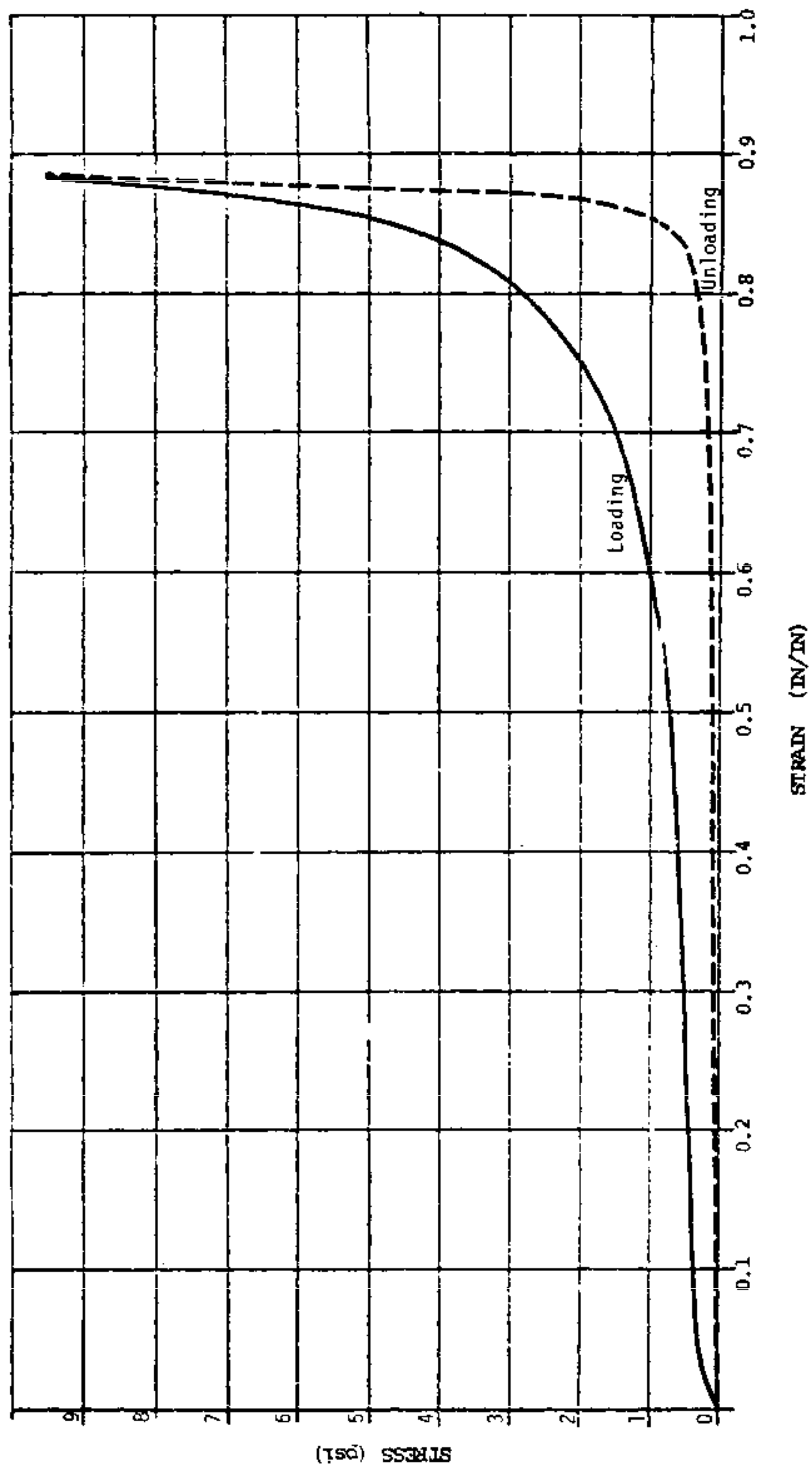


CHART 4. POLYURETHANE ESTER 1.5 PCF

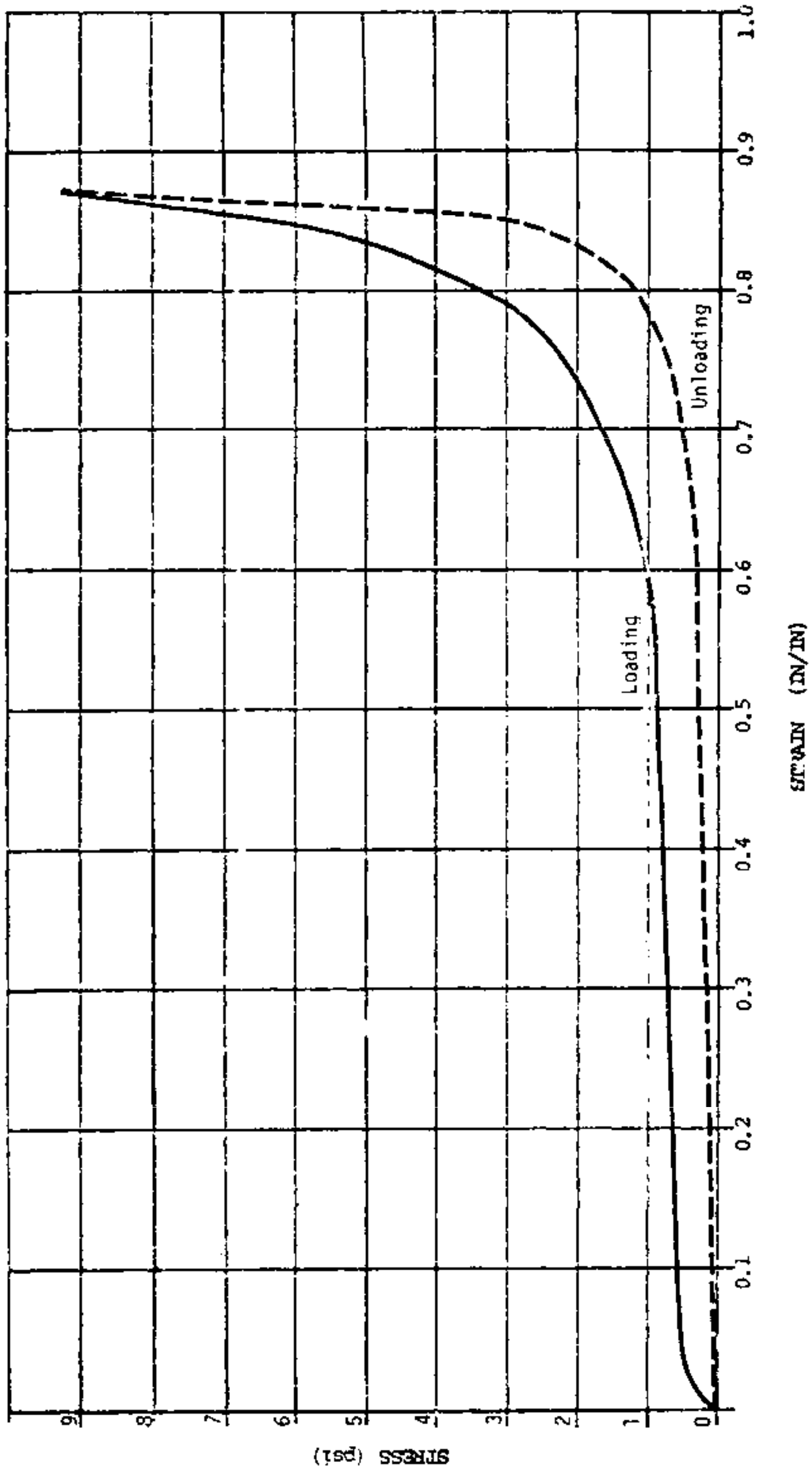
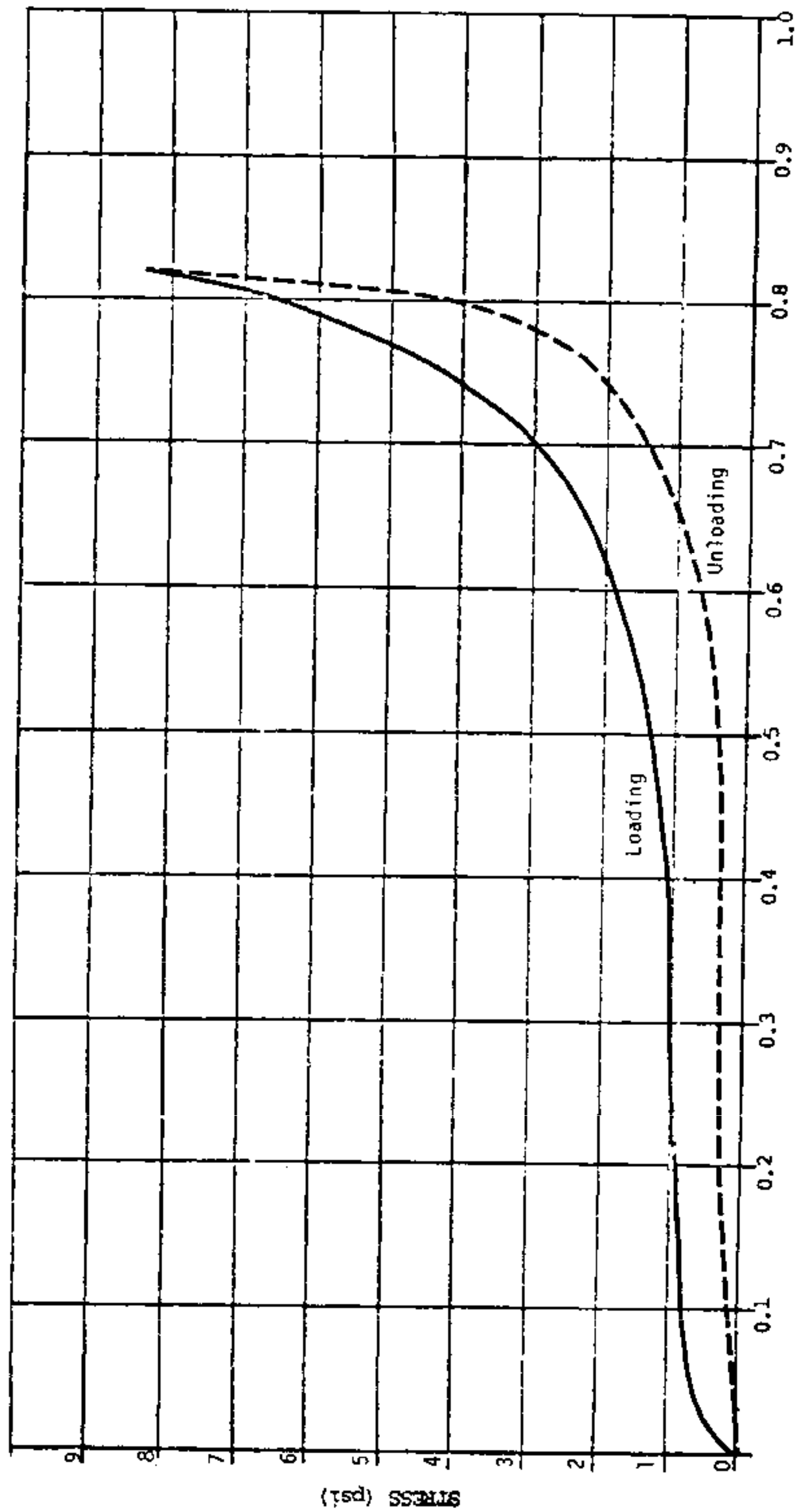


CHART 5. POLYURETHANE ESTER 2 PCF



STRAIN (IN/IN)

CHART 6. POLYURETHANE ESTER 4 PCF

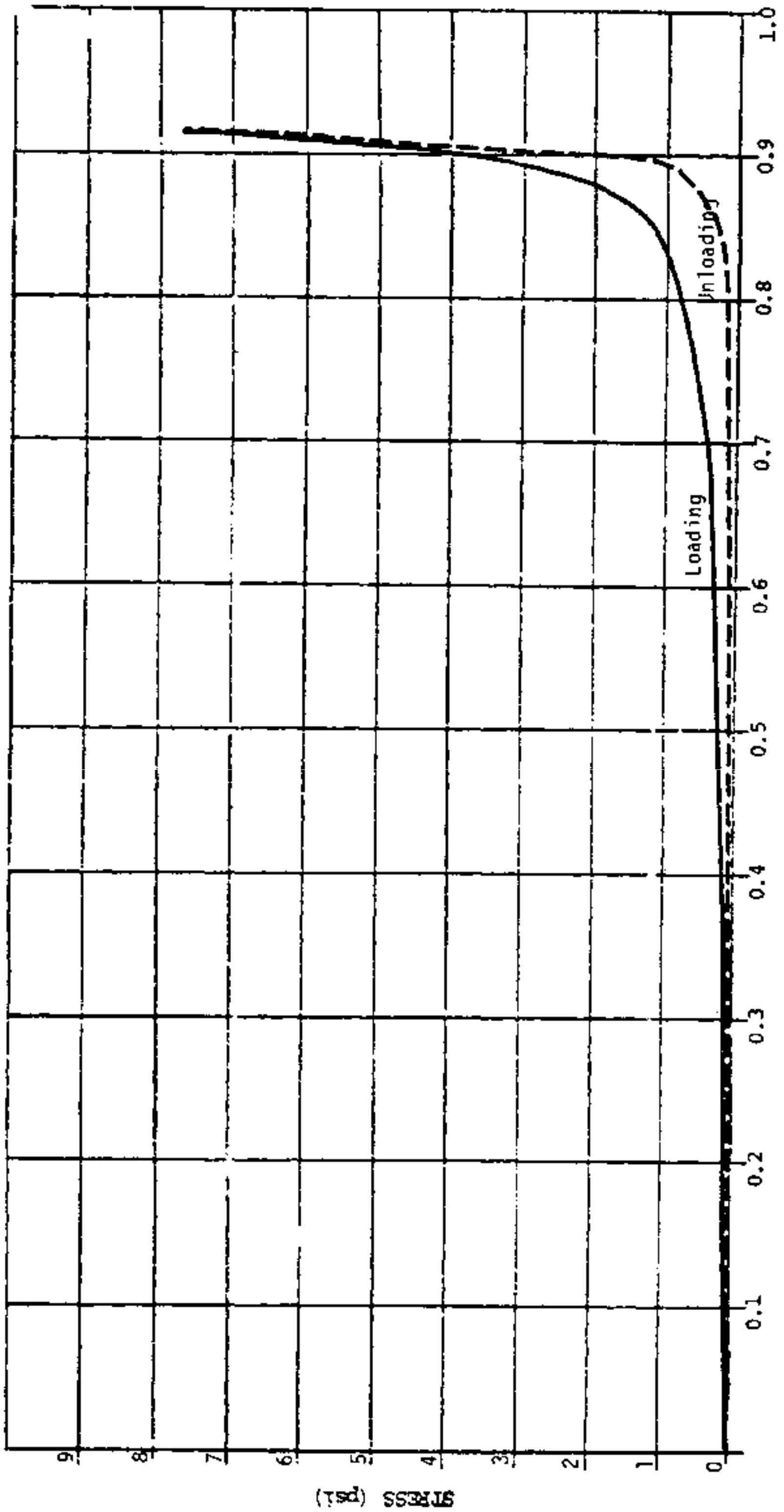


CHART 7. RUBBERIZED HAIR, TYPE II

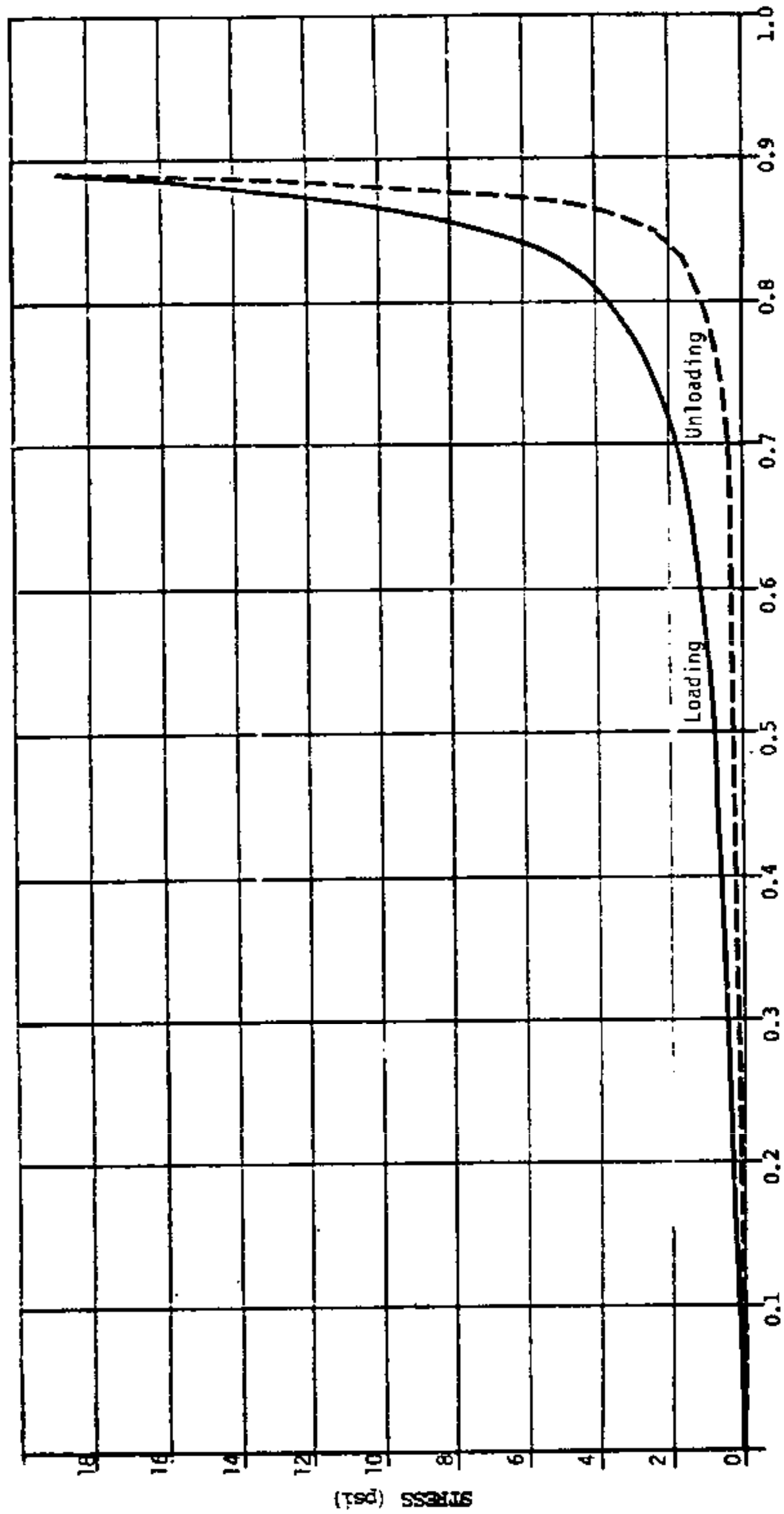


CHART 8. RUBBERIZED HAIR, TYPE III

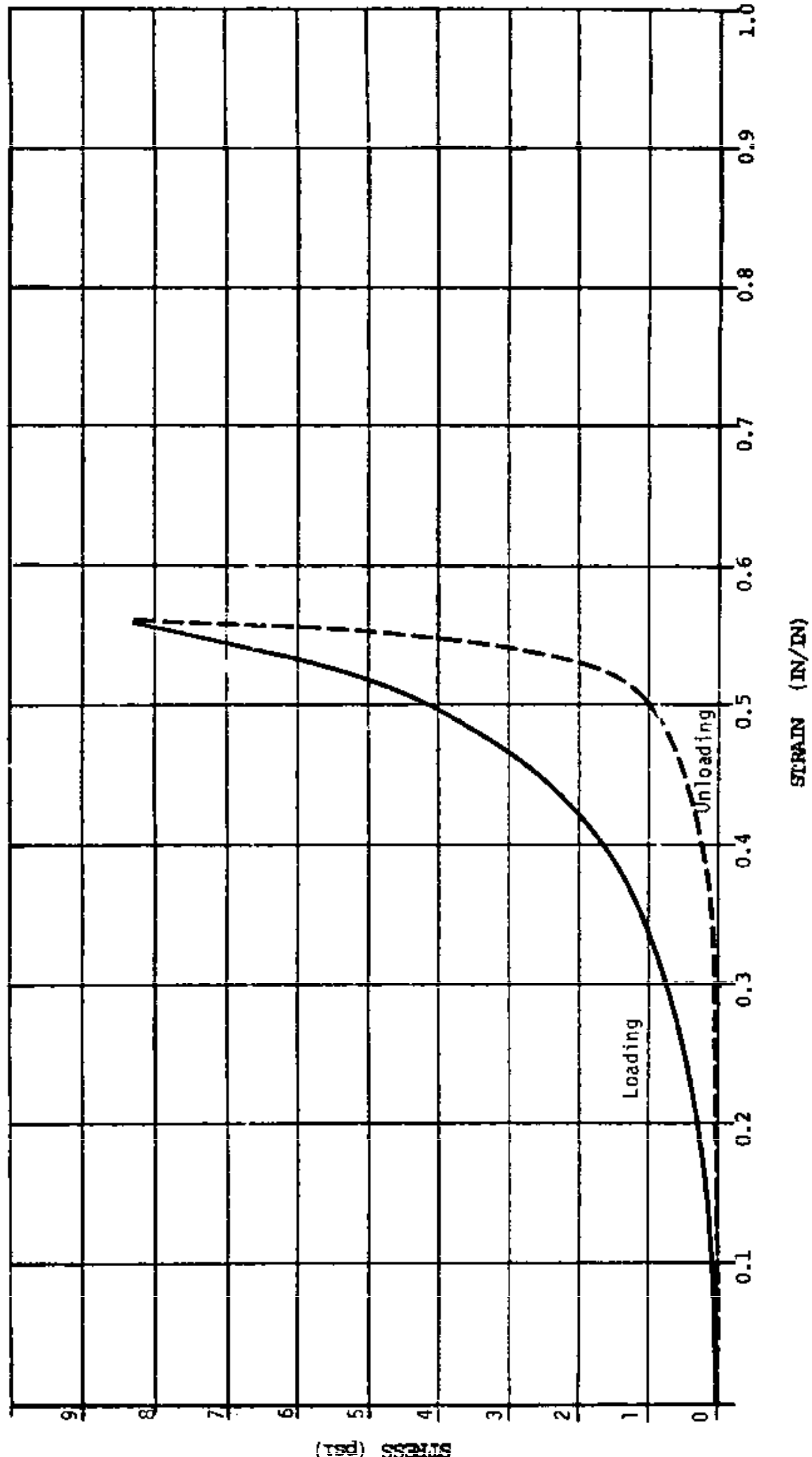
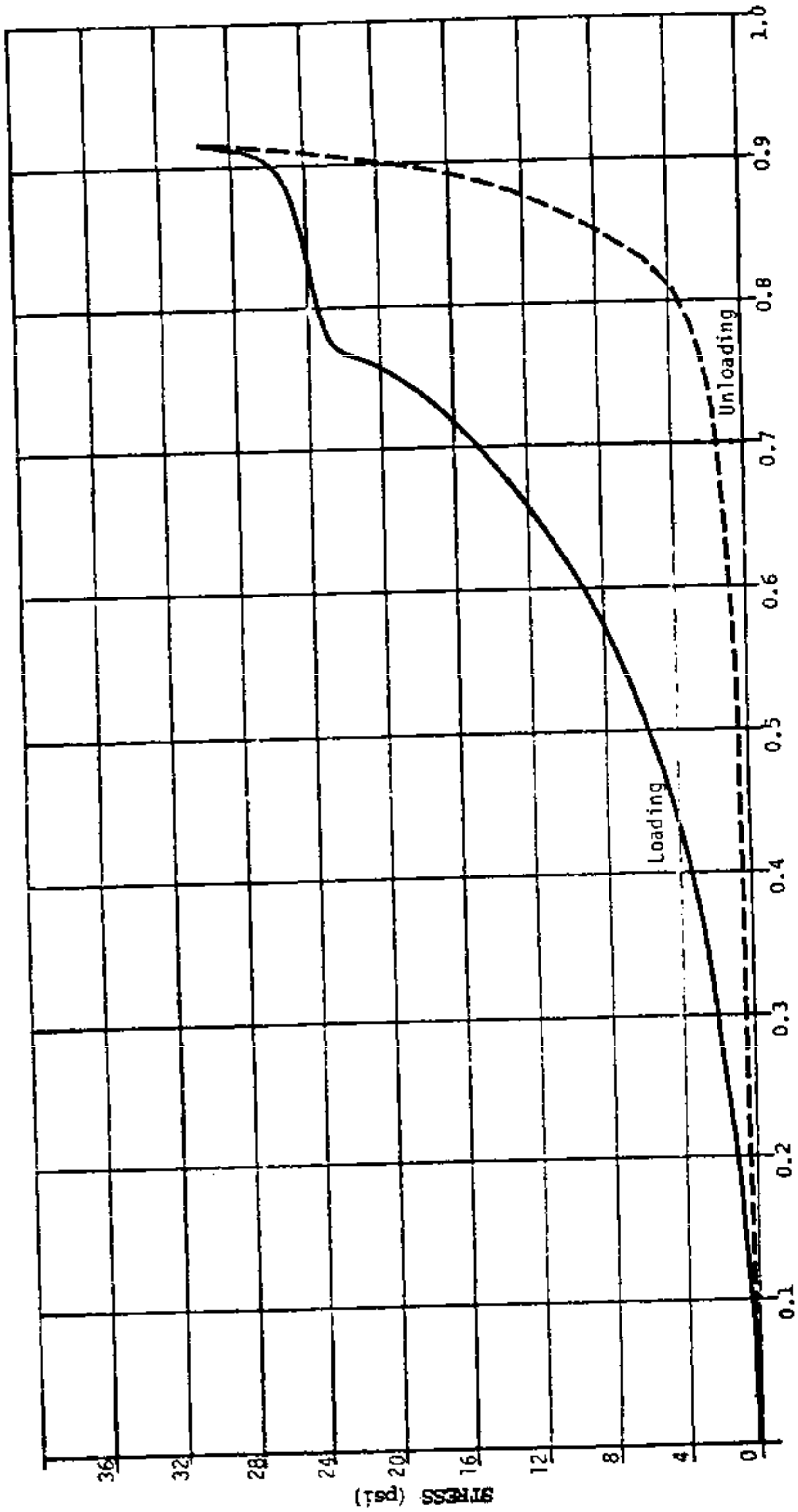


CHART 19. CELLULOSE WADDING



STRAIN (IN/IN)
CHART 20: AIR INCAPSULATED FILM

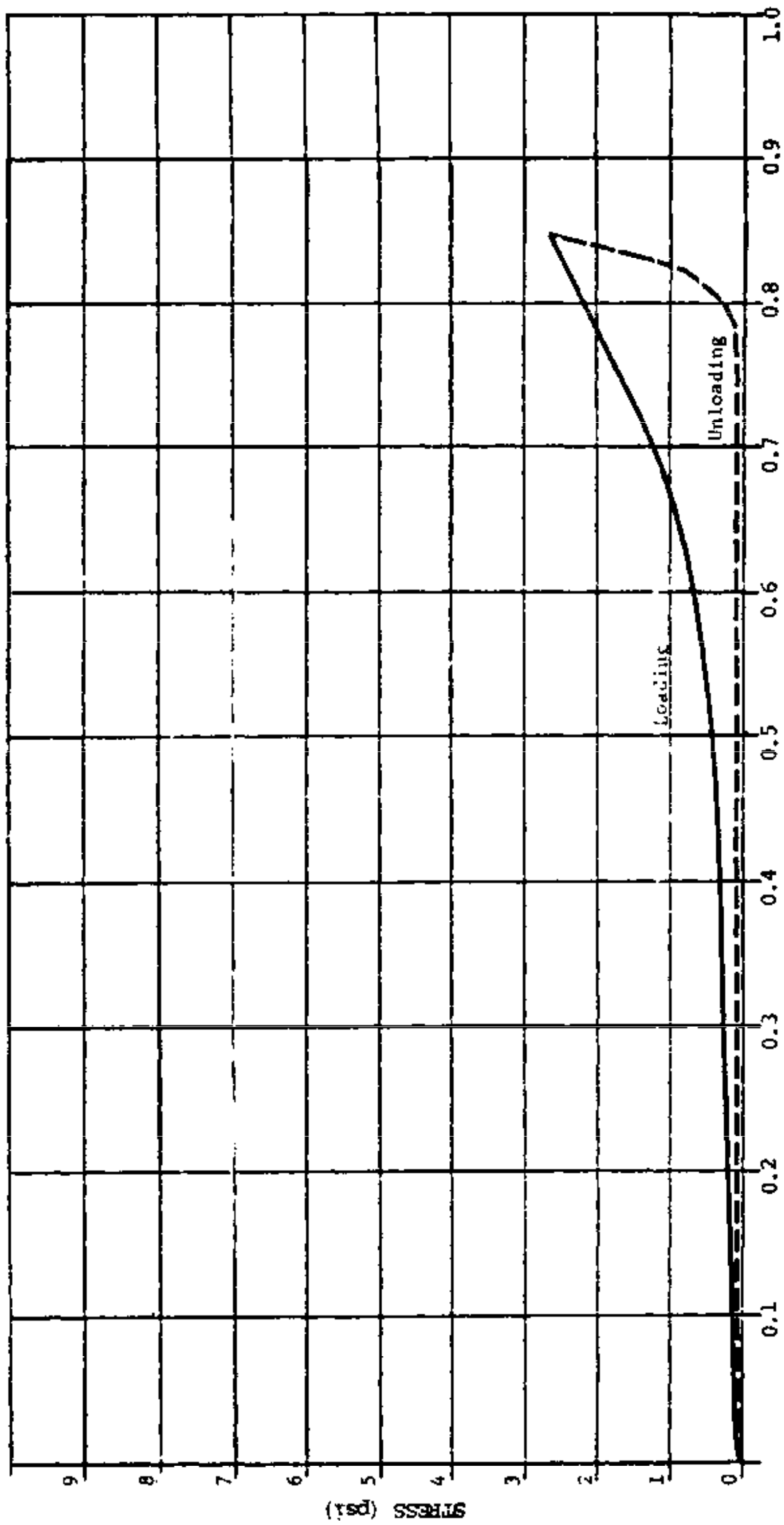


CHART 21. HEXOGONAL FILM, OPEN CELL

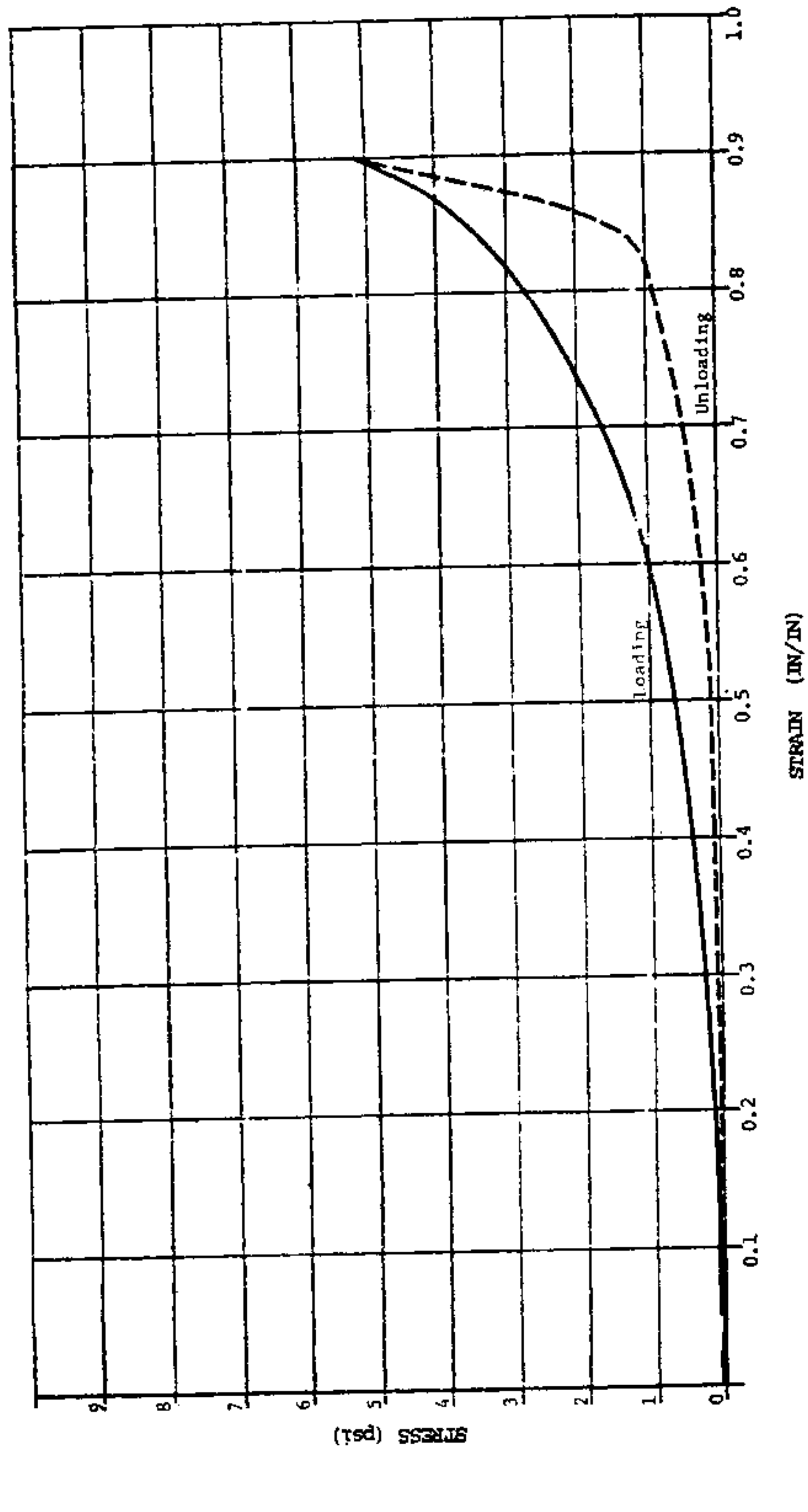


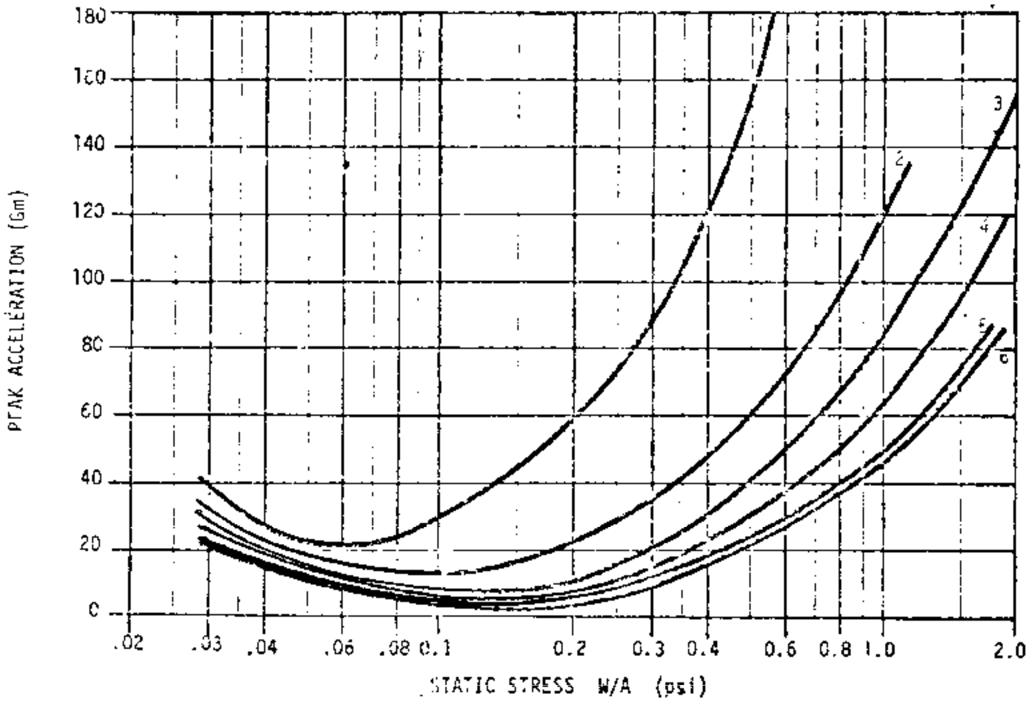
CHART 22. HEXOGONAL FILM, REINFORCED CELL

APPENDIX V. PEAK ACCELERATION - STATIC STRESS CURVES

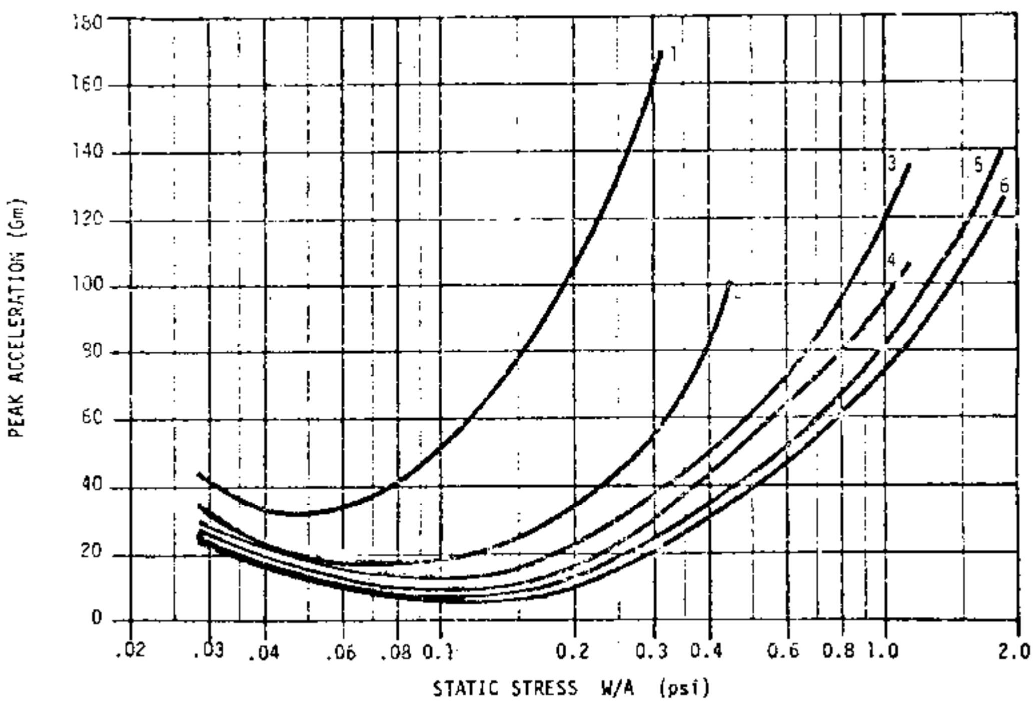
Peak acceleration - static stress curves (Graphs 1.12 thru 22.48) are presented in this Appendix for drop heights of 12, 18, 24, 30, 36, 42 and 48 inches. Material thicknesses are given in inches at the end of each curve.

For discussion of the derivation of Gin-W/A curves, refer to 6.1.2.1; for details about their use, refer to 3.2.1.1.

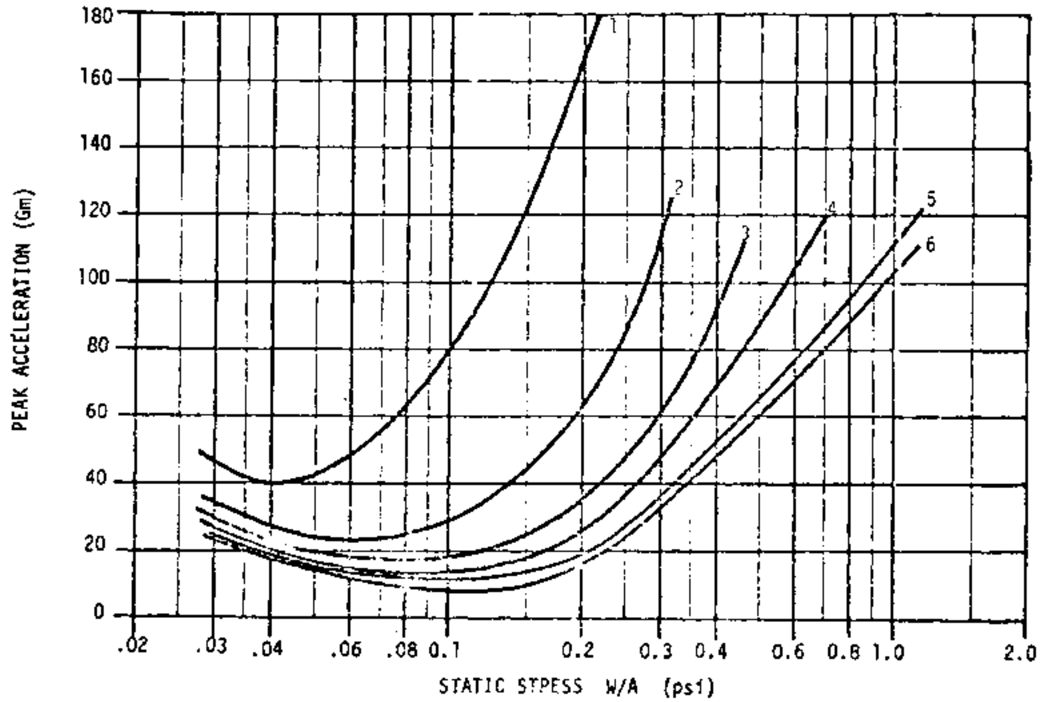
All data given herein were derived from empirical tests conducted under contract by AFPEA, Wright-Patterson AFB OH, under controlled atmospheric conditions of 73°F and 50 percent relative humidity and are generally representative of commercially available materials (complete listing on Page xiv). However, due to manufacturing variations in some materials, shock levels in the resulting package may not be identical to the data represented here. If excessive variation is suspected, free fall drop testing as outlined in Section 6.3 is encouraged to verify desired levels of protection.



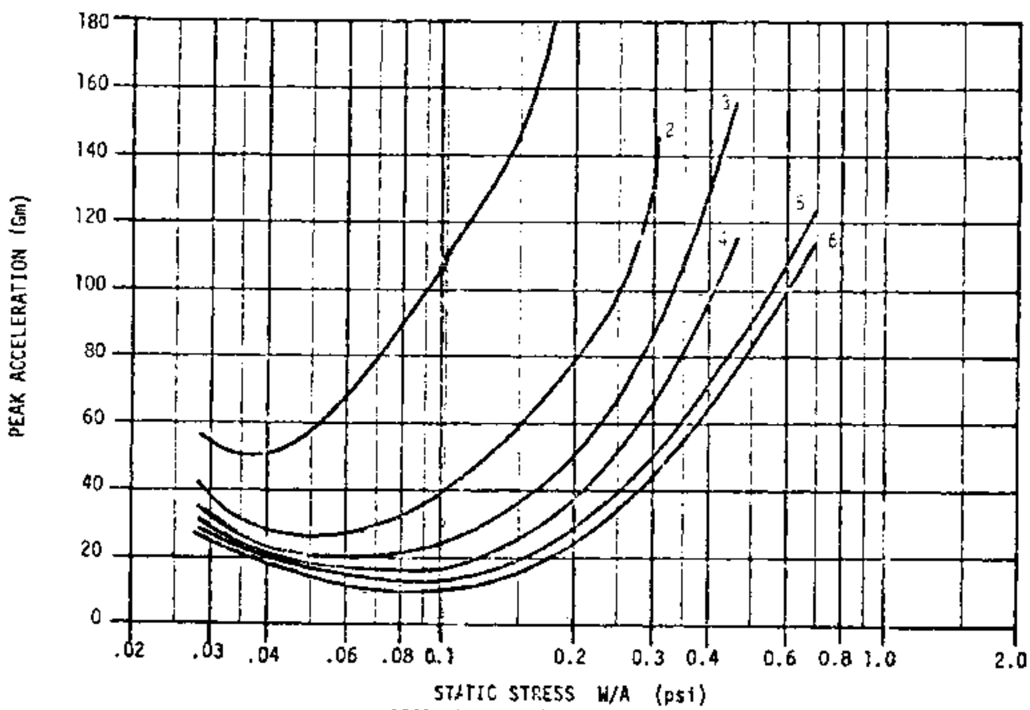
GRAPH 1.12: POLYURETHANE ETHER,
1.5 pcf, 12" Drop Height



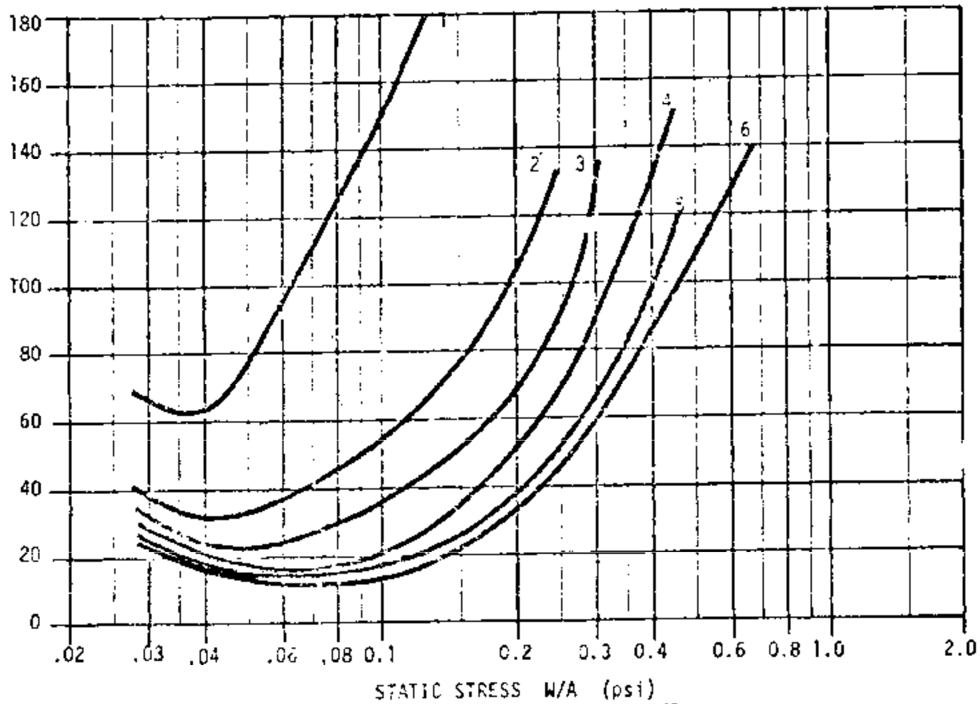
GRAPH 1.18: POLYURETHANE ETHER
1.5 pcf, 18" Drop Height



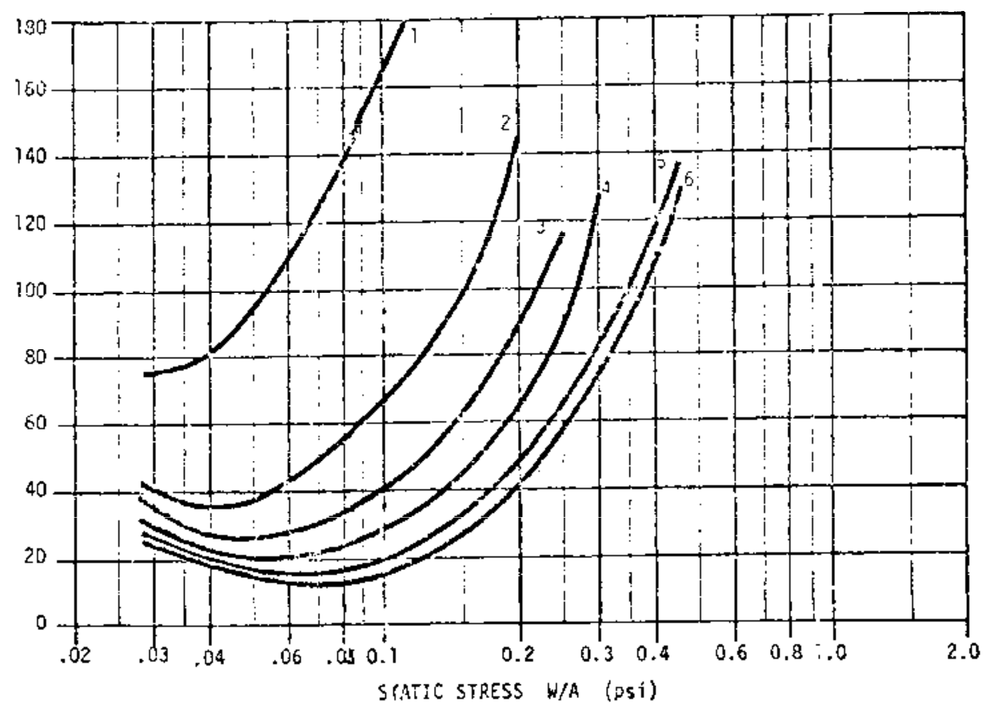
GRAPH 1.24: POLYURETHANE ETHER,
1.5 pcf, 24" Drop Height



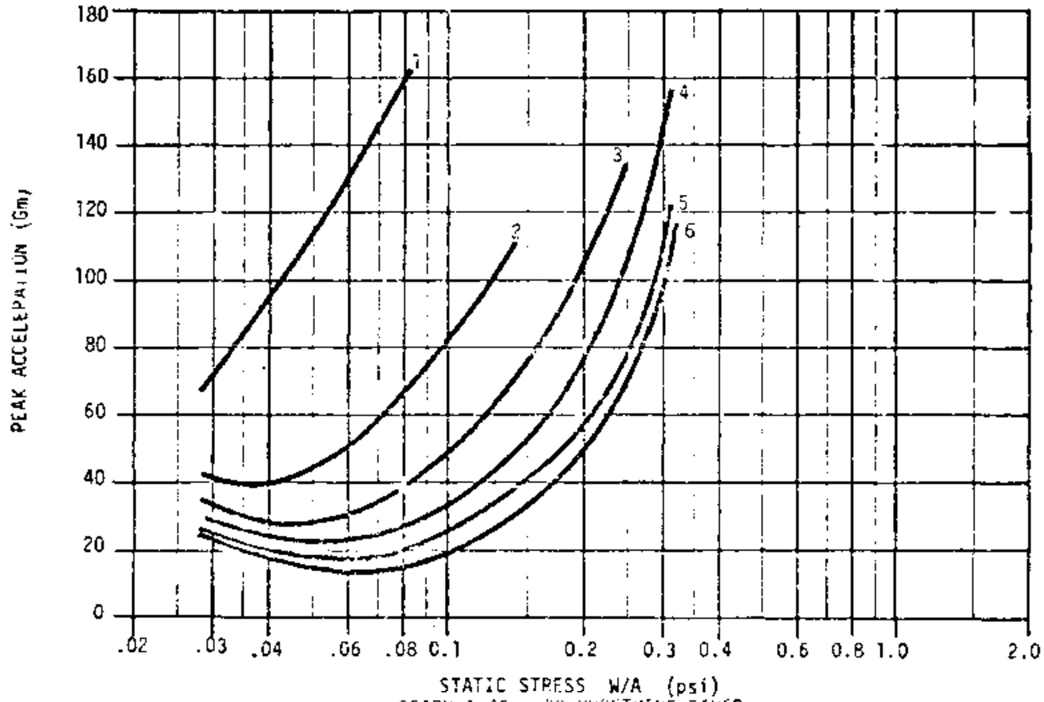
GRAPH 1.30: POLYURETHANE ETHER,
1.5 pcf, 30" Drop Height



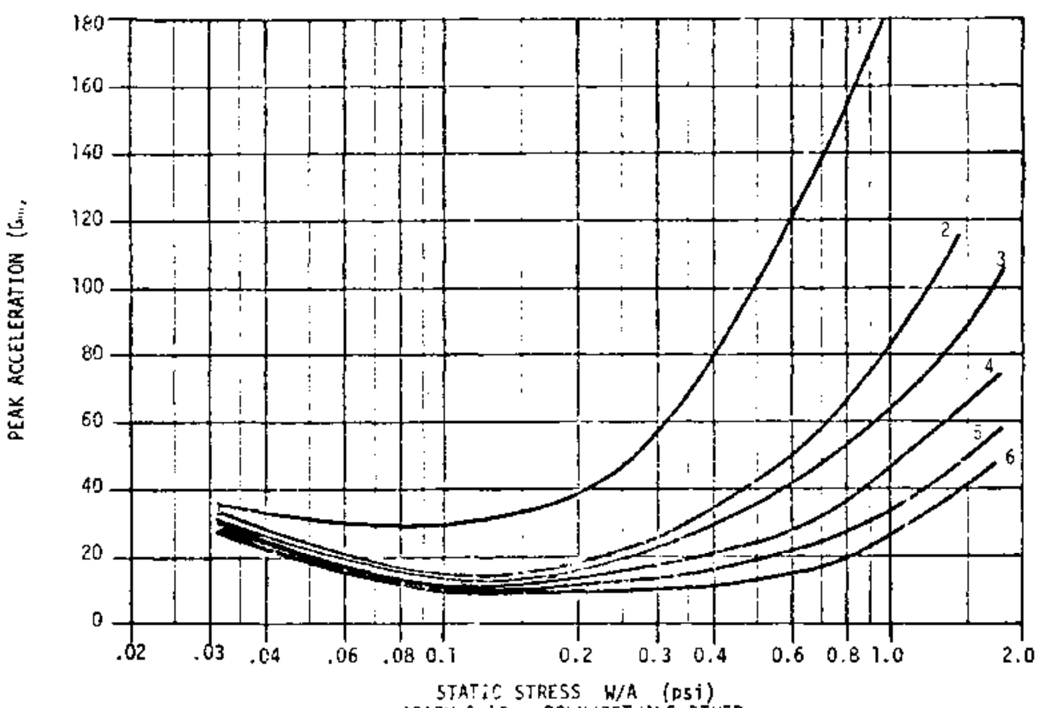
GRAPH 1.36: POLYURETHANE ETHER,
1.5 pcf, 36" Drop Height



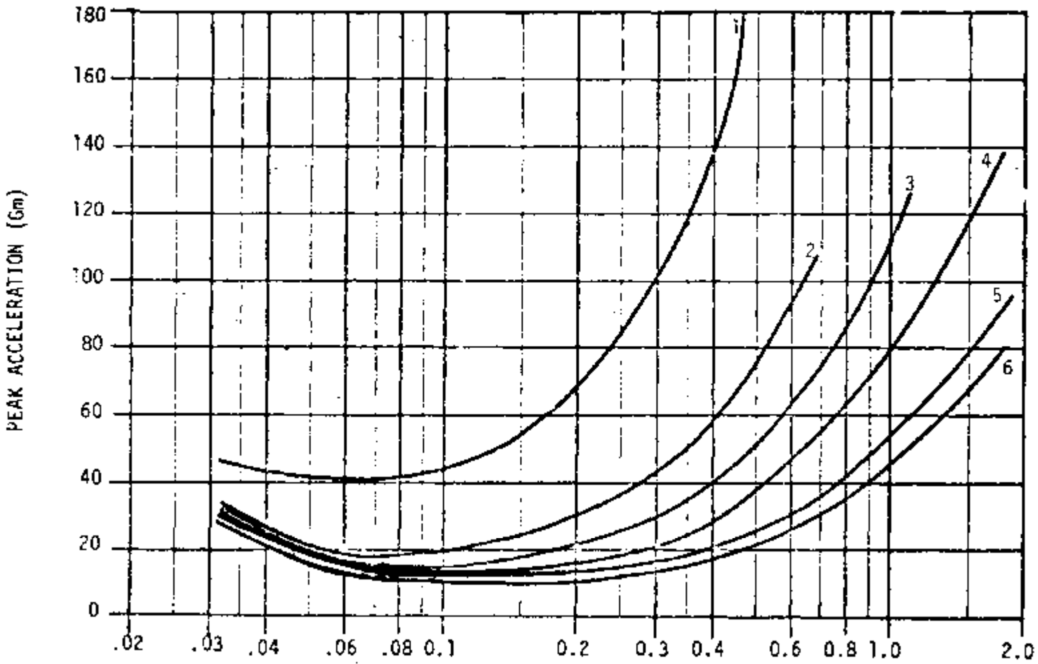
GRAPH 1.42: POLYURETHANE ETHER
1.5 pcf, 42" Drop Height



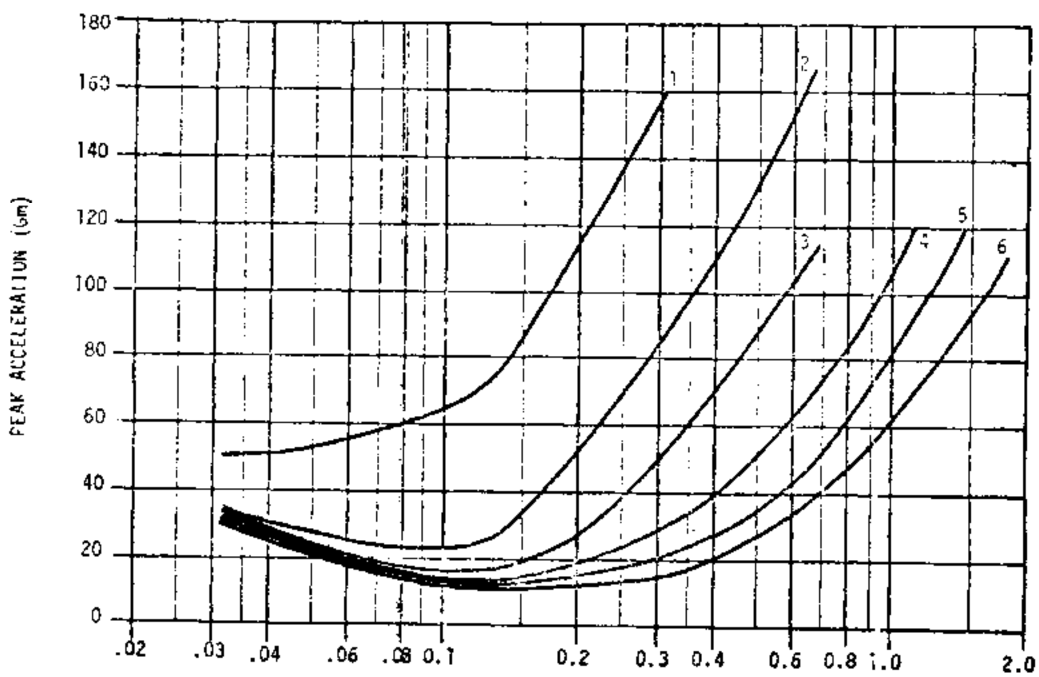
GRAPH 1.48: POLYURETHANE ETHER,
1.5 pcf, 43" Drop Height



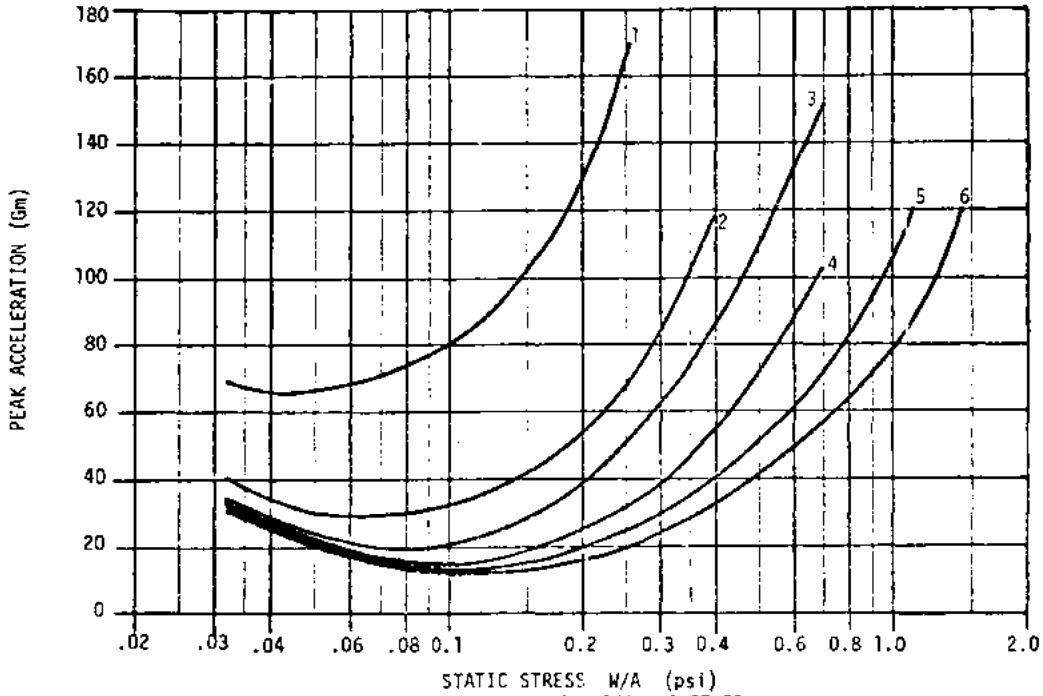
GRAPH 2.12: POLYURETHANE ETHER,
2 pcf, 12" Drop Height



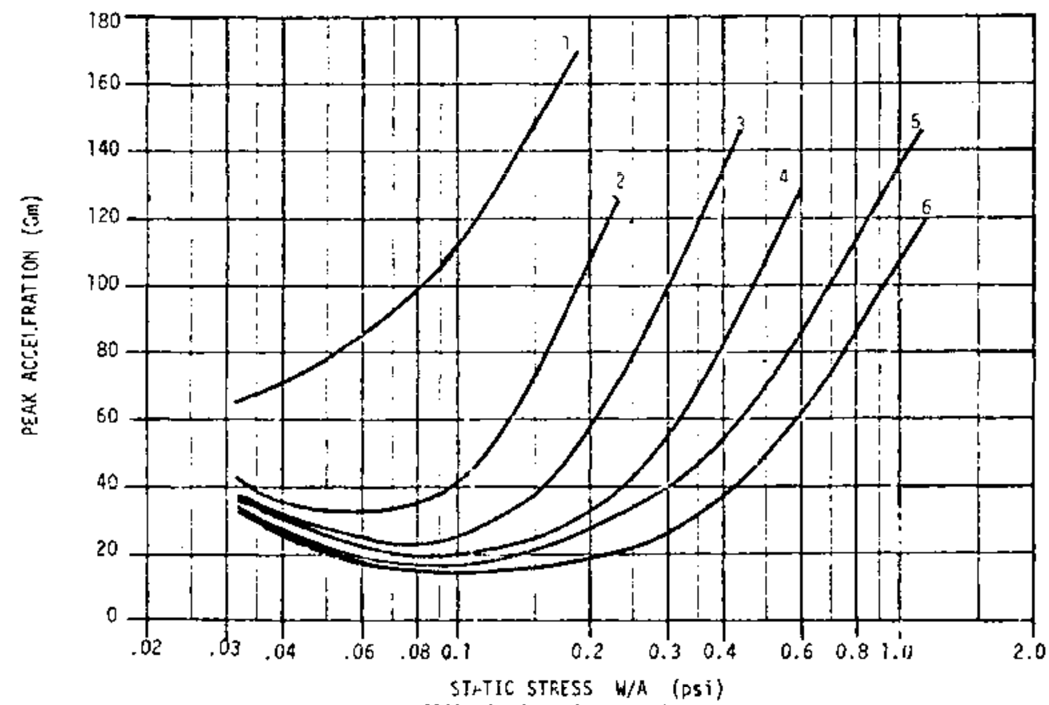
GRAPH 2.18: POLYURETHANE ETHER,
2 pcf, 18" Drop Height



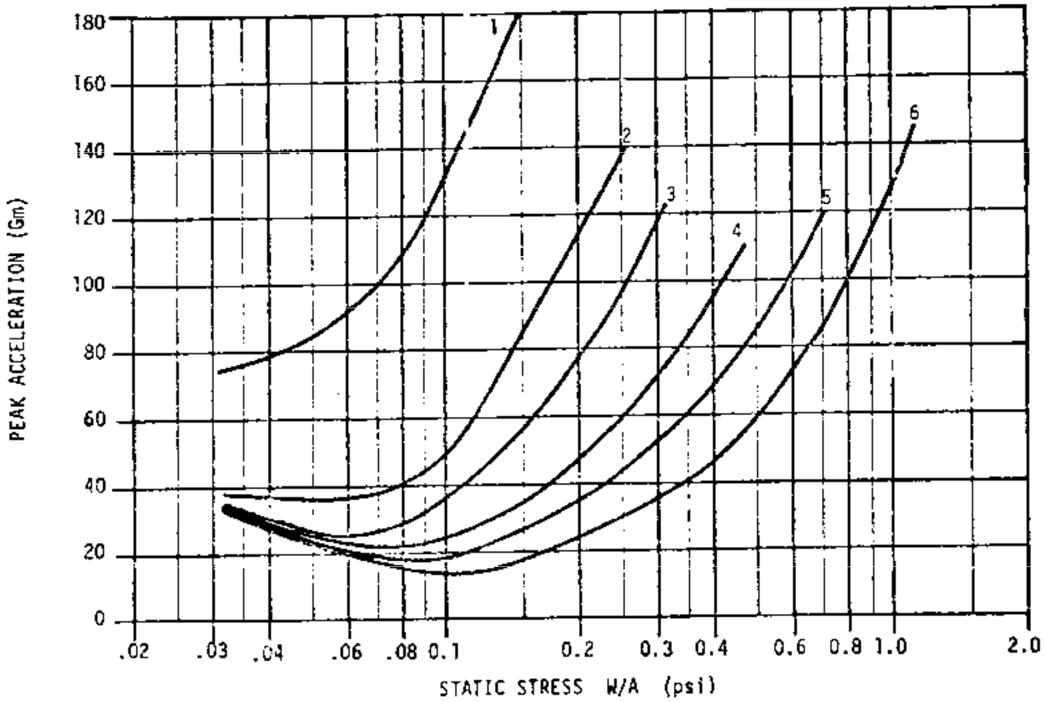
GRAPH 2.24: POLYURETHANE ETHER
2 pcf, 24" Drop Height



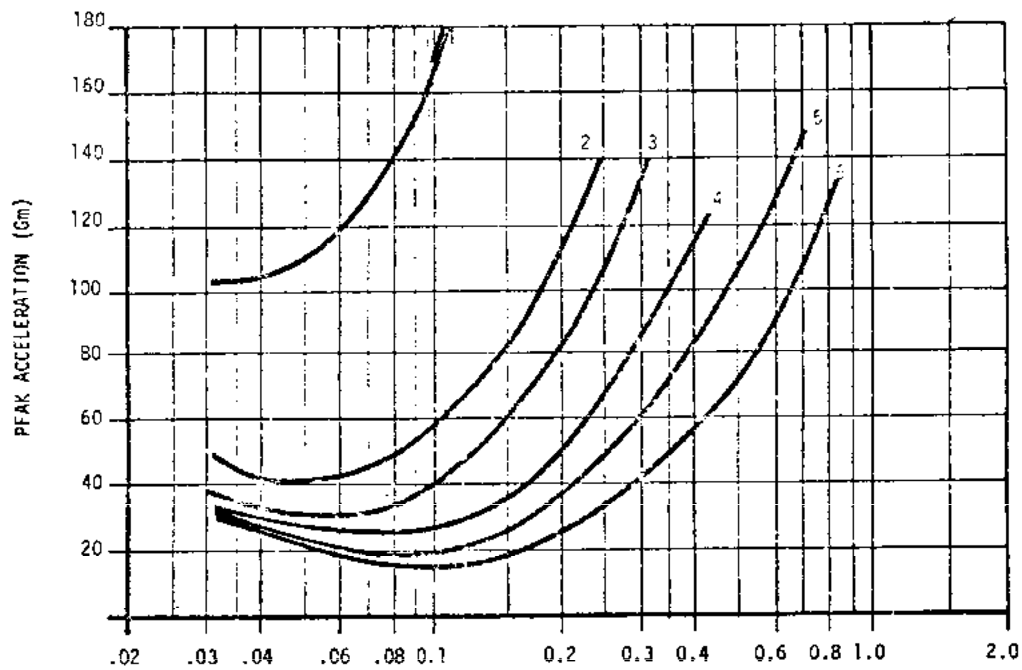
GRAPH 2.30: POLYURETHANE ETHER
2 pcf, 30" Drop Height



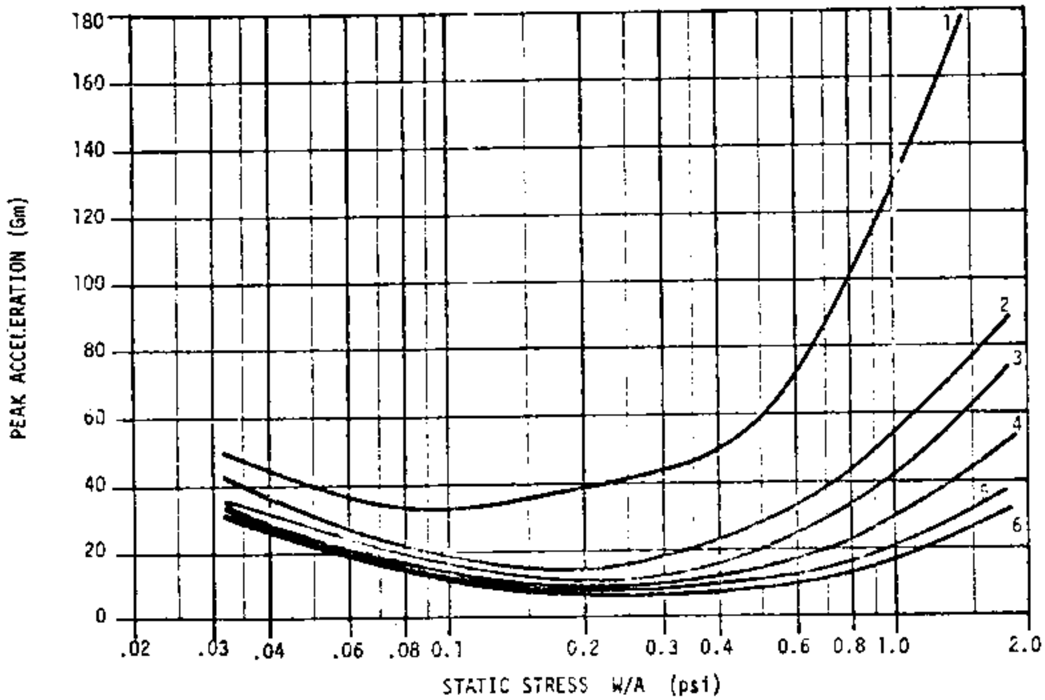
GRAPH 2.36: POLYURETHANE ETHER
2 pcf, 36" Drop Height



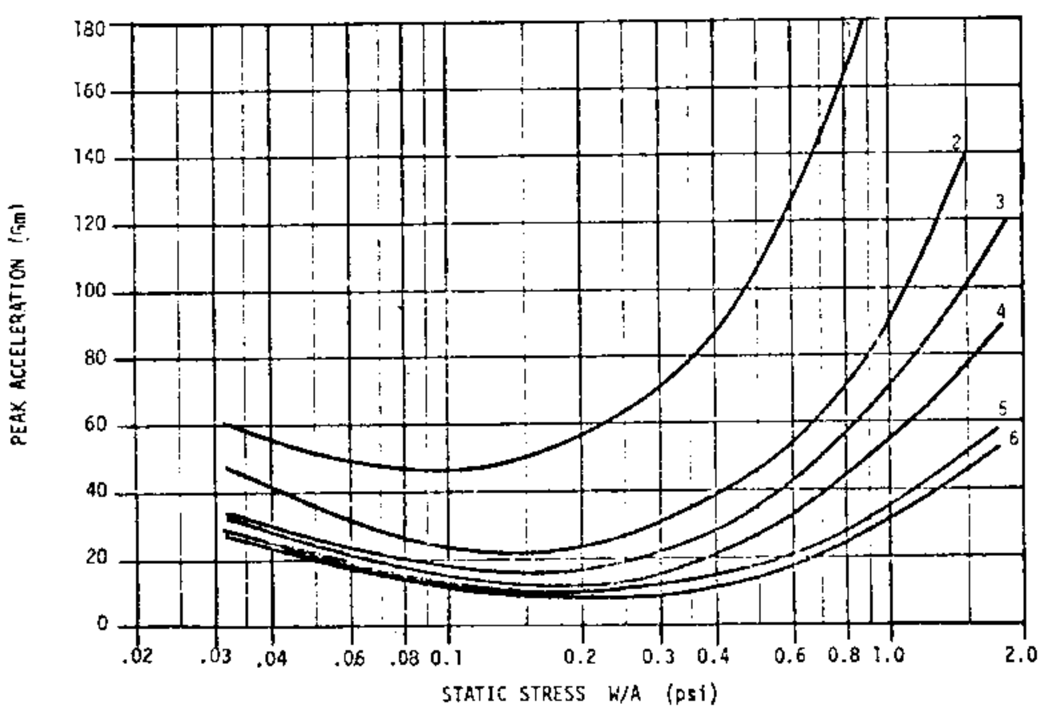
GRAPH 2.42: POLYURETHANE ETHER,
2 pcf, 42" Drop Height



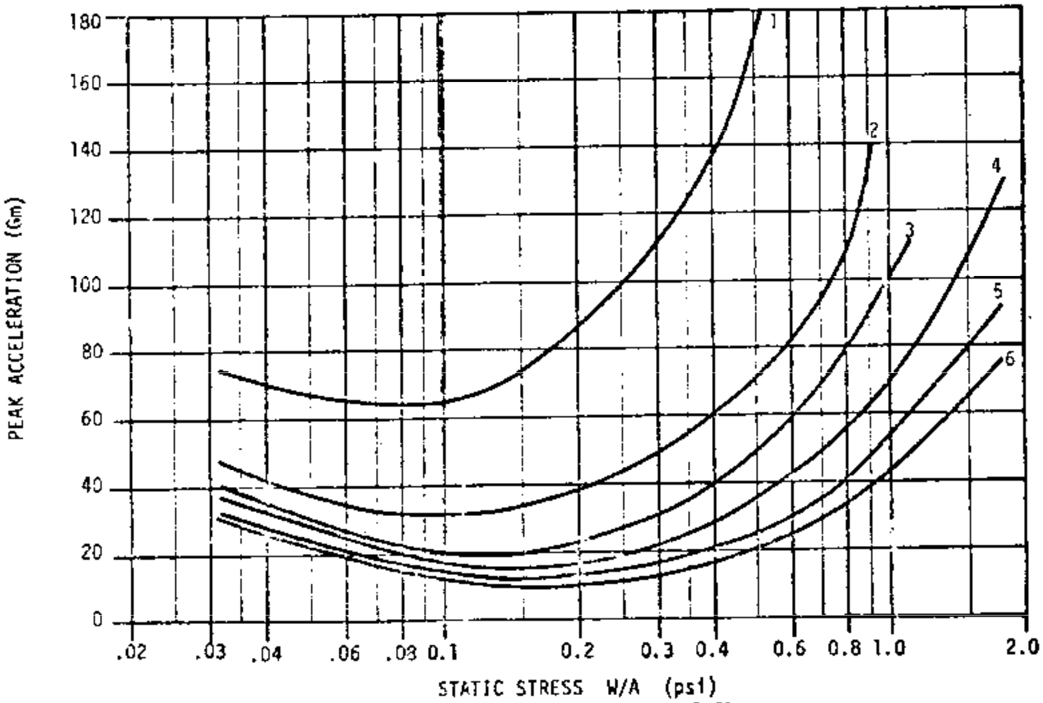
GRAPH 2.-8: POLYURETHANE ETHER
2 pcf, 48" Drop Height



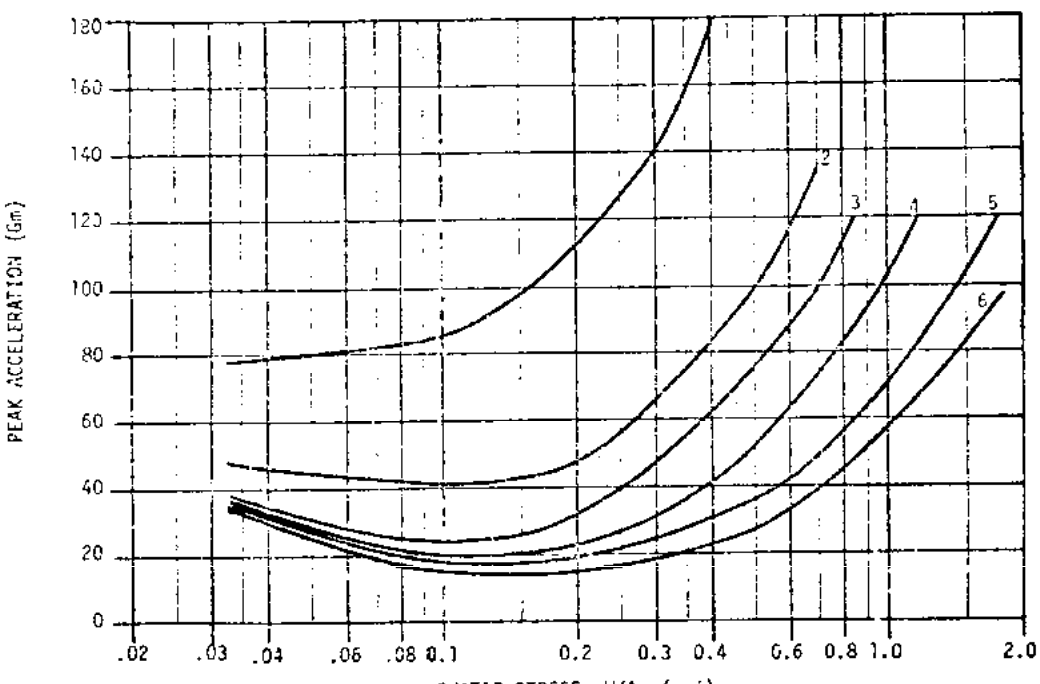
GRAPH 3.12: POLYURETHANE ETHER,
4 pcf, 12" Drop Height



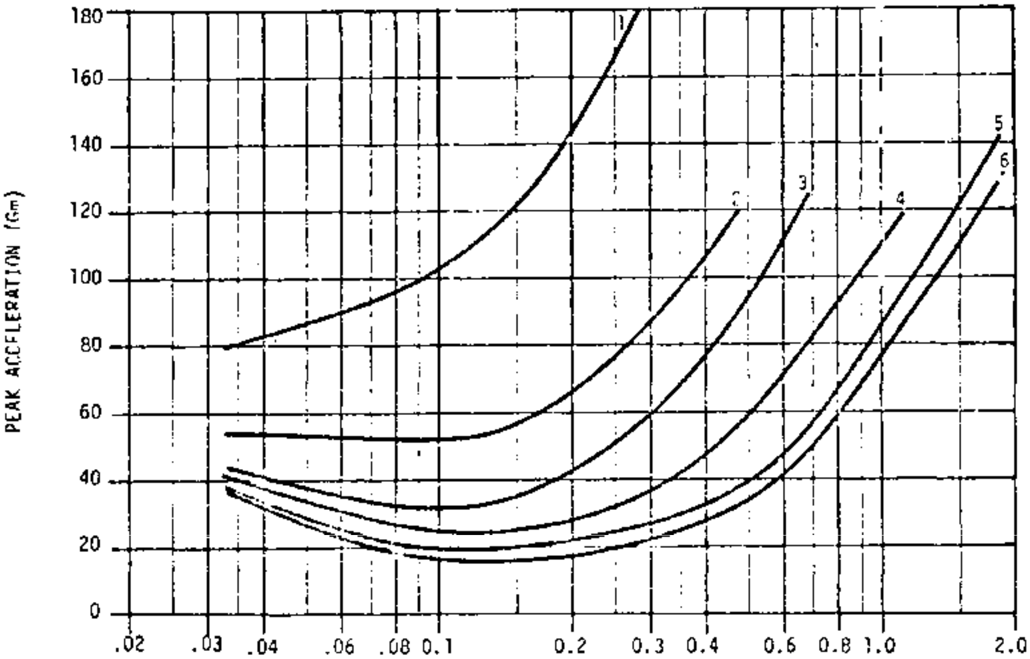
GRAPH 3.18: POLYURETHANE ETHER,
4 pcf, 18" Drop Height



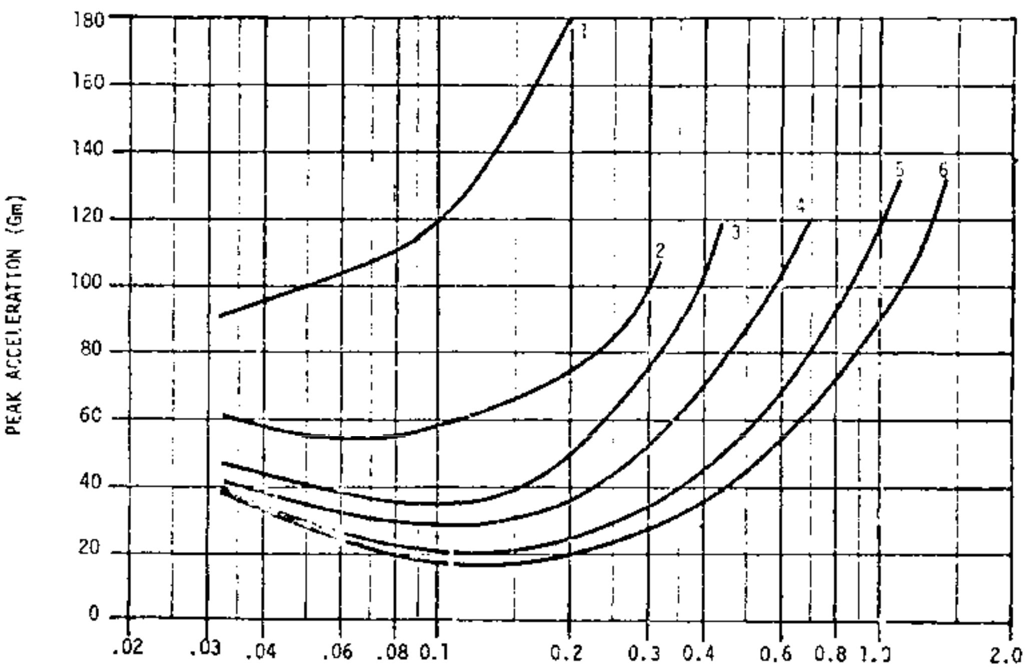
GRAPH 3.24: POLYURETHANE ETHER,
4 pcf, 24" Drop Height



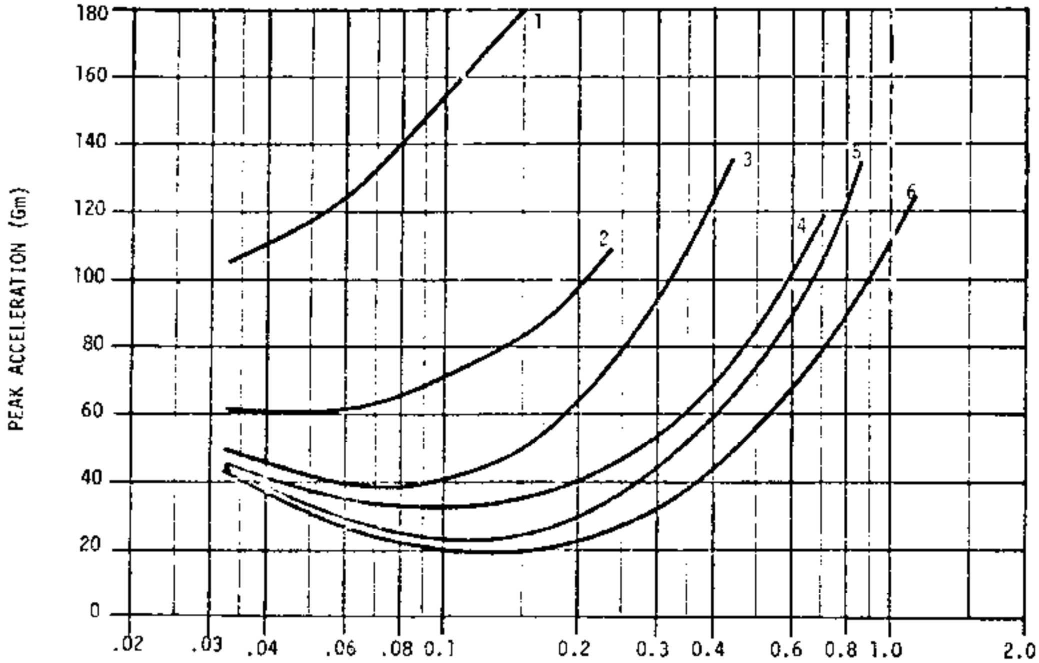
GRAPH 3.30: POLYURETHANE ETHER,
4 pcf, 30" Drop Height



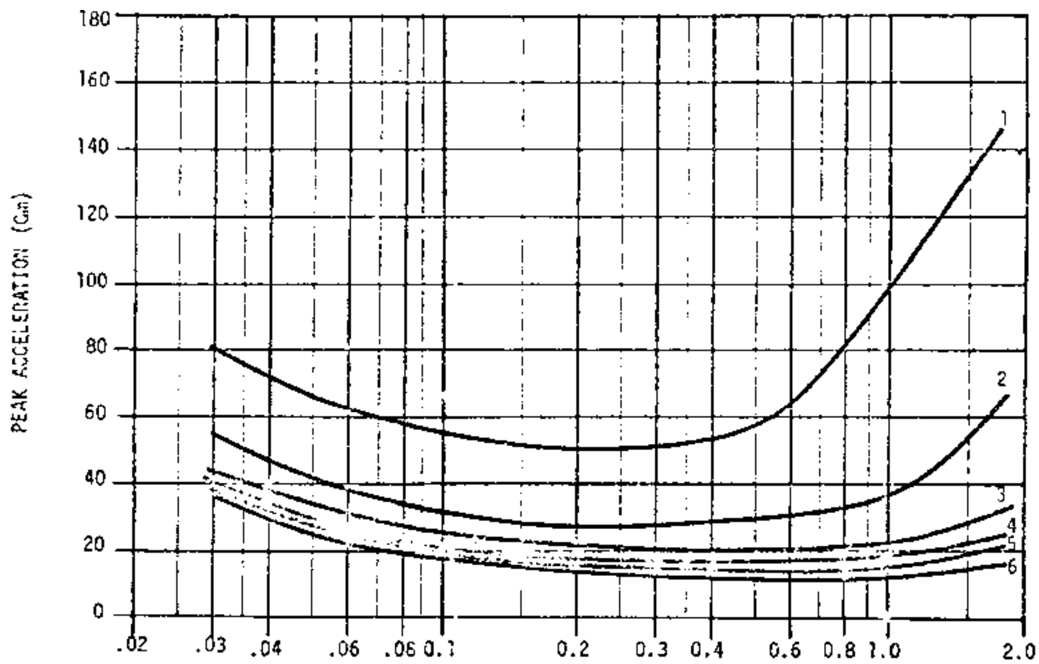
GRAPH 3.36: POLYURETHANE ETHER
4pcf, 36" Drop Height



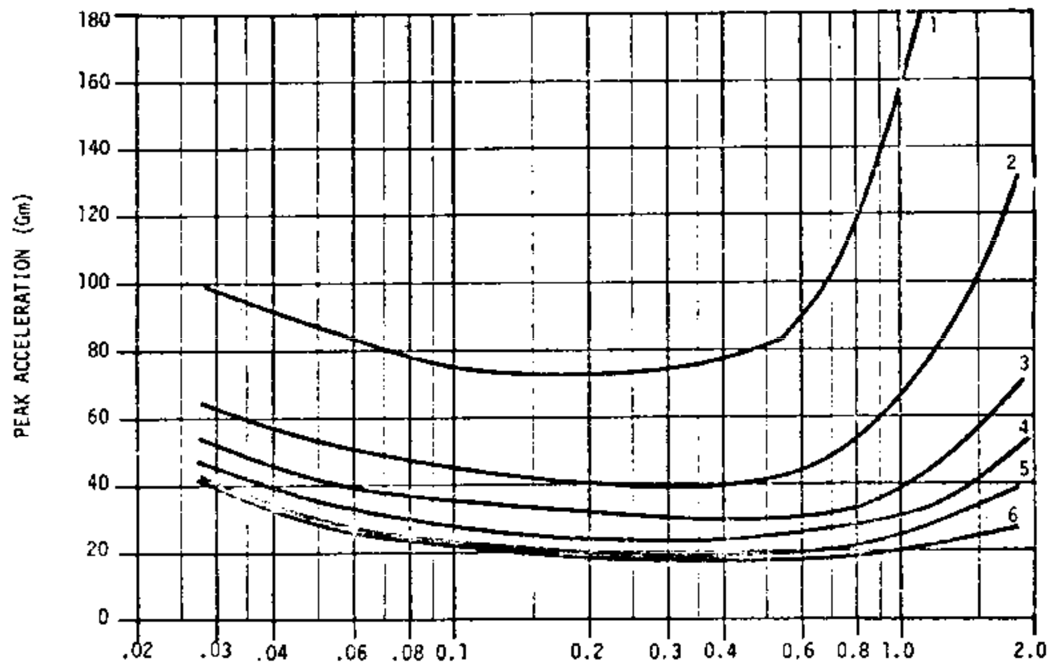
GRAPH 3.42: POLYURETHANE ETHER,
4 pcf, 42" Drop Height



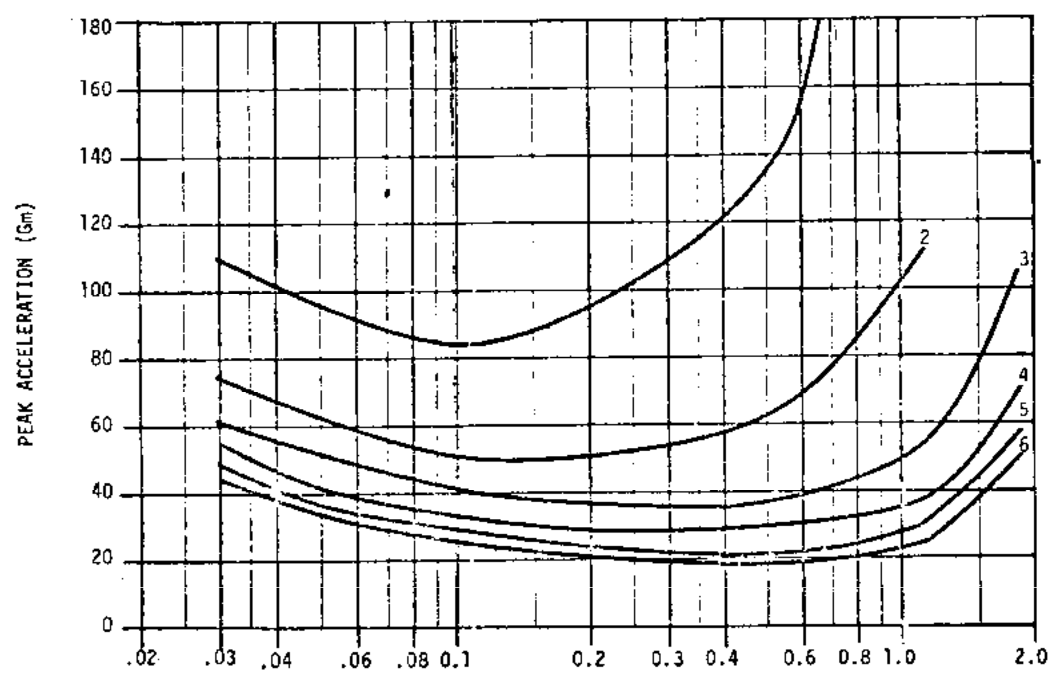
GRAPH 3.48: POLYURETHANE ETHER, 4 pcf, 48" Drop Height



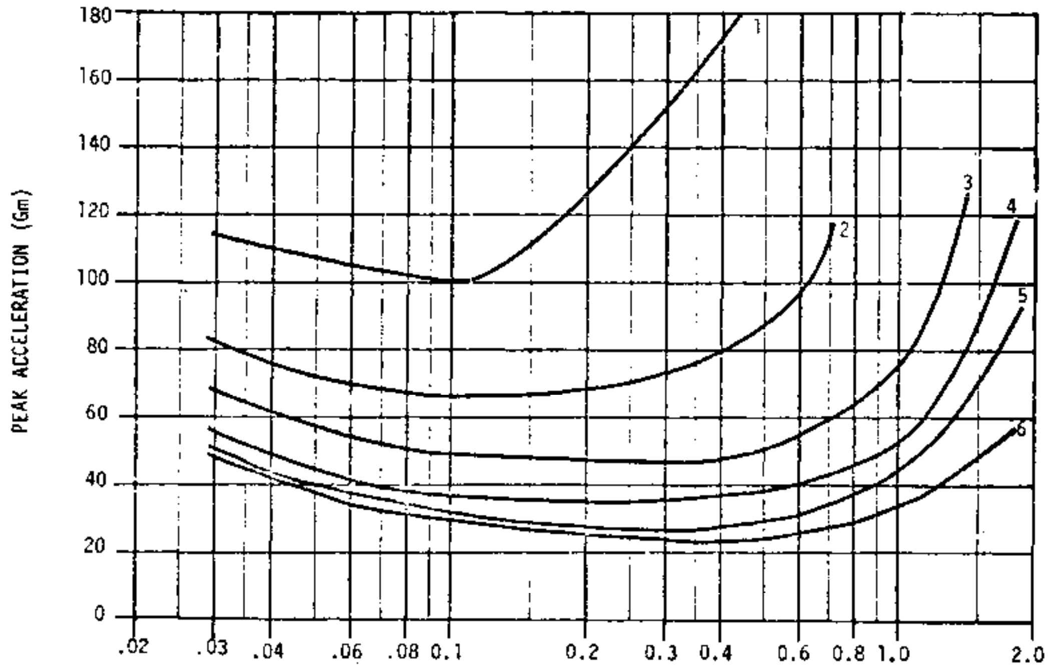
GRAPH 4.12: POLYURETHANE ESTER, 1.5 pcf, 12" Drop Height



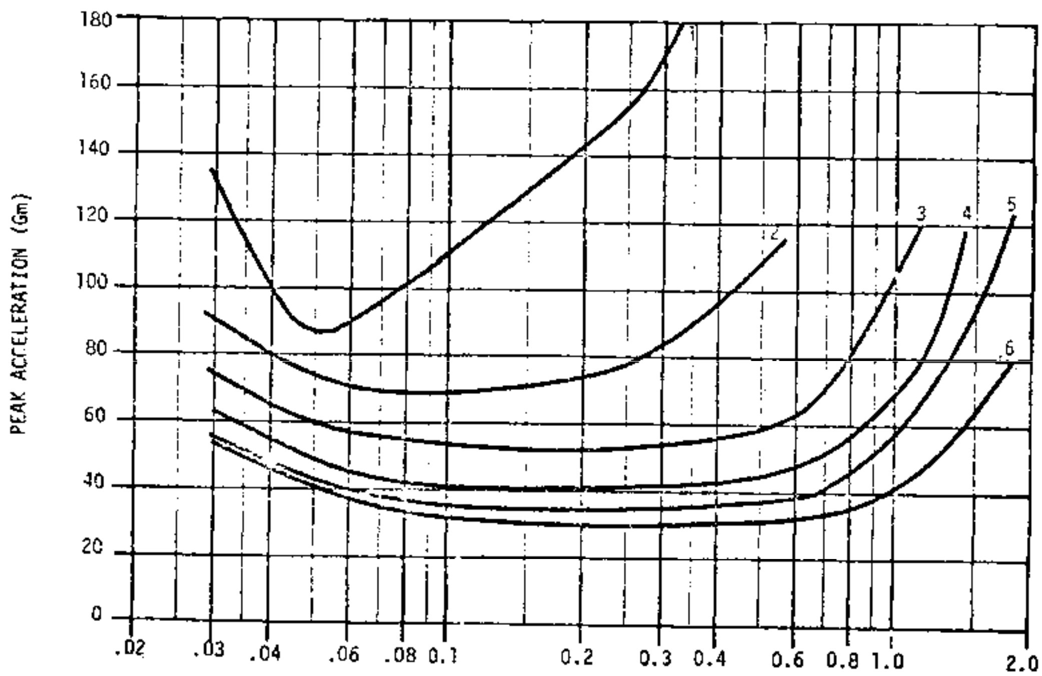
GRAPH 4.18: POLYURETHANE ESTER,
1.5 pcf, 18" Drop Height



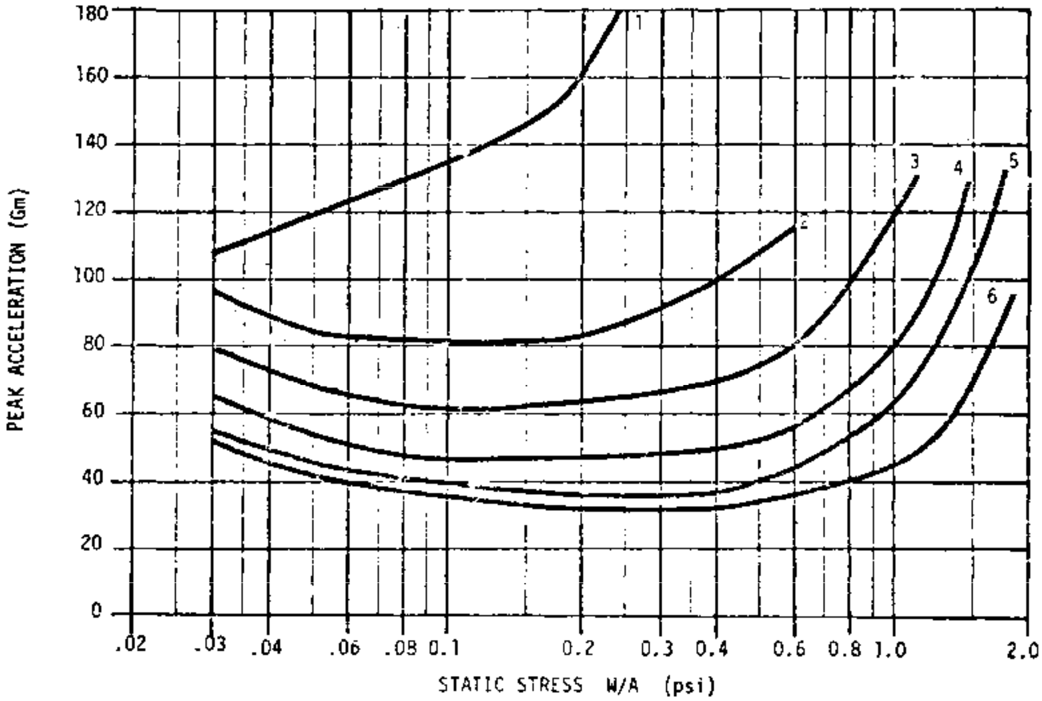
GRAPH 4.24: POLYURETHANE ESTER,
1.5 pcf, 24" Drop Height



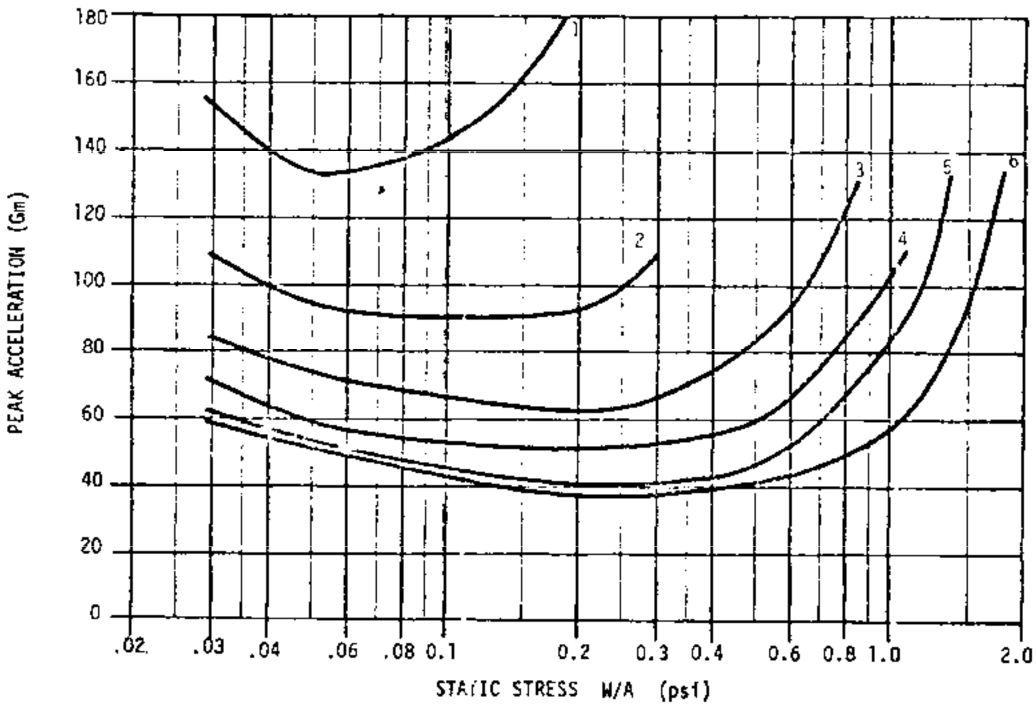
GRAPH 4.30: POLYURETHANE ESTER,
1.5 pcf, 30" Drop Height



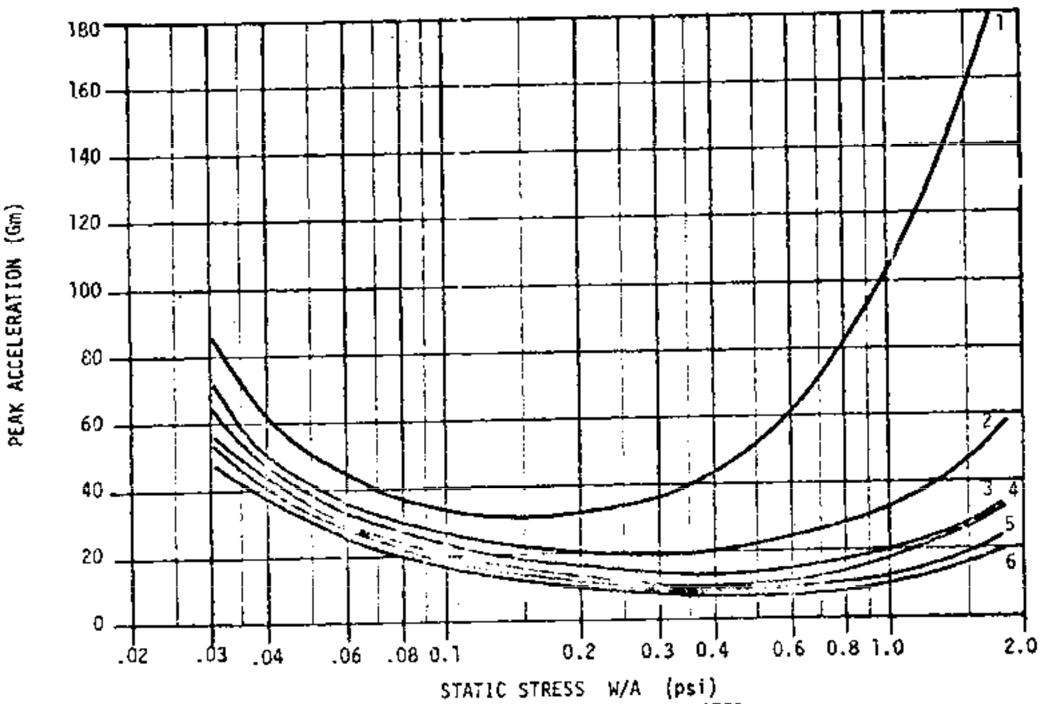
GRAPH 4.36: POLYURETHANE ESTER,
1.5 pcf, 36" Drop Height



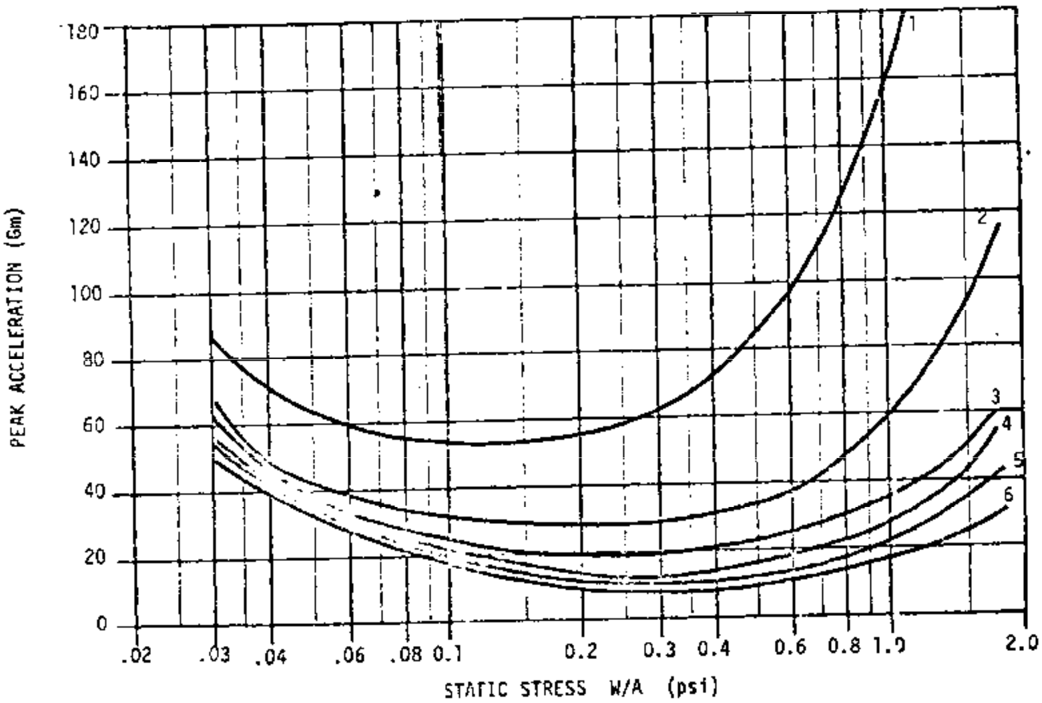
GRAPH 4.42: POLYURETHANE ESTER,
1.5 pcf, 42" Drop Height



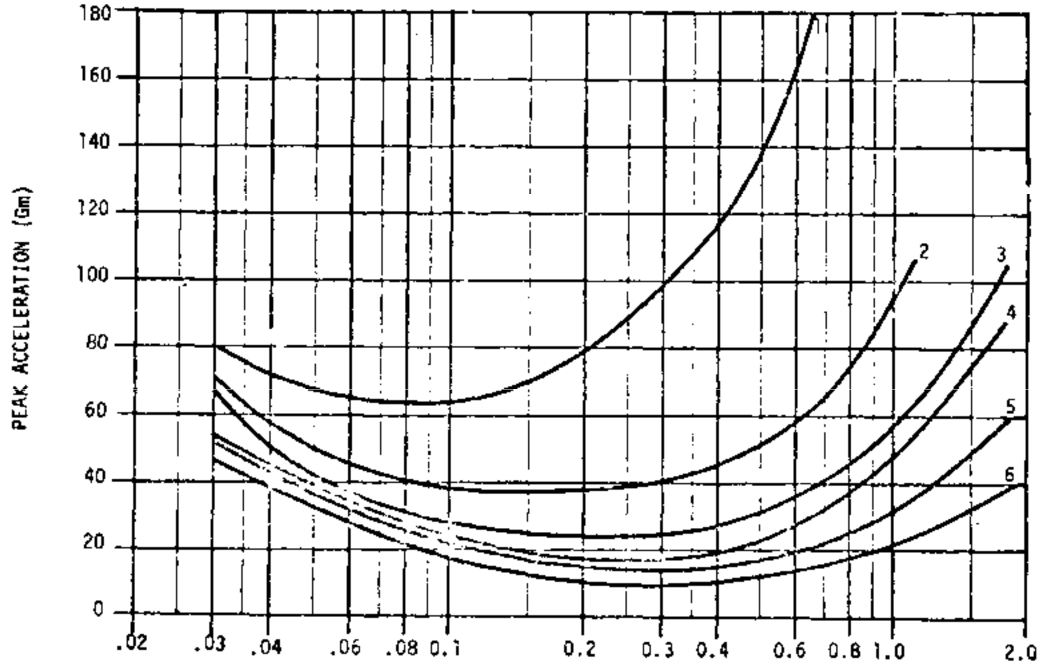
GRAPH 4.48: POLYURETHANE ESTER,
1.5 pcf, 48" Drop Height



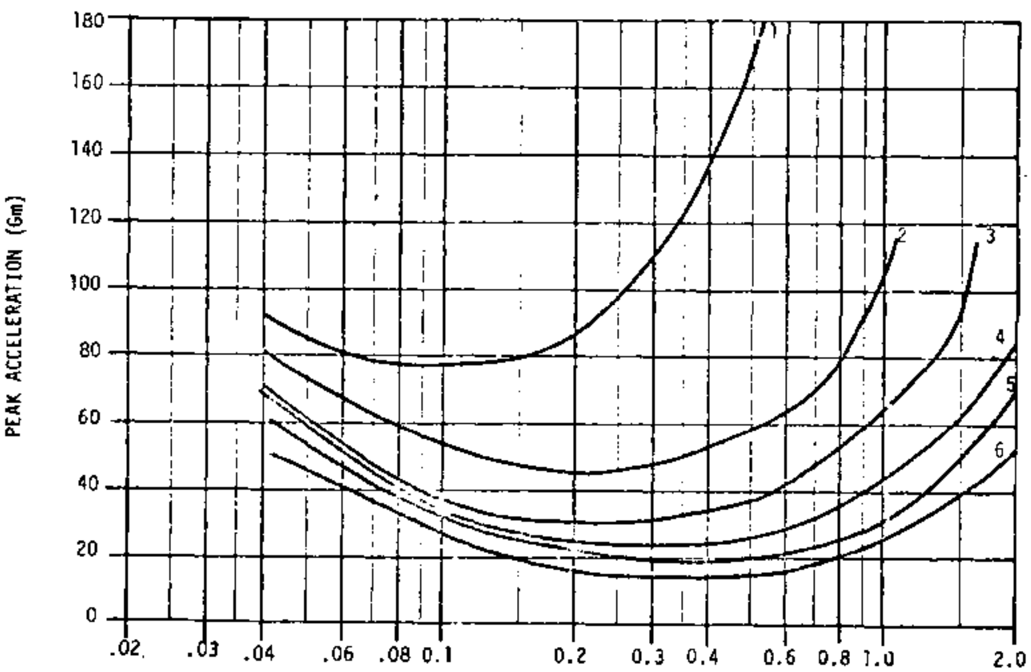
GRAPH 5.12: POLYURETHANE ESTER,
2 pcf, 12" Drop Height



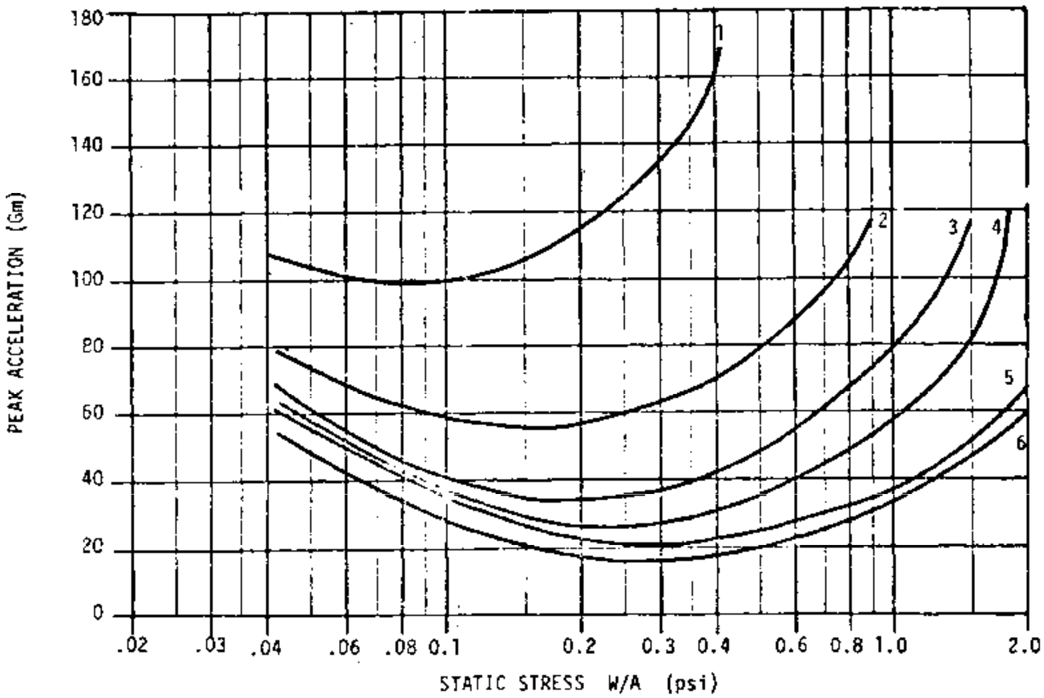
GRAPH 5.18: POLYURETHANE ESTER,
2 pcf, 18" Drop Height



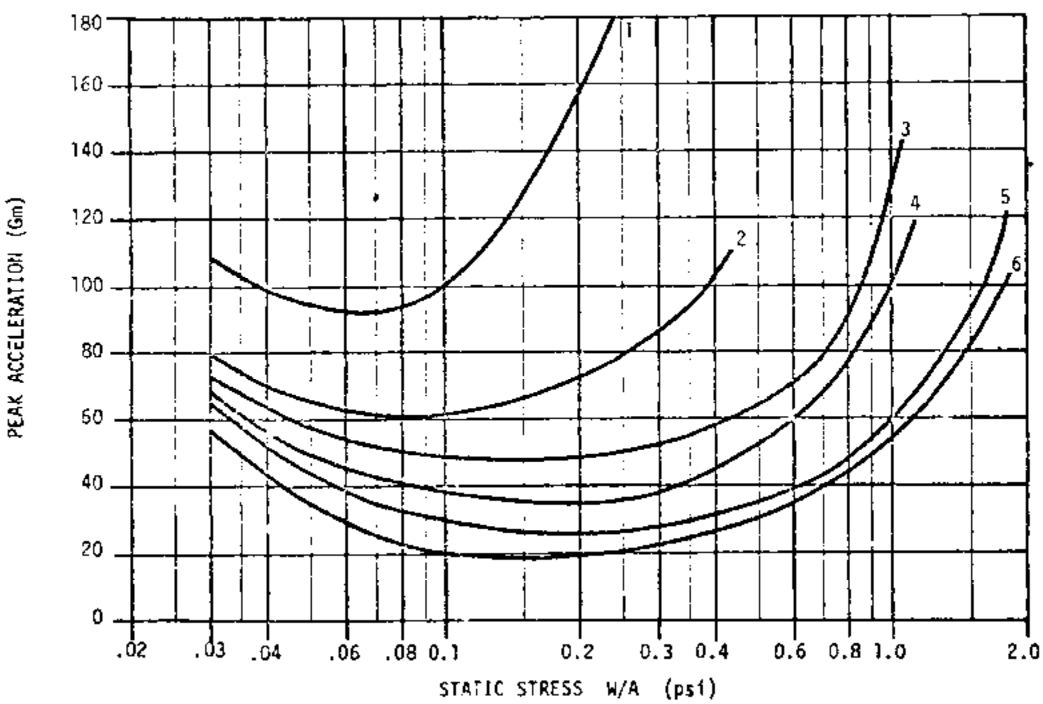
GRAPH 5.24: POLYURETHANE ESTER, 2 pcf, 24" Drop Height



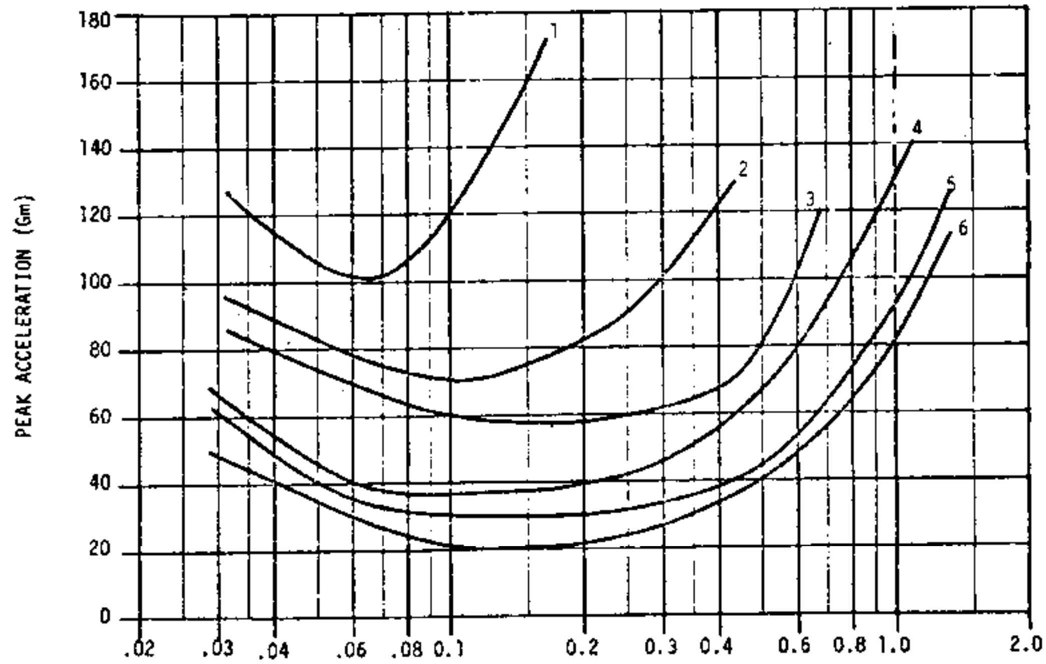
GRAPH 5.30: POLYURETHANE ESTER, 2 pcf, 30" Drop Height



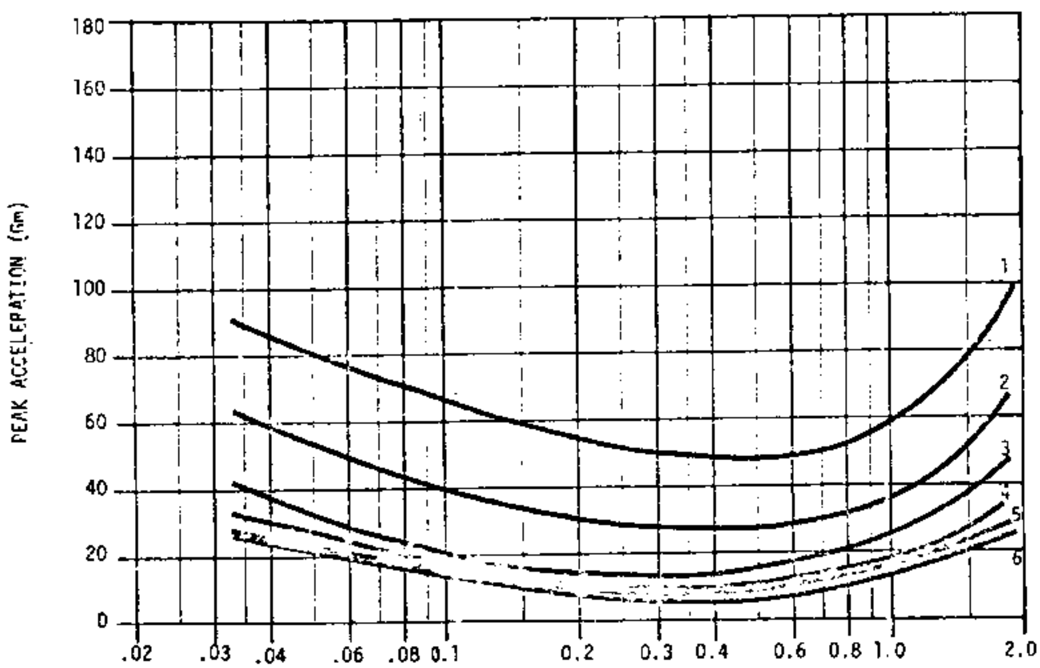
GRAPH 5.36: POLYURETHANE ESTER,
2 pcf, 36" Drop Height



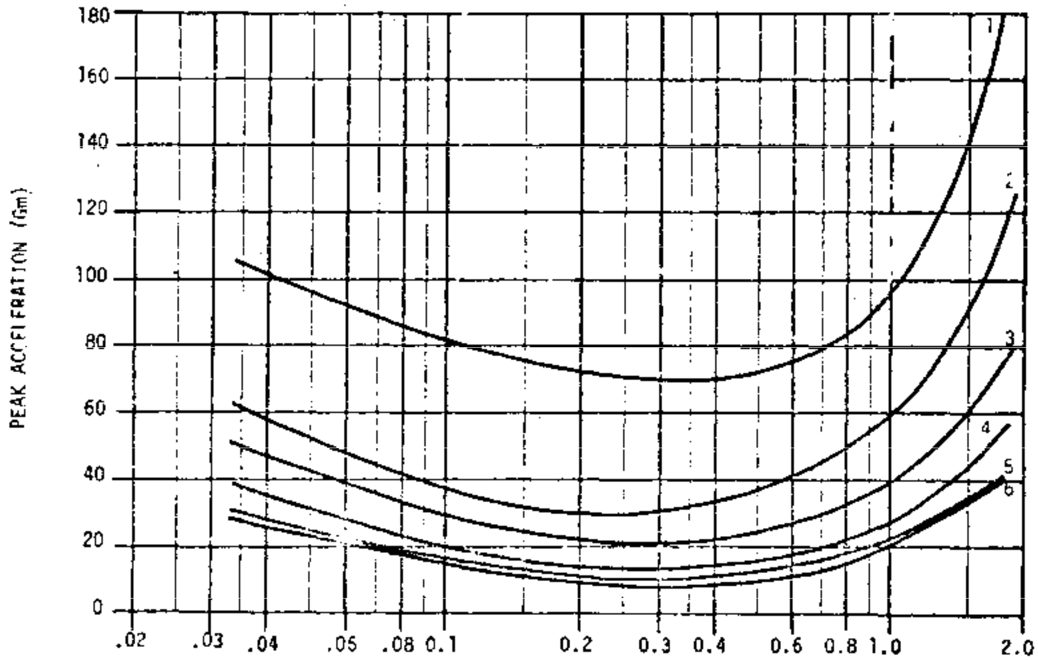
GRAPH 5.42: POLYURETHANE ESTER,
2 pcf, 42" Drop Height



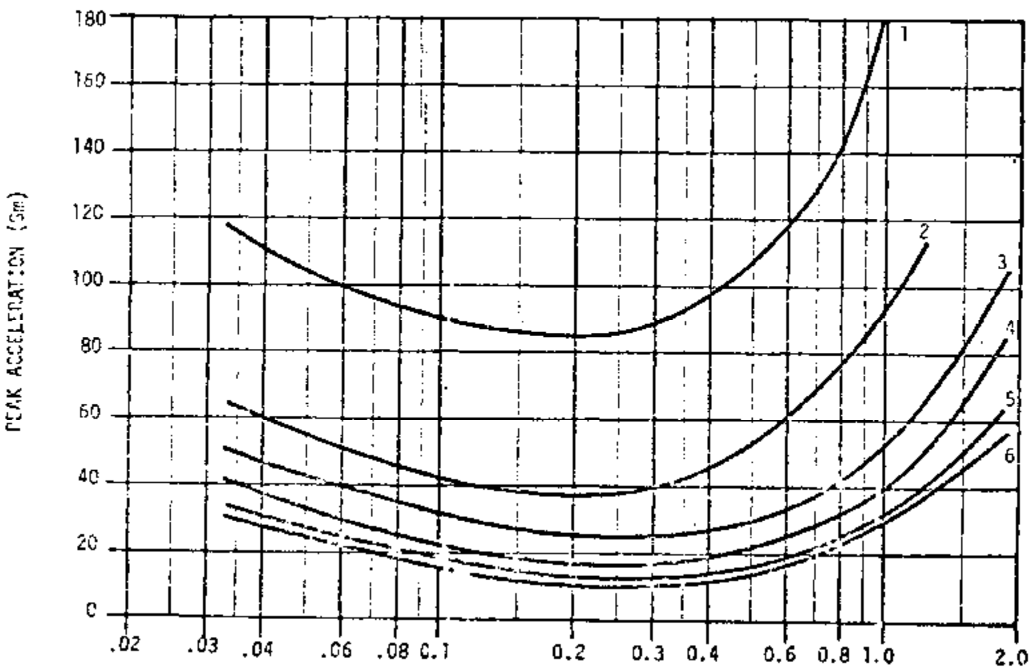
GRAPH 5.48: POLYURETHANE ESTER,
2 pcf, 48" Drop Height



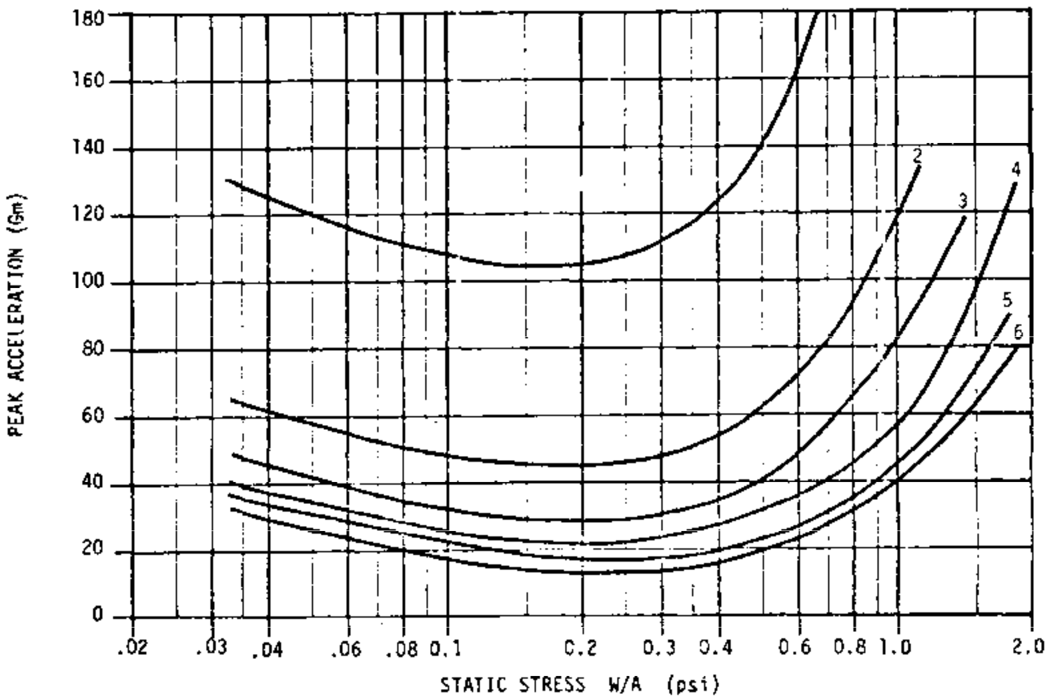
GRAPH 6.12: POLYURETHANE ESTER,
4 pcf, 12" Drop Height



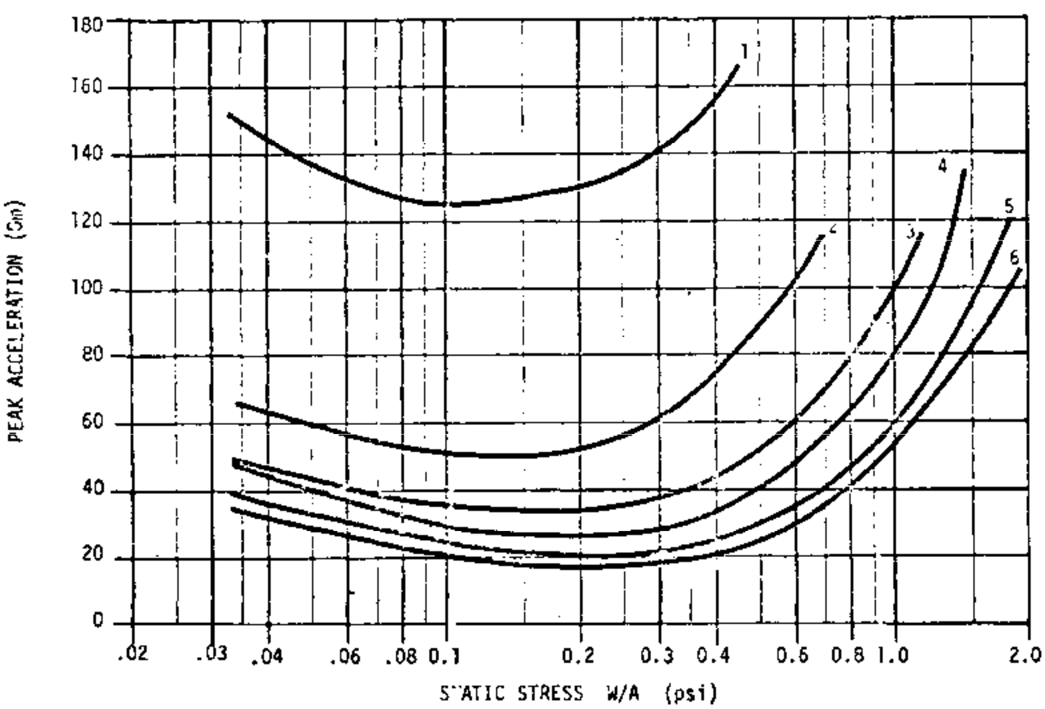
GRAPH 6.18: POLYURETHANE ESTER, 4 pcf, 18" Drop Height



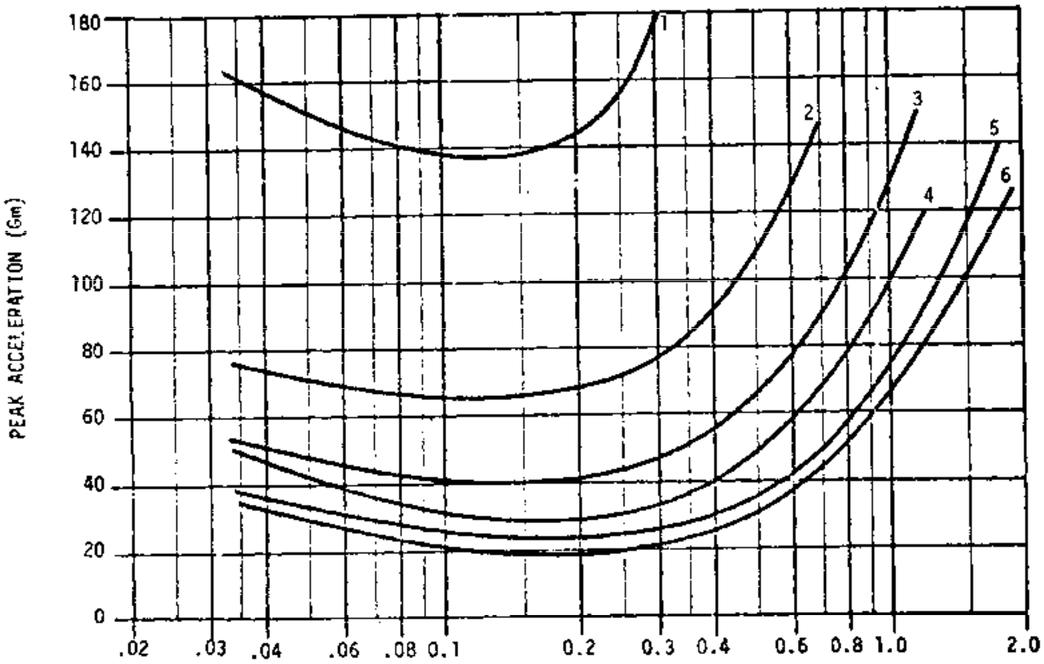
GRAPH 6.24: POLYURETHANE ESTER, 4 pcf, 24" Drop Height



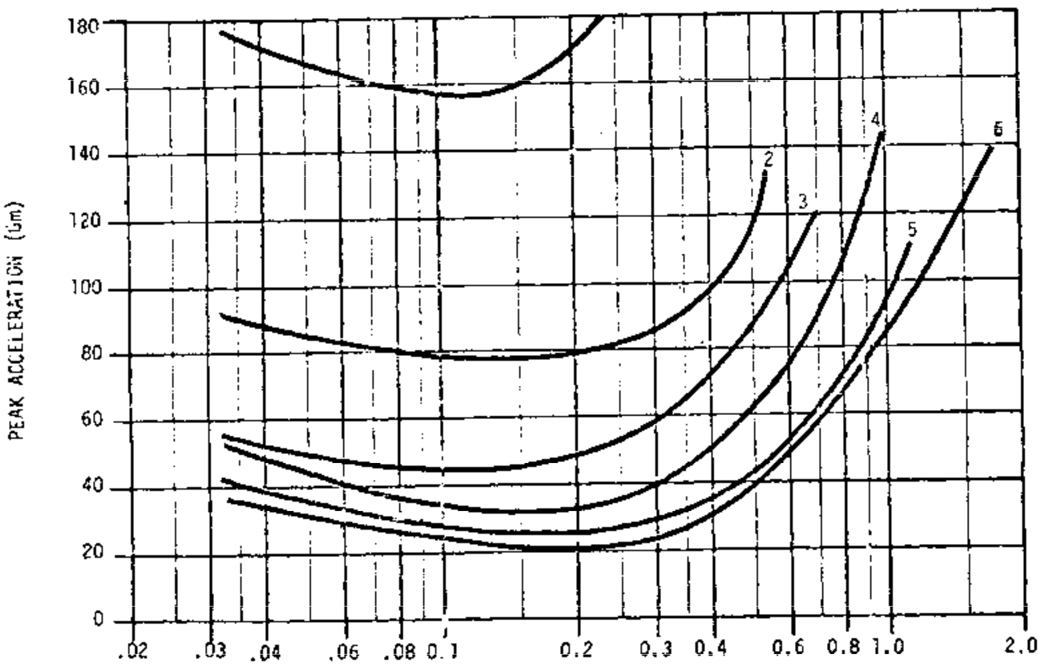
GRAPH 6.30: POLYURETHANE ESTER,
4 pcf, 30" Drop Height



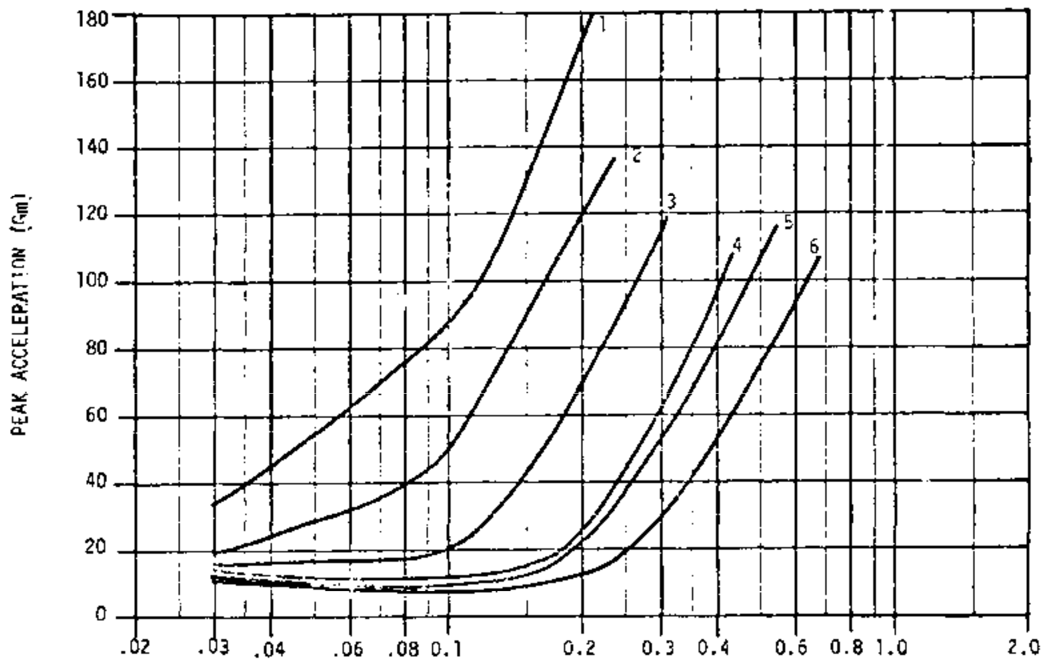
GRAPH 6.36: POLYURETHANE ESTER,
4 pcf, 36" Drop Height



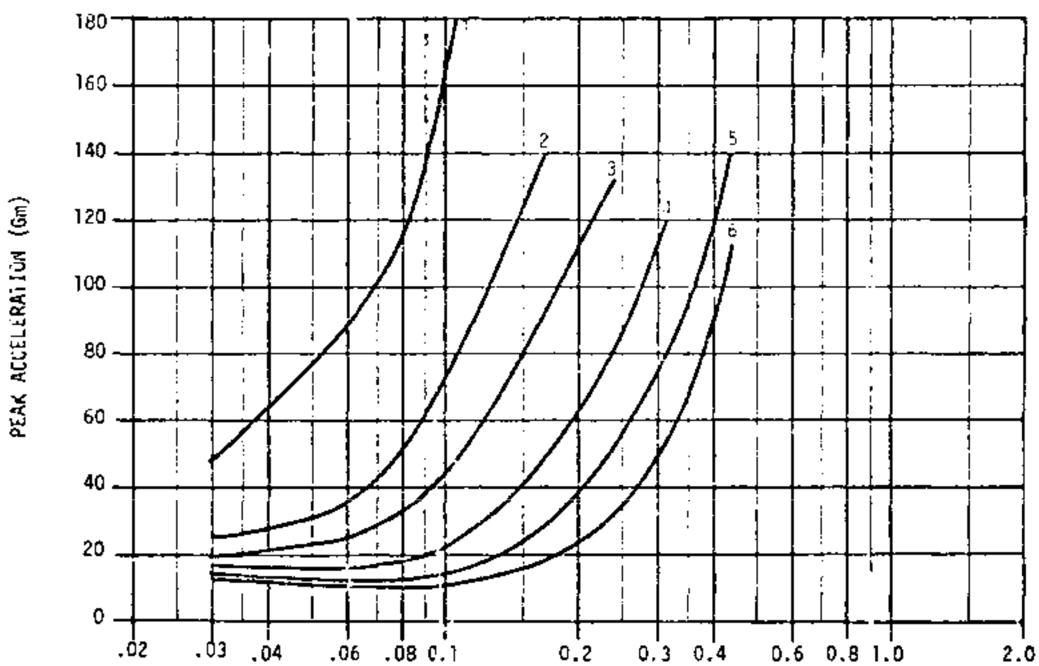
STATIC STRESS W/A (psi)
GRAPH 6.42: POLYURETHANE ESTER,
4 pcf, 42" Drop Height



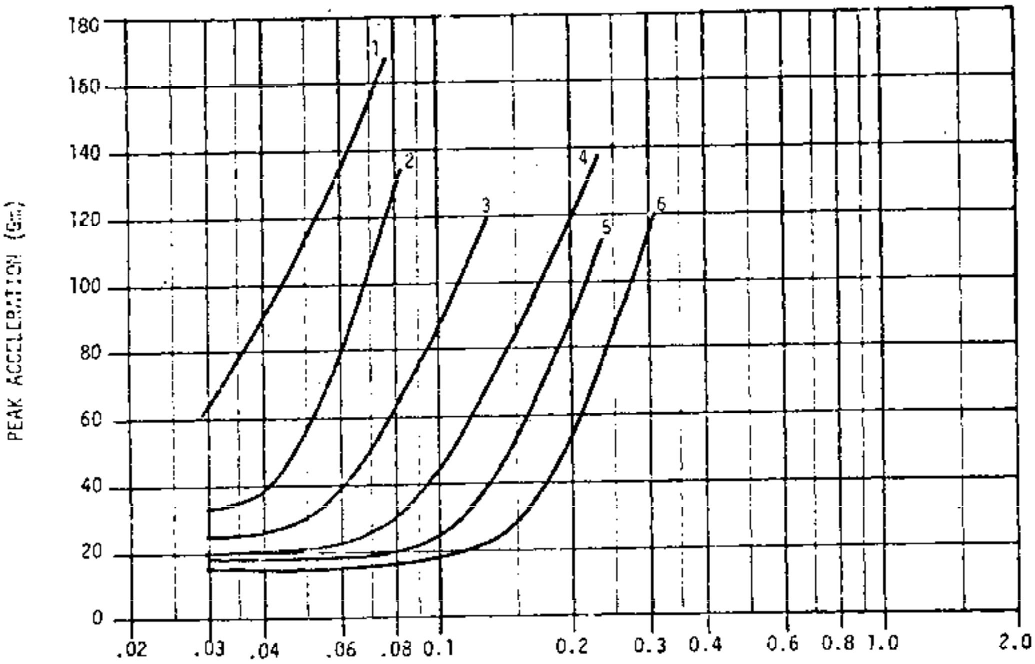
STATIC STRESS W/A (psi)
GRAPH 6.48: POLYURETHANE ESTER,
4 pcf, 48" Drop Height



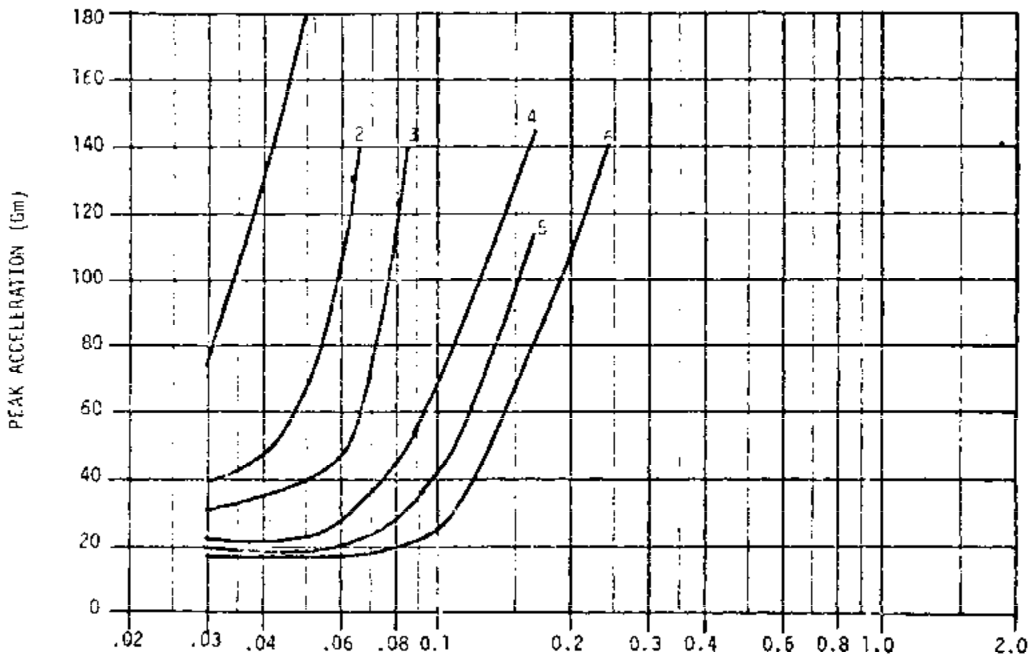
GRAPH 7.12: RUBBERIZED HAIR,
Type II, 12" Drop Height



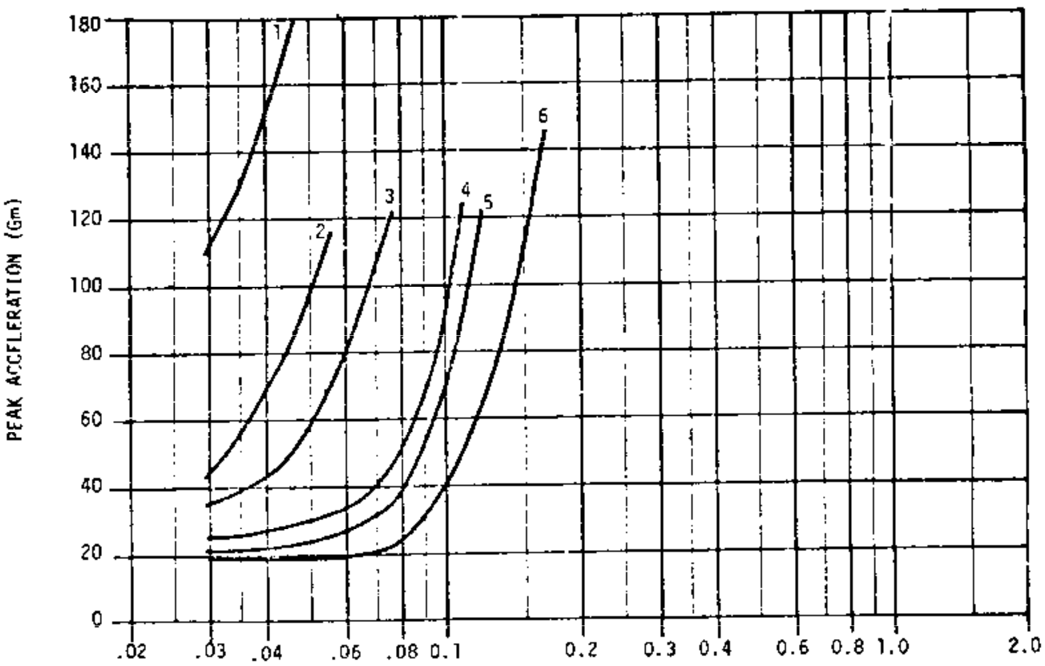
GRAPH 7.18: RUBBERIZED HAIR,
Type II, 18" Drop Height



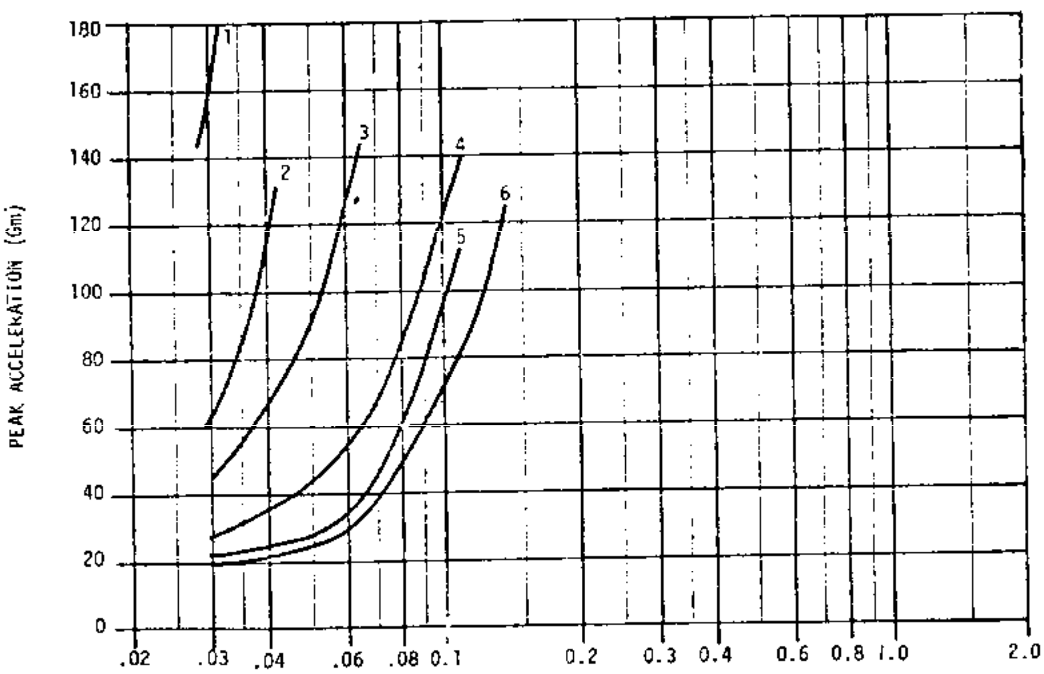
GRAPH 7.24: RUBBERIZED HAIR,
Type II, 24" Drop Height



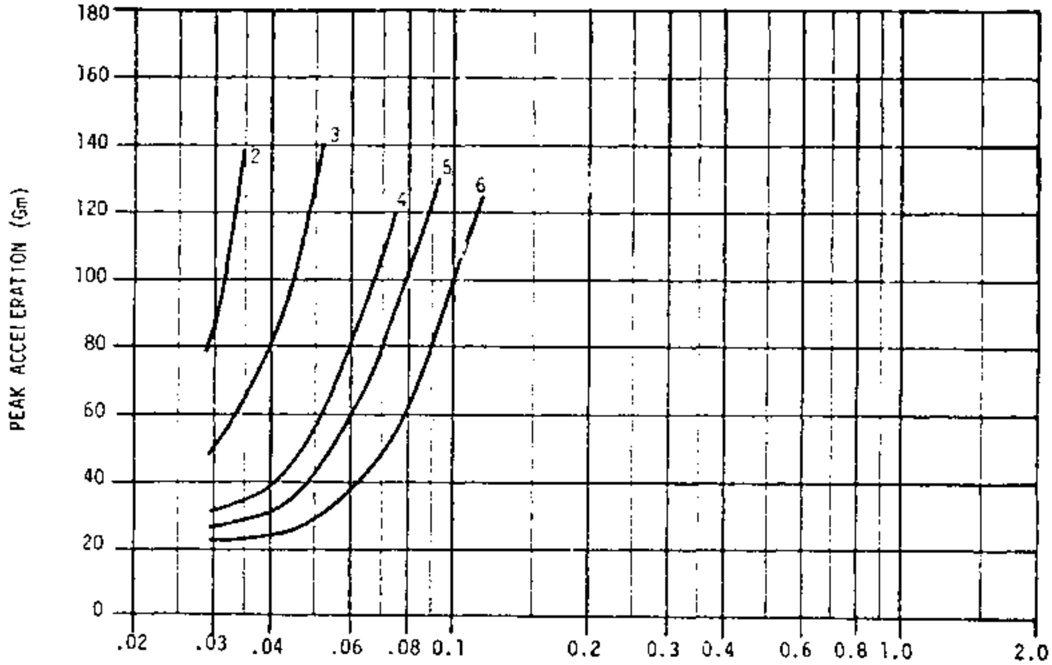
GRAPH 7.30: RUBBERIZED HAIR,
Type II, 30" Drop Height



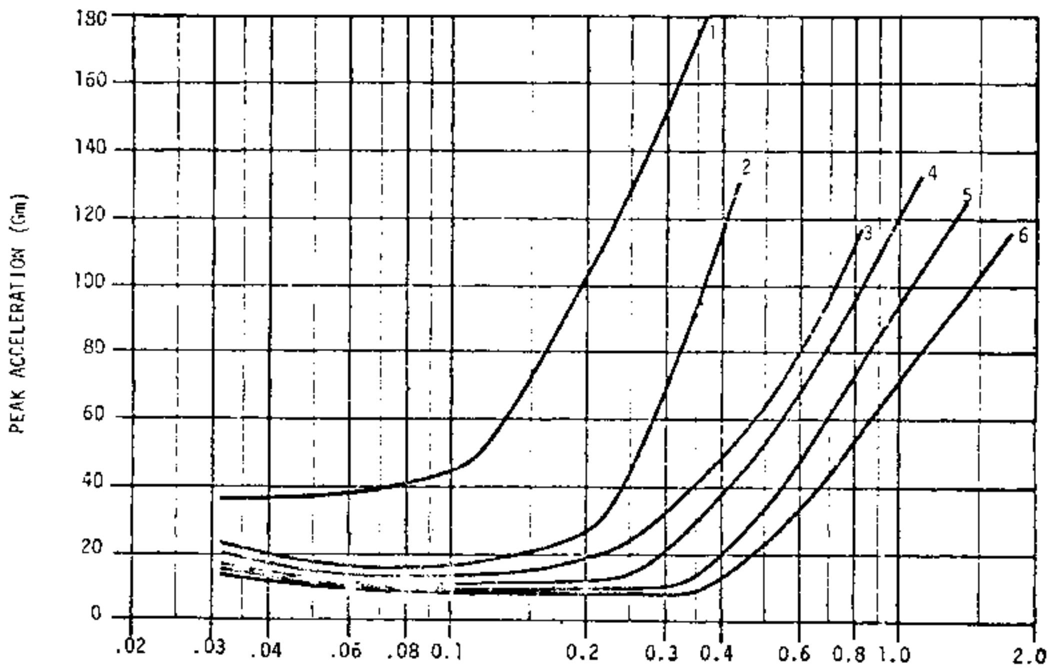
GRAPH 7.36: RUBBERIZED HAIR,
Type II, 36" Drop Height



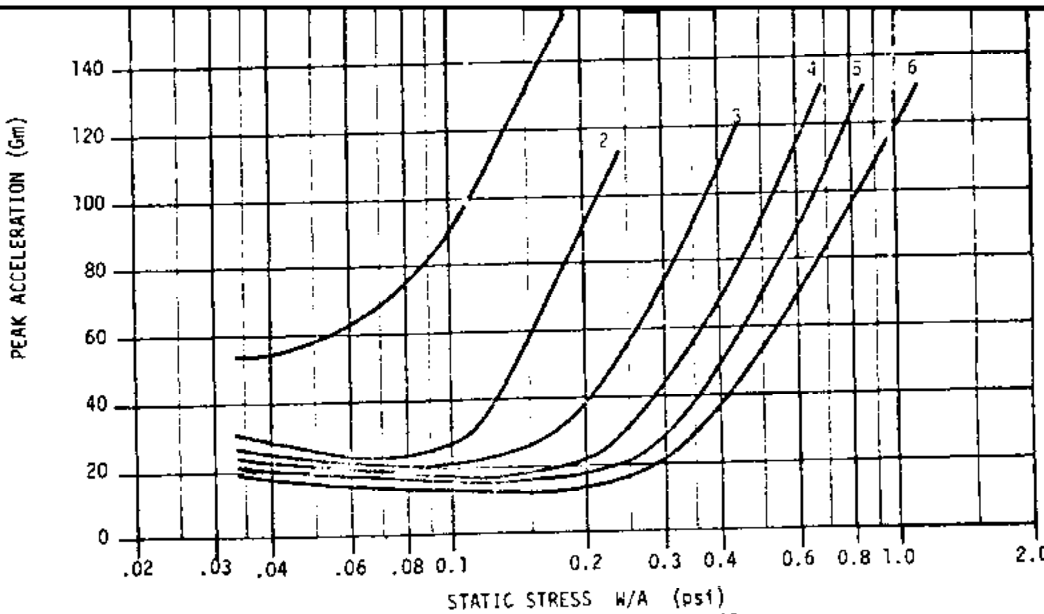
GRAPH 7.42: RUBBERIZED HAIR,
Type II, 42" Drop Height



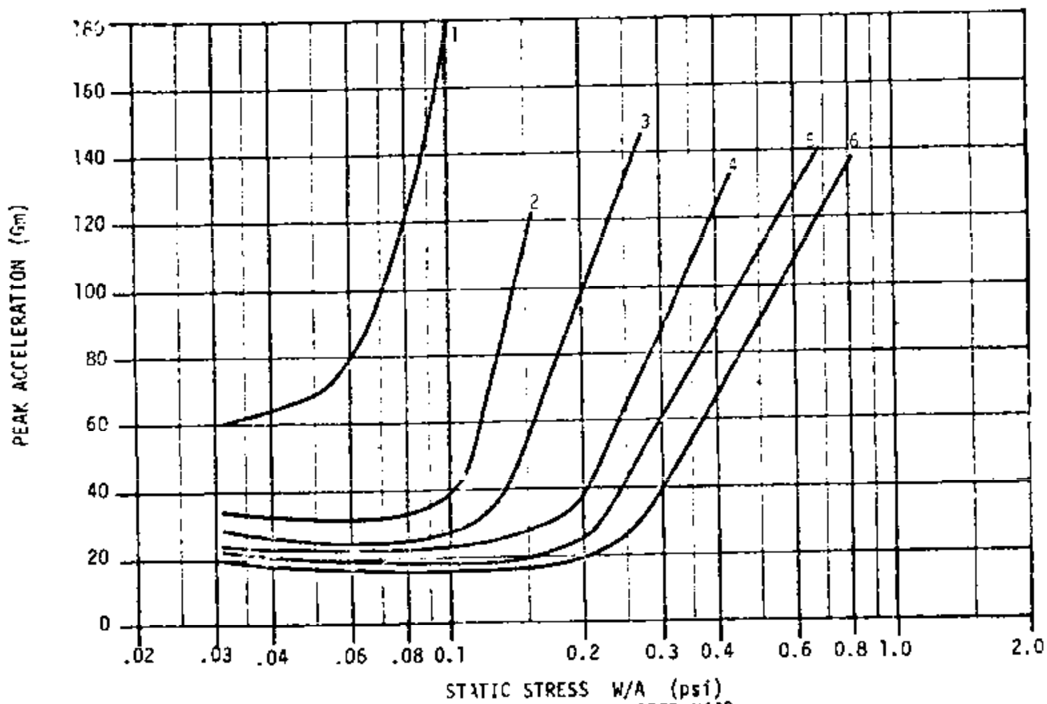
GRAPH 7.48: RUBBERIZED HAIR,
Type II, 48" Drop Height



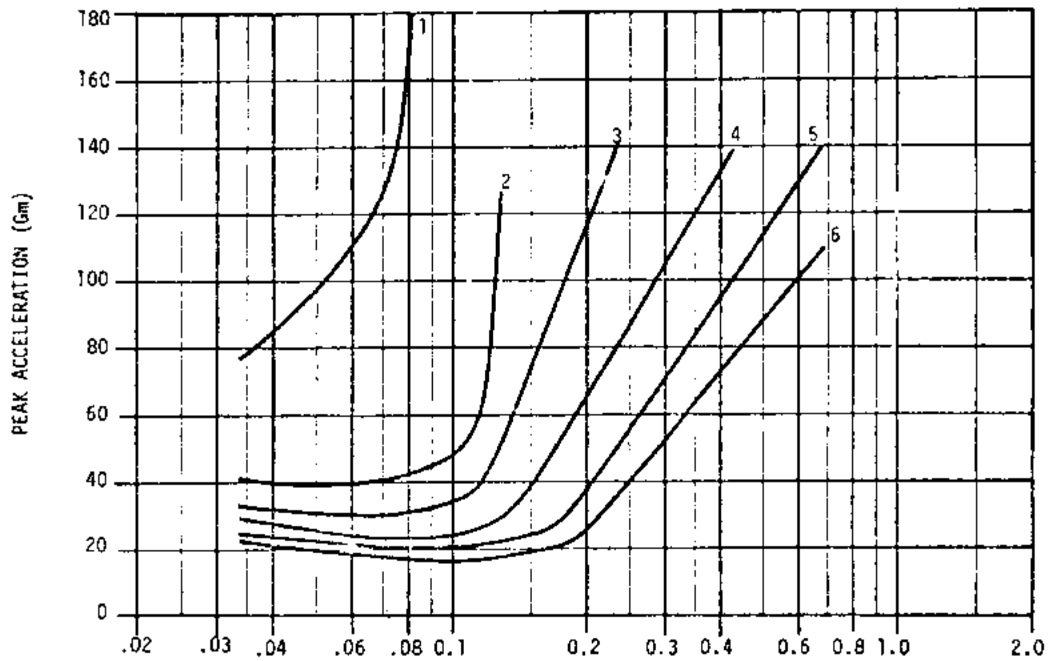
GRAPH 8.12: RUBBERIZED HAIR,
Type III, 12" Drop Height



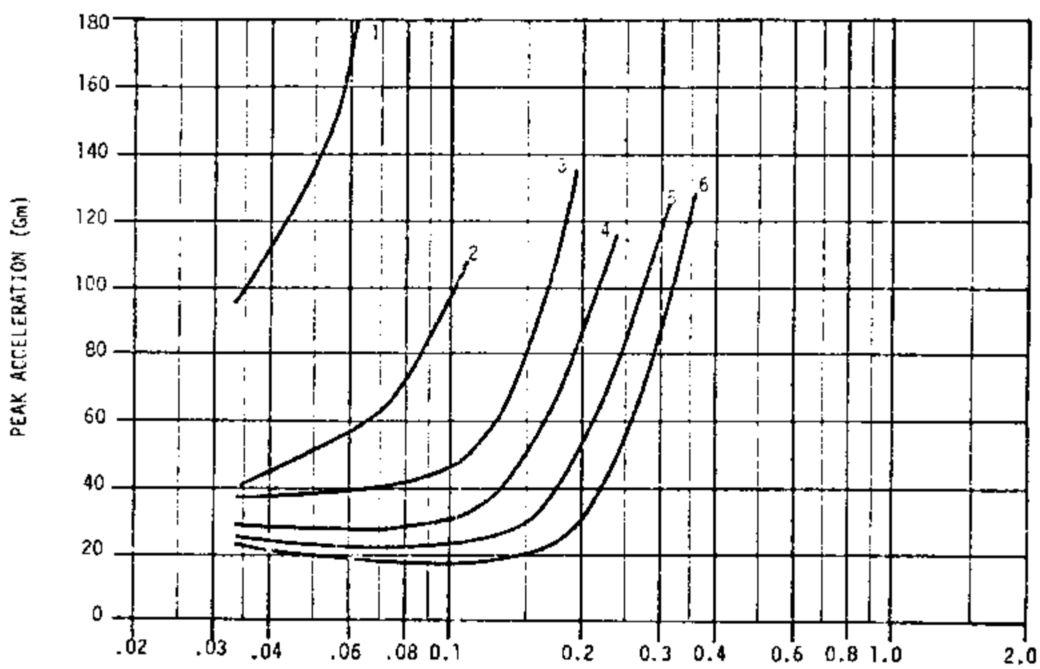
GRAPH 8.18: RUBBERIZED HAIR,
Type III, 18" Drop Height



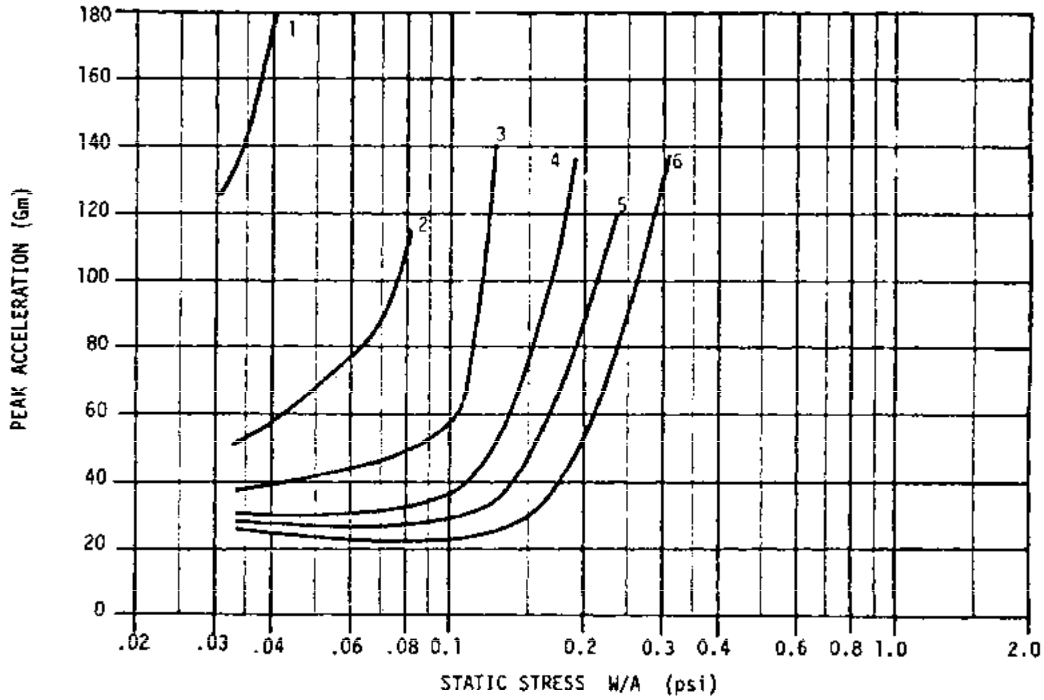
GRAPH 8.24: RUBBERIZED HAIR,
Type III, 24" Drop Height



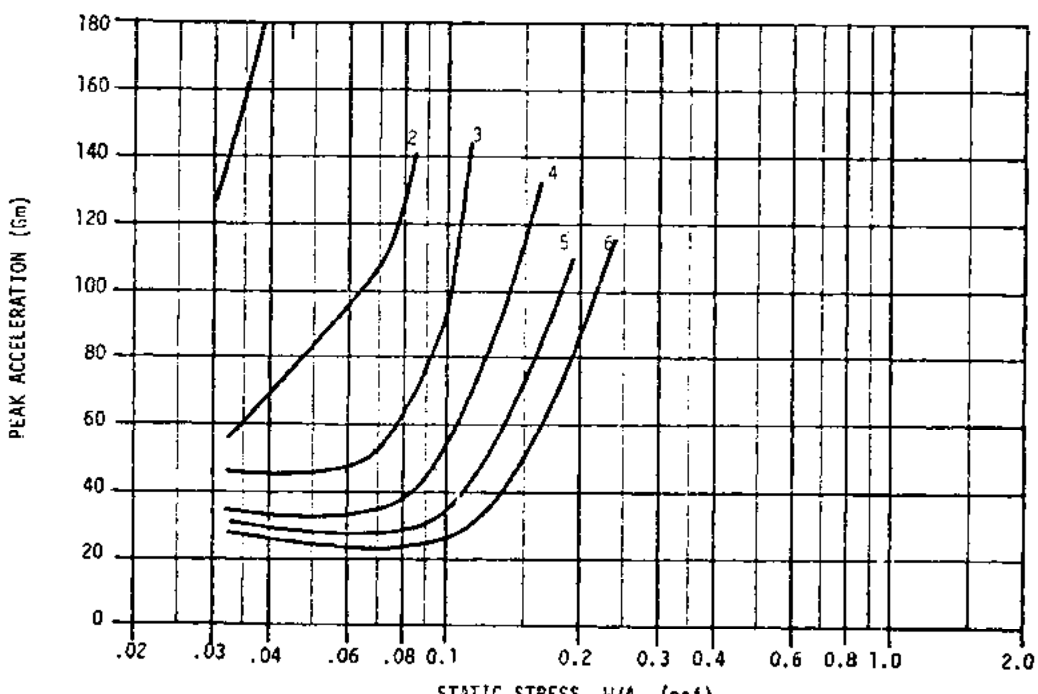
GRAPH 8.30: RUBBERIZED HAIR,
TYPE III, 30" Drop Height



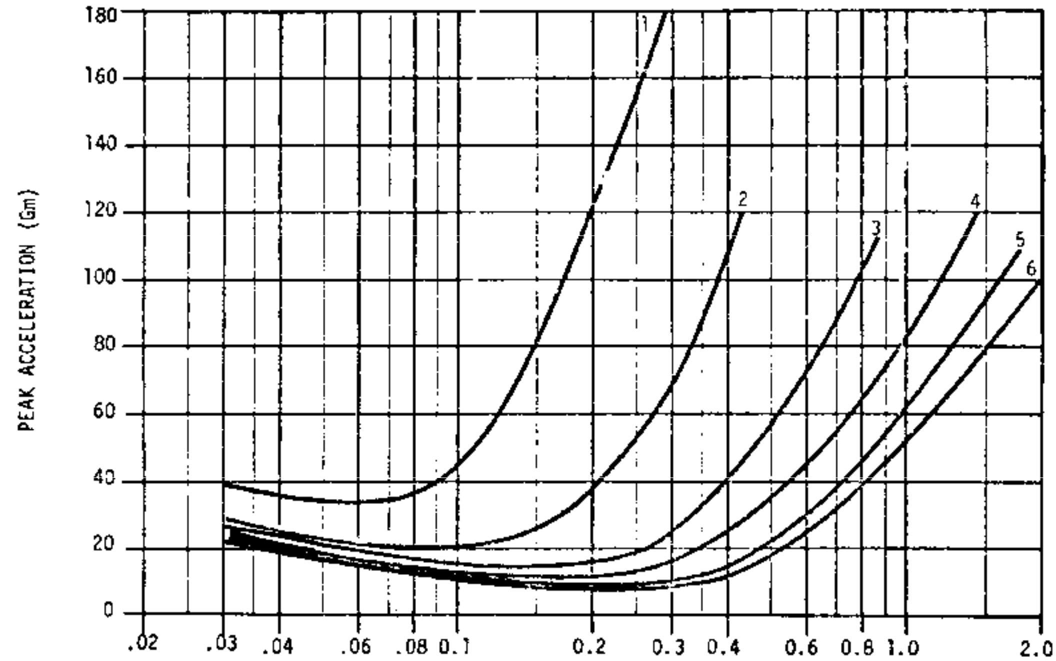
GRAPH 8.36: RUBBERIZED HAIR,
Type III, 36" Drop Height



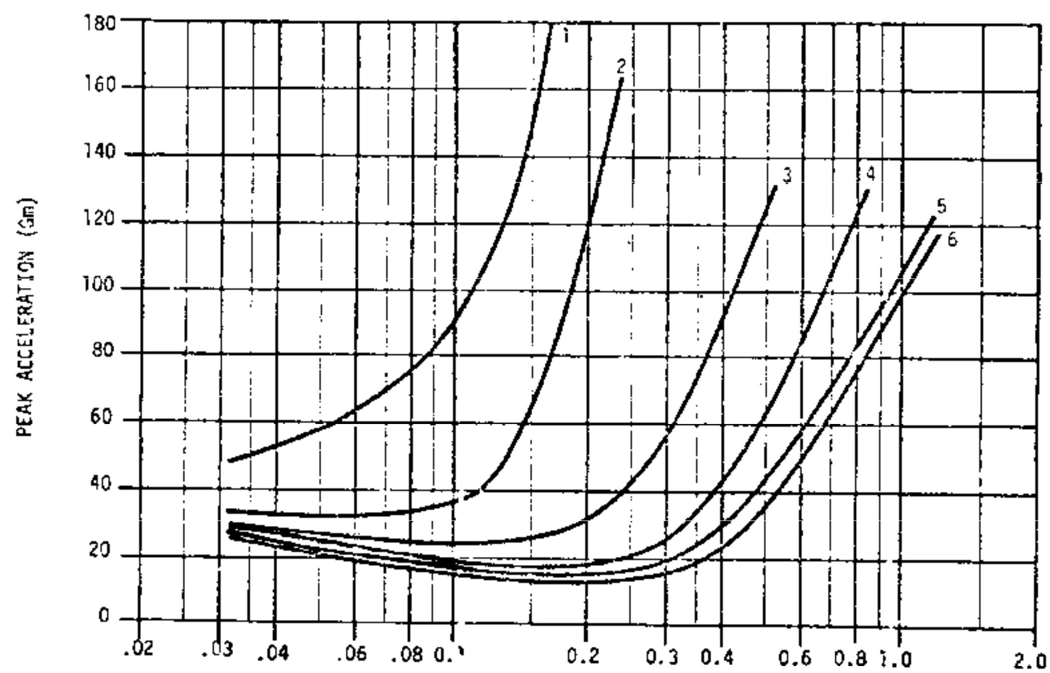
GRAPH 8.42: RUBBERIZED HAIR, Type III, 42" Drop Height



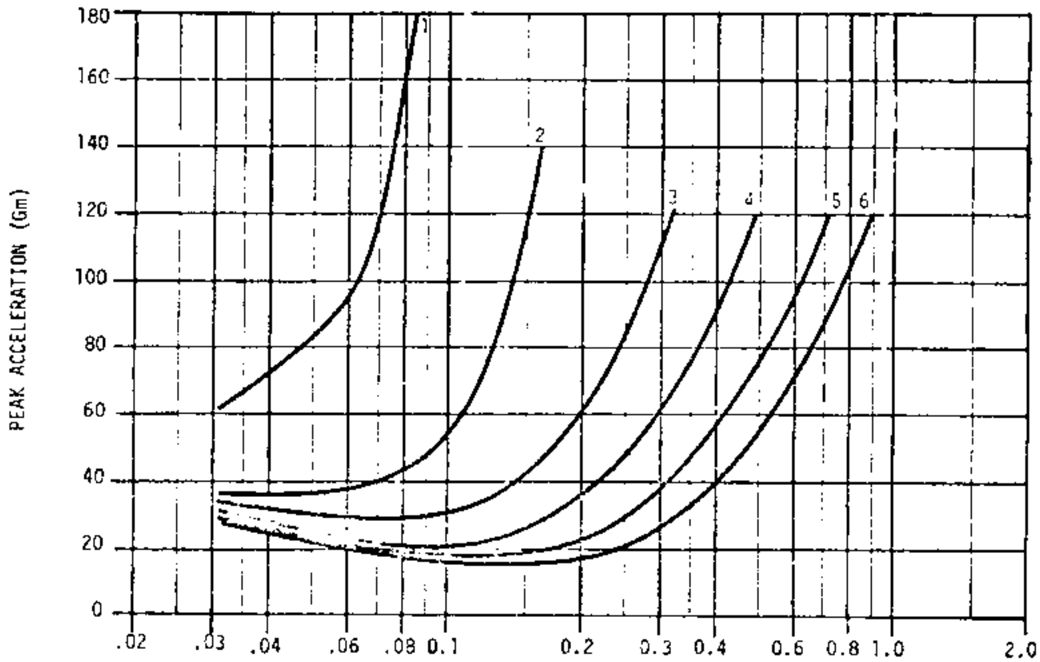
GRAPH 8.48: RUBBERIZED HAIR, Type III, 48" Drop Height



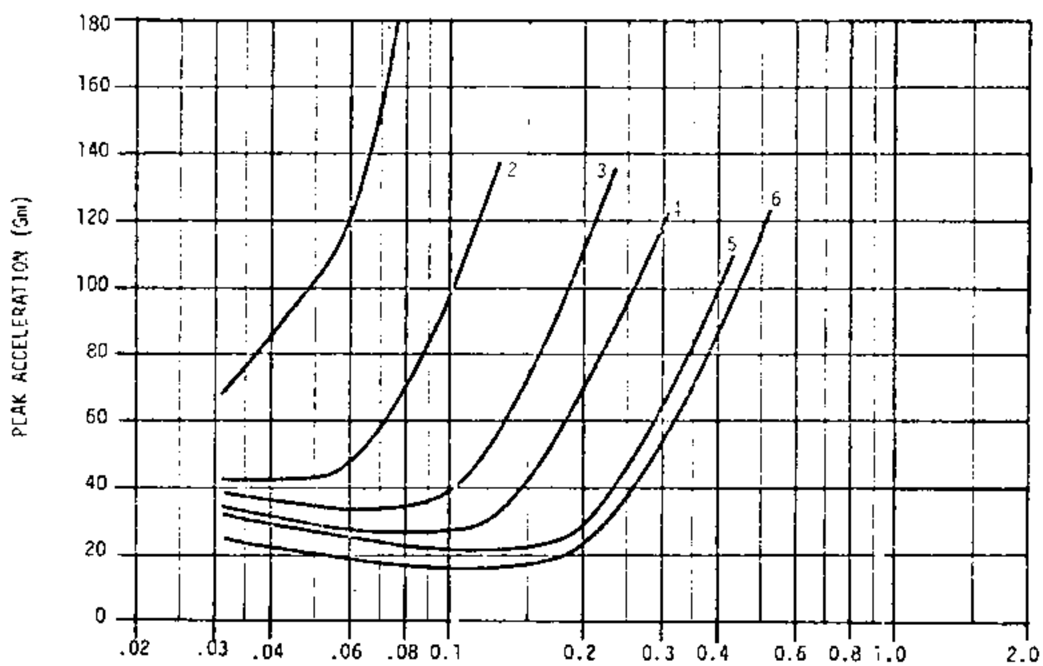
STATIC STRESS W/A (psi)
GRAPH 9.12: RUBBERIZED HAIR,
Type IV, 12" Drop Height



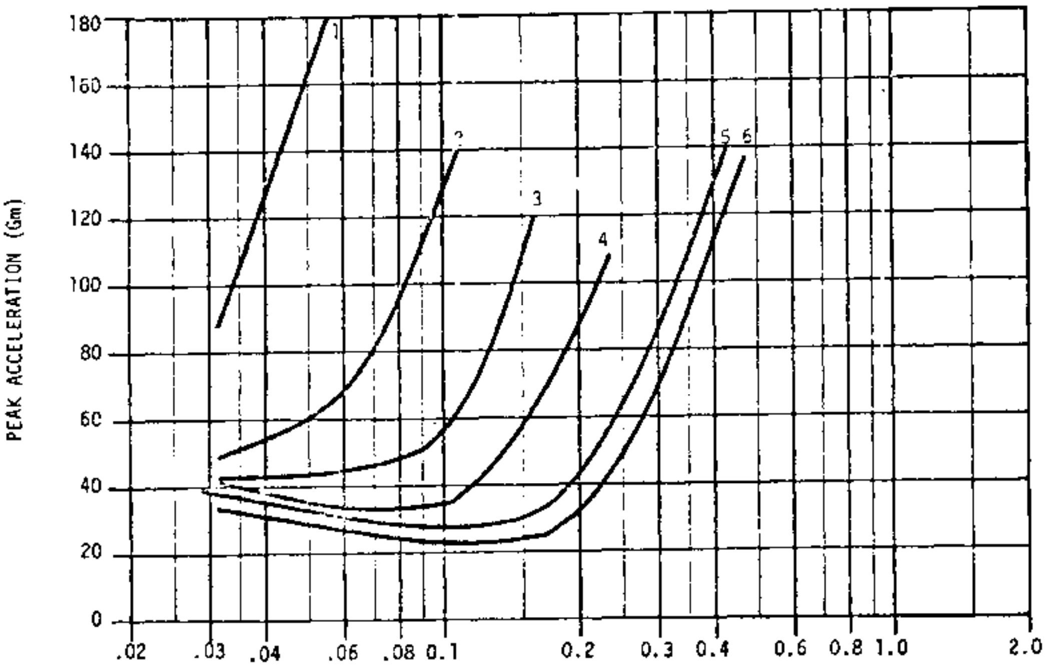
STATIC STRESS W/A (psi)
GRAPH 9.18: RUBBERIZED HAIR,
Type IV, 18" Drop Height



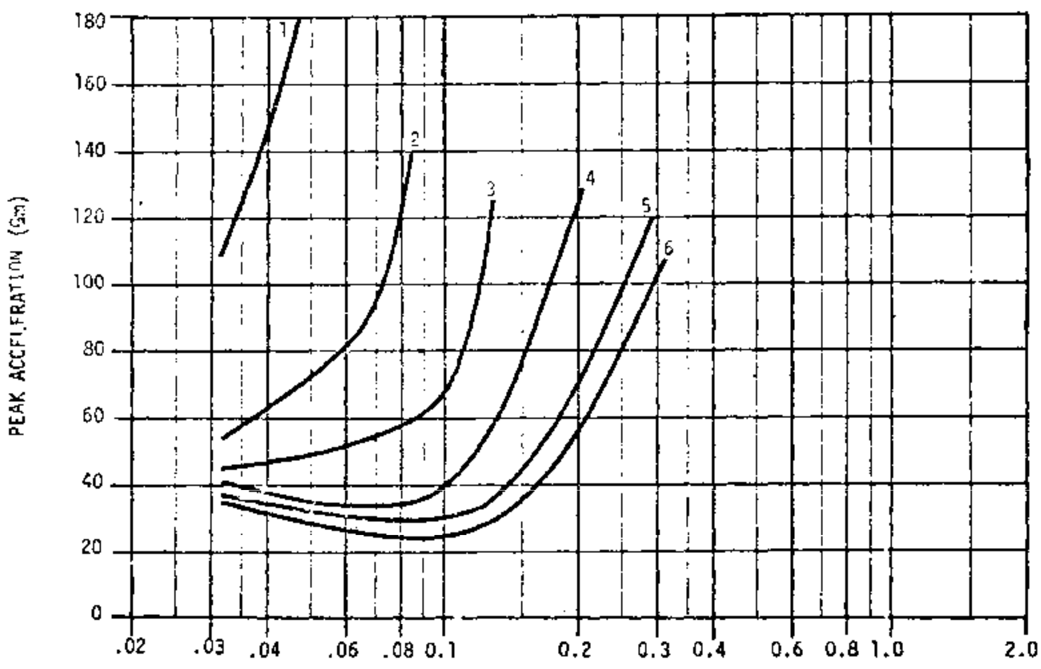
GRAPH 9.24: RUBBERIZED HAIR,
Type IV, 24" Drop Height



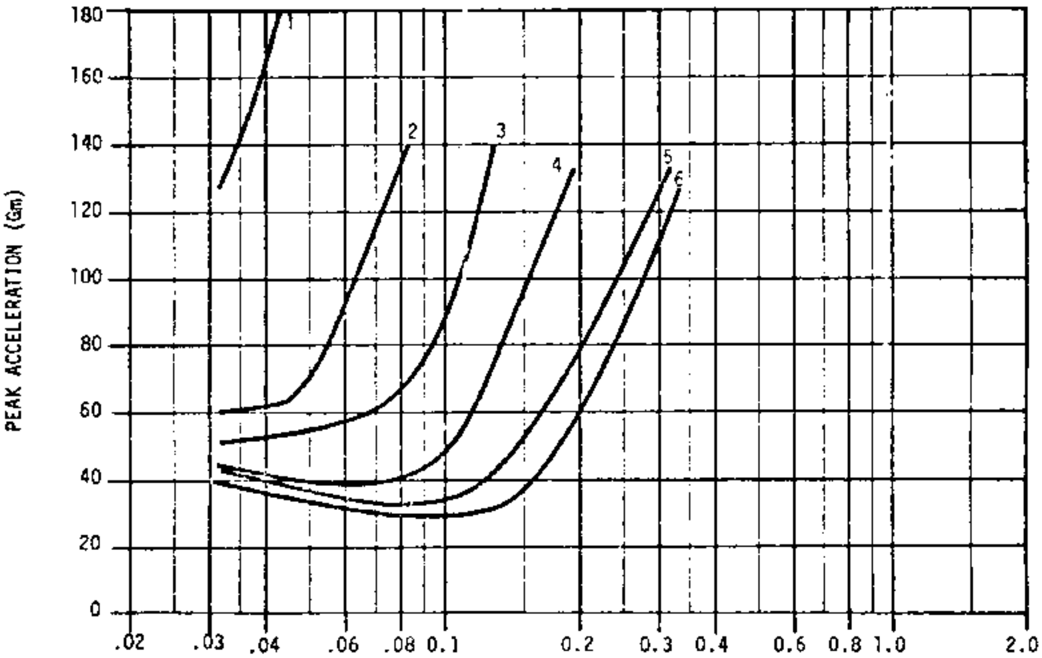
GRAPH 9.30: RUBBERIZED HAIR,
Type IV, 30" Drop Height



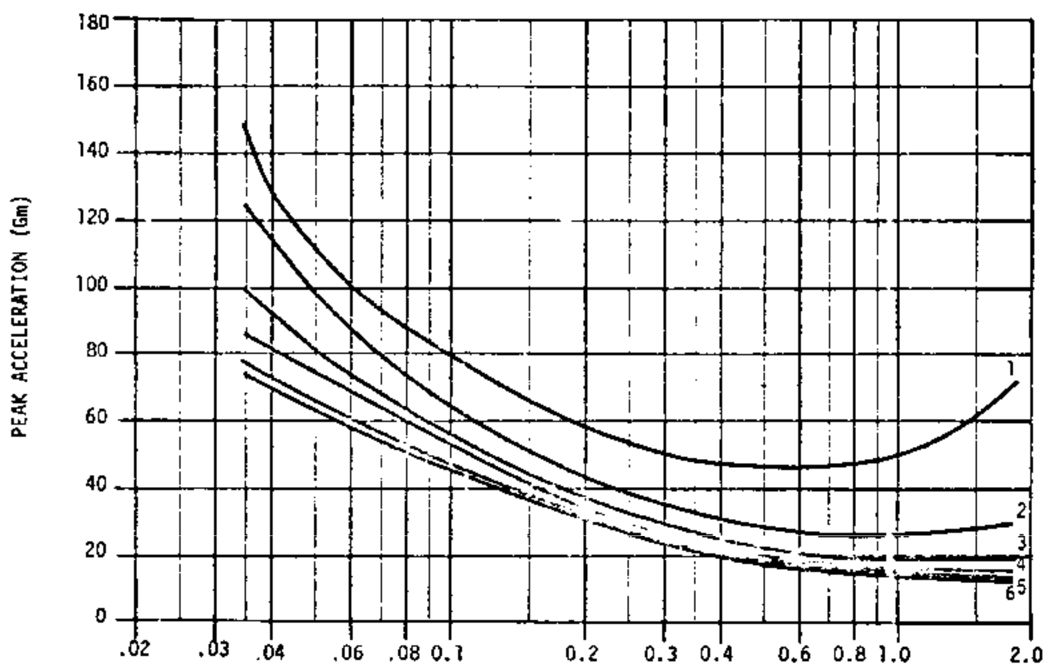
GRAPH 9.36: RUBBERIZED HAIR,
Type IV, 36" Drop Height



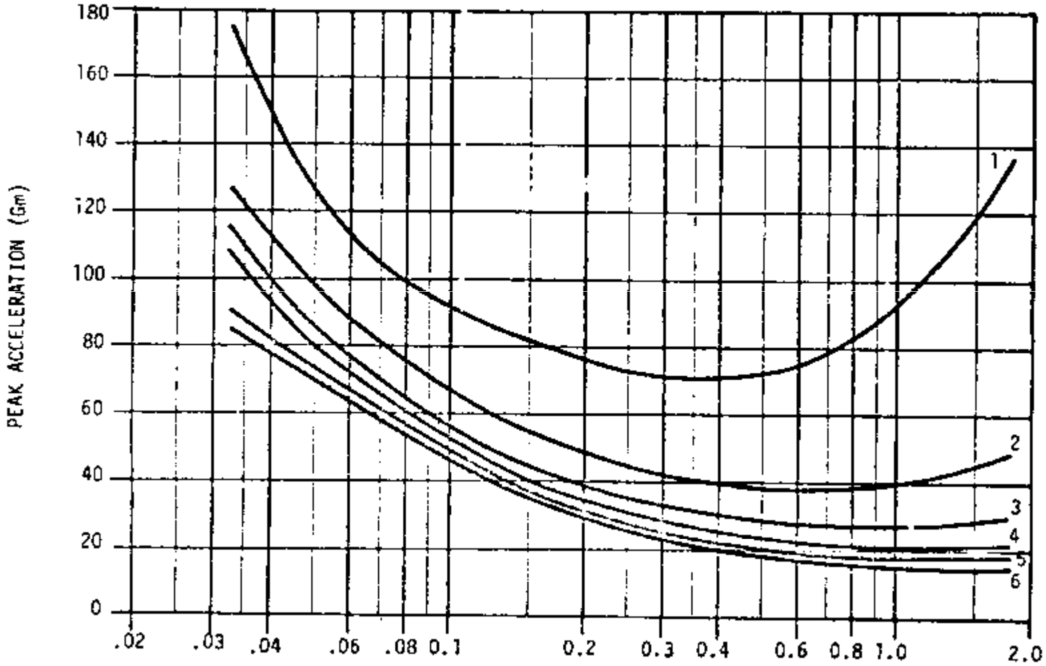
GRAPH 9.42: RUBBERIZED HAIR,
Type IV, 42" Drop Height



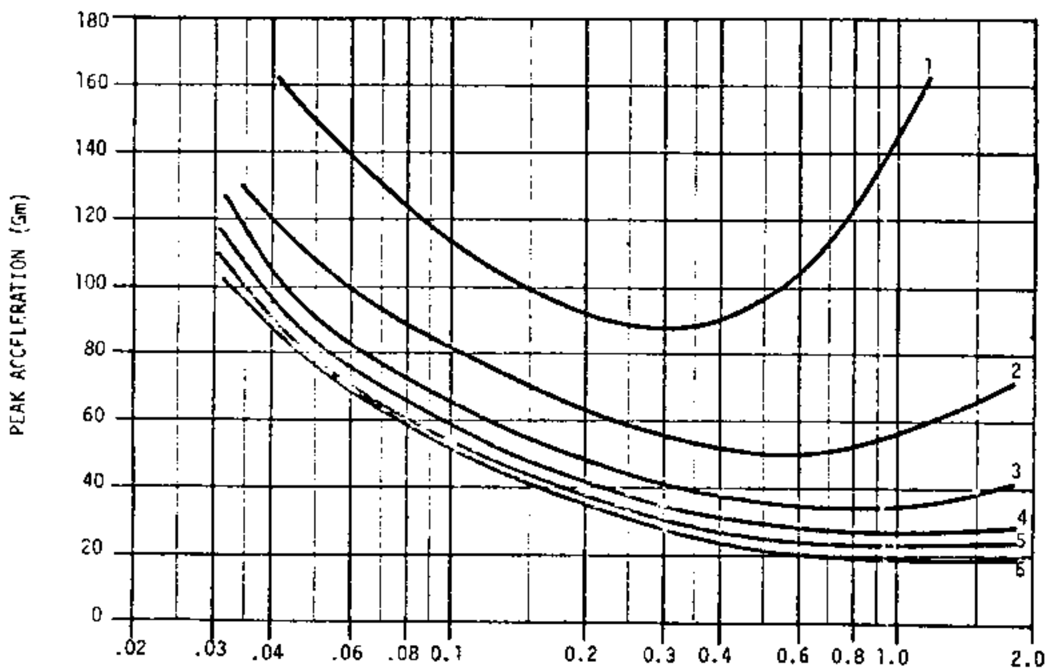
STATIC STRESS W/A (psi)
GRAPH 9.48: RUBBERIZED HAIR,
Type IV, 48" Drop Height



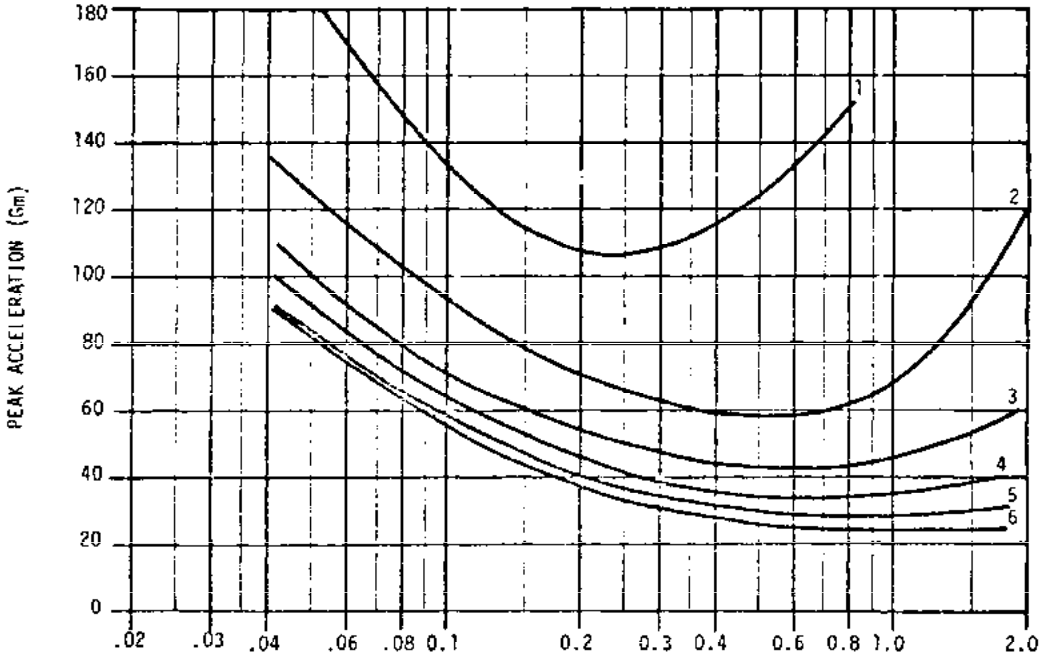
STATIC STRESS W/A (psi)
GRAPH 10.12: POLYETHYLENE,
2 pcf, 12" Drop Height



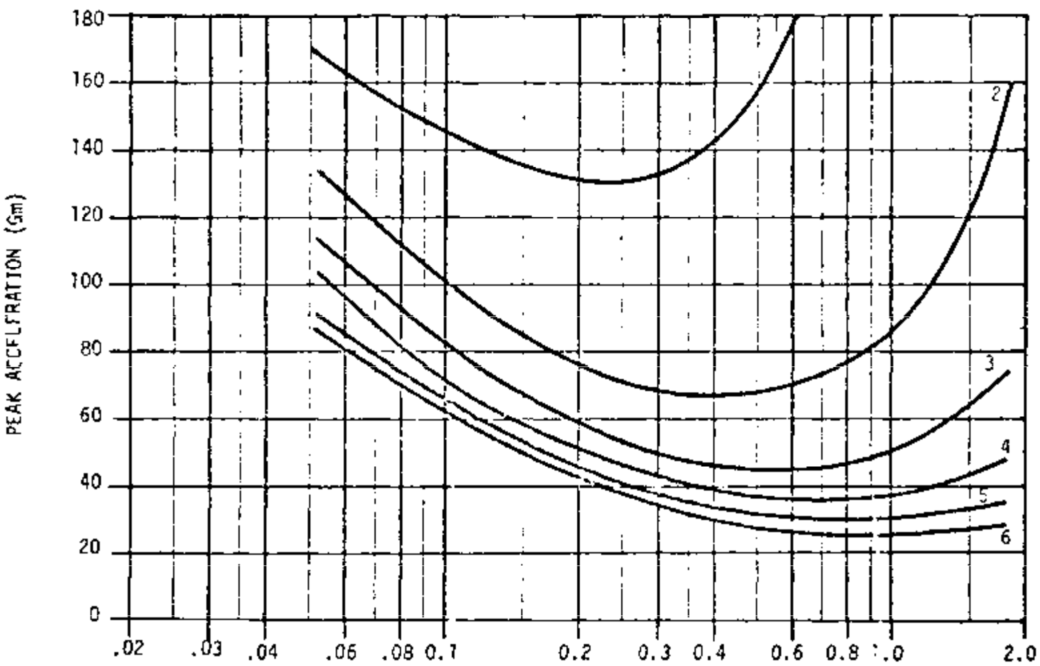
GRAPH 10.18: POLYETHYLENE, 2 pcf, 18" Drop Height



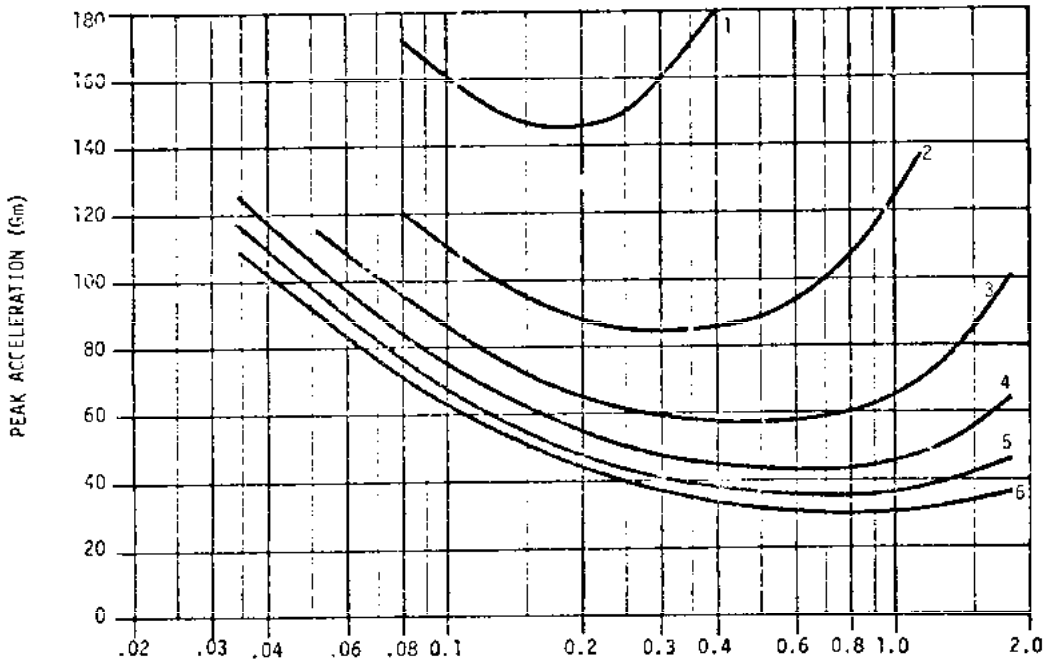
GRAPH 10.24: POLYETHYLENE, 2 pcf, 24" Drop Height



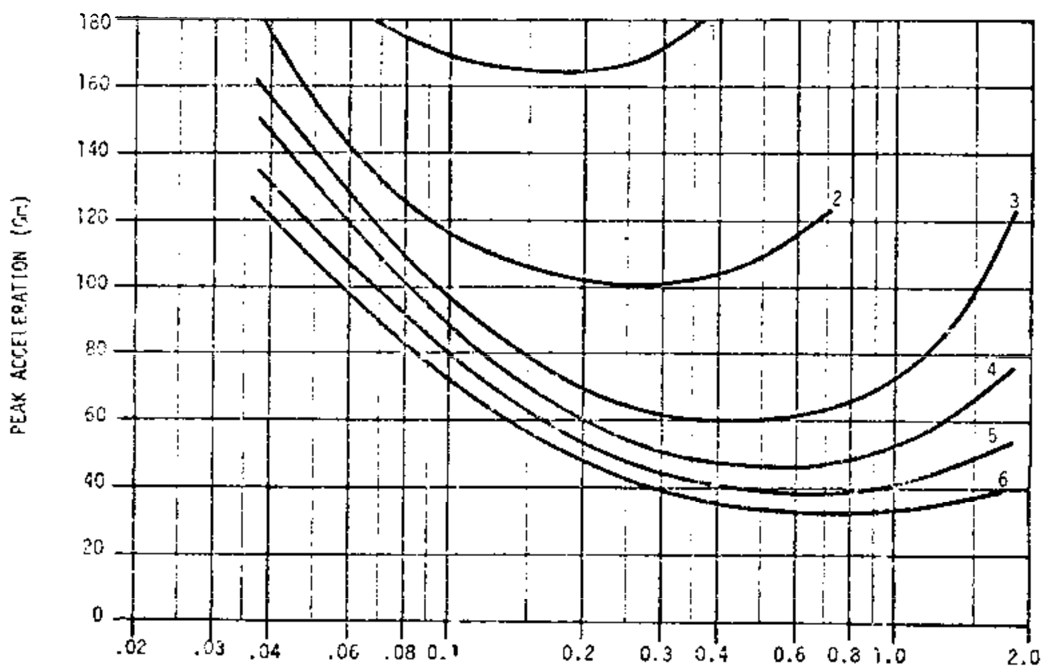
GRAPH 10.30: POLYETHYLENE,
2 pcf, 30" Drop Height



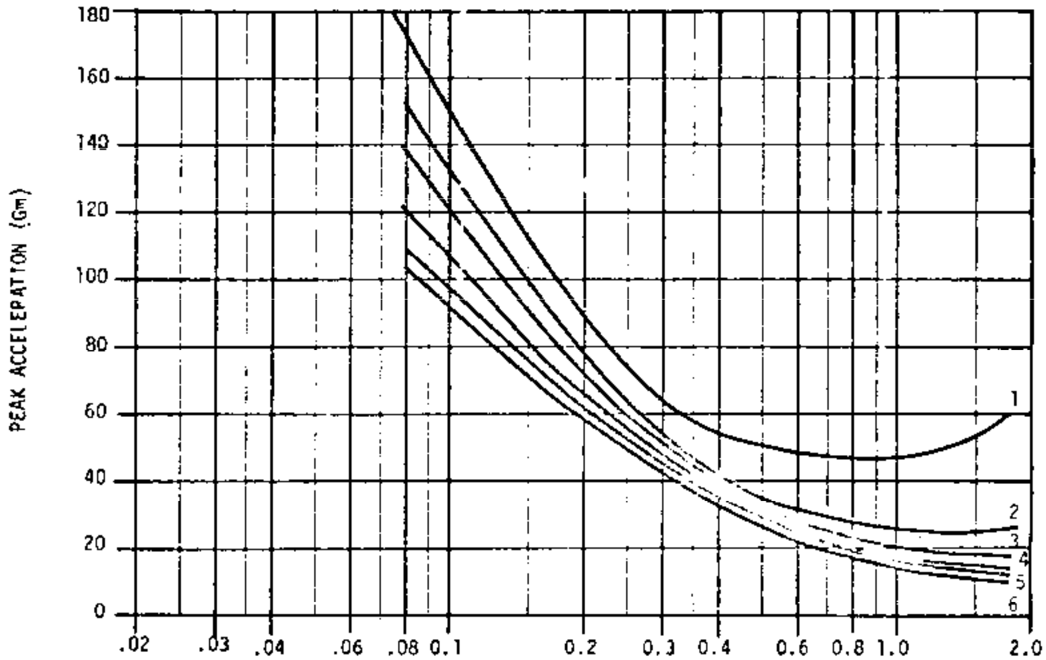
GRAPH 10.35: POLYETHYLENE,
2 pcf, 36" Drop Height



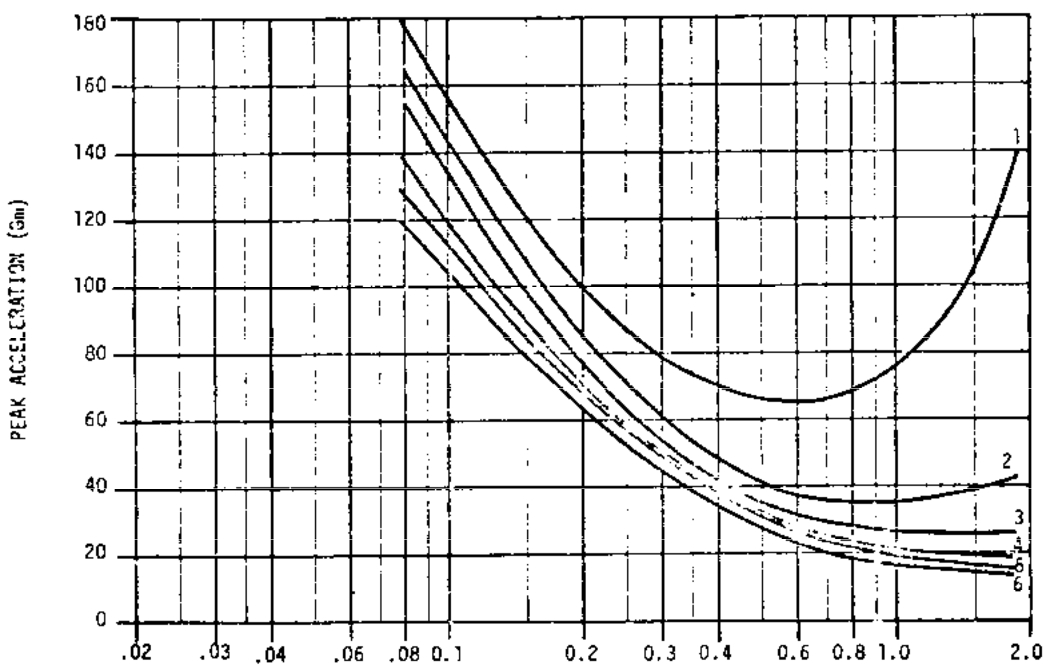
GRAPH 10.42: POLYETHYLENE,
2 pcf, 42" Drop Height



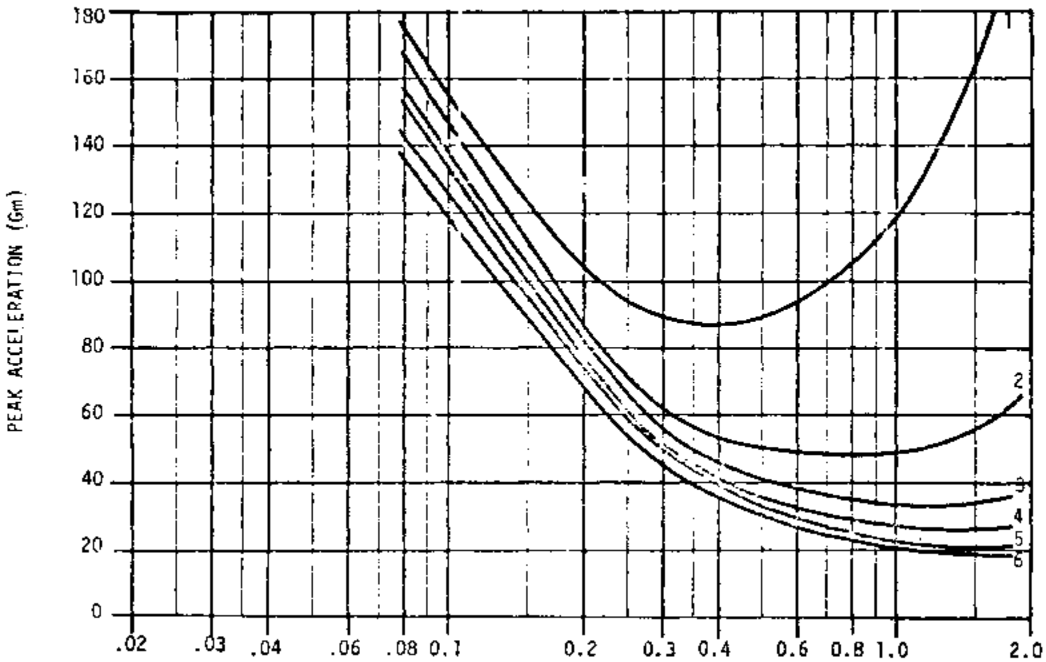
GRAPH 10.48: POLYETHYLENE,
2 pcf, 48" Drop Height



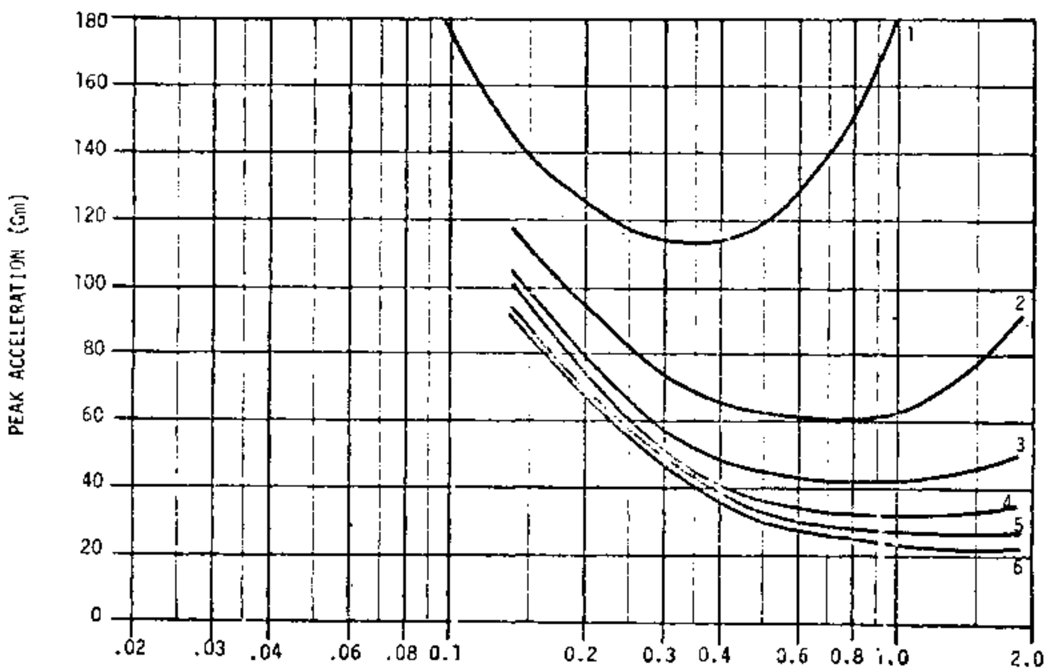
GRAPH 11.12: POLYETHYLENE,
4 pcf, 12" Drop Height



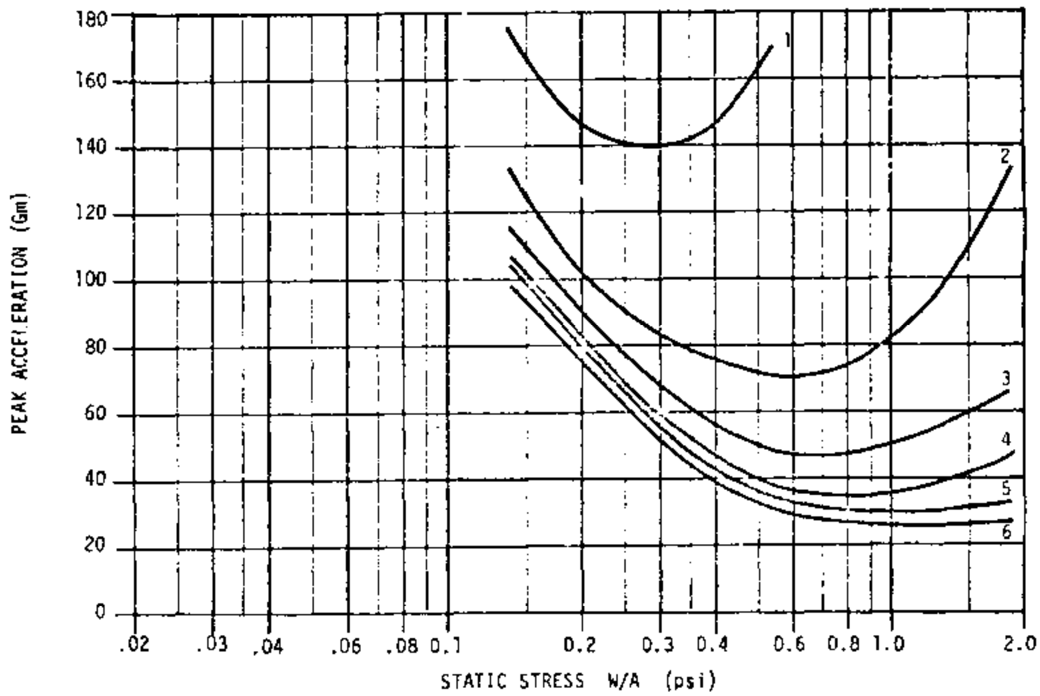
GRAPH 11.18: POLYETHYLENE,
4 pcf, 18" Drop Height



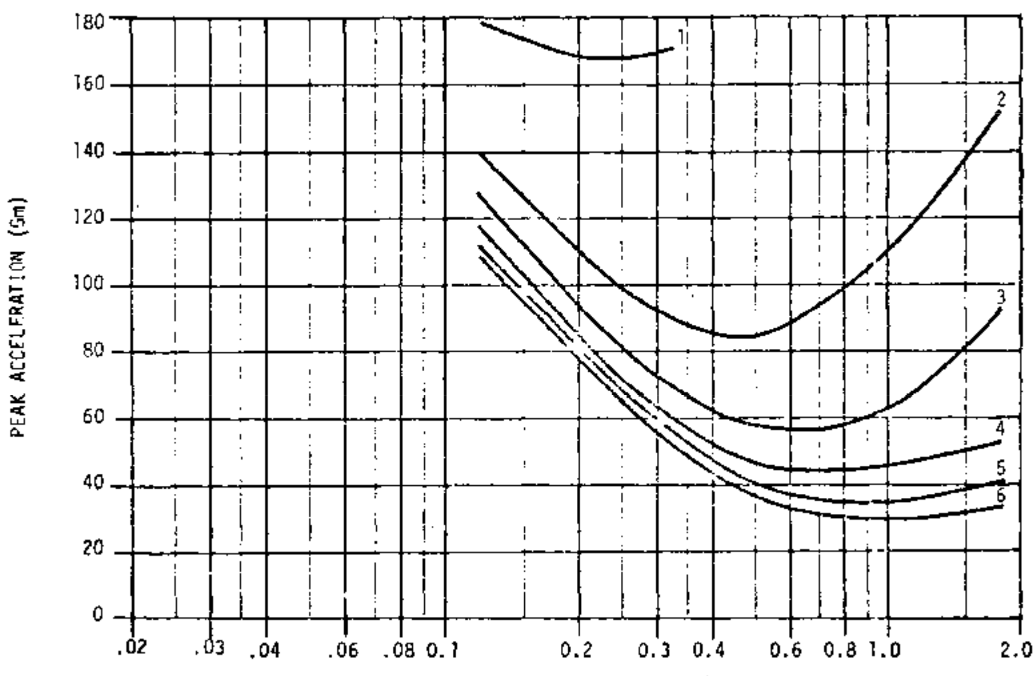
STATIC STRESS W/A (psi)
GRAPH 11.24: POLYETHYLENE,
4 pcf, 24" Drop Height



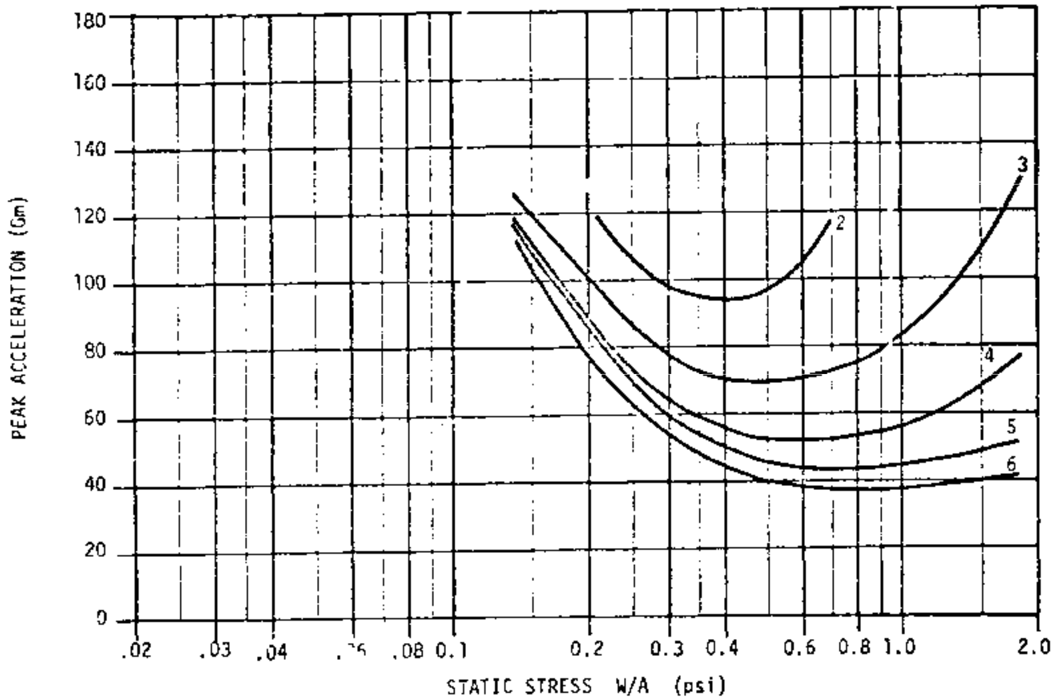
STATIC STRESS W/A (psi)
GRAPH 11.30: POLYETHYLENE,
3 pcf, 30" Drop Height



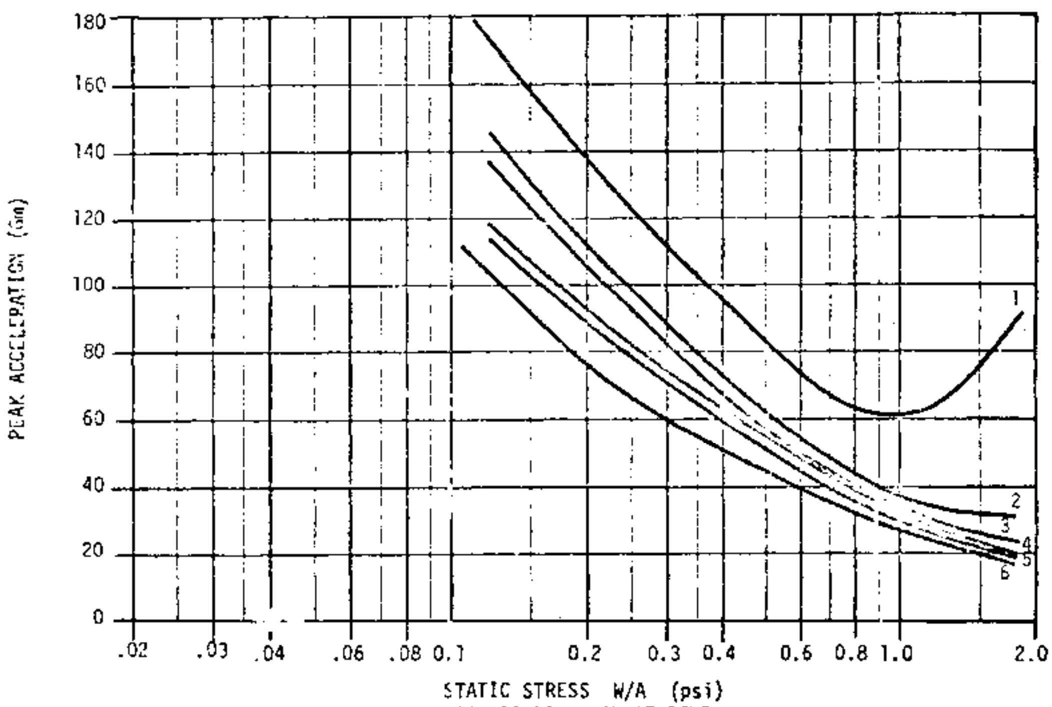
GRAPH 11.36: POLYETHYLENE, 4 pcf, 36" Drop Height



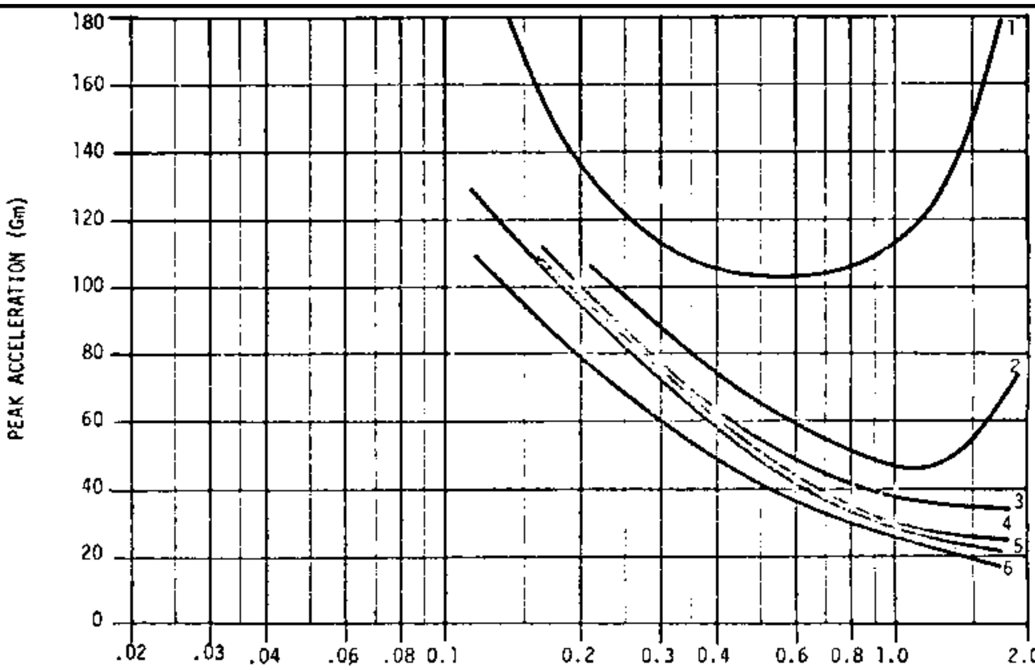
GRAPH 11.42: POLYETHYLENE, 4 pcf, 42" Drop Height



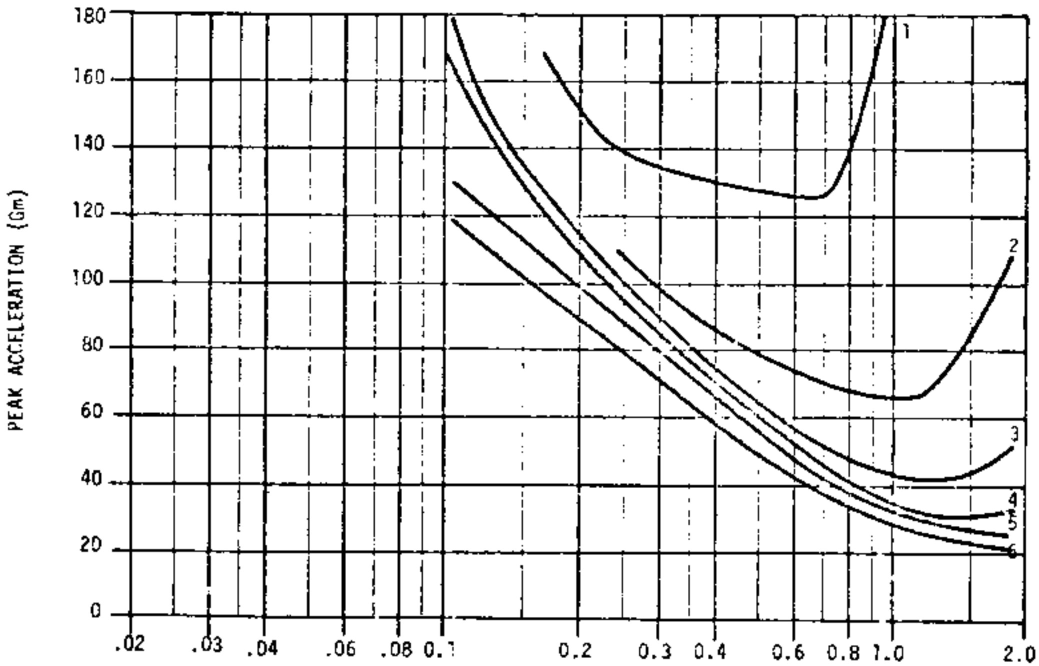
GRAPH 11.48: POLYETHYLENE,
[illegible] pcf, 48" Drop Height



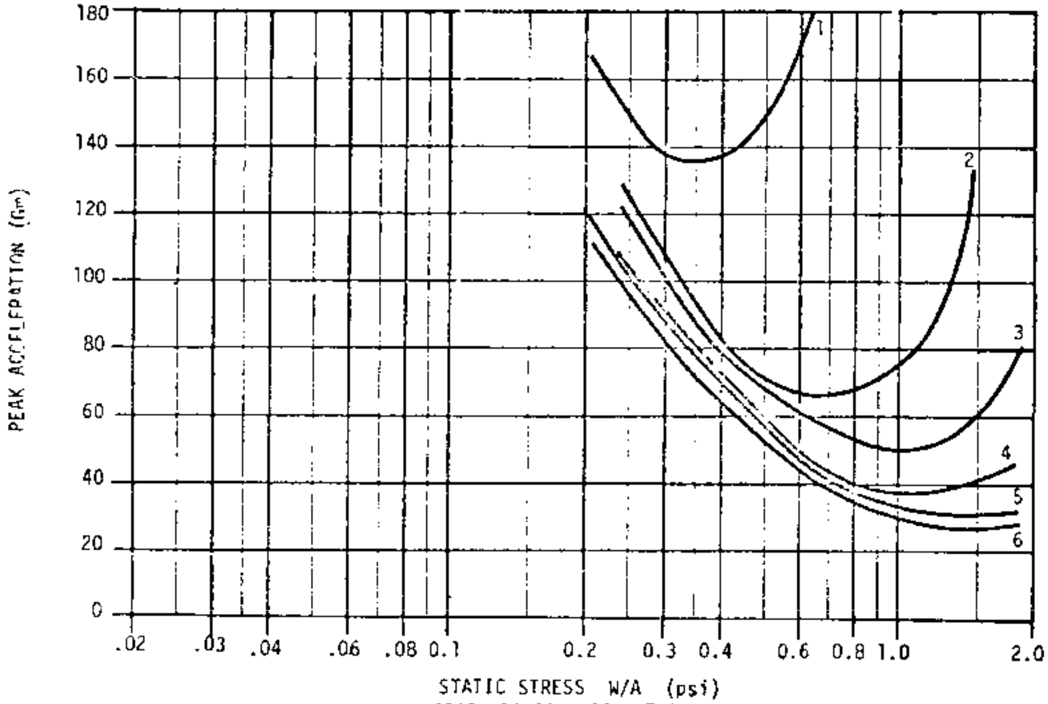
GRAPH 12.12: POLYSTYRENE,
1.5 pcf, 12" Drop Height



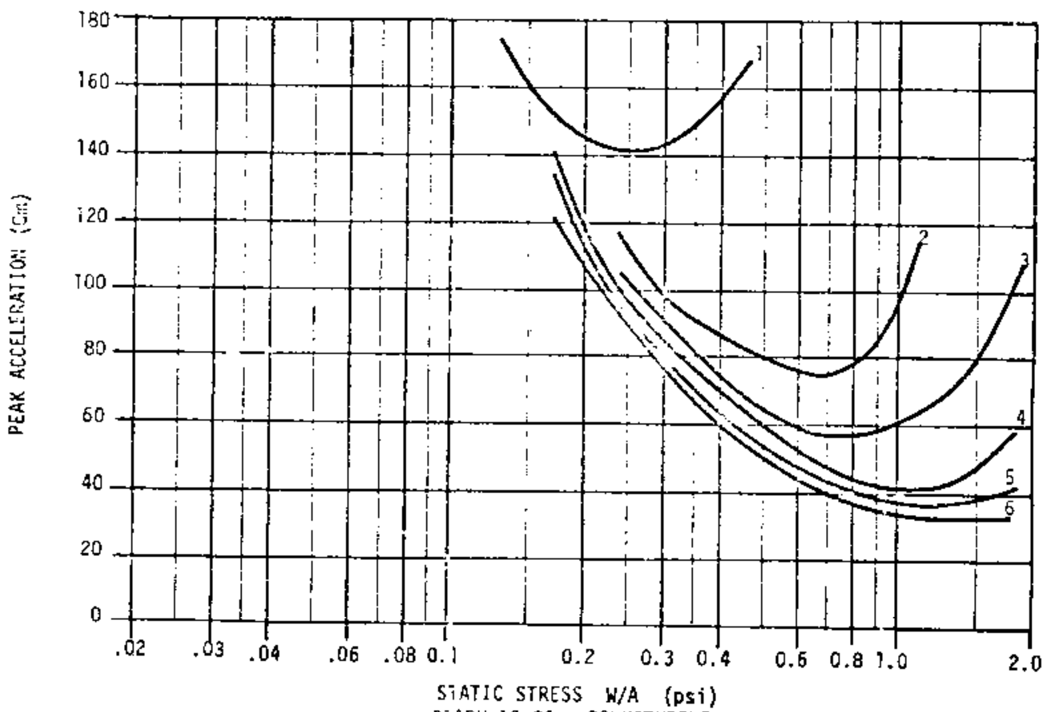
STATIC STRESS W/A (psi)
GRAPH 12.18: POLYSTYRENE,
1.5 pcf, 18" Drop Height



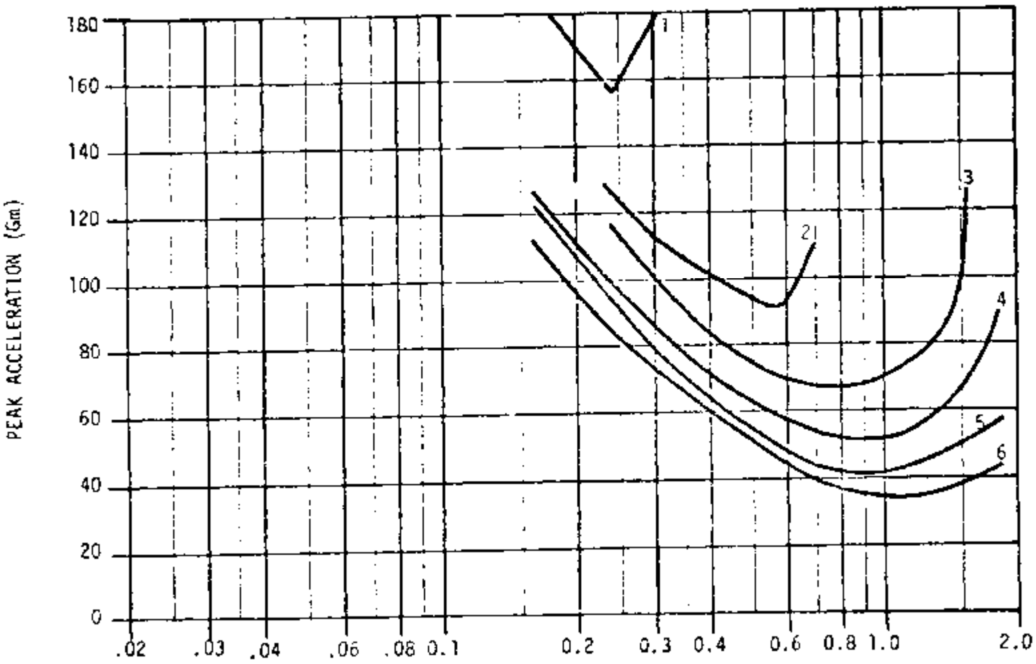
STATIC STRESS W/A (psi)
GRAPH 12.24: POLYSTYRENE,
1.5 pcf, 24" Drop Height



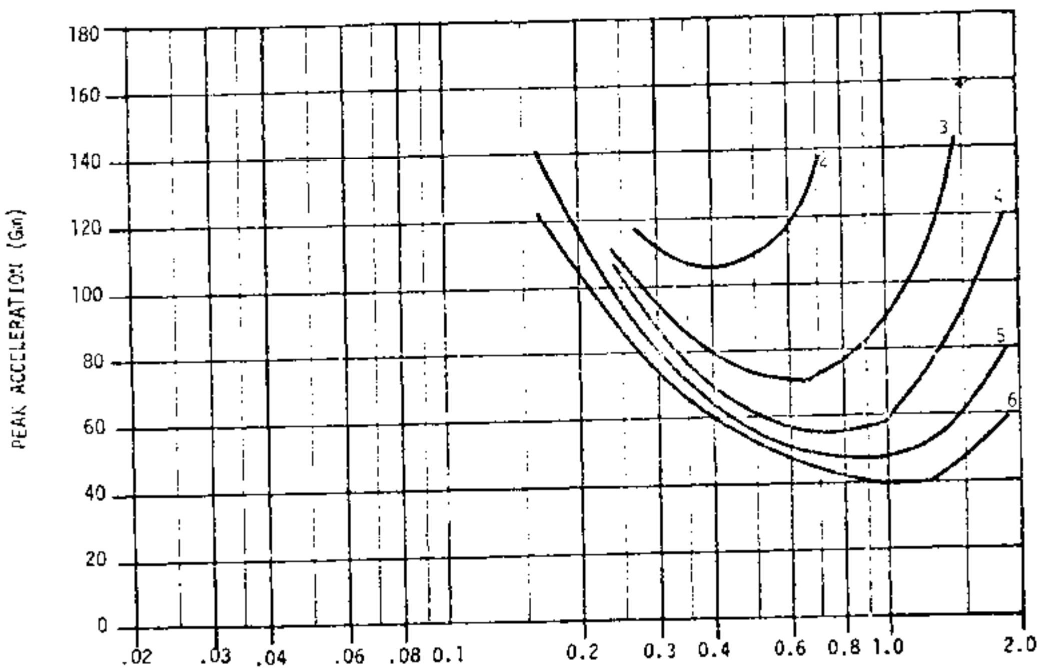
GRAPH 12.30: POLYSTYRENE,
1.5 pcf, 30" Drop Height



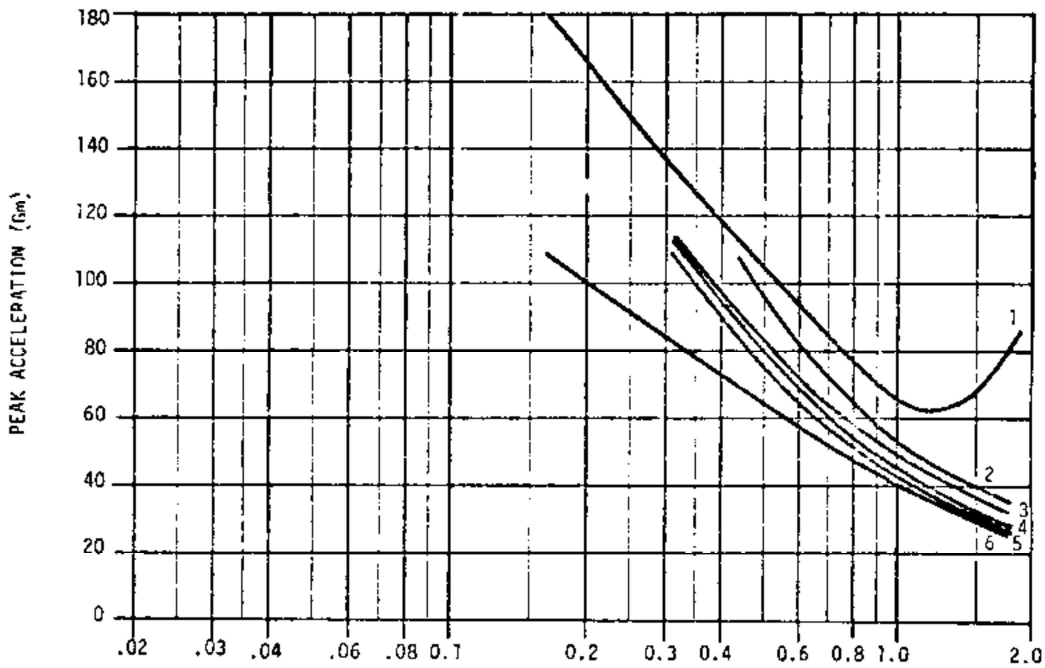
GRAPH 12.36: POLYSTYRENE,
1.5 pcf, 36" Drop Height



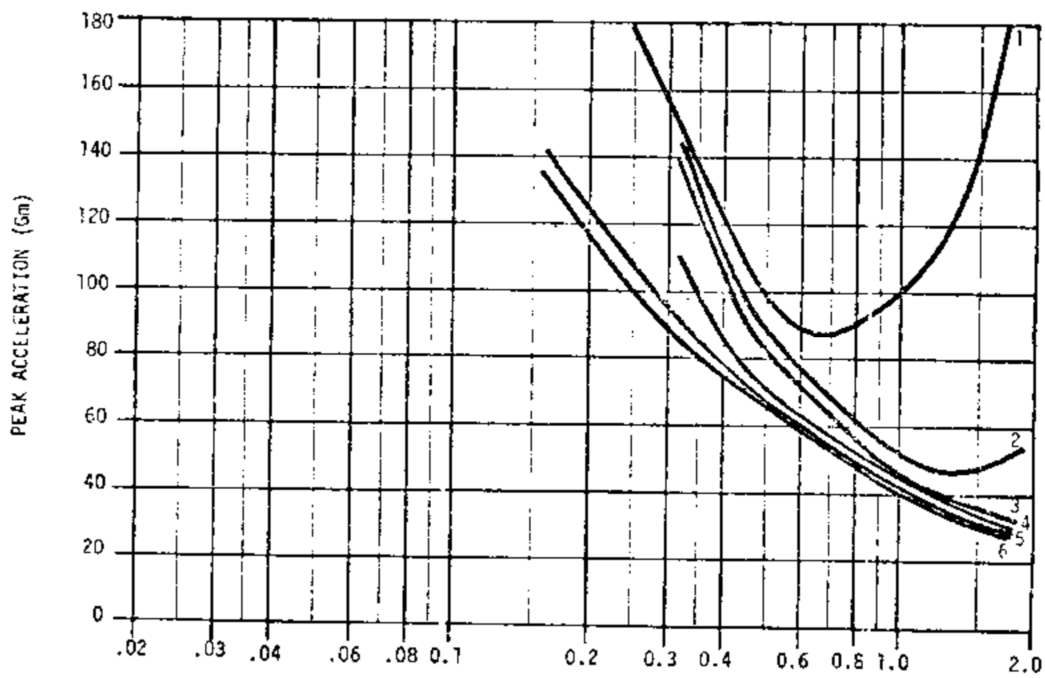
GRAPH 12.42: POLYSTYRENE, 1.5 pcf, 42" Drop Height



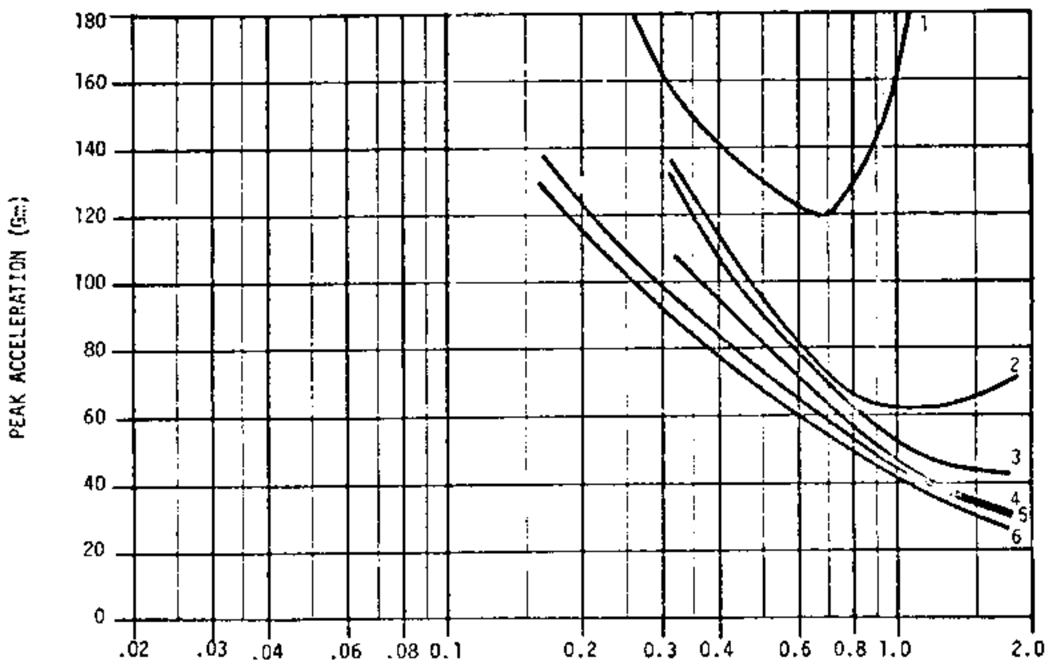
GRAPH 12.48: POLYSTYRENE, 1.5 pcf, 48" Drop Height



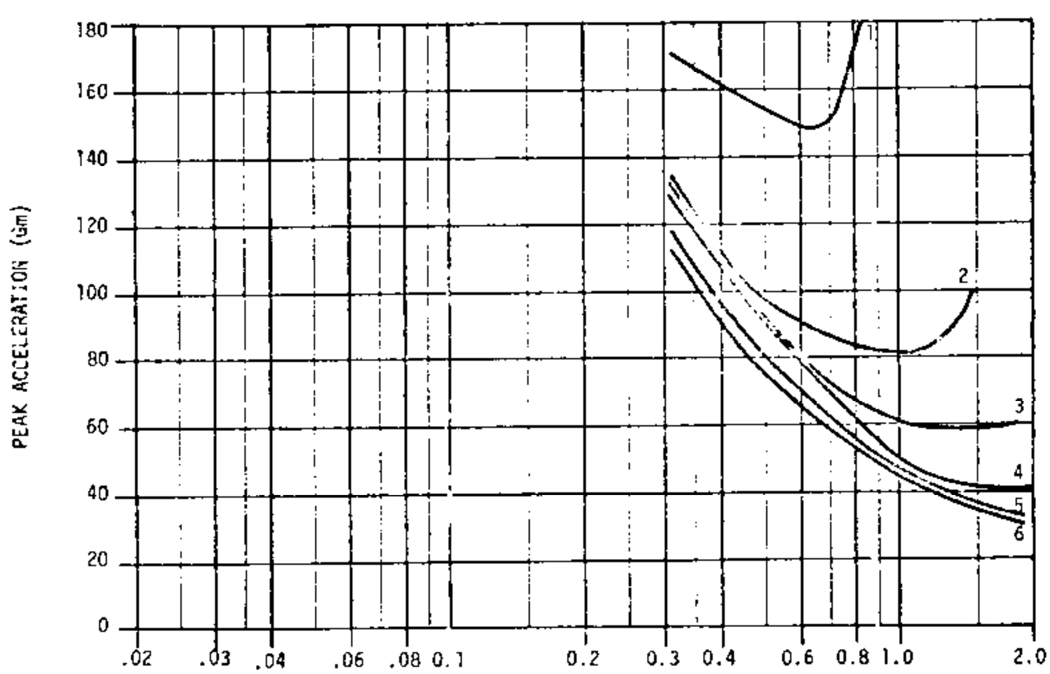
STATIC STRESS W/A (psi)
GRAPH 13.12: POLYSTYRENE,
2.5 pcf, 12" Drop Height



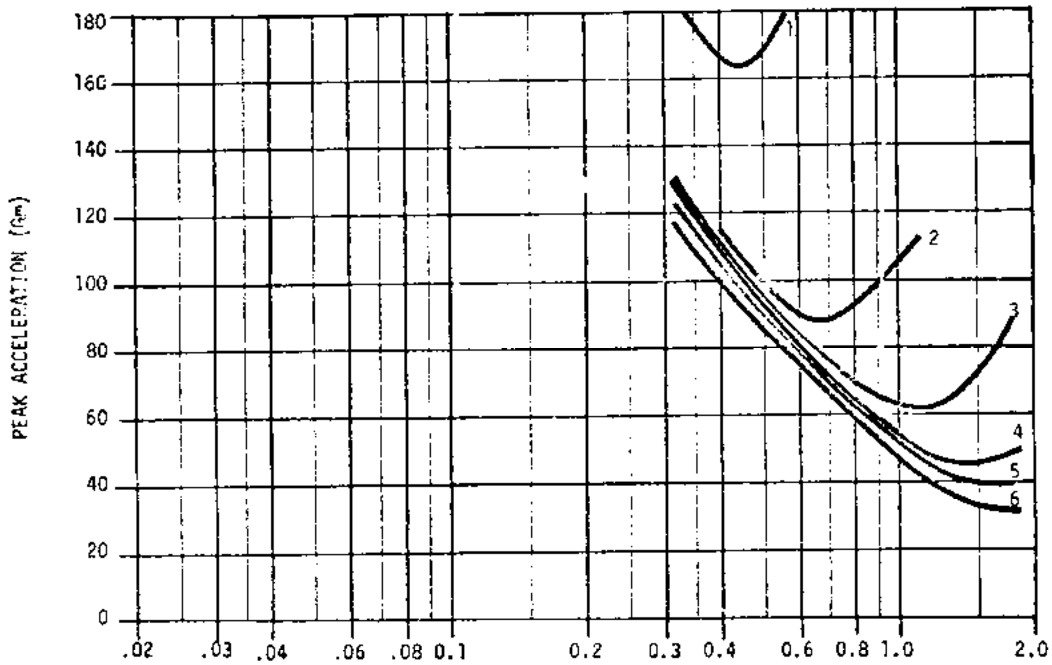
STATIC STRESS W/A (psi)
GRAPH 13.18: POLYSTYRENE,
2.5 pcf, 18" Drop Height



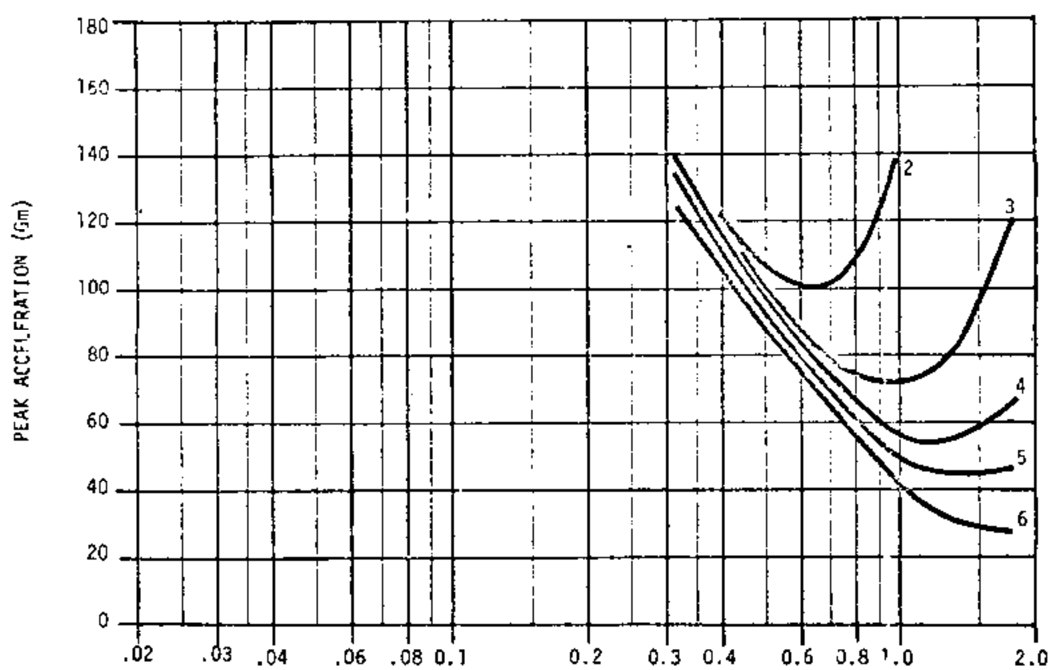
GRAPH 13.24: POLYSTYRENE,
2.5 pcf, 24" Drop Height



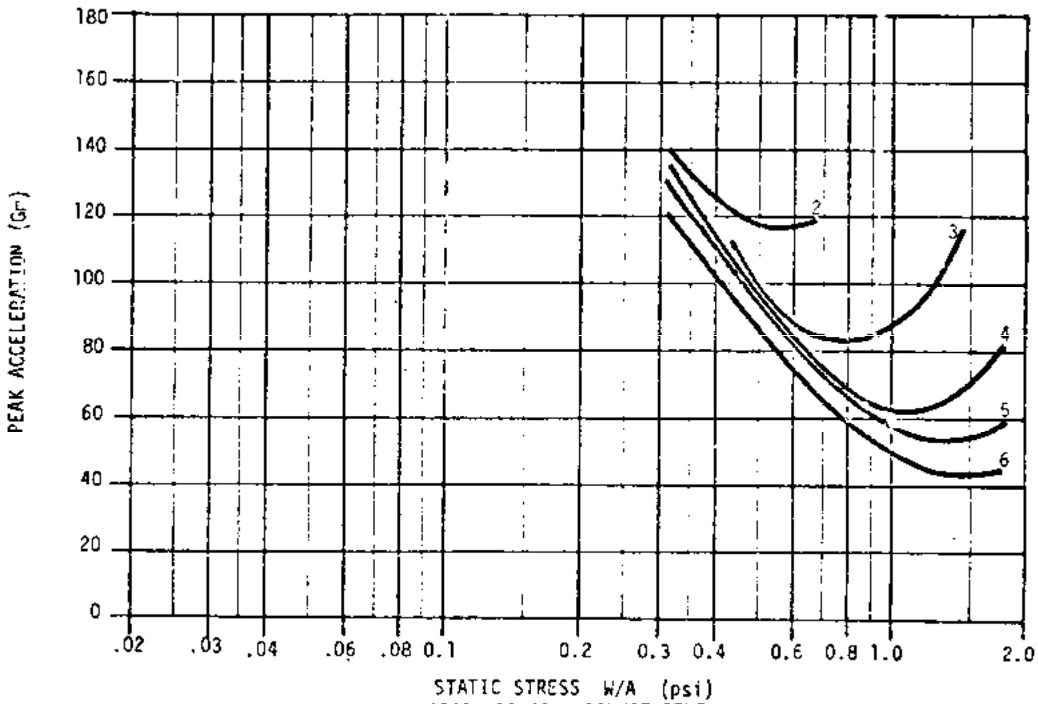
GRAPH 13.30: POLYSTYRENE,
2.5 pcf, 30" Drop Height



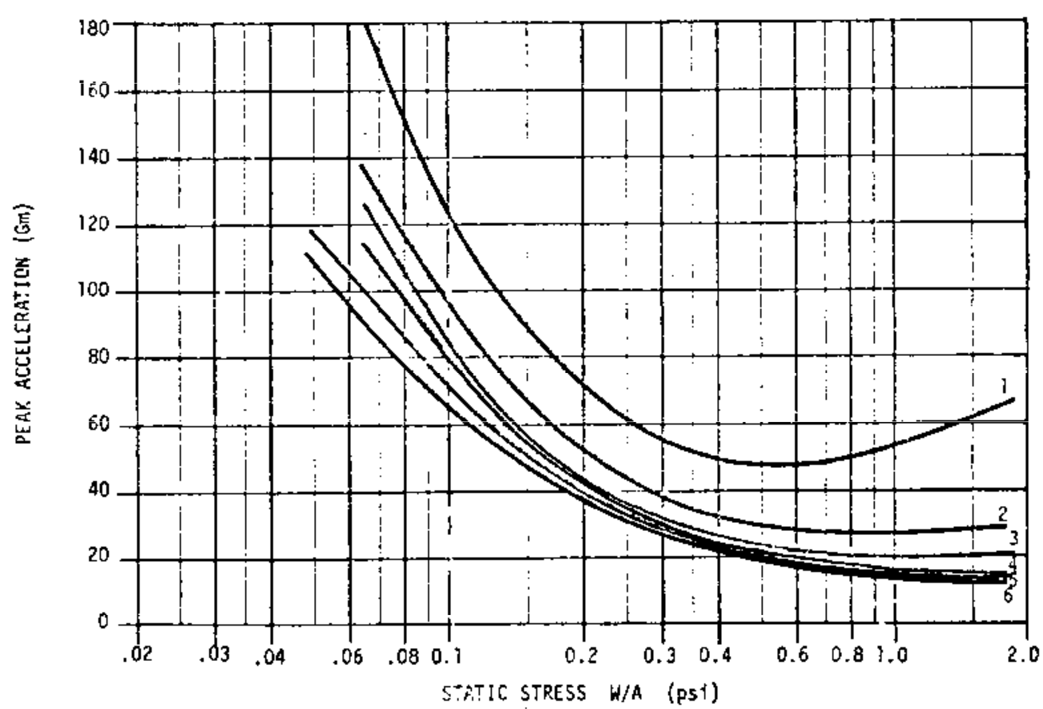
STATIC STRESS W/A (psi)
GRAPH 13.36: POLYSTYRENE,
2.5 pcf, 36" Drop Height



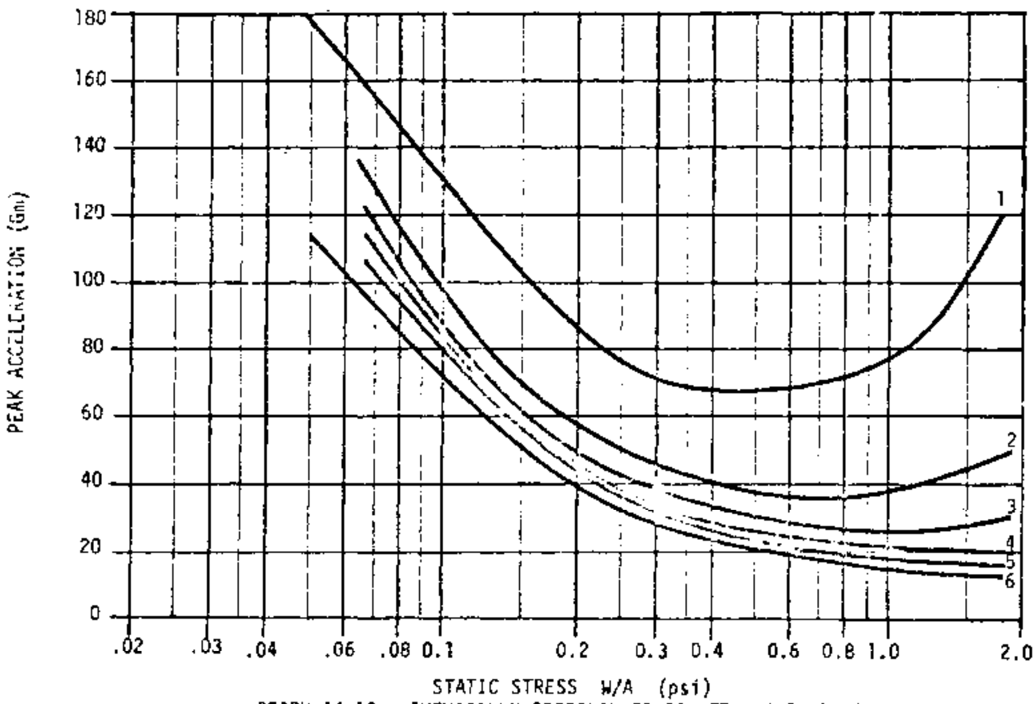
STATIC STRESS W/A (psi)
GRAPH 13.42: POLYSTYRENE,
2.5 pcf, 42" Drop Height



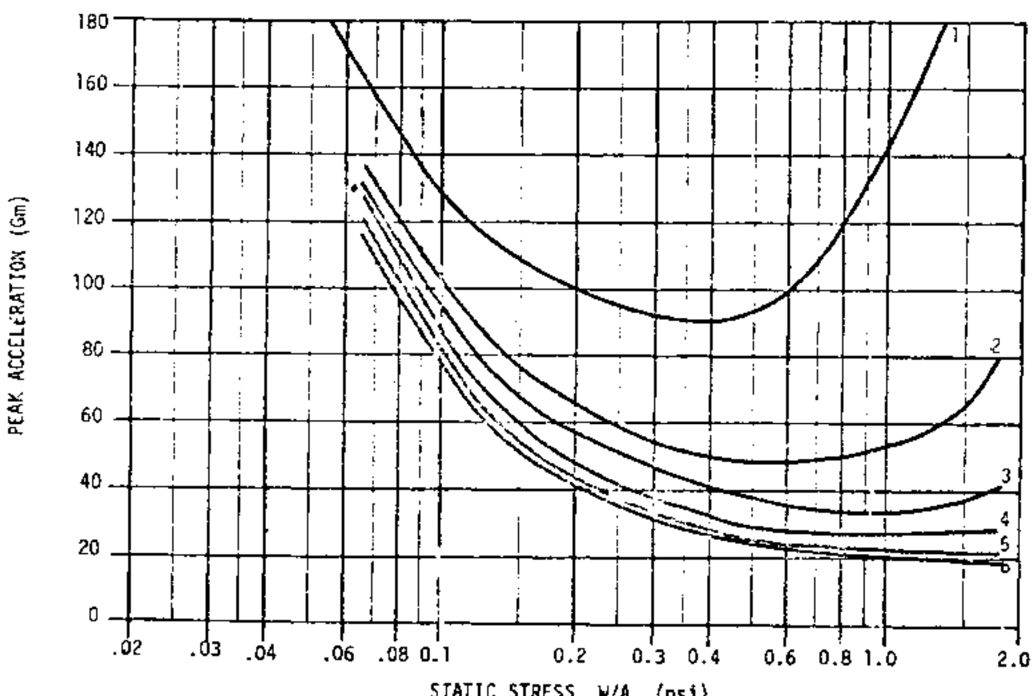
GRAPH 13.49: POLYSTYRENE, 2.5 pcf, 48" Drop Height



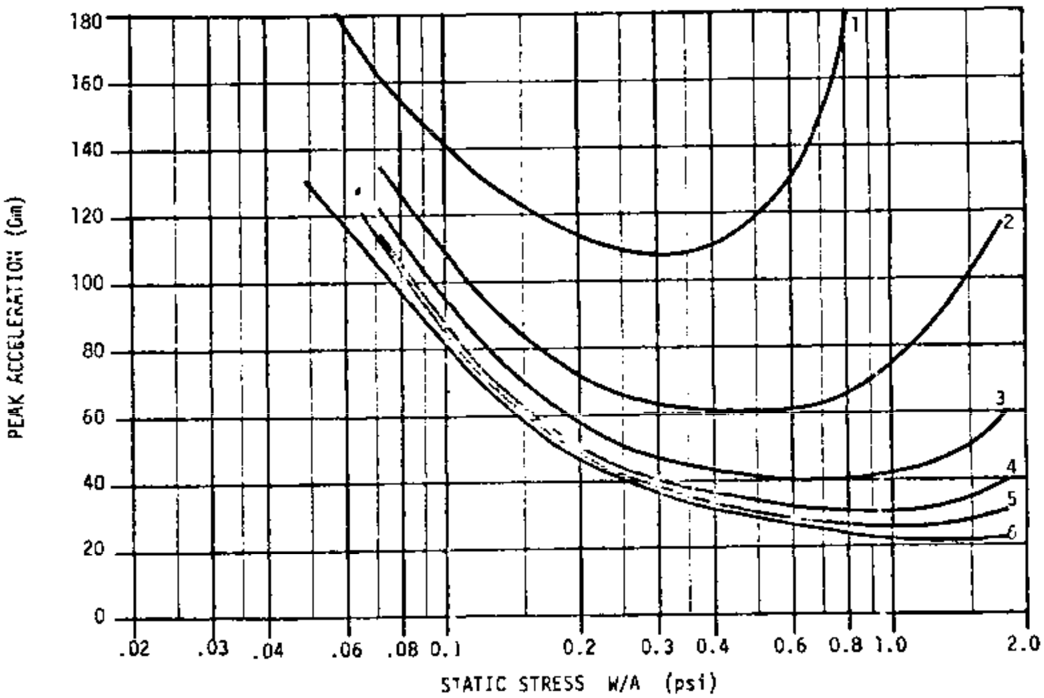
GRAPH 14.12: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf
12" Drop Height



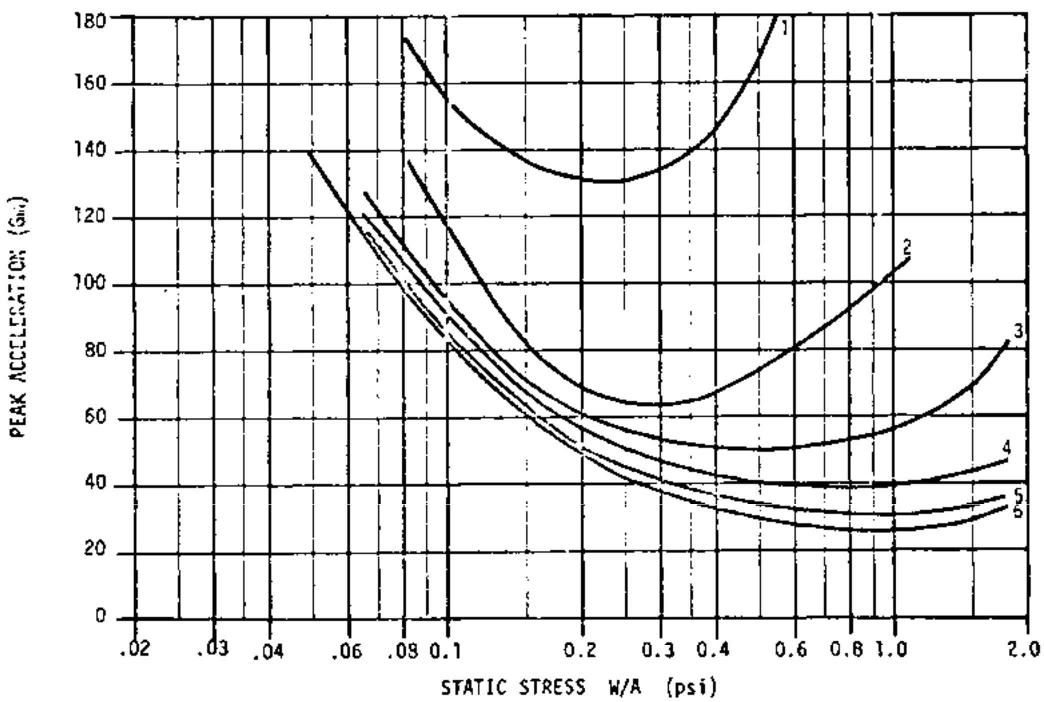
GRAPH 14.18: CHEMICALLY CROSSLINKED POLYETHYLENE, 2pcf
18" Drop Height



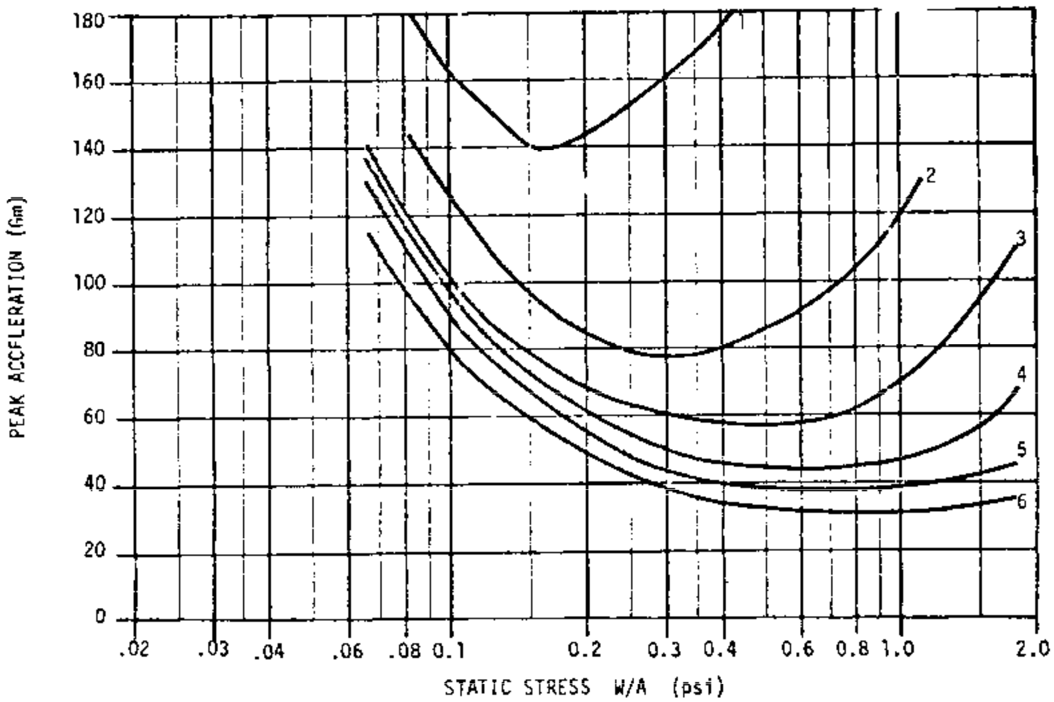
GRAPH 14.24: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf
24" Drop Height



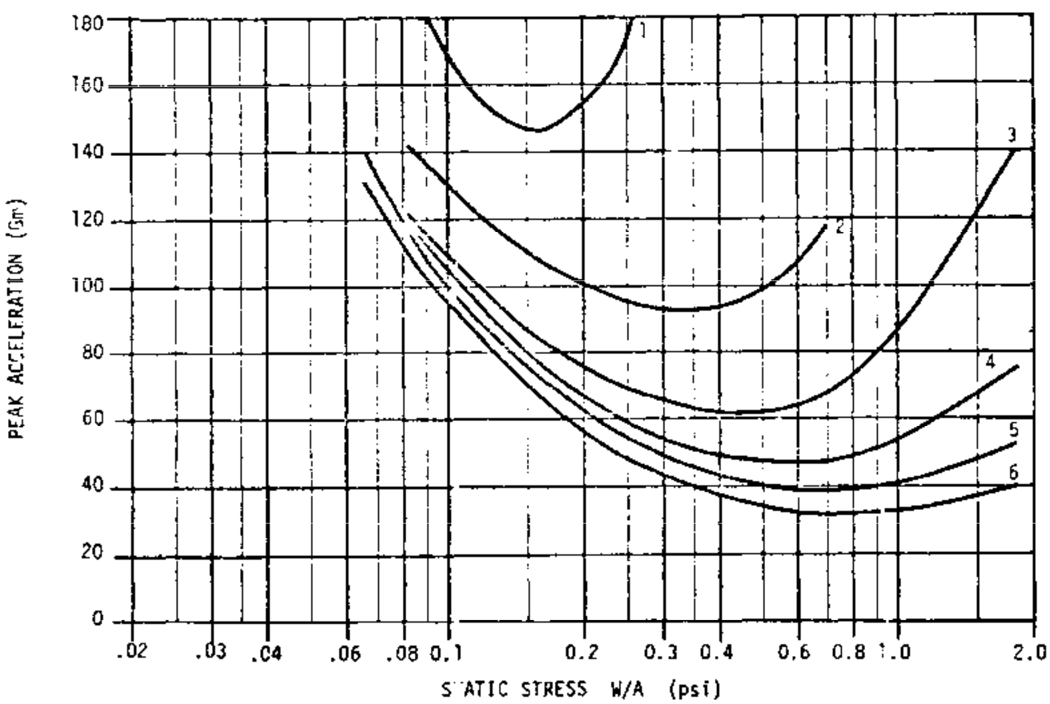
GRAPH 14.30: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf
30" Drop Height



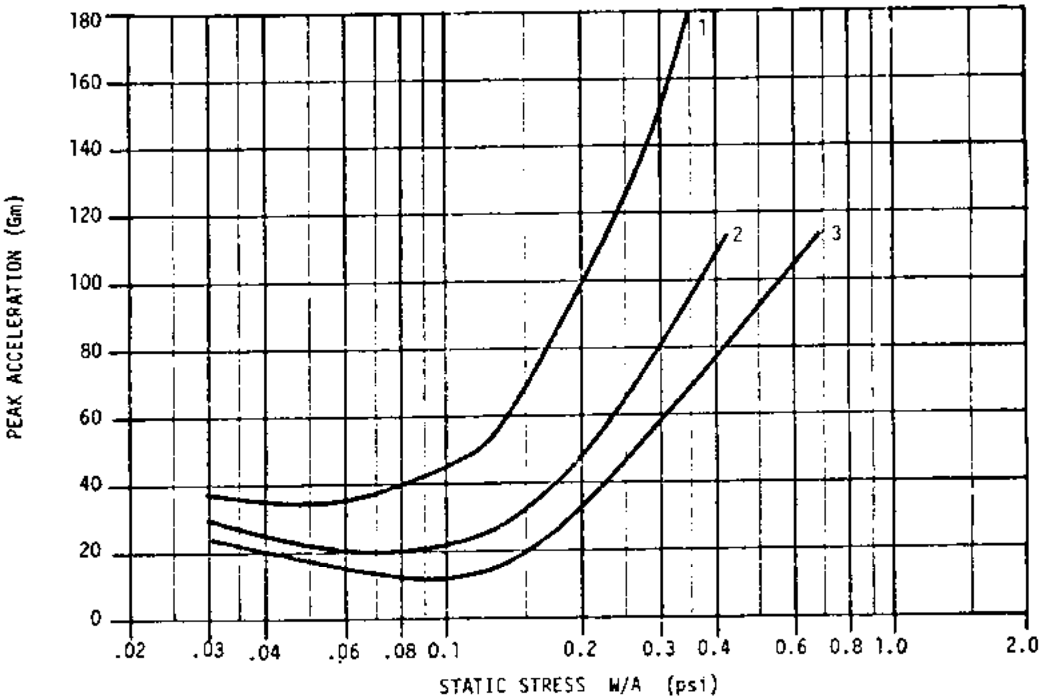
GRAPH 14.36: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf
36" Drop Height



GRAPH 14.42: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf
42" Drop Height

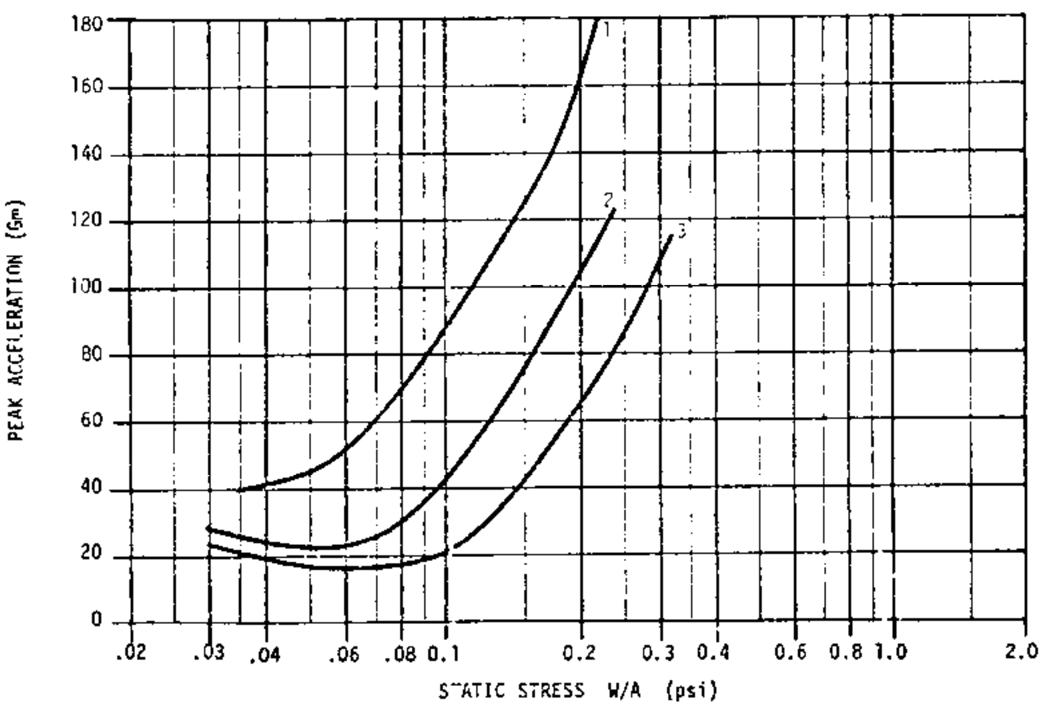


GRAPH 14.48: CHEMICALLY CROSSLINKED POLYETHYLENE, 2 pcf
48" Drop Height



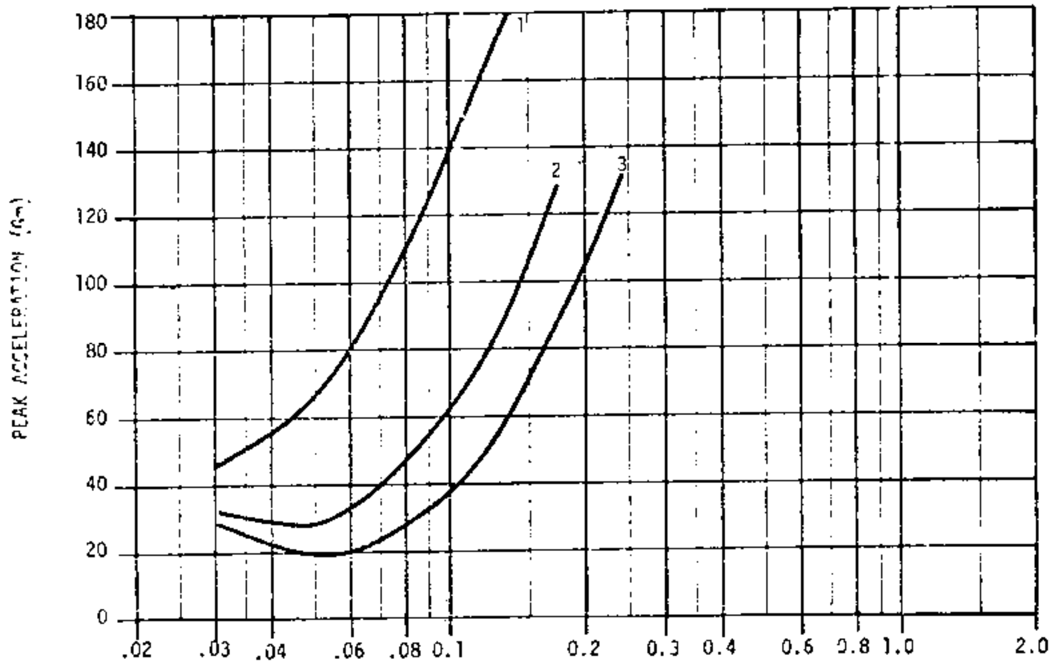
GRAPH 15.12: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (1.0" overall, 1.38" pitch, 0.42" valley) 12" Drop Height

(See CHART 15 for material description)



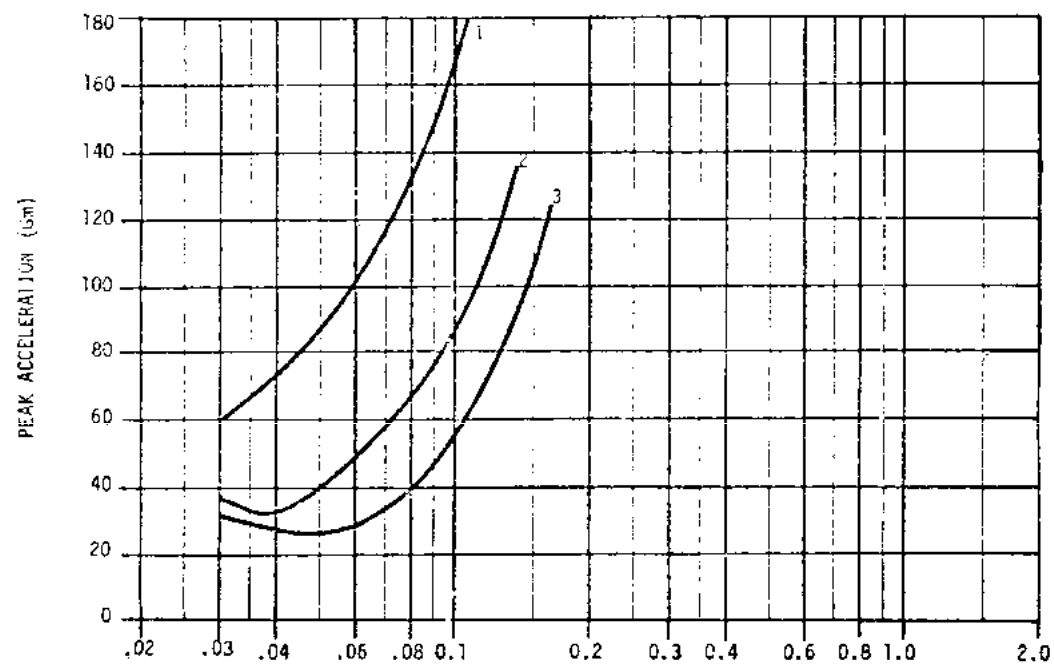
GRAPH 15.13: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (1.0" overall, 1.38" pitch, 0.42" valley) 18" Drop Height

(See CHART 15 for material description)



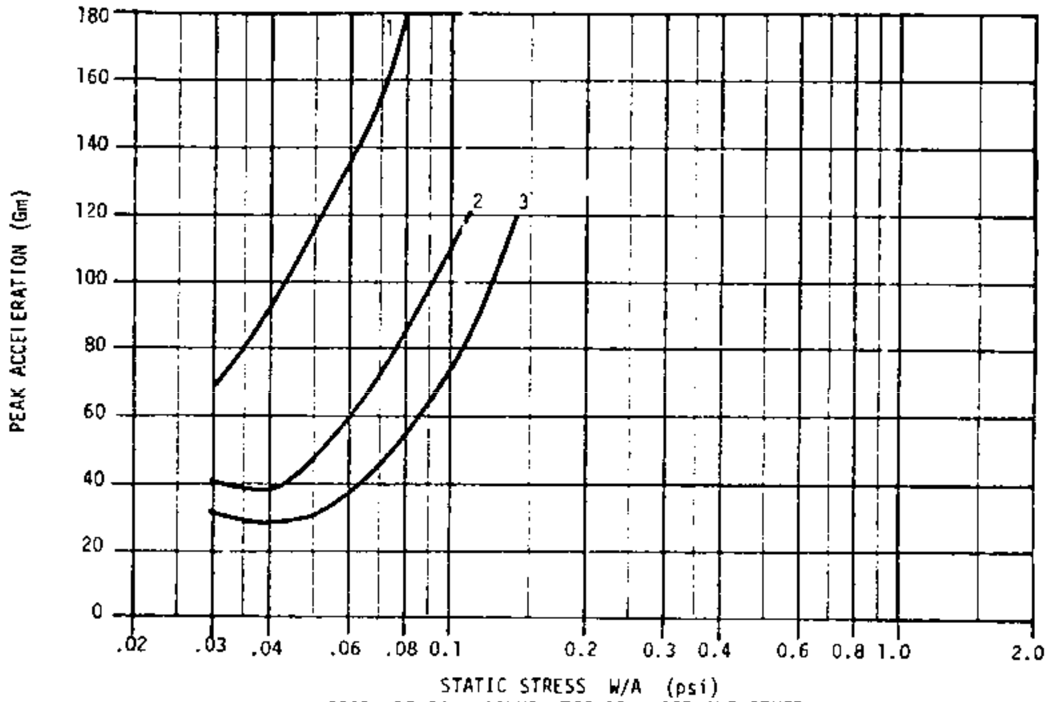
GRAPH 15.24: CONVOLUTED POLYURETHANE ETHER, 1.35 pcf, (1.0" overall, 1.38" pitch, 0.42" valley) 24" Drop Height

(See CHART 15 for material description)



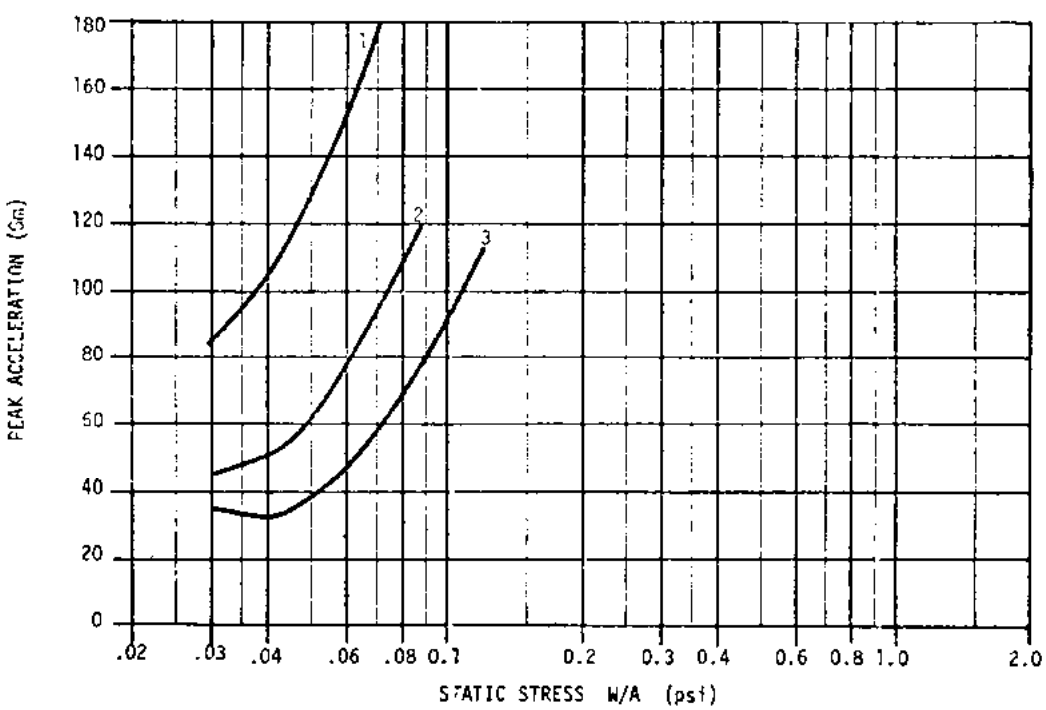
GRAPH 15.30: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (1.0"overall, 1.38" pitch, 0.42" valley) 30" Drop Height

(See CHART 15 for material description)



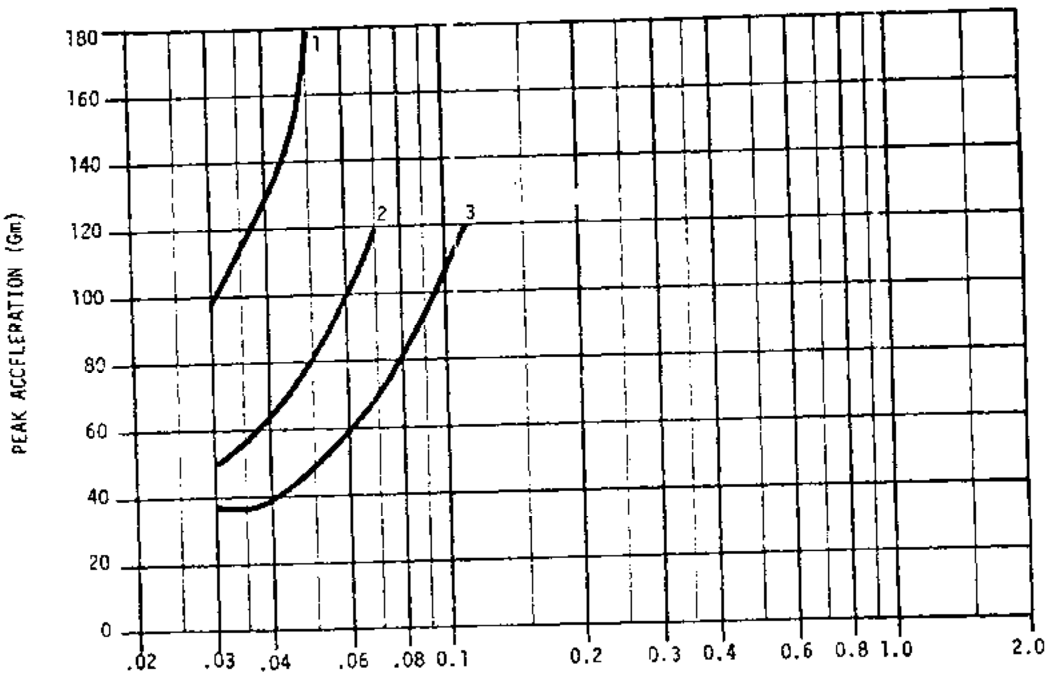
GRAPH 15.36: CONVOLUTED POLYURETHANE ETHER,
1.15 pcf, (1.0"overall, 1.38" pitch,
0.42" valley) 36" Drop Height

(See CHART 15 for material description)



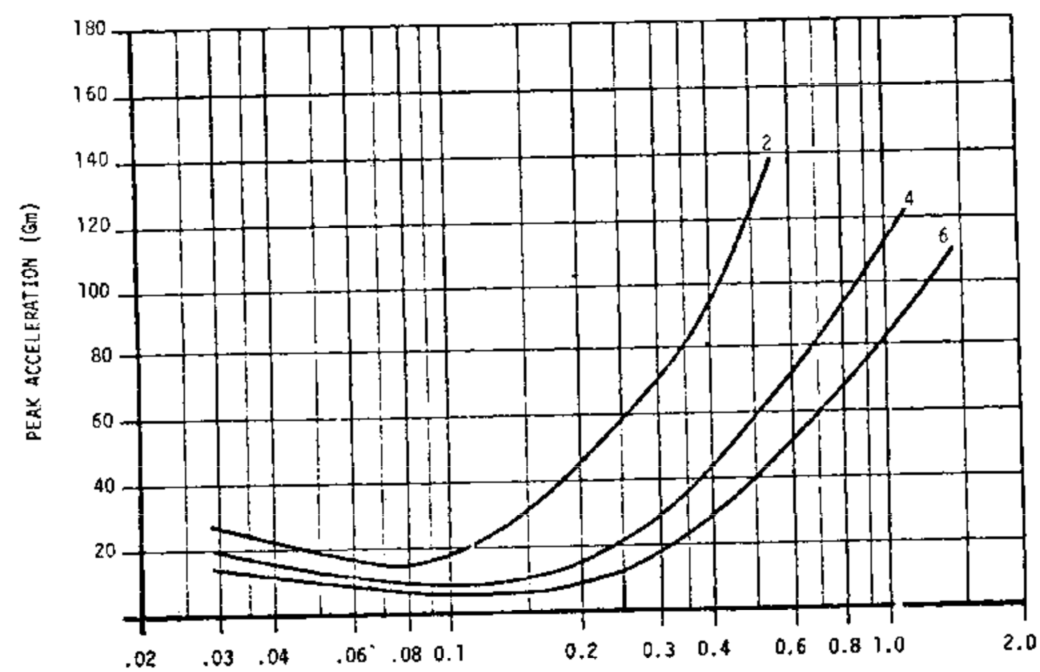
GRAPH 15.42: CONVOLUTED POLYURETHANE ETHER,
1.15 pcf, (1.0"overall, 1.38" pitch,
0.42" valley) 42" Drop Height

(See CHART 15 for material description)



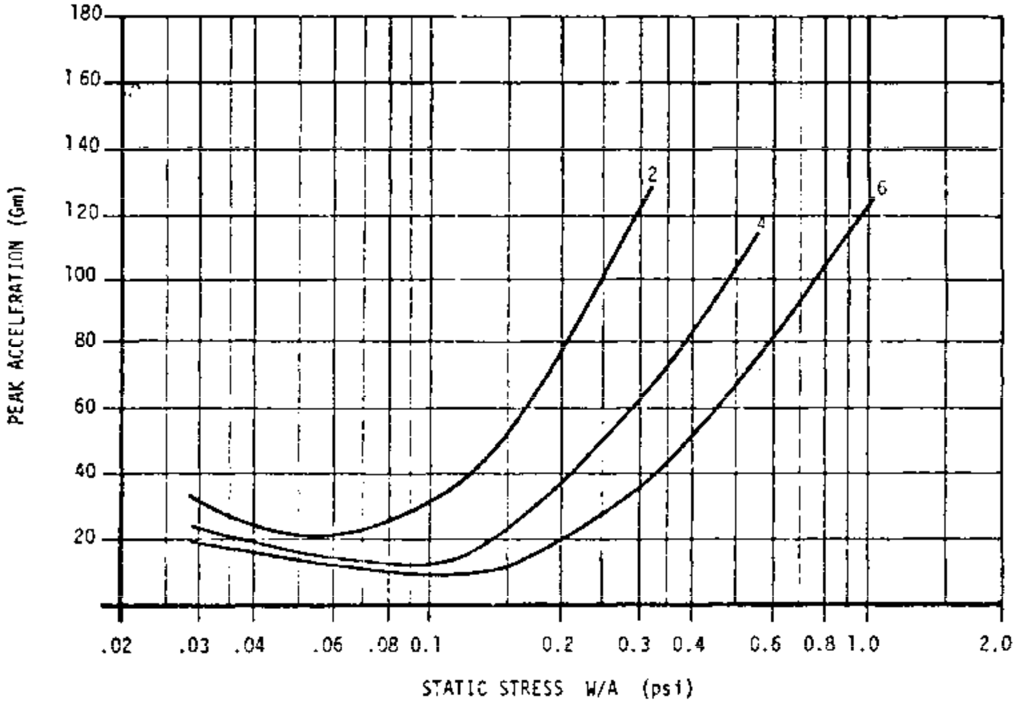
GRAPH 15.48: CONVOLUTED POLYURETHANE ETHER,
1.15 pcf, (1.0"overall, 1.38" pitch,
0.42" valley) 48" Drop Height

(See CHART 15 for material description)



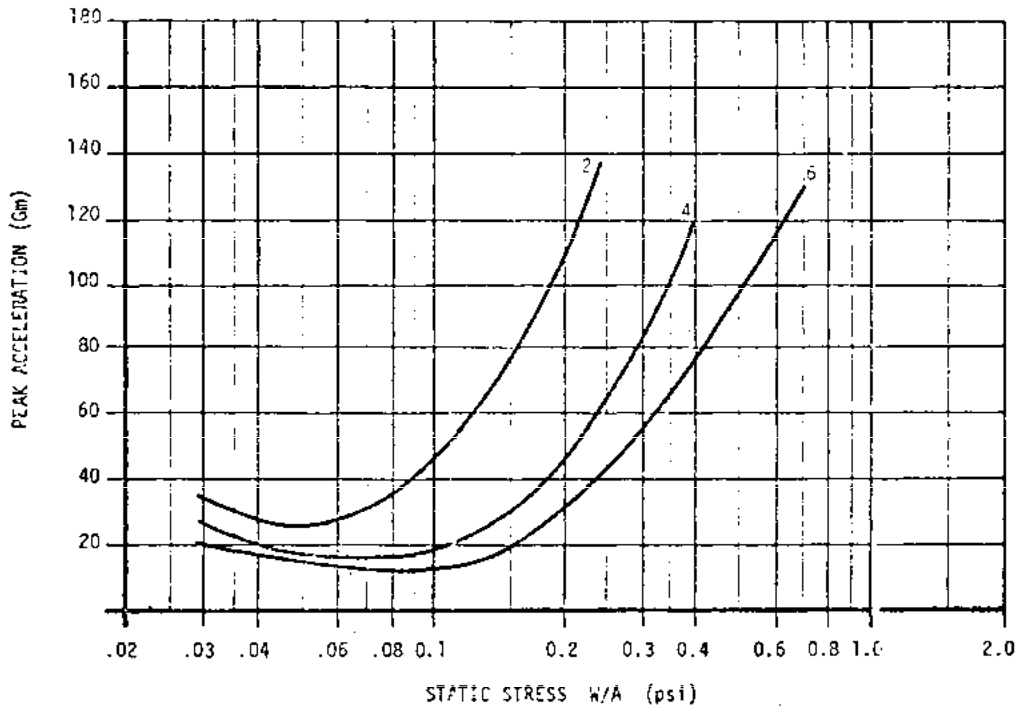
GRAPH 16.12: CONVOLUTED POLYURETHANE ETHER,
1.15 pcf, (2.1" overall, 1.38" pitch,
0.88" valley), 12" Drop Height

(See CHART 16 for material description)



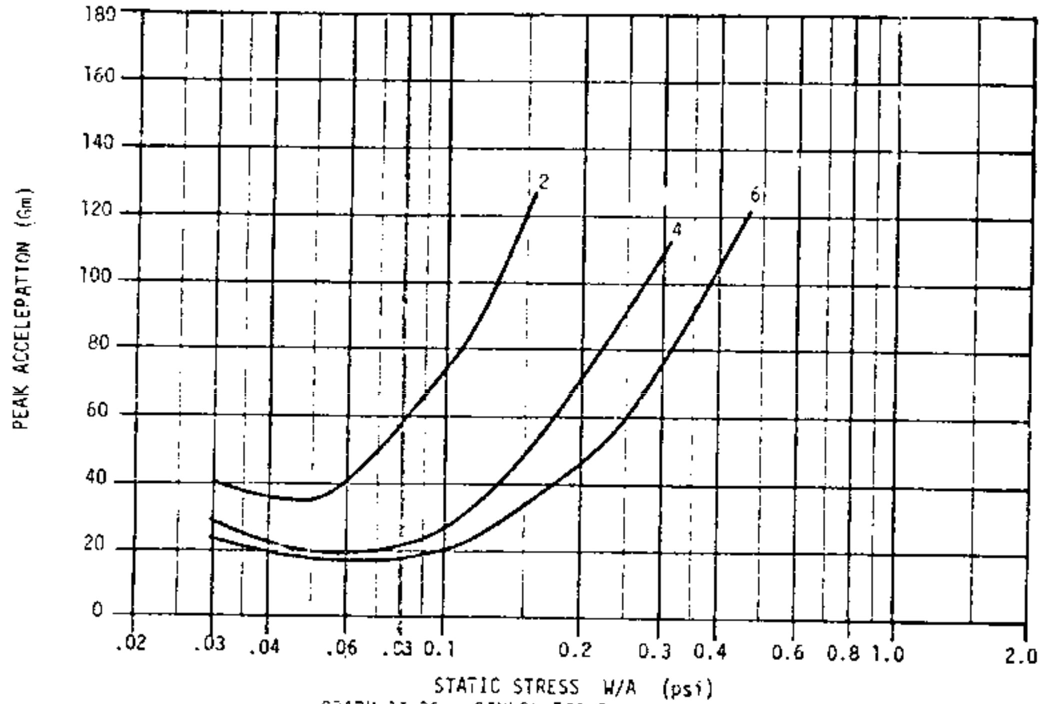
GRAPH 16.18: CONVOLUTED POLYURETHANE ETHER,
1.15 pcf, (2.1" overall, 1.38" pitch,
0.88" valley), 18" Drop Height

(See CHART 16 for material description)



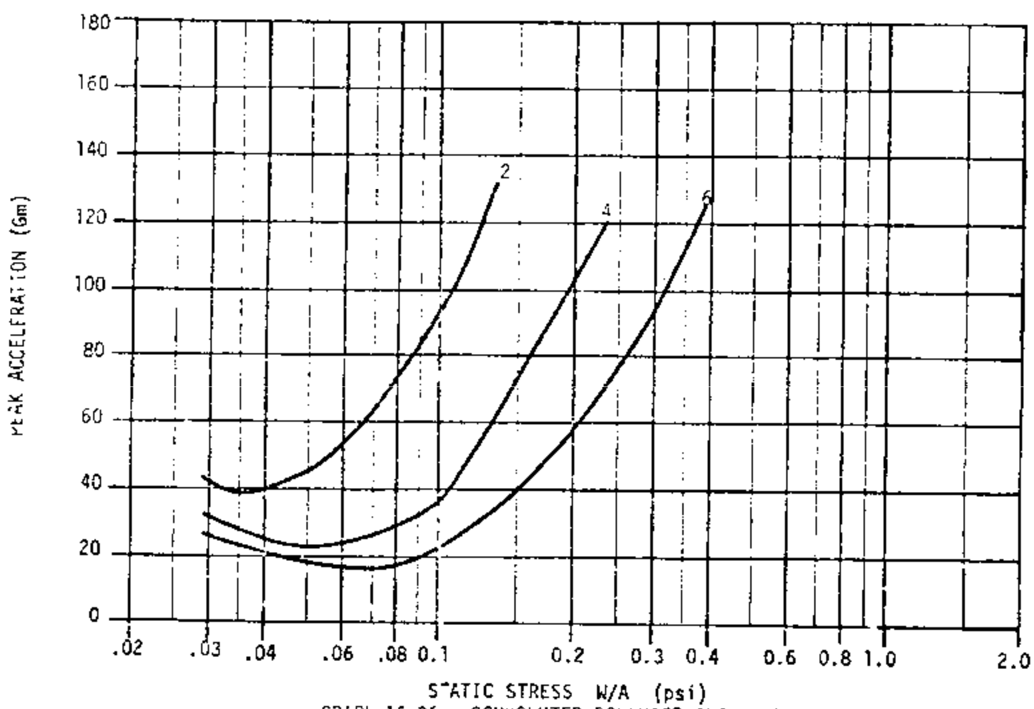
GRAPH 16.24: CONVOLUTED POLYURETHANE ETHER,
1.15 pcf, (2.1" overall, 1.38" pitch,
0.88" valley), 24" Drop Height

(See CHART 16 for material description)



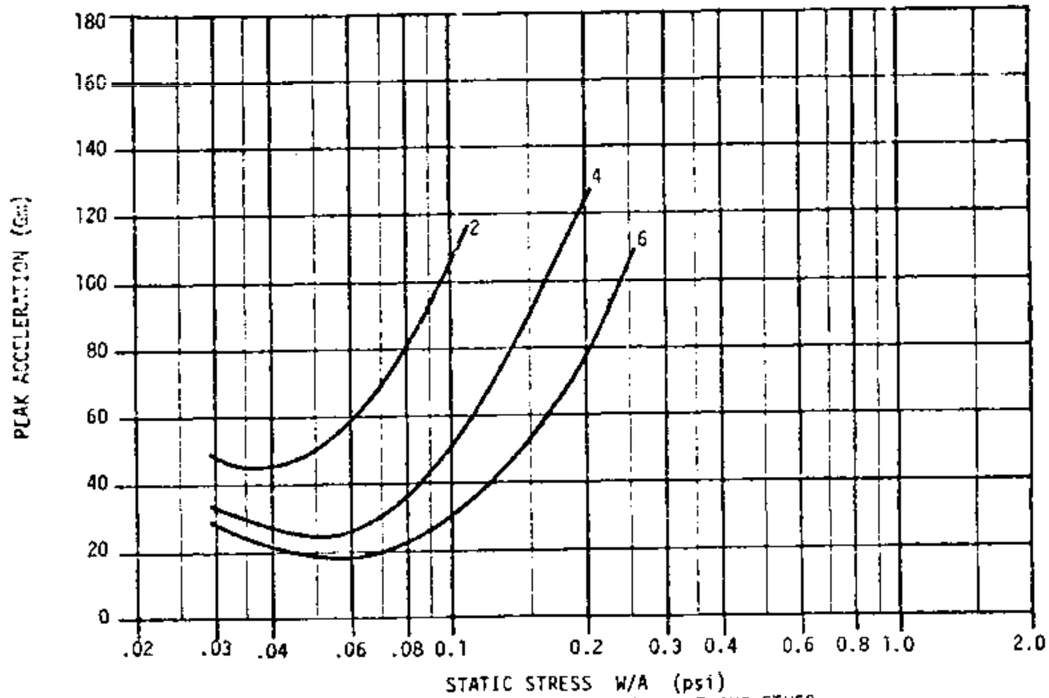
GRAPH 16.30: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (2.1" overall, 1.38" pitch, 0.88" valley), 30" Drop Height

(See CHART 16 for material description)



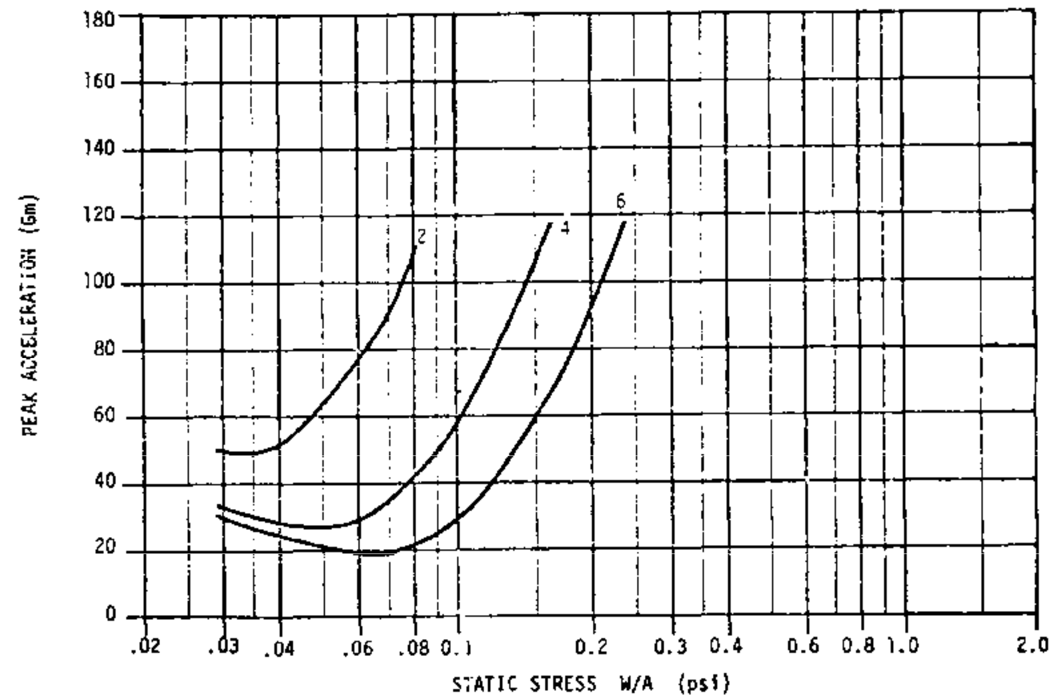
GRAPH 16.36: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (2.1" overall, 1.38" pitch, 0.88" valley), 36" Drop Height

(See CHART 16 for material description)



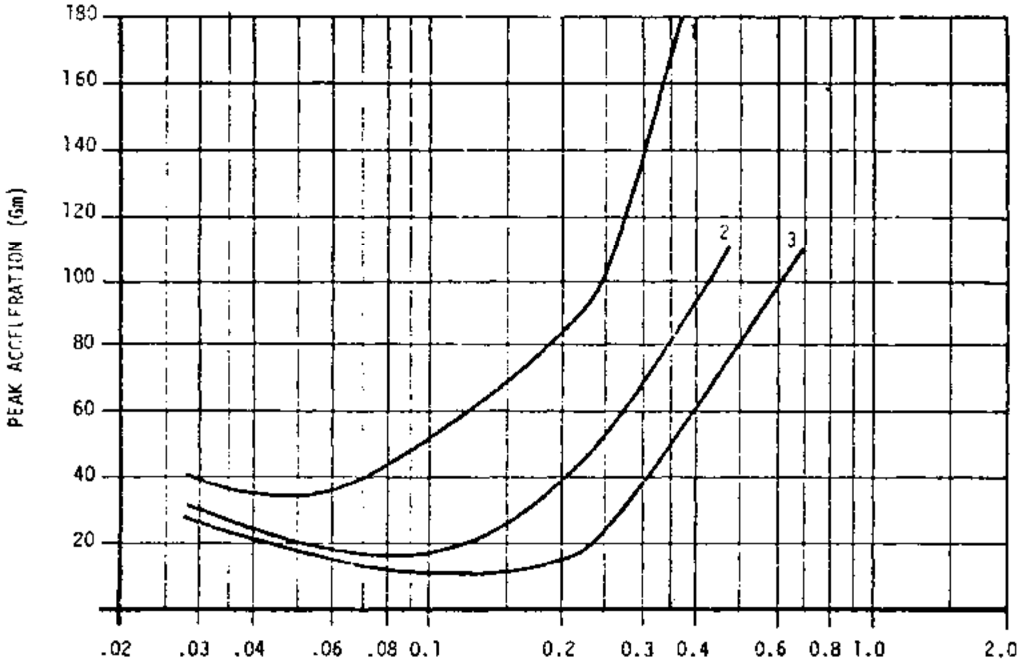
GRAPH 16.42: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (2.1" overall, 1.38"pitch, 0.88" valley), 42" Drop Height

(See CHART 16 for material description)



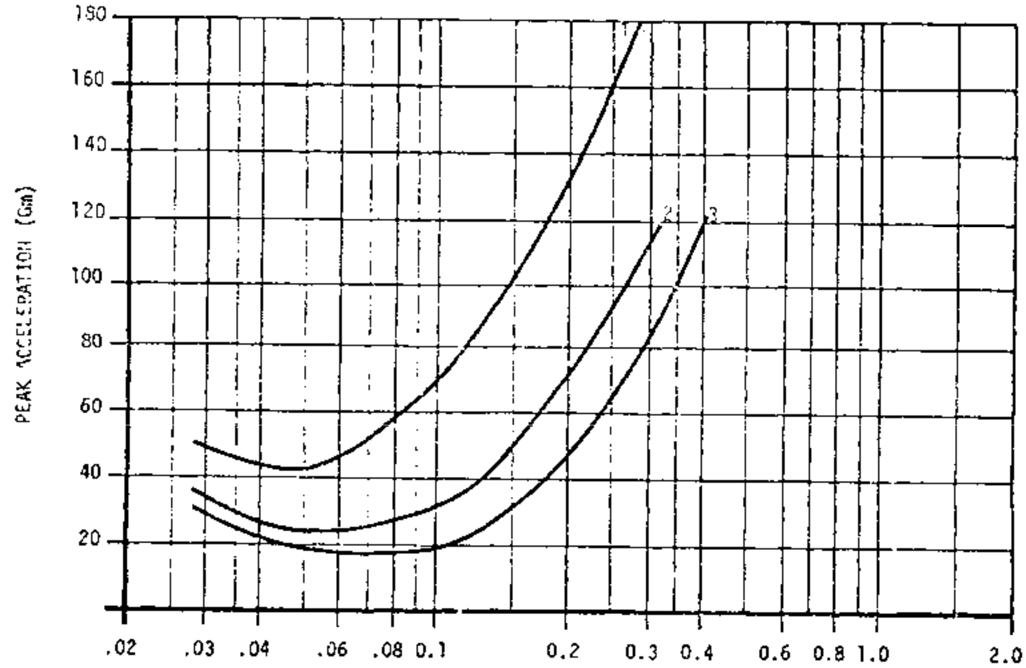
GRAPH 16.43: CONVOLUTED POLYURETHANE ETHER, 1.15 pcf, (2.1" overall, 1.38" pitch 0.88" valley), 48" Drop Height

(See CHART 16 for material description)



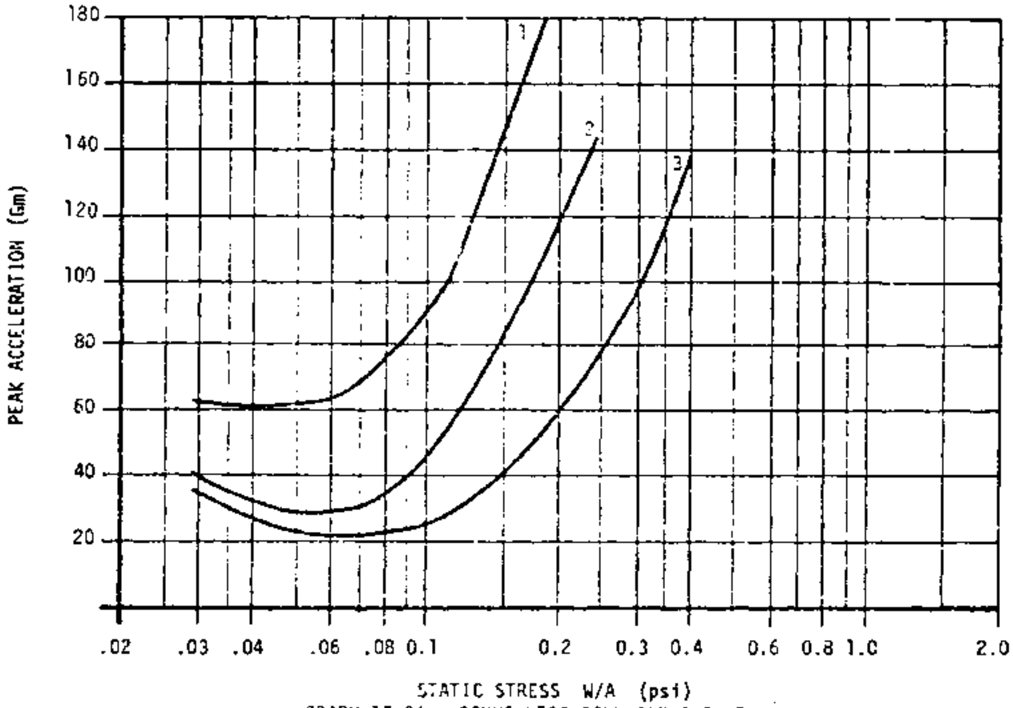
GRAPH 17.12: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, (1.0" overall, 1.38" pitch,
0.42" valley), 12" Drop Height

(See CHART 17 for material description)

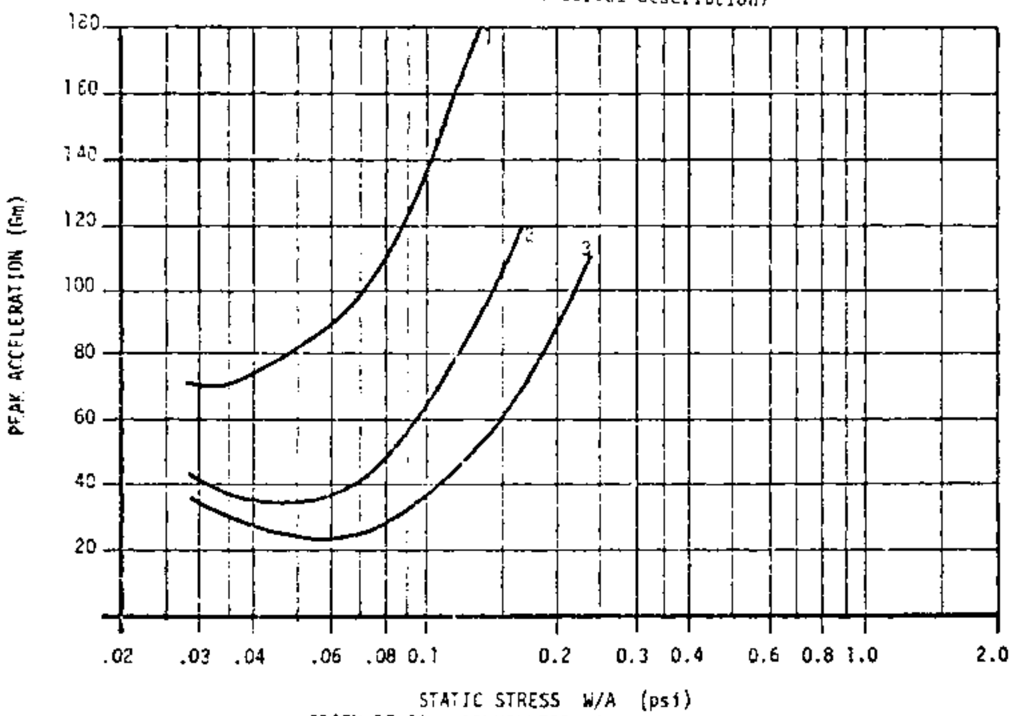


GRAPH 17.18: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, (1.0" overall, 1.38" pitch,
0.42" valley), 18" Drop Height

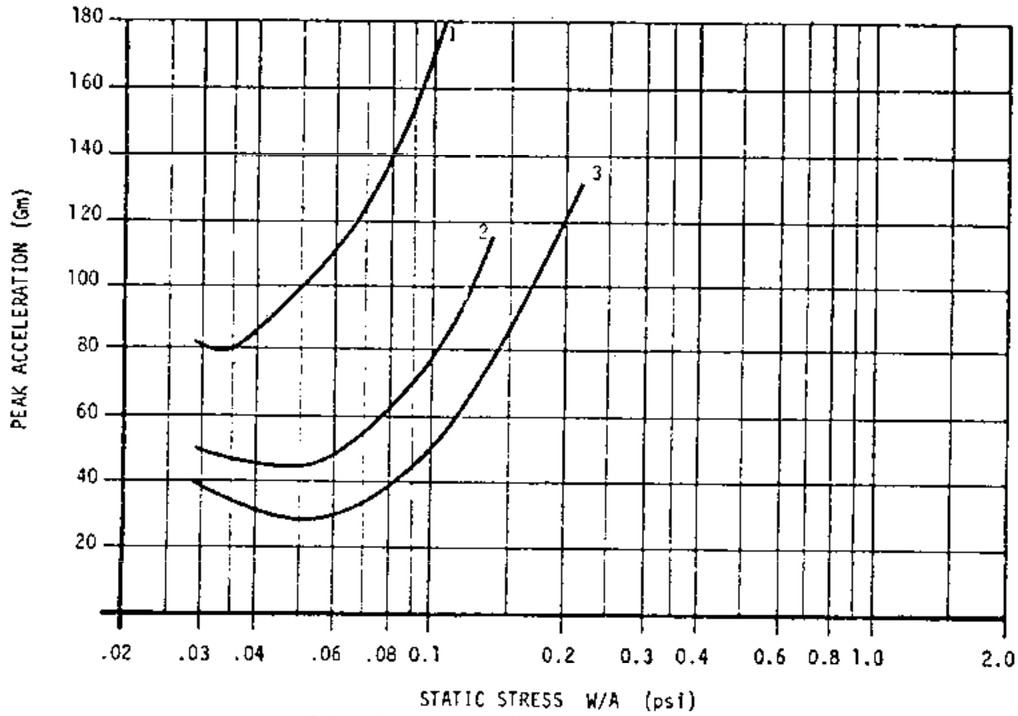
(See CHART 17 for material description)



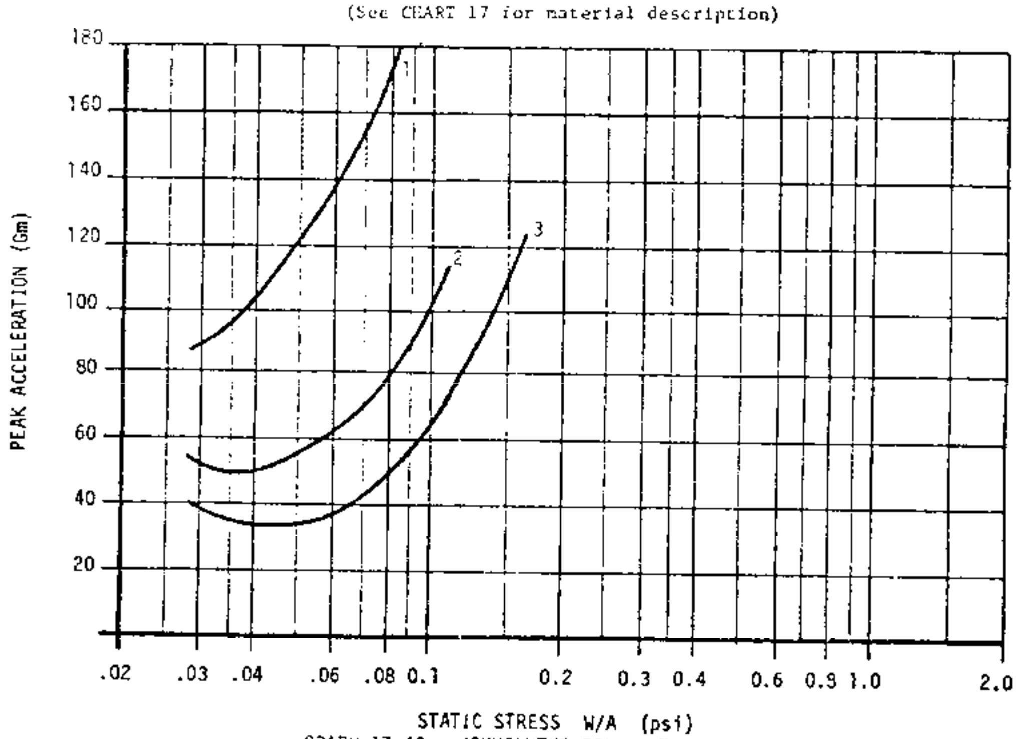
GRAPH 17.24: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, (1.0" overall, 1.38" pitch,
0.42" valley), 24" Drop Height
(See CHART 17 for material description)



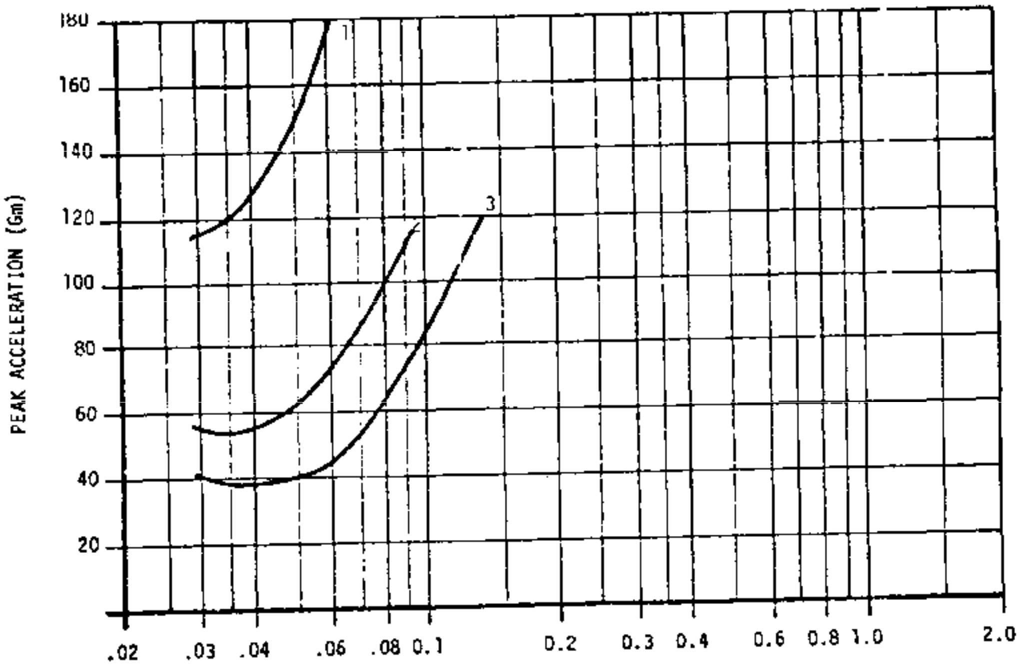
GRAPH 17.30: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, 1.0" overall, 1.38" pitch,
0.42" valley), 30" Drop Height
(See CHART 17 for material description)



GRAPH 17.36: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, ([illegible].0" overall, 1.38" pitch,
0.42" valley), 36" Drop Height
(See CHART 17 for material description)

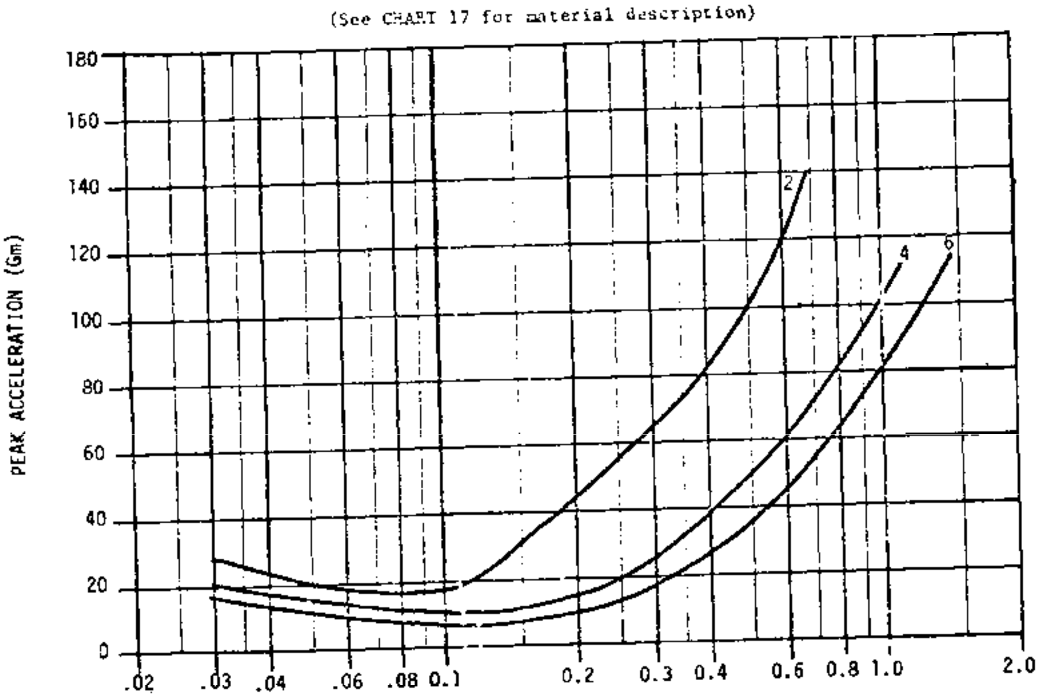


GRAPH 17.42: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, ([illegible].0" overall, 1.38" pitch,
0.42" valley), 42" Drop Height
(See CHART 17 for material description)



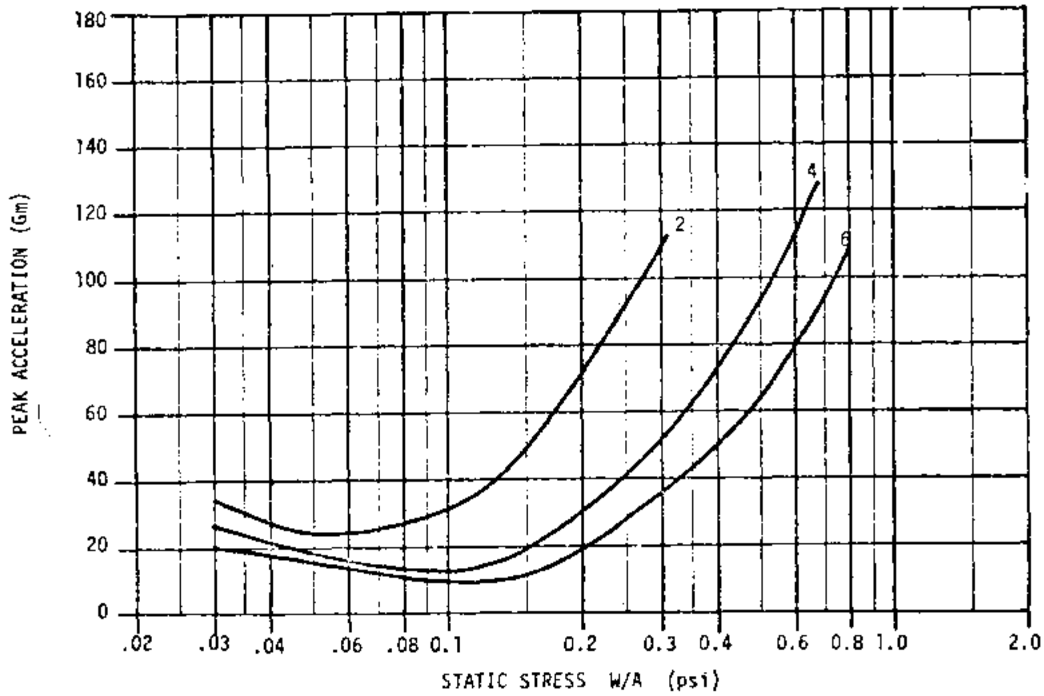
GRAPH 17.43: CONVOLUTED POLYURETHANE ETHER, 1.5 pcf, (1.0" overall, 1.38" pitch, 0.42" valley), 48" Drop Height

(See CHART 17 for material description)

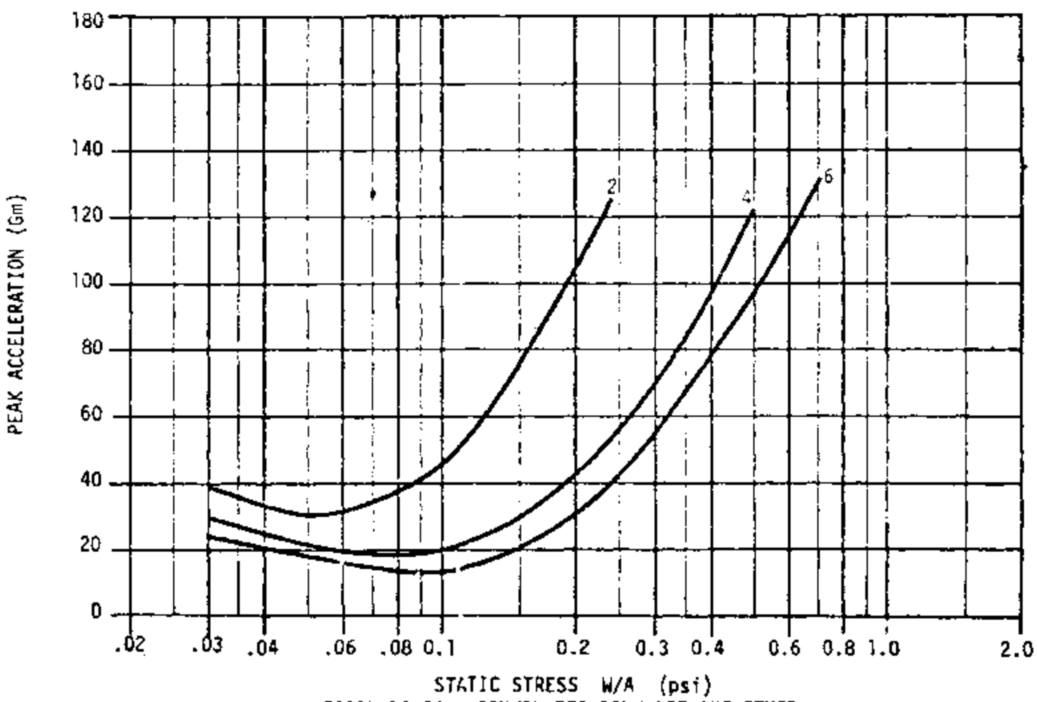


GRAPH 18.12: CONVOLUTED POLYURETHANE ETHER, 1.5 pcf, (2.1"overall, 1.38" pitch, 0.36" valley), 12" Drop Height

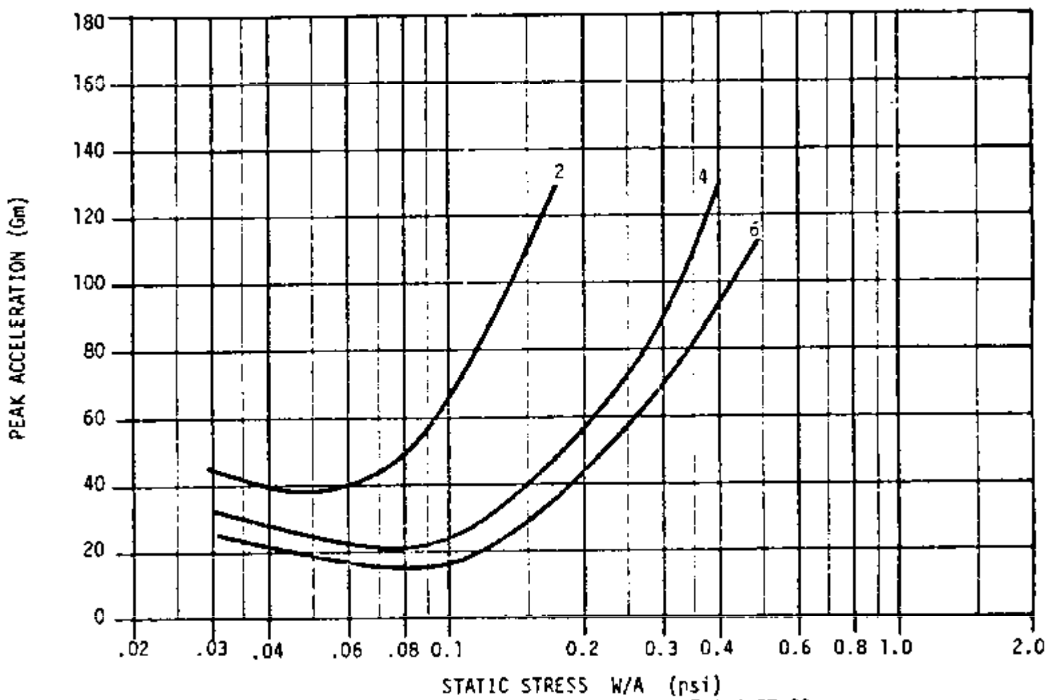
(See CHART 18 for material description)



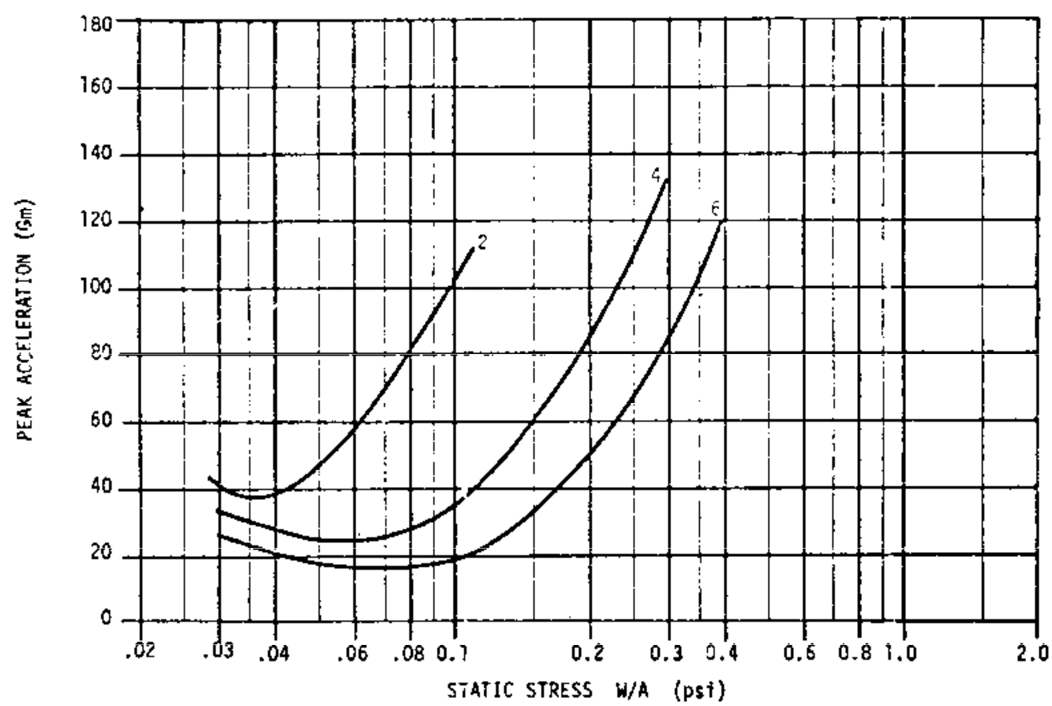
GRAPH 18.18: CONVOLUTED POLYURETHANE ETHER, 1.5 pcf, (2.1" overall, 1.38" pitch, 0.88" valley), 18" Drop Height
(See CHART 18 for material description)



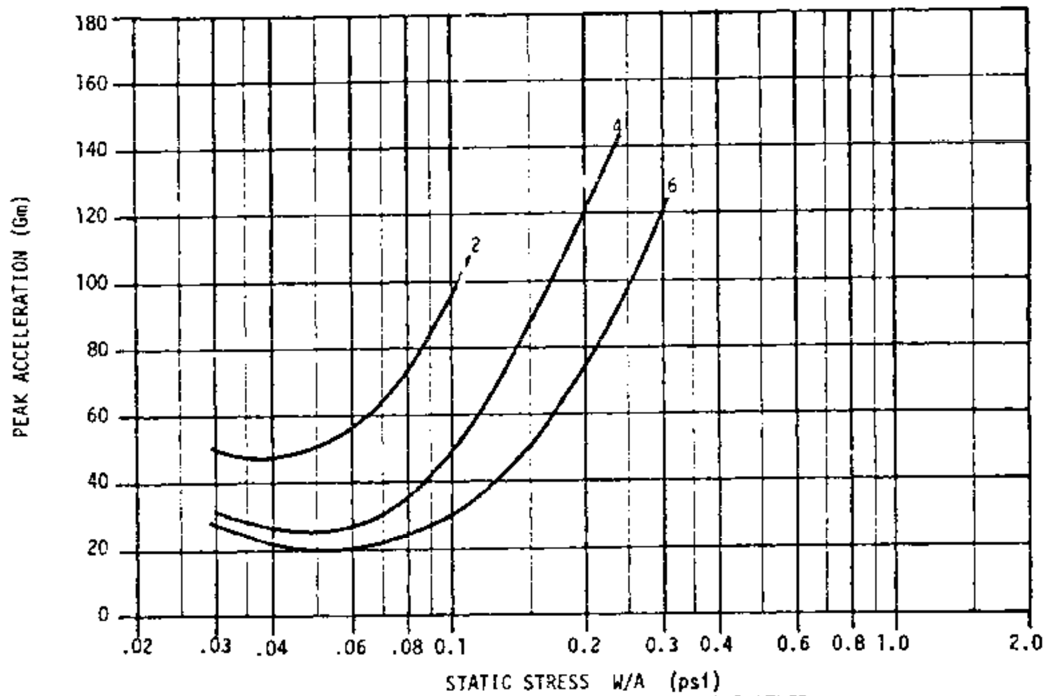
GRAPH 18.24: CONVOLUTED POLYURETHANE ETHER, 1.5 pcf, (2.1" overall, 1.38" pitch 0.88"valley), 24" Drop Height
(See CHART 18 for material description)



GRAPH 18.30: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, (2.1" overall, 1.38" pitch,
0.93"valley), 30" Drop Height
(See CHART 18 for material description)

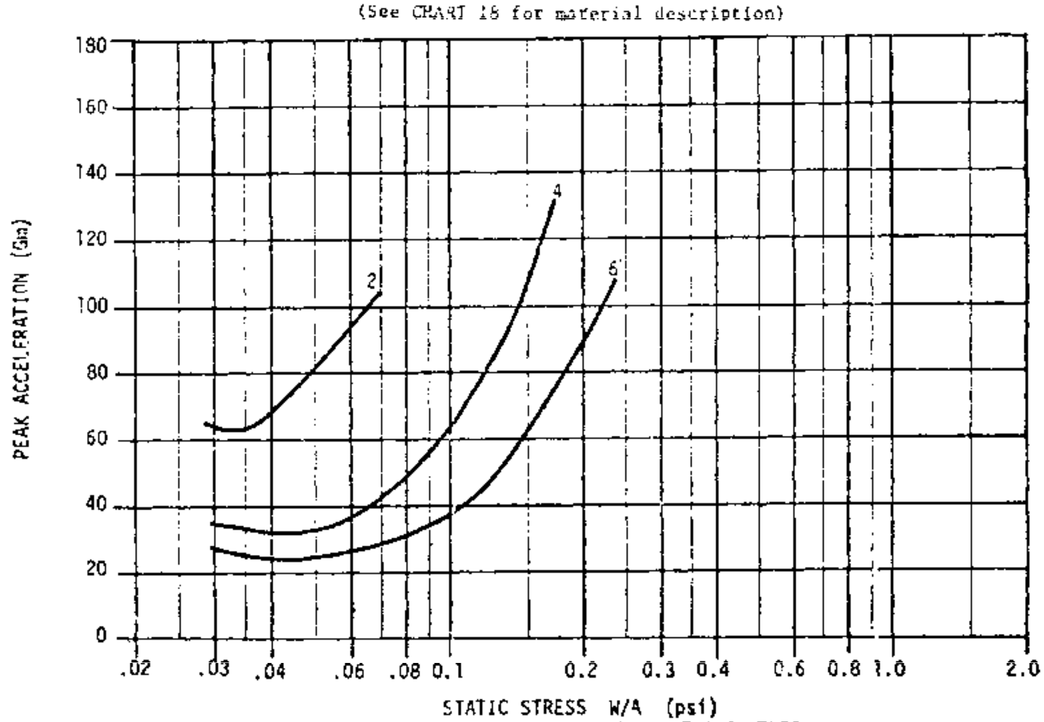


GRAPH 18.36: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, (2.1" overall, 1.38" pitch
0.08"valley), 36" Drop Height
(See CHART 18 for material description)



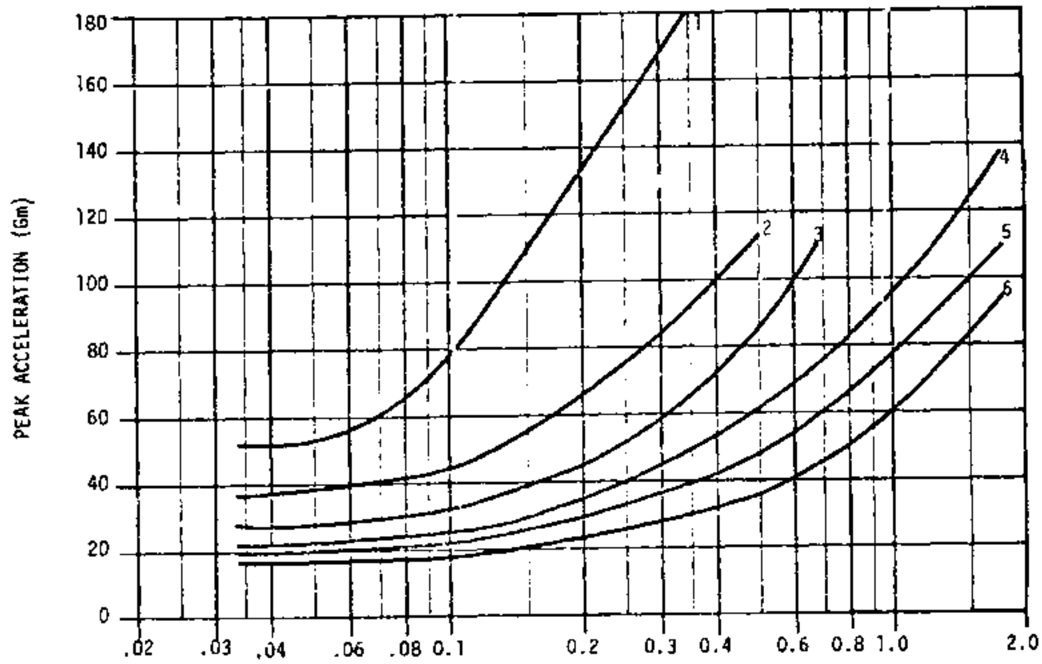
GRAPH 18.42: CONVOLUTED POLYURETHANE ETHER,
1.5 pcf, (2.1" overall, 1.38" pitch
0.88" valley), 42" Drop Height

(See CHART 18 for material description)

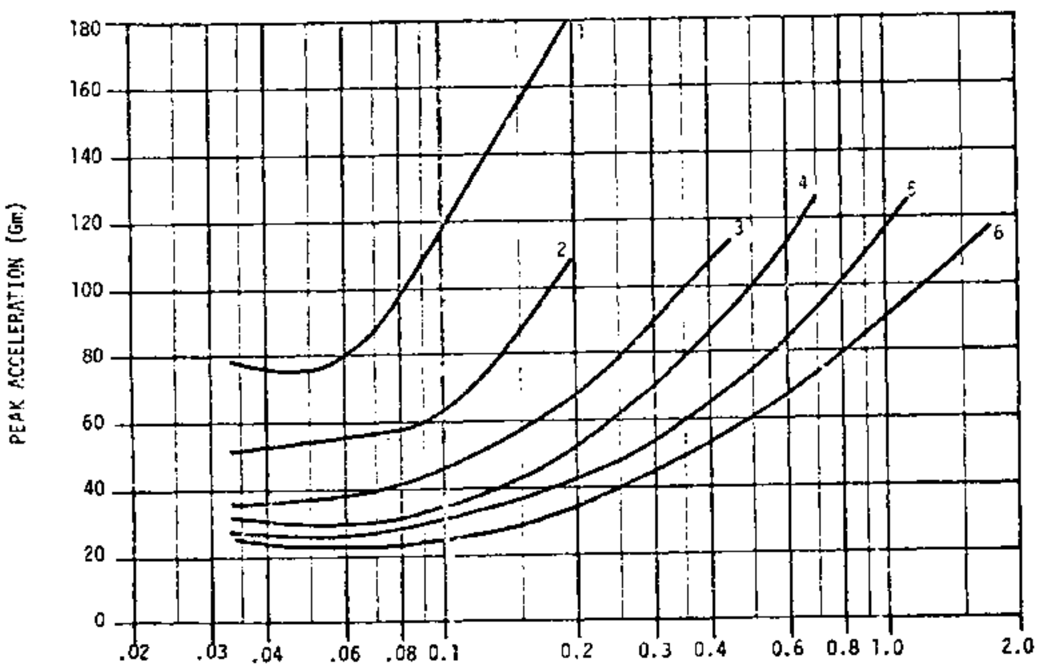


GRAPH 18.48 CONVOLUTED POLYURETHANE ETHER,
1.5 pcf. (2.1" overall, 1.38" pitch,
0.88" valley), 48" Drop Height

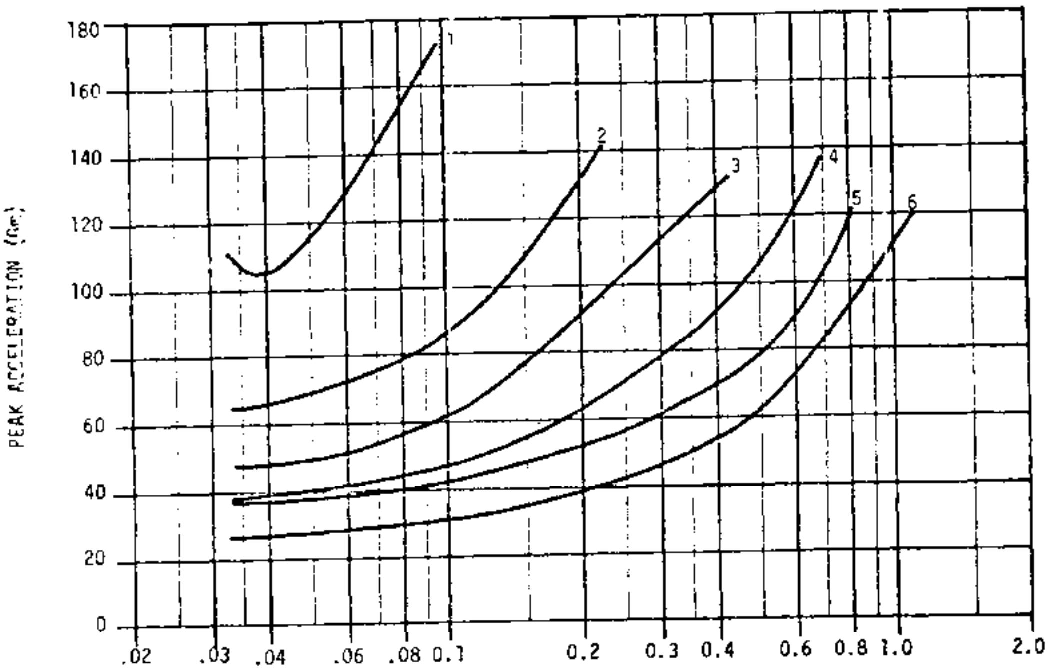
(See CHART 18 for material description)



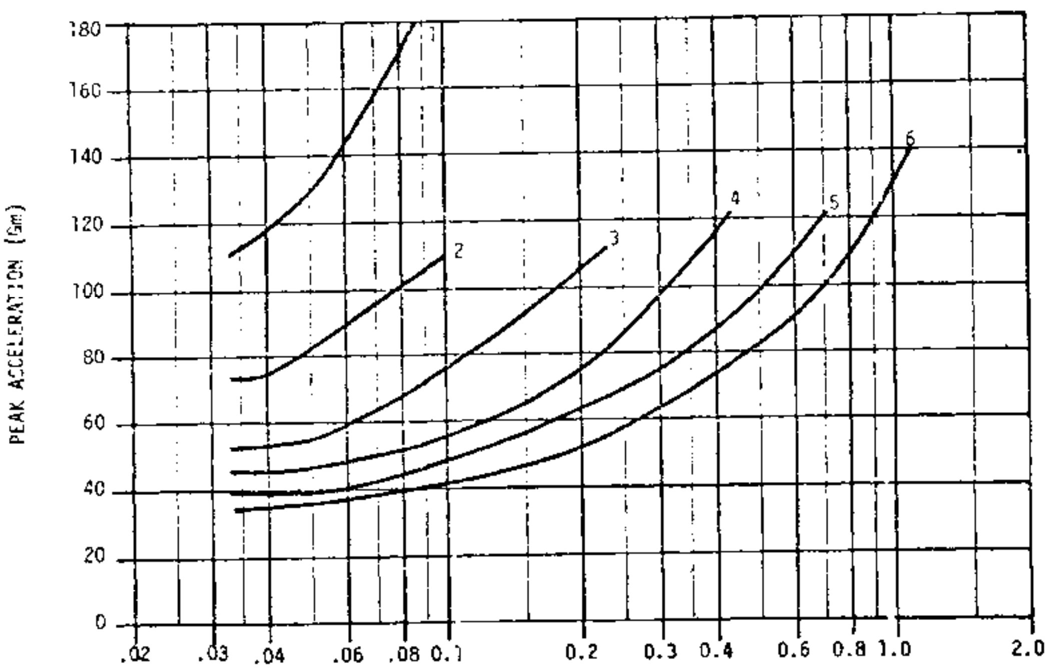
GRAPH 19.12: CELLULOSE WADDING,
12" Drop Height



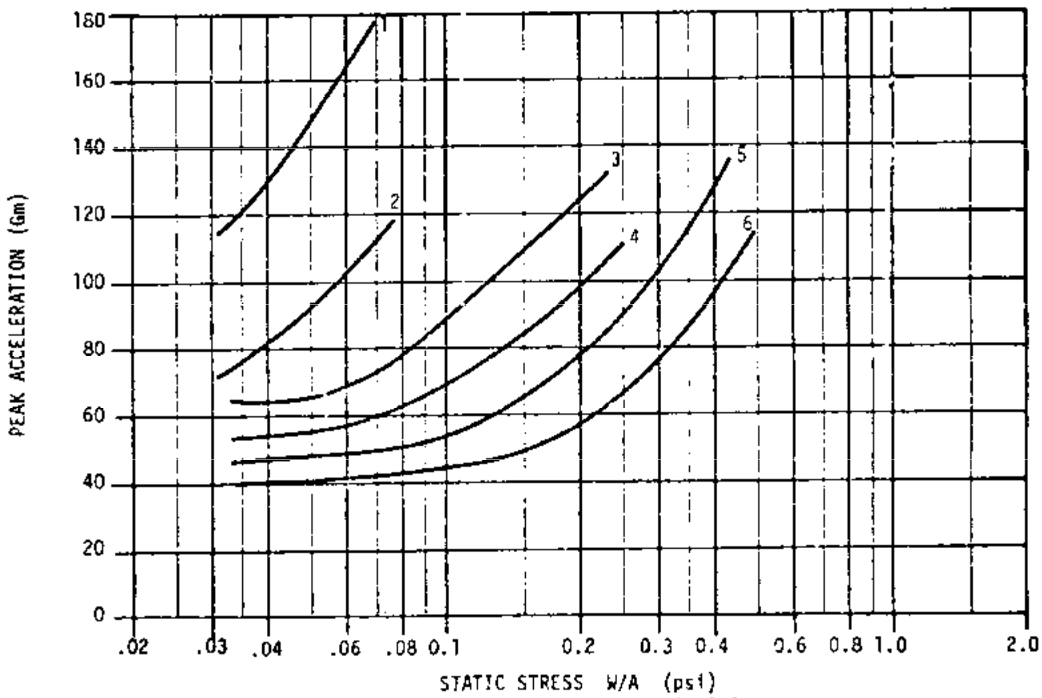
GRAPH 19.18: CELLULOSE WADDING,
18" Drop Height



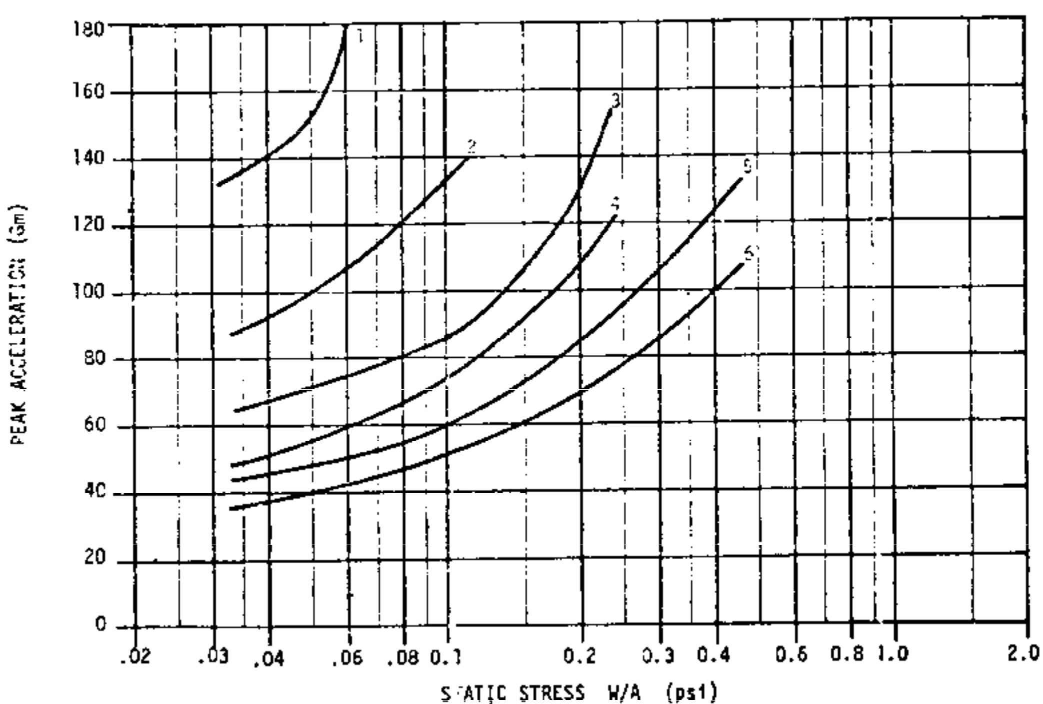
STATIC STRESS W/A (psi)
GRAPH 19.24: CELLULOSE WADDING,
24" Drop Height



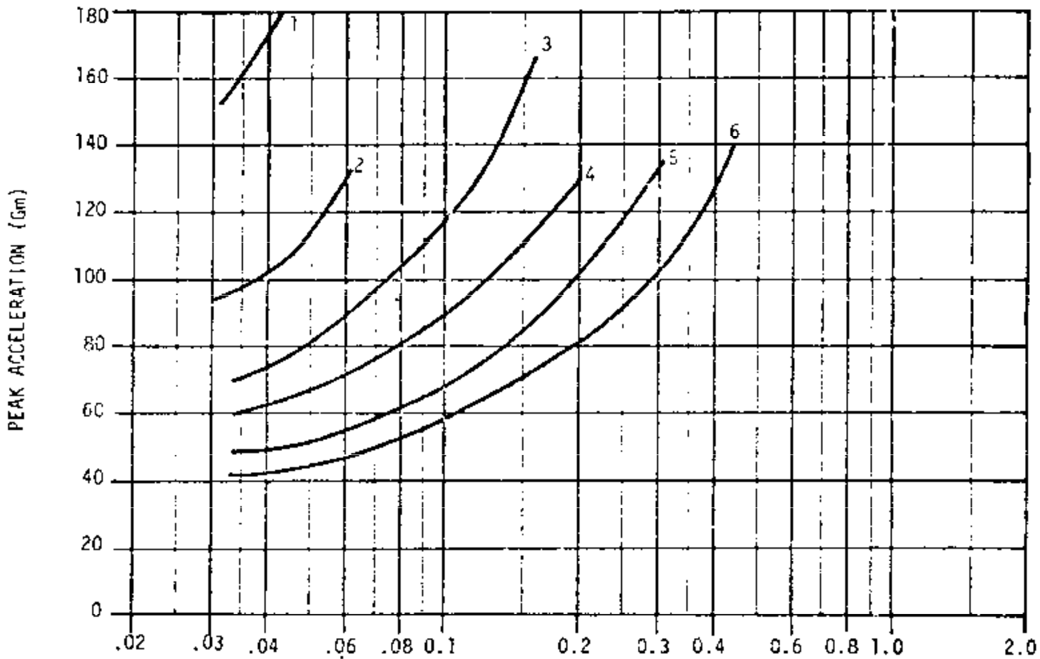
STATIC STRESS W/A (psi)
GRAPH 19.30: CELLULOSE WADDING,
30" Drop Height



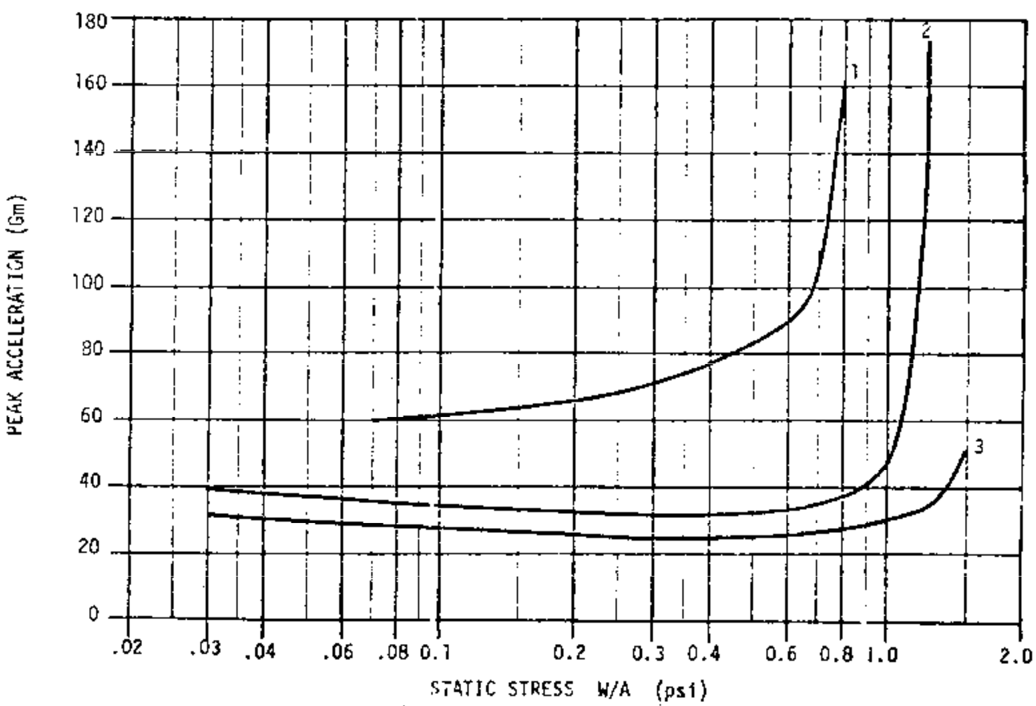
GRAPH 19.36: CELLULOSE WADDING,
36" Drop Height



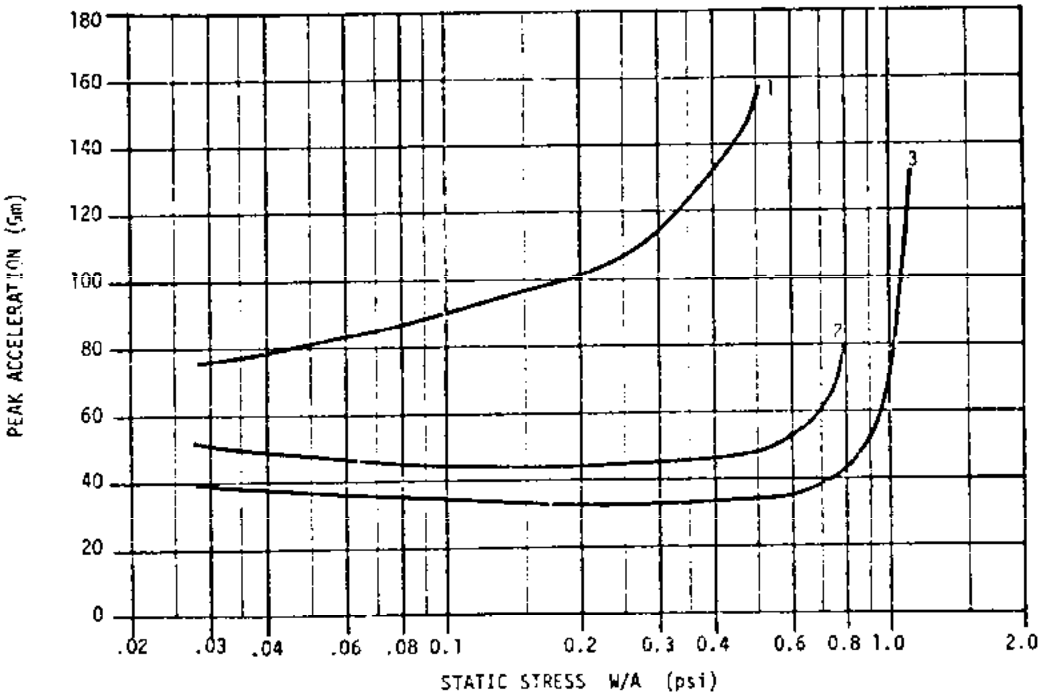
GRAPH 19.42: CELLULOSE WADDING,
42" Drop Height



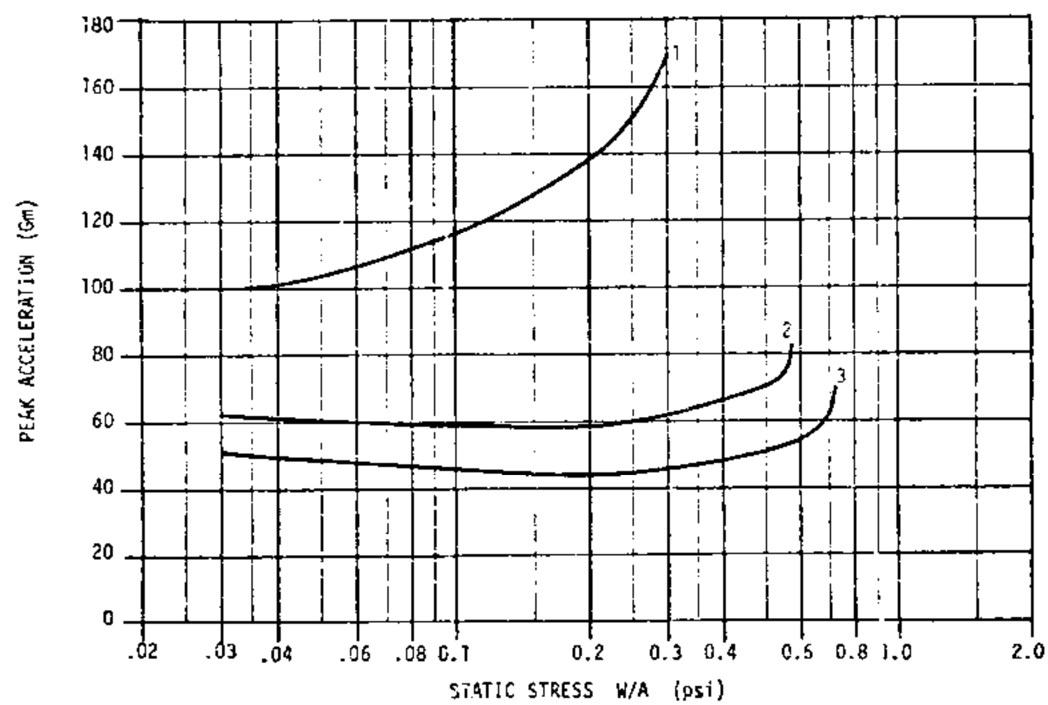
GRAPH 19.48: CELLULOSE WADDING,
48" Drop Height



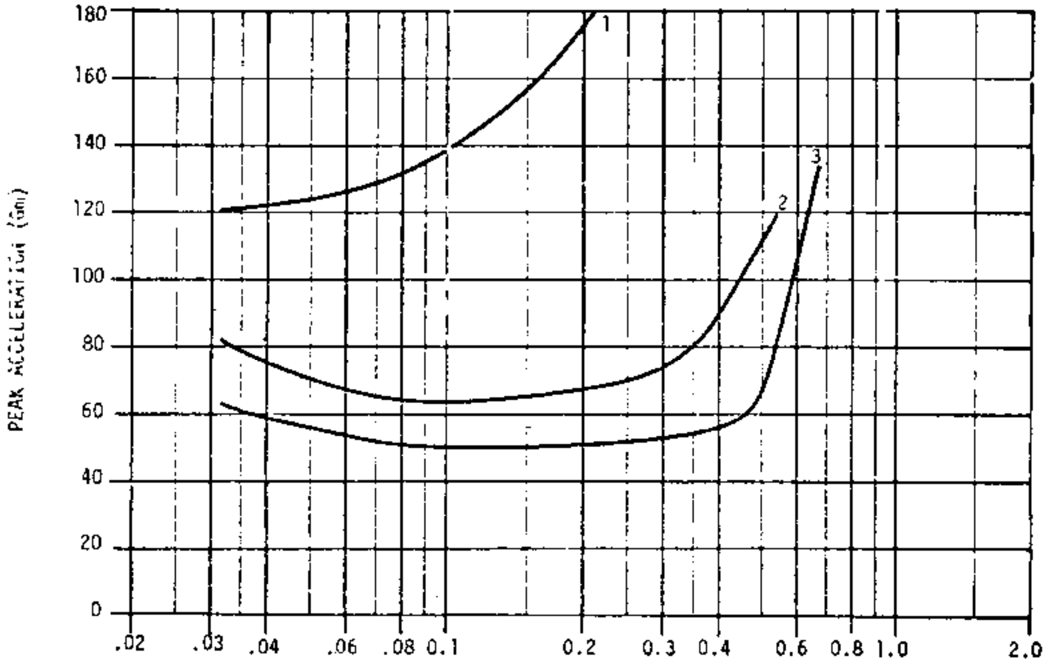
GRAPH 20.12: AIR INCAPSULATED FILM, SD-240
12" Drop Height



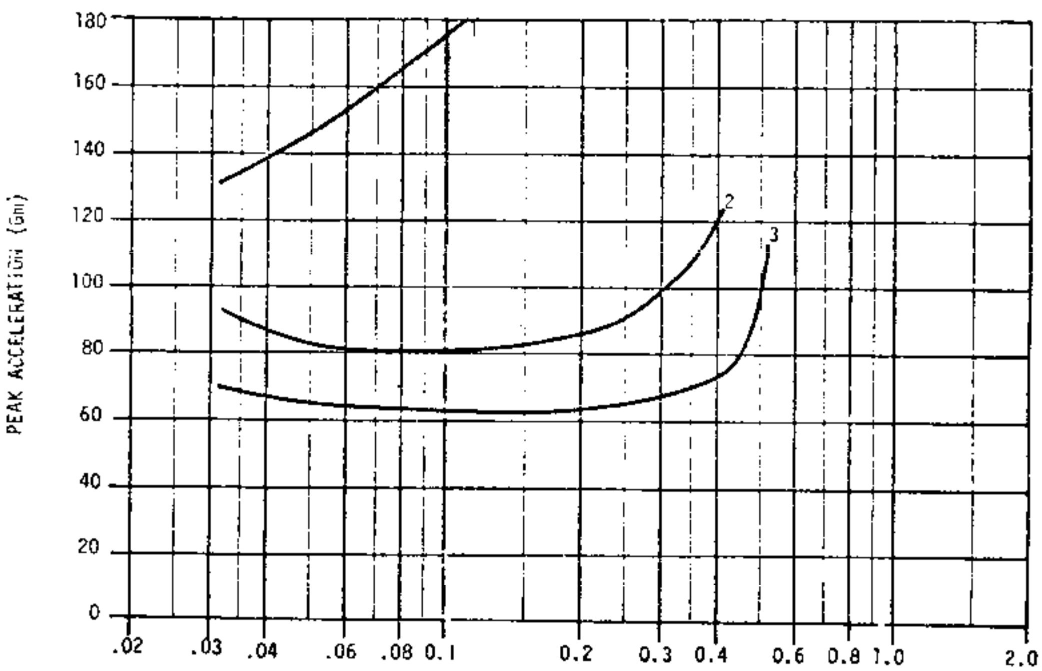
GRAPH 20.18: AIR INCAPSULATED FILM, SD-240
18" Drop Height



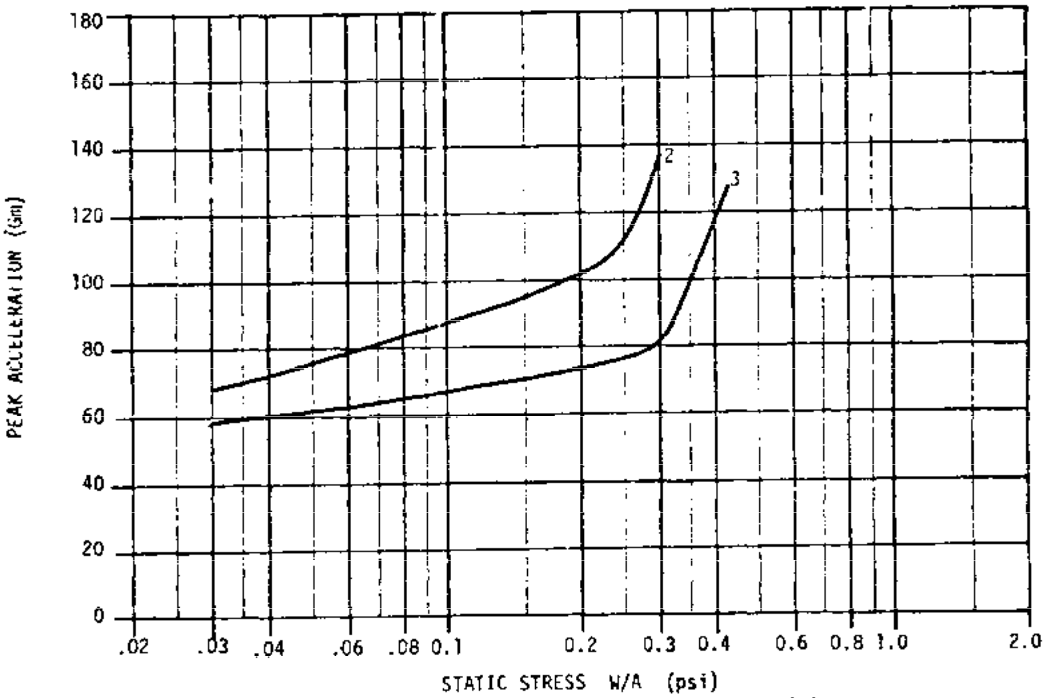
GRAPH 20.24: AIR INCAPSULATED FILM, SD-240
24" Drop Height



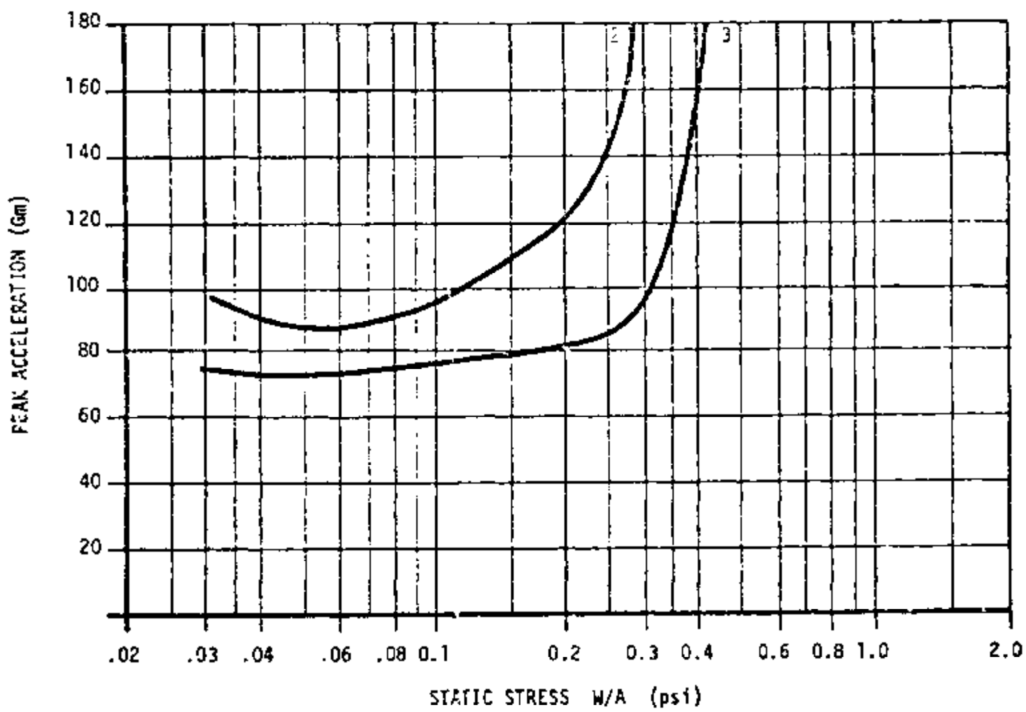
GRAPH 20.30: AIR INCAPSULATED FILM, SD-240
30" Drop Height



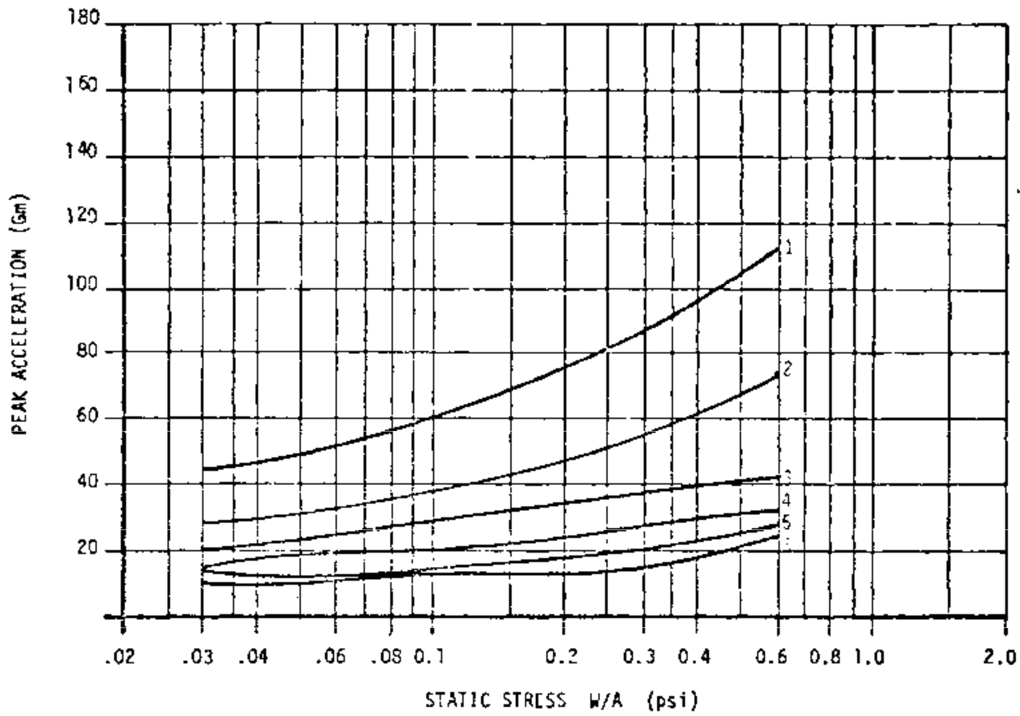
GRAPH 20.36: AIR INCAPSULATED FILM, SD-240
36" Drop Height



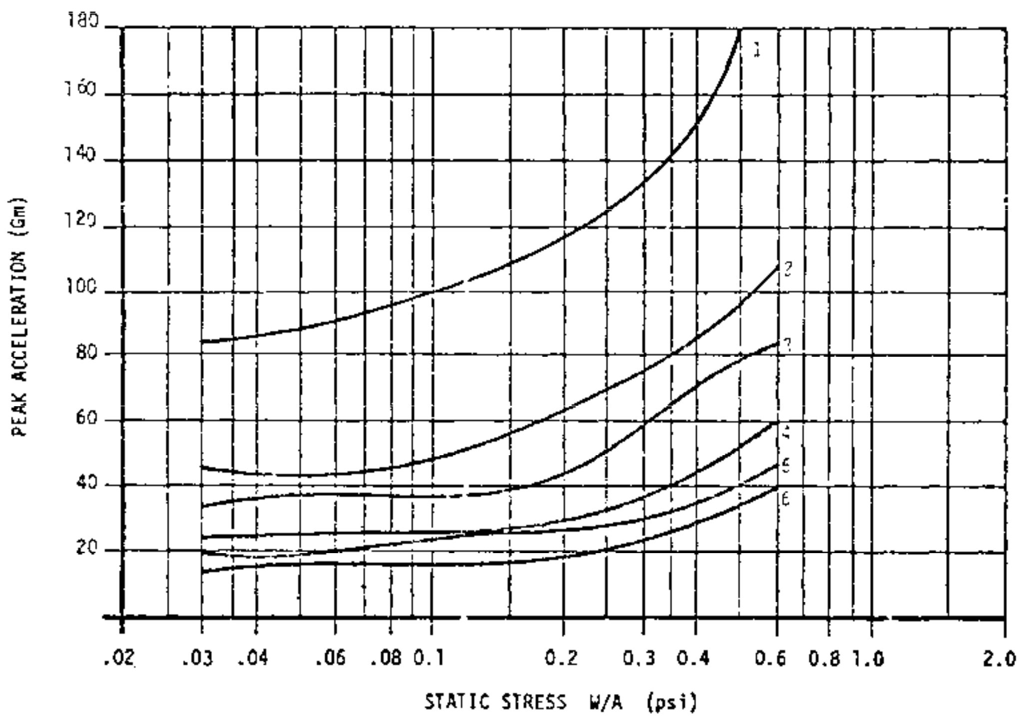
GRAPH 20.42: AIR INCAPSULATED FILM, SD-240
42" Drop Height



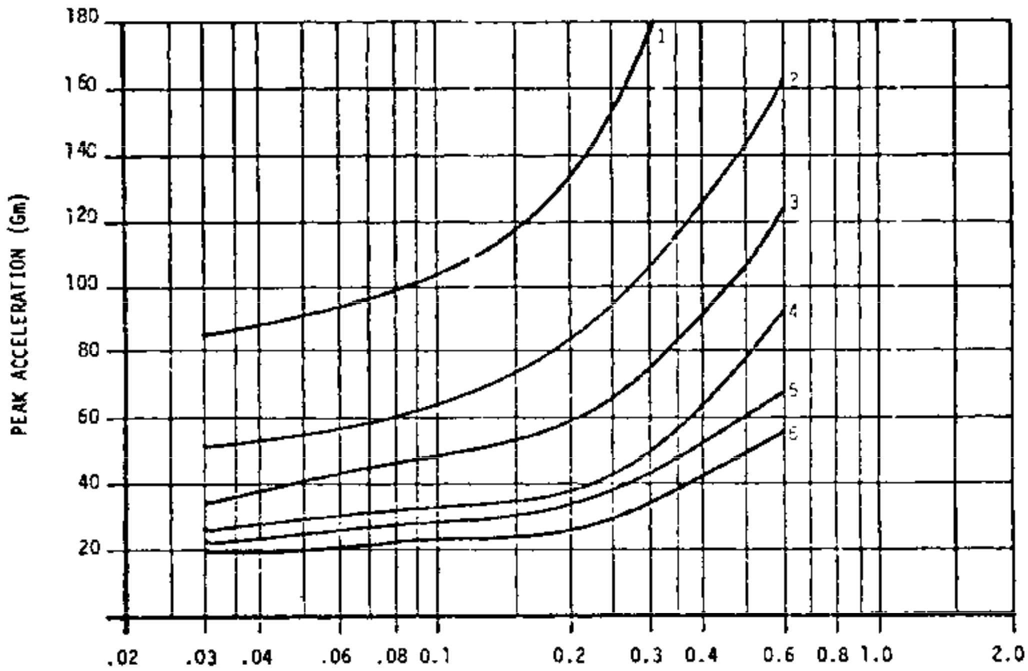
GRAPH 20.48: AIR INCAPSULATED FILM, SD-240
48" Drop Height



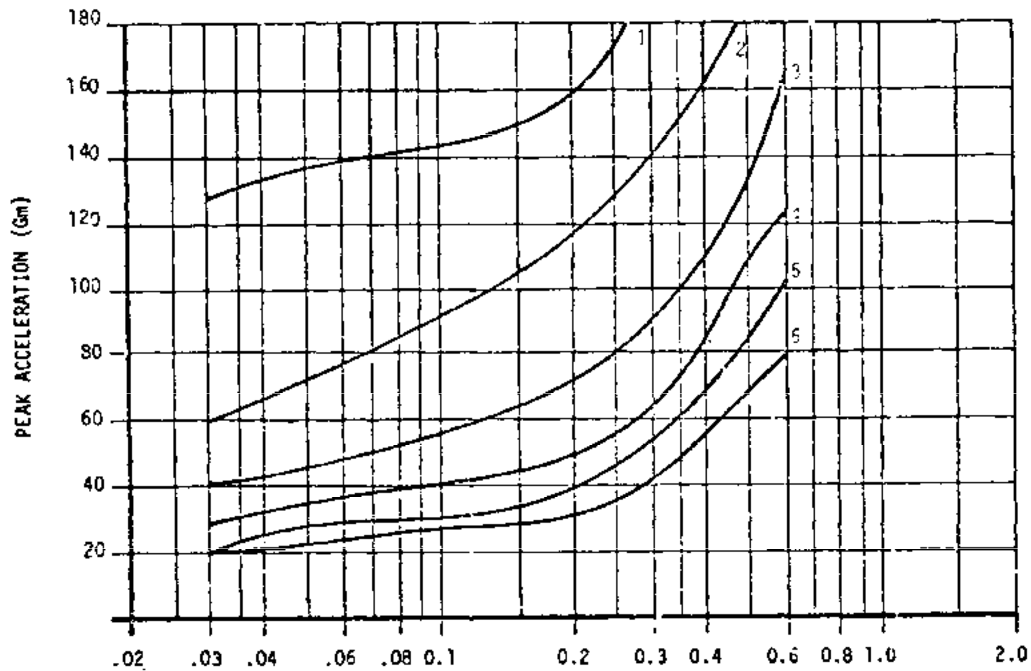
GRAPH 21.12 HEXOGONAL FILM (OPEN CELL)
12" Drop Height



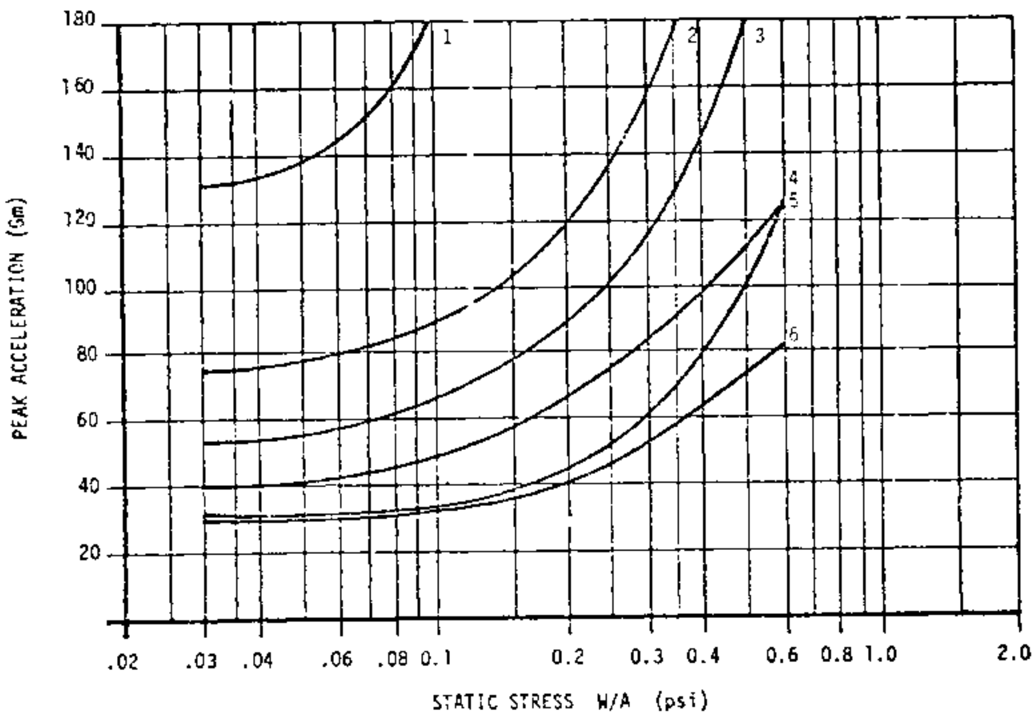
GRAPH 21.18 HEXOGONAL FILM (OPEN CELL)
18" Drop Height



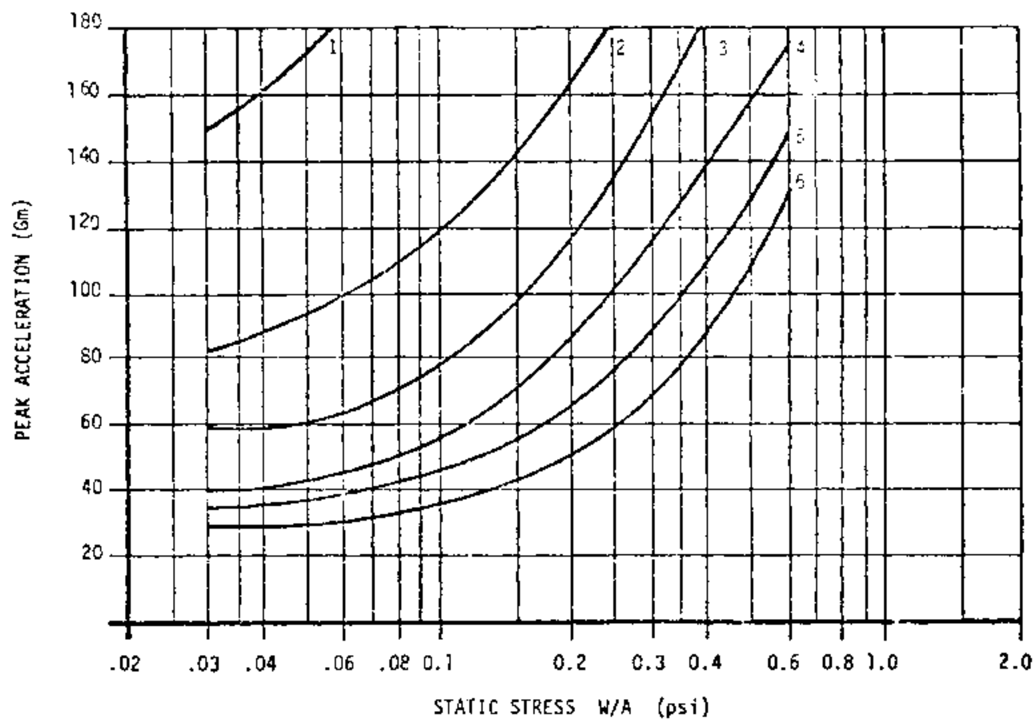
GRAPH 21.24 HEXOGONAL FILM (OPEN CELL)
24" Drop Height



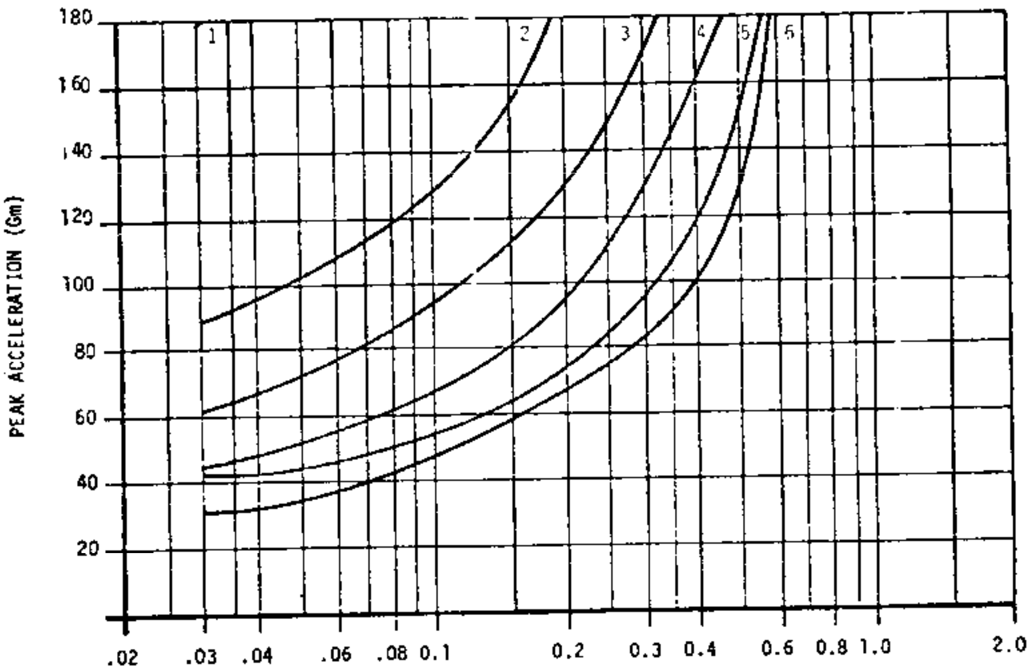
GRAPH 21.30 HEXOGONAL FILM (OPEN CELL)
30" Drop Height



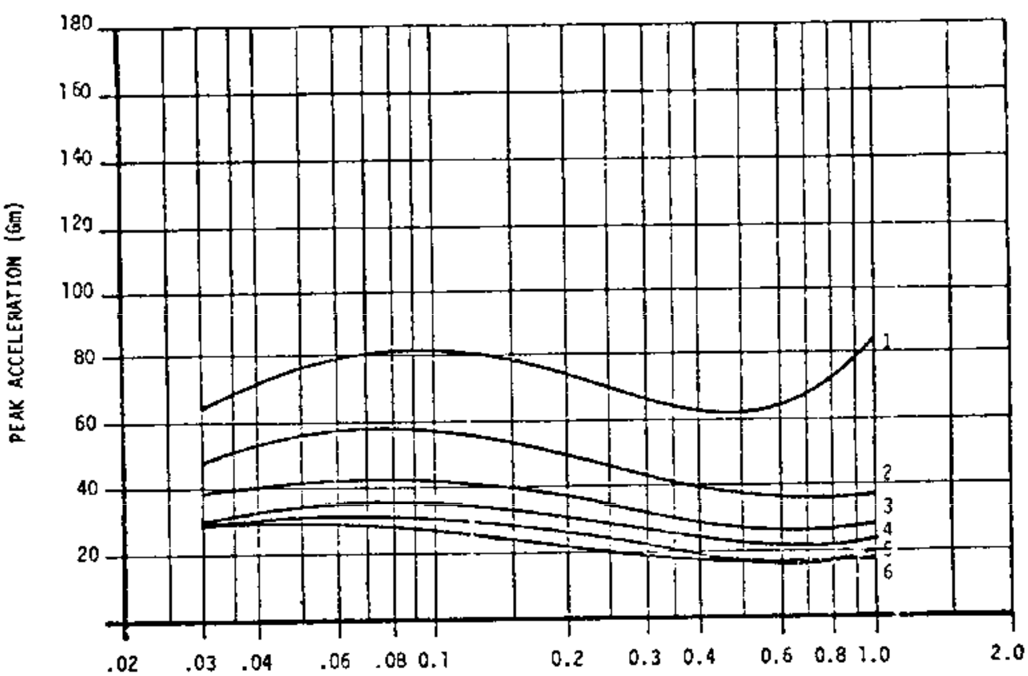
GRAPH 21.36 HEXOGONAL FILM (OPEN CELL)
36" Drop Height



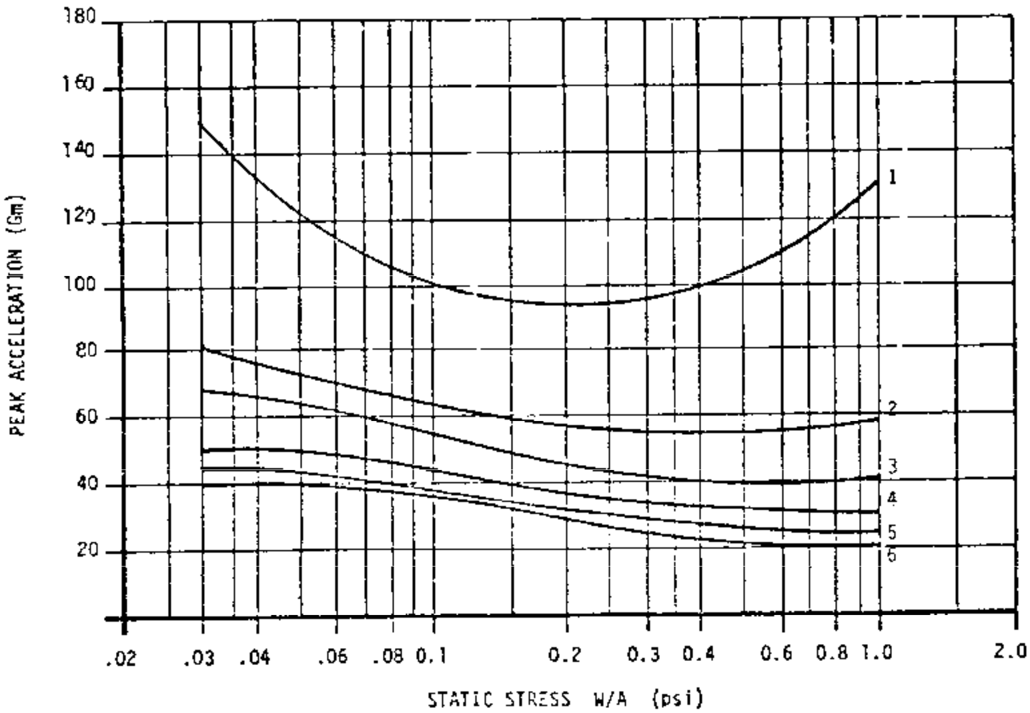
GRAPH 21.42 HEXOGONAL FILM (OPEN CELL)
42" Drop Height



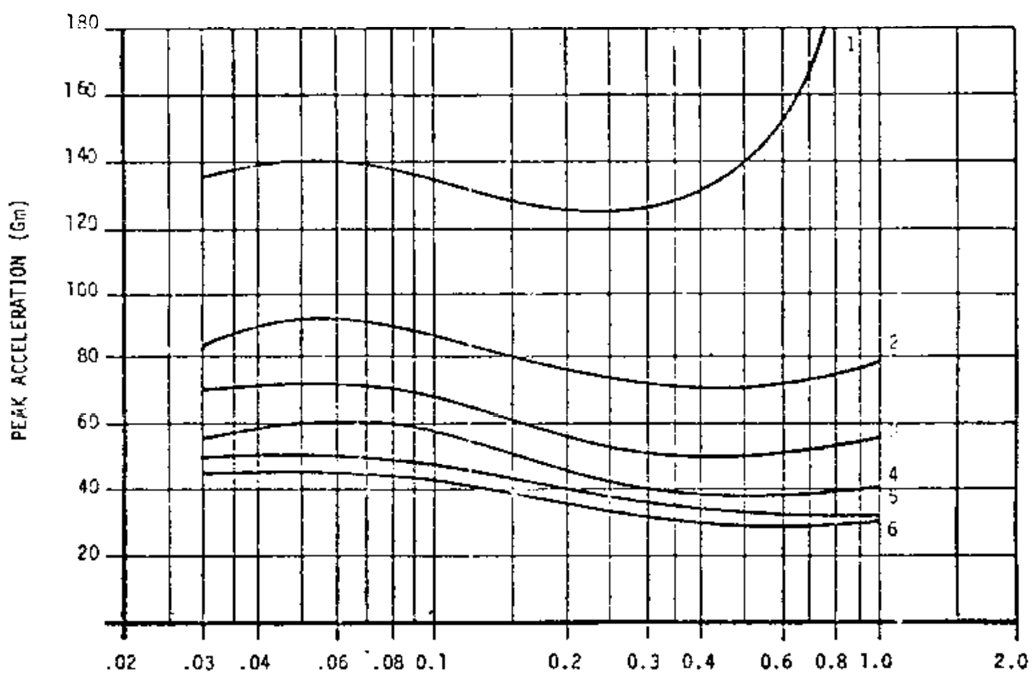
GRAPH 21.48 HEXOGONAL FILM (OPEN CELL)
48" Drop Height



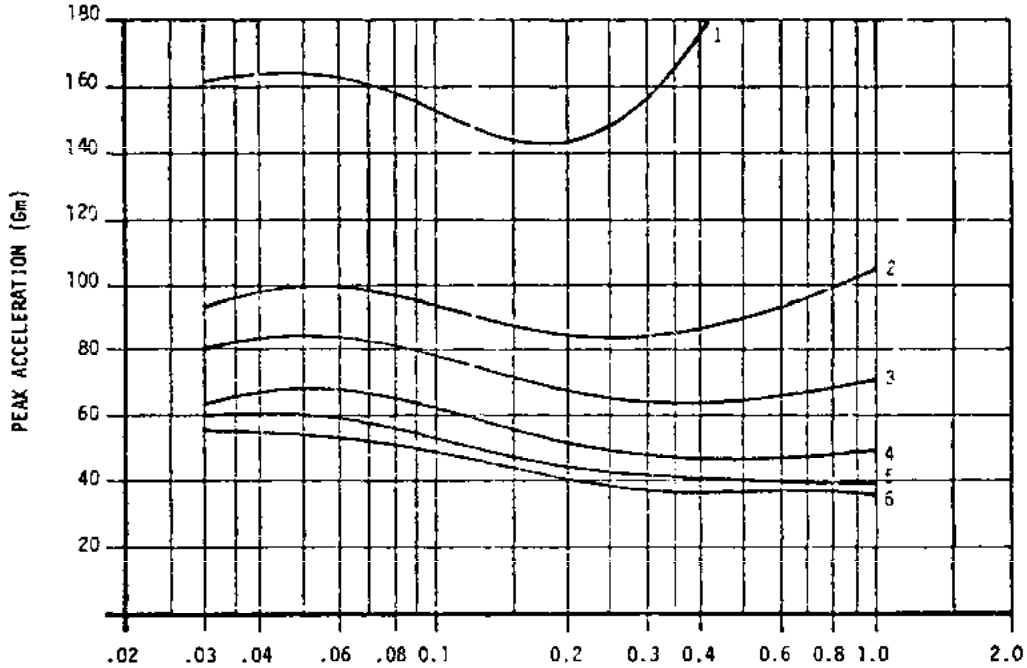
GRAPH 22.12 HEXOGONAL FILM (REINFORCED CELL)
12" Drop Height



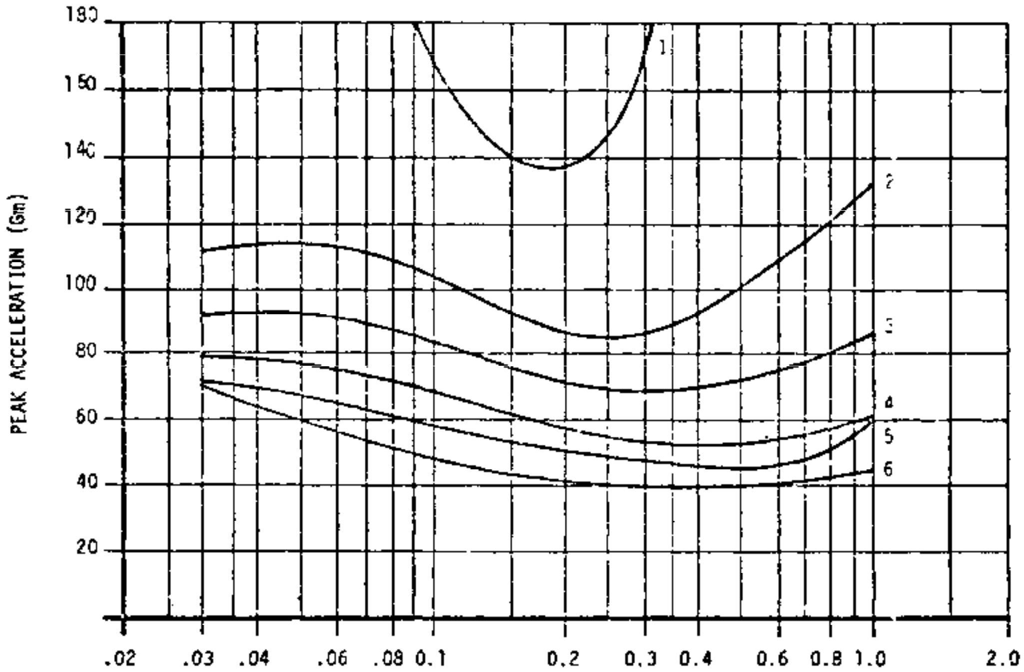
GRAPH 22.18 HEXOGONAL FILM (REINFORCED CELL)
18" Drop Height



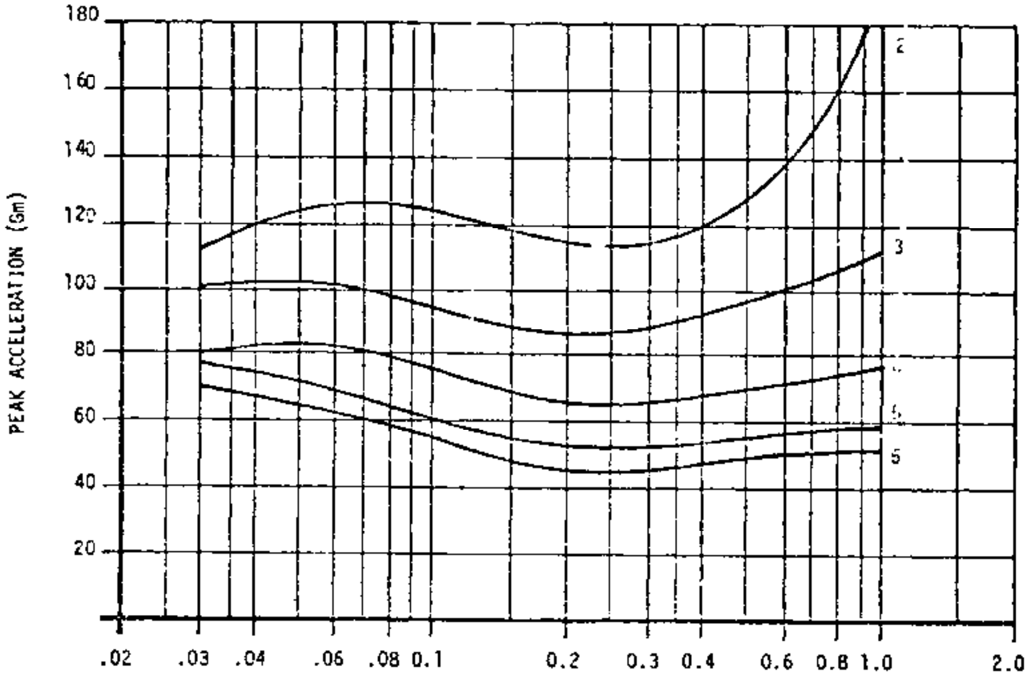
GRAPH 22.24 HEXOGONAL FILM (REINFORCED CELL)
24" Drop Height



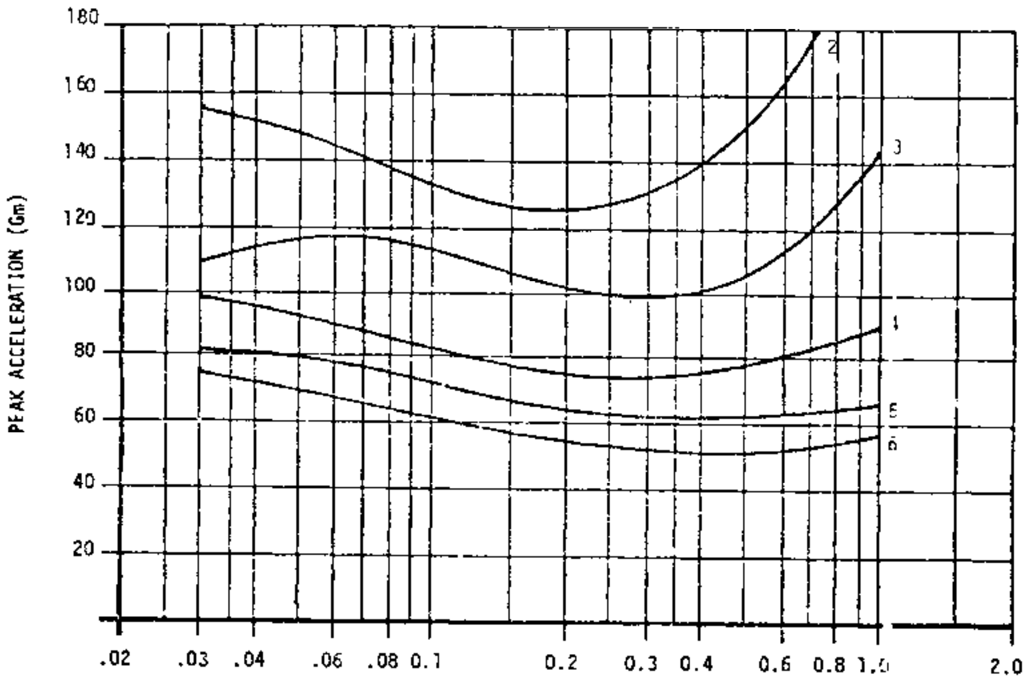
GRAPH 22.30 HEXOGONAL FILM (REINFORCED CELL)
30" Drop Height



GRAPH 22.36 HEXOGONAL FILM (REINFORCED CELL)
36" Drop Height



GRAPH 22.42 HEXOGONAL FILM (REINFORCED CELL)
42" Drop Height



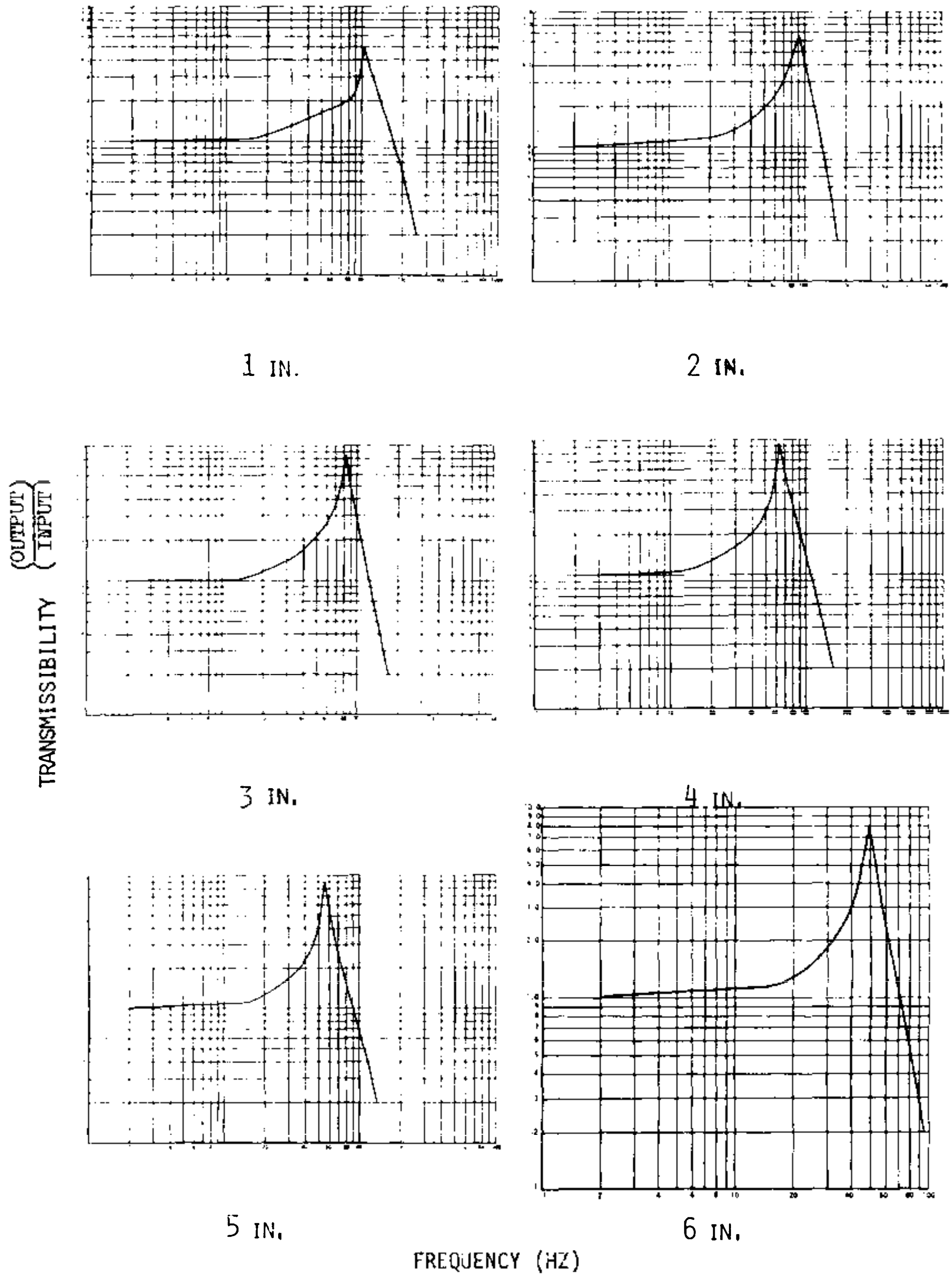
GRAPH 22.48 HEXOGONAL FILM (REINFORCED CELL)
48" Drop Height

APPENDIX VI. TRANSMISSIBILITY-FREQUENCY CURVES

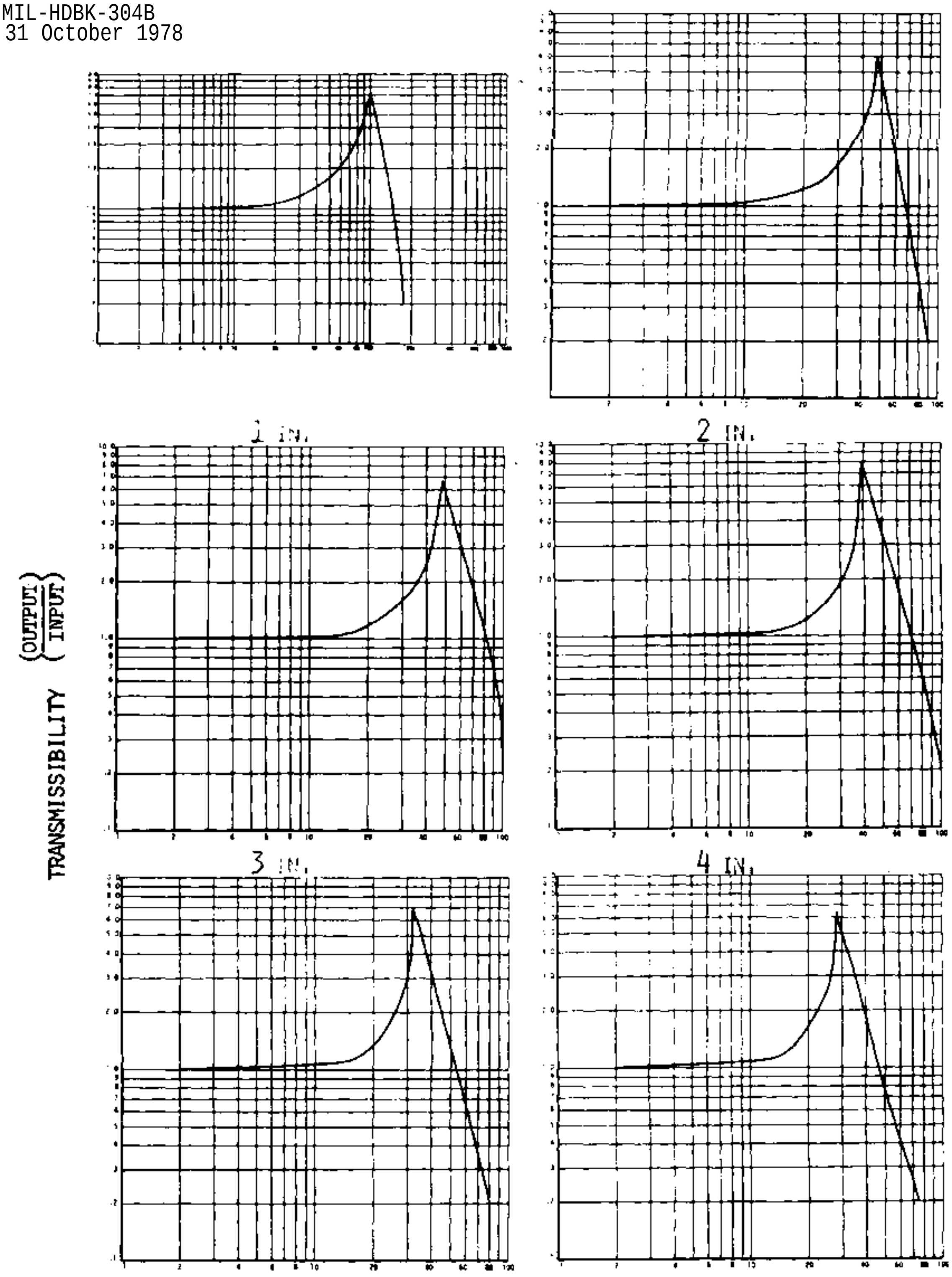
Transmissibility-frequency curves 1.1 thru 22.10 are presented in this Appendix for 1, 2, 3, 4, 5, and 6 inches of material thickness at ten different static stress levels.

Derivation of transmissibility curves is described in 2.3.2.2.1 and 6.1.2.2. while their use is discussed in 2.3.2.1.1 and 3.2.2.

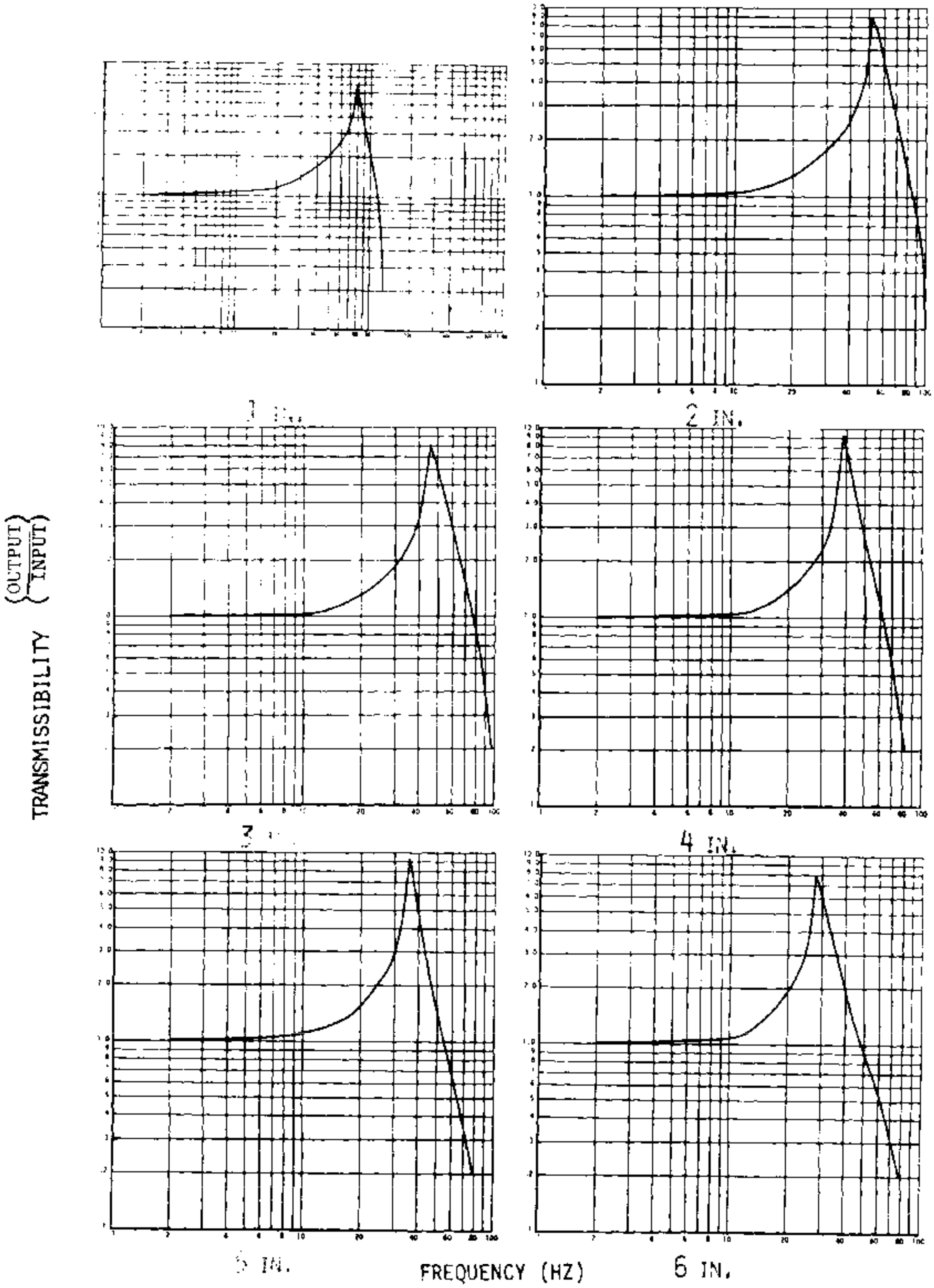
All data given herein were derived from empirical tests conducted under contract by AFPEA, Wright-Patterson AFB OH, under controlled atmospheric conditions of 73°F and 50 percent relative humidity and are generally representative of commercially available materials (complete listing on page xv). However, due to manufacturing variations in some materials, transmissibility levels in the resulting package may not be identical to the data represented here. If excessive variation is suspected, transmissibility testing as outlined in Section 6.1.2.2 is encouraged to verify desired levels of protection.



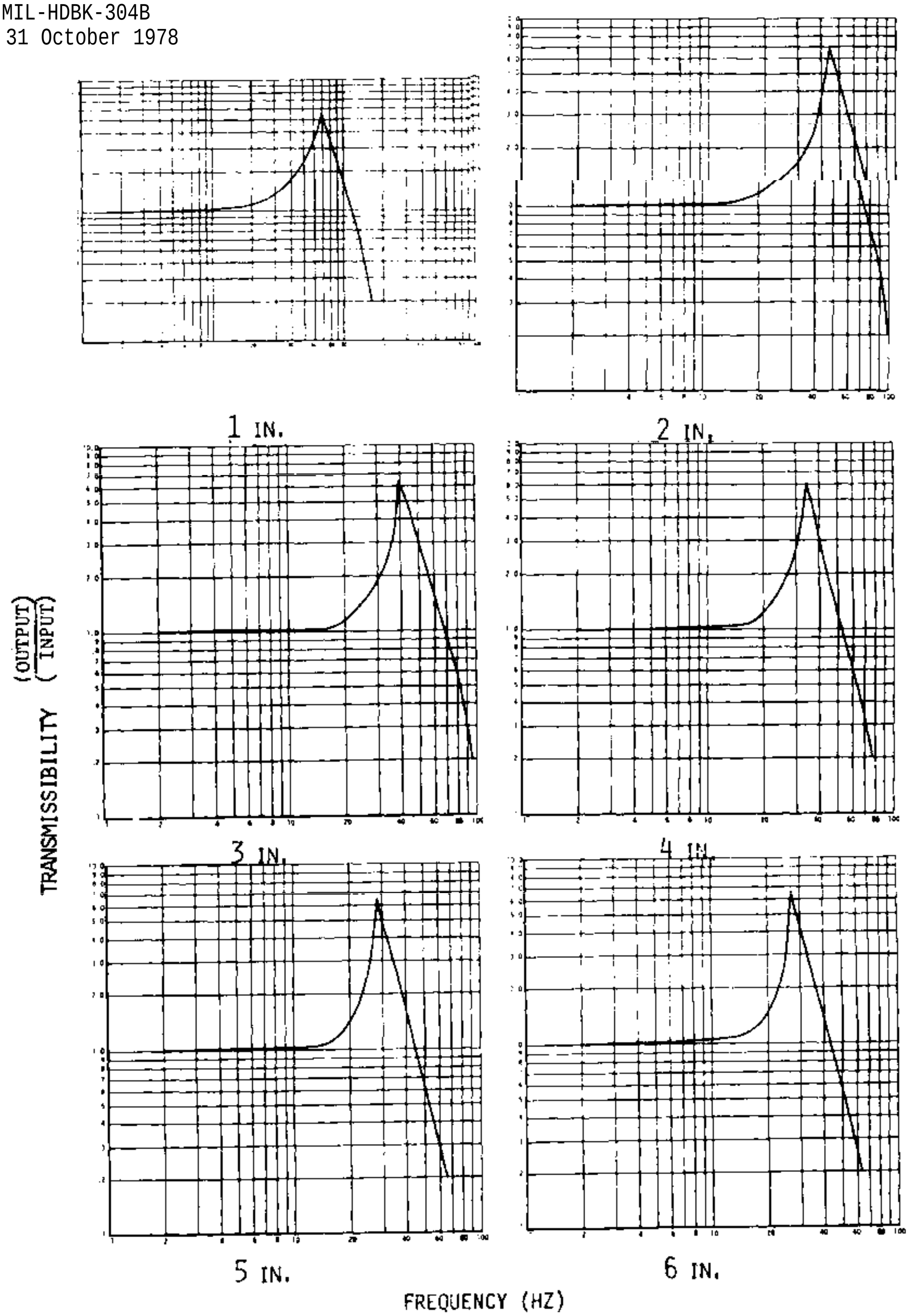
CURVE 1.1 POLYURETHANE ETHER, 1.5 LB/CU FT .045 PSI



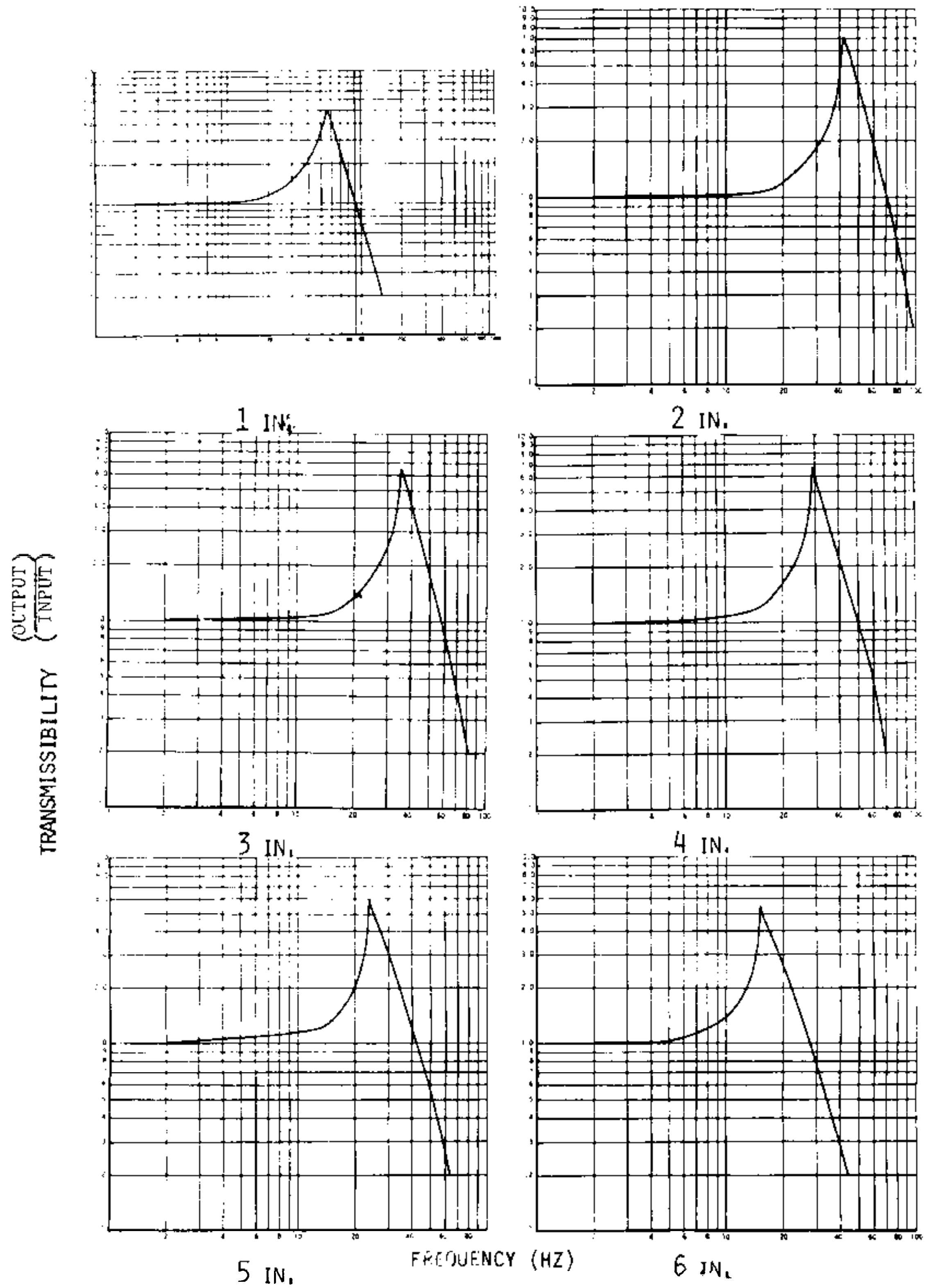
CURVE 1.2 POLYURETHANE ETHER, 1.5 LB/CU FT .076 PSI



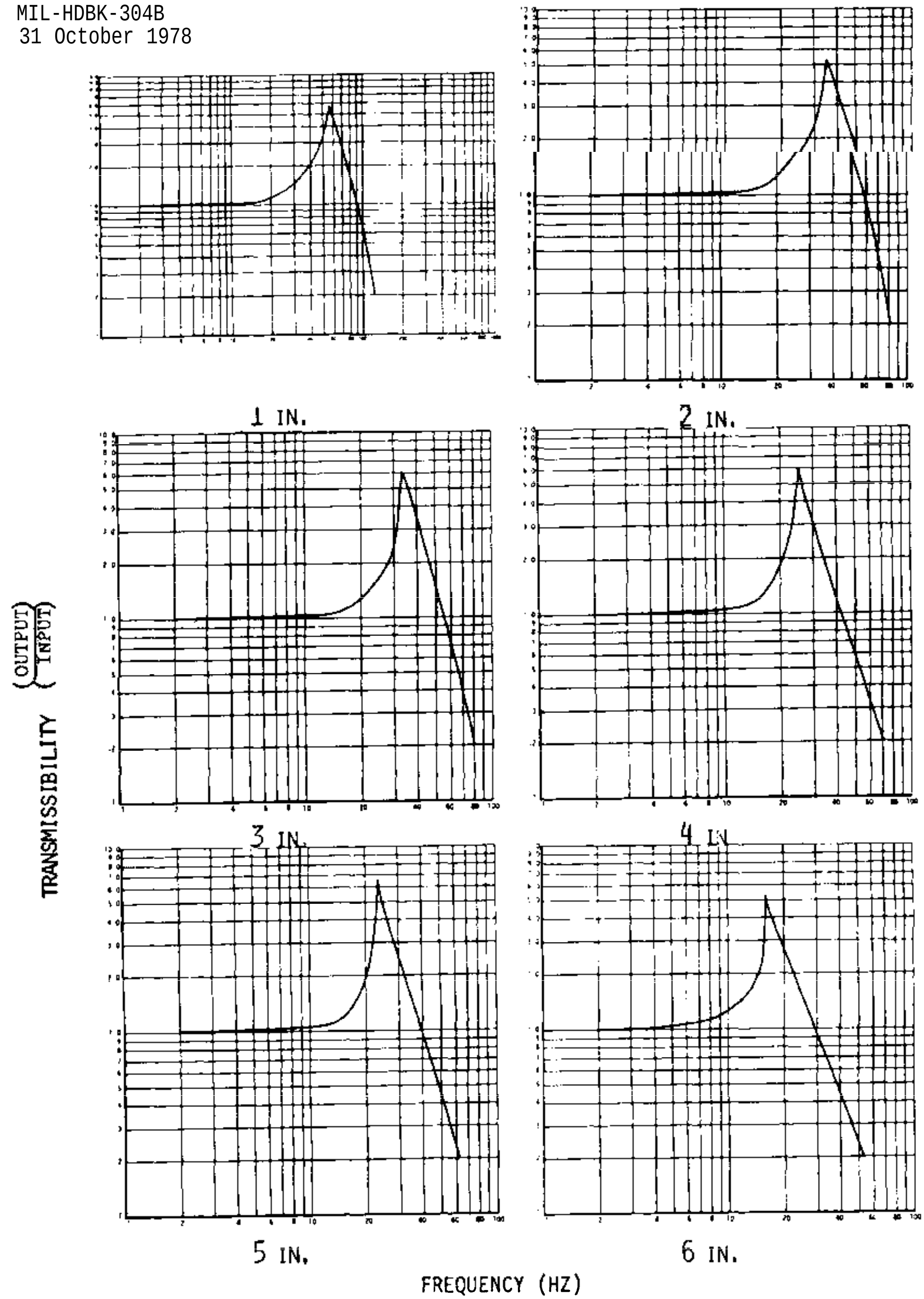
CURVE 1.3 POLYURETHANE ETHER, 1.5 LB/CU FT .100 PSI



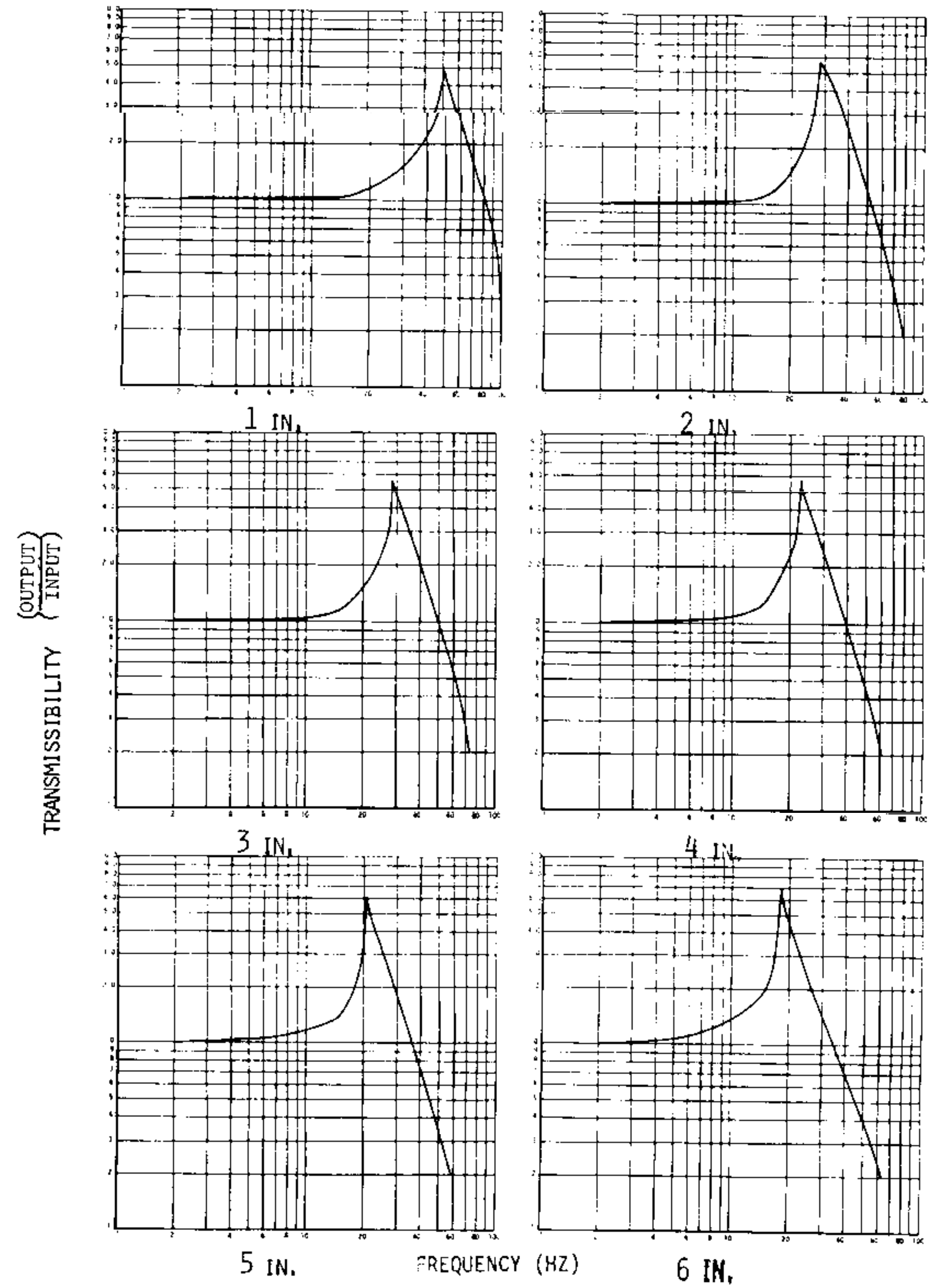
CURVE 1.4 POLYURETHANE, 1.5 LB/CU FT .100 PSI



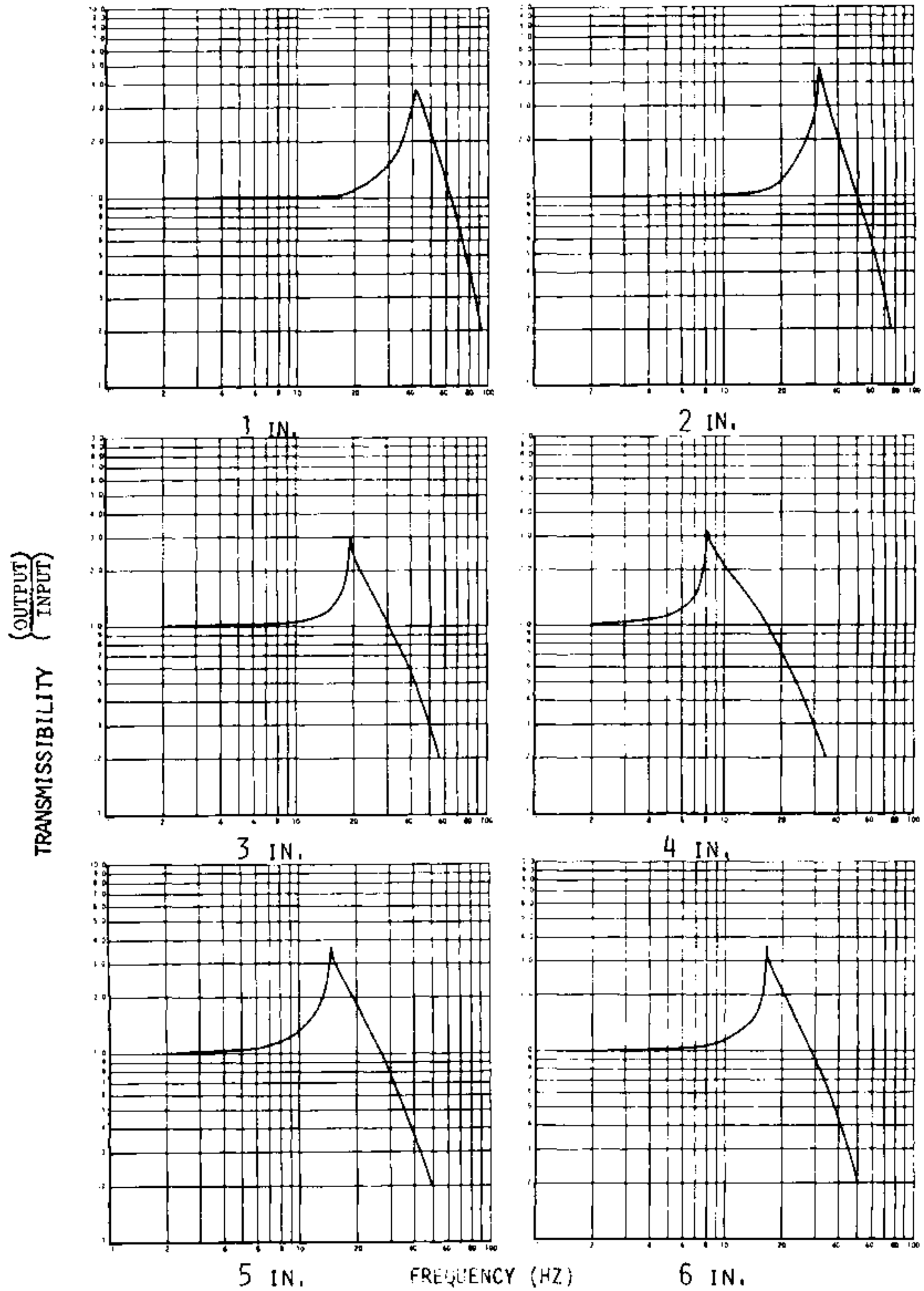
CURVE 1.5 POLYURETHANE ETHER, 1.5 LB/CU FT .180 PSI



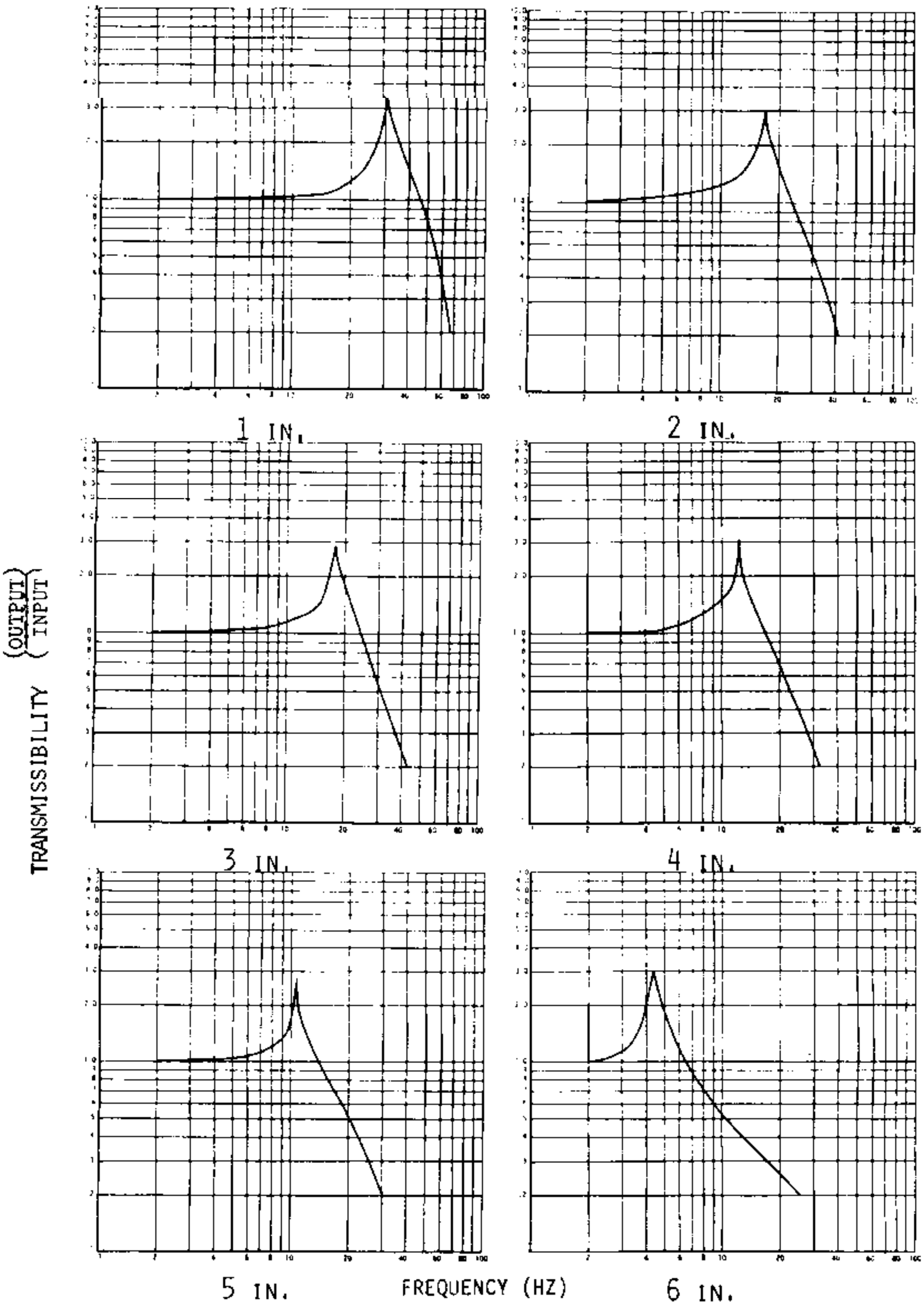
CURVE 1.6 POLYURETHANE ETHER, 1,5 LB/CU FT



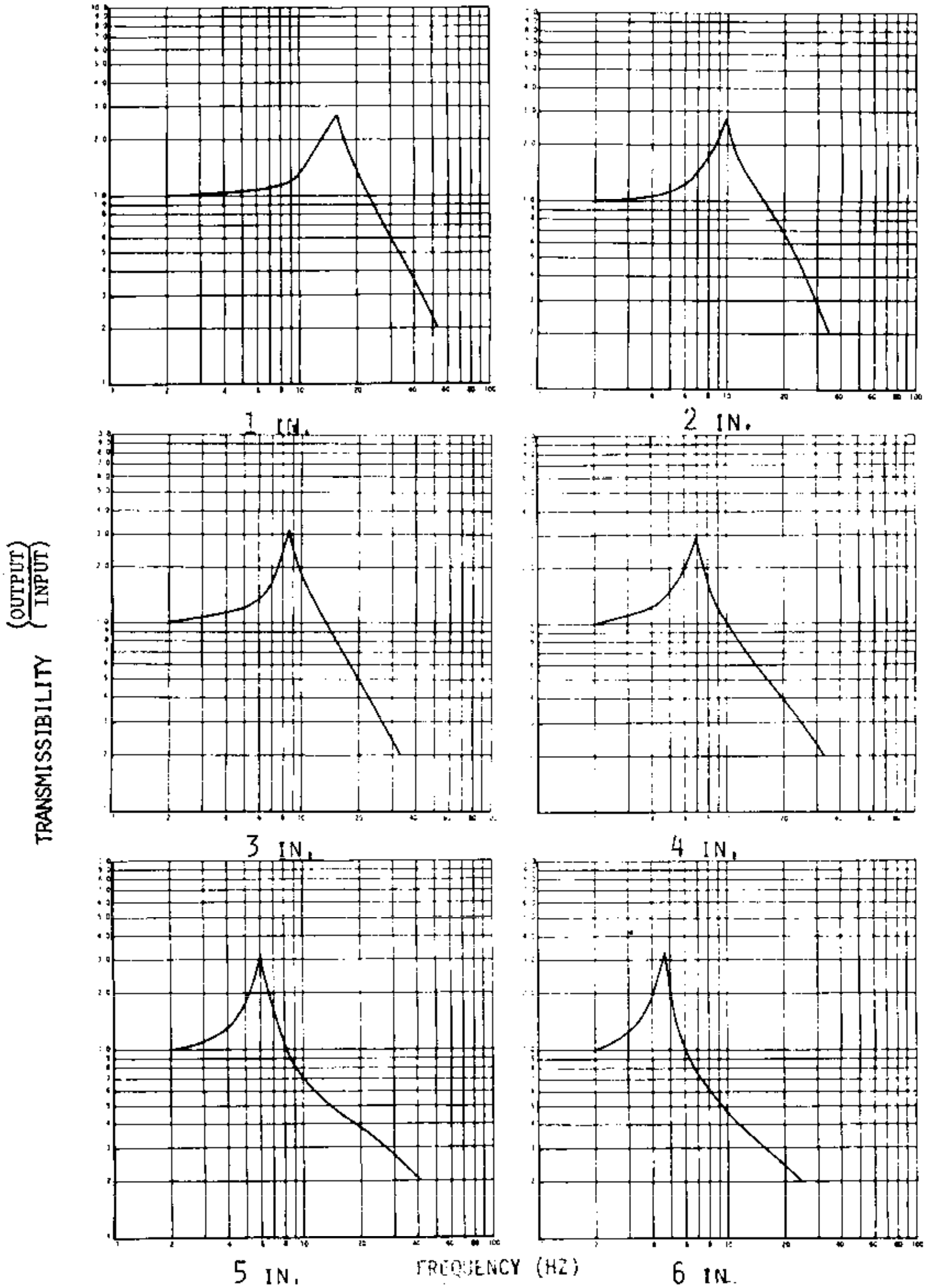
CURVE 1.7 POLYURETHANE ETHER 1.5 LB/CU FT, .250 PSI



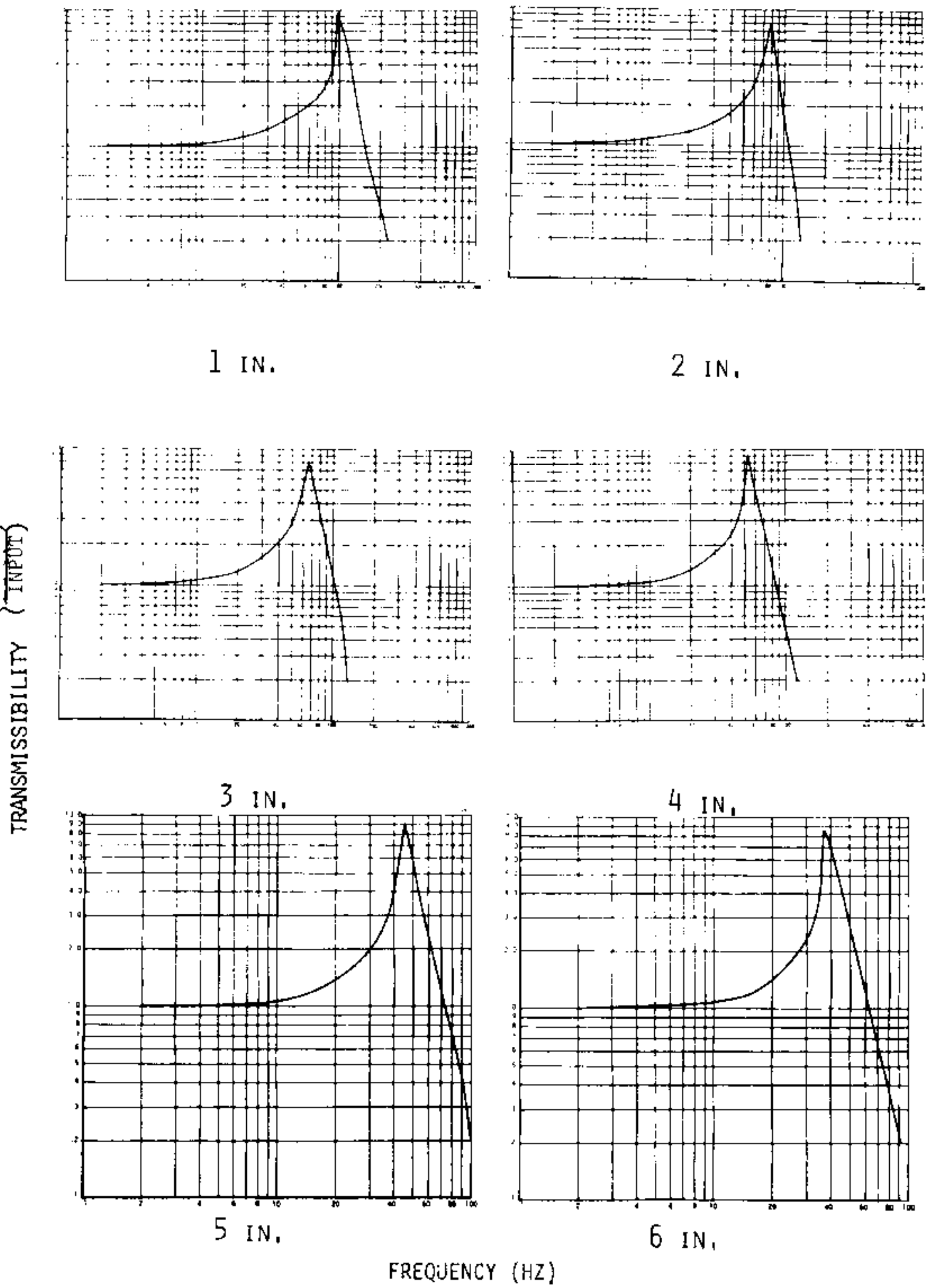
CURVE 1.8 POLYURETHANE ETHER, 1.5 LB/CU FT



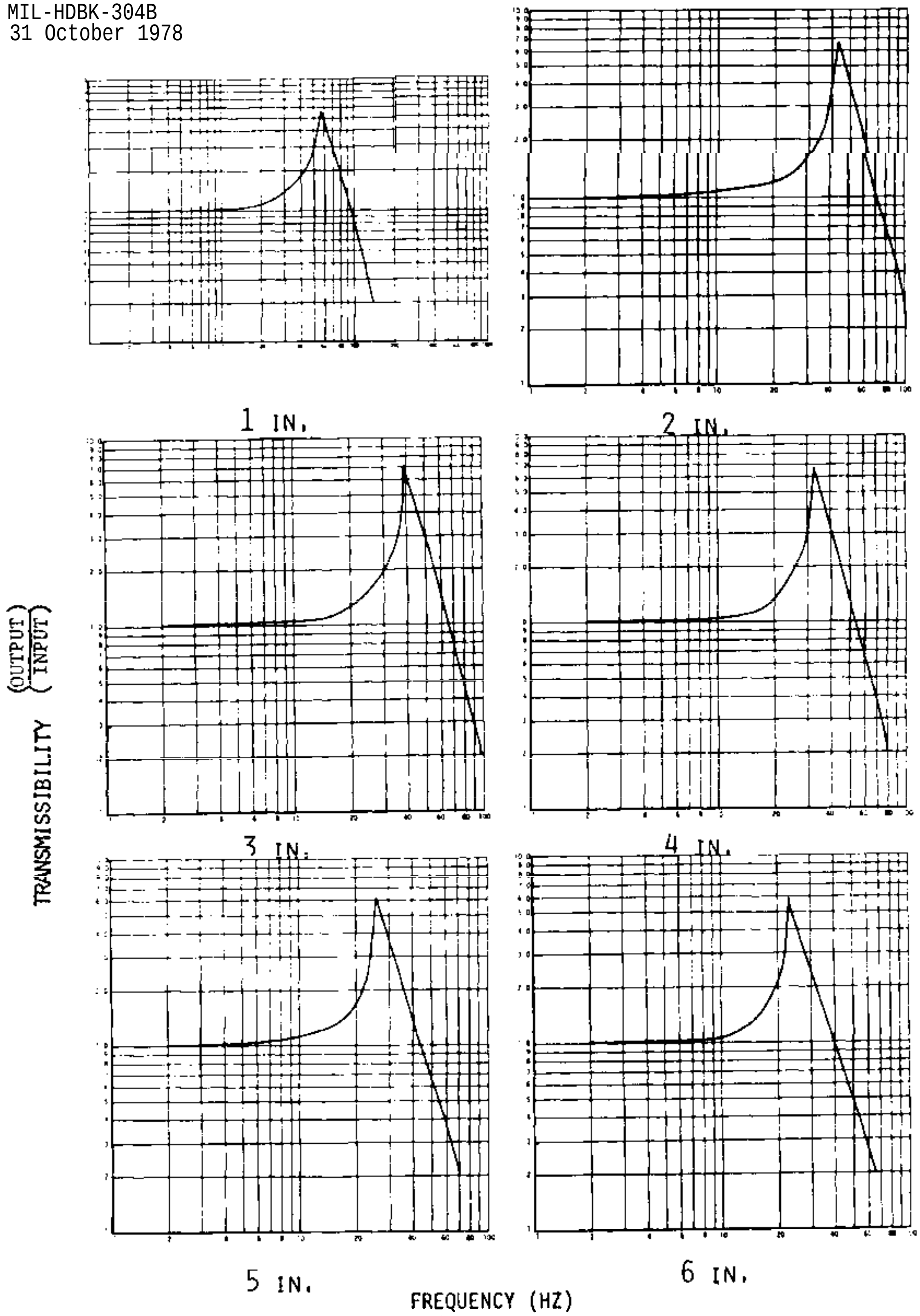
CURVE 1.9 POLYURETHANE ETHER, 1.5 LB/CU FT .464 PSI



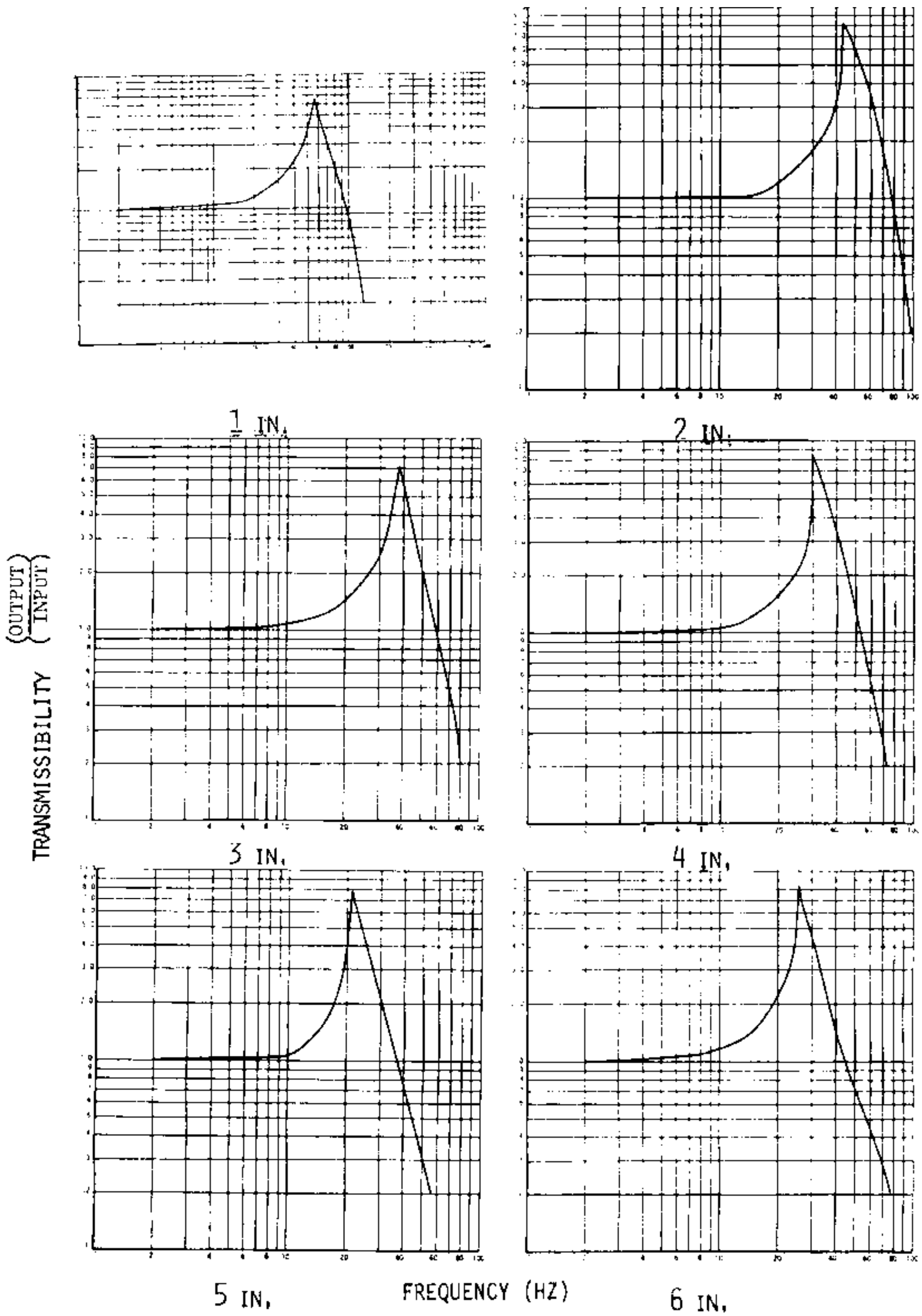
CURVE 1.9 POLYURETHANE ETHER, 1.5 LB/CU FT .464 PSI



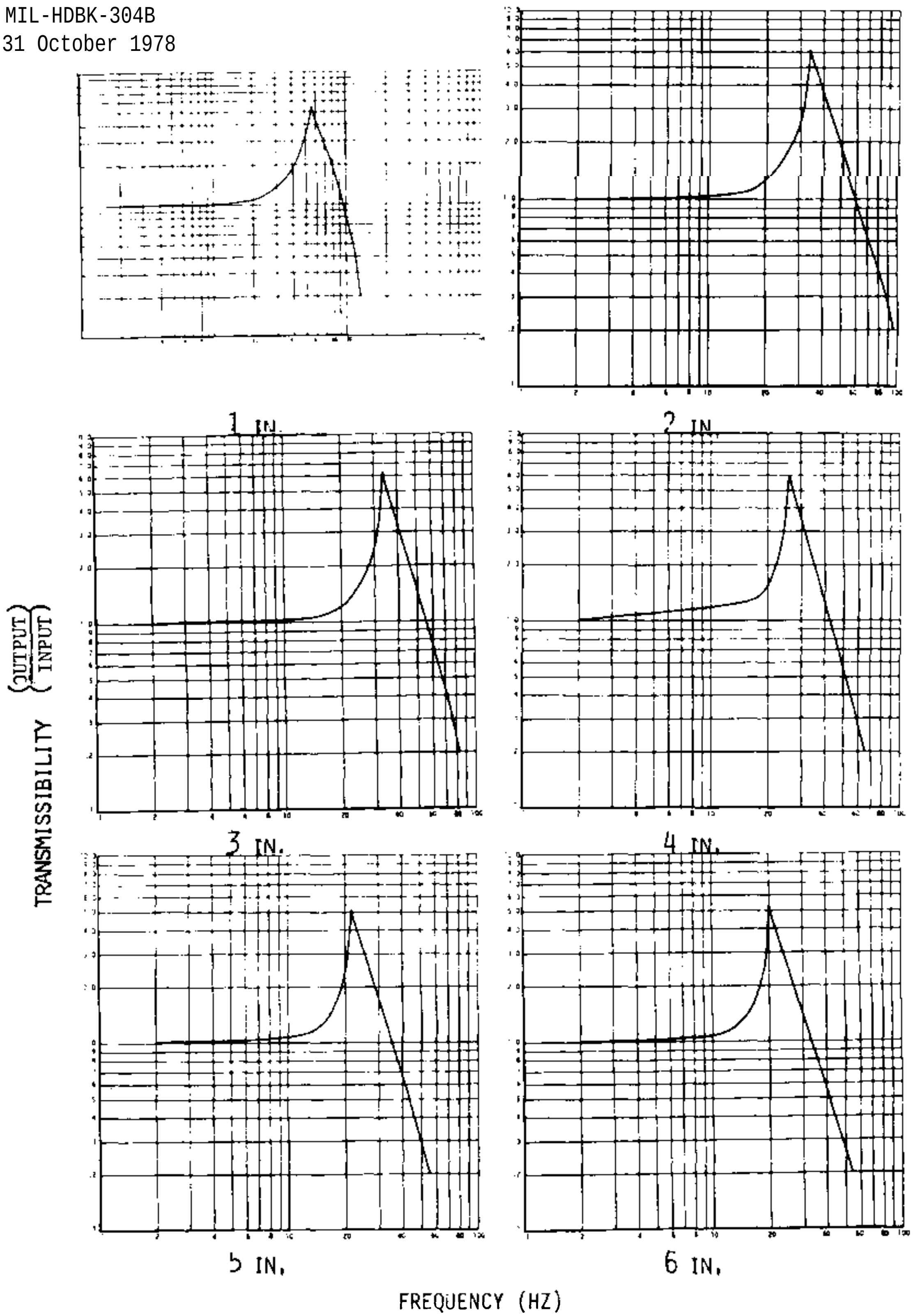
CURVE 2.1 POLYURETHANE ETHER, 2,0 LB/CU FT .045 PSI



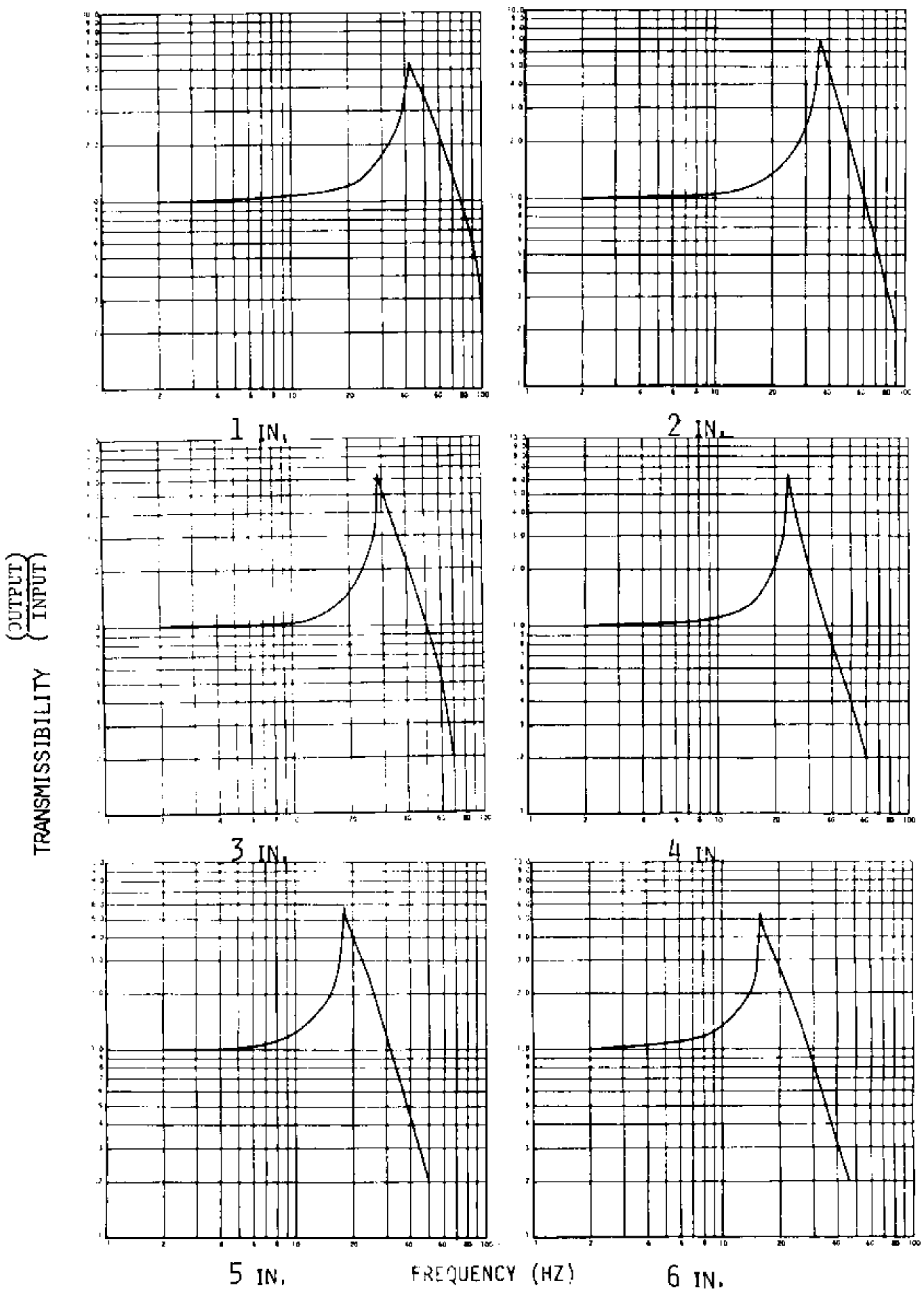
CURVE 2.2 POLYURETHANE ETHER, 2.0 LB/cu FT ,076 PSI



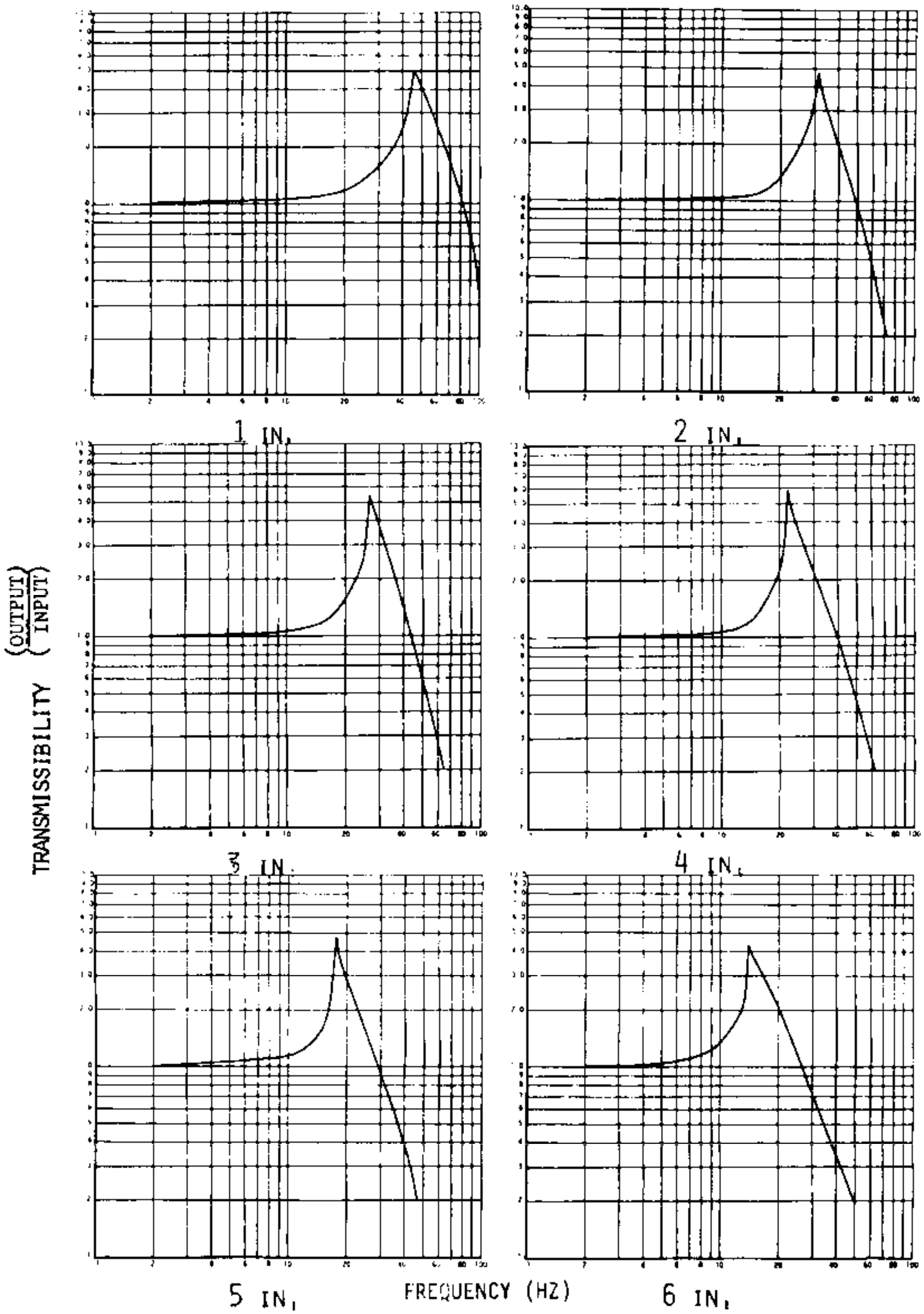
CURVE 2.3 POLYURETHANE ETHER, 2.0 LB/CU FT .100 PSI



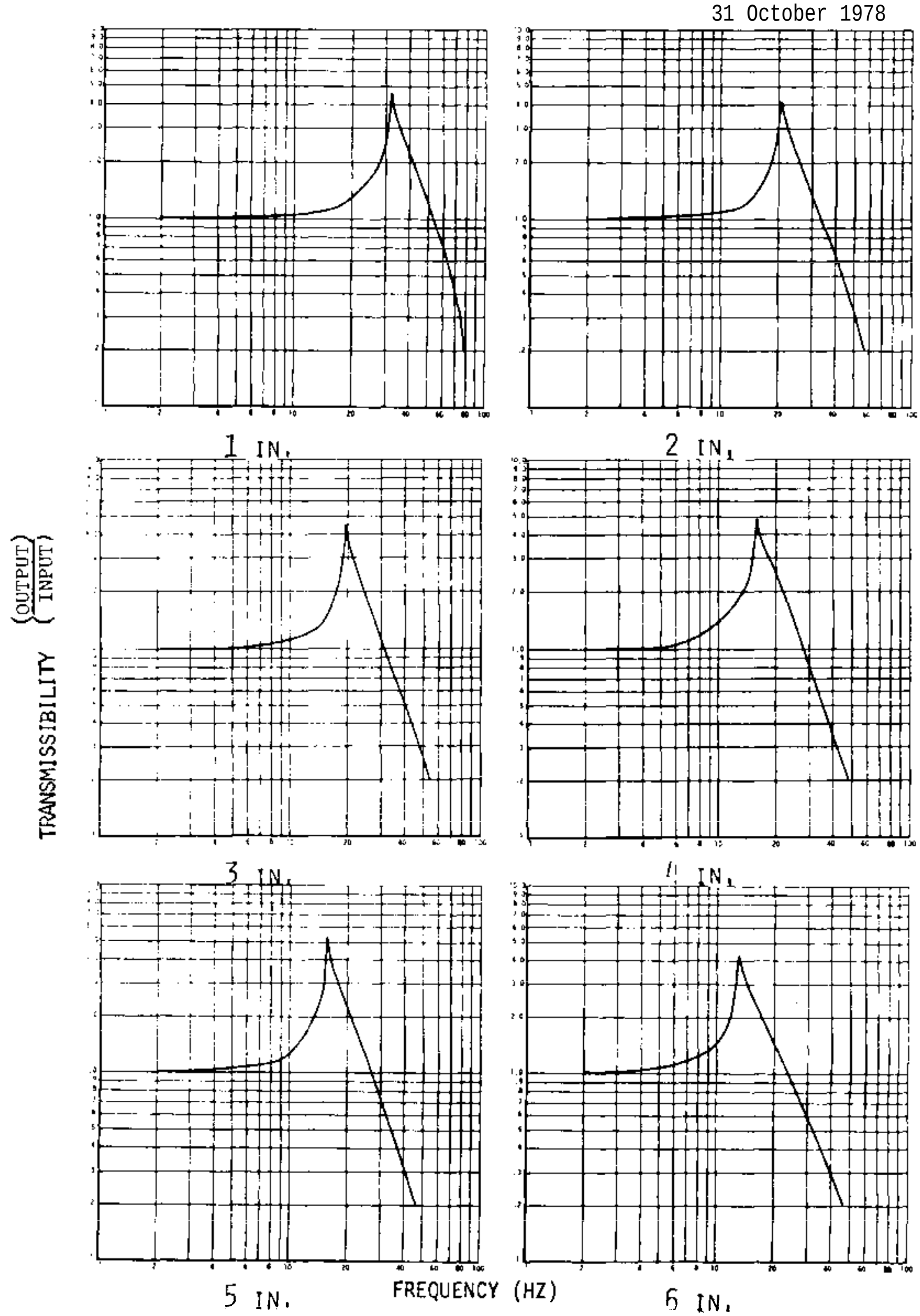
CURVE 2.4 POLYURETHANE ETHER, 2.0 LB/CU FT .133 PSI



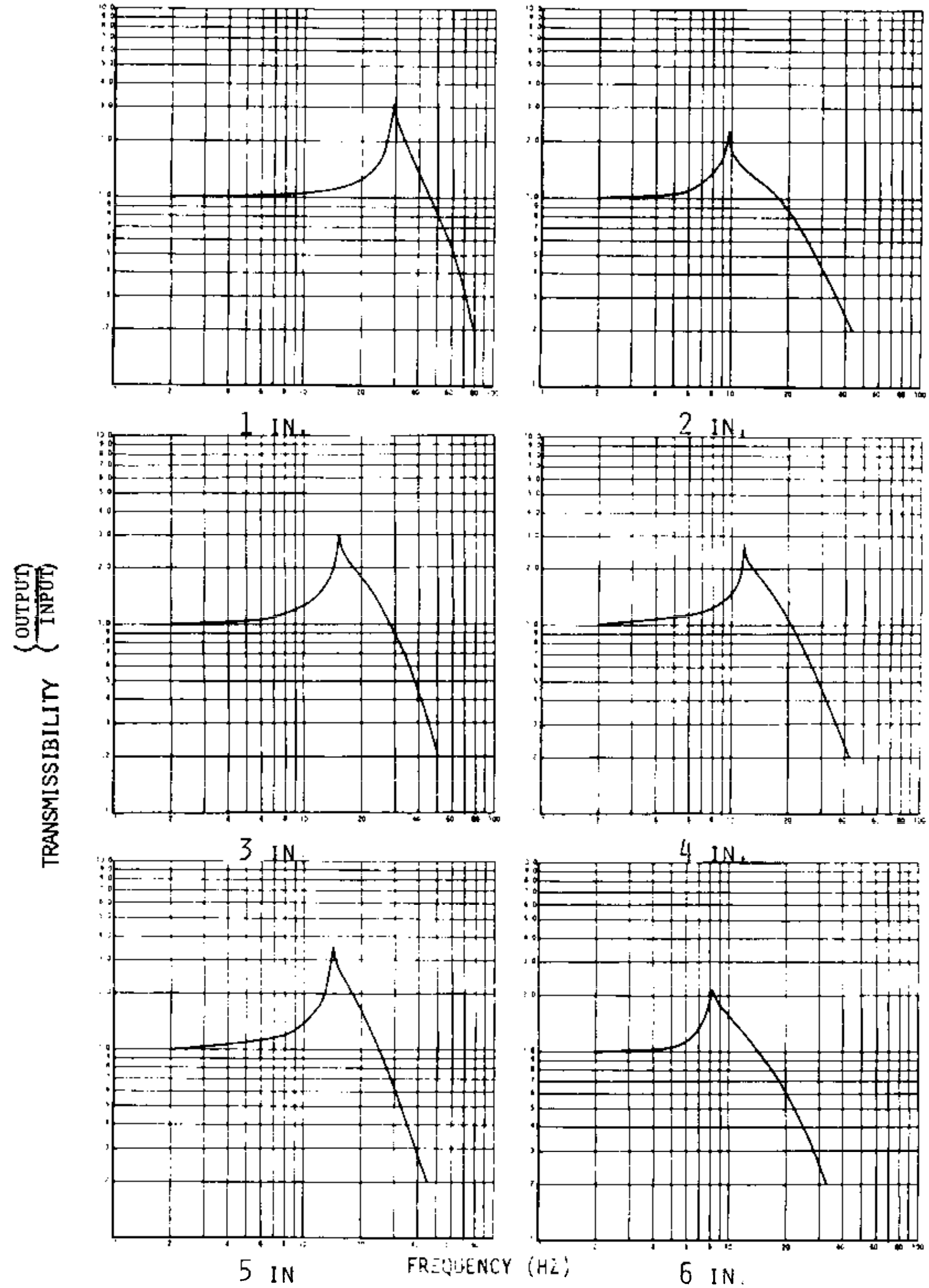
CURVE 2.5 POLYURETHANE ETHER, 2.0, LB/CU FT .180 PSI



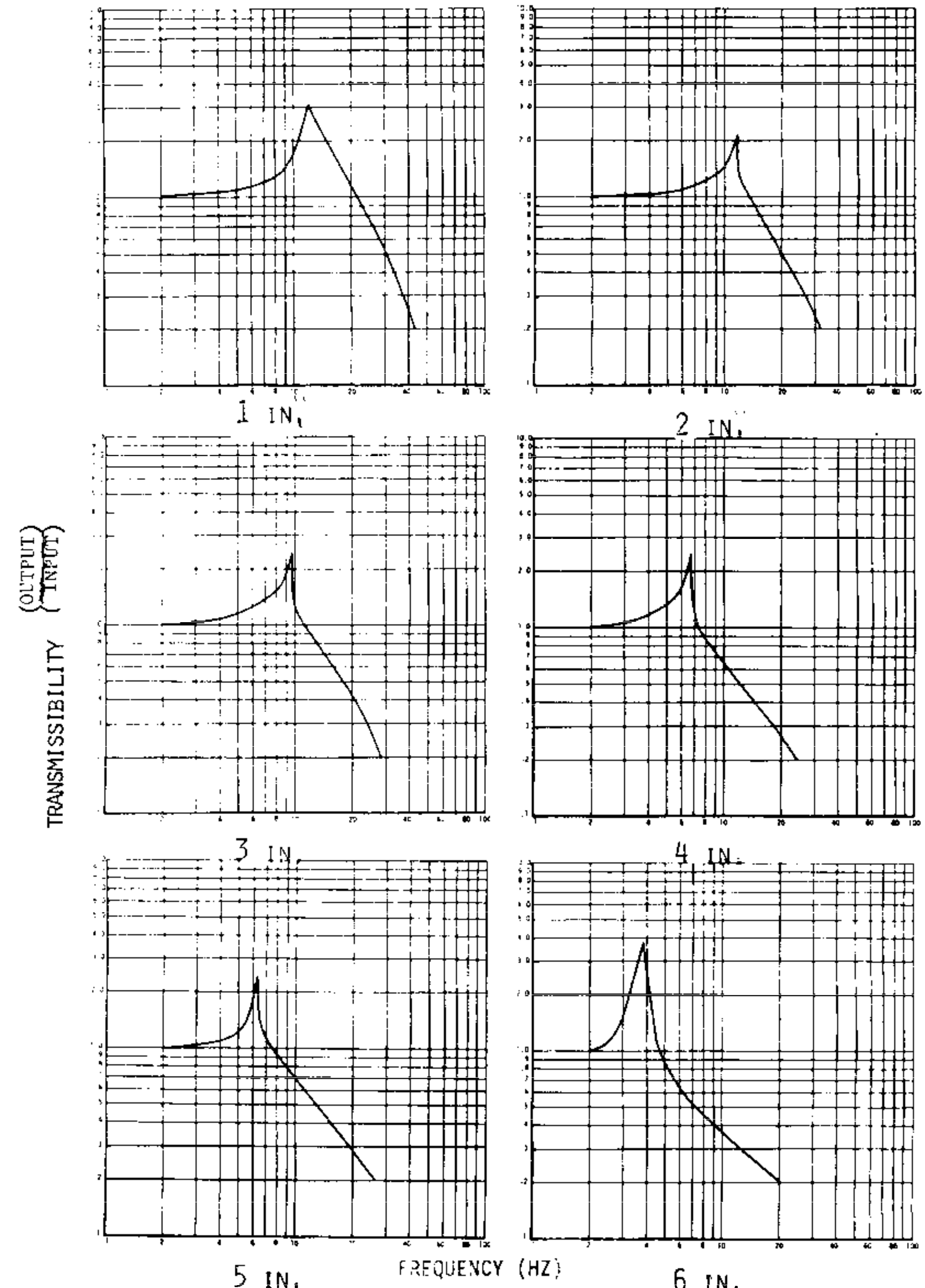
CURVE 2.6 POLYURETHANE ETHER, 2.0 LB/CU FT .211 PSI



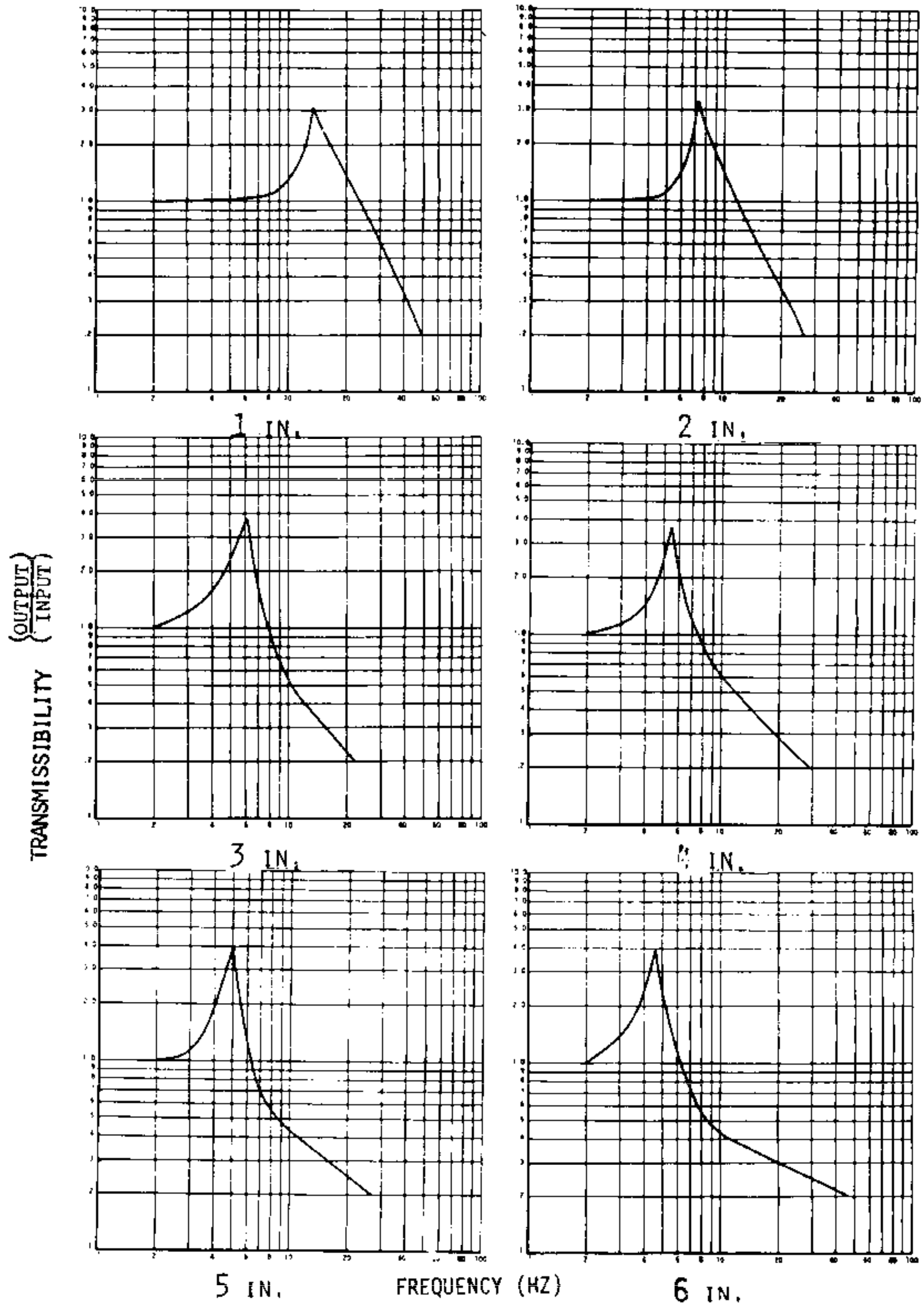
CURVE 2.7 POLYURETHANE ETHER, 2.0 LB/CU FT .250 PSI



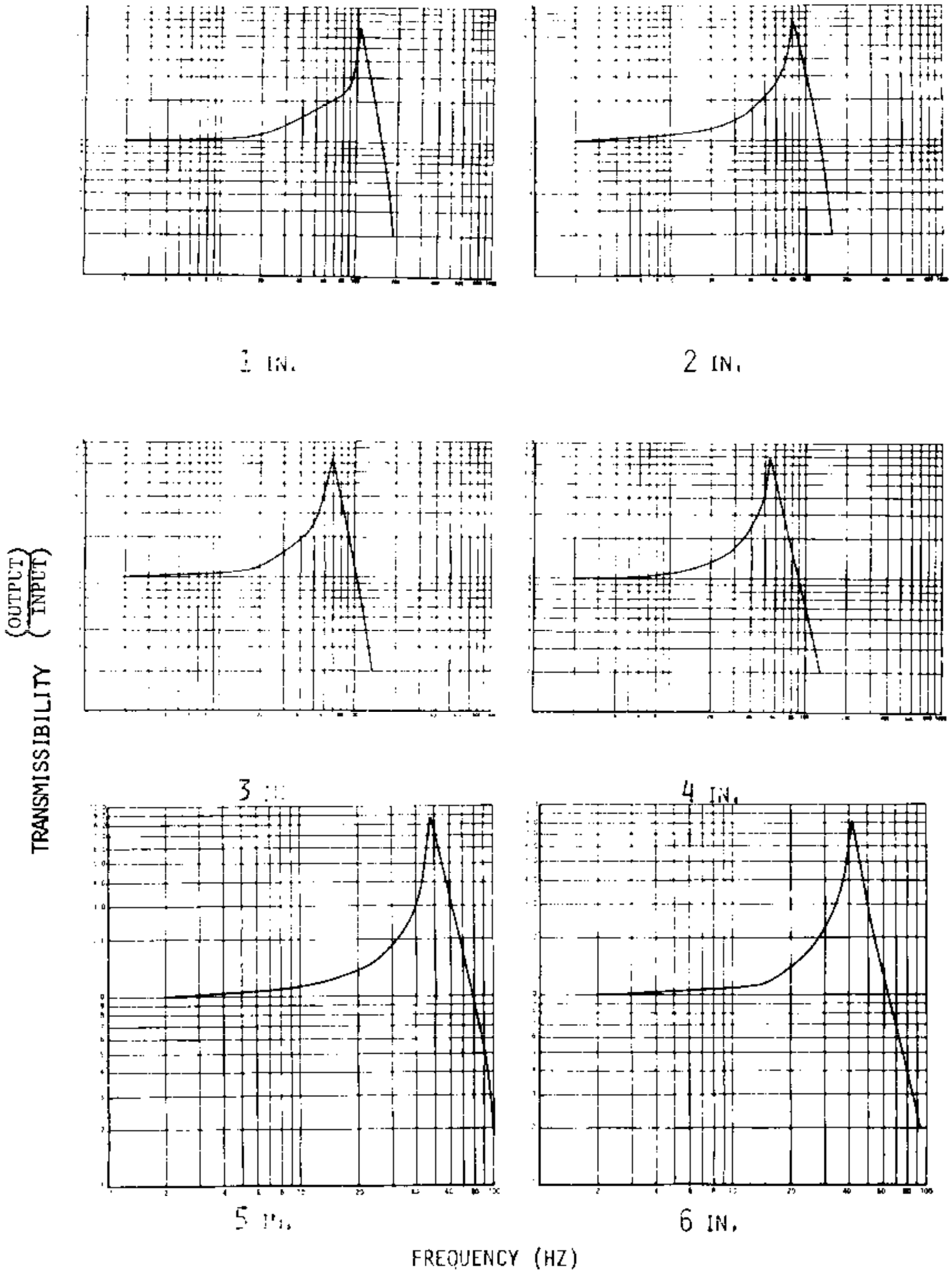
CURVE 2.8 POLYURETHANE ETHER, 2.0 LB/cu FT .314 PSI



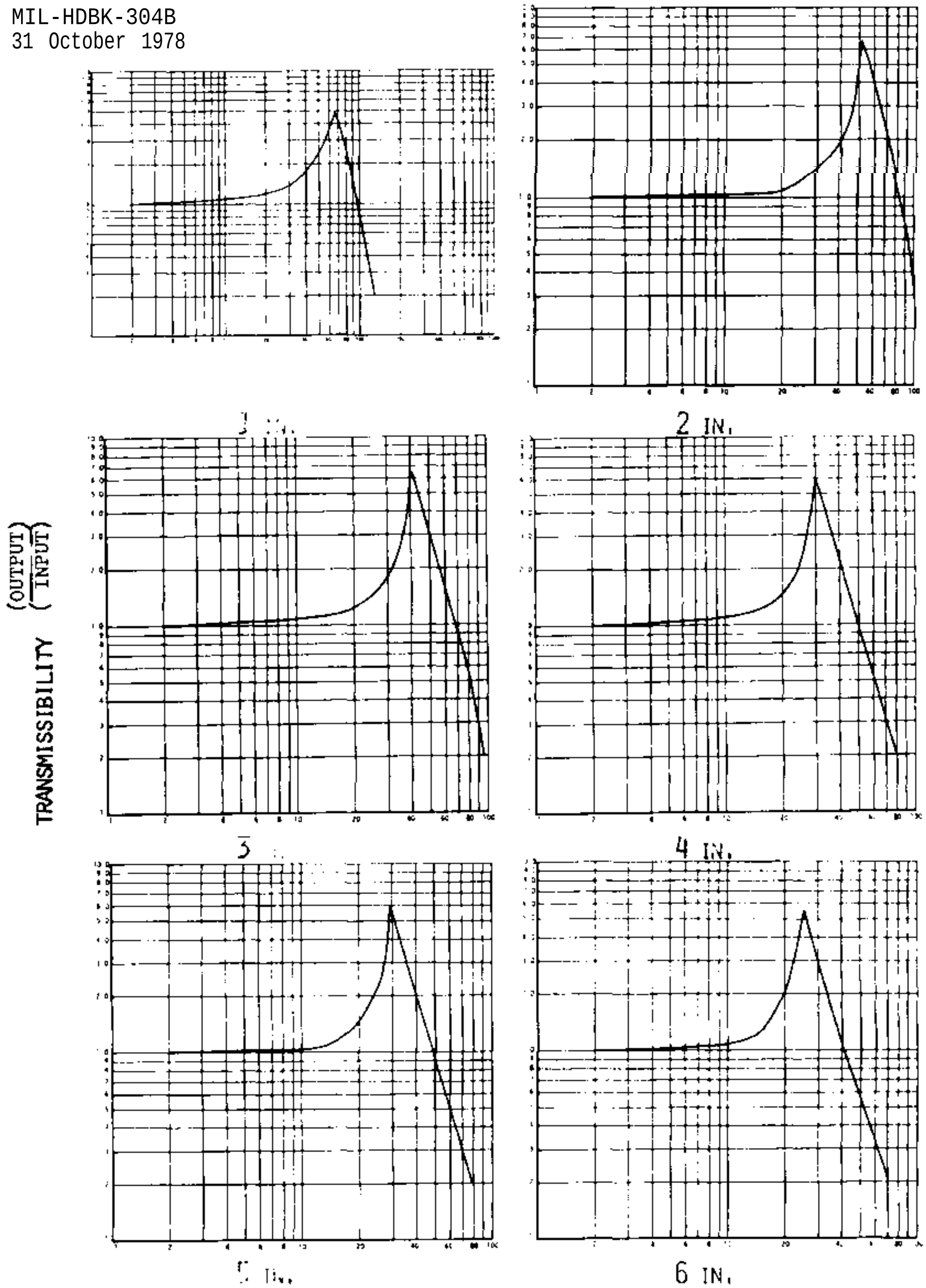
CUREVE 2.9 POLYURETHANE ETHER, 2.0 LB/CU FT .464 PSI



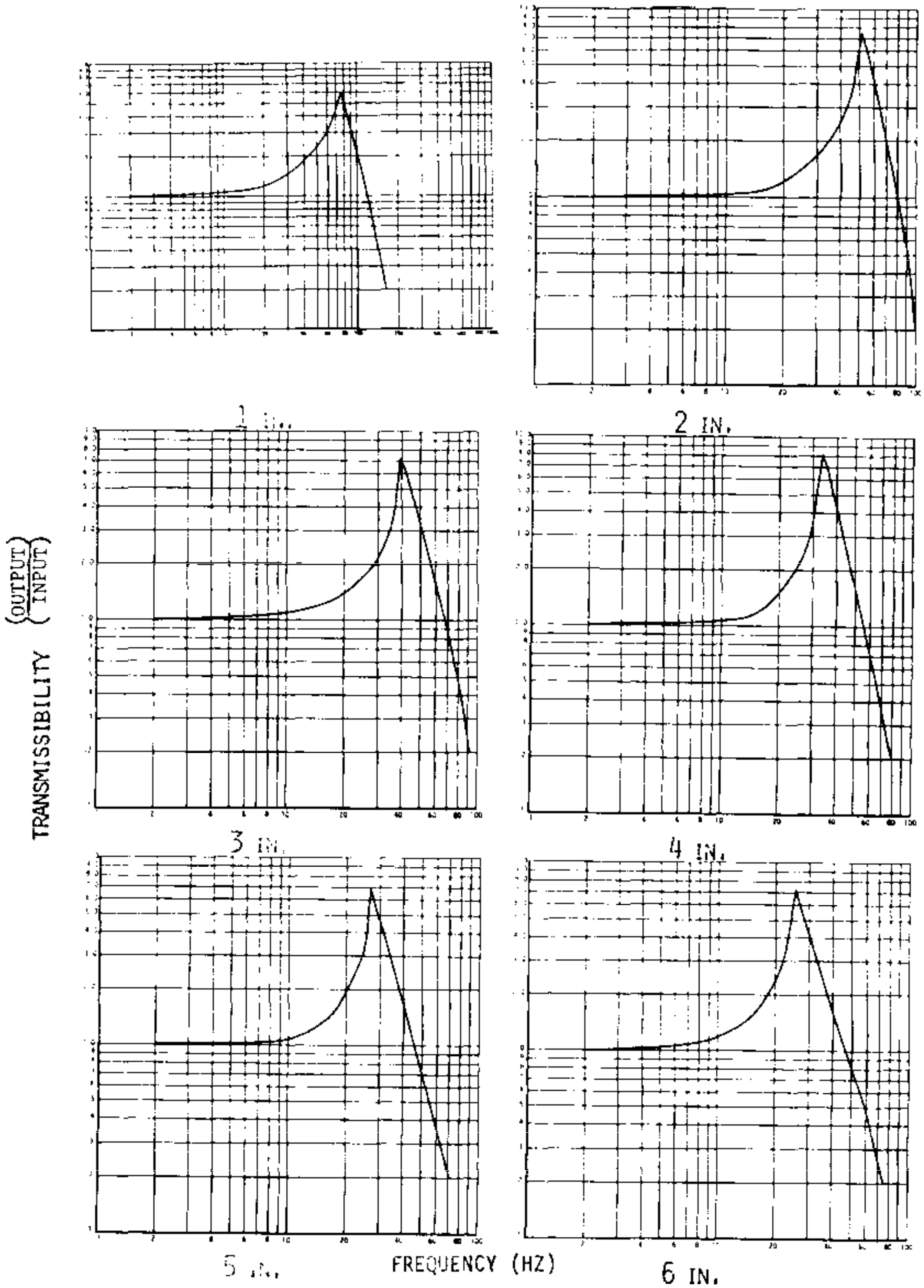
CURVE 2.10 POLYURETHANE ETHER, 2.0 LB/CU FT .533 PSI



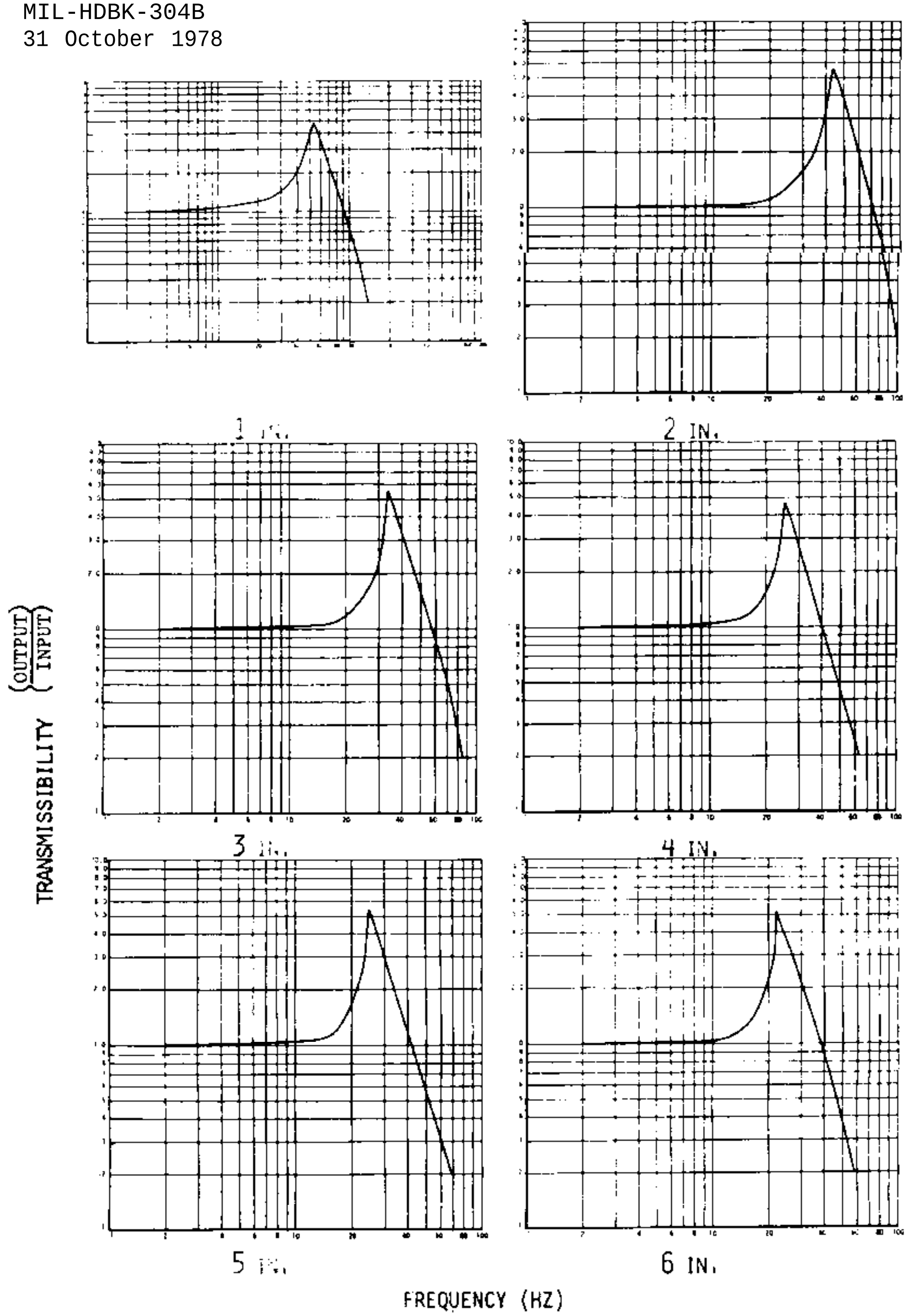
CURVE 3.1 POLYURETHANE ETHER, 4.0 LB/CU FT .045 PSI



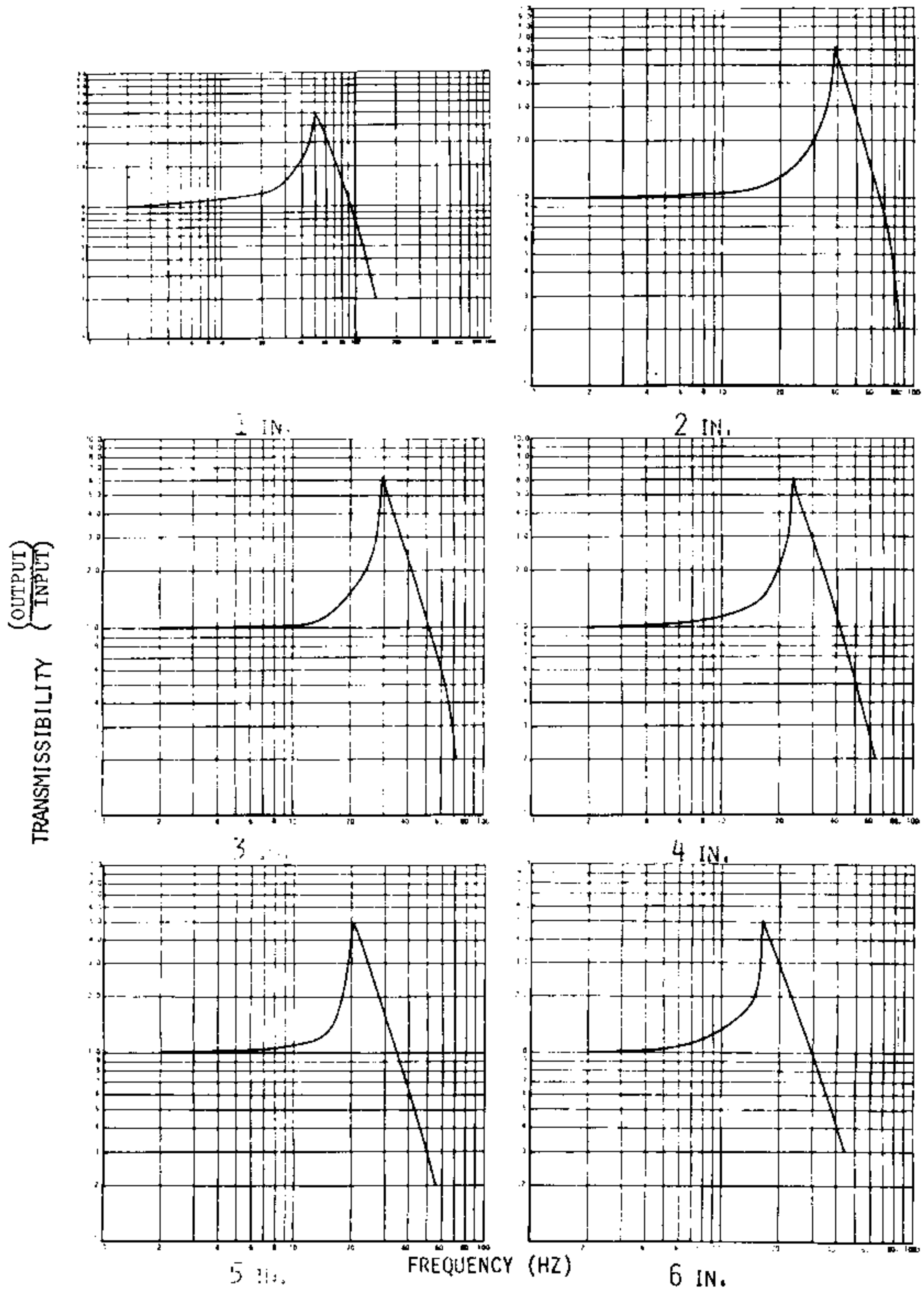
CURVE 3.2 POLYURETHANE ETHER, 4.0 LB/CU FT .076 PSI



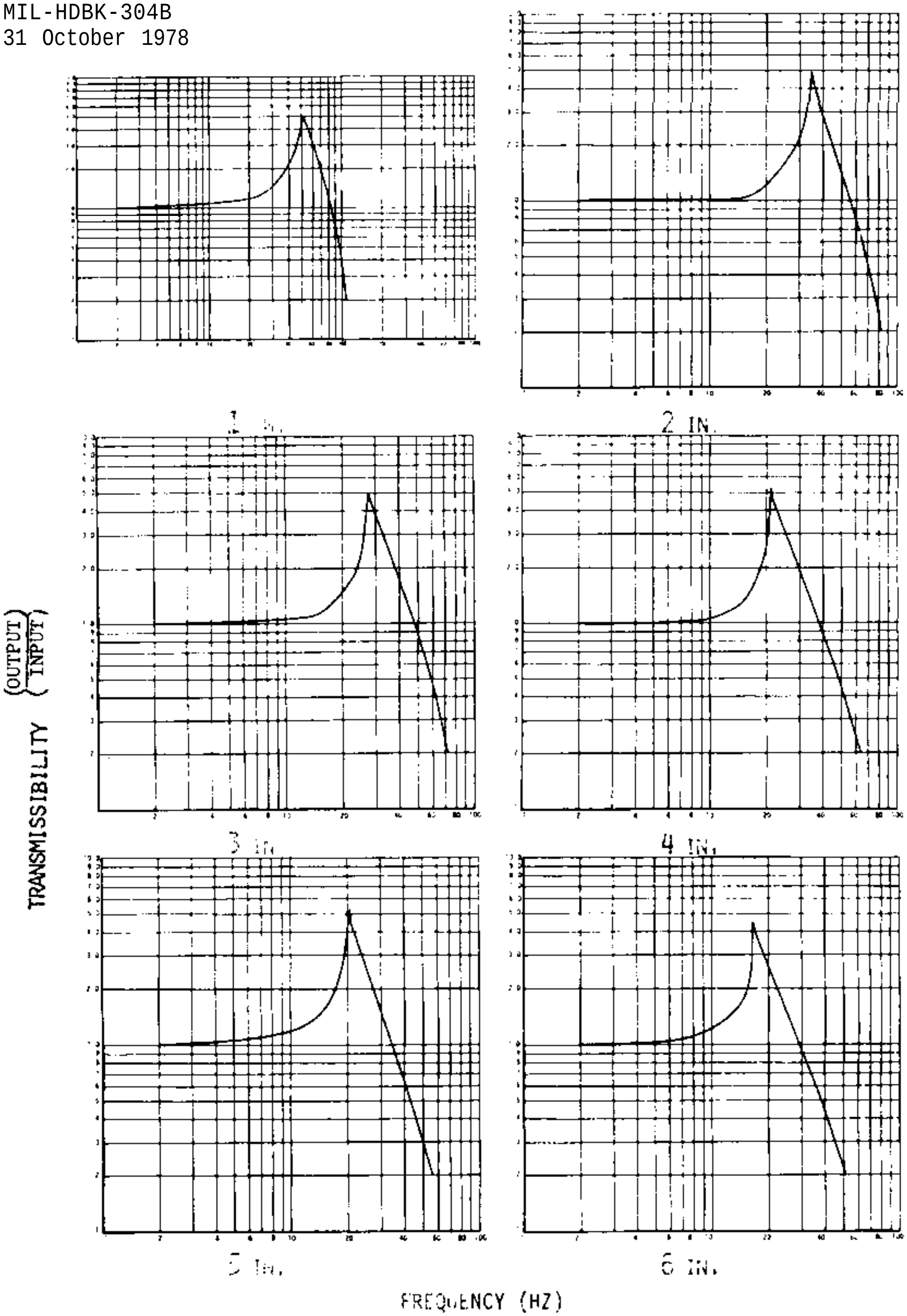
CURVE 3.3 POLYURETHANE ETHER, 4.0 LB/CU FT .100 PSI



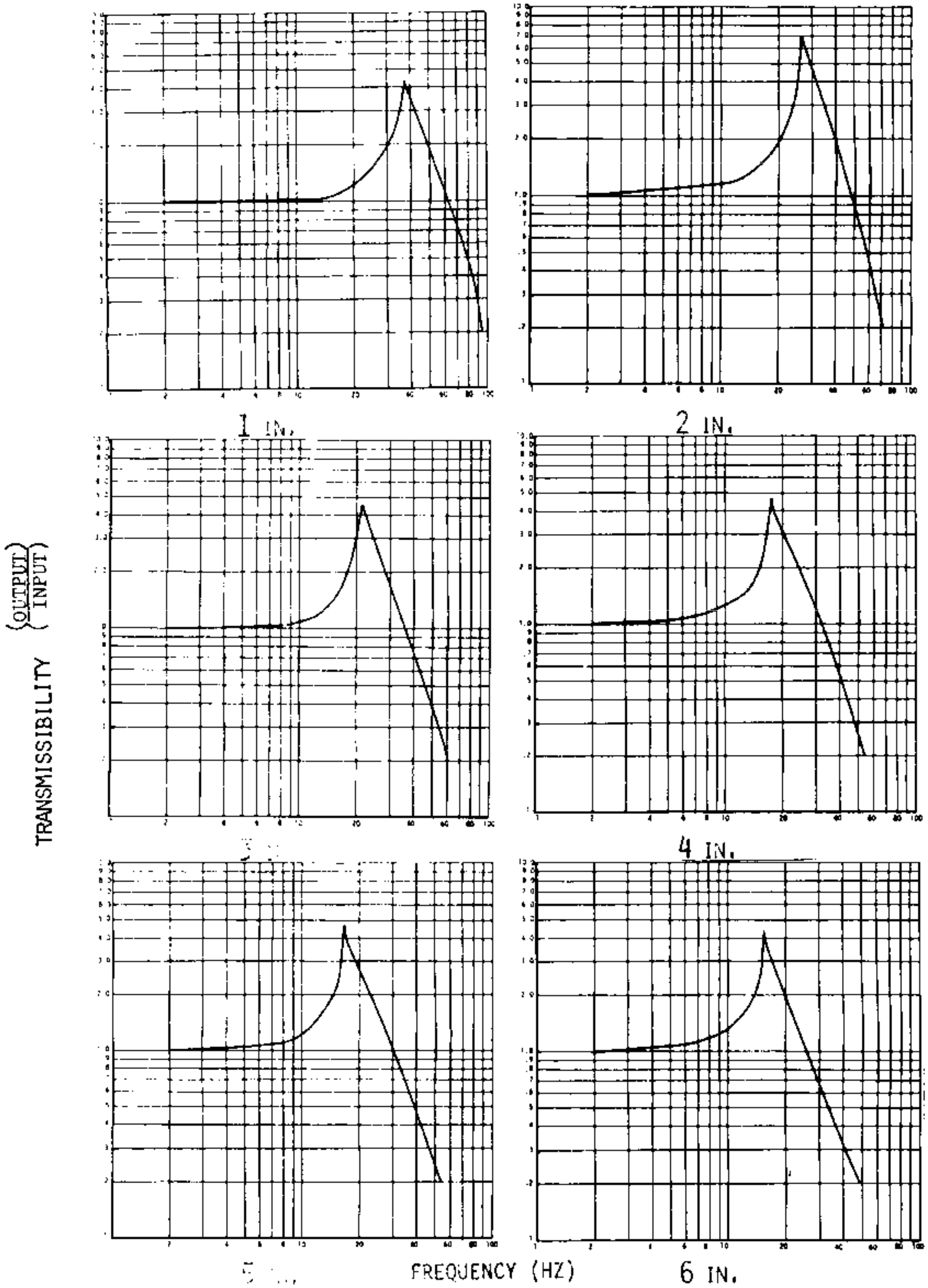
CURVE 3.4 POLYURETHANE ETHER, 4.0 LB/CU FT .133 PSI



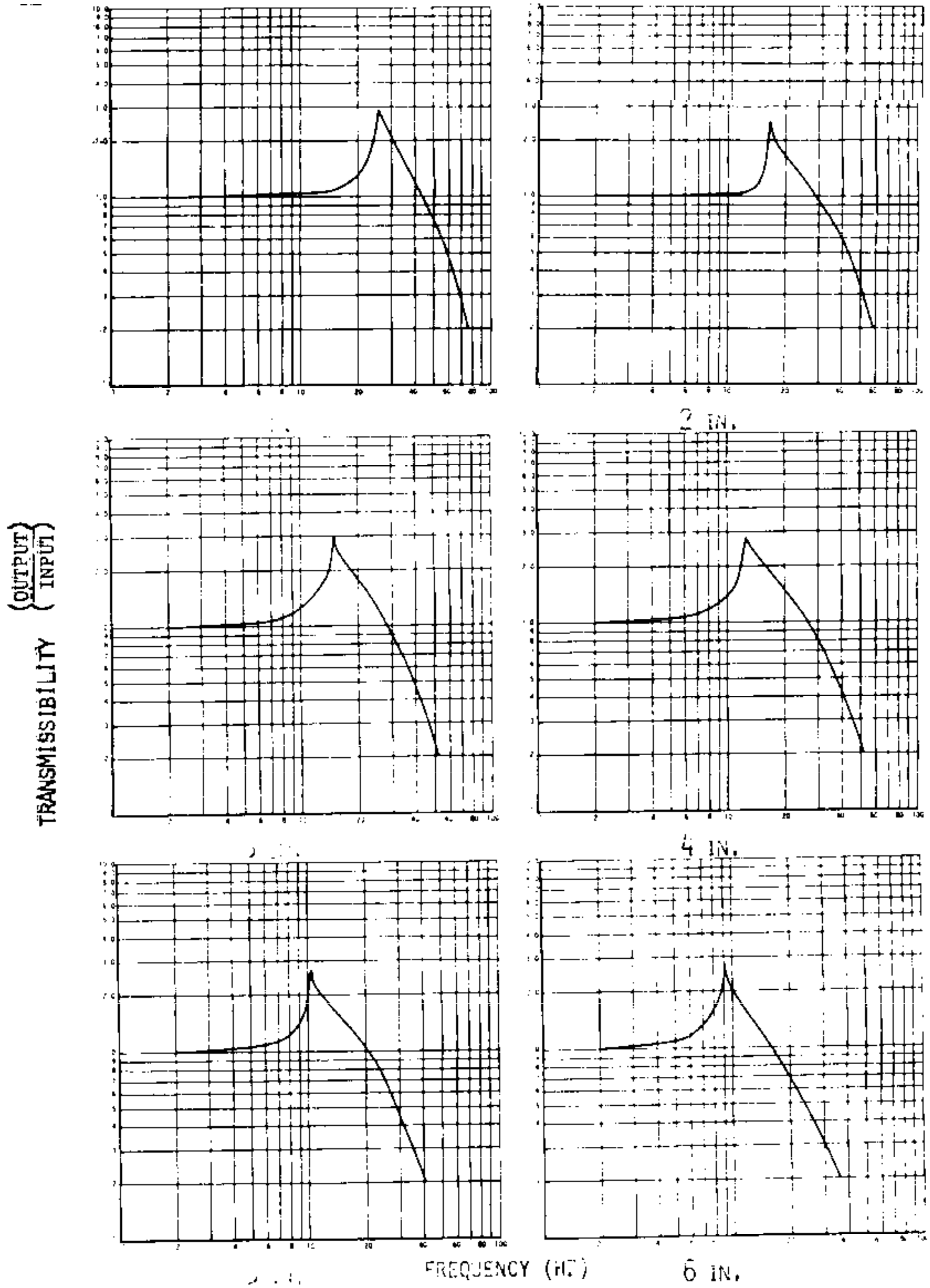
CURVE 3.5 POLYURETHANE ETHER, 4.0 LB/CU FT .180 PSI



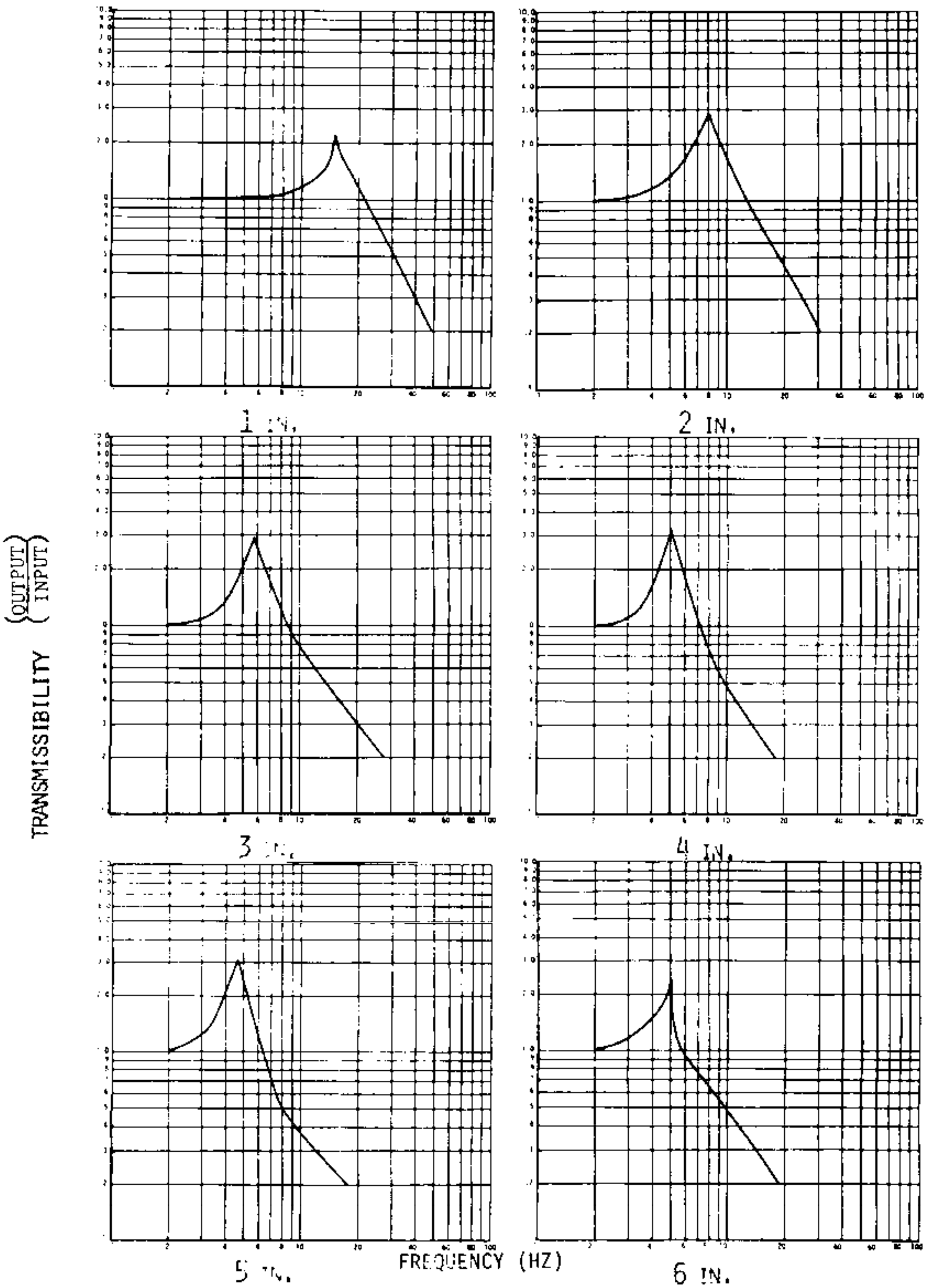
CURVE 3.6 POLYURETHEANE ETHER, 4.0 LB/CU FT .211 PSI



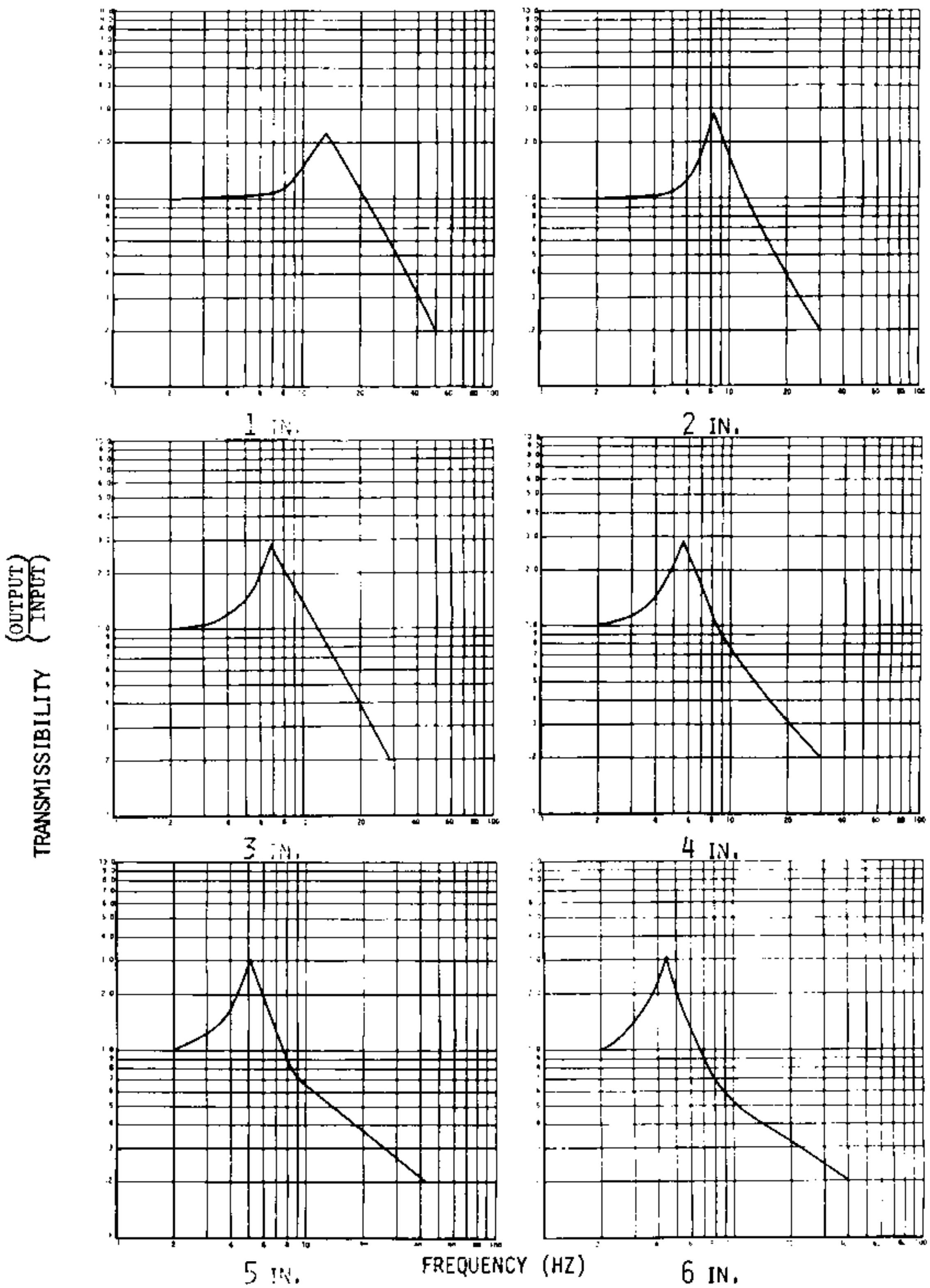
CURVE 3.7 POLYURETHANE ETHER, 4.0 LB/CU FT .250 PSI



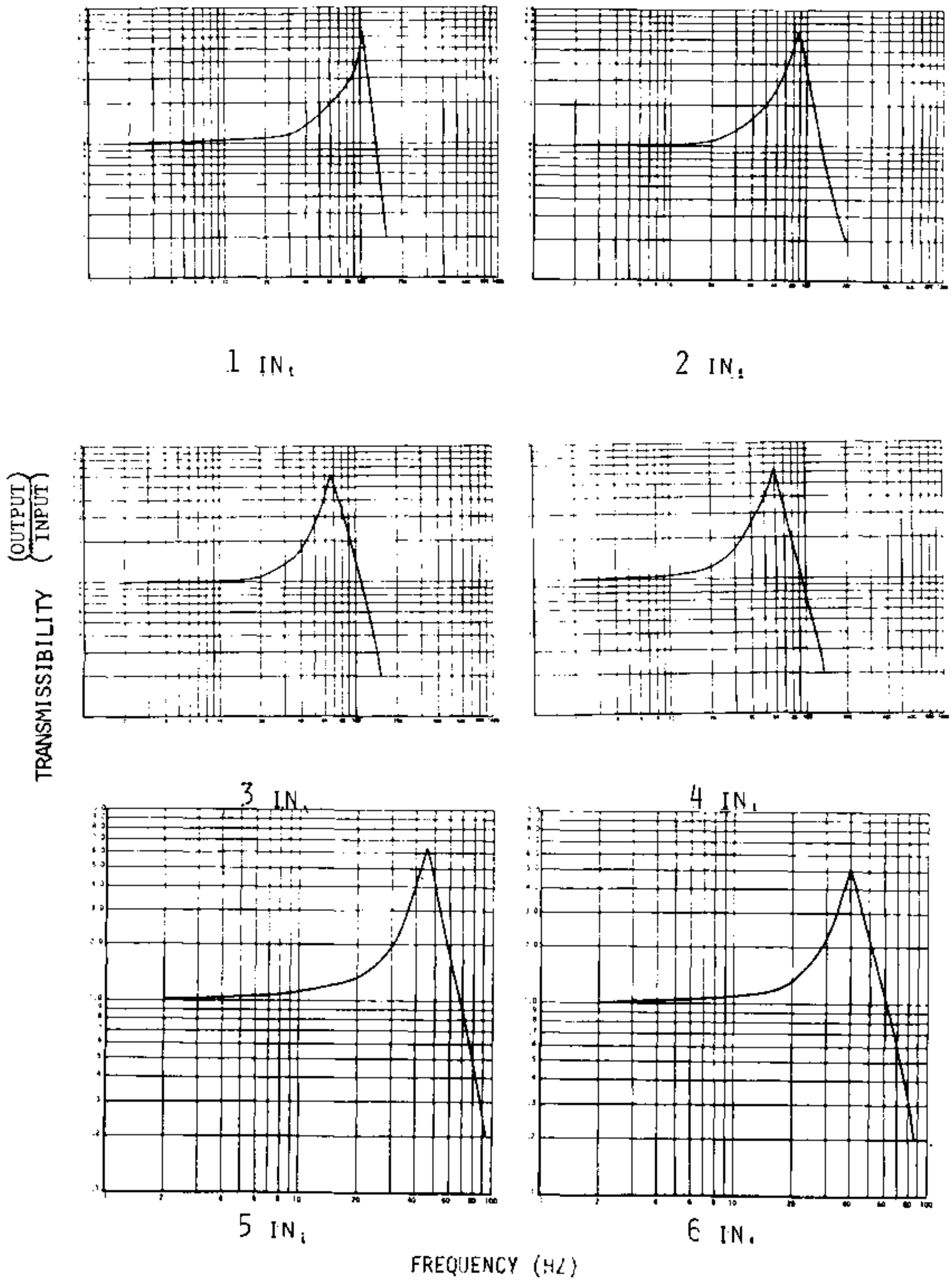
CURVE 3.8 POLYURETHANE ETHER, 4.0 LB/CU FT .314 PSI



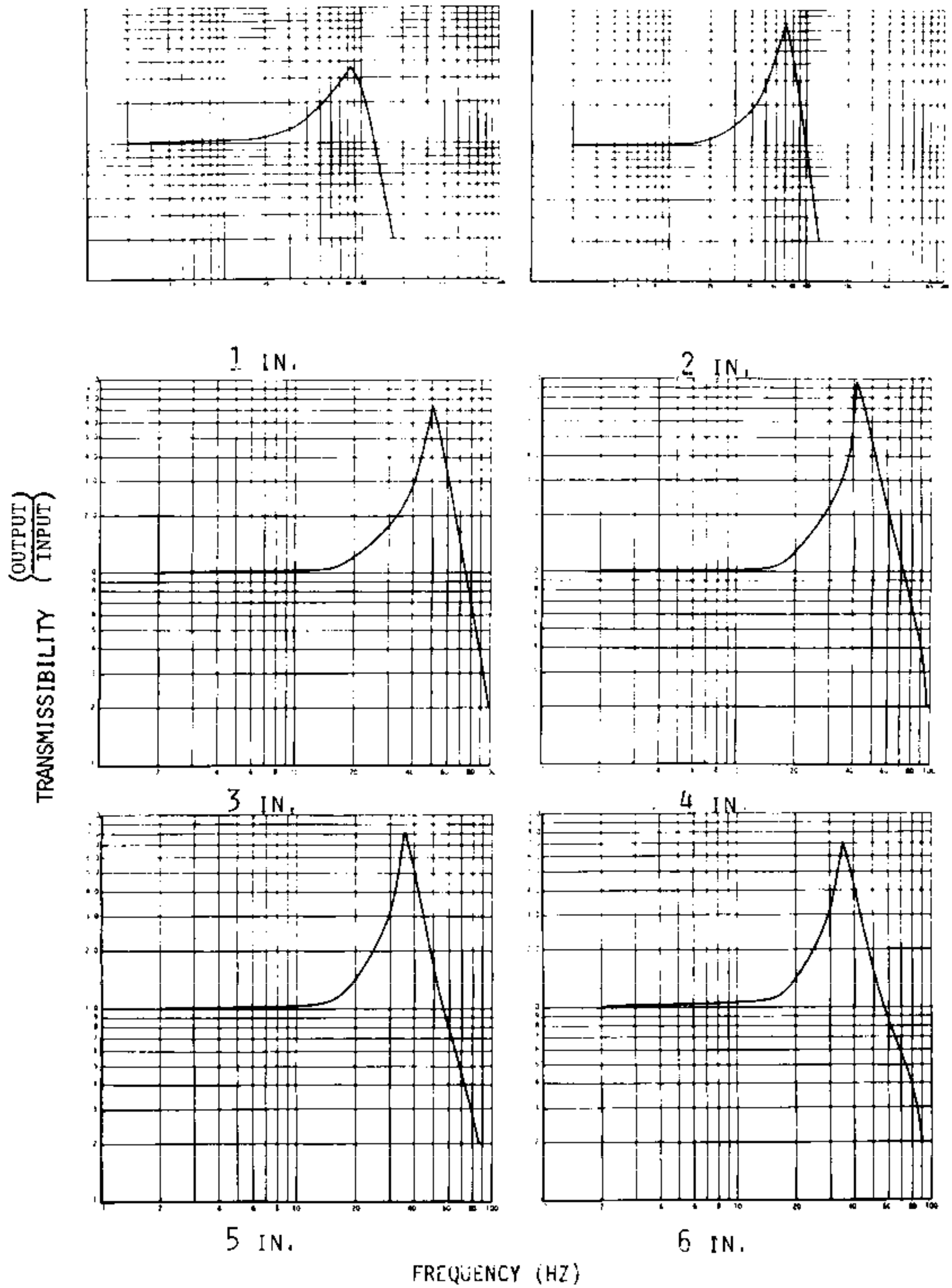
CURVE 3.9 POLYURETHANE ETHER, 4.0 LB/CU FT .464 PSI



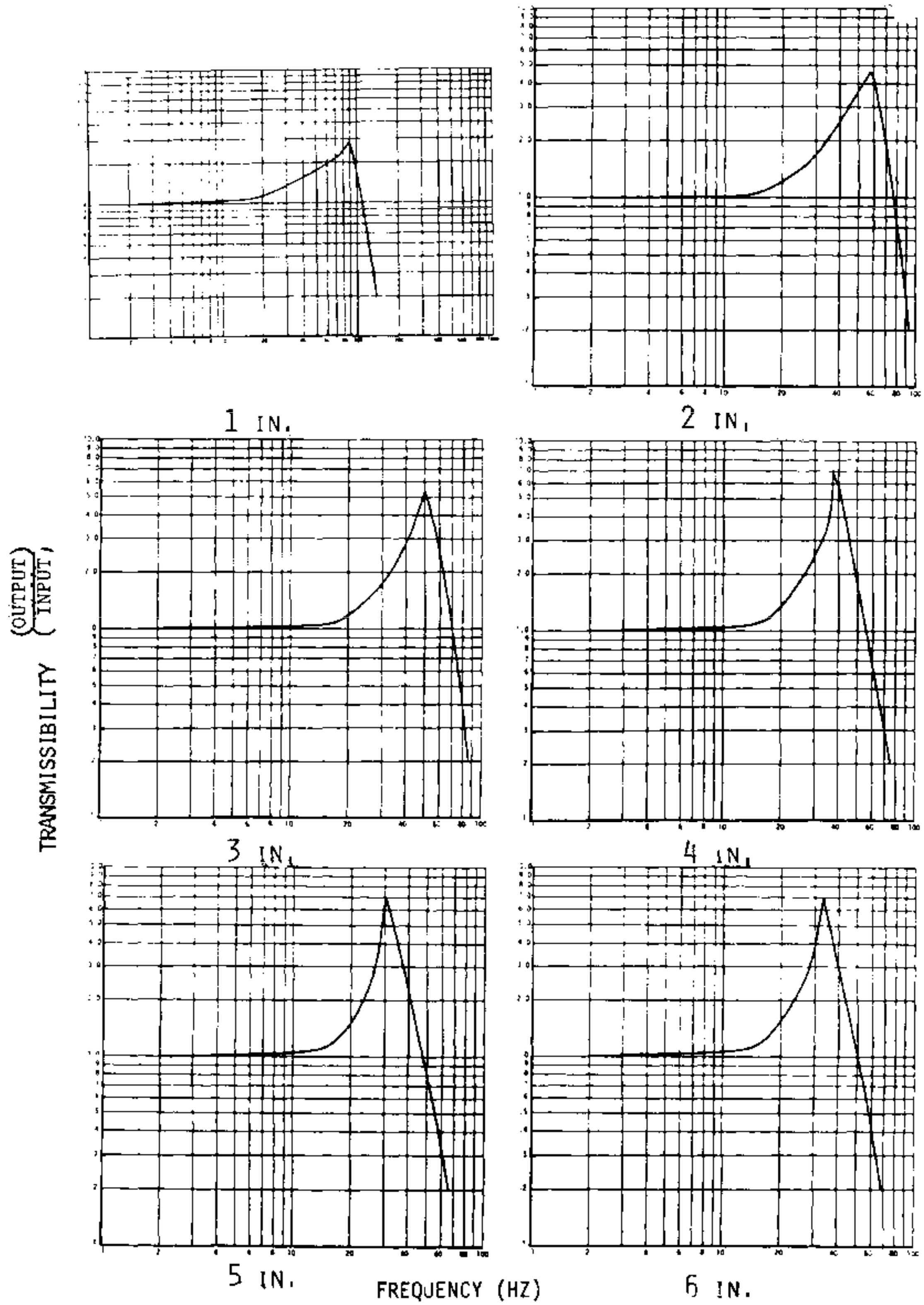
CURVE 3.10 POLYURETHANE ETHER, 4.0 LB/CU FT .533 PSI



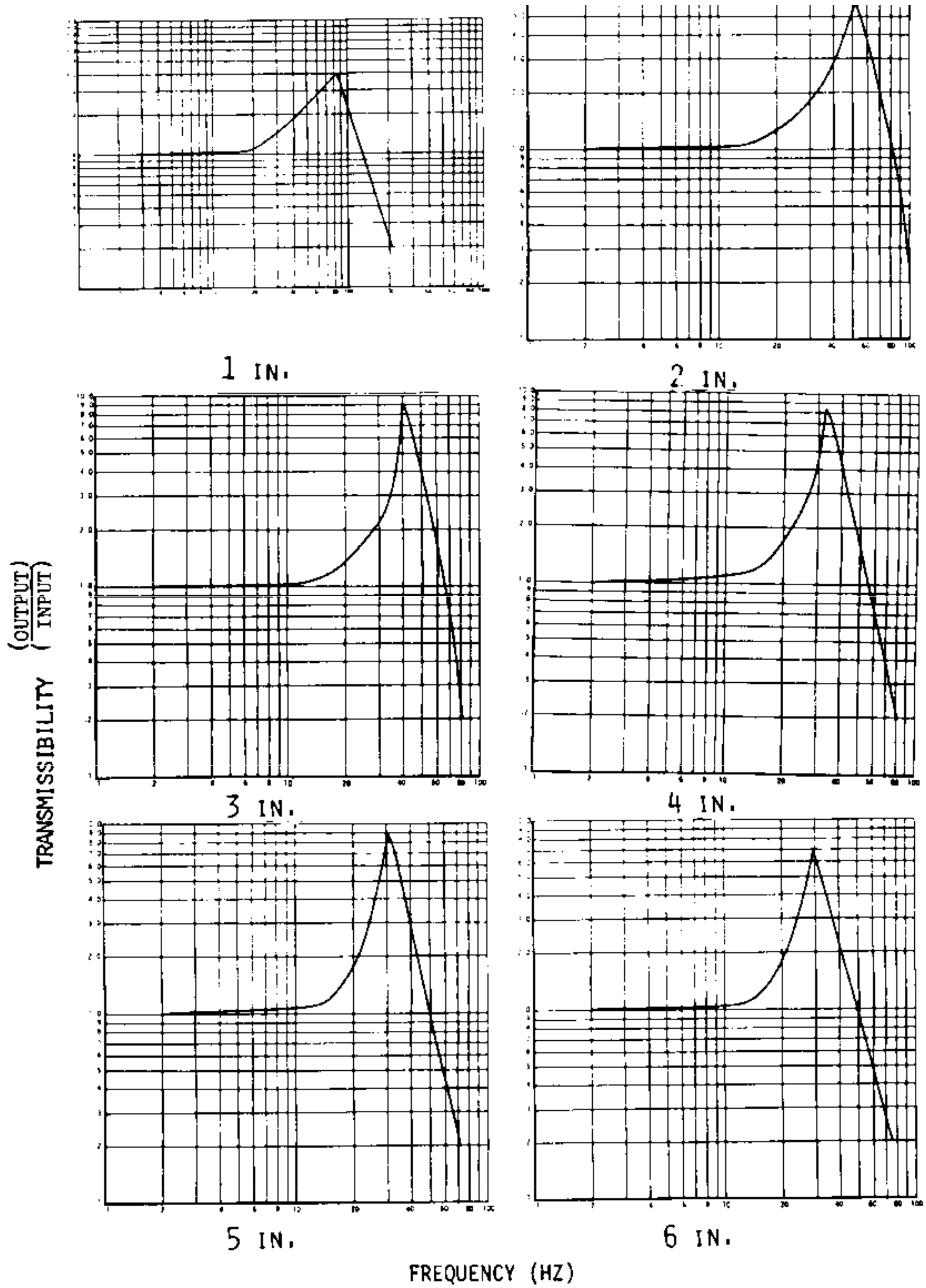
CURVE 4.1 POLYURETHANE ESTER, 1.5 LB/CU FT .045 PSI



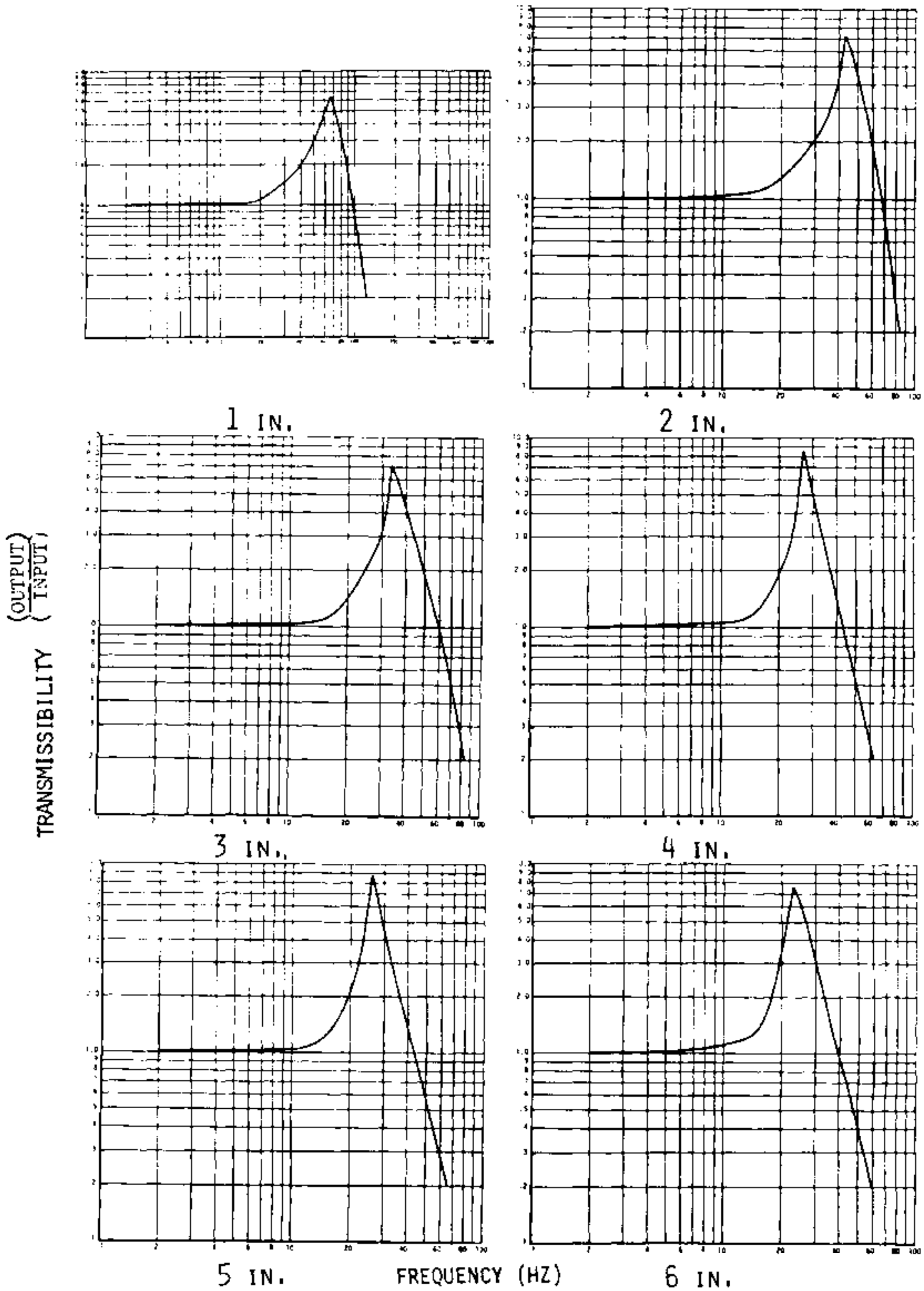
CURVE 4.2 POLYURETHANE ESTER, 1.5 LB/CU FT .07 PSI



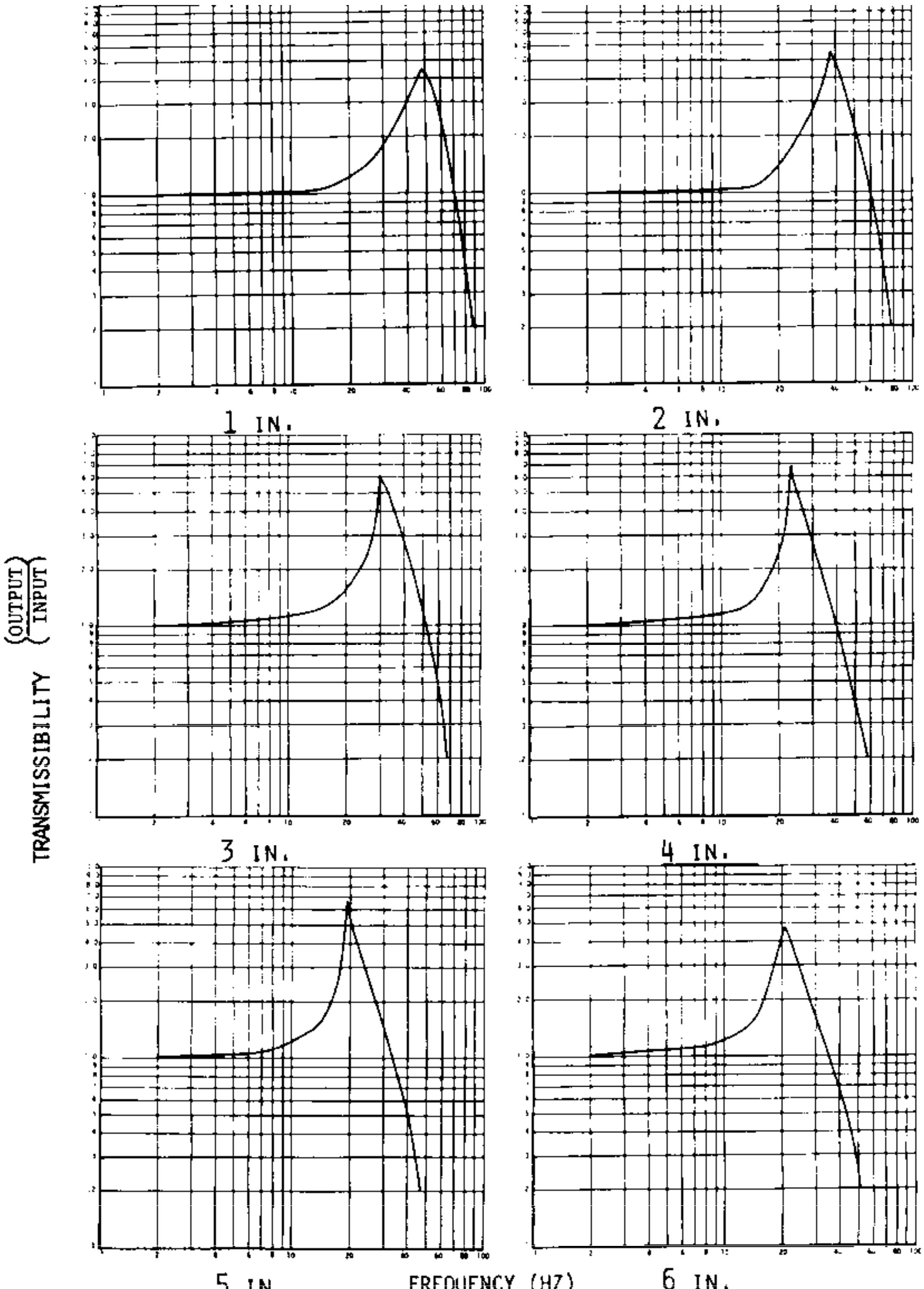
CURVE 4.3 POLYURETHANE ESTER, 1.5 LB/CU FT .09 PSI



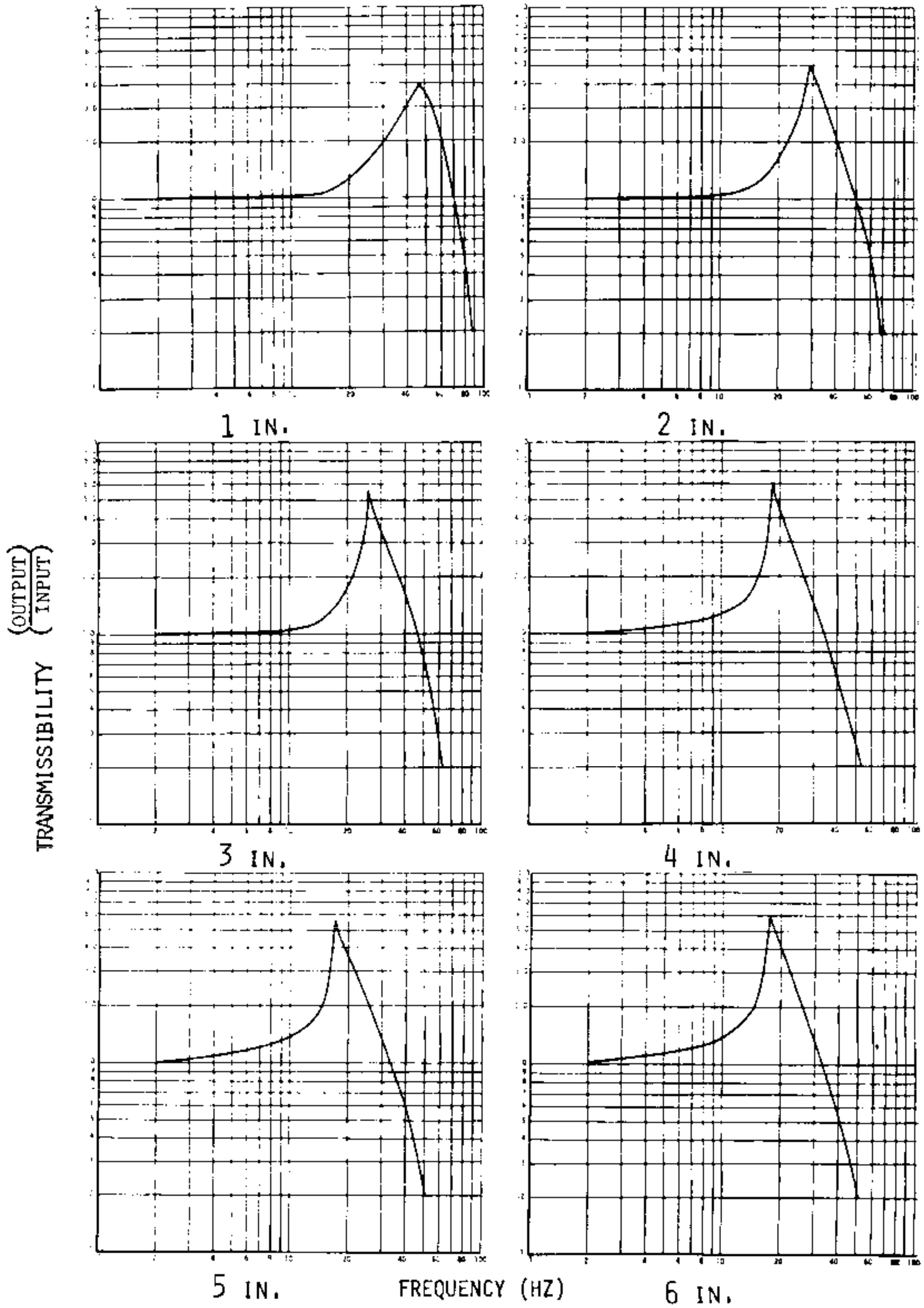
CURVE 4.4 POLYURETHANE ESTER, 1.5 LB/CU FT .12 PSI



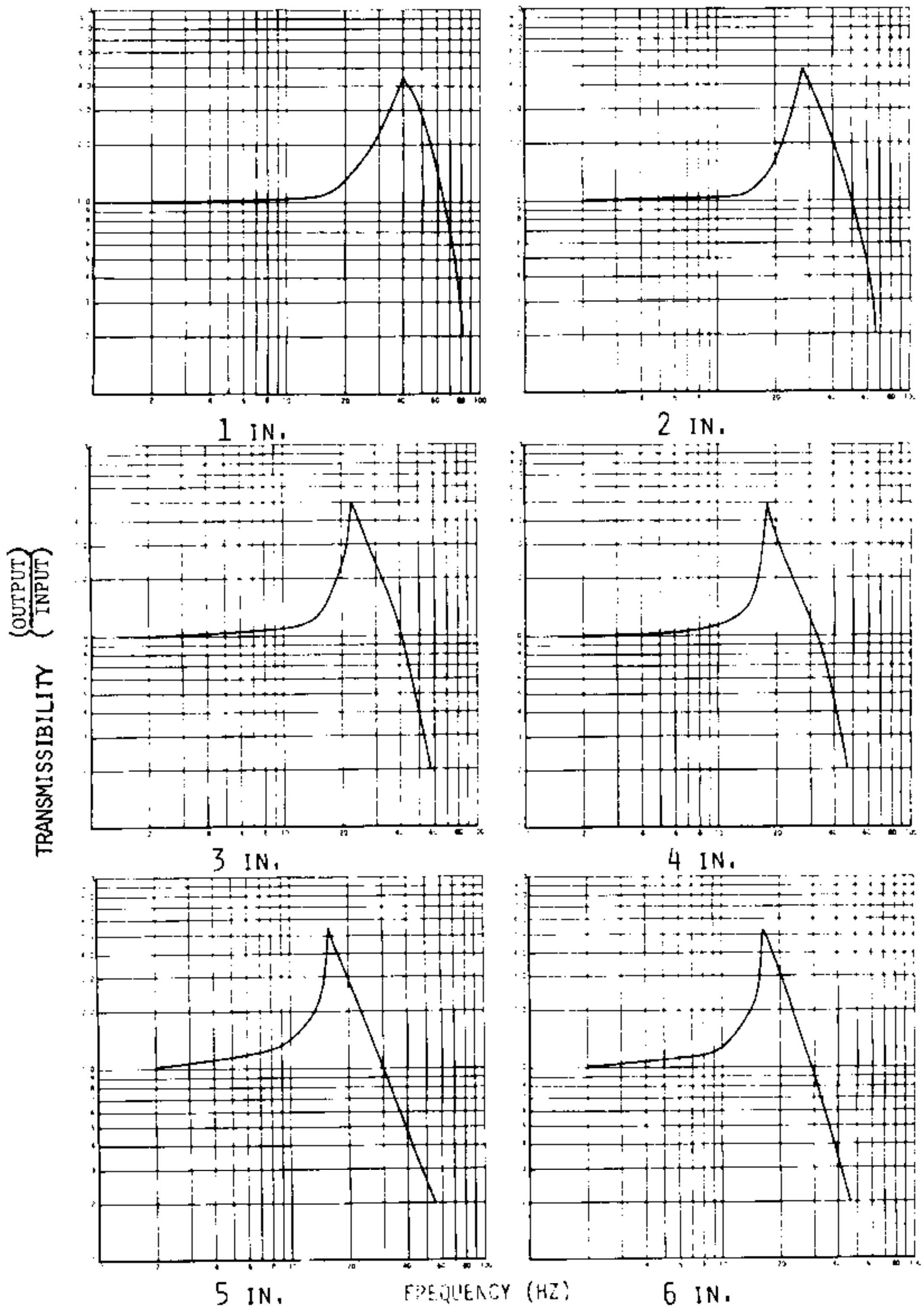
CURVE 4.5 POLYURETHANE ESTER, 1.5 LB/CU FT .15 PSI



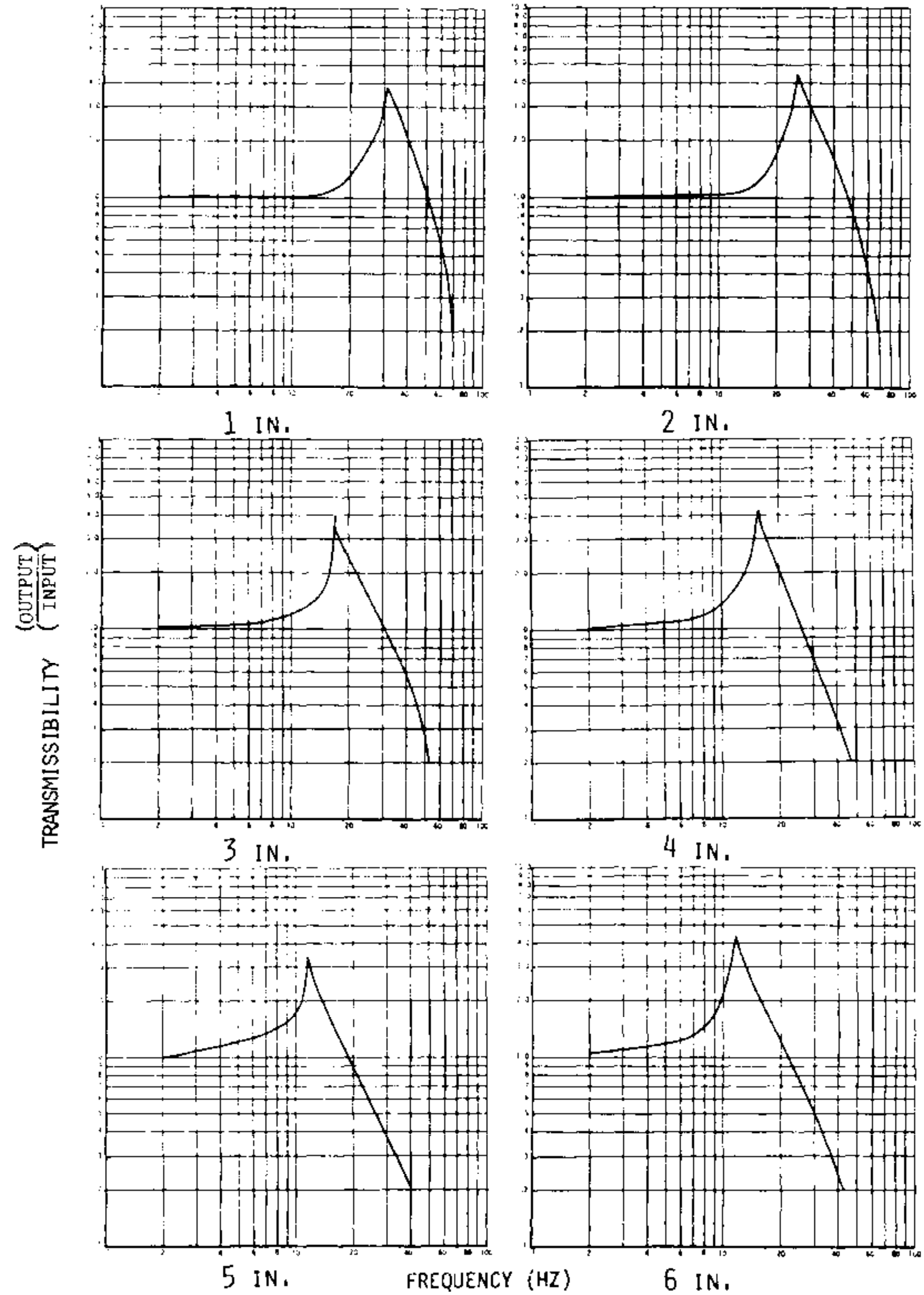
CURVE 4.6 POLYURETHANE ESTER, 1.5 LB/CU FT .20 PSI



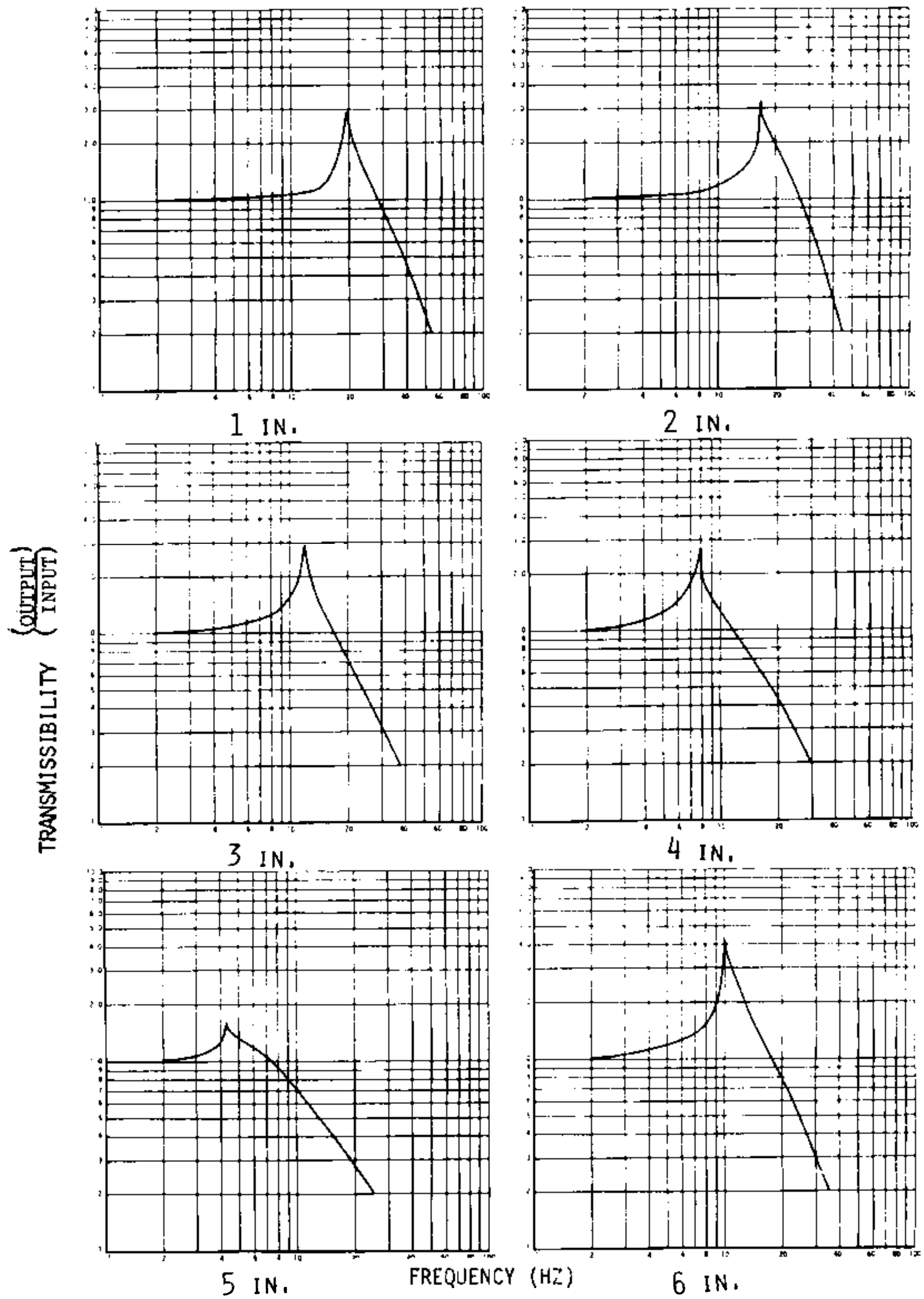
CURVE 4.7 POLYURETHANE ESTER, 1.5 LB/CU FT .24 PSI



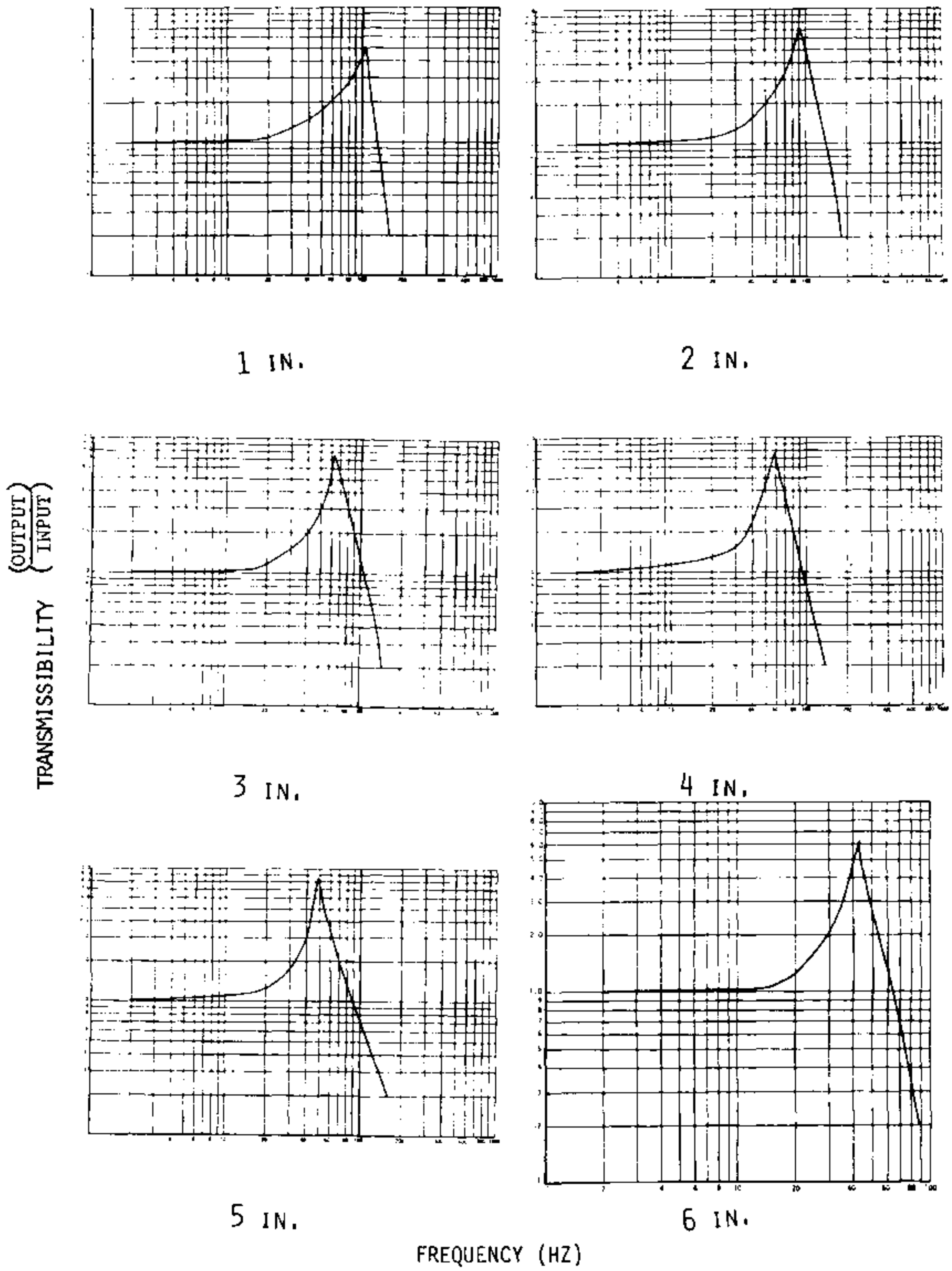
CURVE 4.8 POLYURETHANE ESTER, 1.5 LB/CU FT .27 PSI



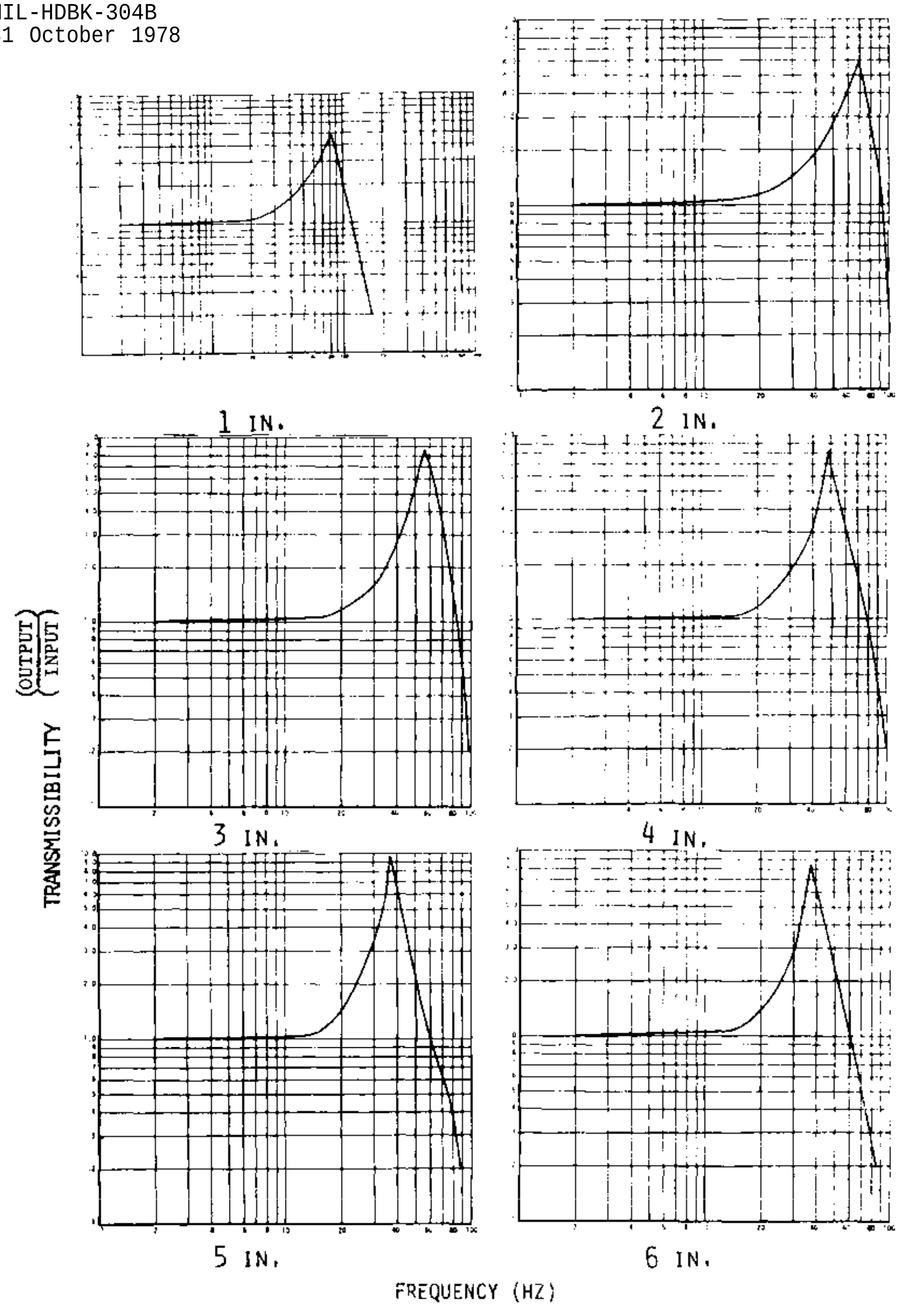
CURVE 4.9 POLYURETHANE ESTER, 1.5 LB/CU FT .34 PSI



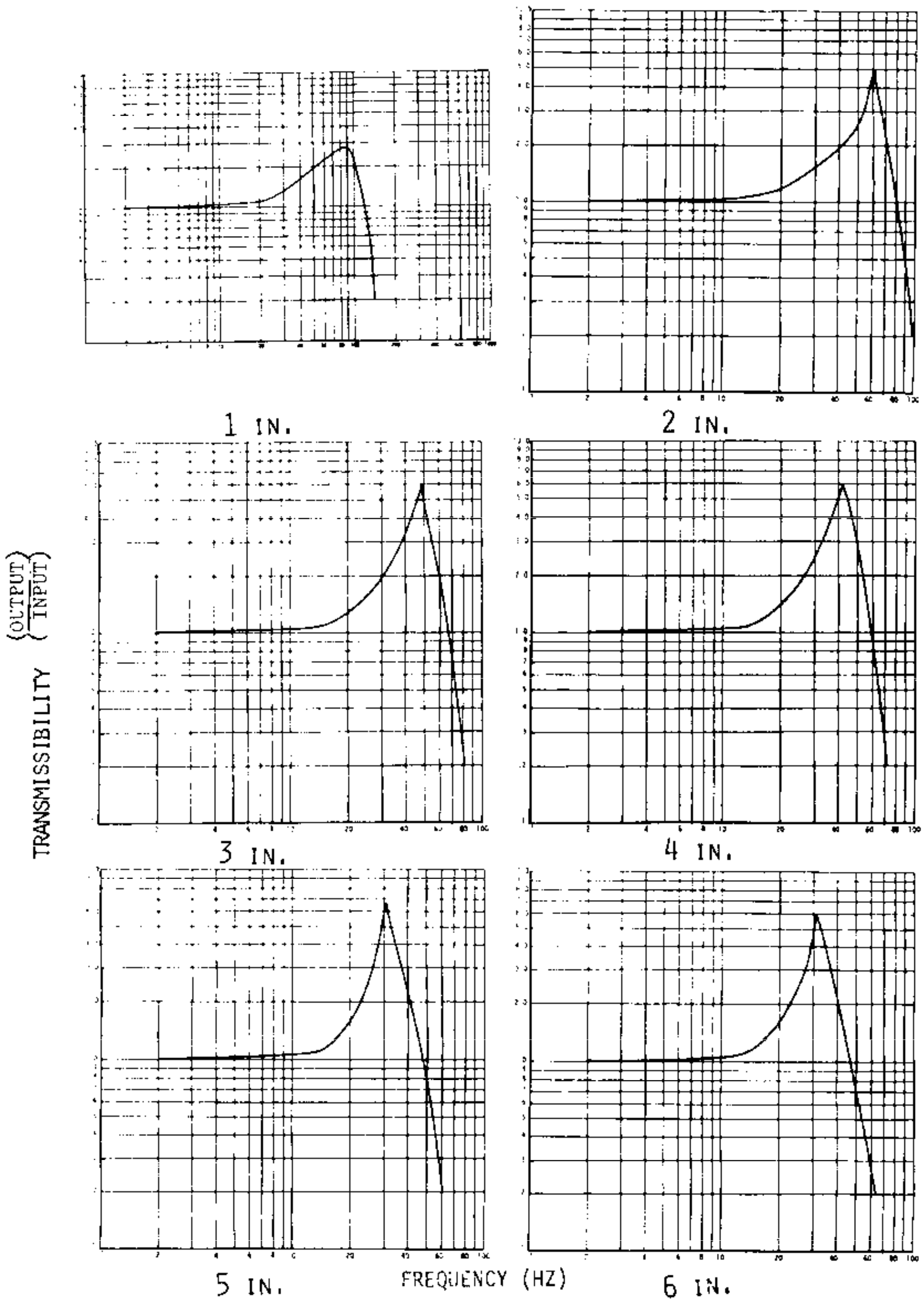
CURVE 4.10 POLYURETHANE ESTER, 1.5 LB/CU FT   .45 PSI



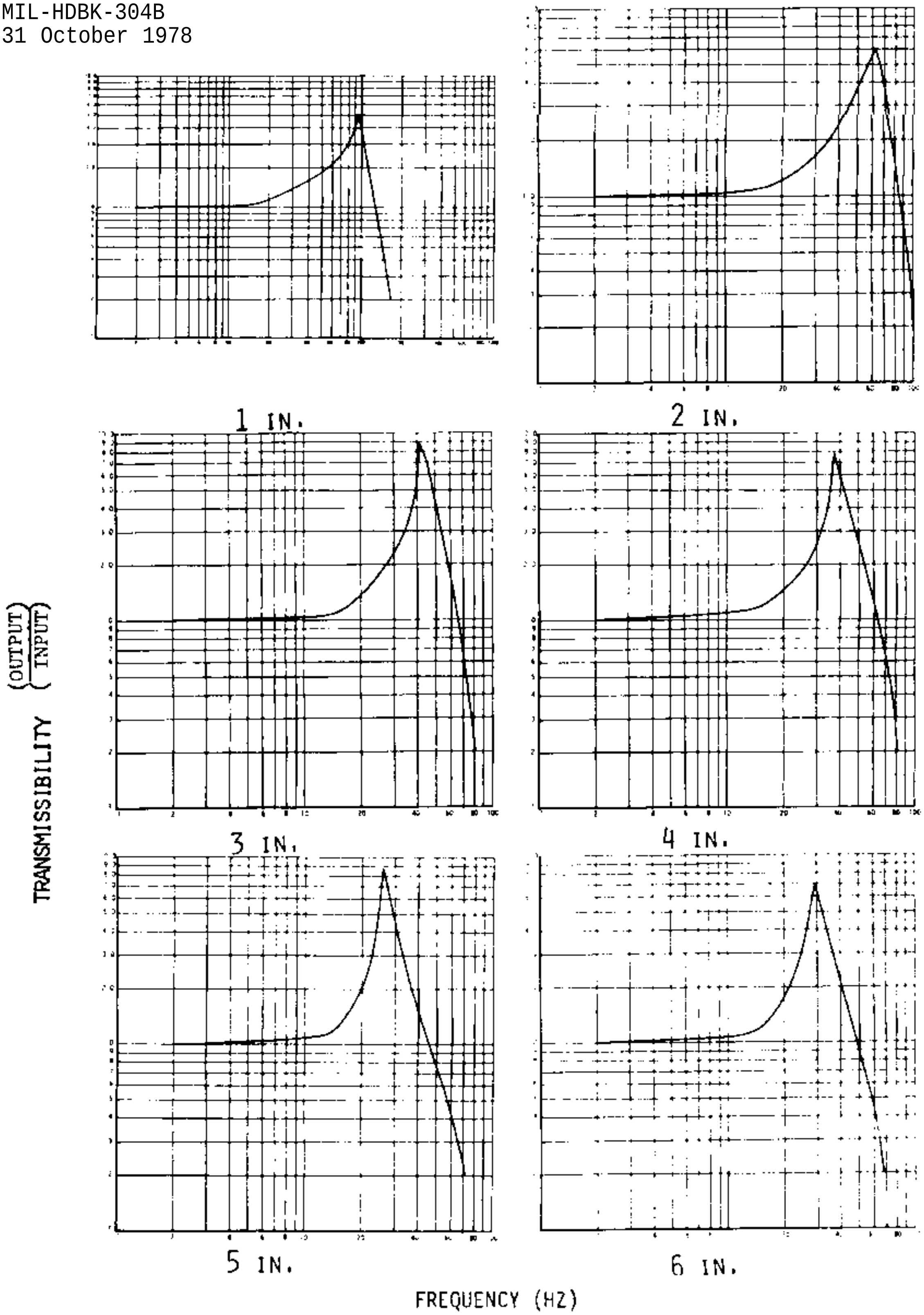
CURVE 5.1 POLYURETHANE ESTER 2.0 LB/CU FT .045 PSI



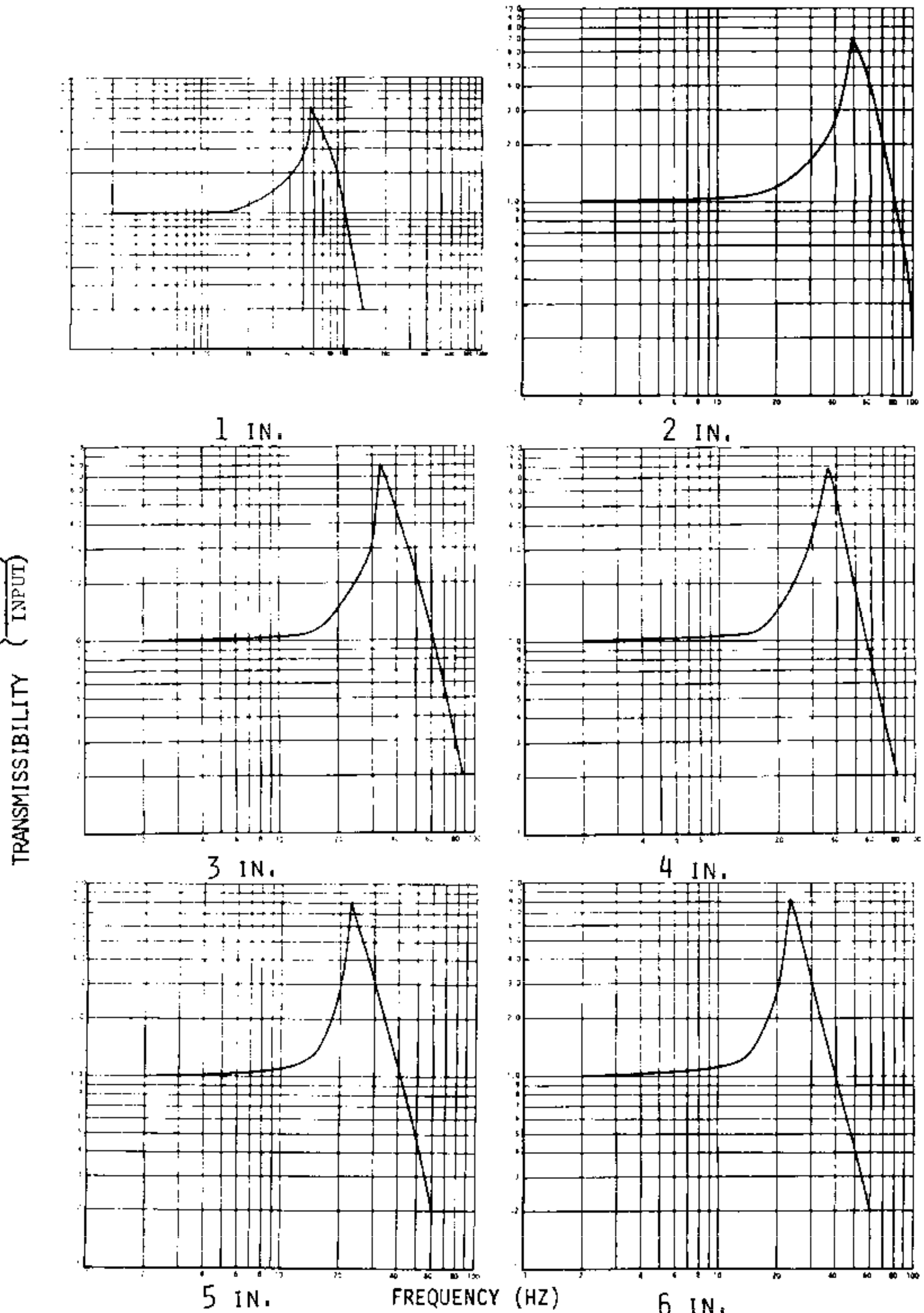
CURVE 5.2 POLYURETHANE ESTER, 2.0 LB/CU FT .07 PSI



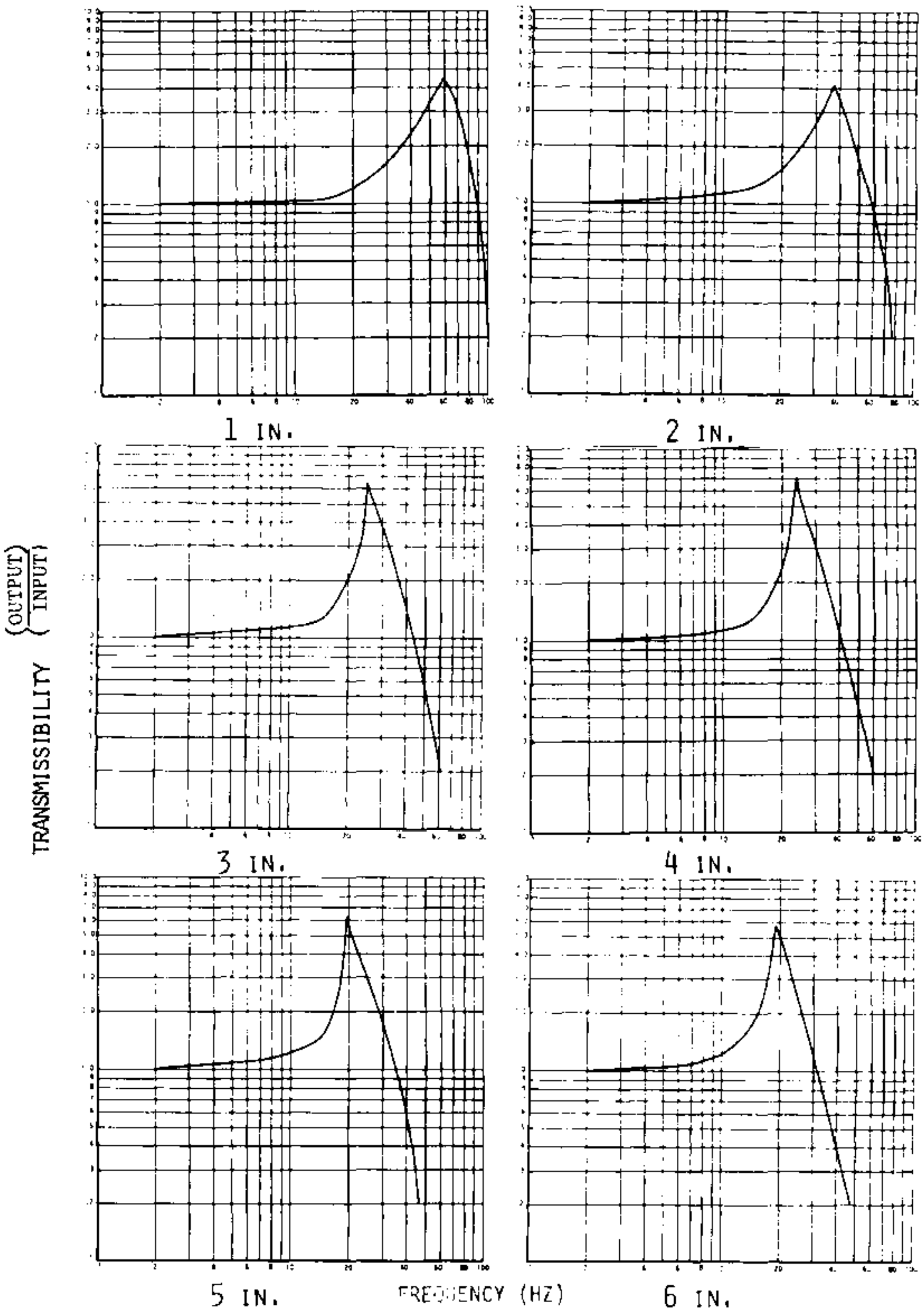
CURVE 5.3 POLYURETHANE ESTER, 2.0 LB/CU FT .09 PSI



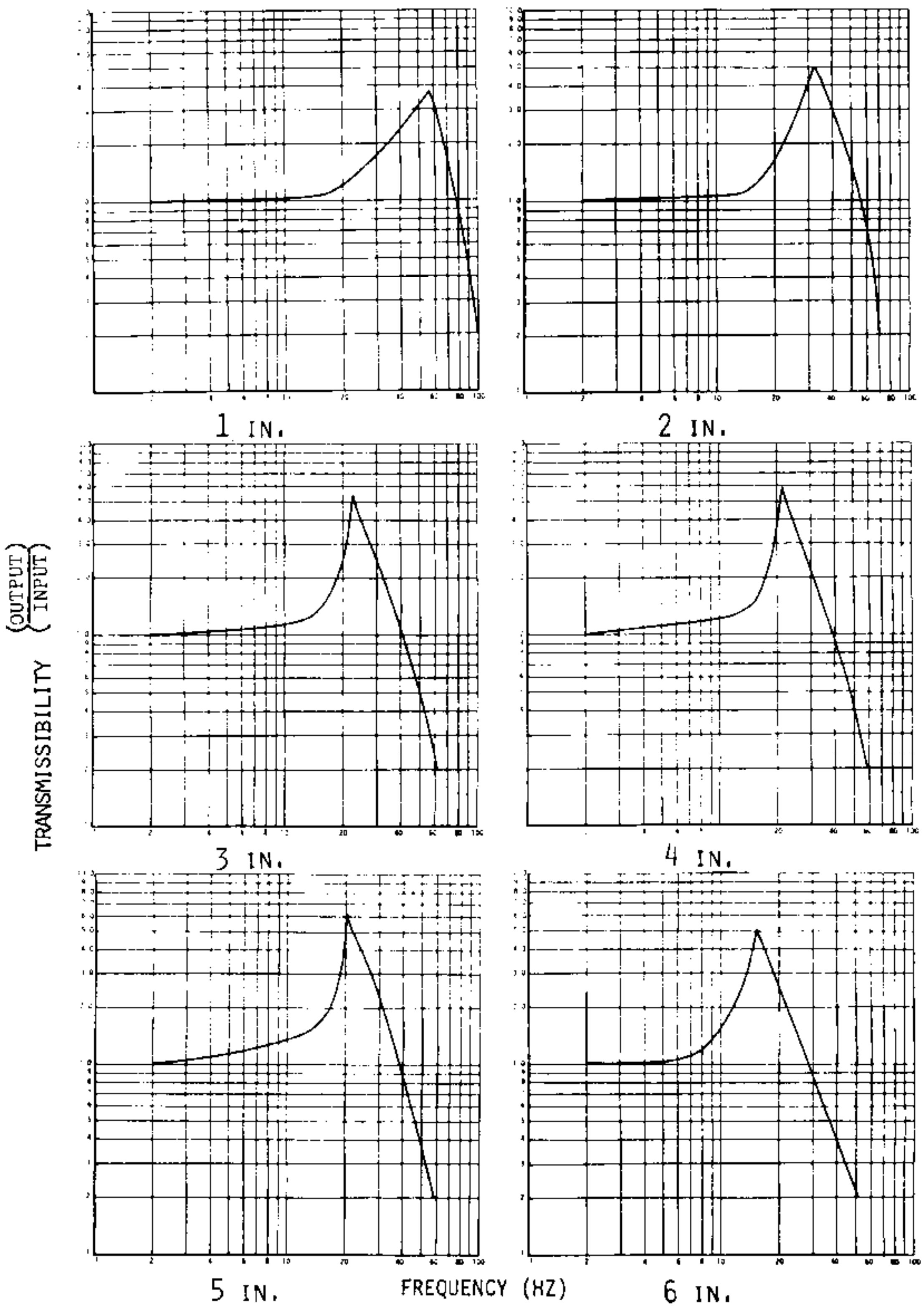
CURVE 5.4 POLYURE THANE ESTER, 2.0 LB/CU FT .12 PSI



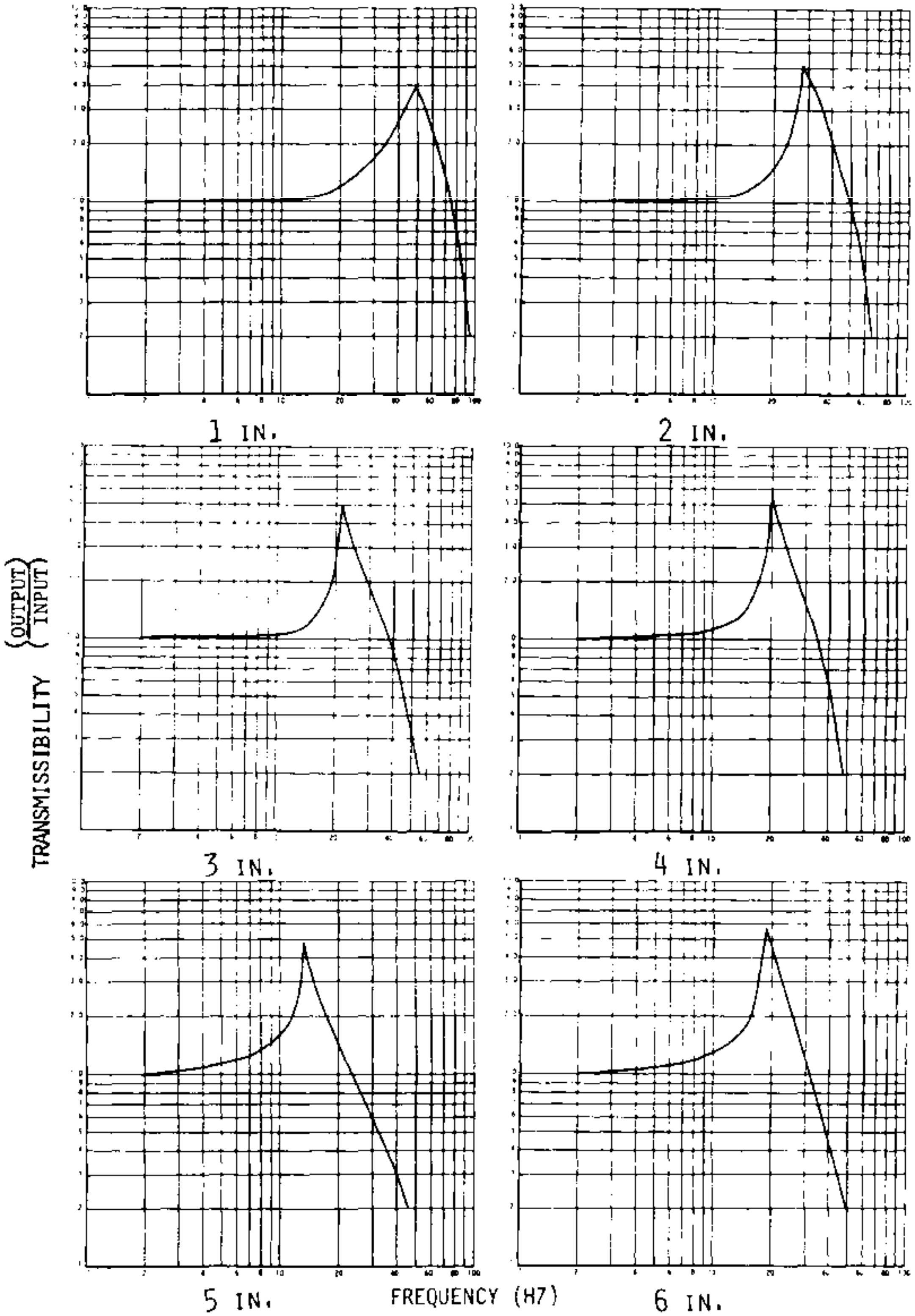
CURVE 5.5 POLYURETHANE ESTER, 2.0 LB/CU FT .15 PSI



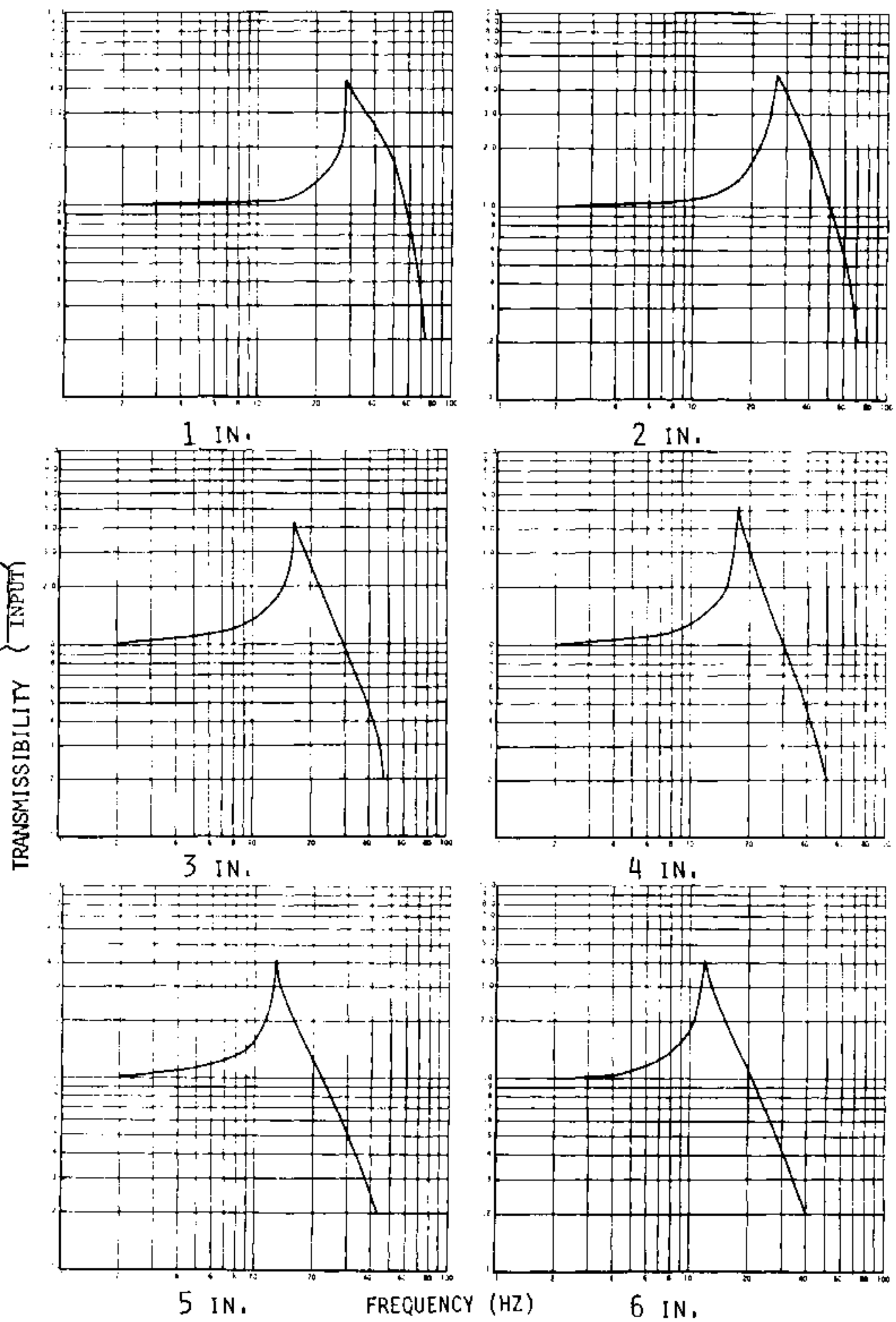
CURVE 5.6 POLYURETHANE ESTER, 2.0 LB/CU FT .20 PSI



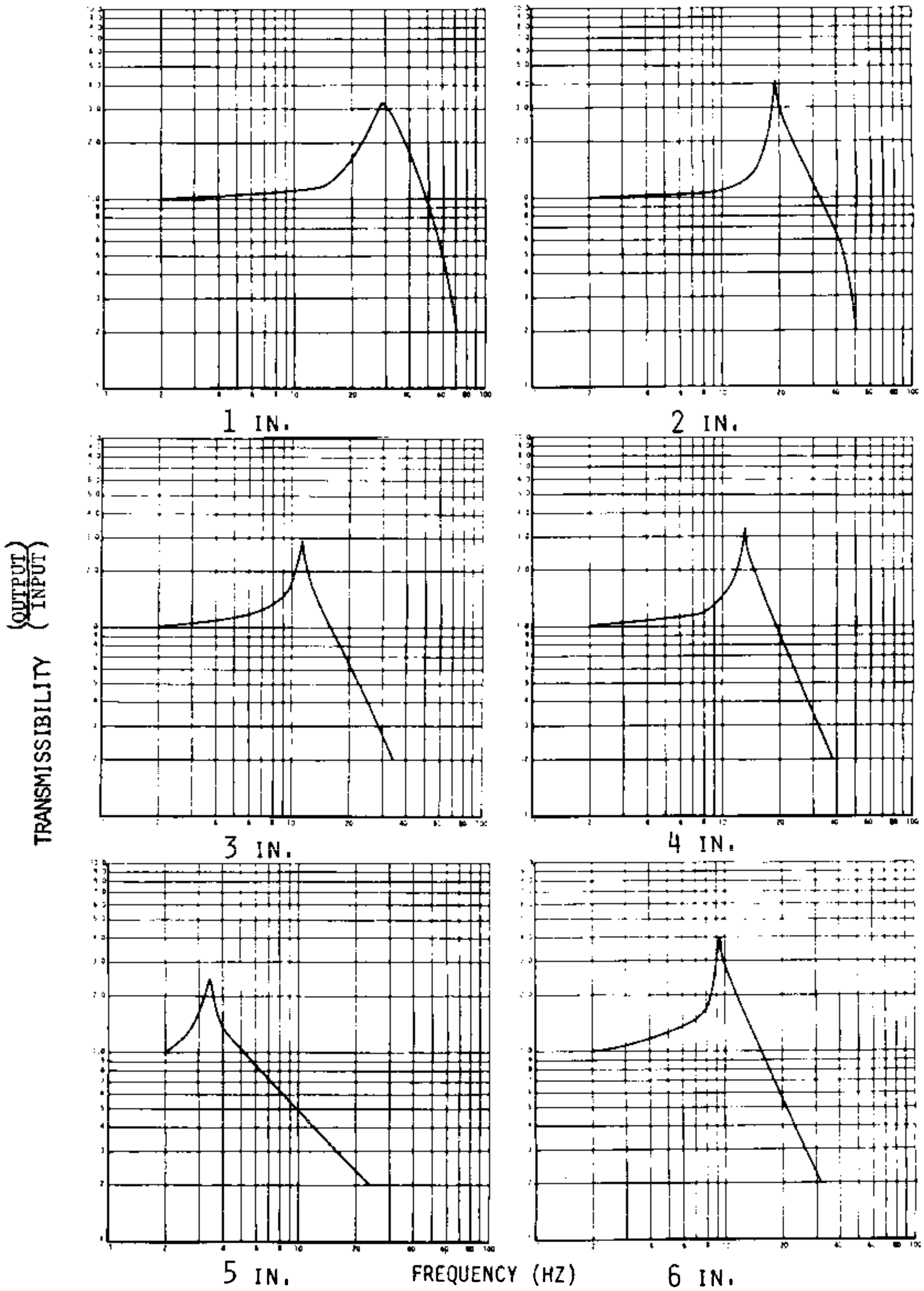
CURVE 5.7 POLYURETHANE ESTER, 2.0 LB/CU FT .24 PSI



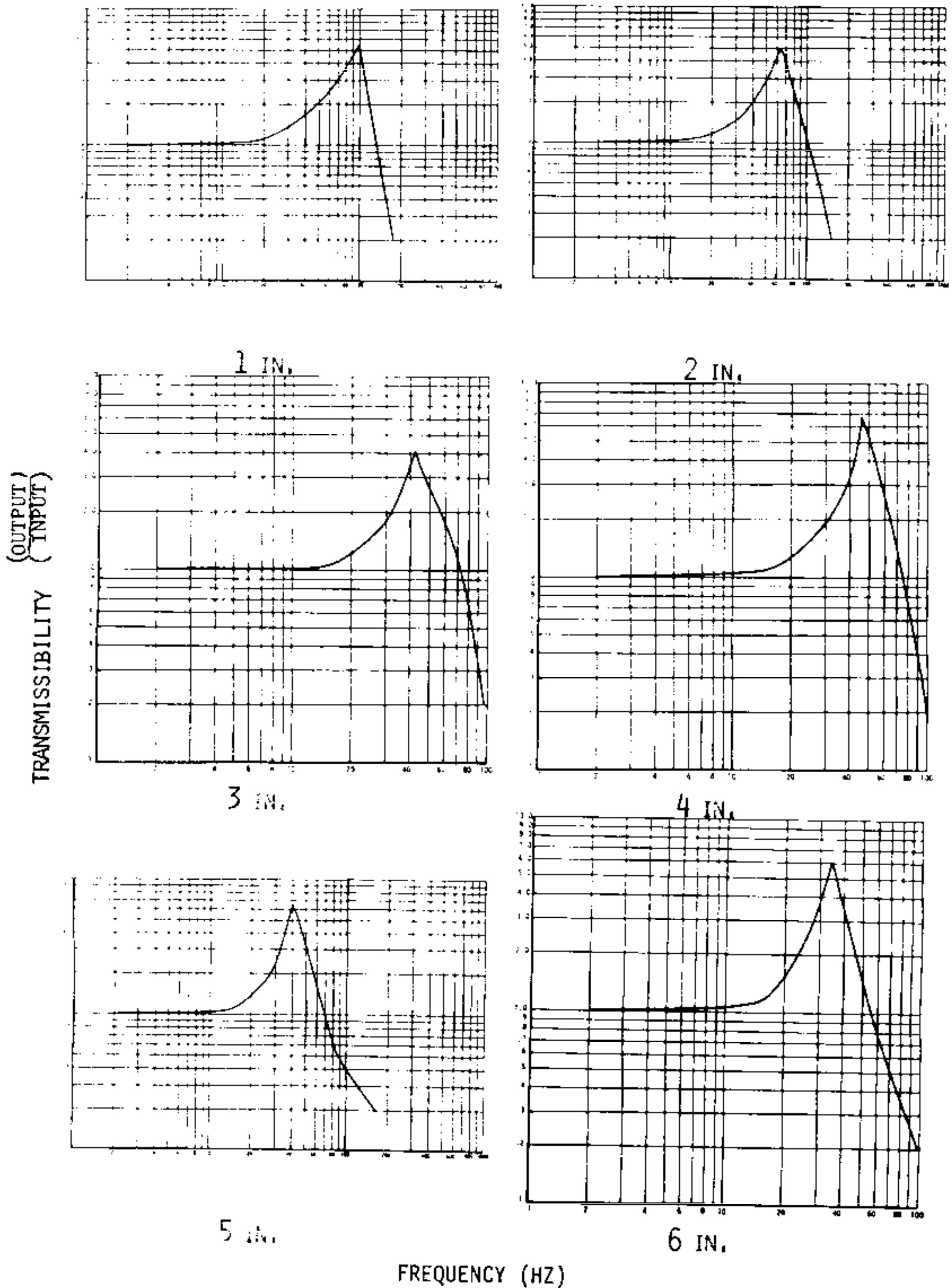
CURVE 5.8 POLYURETHANE ESTER, 2.0 LB/CU FT .27 PSI



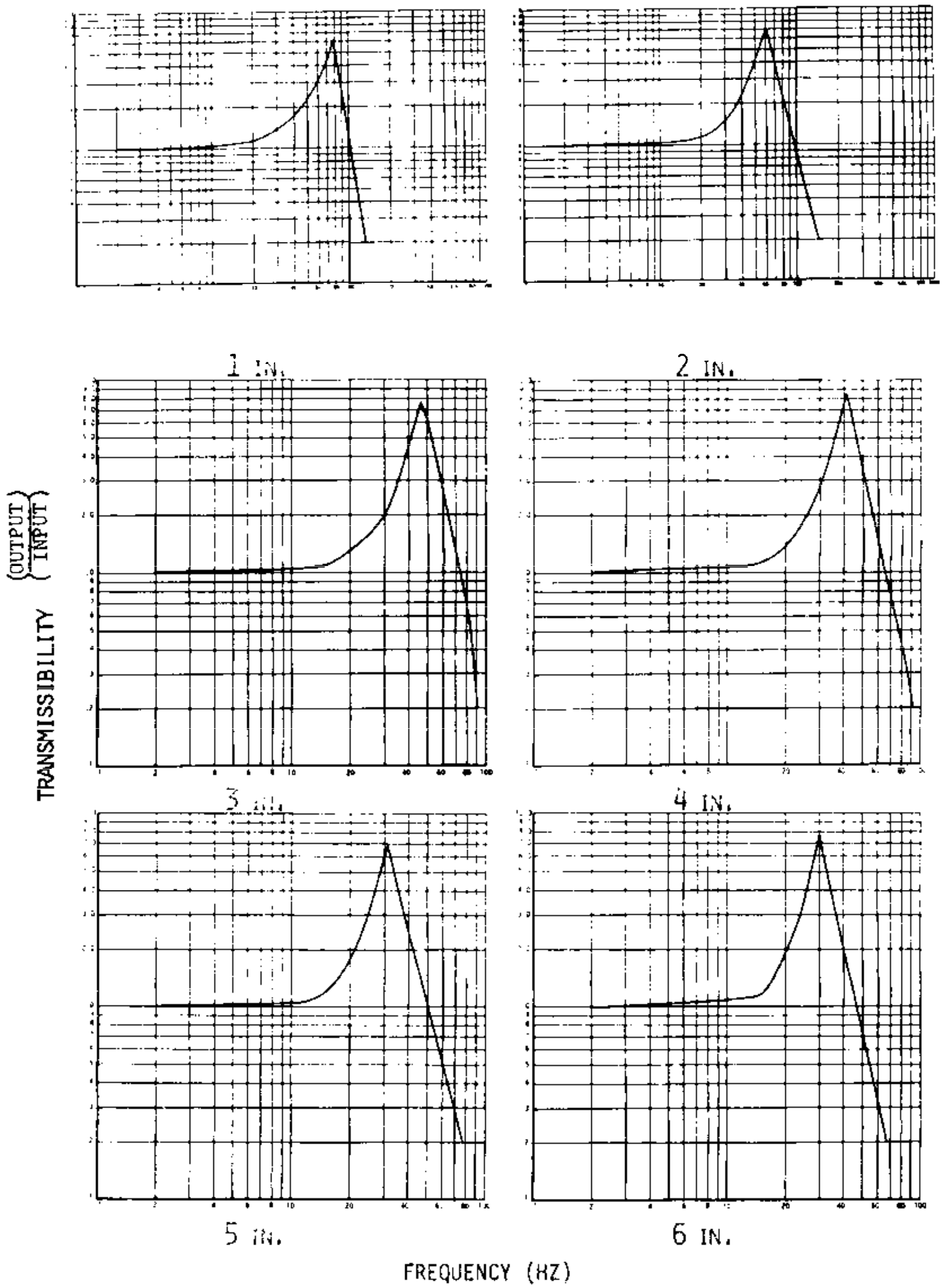
CURVE 5.9 POLYURETHANE ESTER, 2.0 LB/CU FT .34 PSI



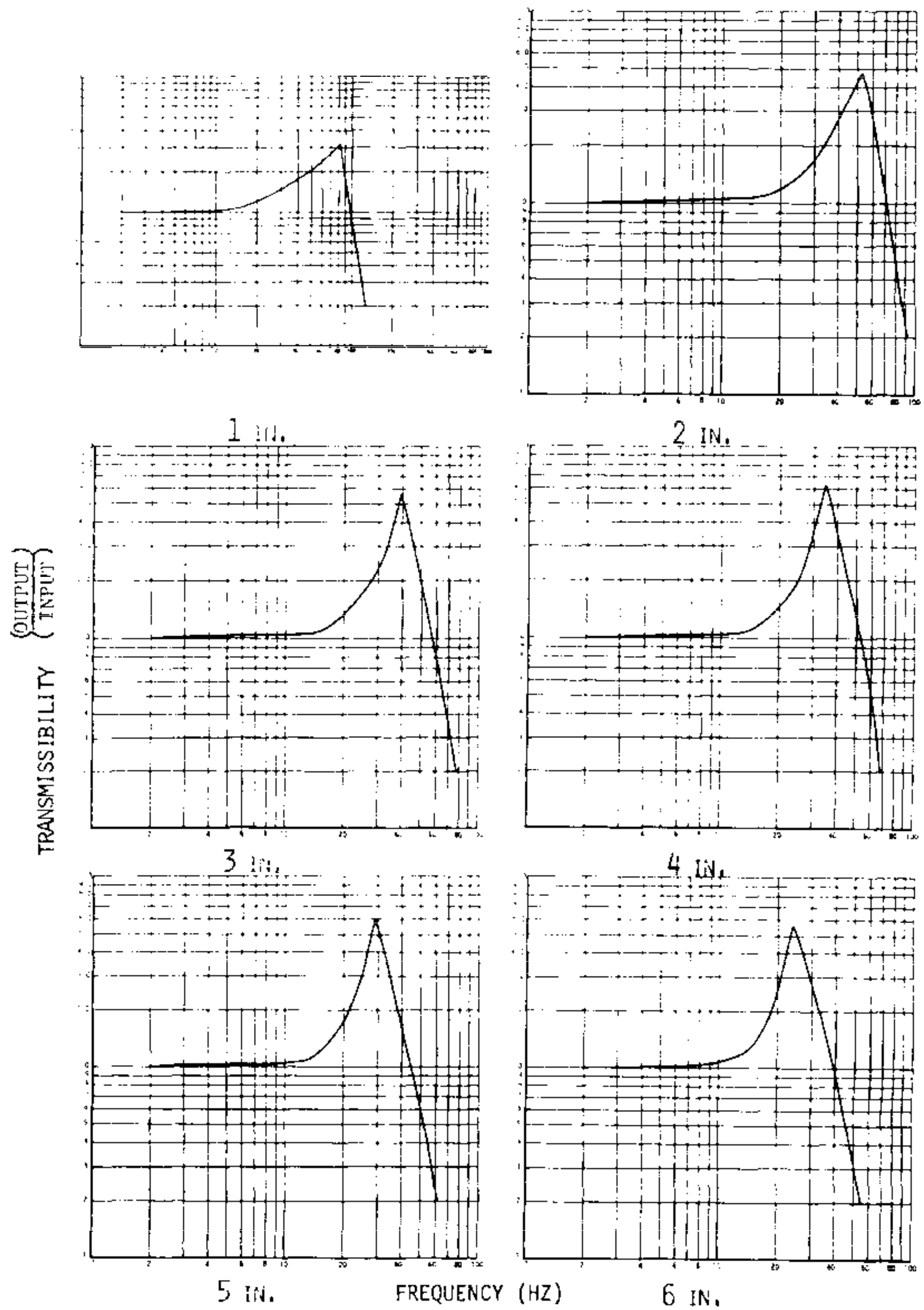
CURVE 5.10 POLYURETHANE ESTER 2.0 LB/CU FT .45 PSI



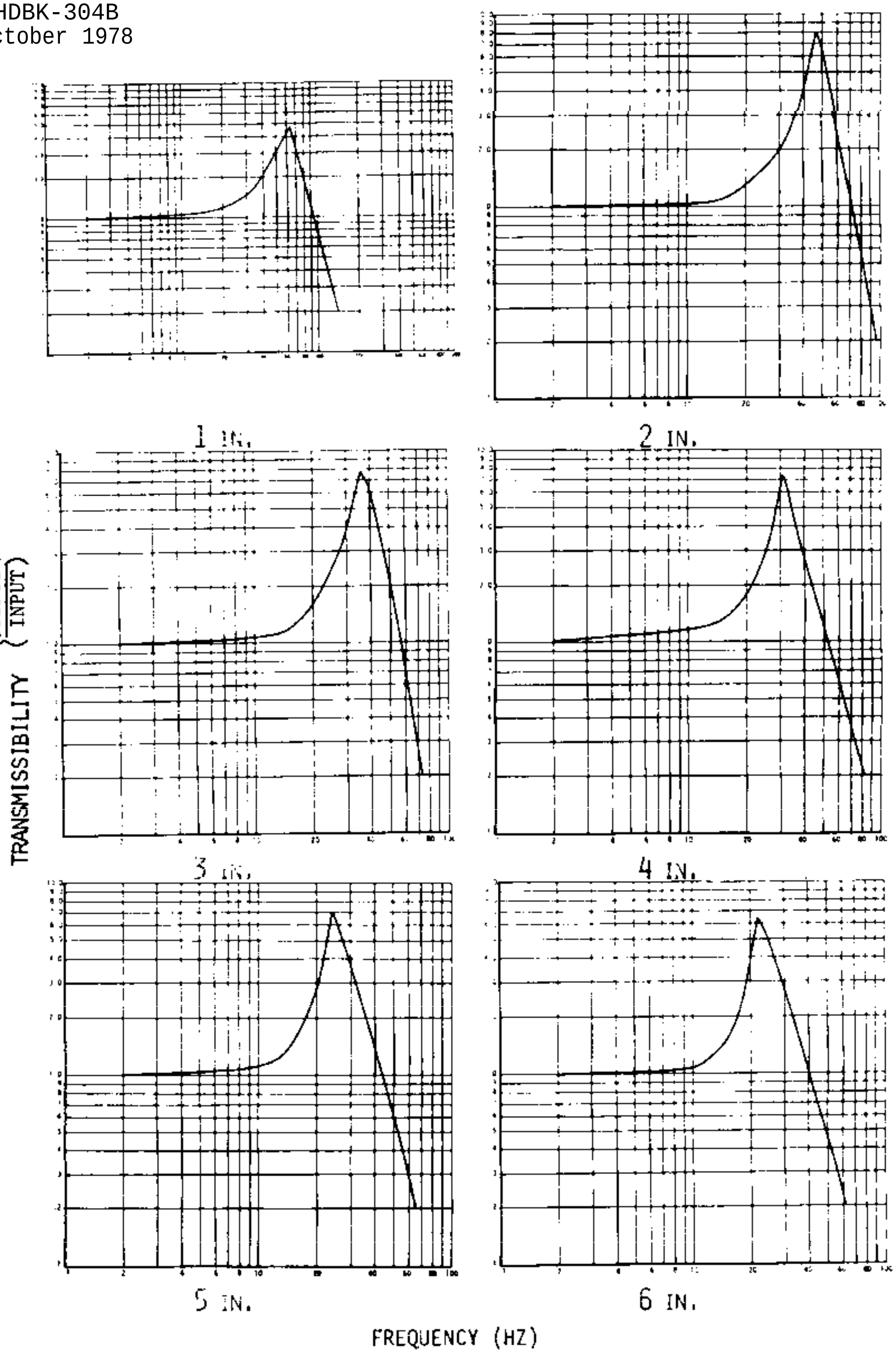
CURVE 6.1 POLYURETHANE ESTER, 4.0 LB/CU FT .045 PSI



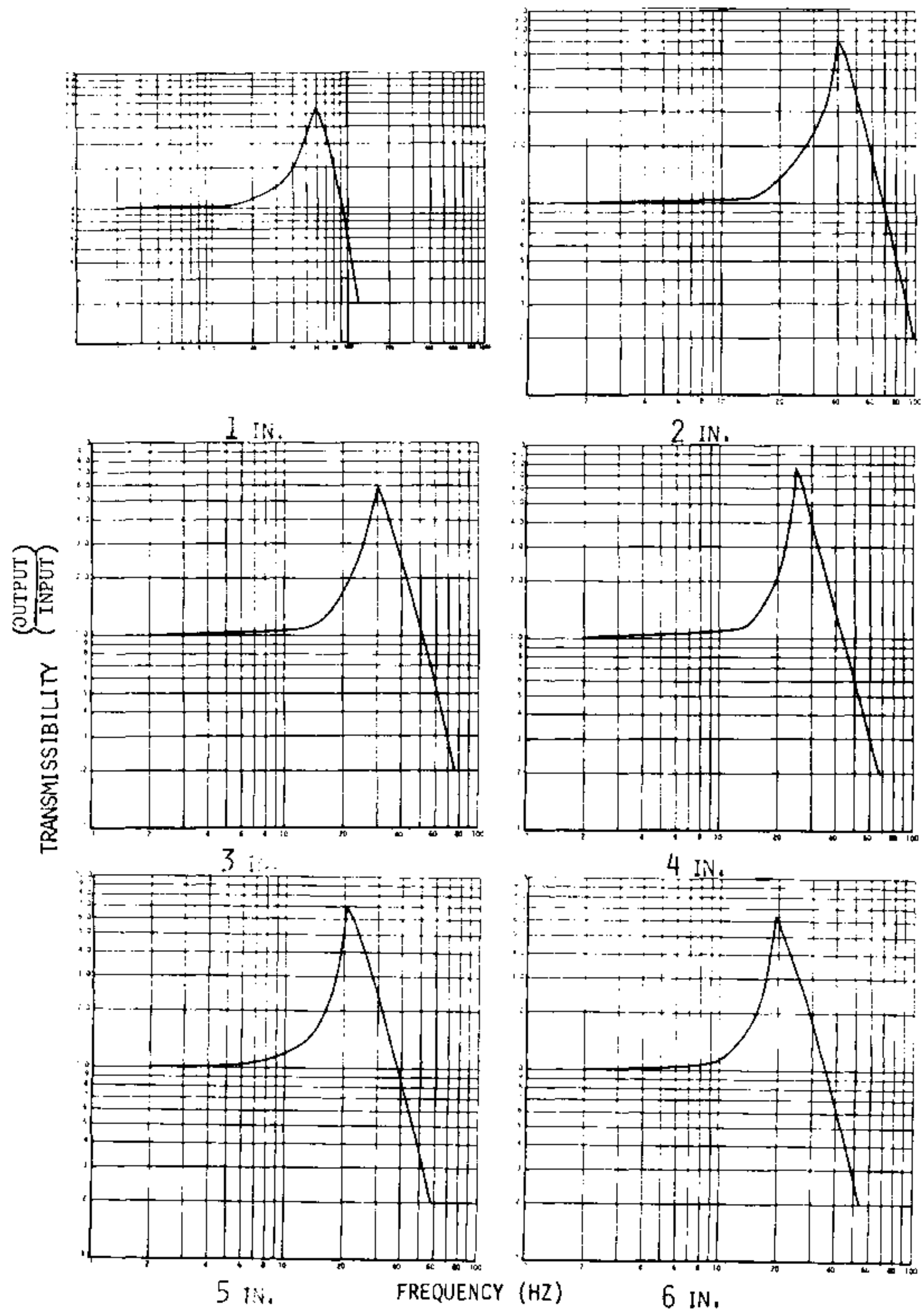
CURVE 6.2 POLYURETHANE ESTER, 4.0 LB/CU FT .07 PSI



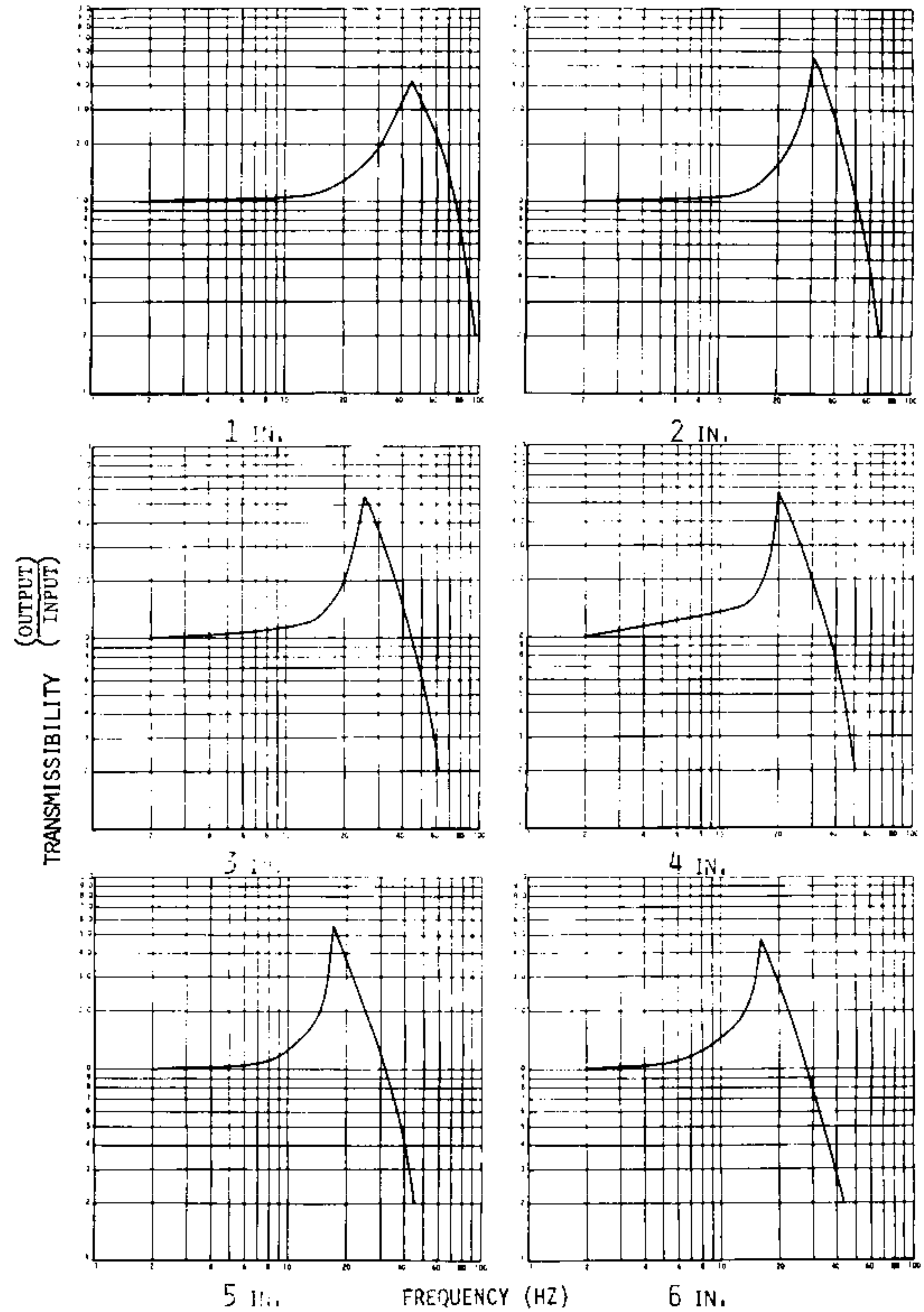
CURVE 6.3 POLYURETHANE ESTER, 4.0 LB/CU FT .09 PSI



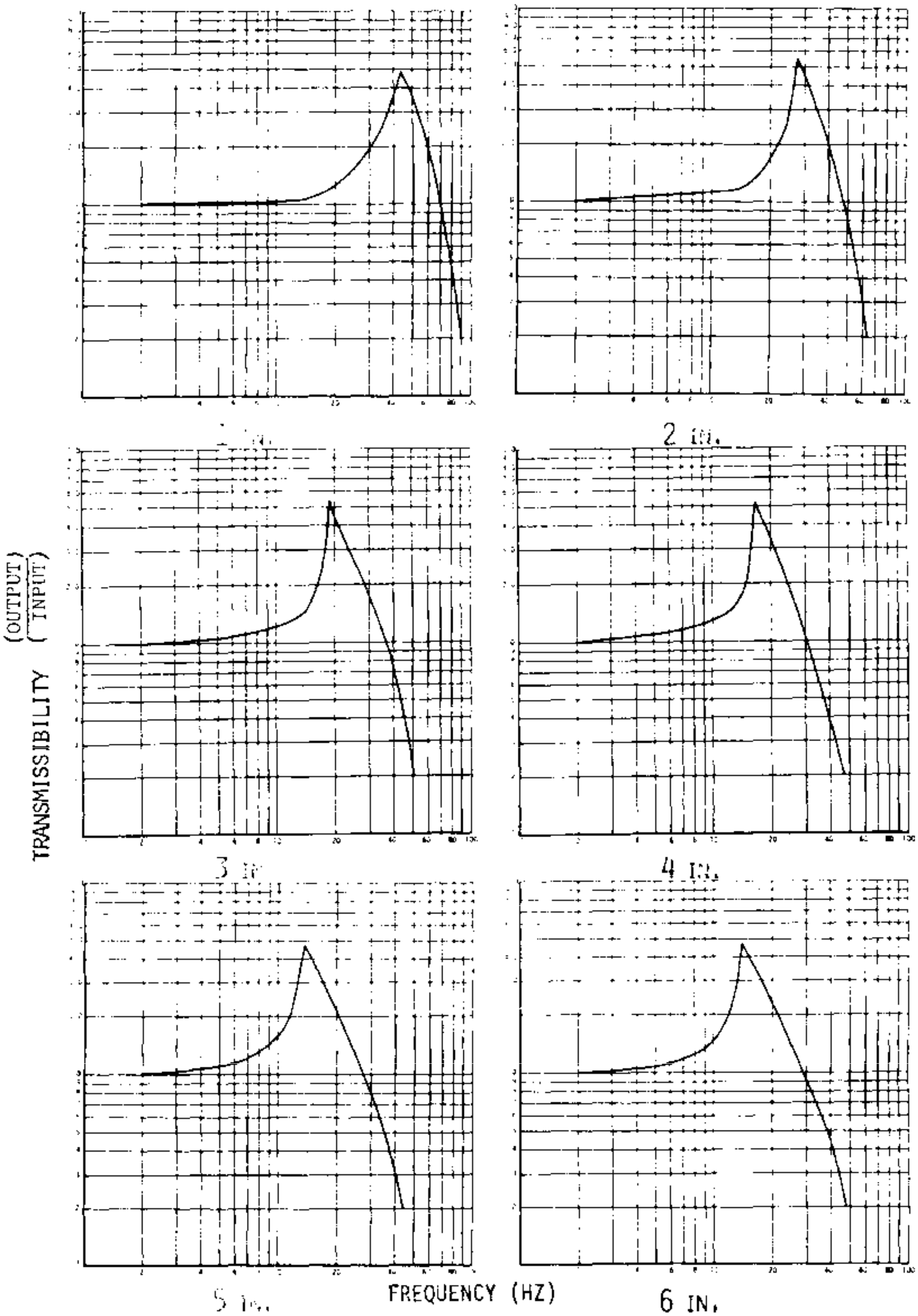
CURVE 6.4 POLYURETHANE ESTER, 4.0 LB/CU FT .12 PSI



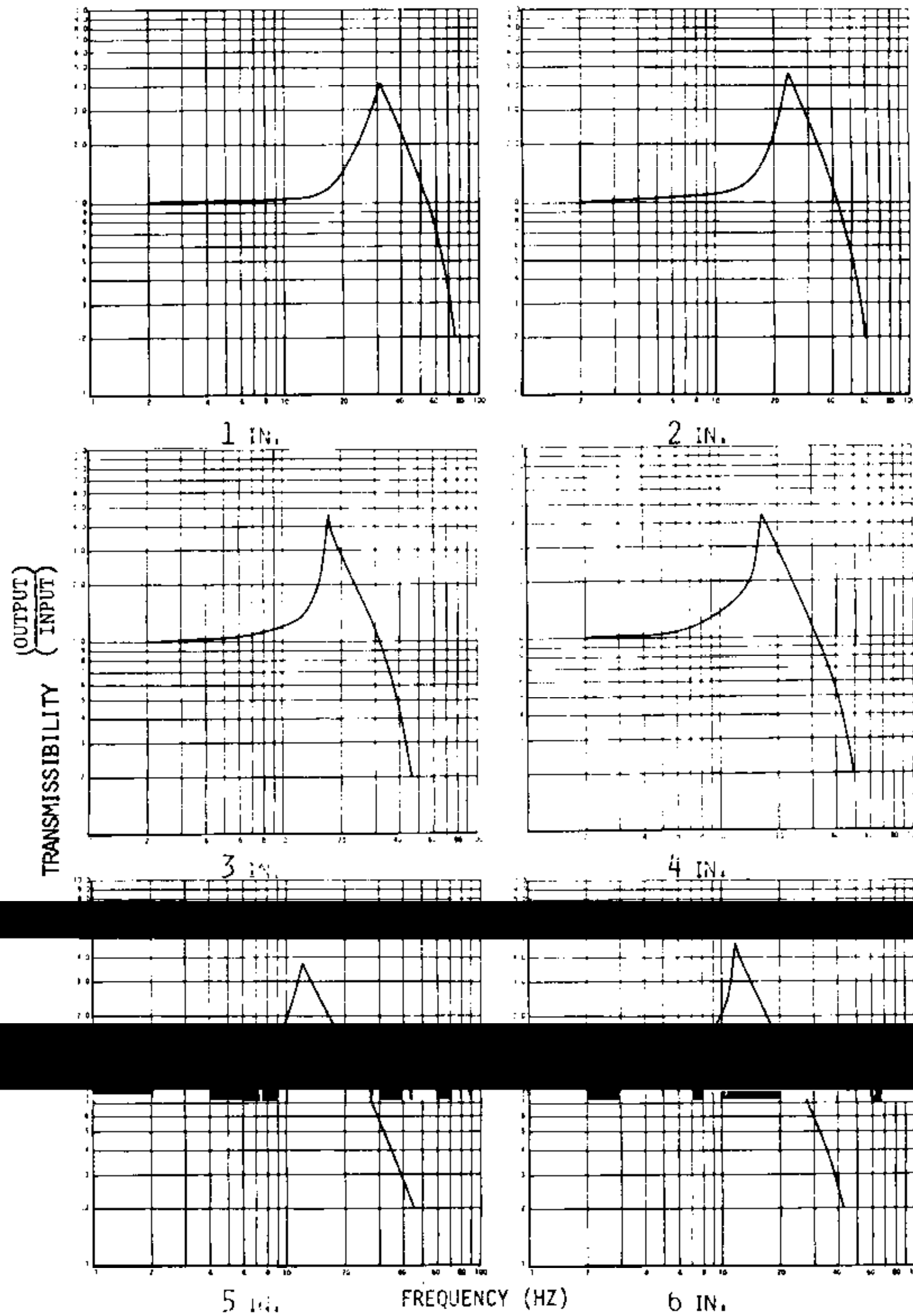
CURVE 6.5 POLYURETHANE ESTER, 4.0 LB/CU FT .15 PSI



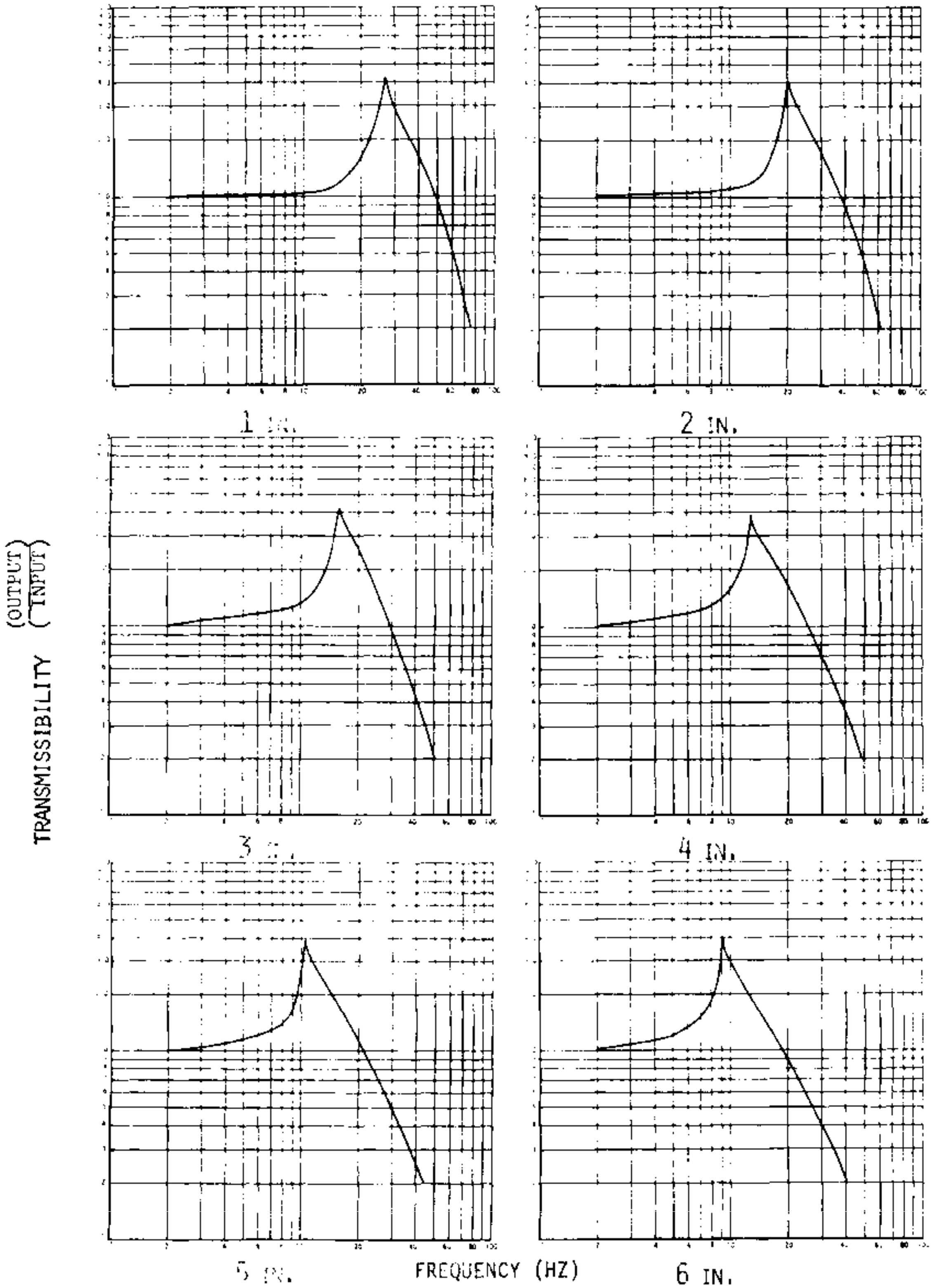
CURVE 6.6 POLYURETHANE ESTER, 4.0 LB/CU FT .20 PSI



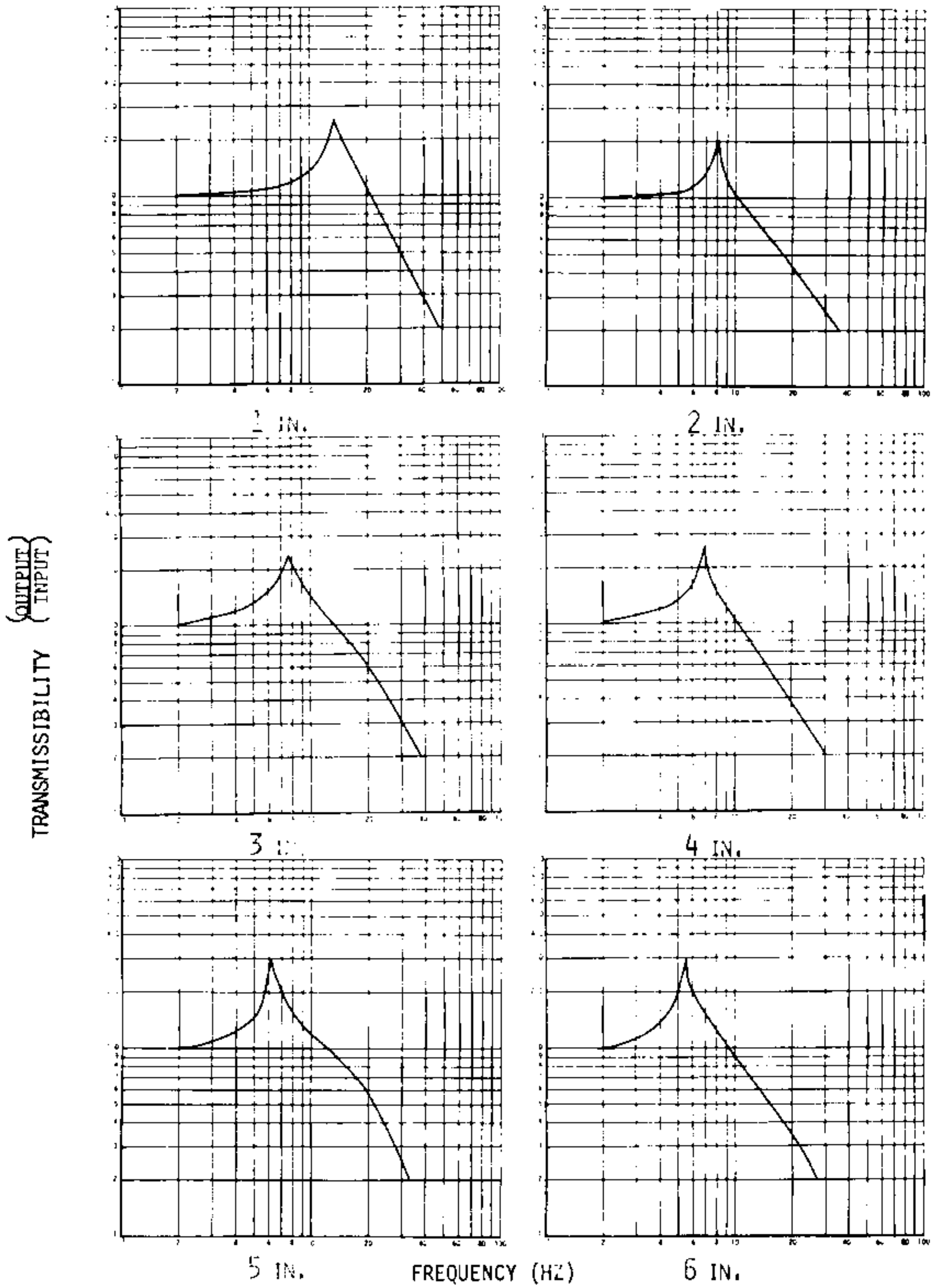
CURVE 6.7 POLYURETHANE ESTER, 4.0 LB/CU FT .24 PSI



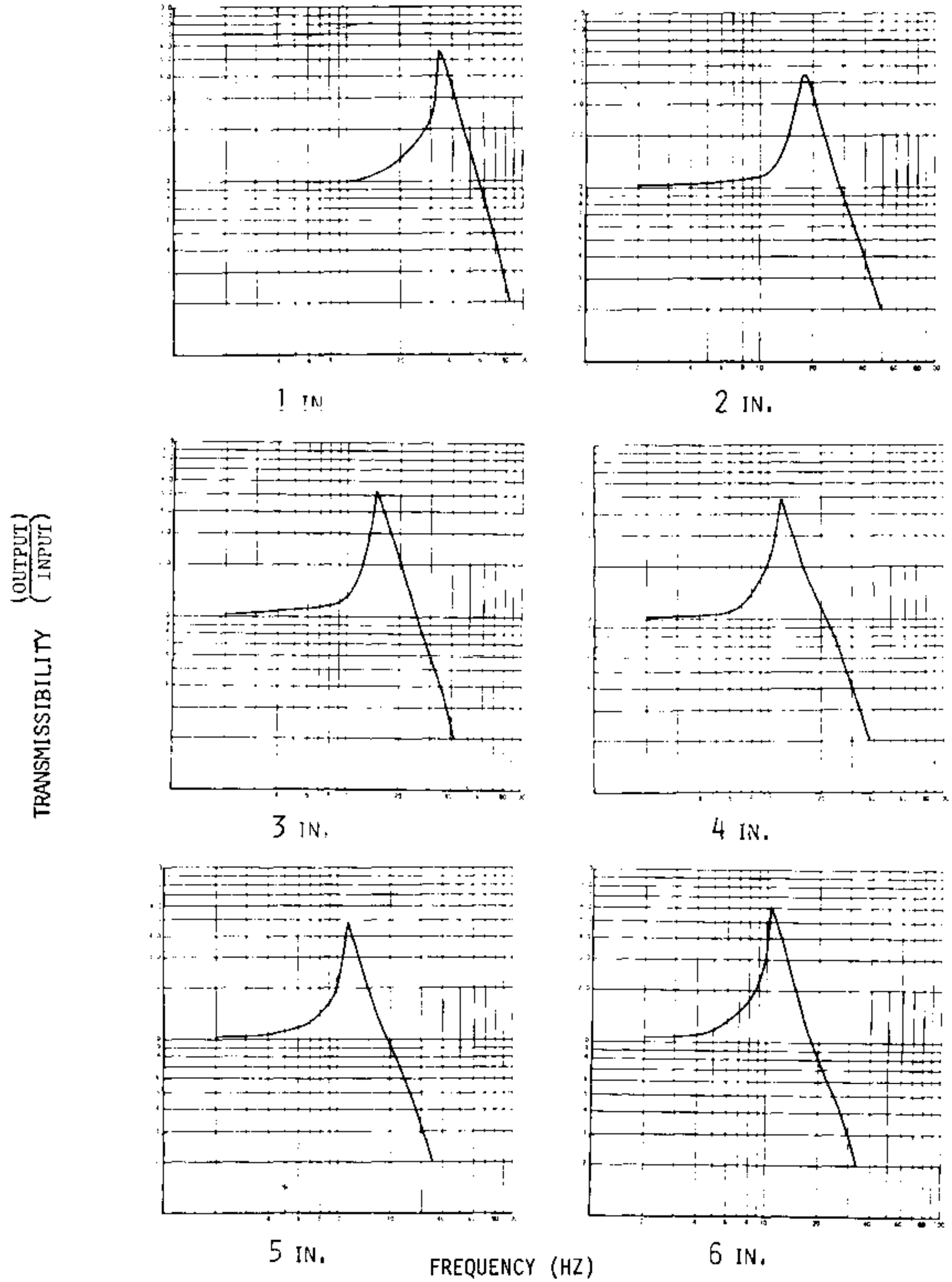
CURVE 6.8 POLYURETHANE ESTER, 4.0 LB/CU FT .27 PSI



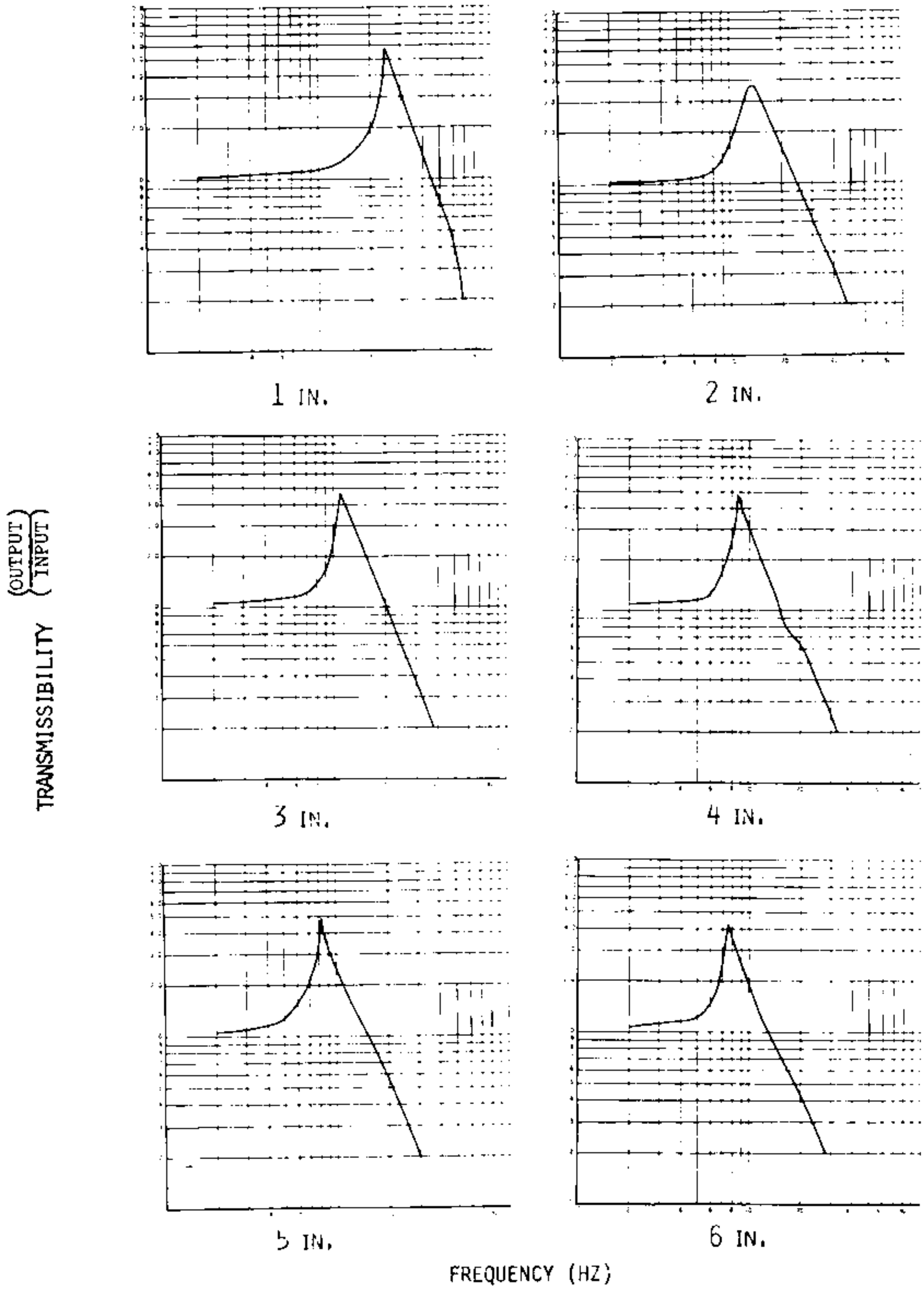
CURVE 6.9 POLYURETHANE ESTER, 4.0 LB/CU FT .34 PSI



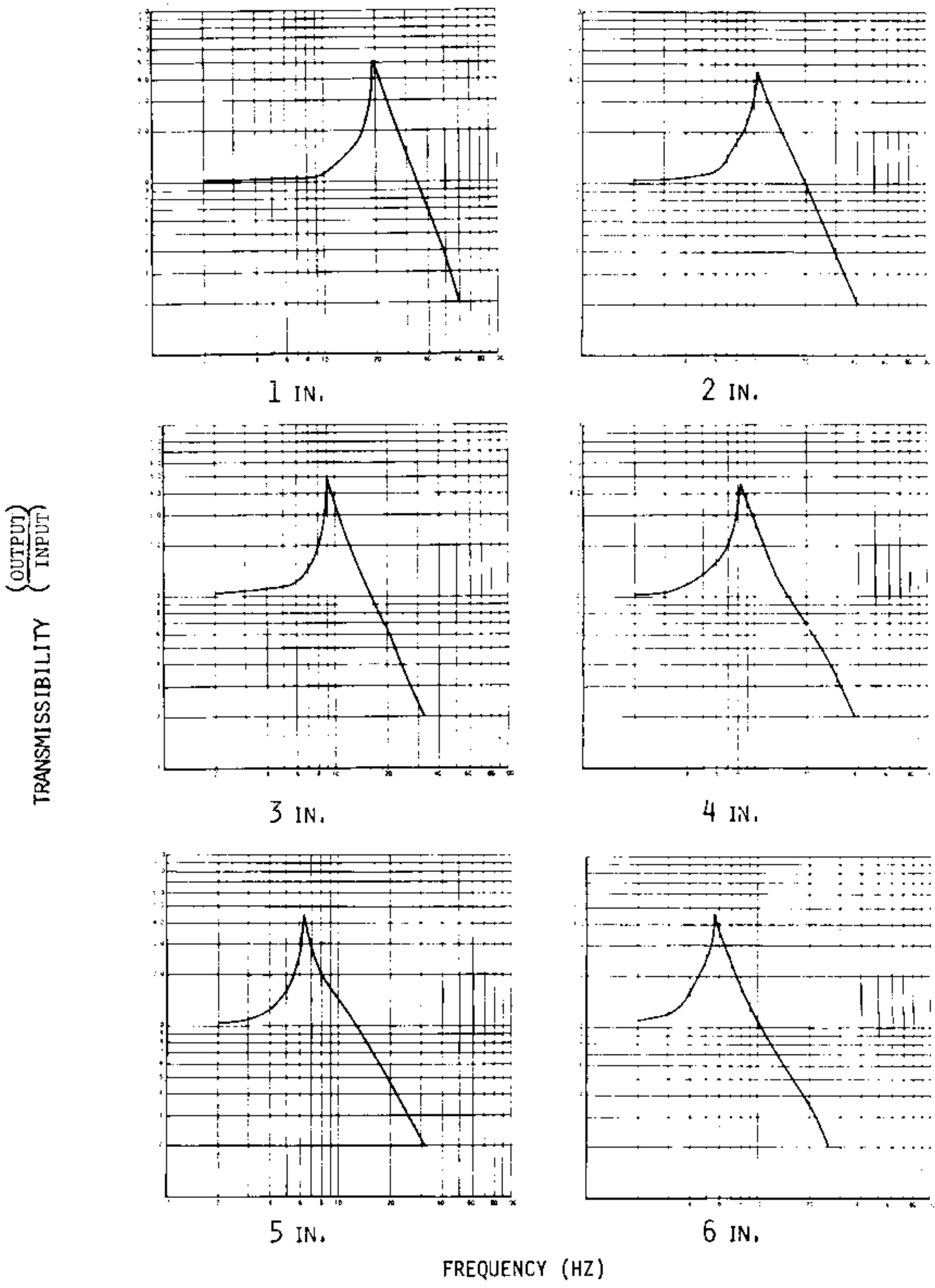
CURVE 6.10 POLYURETHANE ESTER, 4.0 LB/CU FT .45 PSI



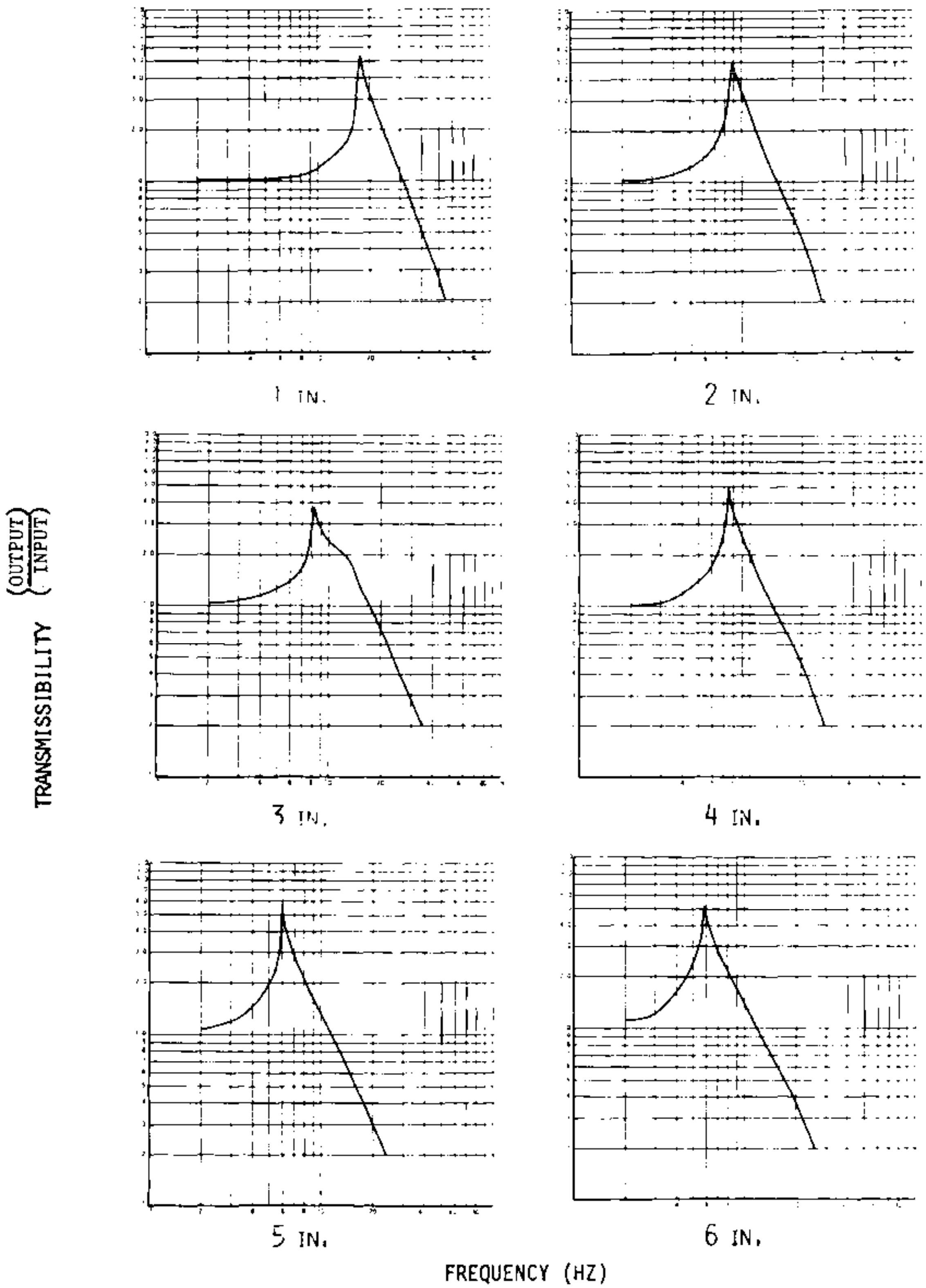
CURVE 7.1 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .045 PSI



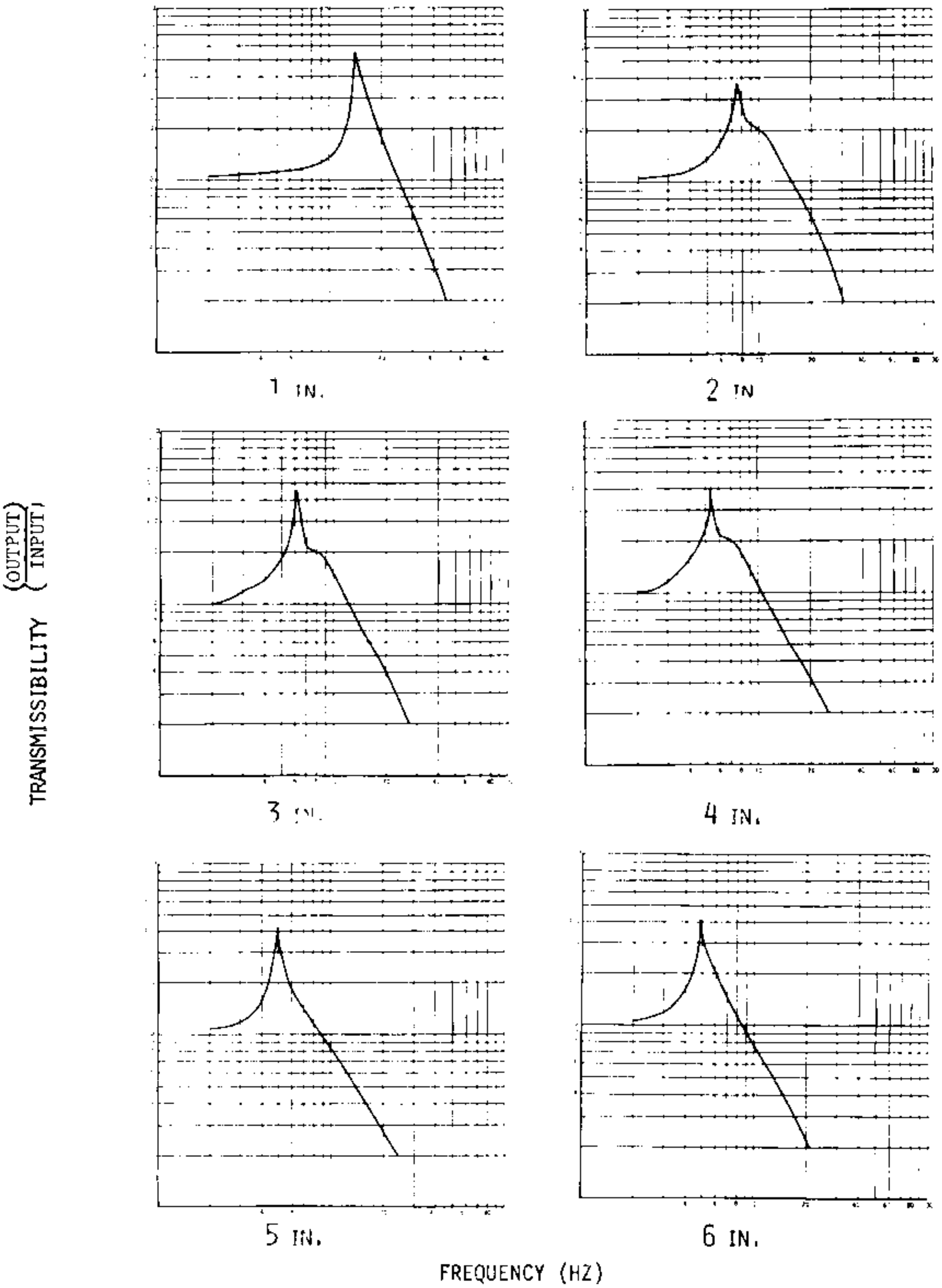
CURVE 7.2 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .076 PSI



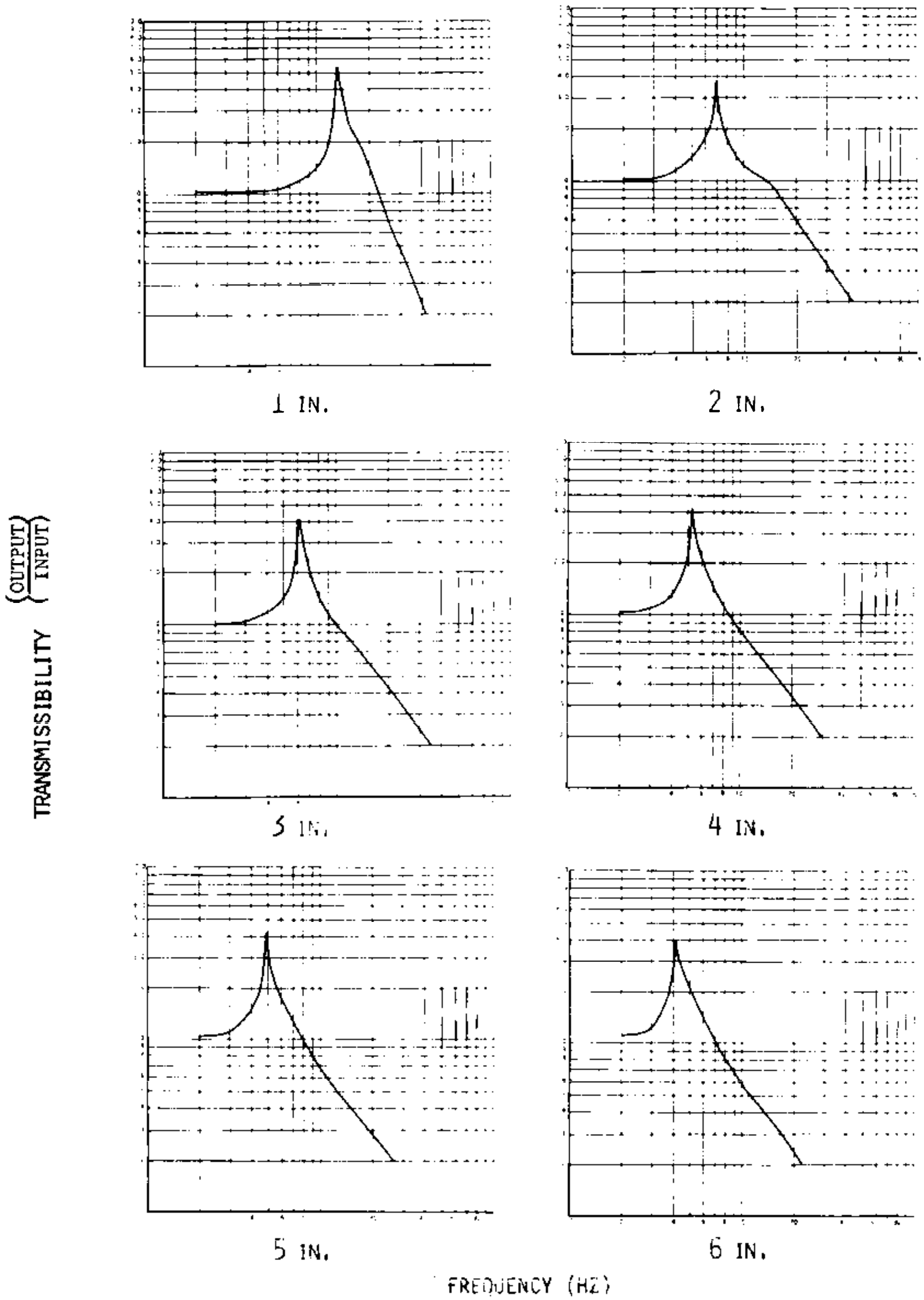
CURVE 7.3 RUBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .092 PSI



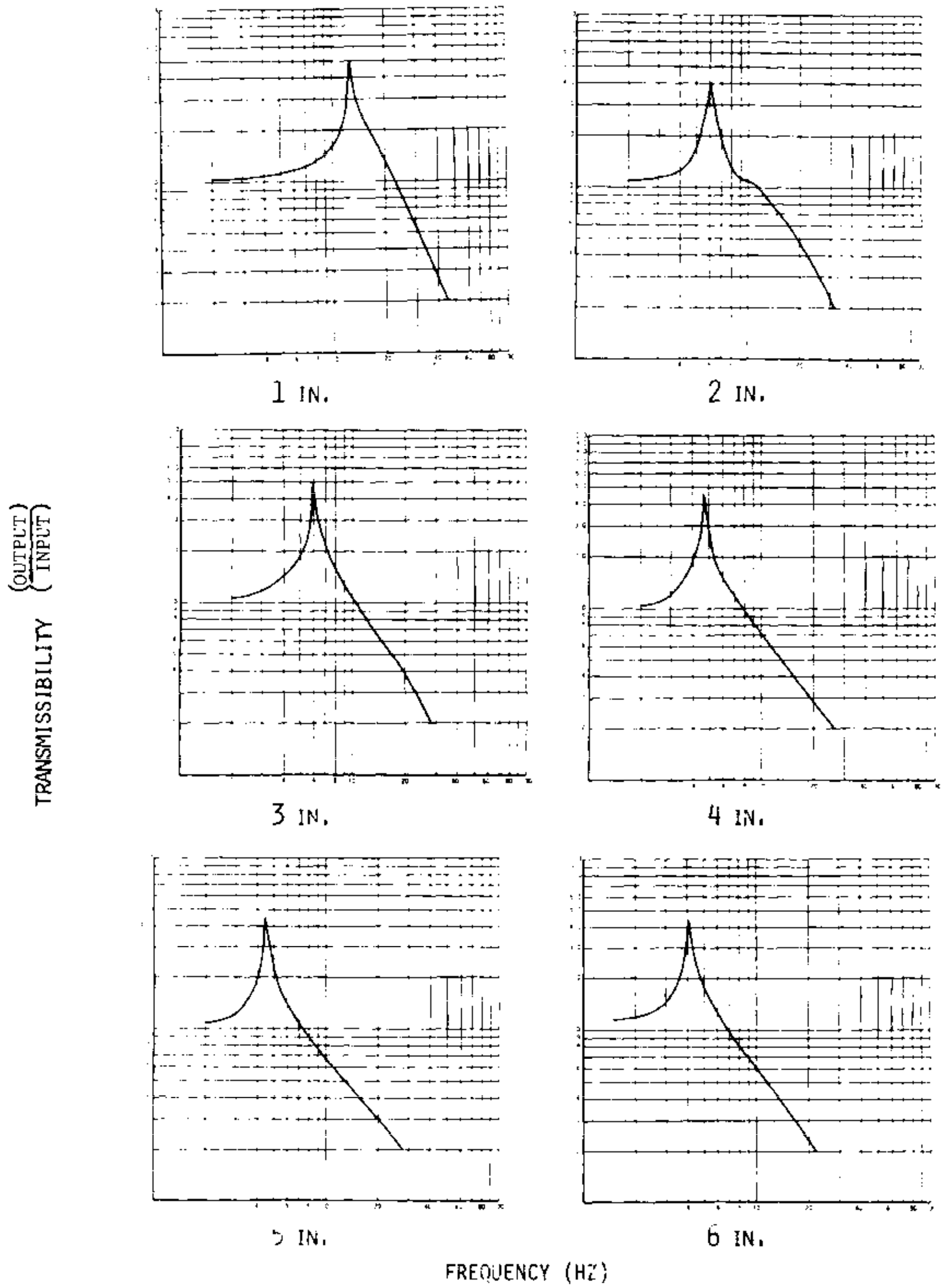
CURVE 7.4 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .108 PSI



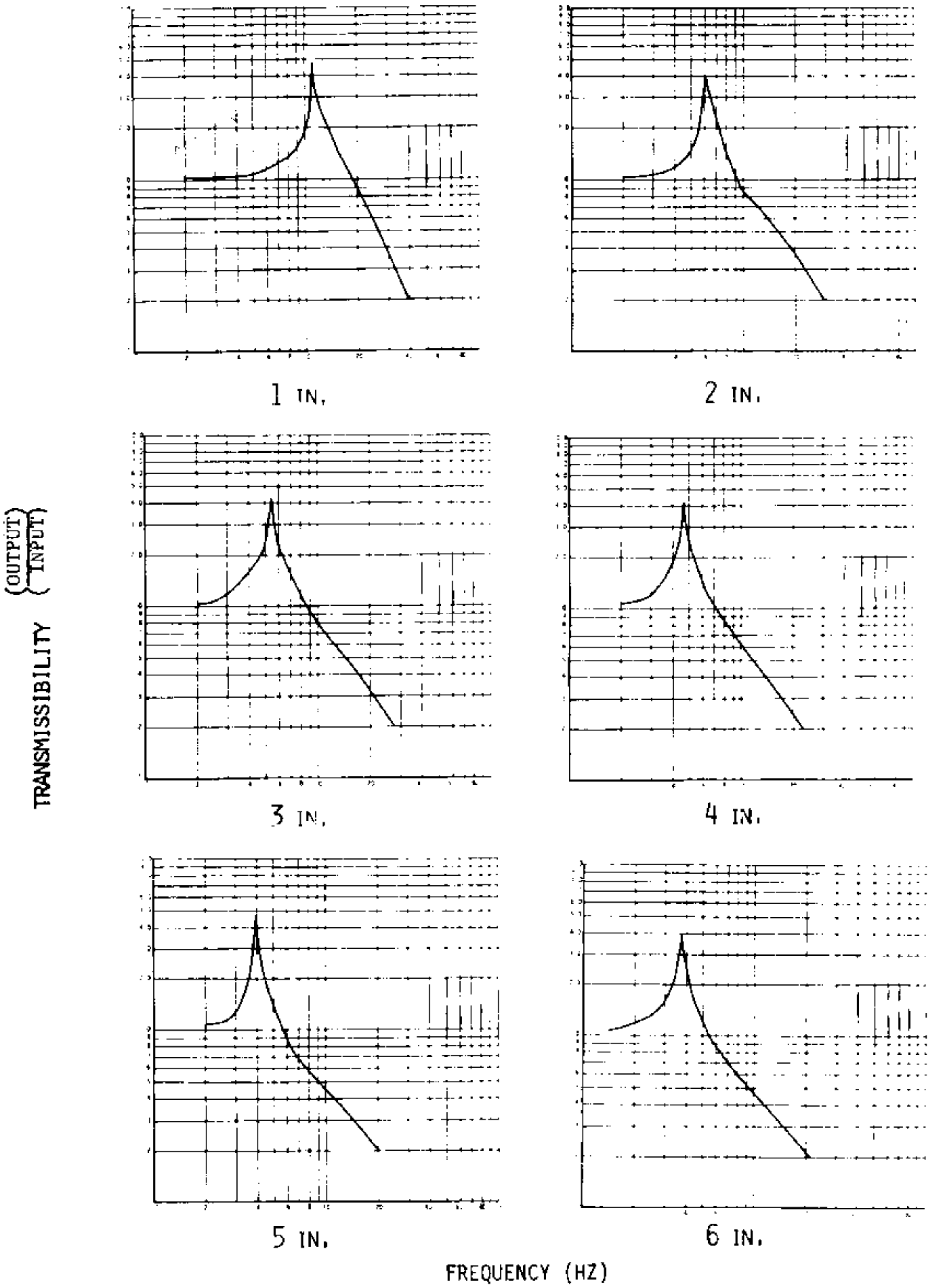
CURVE 7.5 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .148 PSI



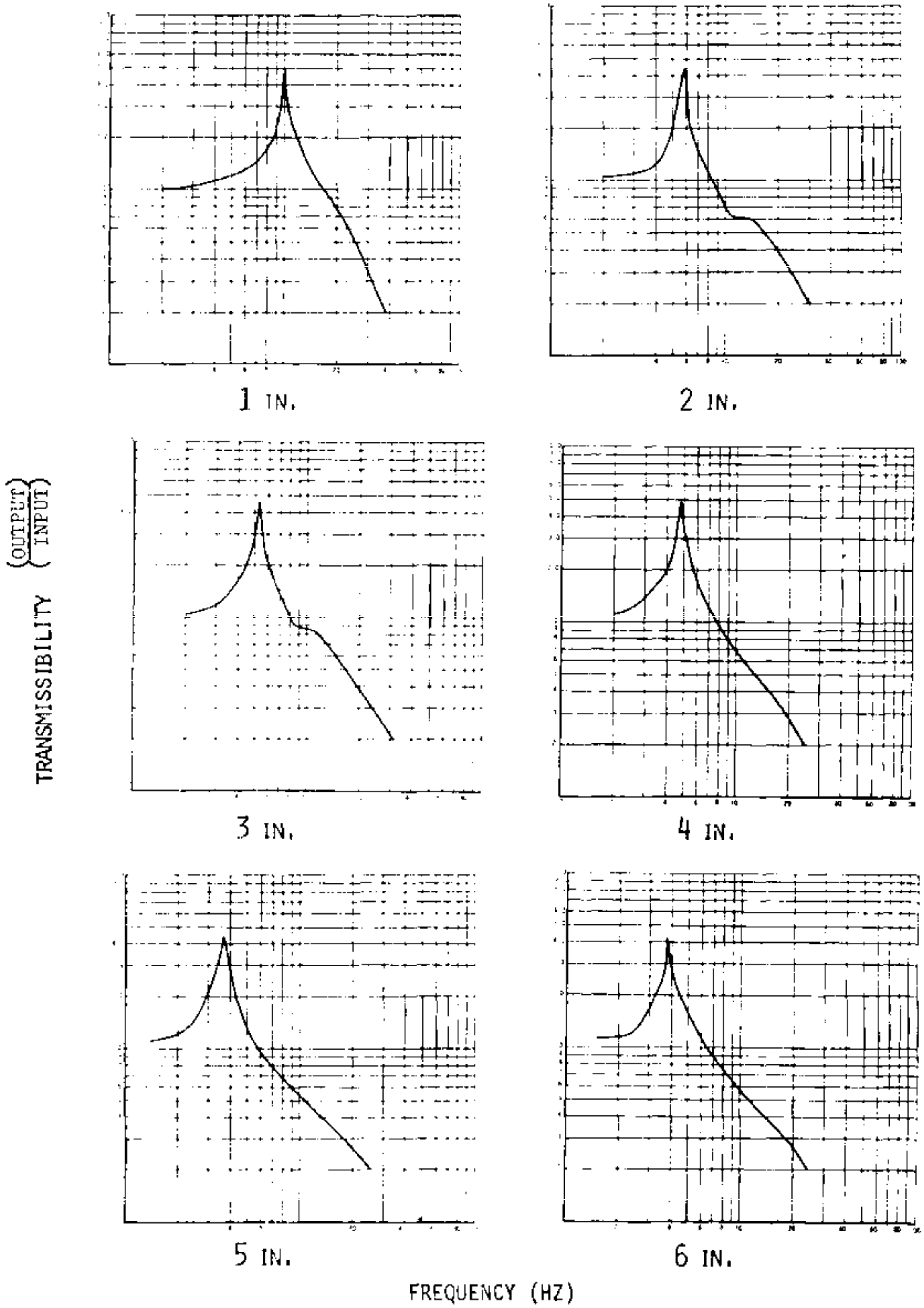
CURVE 7.6 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .180 PSI



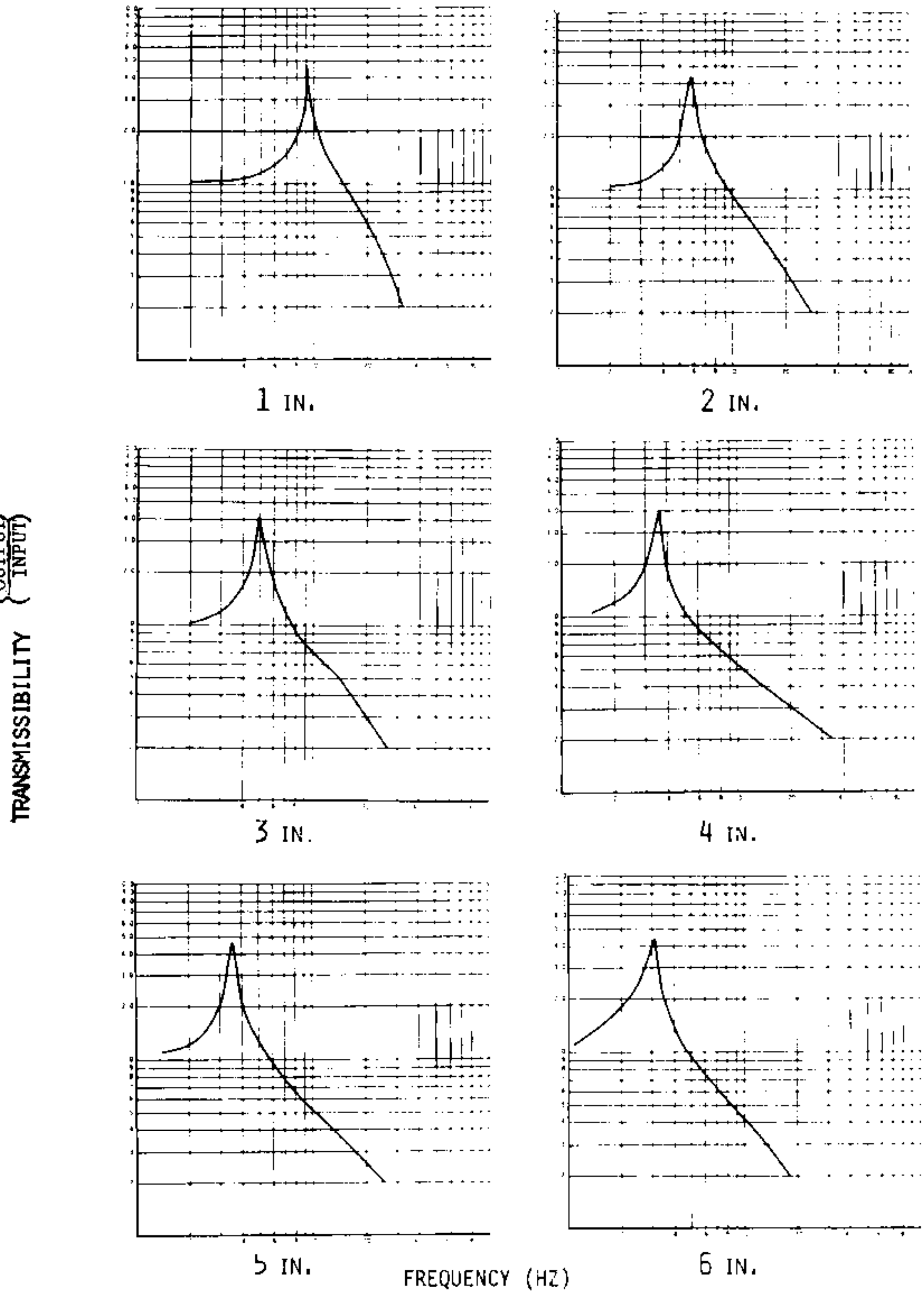
CURVE 7.7 RUBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .211 PSI



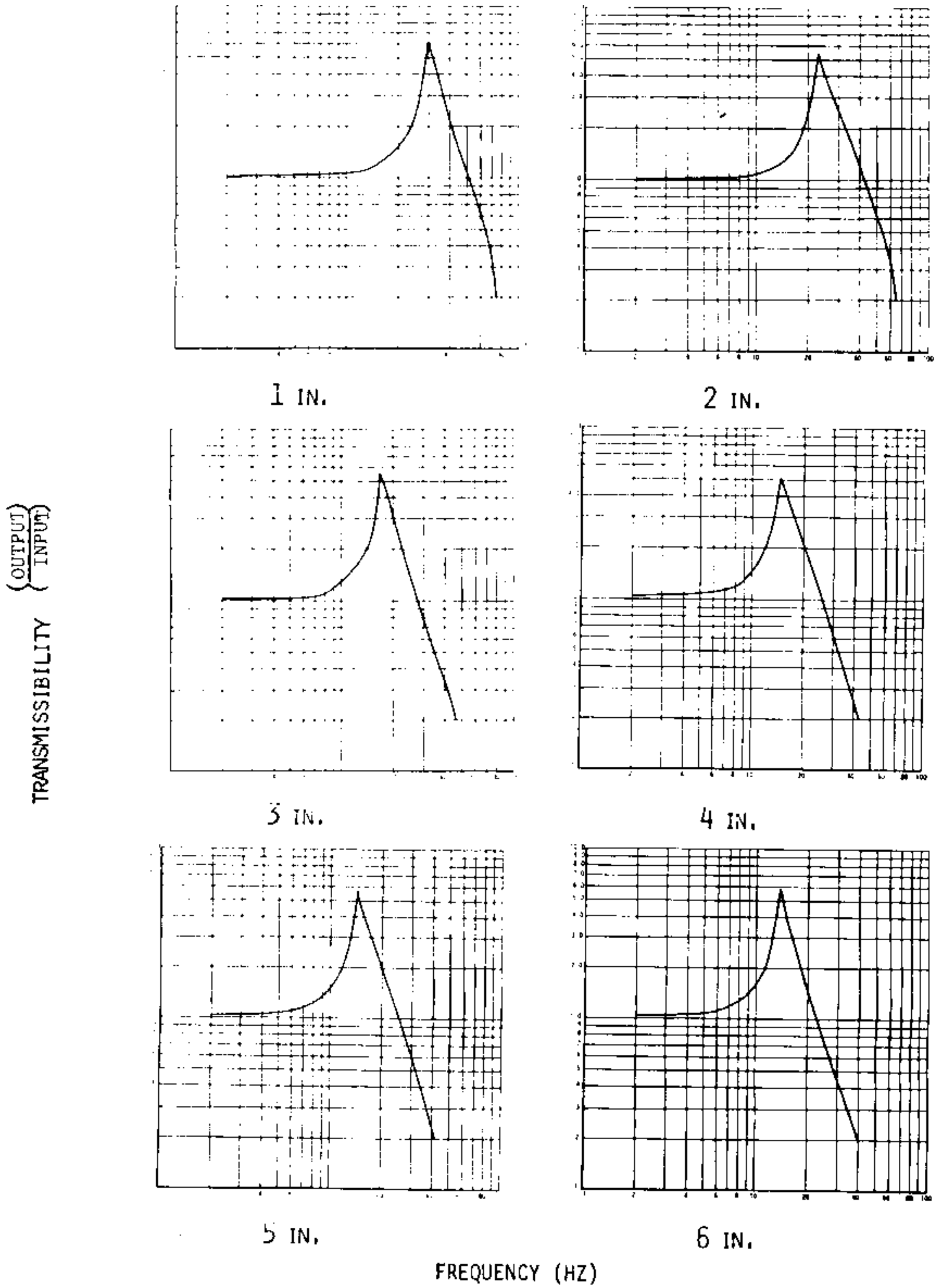
CURVE 7.8 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .252 PSI



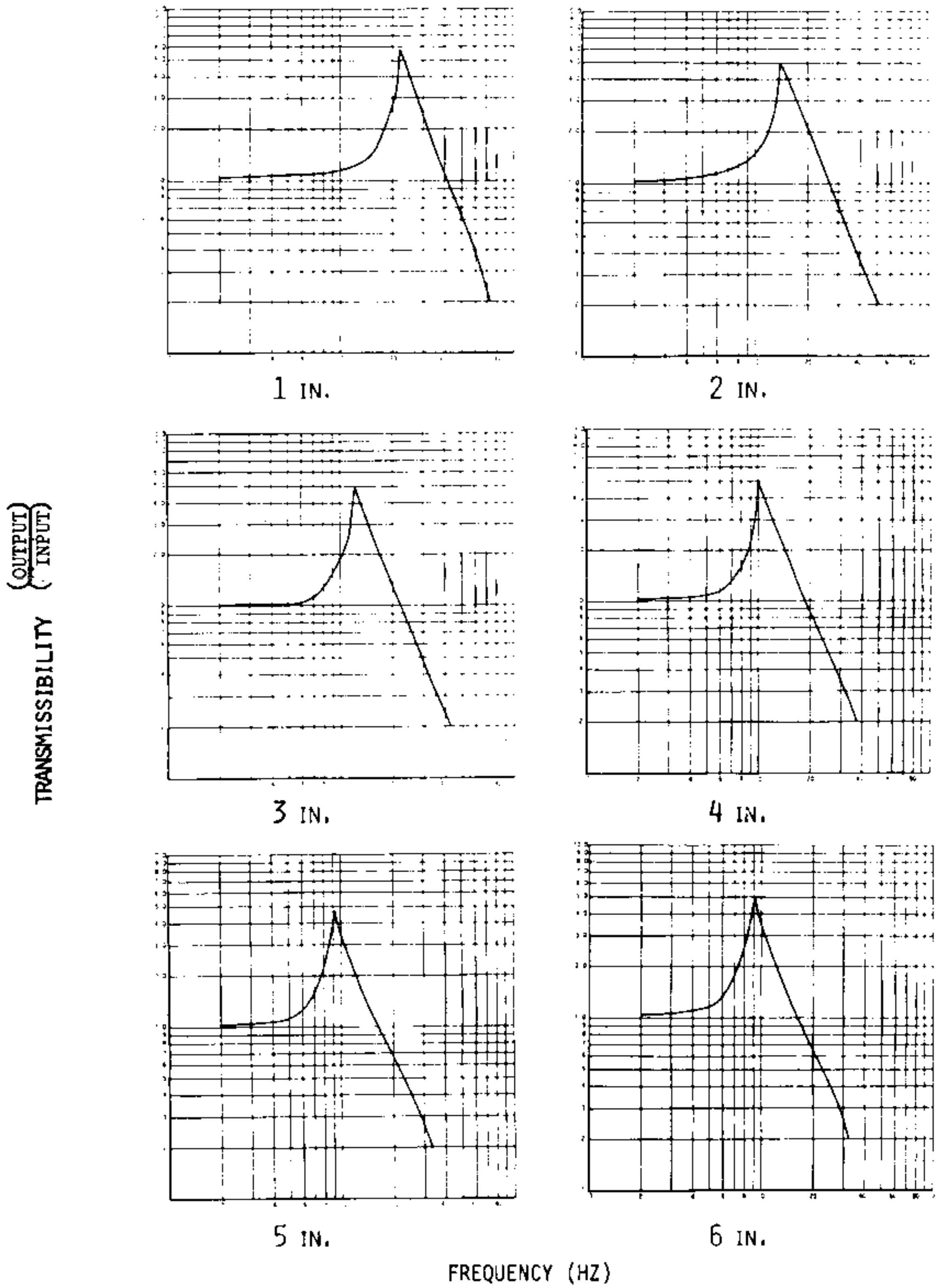
CURVE 7.9 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .283 PSI



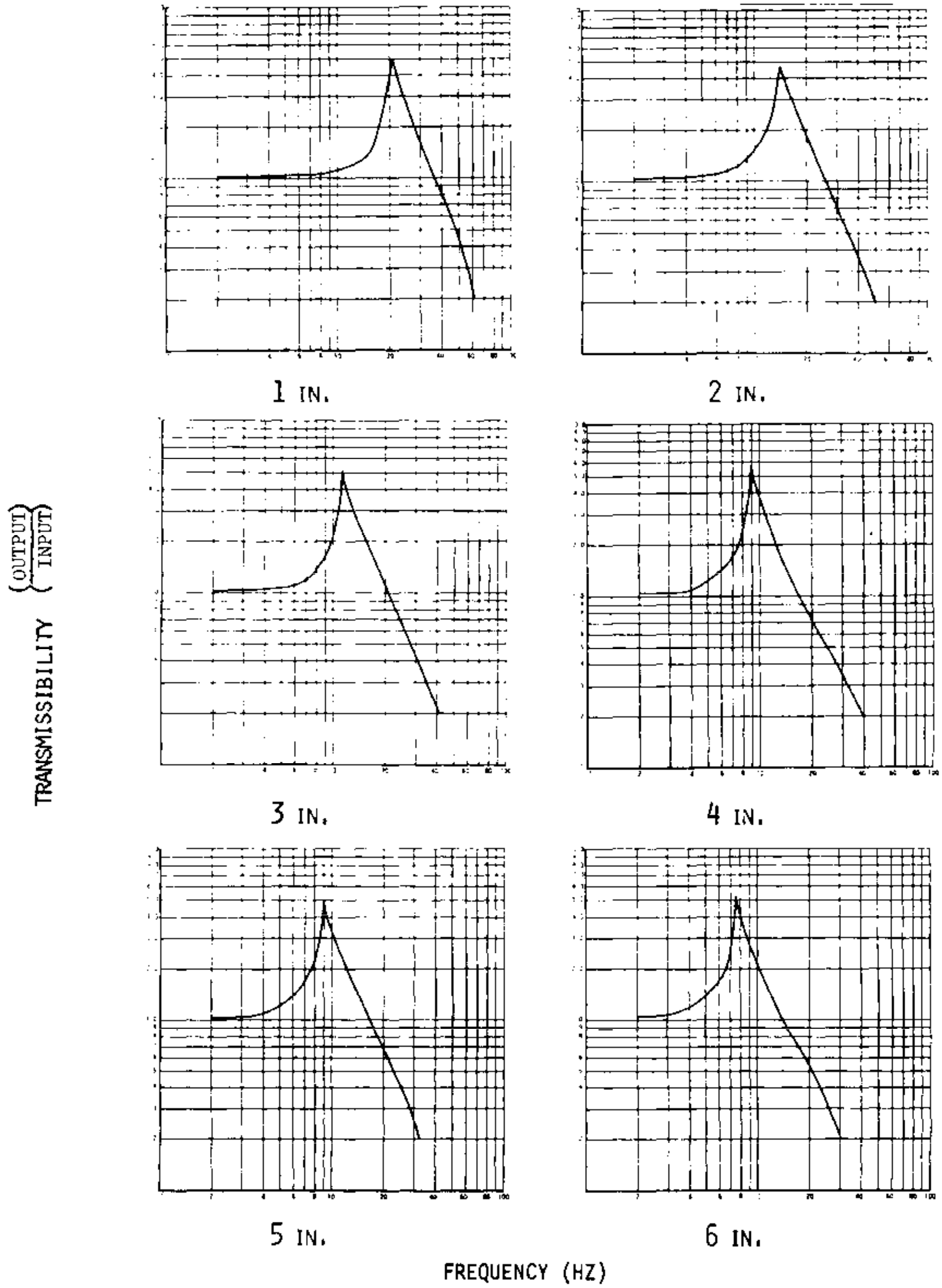
CURVE 7.10 RUBBERIZED HAIR, TYPE II, 1.1 LBS/CU FT .354 PSI



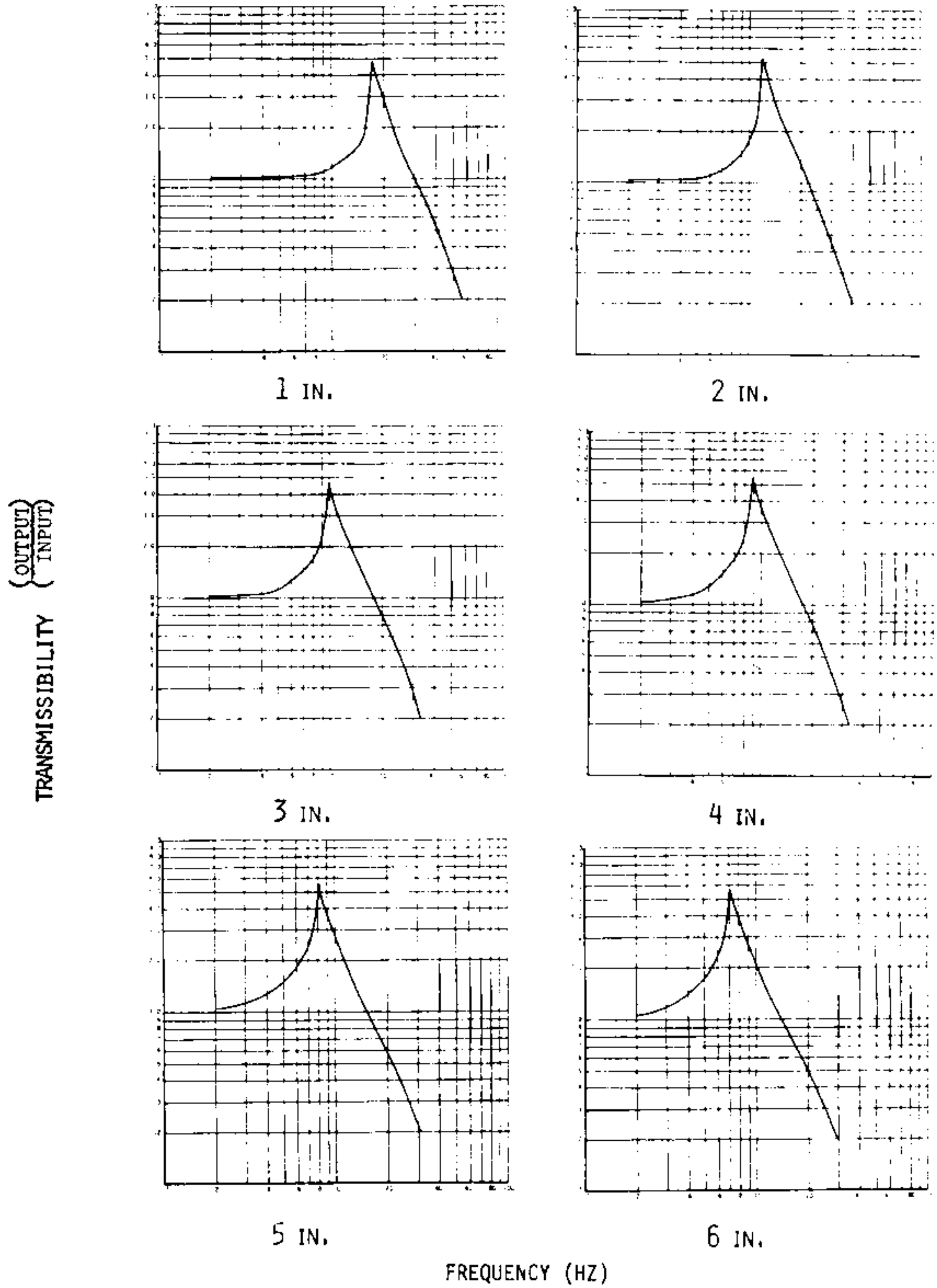
CURVE 8.1 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .045 PSI



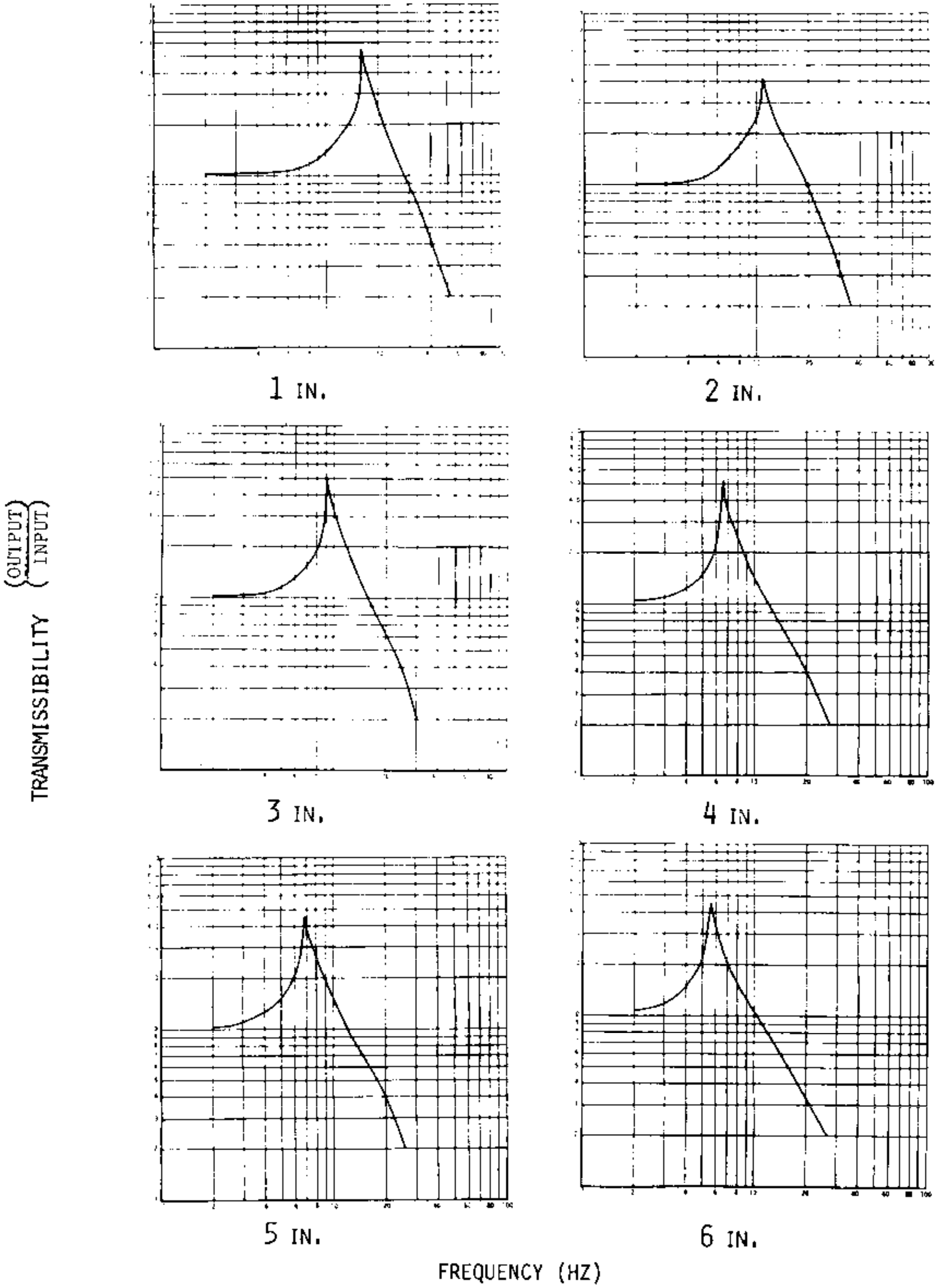
CURVE 8.2 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .076 PSI



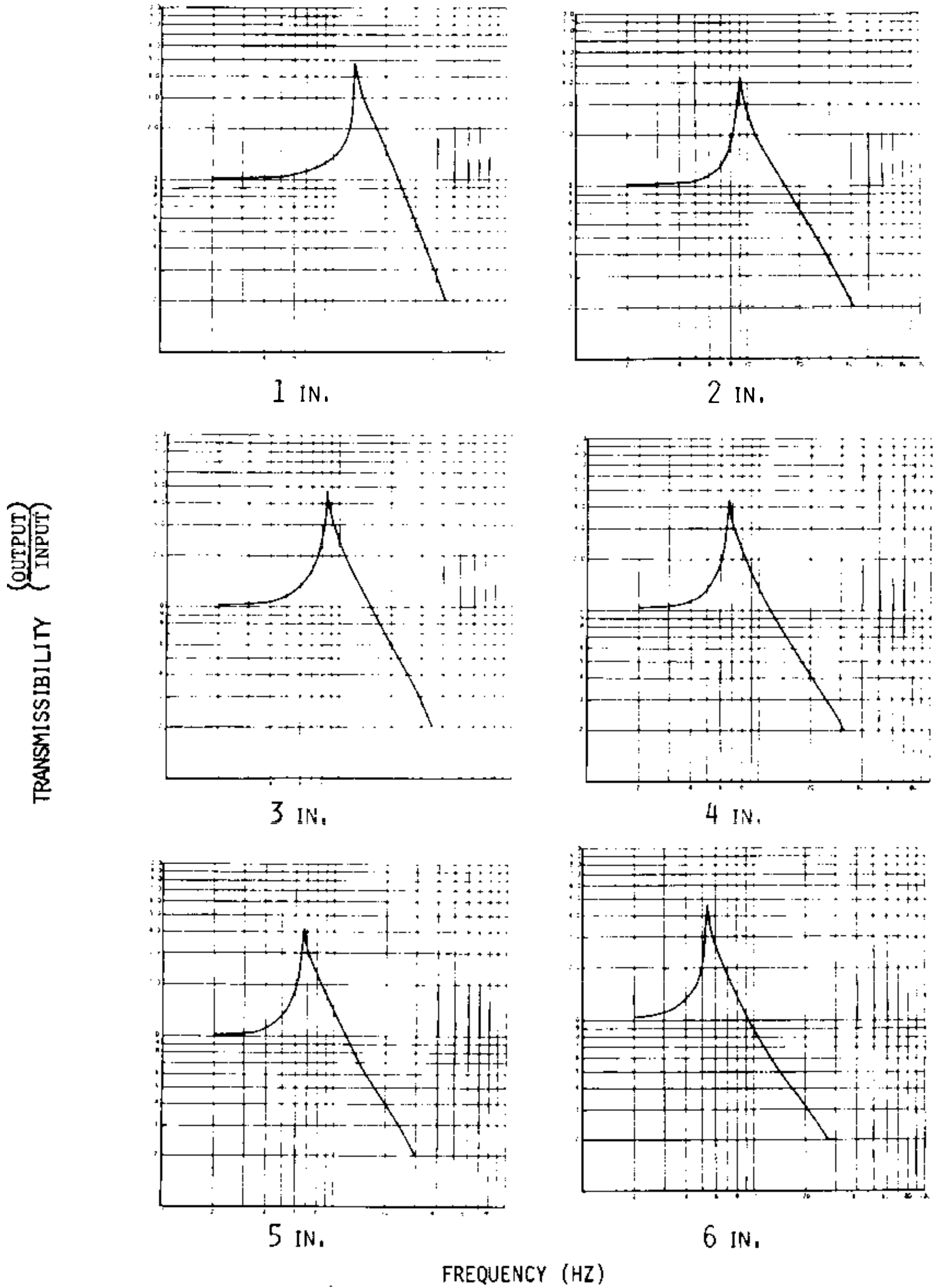
CURVE 8.3 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .092 PSI



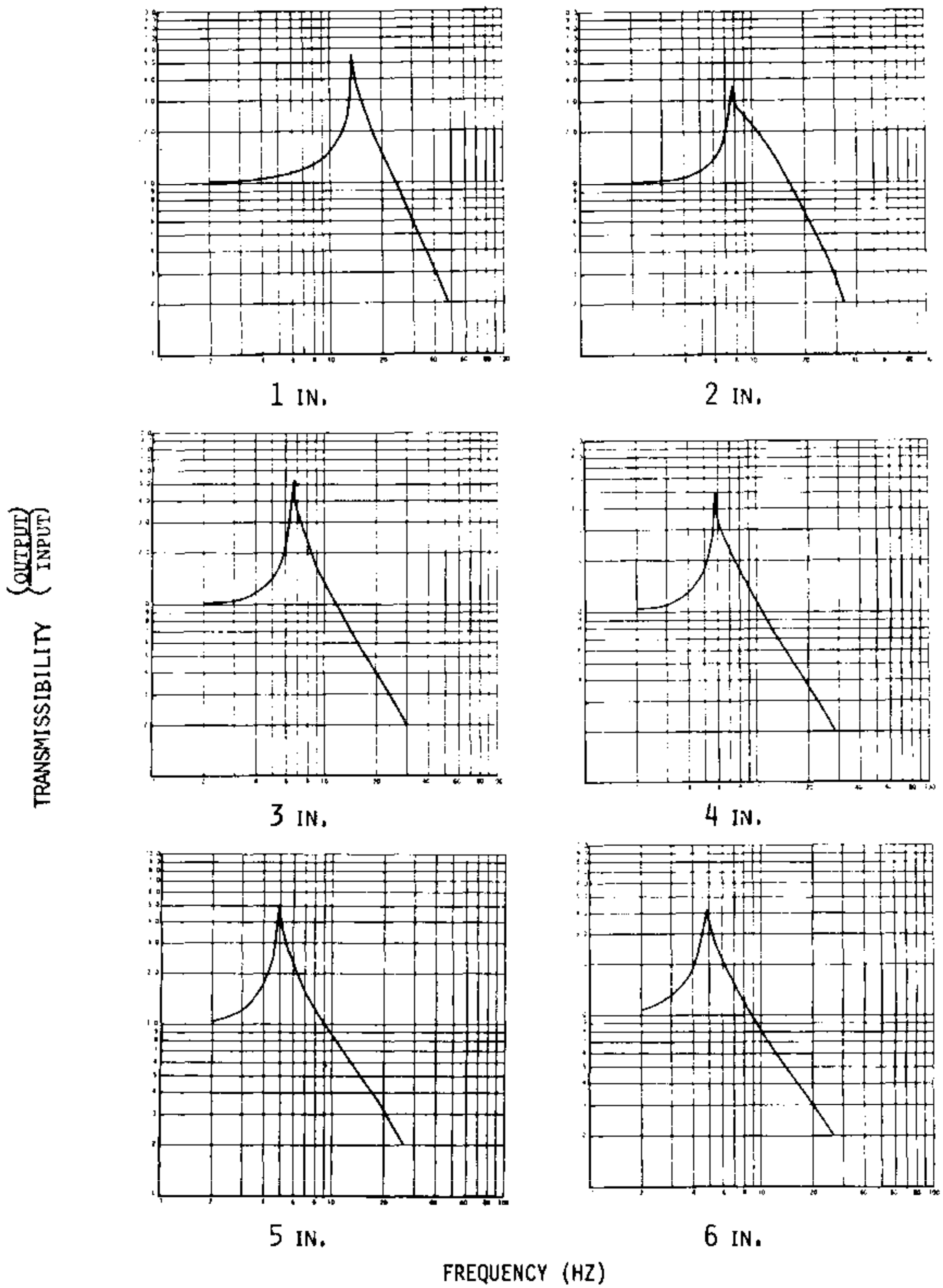
CURVE 8.4 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .108 PSI



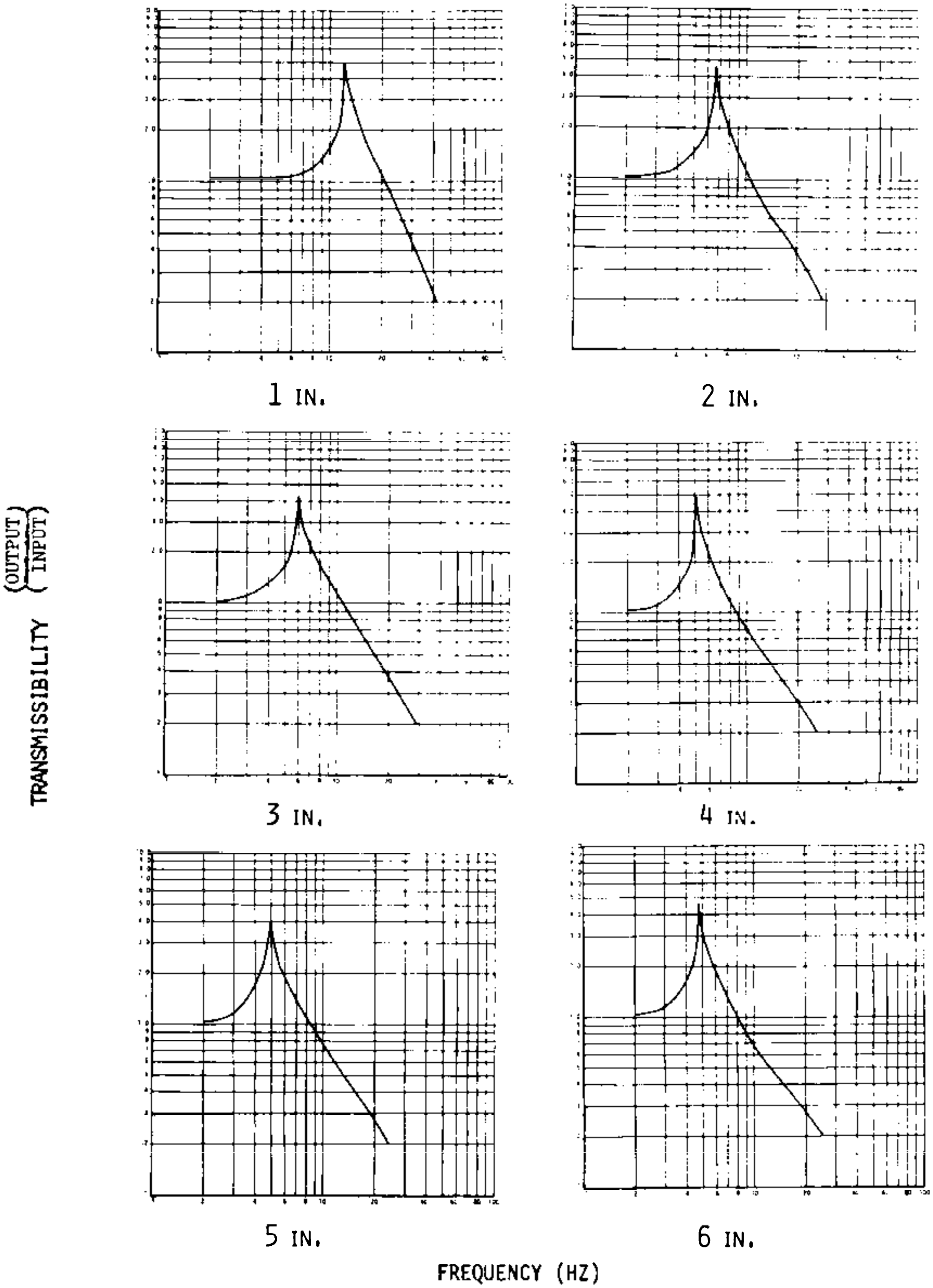
CURVE 8.5 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .148 PSI



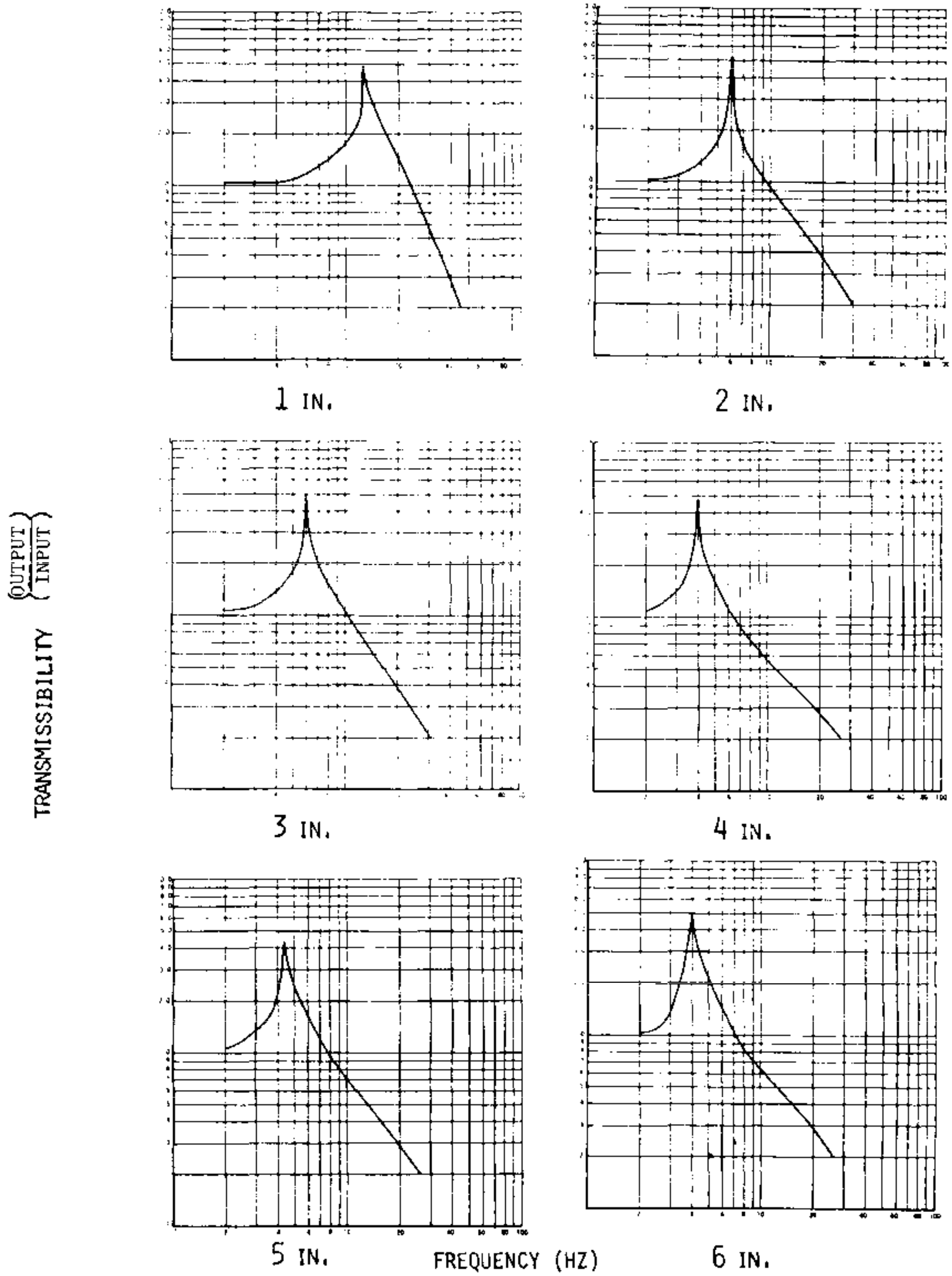
CURVE 8.6 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .180 PSI



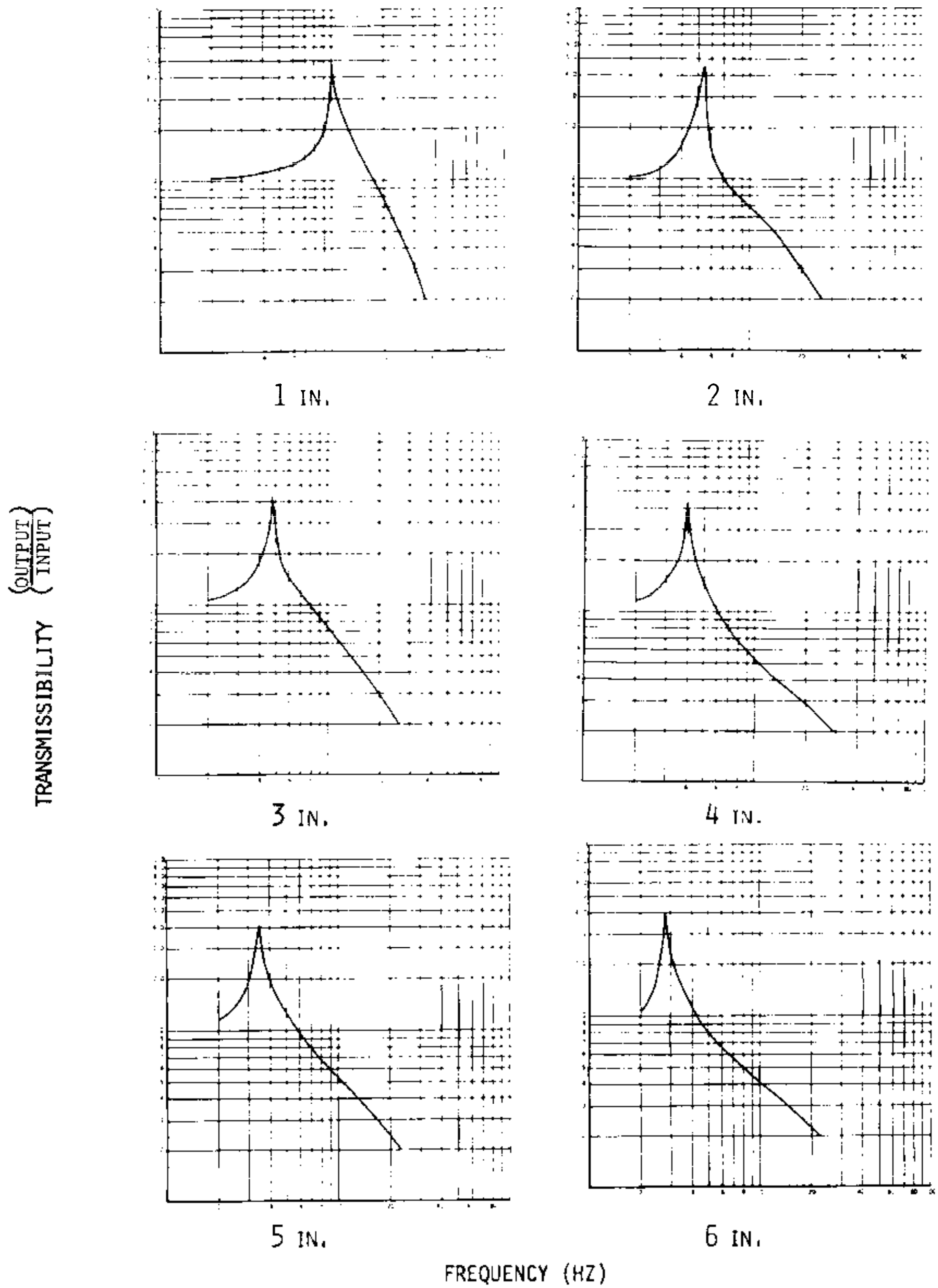
CURVE 8.7 RUBBERIZED HAIR, TYPE III,1.5 LBS/CU FT .211 PSI



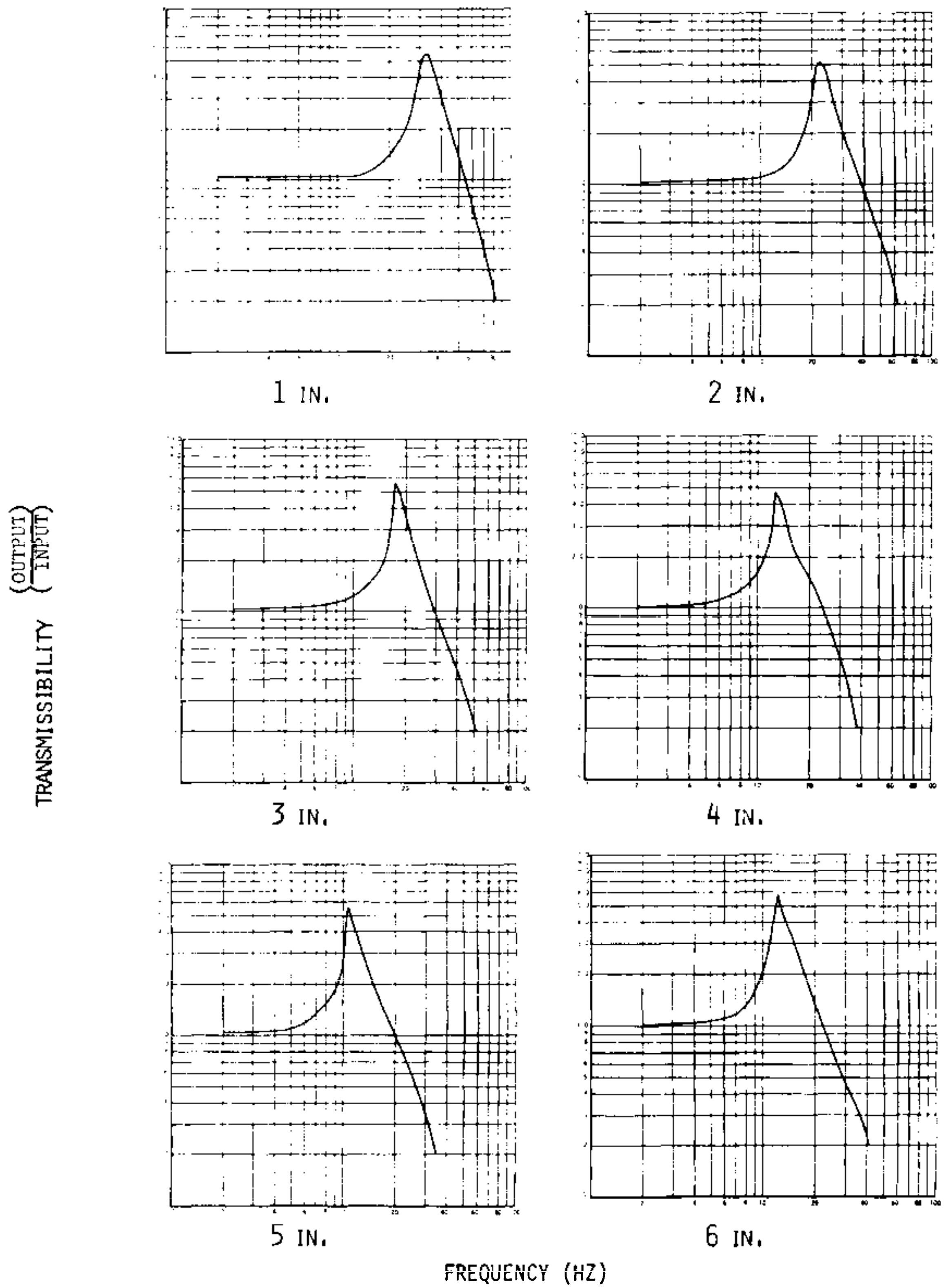
CURVE 8.8 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .252 PSI



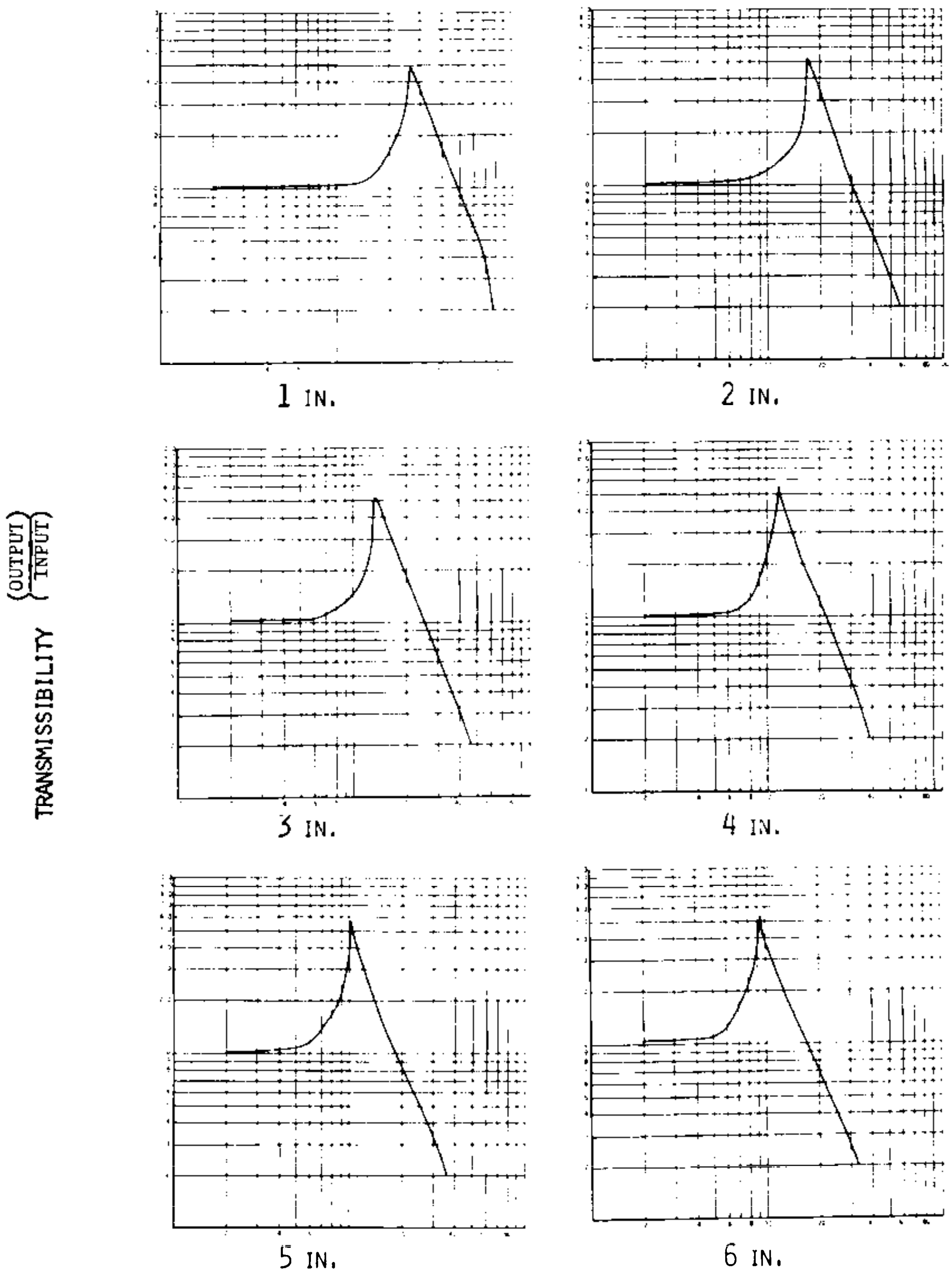
CURVE 8.9 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .283 PSI



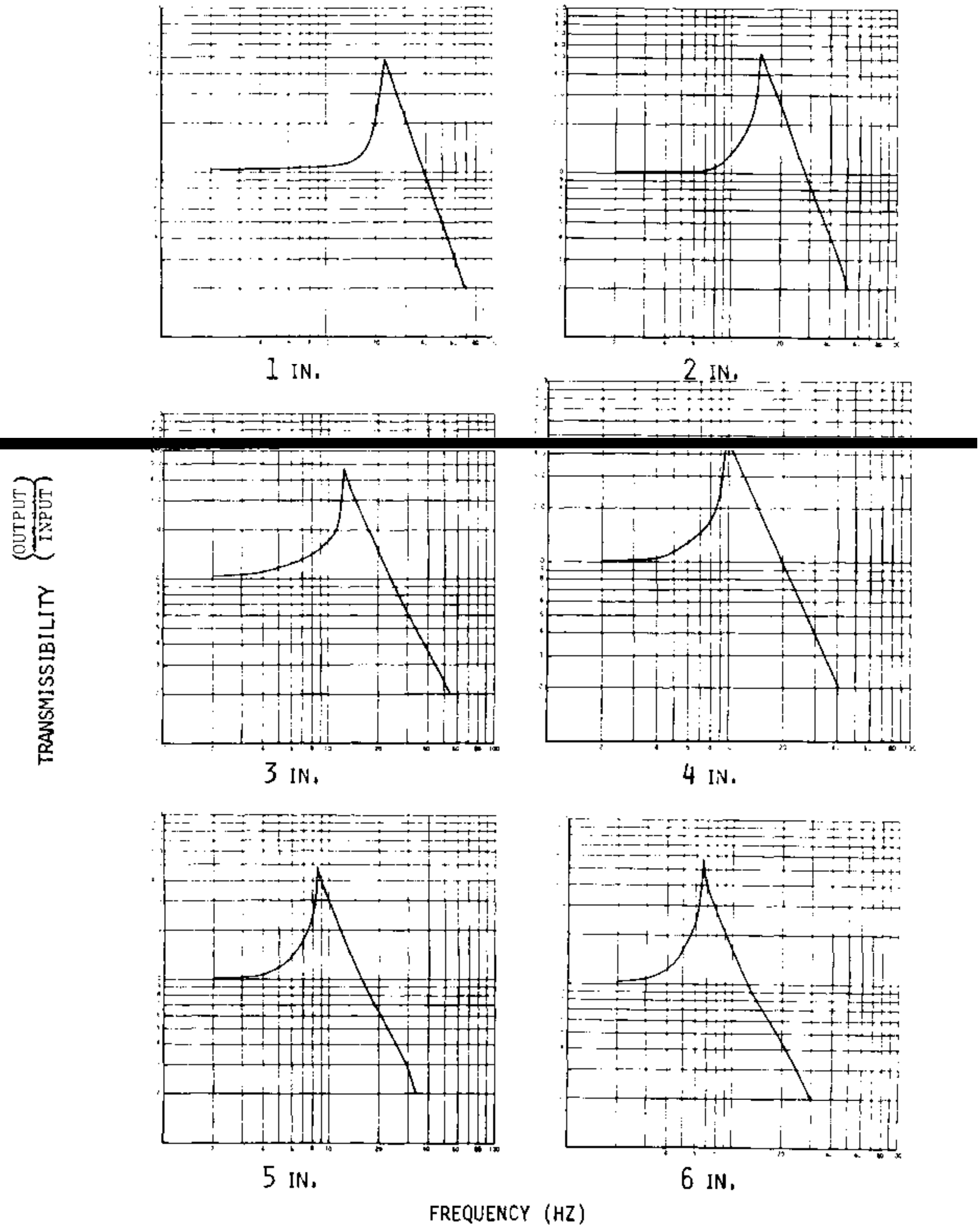
CURVE 8.10 RUBBERIZED HAIR, TYPE III, 1.5 LBS/CU FT .354 PSI



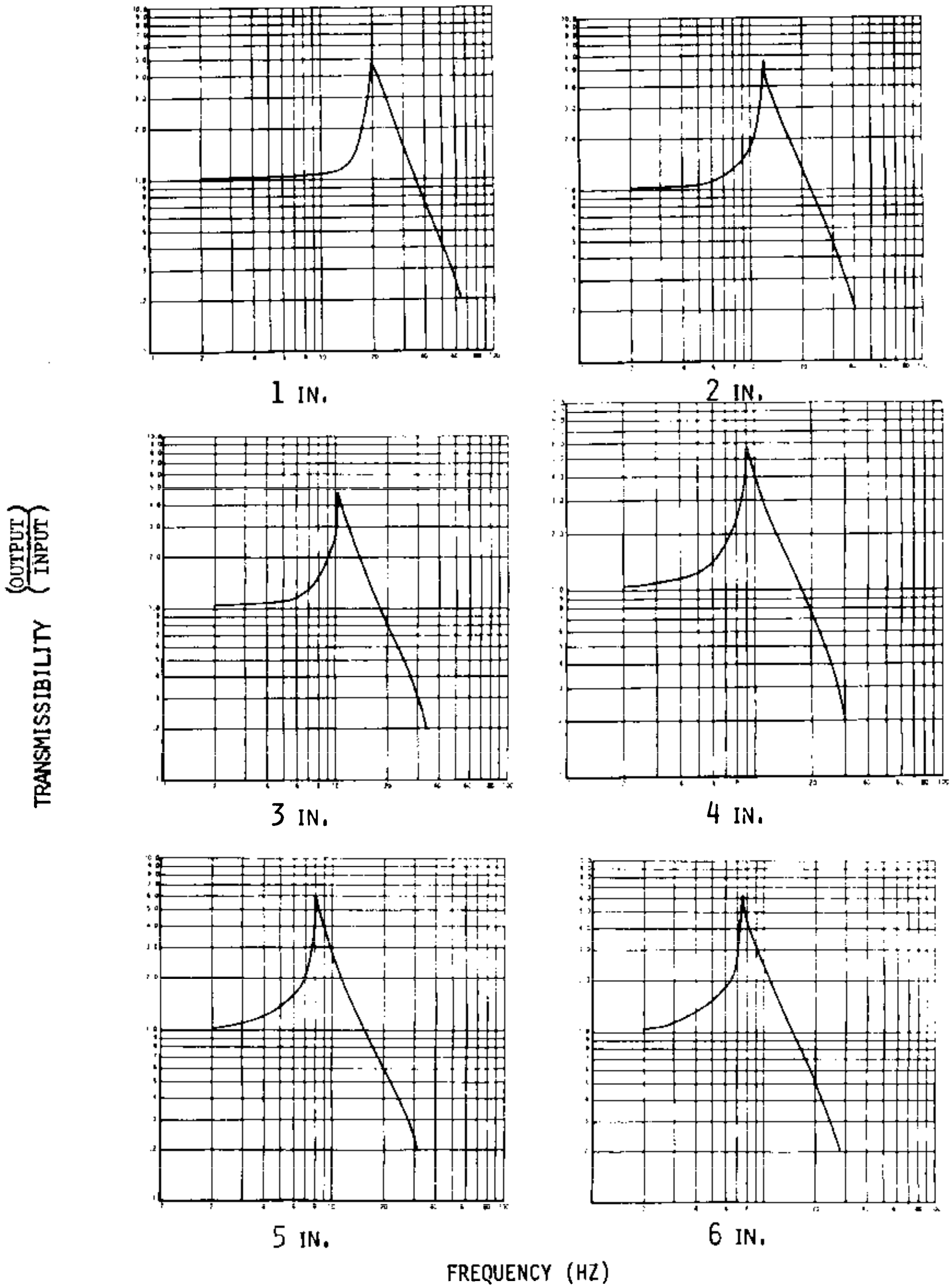
CURVE 9.1 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .045 PSI



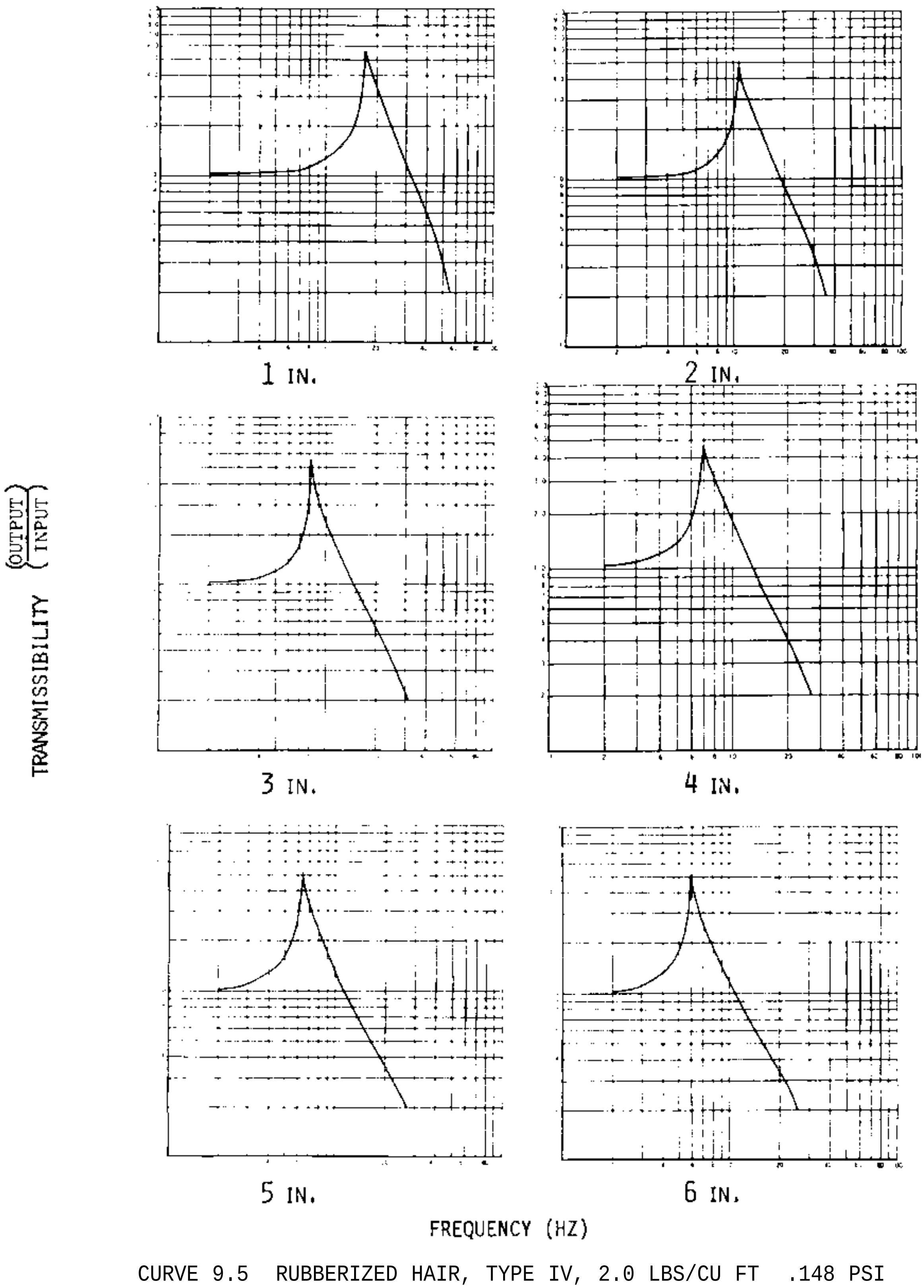
CURVE 9.2 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .076 PSI



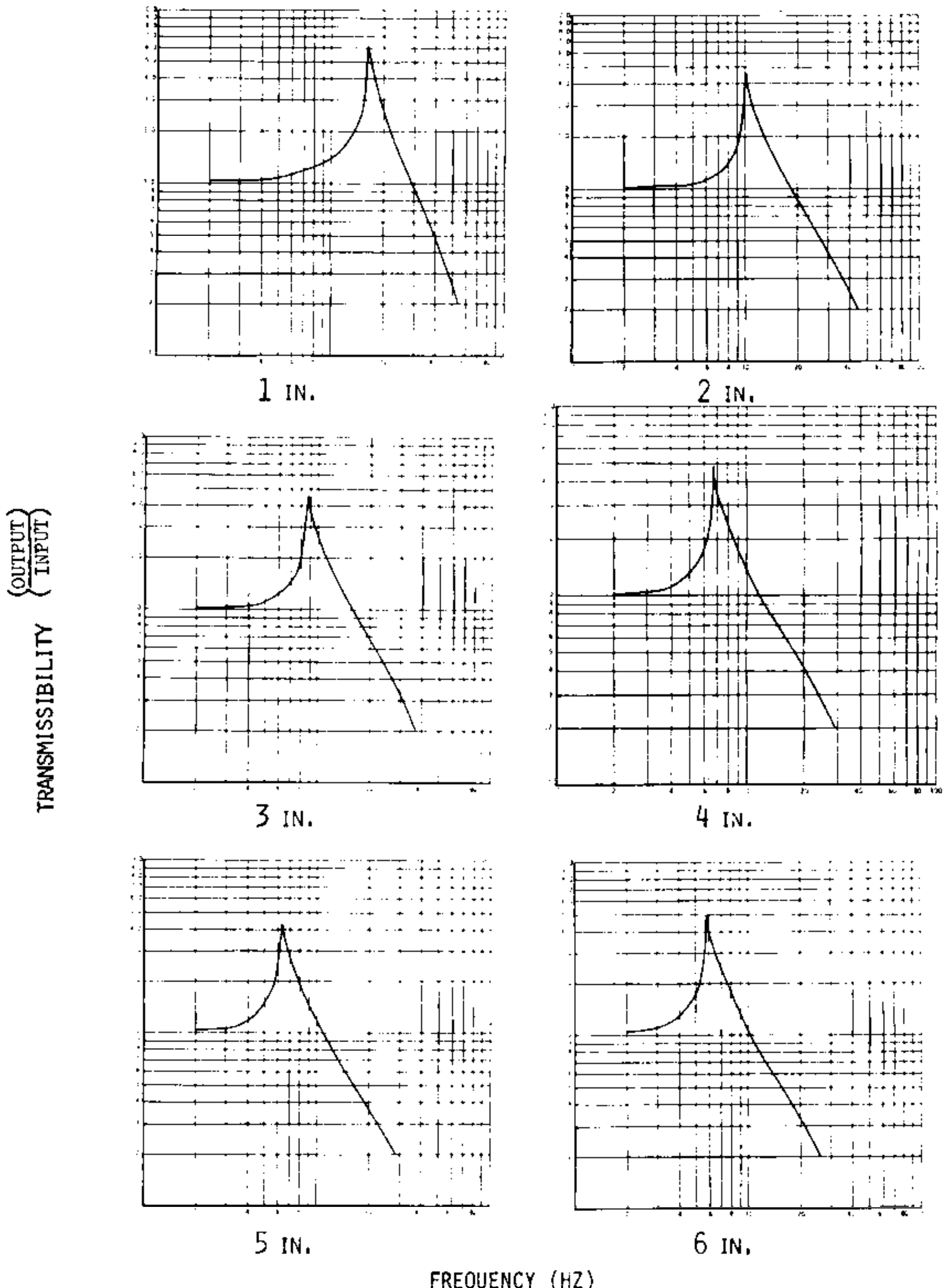
CURVE 9.3 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .092 PSI



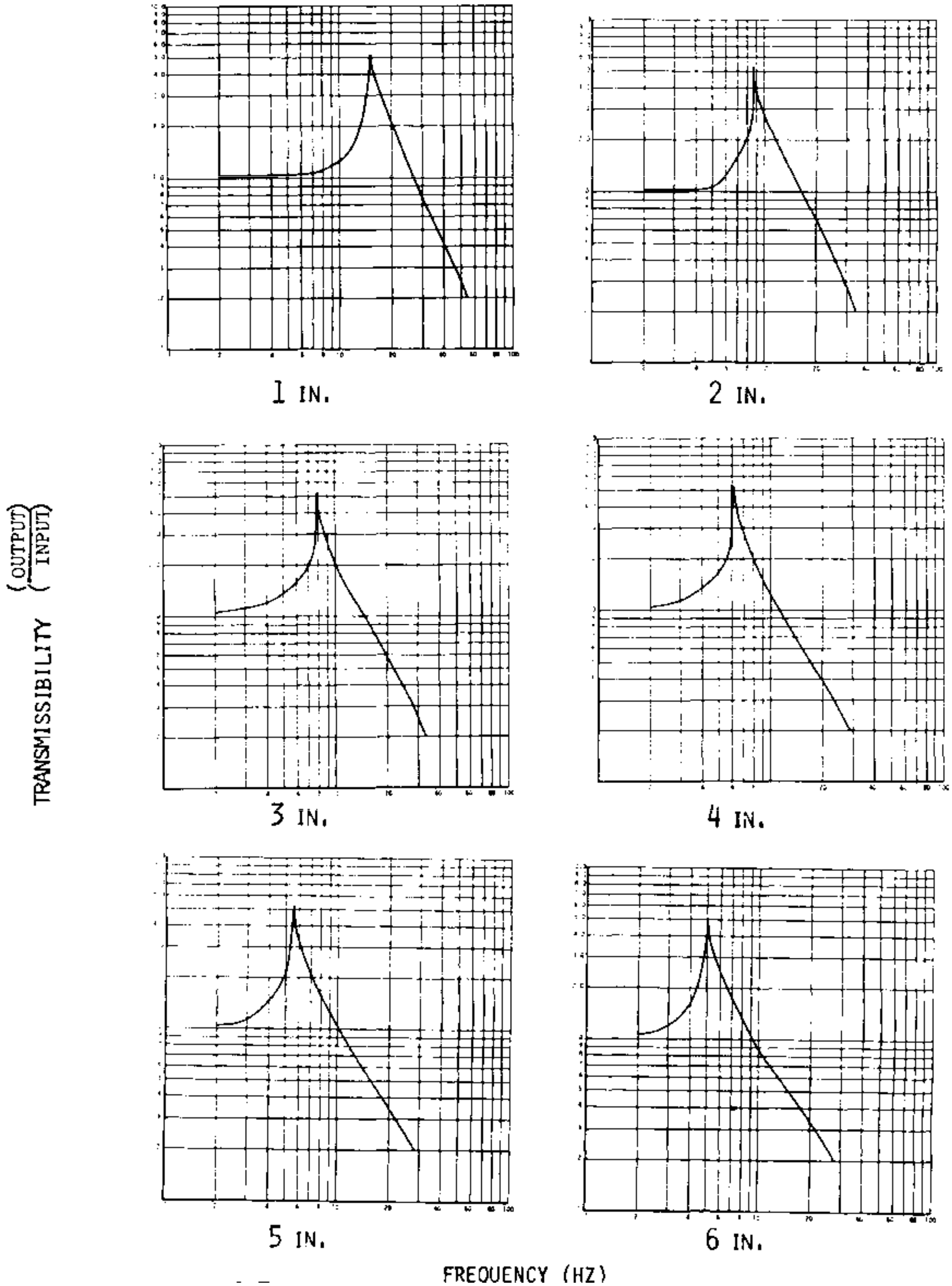
CURVE 9.4 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .108 PSI



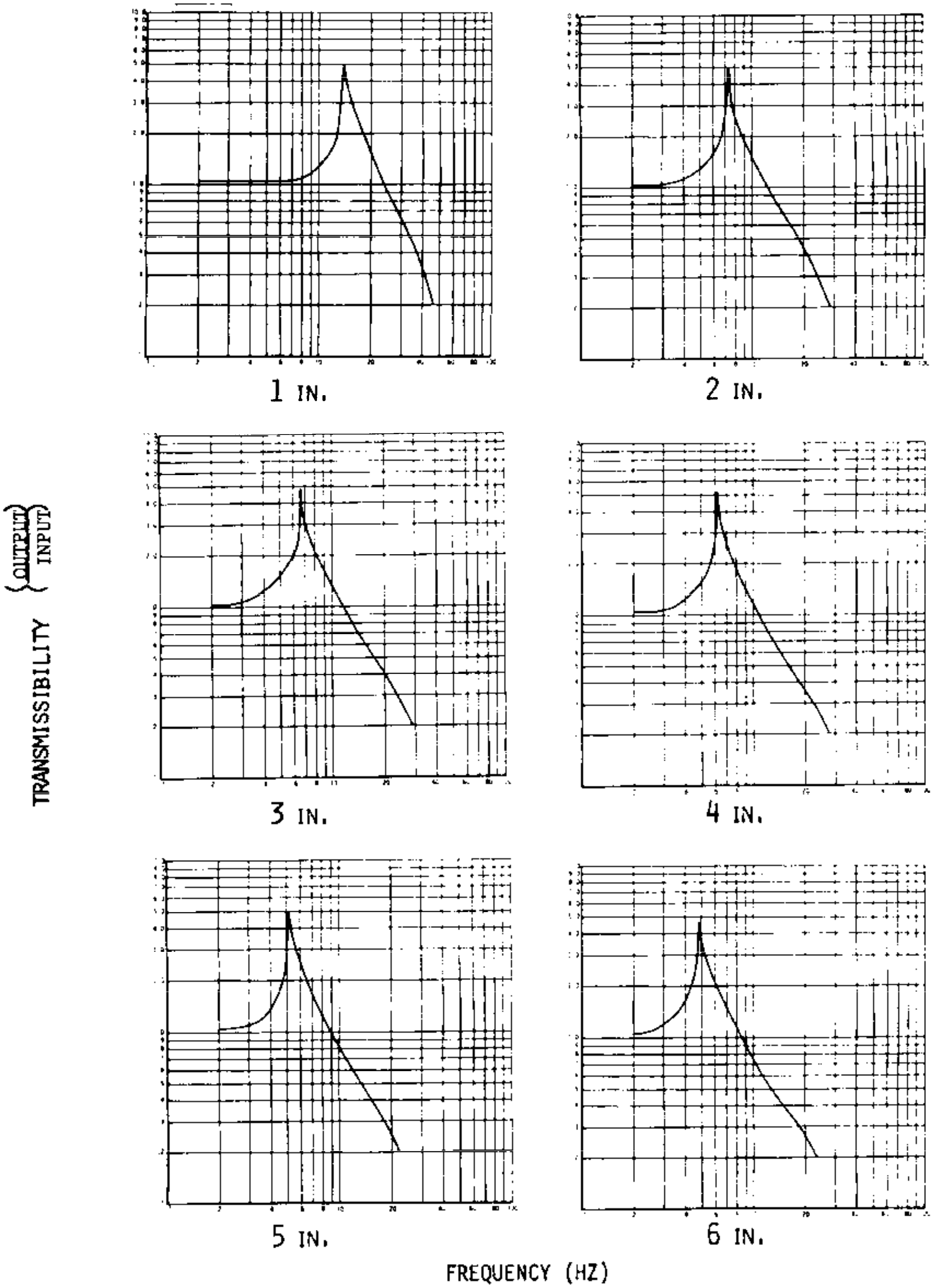
CURVE 9.5 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .148 PSI



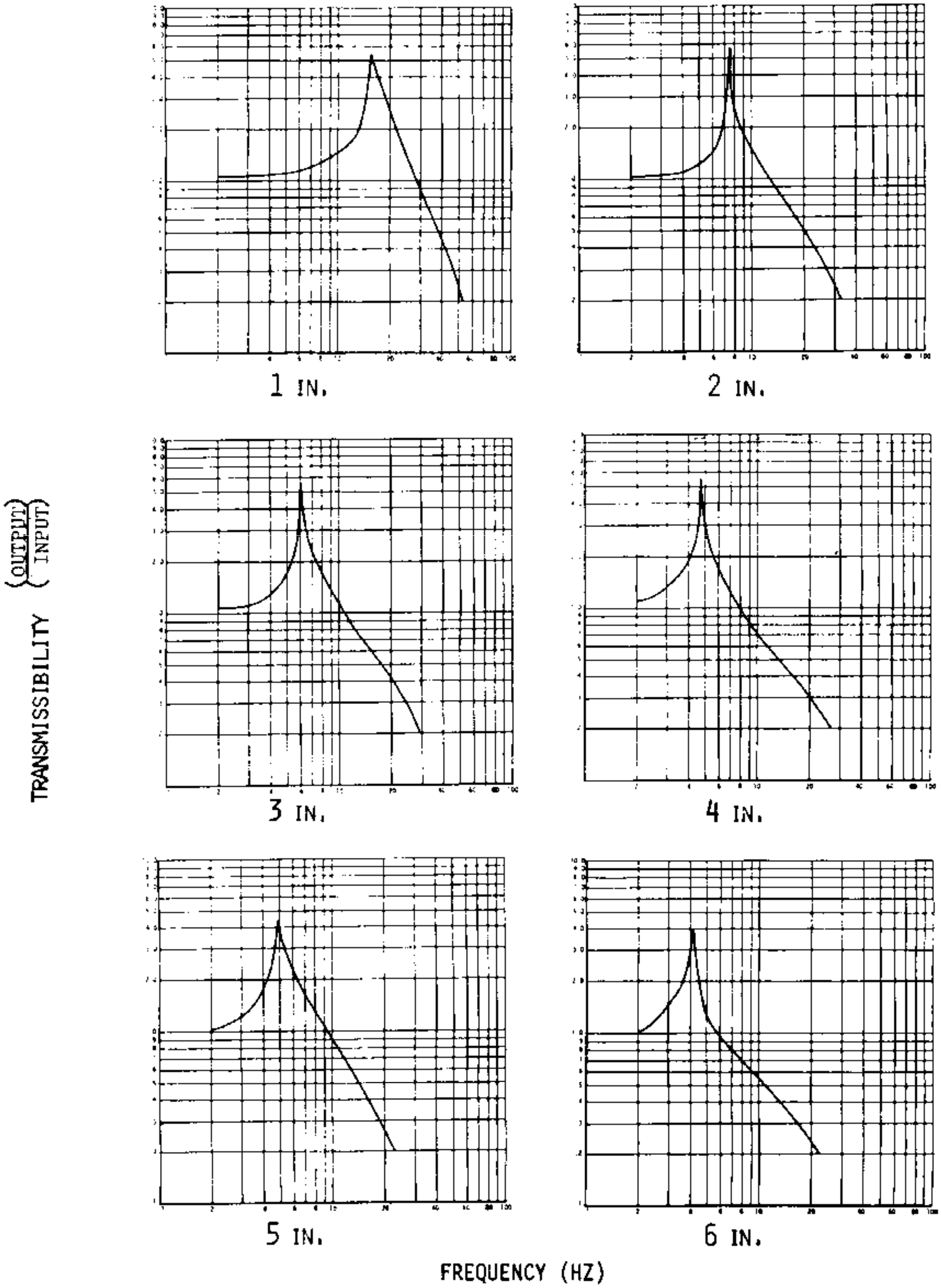
CURVE 9.6 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .180 PSI



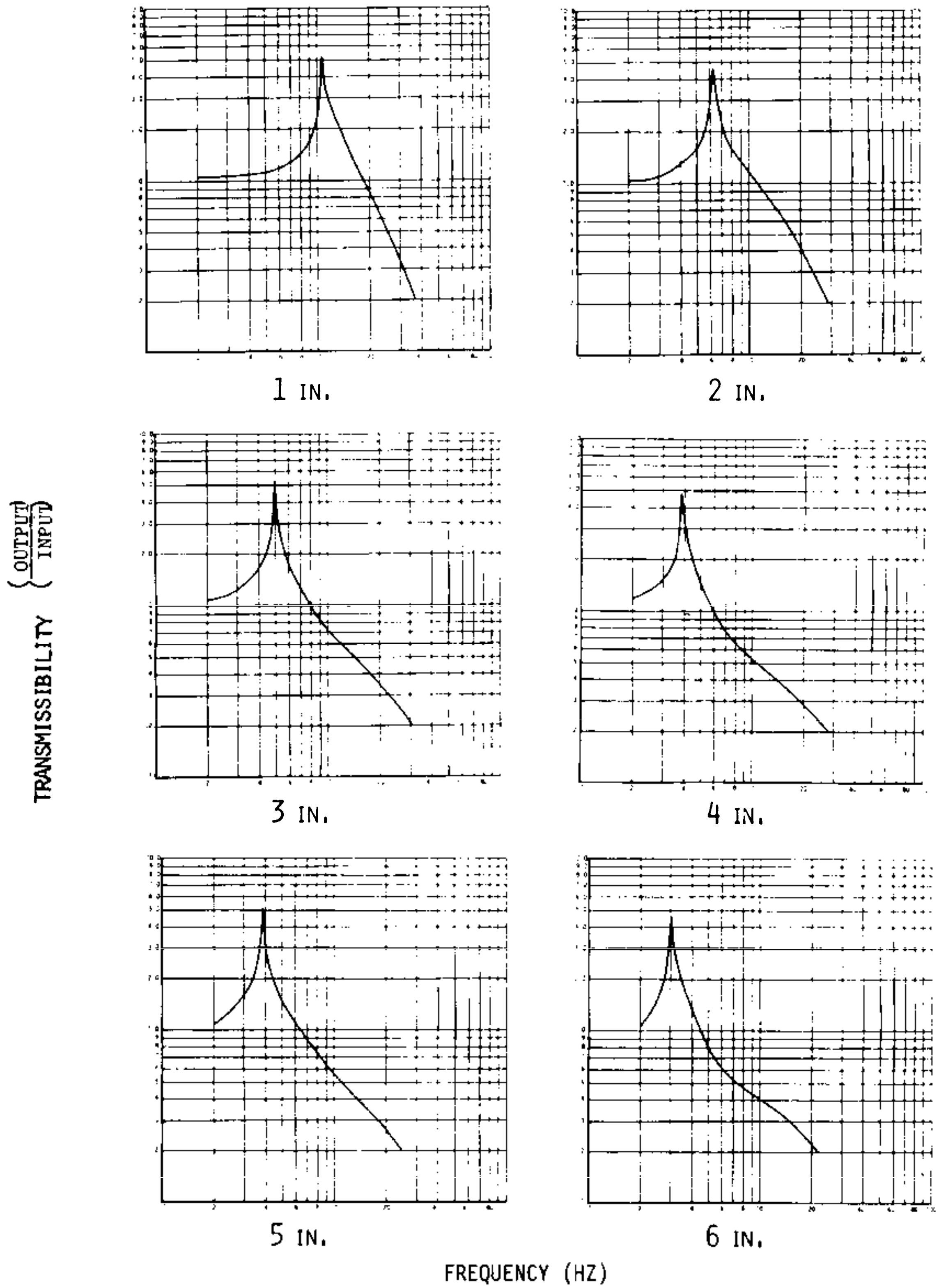
CURVE 9.7 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .211 PSI



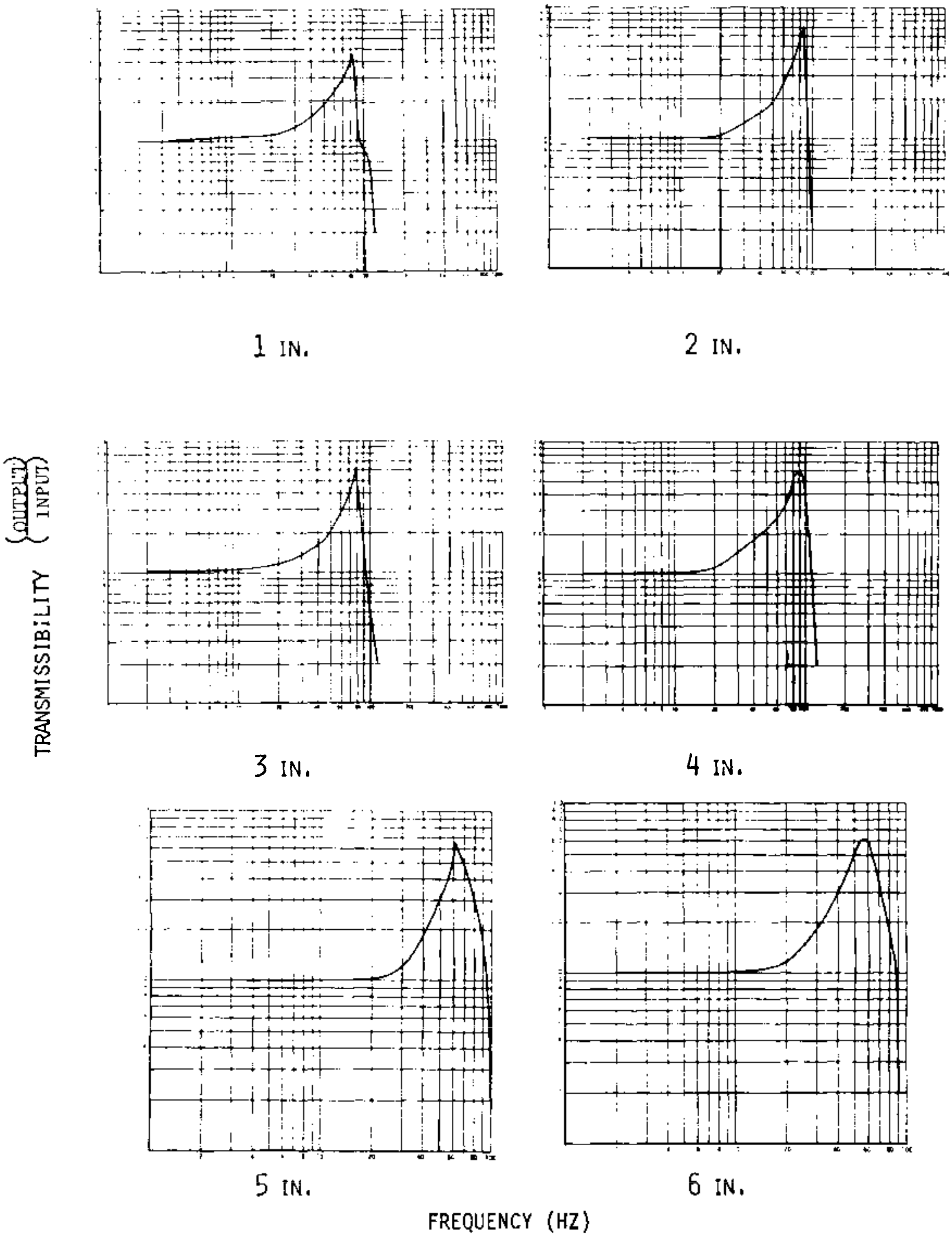
CURVE 9.8 RUBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .252 PSI



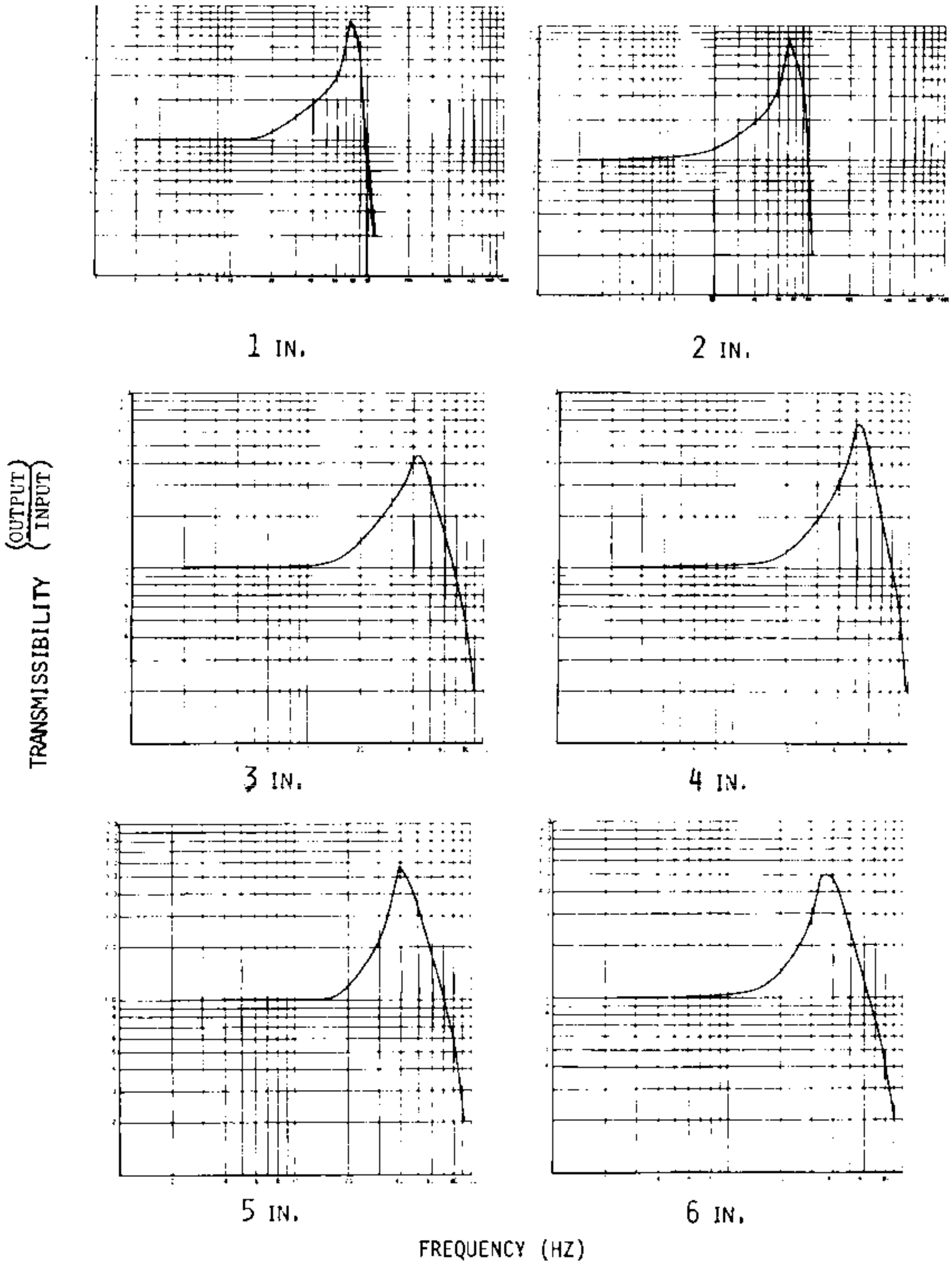
CURVE 9.9 RUBBERIZED HAIR, TYPE III, 2.0 LBS/CU FT .283 PSI



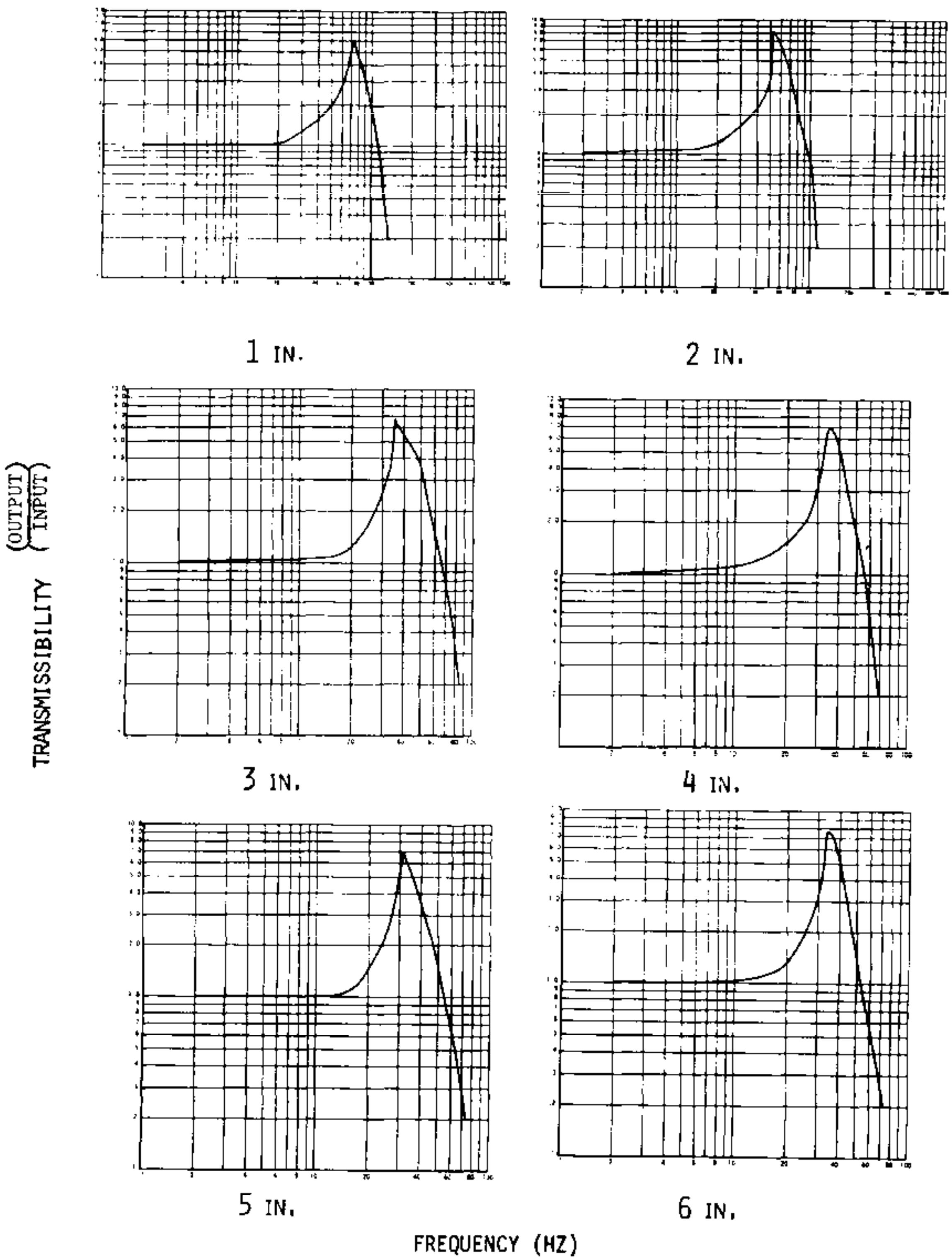
CURVE 9.10 RUBBERIZED HAIR, TYPE IV, 2.0 LBS/CU FT .354 PSI



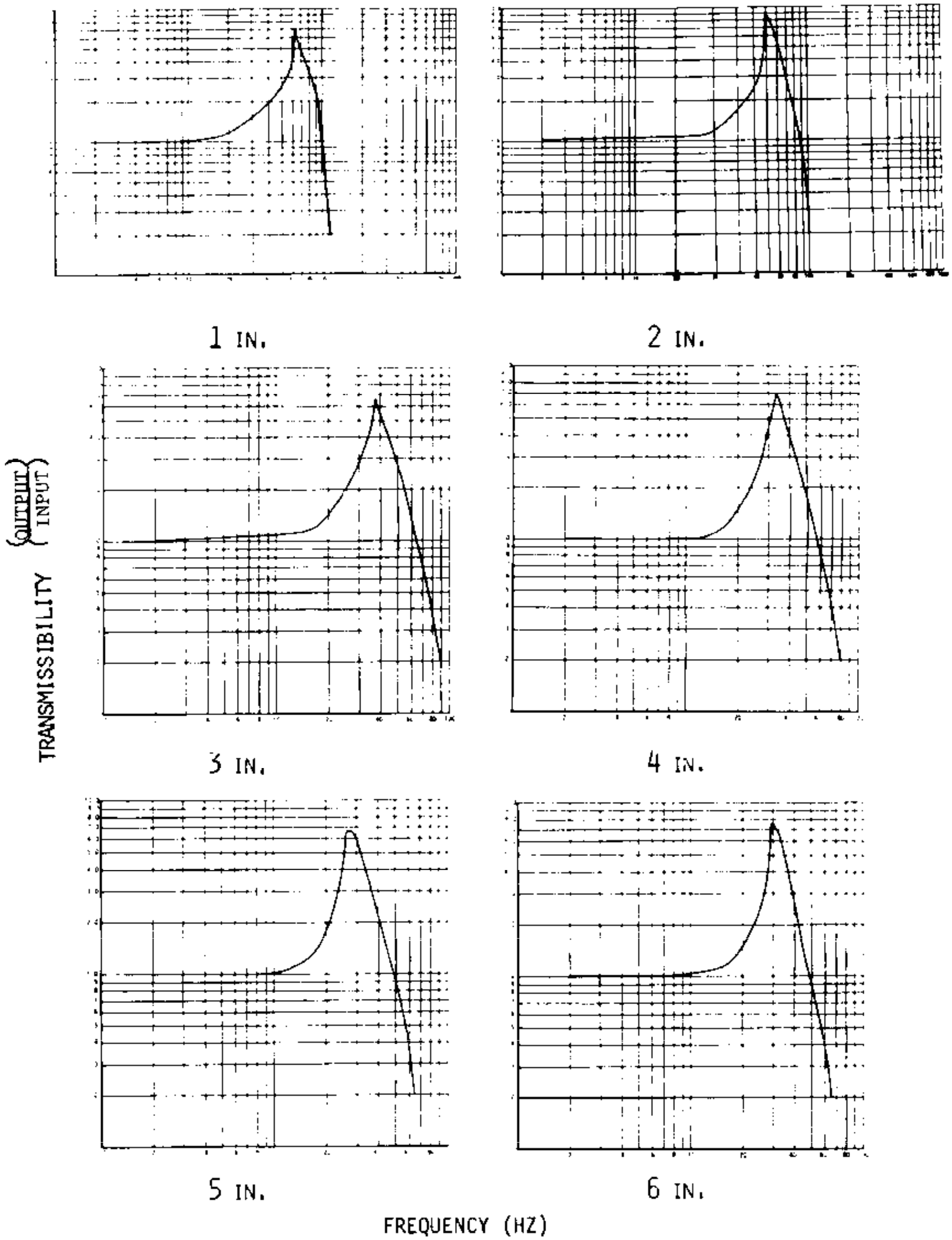
CURVE 10.1 POLYETHYKENE, 2.0 LBS/CU FT .09 PSI



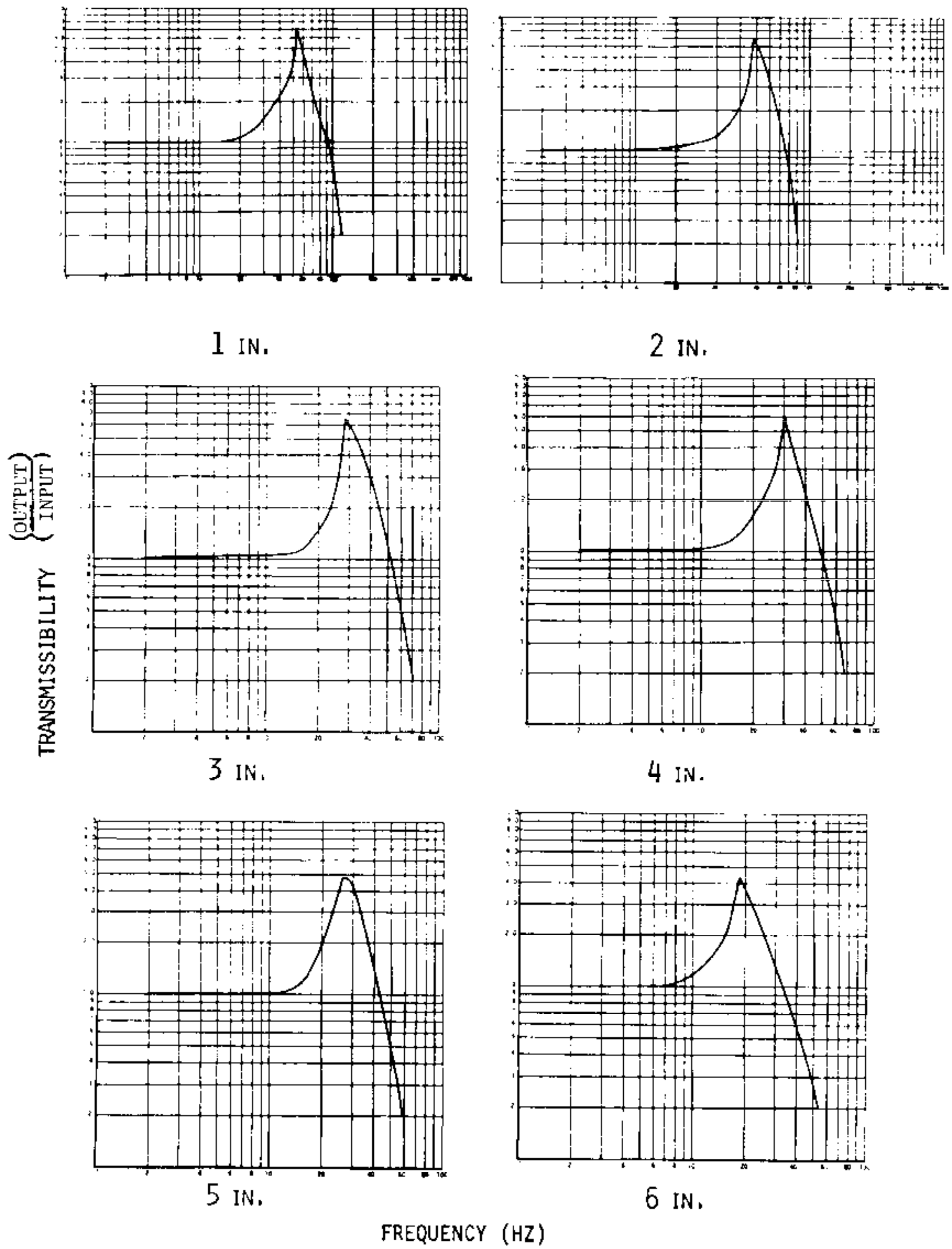
CURVE 10.2 POLYETHYLENE, 2.0 LBS/CU FT .26 PSI



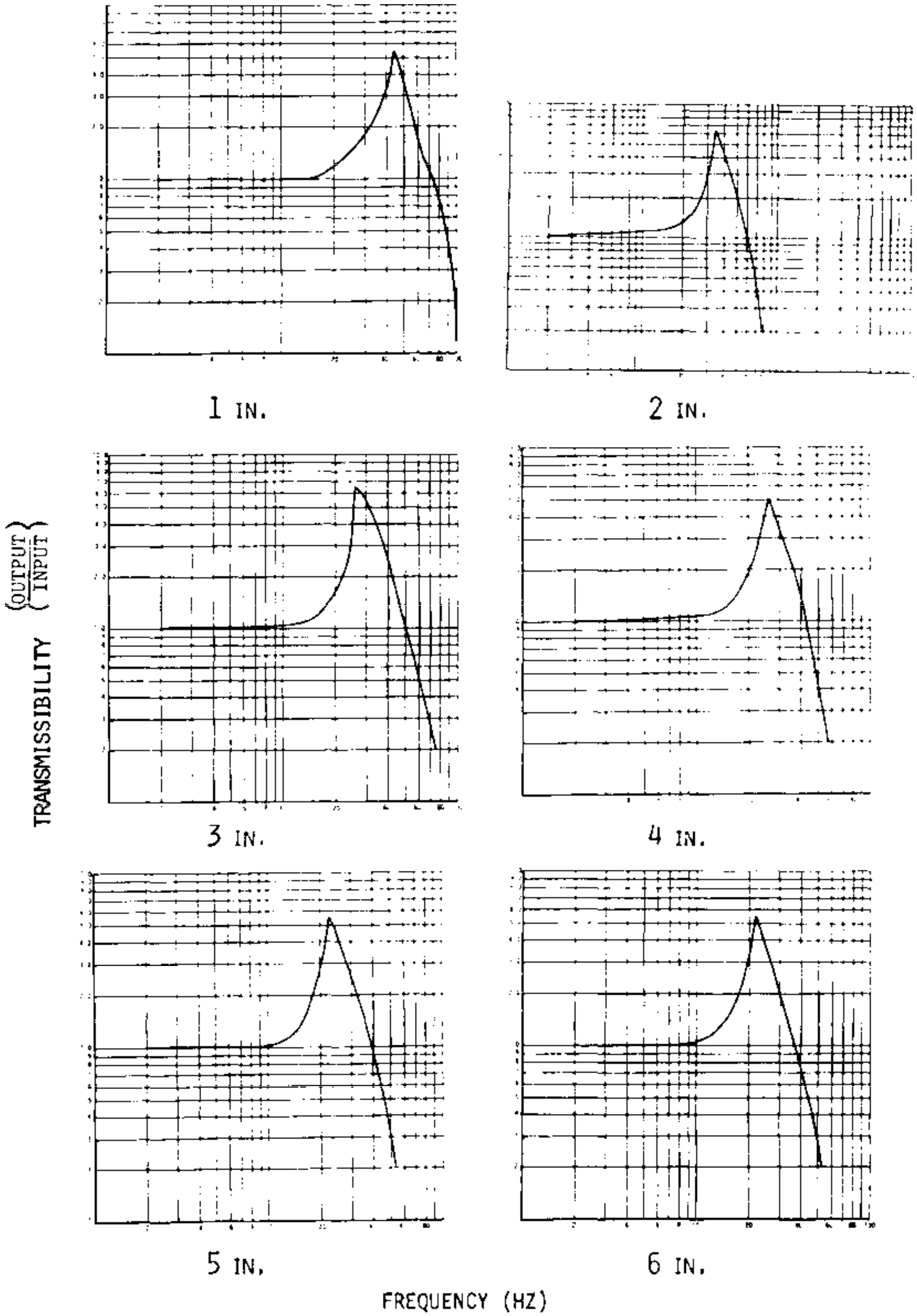
CUVRE 10.3 POLYETHYLENE, 2.0 LBS/CU FT .50 PSI



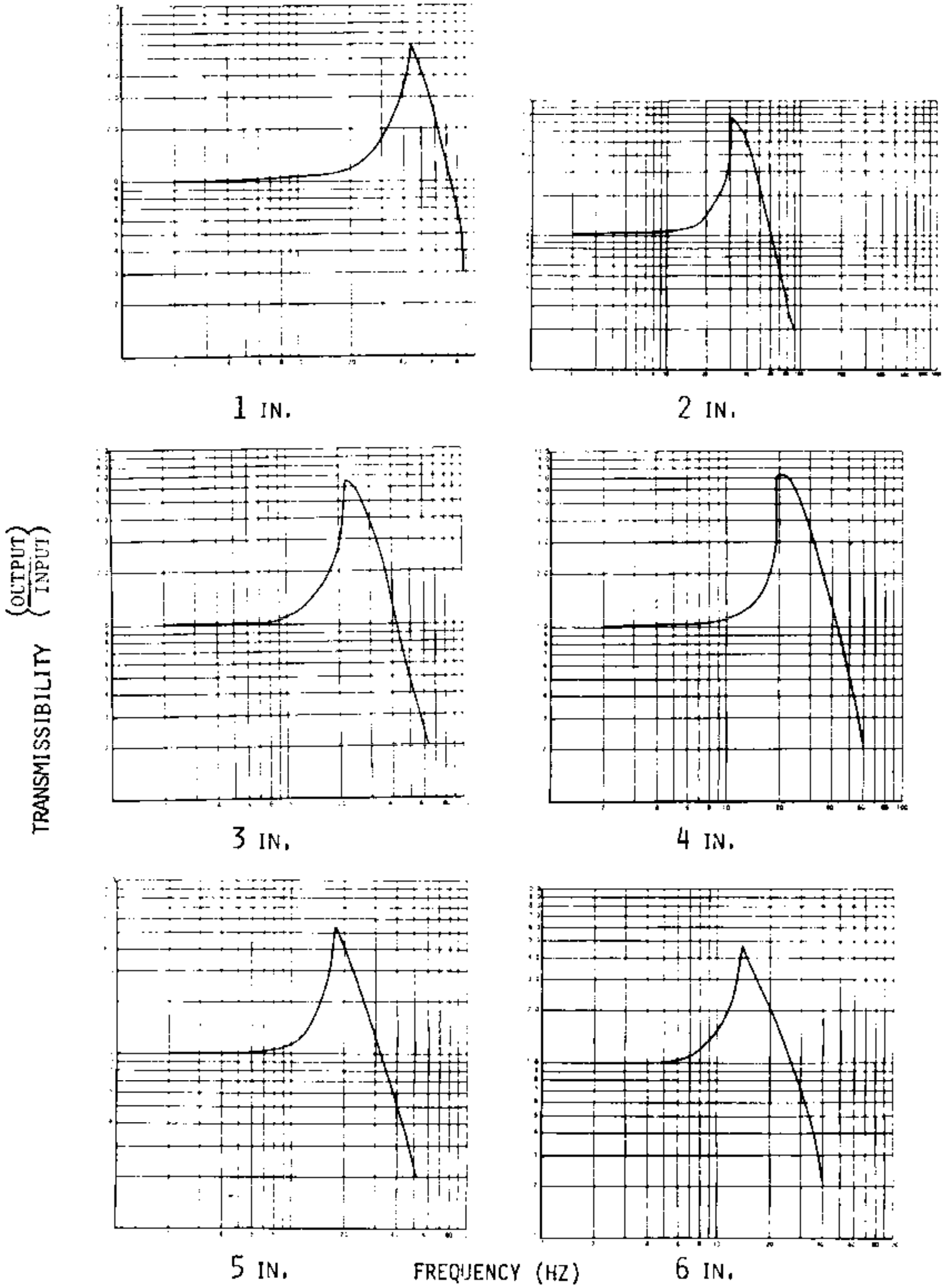
CURVE 10.4 POLYETHYLENE, 2.0 LBS/CU FT .61 PSI



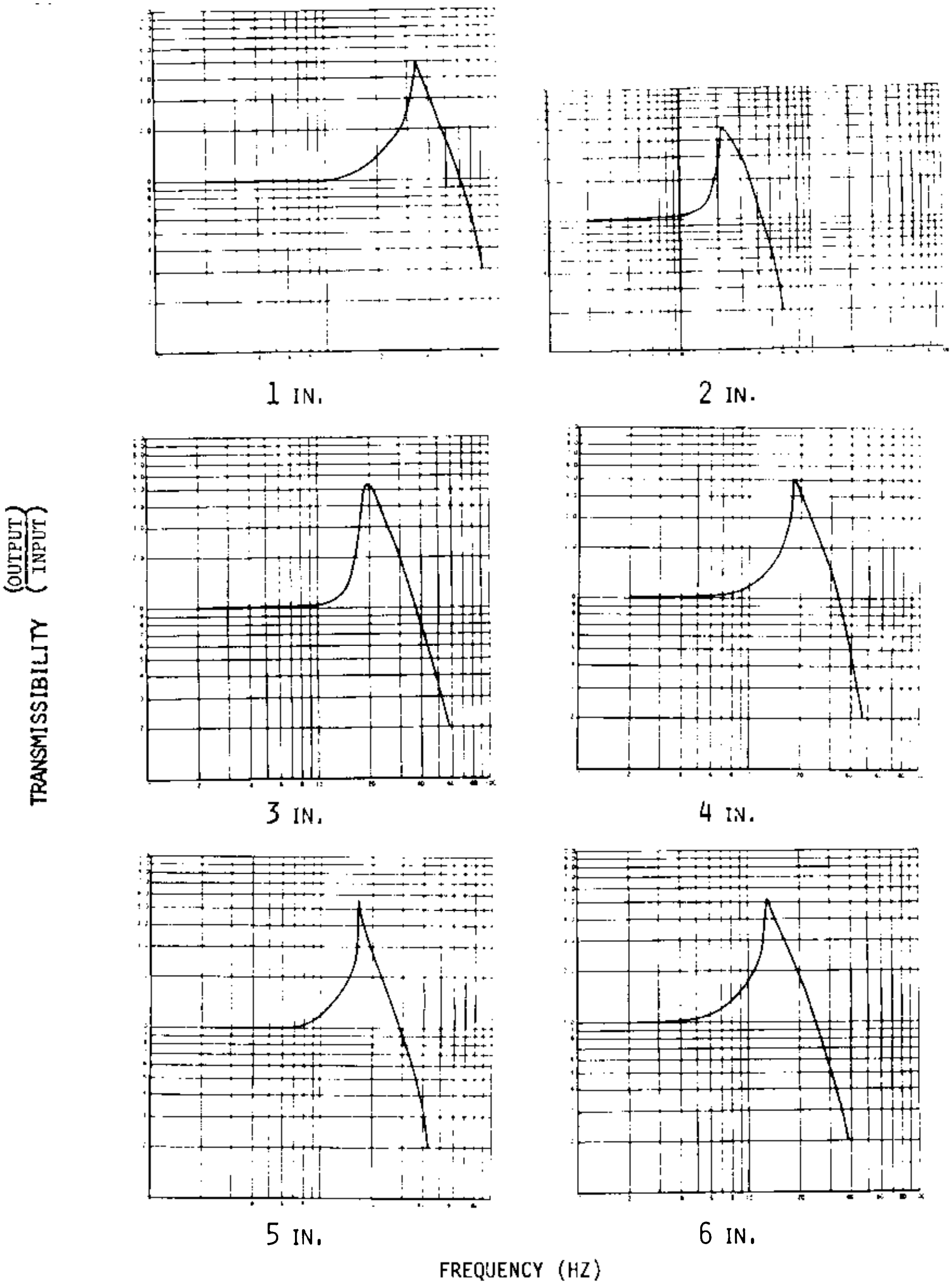
CURVE 10.5 POLYETHYLENE, 2.0 LBS/CU FT .81 PSI



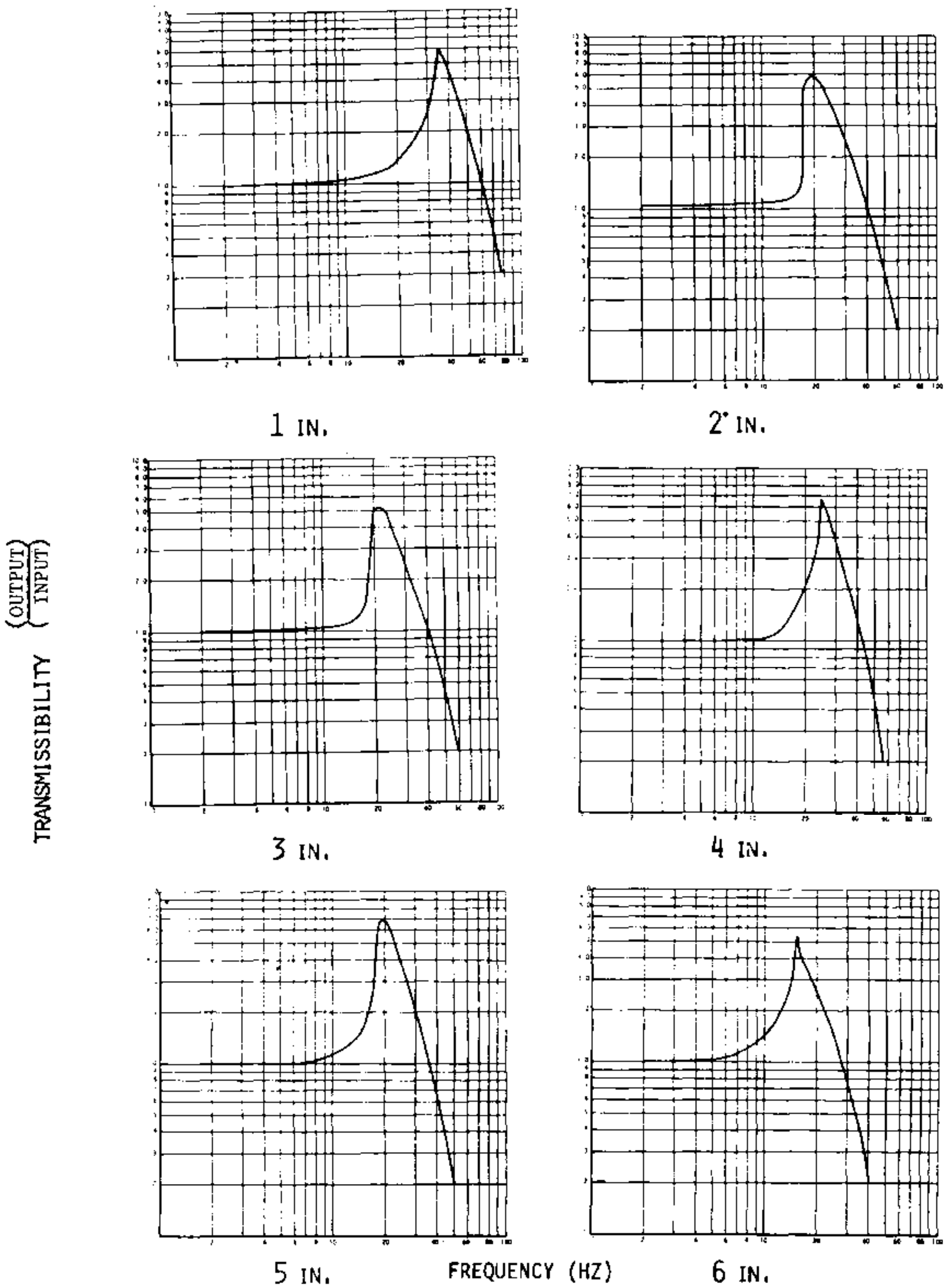
CURVE 10.6 POLYETHYLENE, 2.0 LBS/CU FT 1.0 PSI



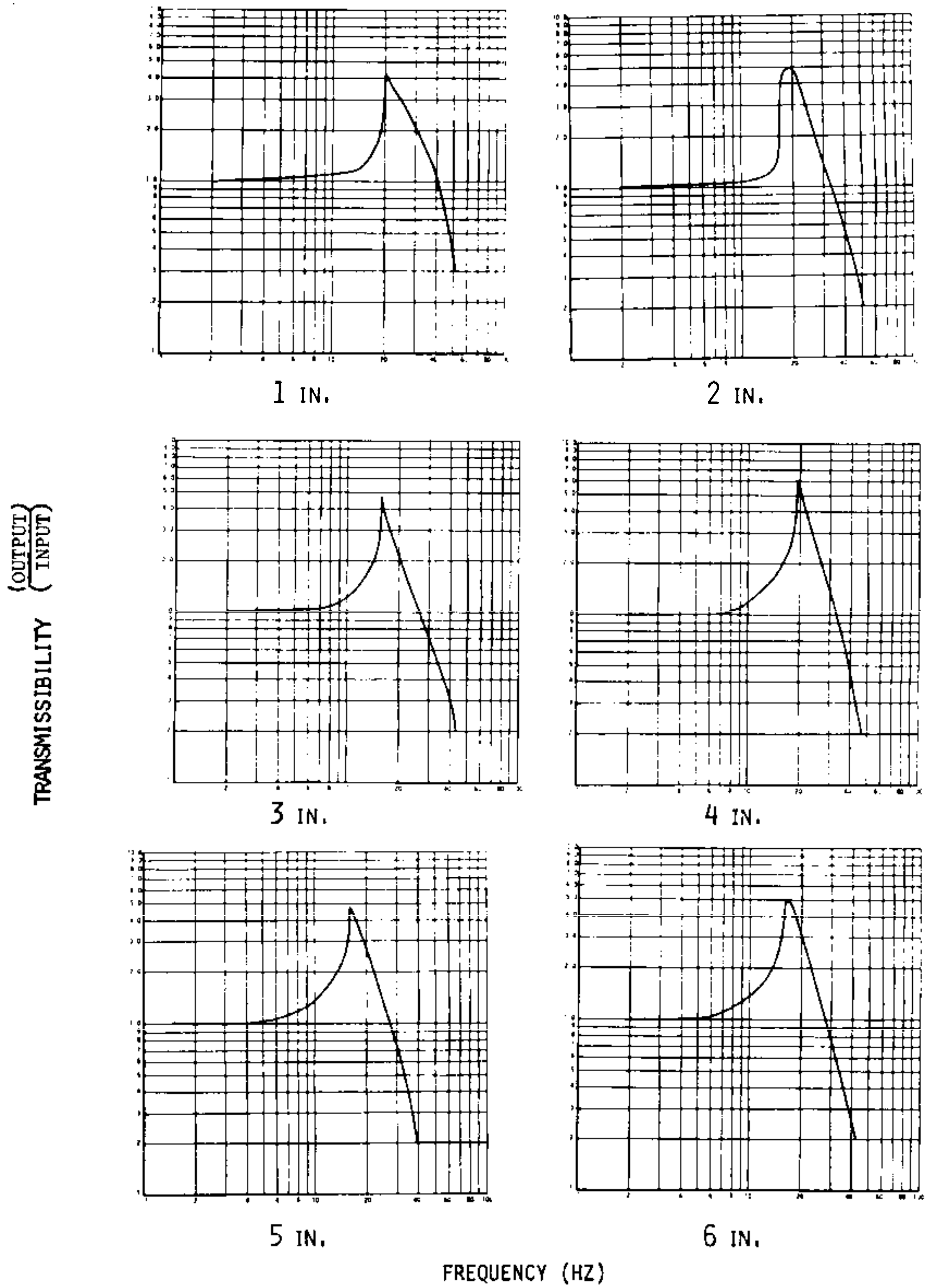
CURVE 10.7 POLYETHYLENE, 2.0 LBS/CU FT 1.2 PSI



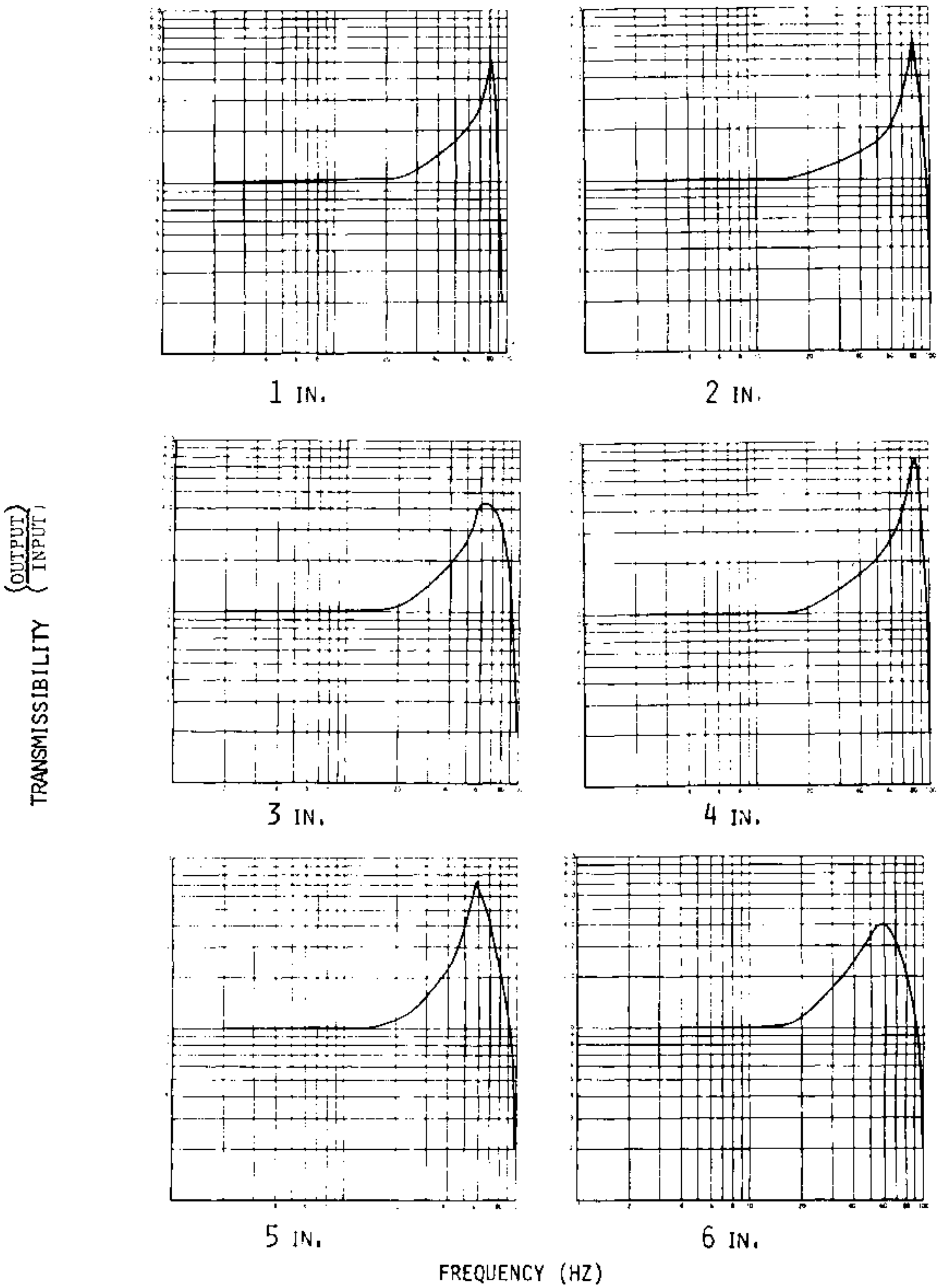
CURVE 10.8 POLYETHYLENE, 2.0 LBS/CU FT 1.3 PSI



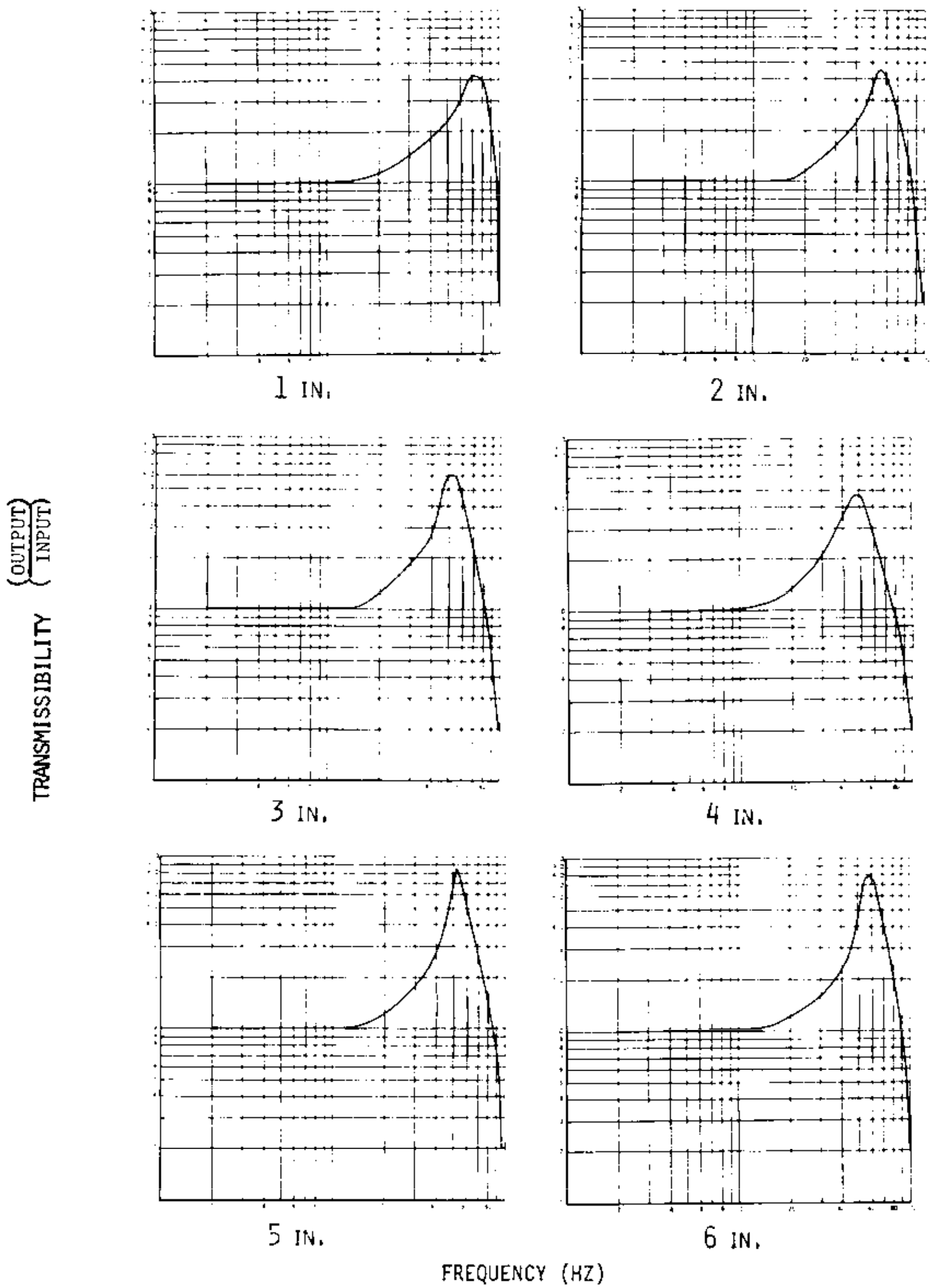
CURVE 10.9 POLYETHYLENE, 2.0 LBS/CU FT 1.5 PSI



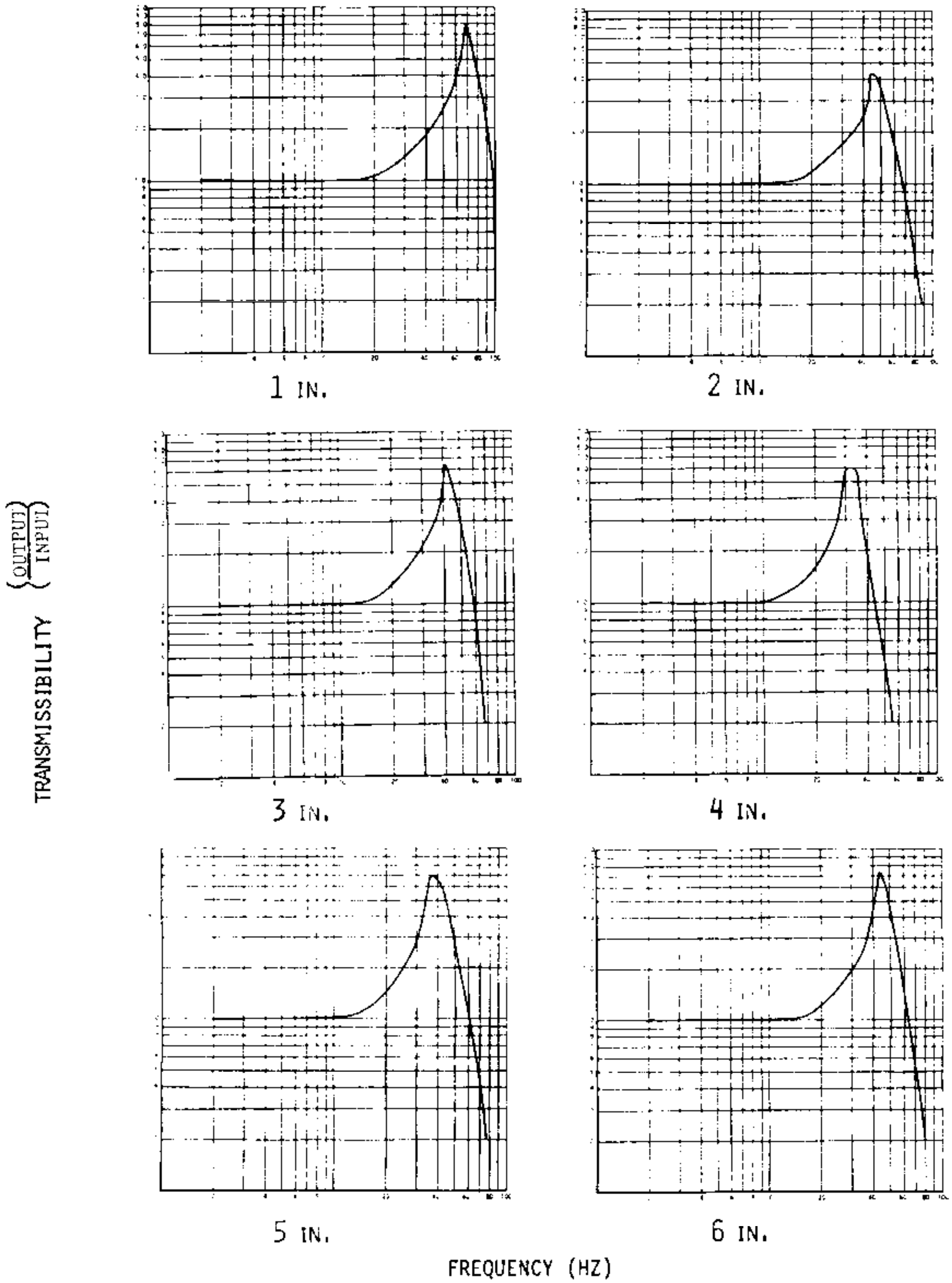
CURVE 10.10 POLYETHYLENE, 2.0 LBS/CU FT 2.0 PSI



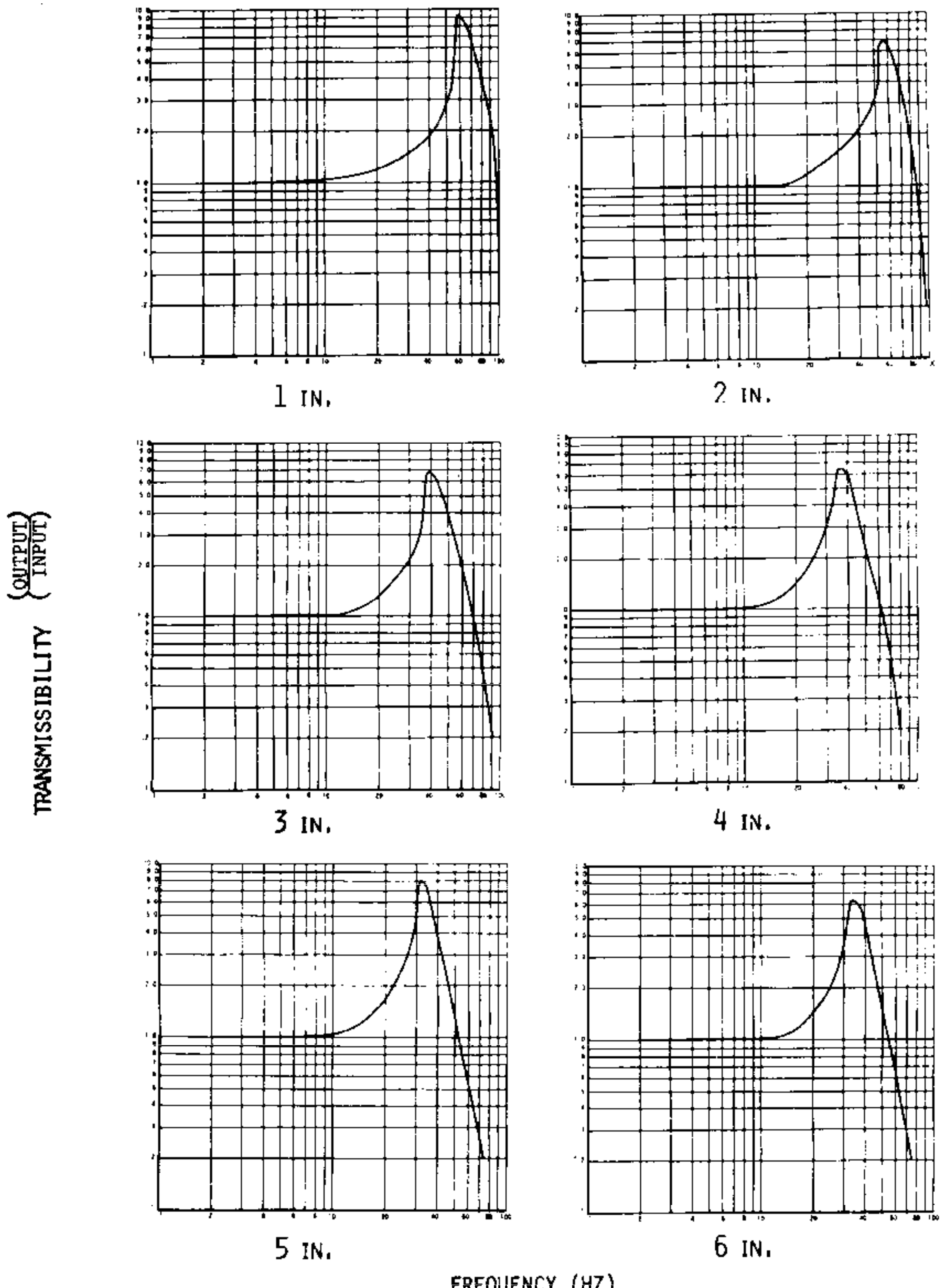
CURVE 11.1 POLYETHYLENE, 4.0 LBS/CU FT .09 PSI



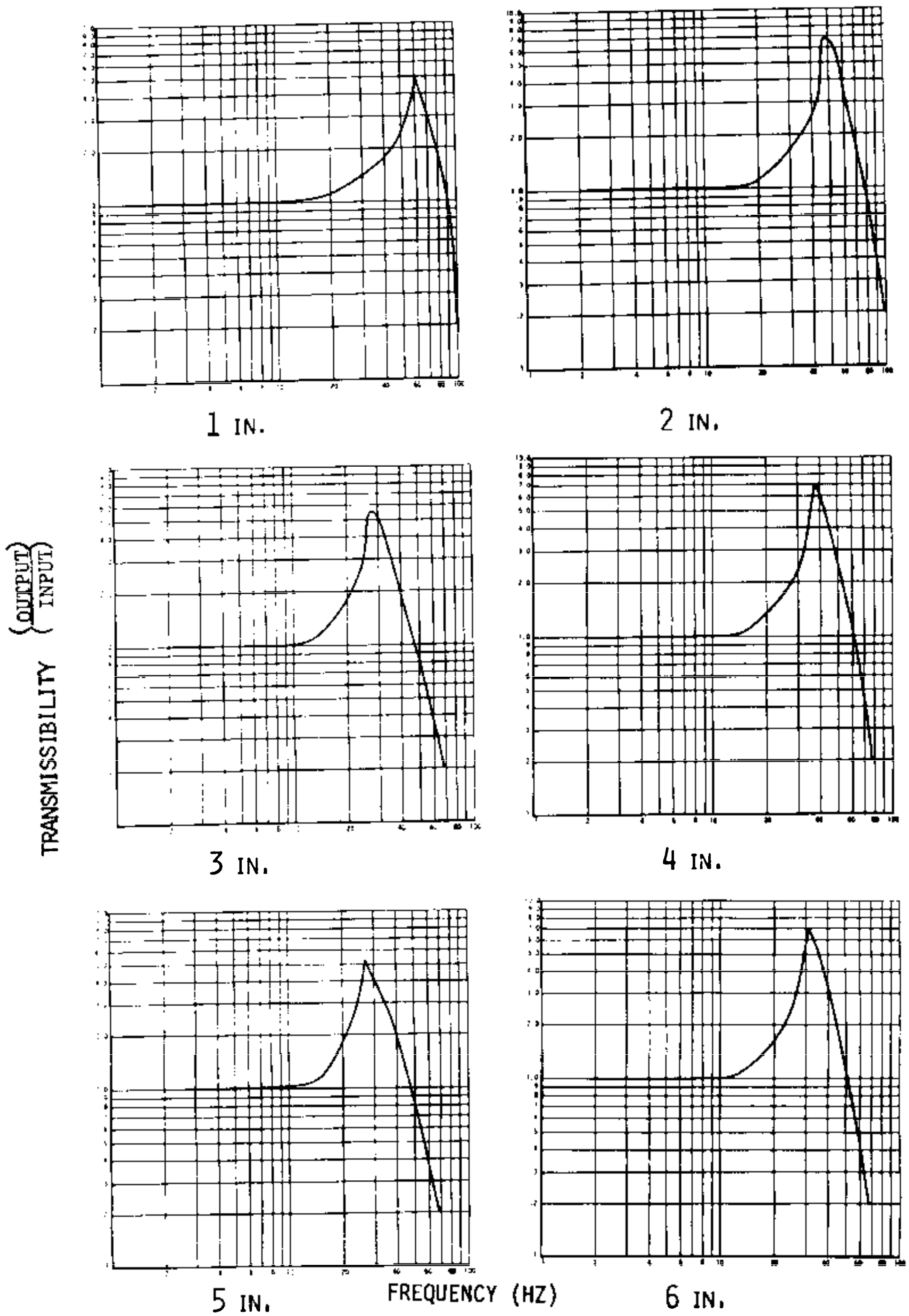
CURVE 11.2 POLYETHYLENE, 4.0 LBS/CU FT .26 PSI



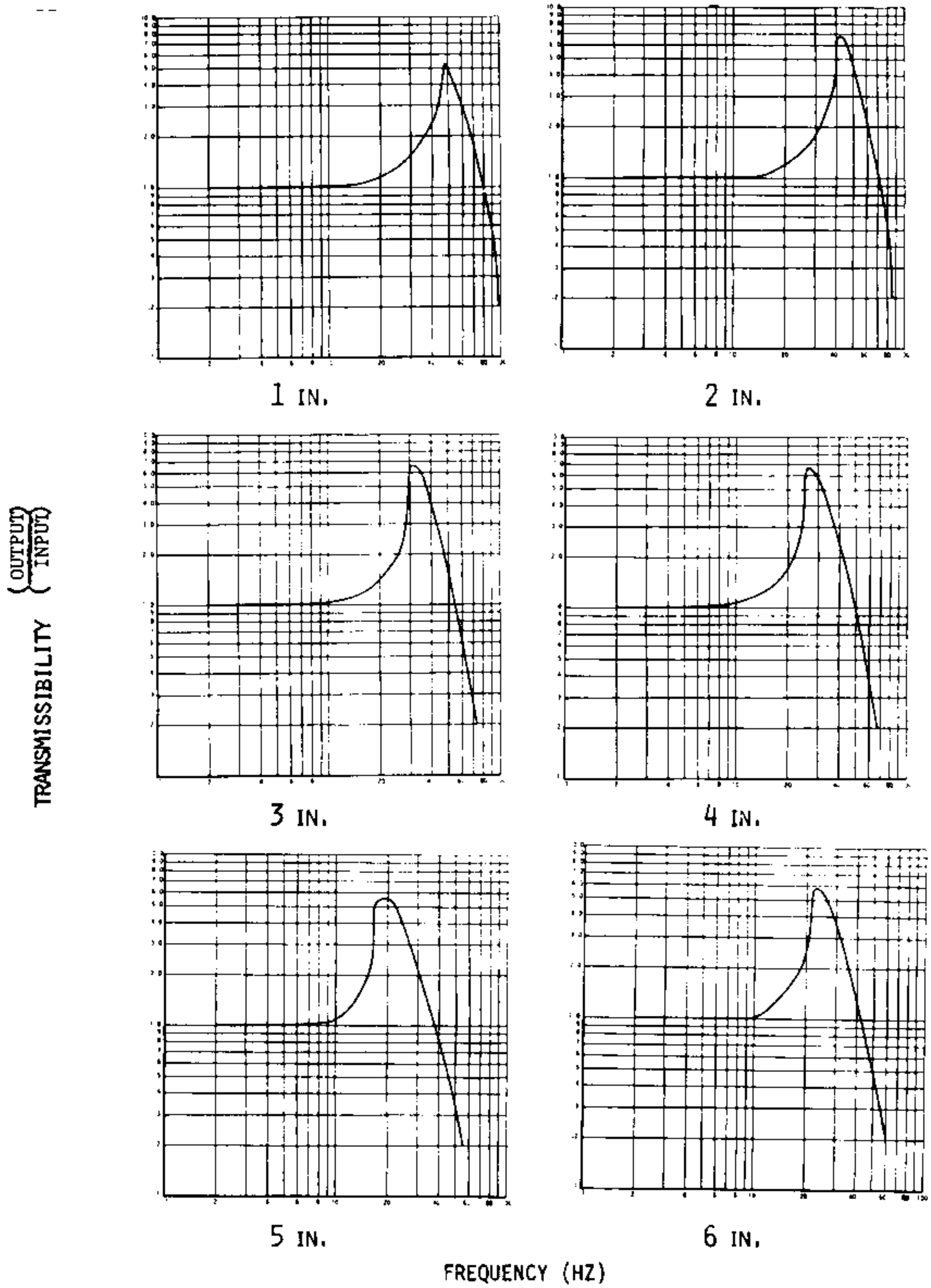
CURVE 11.3 POLYETHYLENE, 4.0 LBS/CU FT .50 PSI



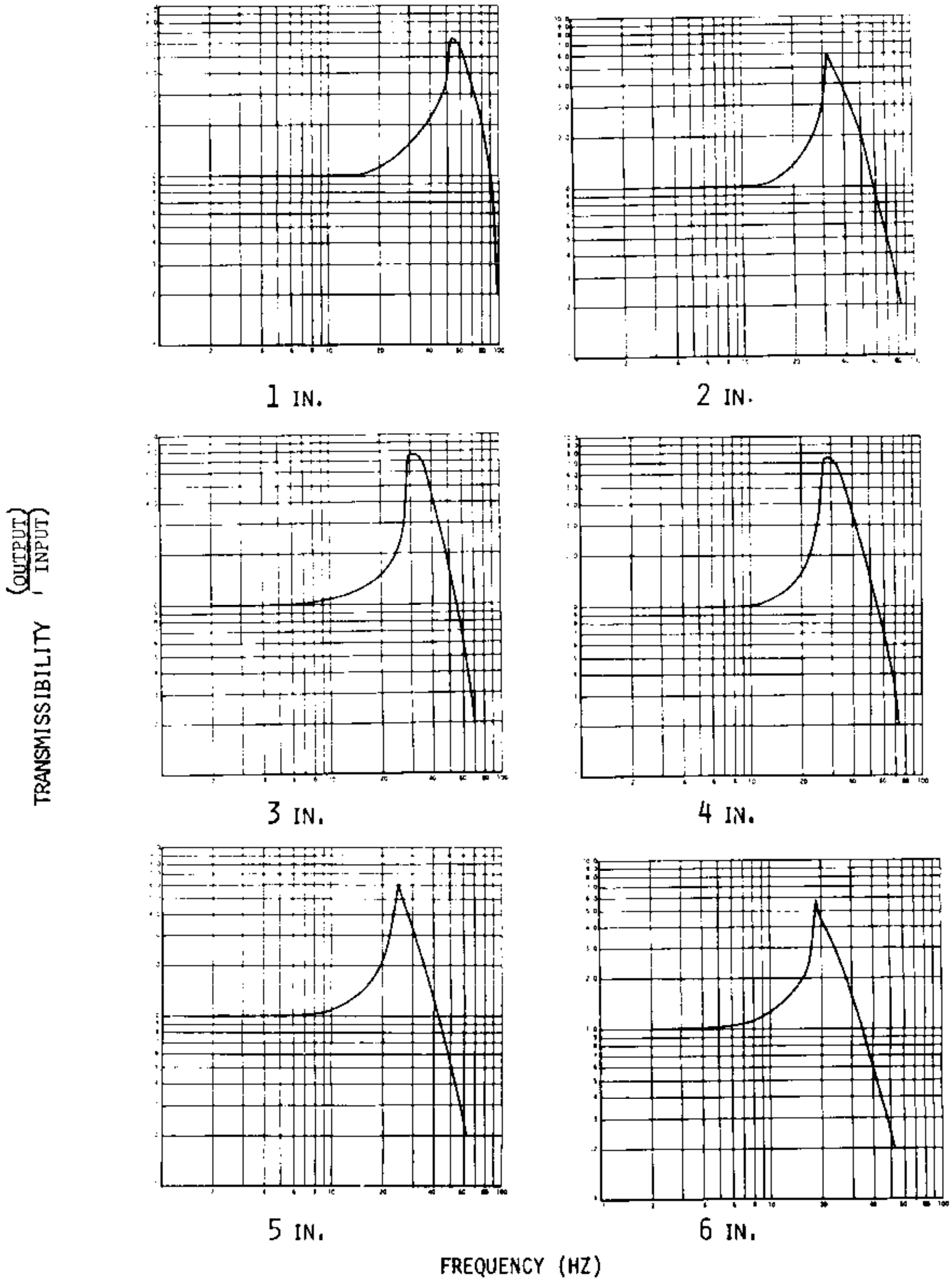
CURVE 11.4 POLYETHYLENE, 4.0 LBS/CU FT .61 PSI



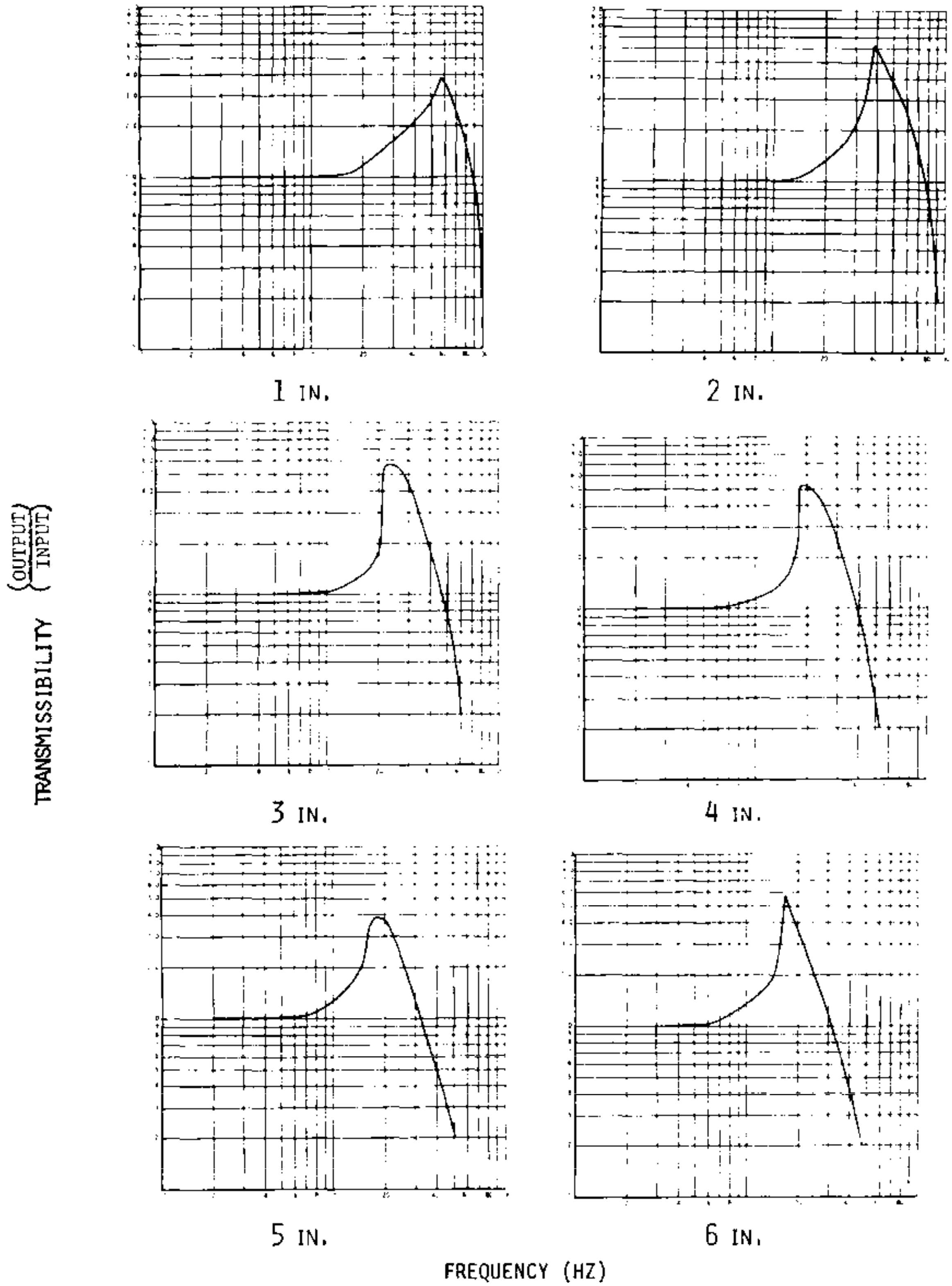
CURVE 11.5 POLYETHYLENE, 4.0 LBS/CU FT .81 PSI



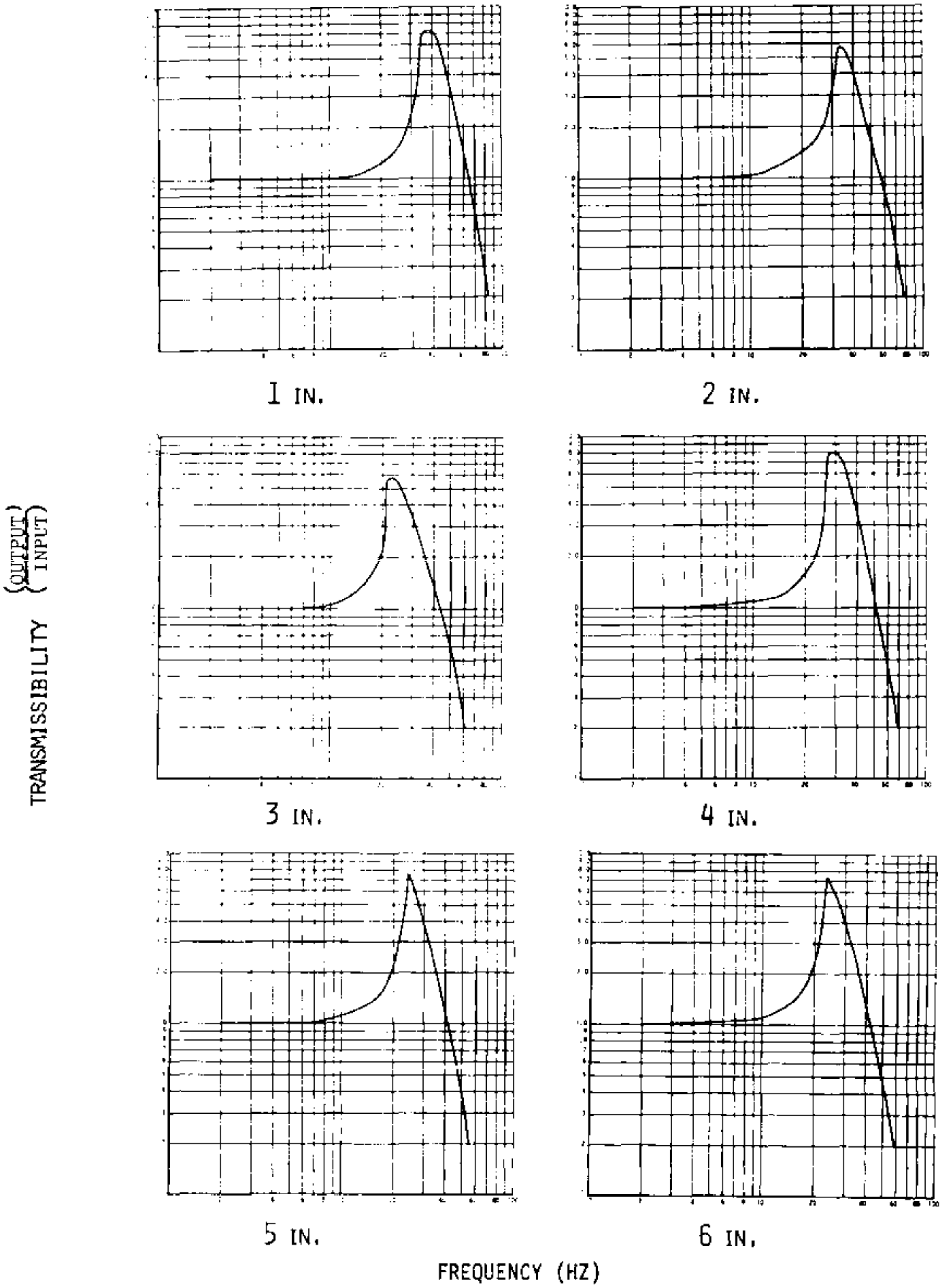
CURVE 11.7 POLYETHYLENE, 4.0 LBS/CU FT 1.2 PSI



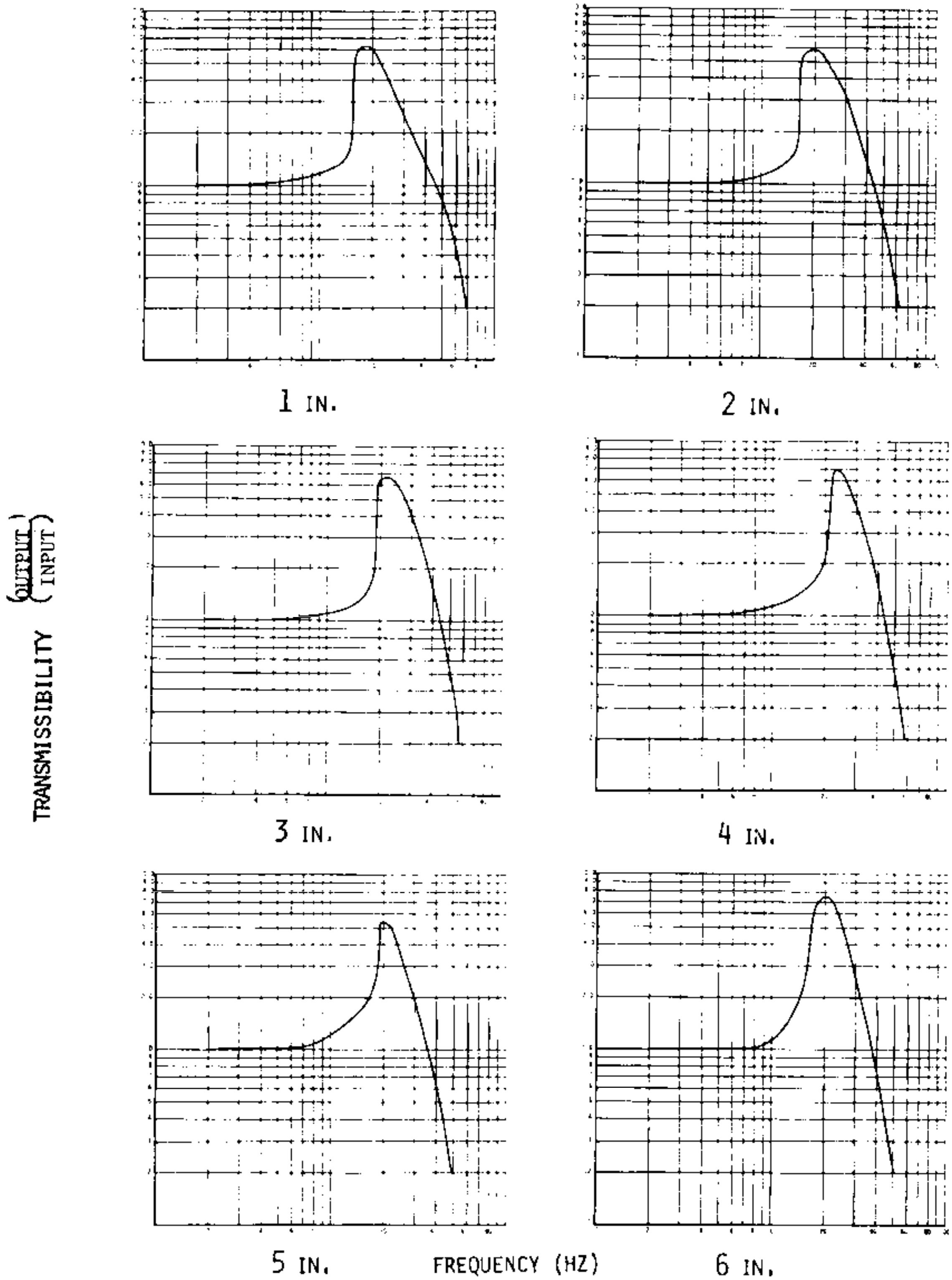
CURVE 11.7 POLYETHYLENE, 4.0 LBS/CU FT 1.2 PSI



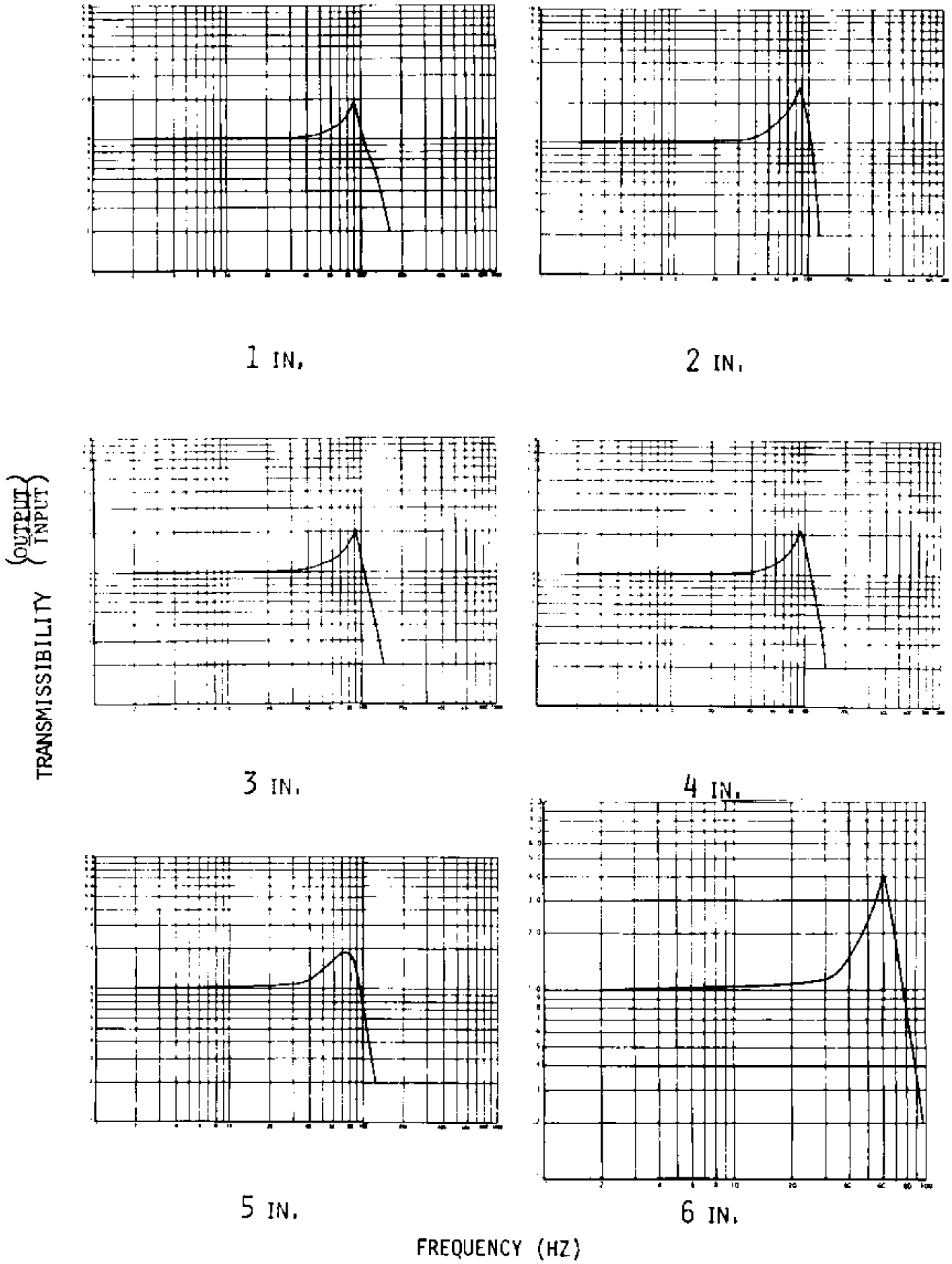
CURVE 11.8 POLYETHYLENE, 4.0 LBS/CU FT 1.3 PSI



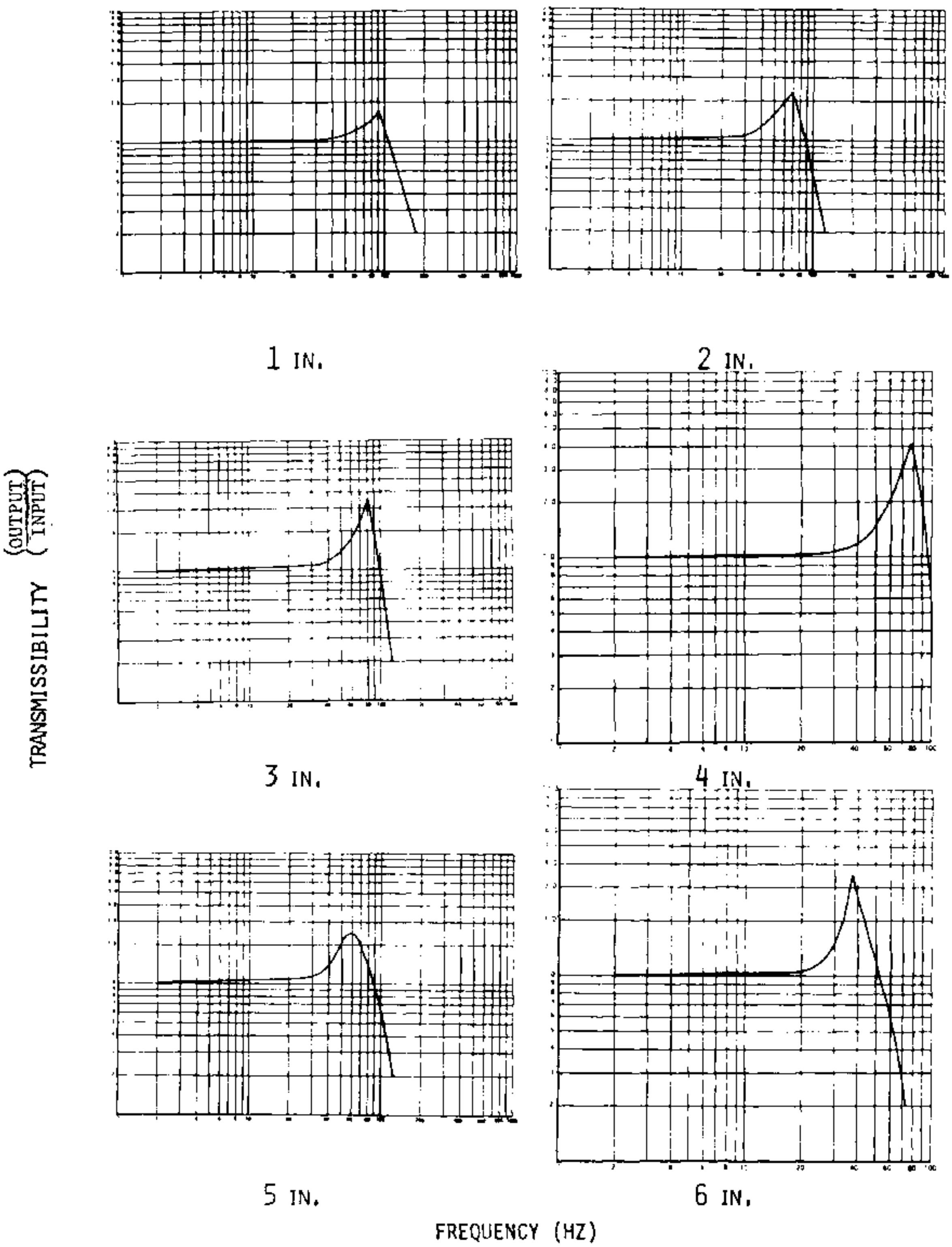
CURVE 11.9 POLYETHYLENE, 4.0 LBS/CU FT 1.5 PSI



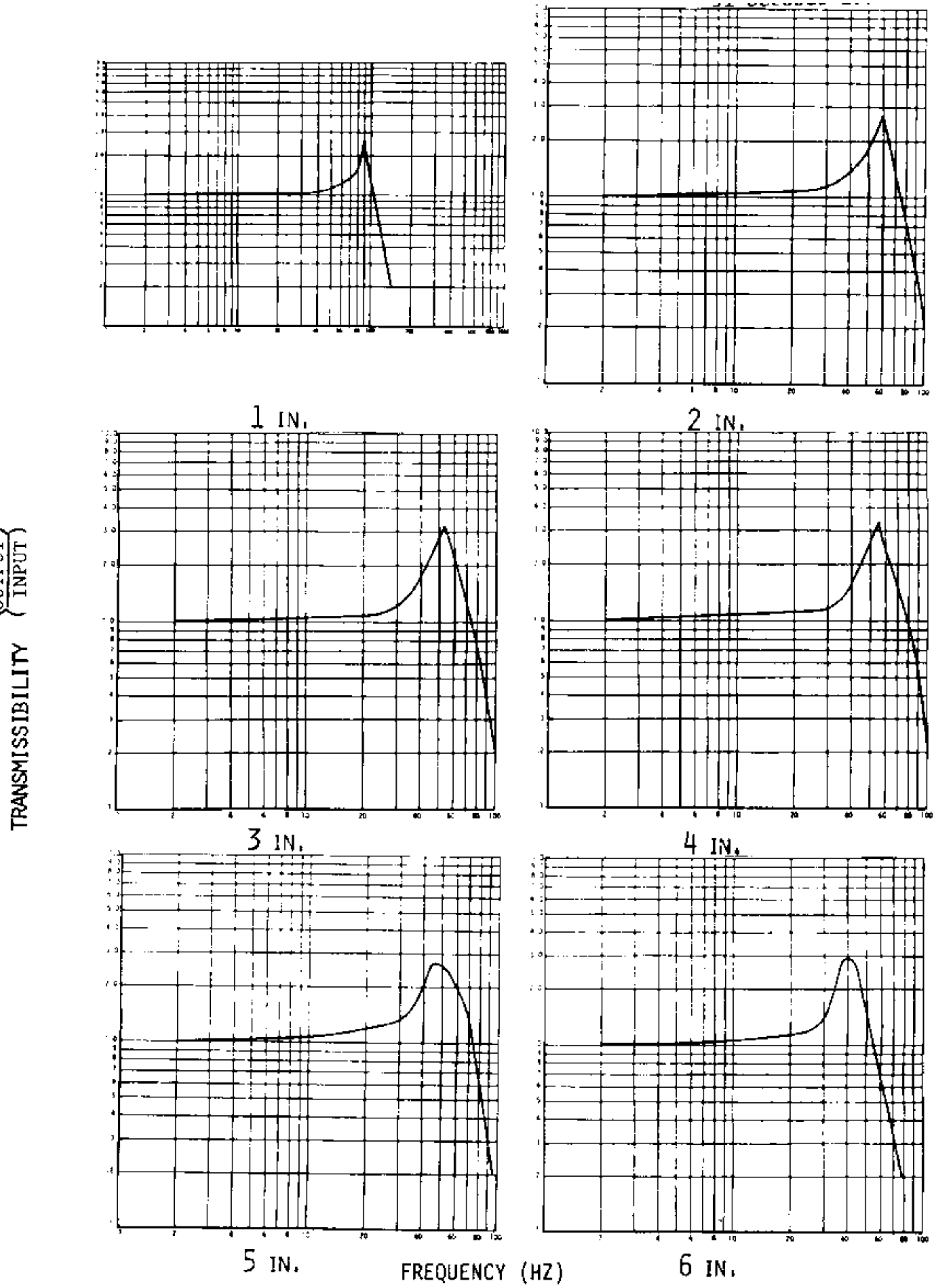
CURVE 11.10 POLYETHYLENE, 4.0 LBS/CU FT 2.0 PSI



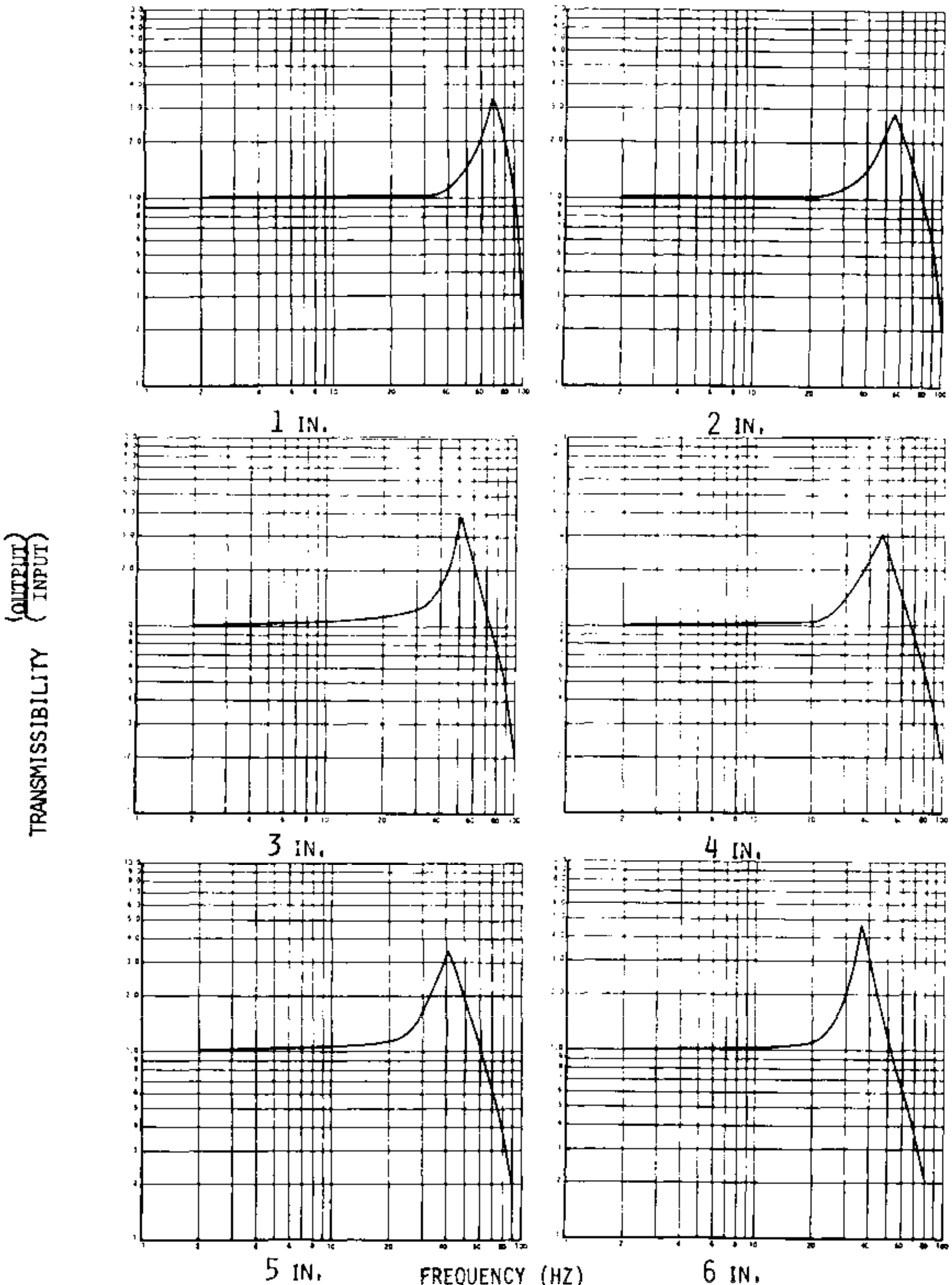
CURVE 12.1 POLYSTYRENE FOAM, 1.5 LBS/CU FT .1 PSI



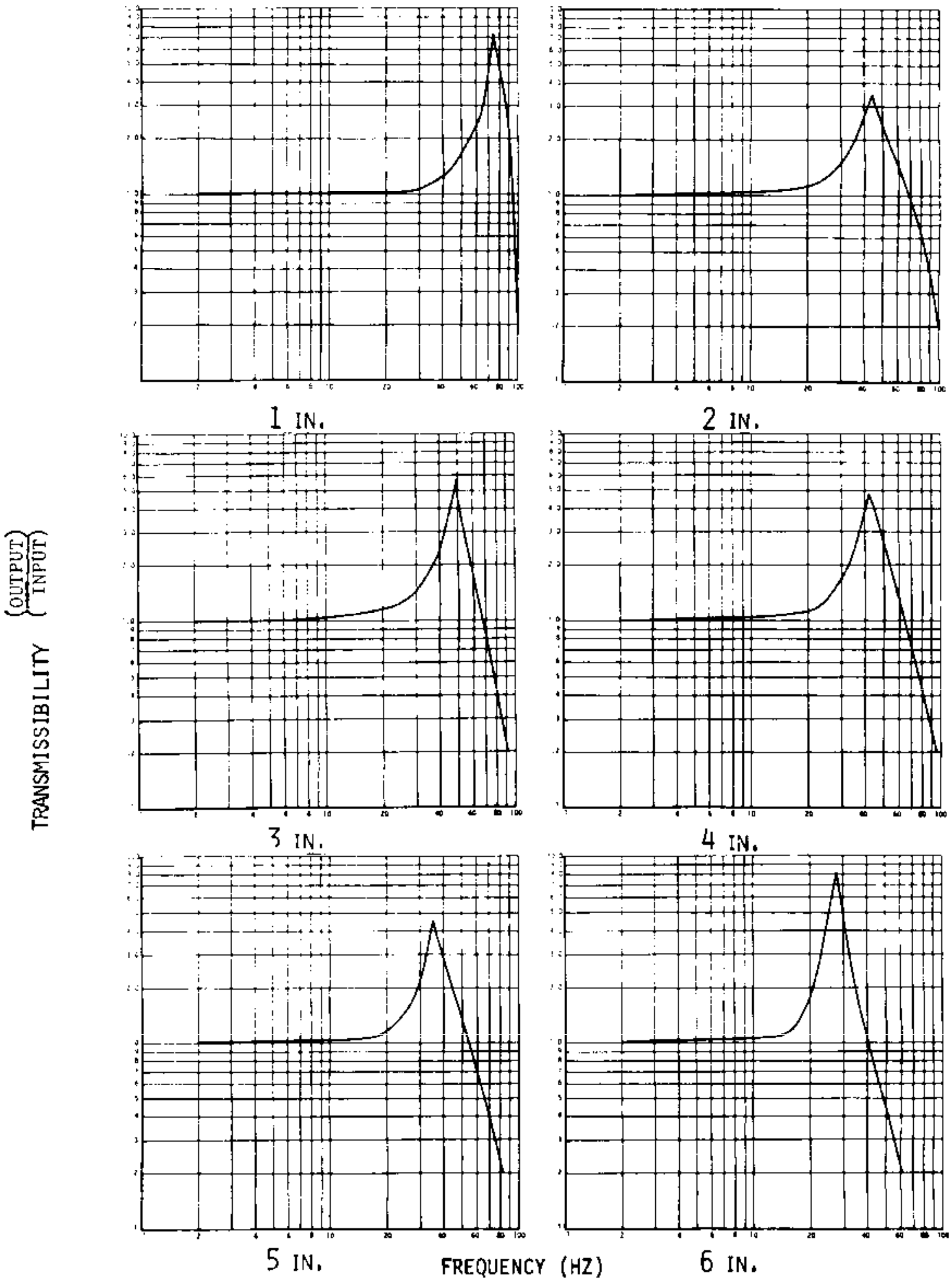
CURVE 12.2 POLYSTYRENE FOAM, 1.5 LBS/CU FT .25 PSI



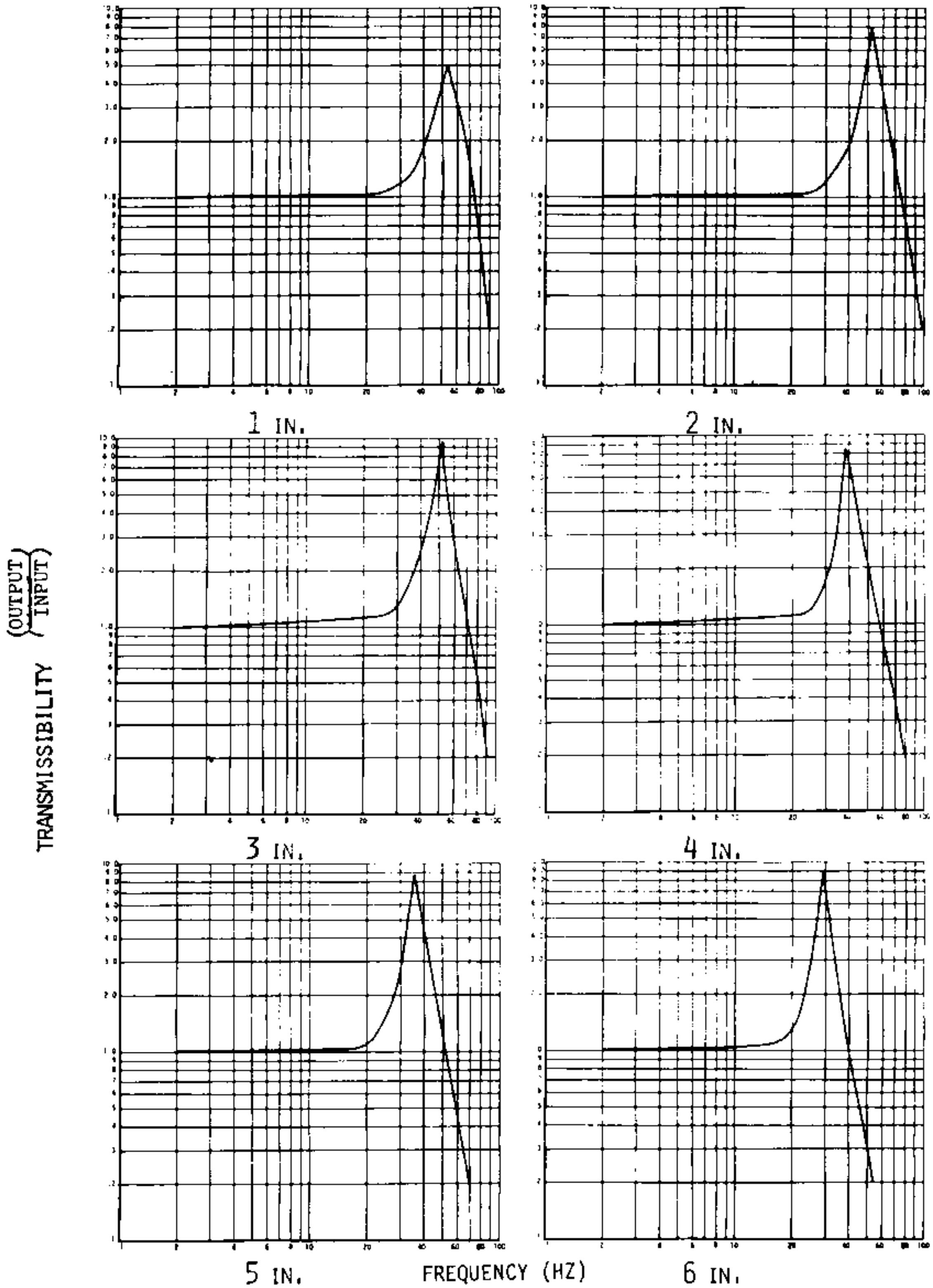
CURVE 12.3 POLYSTYRENE FOAM, 1.5 LBS/CU FT .464 PSI



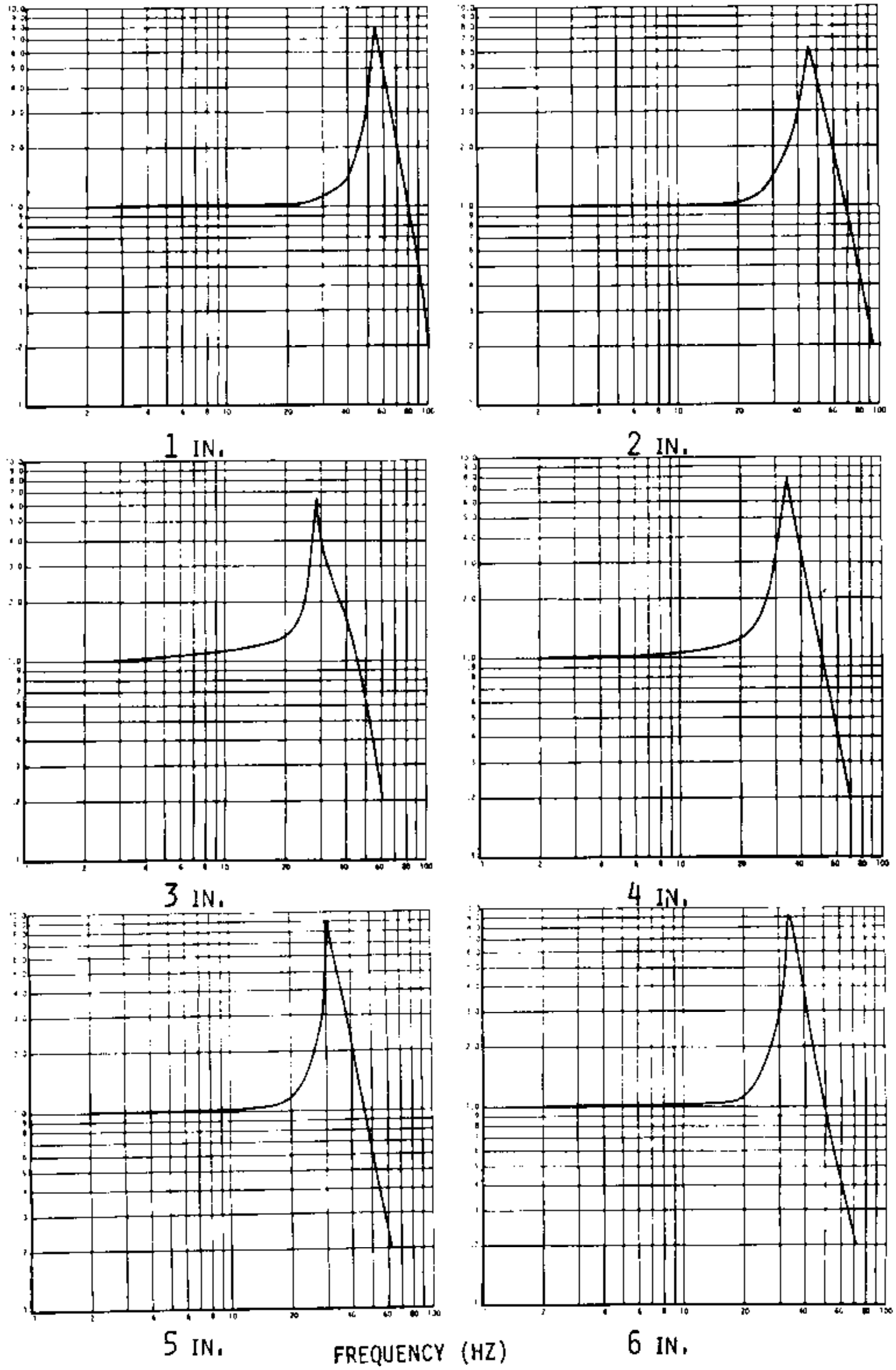
CURVE 12.4 POLYSTYRENE FOAM, 1.5 LBS/CU FT .533 PSI



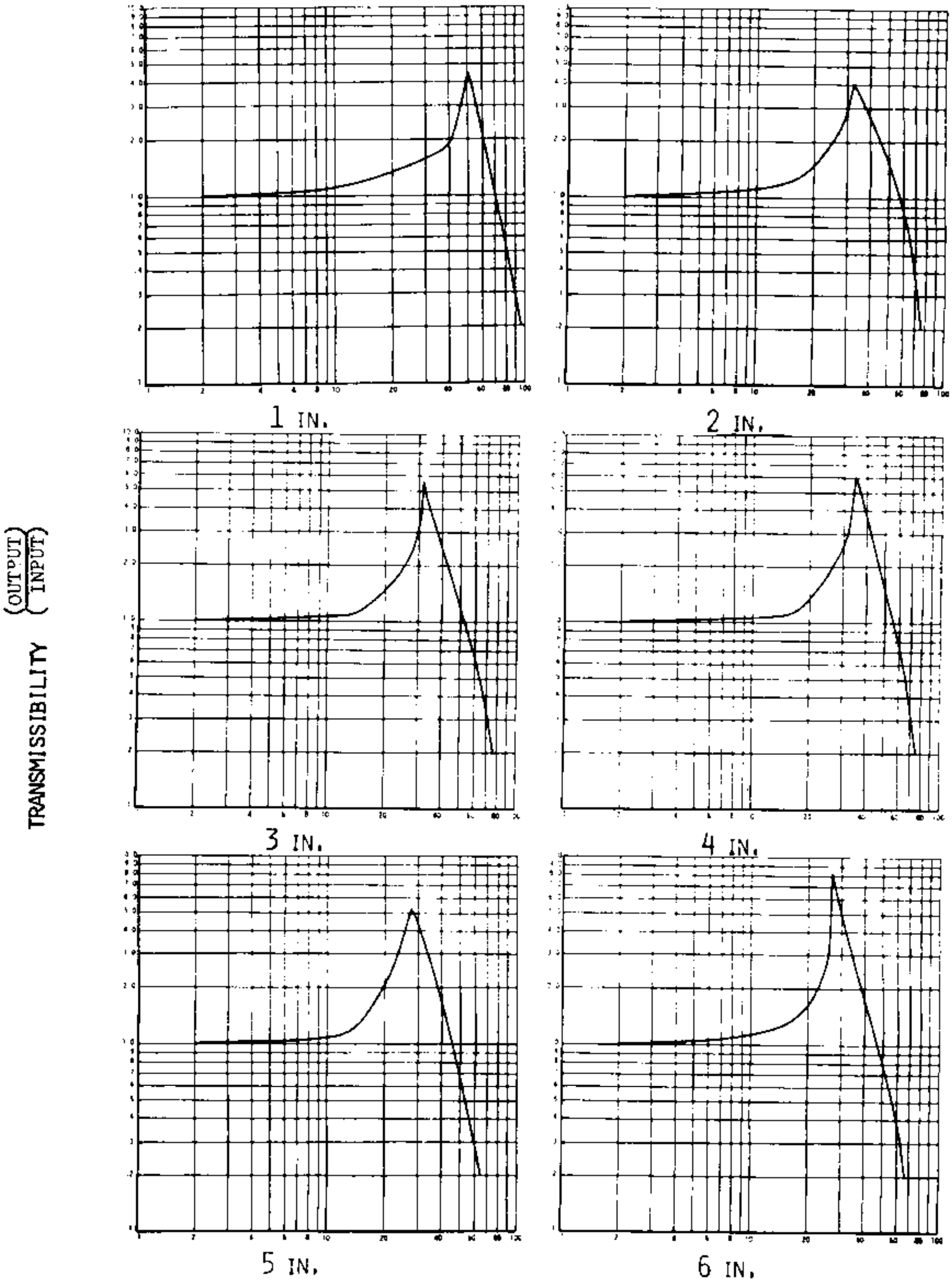
CURVE 12.5 POLYSTYRENE FOAM, 1.5 LBS/CU FT .64 PSI



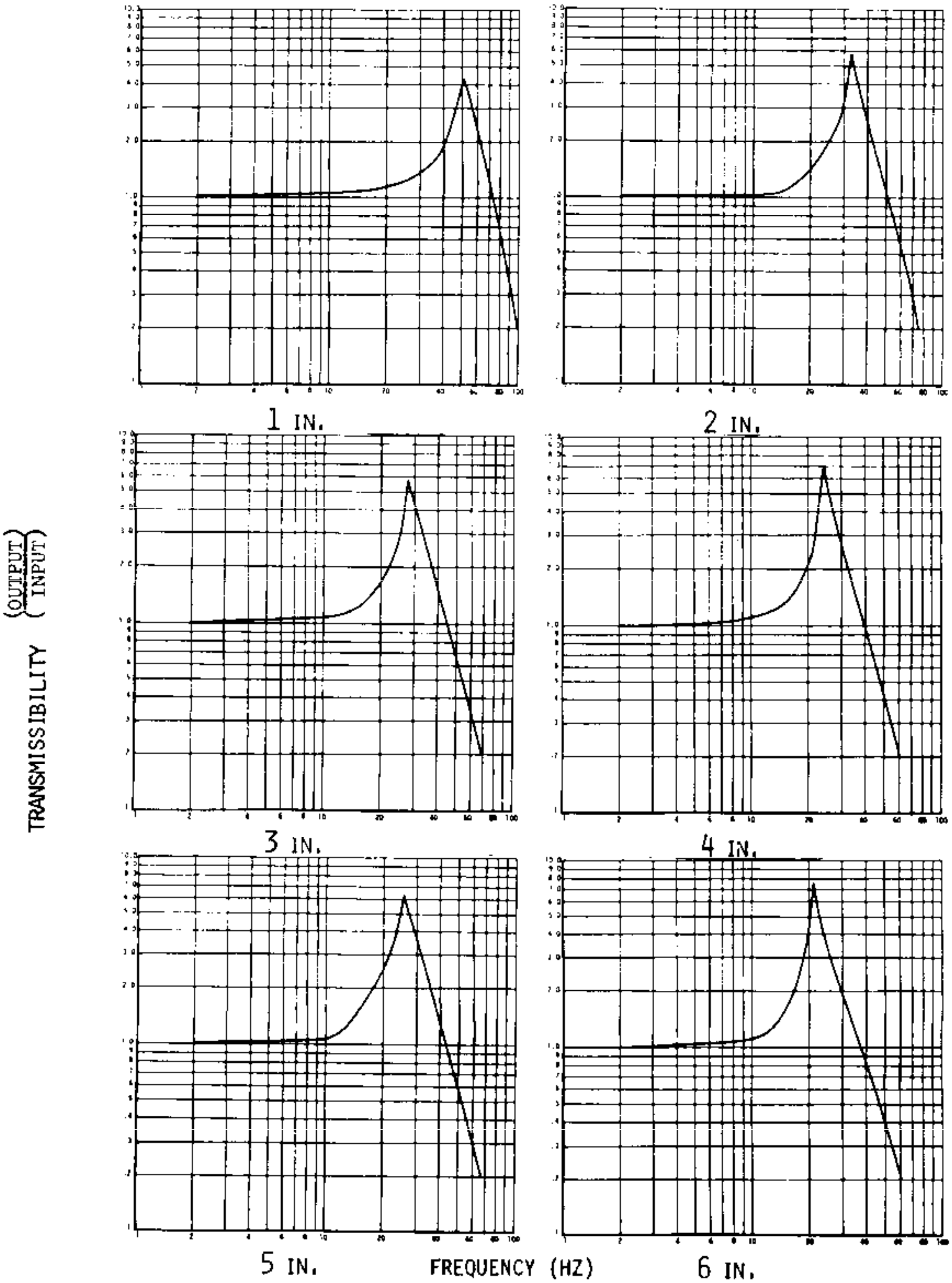
CURVE 12.7 POLYSTYRENE FOAM, 1.5 LBS/CU FT .95 PSI



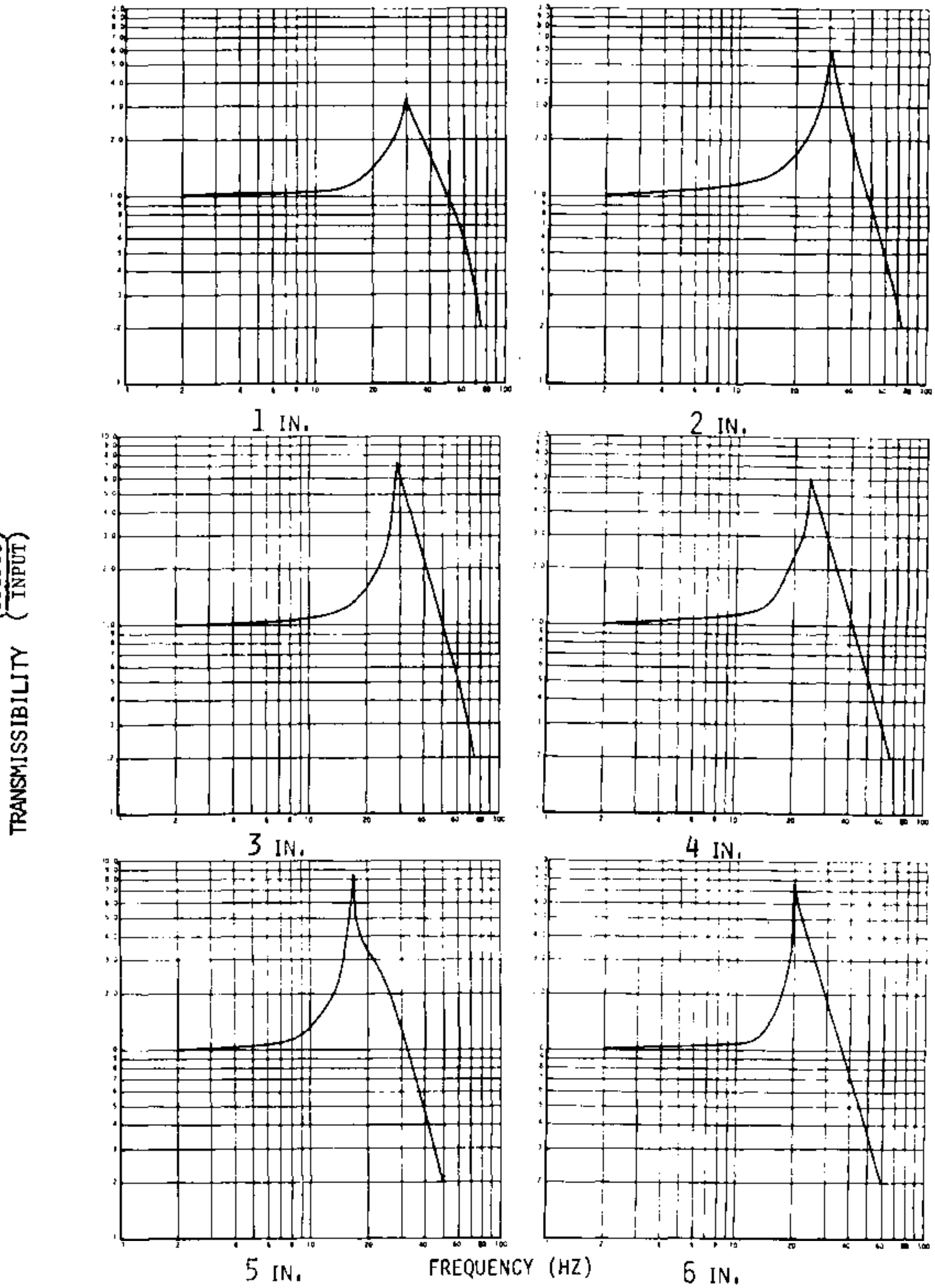
CURVE 12.7 POLYSTRENE FOAM, 1.5 LBS/CU FT .95 PSI



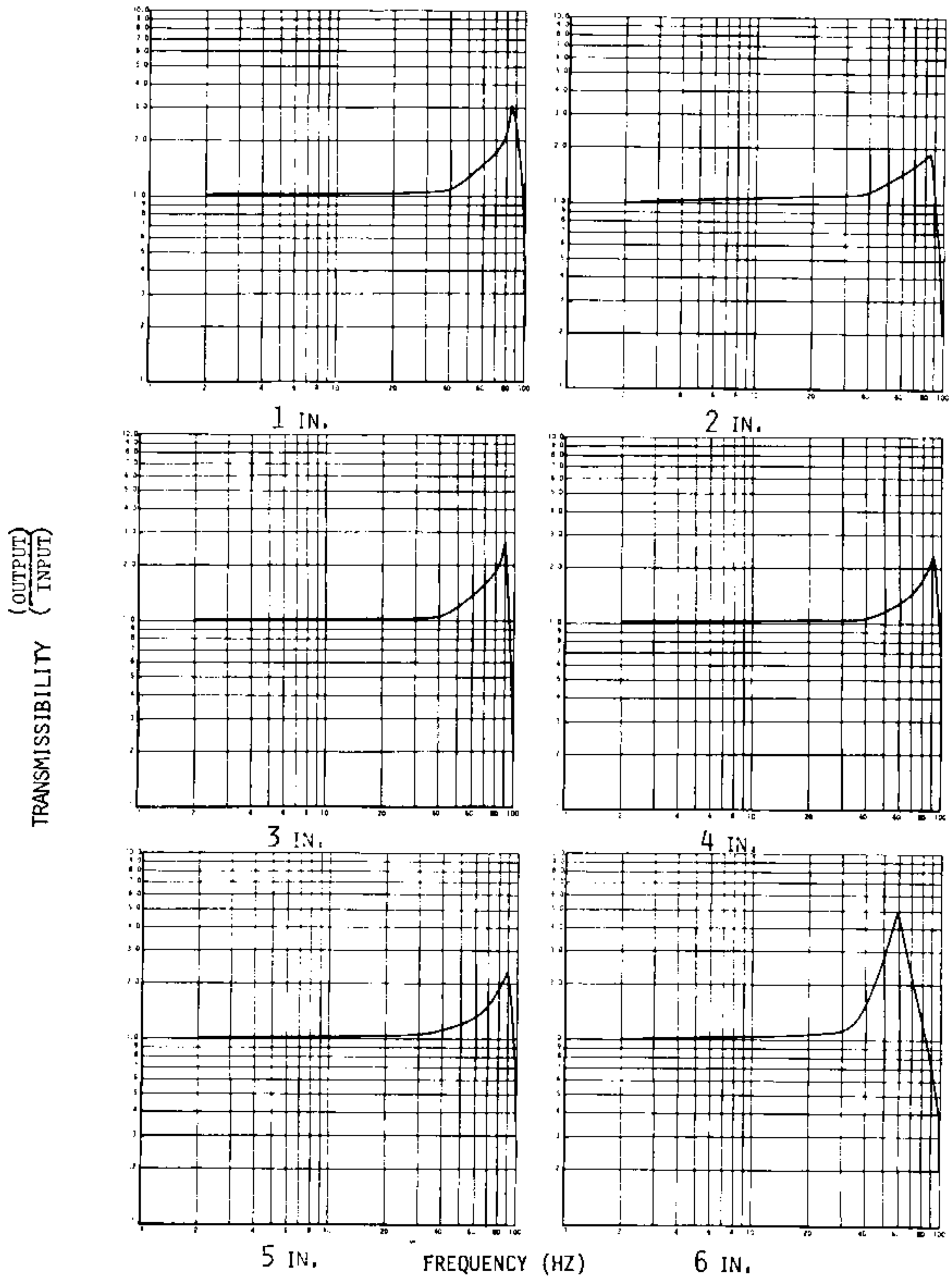
CURVE 12.8 POLYSTYRENE FOAM, 1.5 LBS/CU FT 1.15 PSI



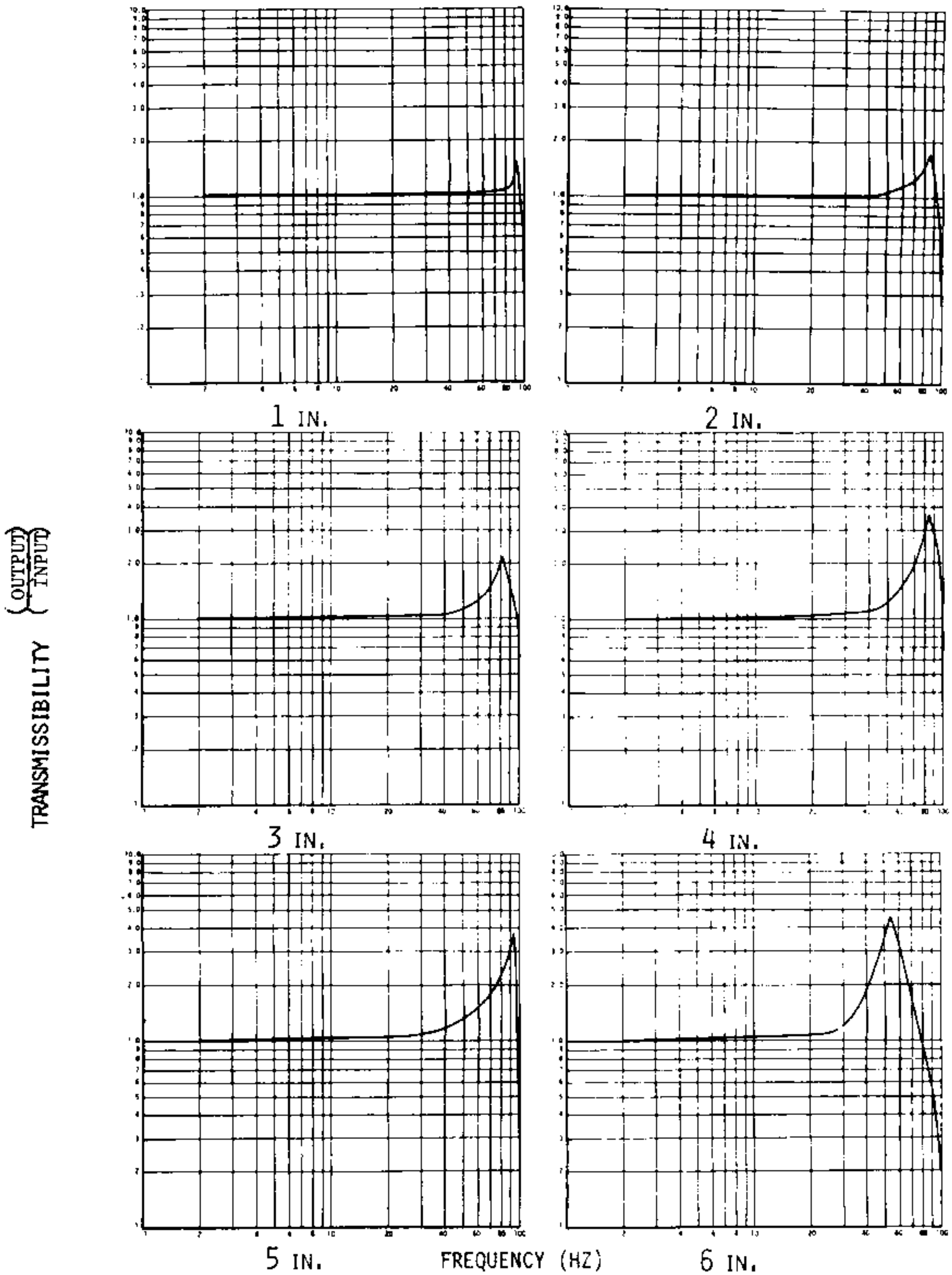
CURVE 12.9 FOLYST'YRENE FOAM, 1.5 LBS/CU FT 1.48 PSI



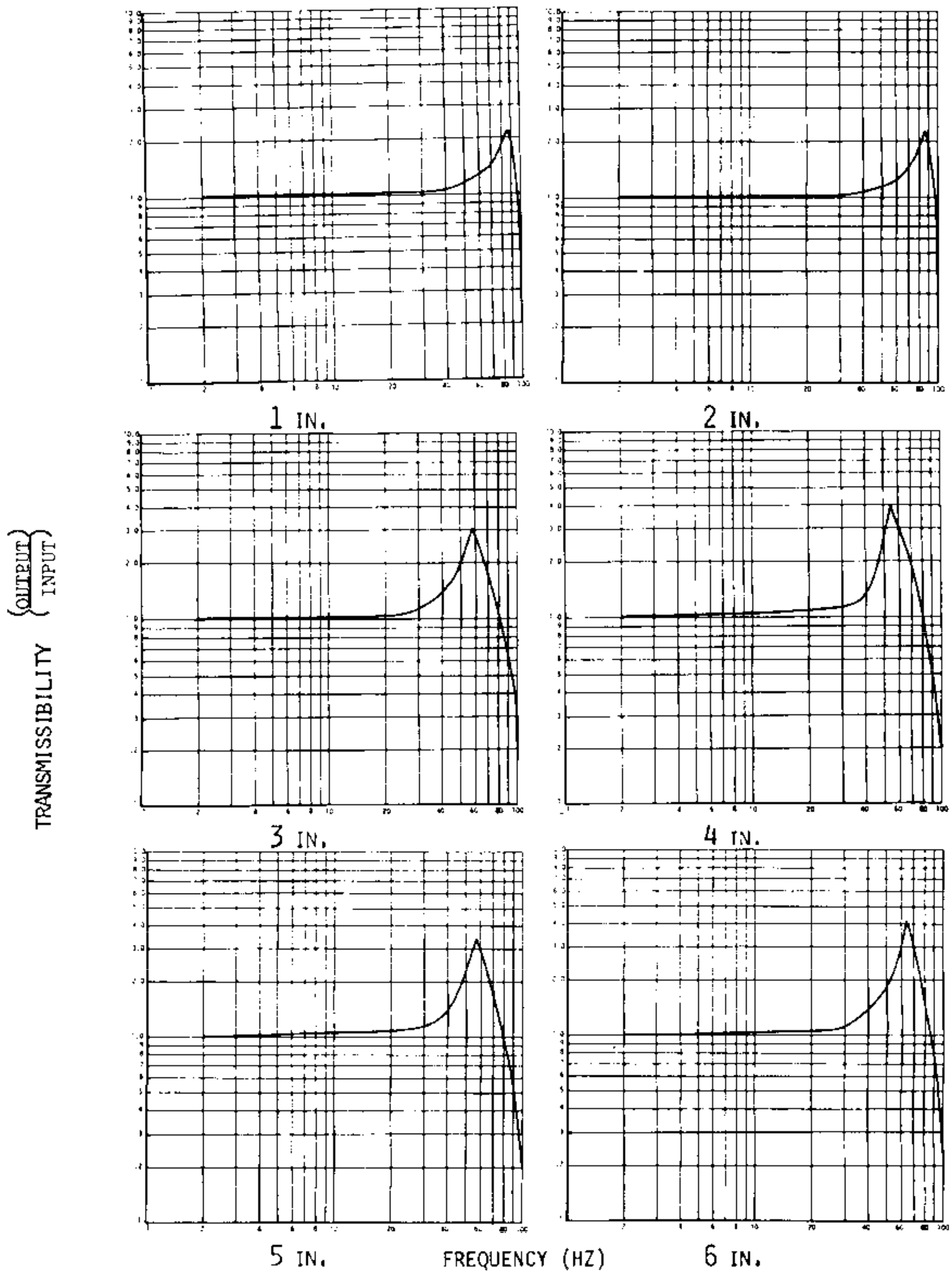
CURVE 12.10 POLYSTYRENE FOAM, 1.5 LBS/CU FT 1.95 PSI



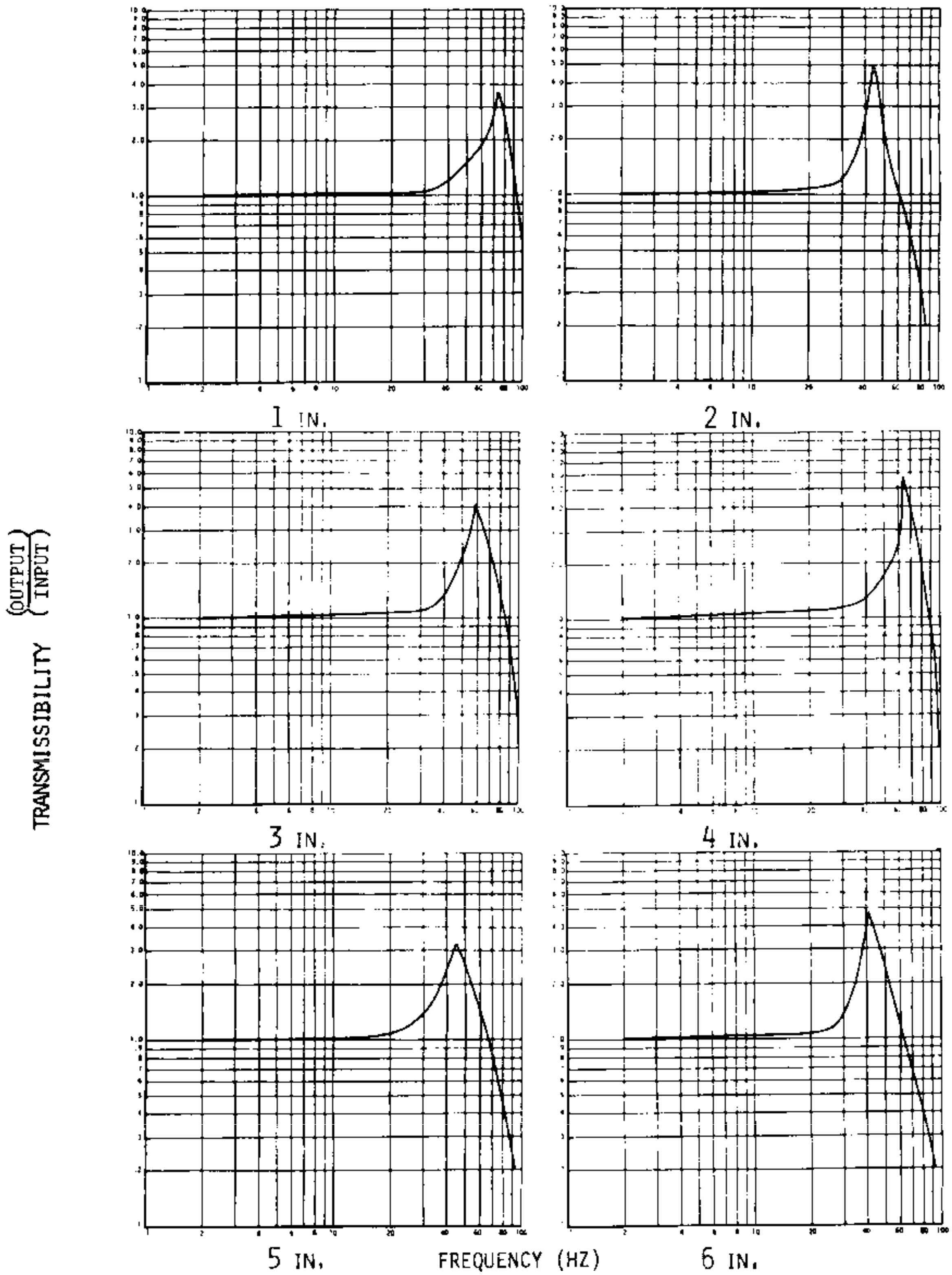
CURVE 13.1 POLYSTYRENE FOAM, 2.5 LBS/CU FT .1 PSI



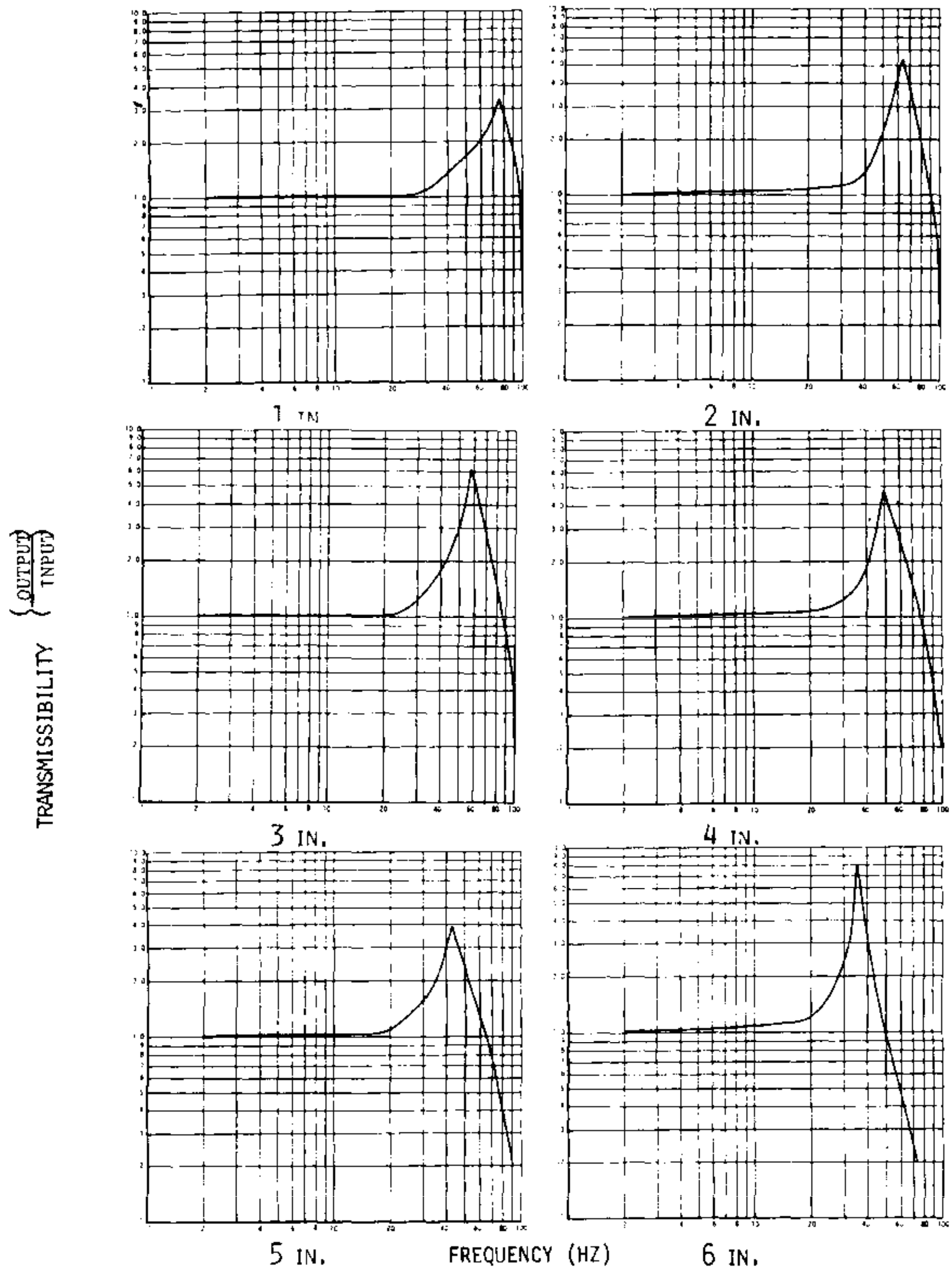
CURVE 13.2 POLYSYRENE FOAM, 2.5 LBS/CU FT .25 PSI



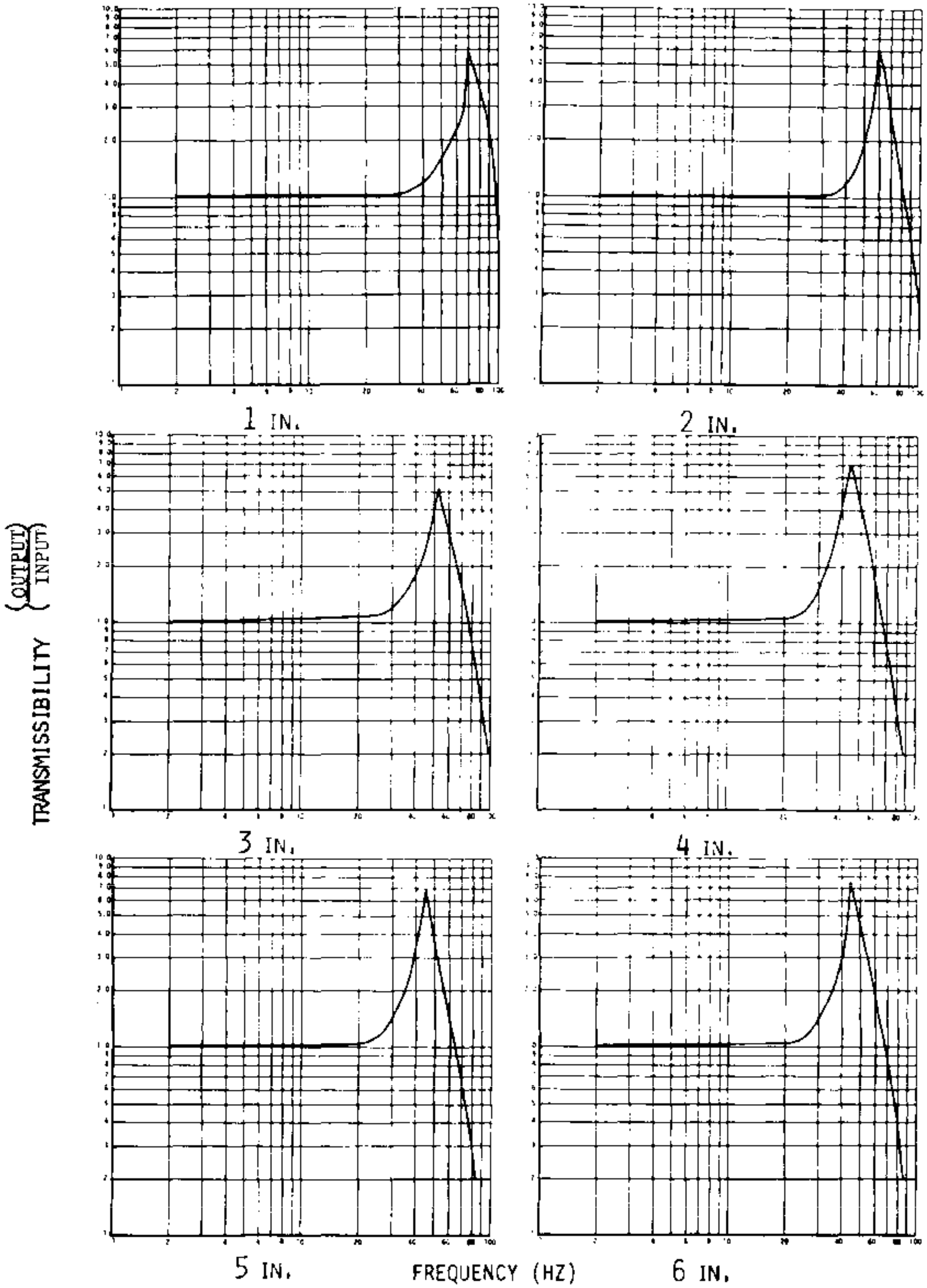
CURVE 13,3 POLYSTYRENE FOAM, 2.5LBS/CU FT .464 PSI



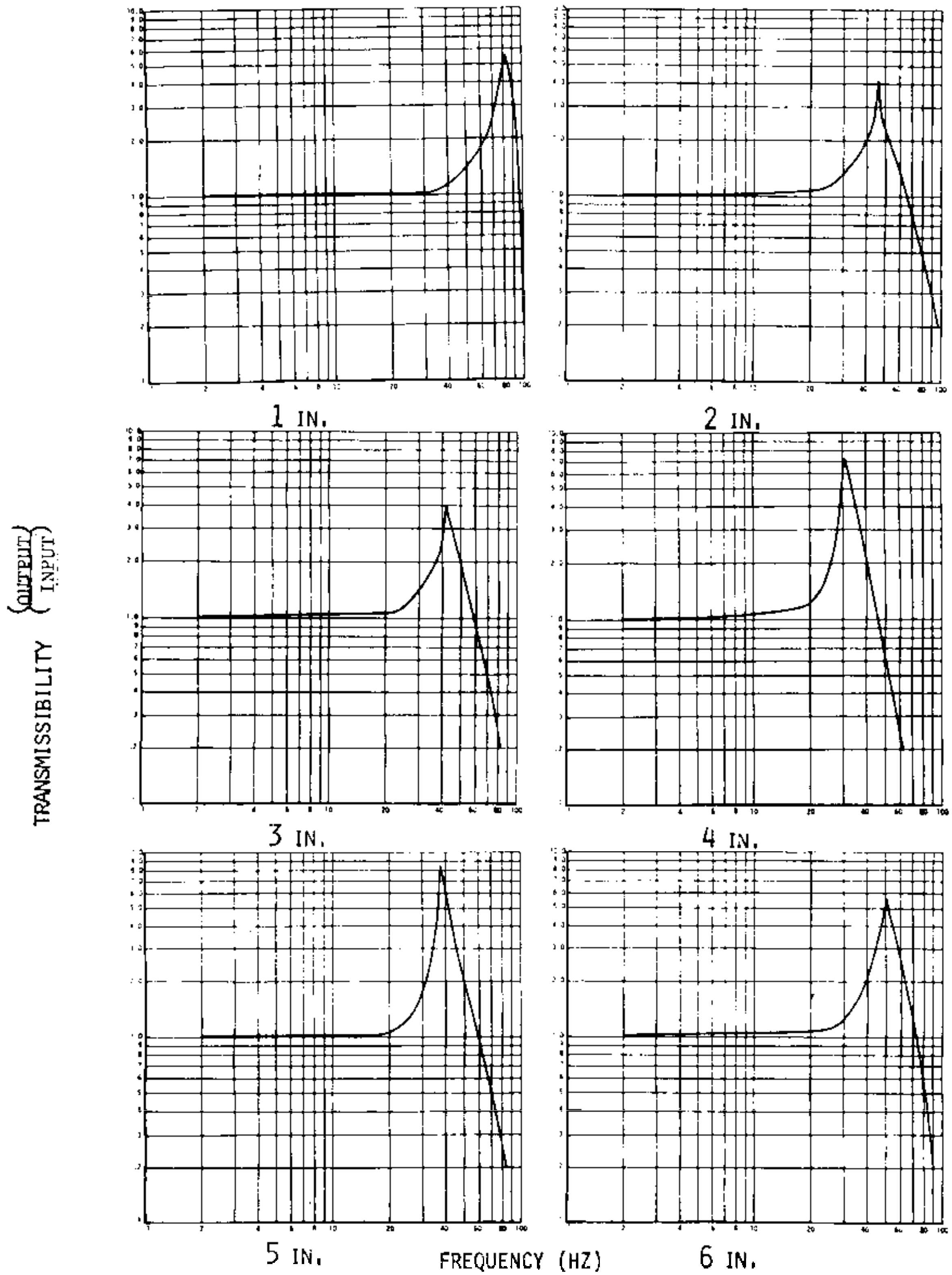
CURVE 13.4 POLYSTYRENE FOAM, 2.5 LBS/CU FT .533 PSI



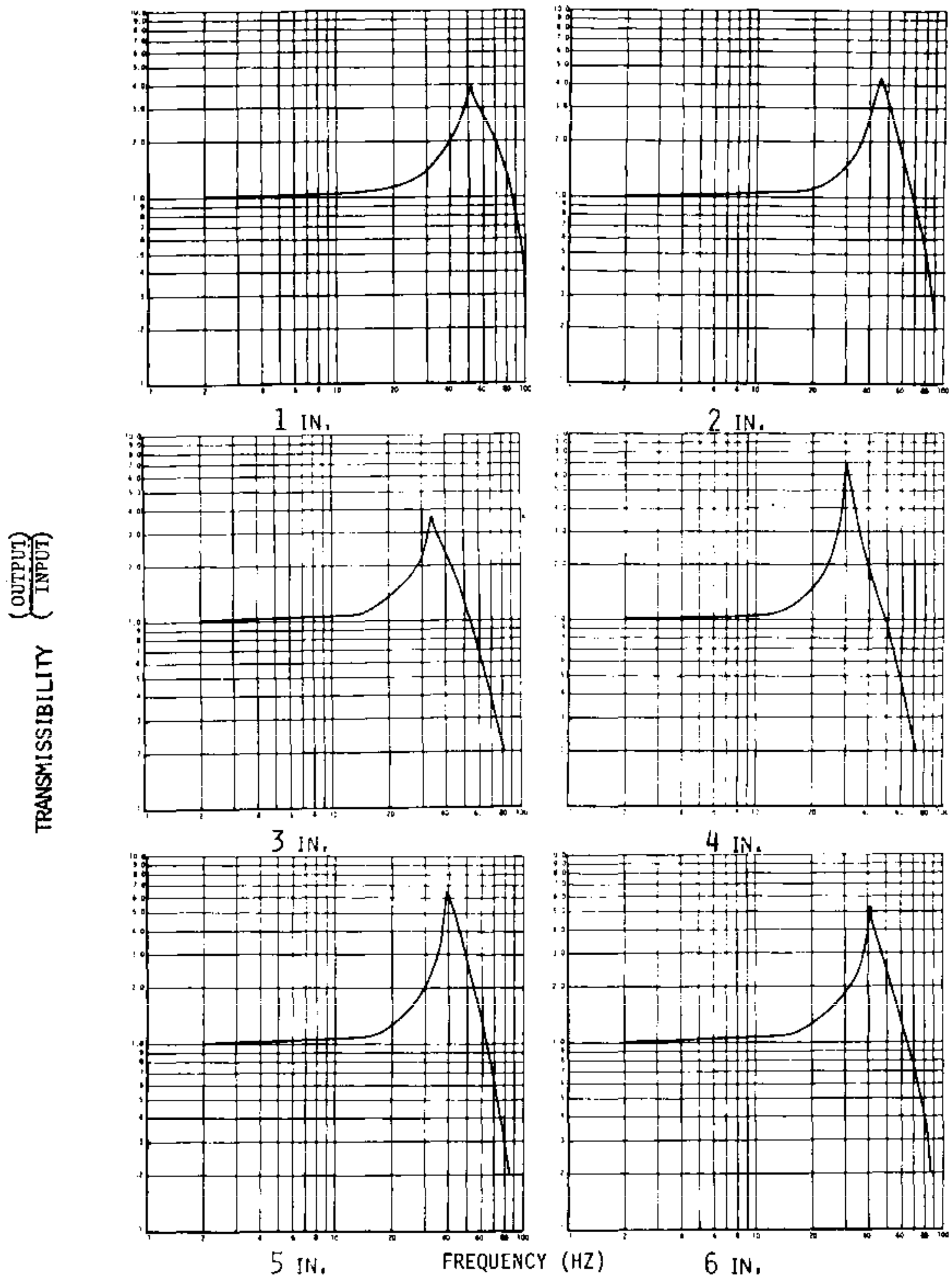
CURVE 13.5 POLYSTYRENE FOAM, 2.5 LBS/CU FT ,64 PSI



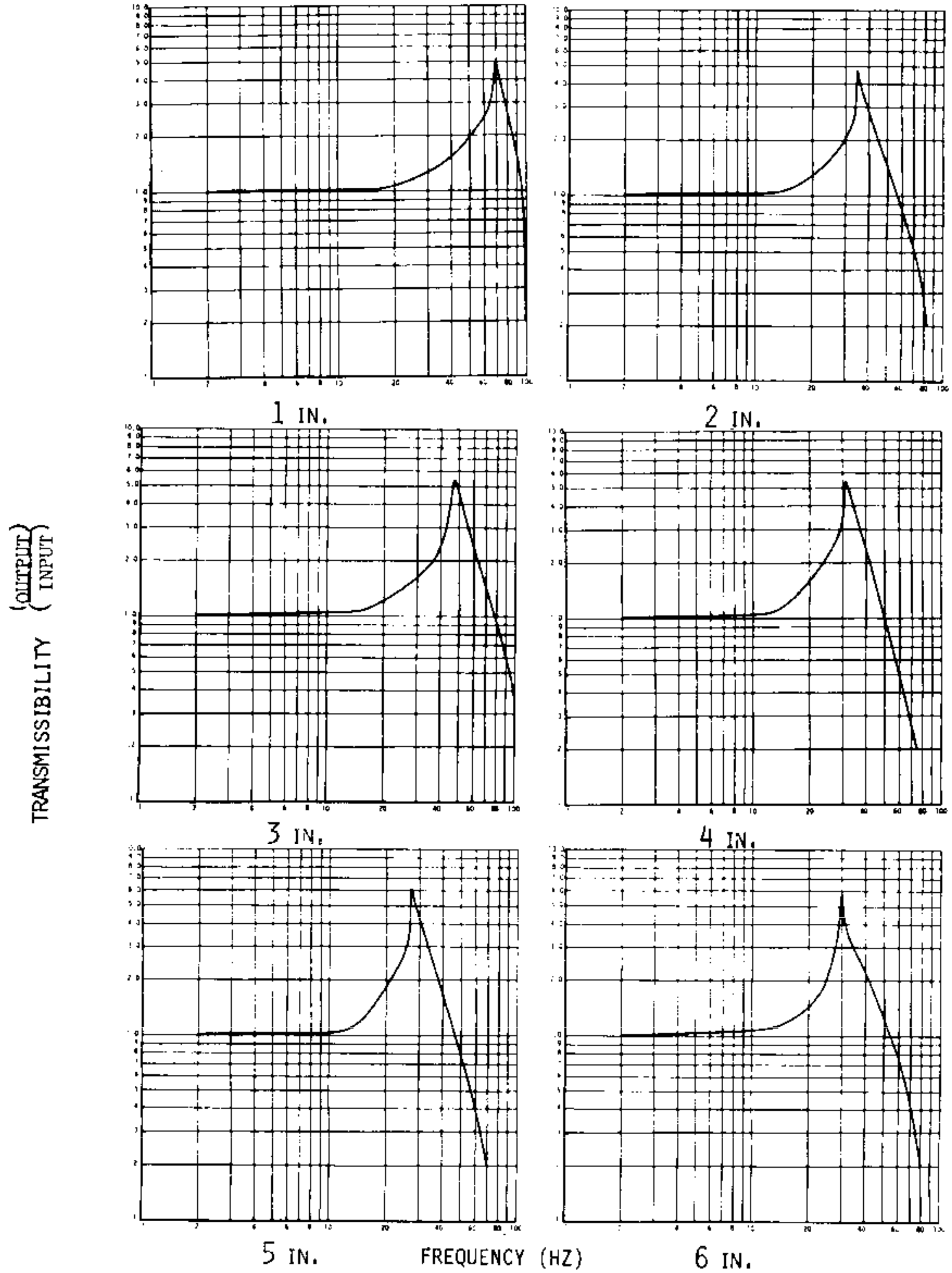
CURVE 13.6 POLYSTYRENE FOAM, 2,5 LBS/CU FT ,74 PSI



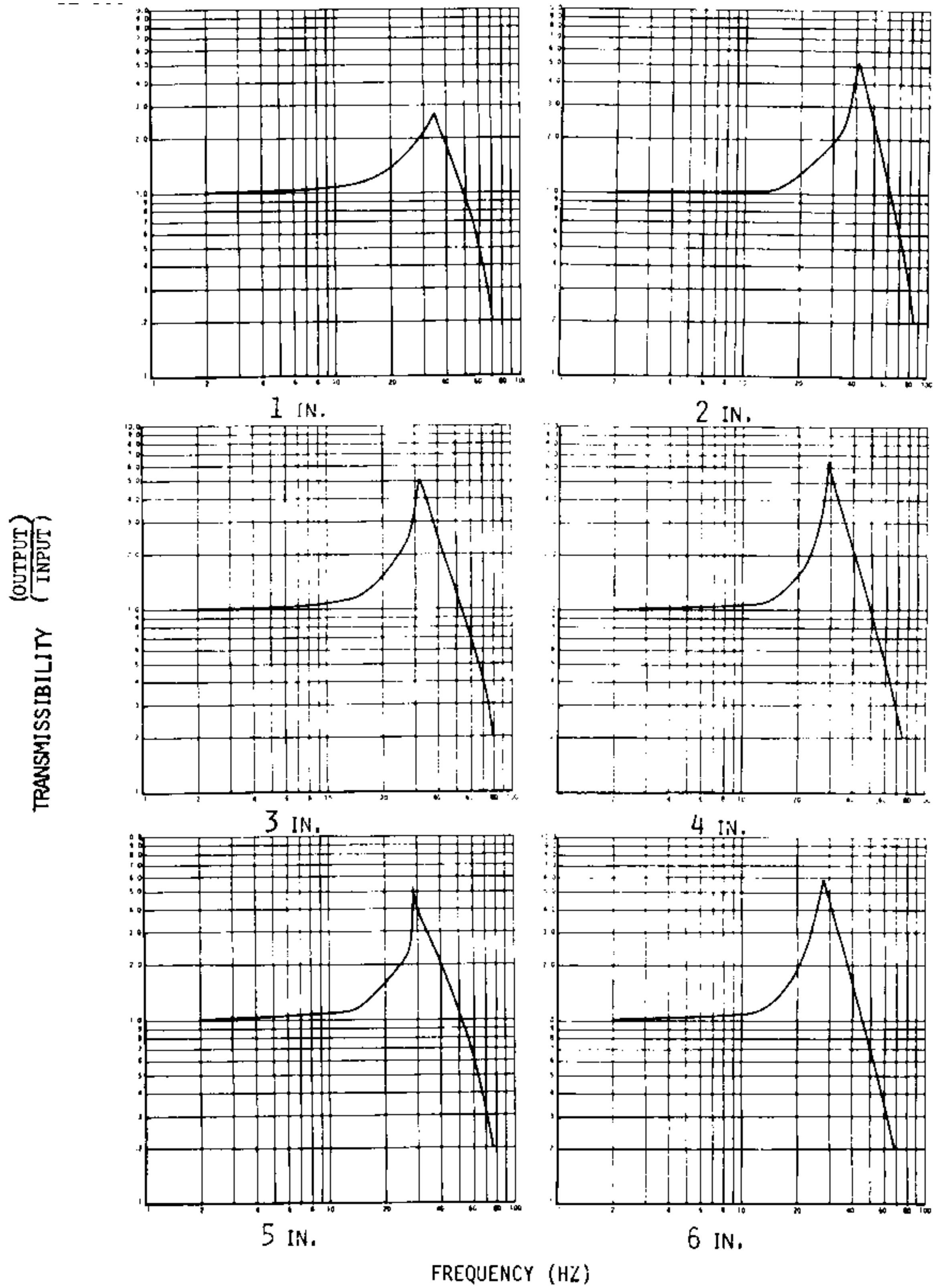
CURVE 13.7 POLYSTYRENE FOAM, 2.5 LBS/CU FT .95 PSI



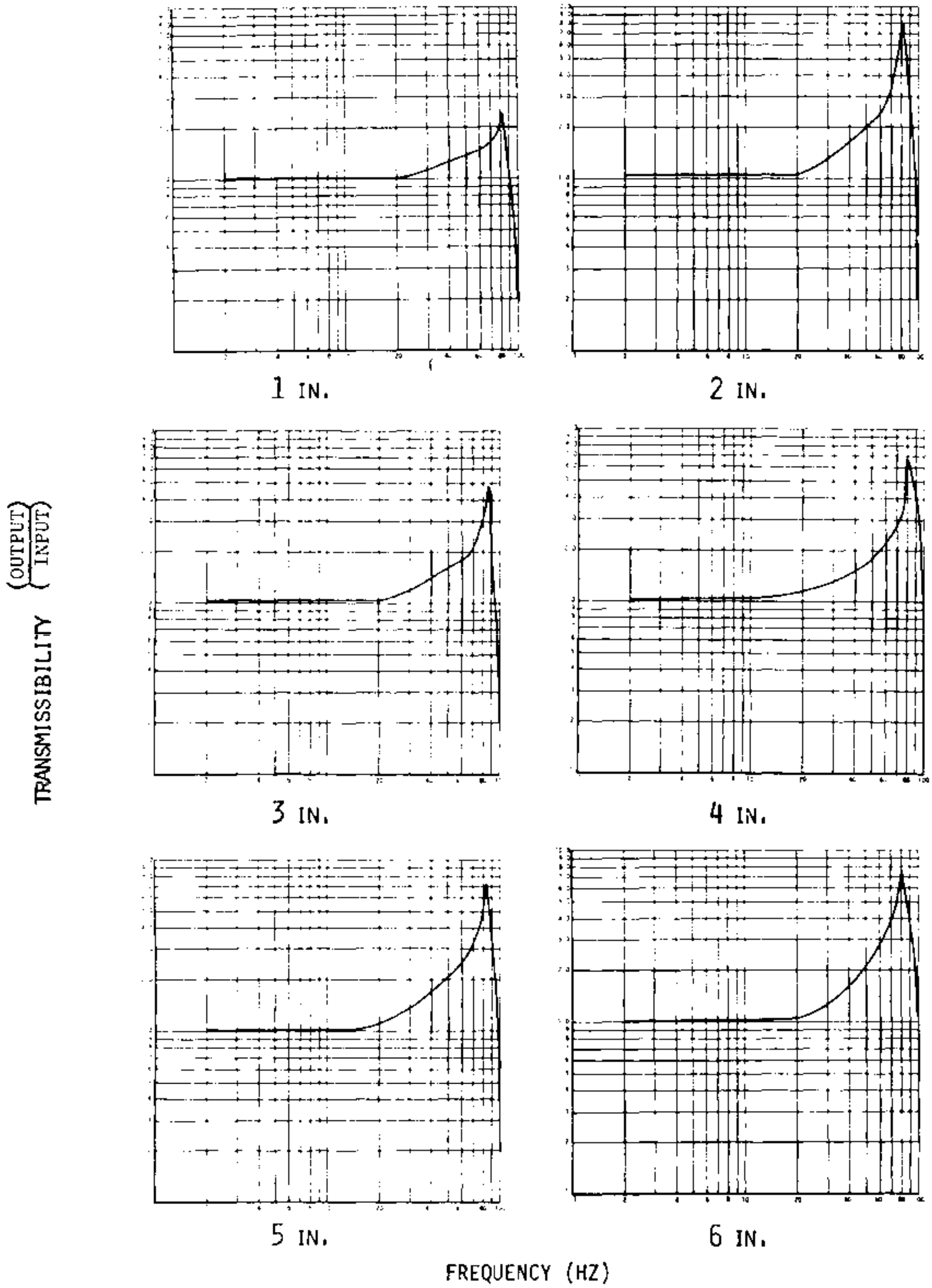
CURVE 13.8 POLYSTYRENE FOAM, 2.5 LBS/CU FT 1.15 PSI



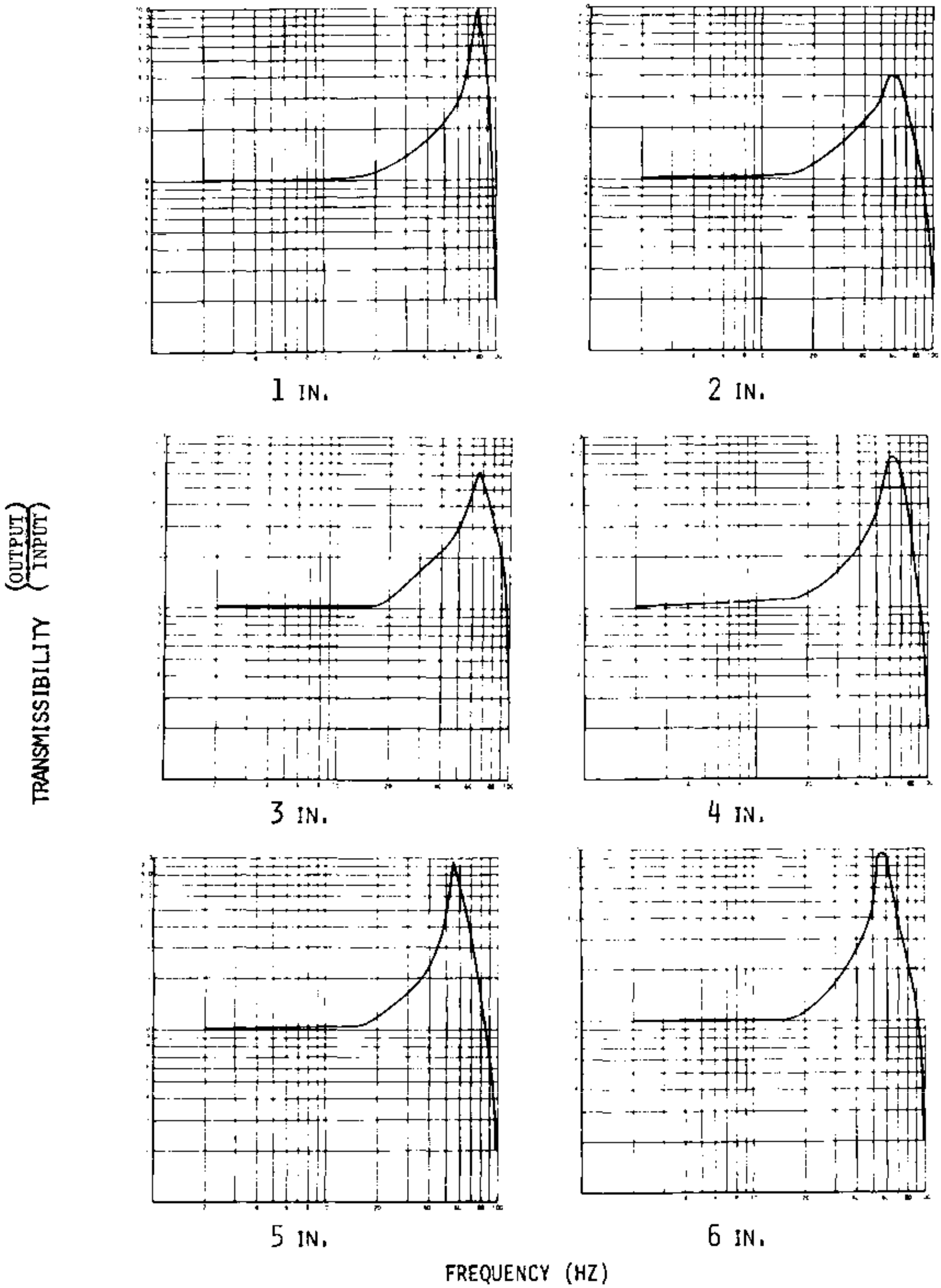
CURVE 13.9 POLYSTYRENE FOAM, 2.5 LBS/CU FT 1.48 PSI



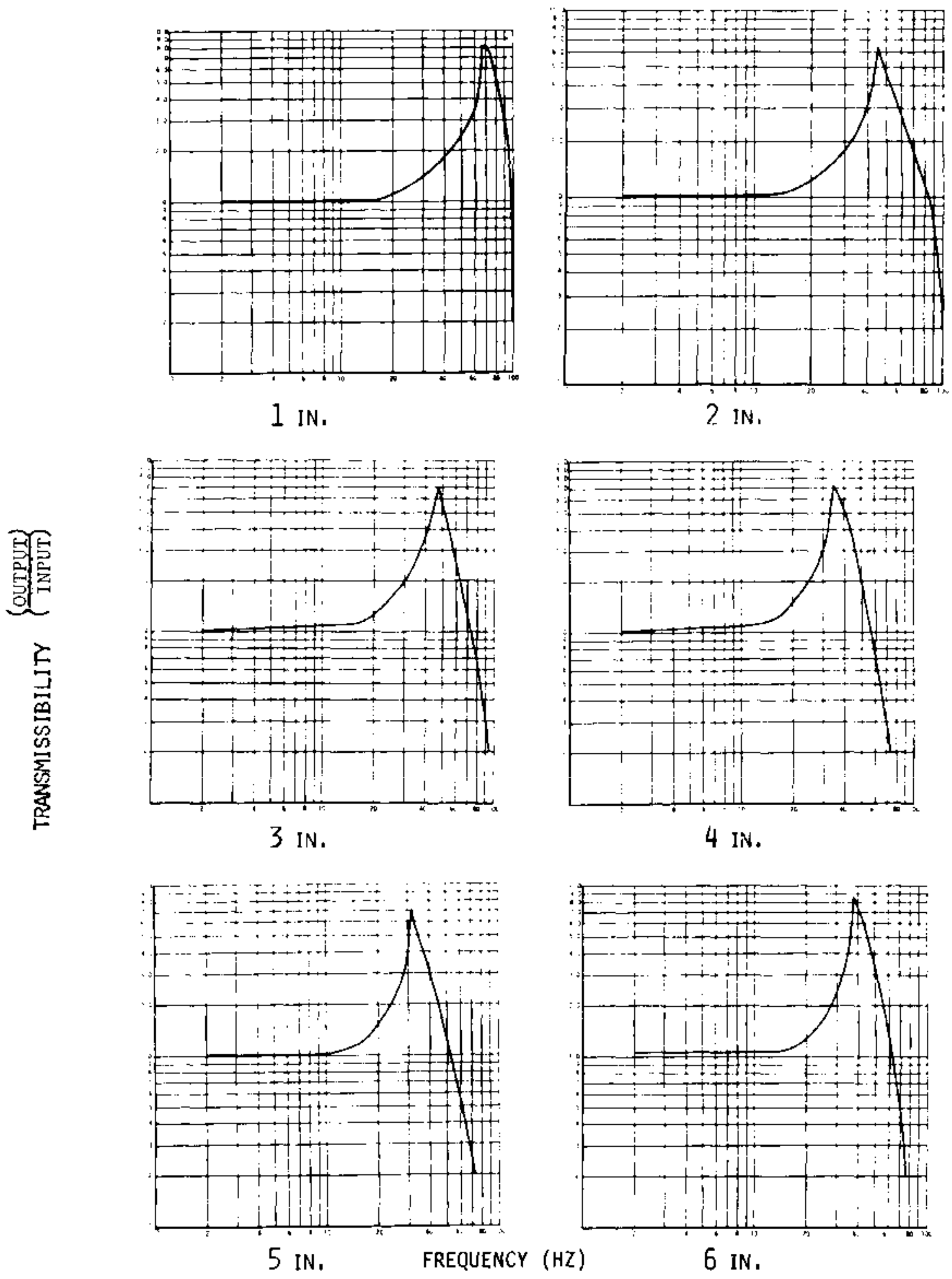
CURVE 13.10 POLYSTYRENE FOAM, 2.5 LBS/CU FT 1.95 PSI



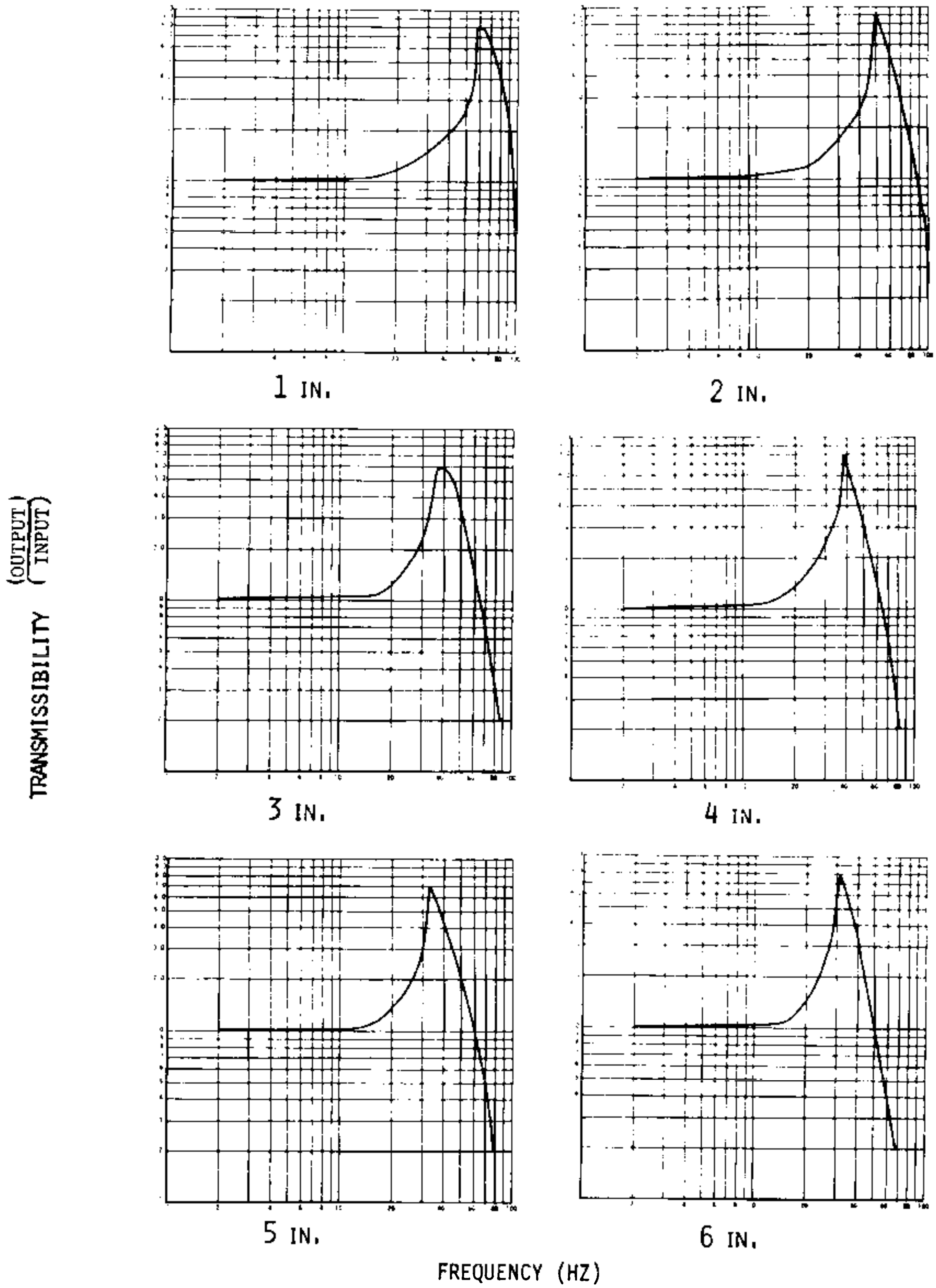
CURVE 14.1 POLYETHYRENE, CHEMICALLY CROSSLINKED, L-200, 2.0 PCF .09 PSI



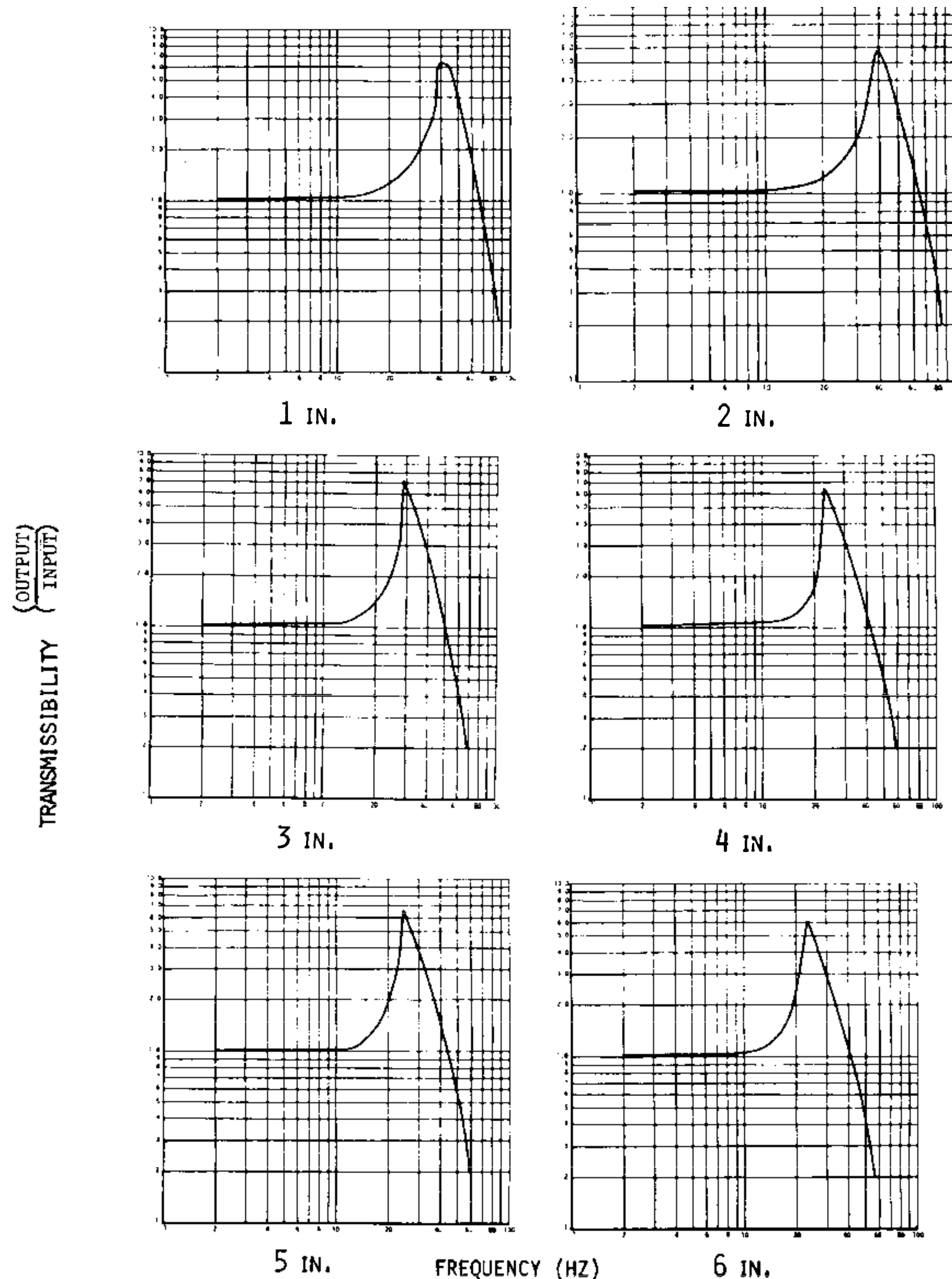
CURVE 14,2 POLYETHYLENE, CHEMICALLY CROSSLINKED,L-200 2.0 PCF .26 PSI



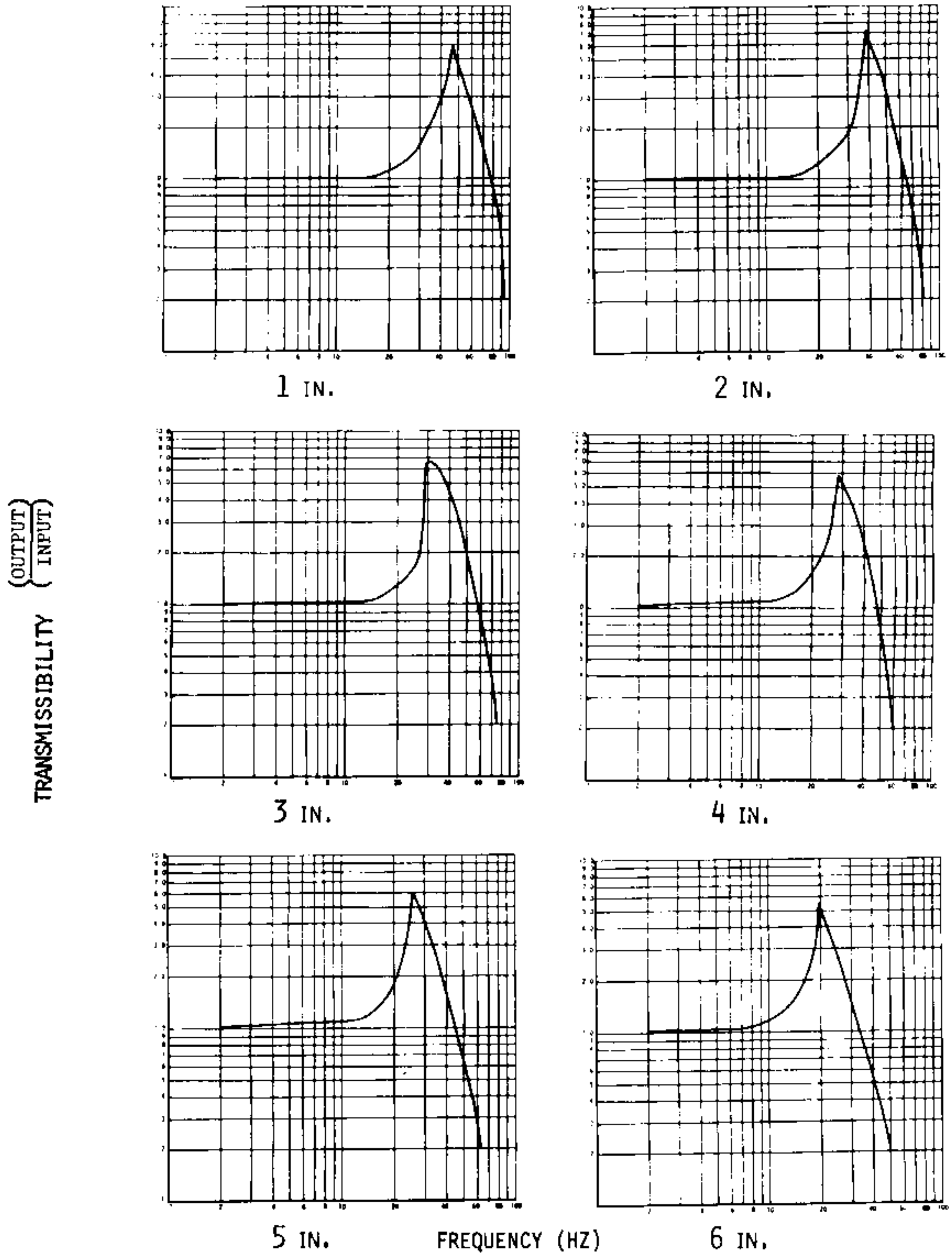
CURVE 14.3 POLYETHYLENE, CHEMICALLY CROSSLINKED, L-200, 2,0 PCF ,50 PSI



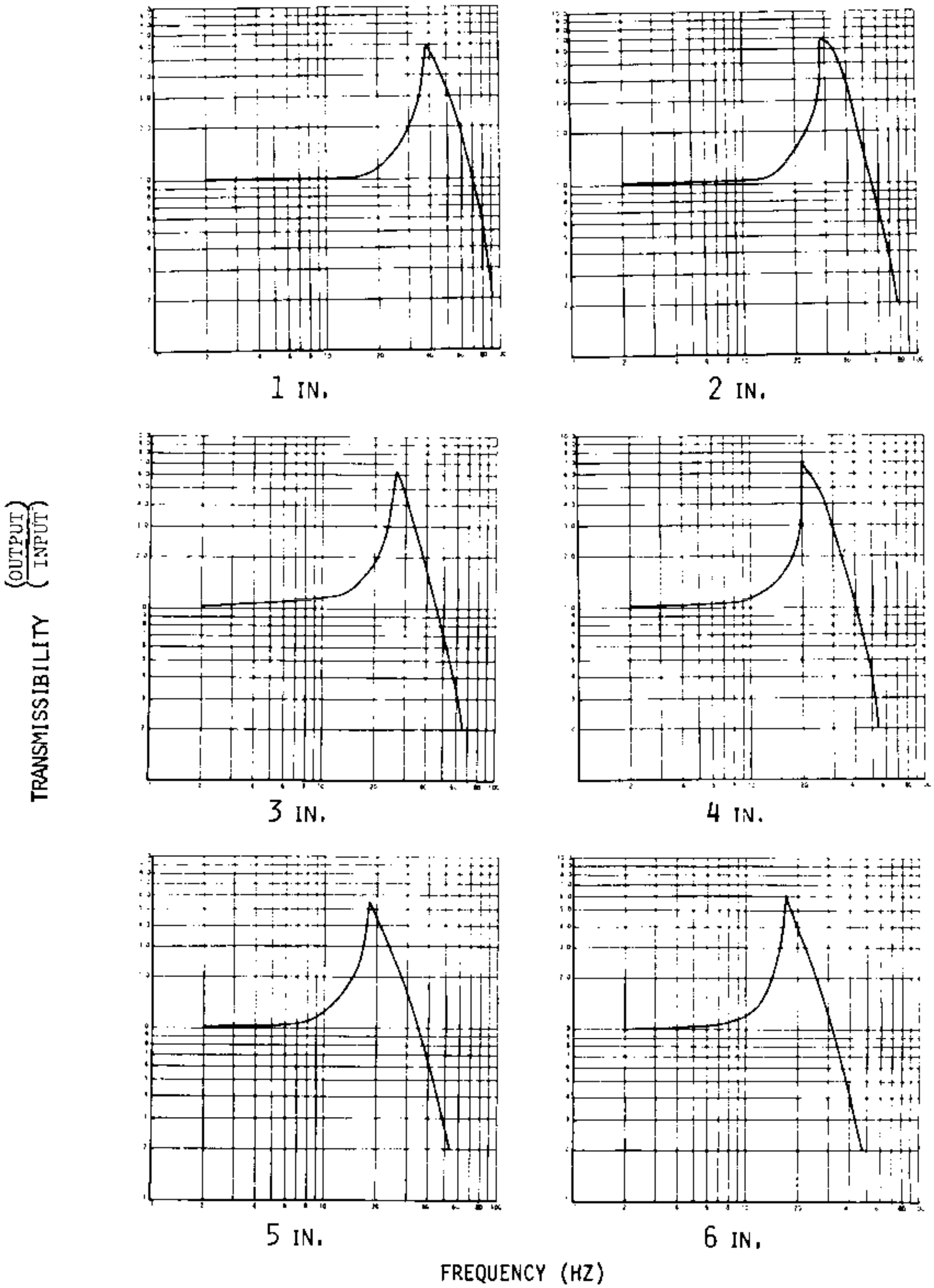
CURVE 14.4 POLYETHYLENE, CHEMCALLY CROSSLINKED, L-200, 2.0 PCF .61 PSI



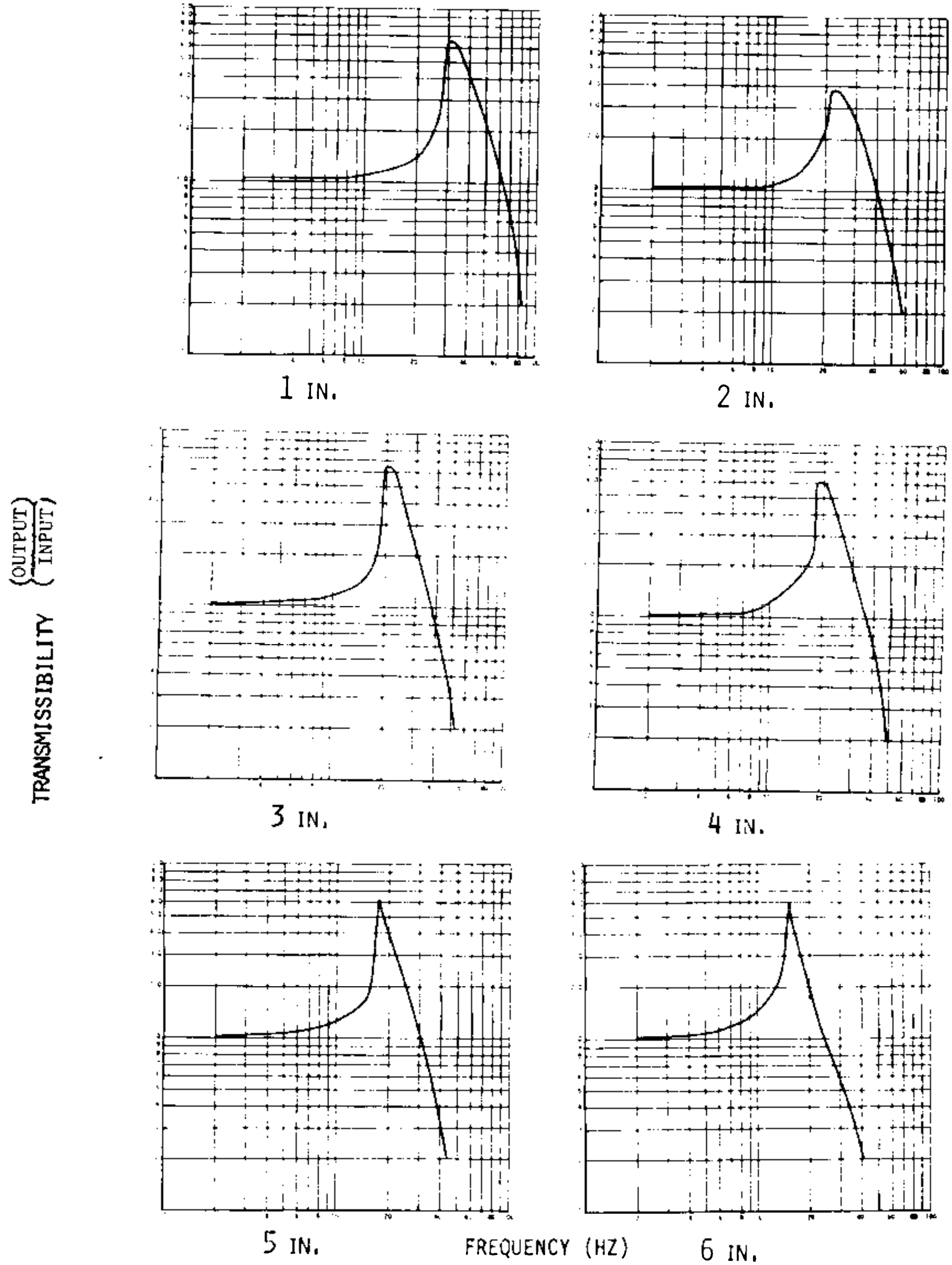
CURVE 14.5 POLYETHYLENE, CHEMICALLY CROSSLINKED, L-200, 2.0 PCF .81 PSI



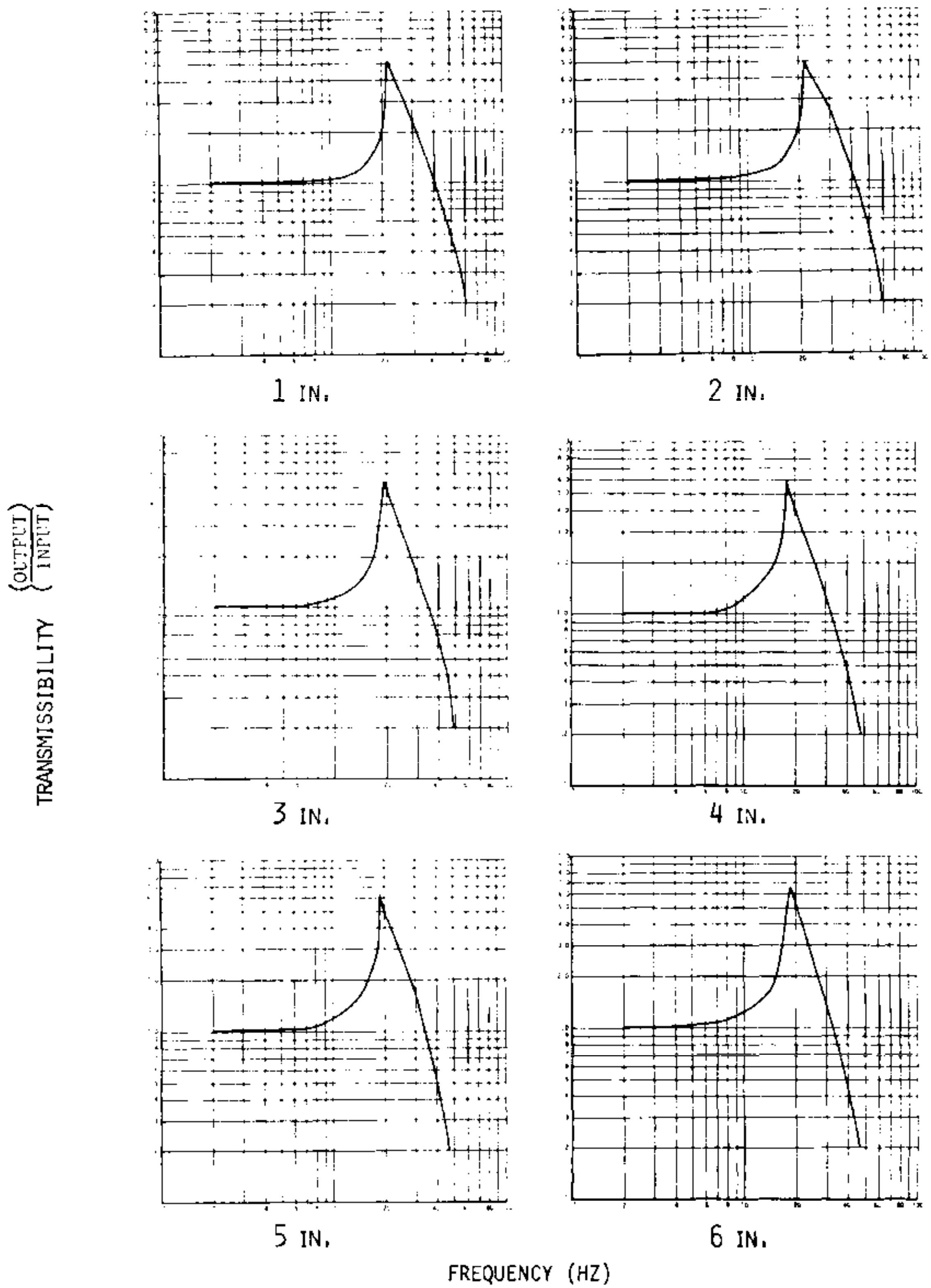
CURVE 14.6 POLYETHYLENE, CHEMICALL CROSSLINKED, L-200, 2.0 PCF .99 PSI



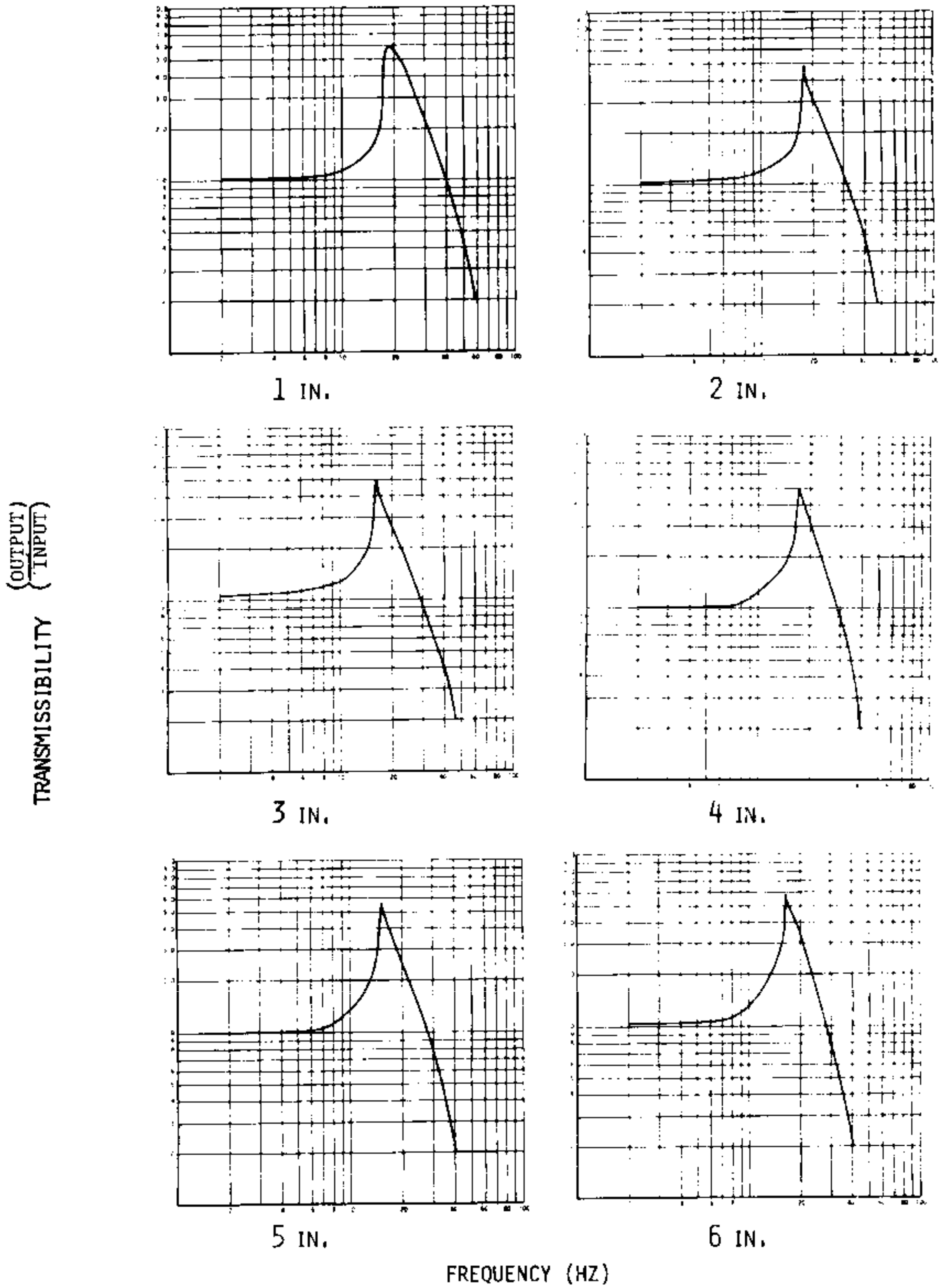
CURVE 14.7 POLYETHYLENE,CHEMICALLY CROSSLINKED, L-200, 2.0 PCF 1.2 PSI



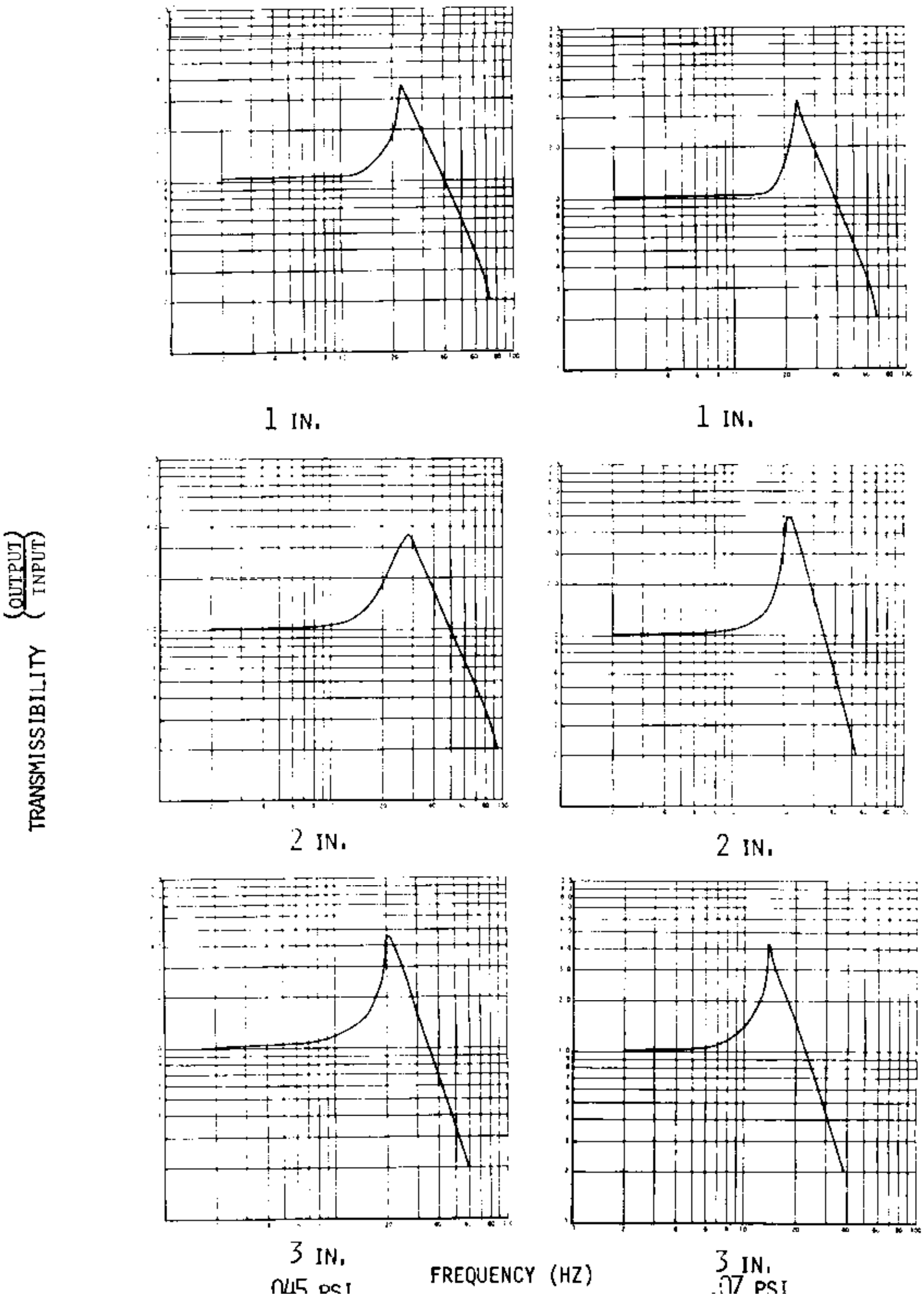
CURVE 14.8 POLYETHYLENE, CHEMICALLY CROSSLINKED, L-200, 2.0 PCF 1.3 PSI



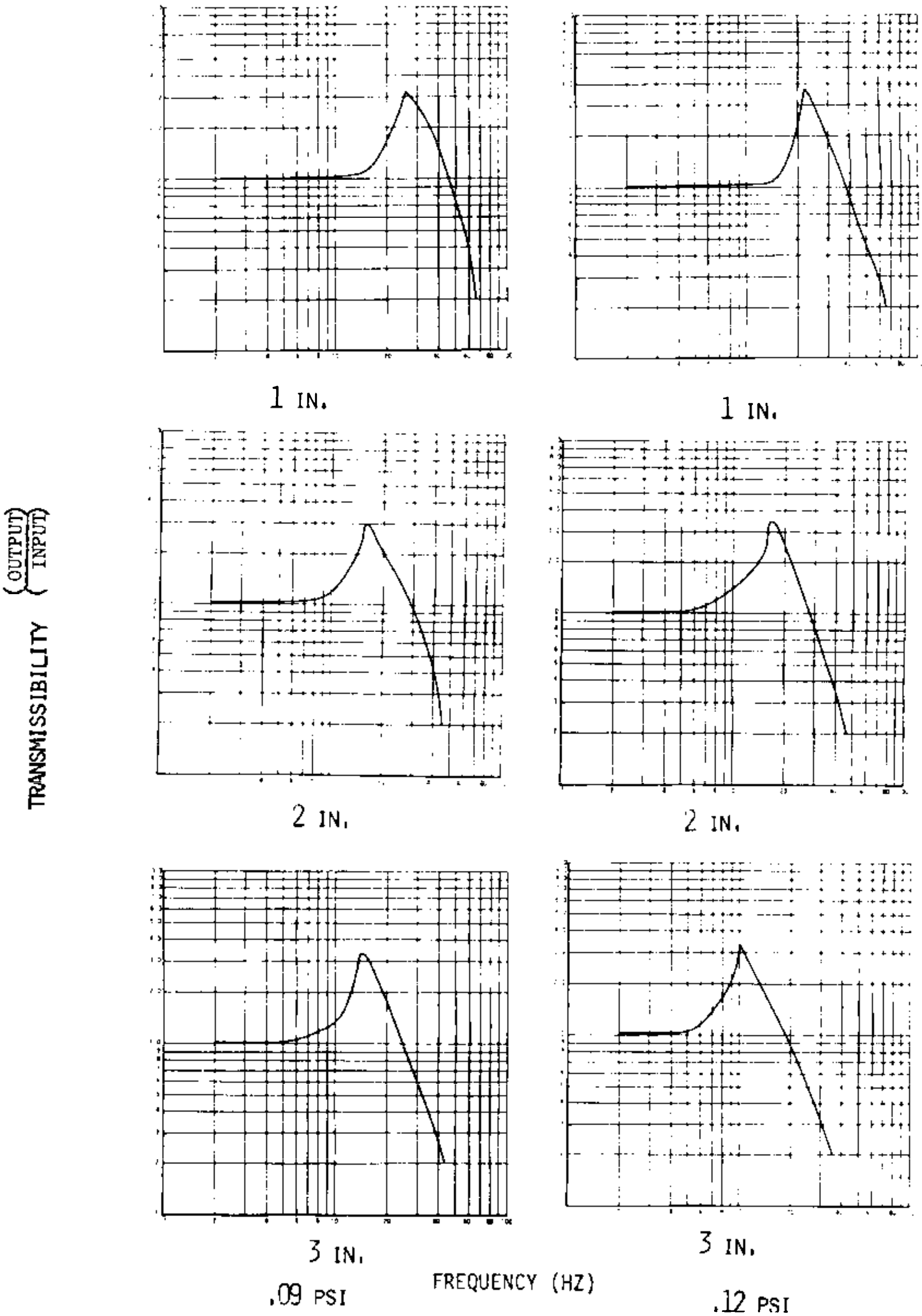
CURVE 14.9 POLYETHYLENE, CHEMICALLY CROSSLINKED, L-200,2.0 PCF 1.5 PSI



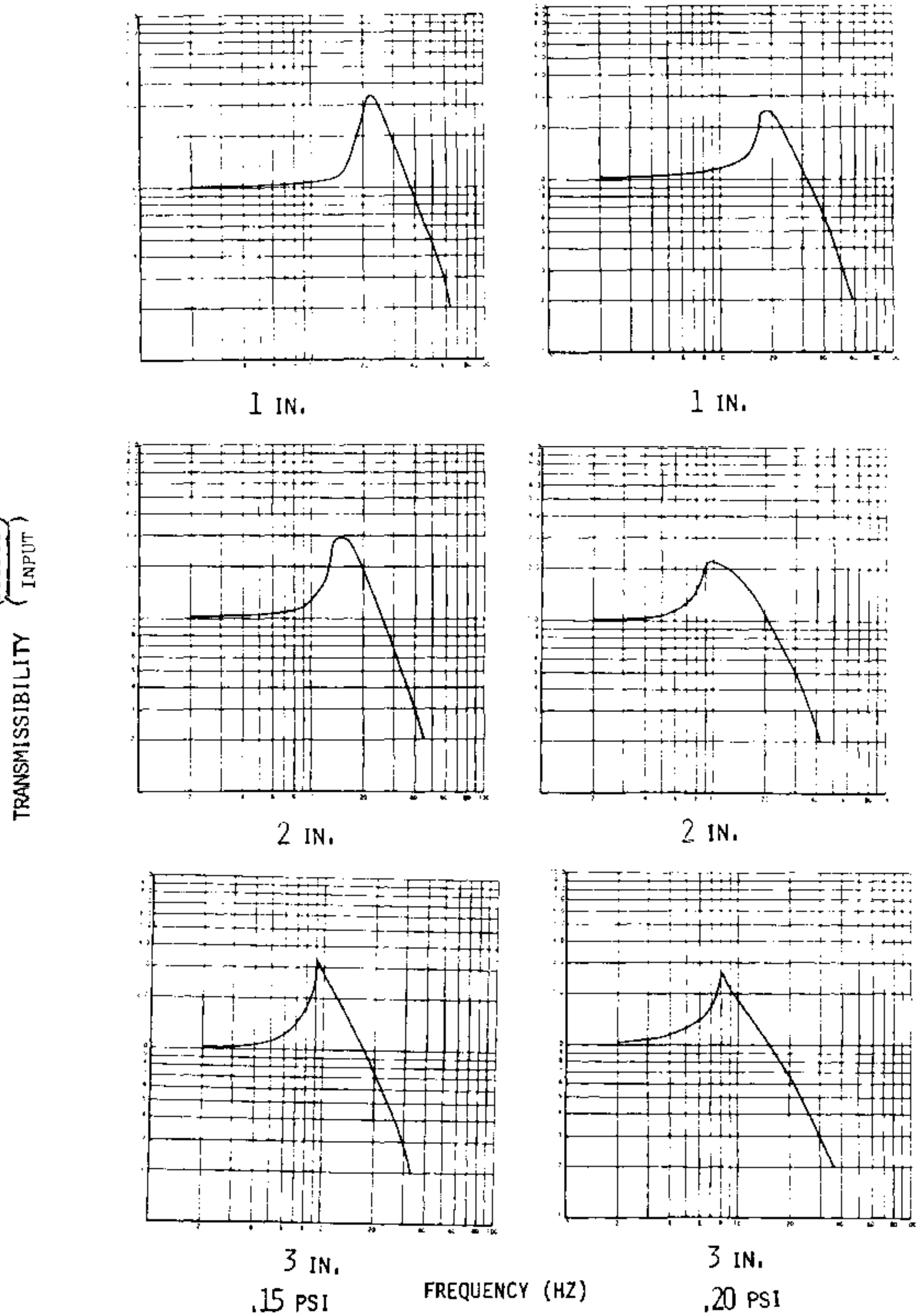
CURVE 14.10 POLYETHYLENE, CHEMICALLY CROSSLINKED, L-200, 2.0 PCF 2.0 PSI



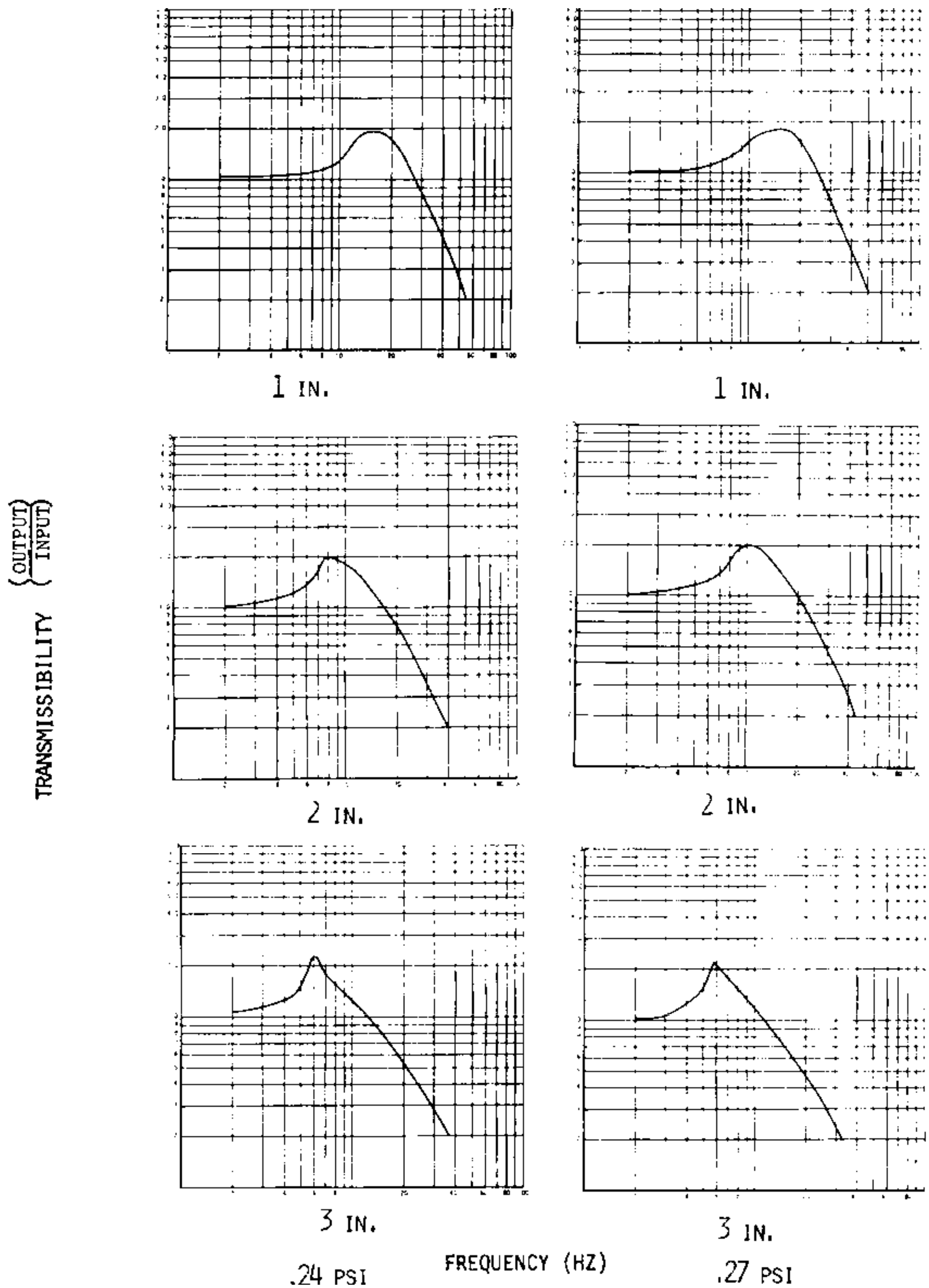
CURVE 15.1 CONVOLUTED POLYURETHANE, 1.15 PCF, 1.0" PLY THICKNESS



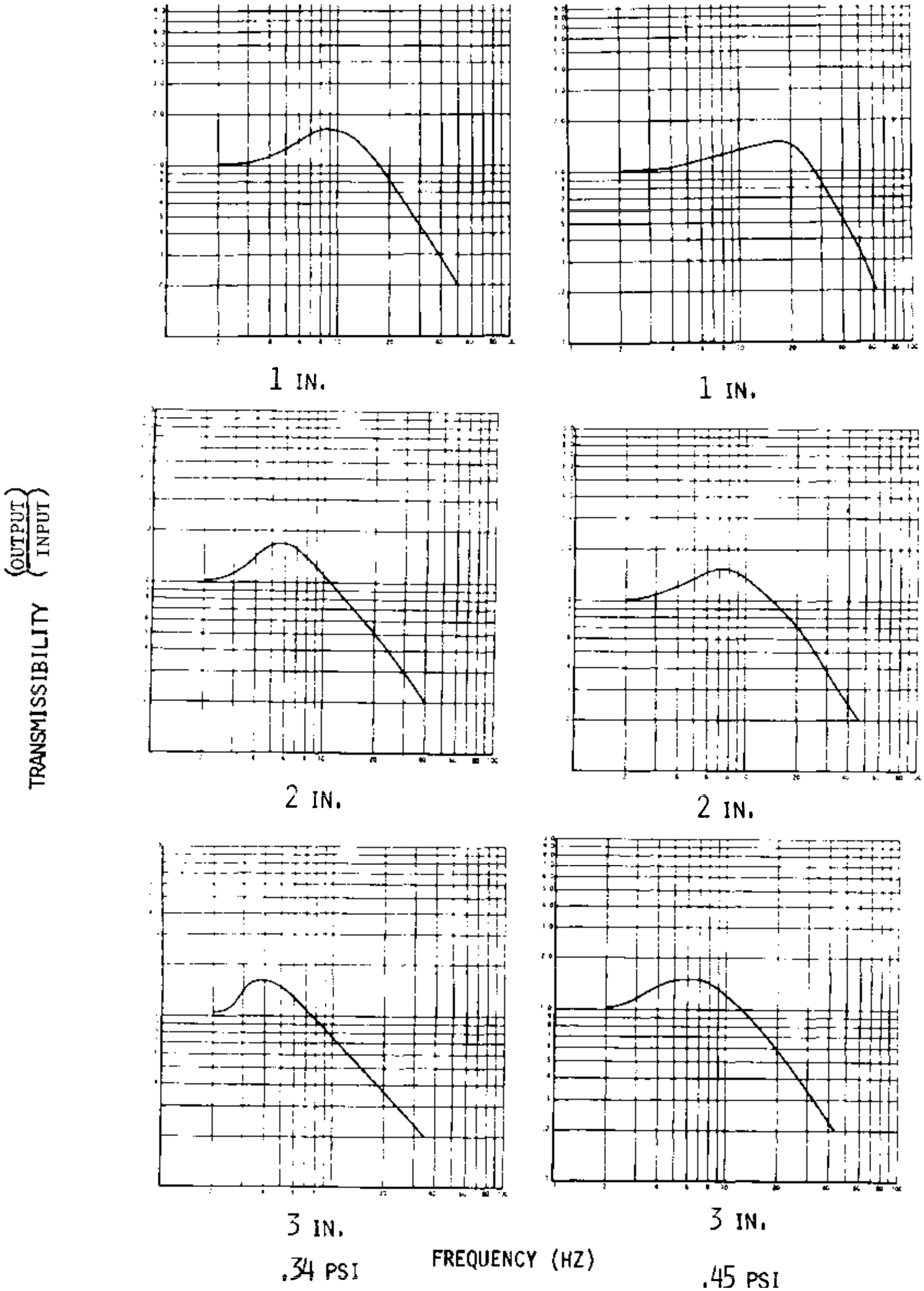
CURVE 15.2 CONVOLUTED POLYURETHANE, 1.15 PCF, 1.0" PLY THICKNESS



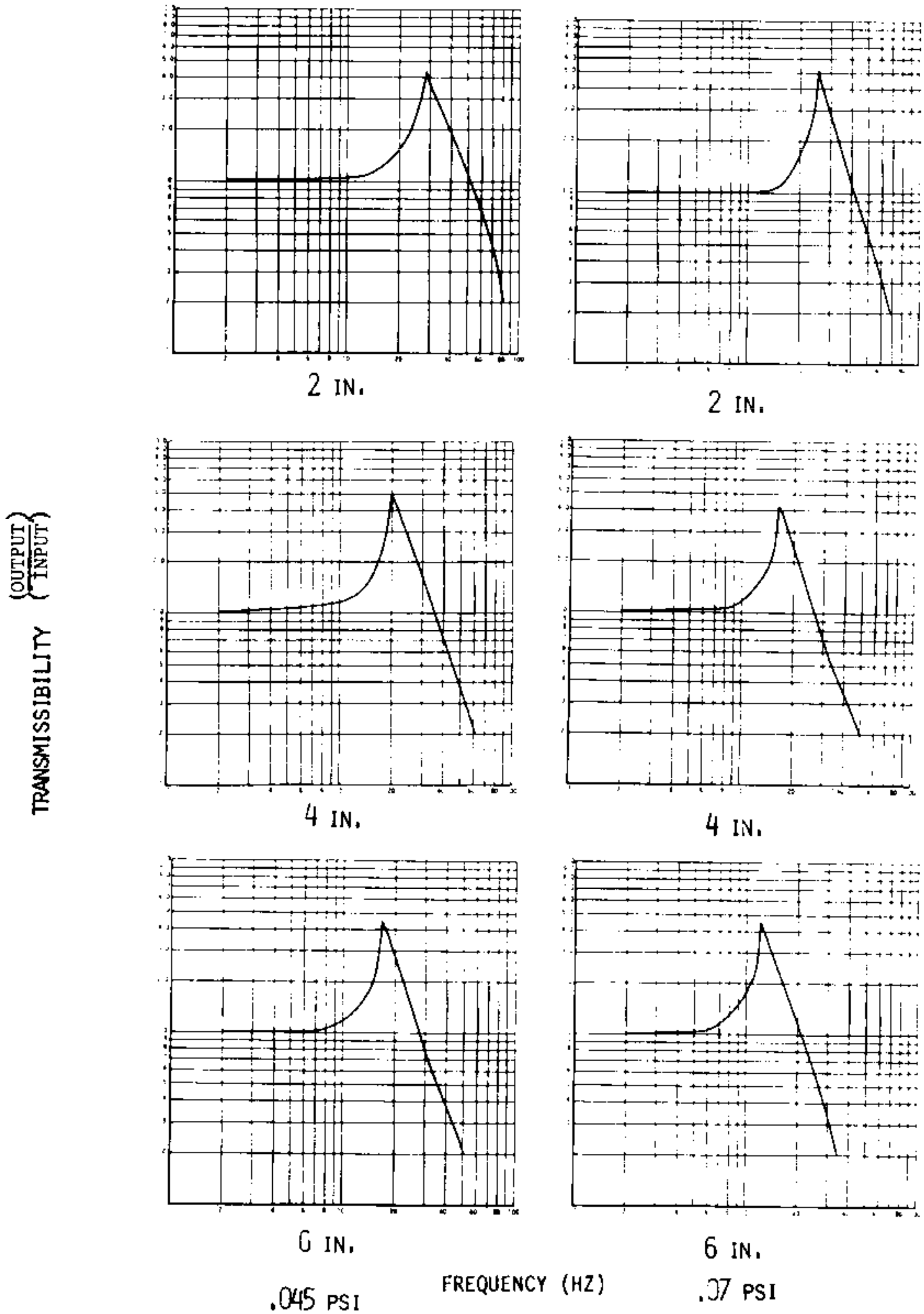
CURVE 15,3 CONVOLUTED POLYURETHANE, 1.15, PCF, 1.0" PLY THICKNESS



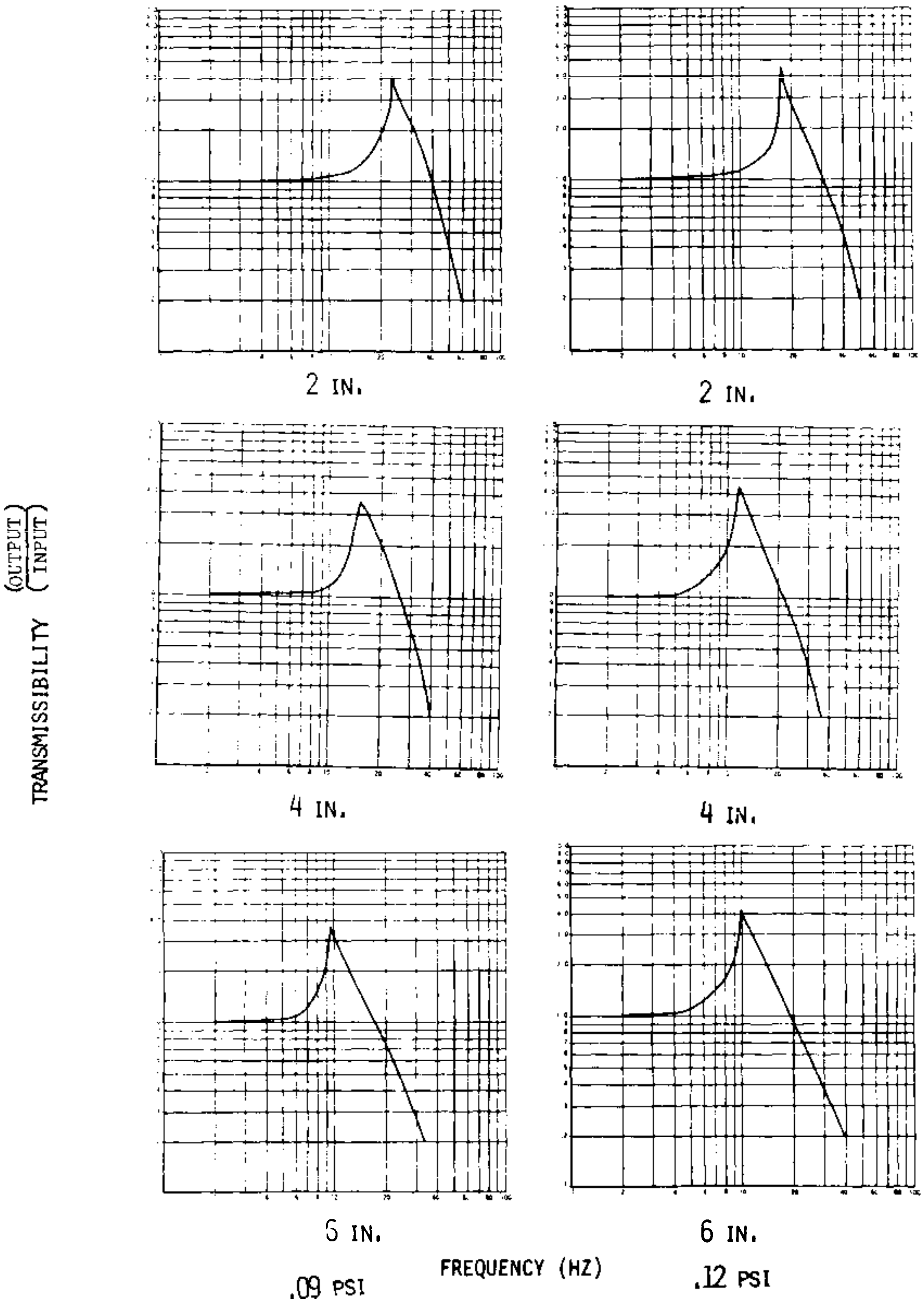
CURVE 15.4 CONVOLUTED POLYURETHANE, 1.15 PCF, 1.0″ PLY THICKNESS



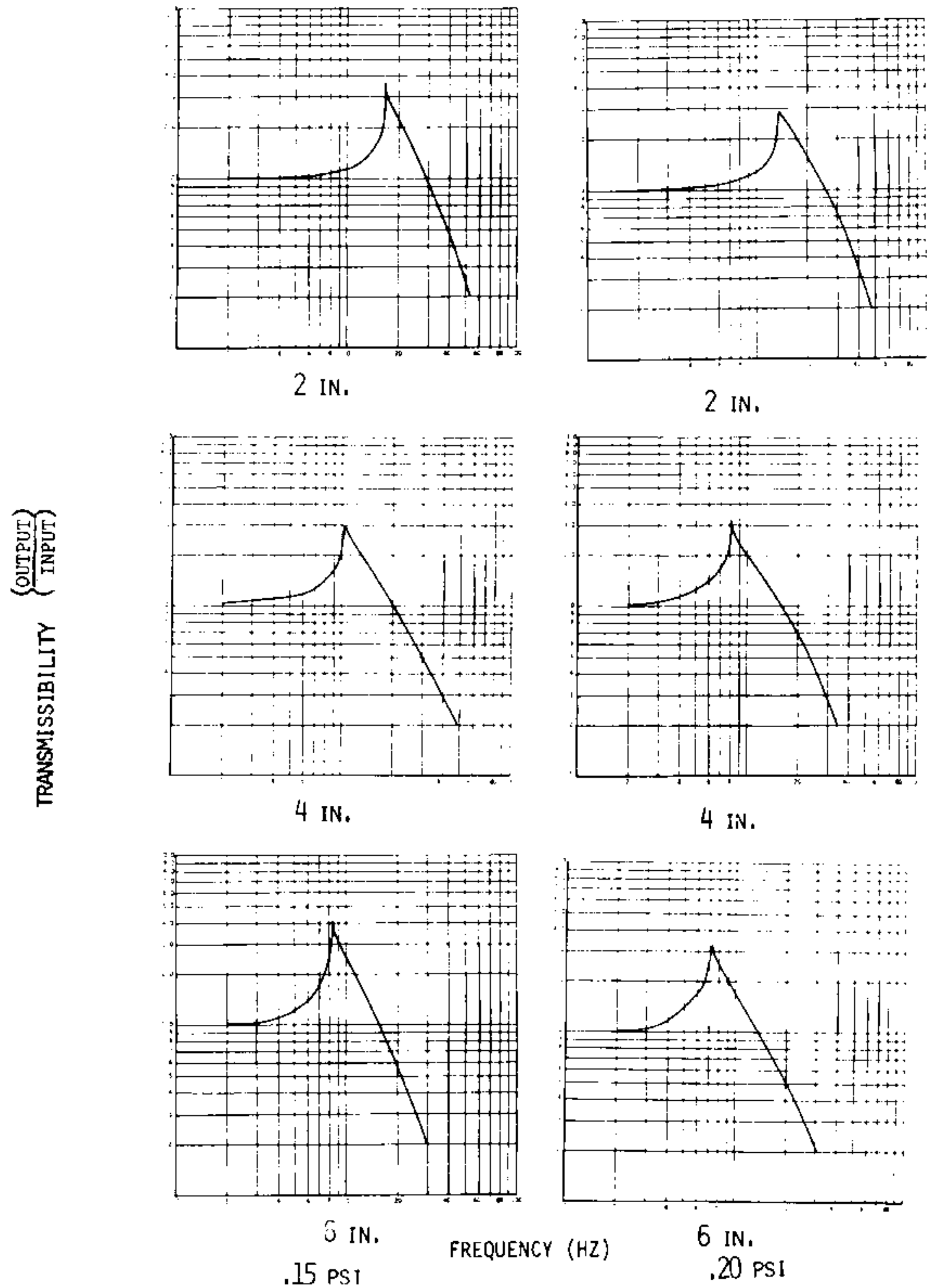
CURVE 15.5 CONVOLUTED POLYURETHANE, 1.15 PCF, 1.0" PLY THICKMESS



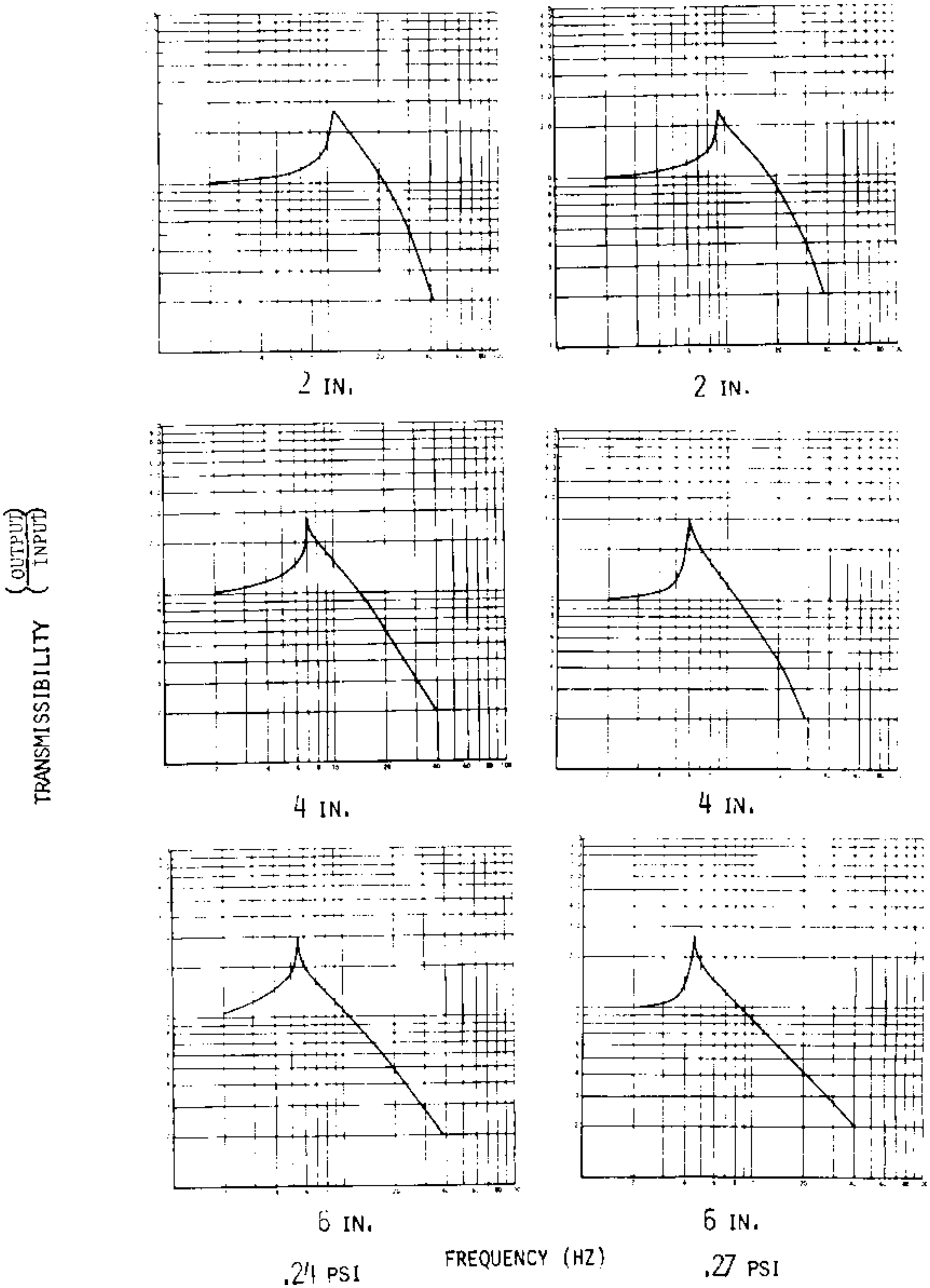
CURVE 16.1 CONVOLUTED POLYURETHANE, 1.15 PCF, 2.1" PLY THICKNESS



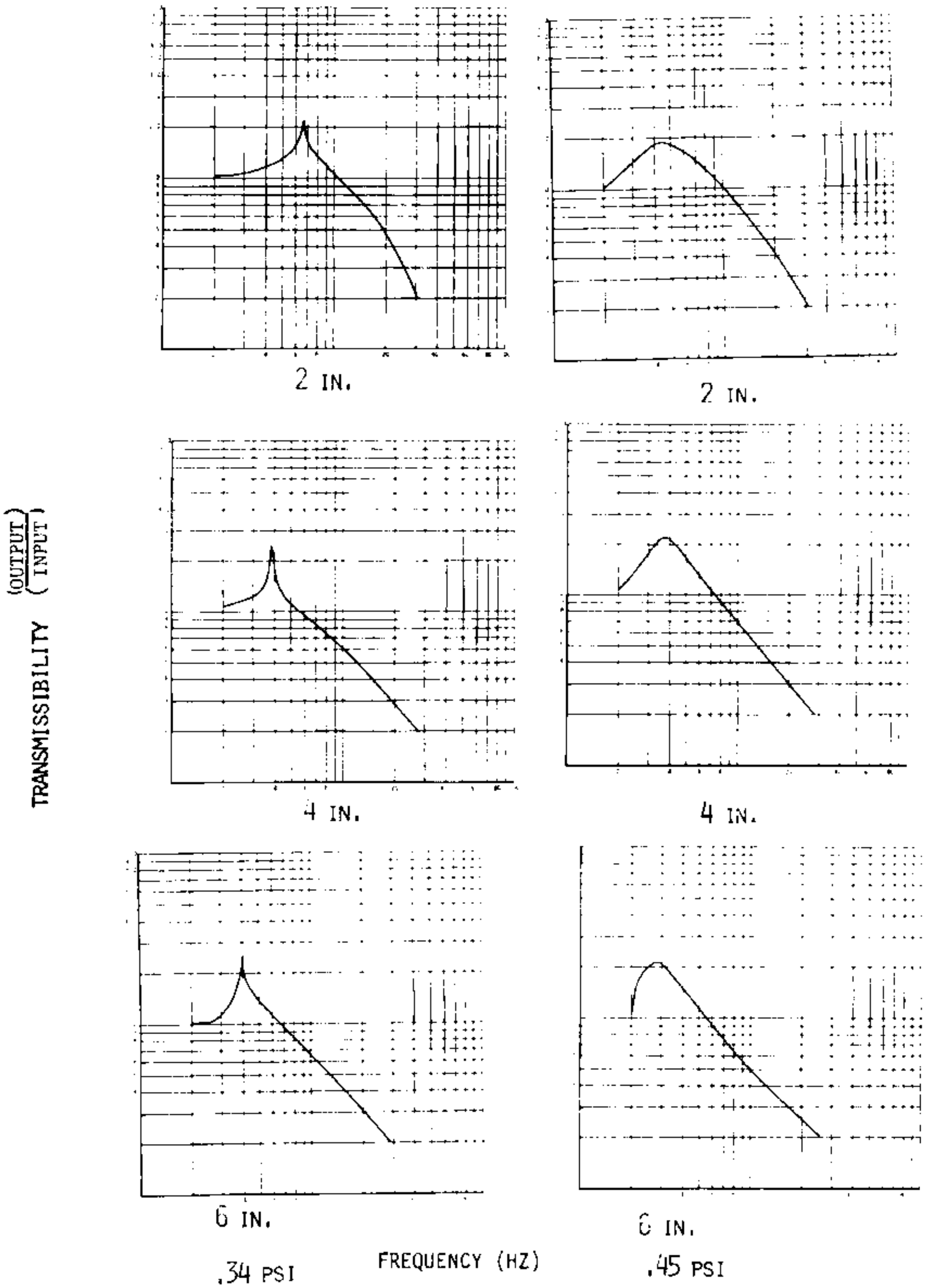
CURVE 16.2 CONVOLUTED POLYURETHANE, 1.15 PCF, 2.1″ PLY THICKNESS



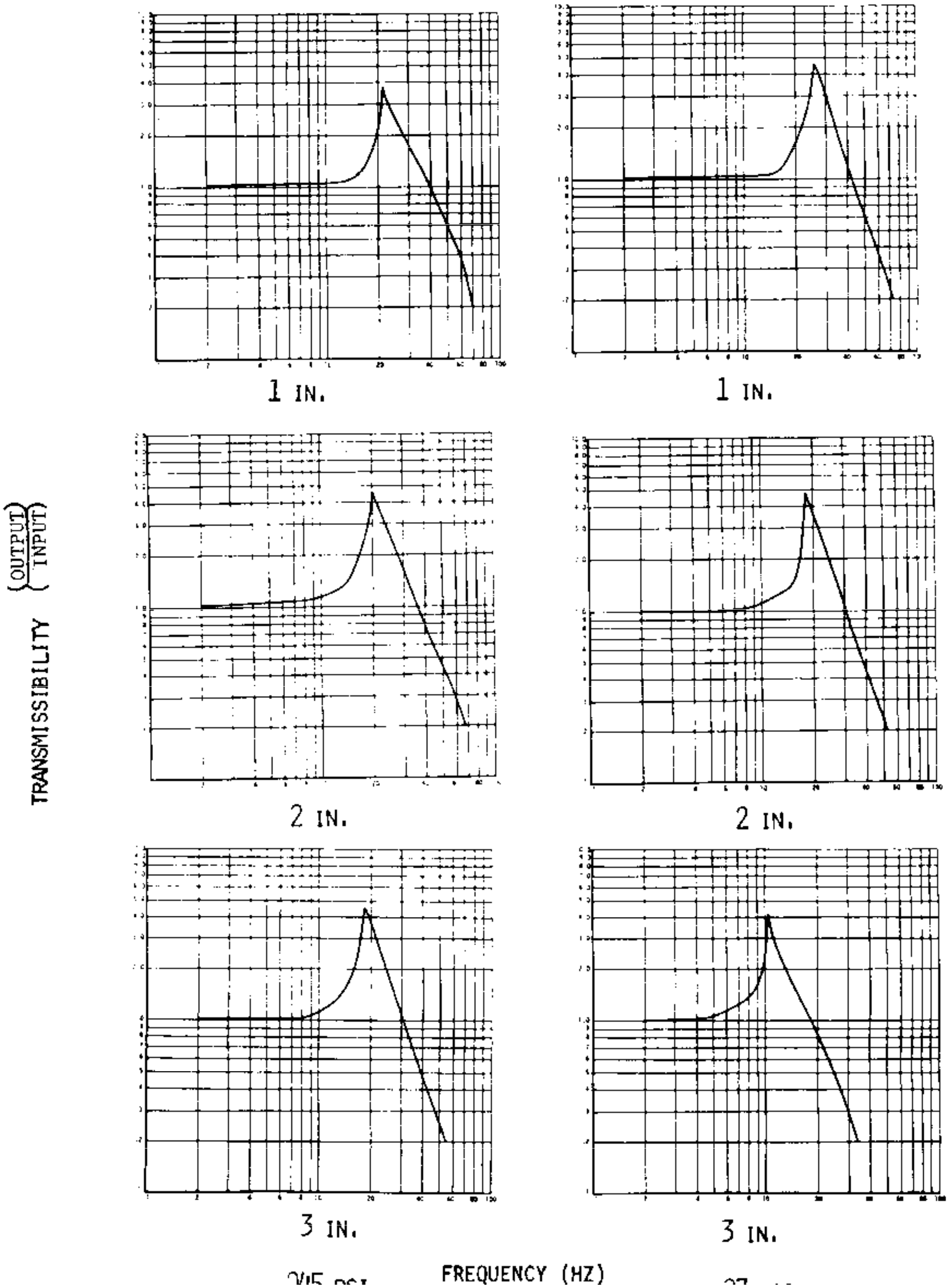
CURVE 16,3 CONVOLUTED POLYURETHANE, 1.15 PCF, 2.1″ PLY THICKNESS



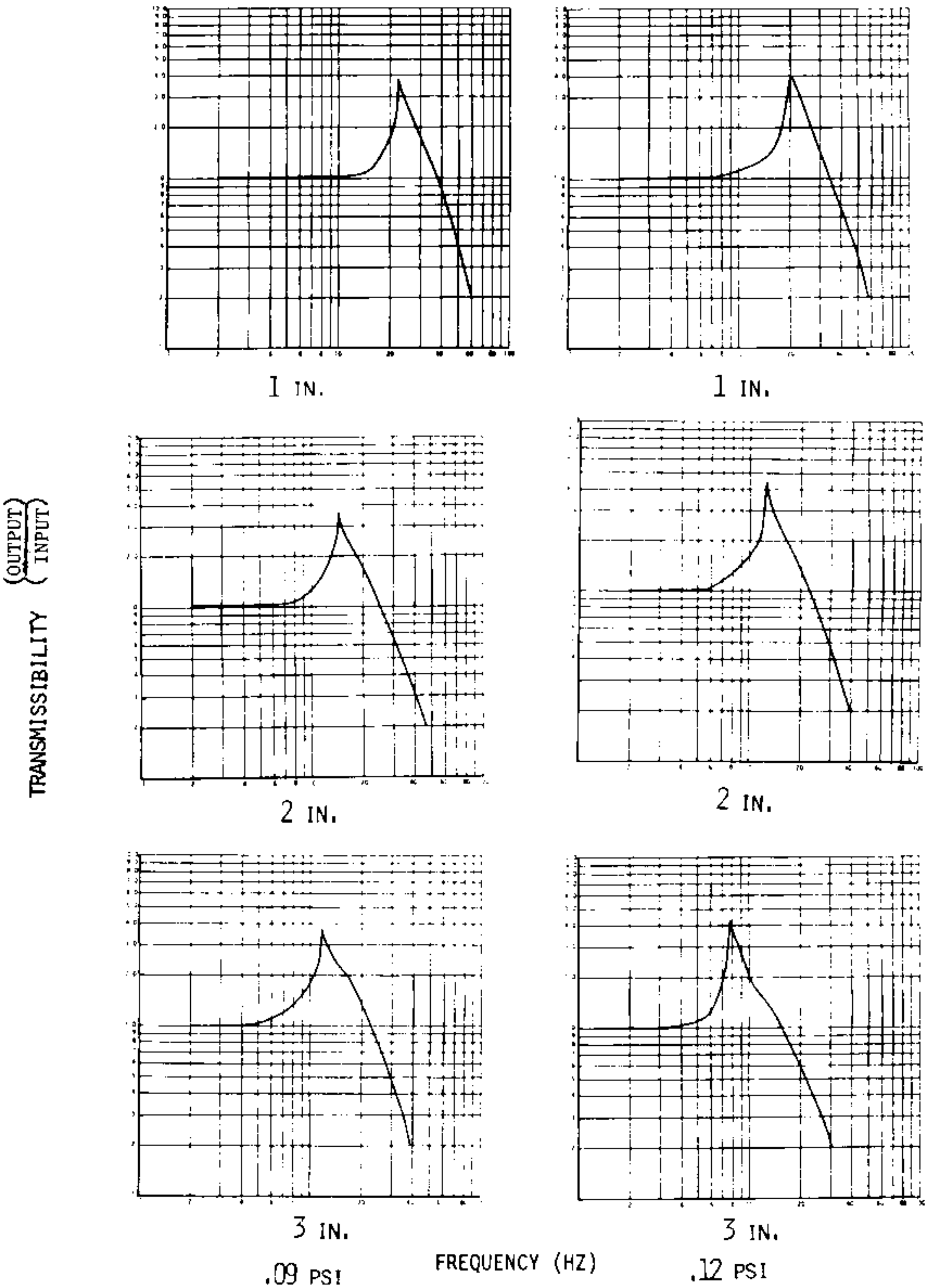
CURVE 16.4 CONVOLUTED POLYURETHANE, 1.15 PCF,2.1" PLY THICKNESS



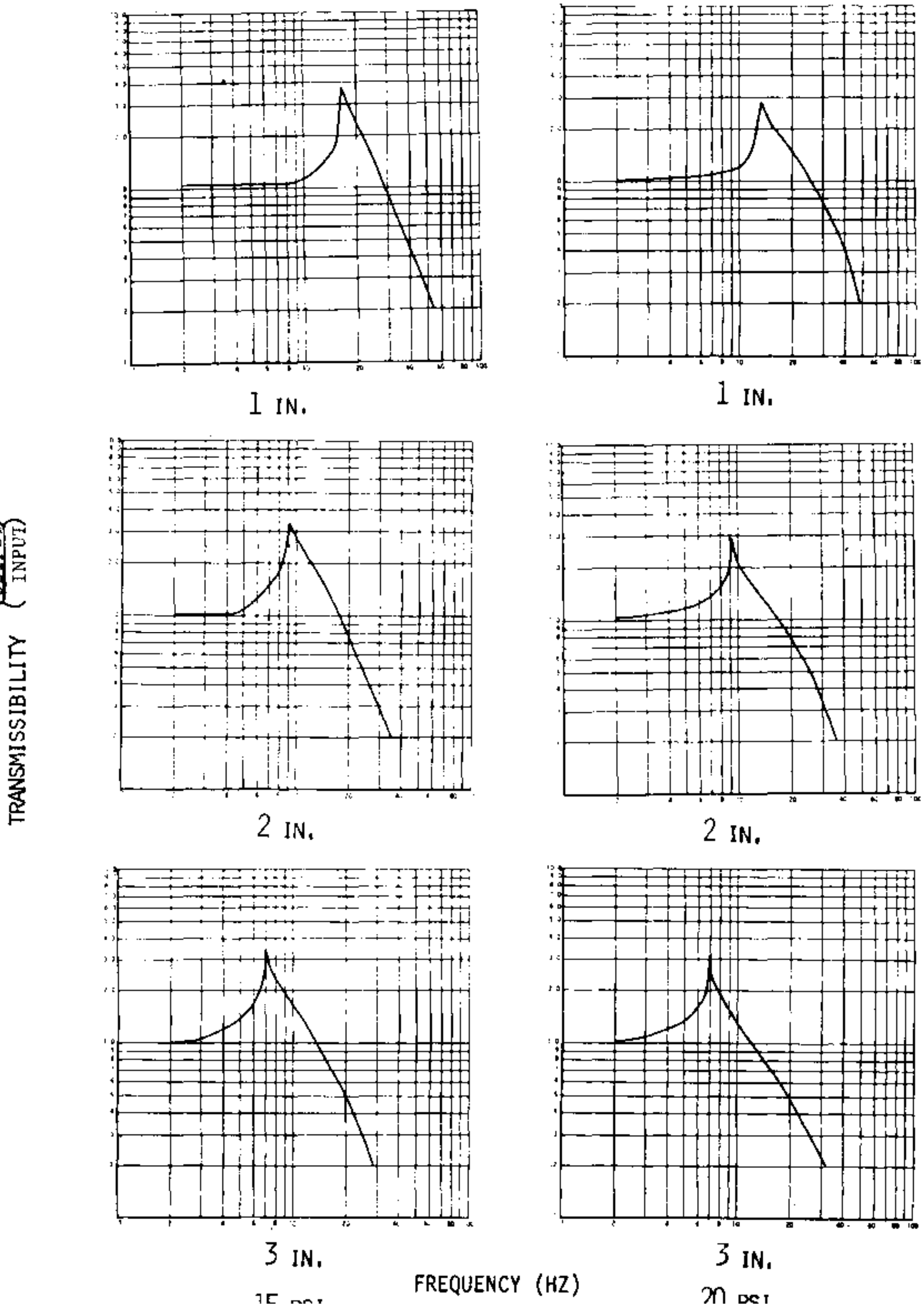
CURVE 16.5 CONVOLUTED POLYURETHANE, 1.15 PCF, 2.1" PLY THICKNESS



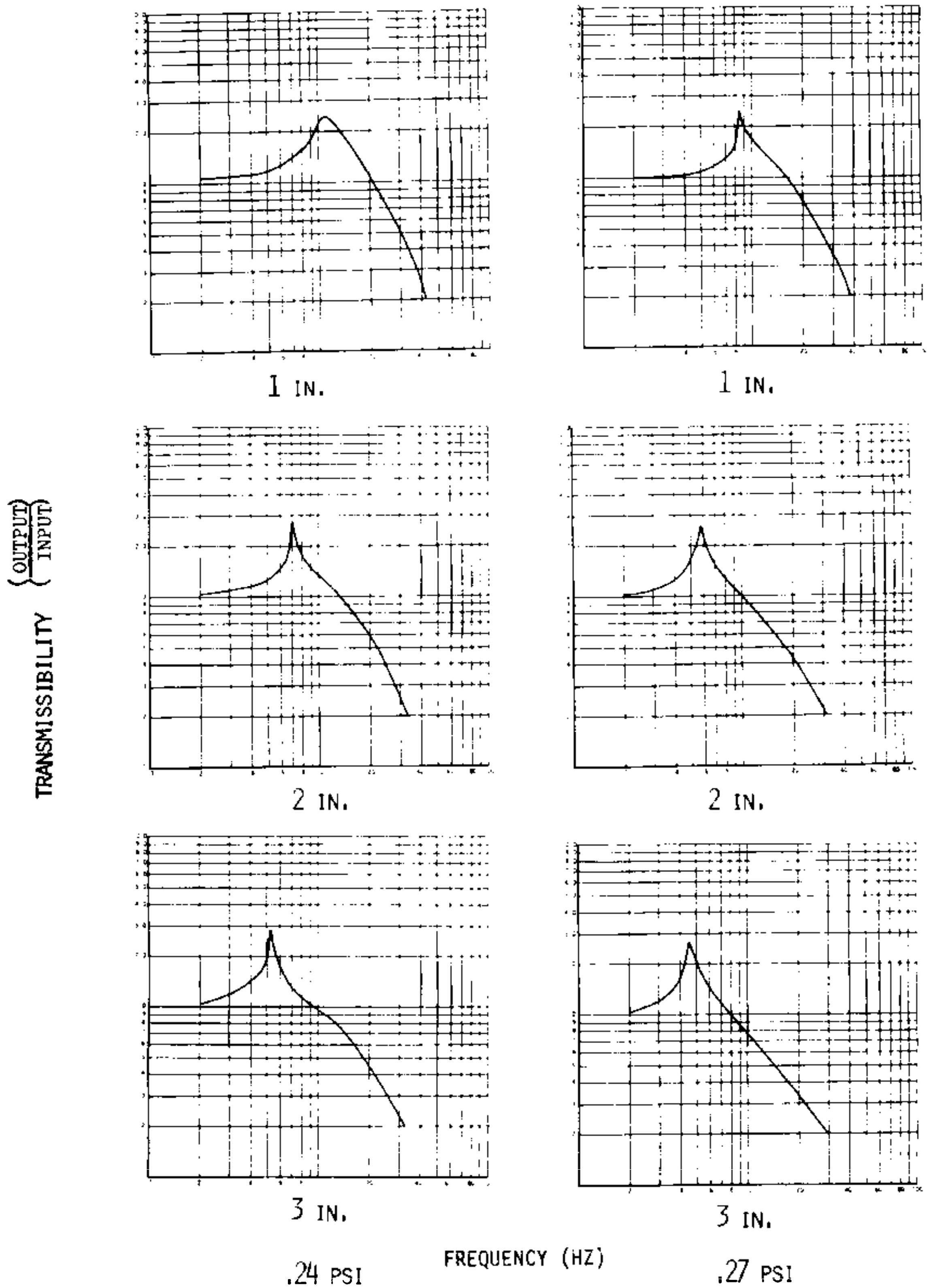
CURVE 17.1 CONVOLUTED POLYURETHANE, 1.5PCF, 1.0" PLY THICKNESS



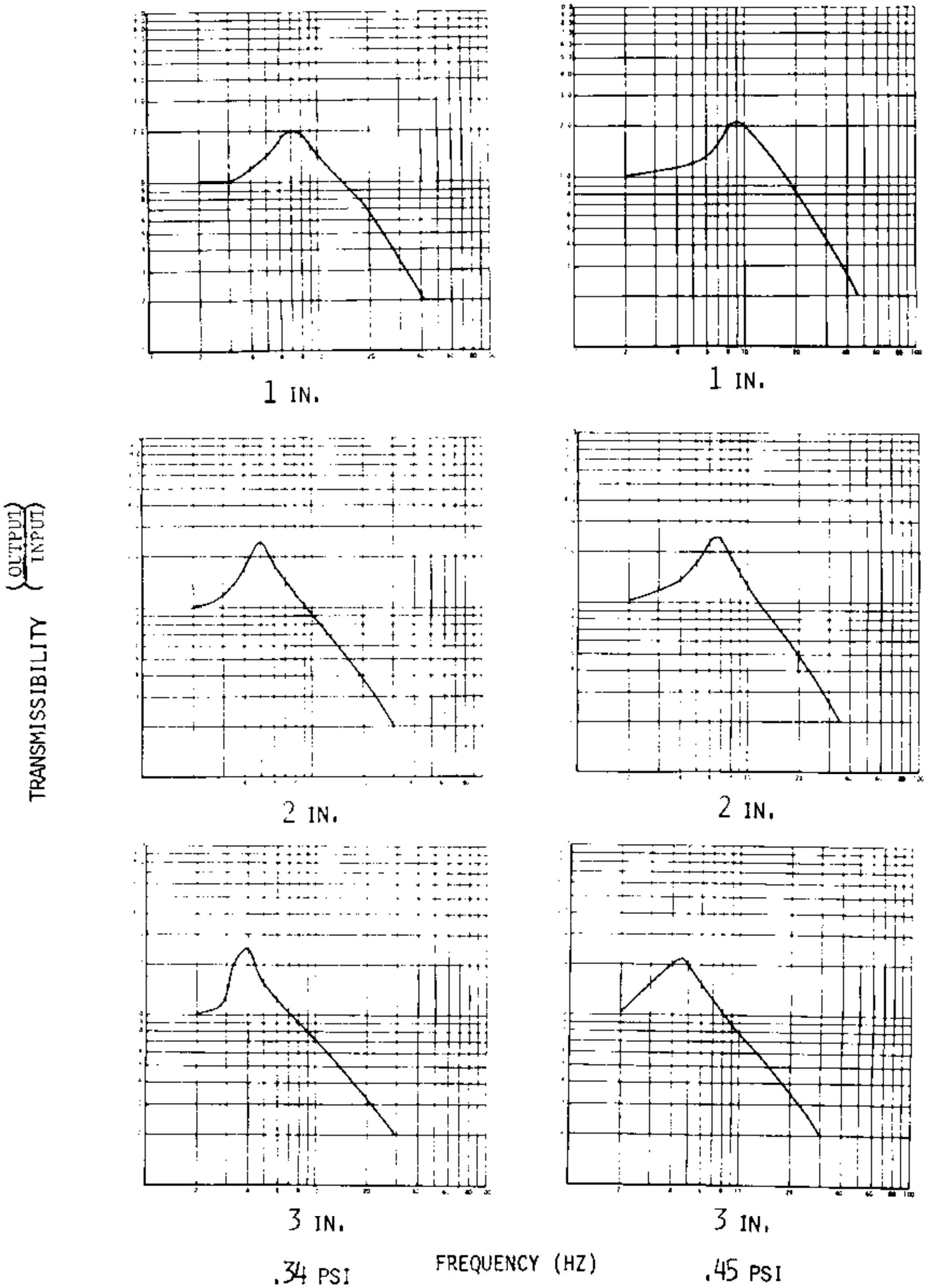
CURVE 17.2 CONVOLUTED POLYURETHANE, 1.5 PCF, 1.0" PLY THICKNESS



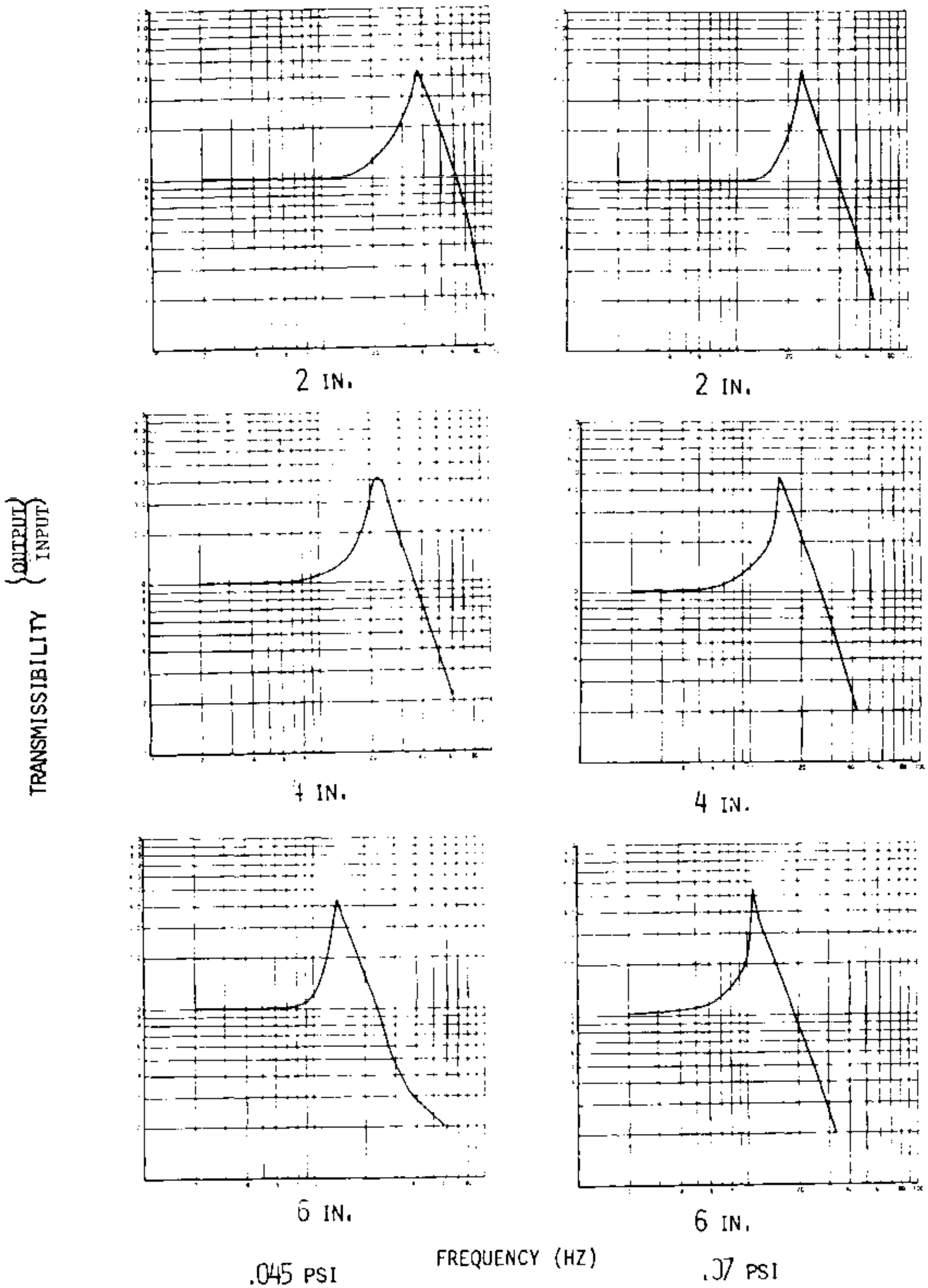
CURVE 17.3 CONVOLUTED POLYURETHANE, 1.5 PCF, 1.0″ PLY THICKNESS



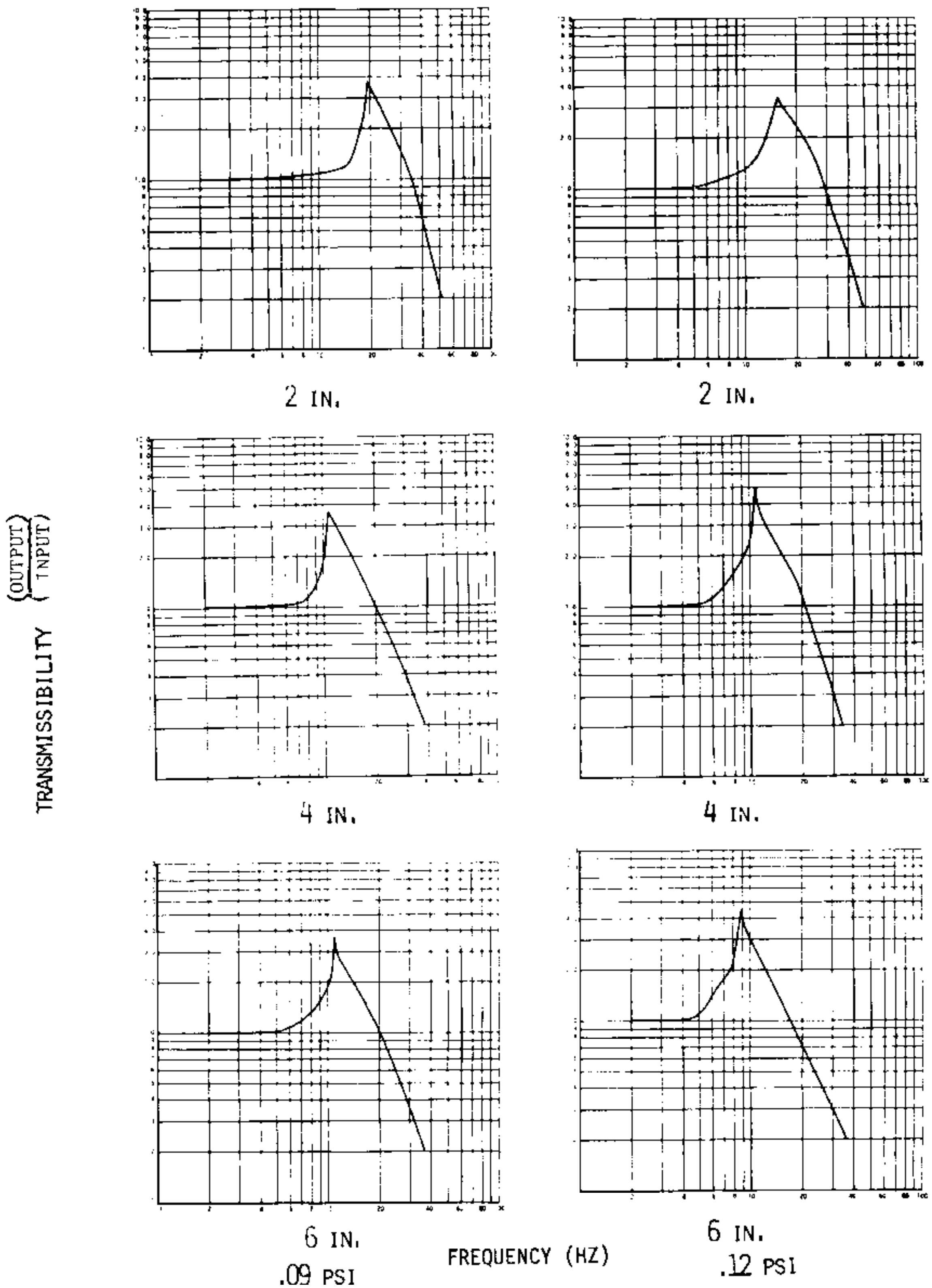
CURVE 17.4 CONVOLUTED POLYURETHANE, 1.5 PCF, 1,0" PLY THICKNESS



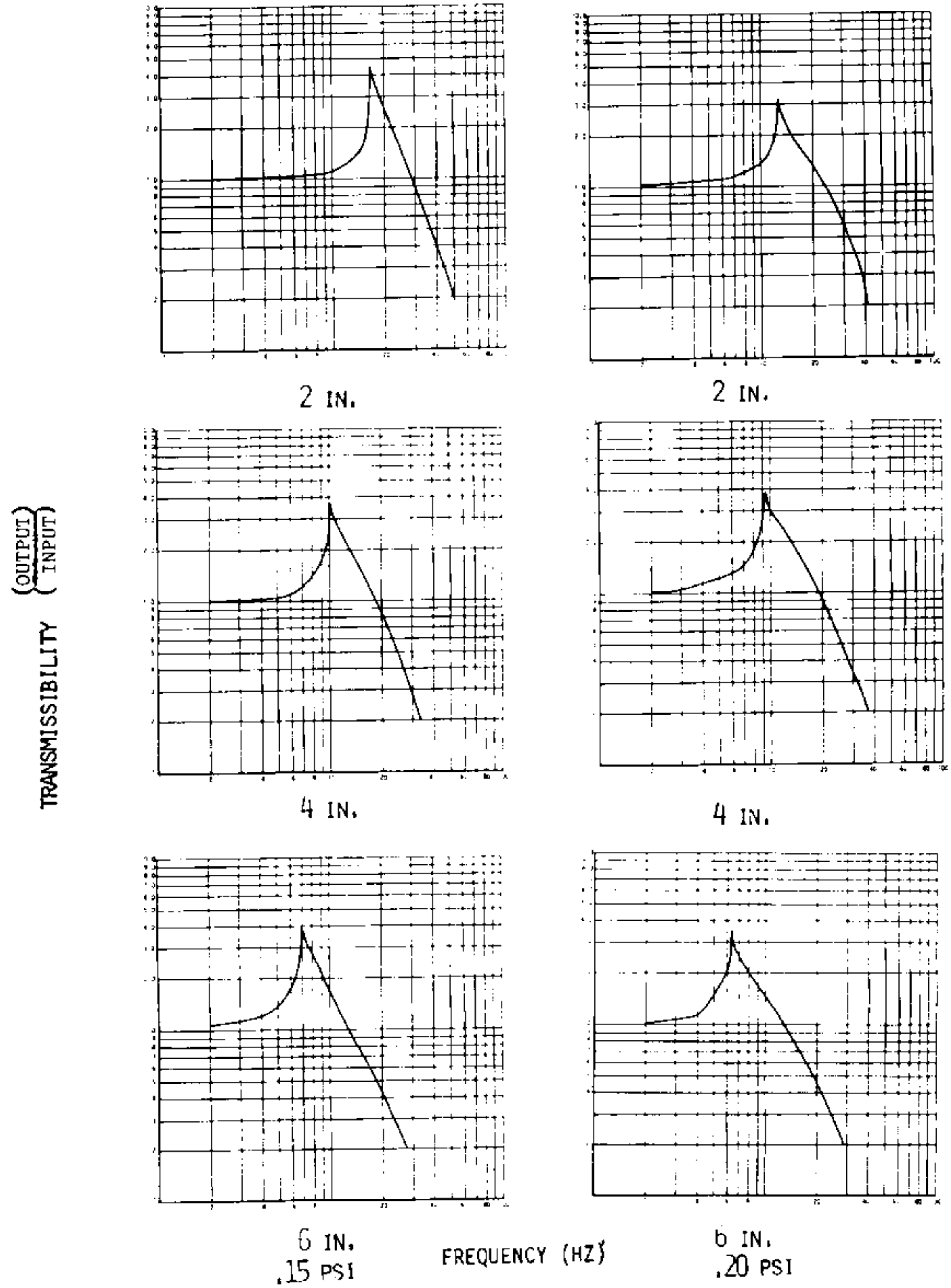
CURVE 17.5 CONVOLUTED POLYURETHANE, 1.5 PCF, 1.0″ PLY THICKNESS



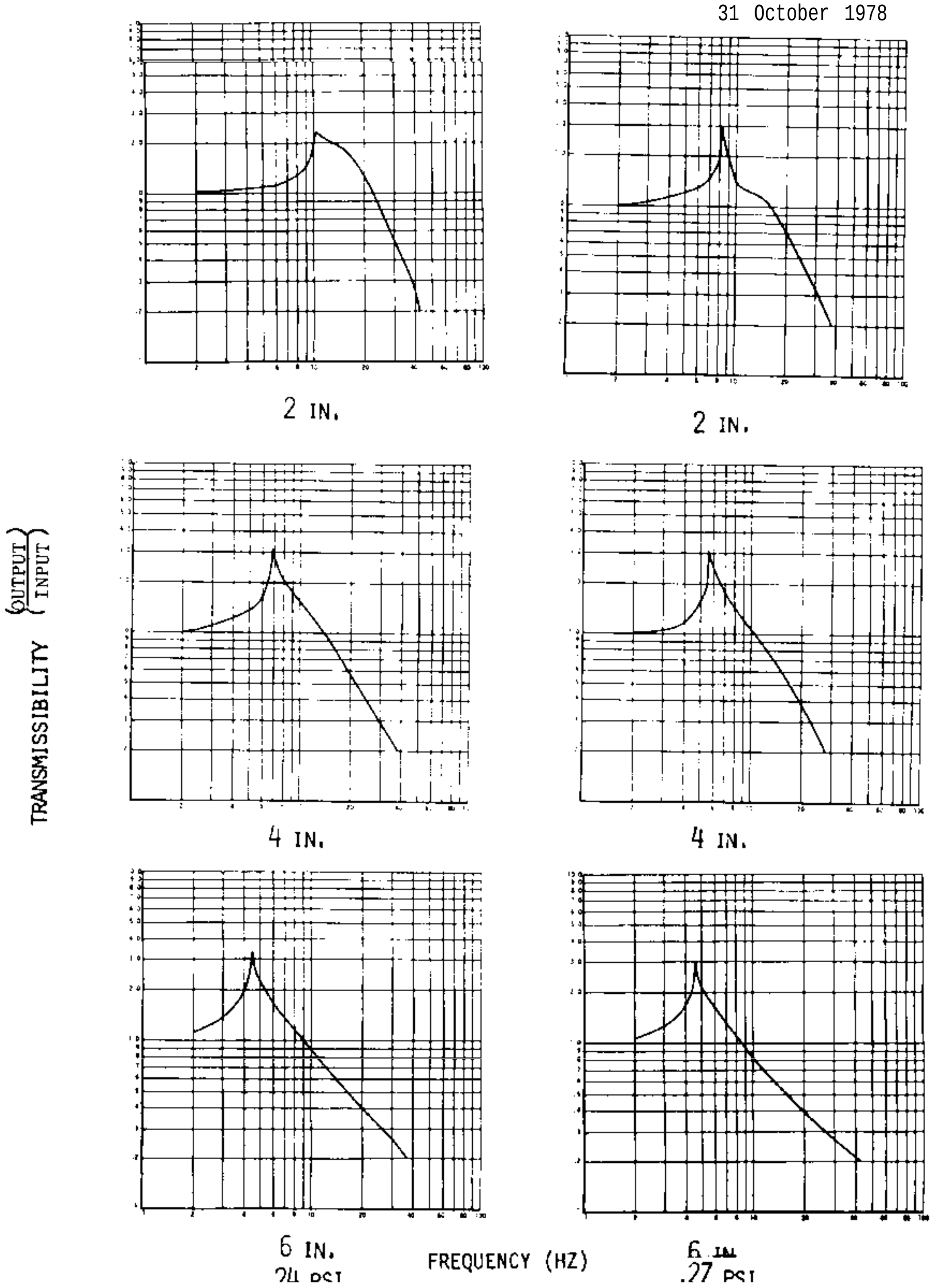
CURVE 18.1 CONVOLUTED POLYURETHANE, 1,5 PCF, 2,1″ PLY THICKNESS



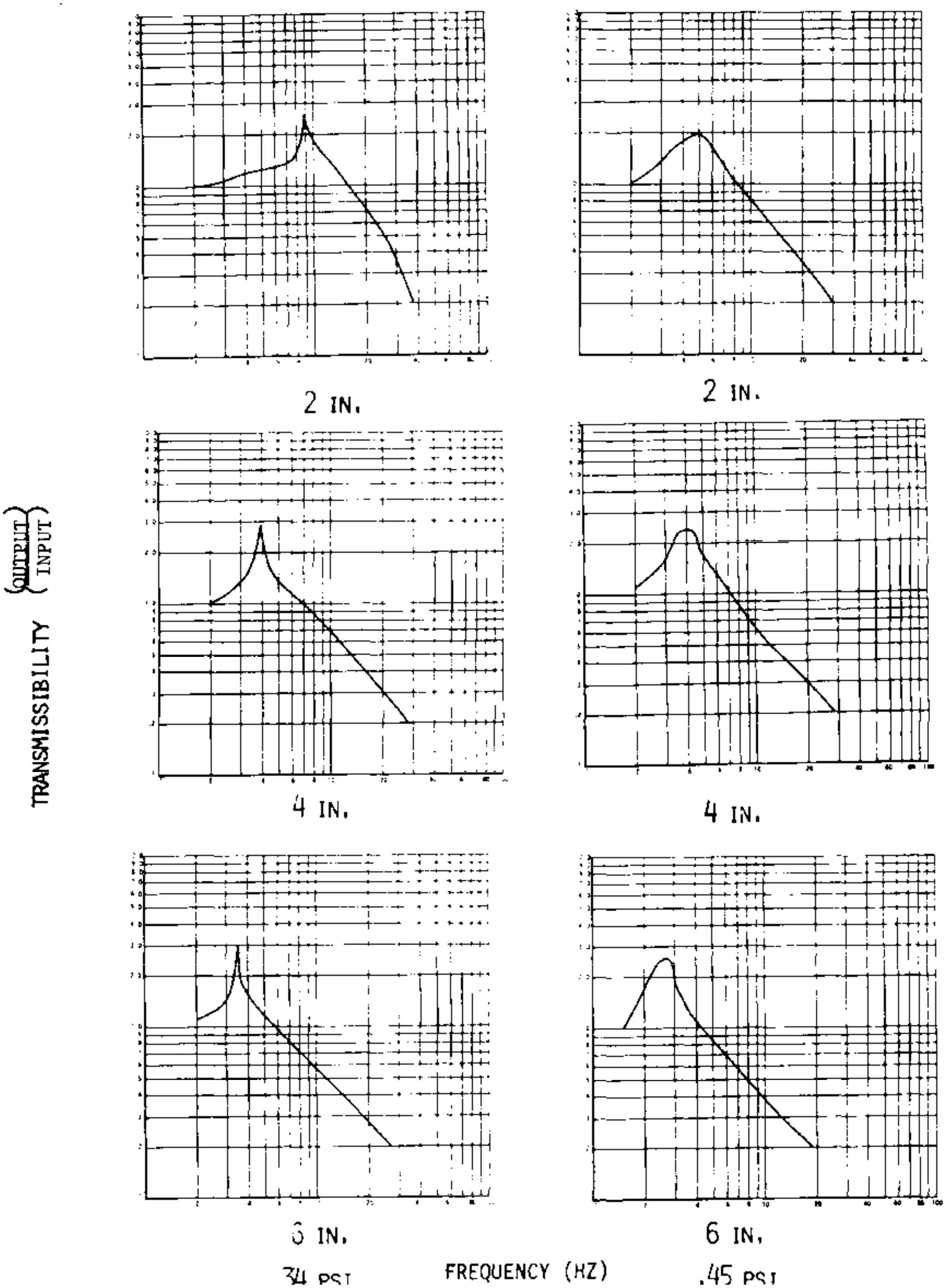
CURVE 18.2 CONVOLUTED POLYURETHANE, 1.5 PCF, 2.1" PLY THICKNESS



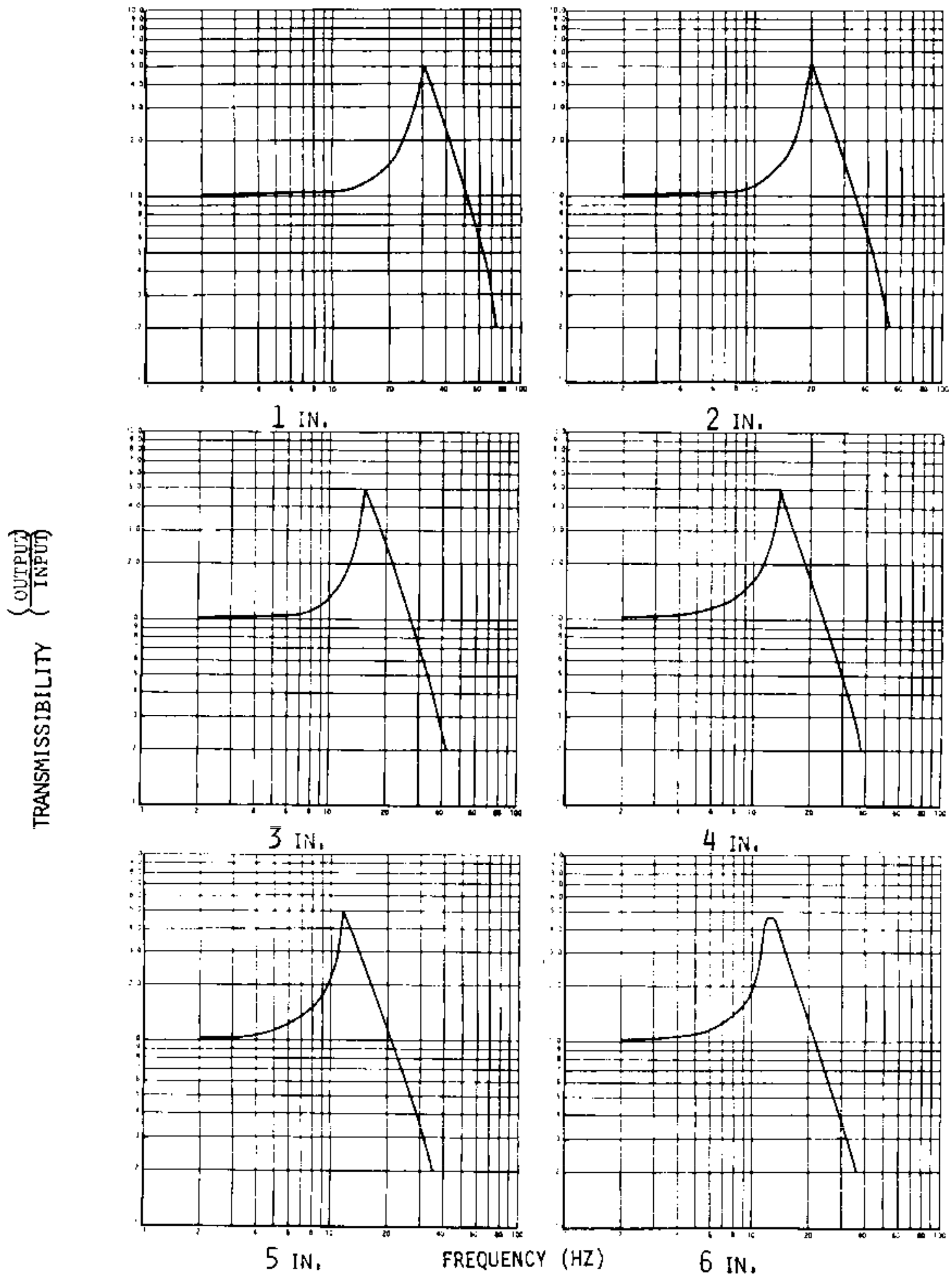
CURVE 18.3 CONVOLUTED POLYURETHANE, l.5 PCF, 2.1" PLY THICKNESS



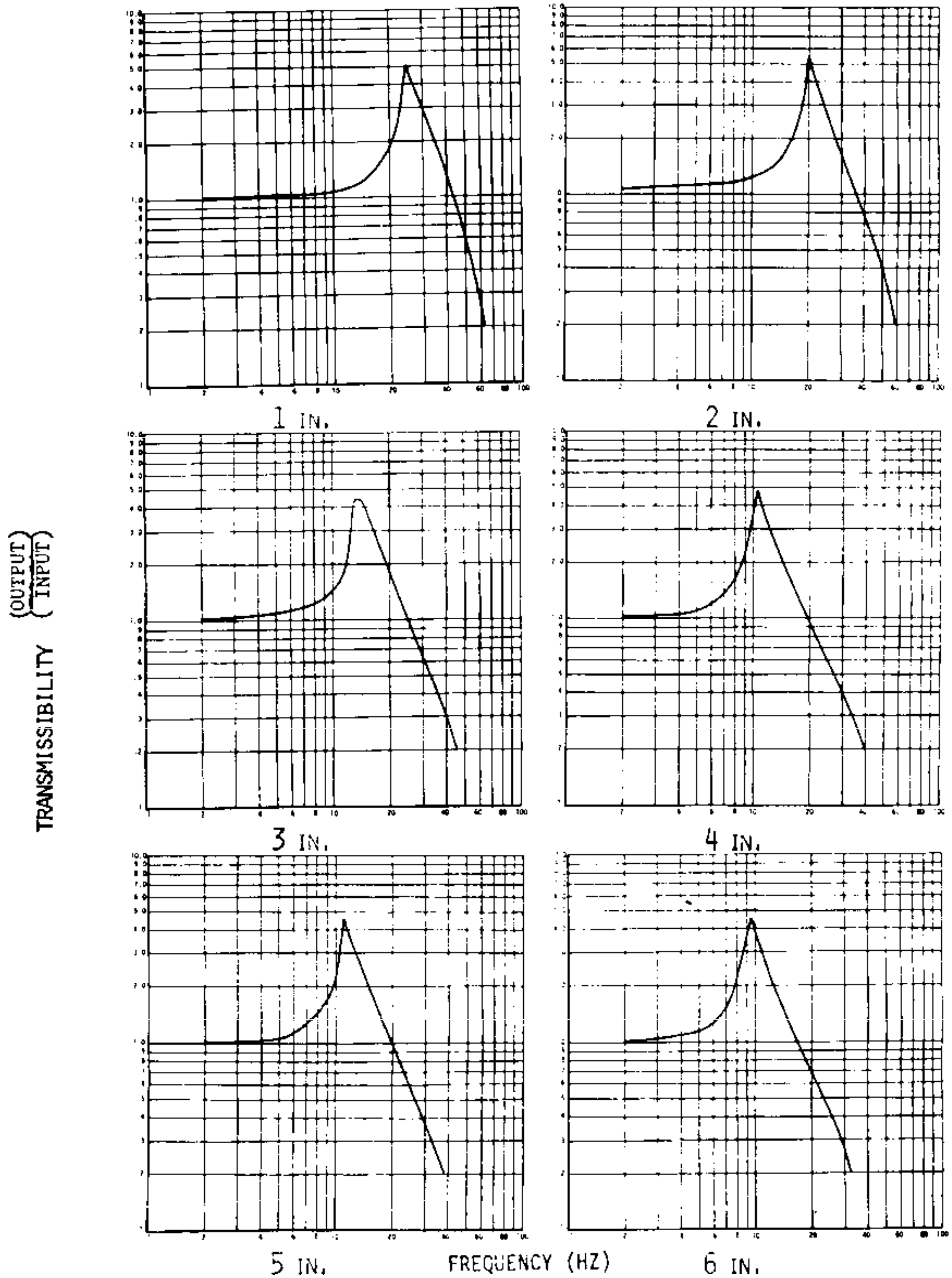
CURVE 18.4 CONVOLUTED POLYURETHANE, 1.5 PCF, 2.1" PLY THICKNESS



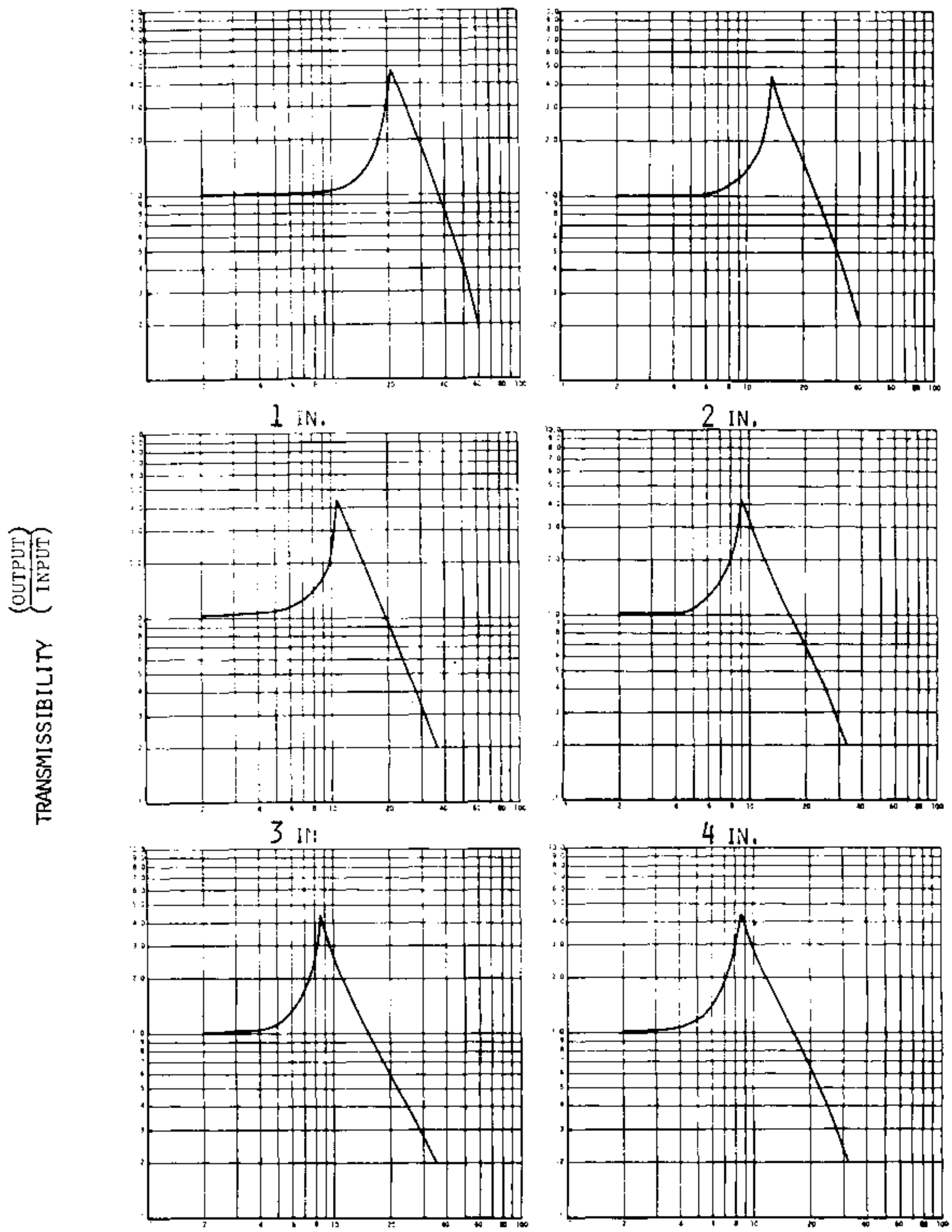
CURVE 18.5 CONVOLUTED POLYURETHANE, 1.5 PCF, 2.1″ PLY THICKNESS



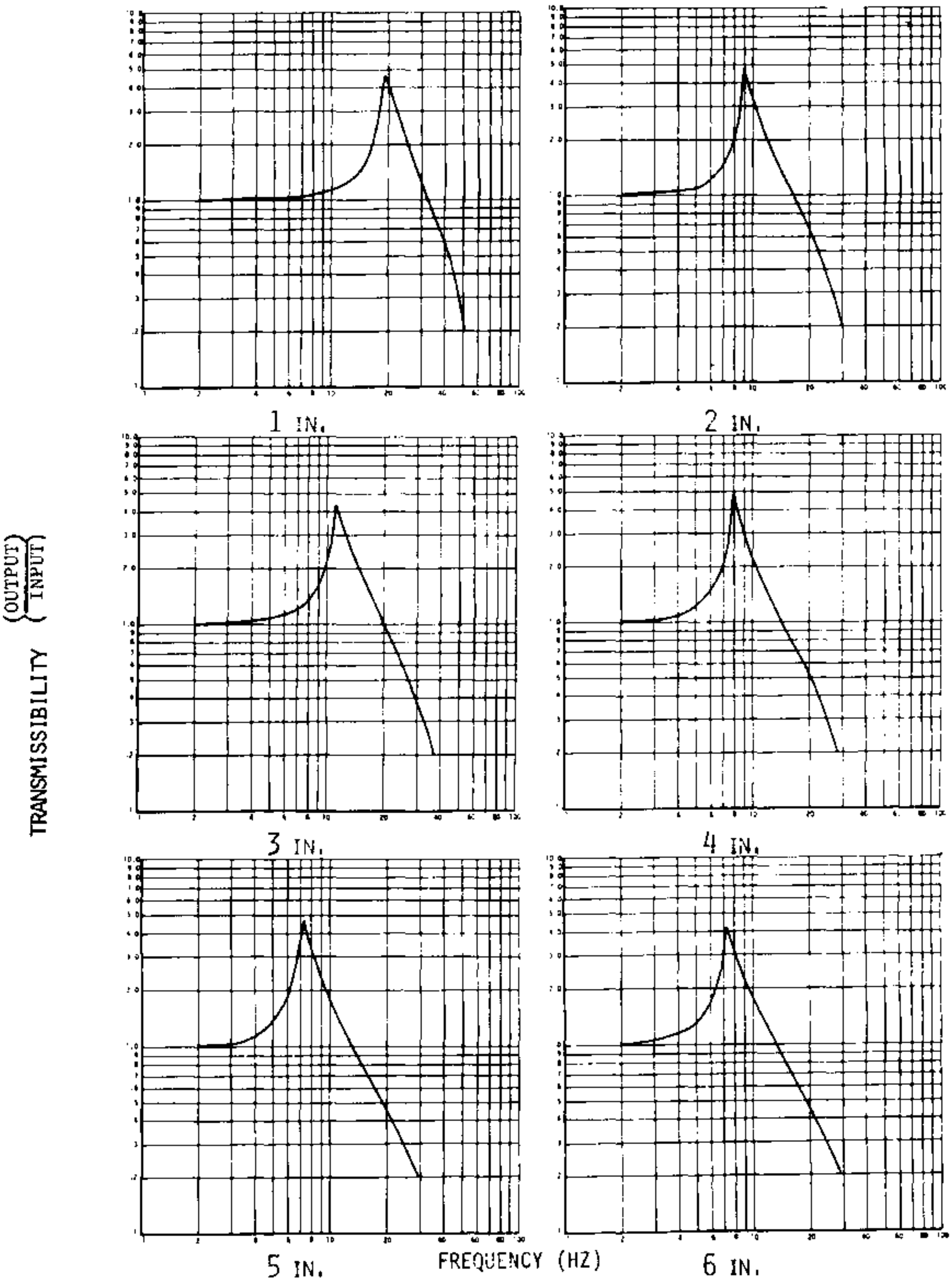
CURVE 13.1 CELLULOSE WADDING, 2 LB/CU FT .045 PSI



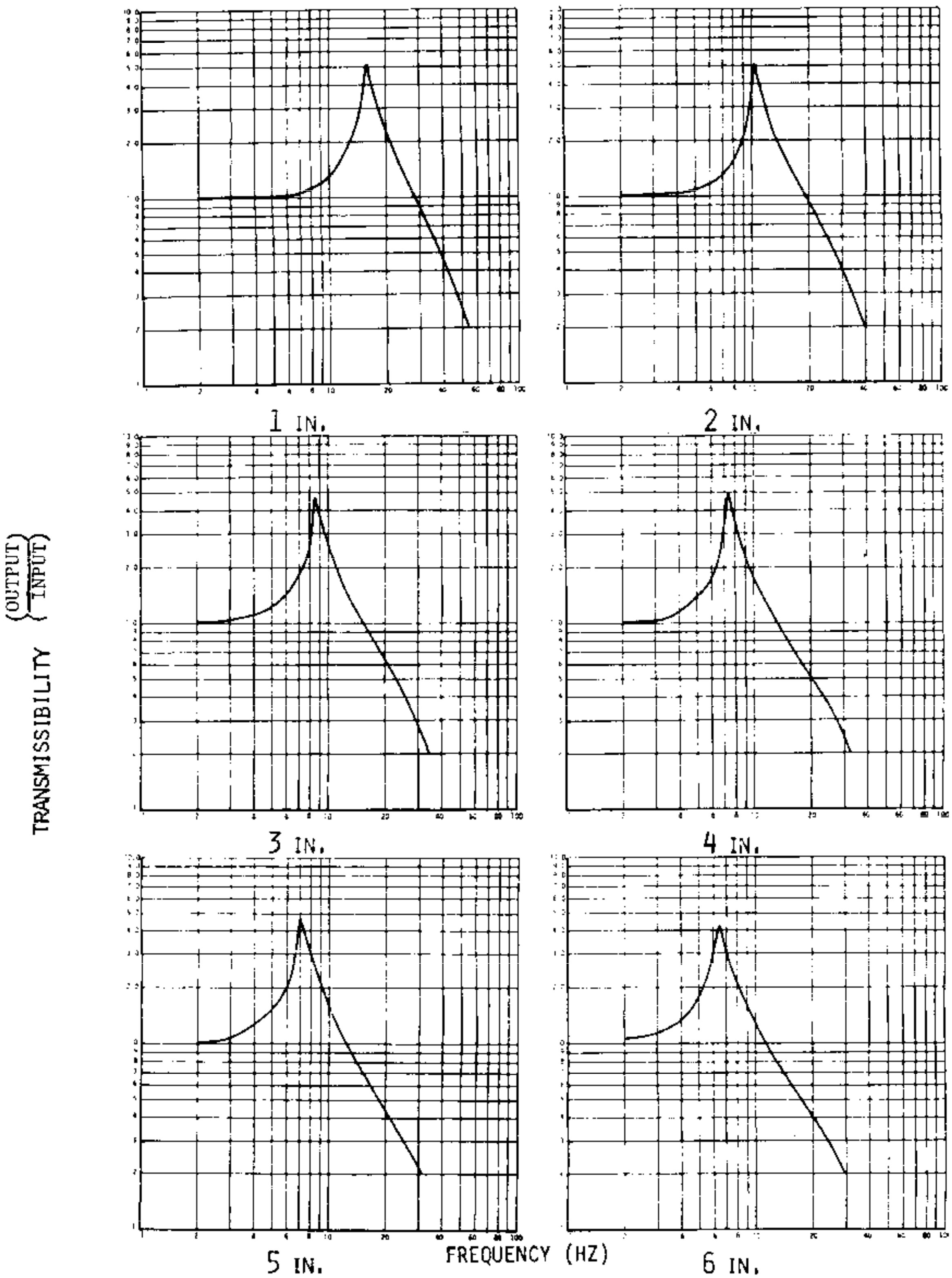
CURVE 19.2 CELLULOSE WADDING, 2 LB/CU FT ,077 PSI



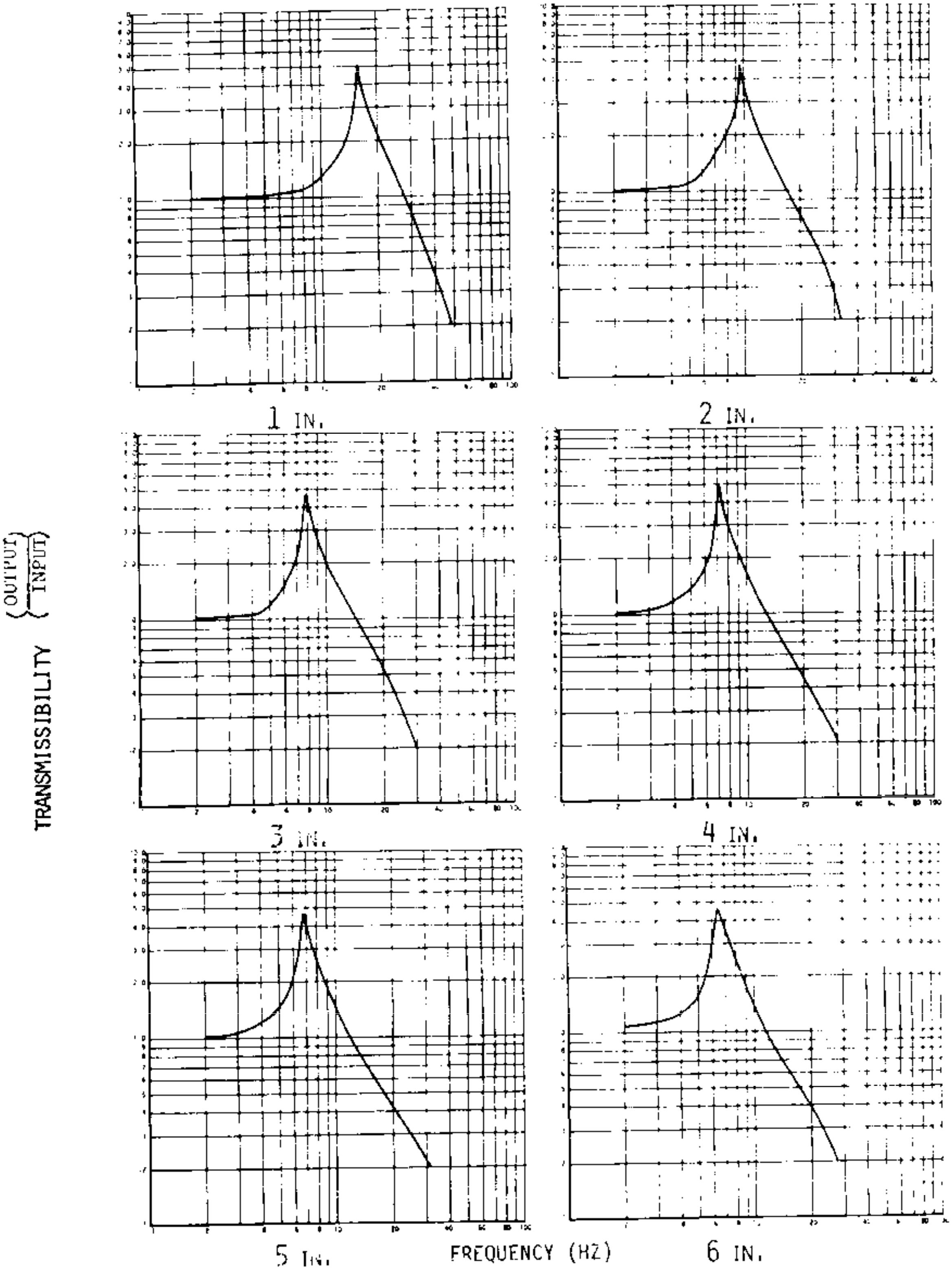
CURVE 19.3 CELLULOSE WADDING, 2 LB/CU FT .11 PSI



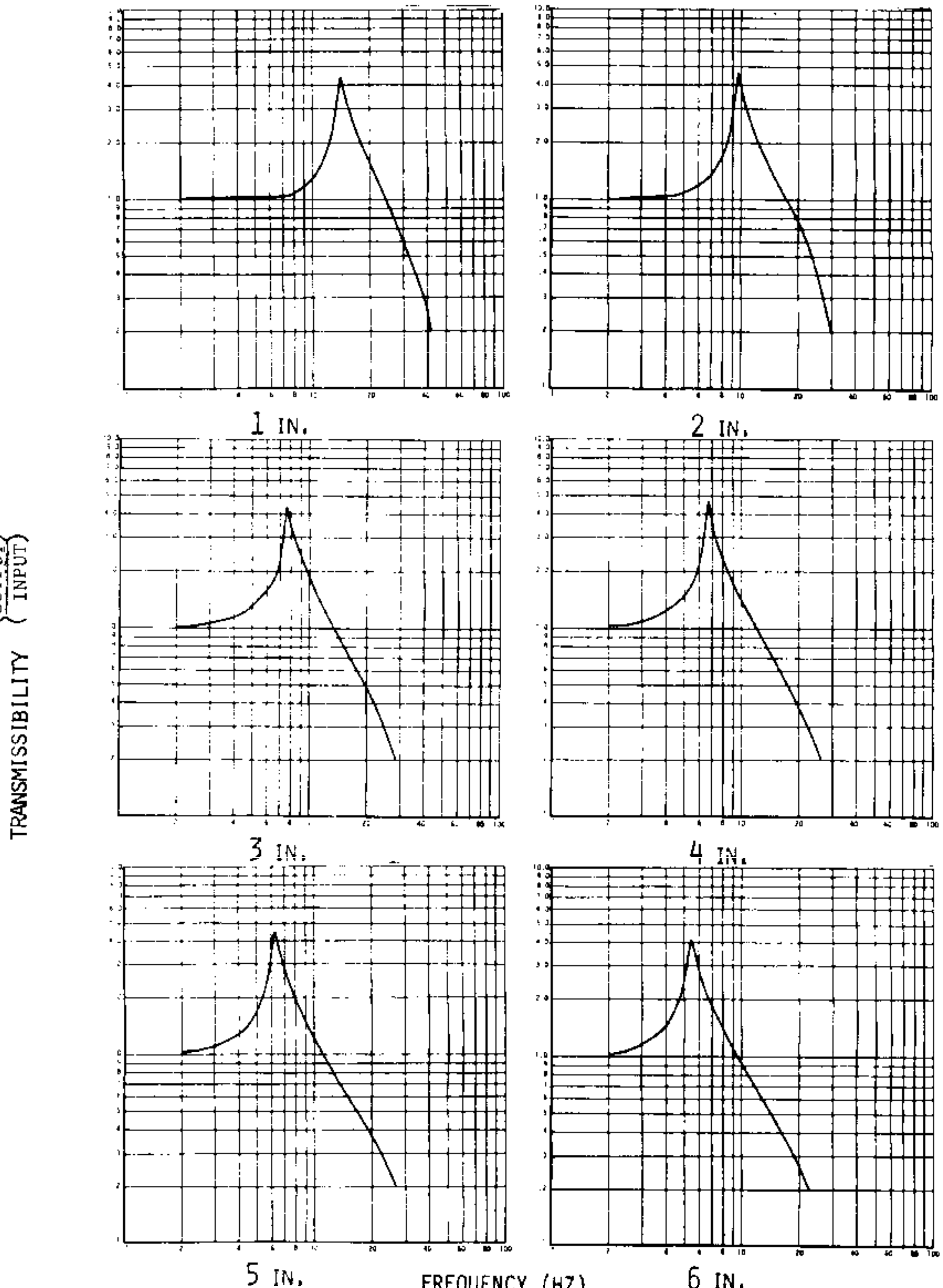
CURVE 19.4 CELLULOSE WADDING, 2 LB/CU FT ,148 PSI



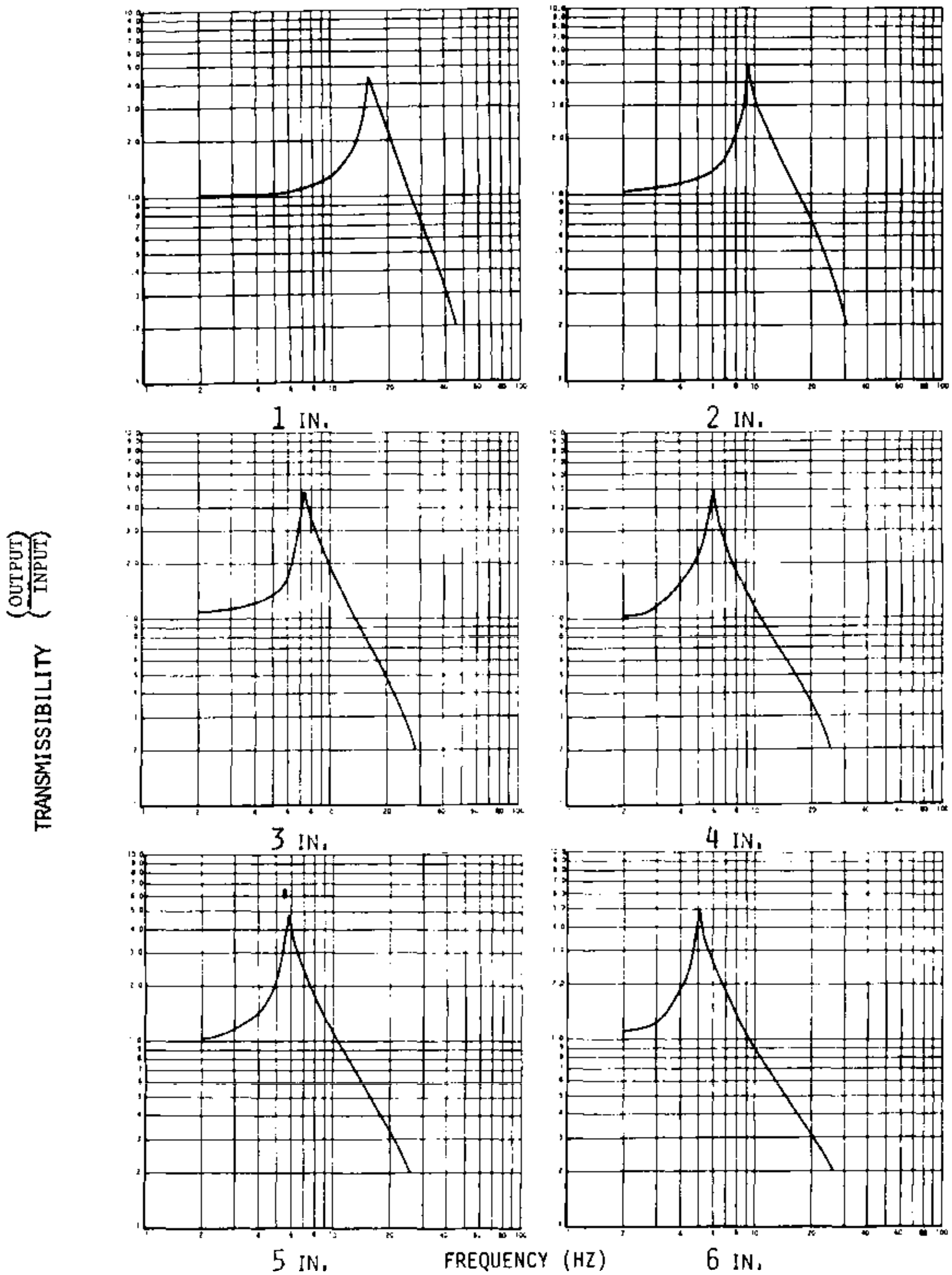
CURVE 19.5 CELLULOSE WADDING, 2 LB/CU FT ,18 PSI



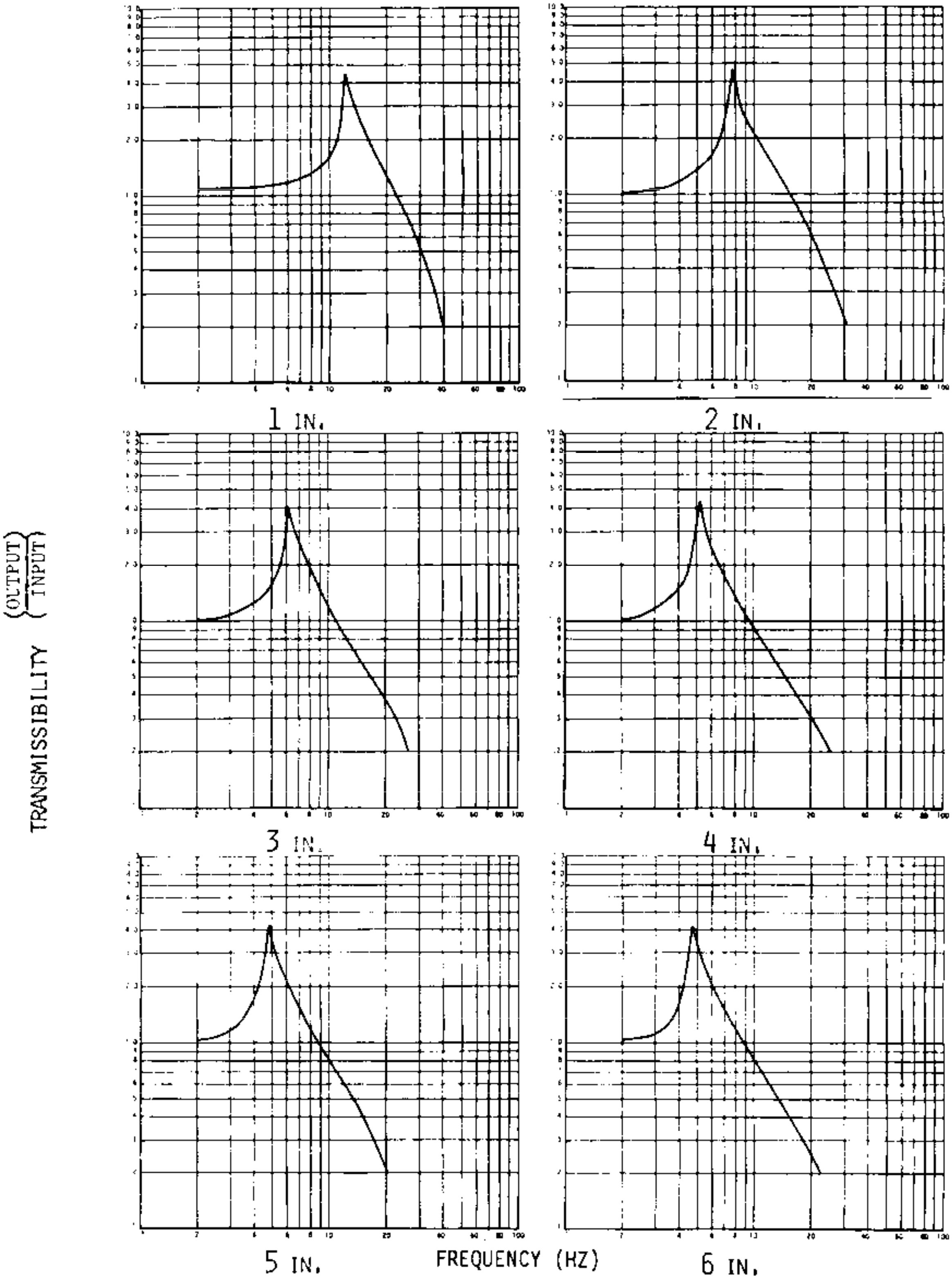
CURVE 19.6 CELLULOSE WADDING, 2 LB/CU FT .211 PSI



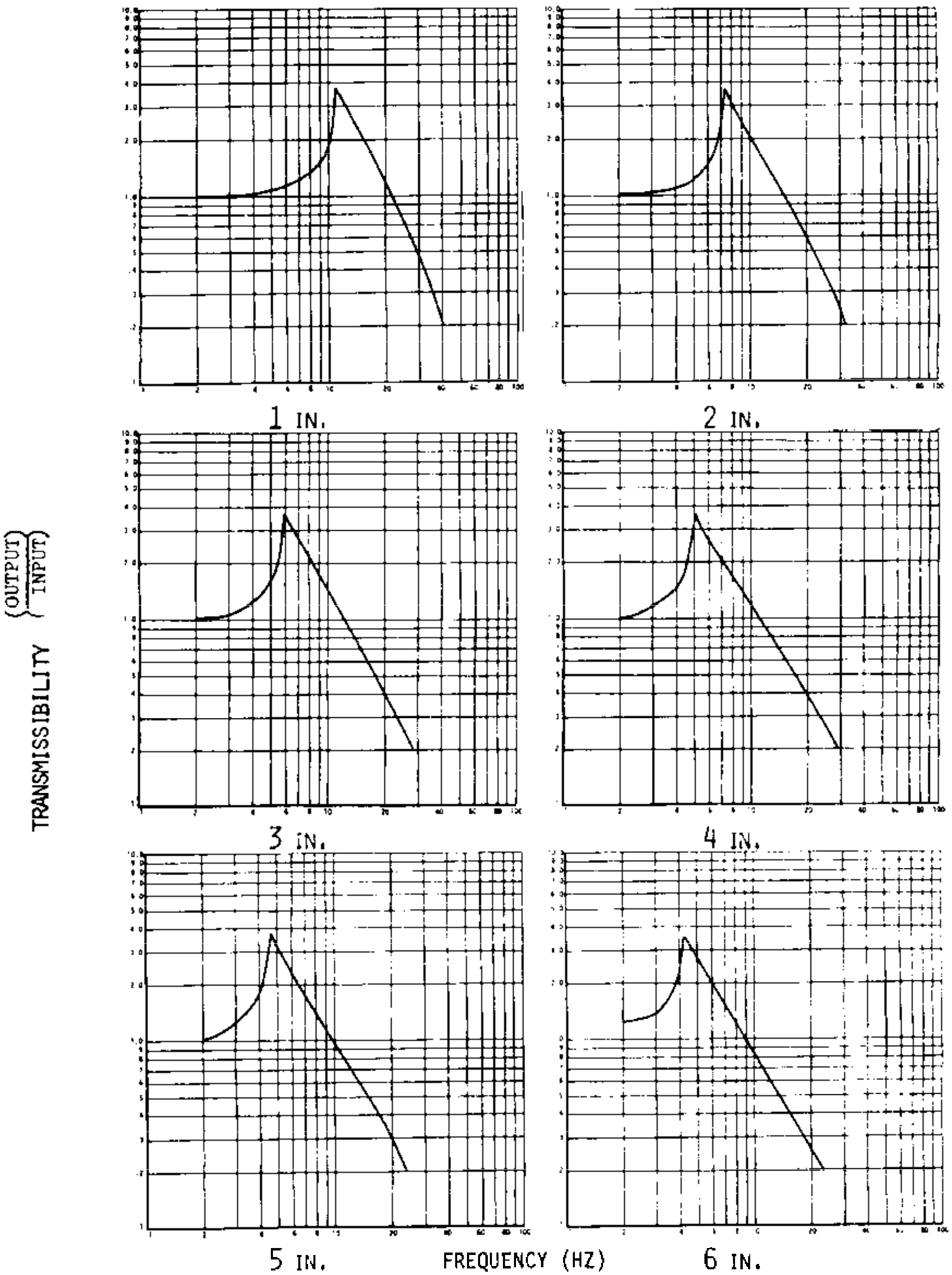
CURVE 19.7 CELLULOSE WADDING, 2 LB/CU FT .252 PSI



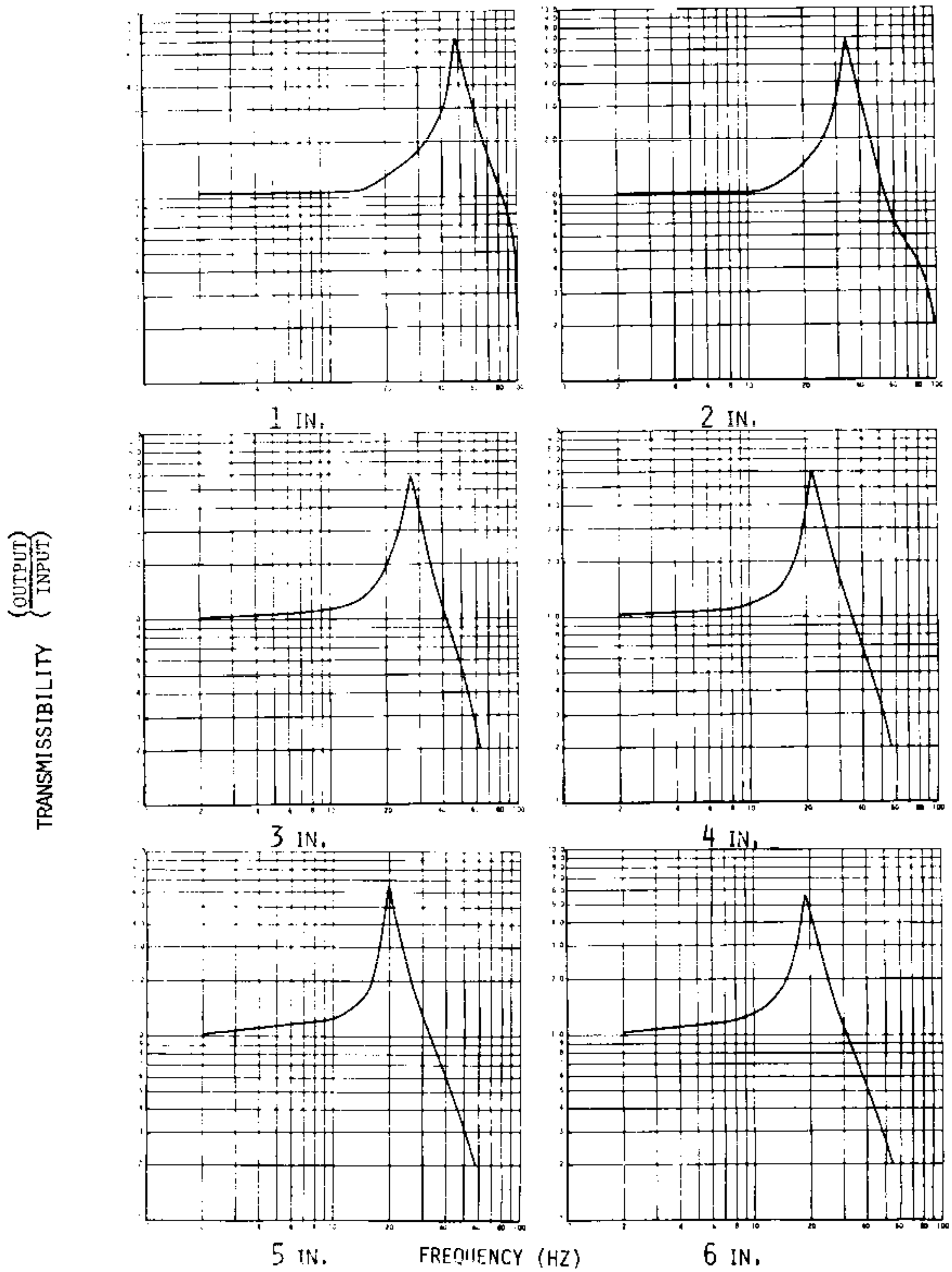
CURVE 19.8 CELLULOSE WADDING, 2 LB/CU FT .283 PSI



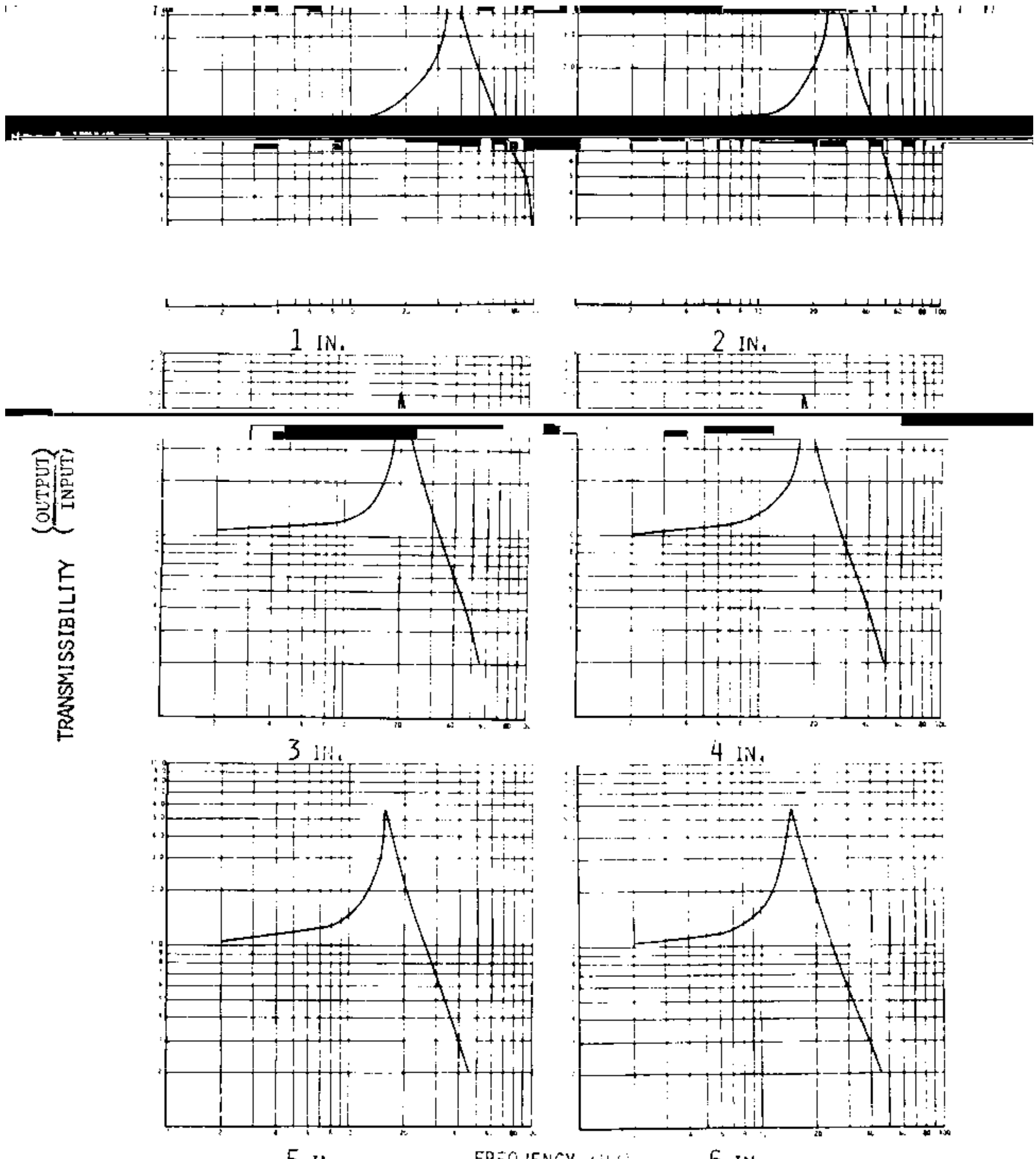
CURVE 19.9 CELLULOSE WADDDING, 2 LB/CU FT .484 PSI



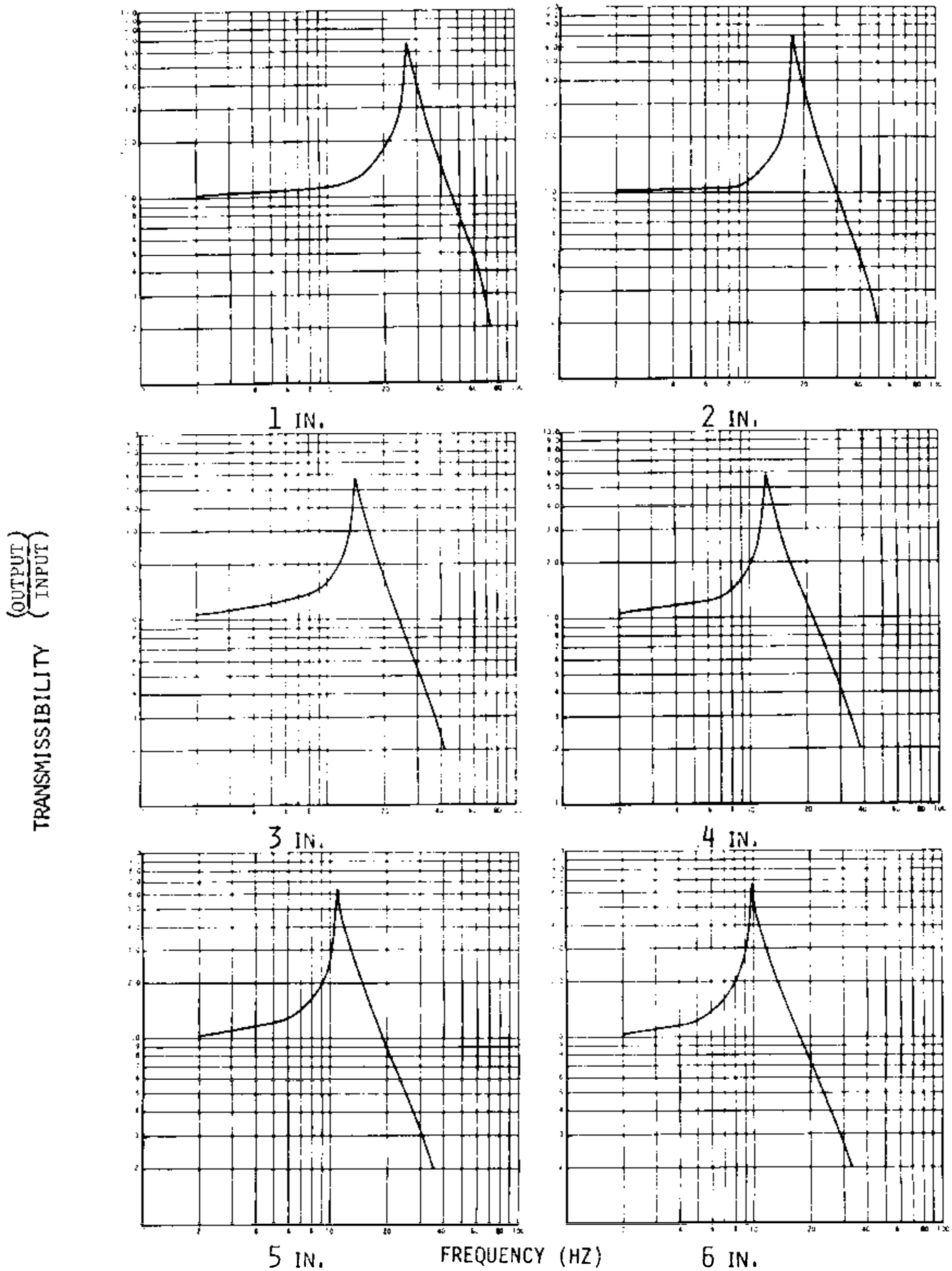
CURVE 19.10 CELLULOSE WADDING, 2 LB/CU FT .80 PSI



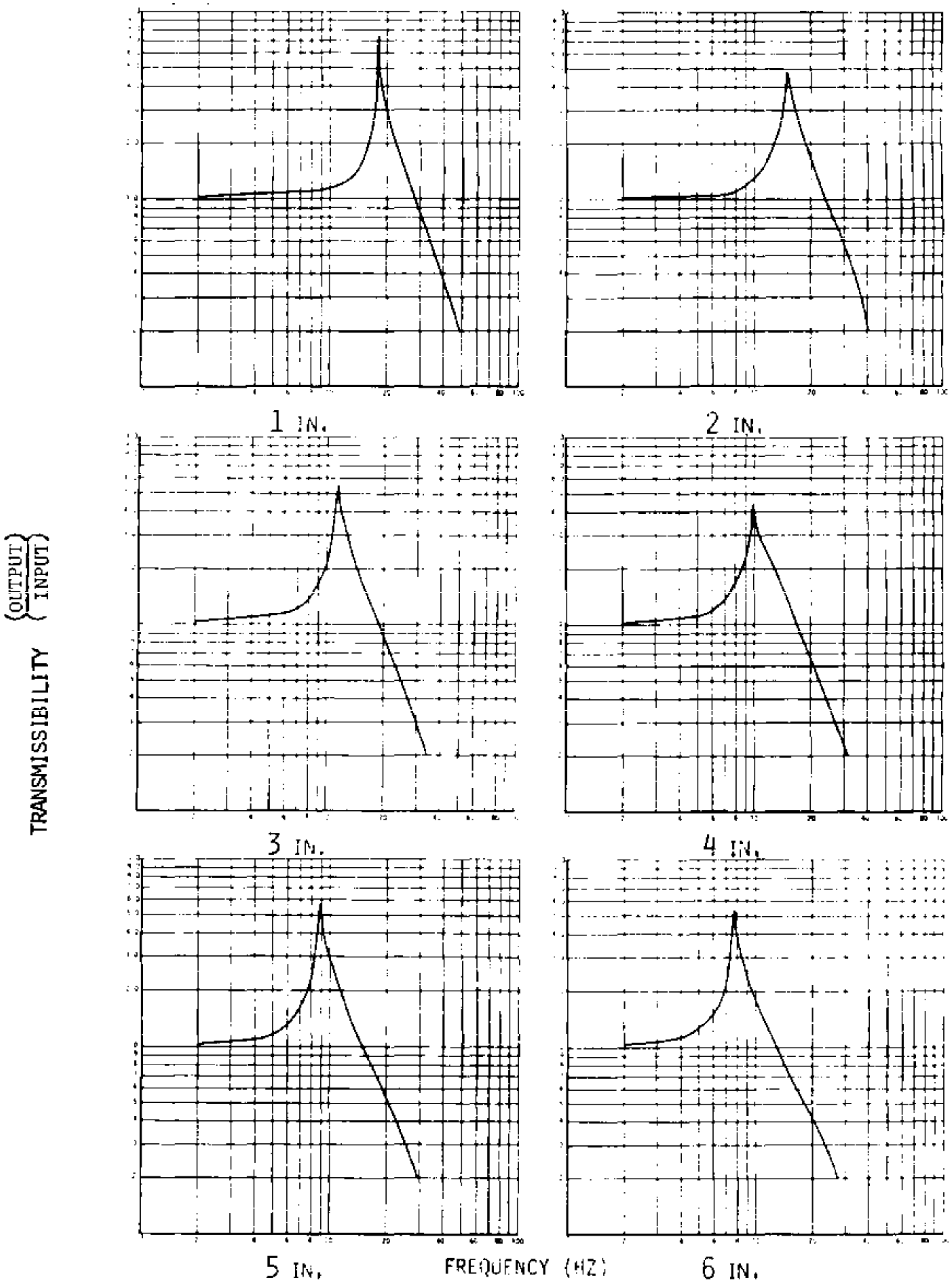
CURVE 20.1 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .045 PSI



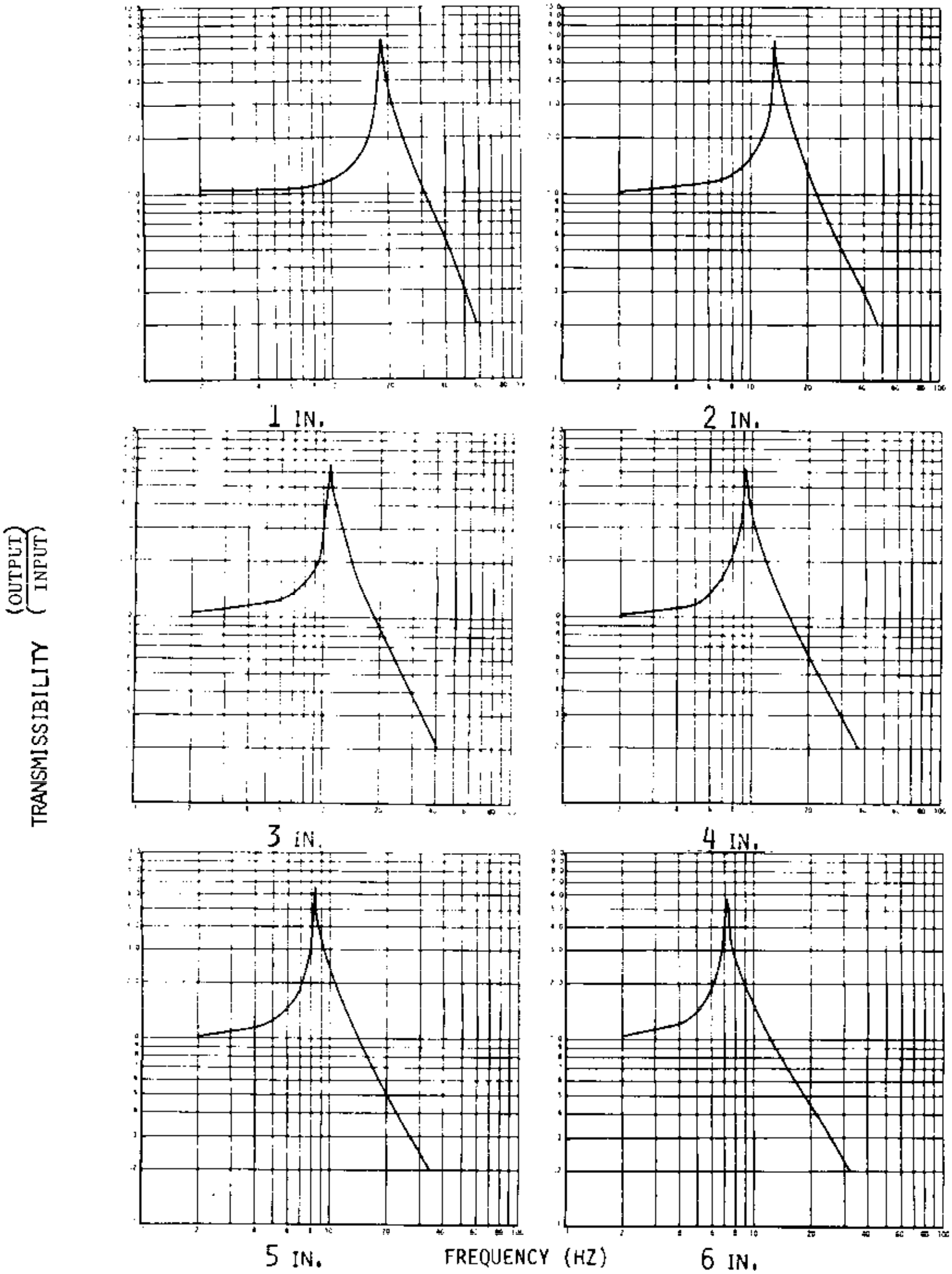
CURVE 20.2 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .076 PSI



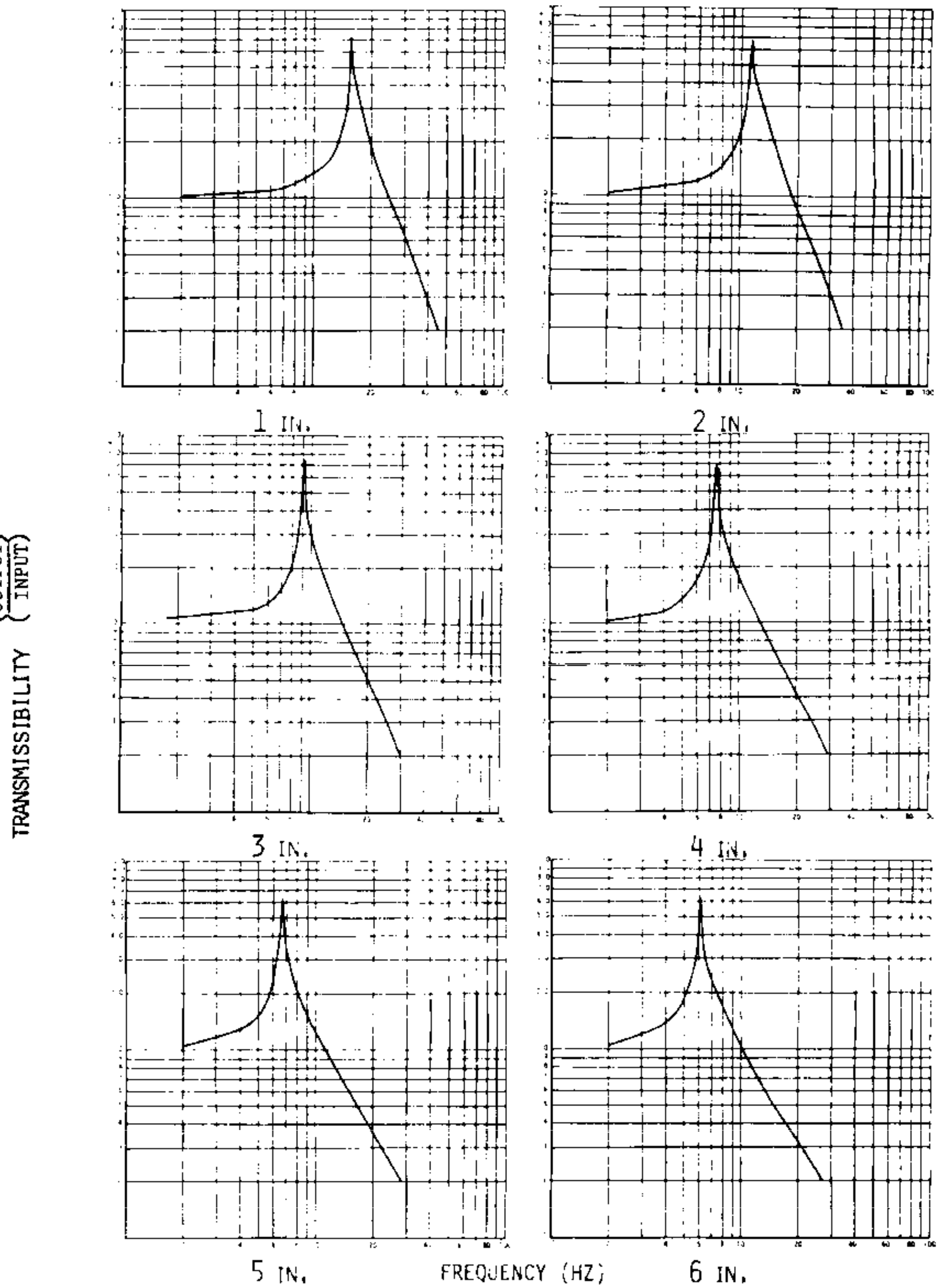
CURVE 20.3 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .133 PSI



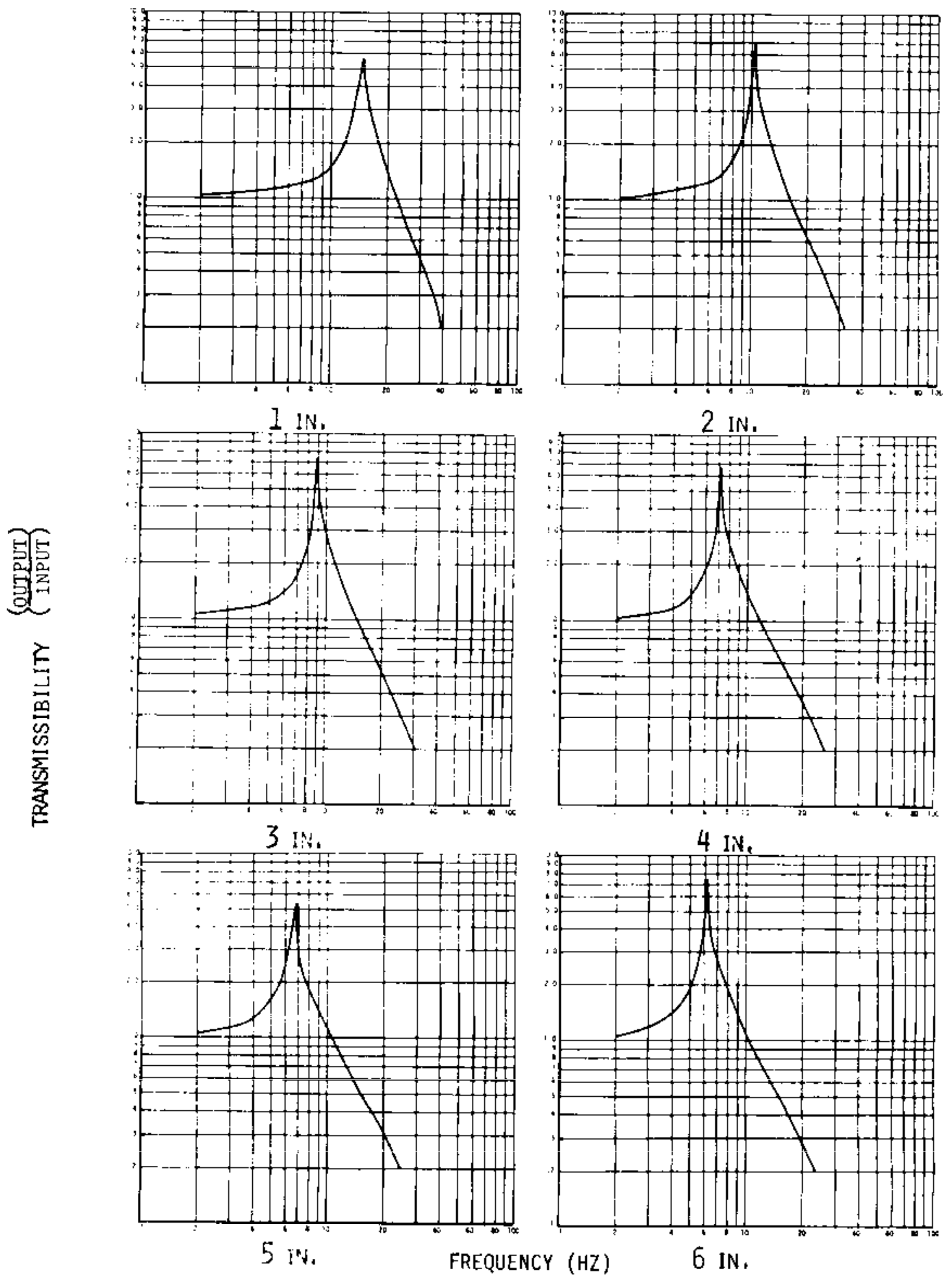
CURVE 20.4 AIR INCAPSULATED FILM 0.5" PLY THICKNESS .250 PSI



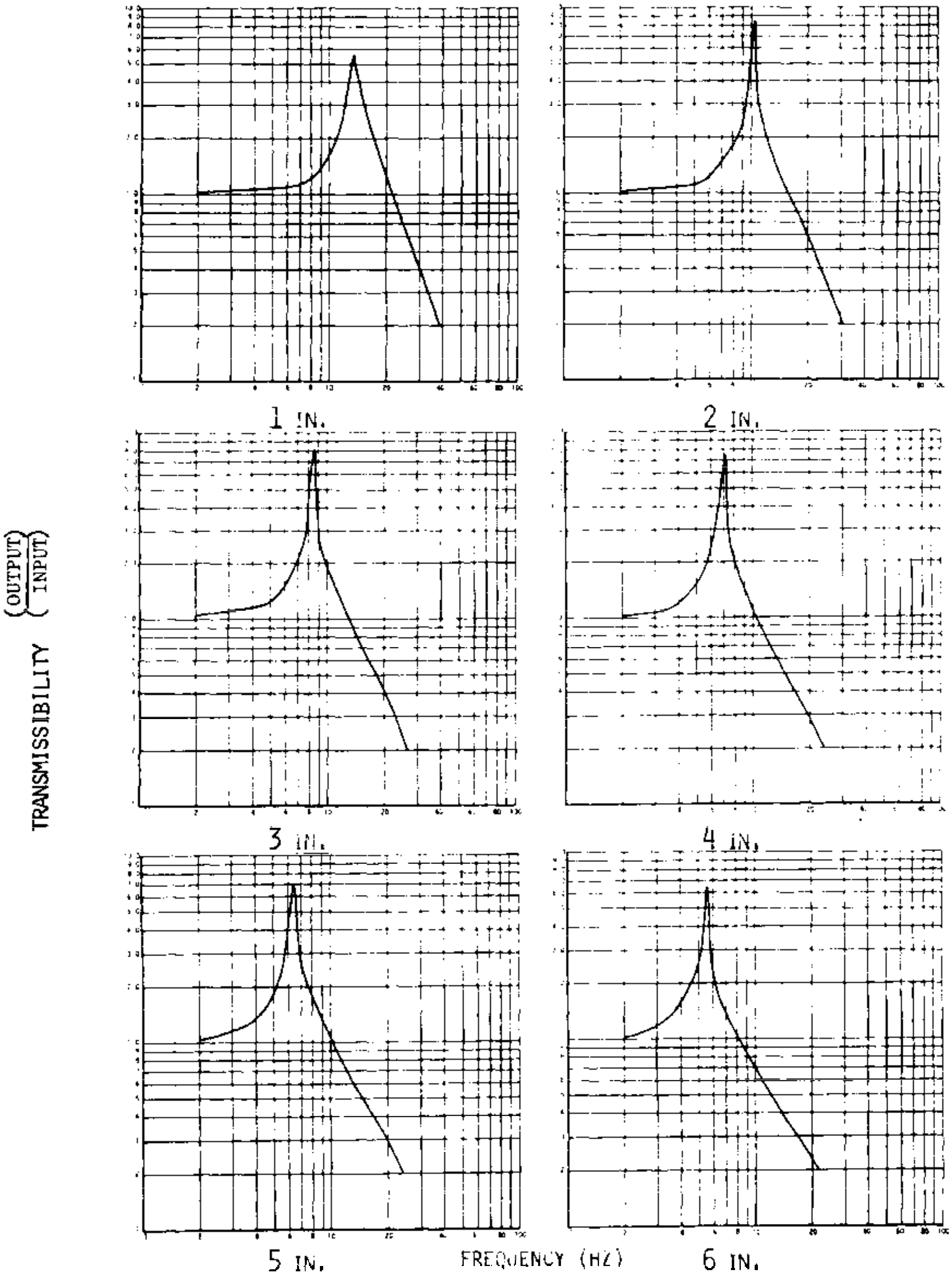
CURVE 20.5 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .314 PSI



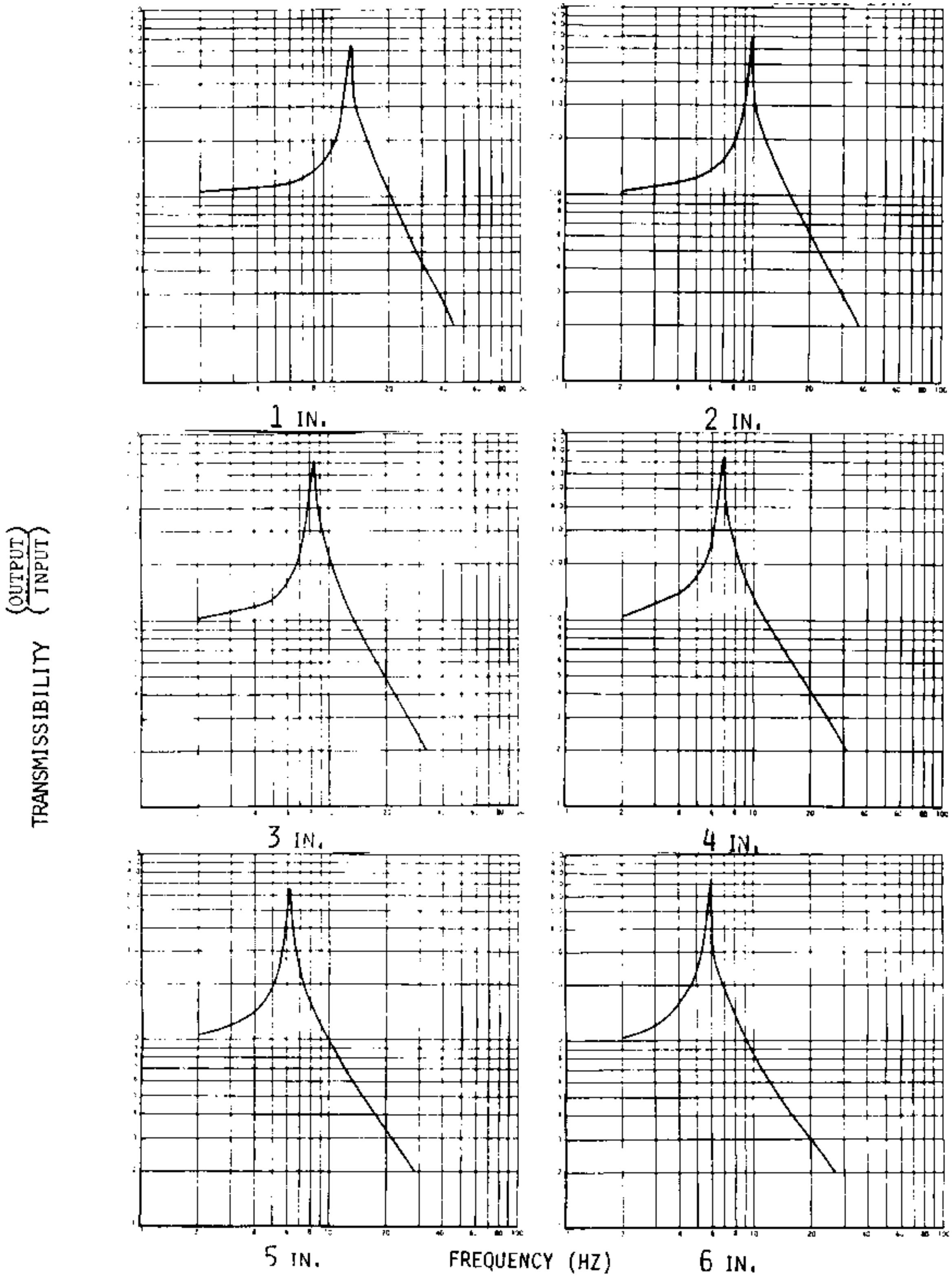
CURVE 20,6 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .464 PSI



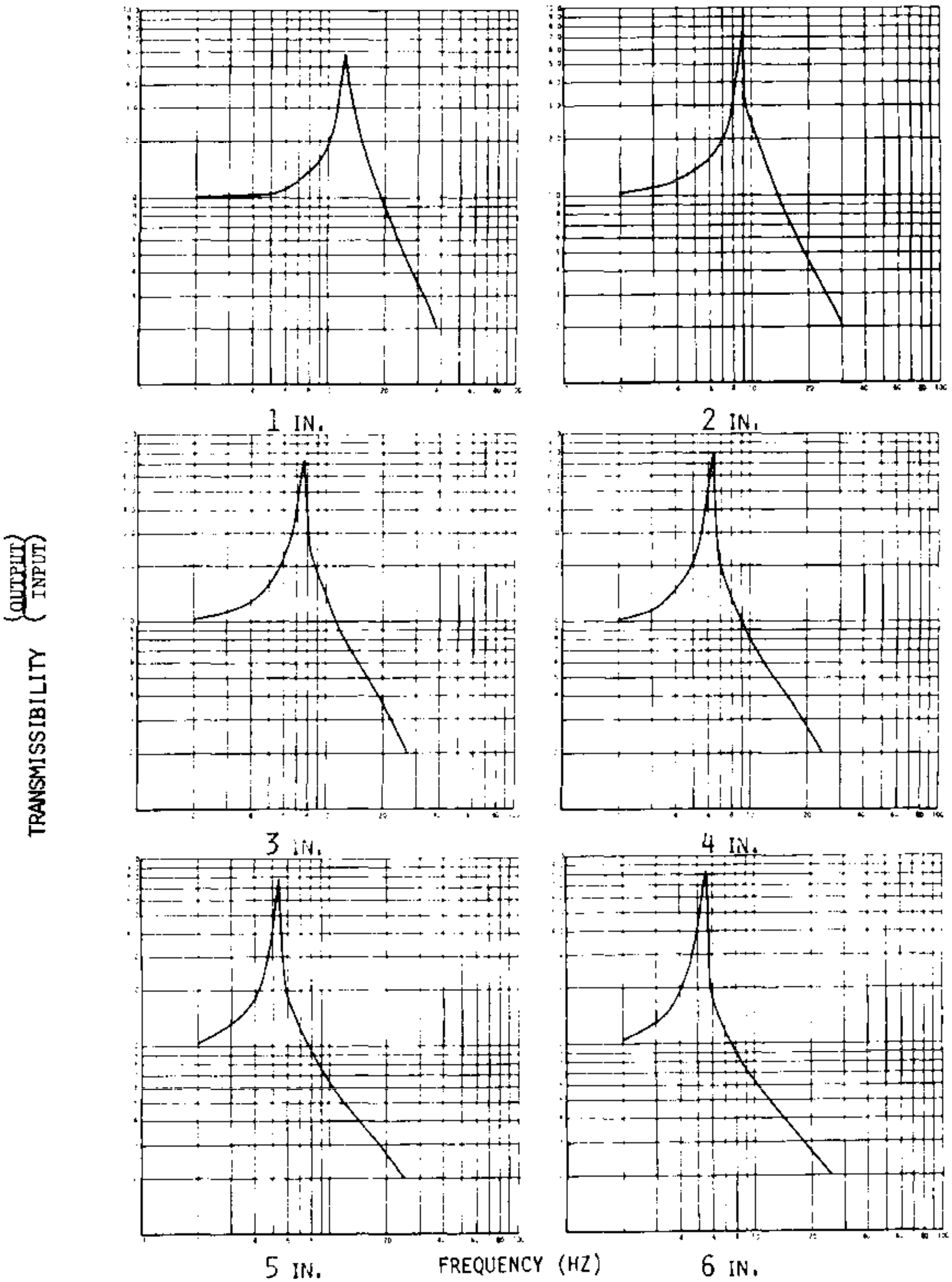
CURVE 20.7 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .533 PSI



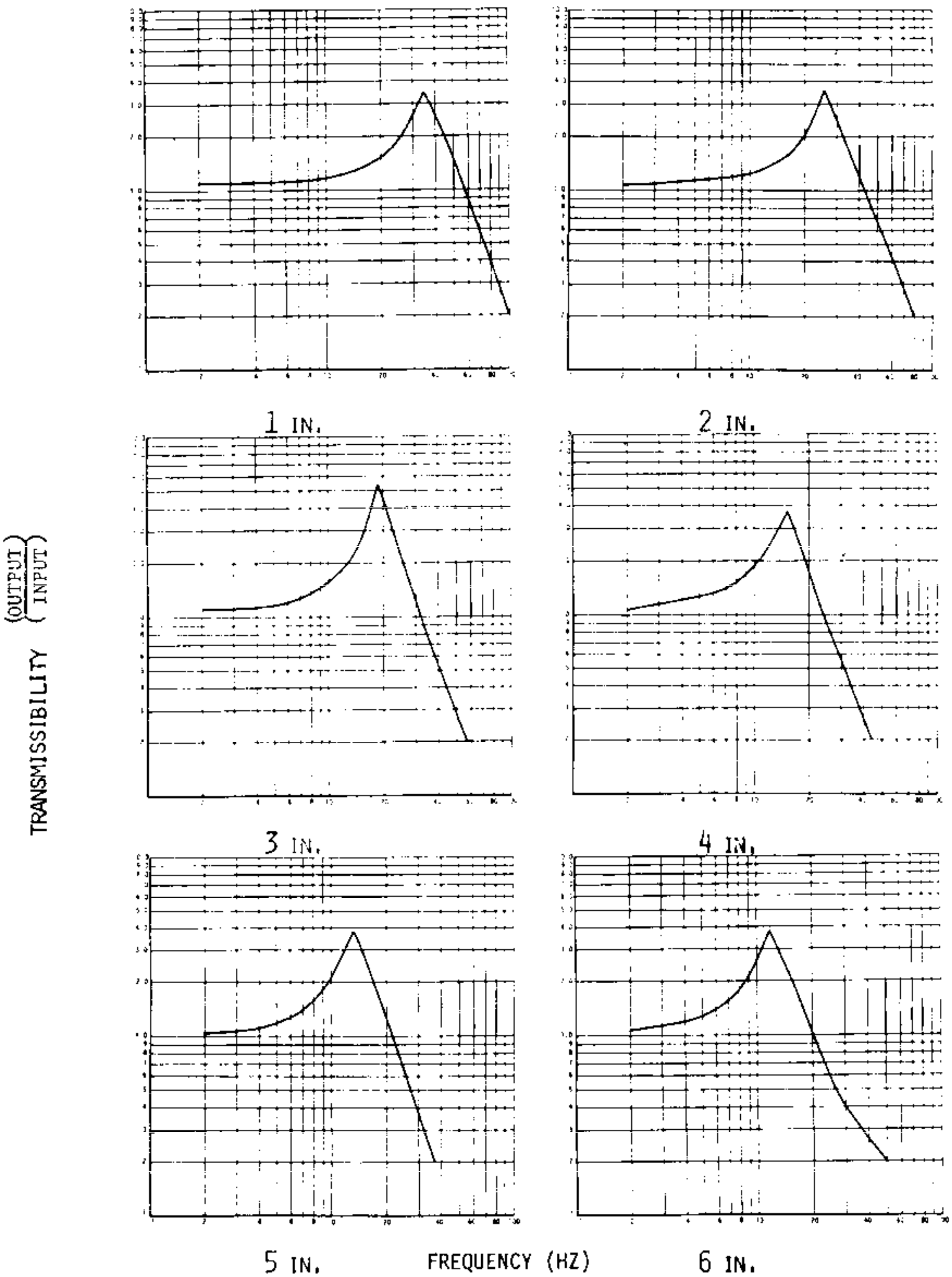
CURVE 20.8 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .64 PSI



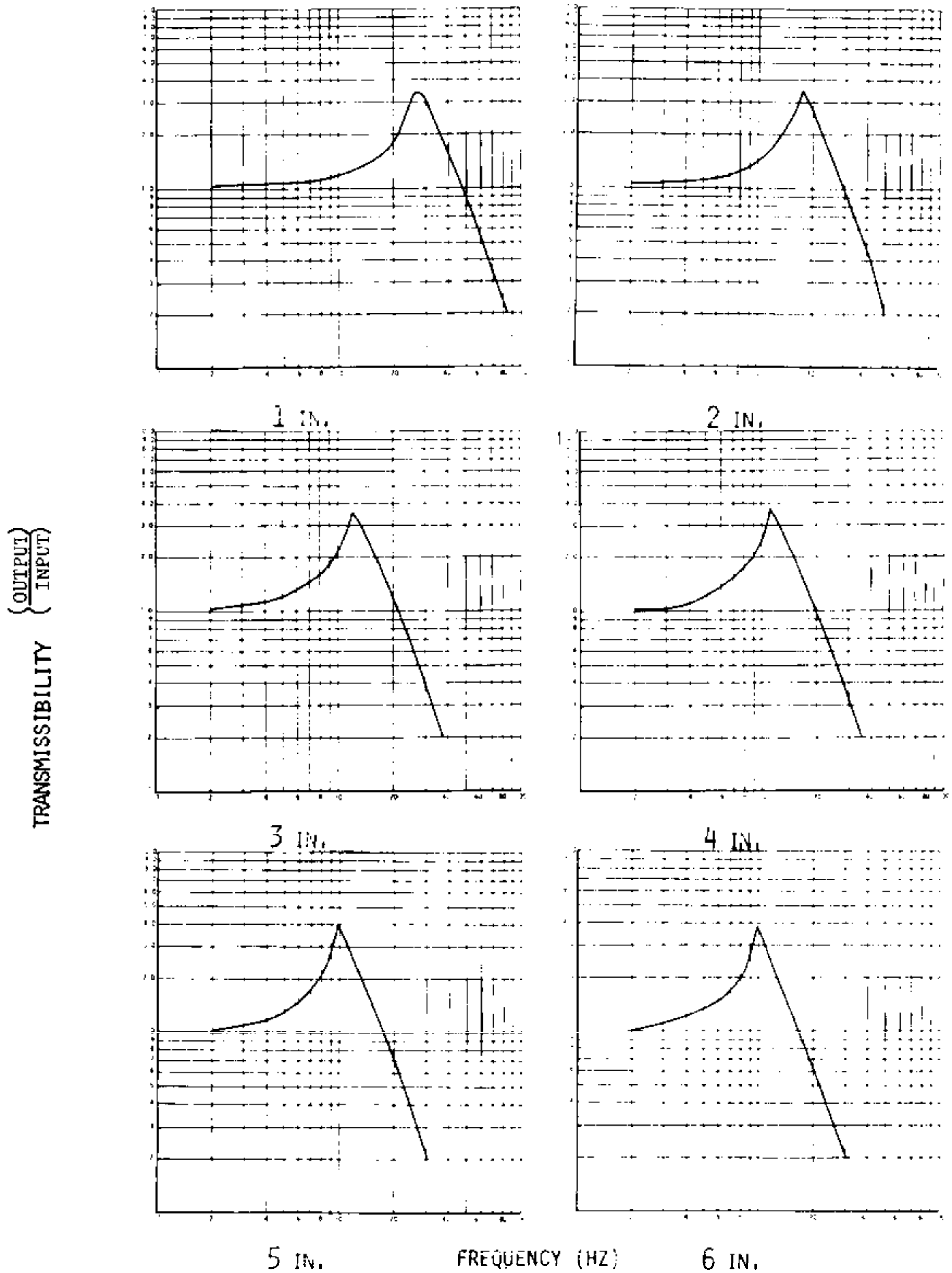
CURVE 20.9 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .74 PSI



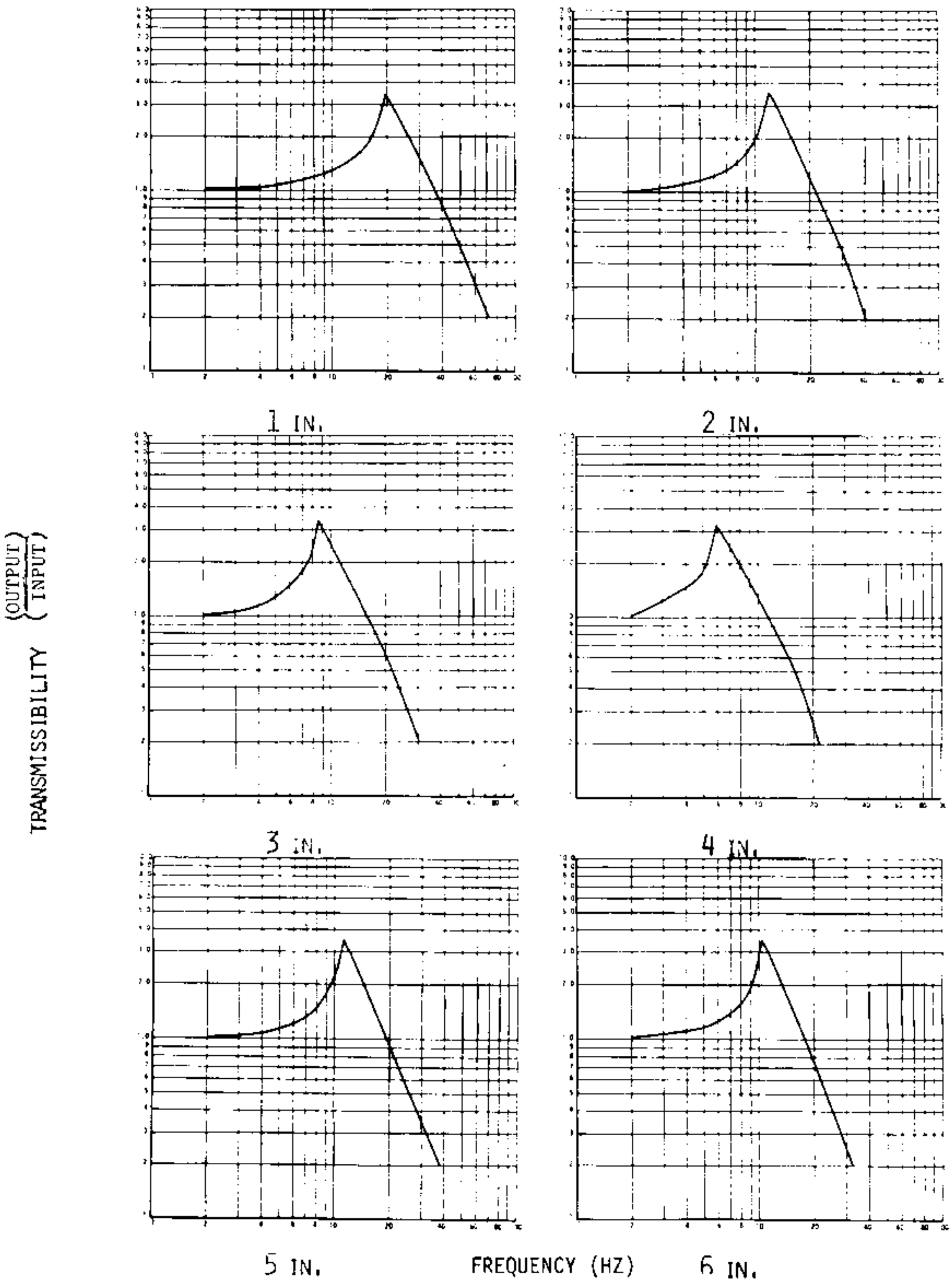
CURVE 20.10 AIR INCAPSULATED FILM, 0.5" PLY THICKNESS .95 PSI



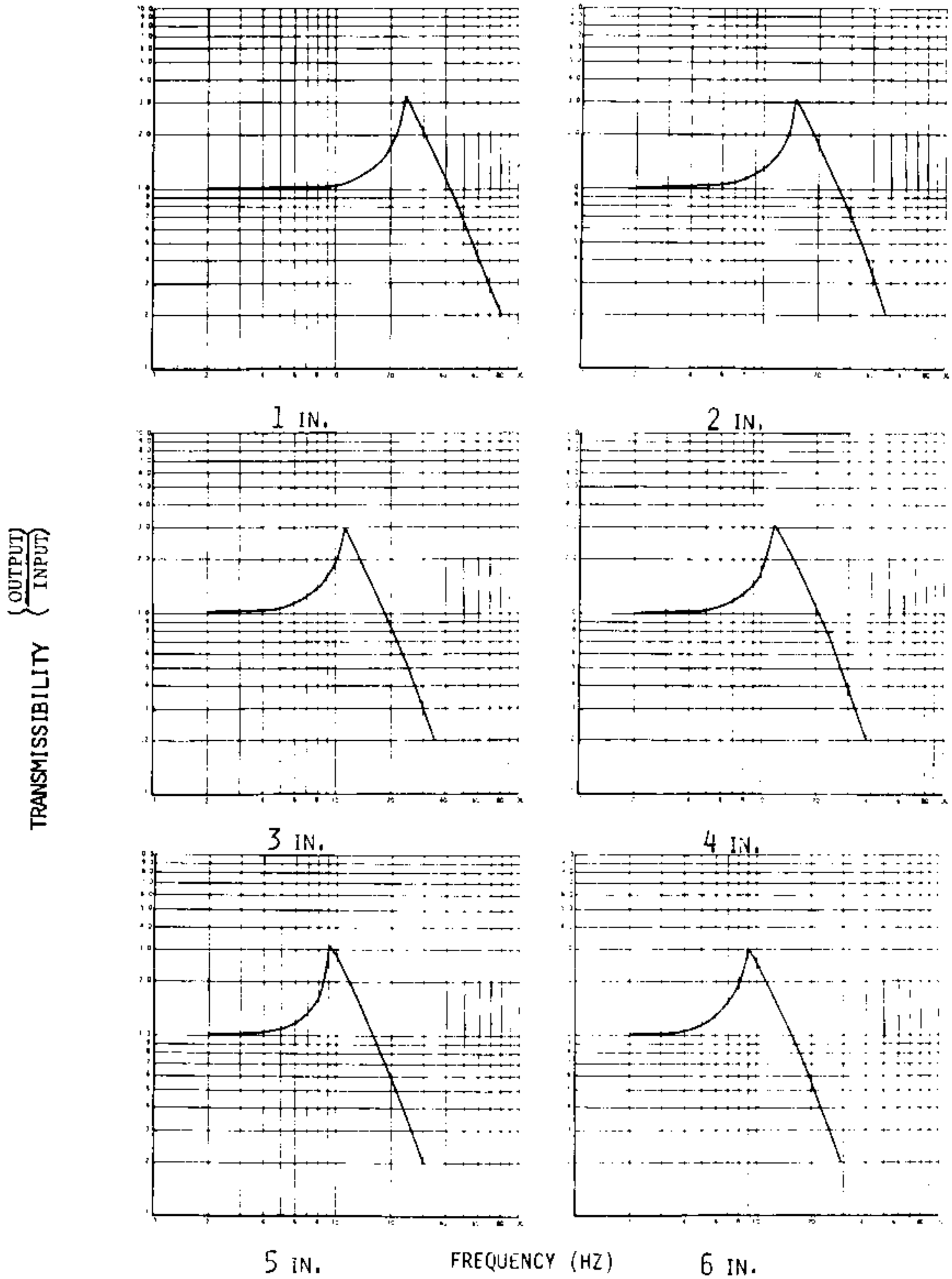
CURVE 21.1 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .07 PSI



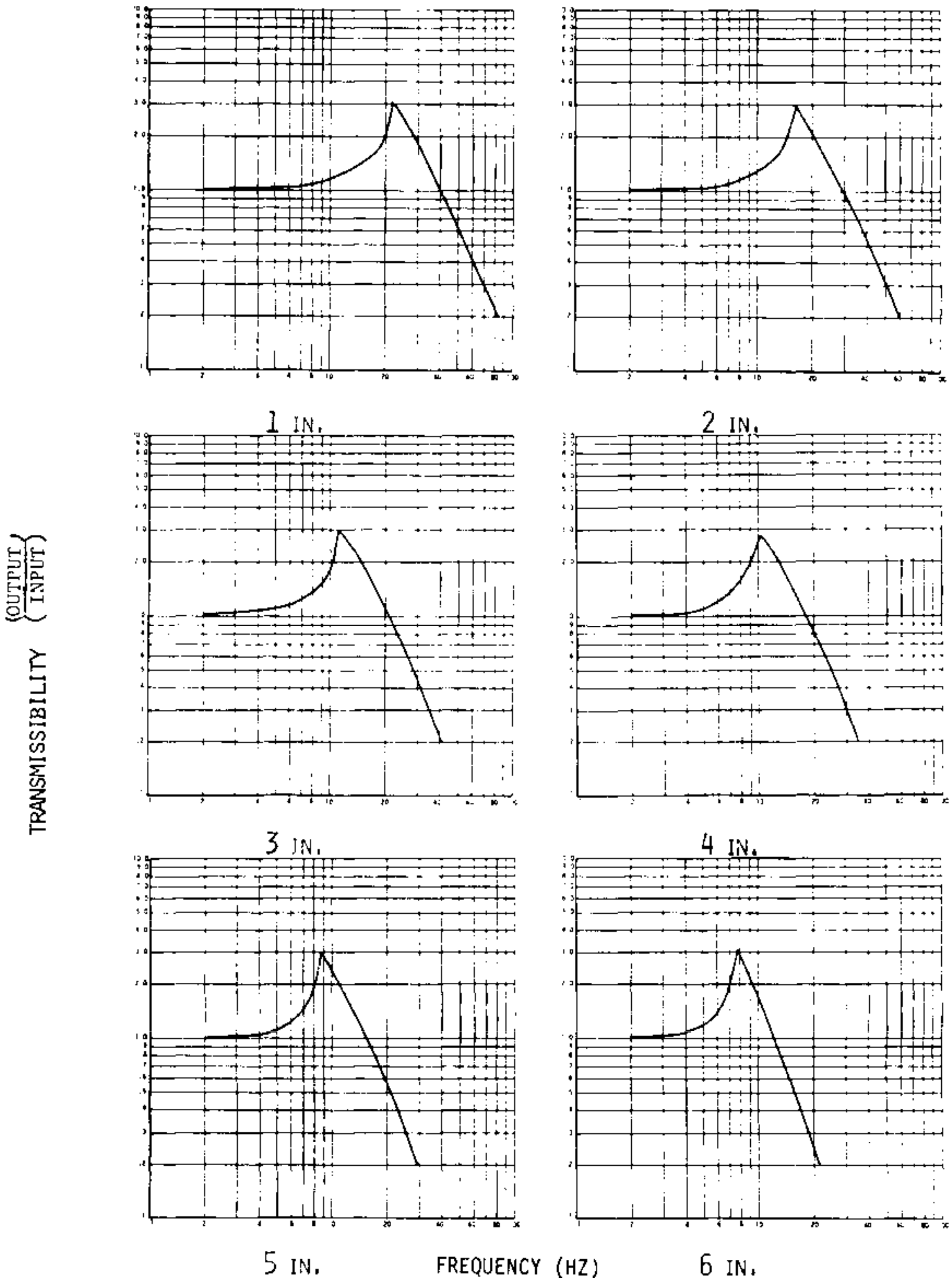
CURVE 21.2 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .11 PSI



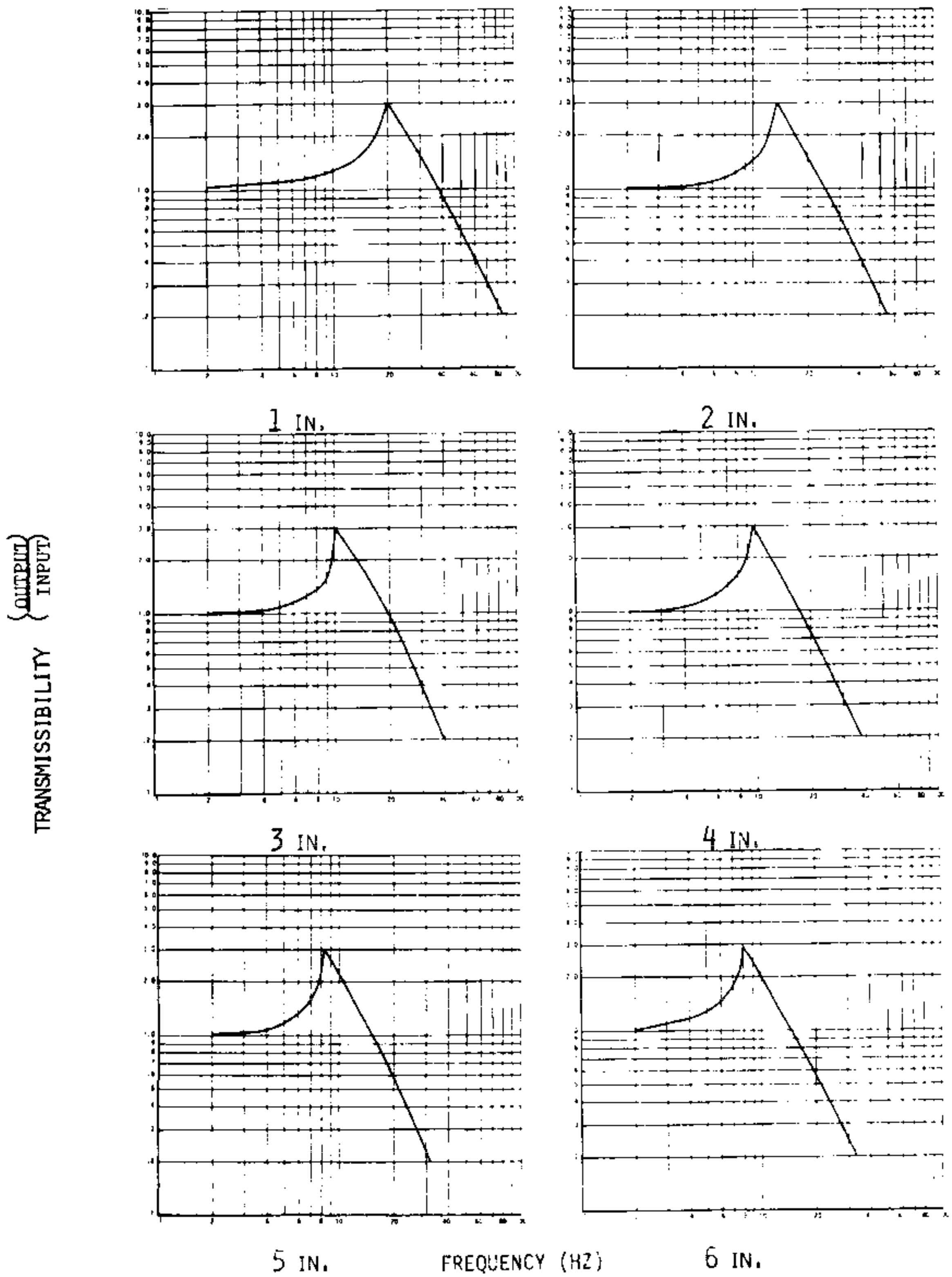
CURVE 21.3 HEXOGONAL FILM, OPEN CELL, 0.25"PLY THICKNESS ,20 PSI



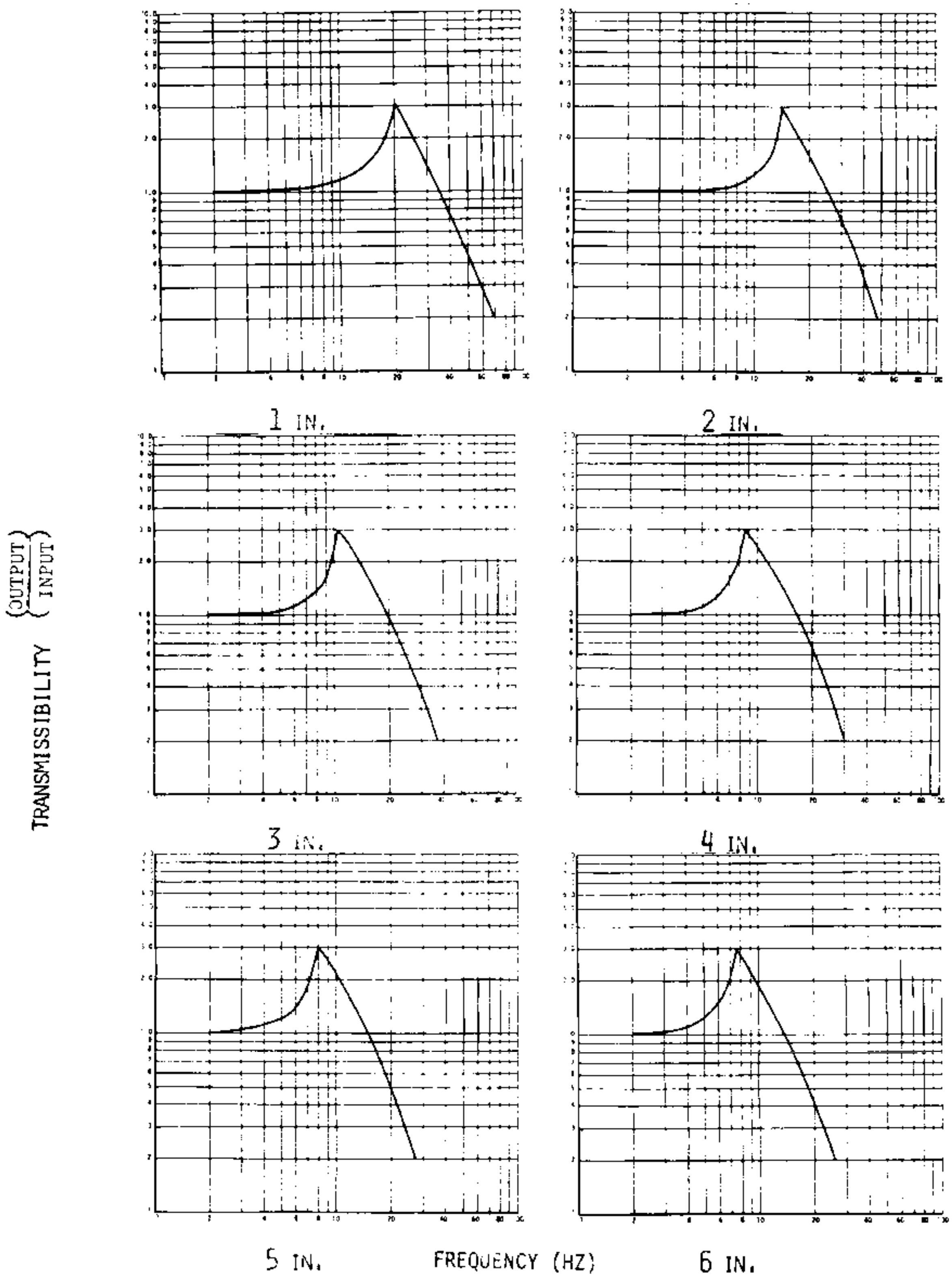
CURVE 21.4 HEXOGONAL FILM, OPEN CELL, 0,25" PLY THICKNESS .32 PSI



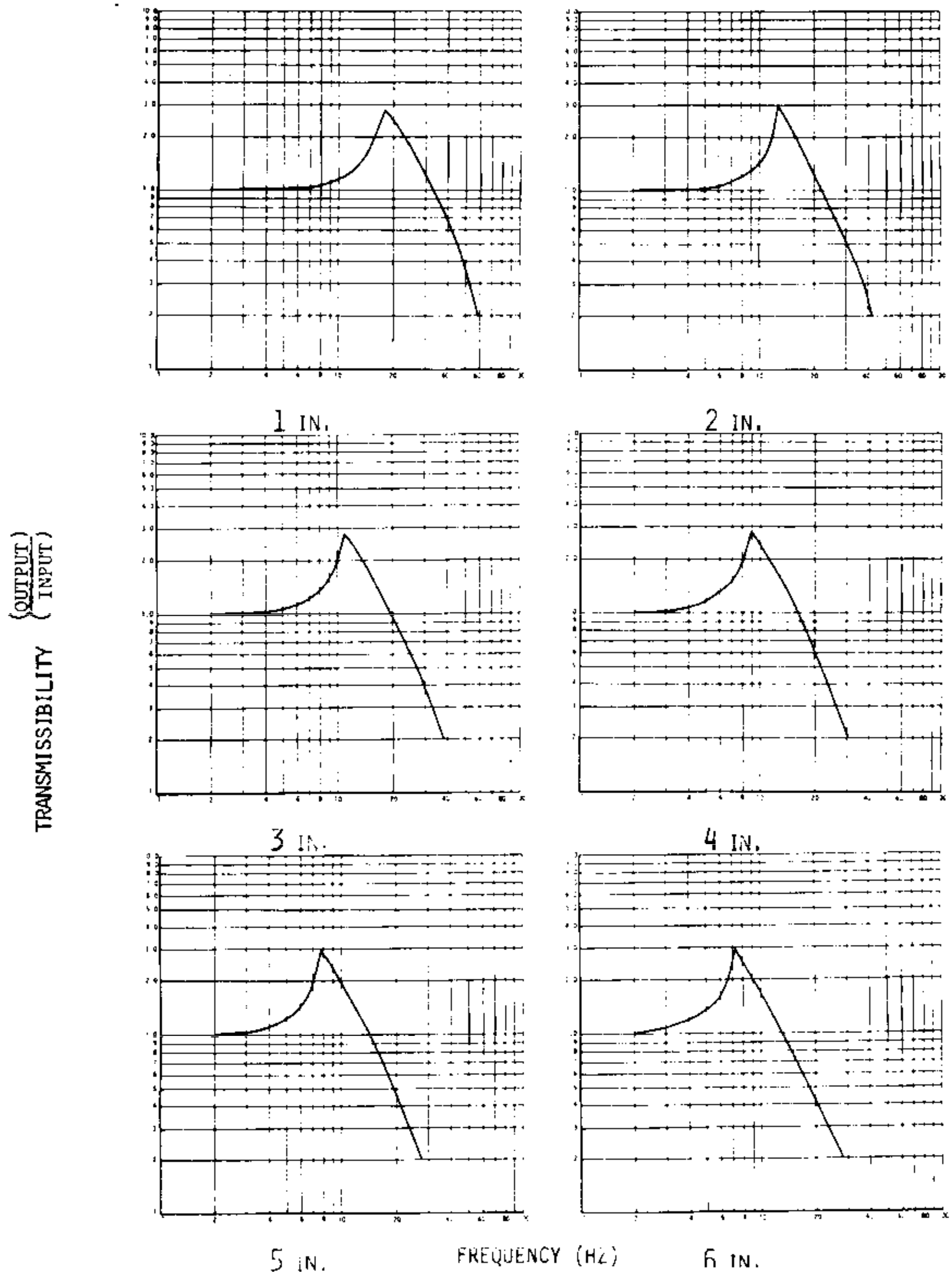
CURVE 21.5 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .39 PSI



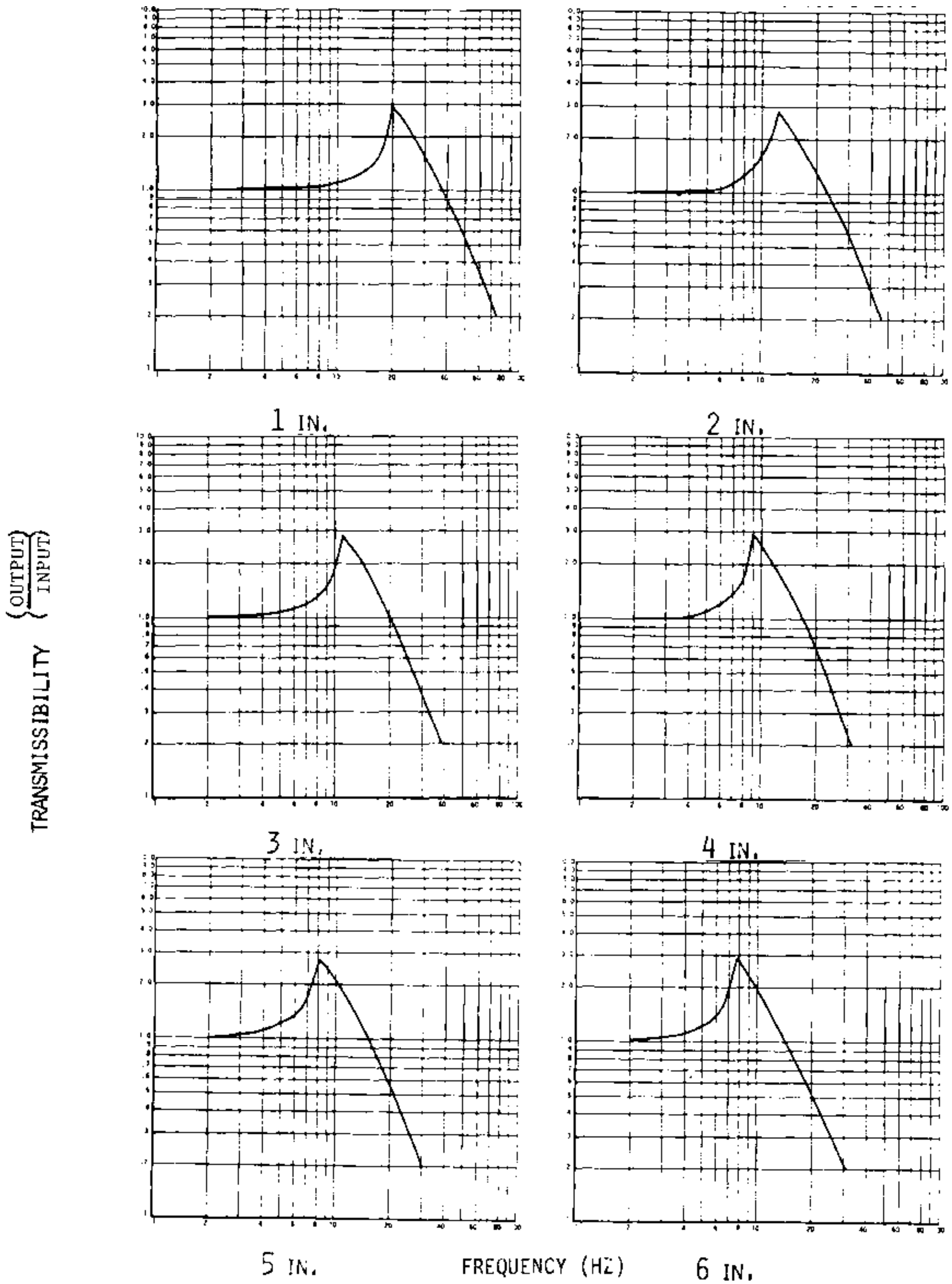
CURVE 21.6 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .50 PSI



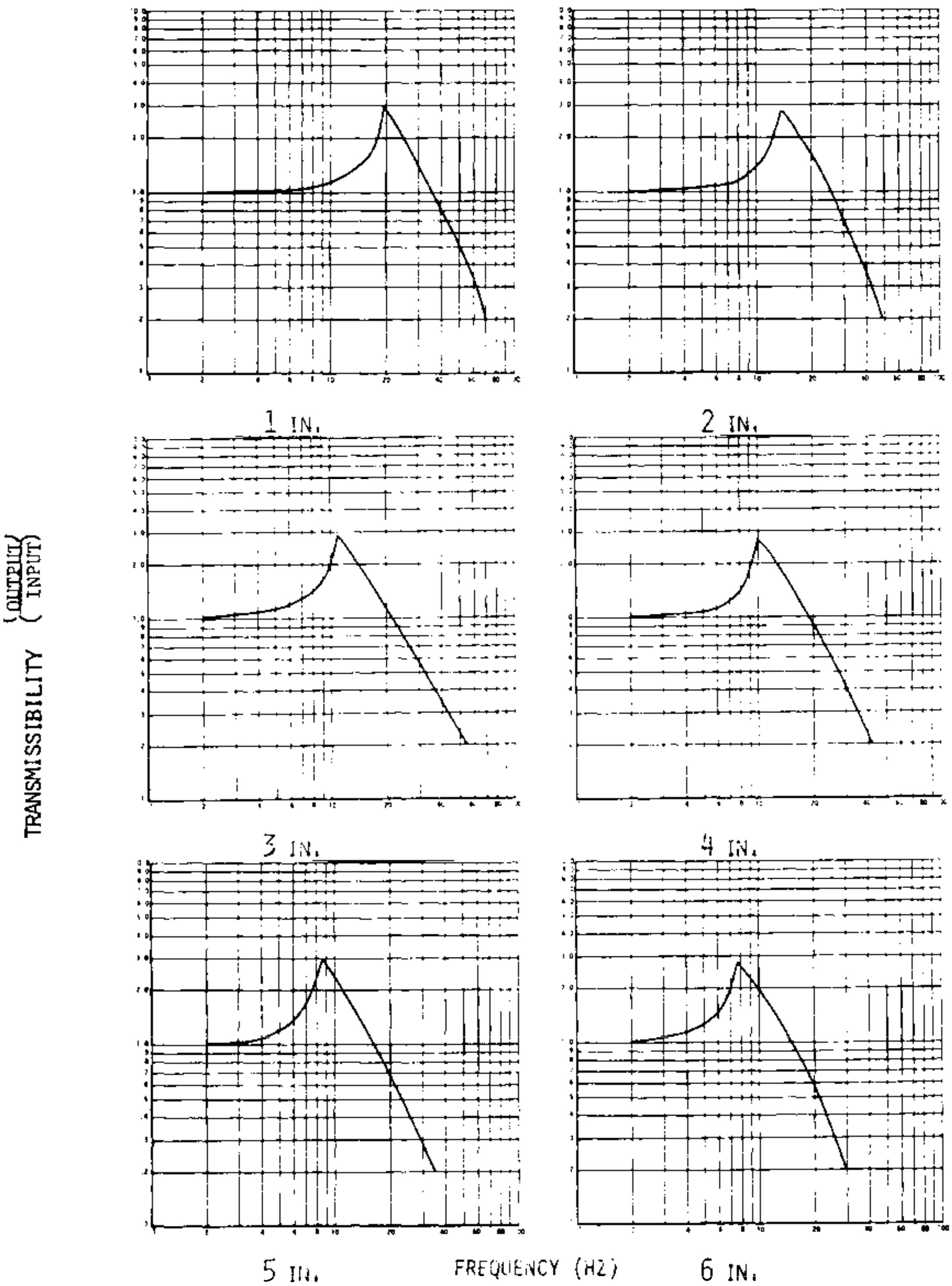
CURVE 21.7 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .60 PSI



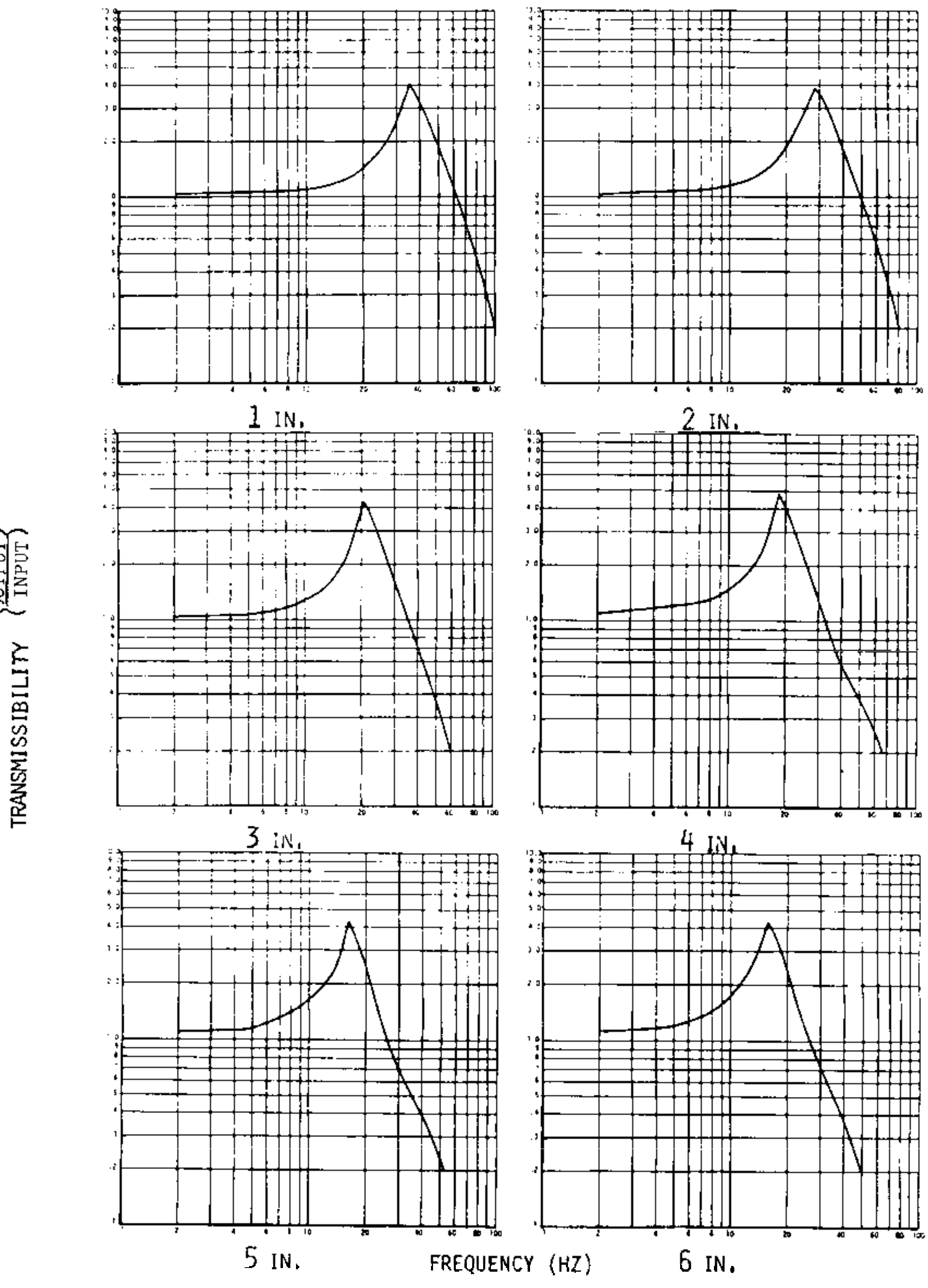
CURVE 21.8 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .70 PSI



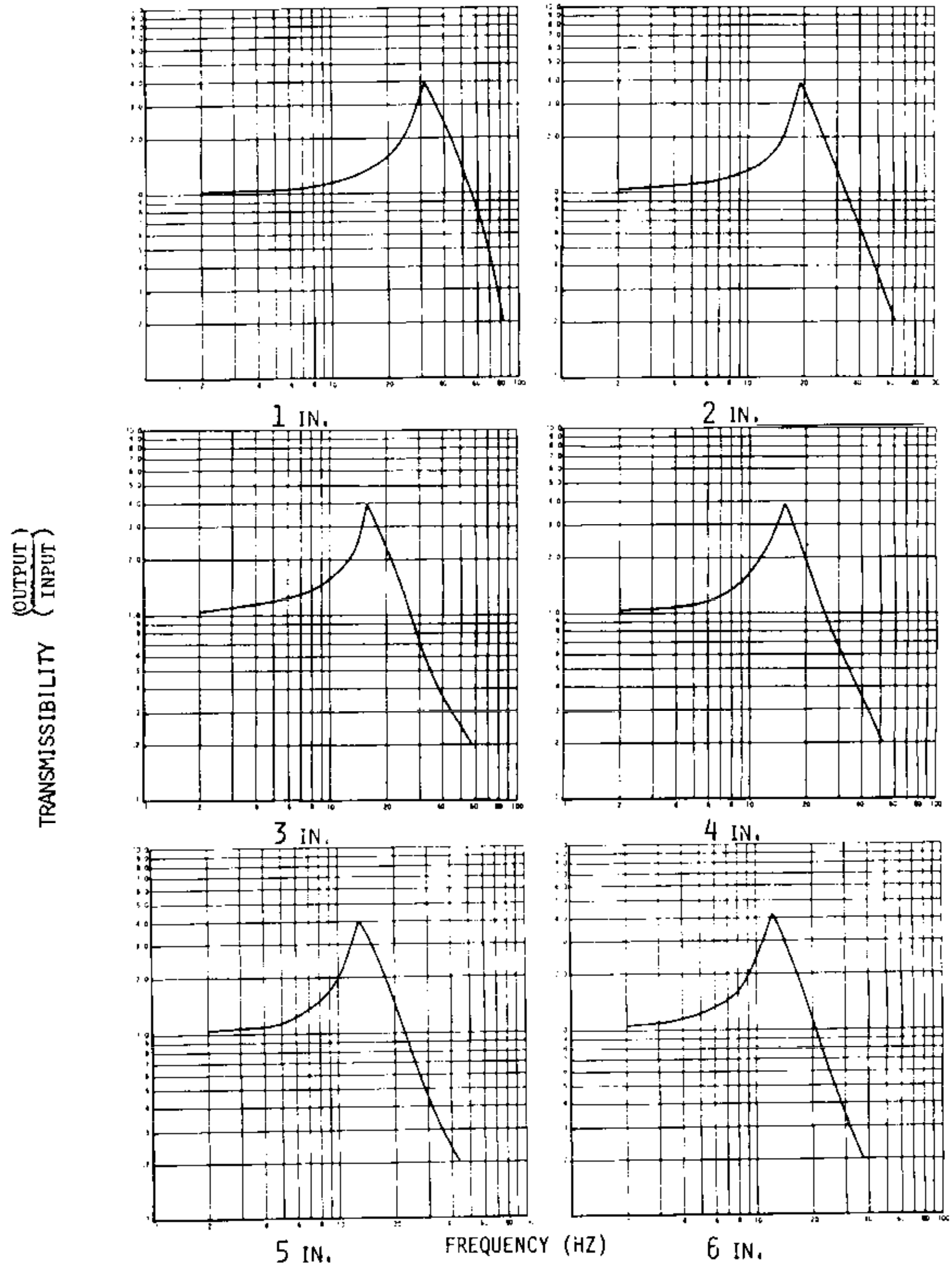
CURVE 21.9 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS .85 PSI



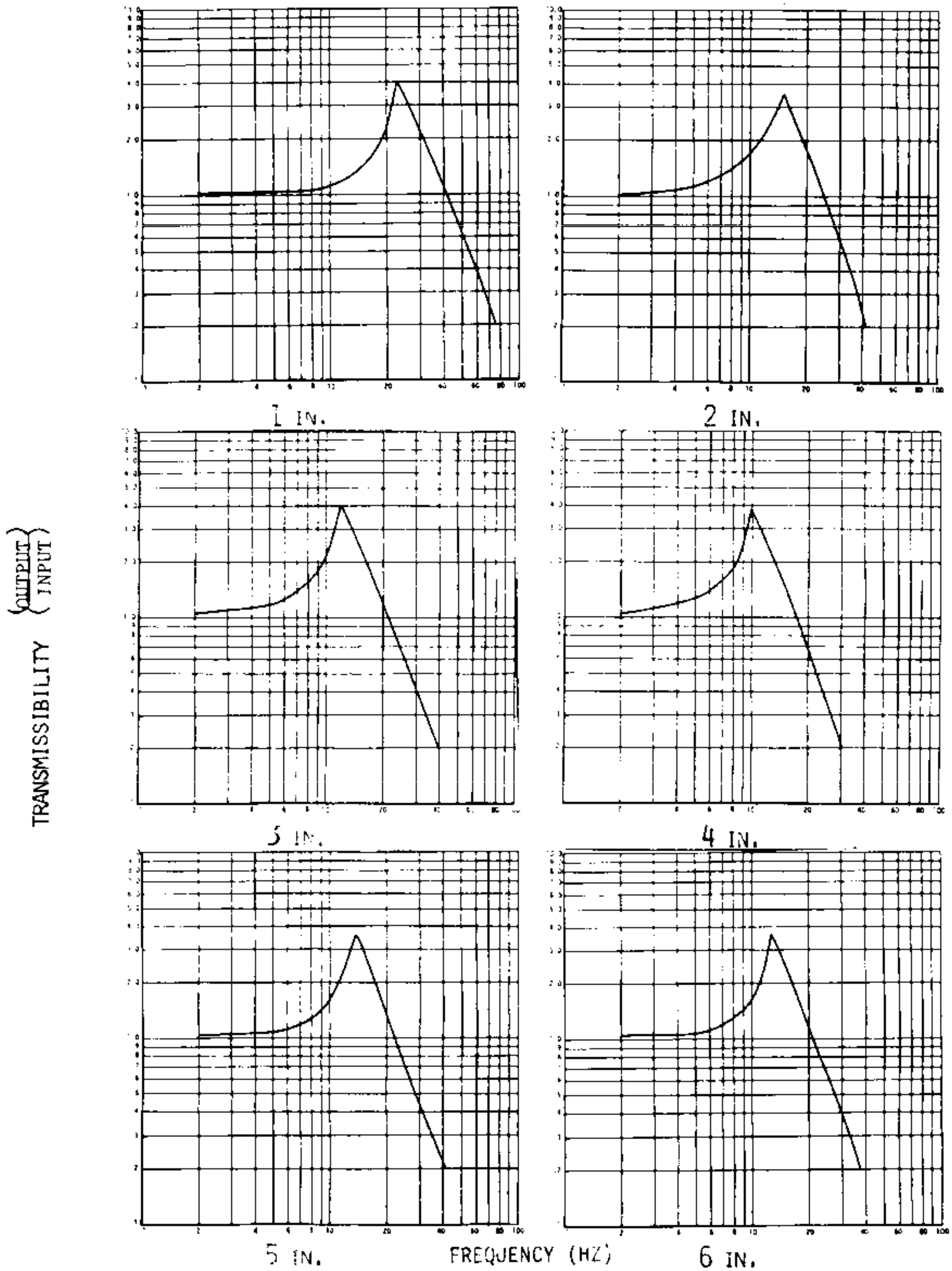
CURVE 21.10 HEXOGONAL FILM, OPEN CELL, 0.25" PLY THICKNESS 1.0 PSI



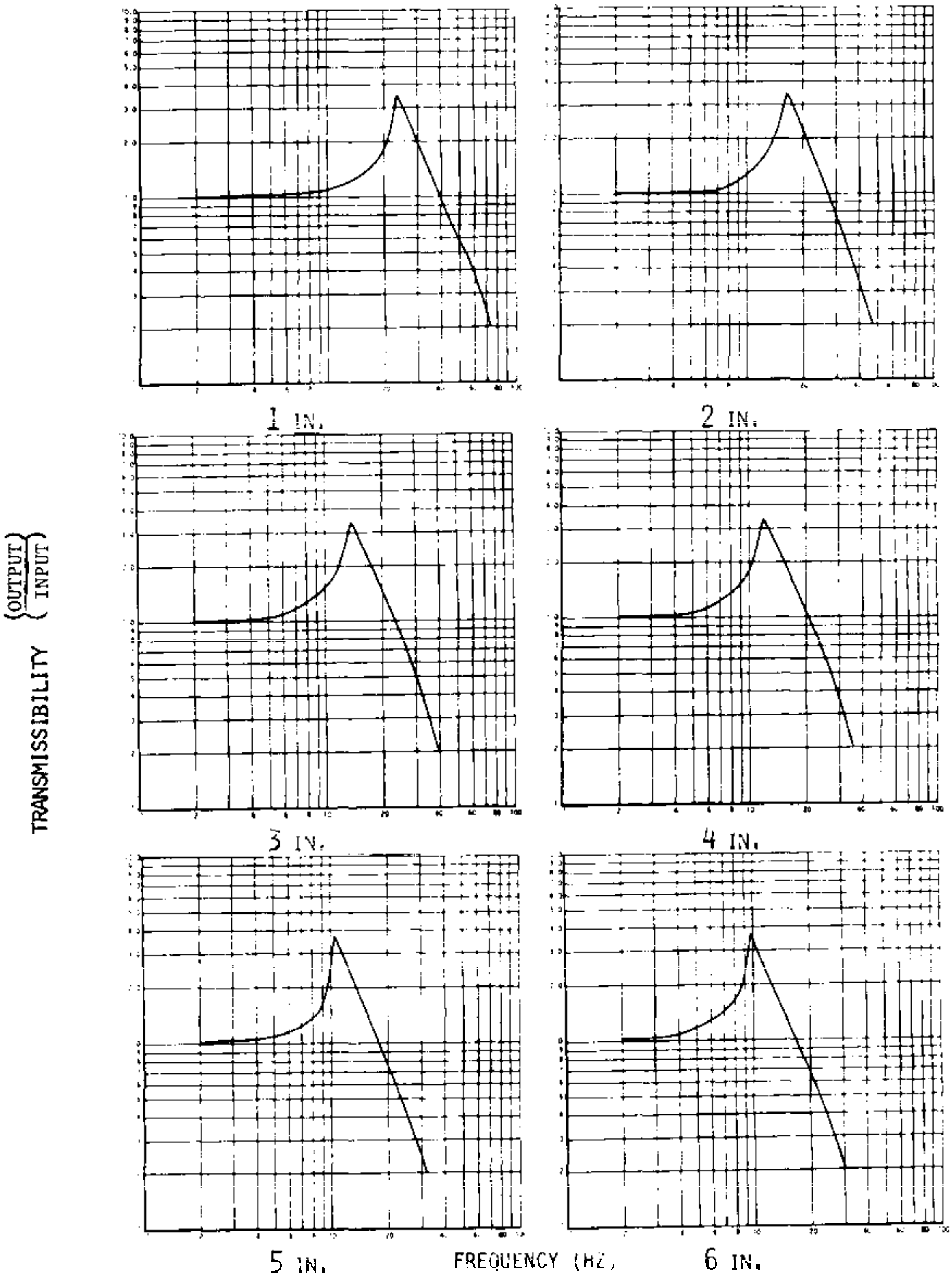
CURVE 22.1 HEXOGONAL FILM, REINFORCED CELL, 0.25" PLY THICKNESS .07 PSI



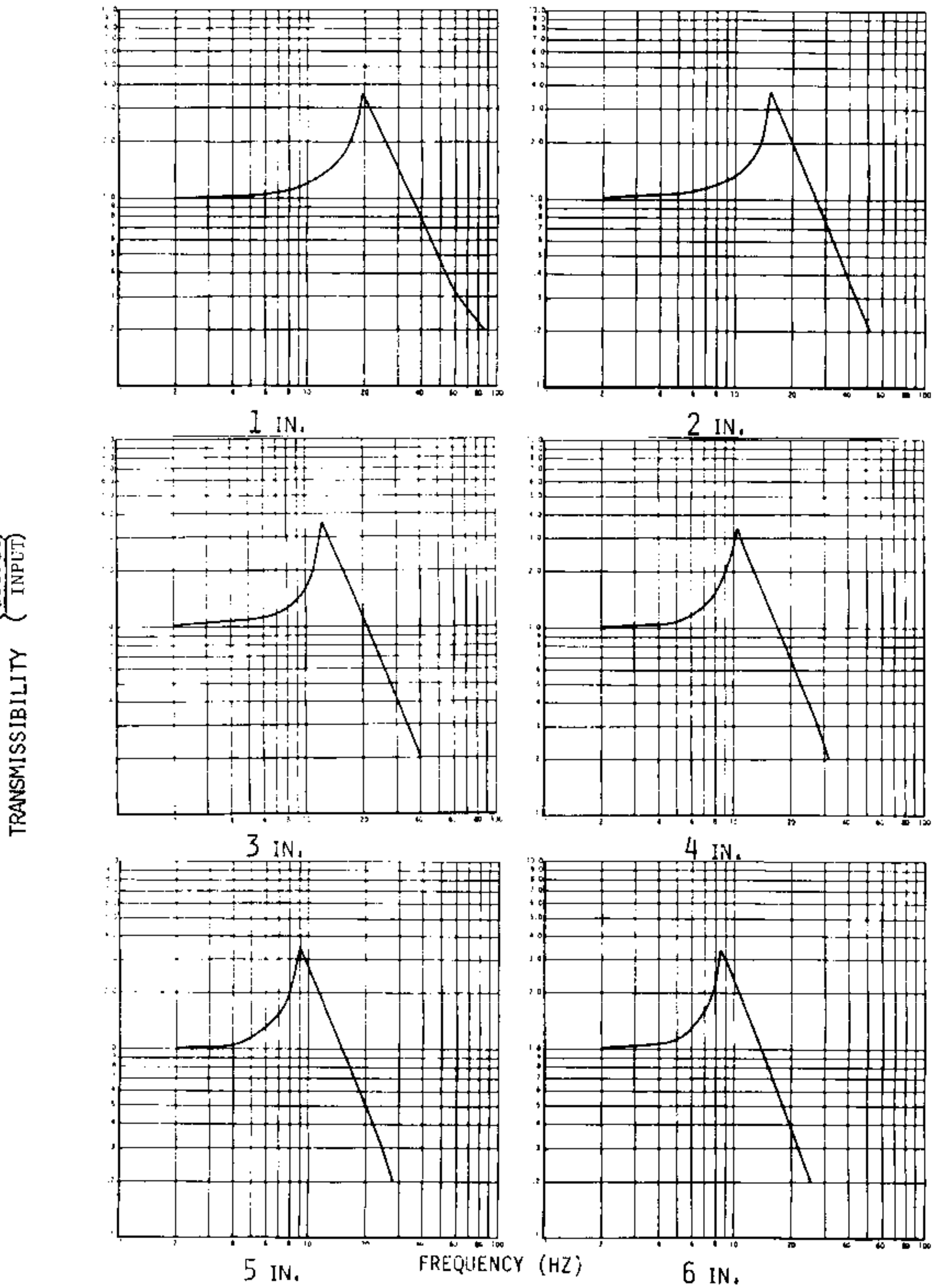
CURVE 22.2 HEXOGONAL FILM,REINFORCED CELL, 0.5" PLY THICKNESS .11 PSI



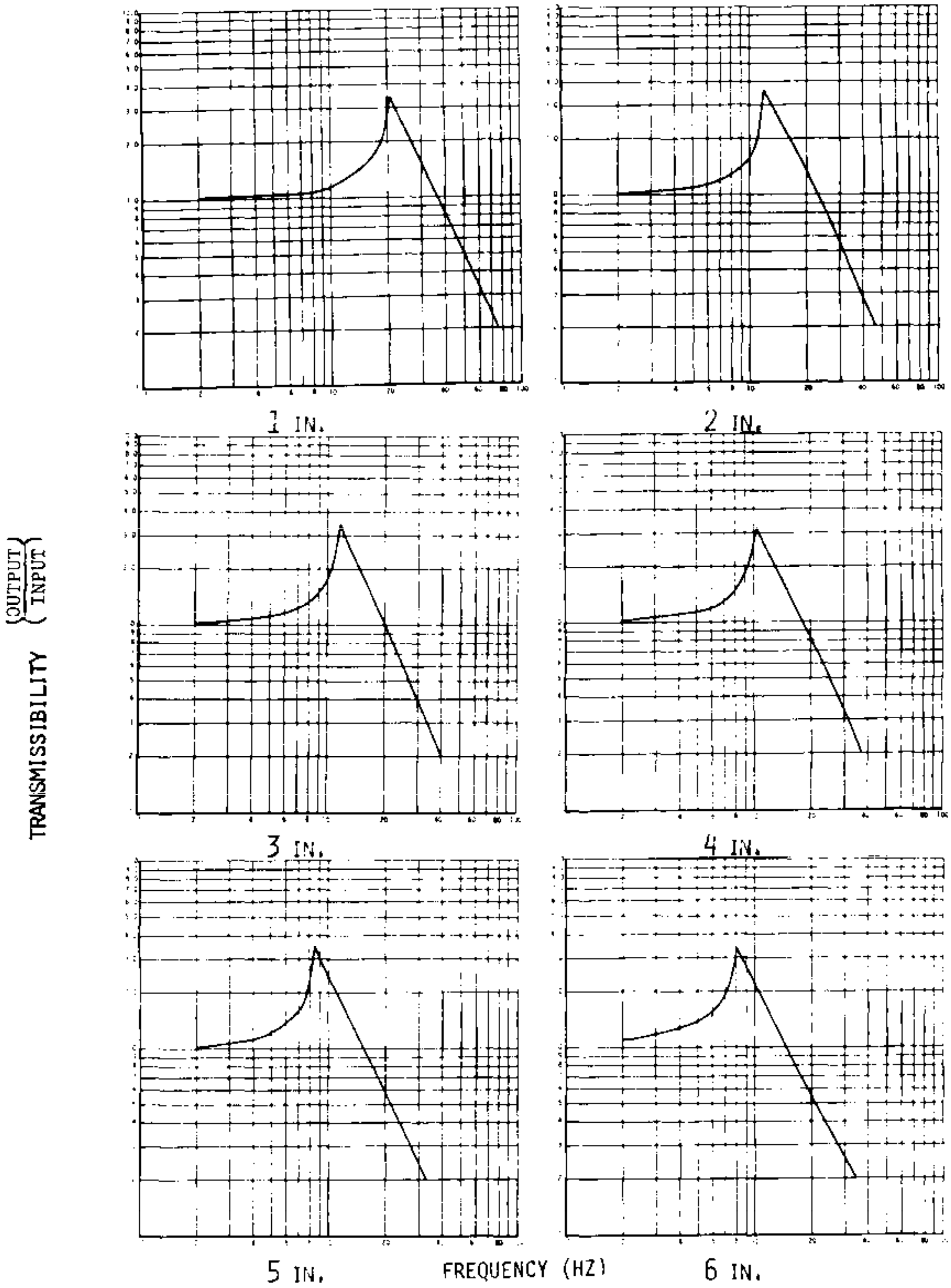
CURVE 22.3 HEXOGONAL FILM, Reinforced CELL, 0.25"PLY THICKNESS .20 PSI



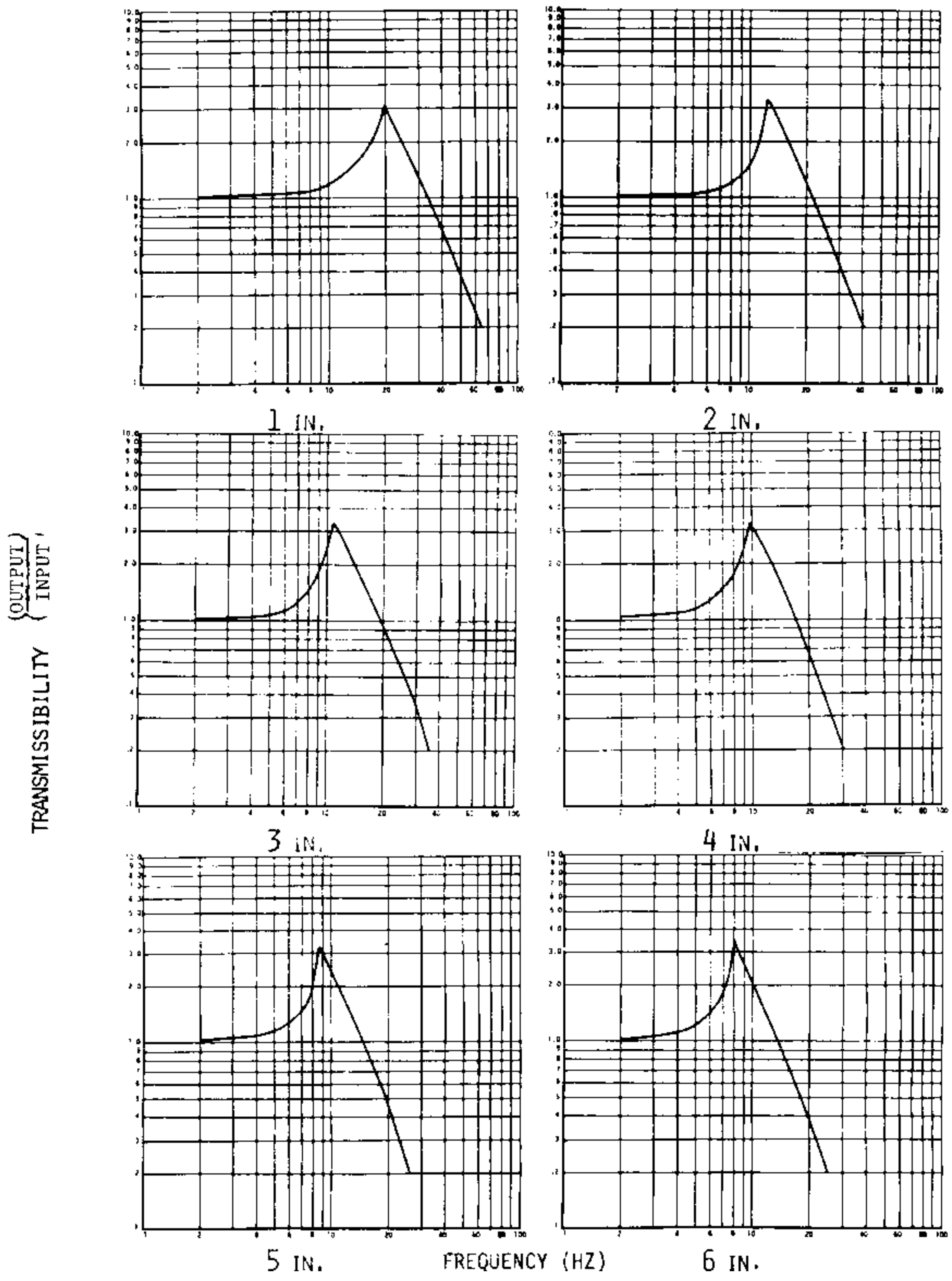
CURVE 22.4 HEXOGONAL FILM, REINFORCED CELL, 0.25" PLY THICKNESS .32 PSI



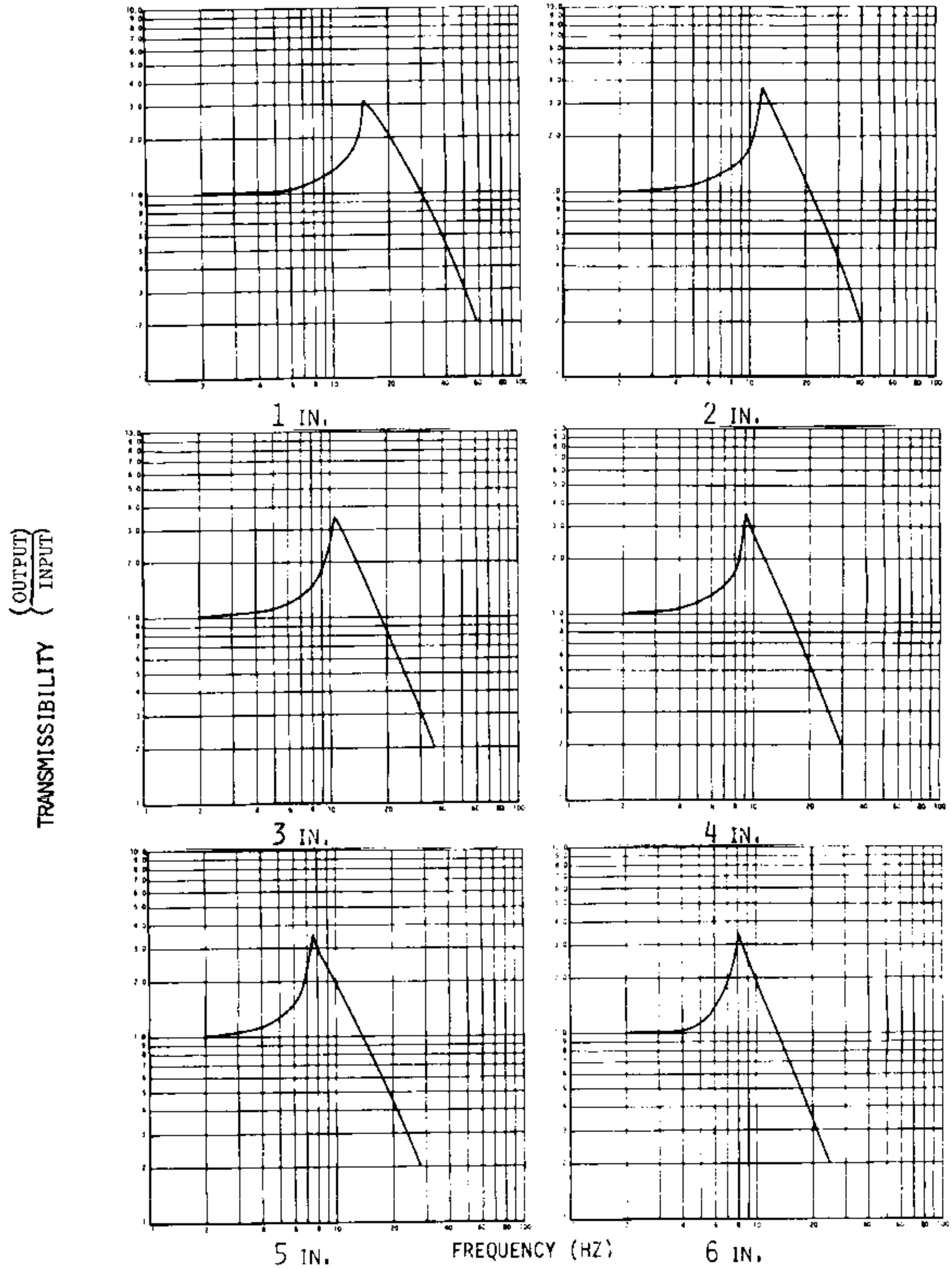
CURVE 22.5 HEXOGONAL FILM, REINFORCED CELL 0.25" PLY THICKNESS .39 PS1



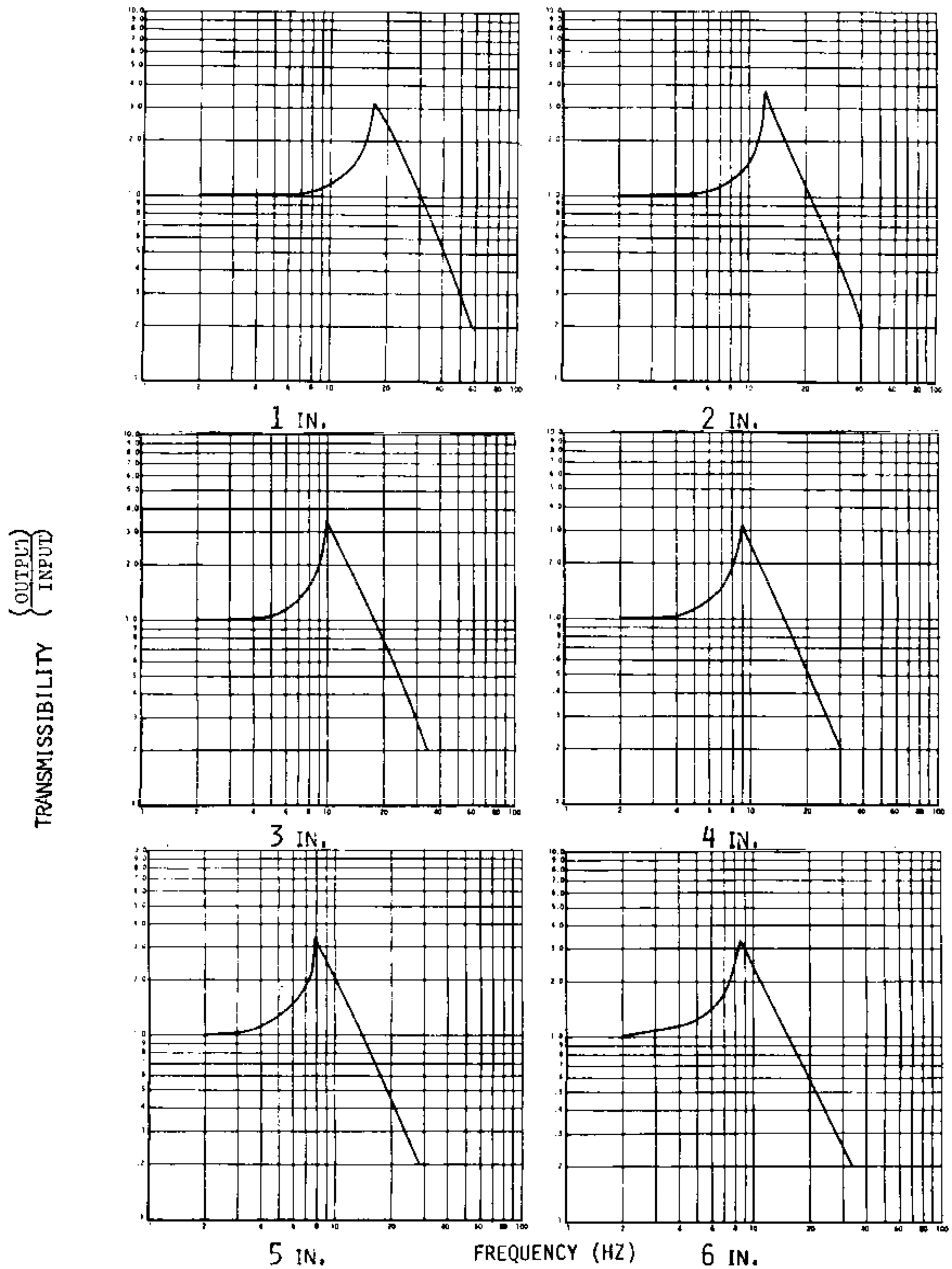
CURVE 22.6 HEXOGONAL FILM, REINFORCED CELL 0.25" PLY THICKNESS .50 PSI



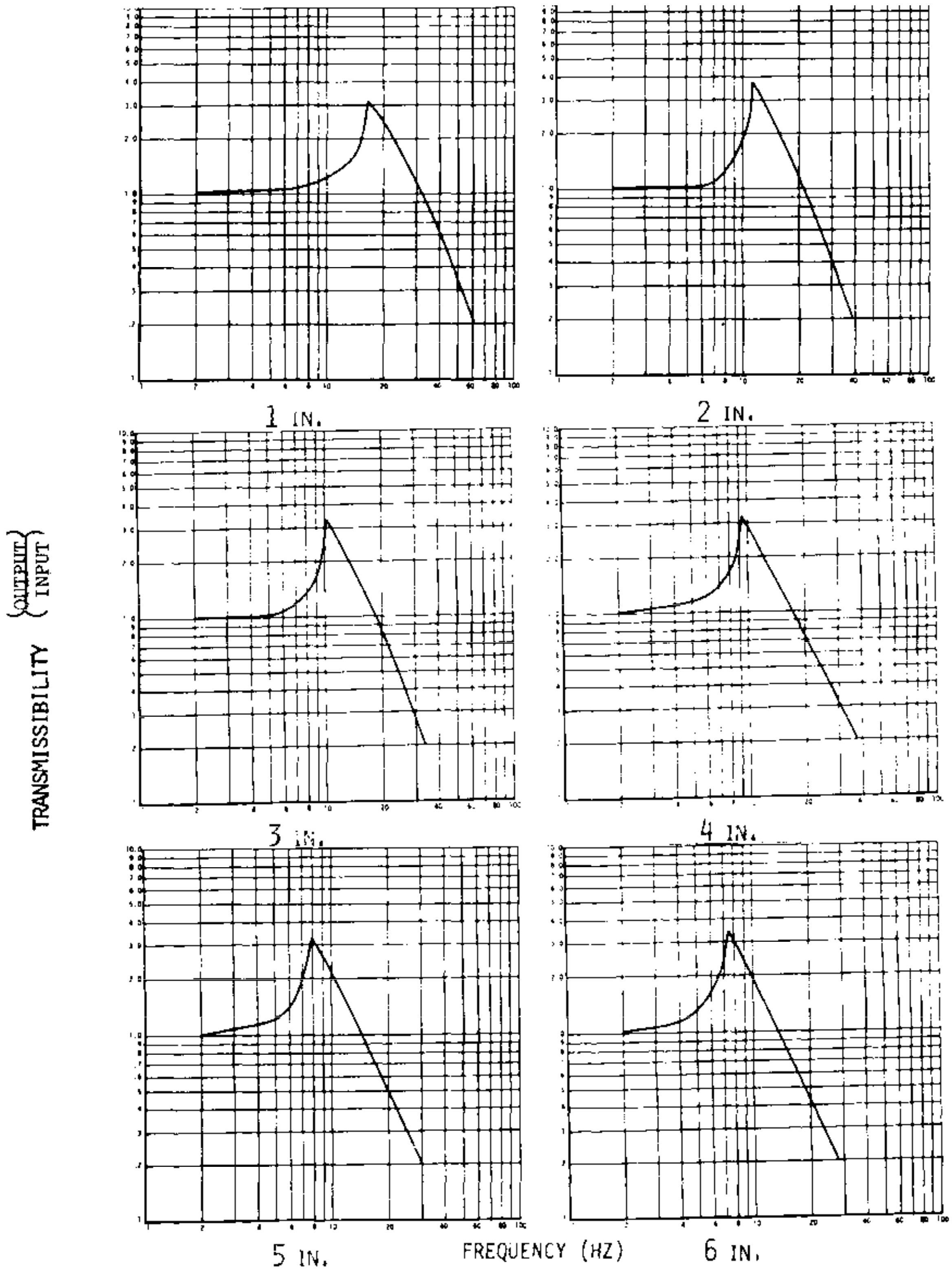
CURVE 22.7 HEXOGONAL FILM, REINFORCED CELL, 0.25" PLY THICKNESS .60 PSI



CURVE 22.8 HEXOGONAL FILM, REINFORCED CELL, 0.25"PLY THICKNESS .70 PSI



CURVE 22.9 HEXOGONAL FILM, REINFORCED CELL, 0.25" PLY THICKNESS .85 PSI



CURVE 22.10 HEXOGONAL FILM, REINFORCED CELL, 0.25"PLY THICKNESS 1.0 PSI

APPENDIX VII

TRANSMISSIBILITY FREQUENCY TABLES

The information presented in Tables 1 through 22 is based on the Transmissibility Curves presented in Appendix VI. Frequency values are presented for selected transmissibility conditions of importance in both the design and analysis of protective packaging systems. The symbol "Q" denotes the ratio of the response of the packaged item to the magnitude of the vibration input. Values of the transmissibility ratio, Q, greater than one indicate amplification of the vibration input while values less than one indicate isolation of the packaged item from the vibration environment. The tabular column labeled "Q MAX" indicates the frequency at which maximum transmissibility occurs (resonance).

TABLE 1 - POLYURETHANE ETHER, 1.5 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	21	105	172	185	200	220	245
1 Inch	0.076	30	95	140	150	158	166	173
1 Inch	0.100	22	80	110	115	120	124	130
1 Inch	0.133	26	68	122	129	136	145	162
1 Inch	0.180	23	56	106	112	120	130	140
1 Inch	0.211	22	56	94	97	104	112	120
1 Inch	0.250	21	50	84	88	93	99	107
1 Inch	0.314	23	41	66	70	76	84	94
1 Inch	0.464	20	31	46	50	55	61	67
1 Inch	0.533	10	16	23	26	30	40	53
2 Inch	0.045	25	86	135	142	150	162	175
2 Inch	0.076	22	46	69	73	75	82	88
2 Inch	0.100	18	51	86	92	98	106	115
2 Inch	0.133	22	44	74	78	84	95	101
2 Inch	0.180	22	41	70	75	79	88	95
2 Inch	0.211	19	34	54	59	65	72	80
2 Inch	0.250	17	31	52	56	62	68	77
2 Inch	0.314	21	31	50	54	58	66	74
2 Inch	0.464	9	17	24	26	29	34	41
2 Inch	0.533	7	10	16	19	23	27	36
3 Inch	0.045	20	80	121	127	135	146	162
3 Inch	0.076	22	47	78	84	90	100	112
3 Inch	0.100	19	45	74	79	84	90	96
3 Inch	0.133	22	39	67	72	77	85	95
3 Inch	0.180	18	35	57	62	66	71	79
3 Inch	0.211	20	33	55	59	64	70	80
3 Inch	0.250	16	28	50	54	59	66	73
3 Inch	0.314	16	19	32	36	39	46	57
3 Inch	0.464	15	18	24	27	30	34	43
3 Inch	0.533	5	9	14	15	19	24	34
4 Inch	0.045	20	62	108	116	126	140	157
4 Inch	0.076	20	40	67	72	80	88	100
4 Inch	0.100	16	38	63	66	71	76	83
4 Inch	0.133	20	33	53	56	62	68	77
4 Inch	0.180	16	29	50	53	57	63	68
4 Inch	0.211	15	25	42	45	50	56	70
4 Inch	0.250	15	23	39	42	46	53	62
4 Inch	0.314	11	16	29	32	36	42	50
4 Inch	0.464	7	12	17	19	22	26	33
4 Inch	0.533	4	7	10	11	14	21	33
5 Inch	0.045	18	55	90	96	105	116	130
5 Inch	0.076	18	33	53	57	62	70	80
5 Inch	0.100	17	30	55	60	64	70	79
5 Inch	0.133	18	28	44	46	51	57	65
5 Inch	0.180	15	24	41	44	48	54	63
5 Inch	0.211	17	23	39	42	46	52	62
5 Inch	0.250	11	21	36	39	42	49	59
5 Inch	0.314	8	15	27	29	33	39	50
5 Inch	0.464	8	11	14	17	19	23	31
5 Inch	0.533	3	6	8	9	11	20	42
6 Inch	0.045	18	48	72	76	82	89	94
6 Inch	0.076	16	28	45	49	54	62	71
6 Inch	0.100	14	28	49	54	59	67	76
6 Inch	0.133	17	27	42	45	49	56	63
6 Inch	0.180	8	15	27	29	32	37	47
6 Inch	0.211	9	16	28	31	36	41	52
6 Inch	0.250	8	18	34	37	42	49	51
6 Inch	0.314	6	8	17	19	22	26	34
6 Inch	0.464	3	4	6	7	9	13	27
6 Inch	0.533	3	5	6	7	8	12	25

TABLE 2 - POLYURETHANE ETHER, 2.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH						
		Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	21	100	150	160	175	200	220
1 Inch	0.076	23	56	94	100	109	120	140
1 Inch	0.100	18	56	94	99	104	113	122
1 Inch	0.133	26	53	96	102	107	113	122
1 Inch	0.180	23	41	78	82	90	100	116
1 Inch	0.211	23	44	80	88	95	106	122
1 Inch	0.250	19	32	51	56	62	70	78
1 Inch	0.314	20	29	48	51	56	66	79
1 Inch	0.464	7	12	21	24	28	33	42
1 Inch	0.533	10	13	23	26	29	36	50
2 Inch	0.045	18	78	118	122	128	132	135
2 Inch	0.076	25	42	71	77	83	94	110
2 Inch	0.100	19	43	76	78	83	89	96
2 Inch	0.133	20	34	59	65	71	81	94
2 Inch	0.180	18	35	60	64	72	78	89
2 Inch	0.211	18	34	51	54	57	63	73
2 Inch	0.250	15	20	33	36	40	45	54
2 Inch	0.314	8	10	19	22	26	32	43
2 Inch	0.464	7	12	14	15	18	24	33
2 Inch	0.533	6	7	11	13	16	20	27
3 Inch	0.045	20	64	104	106	112	117	120
3 Inch	0.076	20	38	65	68	76	84	98
3 Inch	0.100	18	37	59	62	67	72	79
3 Inch	0.133	21	33	55	59	63	70	80
3 Inch	0.180	17	28	50	53	56	62	70
3 Inch	0.211	17	26	42	46	50	55	67
3 Inch	0.250	12	20	32	34	38	43	54
3 Inch	0.314	10	15	29	31	35	41	51
3 Inch	0.464	15	7	11	14	16	21	29
3 Inch	0.533	13	6	7	8	9	13	22
4 Inch	0.045	18	53	83	90	98	107	122
4 Inch	0.076	19	32	53	57	63	70	80
4 Inch	0.100	16	32	52	56	60	65	73
4 Inch	0.133	18	26	42	44	49	56	66
4 Inch	0.180	14	23	37	40	44	49	60
4 Inch	0.211	16	22	39	41	45	52	63
4 Inch	0.250	9	16	28	30	33	39	49
4 Inch	0.314	8	12	21	23	27	31	41
4 Inch	0.464	4	7	7	8	12	15	25
4 Inch	0.533	3	5	7	8	9	14	30
5 Inch	0.045	16	45	70	76	82	90	103
5 Inch	0.076	15	26	44	47	52	59	70
5 Inch	0.100	13	21	36	40	42	47	56
5 Inch	0.133	15	21	35	37	41	45	55
5 Inch	0.180	11	18	31	33	36	41	49
5 Inch	0.211	13	17	28	31	34	40	46
5 Inch	0.250	9	16	26	28	32	38	48
5 Inch	0.314	9	14	25	27	31	36	44
5 Inch	0.464	5	6	7	9	12	15	27
5 Inch	0.533	3	5	6	7	8	11	27
6 Inch	0.045	16	36	62	67	73	82	90
6 Inch	0.076	13	23	38	41	46	55	65
6 Inch	0.100	11	25	45	49	55	65	74
6 Inch	0.133	14	20	33	35	39	44	54
6 Inch	0.180	8	16	28	30	34	38	47
6 Inch	0.211	9	14	25	28	31	37	49
6 Inch	0.250	7	13	24	27	20	35	45
6 Inch	0.314	6	8	15	18	21	25	35
6 Inch	0.464	3	4	5	5	6	9	21
6 Inch	0.533	3	5	6	7	8	10	47

TABLE 3 - POLYURETHANE ETHER, 4.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	20	108	146	156	163	172	183
1 Inch	0.076	25	66	104	110	116	123	132
1 Inch	0.100	21	75	123	130	138	147	157
1 Inch	0.133	25	54	90	98	107	119	138
1 Inch	0.180	20	49	90	98	107	120	139
1 Inch	0.211	22	51	83	87	92	98	106
1 Inch	0.250	20	35	63	68	75	83	89
1 Inch	0.314	19	25	45	50	56	65	76
1 Inch	0.464	11	15	22	25	28	35	48
1 Inch	0.533	9	13	21	24	29	36	50
2 Inch	0.045	17	80	130	136	141	148	154
2 Inch	0.076	25	51	85	88	94	100	107
2 Inch	0.100	20	50	82	86	91	96	102
2 Inch	0.133	24	42	72	76	82	90	100
2 Inch	0.180	18	38	66	70	75	80	86
2 Inch	0.211	20	34	57	61	66	74	82
2 Inch	0.250	15	26	45	49	54	60	68
2 Inch	0.314	16	17	30	35	40	47	58
2 Inch	0.464	4	8	12	14	18	23	28
2 Inch	0.533	6	8	12	13	15	21	30
3 Inch	0.045	20	68	110	115	120	129	137
3 Inch	0.076	20	40	67	72	79	90	96
3 Inch	0.100	16	39	67	71	76	84	92
3 Inch	0.133	22	33	56	62	66	76	86
3 Inch	0.180	16	29	51	55	61	66	73
3 Inch	0.211	17	27	48	52	57	63	74
3 Inch	0.250	13	21	37	41	45	52	60
3 Inch	0.314	10	15	28	32	37	42	52
3 Inch	0.464	4	6	9	10	12	17	29
3 Inch	0.533	4	7	10	12	16	21	30
4 Inch	0.045	17	54	86	92	98	105	116
4 Inch	0.076	16	30	50	53	58	65	75
4 Inch	0.100	18	34	55	57	63	70	78
4 Inch	0.133	17	25	30	42	46	53	64
4 Inch	0.180	14	23	41	44	49	55	64
4 Inch	0.211	13	21	38	41	45	52	64
4 Inch	0.250	9	17	32	34	38	44	54
4 Inch	0.314	8	12	27	30	34	40	51
4 Inch	0.464	3	5	7	8	9	11	19
4 Inch	0.533	3	6	8	9	12	16	31
5 Inch	0.045	18	48	78	82	88	95	105
5 Inch	0.076	16	29	49	54	59	68	78
5 Inch	0.100	14	27	46	50	53	60	70
5 Inch	0.133	17	25	41	43	47	54	68
5 Inch	0.180	15	20	35	37	42	47	55
5 Inch	0.211	11	20	34	37	41	46	56
5 Inch	0.250	9	16	30	33	37	43	54
5 Inch	0.314	8	10	21	24	27	33	41
5 Inch	0.464	3	5	6	7	8	10	18
5 Inch	0.533	3	5	8	9	11	18	44
6 Inch	0.046	17	41	65	70	76	81	90
6 Inch	0.076	14	25	41	44	50	58	70
6 Inch	0.100	11	25	45	51	56	65	75
6 Inch	0.133	15	22	36	39	42	48	57
6 Inch	0.180	8	16	30	33	36	41	51
6 Inch	0.211	10	16	30	33	36	42	53
6 Inch	0.250	8	15	26	28	31	37	49
6 Inch	0.314	6	89	17	19	22	26	36
6 Inch	0.464	4	5	6	7	10	12	19
6 Inch	0.533	3	4	7	8	9	15	42

TABLE 4 - POLYURETHANE ESTER, 1.5 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	32	102	126	129	133	142	160
1 Inch	0.070	24	82	120	128	131	143	170
1 Inch	0.090	22	85	108	117	122	128	140
1 Inch	0.120	24	82	110	122	135	155	205
1 Inch	0.150	23	65	98	100	104	108	115
1 Inch	0.200	18	47	70	72	76	82	87
1 Inch	0.240	20	46	70	72	76	82	85
1 Inch	0.270	20	40	65	68	71	75	84
1 Inch	0.340	18	31	52	55	60	65	70
1 Inch	0.450	16	20	28	32	36	42	54
2 Inch	0.045	24	85	128	132	142	160	200
2 Inch	0.070	19	69	96	99	102	108	123
2 Inch	0.090	21	58	77	81	84	90	98
2 Inch	0.120	18	52	80	82	86	93	123
2 Inch	0.150	18	42	70	72	74	78	86
2 Inch	0.200	18	37	62	64	66	69	77
2 Inch	0.240	15	28	49	52	58	62	67
2 Inch	0.270	16	28	48	51	56	62	66
2 Inch	0.340	13	25	47	51	56	62	68
2 Inch	0.450	10	17	26	29	32	38	44
3 Inch	0.045	21	63	120	122	128	132	152
3 Inch	0.070	18	50	66	81	84	88	94
3 Inch	0.090	20	54	68	72	76	80	89
3 Inch	0.120	16	39	66	68	70	74	80
3 Inch	0.150	18	33	61	64	68	74	84
3 Inch	0.200	16	30	52	54	60	64	69
3 Inch	0.240	16	25	46	47	51	57	63
3 Inch	0.270	15	22	40	42	45	50	58
3 Inch	0.340	8	17	30	35	40	46	52
3 Inch	0.450	6	12	18	20	22	27	37
4 Inch	0.045	19	58	90	97	110	122	135
4 Inch	0.070	19	41	75	77	85	90	95
4 Inch	0.090	19	36	58	60	63	66	70
4 Inch	0.120	16	32	56	61	64	68	84
4 Inch	0.150	15	26	44	47	50	55	68
4 Inch	0.200	15	23	41	43	45	48	59
4 Inch	0.240	8	18	34	37	40	43	56
4 Inch	0.270	12	18	32	35	39	42	46
4 Inch	0.340	8	16	26	28	31	37	47
4 Inch	0.450	5	8	12	14	16	21	30
5 Inch	0.045	20	45	67	72	77	90	93
5 Inch	0.070	18	36	55	58	68	80	85
5 Inch	0.090	17	30	47	50	54	60	66
5 Inch	0.120	15	31	50	52	57	63	74
5 Inch	0.150	15	21	43	46	51	56	66
5 Inch	0.200	9	19	35	38	41	43	48
5 Inch	0.240	7	17	34	38	40	44	52
5 Inch	0.270	8	16	30	32	37	41	54
5 Inch	0.340	5	12	19	21	24	29	39
5 Inch	0.450	4	5	8	9	11	15	26
6 Inch	0.045	20	40	62	65	72	79	85
6 Inch	0.070	18	35	55	58	70	83	90
6 Inch	0.090	16	32	48	52	56	62	68
6 Inch	0.120	15	29	48	54	58	64	88
6 Inch	0.150	14	23	40	43	48	52	63
6 Inch	0.200	10	20	35	39	43	48	50
6 Inch	0.240	10	17	32	35	40	44	50
6 Inch	0.270	9	16	30	32	34	40	45
6 Inch	0.340	6	12	21	24	28	32	42
6 Inch	0.450	5	10	18	20	23	26	35

TABLE 5 - POLYURETHANE ESTER - 2.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH						
		Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	25	100	125	130	134	148	160
1 Inch	0.070	27	80	111	120	125	135	163
1 Inch	0.090	25	84	108	113	120	130	140
1 Inch	0.120	20	92	126	134	142	150	160
1 Inch	0.150	22	54	92	97	100	110	140
1 Inch	0.200	21	58	88	91	95	100	121
1 Inch	0.240	20	56	77	82	85	90	97
1 Inch	0.270	20	47	74	76	82	87	96
1 Inch	0.340	18	28	57	61	65	70	75
1 Inch	0.450	16	29	48	52	59	64	70
2 Inch	0.045	24	89	132	135	158	165	170
2 Inch	0.070	22	67	93	96	100	103	116
2 Inch	0.090	22	58	83	86	88	92	99
2 Inch	0.120	19	61	82	86	92	110	130
2 Inch	0.150	19	48	78	82	90	98	130
2 Inch	0.200	16	37	60	63	66	71	76
2 Inch	0.240	16	32	57	60	62	66	69
2 Inch	0.270	17	27	48	50	58	62	66
2 Inch	0.340	16	27	30	55	60	64	69
2 Inch	0.450	13	19	32	35	41	46	50
3 Inch	0.045	21	62	118	122	128	134	142
3 Inch	0.070	20	57	85	88	90	95	100
3 Inch	0.090	19	48	66	68	71	74	83
3 Inch	0.120	18	40	67	70	72	75	82
3 Inch	0.150	18	32	64	65	69	74	105
3 Inch	0.200	15	25	43	46	48	52	62
3 Inch	0.240	15	22	41	43	47	52	62
3 Inch	0.270	13	21	39	41	44	49	56
3 Inch	0.340	8	16	29	31	36	44	48
3 Inch	0.450	6	11	16	18	21	25	35
4 Inch	0.045	19	56	92	120	125	128	130
4 Inch	0.070	21	47	80	82	85	90	95
4 Inch	0.090	18	41	60	62	65	68	74
4 Inch	0.120	17	37	65	68	71	75	80
4 Inch	0.150	17	36	55	60	67	72	90
4 Inch	0.200	15	23	41	43	45	59	60
4 Inch	0.240	12	21	40	42	45	48	60
4 Inch	0.270	12	20	35	38	42	44	48
4 Inch	0.340	9	17	29	32	36	44	50
4 Inch	0.450	8	13	19	22	24	28	38
5 Inch	0.045	20	47	76	80	110	125	160
5 Inch	0.070	17	36	58	64	70	82	88
5 Inch	0.090	16	31	49	51	53	55	60
5 Inch	0.120	16	26	46	51	55	60	72
5 Inch	0.150	12	22	40	44	48	52	60
5 Inch	0.200	10	19	36	39	41	44	47
5 Inch	0.240	6	20	39	41	44	47	60
5 Inch	0.270	8	13	24	26	30	37	47
5 Inch	0.340	6	13	23	25	28	31	44
5 Inch	0.450	3	6	6	7	9	12	24
6 Inch	0.045	19	42	64	69	74	80	87
6 Inch	0.070	18	37	60	64	70	78	84
6 Inch	0.090	16	31	47	49	52	55	66
6 Inch	0.120	16	29	48	53	56	60	66
6 Inch	0.150	15	23	38	42	46	52	60
6 Inch	0.200	10	19	31	33	38	42	46
6 Inch	0.240	9	15	28	32	35	41	52
6 Inch	0.270	8	18	31	34	38	42	46
6 Inch	0.340	6	12	22	24	28	32	40
6 Inch	0.450	4	9	15	18	20	24	31

TABLE 6 - POLYURETHANE ESTER, 4.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q-1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	25	105	130	133	145	156	180
1 Inch	0.070	25	77	100	103	105	115	138
1 Inch	0.090	20	79	98	102	105	110	130
1 Inch	0.120	21	64	89	93	100	110	145
1 Inch	0.150	21	61	94	98	100	106	130
1 Inch	0.200	17	45	72	75	82	86	92
1 Inch	0.240	20	43	68	70	74	80	90
1 Inch	0.270	17	31	57	60	62	68	75
1 Inch	0.340	16	26	48	51	59	64	68
1 Inch	0.450	9	13	22	25	28	34	47
2 Inch	0.045	21	63	114	120	123	129	145
2 Inch	0.070	23	58	98	100	104	113	150
2 Inch	0.090	21	52	70	74	78	83	88
2 Inch	0.120	19	45	70	72	75	80	100
2 Inch	0.150	18	39	67	72	76	83	105
2 Inch	0.200	16	30	52	55	60	64	68
2 Inch	0.240	16	27	47	50	55	62	66
2 Inch	0.270	15	23	42	45	47	53	58
2 Inch	0.340	13	20	40	45	48	55	62
2 Inch	0.450	7	8	10	13	18	23	36
3 Inch	0.045	20	42	75	77	81	86	95
3 Inch	0.070	18	45	78	80	83	85	90
3 Inch	0.090	19	38	58	60	62	67	75
3 Inch	0.120	16	36	56	62	66	68	72
3 Inch	0.150	17	31	52	56	63	66	76
3 Inch	0.200	15	25	44	48	49	54	62
3 Inch	0.240	10	19	37	39	42	45	52
3 Inch	0.270	10	17	32	35	38	42	45
3 Inch	0.340	9	16	30	32	38	44	50
3 Inch	0.450	5	8	14	17	21	26	39
4 Inch	0.045	19	45	70	115	120	130	150
4 Inch	0.070	19	40	67	72	80	85	90
4 Inch	0.090	16	34	51	56	60	63	67
4 Inch	0.120	16	31	52	56	62	68	85
4 Inch	0.150	15	24	43	46	51	56	68
4 Inch	0.200	15	20	39	41	43	46	50
4 Inch	0.240	8	17	32	35	40	44	48
4 Inch	0.270	8	16	31	34	39	43	48
4 Inch	0.340	7	13	25	27	30	38	48
4 Inch	0.450	4	7	11	13	15	20	31
5 Inch	0.045	19	40	64	71	78	97	155
5 Inch	0.070	16	31	49	52	58	68	88
5 Inch	0.090	16	29	44	47	49	56	62
5 Inch	0.120	13	24	42	46	52	60	66
5 Inch	0.150	11	21	35	38	43	49	58
5 Inch	0.200	11	17	31	34	38	41	44
5 Inch	0.240	5	14	27	28	34	40	44
5 Inch	0.270	8	12	25	28	32	37	45
5 Inch	0.340	5	10	23	25	28	32	45
5 Inch	0.0450	3	6	13	15	20	24	33
6 Inch	0.045	17	35	56	61	68	79	105
6 Inch	0.070	17	30	46	50	53	58	70
6 Inch	0.090	14	24	40	42	44	48	55
6 Inch	0.120	11	22	38	42	48	54	62
6 Inch	0.150	11	19	32	35	39	45	55
6 Inch	0.200	7	16	27	29	34	40	44
6 Inch	0.240	6	14	28	32	35	42	46
6 Inch	0.270	7	12	24	27	30	35	43
6 Inch	0.340	5	9	20	22	26	31	40
6 Inch	0.450	3	6	10	12	14	18	27

TABLE 7 -RUBBERIZED HAIR, TYPE II

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	17	34	57	60	65	72	84
1 Inch	0.076	13	25	45	50	55	62	68
1 Inch	0.092	11	19	35	38	42	48	62
1 Inch	0.108	10	17	31	34	38	44	55
1 Inch	0.148	8	14	25	28	32	37	47
1 Inch	0.180	8	13	23	24	27	33	42
1 Inch	0.211	6	12	23	25	29	35	46
1 Inch	0.252	6	11	19	21	25	30	39
1 Inch	0.283	6	10	16	20	23	28	30
1 Inch	0.354	6	9	15	16	21	25	33
2 Inch	0.045	11	18	29	31	35	40	50
2 Inch	0.076	8	14	24	27	30	37	48
2 Inch	0.092	6	10	20	22	25	31	41
2 Inch	0.108	5	9	17	19	21	24	30
2 Inch	0.148	5	8	15	18	21	25	31
2 Inch	0.180	4	7	14	16	19	27	42
2 Inch	0.211	4	6	12	14	18	23	32
2 Inch	0.252	4	6	9	11	14	19	29
2 Inch	0.283	4	6	8	9	15	21	30
2 Inch	0.354	4	6	10	11	14	19	28
3 Inch	0.045	9	15	25	27	30	35	42
3 Inch	0.076	7	11	20	22	25	29	39
3 Inch	0.092	9	16	16	21	29	33	38
3 Inch	0.108	4	8	17	20	22	28	35
3 Inch	0.148	3	6	12	14	16	20	27
3 Inch	0.180	4	6	10	12	15	21	35
3 Inch	0.211	3	6	10	12	15	20	28
3 Inch	0.252	3	5	9	10	12	18	28
3 Inch	0.283	3	5	8	11	15	20	32
3 Inch	0.354	3	5	8	9	12	16	27
4 Inch	0.045	7	12	22	24	26	30	38
4 Inch	0.076	6	9	15	17	21	25	33
4 Inch	0.092	4	8	16	18	22	28	38
4 Inch	0.108	4	7	14	15	18	21	27
4 Inch	0.148	3	5	11	12	14	18	26
4 Inch	0.180	4	5	9	10	13	18	30
4 Inch	0.211	3	5	7	9	11	16	27
4 Inch	0.252	3	5	8	9	10	14	24
4 Inch	0.283	3	5	8	9	11	15	25
4 Inch	0.354	2	5	5	6	8	15	35
5 Inch	0.045	6	12	20	21	24	28	35
5 Inch	0.076	5	8	15	17	20	23	31
5 Inch	0.092	4	6	13	15	17	22	32
5 Inch	0.108	3	6	11	13	15	18	24
5 Inch	0.148	3	5	9	11	13	16	22
5 Inch	0.180	3	5	8	9	11	15	27
5 Inch	0.211	3	4	7	9	11	16	28
5 Inch	0.252	3	4	6	7	8	12	20
5 Inch	0.283	2	4	6	7	9	14	26
5 Inch	0.354	2	4	6	7	9	14	26
6 Inch	0.045	5	11	20	21	24	27	33
6 Inch	0.076	5	8	13	15	17	21	29
6 Inch	0.092	3	5	11	12	14	19	26
6 Inch	0.108	3	6	12	13	15	20	26
6 Inch	0.148	3	5	9	10	12	15	21
6 Inch	0.180	3	4	7	8	10	14	22
6 Inch	0.211	2	4	7	8	10	14	23
6 Inch	0.252	2	4	5	6	8	12	21
6 Inch	0.283	3	4	7	8	10	15	25
6 Inch	0.354	1	3	5	6	7	11	18

TABLE 8 - RUBBERIZED HAIR, TYPE III

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	16	30	53	57	61	68	74
1 Inch	0.076	10	22	42	46	52	60	70
1 Inch	0.092	10	20	36	40	46	51	63
1 Inch	0.108	10	17	30	33	38	45	56
1 Inch	0.148	8	16	28	32	35	40	52
1 Inch	0.180	8	13	23	25	29	34	44
1 Inch	0.211	8	13	24	27	30	36	48
1 Inch	0.252	8	12	21	24	27	32	42
1 Inch	0.283	6	13	24	26	30	35	46
1 Inch	0.354	5	10	18	20	23	27	35
2 Inch	0.045	13	23	43	46	51	57	67
2 Inch	0.076	8	14	26	28	32	38	51
2 Inch	0.092	7	15	26	29	33	39	50
2 Inch	0.108	7	12	22	24	27	32	40
2 Inch	0.148	5	11	20	22	24	28	36
2 Inch	0.180	6	9	16	19	22	28	40
2 Inch	0.211	5	8	16	19	22	26	34
2 Inch	0.252	4	7	11	13	15	20	29
2 Inch	0.283	4	6	10	11	15	20	30
2 Inch	0.354	3	5	7	9	12	16	25
3 Inch	0.045	9	17	28	30	33	39	47
3 Inch	0.076	7	12	22	24	27	32	43
3 Inch	0.092	6	11	21	23	26	31	42
3 Inch	0.108	5	10	18	21	23	27	33
3 Inch	0.148	5	9	16	18	21	24	30
3 Inch	0.180	5	8	15	17	20	26	35
3 Inch	0.211	4	7	12	13	15	22	30
3 Inch	0.252	4	6	11	13	15	20	29
3 Inch	0.283	3	6	10	12	15	21	32
3 Inch	0.354	3	5	9	10	13	17	26
4 Inch	0.045	8	15	26	28	30	35	44
4 Inch	0.076	6	10	19	21	24	29	39
4 Inch	0.092	4	9	17	19	22	28	35
4 Inch	0.108	5	9	18	20	23	26	33
4 Inch	0.148	4	7	12	14	15	20	26
4 Inch	0.180	4	7	12	13	16	21	26
4 Inch	0.211	3	6	11	12	15	20	30
4 Inch	0.252	3	5	8	10	12	17	27
4 Inch	0.283	2	4	6	8	10	15	29
4 Inch	0.354	2	4	6	7	9	14	29
5 Inch	0.045	8	14	25	27	30	35	41
5 Inch	0.076	6	9	17	19	21	25	32
5 Inch	0.092	5	9	17	20	23	26	33
5 Inch	0.108	4	8	15	17	20	24	31
5 Inch	0.148	3	7	12	14	16	20	26
5 Inch	0.180	4	7	12	13	15	21	30
5 Inch	0.211	3	5	9	10	14	17	26
5 Inch	0.252	3	5	9	10	12	16	25
5 Inch	0.283	3	5	7	9	11	16	27
5 Inch	0.354	2	4	6	7	9	14	25
6 Inch	0.045	7	14	22	25	28	32	40
6 Inch	0.076	6	9	17	19	21	25	32
6 Inch	0.092	4	8	14	16	19	23	30
6 Inch	0.108	3	7	14	15	18	23	29
6 Inch	0.148	3	6	11	12	14	18	26
6 Inch	0.180	3	5	9	11	13	18	27
6 Inch	0.211	3	5	8	10	12	17	27
6 Inch	0.252	3	5	8	9	11	15	25
6 Inch	0.283	3	4	7	9	10	15	28
6 Inch	0.354	2	3	4	5	6	11	23

TABLE 9 - RUBBERIZED HAIR, TYPE IV

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	17	33	55	59	65	73	85
1 Inch	0.076	16	27	49	54	60	68	78
1 Inch	0.092	16	23	39	43	48	60	70
1 Inch	0.108	15	20	35	39	44	54	64
1 Inch	0.148	8	17	32	35	39	45	55
1 Inch	0.180	6	16	29	33	37	43	54
1 Inch	0.211	9	15	27	30	34	41	55
1 Inch	0.252	9	14	24	26	31	37	47
1 Inch	0.283	7	15	29	32	36	43	53
1 Inch	0.354	6	11	19	21	24	28	37
2 Inch	0.045	12	22	39	42	46	53	62
2 Inch	0.076	9	17	31	33	40	47	58
2 Inch	0.092	8	16	28	31	35	41	52
2 Inch	0.108	6	12	23	25	28	32	41
2 Inch	0.148	7	11	20	22	24	28	36
2 Inch	0.180	6	10	19	21	25	32	45
2 Inch	0.211	6	9	16	19	22	26	34
2 Inch	0.252	4	7	12	14	18	21	29
2 Inch	0.283	5	7	13	15	18	24	33
2 Inch	0.354	3	6	12	14	16	21	29
3 Inch	0.045	9	18	30	33	37	42	53
3 Inch	0.076	7	13	25	27	31	36	46
3 Inch	0.092	6	12	24	27	30	40	57
3 Inch	0.108	6	10	19	21	23	27	34
3 Inch	0.148	5	8	15	17	20	23	30
3 Inch	0.180	6	9	15	18	21	27	37
3 Inch	0.211	4	8	15	16	20	25	34
3 Inch	0.252	4	7	12	14	15	20	29
3 Inch	0.283	4	6	11	13	15	21	30
3 Inch	0.354	3	5	8	6	13	19	31
4 Inch	0.045	7	13	24	25	29	32	38
4 Inch	0.076	7	12	22	24	26	31	39
4 Inch	0.092	6	10	19	22	25	30	41
4 Inch	0.108	5	9	18	20	22	26	31
4 Inch	0.148	4	7	13	14	17	21	27
4 Inch	0.180	5	7	12	13	16	21	30
4 Inch	0.211	3	6	11	13	15	21	29
4 Inch	0.252	4	6	11	12	14	19	28
4 Inch	0.283	3	5	8	9	11	17	27
4 Inch	0.354	2	4	6	7	9	14	29
5 Inch	0.045	6	11	20	23	25	29	35
5 Inch	0.076	6	10	19	21	24	28	36
5 Inch	0.092	5	9	16	19	22	26	35
5 Inch	0.108	3	8	15	17	21	25	32
5 Inch	0.148	3	6	11	13	15	19	27
5 Inch	0.180	4	6	11	13	15	20	29
5 Inch	0.211	3	6	10	12	15	19	29
5 Inch	0.252	4	5	9	10	13	15	23
5 Inch	0.283	3	5	9	11	14	17	24
5 Inch	0.354	3	4	6	8	10	15	26
6 Inch	0.045	5	12	22	24	26	32	41
6 Inch	0.076	8	9	17	19	22	25	33
6 Inch	0.092	3	7	13	14	18	22	30
6 Inch	0.108	3	8	14	16	19	22	28
6 Inch	0.148	3	6	11	12	14	19	26
6 Inch	0.180	4	6	10	12	14	19	27
6 Inch	0.211	3	5	9	11	14	18	28
6 Inch	0.252	3	5	8	10	11	15	24
6 Inch	0.283	3	4	6	7	10	14	23
6 Inch	0.354	2	3	5	5	6	9	23

TABLE 10 - POLYETHYLENE, 2.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.090	25	82	96	100	102	106	112
1 Inch	0.260	21	75	98	100	106	107	110
1 Inch	0.500	27	73	110	114	116	120	126
1 Inch	0.610	21	61	98	100	103	106	109
1 Inch	0.810	25	53	90	96	100	104	112
1 Inch	1.000	20	44	76	80	82	90	95
1 Inch	1.200	20	45	73	78	83	85	91
1 Inch	1.300	17	33	63	66	70	76	84
1 Inch	1.500	17	34	58	62	66	72	80
1 Inch	2.000	15	20	40	43	46	49	56
2 Inch	0.090	25	85	94	95	96	100	106
2 Inch	0.260	20	73	96	98	100	102	106
2 Inch	0.500	20	55	92	96	102	110	122
2 Inch	0.610	20	54	85	88	93	100	110
2 Inch	0.810	19	40	64	66	70	76	82
2 Inch	1.000	18	36	59	62	66	70	78
2 Inch	1.200	17	35	60	63	66	73	82
2 Inch	1.300	15	25	43	46	52	56	66
2 Inch	1.500	16	22	38	44	47	51	58
2 Inch	2.000	15	19	34	37	40	45	55
3 Inch	0.090	20	80	95	97	99	103	108
3 Inch	0.260	17	41	66	70	76	86	98
3 Inch	0.500	19	41	67	70	74	80	89
3 Inch	0.610	17	40	65	68	73	80	90
3 Inch	0.810	17	31	54	56	59	65	74
3 Inch	1.000	16	28	49	54	57	62	69
3 Inch	1.200	12	25	43	50	55	56	60
3 Inch	1.300	14	21	36	38	41	47	56
3 Inch	1.500	16	24	40	42	45	50	60
3 Inch	2.000	10	16	25	28	31	35	44
4 Inch	0.090	22	92	110	111	116	120	128
4 Inch	0.260	20	52	84	88	95	104	118
4 Inch	0.500	13	35	55	57	60	63	67
4 Inch	0.610	17	34	56	60	65	72	82
4 Inch	0.810	16	30	48	50	55	59	66
4 Inch	1.000	15	27	42	45	48	52	60
4 Inch	1.200	12	25	42	44	48	52	59
4 Inch	1.300	10	18	33	35	38	42	49
4 Inch	1.500	15	25	42	44	46	52	58
4 Inch	2.000	10	19	33	35	38	42	49
5 Inch	0.090	30	80	96	96	97	98	100
5 Inch	0.260	20	40	68	74	80	90	106
5 Inch	0.500	18	32	54	56	61	67	78
5 Inch	0.610	15	29	48	51	55	61	64
5 Inch	0.810	16	27	43	47	50	53	58
5 Inch	1.000	14	22	39	42	45	49	55
5 Inch	1.200	11	18	32	34	38	43	51
5 Inch	1.300	10	16	29	31	34	39	47
5 Inch	1.500	11	21	35	38	41	46	53
5 Inch	2.000	8	16	27	29	32	35	42
6 Inch	0.090	21	56	89	90	91	94	99
6 Inch	0.260	17	36	66	70	76	82	91
6 Inch	0.500	19	35	54	56	60	68	73
6 Inch	0.610	17	31	49	52	56	61	66
6 Inch	0.810	10	18	33	35	39	42	52
6 Inch	1.000	13	22	27	39	42	46	55
6 Inch	1.200	8	14	27	29	32	36	44
6 Inch	1.300	7	13	25	27	29	33	41
6 Inch	1.500	8	15	27	29	31	38	43
6 Inch	2.000	8	17	28	30	32	37	44

TABLE 11 - POLYETHYLENE, 4.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH						
		Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.090	27	82	90	91	92	93	94
1 Inch	.260	21	78	100	102	105	107	112
1 Inch	0.500	24	68	105	110	112	113	114
1 Inch	0.610	22	65	101	103	104	107	109
1 Inch	0.810	22	60	90	93	98	106	123
1 Inch	1.000	21	49	79	81	88	94	98
1 Inch	1.200	22	58	94	100	102	105	109
1 Inch	1.300	21	58	86	91	95	102	110
1 Inch	1.500	20	40	65	70	74	77	82
1 Inch	2.000	16	26	51	54	58	62	69
2 Inch	0.090	21	82	98	99	100	103	105
2 Inch	0.260	20	56	84	85	88	90	95
2 Inch	0.500	20	47	67	70	74	79	85
2 Inch	0.610	20	59	96	100	105	110	117
2 Inch	0.810	22	50	80	81	89	94	102
2 Inch	1.000	19	43	70	71	77	82	87
2 Inch	1.200	18	42	72	78	82	88	96
2 Inch	1.300	16	35	56	62	67	72	78
2 Inch	1.500	16	33	56	59	62	69	75
2 Inch	2.000	15	24	44	47	51	55	61
3 Inch	0.090	25	59	92	93	95	96	99
3 Inch	0.260	19	54	80	85	90	95	98
3 Inch	0.500	19	43	57	59	61	64	67
3 Inch	0.610	18	41	68	70	74	76	80
3 Inch	0.810	15	29	37	50	54	58	64
3 Inch	1.000	17	33	55	57	63	68	74
3 Inch	1.200	16	34	55	59	63	68	74
3 Inch	1.300	16	27	45	49	53	56	62
3 Inch	1.500	15	25	43	47	50	55	62
3 Inch	2.000	16	27	44	46	50	53	59
4 Inch	0.090	24	85	99	101	102	106	109
4 Inch	0.260	18	47	76	82	88	90	92
4 Inch	0.500	17	33	45	46	48	50	52
4 Inch	0.610	18	38	60	64	67	72	78
4 Inch	0.810	18	39	60	62	65	68	71
4 Inch	1.000	15	30	49	54	55	60	64
4 Inch	1.200	16	32	52	56	59	65	73
4 Inch	1.300	12	21	37	40	44	47	52
4 Inch	1.500	16	32	51	55	58	64	70
4 Inch	2.000	11	25	43	45	48	53	57
5 Inch	0.090	21	60	95	97	99	100	102
5 Inch	0.260	19	53	83	86	89	94	98
5 Inch	0.500	17	37	62	66	68	73	78
5 Inch	0.610	16	33	54	58	63	70	76
5 Inch	0.810	16	28	45	50	54	62	68
5 Inch	1.000	12	20	38	41	44	47	51
5 Inch	1.200	13	25	42	45	49	54	60
5 Inch	1.300	8	19	32	33	40	43	48
5 Inch	1.500	14	25	41	44	47	51	59
5 Inch	2.000	10	20	35	37	40	44	50
6 Inch	0.090	19	52	91	98	99	100	103
6 Inch	0.260	20	57	90	94	96	100	104
6 Inch	0.500	21	44	65	70	73	75	78
6 Inch	0.610	17	35	55	60	63	66	72
6 Inch	0.810	16	33	51	55	60	64	68
6 Inch	1.000	14	26	41	44	47	52	58
6 Inch	1.200	10	19	34	37	40	44	53
6 Inch	1.300	9	17	31	33	36	41	46
6 Inch	1.500	13	25	41	44	47	52	59
6 Inch	2.000	14	22	37	39	42	47	51

TABLE 12 - POLYSTYRENE, 1.5 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.100	55	87	100	105	130	142	165
1 Inch	0.250	55	90	107	117	129	145	172
1 Inch	0.464	55	86	98	102	107	113	123
1 Inch	0.533	43	70	90	94	98	102	107
1 Inch	0.640	36	73	98	100	102	107	111
1 Inch	0.740	28	53	73	74	78	81	89
1 Inch	0.950	28	54	78	82	90	93	100
1 Inch	1.150	19	50	68	72	76	82	92
1 Inch	1.480	19	50	71	75	80	87	100
1 Inch	1.950	16	30	46	55	60	67	75
2 Inch	0.100	45	85	103	106	108	111	117
2 Inch	0.250	40	70	88	93	100	109	125
2 Inch	0.464	35	59	75	78	83	90	103
2 Inch	0.533	35	55	80	84	89	97	110
2 Inch	0.640	23	44	76	79	83	90	100
2 Inch	0.740	31	52	73	77	83	87	96
2 Inch	0.950	27	45	66	69	74	79	86
2 Inch	1.150	18	33	57	61	64	67	81
2 Inch	1.480	17	34	53	58	62	65	74
2 Inch	1.950	16	30	50	52	59	63	74
3 Inch	0.100	50	88	100	107	114	124	142
3 Inch	0.250	41	78	103	106	109	113	121
3 Inch	0.464	30	52	75	82	86	95	110
3 Inch	0.533	36	51	74	78	84	92	106
3 Inch	0.640	28	48	66	70	75	80	87
3 Inch	0.740	30	51	60	71	78	84	89
3 Inch	0.950	21	29	39	40	48	50	64
3 Inch	1.150	16	31	51	56	60	66	76
3 Inch	1.480	16	27	45	48	51	56	66
3 Inch	1.950	18	28	49	52	57	64	72
4 Inch	0.100	50	94	107	112	117	126	140
4 Inch	0.250	43	78	100	103	108	113	120
4 Inch	0.464	33	53	78	85	89	94	106
4 Inch	0.533	27	47	66	70	77	87	101
4 Inch	0.640	24	42	67	69	72	82	93
4 Inch	0.740	25	39	55	57	63	69	81
4 Inch	0.950	22	33	50	52	55	59	68
4 Inch	1.150	18	35	53	58	63	65	74
4 Inch	1.480	15	24	39	42	45	52	62
4 Inch	1.950	14	24	40	44	48	54	66
5 Inch	0.100	42	78	96	98	102	110	122
5 Inch	0.250	35	60	86	92	98	109	126
5 Inch	0.464	29	45	72	75	80	87	100
5 Inch	0.533	25	40	60	64	66	76	88
5 Inch	0.640	21	35	54	57	62	70	82
5 Inch	0.740	22	35	51	53	57	62	70
5 Inch	0.950	21	31	45	47	50	54	61
5 Inch	1.150	14	28	47	51	54	56	63
5 Inch	1.480	13	25	44	47	51	56	66
5 Inch	1.950	9	17	31	34	37	42	51
6 Inch	0.100	32	60	77	81	83	87	93
6 Inch	0.250	25	38	53	55	59	65	72
6 Inch	0.464	23	40	55	58	62	68	78
6 Inch	0.533	23	35	53	57	62	70	85
6 Inch	0.640	17	27	35	42	45	51	62
6 Inch	0.740	20	29	40	42	44	47	54
6 Inch	0.950	22	34	48	51	54	60	72
6 Inch	1.150	14	27	43	50	54	60	66
6 Inch	1.480	13	21	37	40	44	50	60
6 Inch	1.950	13	20	36	39	41	47	59

TABLE 13 - POLYSTYRENE, 2.5 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.100	46	85	102	105	108	111	119
1 Inch	0.250	85	89	98	100	106	113	124
1 Inch	0.464	51	86	98	100	105	111	119
1 Inch	0.533	40	73	92	94	98	102	108
1 Inch	0.640	35	72	100	103	110	116	126
1 Inch	0.740	41	70	98	99	101	103	107
1 Inch	0.950	43	78	100	102	104	107	110
1 Inch	1.150	26	49	85	92	96	99	102
1 Inch	1.480	23	68	95	99	101	104	107
1 Inch	1.950	18	34	51	54	57	63	70
2 Inch	0.100	43	75	92	94	95	98	100
2 Inch	0.250	80	85	96	102	108	116	126
2 Inch	0.464	55	90	101	105	110	115	120
2 Inch	0.533	31	45	59	63	68	76	84
2 Inch	0.640	38	63	86	93	96	100	107
2 Inch	0.740	40	60	86	88	91	93	100
2 Inch	0.950	28	46	65	68	71	85	93
2 Inch	1.150	25	45	70	75	78	82	88
2 Inch	1.480	18	35	55	60	70	75	82
2 Inch	1.950	18	42	62	66	70	76	82
3 Inch	0.100	50	88	103	106	110	118	128
3 Inch	0.250	53	83	102	107	112	120	127
3 Inch	0.464	32	57	76	86	92	100	110
3 Inch	0.533	37	60	85	88	91	96	100
3 Inch	0.640	30	58	86	92	95	100	105
3 Inch	0.740	30	53	73	76	80	85	94
3 Inch	0.950	27	40	55	59	64	74	82
3 Inch	1.150	17	35	55	58	63	69	78
3 Inch	1.480	19	47	75	81	89	99	111
3 Inch	1.950	17	32	51	61	65	70	78
4 Inch	0.100	47	90	98	103	110	120	130
4 Inch	0.250	50	84	110	112	116	120	129
4 Inch	0.464	38	55	78	80	85	92	102
4 Inch	0.533	29	65	88	89	92	98	102
4 Inch	0.640	26	49	75	80	83	95	100
4 Inch	0.740	27	45	67	70	73	80	87
4 Inch	0.950	20	32	44	46	50	55	65
4 Inch	1.150	17	30	49	51	56	62	71
4 Inch	1.480	16	31	50	52	60	66	76
4 Inch	1.950	16	29	48	50	56	63	74
5 Inch	0.100	45	90	107	109	110	116	120
5 Inch	0.250	42	94	110	112	115	119	128
5 Inch	0.464	35	56	80	84	88	95	105
5 Inch	0.533	25	45	68	69	72	82	95
5 Inch	0.640	22	42	62	65	70	75	85
5 Inch	0.740	28	44	65	67	71	78	82
5 Inch	0.950	24	38	54	56	66	72	82
5 Inch	1.150	19	40	61	64	69	75	83
5 Inch	1.480	16	27	46	49	54	61	69
5 Inch	1.950	15	28	50	59	63	67	76
6 Inch	0.100	35	57	86	92	94	99	106
6 Inch	0.250	30	56	75	80	85	93	105
6 Inch	0.464	33	63	83	85	93	101	115
6 Inch	0.533	29	42	60	65	70	80	90
6 Inch	0.640	21	35	50	53	56	62	73
6 Inch	0.740	28	45	65	69	72	78	82
6 Inch	0.950	30	50	73	76	79	81	89
6 Inch	1.150	19	42	64	70	75	82	85
6 Inch	1.480	16	30	52	65	67	72	80
6 Inch	1.950	14	29	45	47	54	58	68

TABLE 14 - CHEMICALLY CROSSLINKED POLYETHYLENE, 2.0 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.3	Q=.6	Q=.4	Q=.2
1 Inch	0.090	32	80	90	92	94	98	110
1 Inch	0.260	26	80	92	94	96	98	102
1 Inch	0.500	22	72	108	110	113	116	123
1 Inch	0.610	22	65	100	105	108	110	114
1 Inch	0.810	22	42	65	70	72	80	90
1 Inch	1.000	22	46	78	82	88	90	94
1 Inch	1.200	20	43	70	74	80	83	90
1 Inch	1.300	17	35	62	66	71	80	88
1 Inch	1.500	16	22	40	42	46	51	59
1 Inch	2.000	11	21	40	42	46	51	59
2 Inch	0.090	25	76	94	95	98	100	104
2 Inch	0.260	20	56	92	96	100	104	111
2 Inch	0.500	20	47	82	86	88	94	98
2 Inch	0.610	21	53	84	89	90	94	98
2 Inch	0.810	19	40	65	70	74	78	82
2 Inch	1.000	19	41	64	67	70	76	80
2 Inch	1.200	16	33	56	60	63	69	76
2 Inch	1.300	15	21	40	43	46	49	54
2 Inch	1.500	15	22	41	44	47	51	55
2 Inch	2.000	10	18	32	34	38	42	48
3 Inch	0.090	30	85	98	102	105	110	115
3 Inch	0.260	21	64	96	98	100	102	103
3 Inch	0.500	20	48	70	72	75	78	82
3 Inch	0.610	19	40	65	68	71	73	76
3 Inch	0.810	18	31	50	54	56	62	66
3 Inch	1.000	17	35	56	60	65	69	73
3 Inch	1.200	11	27	44	52	55	60	64
3 Inch	1.300	15	22	38	40	44	48	52
3 Inch	1.500	11	19	35	37	40	45	50
3 Inch	2.000	9	16	28	31	34	39	44
4 Inch	0.090	25	84	103	105	108	110	113
4 Inch	0.260	21	62	96	100	101	101	105
4 Inch	0.500	17	36	55	62	65	70	76
4 Inch	0.610	17	40	64	68	72	76	82
4 Inch	0.810	16	25	42	45	48	52	58
4 Inch	1.000	16	29	47	50	54	61	72
4 Inch	1.200	11	22	40	42	46	50	56
4 Inch	1.300	11	21	35	38	41	45	50
4 Inch	1.500	10	18	32	35	37	41	49
4 Inch	2.00	9	17	29	31	34	37	41
5 Inch	0.090	22	84	105	108	113	120	130
5 Inch	0.260	20	56	91	94	96	100	105
5 Inch	0.500	17	33	52	55	60	65	76
5 Inch	0.610	17	35	57	64	69	78	92
5 Inch	0.810	15	26	44	47	50	56	66
5 Inch	1.000	15	26	43	47	53	56	64
5 Inch	1.200	9	18	34	37	40	46	55
5 Inch	1.300	10	17	30	32	35	38	45
5 Inch	1.500	9	19	34	36	38	43	49
5 Inch	2.000	10	15	28	30	33	37	42
6 Inch	0.090	20	80	116	119	120	122	126
6 Inch	0.260	18	56	90	92	94	96	100
6 Inch	0.500	17	39	60	63	68	72	75
6 Inch	0.610	17	33	51	54	58	64	68
6 Inch	0.810	14	25	41	43	46	51	54
6 Inch	1.000	11	20	34	36	39	42	47
6 Inch	1.200	10	17	31	33	36	41	50
6 Inch	1.300	7	16	26	28	30	34	41
6 Inch	1.500	9	19	32	34	37	41	46
6 Inch	2.000	9	17	28	30	32	36	39

TABLE 15-16 - CONVOLUTED POLYURETHANE 1.15 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH						
		Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 PLY=1 In	0.045	15	23	40	45	52	60	72
1 Ply=1 In	0.070	17	24	40	44	49	56	68
1 Ply=1 In	0.090	17	26	44	48	53	58	66
1 Ply=1 In	0.120	16	22	37	40	45	52	64
1 Ply=1 In	0.150	15	22	37	42	47	52	64
1 PLY=1 In	0.200	13	18	32	36	41	47	60
1 Ply=1 In	0.240	10	17	28	32	36	43	57
1 Ply=1 In	0.270	7	13	26	28	32	38	56
1 Ply=1 In	0.340	4	9	18	21	25	31	44
1 Ply=1 In	0.450	6	17	27	31	37	38	62
2 Ply=2 In	0.045	14	29	50	55	61	72	76
1 Ply=2 In	0.045	16	28	53	56	63	72	82
2 Ply=2 In	0.070	12	21	34	37	41	45	54
1 Ply=2 In	0.070	17	26	42	45	51	57	70
2 Ply=2 In	0.090	10	16	30	32	35	40	46
1 Ply=2 In	0.090	15	24	41	43	46	52	62
2 Ply=2 In	0.120	10	17	28	30	33	38	47
1 Ply=2 In	0.120	12	17	30	33	37	42	49
2 Ply=2 In	0.150	10	14	26	28	30	35	45
1 Ply=2 In	0.150	12	17	30	32	37	42	54
2 Ply=2 In	0.200	7	9	21	23	26	32	42
1 Ply=2 In	0.200	10	14	26	28	32	38	46
2 Ply=2 In	0.240	5	8	17	20	23	28	42
1 Ply=2 In	0.240	7	11	21	24	27	32	40
1 Ply=2 In	0.270	6	9	19	22	25	30	38
2 Ply=2 In	0.270	5	10	20	23	27	32	43
1 Ply=2 In	0.340	4	7	11	14	18	22	34
2 Ply=2 In	0.340	3	6	11	14	18	24	45
1 Ply=2 In	0.450	3	4	11	12	14	21	33
2 Ply=2 In	0.450	4	8	14	18	23	29	50
3 Ply=3 In	0.045	10	20	34	38	42	48	62
3 Ply=3 In	0.070	8	14	22	24	26	31	41
3 Ply=3 In	0.090	8	14	25	27	30	35	40
3 Ply=3 In	0.120	6	10	19	21	23	27	35
3 Ply=3 In	0.150	6	9	18	20	23	26	34
3 Ply=3 In	0.200	6	8	15	18	22	26	38
3 Ply=3 In	0.240	4	6	12	15	19	24	37
3 Ply=3 In	0.270	4	6	12	14	17	23	34
3 Ply=3 In	0.340	3	4	8	10	13	19	45
3 Ply=3 In	0.450	3	6	13	17	21	27	45
2 Ply=4 In	0.045	11	20	34	38	42	49	61
2 Ply=4 In	0.070	10	16	26	29	33	38	53
2 Ply=4 In	0.090	11	15	26	28	31	35	40
2 Ply=4 In	0.120	6	12	22	24	26	30	36
2 Ply=4 In	0.150	6	11	21	23	27	35	50
2 Ply=4 In	0.200	5	8	17	19	22	26	34
2 Ply=4 In	0.240	4	7	14	17	22	25	40
2 Ply=4 In	0.270	4	6	13	14	17	22	29
2 Ply=4 In	0.340	3	4	6	8	10	14	31
2 Ply=4 In	0.450	2	4	7	9	11	15	30
3 Ply=6 In	0.045	10	17	28	30	33	40	57
3 Ply=6 In	0.070	7	12	21	23	24	28	34
3 Ply=6 In	0.090	7	10	18	20	23	27	35
3 Ply=6 In	0.120	6	10	20	23	25	29	42
3 Ply=6 In	0.150	5	8	15	18	20	23	30
3 Ply=6 In	0.200	4	7	14	16	19	23	31
3 Ply=6 In	0.240	3	5	11	14	15	23	44
3 Ply=6 In	0.270	4	5	9	10	14	22	45
3 Ply=6 In	0.340	3	4	7	9	11	15	33
3 Ply=6 In	0.450	2	3	6	7	8	12	27

TABLE 17-18 - CONVOLUTED POLYURETHANE 1.5 PCF

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Ply=1 In	0.045	16	21	40	44	50	61	69
1 Ply=1 In	0.070	17	26	42	45	50	61	77
1 Ply=1 In	0.090	16	23	39	42	44	50	60
1 Ply=1 In	0.120	10	20	34	37	42	47	56
1 Ply=1 In	0.150	10	17	28	33	35	42	55
1 Ply=1 In	0.200	10	14	26	39	33	40	48
1 Ply=1 In	0.240	6	11	21	24	27	33	42
1 Ply=1 In	0.270	6	9	18	19	22	28	37
1 Ply=1 In	0.340	4	7	14	18	22	27	43
1 Ply=1 In	0.450	5	9	18	20	25	32	45
2 Ply=2 In	0.045	11	21	36	40	45	55	67
1 PLY=2 In	0.045	17	38	62	68	72	77	85
2 Ply=2 In	0.070	11	18	30	32	36	42	53
1 Ply=2 In	0.070	16	24	40	43	48	55	67
2 Ply=2 In	0.090	10	15	26	28	32	37	42
1 Ply=2 In	0.090	15	20	35	38	40	43	54
2 Ply=2 In	0.120	7	13	23	25	27	31	43
1 Ply=2 In	0.120	12	16	29	31	34	40	48
2 Ply=2 In	0.150	5	9	18	20	22	27	36
1 Ply=2 [illegible]	0.150	11	17	28	31	35	42	52
2 Ply=2 In	0.200	6	8	15	19	22	26	36
1 Ply=2 In	0.200	8	13	24	26	30	36	42
2 Ply=2 In	0.240	4	7	14	16	20	24	37
1 Ply=2 In	0.240	7	10	23	25	28	34	43
2 Ply=2 In	0.270	4	6	10	12	15	21	35
1 Ply=2 In	0.270	6	8	17	19	22	27	37
2 Ply=2 In	0.340	3	5	9	12	14	20	34
1 Ply=2 In	0.340	5	9	17	19	23	28	38
1 Ply=2 In	0.450	3	5	8	10	13	20	34
2 Ply=2 In	0.450	3	6	12	14	17	24	37
3 Ply=3 In	0.045	10	18	30	33	37	44	60
3 Ply=3 In	0.070	6	10	19	20	23	27	34
3 Ply=3 In	0.090	6	12	23	25	28	32	39
3 Ply=3 In	0.120	6	8	15	18	20	24	30
3 Ply=3 In	0.150	4	7	14	15	19	23	30
3 Ply=3 In	0.200	4	7	14	15	19	23	33
3 Ply=3 In	0.240	3	5	11	13	17	22	34
3 Ply=3 In	0.270	3	5	8	10	12	17	35
3 Ply=3 In	0.340	3	4	7	9	12	17	30
3 Ply=3 In	0.450	2	4	8	10	13	19	31
2 Ply=4 In	0.045	10	23	35	39	43	49	60
2 Ply=4 In	0.070	8	15	26	27	30	34	45
2 Ply=4 In	0.090	8	11	20	22	25	28	38
2 Ply=4 In	0.120	6	11	21	22	25	28	34
2 Ply=4 In	0.150	6	10	18	21	23	27	34
2 Ply=4 In	0.200	5	9	19	21	24	28	37
2 Ply=4 In	0.240	4	7	14	16	20	25	42
2 Ply=4 In	0.270	4	6	11	13	15	20	29
2 Ply=4 In	0.340	3	4	7	9	12	17	29
2 Ply=4 In	0.450	2	4	7	8	10	15	30
3 Ply=6 In	0.045	10	14	24	25	28	32	64
3 Ply=6 In	0.070	6	11	19	20	22	26	33
3 Ply=6 In	0.090	7	11	20	22	25	28	37
3 Ply=6 In	0.120	5	9	17	19	22	26	41
3 Ply=6 In	0.150	4	7	13	15	18	21	24
3 Ply=6 In	0.200	4	6	13	14	18	22	29
3 Ply=6 In	0.240	3	4	9	10	14	20	45
3 Ply=6 In	0.270	3	5	9	10	13	20	47
3 Ply=6 In	0.340	3	4	6	8	10	14	30
3 Ply=6 In	0.450	2	3	4	5	7	10	21

TABLE 19 -CELLULOSE WADDING

THICKNESS CODE	LOADING	FREQUENCY AT WHICH						
		Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	16	31	53	56	62	70	74
1 Inch	0.077	16	25	43	45	50	55	60
1 Inch	0.110	13	22	38	41	45	51	59
1 Inch	0.148	11	20	33	36	40	45	51
1 Inch	0.180	10	16	29	31	36	43	55
1 Inch	0.211	10	16	27	30	34	40	49
1 Inch	0.252	9	14	24	27	30	36	43
1 Inch	0.283	9	16	26	30	33	39	46
1 Inch	0.464	7	12	23	25	28	32	39
1 Inch	0.800	7	11	22	25	28	33	42
2 Inch	0.045	11	20	34	37	40	45	53
2 Inch	0.077	8	20	36	40	44	50	62
2 Inch	0.110	9	14	24	26	30	34	43
2 Inch	0.148	8	11	20	24	25	.29	38
2 Inch	0.180	6	11	19	22	25	30	40
2 Inch	0.211	6	10	18	20	23	27	34
2 Inch	0.252	6	10	18	20	23	26	32
2 Inch	0.283	5	9	17	19	22	26	33
2 Inch	0.464	4	8	15	18	21	25	31
2 Inch	0.800	5	6	15	19	20	24	31
3 Inch	0.045	9	16	27	29	32	35	41
3 Inch	0.077	8	14	25	28	31	38	49
3 Inch	0.110	7	11	19	21	25	29	37
3 Inch	0.148	6	9	16	19	21	25	31
3 Inch	0.180	5	9	15	20	21	27	35
3 Inch	0.211	5	8	14	16	20	24	30
3 Inch	0.252	5	6	13	15	18	22	30
3 Inch	0.283	4	8	14	15	19	23	29
3 Inch	0.484	4	6	11	12	16	20	28
3 Inch	0.800	4	6	12	14	16	20	26
4 Inch	0.045	7	14	24	26	28	32	38
4 Inch	0.077	6	10	19	22	26	30	40
4 Inch	0.110	6	9	17	19	22	26	33
4 Inch	0.141	5	8	15	16	19	24	32
4 Inch	0.180	4	7	13	15	17	23	33
4 Inch	0.211	4	7	12	15	18	22	28
4 Inch	0.252	4	7	11	13	15	20	28
4 Inch	0.283	3	6	11	13	15	19	27
4 Inch	0.484	3	5	9	11	14	18	24
4 Inch	0.800	3	5	11	13	15	20	29
5 Inch	0.045	6	12	21	23	26	29	36
5 Inch	0.077	6	11	20	22	25	30	41
5 Inch	0.110	6	9	15	17	20	25	32
5 Inch	0.148	4	7	13	15	18	23	26
5 Inch	0.180	4	7	13	15	17	22	31
5 Inch	0.211	4	7	12	14	15	21	29
5 Inch	0.252	4	6	11	13	15	20	26
5 Inch	0.283	3	6	10	12	14	19	25
5 Inch	0.484	3	5	9	10	12	16	20
5 Inch	0.800	3	5	10	11	14	18	25
6 Inch	0.045	9	12	22	24	26	31	38
6 Inch	0.077	6	9	17	19	21	26	3F
6 Inch	0.110	5	9	15	18	20	25	31
6 Inch	0.148	4	8	12	15	17	22	29
6 Inch	0.180	4	6	12	13	15	21	29
6 Inch	0.211	4	6	12	14	15	21	28
6 Inch	0.252	3	5	10	11	13	16	22
6 Inch	0.283	3	5	9	11	13	17	25
6 Inch	0.484	3	5	8	10	12	15	25
6 Inch	0.300	3	4	9	10	12	16	24

TABLE 20 - CELLULAR POLYETHYLENE FILM .5 IN PLY THICKNESS

THICKNESS CODE	LOADING	FREQUENCY AT WHICH Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 Inch	0.045	18	48	86	93	98	110	132
1 Inch	0.076	16	35	61	64	72	81	100
1 Inch	0.133	15	26	45	52	56	64	72
1 Inch	0.250	11	17	27	31	34	39	50
1 Inch	0.314	10	18	31	34	39	44	58
1 Inch	0.464	8	16	25	28	31	35	47
1 Inch	0.533	8	15	23	25	28	33	40
1 Inch	0.640	7	13	22	24	26	31	39
1 Inch	0.740	5	13	21	23	26	32	44
1 Inch	0.950	6	12	20	21	24	28	38
2 Inch	0.045	16	34	54	58	64	72	88
2 Inch	0.076	12	25	42	45	50	56	62
2 Inch	0.133	11	17	29	33	37	42	48
2 Inch	0.250	9	15	24	26	30	35	41
2 Inch	0.314	7	13	23	25	29	35	47
2 Inch	0.464	6	11	19	21	24	28	36
2 Inch	0.533	6	11	15	19	21	25	33
2 Inch	0.640	6	10	15	18	21	24	31
2 Inch	0.740	6	10	15	18	21	25	40
2 Inch	0.950	4	9	13	15	18	22	32
3 Inch	0.045	10	27	42	45	49	54	62
3 Inch	0.064	5	9	13	14	16	20	27
3 Inch	0.076	9	20	33	36	40	47	55
3 Inch	0.133	7	14	24	26	30	34	41
3 Inch	0.250	7	11	19	21	23	27	35
3 Inch	0.314	6	11	19	21	24	29	42
3 Inch	0.464	6	9	15	16	19	23	30
3 Inch	0.533	5	9	15	17	20	23	31
3 Inch	0.740	5	8	14	15	18	23	33
3 Inch	0.950	4	8	11	13	15	19	28
4 Inch	0.045	10	22	35	37	40	46	55
4 Inch	0.076	8	17	29	31	35	39	49
4 Inch	0.133	6	12	22	23	26	30	38
4 Inch	0.250	6	10	17	18	21	25	33
4 Inch	0.314	6	9	15	18	21	25	38
4 Inch	0.464	5	8	13	14	17	21	30
4 Inch	0.533	4	7	12	13	15	20	27
4 Inch	0.640	4	7	11	12	14	17	24
4 Inch	0.740	4	7	12	13	15	21	31
4 Inch	0.950	4	6	9	10	12	16	25
5 Inch	0.045	9	20	33	36	40	46	58
5 Inch	0.076	8	15	26	28	32	37	46
5 Inch	0.133	6	11	19	21	24	28	36
5 Inch	0.250	5	9	15	17	19	23	30
5 Inch	0.314	5	8	14	16	19	23	40
5 Inch	0.464	4	7	11	13	15	20	30
5 Inch	0.533	4	7	11	12	14	18	25
5 Inch	0.640	4	6	10	11	13	17	24
5 Inch	0.740	3	6	10	11	13	18	29
5 Inch	0.950	3	5	8	9	11	15	25
6 Inch	0.045	8	19	32	34	37	44	56
6 Inch	0.076	7	15	25	27	30	36	46
6 Inch	0.133	5	9	17	19	22	25	33
6 Inch	0.250	5	8	13	14	17	21	28
6 Inch	0.314	5	7	12	14	17	22	35
6 Inch	0.464	4	6	10	12	14	19	28
6 Inch	0.533	3	6	10	12	13	18	24
6 Inch	0.640	3	6	8	9	10	14	22
6 Inch	0.740	3	6	9	10	12	16	27
6 Inch	0.950	3	6	7	8	10	14	25

TABLE 21 - HEXOGONAL FILM, OPEN CELL, 0.25 IN,PLY THICKNESS

THICKNESS CODE	LOADING	Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 INCH	0.07	10	35	58	62	70	80	100
1 INCH	0.11	10	27	47	52	57	66	84
1 INCH	0.2	8	20	36	40	46	54	70
1 INCH	0.32	14	24	42	47	52	62	82
1 INCH	0.39	11	22	40	44	51	62	84
1 INCH	0.5	8	20	38	43	50	60	84
1 INCH	0.6	10	21	35	39	44	52	70
1 INCH	0.7	11	18	34	37	42	49	59
1 INCH	0.85	12	20	37	42	47	57	74
1 INCH	1.0	11	19	36	40	46	55	70
2 INCH	0.07	8	26	43	47	52	62	80
2 INCH	0.11	7	17	30	32	36	42	50
2 INCH	0.2	5	12	22	24	27	32	40
2 INCH	0.32	9	15	16	28	32	37	47
2 INCH	0.39	8	16	30	33	38	45	60
2 INCH	0.5	8	12	25	28	32	39	55
2 INCH	0.6	9	14	26	28	32	38	48
2 INCH	0.7	8	13	22	24	28	34	42
2 INCH	0.85	8	12	23	26	30	35	46
2 INCH	1.0	8	14	26	28	32	38	48
3 INCH	0.07	6	19	32	35	38	44	56
3 INCH	0.11	8	12	21	24	26	30	38
3 INCH	0.2	4.5	8.5	16	18	20	24	30
3 INCH	0.32	6.5	11	19	21	23	27	35
3 INCH	0.39	6.5	11	21	23	27	31	41
3 INCH	0.5	6	10	20	22	25	30	40
3 INCH	0.6	7	10.5	20	22	25	29	37
3 INCH	0.7	7	11	20	22	25	30	38
3 INCH	0.85	7	11	20	22	25	30	39
3 INCH	1.0	6	11	22	25	29	37	55
4 INCH	0.07	3.5	15	24	26	29	34	44
4 INCH	0.11	4.6	11	20	22	24	28	35
4 INCH	0.20	2.7	6	11.5	13	15	17	25
4 INCH	0.32	7	12	21	23	26	30	38
4 INCH	0.39	6	10	18	20	23	27	35
4 INCH	0.5	5.5	10	17	19	22	27	38
4 INCH	0.6	5.5	8.5	17	18	21	24	30
4 INCH	0.7	5	9	16	18	20	24	31
4 INCH	0.85	6	9	17	19	21	25	32
4 INCH	1.0	6.9	10	19	22	25	31	42
5 INCH	0.07	5	13	22	23	26	30	37

TABLE 21 - HEXOGONAL FILM, OPEN CELL 0.25, IN.PLY THICKNESS (CONTINUED)

THICKNESS CODE	LOADING	Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
5 INCH	0.11	4	10	17.5	19	21	25	31
5 INCH	0.2	6	11	19	21	24	28	38
5 INCH	0.32	6	9	16	18	20	23.5	30
5 INCH	0.39	6	9	15.5	17	20	23	29
5 INCH	0.5	5	8	15	17	20	24	32
5 INCH	0.6	5	8	15	17	19	22	28
5 INCH	0.7	4.8	8	14	16	18	21	27
5 INCH	0.85	5	8	15	17	19	23	30
5 INCH	1.0	5	8.5	16	18	21	26	35
6 INCH	0.07	4	12	20	22	25	30	50
6 INCH	0.11	4	10	12.5	18	20	24	30
6 INCH	0.2	5	10	18	19.5	22	25	32
6 INCH	0.32	5.5	9	16	17	20	23	30
6 INCH	0.39	5	8	12	13	15	17	21
6 INCH	0.5	4	8	14.5	16	19	23	33
6 INCH	0.6	4.6	7.5	14	15	17	20	16
6 INCH	0.7	4	7.2	13	15	17	21	28
6 INCH	0.85	5	7.8	14	16	18	23	31
6 INCH	1.0	4.5	8	15	17	20	23	30

TABLE 22 - HEXAGONAL FILM, REINFORCED CELL, 0.25 IN.PLY THICKNESS

THICKNESS CODE	LOADING	Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
1 INCH	0.07	19	35	63	68	74	84	100
1 INCH	0.11	12	32	56	60	66	73	82
1 INCH	0.2	12	23	42	45	51	60	75
1 INCH	0.32	13	23	40	43	49	59	74
1 INCH	0.39	10	20	36	40	45	53	88
1 INCH	0.5	11	21	37	41	46	55	76
1 INCH	0.6	10	20	33	37	42	49	64
1 INCH	0.7	8	15	30	33	38	45	58
1 INCH	0.85	10	17	31	34	38	45	58
1 INCH	1.0	9	17	32	36	40	47	62
2 INCH	0.07	11	28	50	54	59	67	80
2 INCH	0.11	7	19	31	37	41	47	62
2 INCH	0.2	6	15	25	27	30	34	42
2 INCH	0.32	9	17	27	29	33	38	47
2 INCH	0.39	8	15	27	30	33	39	52
2 INCH	0.5	7	12	23	26	29	35	46
2 INCH	0.6	8	12	22	24	26	31	41
2 INCH	0.7	6	12	21	23	26	31	39
2 INCH	0.85	8	12	21	23	26	31	40
2 INCH	1.0	8	11	21	23	26	30	39
3 INCH	0.07	8	21	35	38	42	47	60
3 INCH	0.11	5	16	27	29	32	38	58
3 INCH	0.2	5	12	21	23	26	30	40
3 INCH	0.32	7	14	23	26	28	32	40
3 INCH	0.39	7	12.5	21	23	26	30	40
3 INCH	0.5	6	12	20	22	25	30	40
3 INCH	0.6	6.5	11	20	22	24	29	36
3 INCH	0.7	6	11	18	20	23	27	35
3 INCH	0.85	6.5	10	18	20	22	27	34
3 INCH	1.0	7	10	18	20	23	26	33
4 INCH	0.07	4	18	33	35	40	49	68
4 INCH	0.11	6	15	25	27	31	37	52
4 INCH	0.2	4	10	17	19	21	24	31
4 INCH	0.32	7	12	20	23	25	29	36
4 INCH	0.39	6	11	17	19	21	25	32
4 INCH	0.5	6	10	18	20	23	28	37
4 INCH	0.6	5.5	10	17	18	21	24	25
4 INCH	0.7	5	9	15	17	19	22	30
4 INCH	0.85	5.5	9	15	17	19	22	30
4 INCH	1.0	5.5	9.5	17	19	22	27	37

TABLE 22 - HEXOGONAL FILM, REINFORCED CELL, 0.25 IN.PLY THICKNESS (CONTINUED)

THICKNESS CODE	LOADING	Q=1.2	Q=MAX	Q=1.0	Q=.8	Q=.6	Q=.4	Q=.2
5 INCH	0.07	5.5	16	26	28	32	40	53
5 INCH	0.11	6	13	23	25	27	32	44
5 INCH	0.2	7	14	22	24	27	31	41
5 INCH	0.32	6	10	18	20	22	25	32
5 INCH	0.39	5	9	15	17	19	22	28
5 INCH	0.5	5	8.5	15	17	20	24	33
5 INCH	0.6	5	9	15	16	18	21	26
5 INCH	0.7	4.5	7.5	13	15	17	21	28
5 INCH	0.85	4.5	8	14	15	18	21	28
5 INCH	1.0	4.5	8	14	16	18	22	30
6 INCH	0.07	4	16	26	29	32	39	49
6 INCH	0.11	4.5	12	21	23	25	28	38
6 INCH	0.2	7	13	21	23	26	30	38
6 INCH	0.32	5	10	17	18	21	24	30
6 INCH	0.39	5.5	8.5	14	15	17	20	26
6 INCH	0.5	3	8	15	16	19	24	34
6 INCH	0.6	5	8	14	15	17	20	25
6 INCH	0.7	5.4	8	13	14	16	19	25
6 INCH	0.85	4.5	8.6	15	17	20	24	34
6 INCH	1.0	4.5	7.5	13	15	17	20	28

CUSTODIANS

Air Force - 69

Navy - AS

Army - MU

Preparing Activity

Air Force - 69

Project No. - PACK-0565

Review*

Air Force - 11, 99

Navy - SA, OS

Army - EL, SM, AT

User*

Air Force - 10

Navy - MC, YD, SH

Army - ME

* Review/User information is current as of the date of this document. For future coordination of changes to this document, draft circulation should be based on the information in the current DODISS.

*U.S. GOVERNMENT PRINTING OFFICE: 1991--604-034/50364

INSTRUCTIONS: In a continuing effort to make our standardization documents better, the DoD provides this form for use in submitting comments and suggestions for improvements. All users of military standardization documents are invited to provide suggestions. This form may be detached, folded along the lines indicated, taped along the loose edge *(DO NOT STAPLE)*, and mailed. In block 5, be as specific as possible about particular problem areas such as wording which required interpretation, was too rigid, restrictive, loose, ambiguous, or was incompatible, and give proposed wording changes which would alleviate the problems. Enter in block 6 any remarks not related to a specific paragraph of the document. If block 7 is filled out, an acknowledgement will be mailed to you within 30 days to let you know that your comments were received and are being considered.

NOTE: This form may not be used to request copies of documents, nor to request waivers, deviations, or clarification of specification requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

(Fold along this line)

(Fold along this line)

DEPARTMENT OF THE AIR FORCE

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 73236 WASHINGTON D. C.

POSTAGE WILL BE PAID BY THE DEPARTMENT OF THE AIR FORCE

AFALD/PTP
Wright-Patterson AFB, OH 45433

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE

3a. NAME OF SUBMITTING ORGANIZATION

b. ADDRESS (Street, City, State, ZIP Code)

4. TYPE OF ORGANIZATION (Mark one)

- [ ] VENDOR
- [ ] USER
- [ ] MANUFACTURER
- [ ] OTHER (Specify): ______

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER (Last, First, MI) – Optional	b. WORK TELEPHONE NUMBER (Include Area Code) – Optional
c. MAILING ADDRESS (Street, City, State, ZIP Code) – Optional	8. DATE OF SUBMISSION (YYMMDD)