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THE NATURE OF THE SONIC-BOOM PROBLEM

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ABSTRACT

Significant factors of the sonic-boom problem are shown to be numerous and to involve a variety of scientific and engineering disciplines. Special mention is made of the roles of aircraft design, aircraft operations, and the atmosphere in affecting the sonic-boom ground exposures and the effects of sonic booms on people, buildings, etc. The material of this paper is introductory to the more detailed discussions that follow.

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INTRODUCTION

The advent of supersonic commercial air transport operations brings with it a new and different noise problem; namely, the sonic boom which is associated with the shock waves. Whereas other noise problems have generally been localized in extent, there is special concern for the sonic boom because of the large numbers of people that will be exposed. An appreciation for the nature of the problem and the various design and operational factors involved in it are required in order that an acceptable solution may be obtained. It is the objective of this symposium to present status reports on various aspects of the problem and to indicate some particular areas requiring additional research.

Listed in figure 1 are the areas that will be covered by the papers in the symposium. Such topics as the basic phenomena, the nature of the sonic-boom exposure, the factors affecting these exposures, the nature of the response problem involving both people and structures, and techniques for alleviation will be discussed in some detail in the various papers on the program. The main purpose of this paper is to review briefly some of the basic concepts involved in the sonic boom and to set the stage for subsequent more detailed discussions.

BASIC CONCEPTS

Some of the basic phenomena in the problem, which involves the airplane shock waves, can be described with the aid of figure 2. If the shock wave patterns generated by the airplane could be made visible, they might appear as

shown in the sketch of the figure during the entire supersonic portion of the flight. These shock waves extend outward from the airplane to the ground as indicated schematically by the solid lines, both along the ground track and several miles to each side of the ground track, and are reflected from the ground as suggested by the dashed lines. The whole shock wave pattern moves at the speed of the airplane and the passage of the shock waves is observed as a short duration pressure transient. This transient pressure disturbance has the main features of an N-wave as illustrated at the bottom of the figure. The N-wave shape is an idealized representation since the actual signature shapes may vary somewhat due to atmospheric effects and considerations of design. In any case the peak overpressure Δp, the time duration T, and the impulse I are all believed to be significant parameters.

FACTORS AFFECTING GROUND EXPOSURES

The factors which affect the nature and extent of sonic-boom ground exposures fall naturally into the three broad groupings of figure 3. (See refs. 1 through 4.) The first of these is aircraft design. Such factors as the overall aircraft size and weight, and its physical features of volume distribution and lift distribution are known to be significant. With regard to aircraft operations, the altitude of flight, the Mach number, and the flight path including acceleration effects are also known to be significant. The factors mentioned so far are to a certain extent under the control of either the designer or the operator of the aircraft. Of these, increased altitude of operation, reduced overall weight, and optimum physical design are generally

beneficial. There are, in addition, those factors associated with the atmosphere and weather conditions which cannot be controlled. These include atmospheric pressure, temperature, and wind gradients, and turbulence patterns.

NATURE OF GROUND EXPOSURE PATTERNS

In order to better define the nature and extent of sonic-boom ground exposure patterns, the data of figures 4 and 5 are included. In figure 4 is shown schematically, by means of the shaded area, the shape and extent of the sonic-boom exposure pattern for a proposed supersonic transport flight between points (a) and (b). It should be noted that the sonic booms are first observed about 200 miles from the point of take-off and that they cease to be observed approximately the same distance from the destination. The pattern can be, however, several thousand miles in length, but it does not encompass the airport and its immediate vicinity. The width of the pattern is generally greater for increased Mach number and altitude of the aircraft and, for proposed supersonic transport operations, it will extend 30 to 40 miles each side of the ground track. Pressures are not uniform within the shaded region. They are highest in the transonic acceleration region and are generally higher along the ground track than near the edges of the pattern. (See ref. 5.)

Information on the types of pressure signatures encountered in this exposure area can be obtained from the data of figure 5. The magnitudes of the overpressures are shown as a function of altitude for three different types of aircraft. The lower stippled region applies to fighter aircraft, the middle crosshatched region to bomber aircraft, and the top hatched region to maneuvering flight. This latter region represents accelerated flight conditions for operational fighter and bomber aircraft. These three regions represent

exposures currently being experienced during routine military training operations, and pressures as high as about 6 lb/sq ft are indicated. With regard to the expected range of overpressure levels for the supersonic transport, the shaded region has been included. It can be seen that the overpressures for this type of aircraft are expected to be in the same range of values as are being currently experienced for the smaller military aircraft. One important feature of the signatures is illustrated by the wave shape sketches associated with each shaded area. The time duration of the wave for a fighter aircraft is of the order of 0.1 of a second whereas for the proposed supersonic transport, durations of the order of 0.3 of a second are anticipated. The significance of time durations is not completely understood at present, but it is believed that this factor is a significant one with regard to community acceptance. This points up to a practical problem in community response experiments in which current aircraft are made use of to represent future supersonic transport operations. There is no difficulty in simulating the overpressure range, but it has not been possible to properly simulate the time duration range for the proposed transport aircraft.

SPECTRUM OF THE "N-WAVE"

In consideration of the manner in which sonic-boom exposures affect structures and people, it is helpful to have knowledge of the spectral content of the waves. This is indicated schematically in figure 6 where relative amplitudes of the various frequency components as determined by Fourier integral techniques are shown in normalized form as a function of the product of frequency and time duration of the wave. In general, it can be seen that the highest amplitudes are associated with the lower frequencies; in some cases

these are subaudible. The solid curve having several convolutions is essentially the spectrum of the wave. The dashed curve which represents the envelope of this spectrum is seen to drop off at the rate of 6 dB per octave. It should be noted that the higher frequencies which are normally audible are significant for loudness considerations whereas the lower frequencies are important from the standpoint of structural response.

LOADINGS ON BUILDINGS

Shown schematically at the top of figure 7 is the N-type pressure signature on the ground from an aircraft in flight. (See ref. 6.) It should be noted that for the supersonic transport, this signature may be of the order of 1,000 feet in length. As suggested by the sketches at the bottom of the figure, a building is subjected to a variety of loading events as the wave pattern sweeps over it. For instance, reading from left to right the building would first be forced laterally due to the initial positive loading on the front surface. Then it would be forced inward from all directions, then forced outward, and finally displaced laterally again because of the negative pressures acting on the back surface. These loadings which would be applied within a time period of about 0.3 of a second can result in transient vibrations of the building.

SONIC-BOOM STIMULI

A person inside a building would be exposed to a rather complex series of stimuli including auditory, visual, and vibratory inputs. (See ref. 7.) The nature of the acoustic and vibratory inputs can be discussed with the aid of figure 8. At the top of the figure is a sample outside pressure exposure as

measured for one particular case. It can be seen that this wave is of the N-wave type, but it differs in some of its details as do many of those measured in the field.

The bottom three traces represent corresponding inside exposure stimuli. The topmost of these represents the pressure variation inside the building due to the vibratory motions of the building and the cavity resonances. Although this is a pressure disturbance, it generally occurs in a frequency range which is not audible to humans. The audible portion of this signal has the characteristic shape of the next lower trace and is seen to be an order of magnitude lower in amplitude. It is believed that this audible portion of the pressure signal is associated with the rattling of the building structure and furnishings due to the primary mode responses in the building. Finally the bottom trace represents the vibration of the floor which would be sensed by a person either directly or through the furniture. At the present time the inside exposure situation is not well enough understood so that the relative importance of each of these stimuli can be determined, although it is believed that each one is significant.

CONCLUDING REMARKS

A discussion has been given of the nature of the sonic-boom problem, including brief references to the basic concepts involved, exposure patterns, factors affecting exposures, response phenomena, and techniques for alleviation. Other papers to follow will treat these topics in more detail.

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- BASIC CONCEPTS
- NATURE OF SONIC BOOM EXPOSURE SITUATION
- FACTORS AFFECTING EXPOSURE
- RESPONSE PHENOMENA
- ALLEVIATION TECHNIQUES

Figure 1.- Topics relating to the sonic-boom problem.

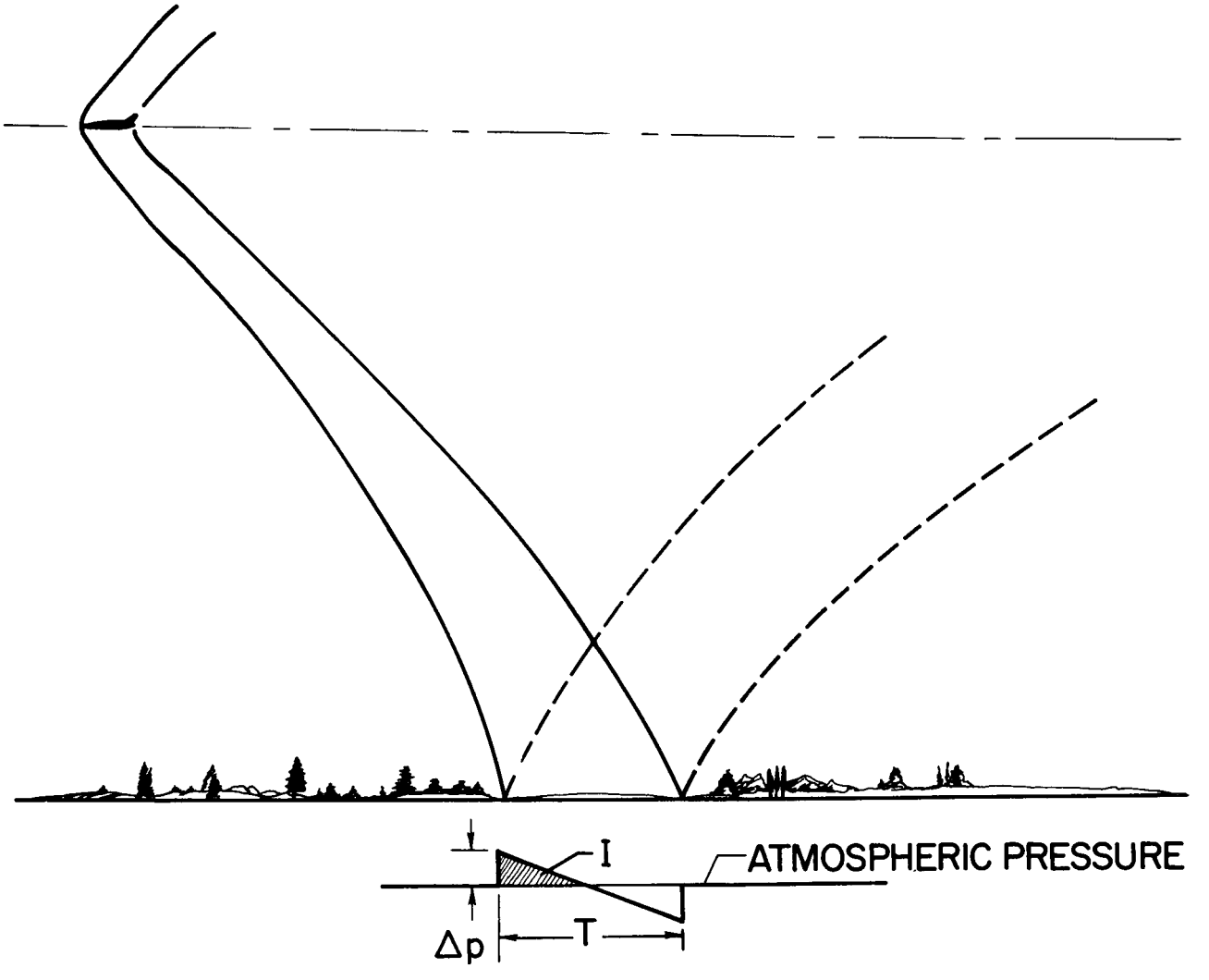

Figure 2.- Nature of the sonic-boom phenomenon.

- AIRCRAFT DESIGN
  - WEIGHT
  - SIZE
  - VOLUME DISTRIBUTION
  - LIFT DISTRIBUTION
- AIRCRAFT OPERATIONS
  - ALTITUDE
  - MACH NUMBER
  - FLIGHT PATH
- ATMOSPHERIC
  - PRESSURE GRADIENT
  - TEMPERATURE GRADIENT
  - WIND GRADIENT
  - TURBULENCE

Figure 3.- Factors affecting sonic booms.

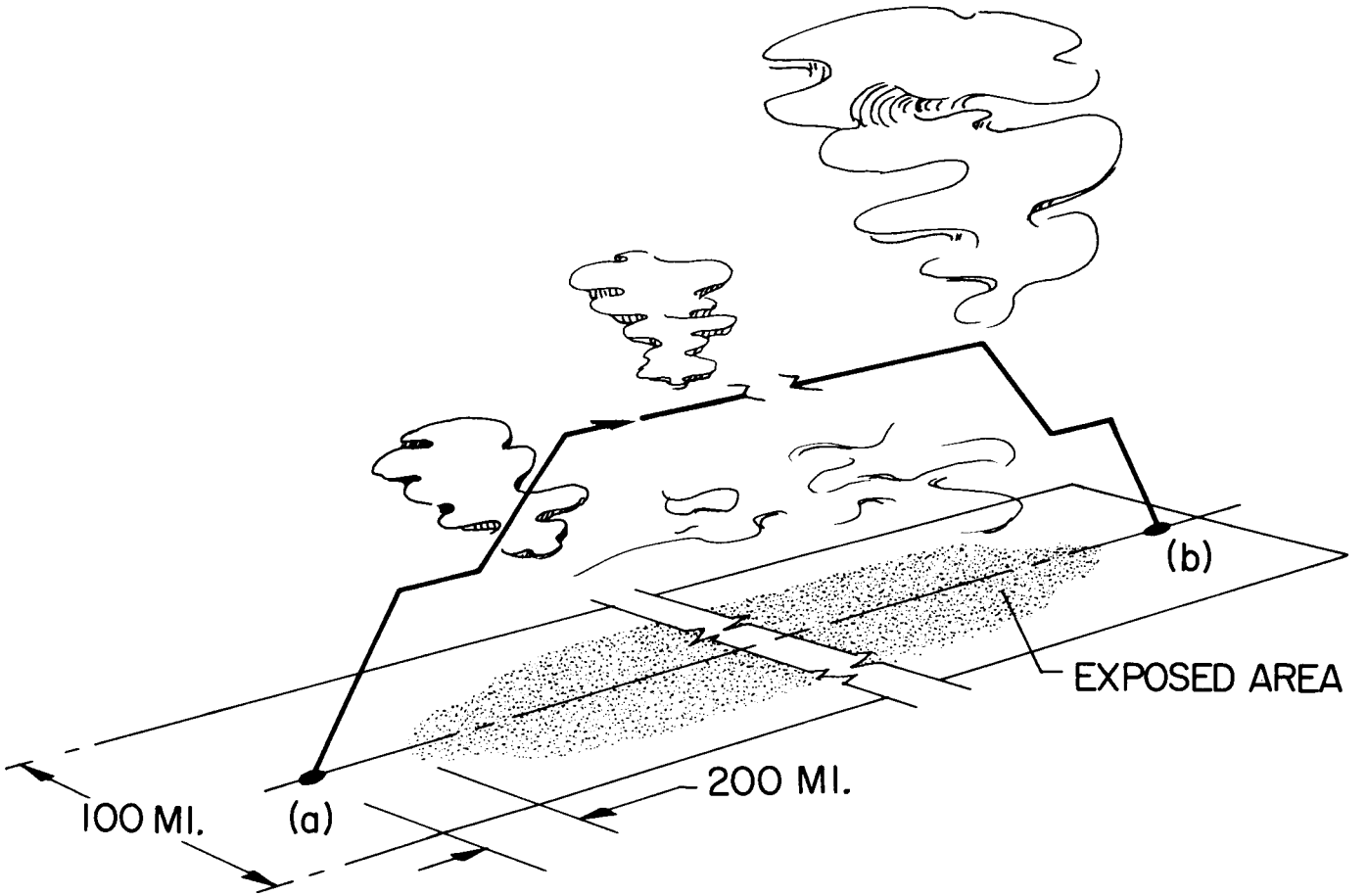

Figure 4.- Ground exposure patterns.

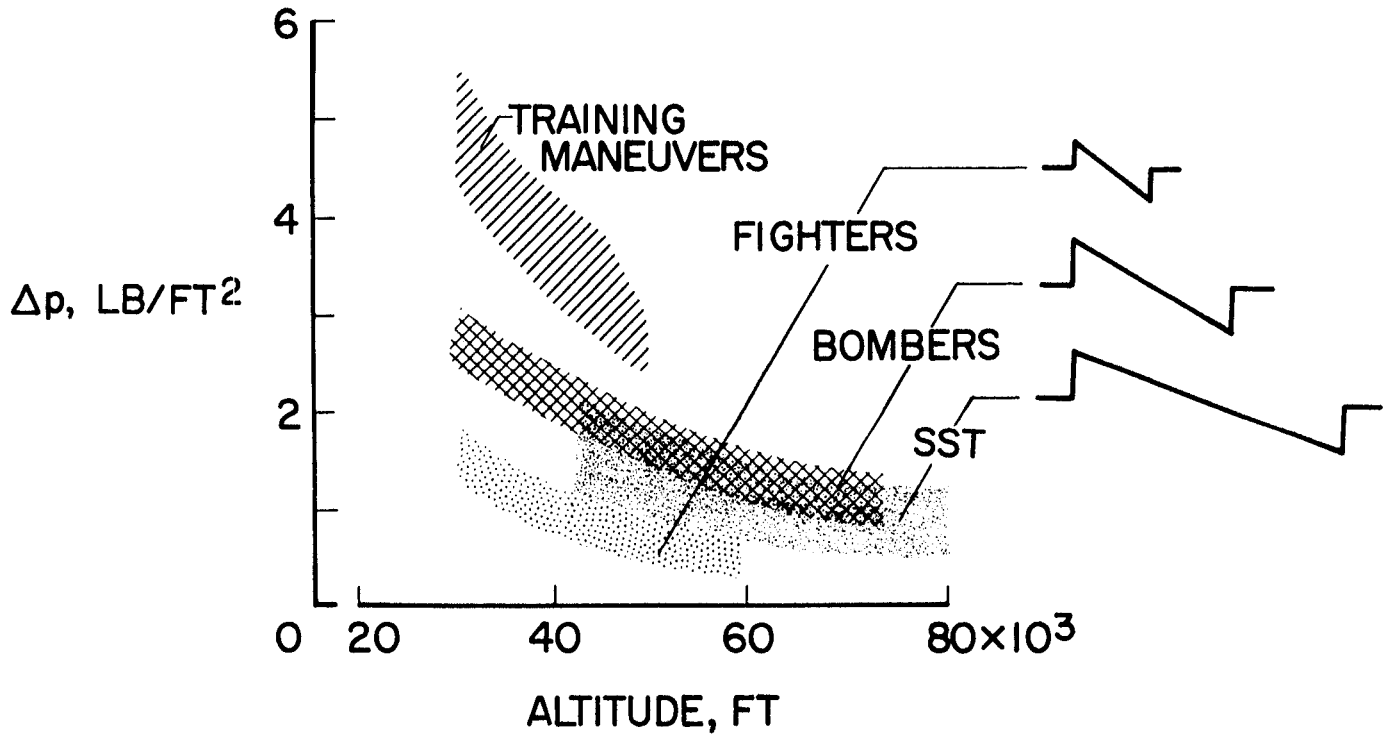

Figure 5.- Sonic-boom overpressures as a function of altitude for three different aircraft.

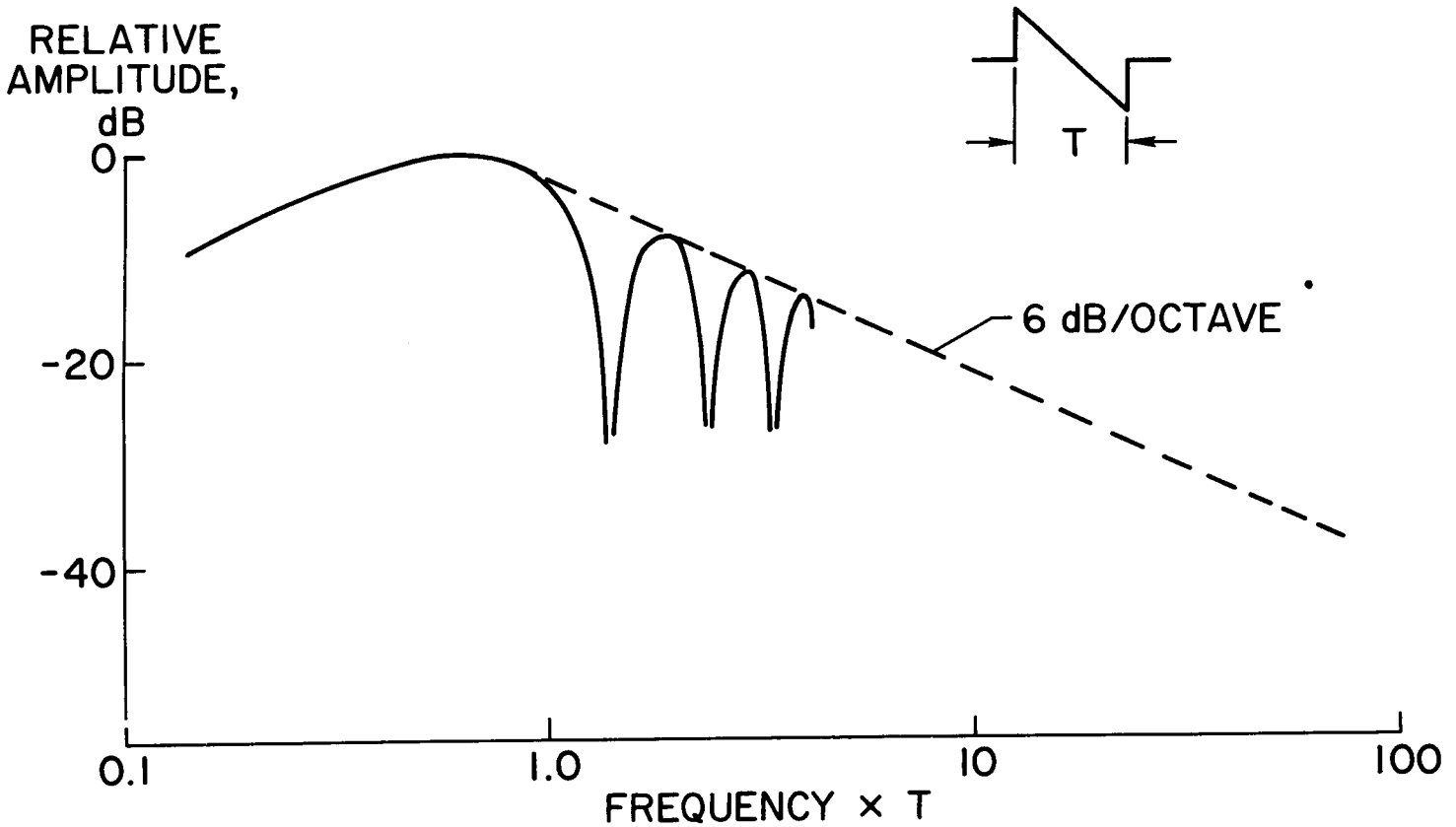

Figure 6.- Characteristic frequency spectra of N-waves.

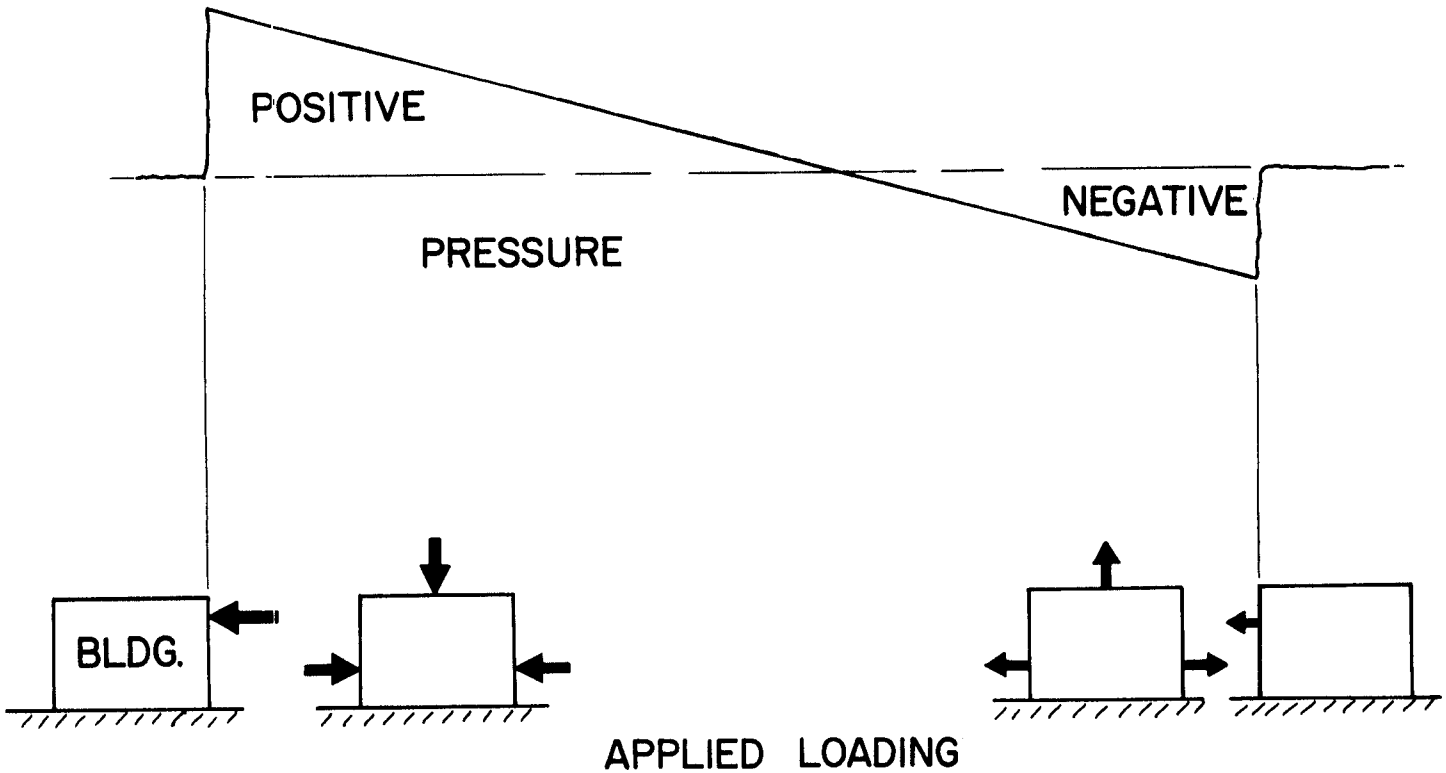

Figure 7.- Sonic-boom loadings on buildings.

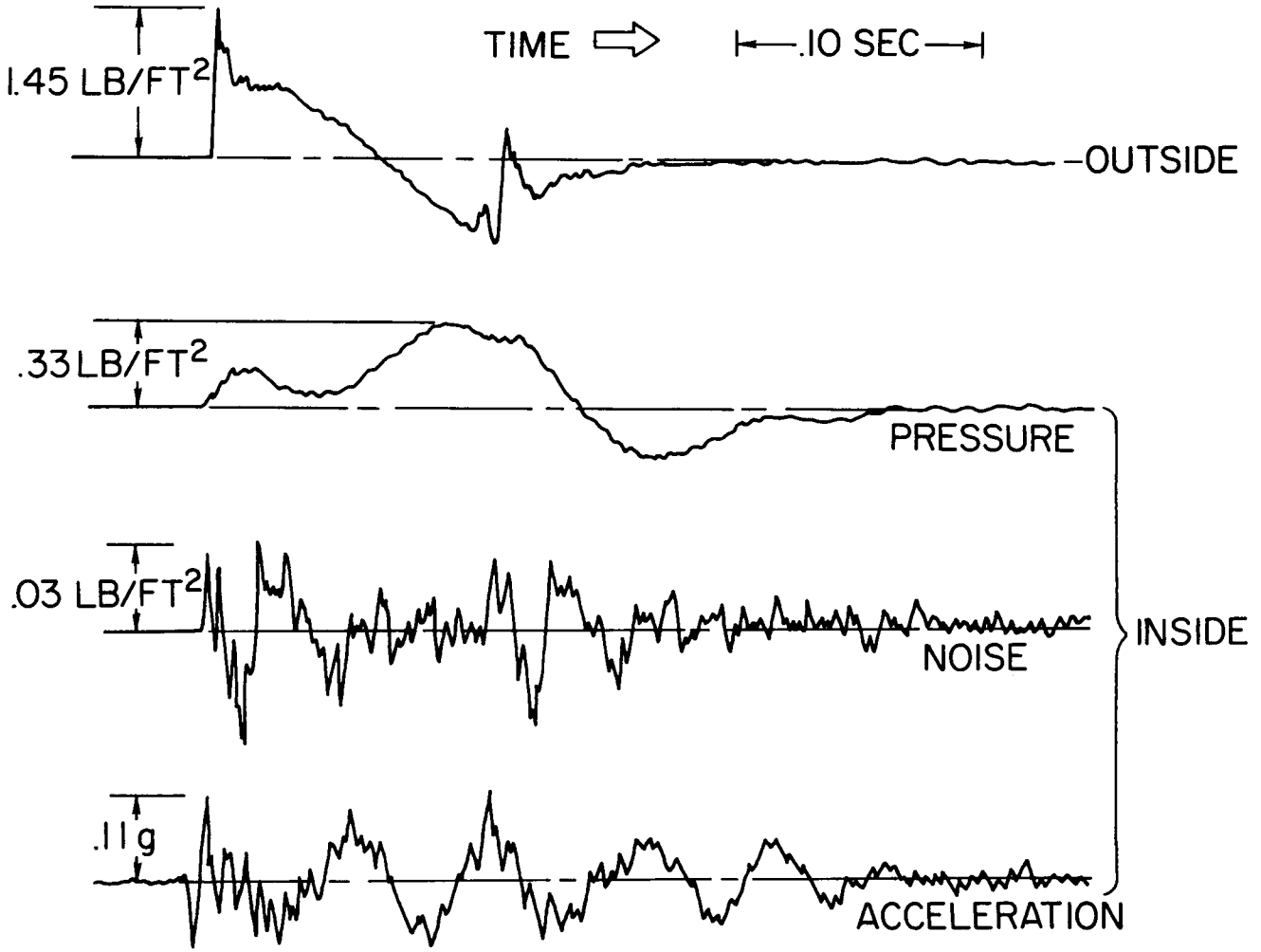

Figure 8.- Outside and inside exposure stimuli due to sonic booms.

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