E-25-643

PROPAGATION OF AIRCRAFT NOISE

A. D. Pierce and W. A. Bell
Principal Investigators

Final Technical Report

Grant No. NSG 1047

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

INTRODUCTION

The work reported here is related to current NASA research interests in the propagation of noise from aircraft. The bulk of this report deals with analytical and laboratory investigations of sound propagation from sources near flat surfaces with finite acoustic impedance. The aims of this work were to develop closed form expressions which may be used to predict sound pressure levels near the ground, to verify these expressions through laboratory experiments, and to try to find a way in which field measurements could be used to obtain the acoustic impedance of the ground surface. In addition to this study, some effort was expended during this contract period on a study of diffraction of sound by barriers. This investigation has been reported by Drs. Pierce and Hadden[1]. Because it is an extensive analytical study, no attempt will be made to summarize it in this report.

THEORETICAL BACKGROUND

The present theoretical analysis is similar to those of Ingard[2] and Delaney and Bazley[3]. 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_o from the source and a height h above the plane as sketched in Figure 1. The essential ingredients of the analysis are: i) the assumption that the surface is one of local reaction, with specific acoustic impedance Z; ii) the use of a plane-wave decomposition of the spherical waves from the source; iii) the use of the plane-wave reflection coefficient

$$R_p = \frac{Z\cos\theta - 1}{Z\cos\theta + 1} \qquad (1)$$

where θ is the angle of incidence with respect to the outward normal to the surface; iv) the use of the method of steepest descents in obtaining the contribution of the pressure reflected from the surface to the receiver - This requires the restriction $kr_2 >> 1$, where $2\pi k$ is the wavelength and r_2 is given by $[r_o^2 + (s + h)^2]^{1/2}$; v) the description of the acoustic pressure at the receiver as comprising a directly-radiated spherical wave from the source at a distance $r_1 = [r_o^2 + (s - h)^2]^{1/2}$ 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,

$$p(r_o, s, h) = \exp(ikr_1)/r_1 + Q\exp(ikr_2)/r_2 \qquad (2)$$

where, as a result of the conditions listed above, the image strength Q may be obtained from, e.g., Delaney and Bazley[3] Equation (12) as

$$Q \simeq 1 - 2\, kr_2 \frac{\int_0^\infty dt\, \exp(-kr_2 t)}{\{[Z(1 + it) + r_o]^2 - (1 - r_o^2)(Z^2 - 1)\}^{1/2}} \qquad (3)$$

with $r_o = \cos^{-1}[(s + h)/r_2]$.

Because the condition $kr_2 >> 1$ was imposed in the use of the steepest descent approximation, the team in t^2 in the denominator of Equation (3) may be neglected, in which case the form

$$Q \simeq 1 - \left[\frac{2\pi\, kr_2}{iZ(Z + r_o)}\right]^{1/2} w\left\{ (1+r_oZ) \left[\frac{ikr_2}{2Z(Z+r_o)}\right]^{1/2}\right\} \qquad (4)$$

may be obtained. The function w(z),

$$w(z) \equiv \exp\,(-z^2)\ \mathrm{erfc}\ (-iz) \qquad (5)$$

which arises in diffraction theory, is discussed and tabulated in Abramovitz and Stegun[4]. The utility of the solution using Equation (4) for calculations is heightened by the fact that Reference 4 also contains formulae by which necessary values of w(z) may be calculated using digital computers. Equations (4) and (5) reduce to Ingard's[2] Equations (13) and (14) with the exception of a widely-noted sign error in Ingard's form.

Substituting Equation (4) into Equation (2) yields

$$p(r_o,s,h) \simeq \exp(ikr_1)/r_1 + [\exp(ikr_2)/r_2] \Bigg(1 - \left[\frac{2\pi kr_2}{iZ(Z+r_o)}\right]^{1/2} w\left\{(1+r_oZ) \left[\frac{ikr_2}{2Z(Z+r_o)}\right]^{1/2}\right\}\Bigg) \qquad (6)$$

as an explicit approximation to the acoustic pressure under the restriction $kr_2 >> 1$.

For calculations, however, it is often more convenient to use Equations (2) and (4) separately: e.g., the most readily measured quantity, the pressure amplitude, is

$$|p| = r_1^{-1} \{1 + 2(r_1/r_2)|Q| \cos [k(r_2-r_1)+ \phi_Q]+(r_1/r_2)^2|Q|^2\}^{1/2} \quad (7)$$

in which $|Q|$ and ϕ_Q are the magnitude and phase of the complex quantity Q. In addition to the limitation $kr_2 >> 1$. the validity of these results is restricted by the condition that no surface wave effects be significant.

EXPERIMENTAL METHOD

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 by the samples.

The sound propagation studies were performed 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 fiberglass above the plywood. A small sound source driven by sinusoidal tones was suspended above a surface. Two measurement techniques were used. In one, 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. In the other measurement mode two receivers were used - one at the surface at a horizontal distance from the source of 7.5 feet, and the second receiver 2.5 feet above the first. For each surface, the sound pressure level at the surface and the difference in phase of the sound pressure at the two receivers were measured as a function of frequency for source heights of six inches, one foot, and two feet.

ANALYSIS OF EXPERIMENTAL RESULTS

Agreement may be sought between the impedance tube data and the sound pressure field measurements in two ways: i) by using the measured specific impedance values in Equations (2) and (4) to obtain a predicted sound field; ii) by performing calculations using selected values for the specific impedance in Equations (2) and (4), finding the value which leads to a good match with the pressure field measurements, and comparing the impedance thus obtained with the measured value. Examples of both approaches will be discussed below. The latter technique is particularly interesting because it is representative of conditions which pertain to practical application of the results.

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

$$\text{SPL(re receiver height of 1 inch)} = 20 \log \left[|p(r_o,s,h)| / |p(r_o,s,1\text{ inch})| \right] \qquad (8)$$

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 probable 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 Figures 8 and 9; 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. Results of further study of this point will be reported at a later date.

In addition to the measurements of SPL vs. receiver height, measurements were made simultaneously of sound pressure level at the surface and phase difference between the surface and a fixed reference position. Such measurements are essential to a technique suggested by Ingard as a way of obtaining the surface impedance, with plane waves incident on the surface, from the changes in pressure amplitude and phase when a hard reference surface is replaced by a surface whose impedance is to be found.

This method has been used by Lawhead and Rudnick[5] with the reference point for the phase angle taken as the input to the driver which acts as the sound source. In the present study, a reference point near the surface receiver was chosen in an attempt to avoid the uncertainty of phase shifts induced by the driver's mechanical response and to lessen the dependence of the recorded phase shift on the temperature of the air in which the test was conducted. However, because of the following considerations based on Equations (6) and (7), it was decided that this surface-replacement technique was not a practical method for obtaining the surface impedance: For the observation point at the surface, we have

$$\frac{|p_{sample,surf.}|}{|p_{rigid,surf.}|} = \frac{1}{2} |1 + Q| \tag{9}$$

in which Equation (4) is to be used for Q. The corresponding difference in phase shifts is

$$\Delta\phi_{sample} - \Delta\phi_{rigid} = \tan^{-1} \left[\frac{Im(Q)}{Re(Q) + 1}\right] \Bigg|_{surf}$$

$$-\tan^{-1} \left[\frac{\sin kr_1 + (\frac{r_1}{r_2}) |Q| \sin (kr_2 + \phi_Q)}{\cos kr_1 + (\frac{r_1}{r_2}) |Q| \cos (kr_2 + \phi_Q)}\right] \Bigg|_{ref} \tag{10}$$

$$+ \tan^{-1} \left[\frac{\sin kr_1 + (\frac{r_1}{r_2}) \sin kr_2}{\cos kr_1 + (\frac{r_1}{r_2}) \cos kr_2}\right]$$

The two features which make this method impractical are the non-cancellation of the last two terms in Equation (10) and the fact that the image source strength, Q, depends so indirectly on the surface impedance. As a result of these considerations, the analysis of the pertinent data has not been pursued.

CONCLUSIONS

A well-known analysis of the propagation of sound over a finite-impedance surface has been reformulated so that the distribution of sound levels above a surface can be predicted, given the surface acoustic impedance, using a function which is tabulated (or readily calculated on a digital computer). Agreement between experimental results for several surfaces and calculations using measured specific impedances is satisfactory; the most troublesome point seems to be obtaining reliable values for the specific impedances.

Report prepared by

W. James Hadden, Jr.
Assistant Professor

Stothe P. Kezios, Director
School of Mechanical Engineering

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1. A. D. Pierce and W. J. Hadden, Jr., "Theory of Sound Diffraction around Absorbing Barriers", presented at an international conference, Acoustic Protection of Residential Areas by Barriers, at the Centre National de la Recherche Scientifique, Laboratoire de Mechanique et d'Acoustique, Marseille, France, February 1975.

2. U. Ingard, J. Acoust. Soc. Amer., 23, 329 (1951).

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Table I

Measured Values of Specific Acoustic Impedance

		Plywood	Fiberglass-Plywood
800	(LRC)*	4.08 + i0.93	0.68 + i0.40
	(GIT)	7.33 + i11.36, 2.68 + i8.78	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.

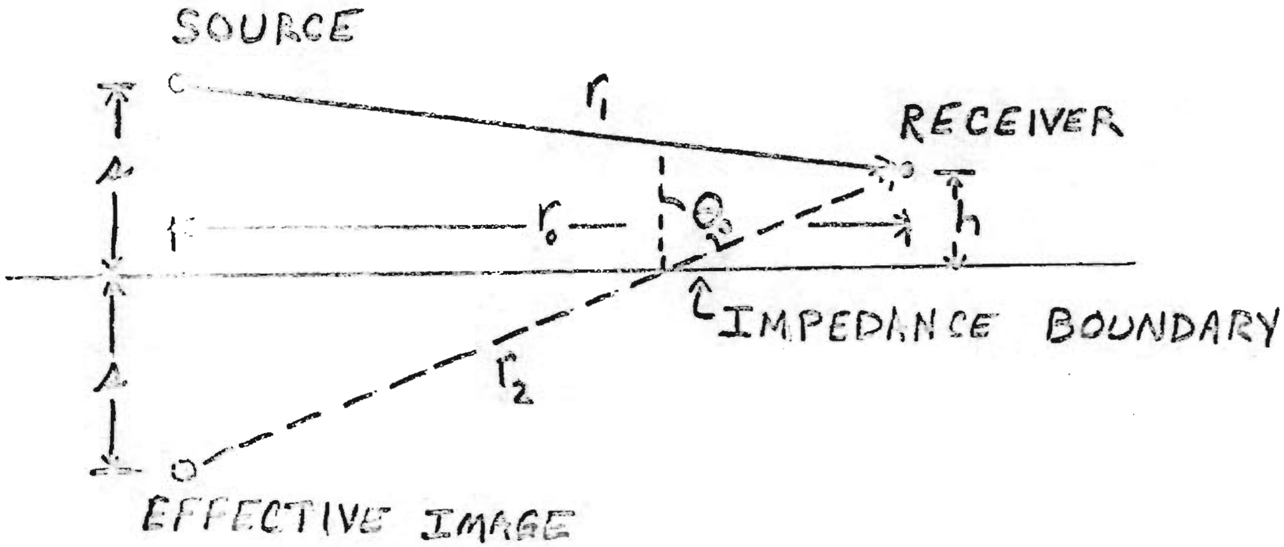

Figure 1. Source-receiver-surface configuration.

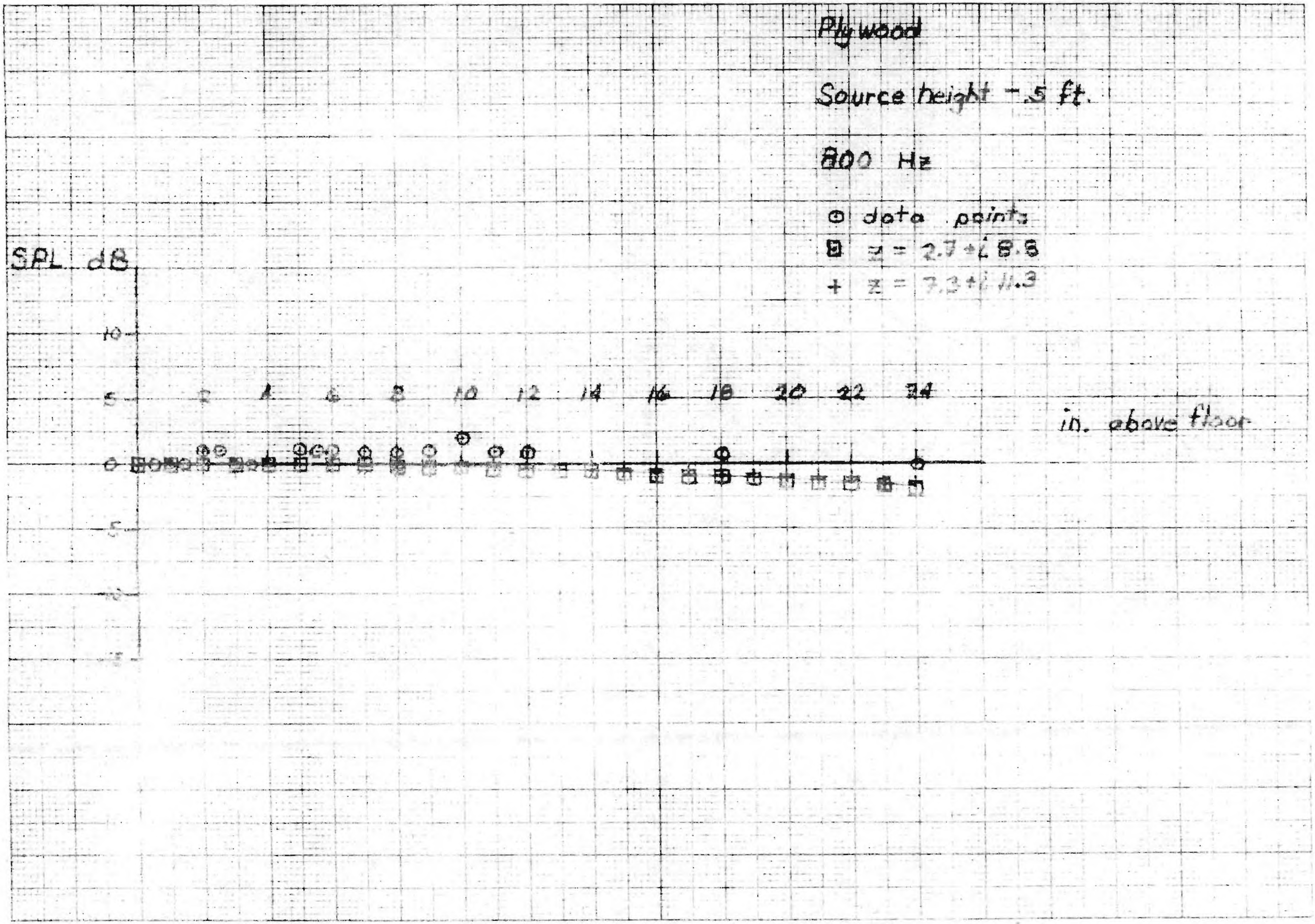

Figure 2. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height of one inch).

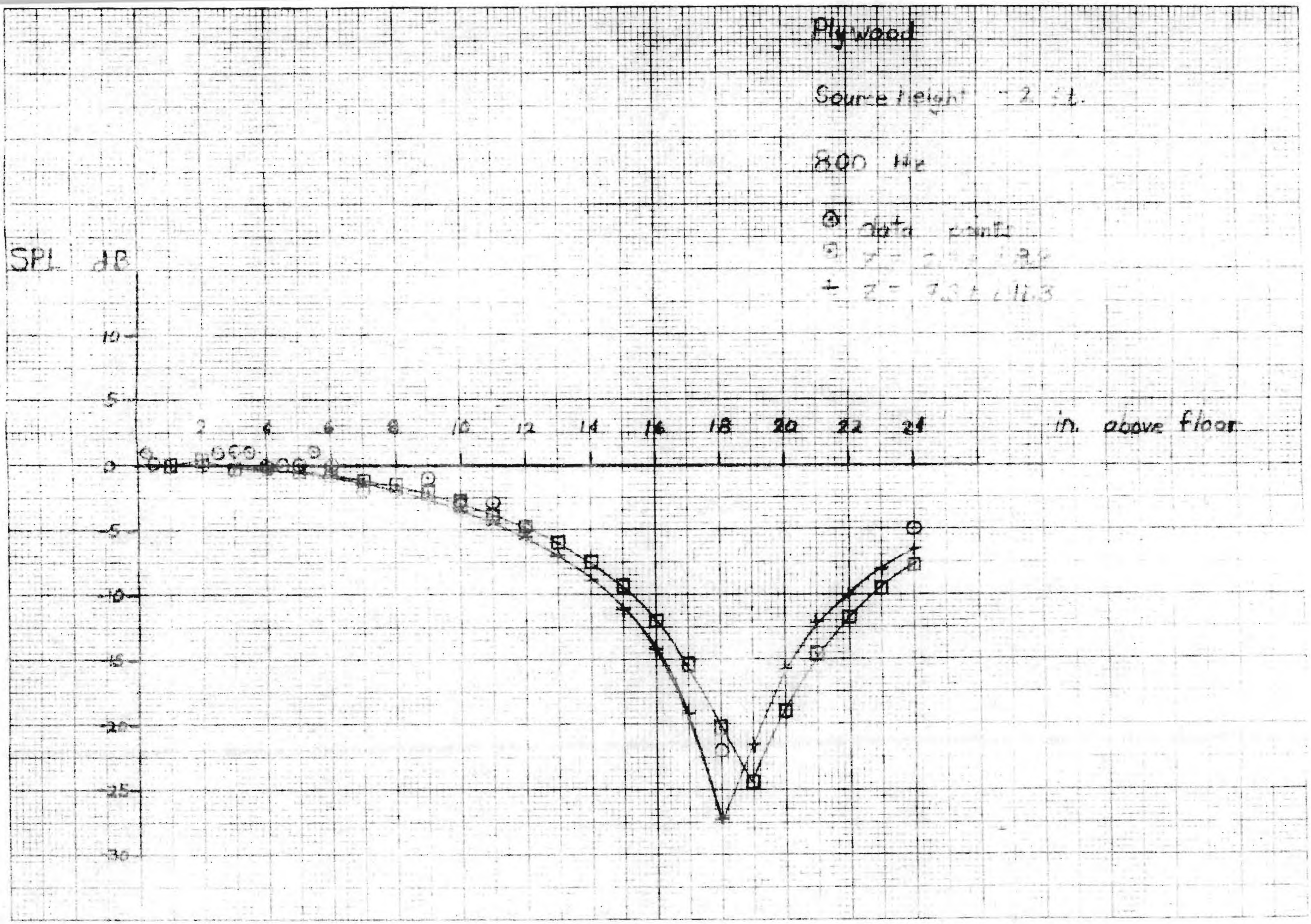

Figure 3. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receive height of one inch).

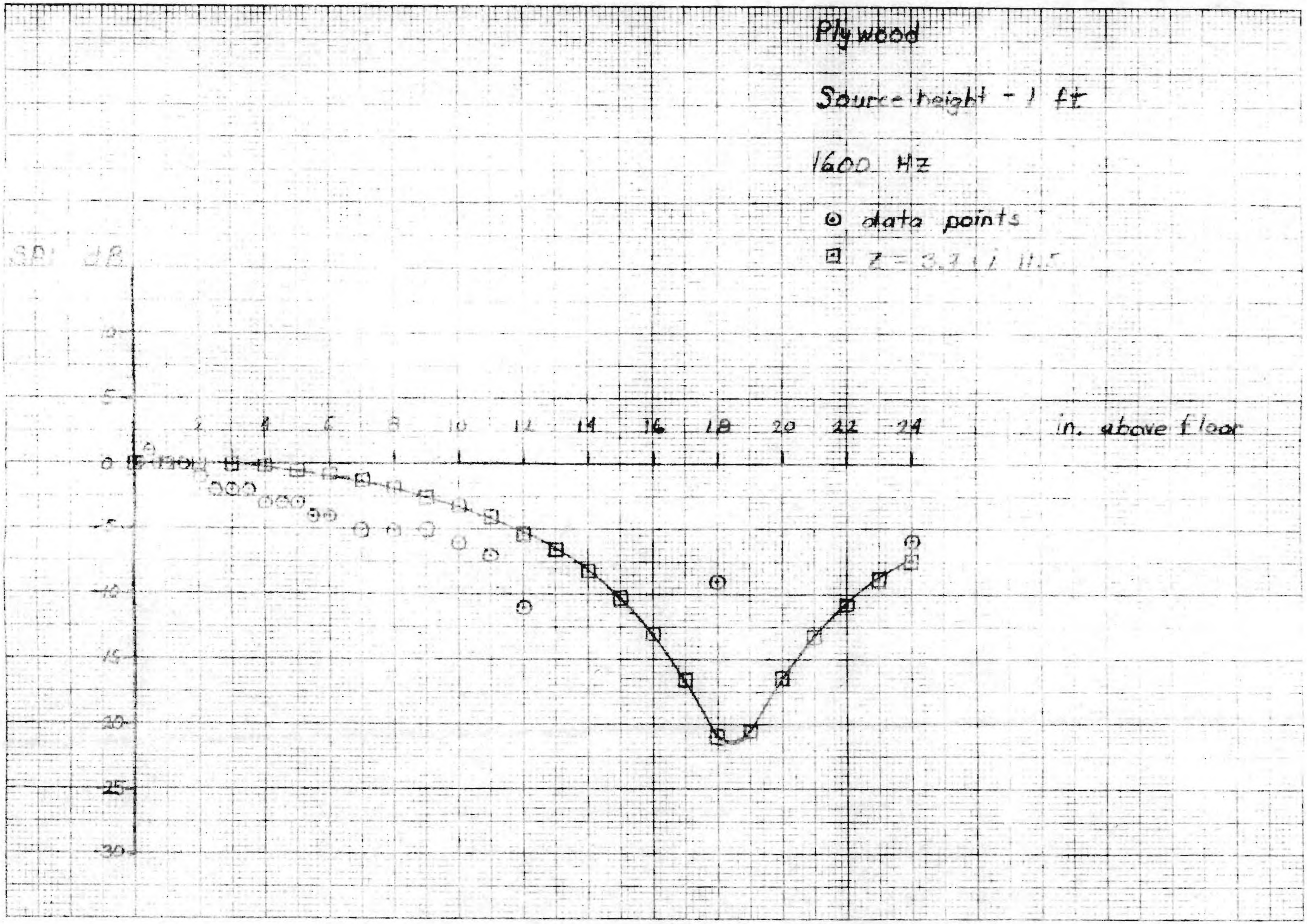

Figure 4. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height of one inch).

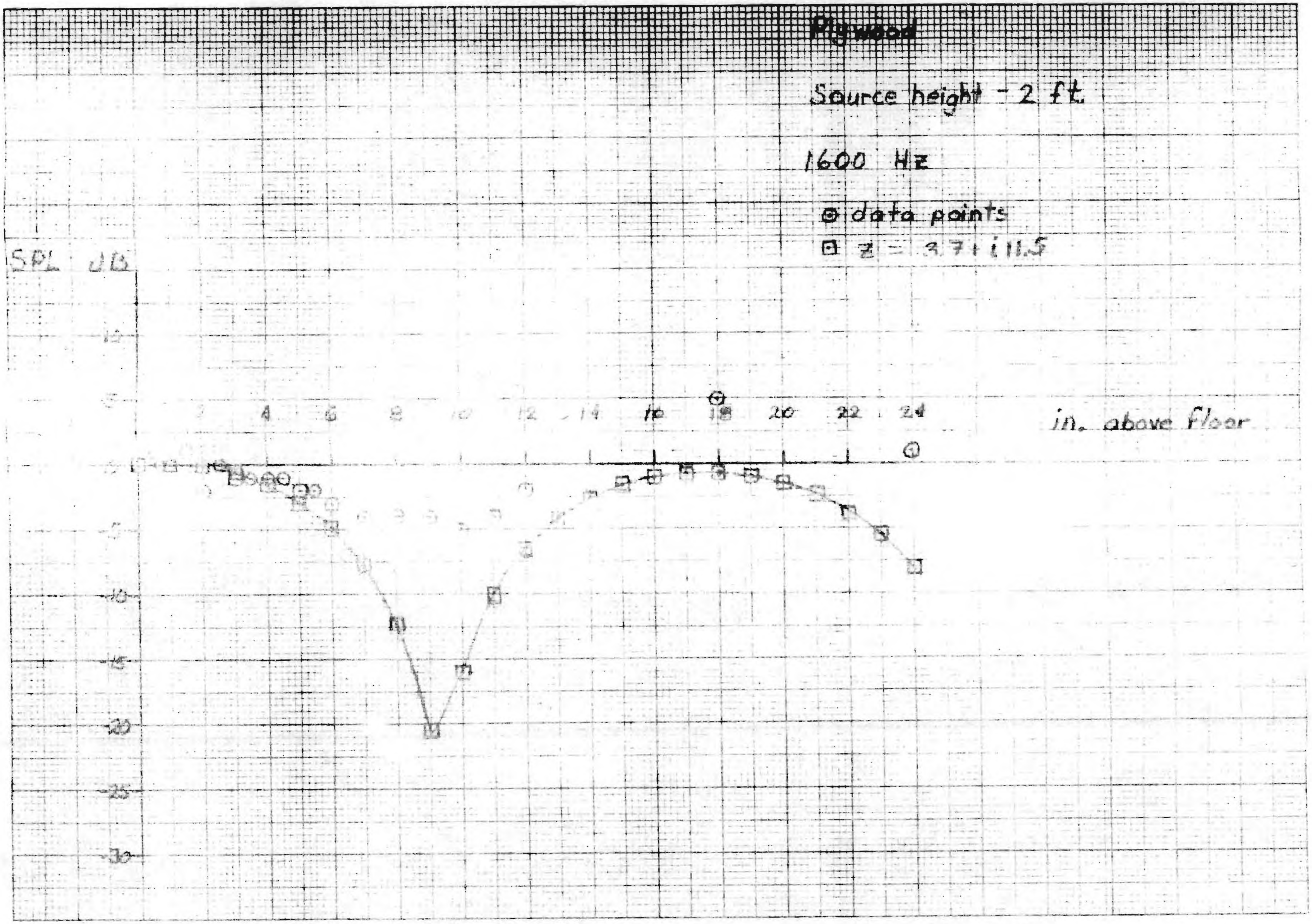

Figure 5. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height on one inch).

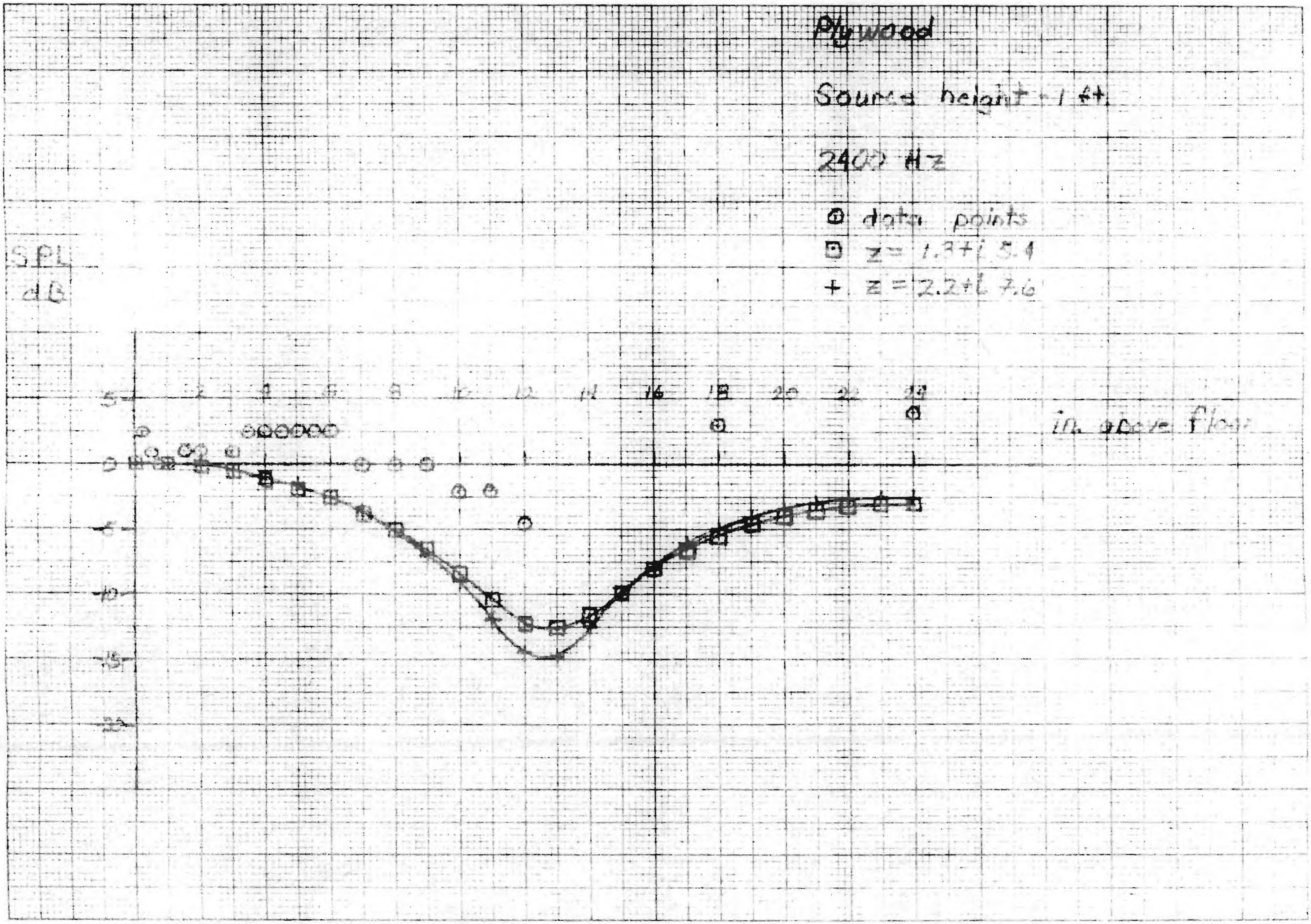

Figure 6. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height of one inch).

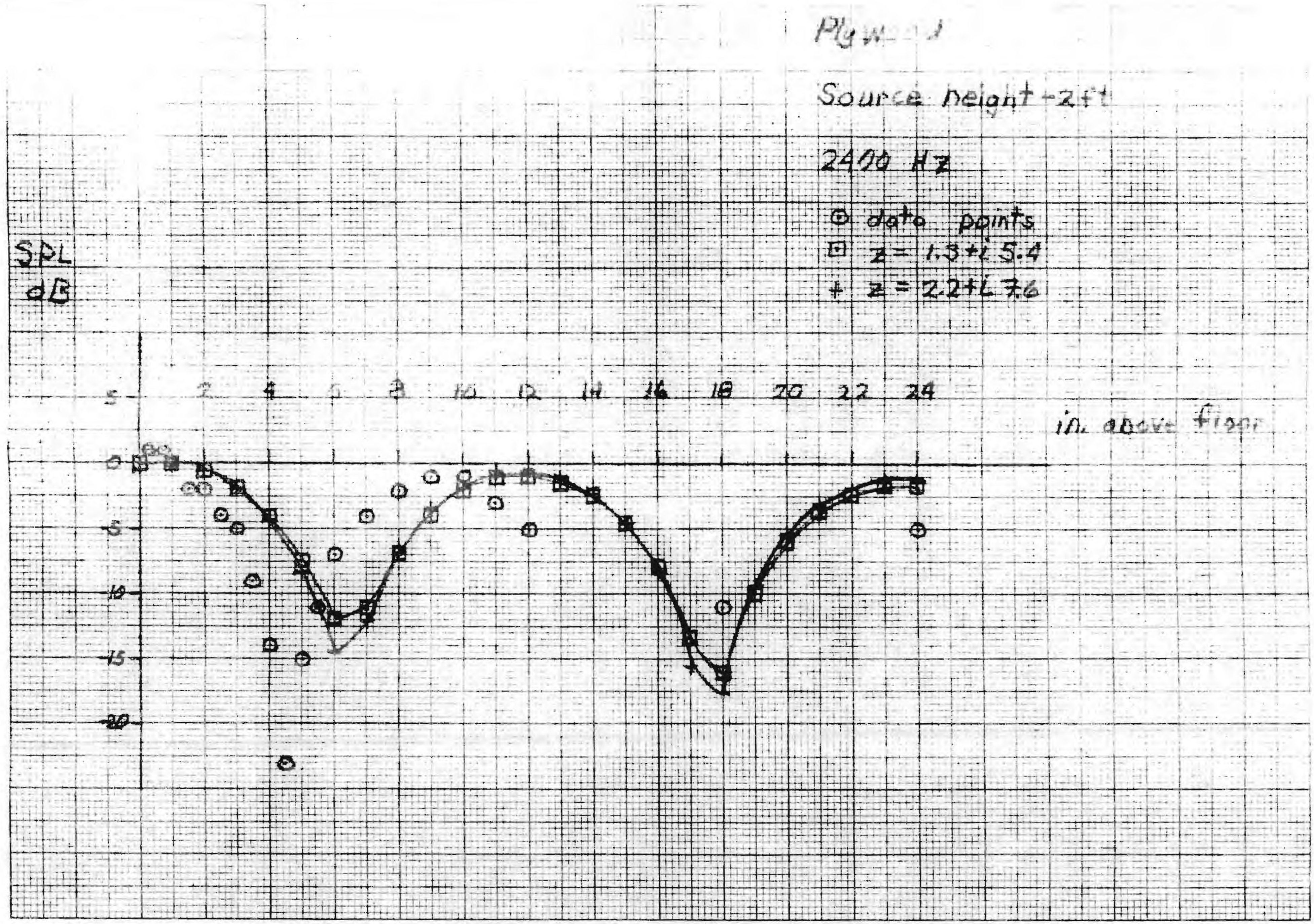

Figure 7. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height of one inch).

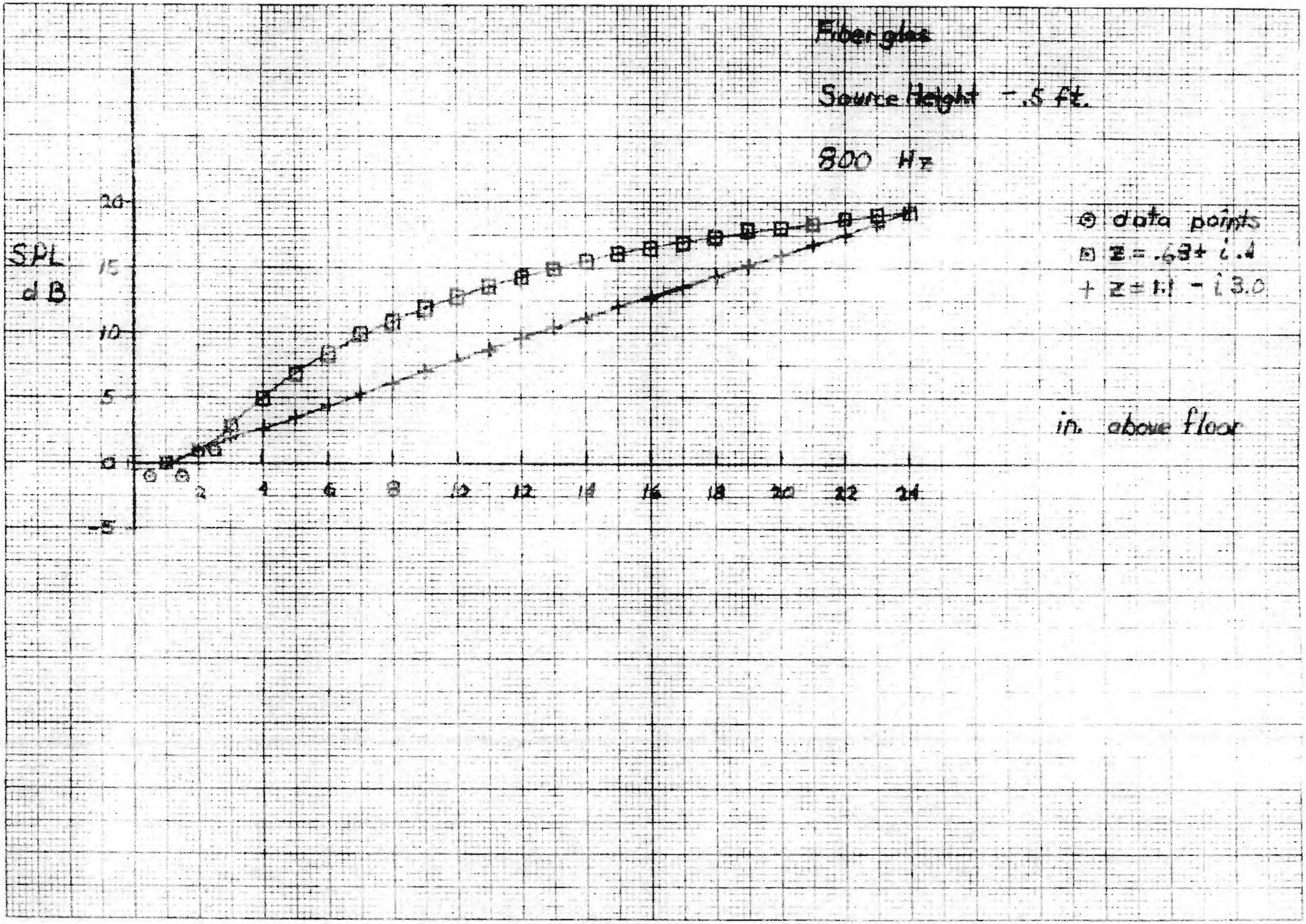

Figure 8. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height of one inch).

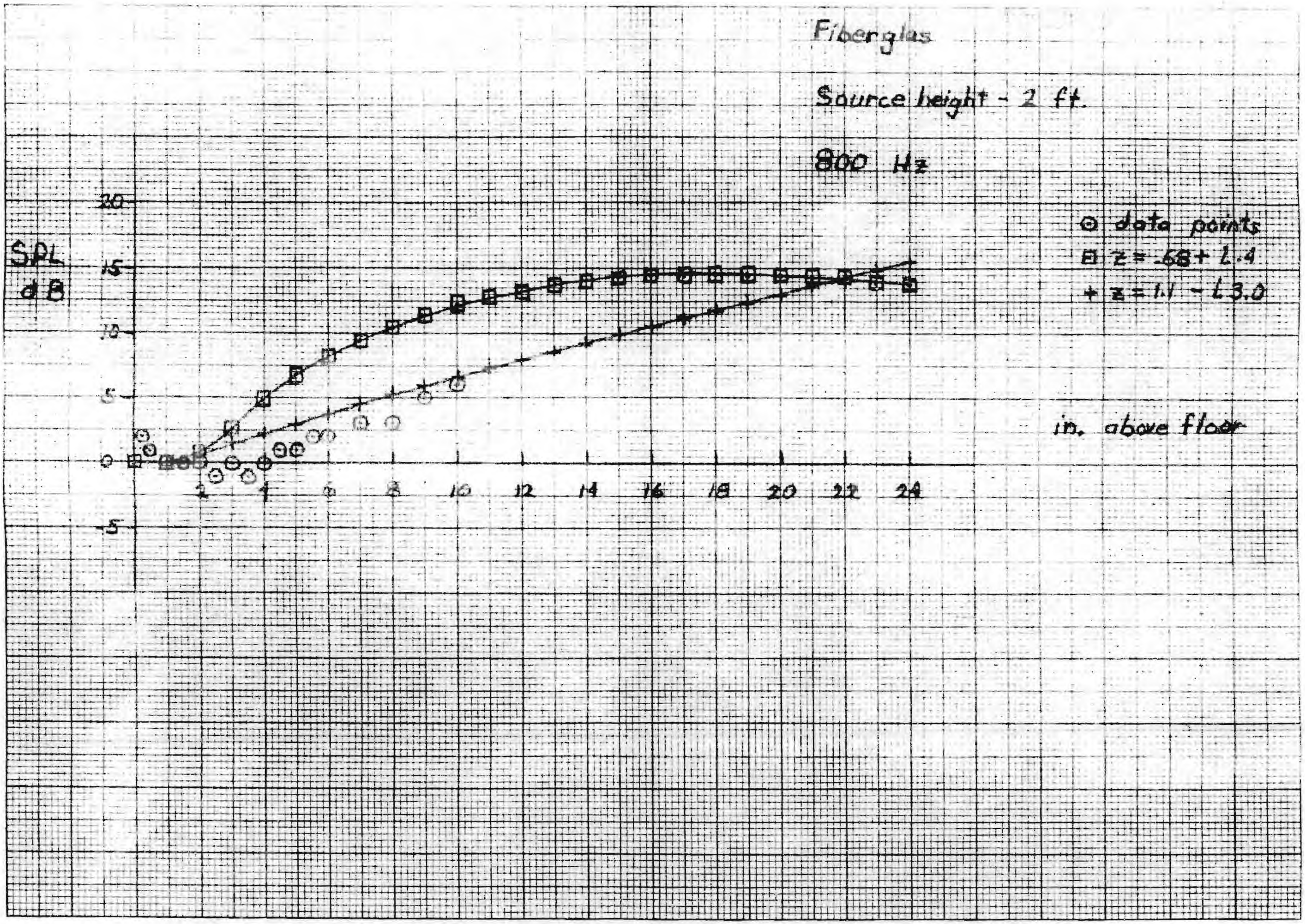

Figure 9. Sound pressure level distribution above surface with finite acoustic impedance (normalized to receiver height of one inch).

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PROPAGATION OF AIRCRAFT NOISE

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

Final Technical Report No. 2
July, 1976

Grant No. NSG 1047

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[1,2] 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 compating 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 infinte-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° grazing angle results than for the 10° 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.[6,7] 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

W. James Hadden, Jr
Assistant Professor

for Stothe P. Kezios, Director
School of Mechanical Engineering

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

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3. W. J. Hadden, Jr., P. M. Sencil, R. A. Vidimos, E. L. Turner, Jr., and A. D. Pierce, "Effect of Variable Ground Impedance on Noise Propagation," Proc. 3rd Interagency Symposium on University Research in Transportation Noise, Salt Lake City, November 1975, pp. 59-73.

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6. W. J. Hadden, Jr., and A. D. Pierce, "Estimation Procedure for Sound Diffraction by Nearly Rigid Wedges," J. Acoust. Soc. Am. 59, S81 (1976).

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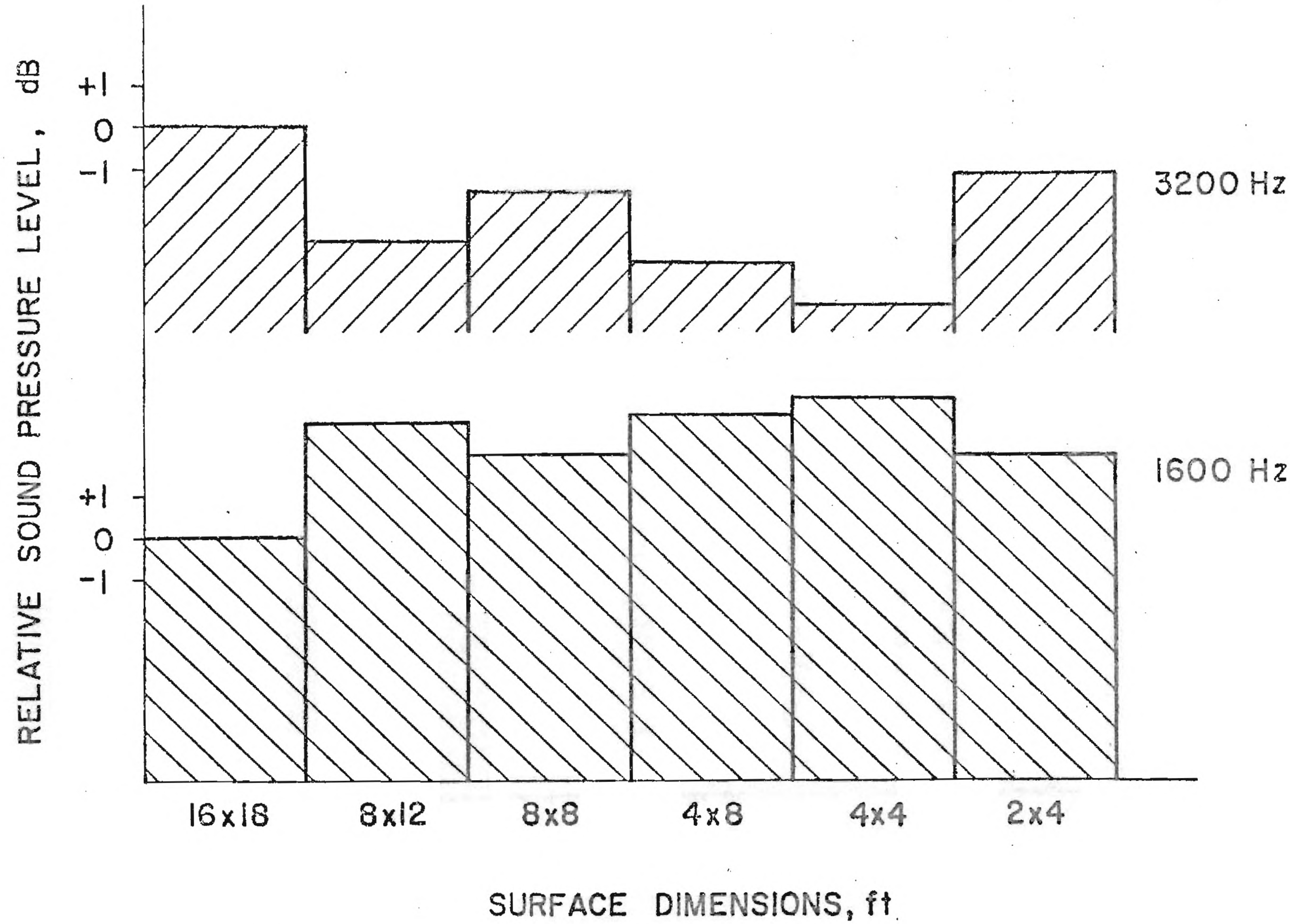


Figure 1: Variation of Far Field Sound Pressure Level with Surface Size: Plywood; 10° Grazing Angle.

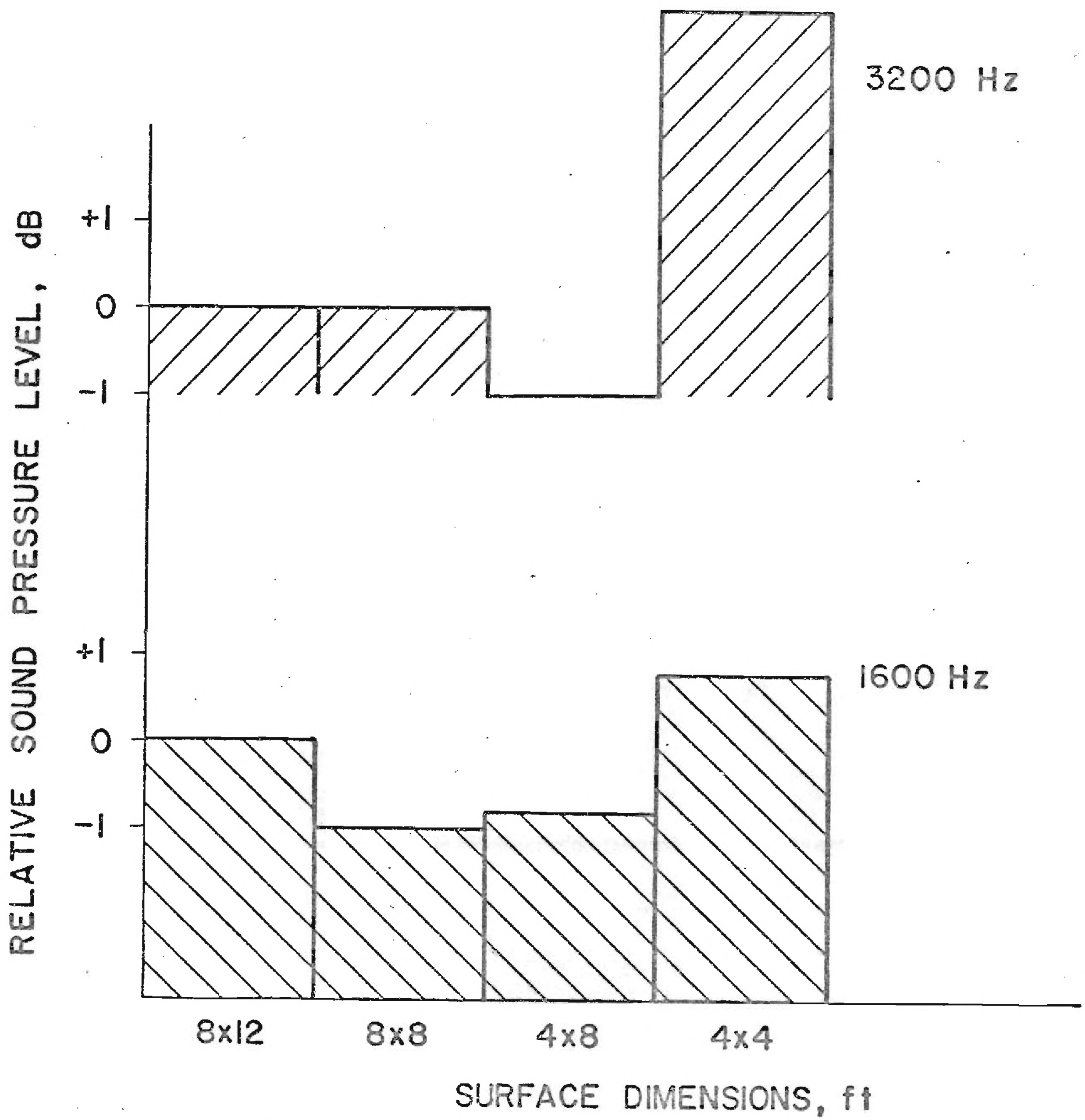


Figure 2: Variation of Far Field Sound Pressure Level with Surface Size:Plywood; 20° Grazing Angle.

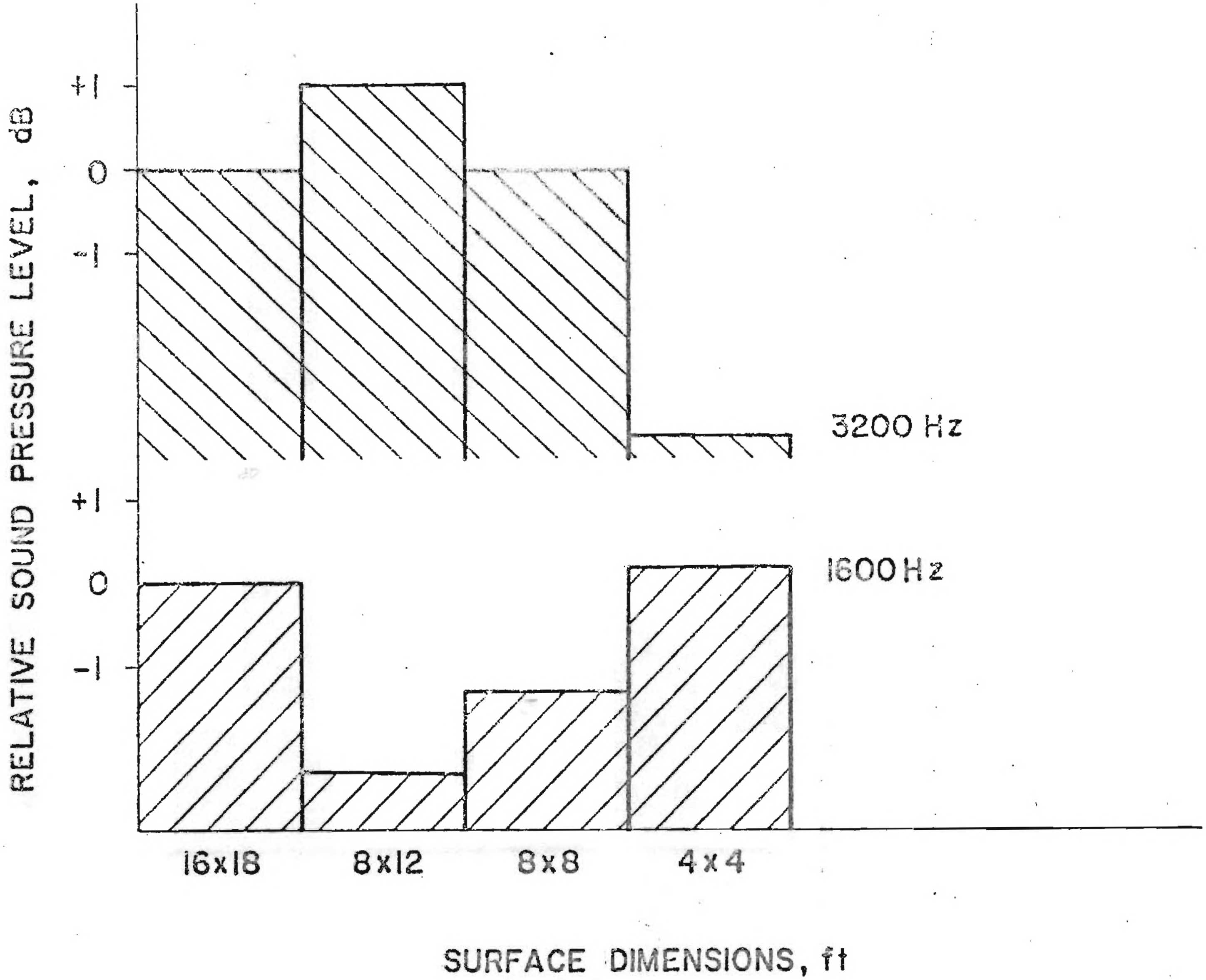


Figure 3: Variation of Far Field Sound Pressure Level with Surface Size: Plywood and Fiberglass; 10° Grazing Angle.

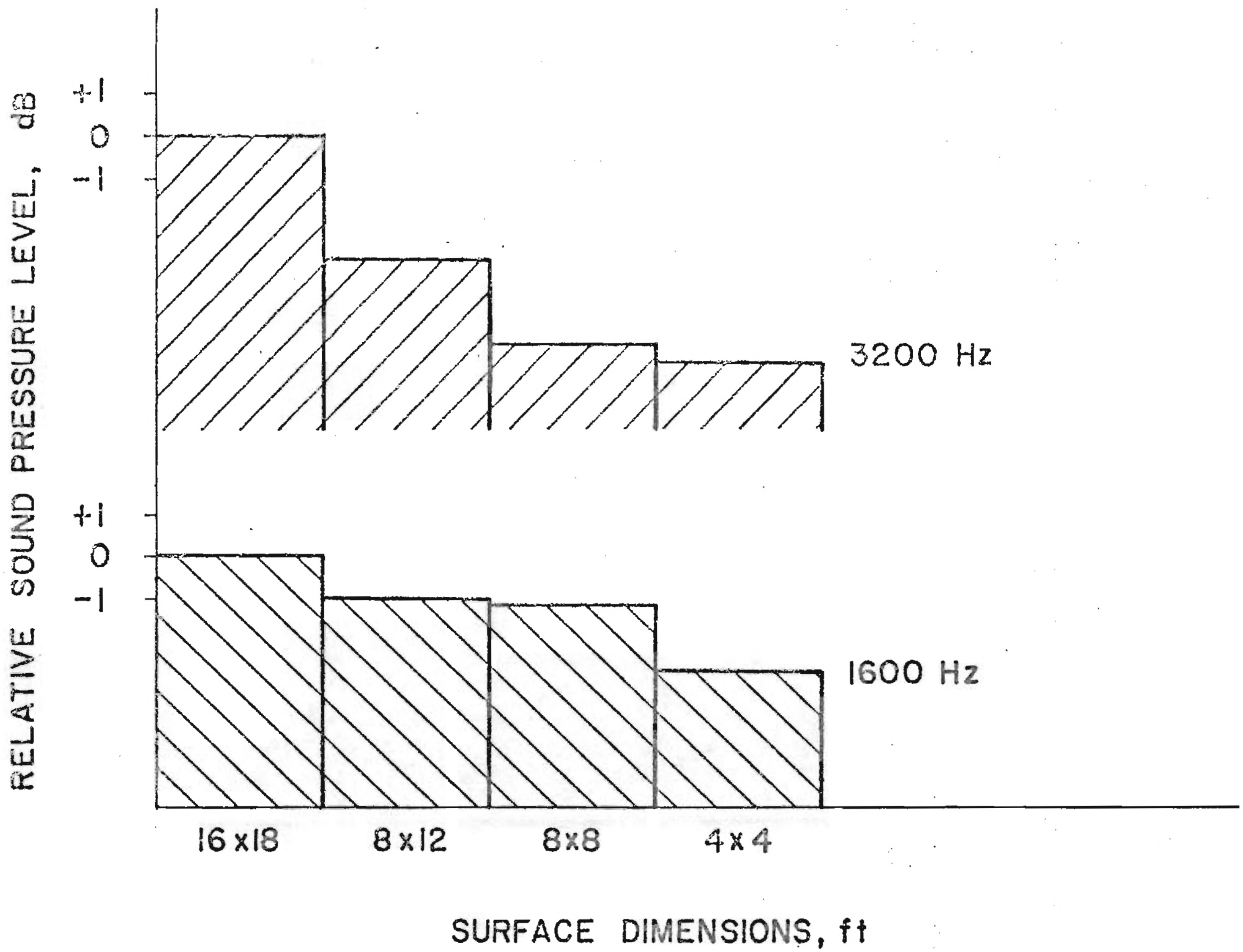
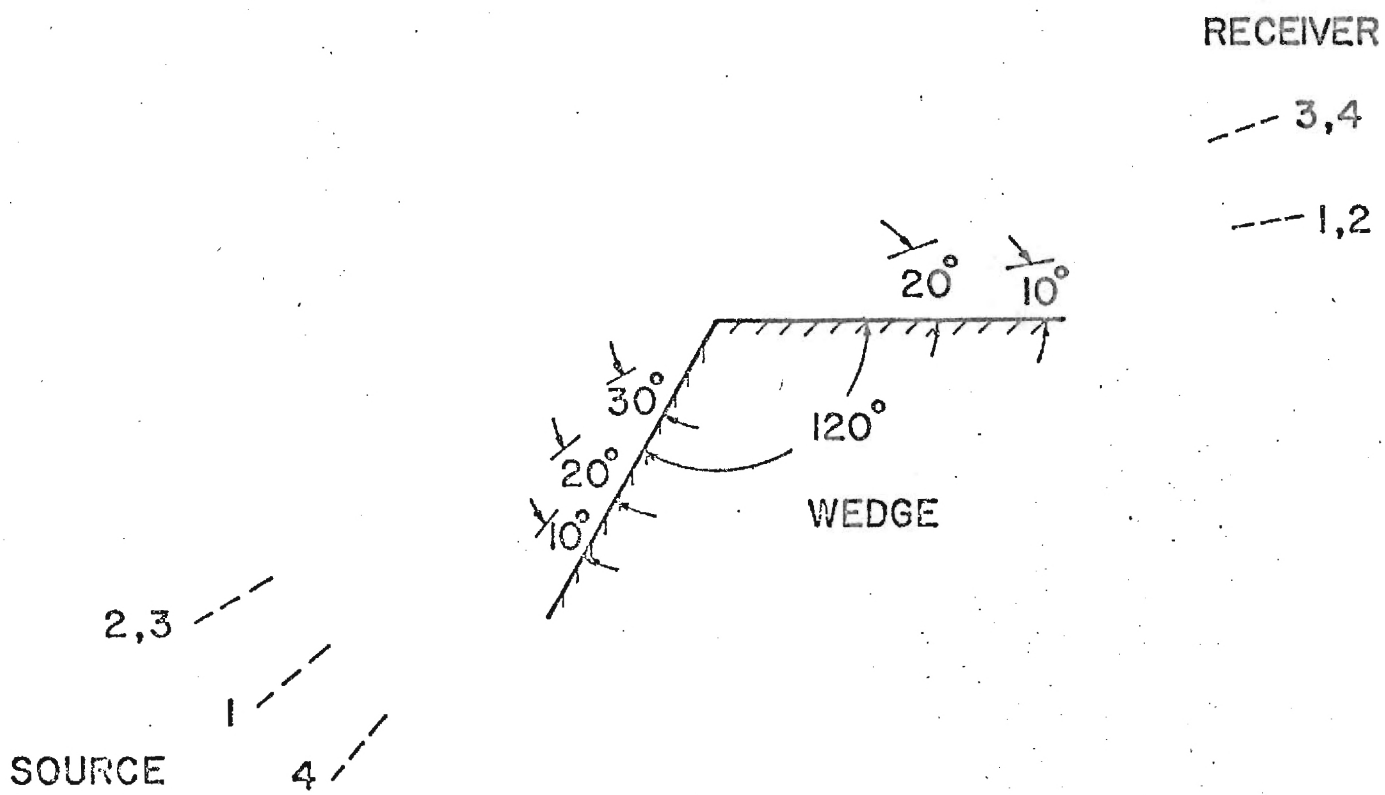


Figure 4: Variation of Sound Pressure Level with Surface Size: Plywood and Fiberglass; 20° Grazing Angle.

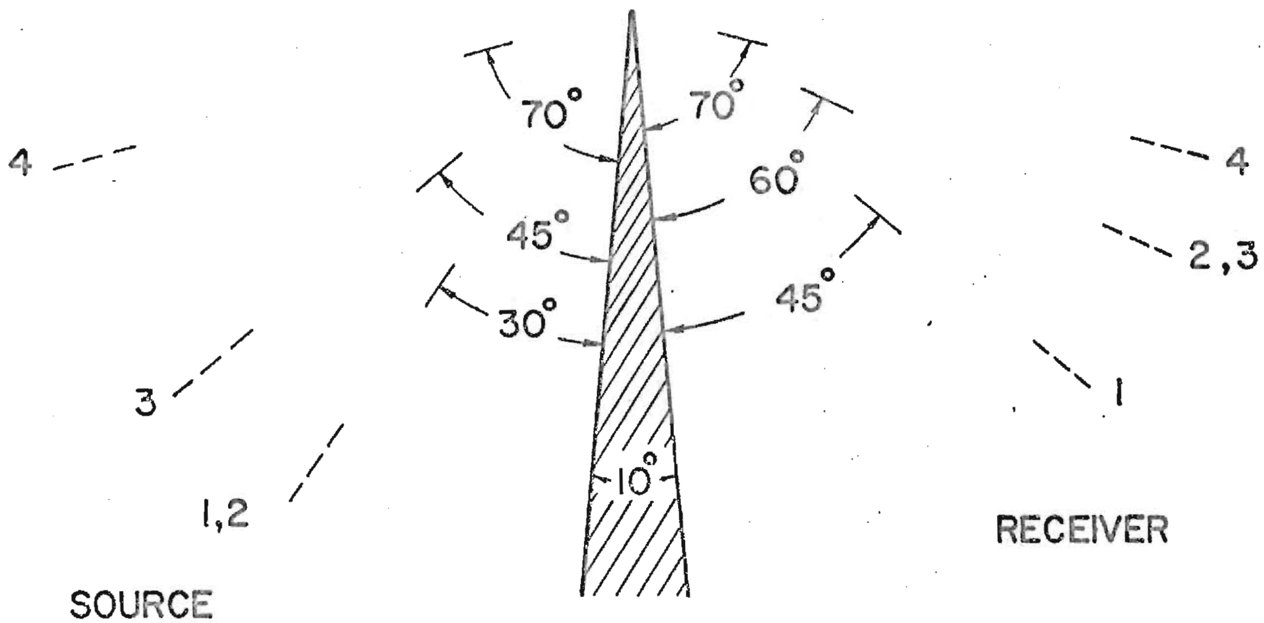


Configuration	1	2	3	4
ΔIL (dB)	6.1	4.6	1.8	6.9

Finite - Impedance Correction for Barrier Insertion Loss

Surface Addmittance = 0.1 − i0.05

Figure 5



Configuration	1	2	3	4
ΔIL (dB)	2.3	1.7	1.1	0.5

Finite - Impedance Correction for Barrier Insertion Loss.

Surface Addmittance = 0.1 – i0.05

Figure 6

BOOK OF PROCEEDINGS

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EFFECTS OF VARIABLE GROUND IMPEDANCE
ON NOISE PROPAGATION

by

W. James Hadden, Jr., Philip M. Sencil, Robin A. Vidimos,
Eddie L. Turner, Jr., and Allan D. Pierce
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia

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_o 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 $r_1 = [r_o^2 + (s - h)^2]^{\frac{1}{2}}$ 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,

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

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 Bazley[1] Equation (12) as

$$Q \simeq 1 - \left[\frac{2\pi kr_2}{iZ(Z + \Gamma_o)}\right]^{\frac{1}{2}} \quad w\left\{(1 + \Gamma_o Z)\left[\frac{ikr_2}{2Z(Z + \Gamma_o)}\right]^{\frac{1}{2}}\right\} \qquad (2)$$

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

$$w(z) \equiv \exp(-z^2)\, \mathrm{erfc}(-iz) \qquad (3)$$

which arises in diffraction theory, is discussed and tabulated in Abramovitz and Stegun[2]. 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[3] Equations (13) and (14) with the exception of a widely-noted sign error in Ingard's form.

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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

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$$20 \log [|p(r_o,s,h)|/|p(r_o,s,1 \text{ inch})|] \qquad (8)$$

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 fiberglas-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 θ_o 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[3] of the propagation of sound over a large surface leads to the conjecture that for $kr_2 >> 1$, 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 θ (10° and 20° 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 fiberglas 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 meaintained 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 fiberglas 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 + i8178	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

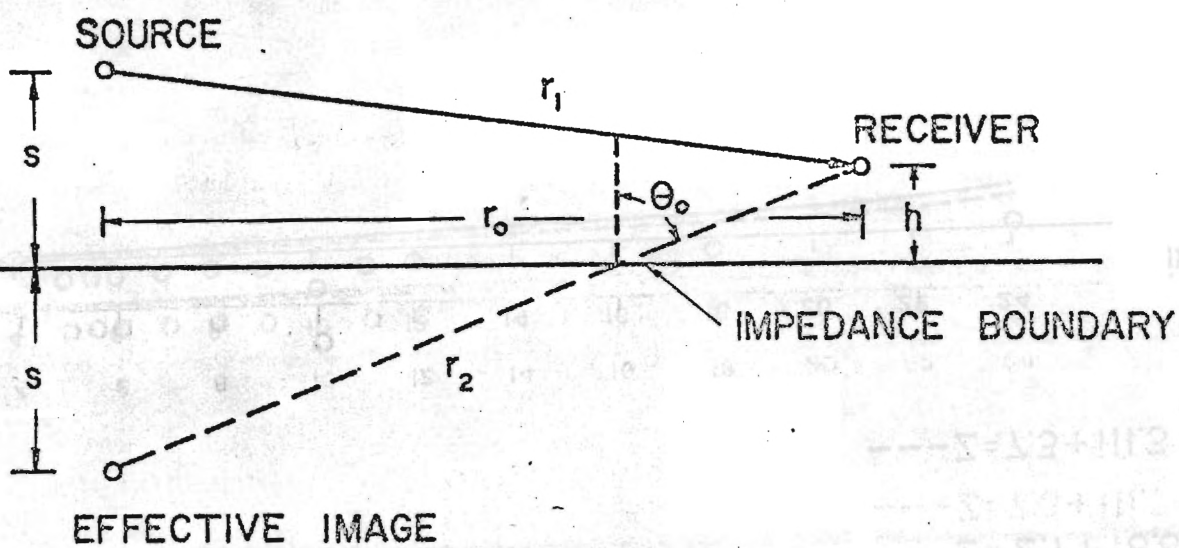


Figure 1. Source-Receiver-Configuration.

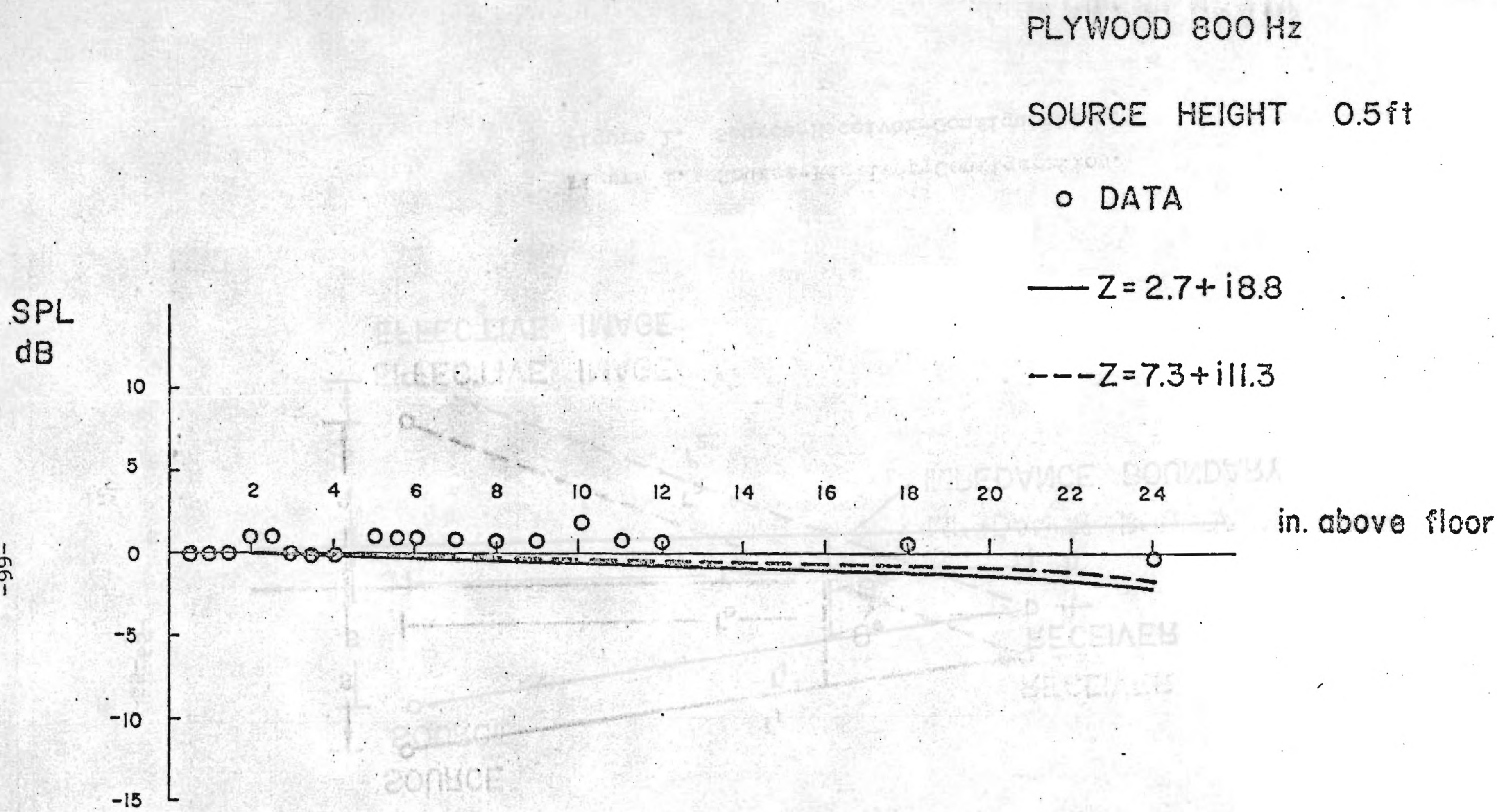


Figure 2. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

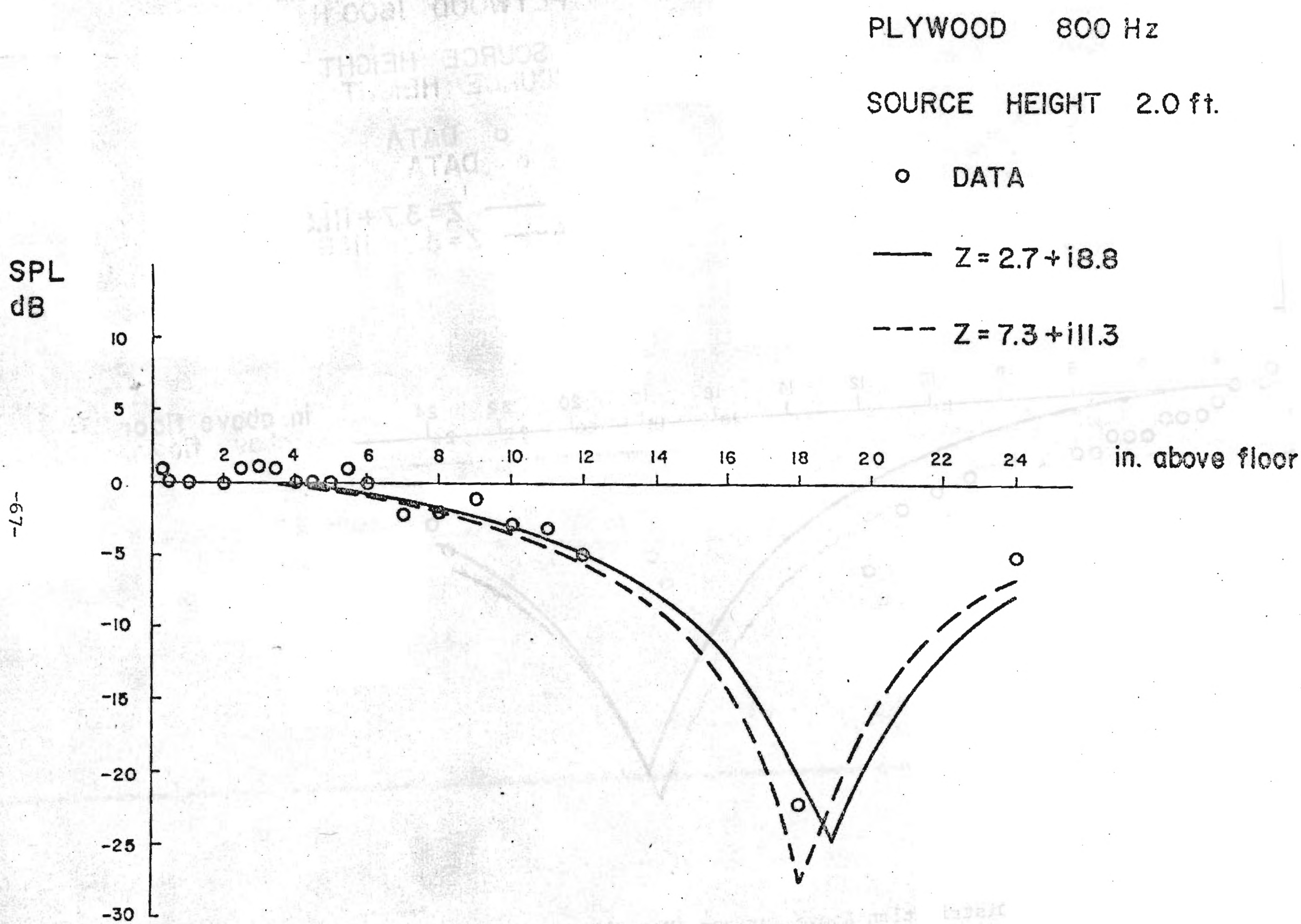


Figure 3. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

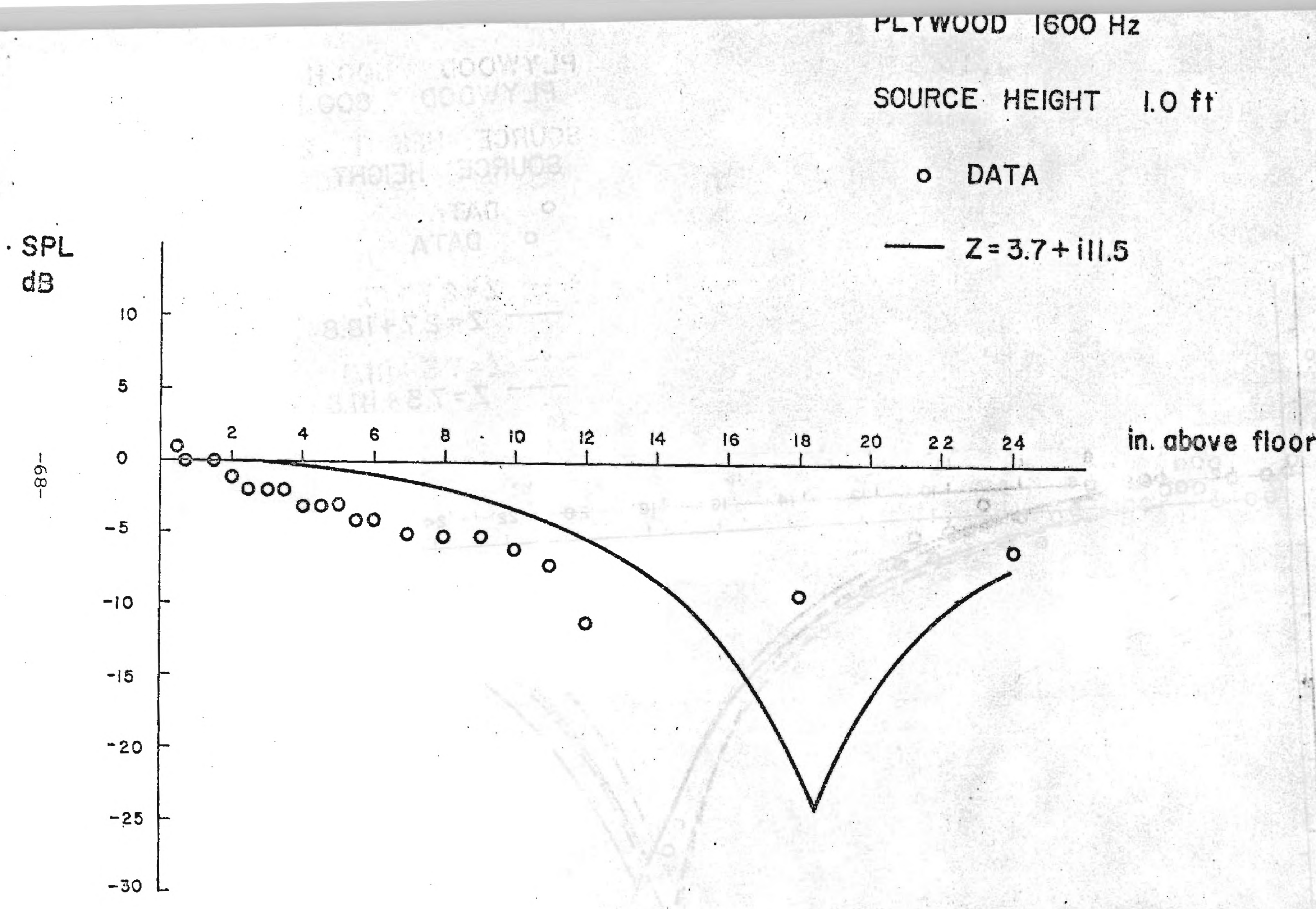


Figure 4. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

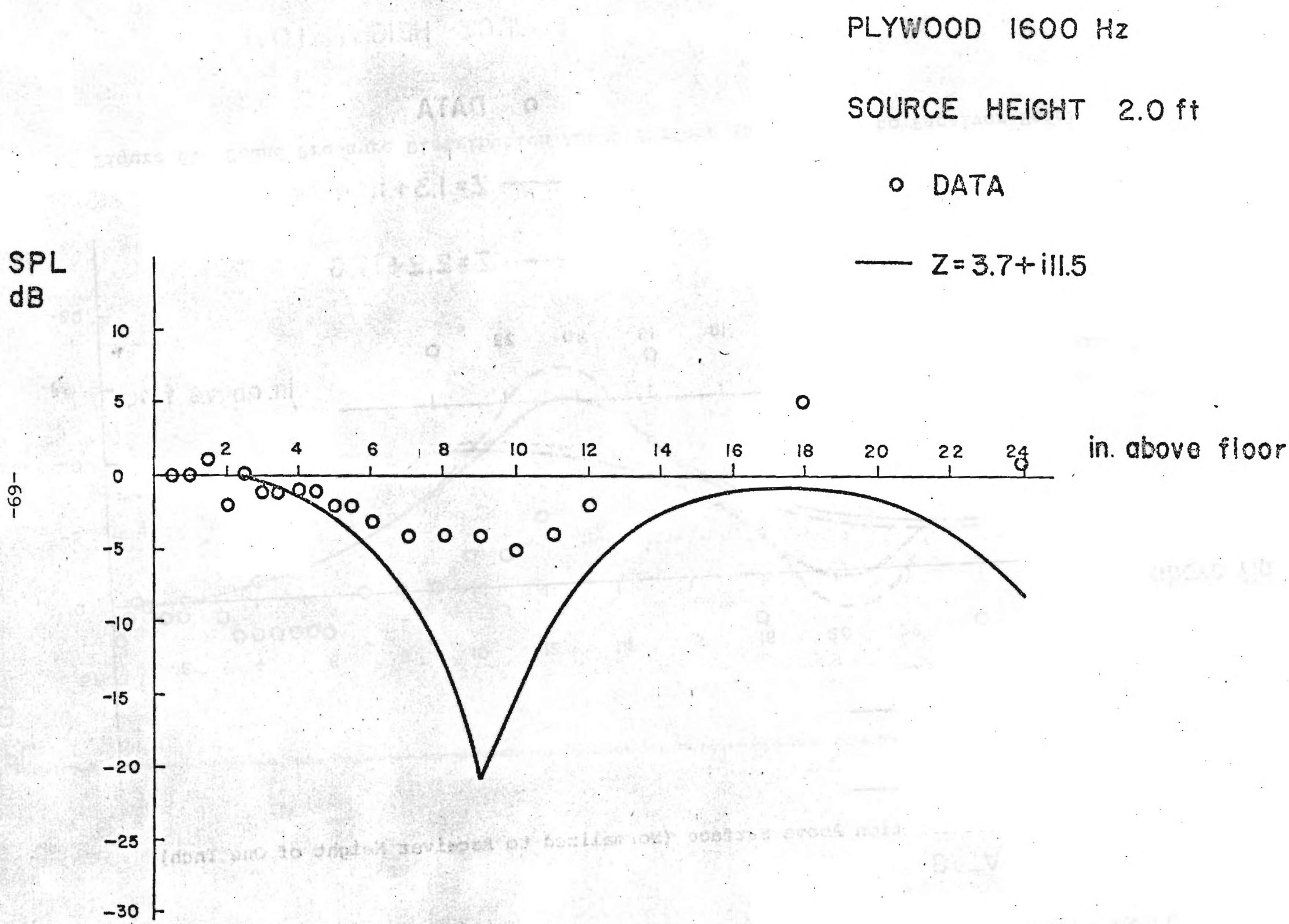


Figure 5. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

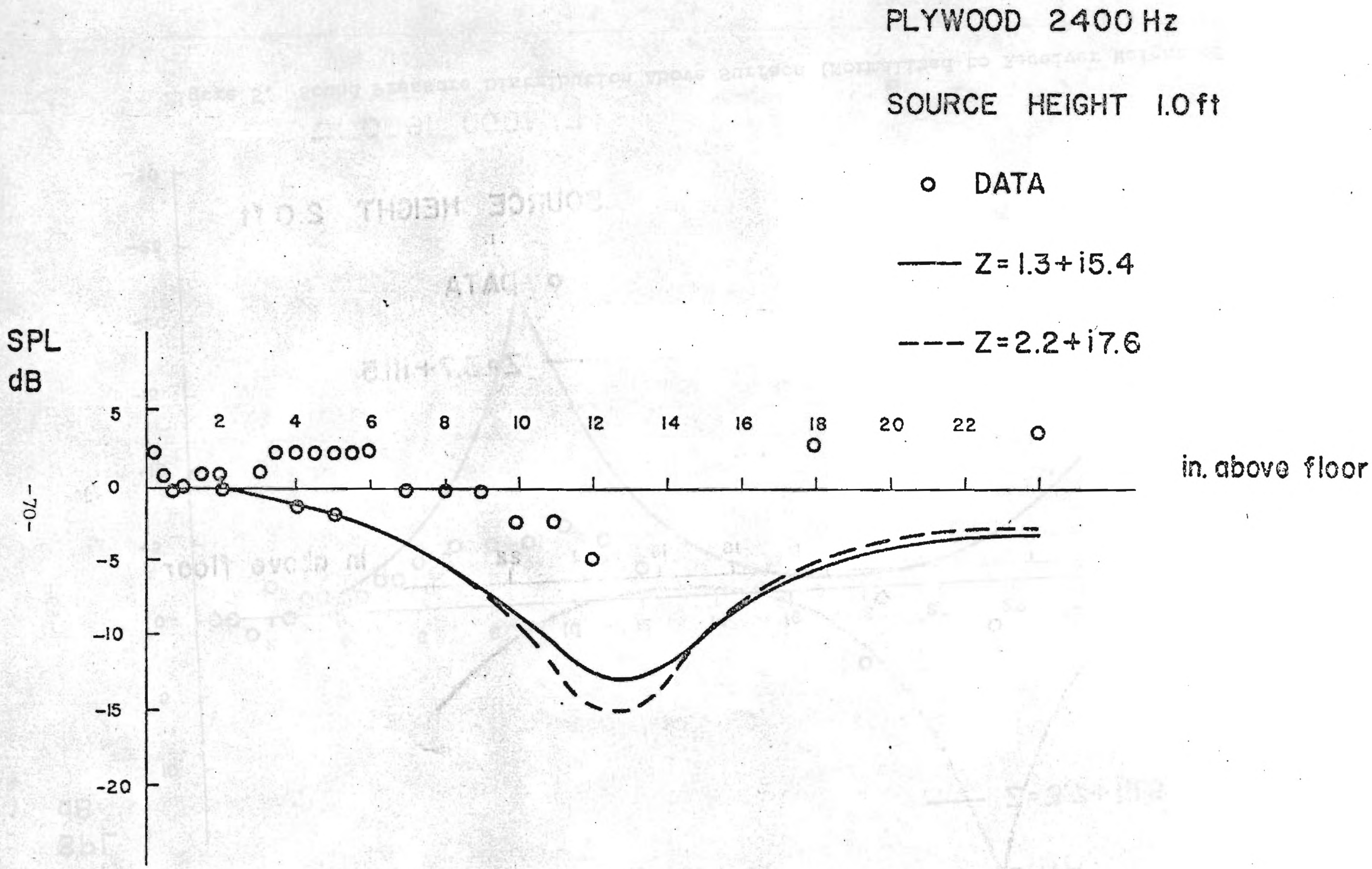


Figure 6. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

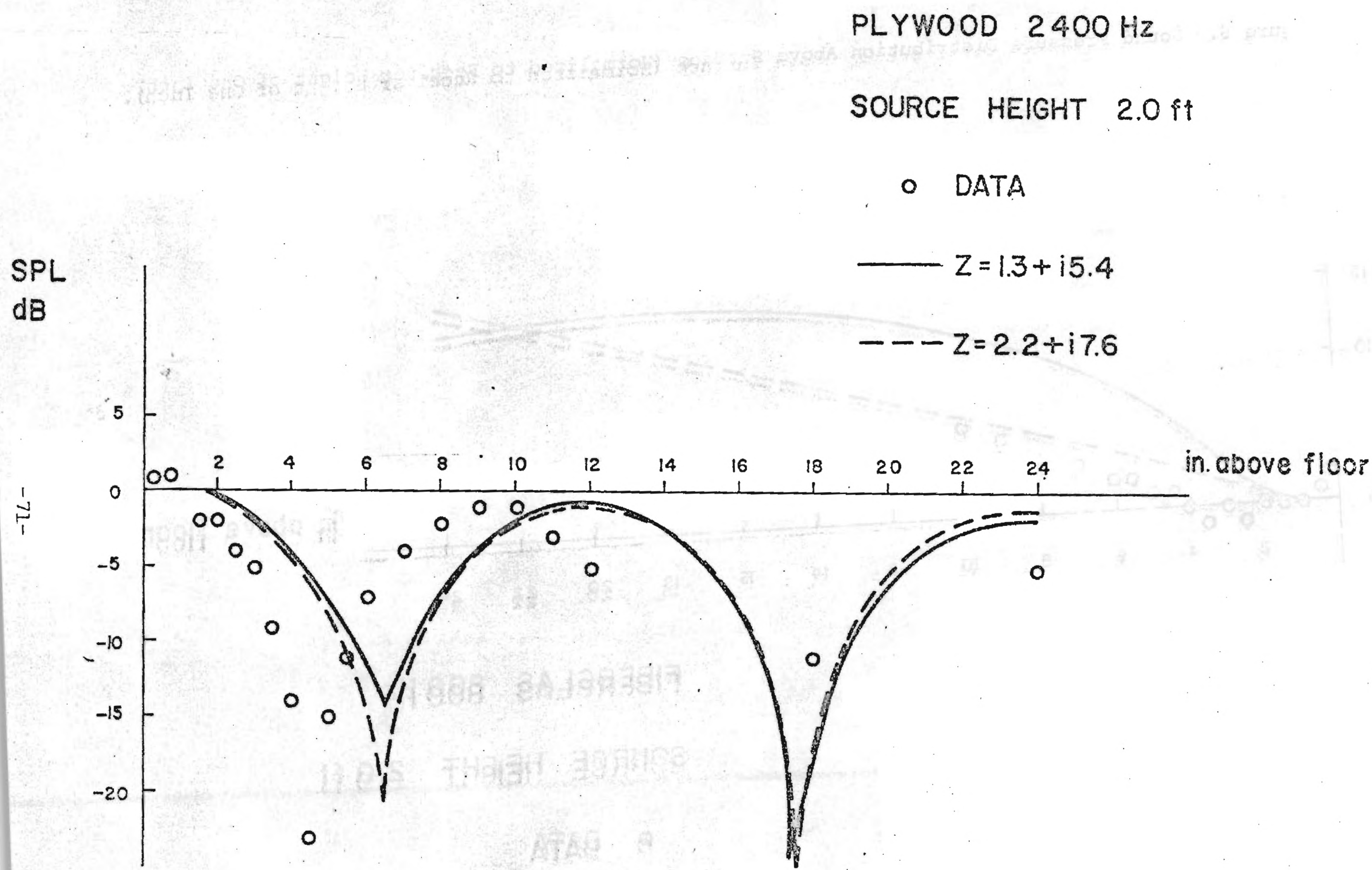
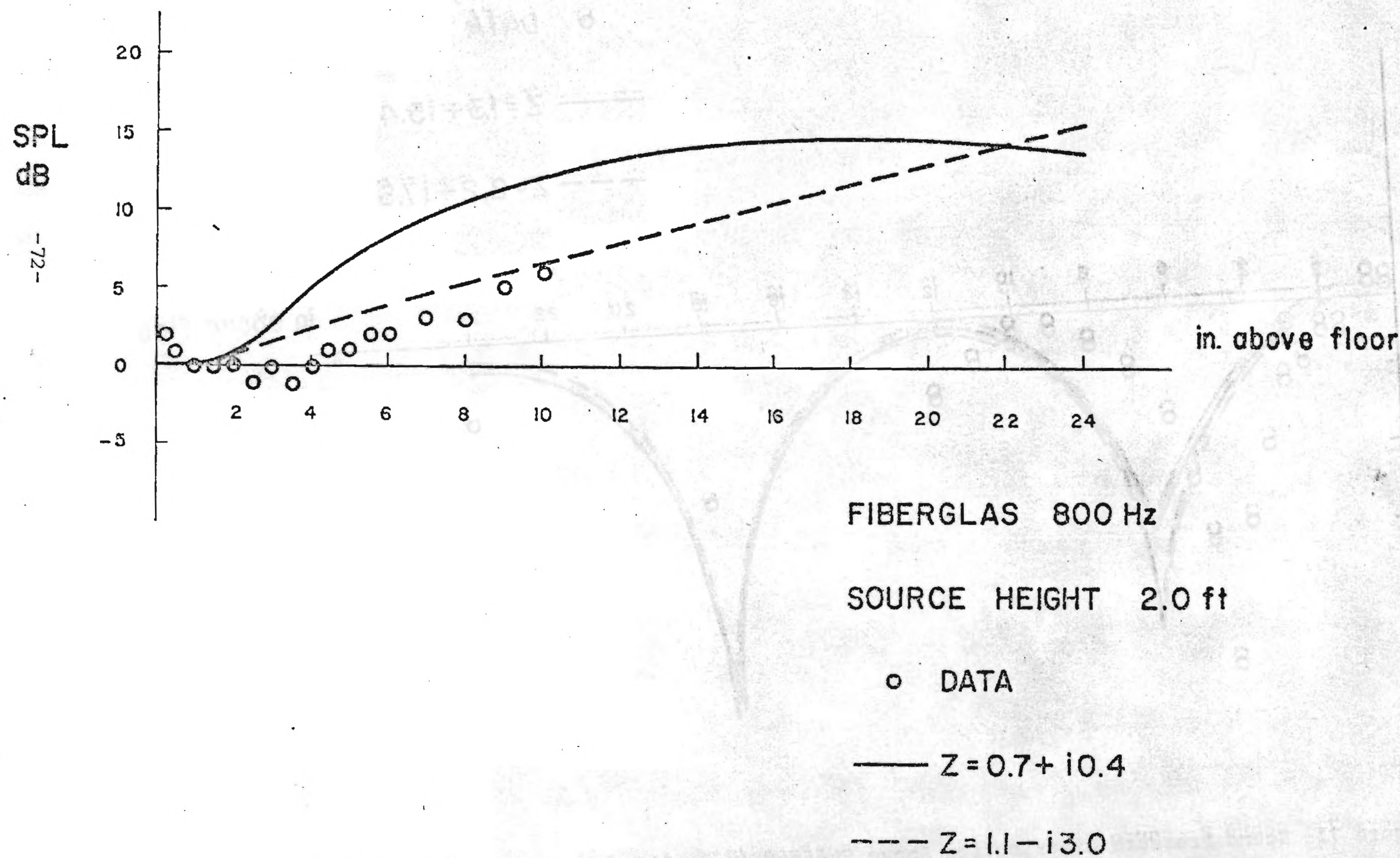


Figure 7. Sound Pressure Distribution Above Surface (Normalized to Receiver Height of One Inch).

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



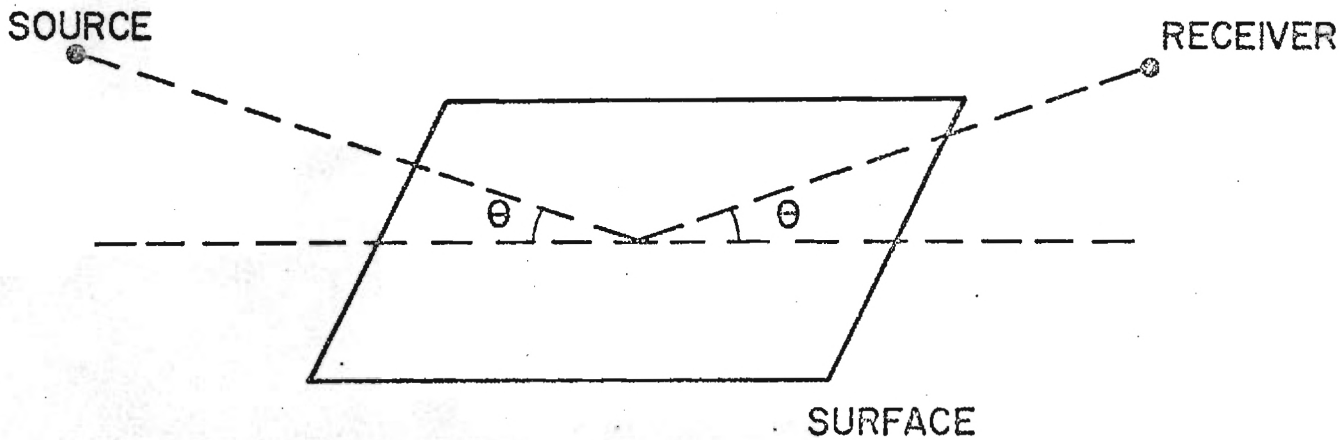


Figure 9. Experiment Geometry: Reflection by Finite Surface.