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SOURCE ?

PROPAGATION OF AIRCRAFT NOISE

A. D. Pierce and W. J. Hadden, Jr.  
Principal Investigators

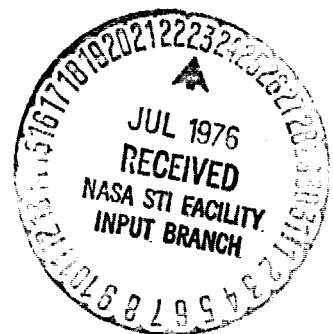
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National Aeronautics and Space Administration  
Langley Research Center  
Hampton, Virginia

## INTRODUCTION

This report presents a summary of work undertaken in conjunction with the subject grant. To avoid needless repetition, extensive use is made of references to publications and previous reports. The major tasks undertaken in this study were i) analytical and laboratory experiments on the propagation of sound from sources near a flat surface of finite acoustic impedance; ii) laboratory experiments dealing with the reflection of sound from finite sized plane patches; and iii) the diffraction of sound by wedge-and trapezoidal-shape barriers. In addition, a series of measurements were made of the background noise levels for various jet flow conditions in the Anechoic Noise Facility of the Langley Research Center's Acoustic and Noise Reduction Laboratory.

## SUMMARY OF ACTIVITIES

### Propagation over Finite Impedance Surfaces

The primary aims of this study were to develop efficient means for predicting the sound pressure levels near the surface for given acoustic impedance, or conversely for estimating the acoustic impedance of the surface from pressure-field measurements. The principal facets of this work<sup>1,2</sup> were a reformulation of the well-known theoretical results in terms of functions widely used in diffraction theory and a series of laboratory experiments on sound propagation over large surfaces whose acoustic impedances were measured independently. On the basis of the agreement between theoretical and experimental results and of the computational efficiency of the theoretical expression for the sound pressure field above the surface, it should be possible to estimate the surface impedance from sound pressure levels measured along an inclined path by comparing SPL vs. distance curves with several values of the impedance and requiring that the theoretical curve match the experimental data.

### Reflection from Finite Surfaces

A set of laboratory experiments on the reflection of sound by finite surfaces with known acoustic impedance was performed in August 1975 in the Anechoic Noise Facility at the Langley Research Center's Acoustics and Noise Reduction Laboratory. Preliminary results of these experiments have been reported in references 3 and 4. For easy reference the text of reference 3 is enclosed herewith, as are the relevant figures from reference 4 (figs. 1-4). For figures 1-4, the source and receiver were located so that the specularly reflected ray from the surface emanated from the center of the panel. The source and receiver were positioned at 7.5 ft. along the inclined paths from the reflection point.

The trends noted from the data analyzed to date are that i) the


critical patch size for significant deviations from the infinite-plane case is smaller at higher frequencies (as might be expected); ii) there is generally greater variability with surface size for the soft surfaces; and, iii) there is more variability exhibited in the results for the  $20^\circ$  grazing angle results than for the  $10^\circ$  path. These results will be compared with an appropriate theoretical development in a manuscript which is being prepared for submission to the Journal of the Acoustical Society of America.

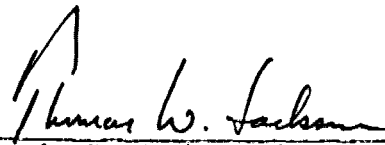
### Barrier Diffraction

A theoretical study of sound by wedge-and trapezoidal-shaped barriers has been conducted during this grant period. This topic is of general interest in the reduction of transportation noise. It is of particular interest in the present study by virtue of possible applications in investigating the noise-shielding effects of having aircraft engines mounted above the wing. An extensive discussion of the effects of barrier geometry and surface impedance on the diffracted sound field is presented in reference 5.

Recently, attention has been concentrated on the prediction of the insertion loss for a wedge-shaped barrier with large, but finite, acoustic impedance.<sup>6,7</sup> Representative values of the change in predicted insertion loss vis a vis a rigid wedge are presented in figure 5 and 6 for two dissimilar wedges and a variety of orientations of sources and receivers. In addition, a manuscript for submission to the archival literature is in the advanced stages of preparation.

Report prepared by

  
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## References

1. W. J. Hadden, Jr., "Propagation of Aircraft Noise," Final Technical report, NASA Grant No. NSG 1047, July 1975.
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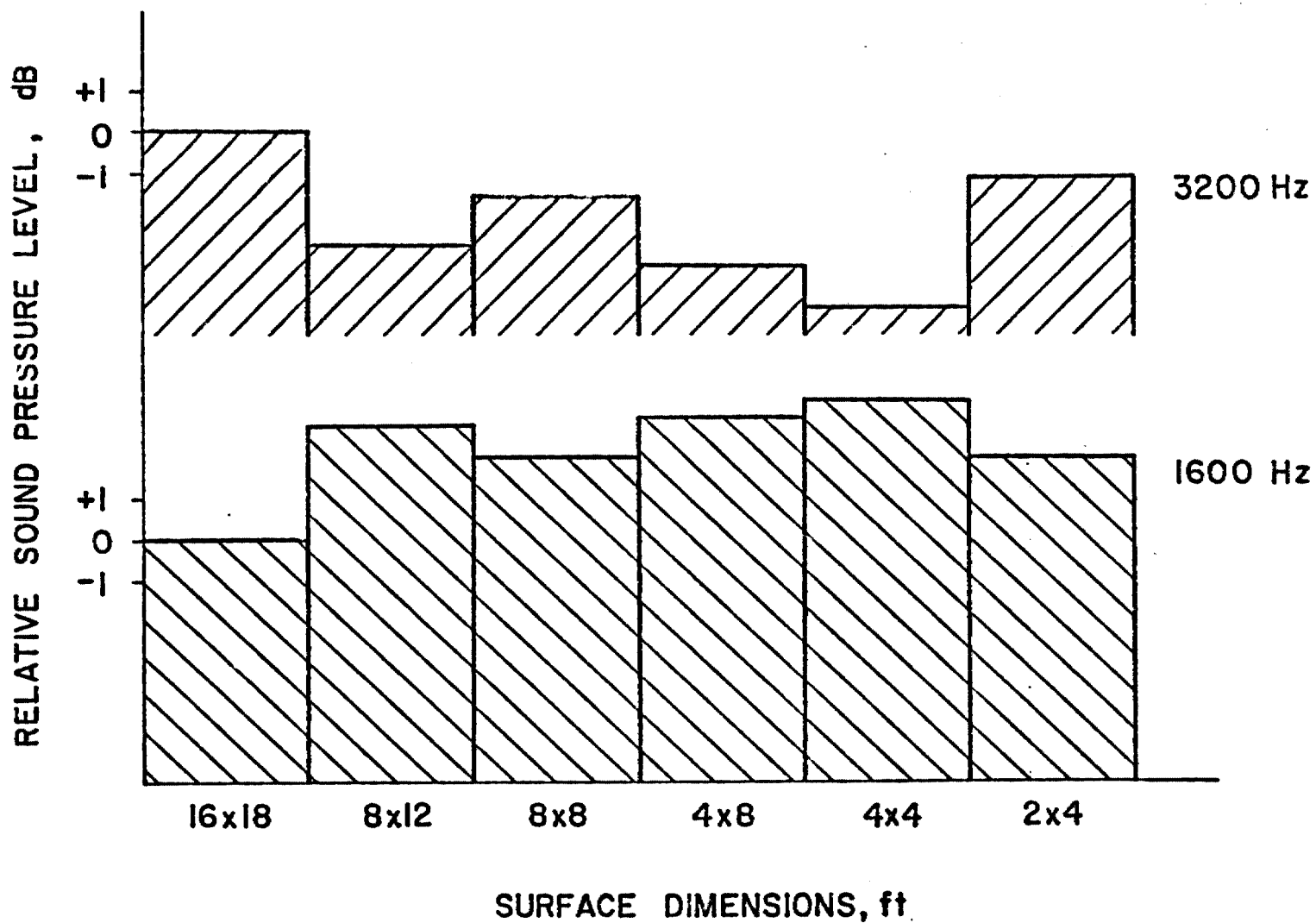


Figure 1: Variation of Far Field Sound Pressure Level with Surface Size: Plywood; 10° Grazing Angle.

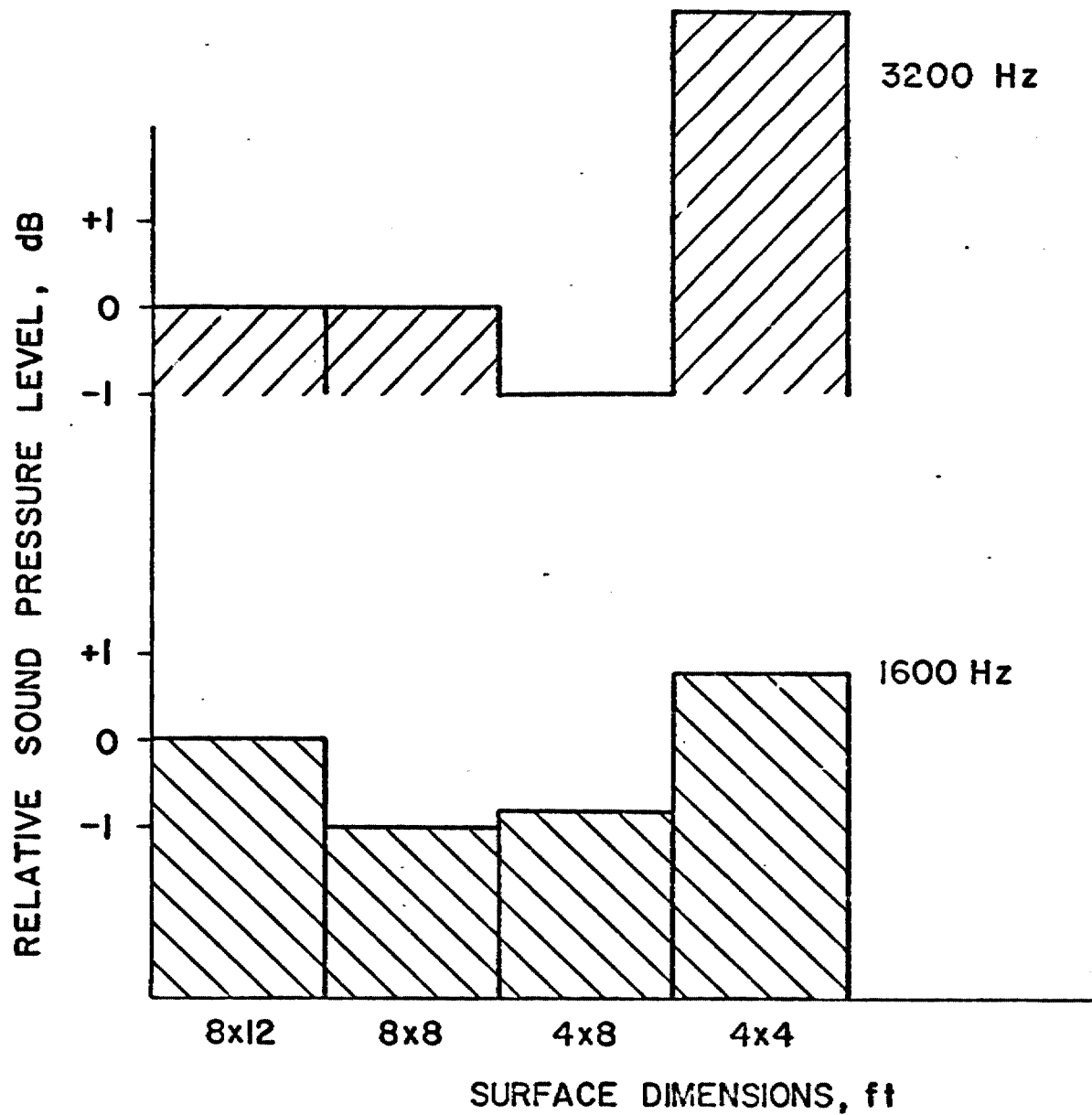


Figure 2: Variation of Far Field Sound Pressure Level with Surface Size: Plywood; 20° Crazing Angle.



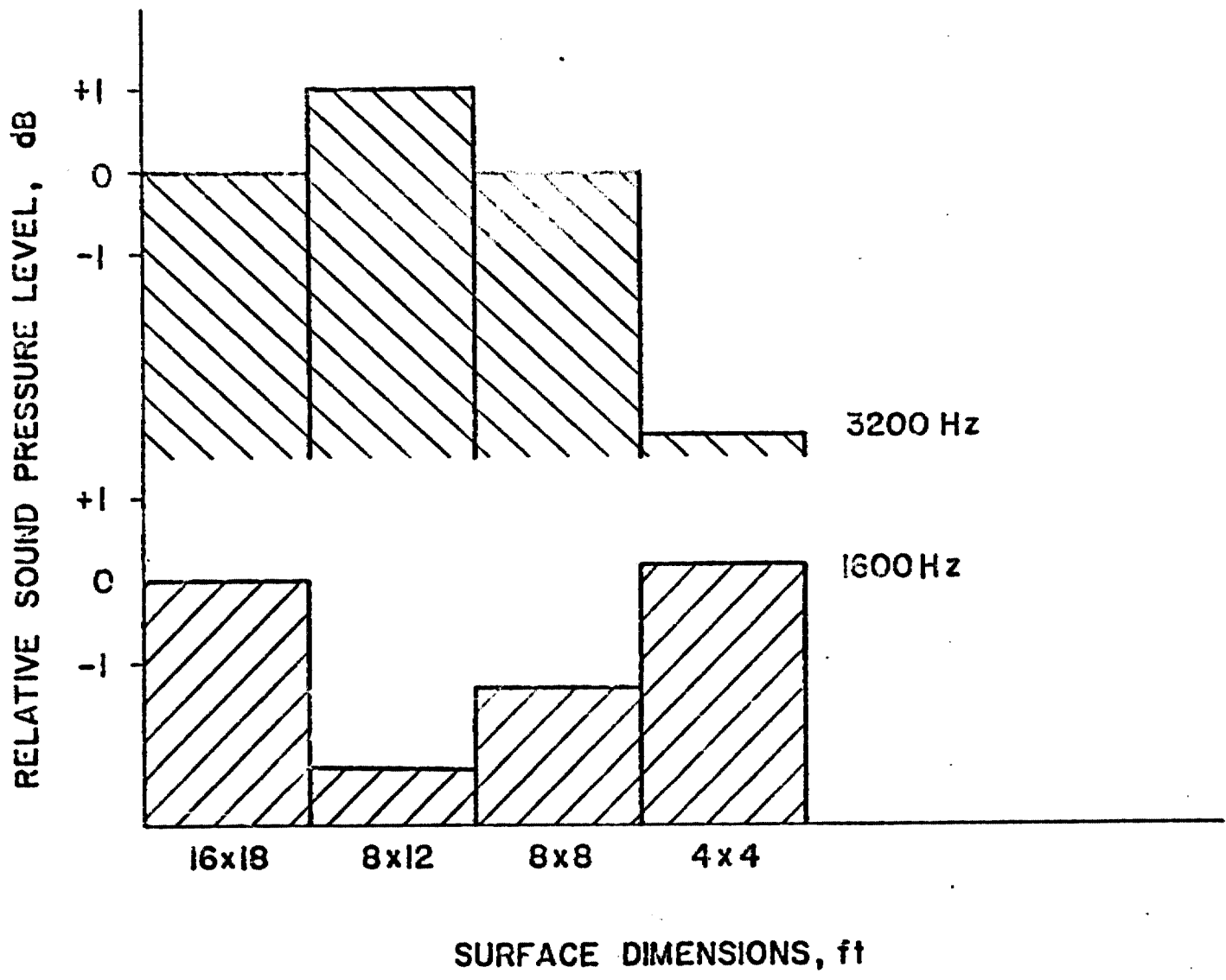


Figure 3: Variation of Far Field Sound Pressure Level with Surface Size: Plywood and Fiberglass; 10° Grazing Angle.

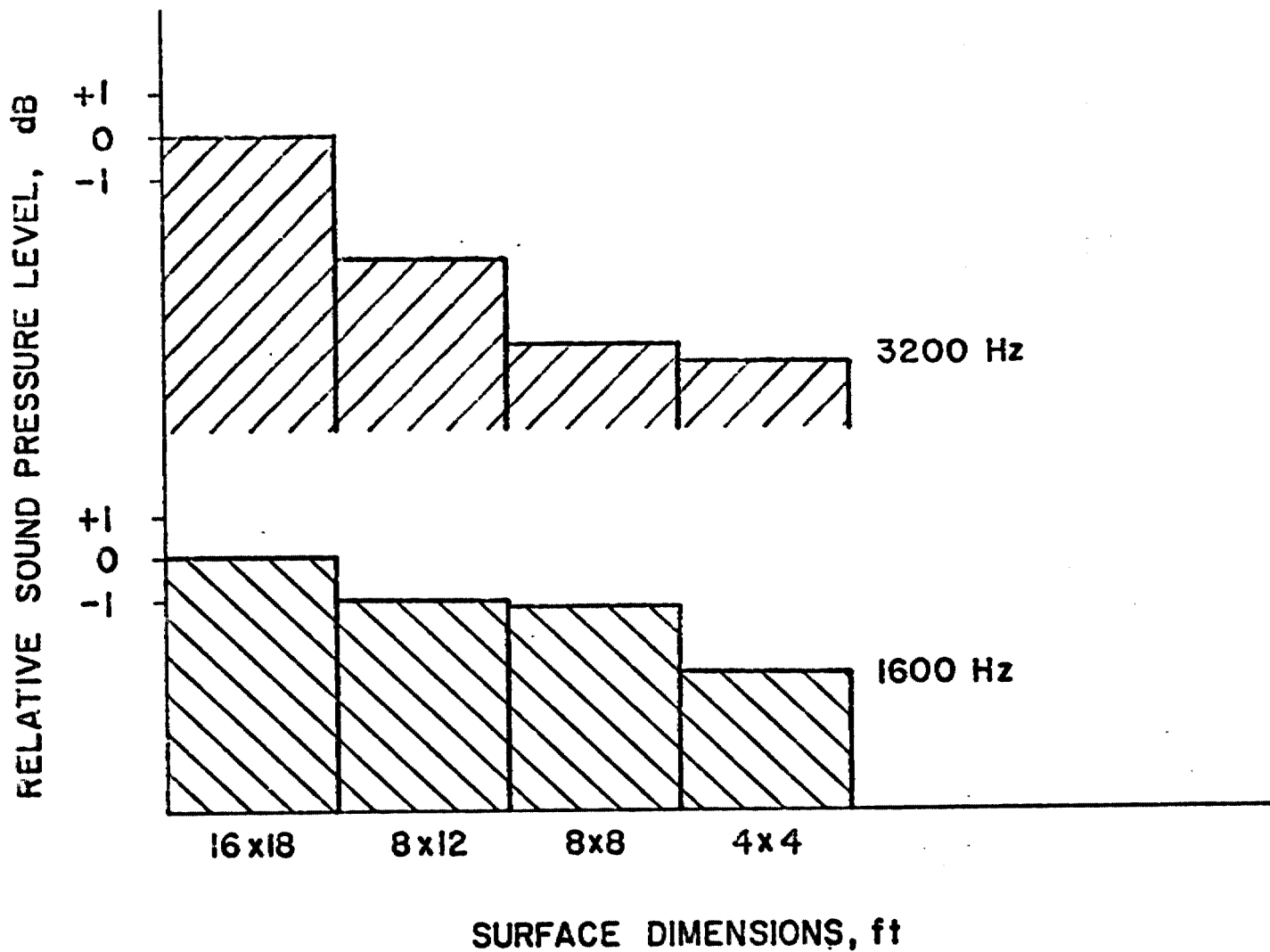
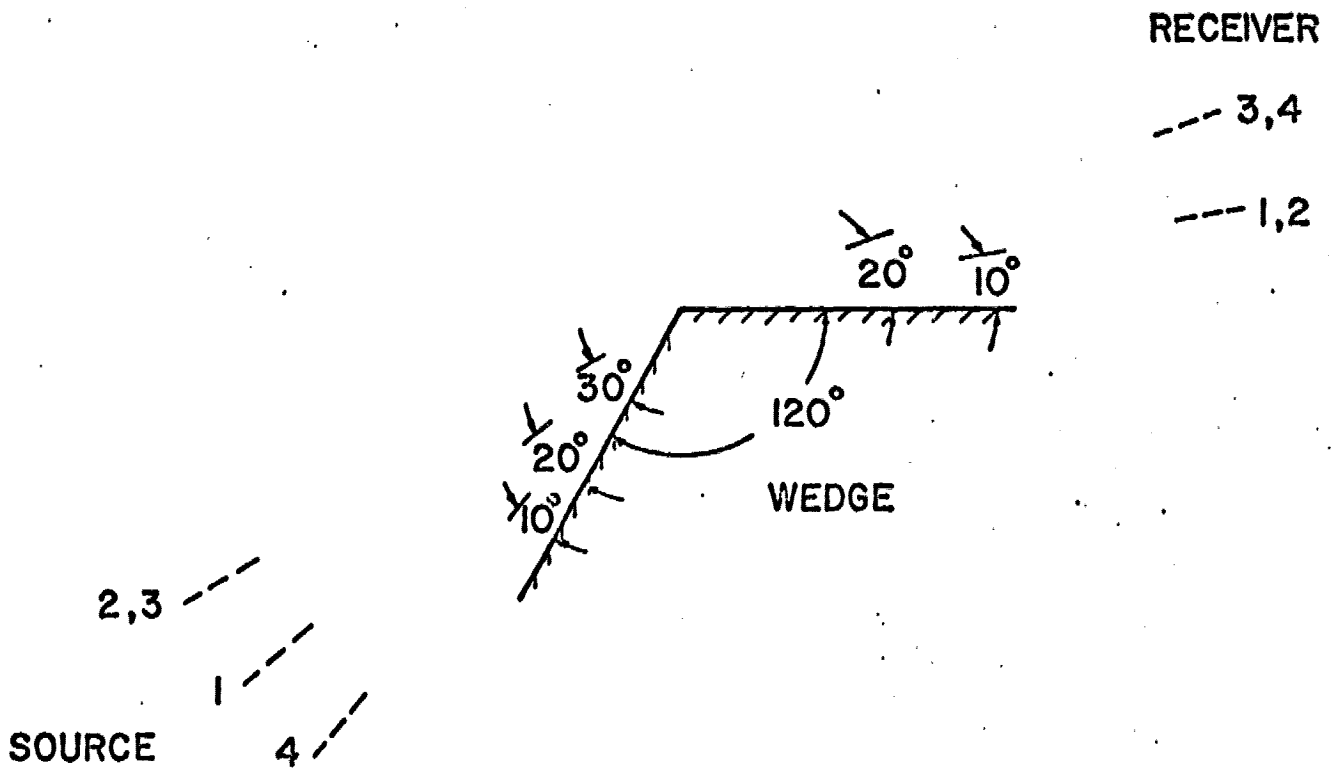


Figure 4: Variation of Sound Pressure Level with Surface Size: Plywood and Fiberglass; 20° Grazing Angle.

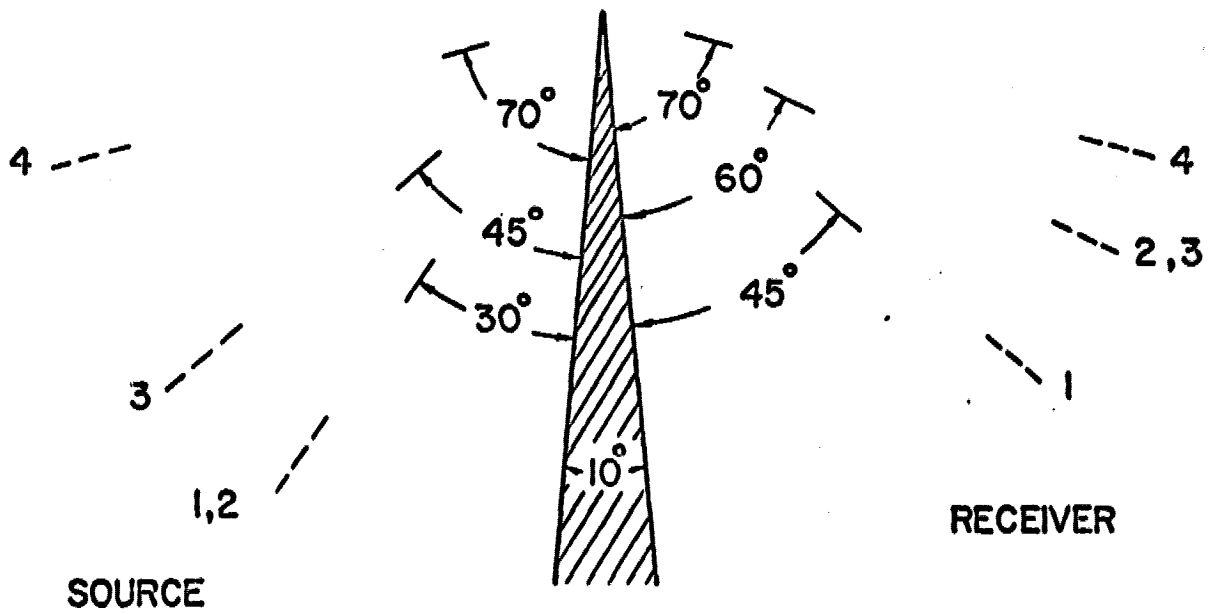


Configuration	1	2	3	4
$\Delta IL$ (dB)	6.1	4.6	1.8	6.9

Finite - Impedance Correction for Barrier Insertion Loss

Surface Admittance =  $0.1 - i0.05$

Figure 5



Configuration	1	2	3	4
$\Delta IL$ (dB)	2.3	1.7	1.1	0.5

Finite - Impedance Correction for Barrier Insertion Loss.

Surface Admittance =  $0.1 - i0.05$

Figure 6

**BOOK OF PROCEEDINGS**

**THIRD INTERAGENCY SYMPOSIUM ON  
UNIVERSITY RESEARCH IN TRANSPORTATION NOISE**

**University of Utah  
Salt Lake City, Utah  
November 12-14, 1975**

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Environmental Protection Agency**

EFFECTS OF VARIABLE GROUND IMPEDANCE  
ON NOISE PROPAGATION

by

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INTRODUCTION

The propagation of sound from sources near the ground to receivers also near the ground is of vital interest in dealing with noise in transportation and has received attention for quite a while. The work we shall present here concerns the effect the acoustic impedance of the ground has on propagated sound. We shall summarize briefly the results of a study of propagation over large uniform surfaces and describe an experimental investigation of sound propagation over surfaces of finite size and surfaces with variable acoustic impedance.

I. LARGE UNIFORM SURFACES

We consider a point source located at a height  $s$  above a plane surface, which is characterized by a finite acoustical impedance, and a receiver at a horizontal distance  $r_0$  from the source and a height  $h$  above the plane as sketched in Figure 1. The acoustic pressure at the receiver comprises a directly-radiated spherical wave from the source at a distance  $r_1 = [r_0^2 + (s - h)^2]^{1/2}$  and a spherical wave from a single image source with source strength  $Q$  at a height  $s$  below the plane, and thus at the distance  $r_2$  from the source,

$$p(r_0, s, h) = \exp(ikr_1)/r_1 + Q \exp(ikr_2)/r_2 \quad (1)$$

where, under the restriction  $kr_2 \gg 1$  ( $2\pi k$  is the wavelength), the image strength  $Q$  may be obtained from, e.g., Delaney and Razley<sup>1</sup> Equation (12) as

$$Q = 1 - \left[ \frac{2\pi k r_2}{iZ(Z + \Gamma_0)} \right]^{1/2} \times \left\{ (1 + \Gamma_0 Z) \left[ \frac{ikr_2}{2Z(Z + \Gamma_0)} \right]^{1/2} \right\} \quad (2)$$

with  $\Gamma_0 = \cos^{-1}[(c + h)/r_2]$ . The function  $w(z)$

$$w(z) \equiv \exp(-z^2) \operatorname{erfc}(-iz) \quad (3)$$

which arises in diffraction theory, is discussed and tabulated in Abramovitz and Stegun<sup>2</sup>. The utility of the solution using Equation (4) for calculations is heightened by the fact that Reference 2 also contains formulae by which necessary values of  $w(z)$  may be calculated using digital computers. Equations (2) and (3) reduce to Ingard's<sup>3</sup> Equations (13) and (14) with the exception of a widely-noted sign error in Ingard's form.

The experimental phase of this study is divided into two parts - measurement of the normal impedance of materials used as ground surfaces, and investigation of sound propagation over large surfaces made from these materials. The normal impedance measurements were made using apparatus in the Aircraft Noise Reduction Laboratory at Langely Research Center; some additional measurements were made at Georgia Institute of Technology. Selected results of these measurements are presented in Table I. The variations in the impedance values are indicative of the difficulty experienced in obtaining satisfactory termination of the impedance tubes.

The sound propagation studies were performed during the summer of 1974 in the Anechoic Noise Facility at LRC. Three different surfaces, each roughly 12 ft. x 16 ft. in size, were used in these investigations: as a reference (presumably hard) surface, 3/4 inch plywood; as softer surfaces, one-inch and two-inch blankets of fiberglas above the plywood. A small sound source driven by sinusoidal tones was suspended above a surface. The sound pressure level was recorded, at a horizontal distance from the source of 7.5 feet, as a function of frequency for several elevations of the receiver above the surface. The frequency range used was 300 - 3000 Hz, the receiver heights varied between one inch and two feet and source heights of six inches, one foot and two feet were used.

Comparisons between calculated and measured quantities will be presented for several typical frequencies in the range covered by the measurements. The first set of comparisons deals with measurements of sound pressure level as a function of receiver height for a fixed source height, horizontal distance and signal frequency. Calculations were performed using a Univac 1108 digital computer of

SPL (re receiver height of 1 inch) =

$$20 \log \left[ \frac{|p(x_0, s, h)|}{|p(x_0, s, 1 \text{ inch})|} \right] \quad (8)$$

using Equation (7). Comparisons of calculated and measured values are presented in Figures 2 - 7 for the plywood surface. The agreement between the theoretical and experimental results is reasonably good for the 800 Hz case when the value of specific acoustic impedance,  $Z = 7.33 + i11.36$ , from Table I is used. (Using the value  $Z = 4.08 + i0.93$ , also from Table I, does not yield a satisfactory match between the calculations and measurements.)

The agreement between calculated and measured pressure levels is not as good at the higher frequencies, 1600 Hz and 2400 Hz. The probably cause of the discrepancies in these cases is faulty values of the specific impedance, arising because the impedance tubes used had diameters comparable with the wavelength of the signals at these frequencies.

Because of this problem only the 800 Hz case will be illustrated for the fiberglass-and-plywood surface. These results are presented in Figure 8; the agreement between calculated and measured values is again quite good, although the data are incomplete.

Although this test is not exhaustive, the results do indicate that sound level distributions can be predicted using Equation (8) when the surface acoustic impedance is known. As far as the present study is concerned, the limiting factor seems to be obtaining the normal impedance reliably. With respect to obtaining surface impedances from the agreement between calculated and measured sound fields, it appears that larger source heights, e.g. the present two-foot cases, provide better resolution. As indicated in Figure 3, however, there is fairly low sensitivity to the impedance values.

In view of the difficulties experienced with this experimental study, the impedance and sound propagation measurements were repeated during the summer of 1975, the propagation measurements being made in the anechoic room of the Aircraft Noise Reduction Laboratory at the Langley Research Center. In this study the receiver was moved along a path corresponding to a reflected ray - in terms of Figure 1, on a path with an angle  $\theta_0$  with respect to the normal to the surface. The analysis of this data is incomplete at this writing.



## EXPERIMENTS WITH SURFACES OF FINITE EXTENT

In order to predict the sound levels associated with low-flying aircraft, one would like to be able to include the effect of variations in the acoustic properties of the ground cover. It would seem that an important parameter in assessing this effect is the extent of a portion of the surface which affects the sound reflected to a particular receiving location for a given source position. Ingard's analysis<sup>3</sup> of the propagation of sound over a large surface leads to the conjecture that for  $kr_2 \gg 1$ , only a small portion of the surface, located near the vertex of the reflected ray is effective.

In order to test this hypothesis, we performed a set of experiments in the anechoic room of the Aircraft Noise Reduction Laboratory as follows. A point source driver was suspended in the anechoic room as sketched in Fig. 9 at a distance  $x_s$  was chosen to provide a desired grazing angle  $\theta$  ( $10^\circ$  and  $20^\circ$  were used); a light cable was strung from the reflection point at the grazing angle to support a microphone which could be moved along this reflected ray path. A sequence of surfaces, made up of 3/4 inch plywood or 1 inch fiberglass over plywood, were used - the largest surfaces were 8 ft. squares; the smallest, 2 ft. squares; rectangular surfaces of intermediate size were also used. In each case the reflection point was located at the center of the surface used.

The source was driven by pure tones with frequencies ranging from 400 Hz to 3200 Hz; a feedback mechanism was used to insure that the source levels were maintained constant. Sound pressure levels were recorded at each frequency at several locations on the reflected ray path.

The desired result was that for fixed source and receiver locations, the measured sound pressure levels would be invariant under changes of the surface size. Under ideal conditions this trend could be violated in two ways: In the first instance, the receiver could be sufficiently close to the edge of the surface that edge diffraction effects would appear - this effect would be mitigated at higher frequencies. In the second exceptional case, the surface area would be less than the critical size. This effect should first become apparent at high frequencies.

In anticipation of the critical surface size having been reached, measurements were also made in which several of the smaller surfaces were altered either by the addition or removal of the fiberglass covering on part of the plywood base.

The data from this investigation have not yet been analyzed. Preliminary inspection of the data indicate that the trend mentioned above is confirmed.

#### REFERENCES

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Table I

Measured Values of Specific Acoustic Impedance

	Plywood	Fiberglas-Plywood
800 (LRC) *	4.08 + i0.93	0.68 + i0.40
(GIT)	7.33 + i11.36, 2.68 + i18178	1.11 - i3.00, 0.87 - i2.74
1600 (LRC)	3.79 + i0.46	1.15 + 0.06
(GIT)	3.68 + i11.51	0.64 - i1.06
2400 (LRC)	4.06 - i0.04	0.63 - i0.06
(GIT)	1.28 + i5.42, 2.22 + i7.62	0.68 - i0.55

\* Entries marked (LRC) are from measurements made at Langley Research Center; those marked (GIT) were measured at Georgia Institute of Technology

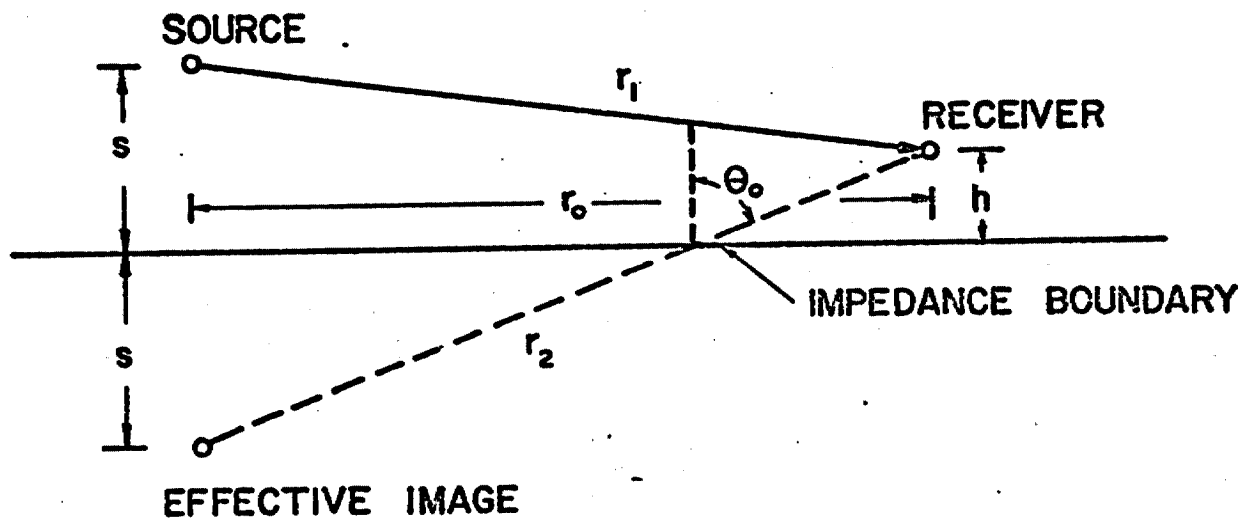


Figure 1. Source-Receiver-Configuration.

PLYWOOD 800 Hz

SOURCE HEIGHT 0.5ft

○ DATA

— Z=2.7+i8.8

--- Z=7.3+i11.3

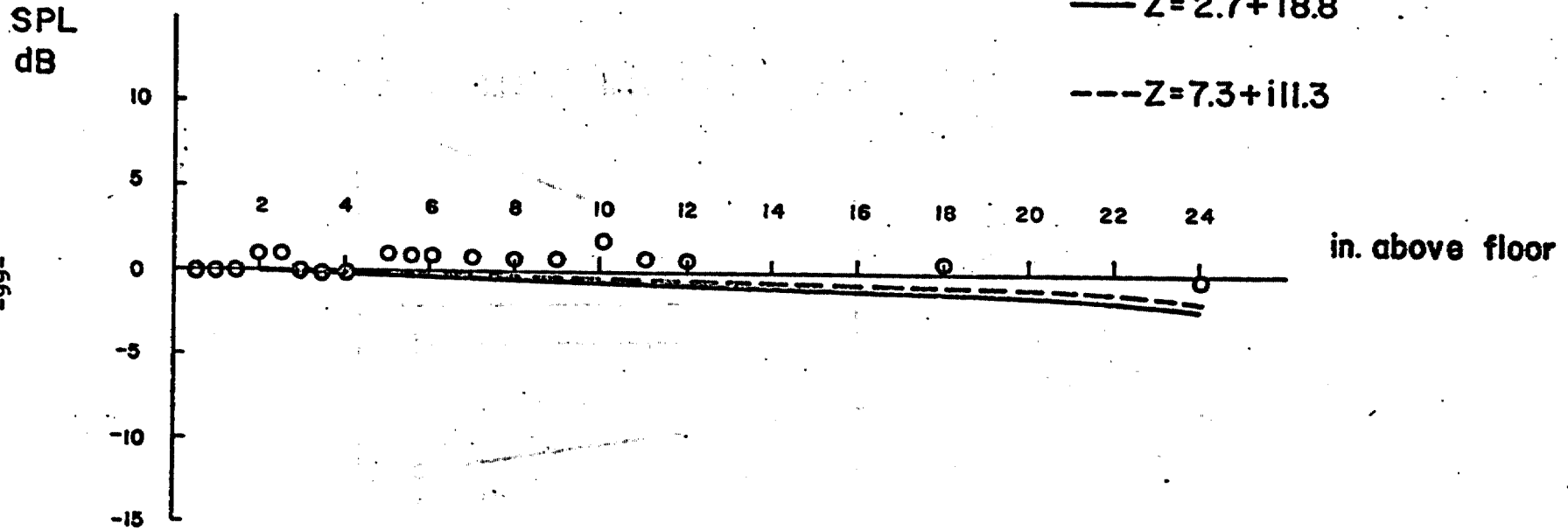


Figure 2. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

PLYWOOD 800 Hz

SOURCE HEIGHT 2.0 ft.

○ DATA

—  $Z = 2.7 + i8.8$

---  $Z = 7.3 + i11.3$

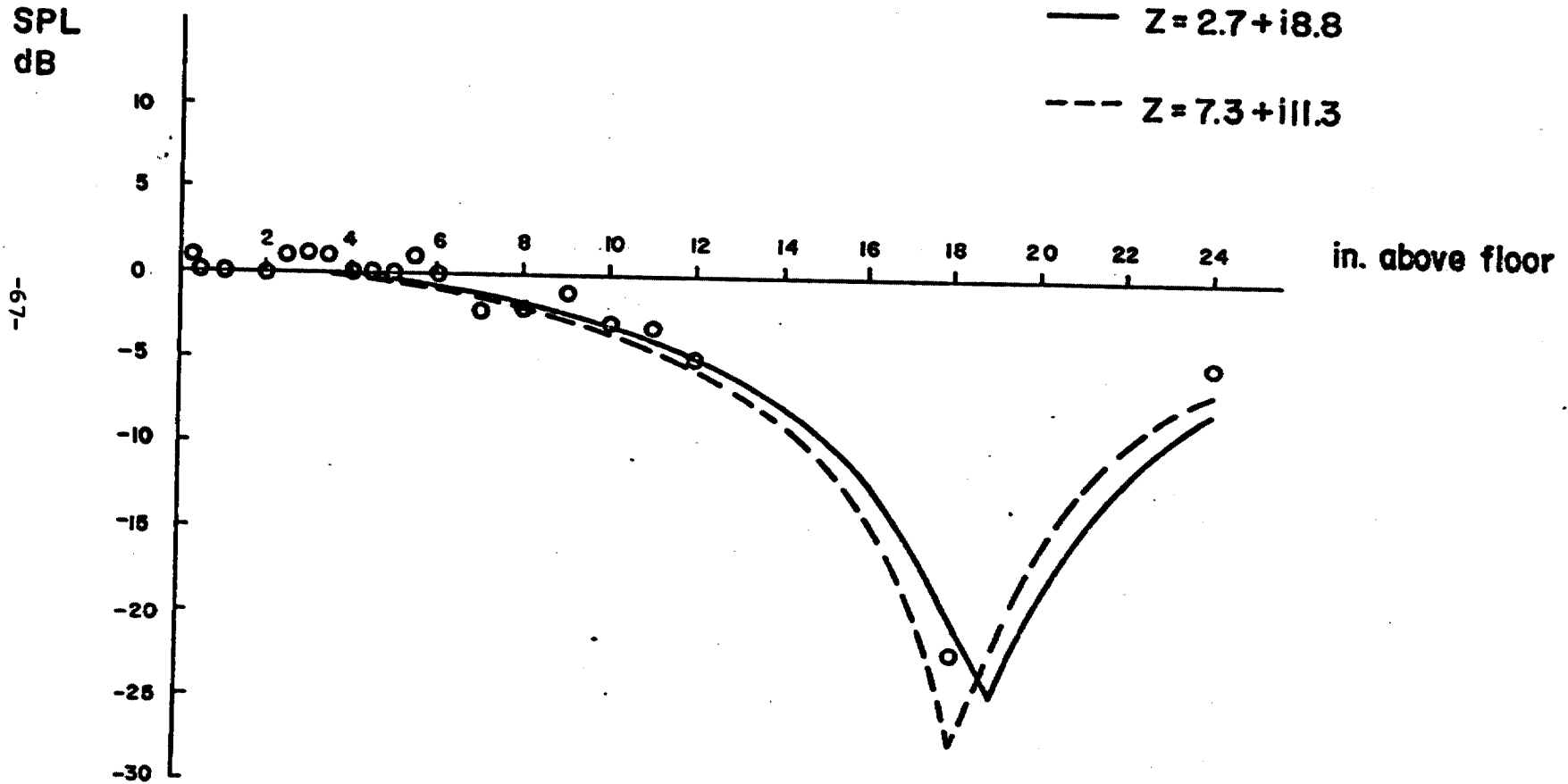


Figure 3. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

PLYWOOD 1600 Hz

SOURCE HEIGHT 1.0 ft

○ DATA

—  $Z = 3.7 + i11.5$

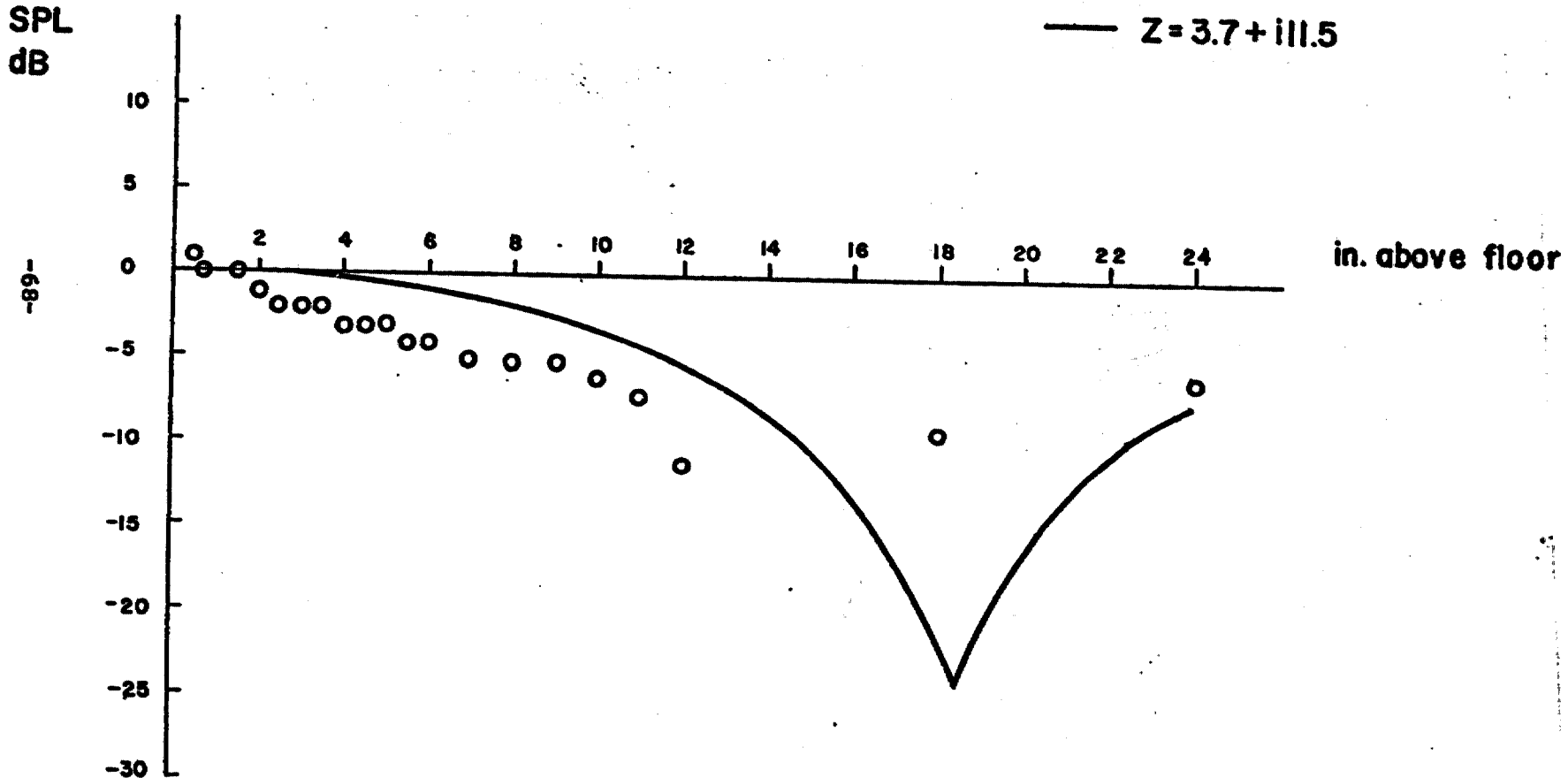


Figure 4. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

PLYWOOD 1600 Hz

SOURCE HEIGHT 2.0 ft

○ DATA

—  $Z=3.7+i11.5$

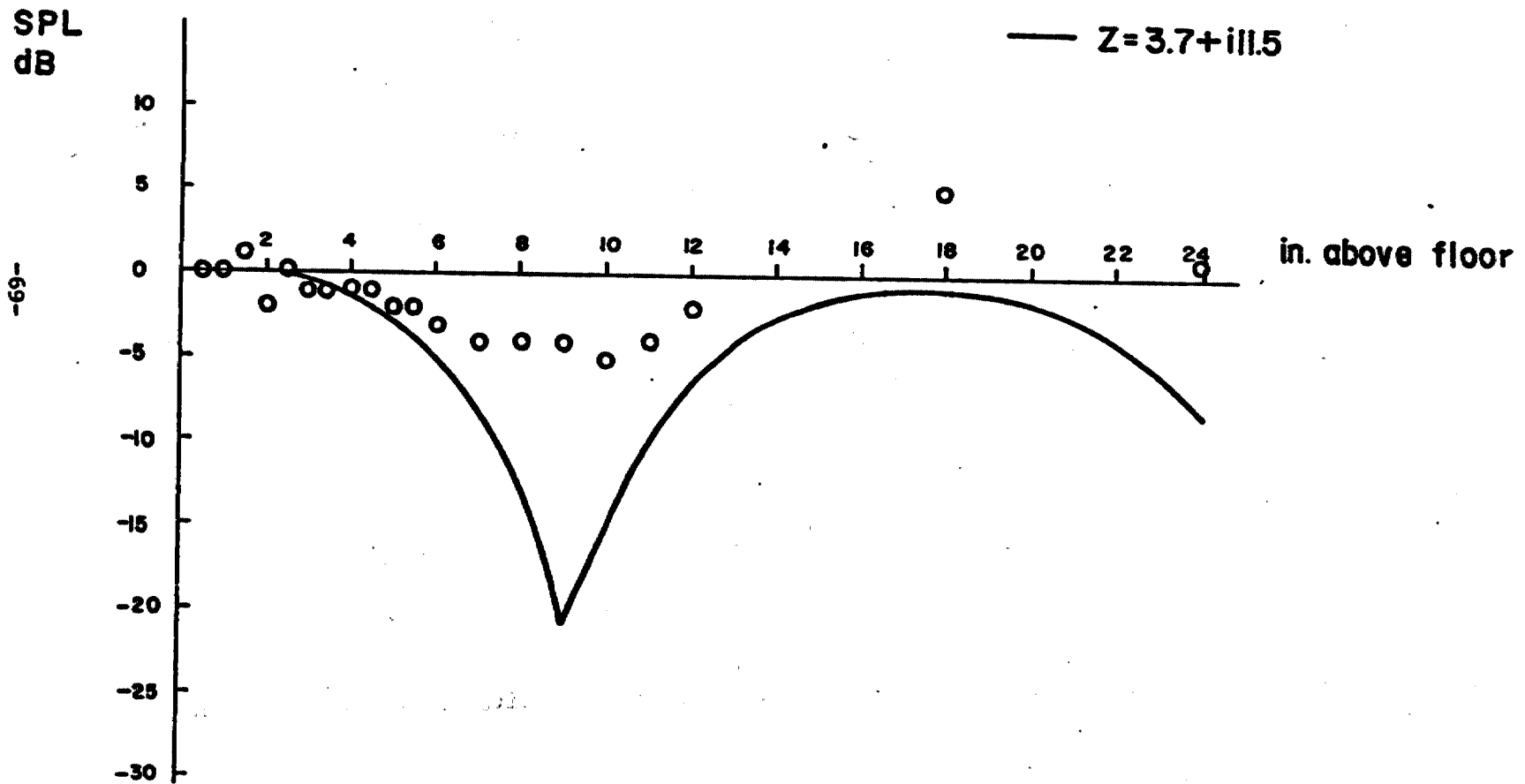


Figure 5. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).



PLYWOOD 2400 Hz

SOURCE HEIGHT 1.0 ft

○ DATA

—  $Z=1.3+i5.4$

---  $Z=2.2+i7.6$

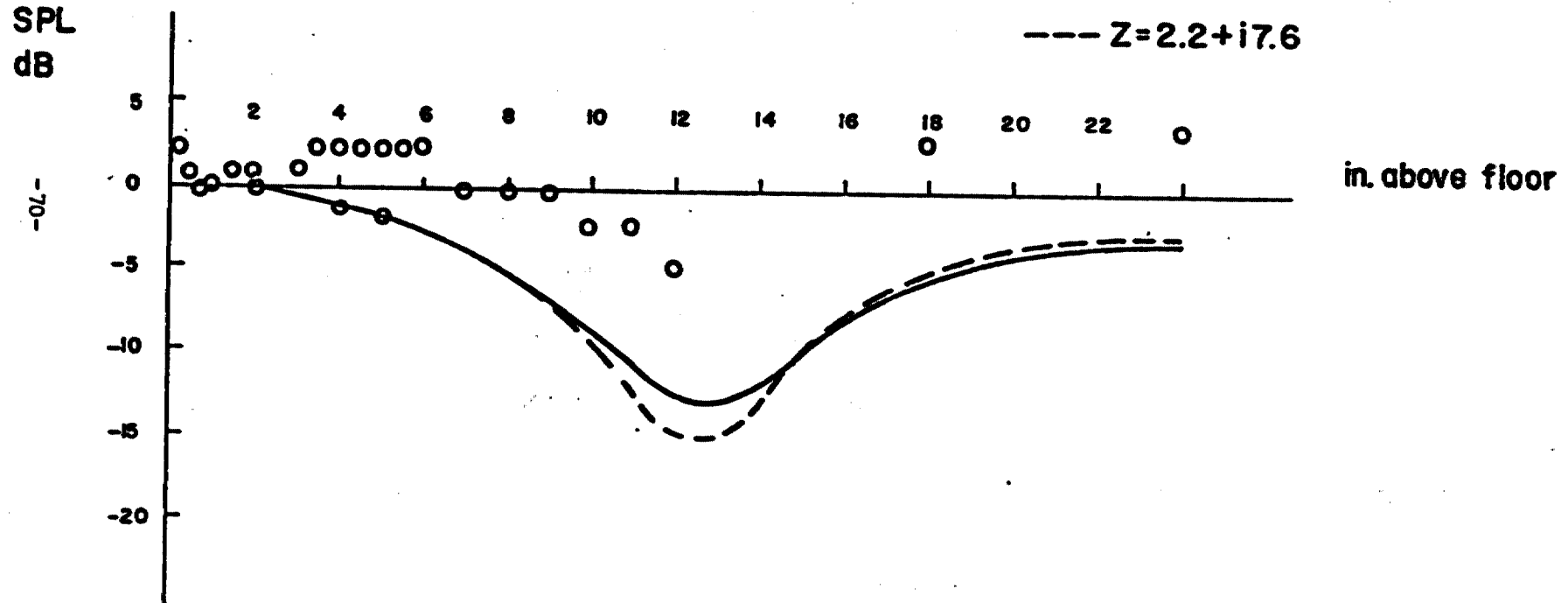


Figure 6. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

PLYWOOD 2400 Hz

SOURCE HEIGHT 2.0 ft

○ DATA

—  $Z=1.3+i5.4$

- - -  $Z=2.2+i7.6$

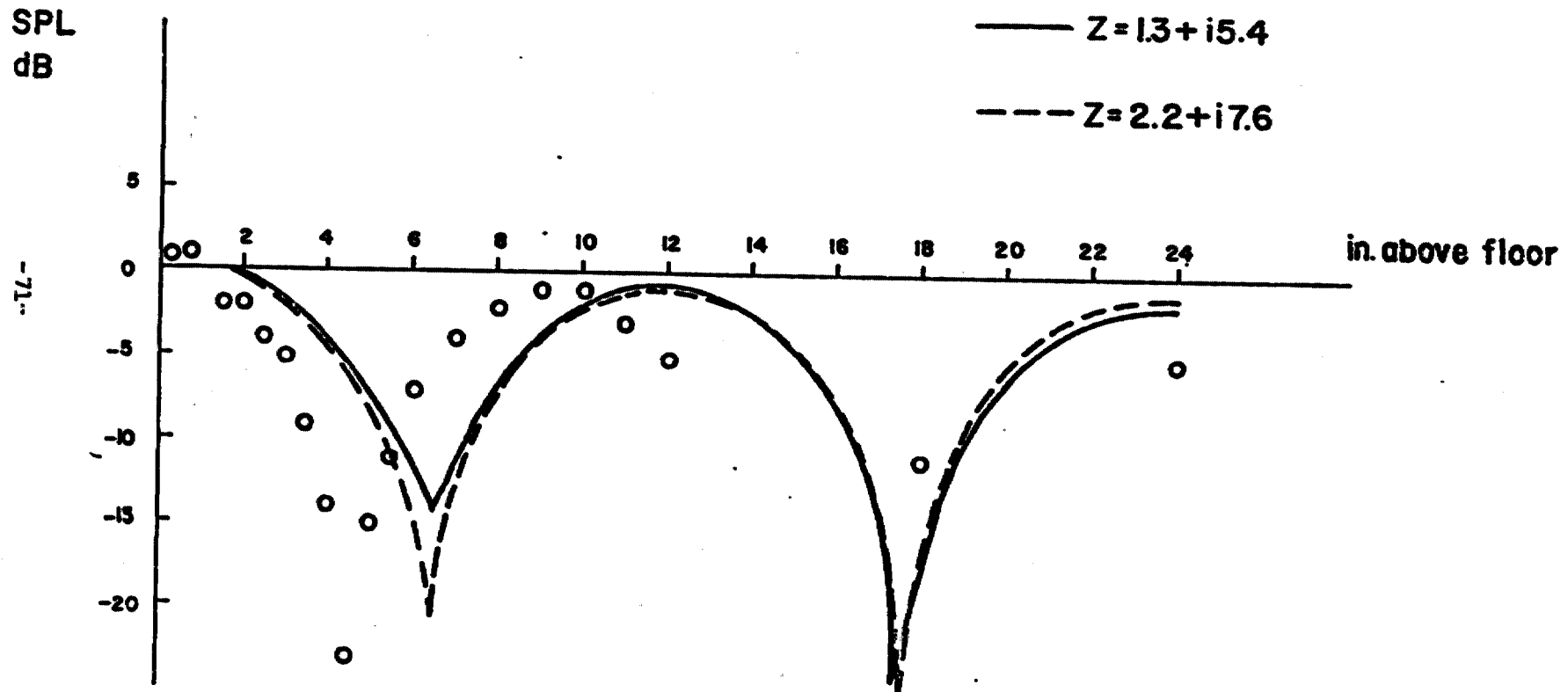
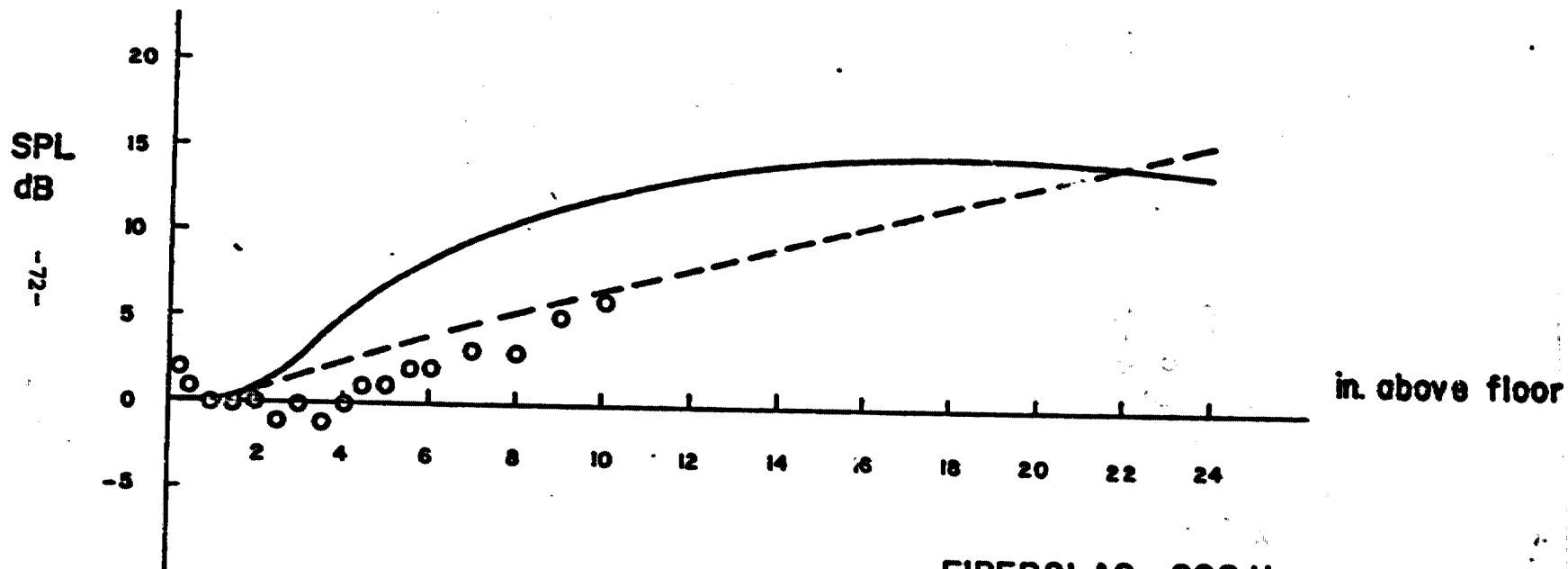


Figure 7. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

Figure 8. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).



FIBERGLAS 800 Hz

SOURCE HEIGHT 2.0 ft

○ DATA

—  $Z = 0.7 + i0.4$

---  $Z = 1.1 - i3.0$

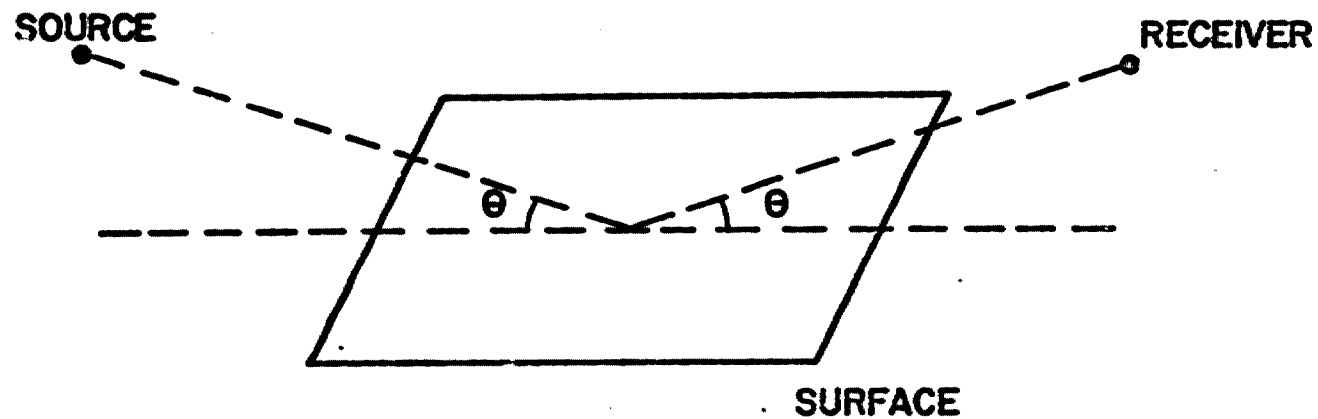


Figure 9. Experiment Geometry: Reflection by Finite Surface.