THE DEVELOPMENT OF A COMPUTER PROGRAM USING A MODIFIED ROOM ACOUSTICS APPROACH TO DETERMINE SOUND LEVELS IN REGULAR ROOMS

by

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1.0 INTRODUCTION

In today's industrial society, workers are often subjected to high noise levels. Nearly everyone is affected regardless of their occupation. Examples range from the laborer in a steel plant to the user of a lawn mower. In fact it has been estimated that nearly forty per cent of the national working force encounters daily noise levels which could cause some form of hearing damage. Industry strives for a continually greater output of a better product manufactured at lower cost than yesterday. The systems developed to produce such a product commonly become faster and noisier. Thus the environment of the worker steadily worsens since the greater loads and speeds imposed on manufacturing equipment usually produce greater noise levels.

Because of concern over noise levels and other environmental factors faced by today's workers Congress passed the Occupational Safety and Health Act of 1970 [1]* as an attempt to curb these situations. The section of this bill dealing with noise was an expanded version of the guidelines presented in the Walsh-Healey Act of 1969 [2].

The primary thrust of the noise section of the Occupational Safety and Health Act is to specify the allowed employee exposure times for various maximum A weighted sound pressure levels. The A level weighting system is simply a system which emphasizes higher frequency noise to

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* The numbers in brackets indicate references contained in the bibliography.

more closely match the response of the human ear. The frequency range more important in this weighting system would be from 500 to 4000 hertz. By more closely matching the response of the human ear this weighting system is thought to better describe sound pressure levels below which no hearing damage will occur. Another provision of this section of the Occupational Safety and Health Act (OSHA) provides fines for failure of industries to comply with these limits. To make compliance an even more important task there is a provision stipulating that earplugs and other protective devices may be used only after all other reasonable engineering means have been exhausted in attempts to alleviate the noise problem.

Faced with this law and its penalties industries have revived interest in available methods to predict and lower noise levels. The greatest need is the prediction of noise in factory spaces and rooms. Unfortunately present methods available to calculate sound levels in rooms have severe limitations and in some cases exhibit a great deal of inaccuracy.

1.1 Limitations

One of the simplest and most practical means of calculating sound levels is through the use of the room acoustics equation commonly given in this form.

$$SPL = SWL + 10 \log_{10}\left(\frac{Q}{4\pi r^2} + \frac{4}{S(\bar{\alpha} + \frac{4V}{S} m)}\right) \quad (1)$$

where:

SPL = sound pressure level, dB.

SWL = sound power level, dB.

Q = directivity index

r = distance from source to receiver, meters

S = total surface area of the room, square meters

$\bar{\alpha}$ = average sound absorption coefficient for the room surfaces, sabines ?

V = the volume of the room, cubic meters

m = air absorption coefficient, meters^{-1}

Descriptions and derivations of this equation may be found in any fundamental text in acoustics, e.g., Embleton [3] and Kinsler and Frey [4]. At this point only some general characteristics of this equation will be discussed. A more complete description is left to later sections.

This equation assumes that there are two types of sound energies in a room. The first type of sound energy is the direct energy. This is the energy which travels directly from the source to the receiver with no reflections from the room surfaces. This sound energy is described by the direct term of the room acoustics equation which is,

$$\frac{Q}{4\pi r^2} \tag{2}$$

This equation assumes that sound energy is radiated in a spherical pattern from the source. Factors for directivity are commonly tabulated which allows radiation patters which are convenient fractions of a sphere to be considered. However, practically sources do not radiate sound energy strictly in spherical or partially spherical patterns. Therefore inaccuracy can result when this term is used with presently available directivity indexes.

The second type of sound energy is that which has reflected from the room surface several times before reaching the receiver. This energy is described by the reverberant term which is,

$$\frac{4}{S\ (\bar{\alpha} + \frac{4V}{S} m)} \tag{3}$$

The assumption is made in deriving this term that the reverberant energy density is constant throughout the room, which allows the room characteristics to be statistically averaged. It is generally acknowledged that there are many rooms where this assumption is violated. Consequently there are many situations where the use of the room acoustics equation results in inaccurate predictions of sound levels.

There are also other limitations on the use of the room acoustics equation. Because of the assumption made in the derivation of the room acoustics equation it can only be used in rooms where the dimensions are large with respect to the wave length of any frequency of sound being considered [3]. For instance the center frequency of the 63 hertz octave band has a wavelength of nearly 18 feet. This length would certainly correspond to possible room dimensions precluding accurate analysis at this frequency using the room acoustics equation.

However, these low frequency noises are attenuated in importance by the A weighted scale. Thus the overall dBA sound level predictions may not be grossly in error from this effect unless low frequency noise dominates in a very small industrial space.

When a receiver point is located near a wall it is possible for the sound pressure wave reflecting from the wall to be of enough magnitude to add significantly to the sound pressure level at the receiver point. The room acoustics equation, however, has no provisions to predict such a situation. Consequently, at receiver points located near a wall this equation predicts lower than actual sound levels.

The final limitation of this equation is simply the number of calculations required to determine sound levels throughout a room. Calculations would have to be made for each of as many as eleven octave bands at several positions throughout the room and then repeated for each noise source present. The result is so many calculations that in practice they are seldom attempted.

The work reported here involved two primary areas of concern. The first was the development of a modified version of the room acoustics equation. The modifications made included improvements to the direct term to allow radiation patterns other than convenient fractions of a sphere to be considered. Also modifications were made to the reverberant term to account for deviations from the assumption of a constant reverberant energy density. Modifications were also included to improve the predictive accuracy of this equation when receiver points are near a wall and when wavelengths of the frequency of sound being analyzed are greater than the room dimensions.

The second area of work was the development of a computer program using this modified room acoustics equation to determine sound pressure levels in rooms. Incorporated in this program were the capabilities to generate an array of receiver points in a room and to perform calculations through up to eleven octave bands and for up to 25 sources. Also this program has the capability to use sound power levels and sound pressure levels given for a source to determine sound pressure levels throughout a room. Furthermore, logic was incorporated into the program to convert several octave band sound pressure levels to an overall dBA sound pressure level.

In order to make the development of this computer program a tractable task the limitations on the number of octave bands and sources mentioned previously were necessary. Another restriction was that the program may be applied only to regular rooms, that is, quadralateral parallelepipeds.

The following sections are presented to describe the work of developing the modifications to the room acoustics equation, the verification of the validity of the modifications made, and the development of the computer program in which the modified equation is used. Finally, two appendices are presented which thoroughly explain the computer program and its use. Before discussing the modifications to the room acoustics equation, a review of the developments of the room acoustics equation and other aspects of room acoustics is necessary.

2.0 LITERATURE REVIEW

Although the science of acoustics spans centuries the particular area of room or architectural acoustics can be traced to its beginning around the first of the twentieth century. It is this area of room acoustics which was of interest in this project. Many of the early accomplishments in the area of room acoustics were the result of the work of W. C. Sabine [5] during the late 1890's and early 1900's. Of course, the presently accepted equations and concepts were developed over the years by many other investigators.

The following paragraphs will discuss the work of W. C. Sabine and other important work in the area of room acoustics. More specifically the controversy concerning mean free path, recent developments in room acoustics and work involving the application of computers to room acoustics will be discussed.

2.1 Early Development of Room Acoustics

W. C. Sabine is generally credited with being the founder of architectural or room acoustics [4]. Although he worked primarily in the area of reverberation time and the acoustics of churches and auditoriums, Sabine created the three basic concepts which have resulted in what is known as room acoustics. The first of these was the concept of sound power absorption by the room surfaces. Sabine [5] even went on to show that the amount of absorption was proportional to the surface area of absorptive material exposed.

The important concept of an average distance between two consecutive reflections of sound from the various room surfaces commonly referred to as the mean free path was also developed by Sabine. Sabine [6] developed a formula for calculating this quantity much like that used today.

The most basic concept Sabine fathered, however, was that the position of absorptive material in a room had no effect on the sound pressure levels throughout the room. This concept is, in general, incorrect. However, at that time Sabine [6] was performing studies in auditoriums which were basically cubic or hemispherical in shape. These were cases in which the assumption that the position of absorptive material had little effect on the behavior of sound energy in the room was esentially correct. The independence of sound pressure levels with respect to the position of absorption material is equivalent to the assumption that the reverberant energy density is constant throughout the room. This is the basic and underlying assumption in the development of the reverberant term in the room acoustics equation. Finally, it should be noted that Sabine attempted to develop simple formulas to predict the behavior of sound energy in rooms. It was this very same desire which brought about the development of the room acoustics equation.

2.2 Controversy Concerning Mean Free Path

Several years after the death of W. C. Sabine, P. E. Sabine [7] published a derivation claiming that

$$MFP = {}^{4V}/_{S} \tag{4}$$

where:

MFP = mean free path, meters

V = volume of the room, cubic meters

S = total surface area of the room, square meters

In the ensuing years a heated debate raged as to whether this was the correct formula for determining mean free path. V. O. Knudsen [8] performed optical experiments on scale models of auditoriums which indicated that mean free path could vary from the value predicted by this equation by as much as eighteen per cent. However, several of the auditoriums examined by Knudsen were of odd shapes, that is in the shape of crosses, L's, and other unusual shapes. The variations shown by Knudsen were, therefore, somewhat questionable as far as predicting the accuracy of Sabine's equation for determining the mean free path in rectangular rooms. The emphasis on rectangular rooms was considered important since this would be the room shape most often encountered. Later Millington [9] provided a comprehensive derivation which confirmed the equation proposed by Sabine. Interest in mean free path subsided until it was revived again after nearly 20 years in 1959 when R. W. Young [13] commented that the quantity had never been defined and listed authors claiming greater than eighteen per cent variation from the formulas proposed by Sabine and Millington. Even today there remains doubt as to the value of mean free path. However, noted authors such as Embleton [3] have persisted in using Sabine's formula.

Between the debate over mean free path in the 1930's and the late 1950's there were many measurements made and several studies concluded [11,12,13]. However in general there were few theoretical developments not only in the area of mean free path but in room acoustics in general during this period.

Because of studies made in large auditoriums and open spaces speculation arose during this period that there was some sort of dissipation of sound energy as the sound passed through the air. During the period between the 1930's and the late 1950's work began on conducting experiments to quantify and apply air absorption in room acoustics. Several experiments were conducted to determine the values of air absorption at various air temperatures and frequencies of sound. Work was also begun on developing theories of molecular interactions involved in this disapation process.

2.3 More Recent Work in Room Acoustics

It was during the late 1950's that work and interest were renewed in the area of room acoustics. Work began on the application of computers to room acoustics calculations. Also work was done in simulating the acoustic response of rooms. For instance, M. N. Schroeder [14] did work in simulating the quality of sound in auditoriums using several speakers controlled by a computer. There were programs developed to add sound pressure levels, to make dBA conversions, and to make rudimentary sound pressure level calculations. But none of these programs could perform the detailed calculations proposed here.

In one interesting piece of work, Allred and Newhouse [15] used a Monte-Carlo technique to statistically determine the mean free path for various rooms. Here once again the values calculated by this method varied by at most eighteen per cent from those calculated using Sabine's formula.

Also during the late 1950's the room acoustics equation was reduced to the form described in equation (1). This development was produced by Embleton [3], Kinsler and Frey [4], and others.

After the development of this equation the limitations of the room acoustics equation began to be documented. H. J. Sabine [16], stated in the 1950's that the room acoustics equation was quite inaccurate in long rooms with relatively low ceilings. Lambert [17] and Embleton [3] each published data demonstrating the difference between the predictions of sound levels using the room acoustics equation and actual measurements.

At present, the room acoustics equation remains in the form shown in Equation (1). Although the above documentation has been published for several years, no valid attempts have been made to modify the room acoustics equation to correct for these documented failures.

In summary, perhaps it should be said that the lack of continual work in room acoustics was due to the lack of need and of interest in more accurate results in sound pressure level calculations. The need and interest have greatly increased recently with the implementation of OSHA. As for the question of mean free path, it would seem rather straight forward to tabulate correct values for various room proportions using some statistical technique. Until this is done an error of at most eighteen per cent or $\pm$ 0.72 dB is not large. Moreover, this is an error in only one term, the reverberant, which is often not the dominant term of the two which determine the sound pressure level. However, better knowledge in this area could improve the predictive capabilities of room acoustics. The important point to note from the previous work is that a comprehensive theory that provides accurate results no matter what the rooms properties is needed in room acoustics. If the calculations become involved they could be performed easily and rapidly by a digital computer.

3.0 MODIFICATIONS TO ROOM ACOUSTICS

It became clear immediately that an area of primary concern was going to be the room acoustics equation and the modifications necessary to allow it to more accurately predict sound levels in actual rooms. The purpose of this particular section is to outline the modifications made to the room acoustics equation and to present a brief explanation of each modification. These modifications were separated into four major sections; those made to the reverberant term, those made to the direct term, those made when wavelengths were greater than the room dimensions, and those made when a receiver point was near a wall. The first to be discussed is the modifications to the reverberant term.

3.1 Reverberant Term Modifications

As stated previously, Lambert [17] and Embleton [3] published data documenting the failure of the room acoustics equation to accurately predict sound levels in a room. The rooms studied by these two investigators were nearly the same in terms of physical size and shape. An important quantity which varied between the studies of Lambert and Embleton was the room constant. This parameter is commonly used as a measure of the sound absorptivity of a room. The room constant is defined as follows,

$$RC = S(\bar{\alpha} + \frac{4V}{S}) \qquad (5)$$

where

RC = room constant, square meters

S = the total surface area of the room surfaces, square meters

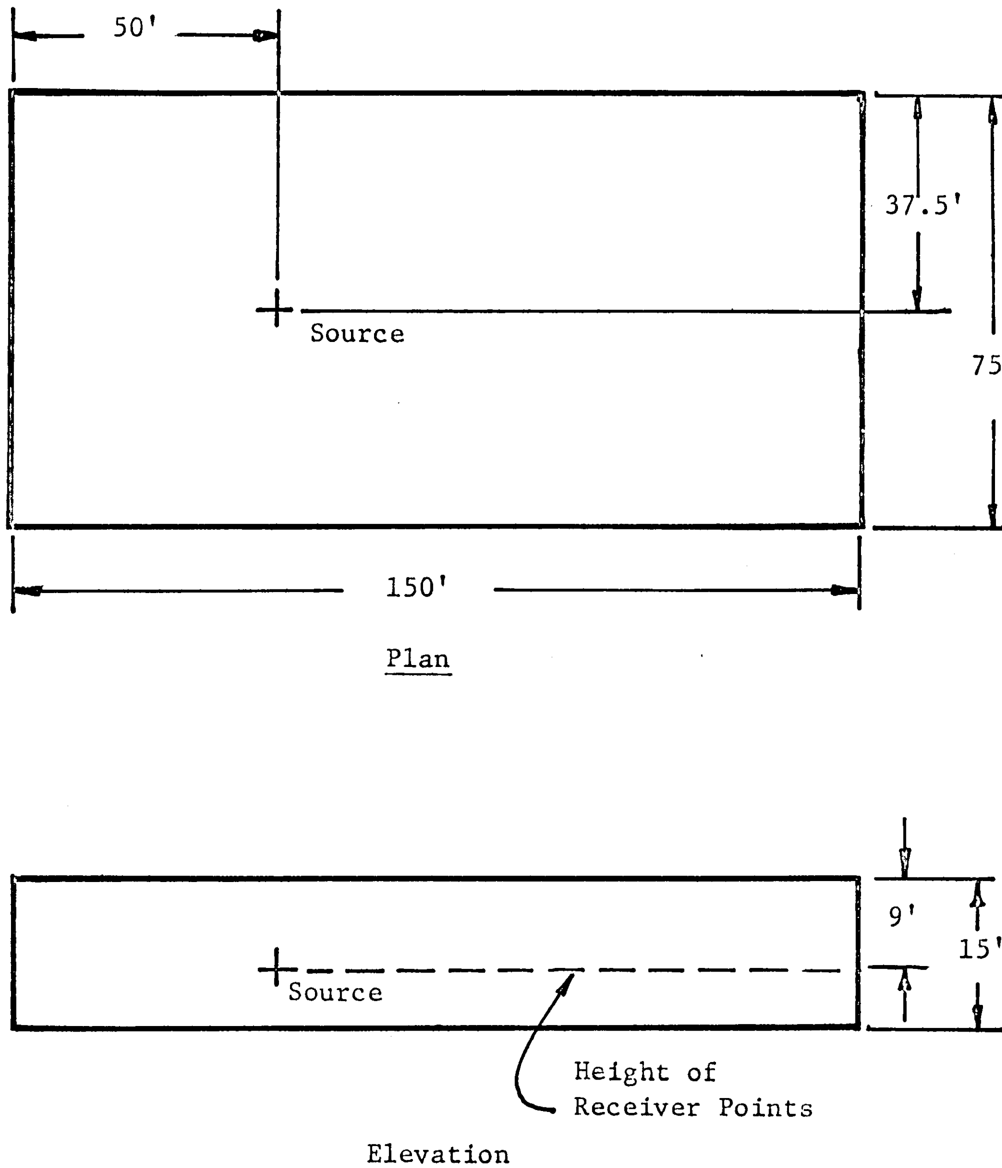
$\bar{\alpha}$ = the average absorption coefficient for the room, sabines

V = the volume of the room, cubic meters

m = air absorption coefficient, meters^{-1}.

This quantity is also used in the reverberant term of the room acoustics equation as can be seen in Equation (3). Also there was a difference in the sound pressure levels measured by Lambert and Embleton. Since the data of Embleton were much more recent these were selected to be used for this work. However, the general trend, departure of the measured and calculated data at large distances from the source, was similar in the rooms described by both authors.

The room described by Embleton was 150 feet (45.72 m.) long, 75 feet (22.86 m.) wide and 15 feet (4.57 m.) high. The source was placed 50 feet (15.24 m.) from one end of the room at a height of 6 feet (1.83 m.). The receiver points ranging in distance from 2 to 100 feet (0.61-30.48 m.) from the source were also at this height. The room constant was given as 8000 square feet (743.22 m.^{2}). This room was further defined as a classroom with an acoustical tile ceiling. For a more complete description the reader should consult Figure 1. Sound pressure levels were measured at each of the receiver points and the sound power subtracted to give the relative sound pressure level.



Description of Room Measured by Embleton.

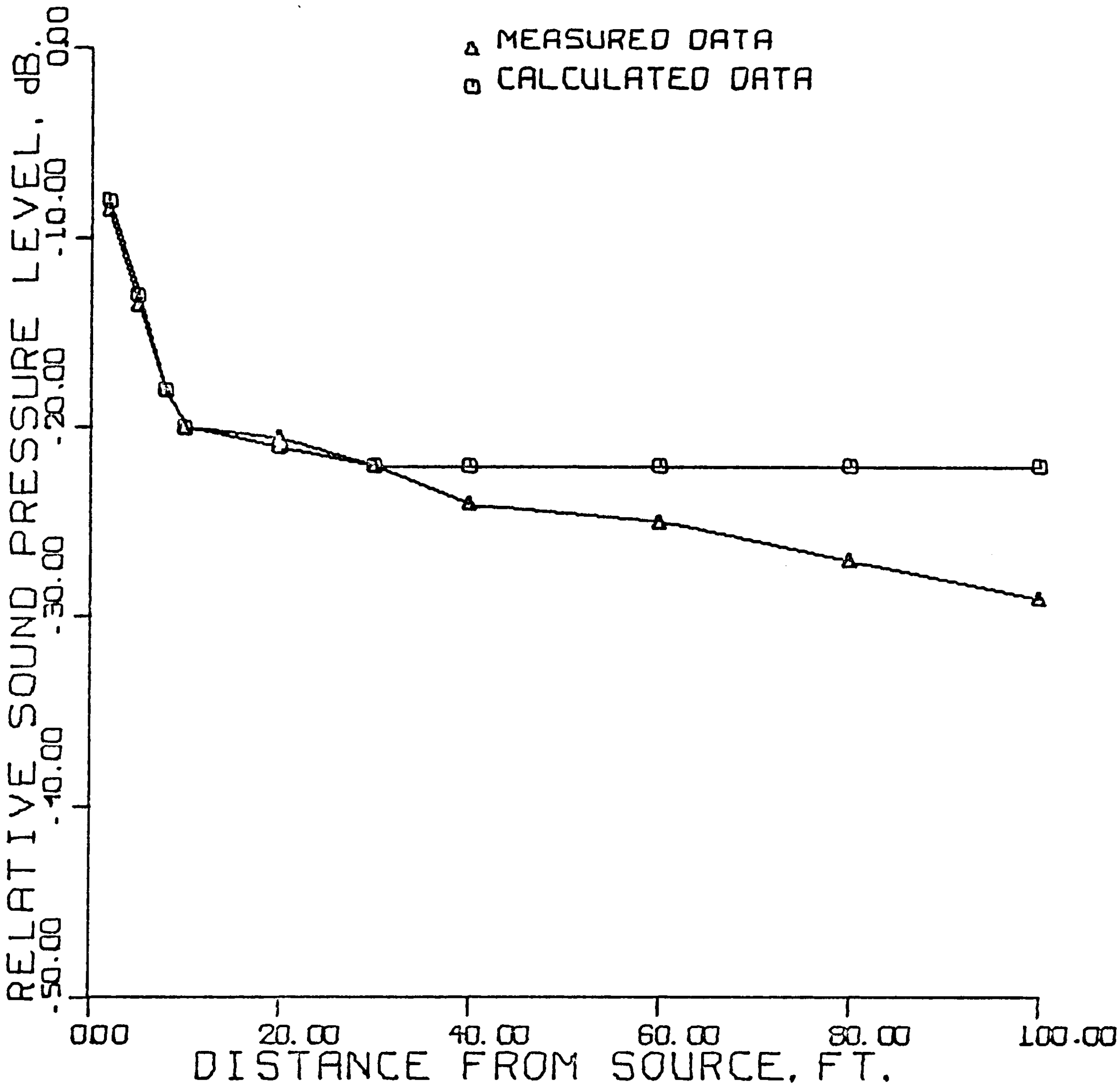
Figure 1

Embleton's calculations were made assuming a sound power level of zero to achieve comparable results. These relative sound pressure levels were then plotted versus distance from the source as in Figure 2.

The room acoustics equation predicted relative sound pressure levels in error by 5 dB at the end of the room. Embleton [3] and Lambert [17] attributed this poor prediction of the room acoustics equation to the lack of a diffuse reverberant sound field in the room. This was caused by the large amount of absorptive material on the ceiling and the strong departure from a cubic room shape. The lack of perfectly diffuse reverberant sound energy would mean a violation of the assumption used in deriving the reverberant term of the room acoustics equation. Thus the reverberant energy density throughout the room was not uniform.

The important trend which resulted in the 5 dB variation at the end of the room was that while the measured values continued to decrease with distance the calculated values approached an asymptotic value 5 dB higher than the final value reached at the end of the room (see Figure 2). The level of this asymptotic value was simply ten multiplied by the log of the reverberant term of the room acoustics equation.

The obvious conclusion was that a modification had to be made to the reverberant term to reflect the continuous decrease in the sound pressure level as seen in Embleton's data. It was decided that the reverberant term should decrease directly with increasing distance since this would coincide with the decrease in sound pressure level exhibited by Embleton's data. Therefore, the reverberant term of the room acoustics equation was multiplied by the factor,



RELATIVE SOUND PRESSURE LEVEL DATA PUBLISHED BY EMBLETON*

FIGURE 2

* TAKEN FROM EMBLETON, TFW, *NOISE AND VIBRATION CONTROL*, CHAP. 9, ED. BY L.L. BERANEK, MCGRAW-HILL, 1971, P. 230

$$\frac{MFP}{r} \cdot \frac{4}{S(\bar{\alpha} + \frac{4V}{S} m)} \tag{6}$$

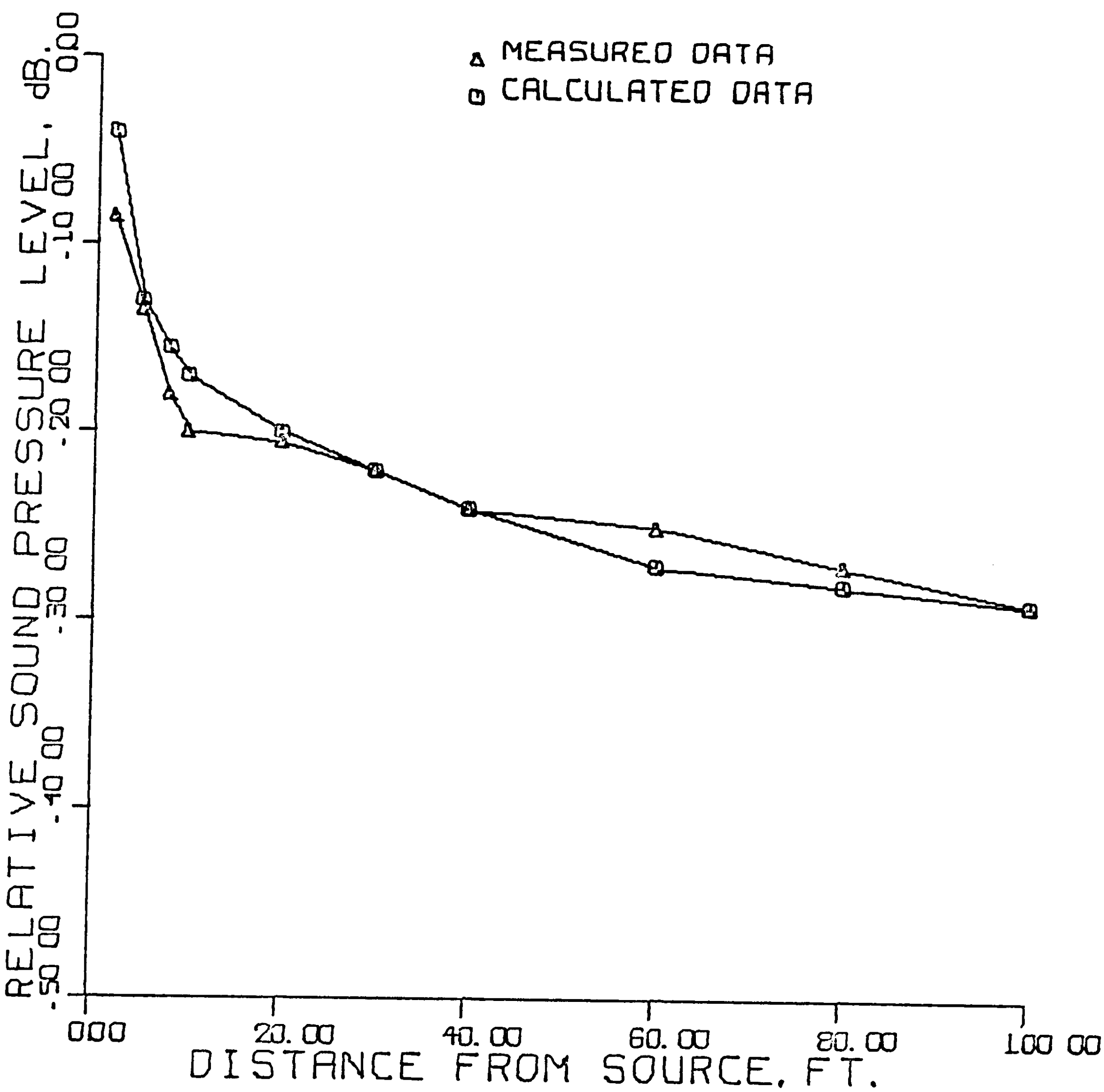
where:

MFP = mean free path, meters

r = the distance from source to receiver, meters.

However before applying this modification it was felt a proper value for air absorption should be included in the calculation. Embleton had not stated whether air absorption, had been included in his calculations. It was assumed he had not since no mention was made of air absorption. Since Embleton did not specify what octave band his measurements were made in or the temperature and relative humidity during these measurements the inclusion of air absorption which is a function of these variables was rather difficult. Since the room was identified as a classroom it was assumed that the octave band at which measurements were taken would be in the speech range from 500 to 4000 hertz. After several trials, comparing calculated values to those published by Embleton, the 2000 hertz octave band was selected. Air absorption values were averaged over temperature ranges of 15 C to 30 C and relative humidity ranges of 30 to 70 per cent. It should be noted that the inclusion of air absorption only resulted in a difference of 1 dB in the final value reached by the calculations.

The results when the modification to the reverberant term was combined with the inclusion of air absorption were quite promising, as can be seen in Figure 3. The curve shapes were generally the same and both reached approximately the same values at the end of the room. However, there were still modifications to be made to the direct term before the



COMPARISON OF RELATIVE SOUND PRESSURE LEVELS MEASURED BY EMBLETON AND CALCULATED USING A MODIFIED ROOM ACOUSTICS EQUATION

FIGURE 3

completely modified room acoustics equation was developed.

3.2 Direct Term Modifications

The essence of the direct term is the directivity index, Q, which is the ratio of spherical surface area, of radius equal to the distance between source and receiver, to the actual area through which the sound energy must propagate. Thus the relationship for Q is,

$$Q = \frac{4\pi r^2}{\text{actual area of radiation}} \tag{7}$$

where:

r = distance from source to receiver, meters.

By defining directivity in this manner it was assumed that equal amounts of energy stream from the source in every direction when Q = 1. This assumption is often violated when real sources are considered and can be a source of error. For example if a source is located on a hard floor then one half of the sound energy is reflected from the floor. Therefore, a-spherical source has a hemispherical radiation pattern. The directivity index would then be 2.

One of the primary limitations found in use of the direct term was that directivity indexes which were tabulated in most fundamental texts [3,4,17] were only for spherical, hemispherical and one eight of a sphere radiation patterns. However, there are instances where radiation patterns could be other than these.

If two parallel walls were within one meter of a source suspended in space the radiation pattern produced would appear as a strip around a sphere of width equal to the distance between the walls. The radius would be the distance between the source and receiver (Figure 4). In most cases as discussed above the distances between the two walls would be small compared to the distance from source to receiver. Therefore, the radiation pattern could be approximated by a cylinder of the same radius with a height equal to the distance between the walls. The value for Q for such a case would be

$$Q \cong \frac{4\pi r^2}{(2\pi r)\ \text{width}} \tag{8}$$

where:

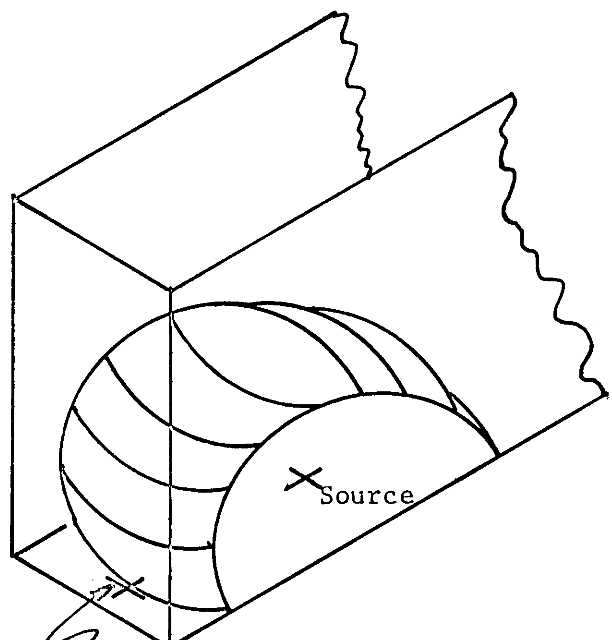
width = the distance between the parallel surfaces, meters

r = the distance from source to receiver, meters

There were several variations of this radiation pattern. For instance, the source could have been located on the floor. This would have resulted in a radiation pattern resembling a half-cylinder. Other possible variations were included in the calculations for directivity in the computer program. This type of radiation would be analogous to sound propagation down a duct or tube.

It should be noted that in the previously mentioned directivity calculations and others one meter was used as the distance between the source and room surfaces before reflective effects were seen. This was an arbitrary choice since Embleton [3] and others simply specify a source as being "near" a reflecting surface.

While examining the above possibilities for areas of radiation, another limitation of the direct term became obvious. Normally the directivity index is determined for the original source position assuming any surface within a meter is a reflecting surface and alters



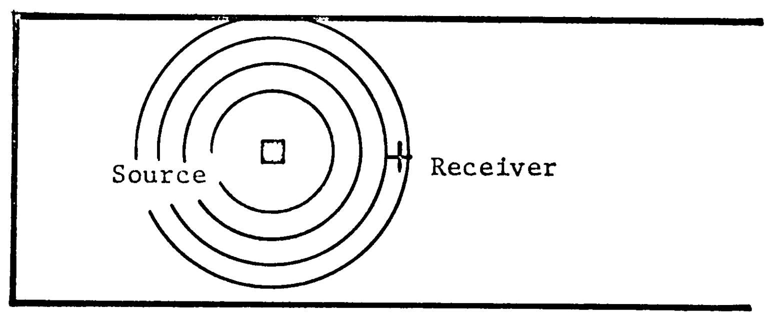
Radiation Pattern of a Source Between Two Walls.

Figure 4

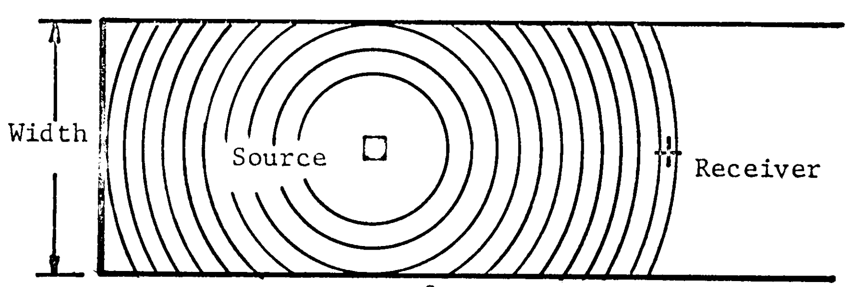
the radiation pattern of the source. However, in some rooms this practice could result in error. For instance, in a long narrow room with a source located on the floor several meters from any other surface, the directivity index would be calculated to be 2. For receiver points near the source this would be the correct directivity index (see Figure 5a). However for points at a great distance from the source the radiation pattern would appear to be different resulting in a new directivity index (see Figure 5b). To accomplish this same effect in the analysis the distance from the source to receiver was subtracted from the distance between the source and each of the room surfaces. If the result of any of these subtractions is zero or negative the surface is considered to alter the radiation pattern and thus the directivity of the source as if it were within one meter of the source.

Another feature of the directivity calculation commonly ignored is that all room surfaces are assumed to reflect all sound energy incident upon them. In the case of an acoustical tile ceiling or other highly absorptive surface this would not be the case. Therefore, logic was incorporated in this program to enable the user to designate a surface as being highly absorptive. The directivity calculation would then neglect any reflection from that surface.

The final modification made to the direct term was simply to include the absorption of sound energy by the air. Although air absorption had been included in the reverberant term previous to this work no attempt had been made to incorporate it on the direct term. Certainly there is air absorption of the direct as well as the reverberant sound



With source on floor Q = 2
(a)



$$Q = \frac{4\pi r^2}{\pi r \times \text{width}}$$

(b)

Directivity Index at Different Distances from the Source.

Figure 5

energy. For instance, in an open space or free-field environment the reverberant term becomes zero leaving only the direct term to represent the decay of sound energy. It would seem obvious that air absorption should be included in such a case. In the case of large factory spaces direct radiation can travel great distances which can result in significant air absorption. Therefore, using the form Kinsler and Frey [18] derived for the decay of sound energy in any fluid the direct term was multiplied by

$$e^{-mr} \tag{9}$$

where:

m = air absorption coefficient, meters^{-1}

r = distance from source to receiver, meters

This completed the modifications made to the direct term. However, there were modifications necessary in two special cases.

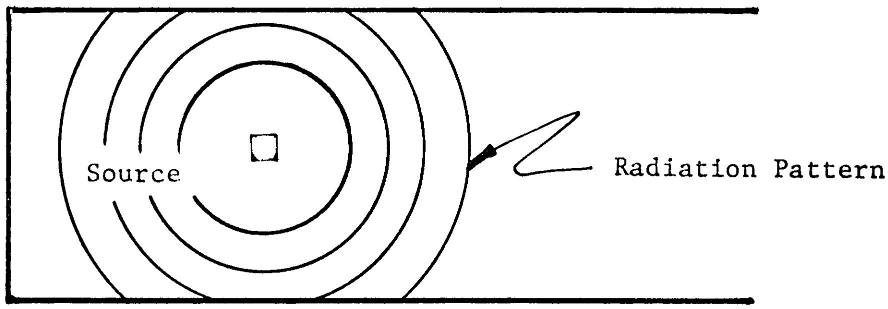
3.3 Wavelengths Greater than Room Dimensions

As stated in a previous section one of the limitations of the room acoustics equation was that it could not be used when the wavelength of the octave band center frequency was greater than any room dimension. The reason for this limitation was simply that the sound wave began to appear as a plane wave propagating down the room if its wavelength became greater than the room dimensions. Moreover, significant standing waves can occur resulting in less chance for diffuse sound fields being generated in such small rooms. Therefore, in a case such as this the analysis would include a special calculation for the directivity index.

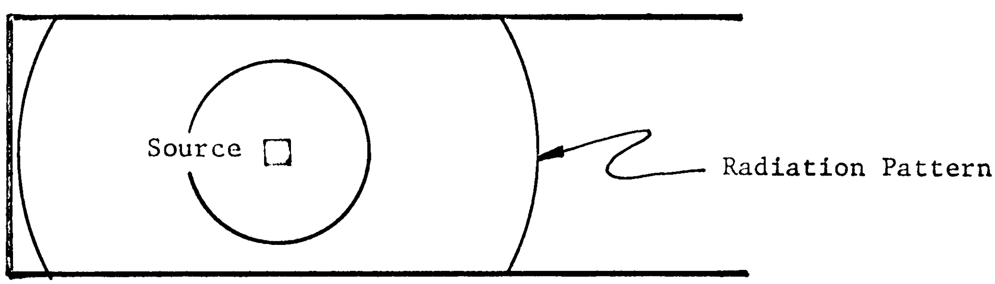
In this calculation any room surface within a wavelength, instead of the previously used one meter, of the source was assumed to reflect the sound energy incident upon it unless the surface had been designated as soft by the user. The directivity index was then calculated accordingly (see Figures 6a and 6b).

There was yet another modification required to account for the wavelength being greater than the room dimensions. The second modification was to increase mean free path in these special cases to the greatest dimension of the room. Beranek [19] stated that for plane waves in a tube the mean free path was the length of the tube. Although this would not be exactly the same conditions as in a room with one or two dimensions less than the wavelength, it much more nearly approximates the conditions than the standard equation for mean free path.

This completed the modifications made to the room acoustics equation when the wavelength of the octave band center frequency was greater than one of the room dimensions. It should be noted that this was only an approximation since room acoustics was never intended to consider such a situation. The accuracy of this particular portion of the program was not expected to be as great as for cases where the wavelengths of sound were much smaller than the room dimensions. In most cases, fortunately, the octave bands at which wavelengths would be greater than room dimensions would be so low as to have little or no effect on the dBA level calculation.



(a) Wavelengths less than room dimensions



(b) Wavelengths greater than room dimensions

Directivity for Wavelengths Greater and Less than the Room Dimensions

Figure 6

3.4 Proximity of Receiver Points to Room Surfaces

The second special case considered was the situation in which a receiver point was located quite near one or more room surfaces. As stated previously there are reflections which occur at walls which could increase the sound pressure level by several decibels. To predict this situation it was decided to apply corrections to the calculated sound pressure levels in such situations.

Since the sound pressure waves arriving at the receiver point near a room surface are traveling in many different directions, many sound pressure waves are not reflected directly to the receiver point. For this reason, assuming diffuse sound reflections, the sound power at the receiver point is assumed to be reflected and not the individual sound pressure waves. Assuming that the reflections occurred from an infinitely hard wall so that all of the incident energy was reflected an increase of 3.0 dB in the sound pressure level would be expected. Near two surfaces 4.8 dB would be the expected increase and near the junction of three surfaces 6.02 dB would be the expected increase.

The corrections of 3.0, 4.8 and 6.0 dB were applied to the sound pressure levels calculated by the program when appropriate. However, after examining the experimental data discussed in later chapters it became evident that there was a frequency effect to be considered in the application of these corrections. It was evident from measurements in two rooms that the increase in sound pressure levels near a surface ceased in the 500 hertz octave band. Consequently, logic was incorporated in the program to eliminate these corrections at and above the 500 hertz octave band.

Finally it should be noted that these corrections are somewhat dependent on wall materials and other factors. No investigations were carried out to further define these corrections or to determine at exactly what frequencies they should be applied. The corrections as applied in this analysis did predict measured sound pressure levels quite well. This will be demonstrated fully in a later section.

To summarize the many modifications it would be useful to reconstruct eh modified room acoustics equation as used in the computer program. It should be noted that also incorporated in this equation were corrections for variations from standard barometric and temperature conditions. Therefore the modified room acoustics equation was,

$$SPL = SWL + 10 \log_{10} \left(\frac{Q^* e^{-mr}}{4\pi r^2} + \frac{MFP}{r} \; \frac{4}{S(\bar{\alpha} + \frac{4V}{S})} \right) - 10 \log_{10} \left(\frac{T + 460}{527} + \frac{30}{BP} \right) \tag{10}$$

where:

SPL = sound pressure level, dB

SWL = sound power level, dB

Q^* = directivity index which is continuously updated to acknowledge changes in directivity because of room geometry, dimensionless

m = absorption of sound by air, meters^{-1}

r = distance from source to receiver, meters

MFP = mean free path, meters

S = total surface area of room, square meters

$\bar{\alpha}$ = average absorption coefficient for room surfaces, sabines

V = volume of the room, cubic meters

T = temperature in the room, °F (temperature at standard conditions is 527 R)

BP = barometric pressure in room, inches of Hg. (barometric pressure at standard conditions is 30 inches of Hg.)

Therefore, with the new equation developed it was necessary to compare its predictions to measurements made in actual rooms to verify its accuracy.

4.0 EXPERIMENTAL VERIFICATION

As stated previously, the published data upon which the modification to the reverberent term of the room acoustics equation was made were somewhat incomplete. Therefore, some experimental verification was required to provide more concrete evidence of the validity of this modification. The objectives for these verifications were, however, more complex than simply justifying this one modification.

4.1 Objectives of the Experimental Measurement Program

The primary objective of the measurements was to demonstrate that the modified room acoustics equation would provide accurate predictions of sound pressure levels in room configurations other than those discussed by Embleton. Also, by using other room configurations it was hoped to demonstrate the limits of accuracy of the sound pressure level predictions. From these limits, estimates could be made of the accuracy a user could rely upon from this program in predicting sound pressure levels in regularly shaped rooms.

Another objective of the measurements made for these verifications was to determine the accuracy of a typical system for determining sound levels in a room. Certainly the accuracy of the program's predictions does not have to exceed the accuracy of the measurement system. In fact, the accuracy under controlled conditions for this verification would be greater than that expected in an industrial environment. Therefore, if the accuracy of predictions was nearly equivalent to that of the measurement system used the predictive ability of the program should be adequate for most industrial environments.

Yet another objective of these measurements was to determine the validity of modifications to correct for the proximity of a receiver point to a wall and wavelengths greater than the room dimensions. Because of the high frequency sound analyzed in the room discussed by Embleton these particular modifications were not involved in the calculations made using the modified room acoustics equation.

There were several modifications made to the room acoustics equation to correct for the effects of irregular room proportions on the sound energy in a room. Therefore it was felt an important objective to make measurements in regularly proportioned rooms to indicate if these modifications had precluded accurate predictions of sound levels in such rooms.

A final objective was to simply generate some accurate data of sound levels which included detailed descriptions of the rooms in which the data were taken. This was something found lacking in existing literature and something which would be greatly needed by later investigators in this area. Care was taken to provide the necessary room information and to provide accurate measurements thus ensuring that these data would be of value to other investigators.

4.2 Experimental Apparatus

To perform the sound pressure level measurements, a Brüel & Kjaer 2204 precision sound level meter with a B&K 1613 octave band filter set was used. A one-inch B&K 1445 microphone with a B&K UA0055 random incidence corrector nose cone was used in conjunction with the sound level meter. As a standard sound power source an ILG reference sound source was used. For the purpose of calibrating the sound level meter and microphone a B&K 4220 pistonphone was used. Also, a B&K Bourdon tube type barometer was used to determine the barometric pressure in the room. The Bourdon tube barometer was previously calibrated against a mercury barometer. This measured barometric pressure was used to arrive at an appropriate correction to the measured sound pressure levels for the deviation from standard barometric conditions. Temperature and relative humidity were determined by the use of dry and wet bulb thermometers. ASHRAE[1] psychrometric charts were used to convert the tempteratures to relative humidity. These data were necessary to select appropriate air absorption coefficients, m, and to make temperature corrections to the measured sound pressure predictions.

Throughout the measurements every attempt was made toward not introducing any uncertainities in addition to those present in the tolerances of the sound generator and measurement system. The ILG reference sound source proved to be a source of a great deal of inaccuracy. Sound power levels were published with this sound source for eight octave bands with center frequencies ranging from 63 to 8000 hertz. However, these sound power levels were determined using three different test procedures and three different sets of sound power levels resulted (see Table 1). Two of the test procedures involved measurements taken

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[1]American Society of Heating, Refrigerating and Air Conditioning Engineer.

Table 1. Sound Power Level Ratings for ILG Sound Source*

	Reverberant Room Method		Free Field Method
Octave Band Center Freq. Hz	ASAZ24.10-1953 Sound Power Level	USAS1 S1.6-1967 Sound Power Level & Accuracy	USAS1 S1.6-1967 Sound Power Level
63	79.0	76.5 ± 1.5	82
125	76.5	77.0 ± .5	81
250	78.0	78.0 ± .5	81
500	79.0	79.0 ± .5	81
1000	79.0	79.0 ± .5	81
2000	80.0	79.5 ± .5	81
4000	78.5	78.0 ± .5	79
8000	77.0	76.5 ± 1.5	78

*Taken from ILG Data Sheet A 8501-032, ILG Industries, Inc., Chicago Division, Chicago, Illinois 60641.

in an extremely non-absorptive or reverberant room. The third test procedure consisted of making measurements in an open environment or free-field conditions. The problem was that an actual room where measurements were taken would have characteristics somewhere in between those of a reverberant room or free-field conditions. In the 63 hertz octave band a variation of $\pm$ 3.5dB was found when all three sound power ratings were considered. At the 8000 hertz octave band the variation had dropped to $\pm$ 1.5dB. Since every sound power reference source was not individually calibrated there was an additional $\pm$ 1dB estimated uncertainty, according to ILG data sheet A 8401-032, among individual sound sources.

Another source of uncertainty was the sound level meter-microphone combination. The random incidence corrector and microphone combination was described in the B&K catalog as having "omnidirectivity ... effective within $\pm$ 3dB" [20]. It was assumed and later confirmed by B&K that this meant that the sound pressure waves arriving at different angles might be weighted differently. This was not the overall accuracy of the combination. In the rooms considered in this verification it is assumed that the sound will be diffuse and as such would have almost certainly little or no effect on the sound pressure levels measured. Although the precision sound level meter was accurate to $\pm$ 0.2 dB reading the meter within such accuracy was not possible since the sound being read was somewhat time varying. At high frequencies an uncertainty in reading the meter of $\pm$ 1dB was possible. However, at lower frequencies random fluctuations during a reading were sometimes as great as 6-8 dB. An uncertainty of $\pm$ 2dB was felt more reasonable at these frequencies.

Although no additional inaccuracy was introduced it was necessary to make corrections to the readings taken in the 2000, 4000, and 8000 hertz octave bands [24]. These corrections were a result of deviations in the response of the one-inch microphone because of its combination with the random incidence corrector. Since the dBA levels read on the meter are derived from the measurements at these and other octave bands, the measured dBA sound pressure levels were disregarded. It was then necessary to calculate dBA levels using the corrected, A-weighted octave band data.

After combining all of the squares of the uncertainties in this measurement system and taking the square root of the sum, as suggested by Holman [21], the expected uncertainties were $\pm$ 4dB at low frequencies and $\pm$ 2dB at the higher frequencies. Again as noted previously this amount of uncertainty would certainly be much less than that encountered in a typical factory space.

4.3 Description of the Experiment

To verify the validity of the modifications made to the room acoustics equation two rooms were selected. Measurements were taken in each of these rooms to be compared with the results of computer calculations of sound pressure levels in these rooms. The first room selected was a long relatively narrow hallway in Derring Hall, an academic building on the Virginia Polytechnic Institute and State University campus. This hallway was selected to further illustrate the ability of the modified room acoustics equation to predict sound levels in irregularly proportioned rooms. Another reason for selection was that its length would reveal any tendencies for the experimental and calculated sound pressure levels to diverge which had not already been revealed in Embleton's room.

The second room selected was a classroom in Randolph Hall on the VPI&SU campus. This classroom was selected because of its regular proportions. By comparisons of calculated and measured sound levels in this room the ability of the modified equation to predict sound levels in non-irregularly proportioned rooms would be demonstrated. This comparison was desired since the room acoustic equation is most accurate in these types of rooms. It was necessary to determine whether this known accuracy had been lost with modifications presented here.

4.3.1 Hallway in Derring Hall

This hallway had walls of painted cinder block, a tile floor, and an acoustical tile ceiling. The hallway was closed at each end by double wooden doors. There were also several wooden and metal doors along the hallway. There was a small cork bulletin board located on a wall of the hallway. This hall was approximately 97 feet (29.6 m.) long, 7 feet (2.1 m.) wide and 8 feet (2.4 m.) high.

4.3.2 Classroom in Randolph Hall

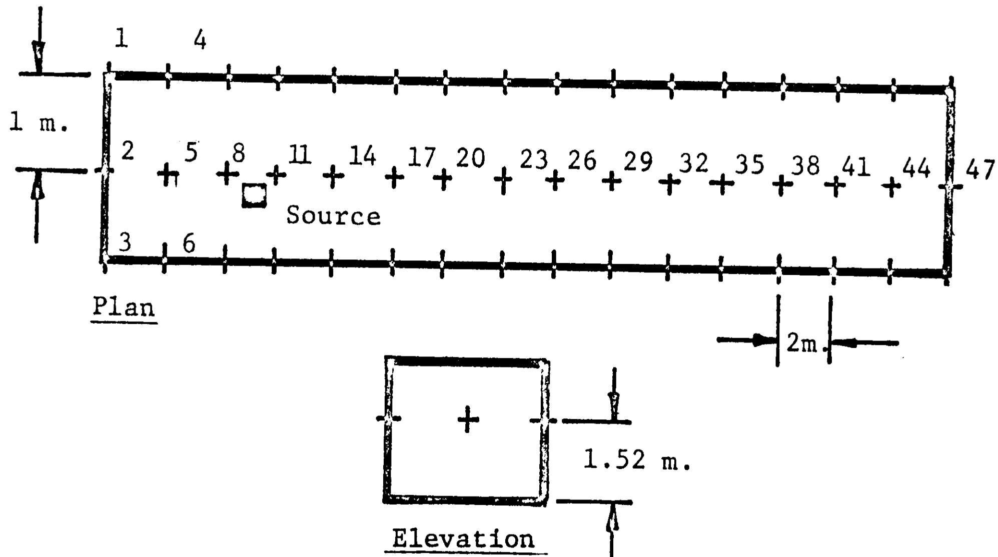
This classroom was approximately 30 feet (9.1 m.) in length, 20 feet (6.1 m.) wide and 11 feet (3.4 m.) high. From the tile floor to a height of 5 feet 6 inches (1.7 m.) the walls were made of glazed tile. From this height to the ceiling the walls were constructed of painted cinder block. The ceiling was covered with acoustical tile. There was one wooden door for this room. Two blackboards and two cork bulletin boards were located on the walls in this room.

4.3.3 Measurements

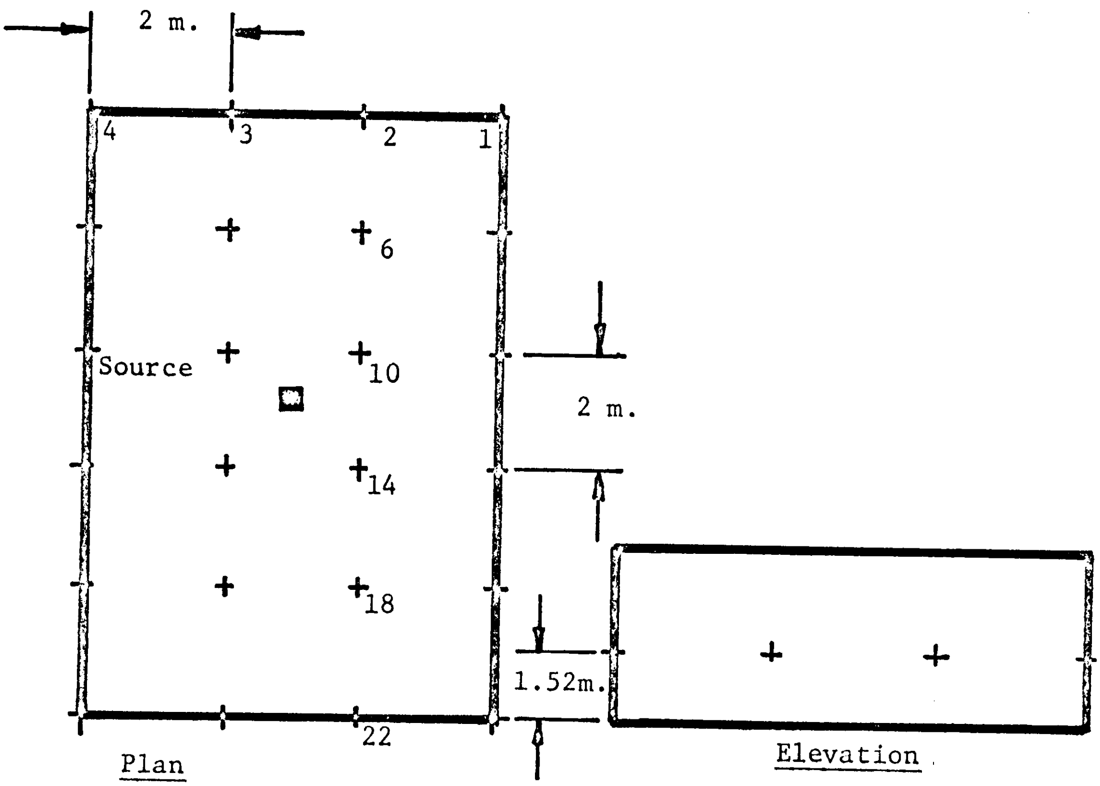
Sound pressure level measurements were conducted at various point throughout each of these rooms (see Figure 7). At each position dBA levels were measured. At positions 2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44, and 47 in the Derring hallway and every position in the Randolph classroom octave band sound pressure level measurements were made in the eight octaves from 63 to 8000 hertz center frequencies. The octave band sound pressure levels were not measured at all the positions in Derring Hall simply because of lack of time to perform all of the necessary measurements.

Checks of background sound pressure levels without the reference noise source operating were made throughout these rooms before the desired measurements were begun. Special attention was given to the points where the lowest sound pressure levels were expected and where the background noise seemed to be the greatest. The background levels were found to be 10 dB or more below the ILG noise levels. Therefore, background noise was assumed to have no effect on the measurements.

Before and after the measurements were made in each of these rooms the dry and wet bulb temperatures were checked along with the barometric pressure and the condition of the sound level meter batteries. The environmental conditions measured in each of these rooms were presented in Tables 2 and 3. The sound level meter was calibrated with the



(a) Positions in Derring Hallway



(b) Positions in Randolph Classroom

Measurement Positions

Figure 7

Table 2. Environmental Conditions in Derring Hall.

Temperature, dry bulb	73 °F
Temperature, wet bulb	64.5 °F
Barometric Pressure	710 mm. Hg.
Relative Humidity	58%

Table 3. Environmental Conditions in Randolph Classroom.

Temperature, dry bulb	77 °F
Temperature, wet bulb	66 °F
Barometric Pressure	710 mm. Hg.
Relative Humanity	55%

pistonphone and the internal electrical calibration circuit before and after each measurement session.

The microphone used for these measurements was also visually checked for any irregularities or damage. Measurements were repeated at random points to insure repeatability.

4.4 Description of the Input for Computation of the Sound Pressure Levels in these Rooms

Obviously, it was necessary to put the basic dimensions, temperatures, etc. for these rooms into the computer program. A more detailed explanation of the required data input to this program can be found in Appendix 1. However, there were some points of the input to the program which should be discussed further for these particular rooms.

One of these was the sound power levels for the source required by this program. There was some doubt as to which of the sound power level ratings were correct because of the highly absorptive ceilings and relatively large dimensions of the room compared to those of the sound source, the sound power levels determined by the free-field method were used.

To put in absorption coefficients for these rooms a calculation of the average absorption coefficient had to be performed for each of the octave bands being considered. The equation used for the calculation follows,

$$\bar{\alpha} = \frac{S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + \ldots + S_n\alpha_n + \sum_{i=1}^{m} \alpha_i}{S_1 + S_2 + S_3 + \ldots + S_n} \tag{11}$$

where:

$\bar{\alpha}$ = average absorption coefficient for the room surface, sabines

$S_1, S_2, S_3, \ldots S_n$ = surface areas of various room surfaces, square meters

$\alpha_1, \alpha_2, \alpha_3, \ldots \alpha_n$ = the absorption coefficients for the room surfaces, sabines.

α_i = the absorption for each of m objects within the room, sabines.

The absorption coefficients for each surface in each octave band were obtained from tabulations for various materials published by Knudsen and Harris [25]. Values of absorption coefficients for the acoustical tile ceiling in Derring Hall were obtained from the manufacturer. These ceiling tile data were also used for the ceiling in Randolph. The tile in Randolph was made by a different firm but no sound absorption coefficients were available. Typically, absorption coefficients do not vary greatly for various manufacturers of similar ceiling tile. The results of the calculations for average absorption coefficients for the various octave bands in the two rooms are presented in Tables 4 and 5.

4.5 Presentation of Results

Comparisons of calculated and measured sound pressure levels for the hallway in Derring Hall are presented in Figures 8-18. Figures 8-10 are the plotted dBA sound pressure levels for the following lengthwise positions down the hallway; 1, 4, 7, ..., 46; 2, 5, 8, ...,

Table 4. Average Absorption Coefficients for Derring Hall

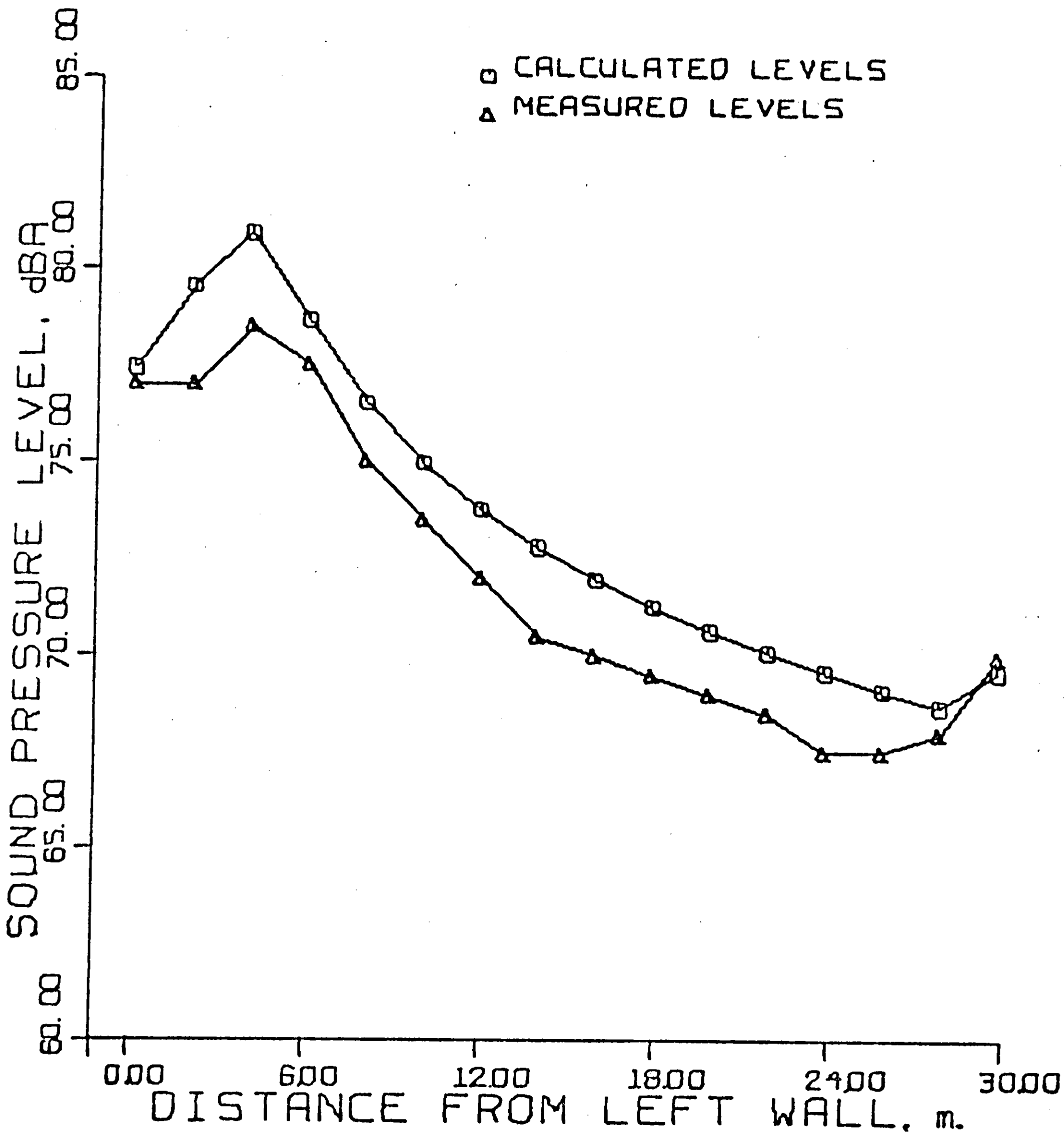
Octave Band Center Freq., Hz.	Average Absorption Coefficient, Sabines
63	0.12
125	0.15
250	0.13
500	0.17
1000	0.22
2000	0.25
4000	0.25
8000	0.30

Table 5. Average Absorption Coefficients for Randolph Classroom

Octave Band Center Freq., Hz.	Average Absorption Coefficient, Sabines
63	0.17
125	0.16
250	0.17
500	0.22
1000	0.29
2000	0.37
4000	0.31
8000	0.32

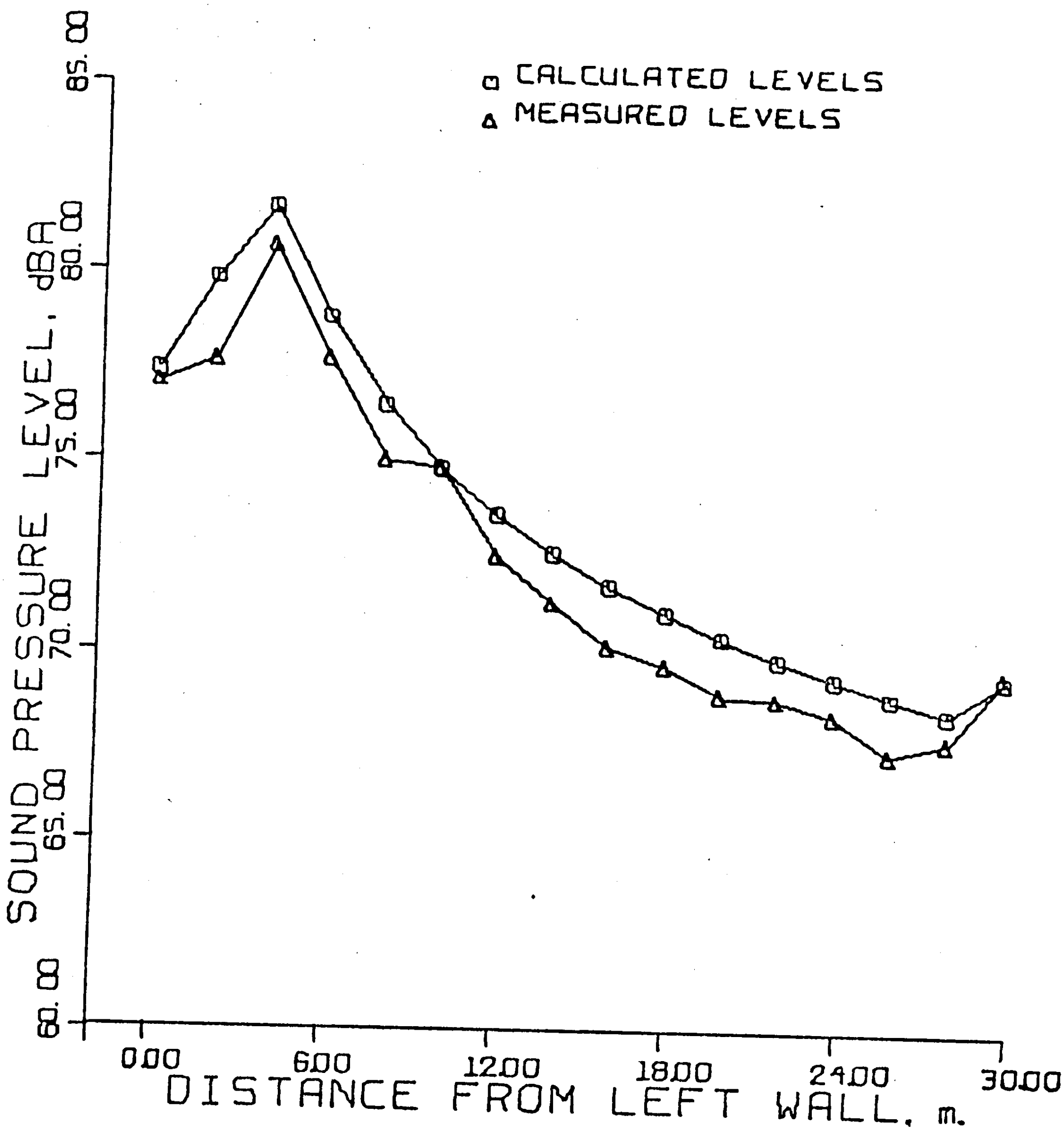
47; and 3, 6, 9, ..., 48 respectively. Figures 11-18 present the plots of sound pressure levels versus position in the room for the eight octave bands for positions 2, 5, 8, ..., 47 down the center of the room. It should be noted that the dBA values measured at positions 1, 4, 7, ..., 46 and 3, 6, 9, ..., 48 were not corrected for the microphone-random incidence corrector combination. The corrections, however, amounted to only 0.5 to 1 dBA at the positions down the center of the room. Figure 9 has corrected dBA levels while those of Figures 8 and 10 are those values measured with no corrections. Figures 8 and 10 are, therefore presented, only for general comparisons and not comparisons of absolute levels.

Comparisons of calculated and measured sound pressure levels for the classroom in Randolph Hall are presented in Figures 19-54. Figures 19-22 are plots of the measured and calculated dBA sound pressure levels versus position for points 1, 5, 9, ..., 21; 2, 6, 10, ..., 22; 3, 7, 11, ..., 23; and 4, 8, 12, ..., 24 respectively down the length of the room. Figures 23-30, 31-38, 39-46 and 47-54 are plots of the octave band sound pressure levels at each of the sets of positions lengthwise down the room.



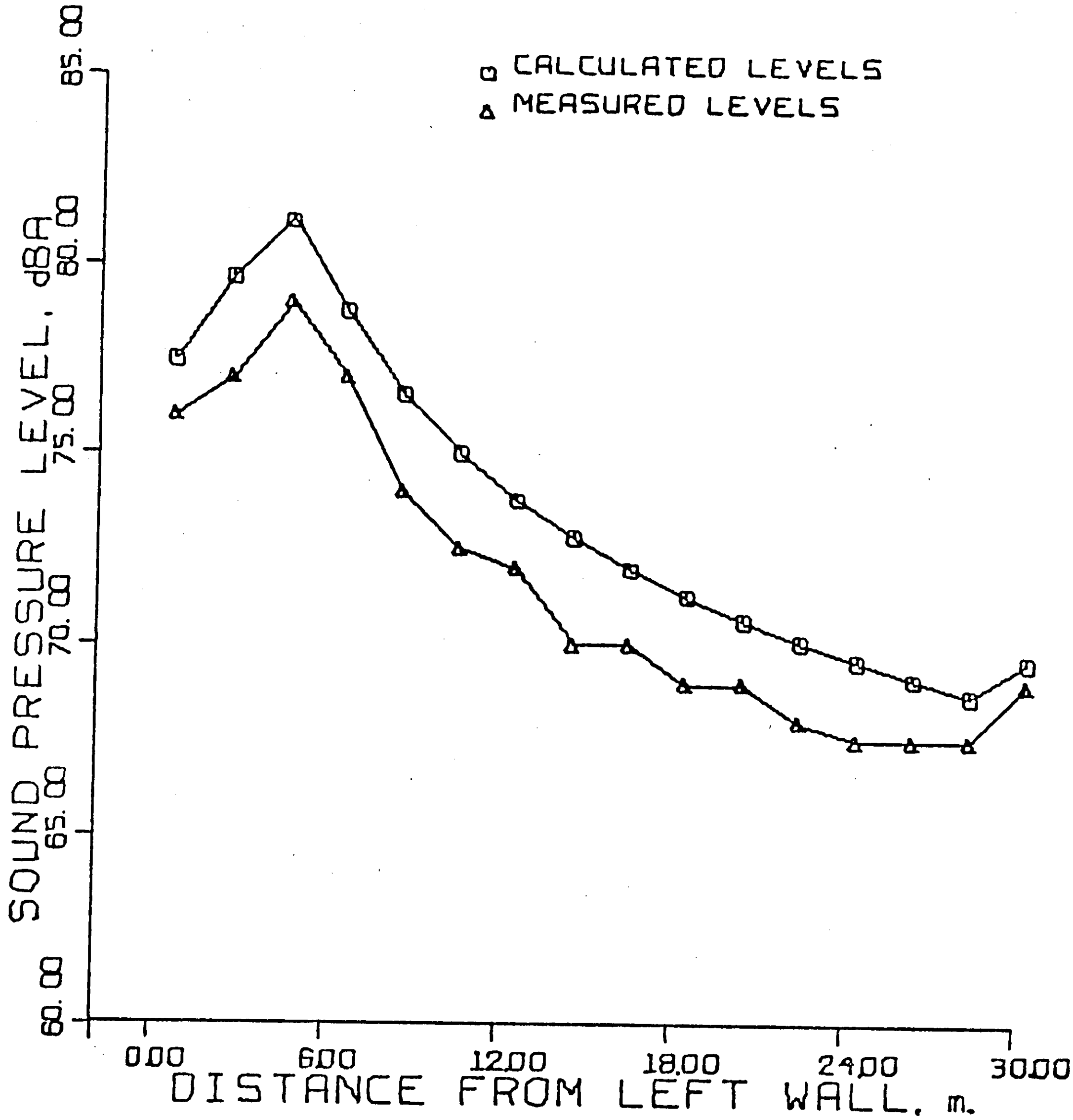
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN DERRING HALL AT POSITIONS 1, 4, 7, . . . , 46

FIGURE 8



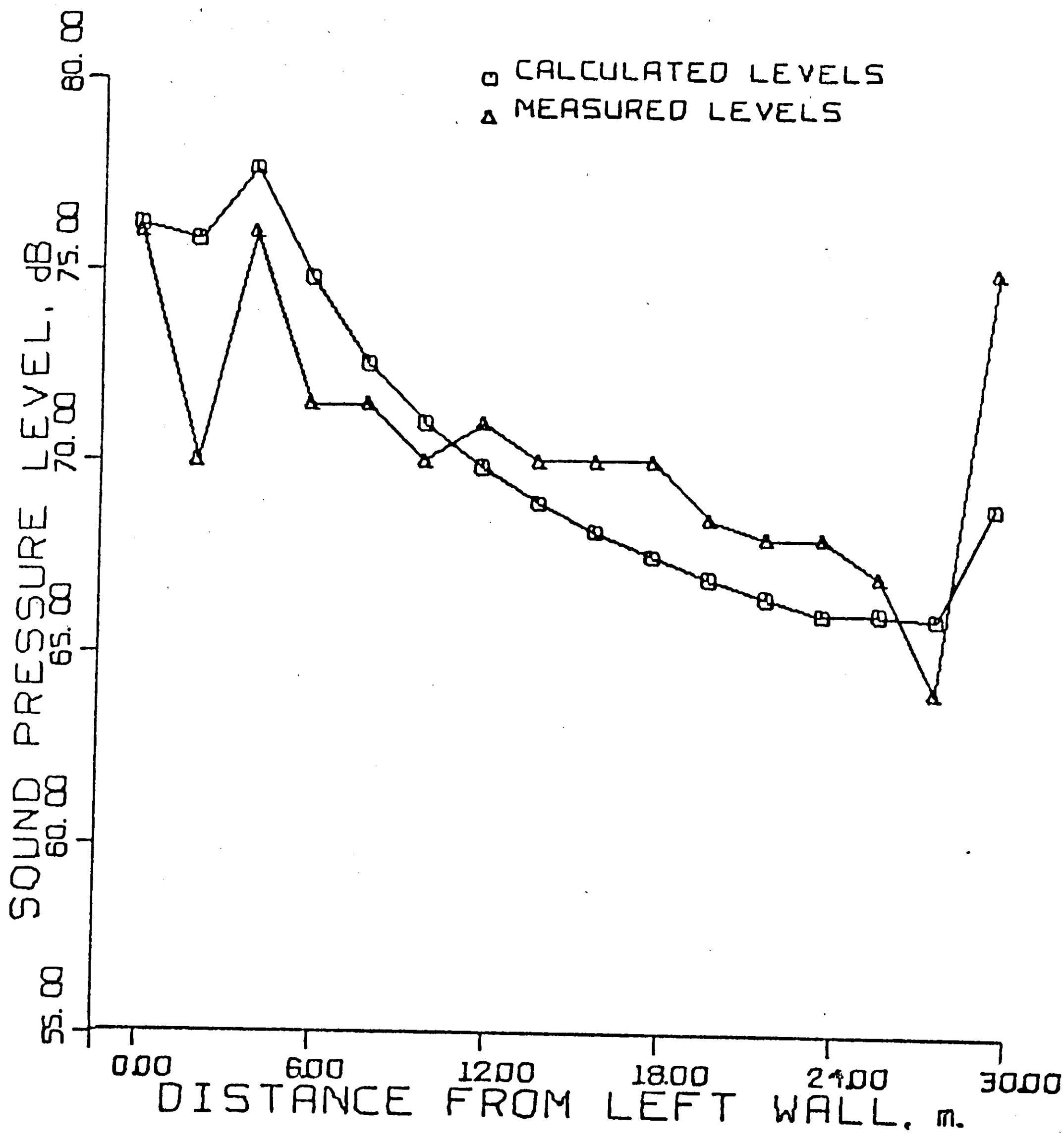
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN DERRING HALL AT POSITIONS 2, 5, 8, ... 47

FIGURE 9



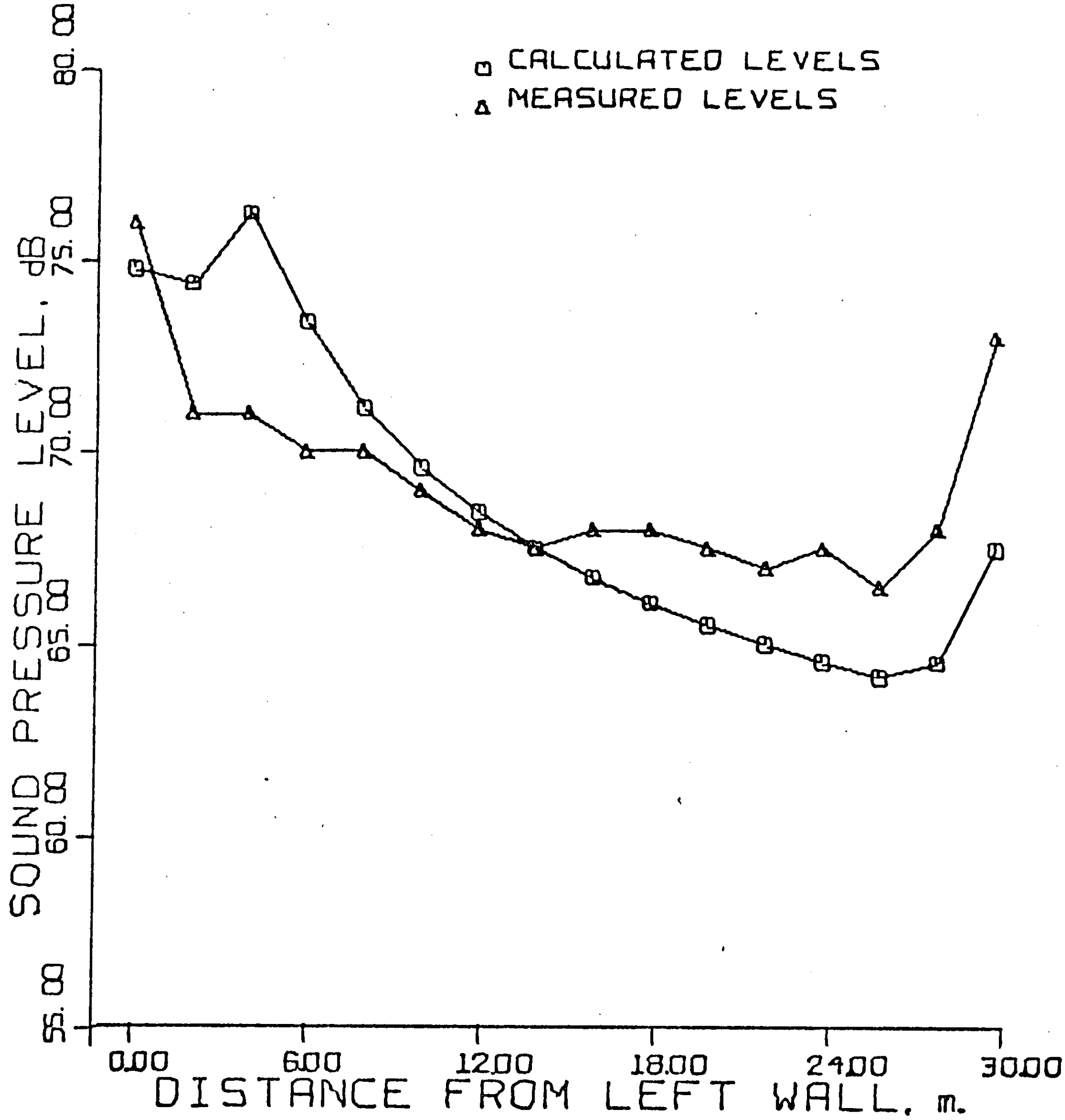
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN DERRING HALL AT POSITIONS 3, 6, 9, . . . , 48

FIGURE 10.



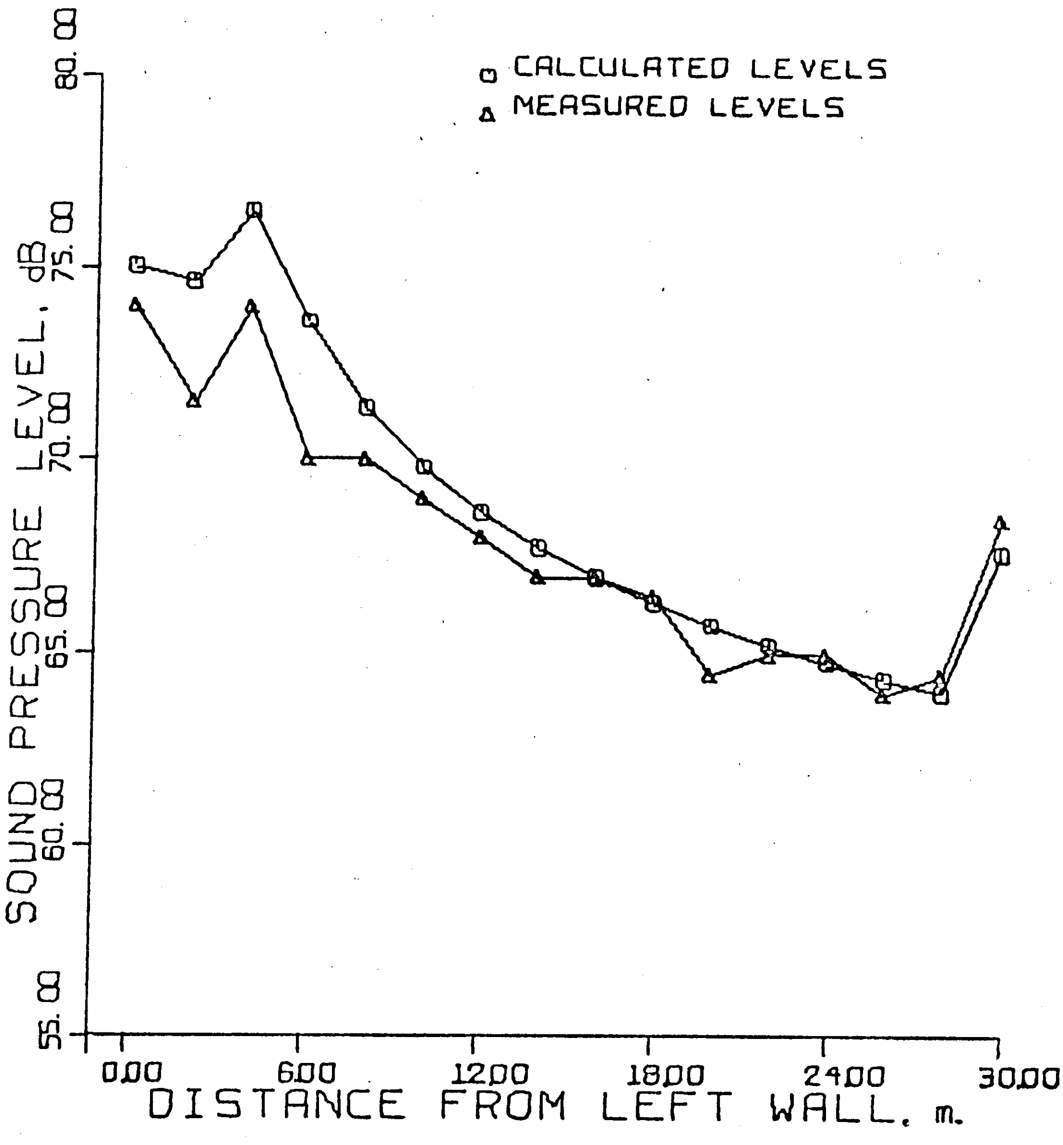
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 63 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 11



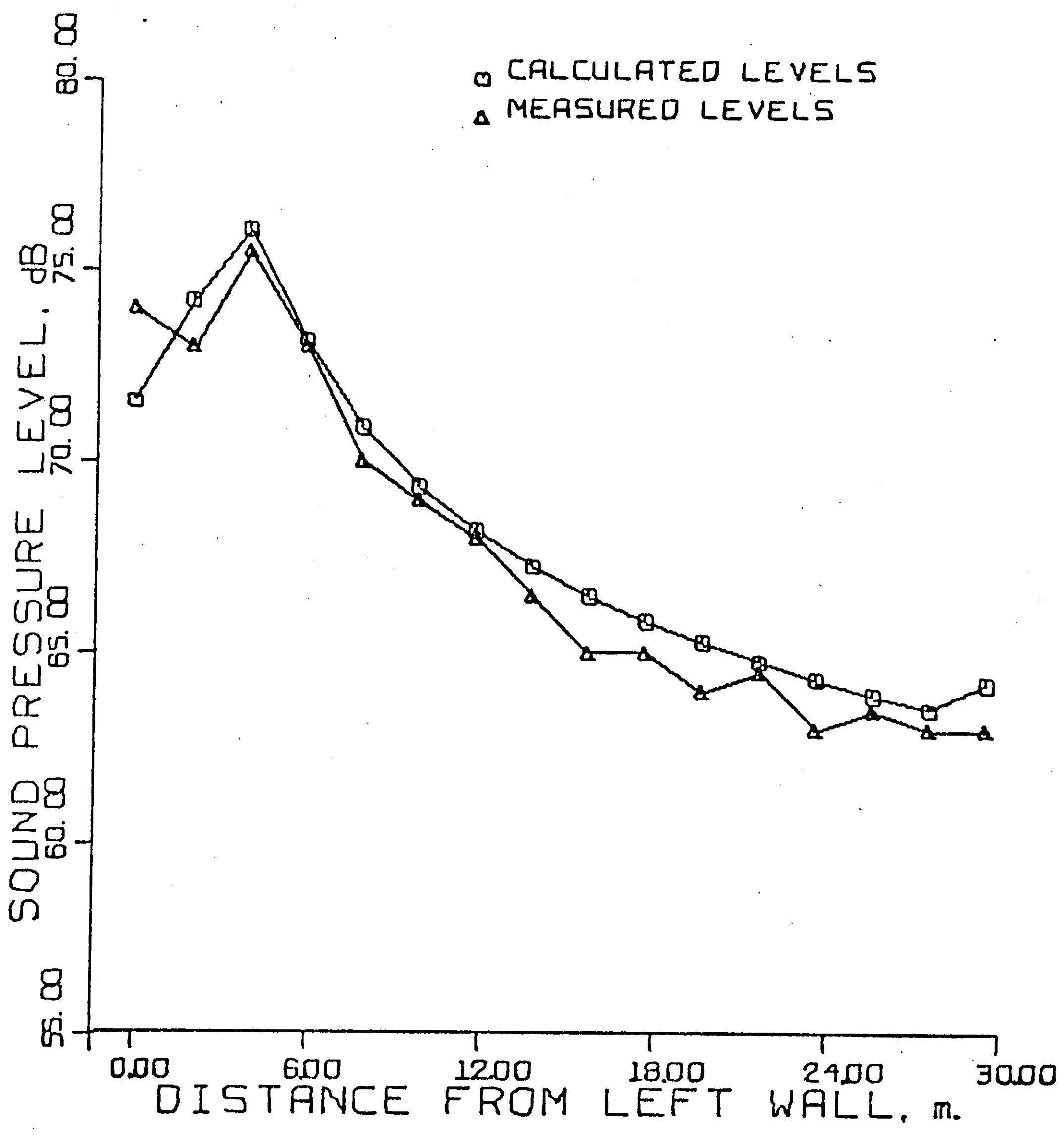
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 125 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 12



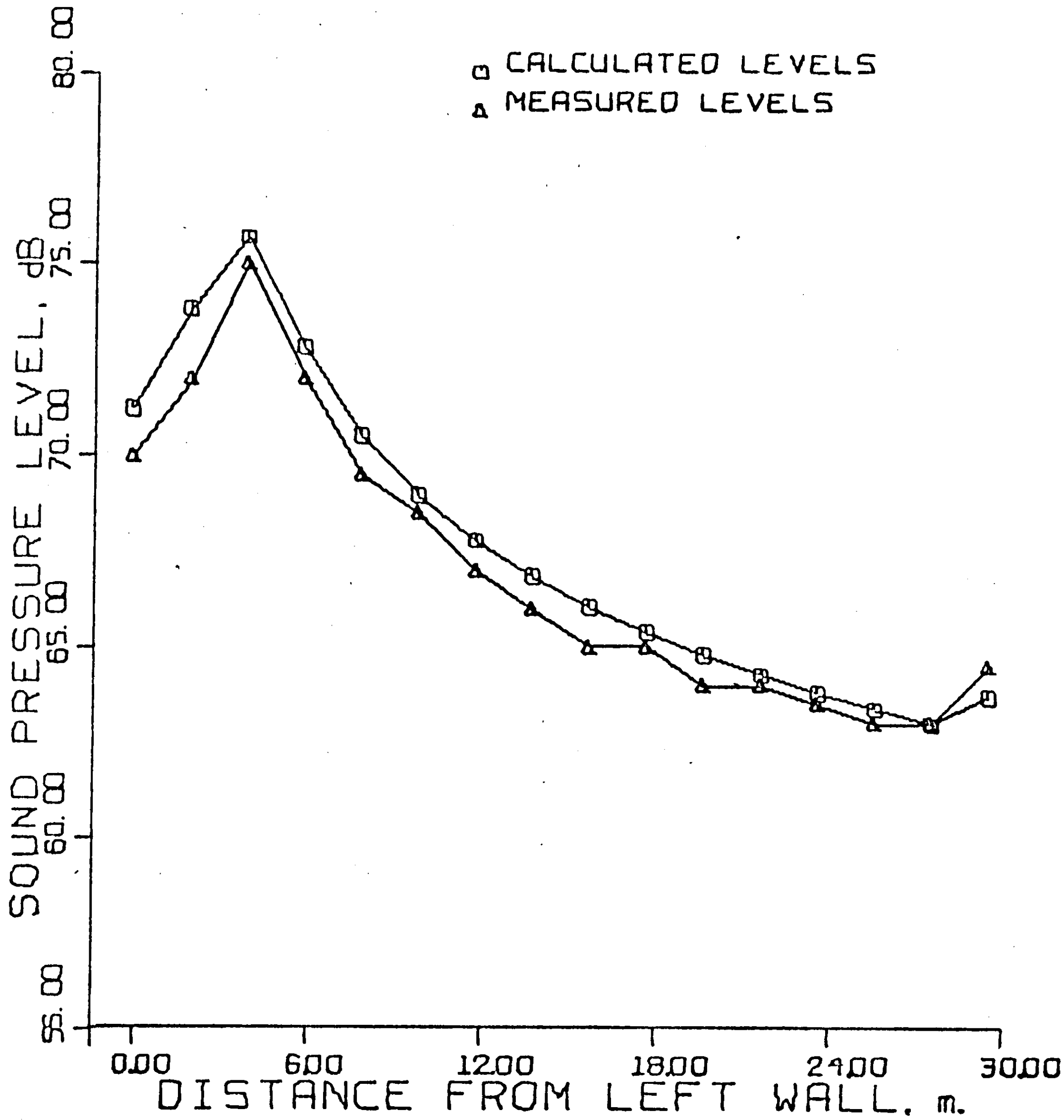
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 250 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 13



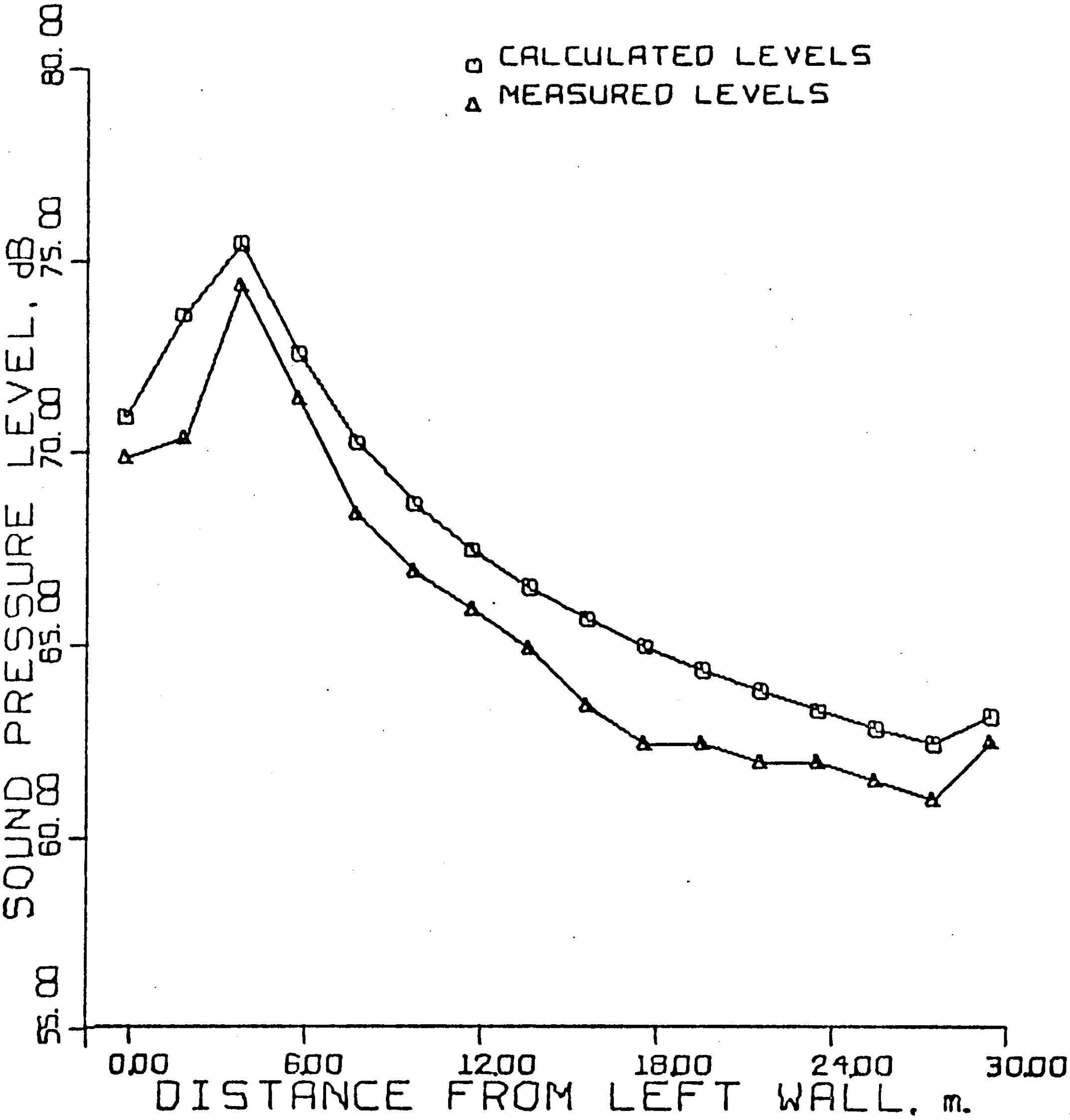
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 500 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 14



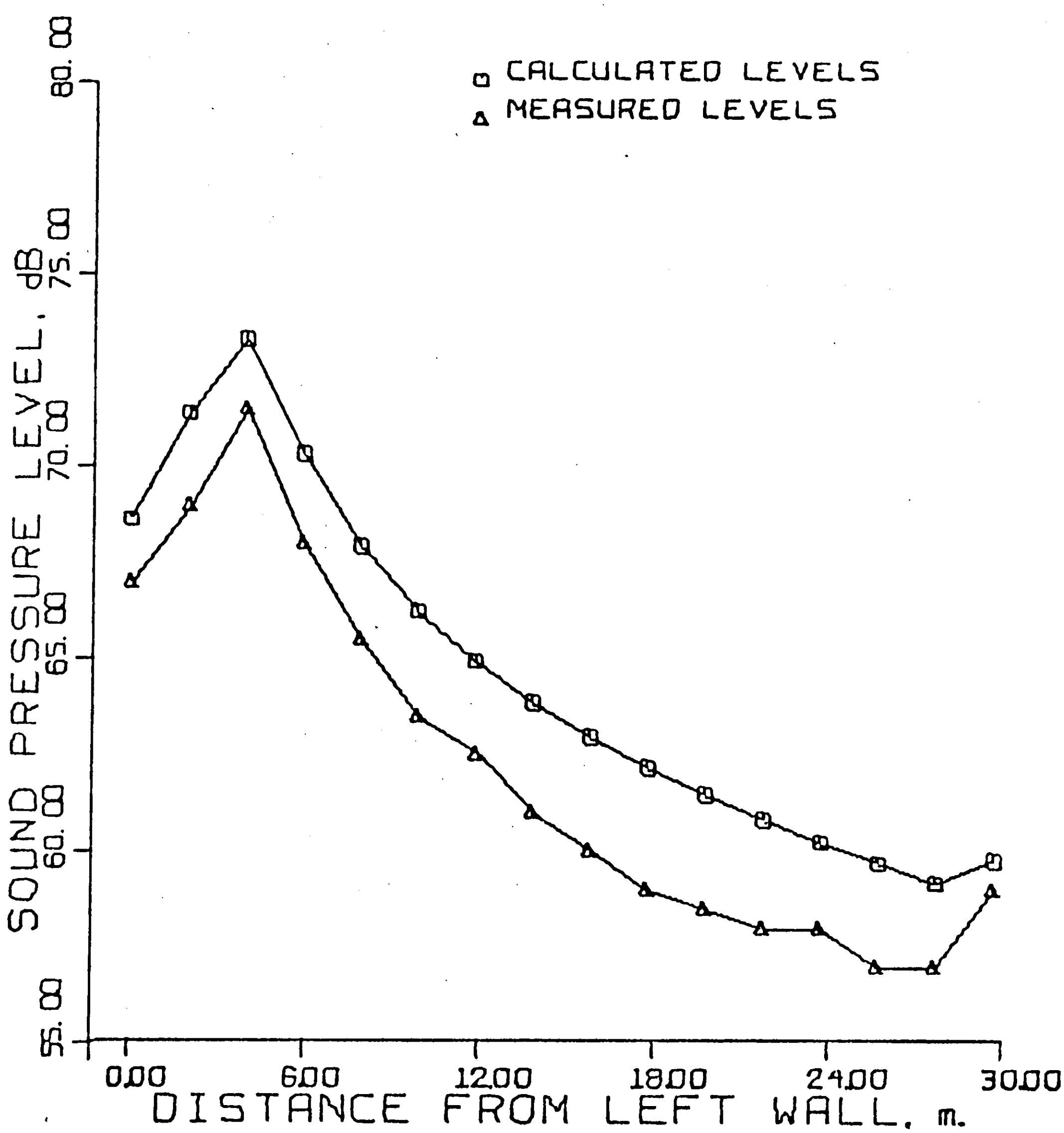
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 1000 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 15



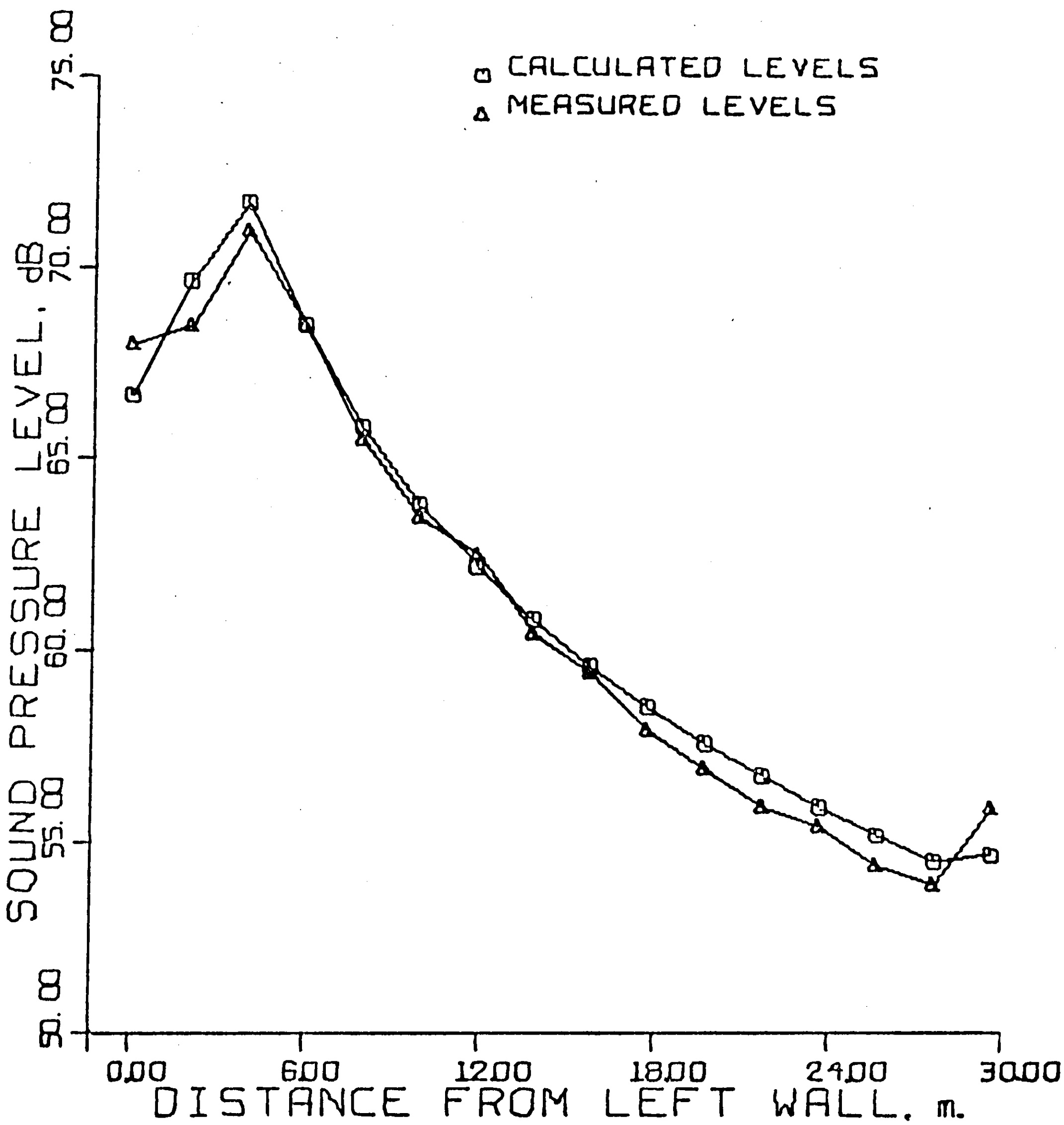
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 2000 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 16



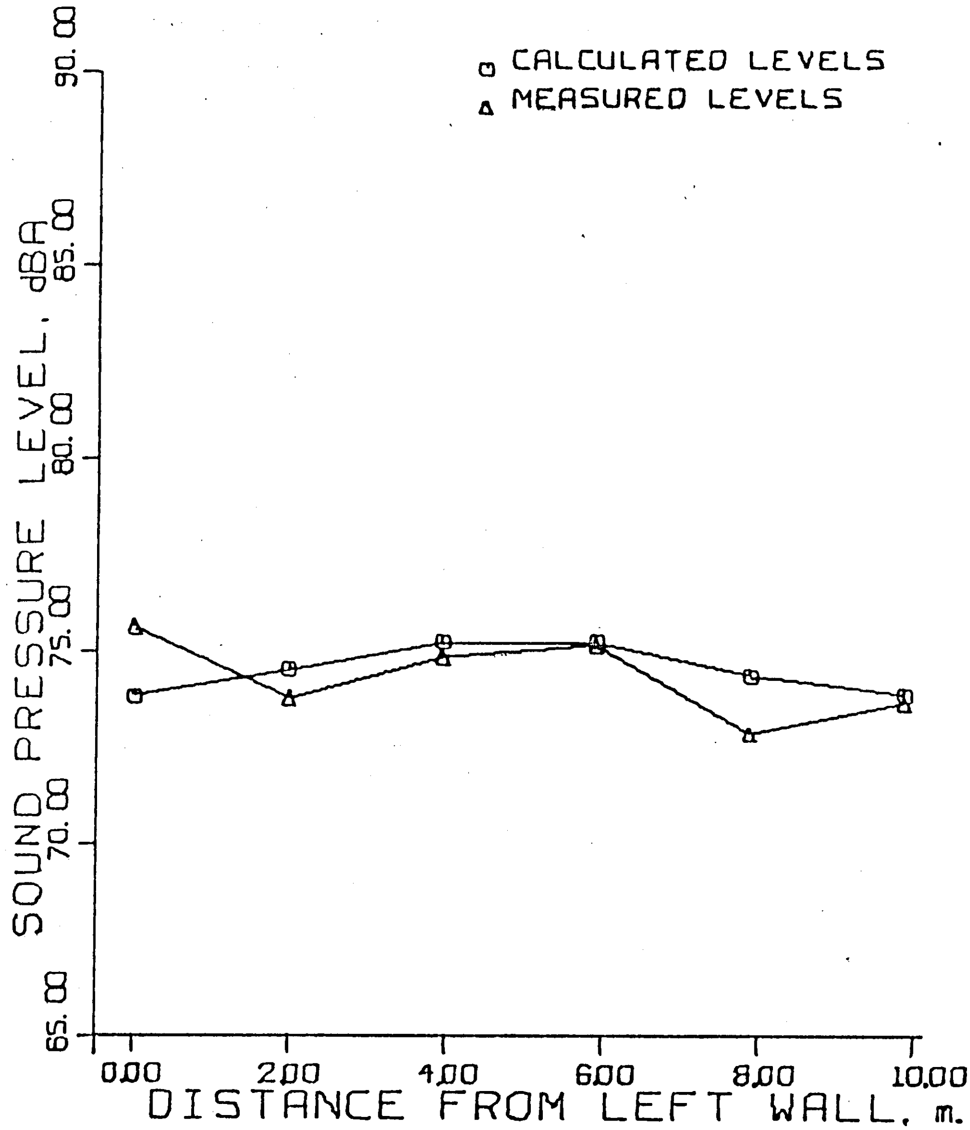
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 4000 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 17



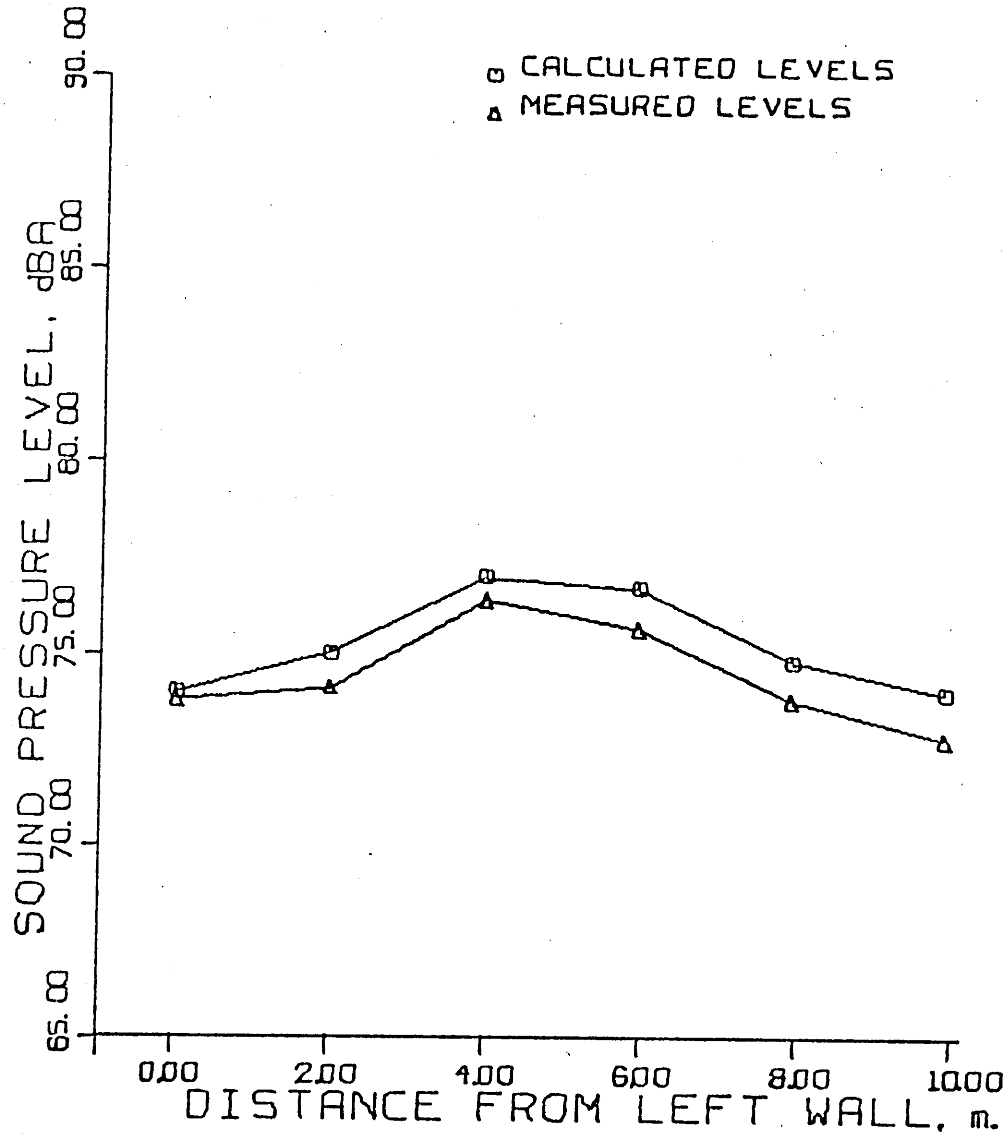
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 8000 HZ. OCTAVE BAND IN DERRING HALL AT POSITIONS 2, 5, 8, . . . , 47

FIGURE 18



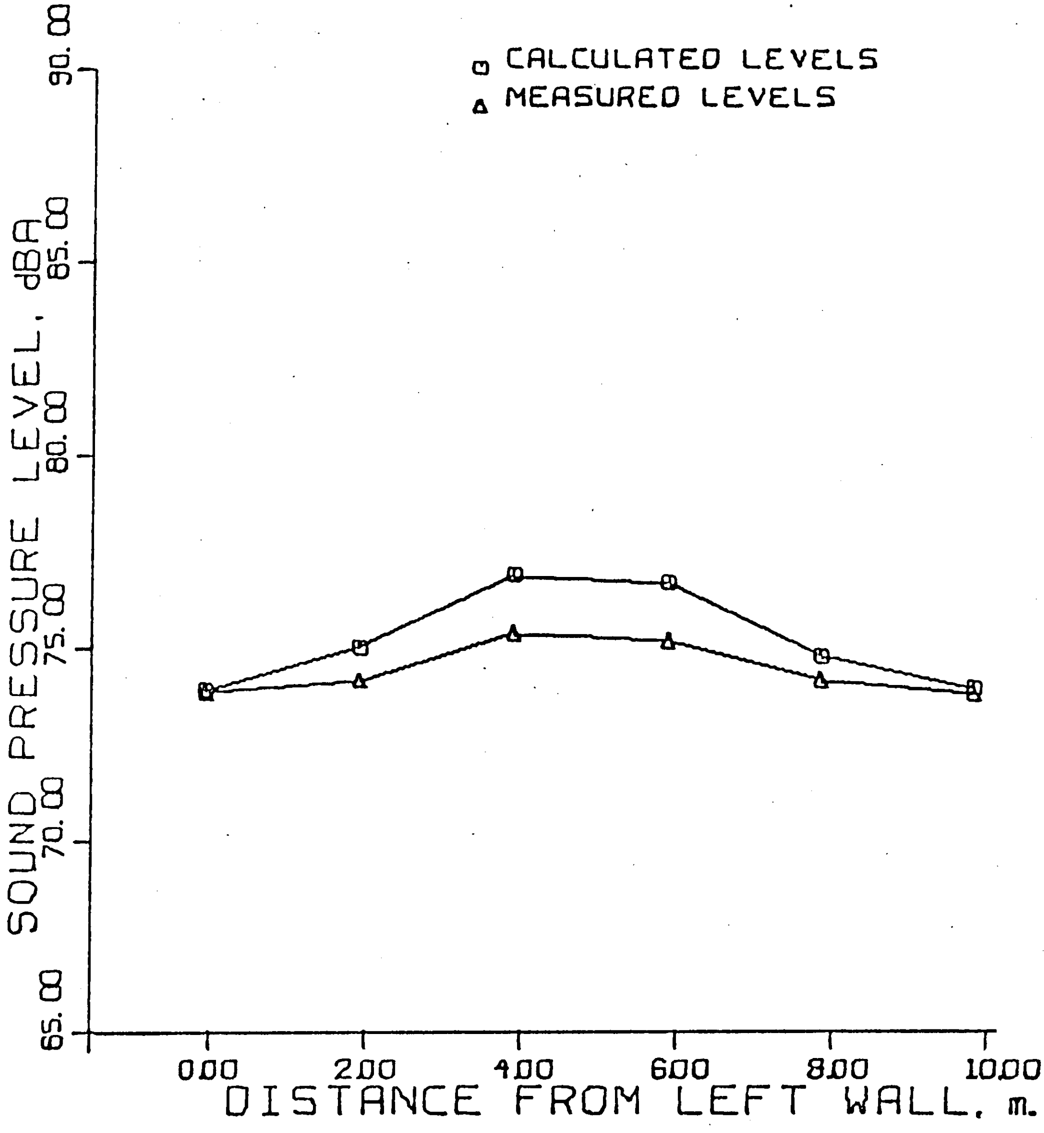
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, . . . , 21.

FIGURE 19



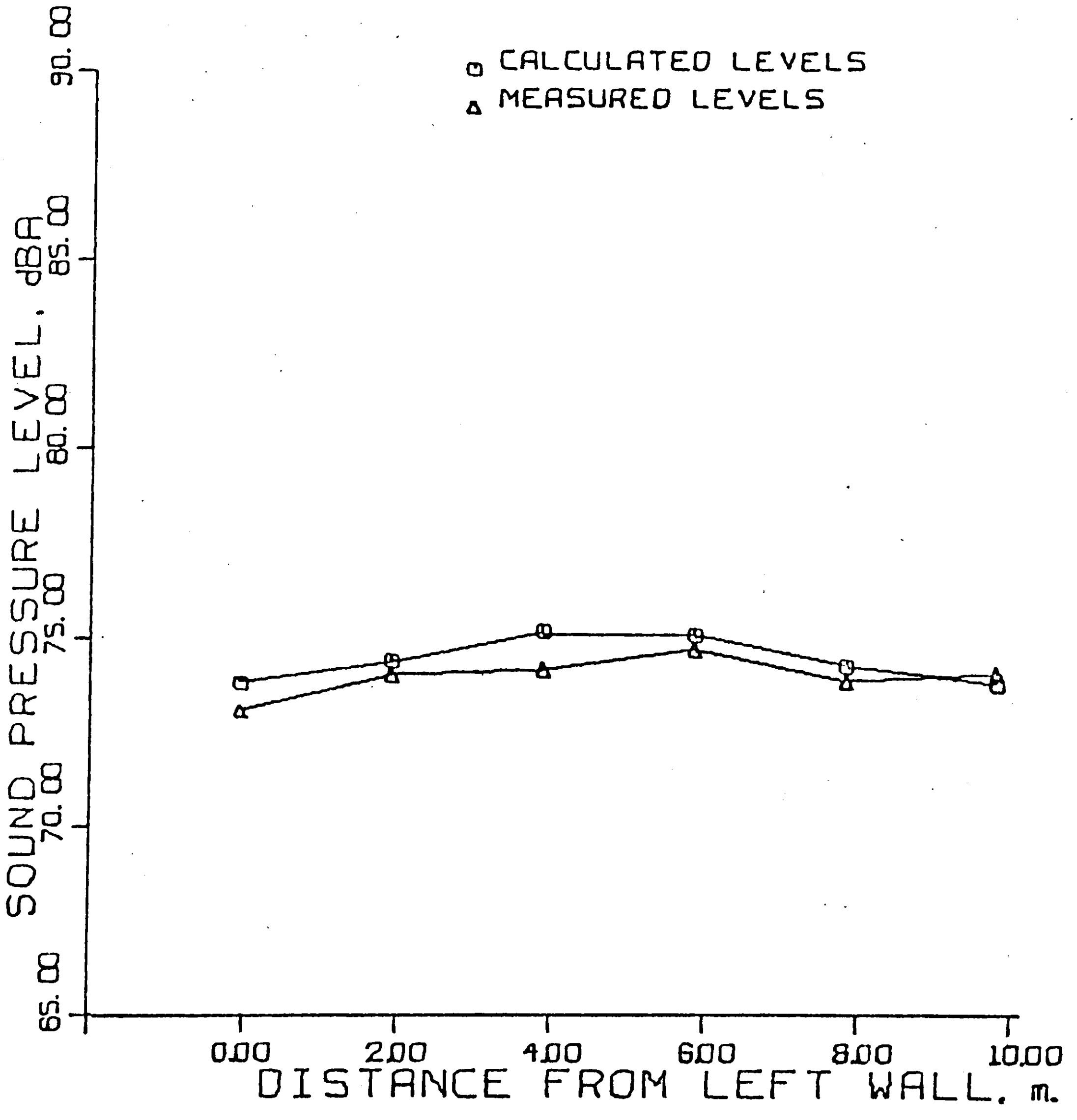
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 20



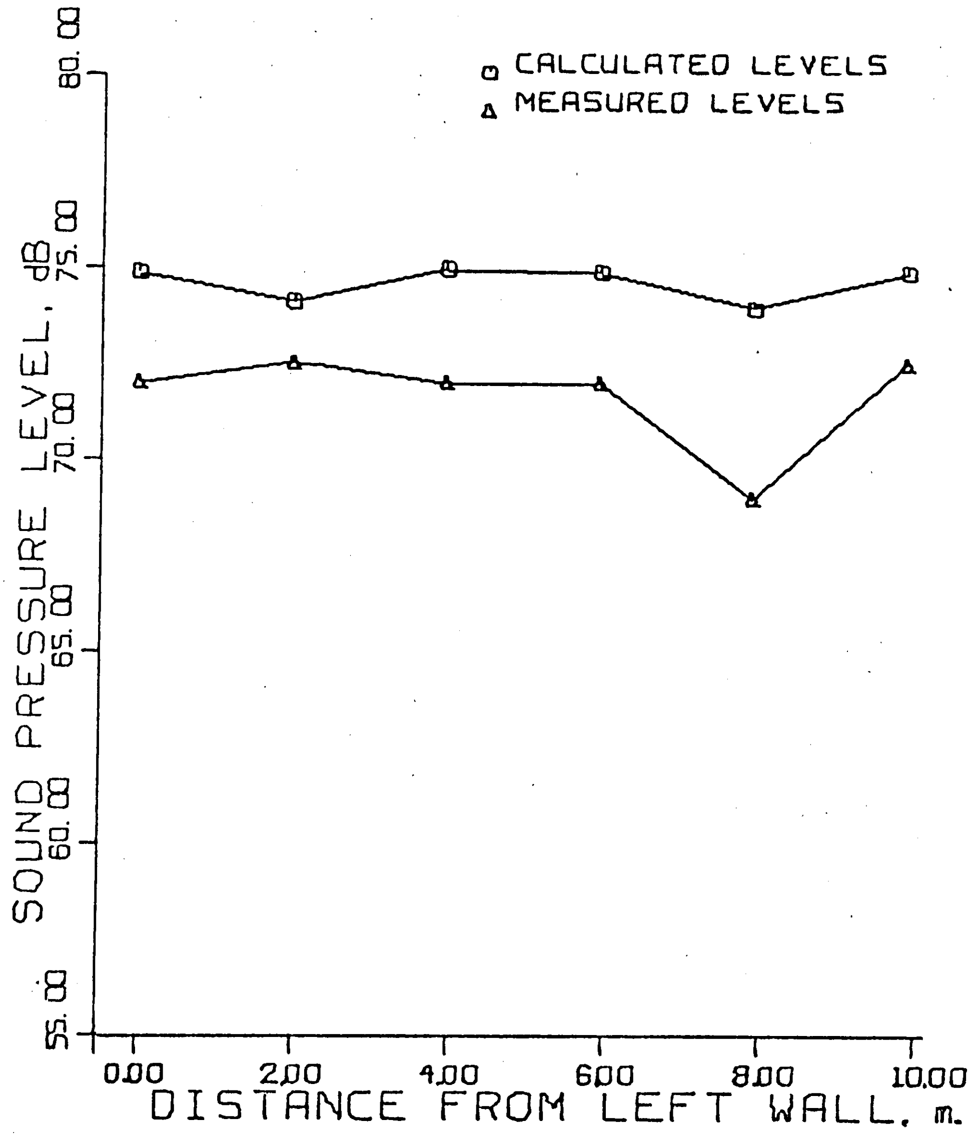
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 23

FIGURE 21.



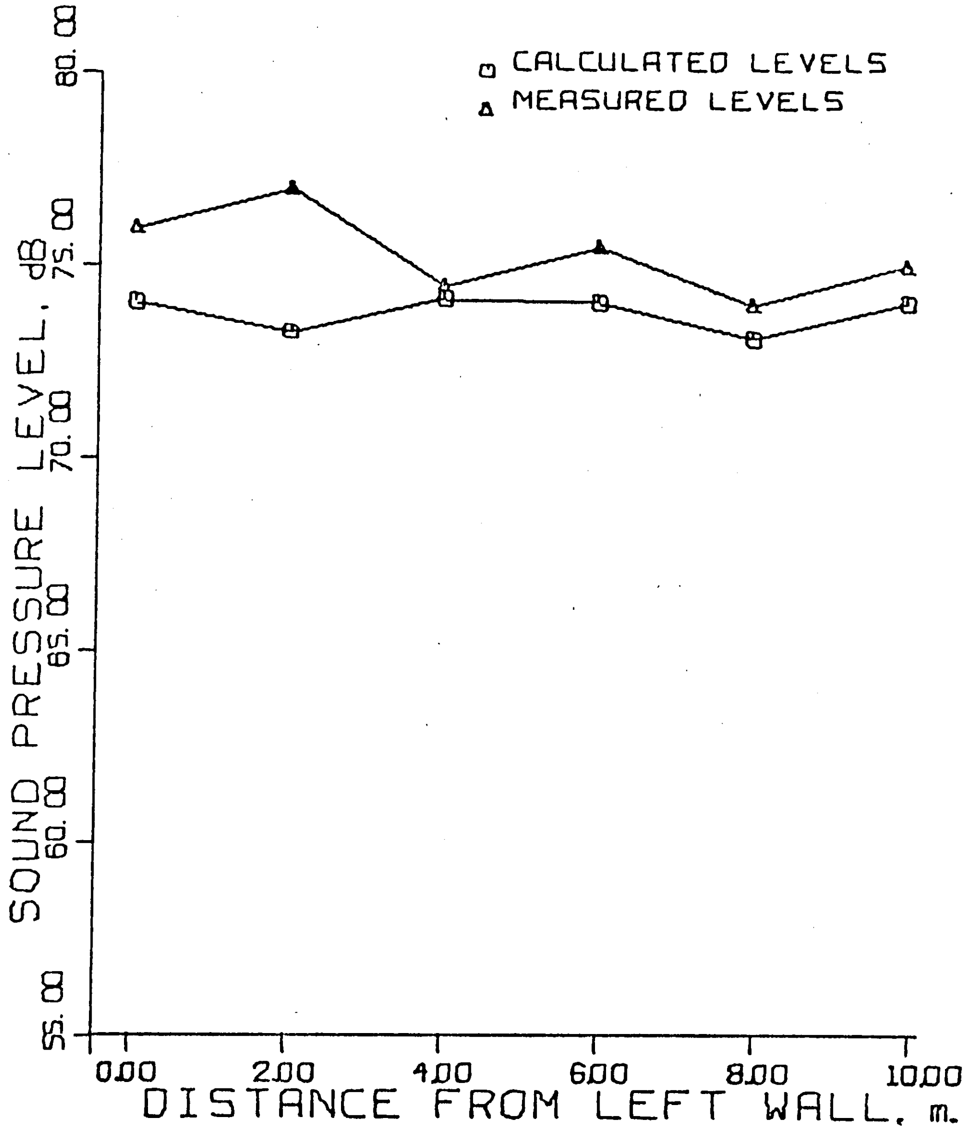
COMPARISON OF MEASURED AND CALCULATED dBA SOUND PRESSURE LEVELS IN RANDOLPH CLASSROOM AT POSTIONS 4, 8, 12, . . . , 24.

FIGURE 22



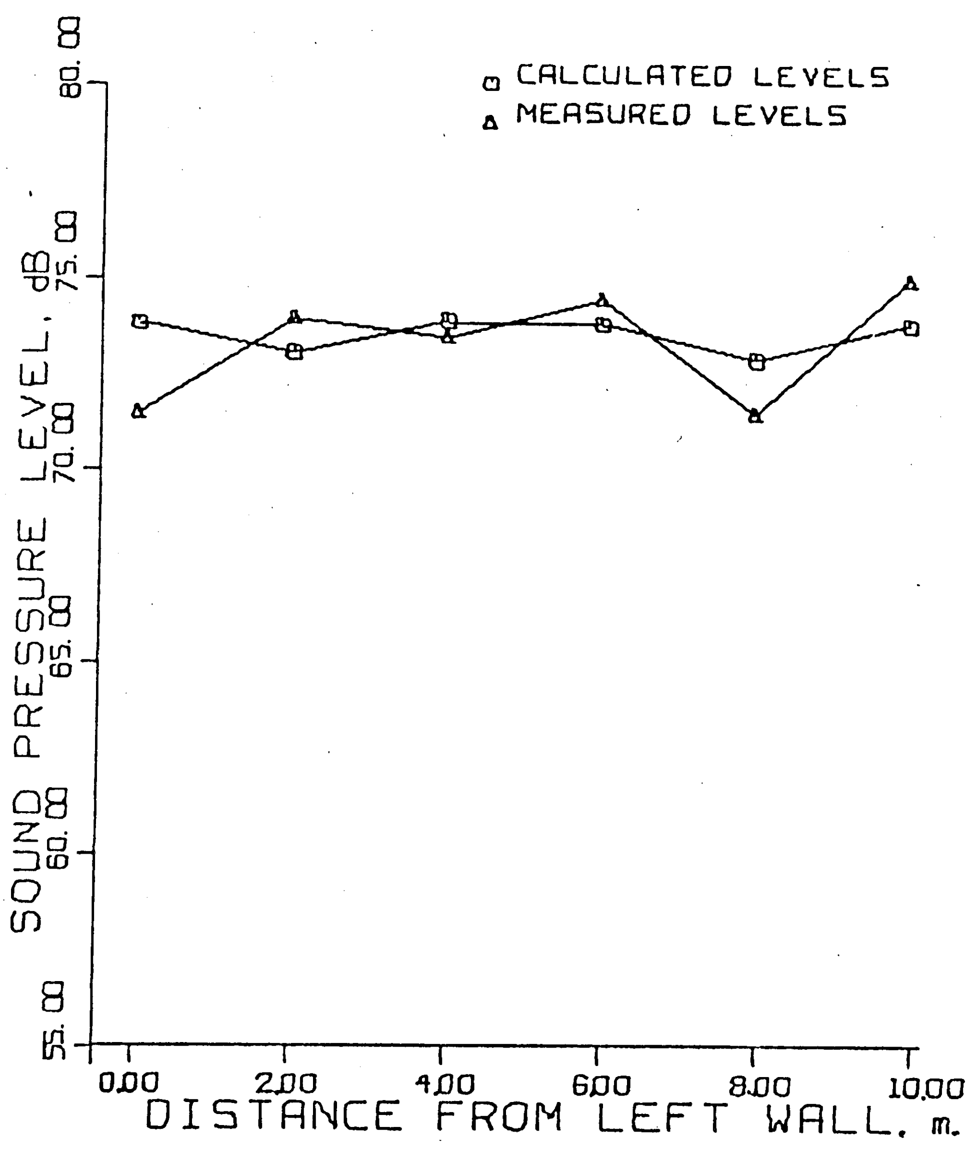
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 630 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, . . . , 21

FIGURE 23



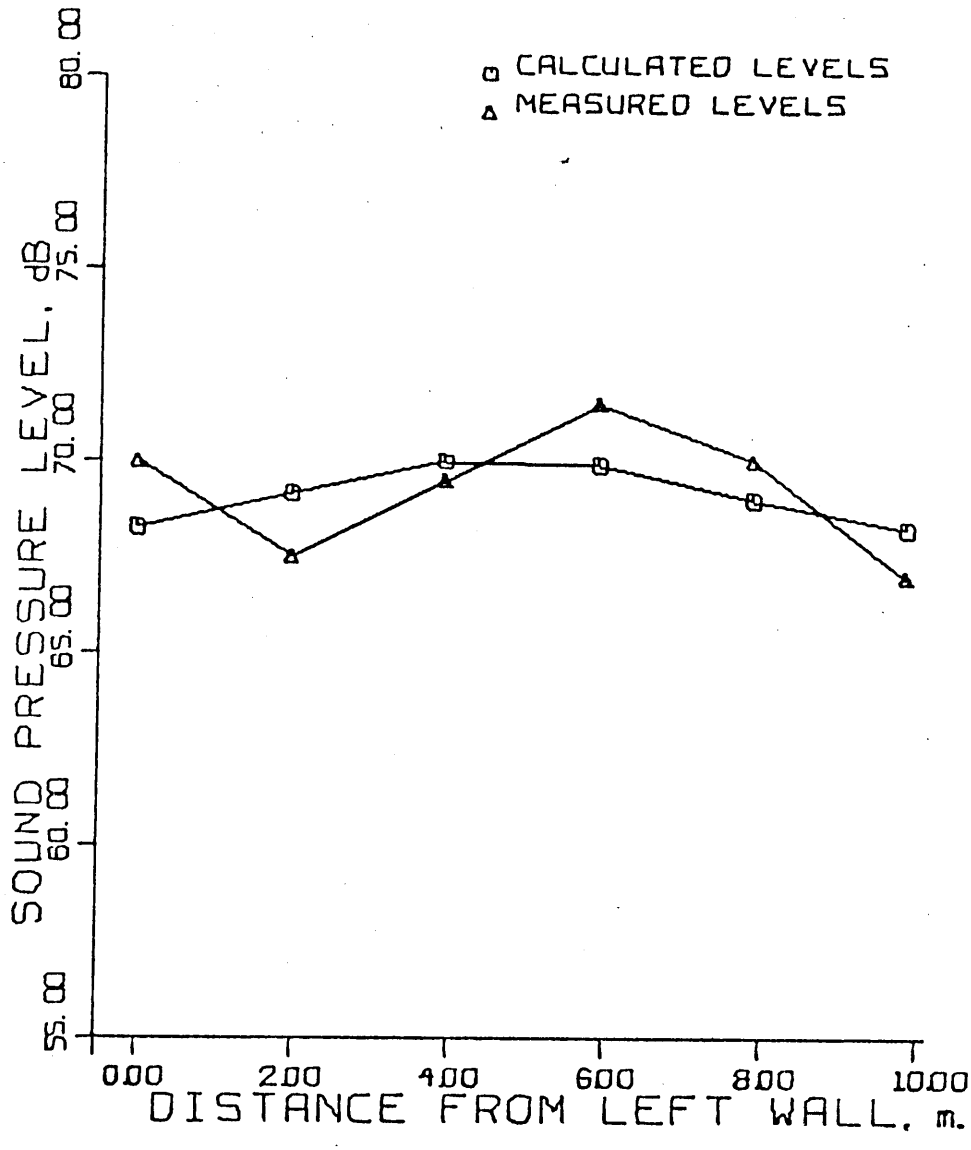
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 125 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, ... , 21

FIGURE 24



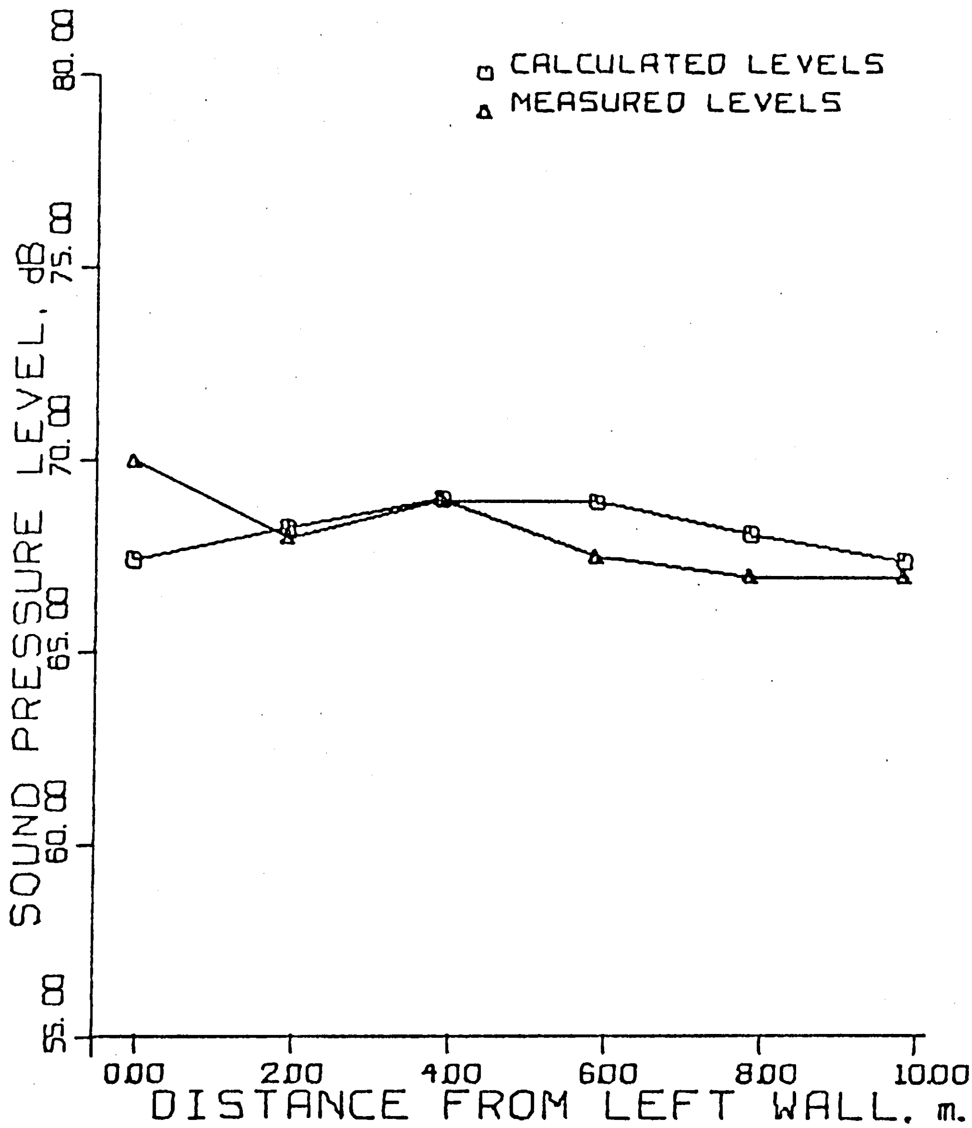
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 250 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, ... 21

FIGURE 25



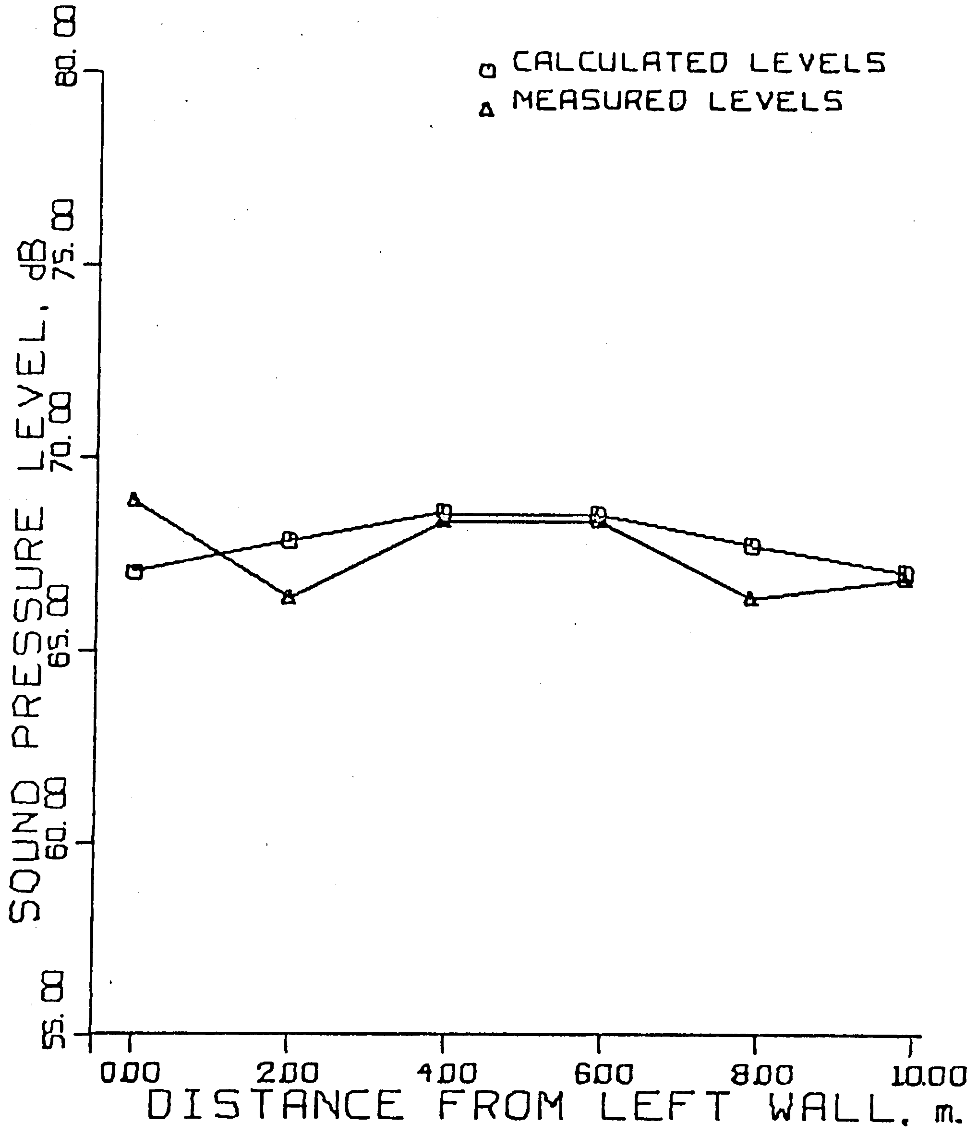
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 500 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, . . . , 21

FIGURE 26



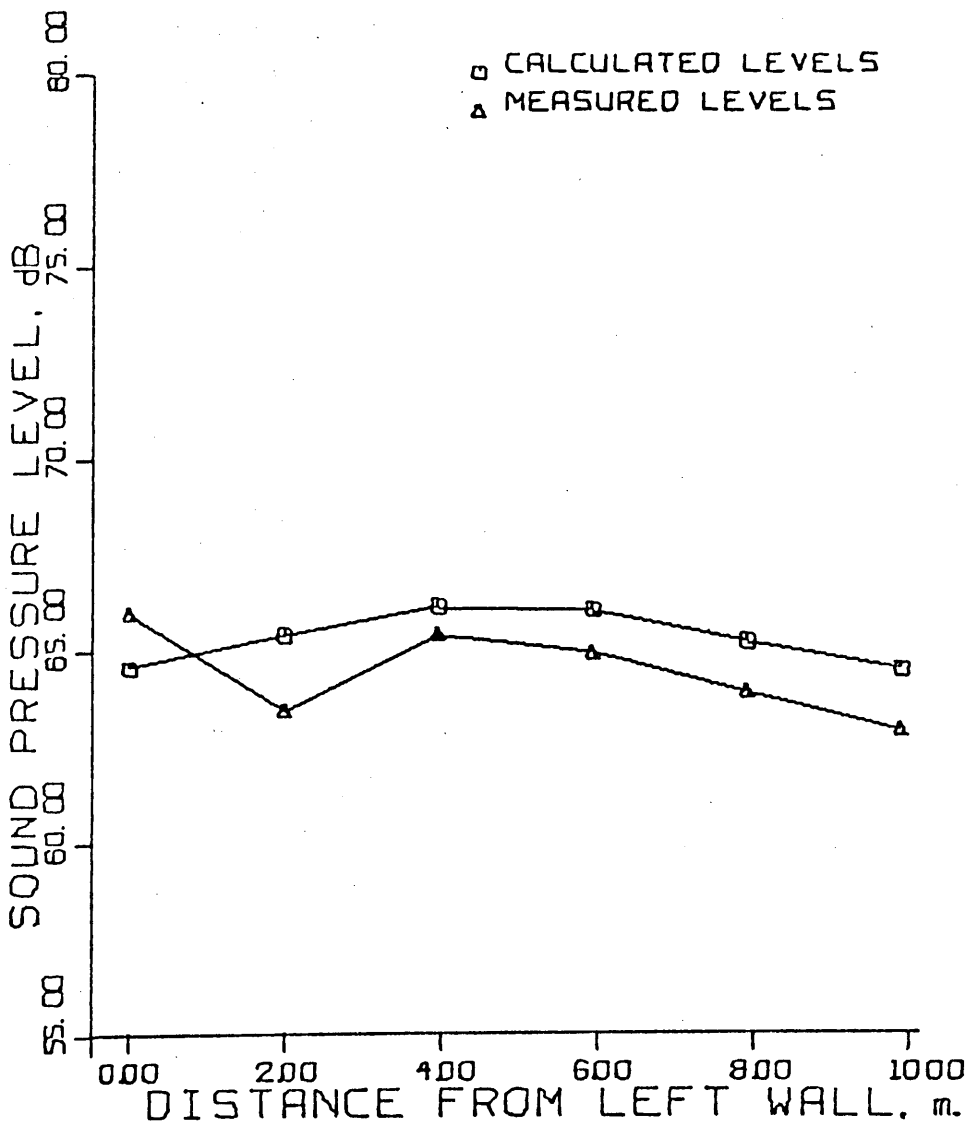
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 1000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, . . . , 21

FIGURE 27



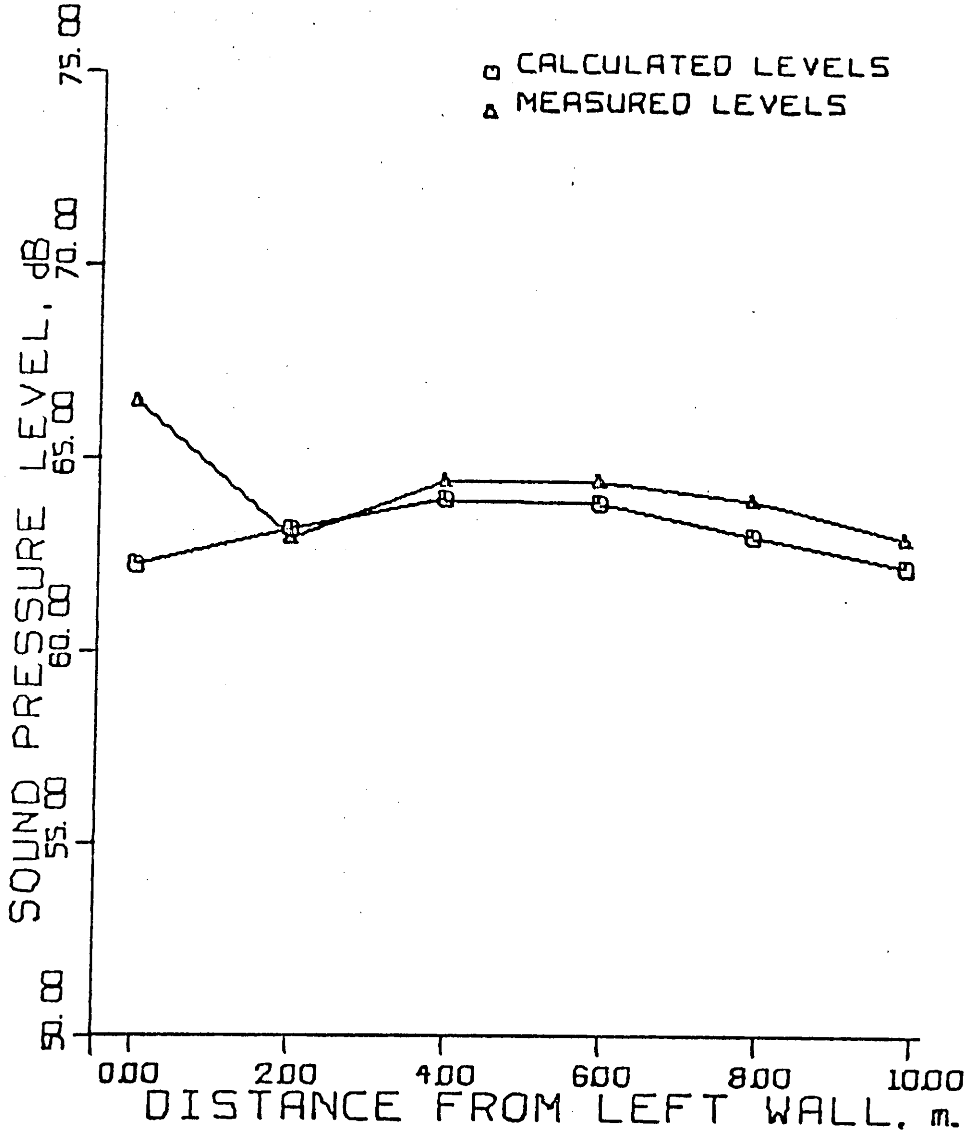
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 2000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, . . . , 21

FIGURE 28



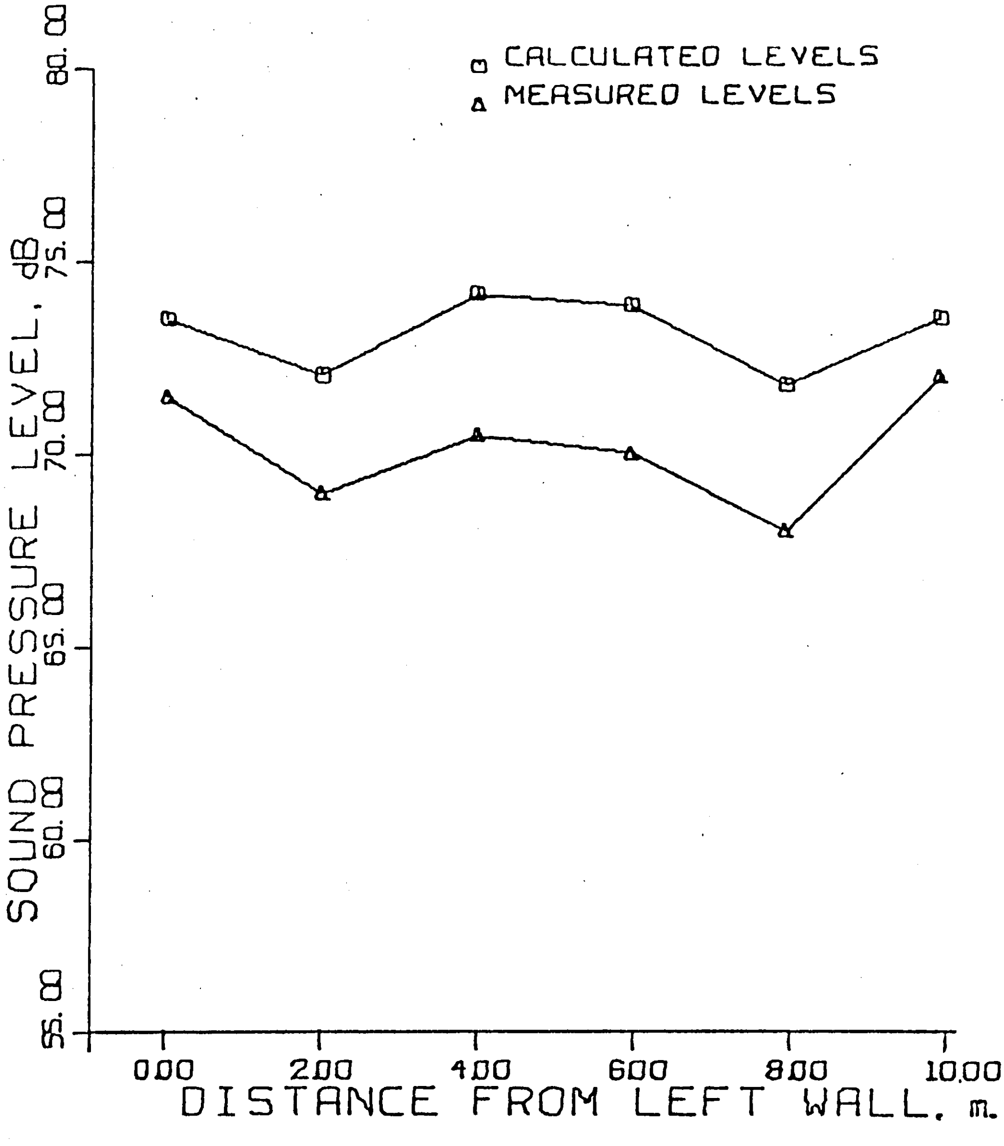
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 4000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, ... 21

FIGURE 29



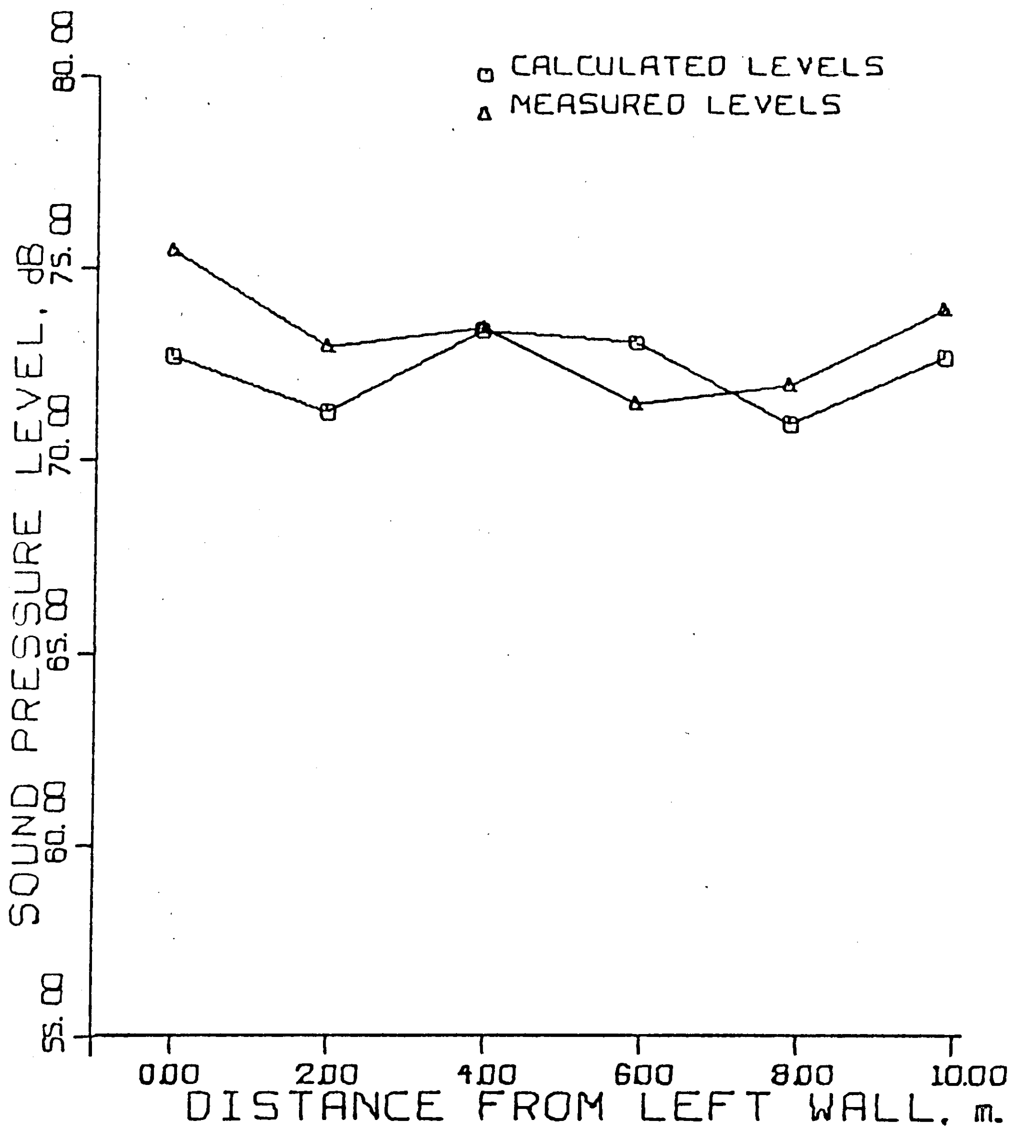
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 8000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 1, 5, 9, . . . , 21

FIGURE 30



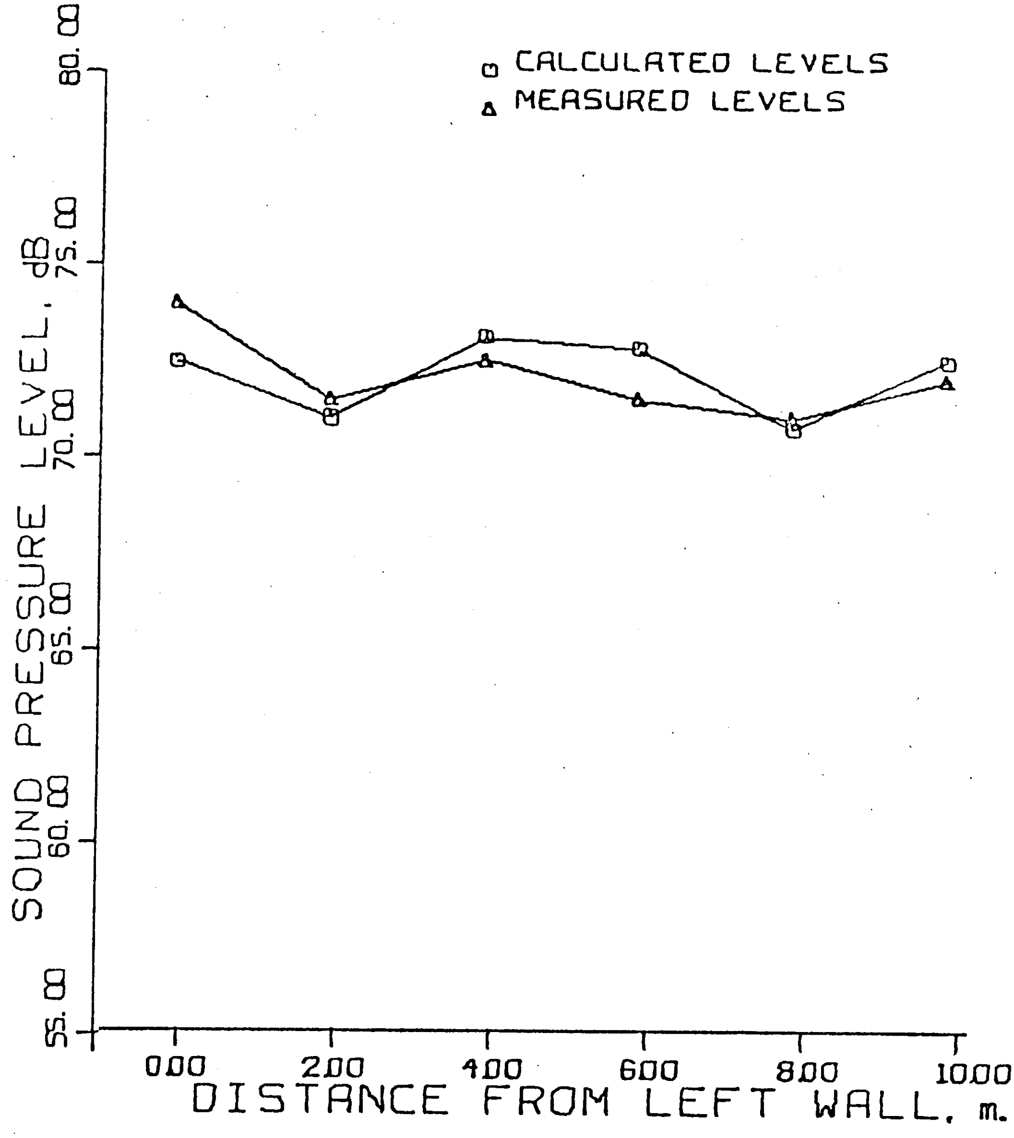
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 630 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 31



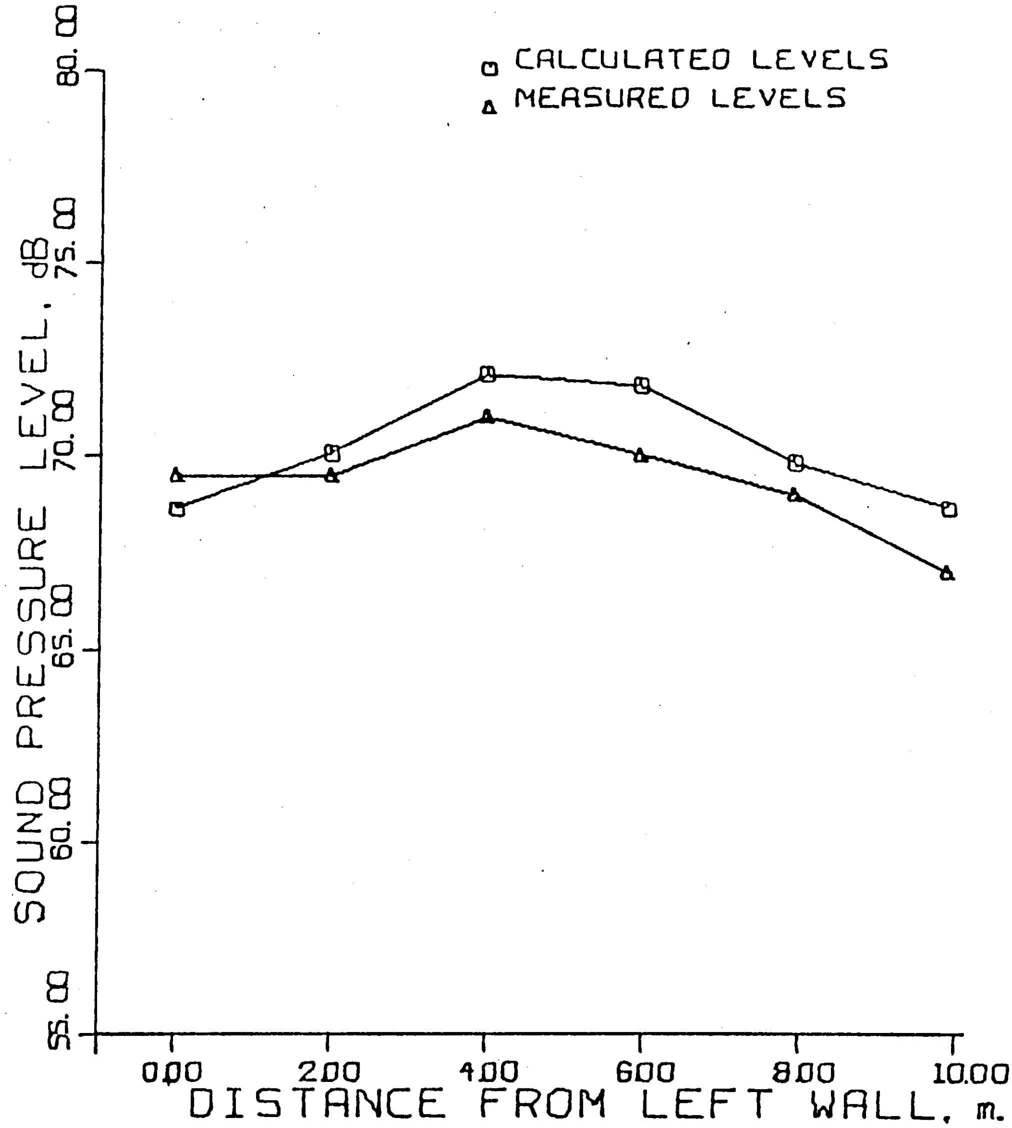
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 125 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 32



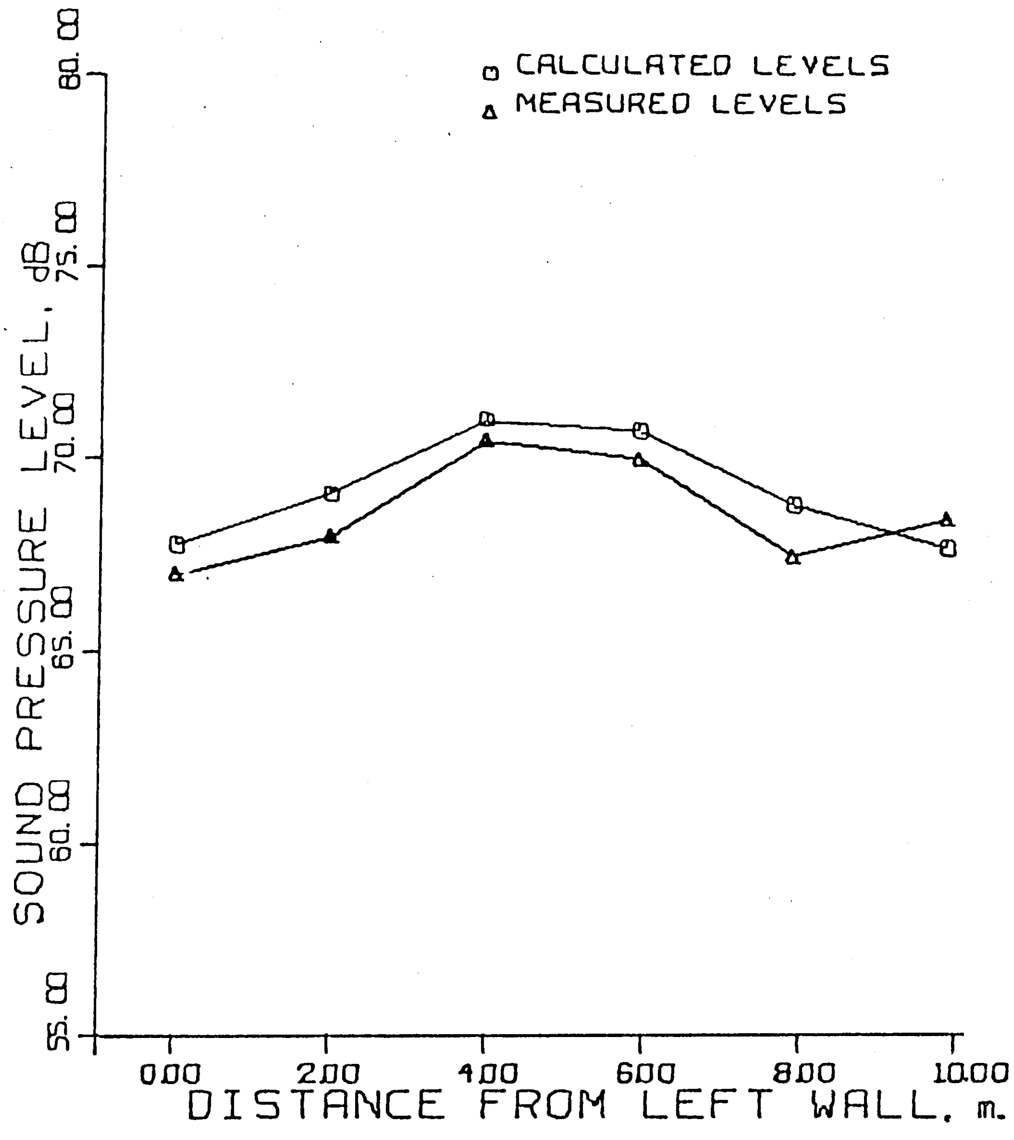
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 250 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 33



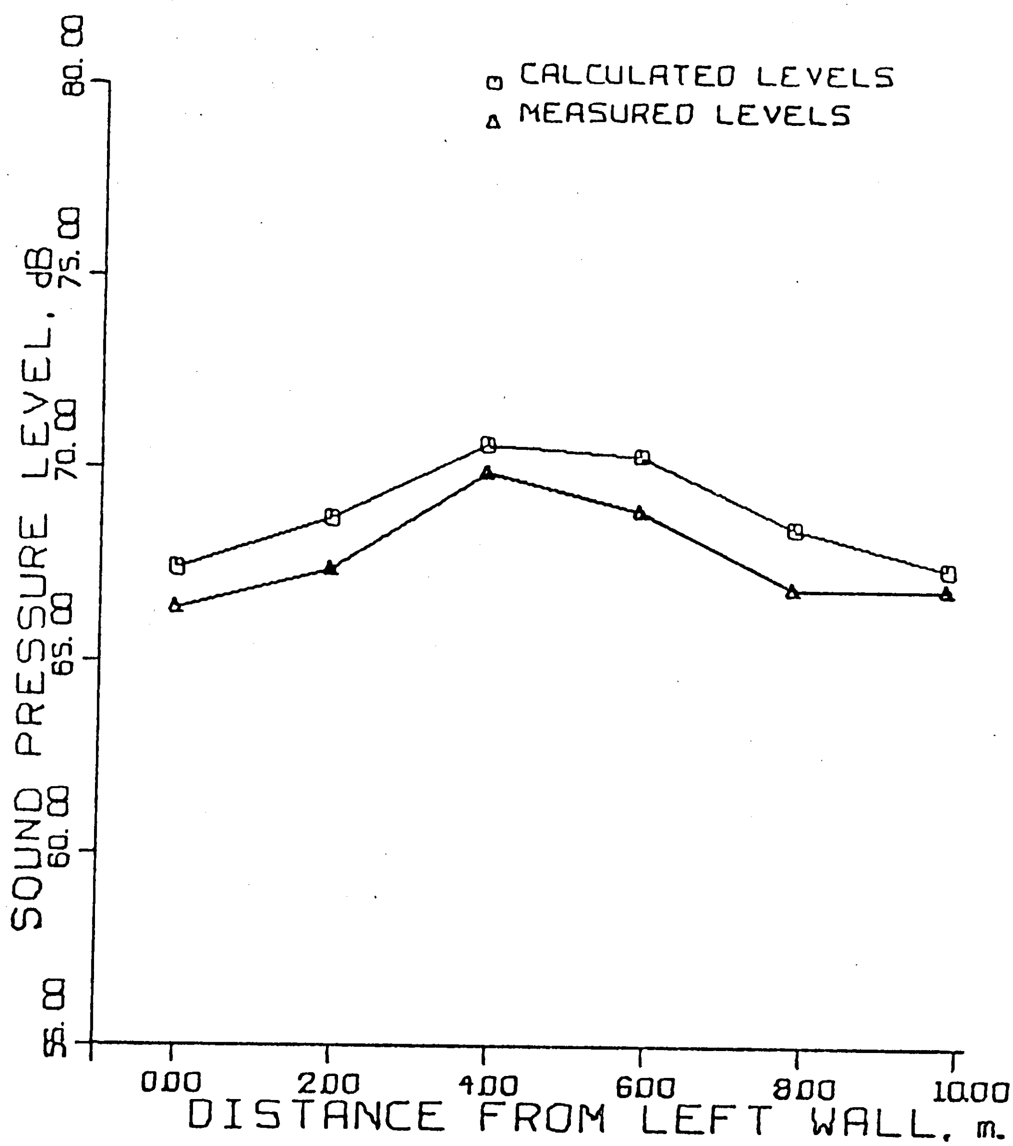
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 500 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 34



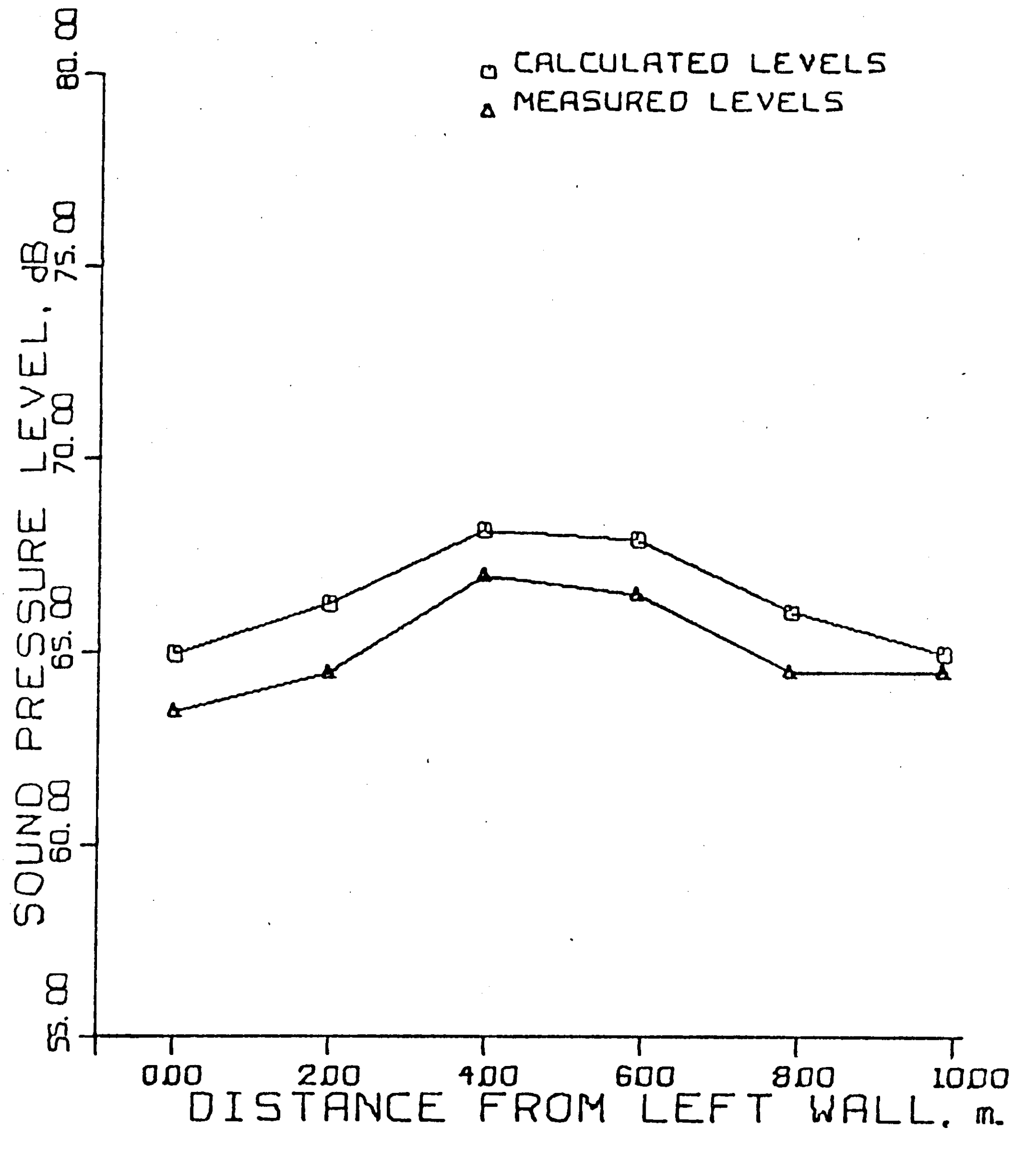
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 1000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 35



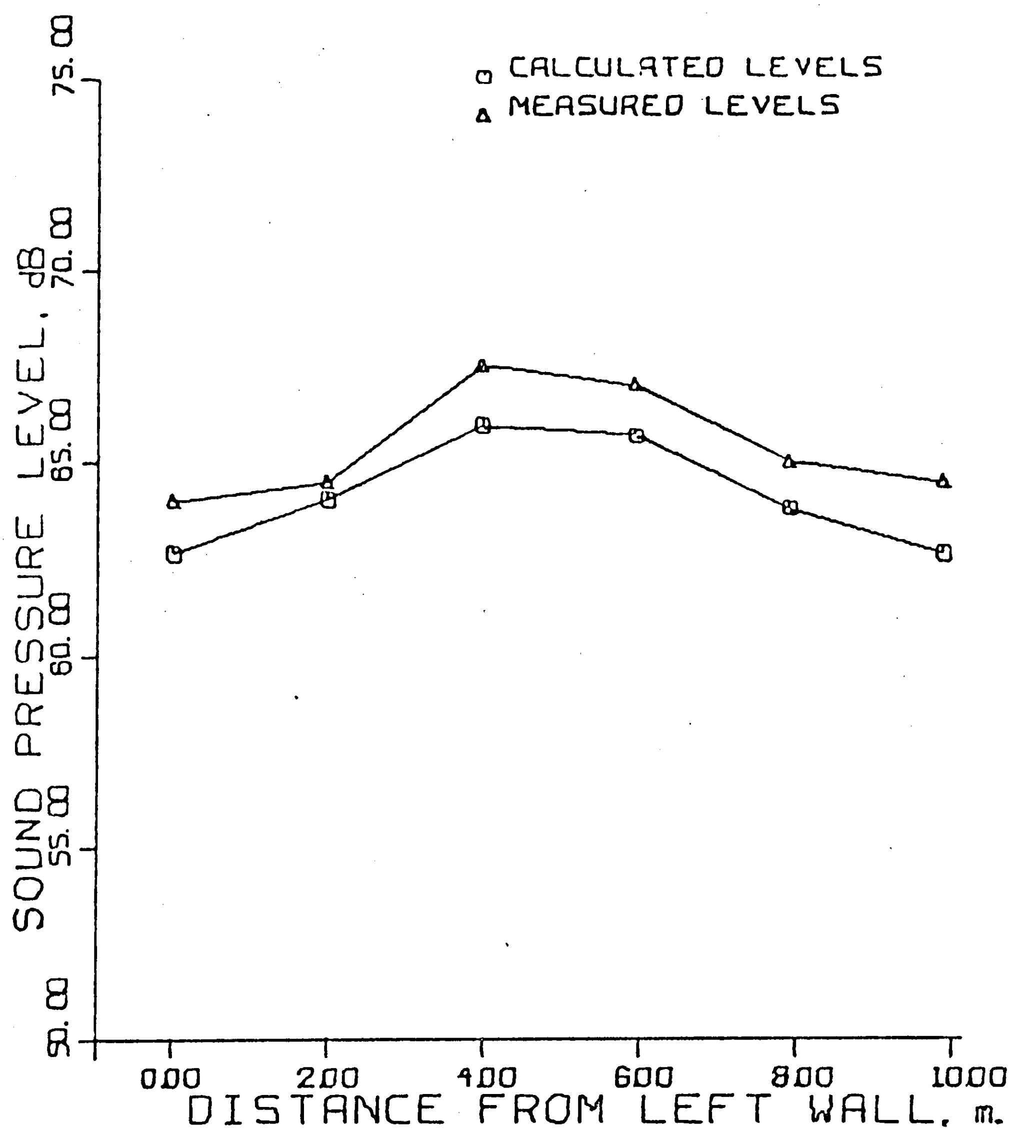
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 2000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, ... , 22

FIGURE 36



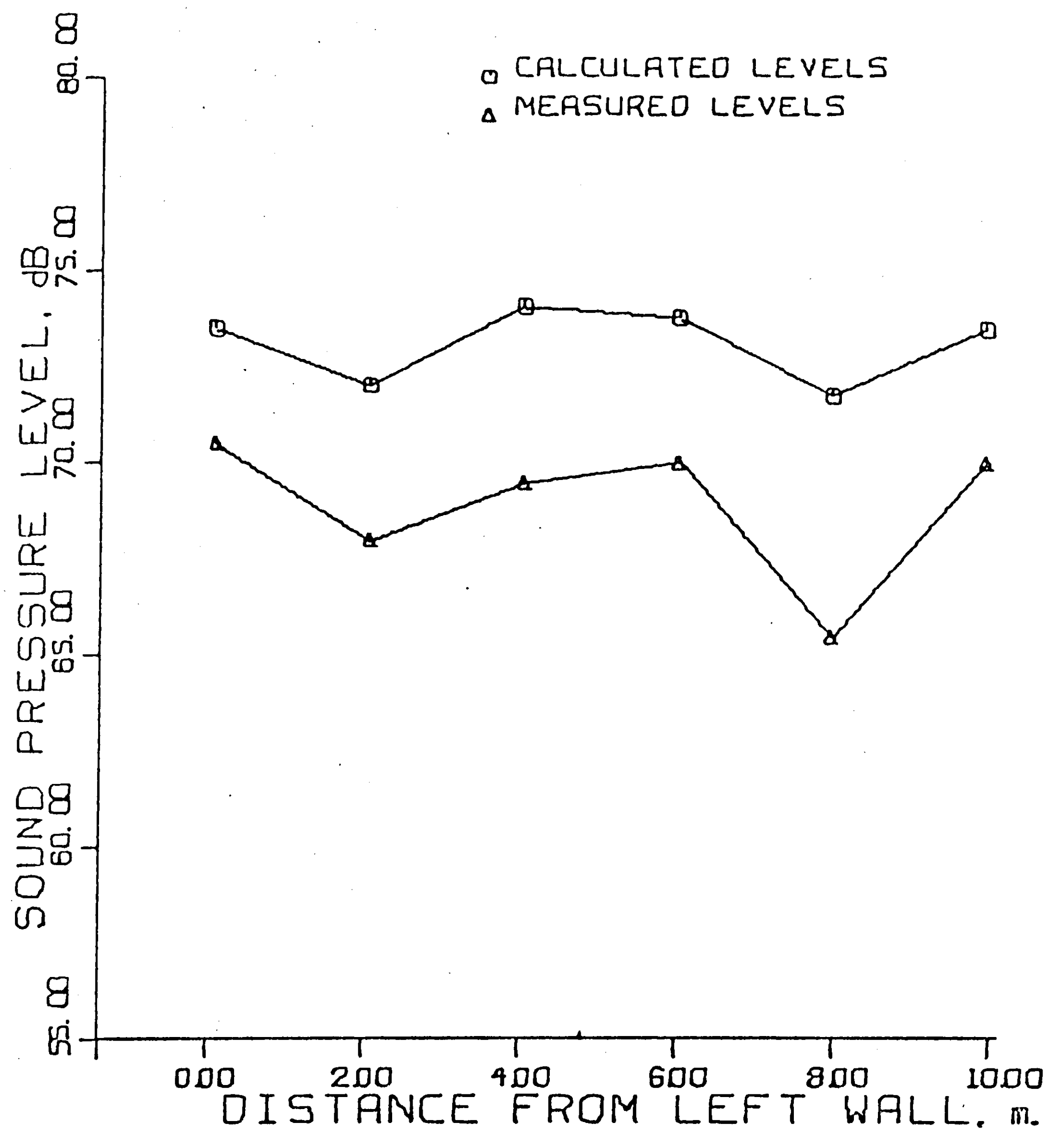
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 4000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 37



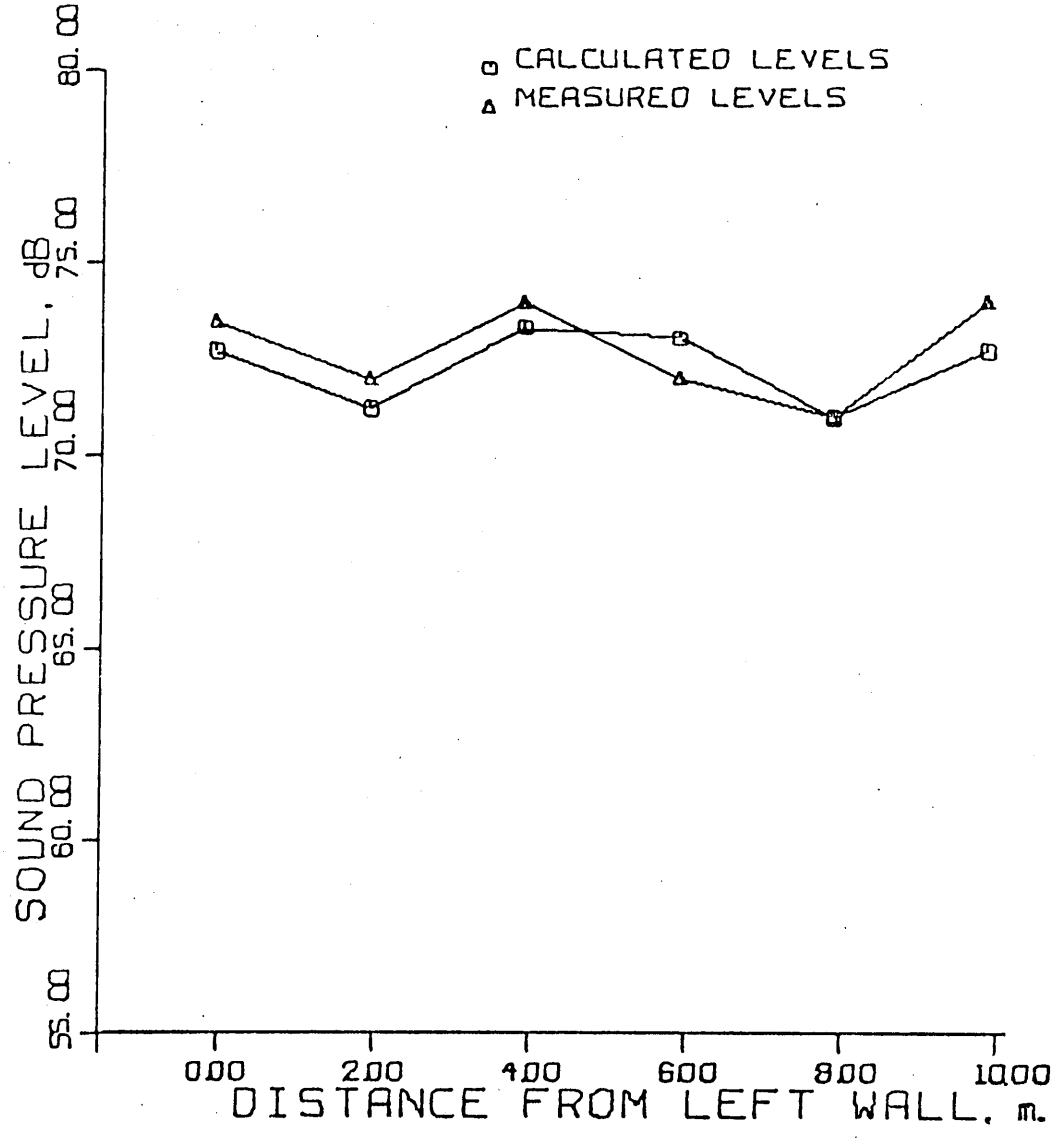
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 8000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 2, 6, 10, . . . , 22

FIGURE 38



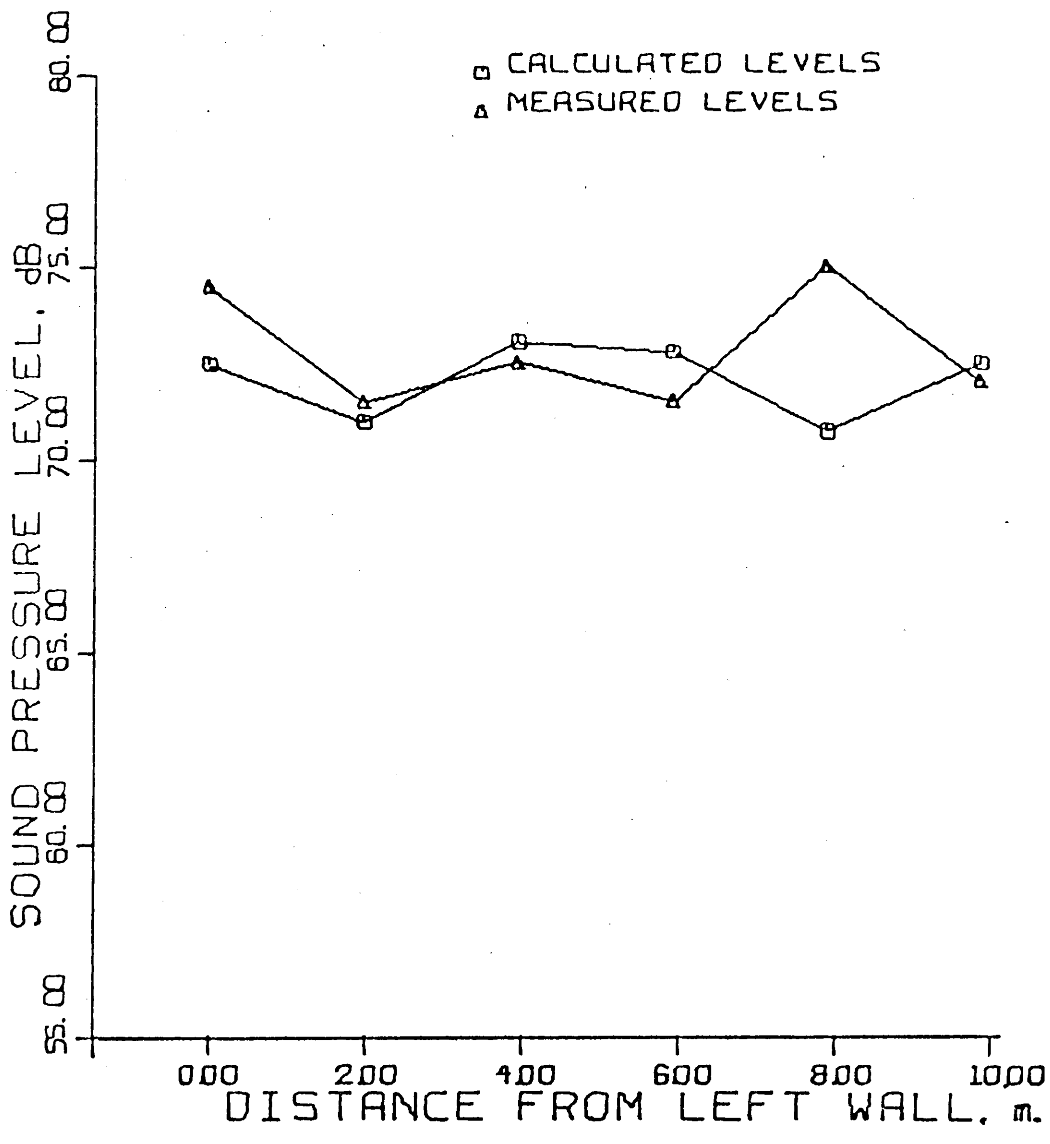
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 630 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 22

FIGURE 39



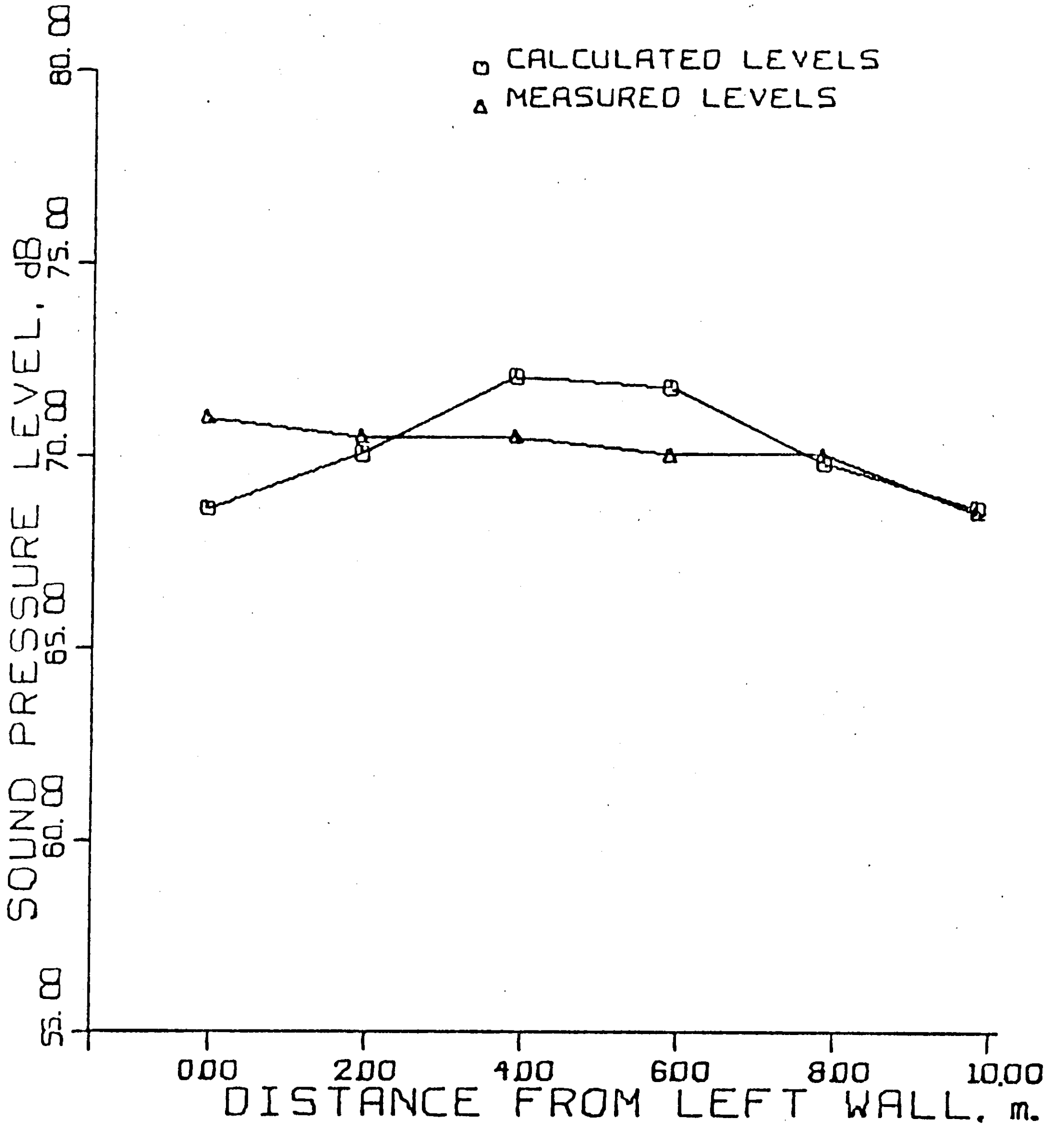
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 125 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 22

FIGURE 40



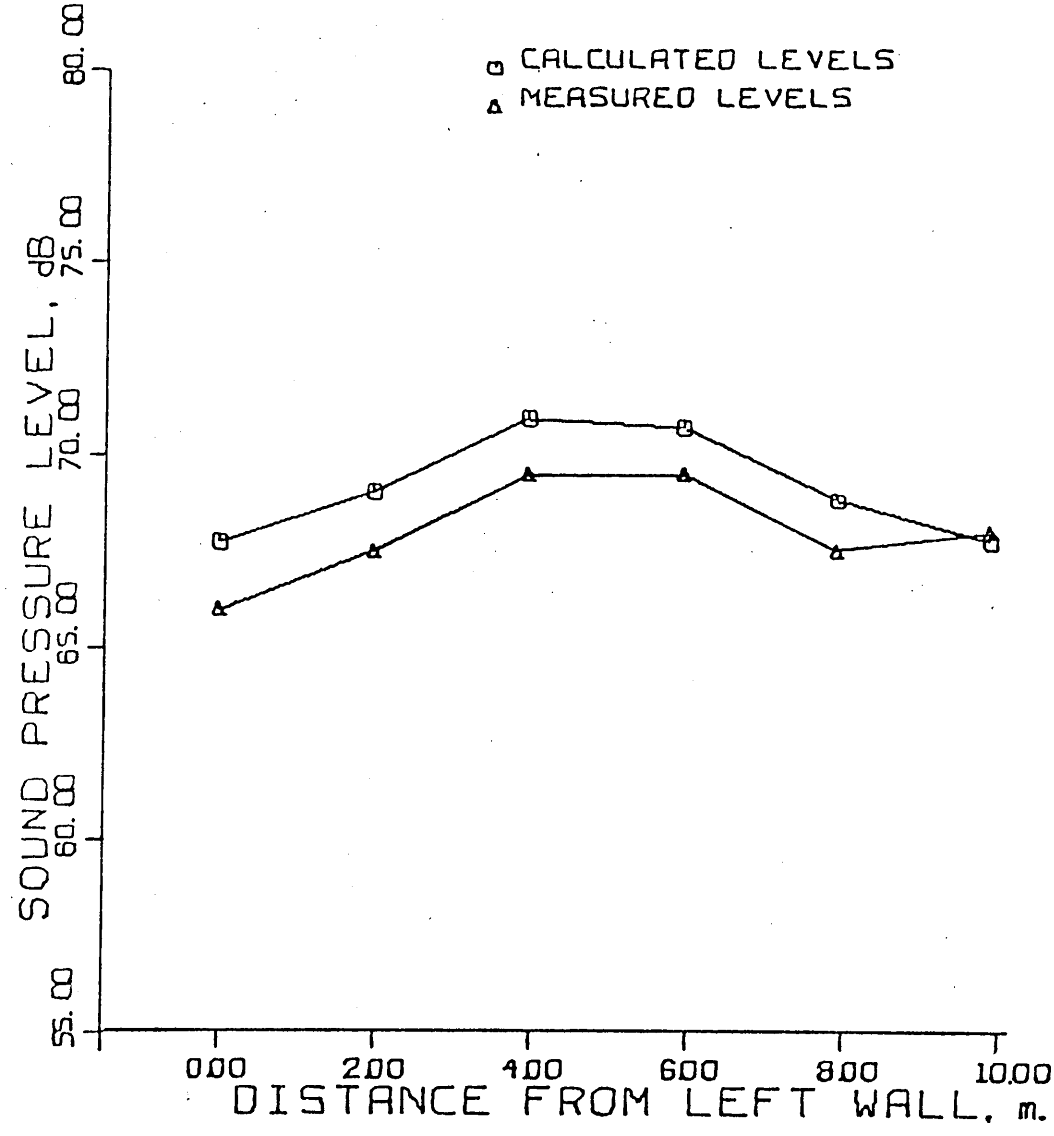
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 250 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 22

FIGURE 41



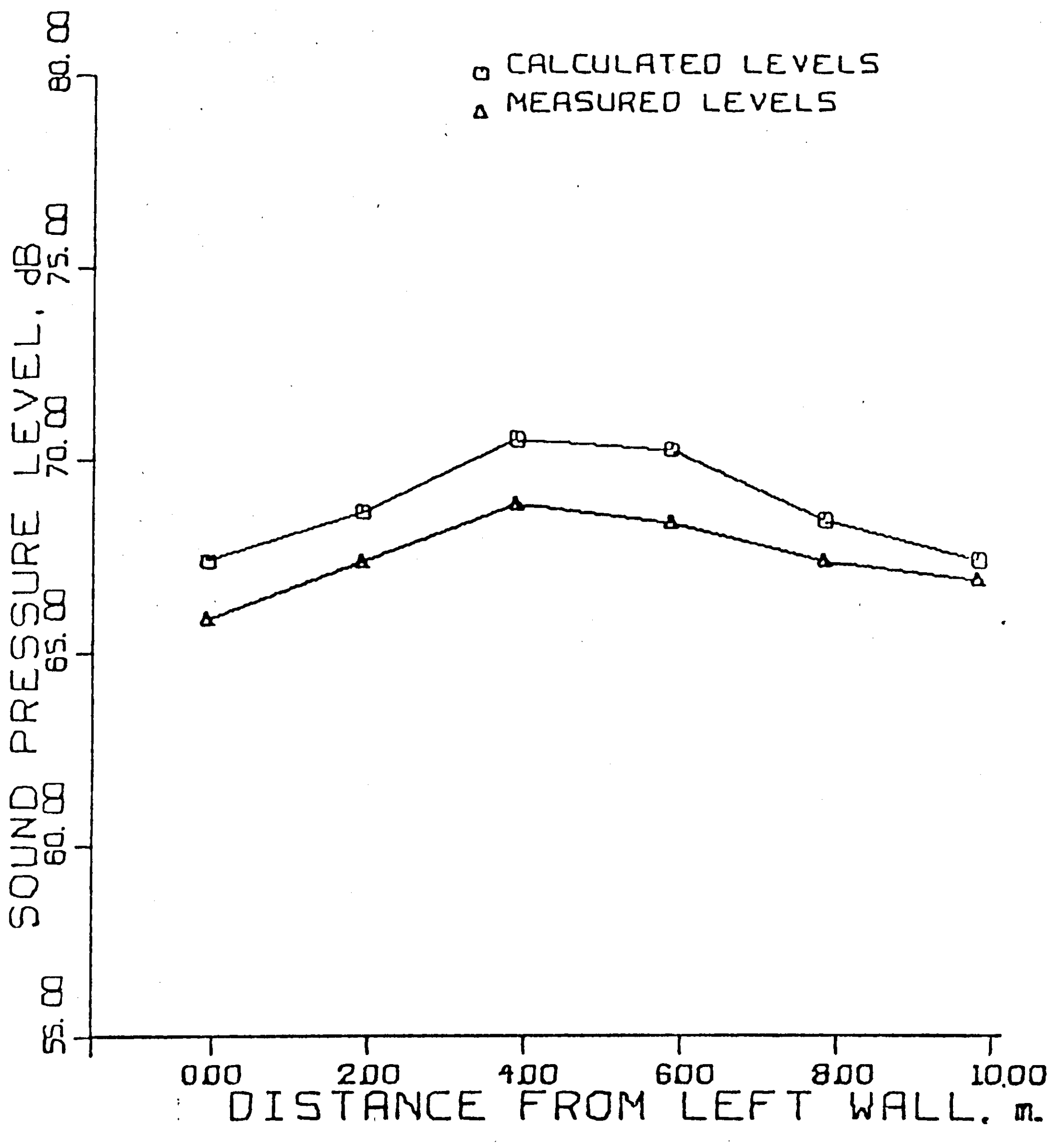
COMPARISON OF MEASURED AND
CALCULATED SOUND PRESSURE
LEVELS IN THE 500 HZ. OCTAVE
BAND IN RANDOLPH CLASSROOM AT
POSITIONS 3, 7, 11, . . . , 22

FIGURE 42



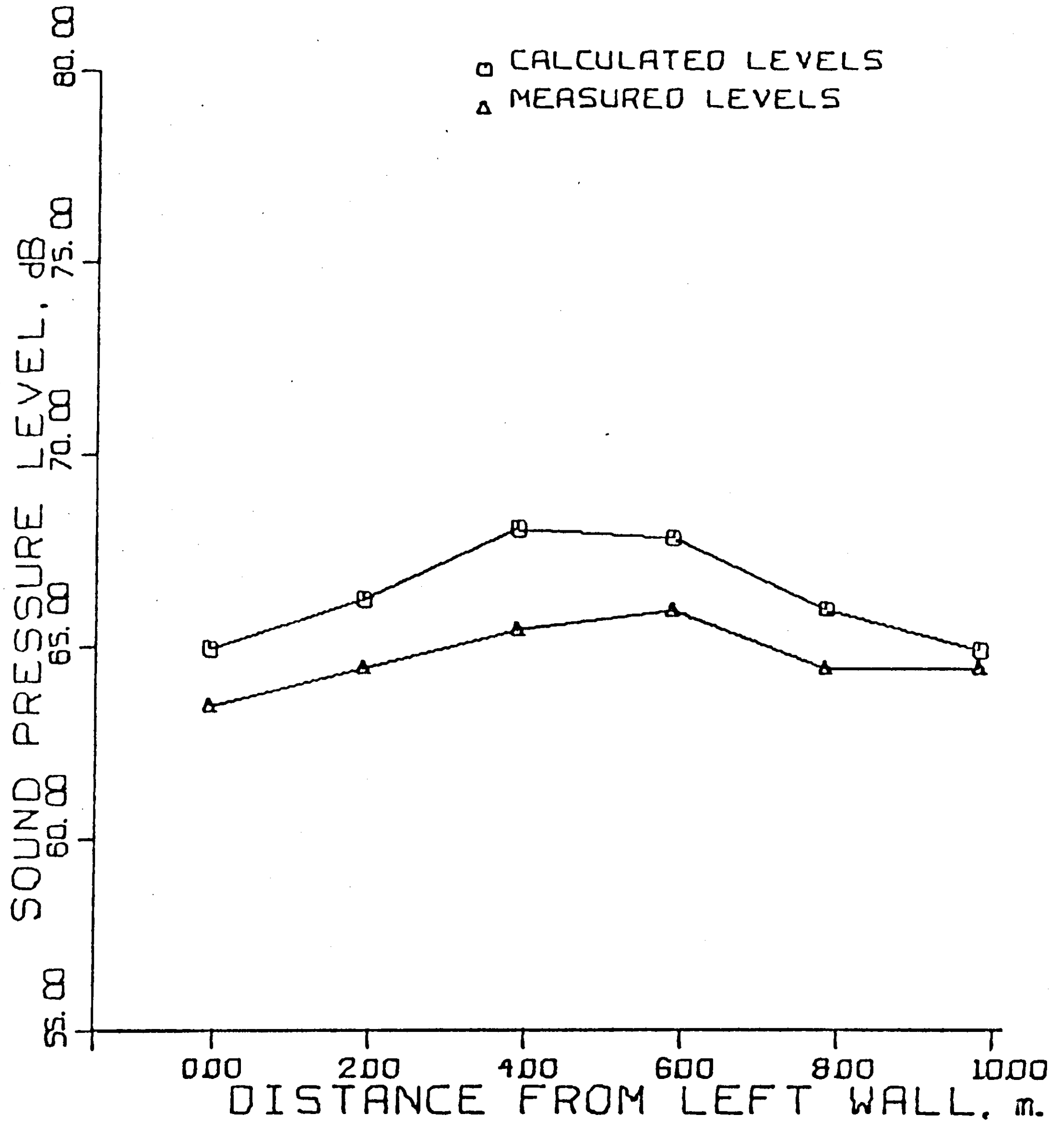
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 1000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 22

FIGURE 43



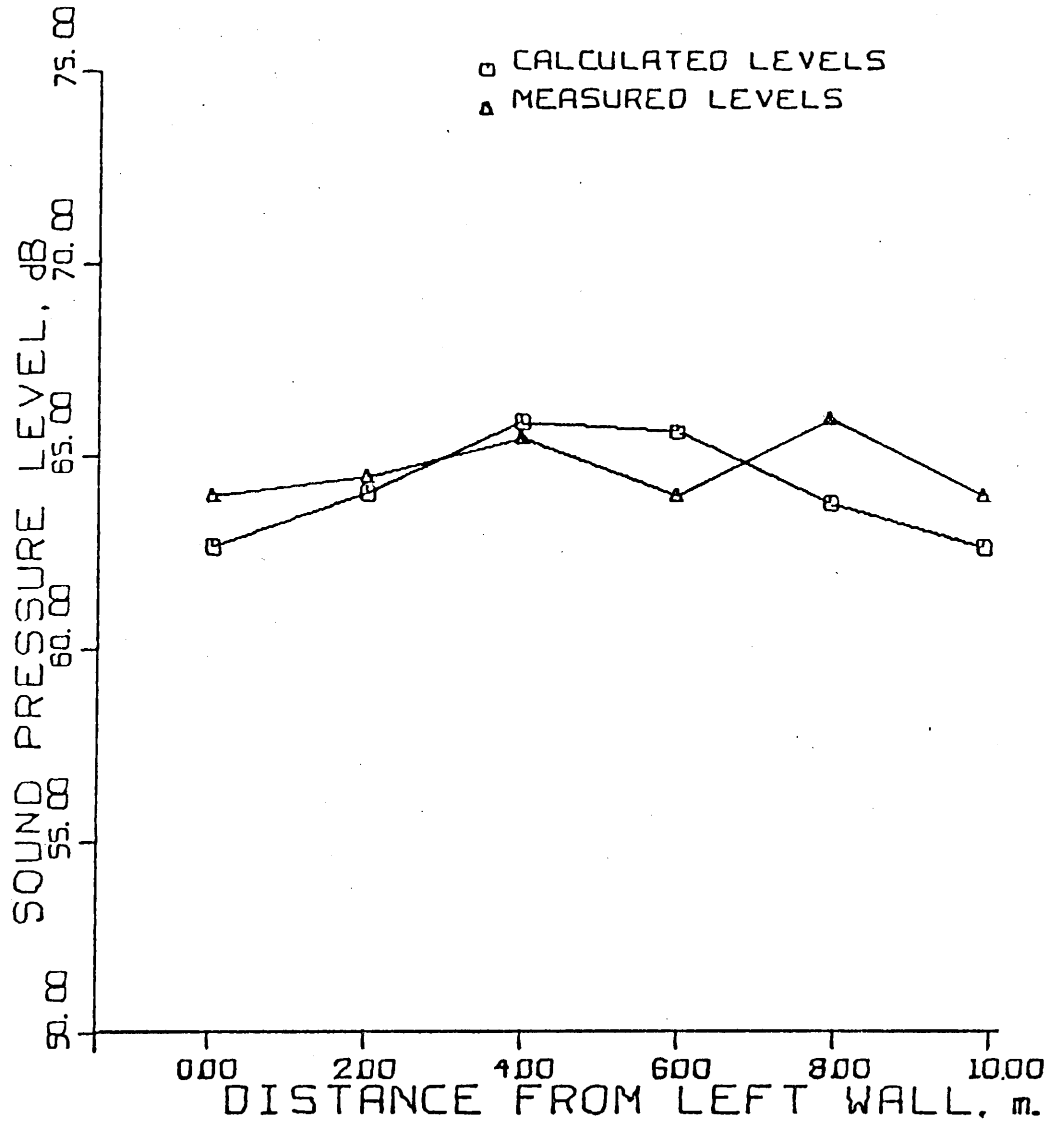
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 2000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, ... 22

FIGURE 44



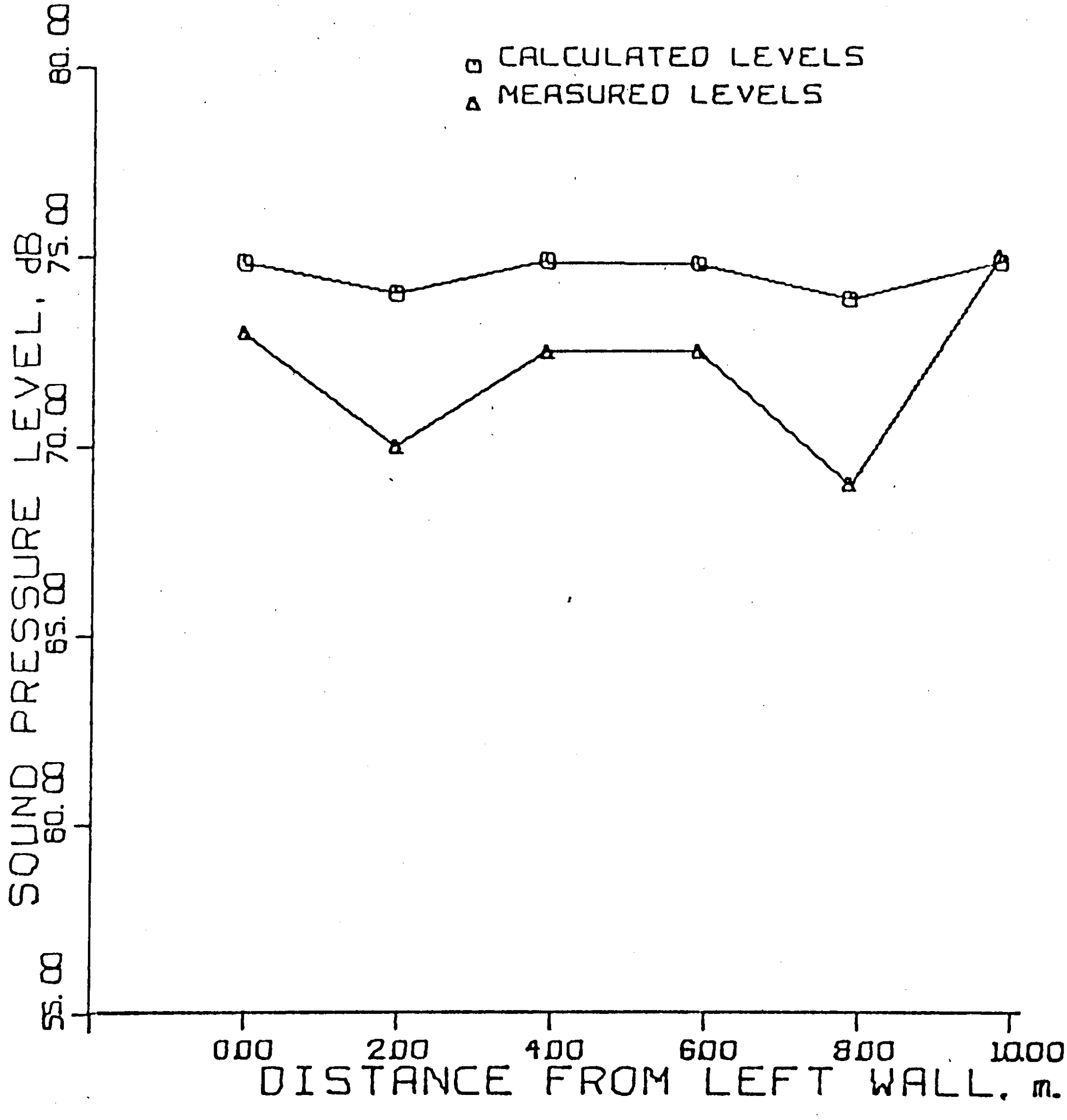
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 4000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 22

FIGURE 45



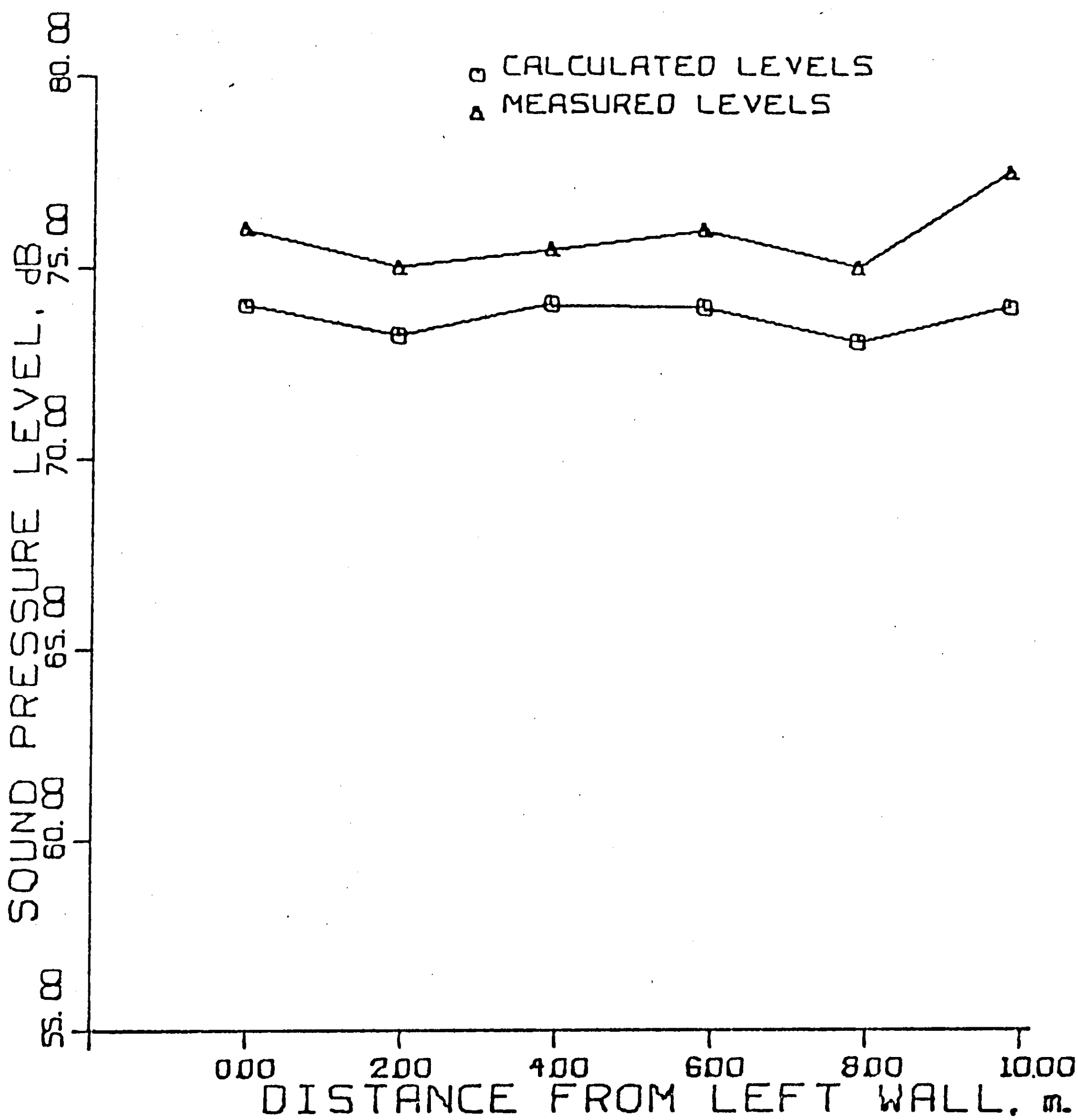
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 8000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 3, 7, 11, . . . , 22

FIGURE 46



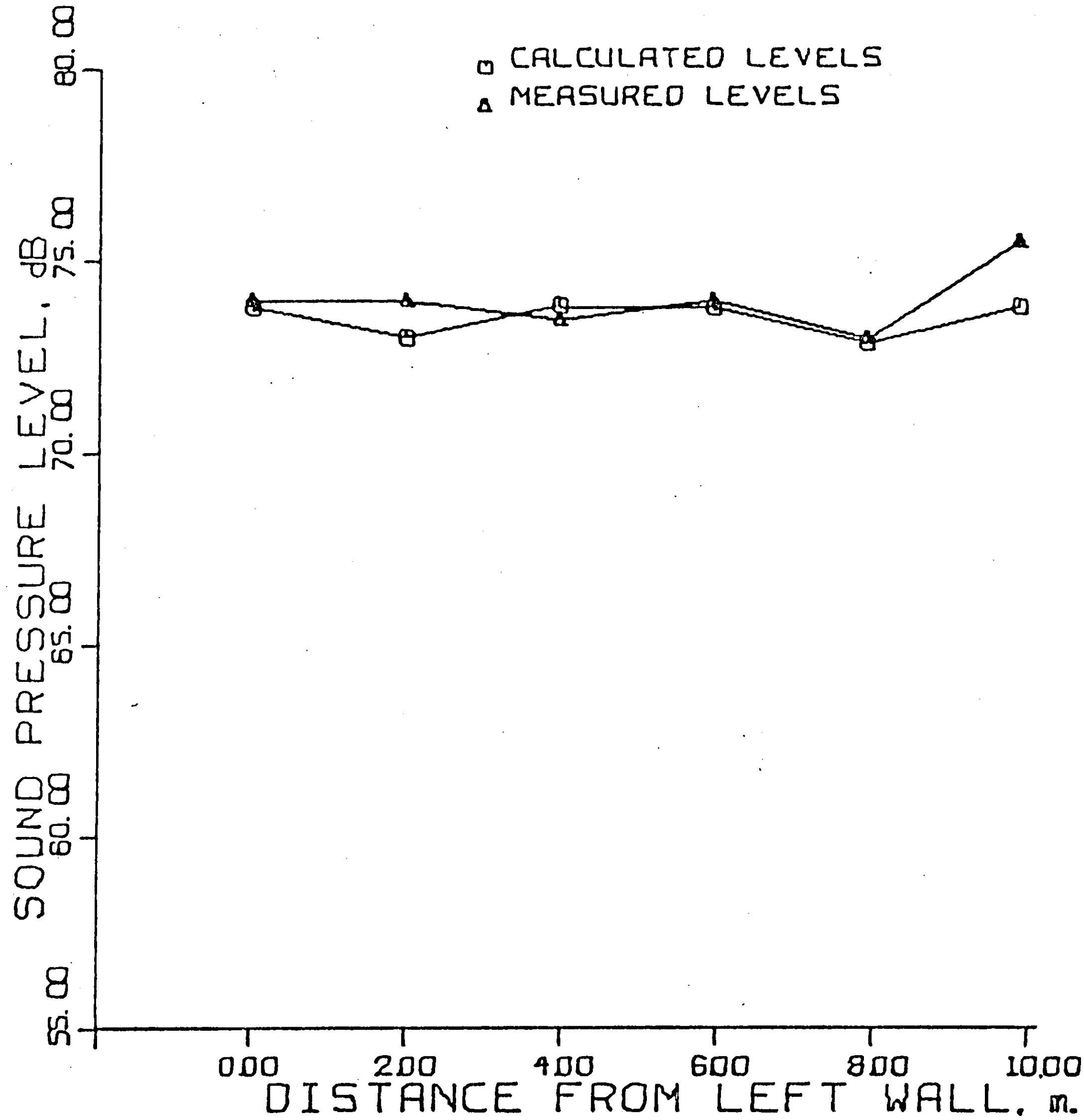
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 630 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 47



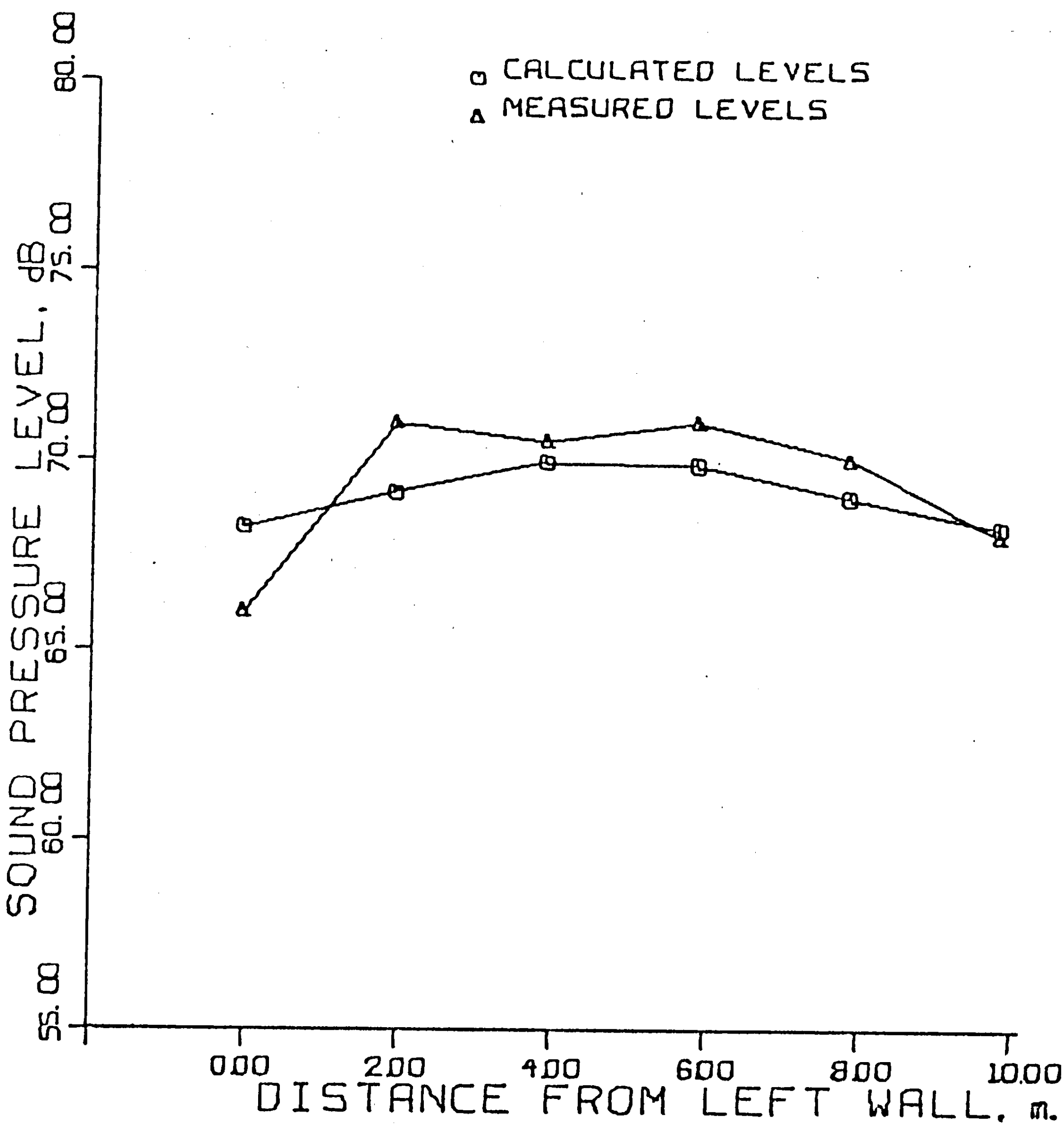
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 125 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 48



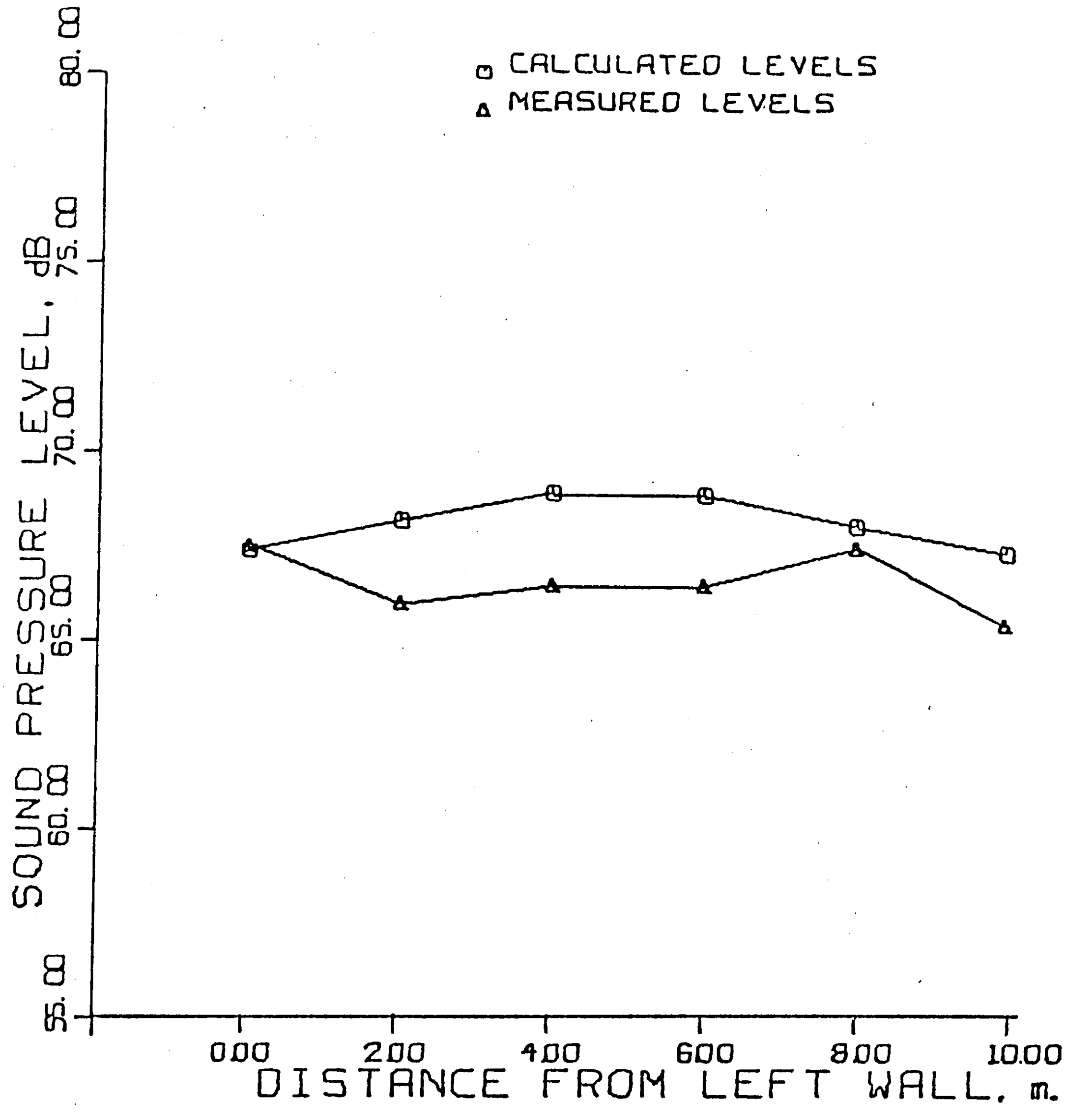
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 250 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 49



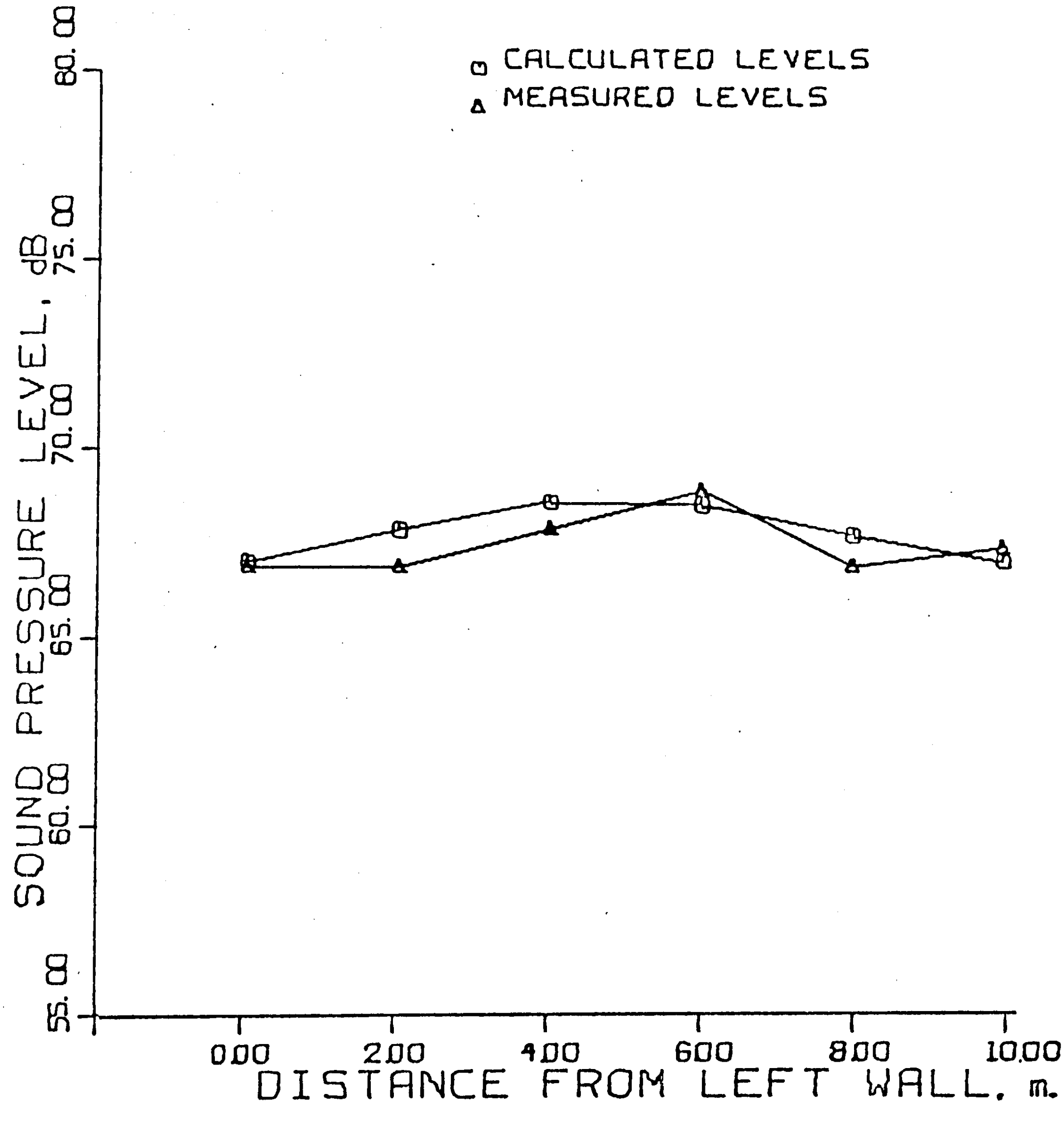
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 500 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 50



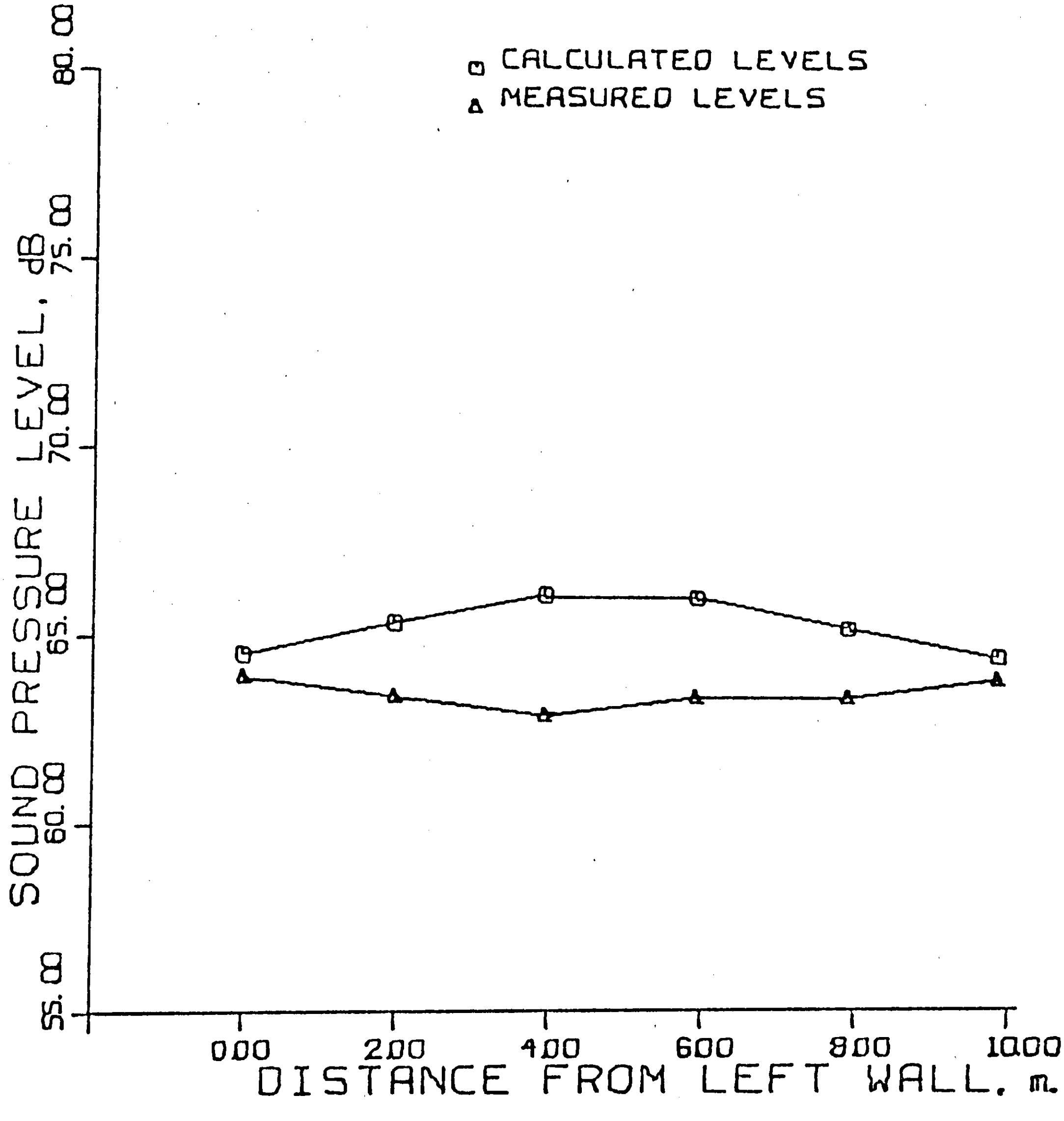
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 1000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 51



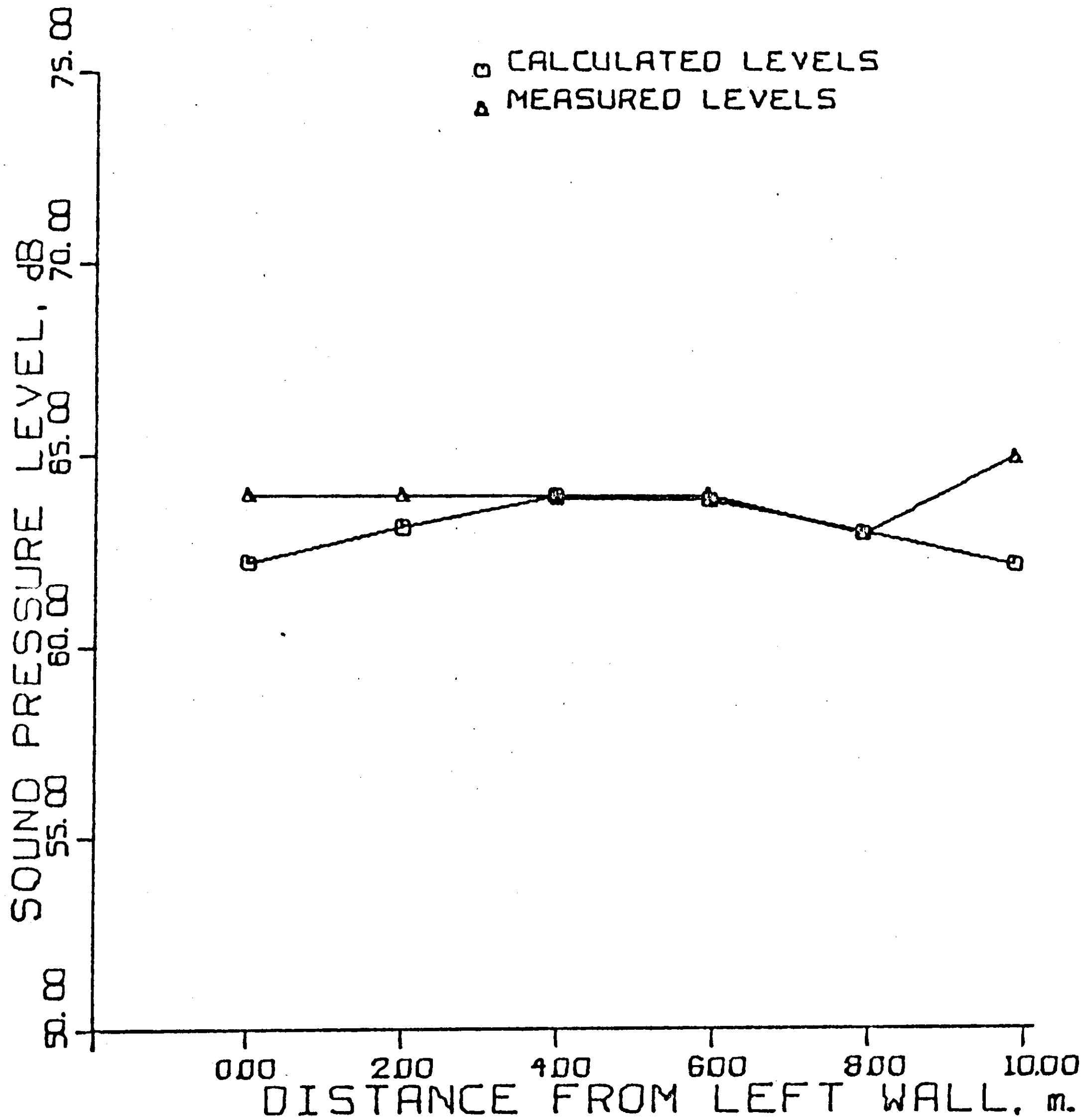
COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 2000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 52



COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 4000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 53



COMPARISON OF MEASURED AND CALCULATED SOUND PRESSURE LEVELS IN THE 8000 HZ. OCTAVE BAND IN RANDOLPH CLASSROOM AT POSITIONS 4, 8, 12, . . . , 24

FIGURE 54

5.0 DISCUSSION OF RESULTS

The previous comparisons of measured and calculated sound pressure levels illustrated much about the performance of the modified room acoustics equation. Although the dBA sound pressure levels are the primary concern of this project, the octave band sound pressure levels reveal much more about the predictions of the modified room acoustics equation. For this reason these comparisons are divided into octave band and dBA sound pressure levels for this discussion. The octave band sound pressure levels were also further divided into those with wavelengths greater than and less than the room dimensions.

5.1 Octave Band Sound Pressure Level Comparisons with Wavelengths Greater than the Room Dimensions

The 63 and 125 hertz octave bands had center frequencies with wavelengths greater than two of the room dimensions in Derring Hall (see Figures 11 and 12). In the classroom in Randolph Hall the 63 hertz center frequency had a wavelength greater than a room dimension (see Figures 23, 31, 39, and 47). The most evident characteristic of these figures was that the measured and predicted sound pressure level curves did not have the same shape. Near the source these curves were very similar in shape but as the receiver points increased in distance from the source the calculated sound pressure levels decreased more rapidly than the measured levels. Also at the most distant position from the source, 47, the measured sound pressure level was approximately 10 dB higher than the level at the previous position, 44, in the

Derring hallway. A similar situation was found in the Randolph classroom. This sudden reversal in the decay of the sound pressure levels with increasing distance was not predicted by the modified room acoustics equation. Aside from this one point the maximum difference between the measured and calculated sound pressure levels in these octave bands never exceeded $\pm$ 6dB. Since the expected error in these low frequencies was $\pm$ 4dB, this amount of error in real data was not of great concern. It should also be remembered that the modifications used for this special case were only approximations and were never expected to exactly predict the behavior of sound energy at these frequencies.

5.2 Octave Band Sound Pressure Level Comparisons with Wavelengths Less than the Room Dimensions

The plots of predicted and measured sound pressure levels versus position in the room generally have the same shape (see Figures 13-18, 24-30, 32-38, 40-46, 48-54). Although in general the shapes of these plots were similar in each figure there were some differences in the levels predicted and measured. In some instances the predicted curve was shifted by a constant amount of nearly every receiver point. There were also single points where errors existed between the predicted and measured sound pressure levels. Even with these differences, however, the maximum error was within $\pm$ 3 dB. This was considered acceptable when compared to an expected error of $\pm$ 4 to $\pm$ 2 dB.

To better illustrate the accuracy of these predictions their accuracy should be compared to the accuracy of predictions using the unmodified room acoustics equation. At the higher frequency octave bands the inaccuracy of the unmodified equation would be the greatest. In the 8000 Hertz center frequency octave band the unmodified equation would have predicted sound pressure levels within only $\pm$ 13 dB in the Derring hallway. At the lower frequency octave bands the predictions would have been better. In fact, in the 125 hertz octave band predictions would have been accurate to within + 6 dB in the hallway. Certainly the predictions of the modified room acoustics equation are as accurate and in most cases much more accurate than those of the unmodified equation.

Another point revealed by these comparisons of measured and predicted sound pressure levels was that above the 500 hertz octave band there was frequently an increase in the sound pressure level at the ends of the room as if reflections had occurred here. This increase was predicted by the computer calculations. The reason for this abrupt increase in the sound pressure level in the predicted data was the continuous monitoring of directivity by the program.

This modified room acoustics equation predicted sound levels in the higher frequency octave bands most accurately. This was significant since these frequencies are weighted most heavily in determining dBA sound pressure levels.

5.3 dBA Sound Pressure Level Comparisons

As in the previous case the shapes of these plots of calculated versus measured dBA sound pressure levels were approximately the same (see Figures 8, 9, 10, 19, 20, 21, and 22). There were some deviations at particular points as well as constant differences between the measured and calculated levels at nearly every point. Although errors were present they never exceeded $\pm$ 2dBA. This error was the same as that expected from the measurement system at high frequencies. It would therefore seem that quite acceptable accuracy had been obtained in terms of dBA sound pressure level predictions. This fact is even more evident when it is noted that unmodified room acoustics would have predicted values in error by as much as + 8dBA in these rooms.

6.0 CONCLUSIONS

There are of course several conclusions to be drawn from this work concerning the accuracy of the modified room acoustics equation and other aspects of the program. In order to present these in a clear and concise manner this section was subdivided into three subsections. These subsections were: the accuracy of predictions, the value of this program, and the limitations to its use.

6.1. Accuracy of Predictions

The error shown by the octave band and dBA sound pressure level predictions was discussed in the previous chapter. However it was of importance that the greatest accuracy was exhibited by the dBA sound pressure level predictions. The ability to predict these dBA levels well was a primary goal of this project. These levels were considered important since these would be desired by the industrial firm concerned with employee safety and compliance with the Occupational Safety and Health Act.

The octave band sound pressure levels were also of importance. For instance if dBA sound pressure levels were found to be too high in an area the octave band levels would be consulted as an attempt to determine the cause of the excessive noise or at least to isolate the particular octave band which caused the dBA level to be excessive. Of course, there are other instances where octave band levels would be important.

Although the errors exhibited in these sound pressure level prediction, $\pm$ 3dB, were greater than those of the dBA predictions, $\pm$ 2dB, they still were much more accurate than the room acoustics equation's predictions. These predictions in fact would probably be within the range of uncertainty of most measurement systems in an industrial environment.

In general the sound pressure level predictions were always as accurate and usually more so than the unmodified room acoustics equation. The accuracy achieved in these predictions would seem acceptable in all but the most critical of situations. In fact only when predictions were within $\pm$ 2 dBA of the OSHA specified exposure limits would there be any concern about the accuracy of the predictions.

6.2 Value of This Program

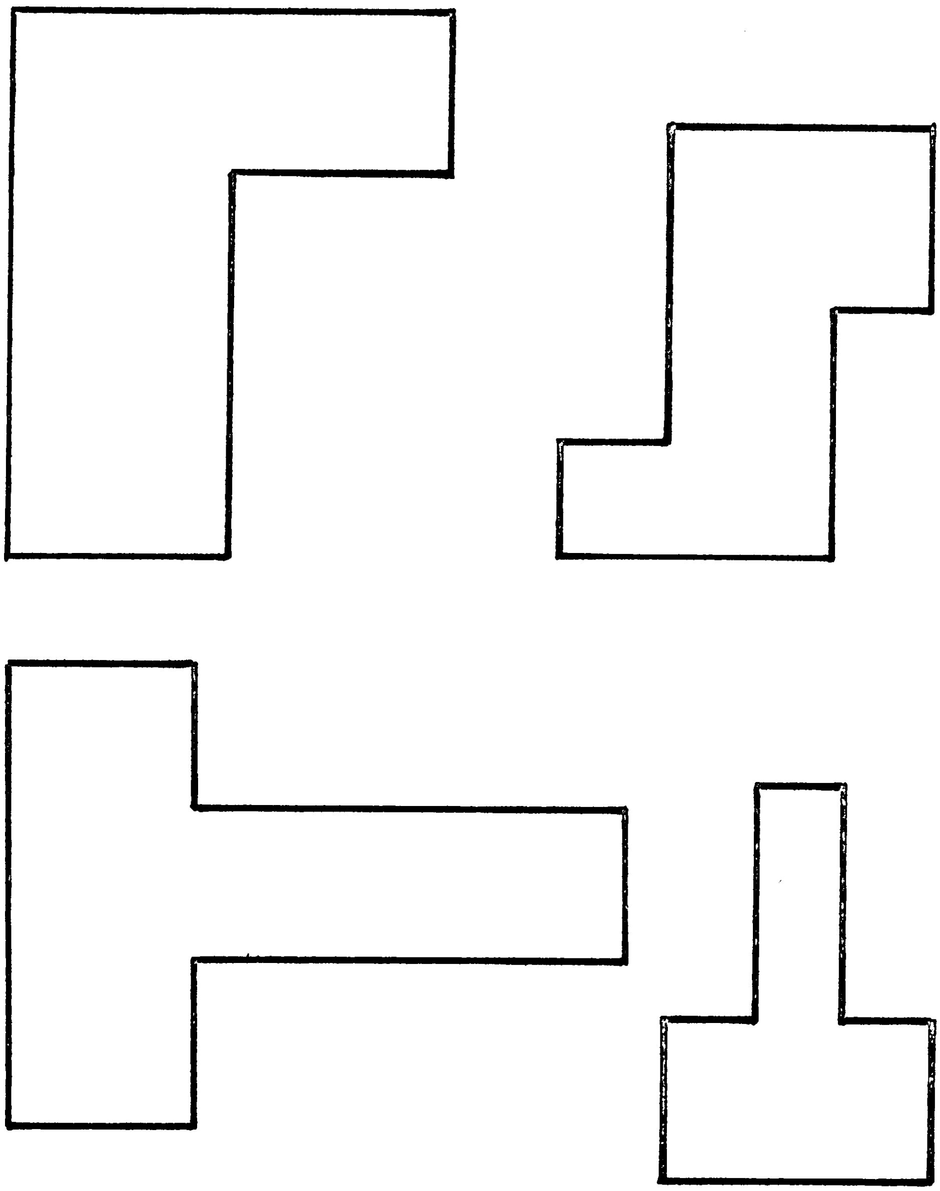
The most obvious use for this program is in the original design of a factory space. By its use, alternative pieces of equipment or even equipment locations could be selected to produce the best environment from a noise standpoint. Machines could be specified accurately as to the maximum allowed sound power levels. Thus the program could be used to help ensure suitable noise environments of the future. Moreover, design decisions concerning the installation of absorptive material or the purchase of higher cost acoustically controlled equipment can be evaluated for its ultimate in situ noise reduction value.

As for the factory already constructed, this program has valuable uses there also. It can be used to determine the effects of a new piece of equipment on noise levels throughout the area. This could be accomplished by adding noise levels predicted for a piece of equipment in a room to those already present in the room. This program could also be used to aid in specifying the maximum sound power levels for a new piece of equipment or the noise reduction necessary on an old piece of equipment. This program could also be used to determine the placement or arrangement of machines or people in a factory space to achieve the best noise environment. Another use would be to check the value of improvements to the factory space such as the addition of absorption material on large surfaces in the factory space. Thus the program has uses in the selection of replacement equipment and other functions in existing factory spaces.

6.3 Limitations of This Program

The primary limitations are concerned with the type of room to which this program may be applied. Certainly it should not be applied to extremely small rooms because of the inaccuracy introduced when the sound wavelengths become larger than the room dimensions. It should also be remembered that irregular patches of absorption or small irregularities in the room shape can lead to errors in the predictions of sound levels at or near these points. Another significant limitation is that irregular rooms such as Figure 55 cannot be analyzed. The number of noise sources is limited to 25 in the present version of the program.

This program has the ability to use a sound pressure level measured in another room and the acoustical description of the room, to generate a sound power level for the sources, and then to calculate sound pressure levels in the room where the source is to be located. This program will also calculate sound pressure levels from a given sound



Irregular Rooms.

Figure 55

power level for a source. Although these conversions can be made the program requires a spectrum of sound power or sound pressure levels. Frequently this data is unavailable. Provisions have been made for the future insertion of a subroutine which would generate a spectrum of sound pressure levels given a dBA level and a source type.

Limitations on the accuracy of this program were discussed in the previous chapter. Although the sound pressure level predictions of this program are not absolutely correct, they are certainly within the tolerance of many measurement systems likely to be used in an industrial environment. However, if the program is used to analyze a room, the limits of accuracy in its predictions should be kept in mind.

In summary it should be said that this program, though having limitations, provides an easy, accurate means to calculate sound pressure levels in a room. However, there are improvements and changes to be made.

7.0 RECOMMENDATIONS

The two primary areas of concern in this work were the development of a computer program to determine noise levels in industrial areas and the modifications made to the room acoustics equation to provide reasonable accuracy in the necessary calculations. Therefore in suggesting areas for future work these subjects will be considered separately.

7.1. The Computer Program

Of the areas mentioned previously where further work is needed the most important would seem to be the capability of the program to analyze irregularly shaped rooms. Very few industrial spaces are regularly shaped. Additions to factories and other physical plant changes usually cause very irregular geometries. Consequently, this would seem to be an urgent need before widespread use of this program would be possible.

Probably the second most important area to be investigated is the capability of generating a spectrum of sound pressure levels given a dBA level and a source type. At present very little is available in terms of sound power levels for equipment and a spectrum generated from dBA levels might be the most accurate if not only means of providing the necessary starting point for this program.

One other area where further work is needed is the classifying of walls as hard or soft for the directivity calculations. This classification should be broken down to graduations between the extremes of hard and soft. Another addition should be applying this classification of wall absorption at each octave band, resulting in directivity varying with octave-band as well as with distance between receiver and source and the location of the source.

Further work is also needed to improve the corrections when a receiver point is close to room surfaces. The present method seems to correct for this situation quite well. However different wall materials and different distances from microphone to surfaces could produce much different results. Some sort of investigation, perhaps using this program, needs to be carried out to develop a fundamental relationship between the proximity to the wall, the wall material, the octave band, and the increase in sound pressure level.

A possibility in factory spaces not considered in this program are barriers or partial walls. These barriers could be large machines, partial walls, or even acoustic enclosures around machines. Provisions must be made in this program to perform calculations in rooms containing these barriers. The present program would simply ignore these barriers and possibly be greatly in error.

At some future date logic should be incorporated in this program so that if desired by the user the source causing the worst dBA levels would be identified.

Another area of this program needing improvement is the calculation of absorption coefficients for a room. Presently the average absorption coefficients must be calculated by the user and entered into the program. It should be possible to develop a subroutine which would perform the necessary calculations to determine the average absorption coefficients for a room. This would involve either entering descriptions of the room surfaces or the absorption coefficients for each octave band for each surface.

An additional feature which should be added to this computer program would be a statement printed out warning the user that octave bands were being analyzed where the wavelengths of center frequencies were larger than the room dimensions. This would seem necessary since an increase in the uncertainty of sound pressure level predictions is involved in such cases.

The area of input and output with respect to this program was purposely neglected in the previous chapters simply because this was relegated to future work. It was felt that problems such as this could only be dealt with after a working program was developed. It is obvious, however, that some sort of option must be included in this program to plot dBA sound pressure levels to enable the user to select the worst and best positions for his personnel.

In general, it is suggested that this program be tested in many more rooms for several reasons. First these tests would determine whether the accuracy shown here holds in other situations. Further data would help support improvements to the logic involved in the calculation of the proximity of receiver points to walls corrections. Of course, there are other reasons for further measurements but these need not be listed. The important fact is that more reliable data is badly needed for any work in the area of room acoustics.

7.2. Recommendations for Further Work in the Area of Room Acoustics

Basically the recommendations for future work in this area fall into one general catagory. This is simply new derivations of the components of the room acoustics equations. As mentioned previously the derivations of the reverberant term including mean free path have been questioned for several years. It seems now with government legislation forcing the issue accurate predictions of sound levels are becoming more essential. The only way to achieve such accuracy is through new derivations of the components of the room acoustics equation or an all together new equation.

These derivations should consider the possibility of other than spherically shaped room as in room acoustics presently. The many assumptions based on plane wave theories must be re-examined. Finally the quantity, mean free path, should be examined to determine whether it is really valid and if so how it is to be evaluated. There is certainly much work to be performed in room acoustics and it is hoped that this work is at least a small step in the correct direction.

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APPENDIX I

USERS GUIDE AND DOCUMENTATION FOR THIS COMPUTER PROGRAM

INTRODUCTION

This program was designed to calculate sound pressure levels in regularly shaped rooms, i.e., quadralateral parallelepipeds. It performs these calculations using a modified room acoustics equation. There are also corrections incorporated for receiver points at walls and other room surfaces. Additional features of this calculation include the capability to consider up to 25 sources and to generate an array of receiver points at a particular vertical height throughout any size room.

One of the more important features of this program is that it allows either sound power levels to be put in for each source or sound pressure levels for each source and the characteristics of the rooms where these levels were measured. From the sound power levels sound pressure level are calculated directly. If sound pressure levels are put in sound power levels are first calculated for each source. Sound pressure levels are then calculated for points throughout the room as in the previous case.

The following sections describe the necessary data input for this program and the output options available to the user. In the final section a listing of the program is given containing a great deal of the program documentation in itself.

INPUT

In order to illustrate the necessary order and correct format for data input, the input forms are provided (see Figure A.1). However, in a program such as this with the many options available a few instructions are required in addition to those presented on the data forms.

One important point is simply that not all of the data illustrated in the forms are necessary for every case where this program is ued. In such a case the unnecessary data should simply be ignored and the next card considered. For instance, if only sound power levels are entered for each source there are no sound pressure levels required to be inputed. Therefore, the sound pressure level cards should be skipped and the surface index cards examined if they are necessary.

With each card set the number of cards required and, where appropriate, the number of values per card are indicated. The data input sheets indicate one of several cards in a series in some cases. If no indication is given for the number of cards required only one is necessary. Also, if the number of cards required is zero that particular variable is not required.

Descriptions are presented of each of the data cards which could possibly be required by this program. It is hoped that these descriptions will clarify any questions concerning the order, units, or other characteristics of the variables being inputed.

Card Set 1--This card contains important parameters used in this program. Each of these parameters is discussed below.

N is the number of sound sources in the room being analyzed. The maximum number of these sources is 25.

NSWL is the number of sources with given sound power levels. The maximum value of this parameter is 25.

NSPL is the number of sources with given sound pressure levels. The maximum value here is also 25.

NOB is the number of octave bands to be used in this analysis. The following octave band center frequencies are represented by the given octave band numbers: 1-16 Hz., 2-31.5 Hz., 3-63 Hz., 4-125 Hz., 5-250 Hz., 6-500 Hz., 7-1000 Hz., 8-2000 Hz., 9-4000 Hz., 10-8000 Hz., and 11-16,000 Hz. Obviously the maximum number of octave bands is eleven. If zero or no value is entered for this variable the program defaults to using ten octave bands. Also it should be noted that the first octave band is always 16 Hz.

NIR is the number of irregularities in the room. Until provisions are made for this program to consider irregular rooms this parameter must always be zero.

IP is the index for printing. If IP is zero there will be no printed output from this program. If IP is any other value control of the printed output is shifted to another section of the data input.

NC is the number of temperature and barometric pressure corrections to the calculated sound power and pressure levels to be made. These corrections simply account for variations from the standard environmental conditions of 30 inches of mercury and 77 F. The first correction is always made to the sound pressure levels calculated for the room being analyzed. All following corrections are made in the sound pressure level to sound power level conversions that are made when sources with given sound pressure levels are present. Also all conversion included by the number of corrections selected have corrections applied to them. For instance if the third sound power to sound pressure conversion was of interest, that is, if the given sound pressure level were measured at a temperature and barometric pressure other than standard conditions, NC would be 4. The first three barometric pressures and temperatures would have to be the standard values. The fourth, however, would be those in the room where the measurements were taken.

NRUN is the number of data sets to be analyzed after and including this particular one. In other words, if there were two other factory spaces to be analyzed after this one NRUN would be 3. The first cards of the next two data sets would have values of 2 and 1 for NRUN, respectively.

NSURF is the number of absorptive surfaces to be considered by the program. This number is common for the room being analyzed and the rooms in which sound pressure levels given for sources were measured. Therefore the largest number of surfaces to be considered in any of these rooms should be entered here. In a room which has fewer surfaces one or more surfaces may be divided into several parts to result in the proper number of surfaces. The maximum number of these is 31. The minimum number of surfaces allowed is one. This minimum is used when average absorption coefficients are calculated externally and entered into the program. Until further modifications are made to the ABSORB subroutine this is the only means to enter and use sound absorption coefficients in the program.

Z is the vertical height of receiver points in the room being analyzed. Z may be expressed in meters or feet provided the proper value for the units index is used. This aspect is discussed in more detail in a later section.

Card Set 2--The variable entered with this card set is the sound power levels for the sources, SWL. These are entered for the entire octave spectrum for each source on each card. Therefore the maximum number per card is eleven and the maximum number of cards is 25. The number of sound power level octave entries per card should equal NOB. The number of cards should be NSWL. It should be noted that the order used in entering data here must be maintained in entering source positions and other data pertaining to these sources.

Card Set 3--The variable entered with this card set is the sound pressure levels of the sources, SPL. Again the same limits apply as above. The number of entries per card should be NOB and the number of cards should be NSPL. Again variables pertaining to these entries should be placed in the same order as these sources were entered.

Card Set 4--Coefficients, ISURF, are inputed on these cards to determine what absorption coefficients are used for the room surfaces. Until a more complete sound absorption routine is developed this number simply indicates which one of a set of average absorption coefficients calculated by the user are selected. Average absorption coefficients for each octave band must be calculated by the user and inserted in the ABSORB subroutine for use in the program. For further details consult subroutine ABSORB of Appendix 2.

Card Set 5--The variables of this card determine whether unit conversions are performed on several variables. The variables inputed here are: ITEMP, IBP, IXYZ, IXYZ1, IXYZ2, IXYZ3, IR1, and IXYZ4. In general the variable controlled by an index is identified by the letters following the I in the index name. For instance, IBP controls whether unit conversions are made on BP, the barometric pressure. There are some cases in which the naming convention is not strictly followed. IXYZ1 controls conversion from feet to meters of X1, Y1, and Z1. Another exception is IXYZ which controls unit conversions of XX, YY, ZZ and Z. It should be noted that all variables controlled by a single index must have the same units. If the units of a variable are metric its index should be one. If the units are english the variables index should be zero. The computer program converts every variable to metric units for its calculations. However, the possibility of using english units for input was incorporated because it was postulated that much of the information available to a user would be in english units. For further details see subroutine UNITS.

Card Set 6--The variables inputed here are the temperatures, TEMP, and the relative humidities, HUMID, in the rooms involved in the necessary calculations. The units of TEMP may be either °C or °F. The order of input of these variables is for the room being analyzed first followed by the values for each of the rooms in which sound pressure levels were measured for the sources in the order of input of the sound pressure levels. Consequently the number of cards in this input set should be N-NSWL+1. The reason for this value instead of NSPL+1 is that there could be sources with dBA levels given for them. In this case spectrum would have to be generated for each source. Although this capability has not been incorporated into the program, provisions have been made for it such as this system for determining the necessary cards. There is a possible maximum of 26 cards in this section including values for the room which is being analyzed and the 25 rooms where sound pressure levels for the sources were measured.

Card Set 7--The dimensions of the rooms involved in these calculations are entered here. These are XX, YY, and ZZ. XX and YY are the horizontal dimensions while ZZ is the vertical dimension. YY should always be the larger of the horizontal dimensions. These sets of dimensions must be in the same order as discussed in previous sections of the room being analyzed first followed by the rooms where sound pressure level measurements were made in the order the sound pressure levels were inputed. These variables may be expressed in feet or meters providing IXYZ has the proper value. The number of cards required is N-NSWL+1. The maximum number of courses would be 26.

Card Set 8--The variable, SA, the surface area of absorptive material in the room is inputed in this data set. These surface areas may be expressed in square feet or meters. Each card contains 8 surface areas. When the number of necessary surface areas is reached for a particular room regardless where this is on the card the next set of areas should be started on a new card. The number of surface areas required is NSURF per room. The number of rooms is N-NSWL+1. Again the order followed is the room being analyzed is first followed by data for the rooms where sound pressure levels for the sources were measured.

Card Set 9--The variable inputed on this card, R1, is the distance from source to receiver in the rooms where sound pressure levels for the sources were measured. The number of these required would be N-NSWL. It should be noted that there are eight R1's per card. The maximum number of these variables is 25. These distances may be expressed in feet or meters.

Card Set 10--Inputed on these cards are the positions of the source in the rooms where sound pressure levels were measured. These variables X4, Y4, and Z4 may be expressed in feet or meters. Since there is only one source per room where the sound pressure levels were measured there is a maximum of 25 sets of positions possible. The number of cards is N-NSWL.

Card Set 11--This card contains the positions of the sources in the room being analyzed, X1, Y1, Z1. The number of cards is of course N. The maximum number of cards is therefore 25. These positions may be expressed in feet or meters providing the proper value of IXYZ1 is used.

Card Set 12--Inputed on this card are the positions of any irregularities in the room being analyzed, X2, Y2, and Z2. Irregularities are of course branches from the main room. These are commonly characterized as a "T" or an "L". The maximum number of cards here would be 5 since there are only 5 irregularities allowed. The actual number of cards is however NIR.

Card Set 13--On these cards the dimensions of the irregularities, X3, Y3 and Z3, are inputed. The same limits and conditions apply as above.

Card Set 14--The barometric pressure, BP, in the various rooms is inputed here. The number of cards is equal to NC with the maximum being 26. The units that this variable is expressed in may be either inches or millimeters of mercury. Again this variable must be inputed first for the room being analyzed and then by the order of the input of the sound pressure levels the conditions for the rooms where sound pressure levels for the sources were measured. If no corrections are to be made to a particular sound level BP could be entered as 30 inches of mercury.

Card Set 15--These variables, DINCR and IYINC, are the increments of the array of receiver points in the X and Y directions respectively. If 0.0 is entered for DINCR a value is automatically selected most compatable with the number of sources in the room and the room size. If 0 is entered for IYINC the value of 2 meters is automatically selected by the computer program. It should be noted that any value entered for these variables is assumed to have units of meters.

Card Set 16--These variables, IXO, IXMAX, IYO, IYMAX, IZO, and IZMAX, are indexes signifying a wall as "hard" or "soft" with respect to sound absorption and are used in the directivity index calculation. These indexes refer to the walls perpendicular to the principal axes of a room. For instance the IXO index refers to the wall perpendicular to the x-direction axis from which the x component of the source positions in the room are referenced. If a source had an X1 position component of 0 it would be at this surface. IXMAX refers to the other wall perpendicular to the X axis. If these indexes are zero the wall is treated as hard in the directivity calculation. If the value is one the wall is assumed soft. Concrete would be a hard wall. An acoustical tile ceiling would be a good example of a soft surface. The number of cards of these variables is N-NSWL+1. The maximum value is of course 26.

Card Set 17--The input here is IWALLS which indicates the proximity of a measurement point to room surfaces in a room where the sound pressure levels were measured. The value of this index is the number of walls including the ceiling and floor that are within six inches of a measurement point. The number of these is N-NSWL+1. There can be as many as 25 of these values. These are all on one card.

Card Set 18--The variables on this card, IDBA and NPOB, are an index to determine the type of output desired and the number octave bands to be printed out respectively. The values of these variables are explained fully in the output section.

Card Set 19--This card is the octave bands, OB, for which sound pressure levels are to be printed out. The number of these variables is equal to NPOB.

In order to more clearly demonstrate the data input to this program the following example is presented and coded on example input sheets (see Figure A.2). A source is located on the floor in the center of a 10 feet high, 12 feet wide, and 100 feet long room. Sound pressure levels were given for the source and these are, in octave bands 1-8; 76, 78, 82, 81, 75, 76, 74, and 70. These levels were measured with the source in the center of a room 20 feet high, 10 feet wide, and 50 feet long. The receiver point was at the source height, six inches from a wall. Temperature and relative humidity in both rooms was 700 F and 50%. The receiver height for the calculations in the room being analyzed was ear height, 5 feet. Two sets of average absorption coefficients have been calculated and inserted in the program for these rooms. ISURF=1 specified the absorption coefficients for the room being analyzed. ISURF=2 specifies the correct absorption for the room in which the sound pressure levels were measured. Measurements in determining the sound pressure level for the source were taken at a distance of 12 feet. The barometric pressure in the room being analyzed was 26.9 inches of mercury necessitating corrections to the calculated sound pressure levels. All of the surfaces in the room where sound pressure levels were measured are assumed hard. In the room being analyzed the ceiling is assumed to be soft. The only other necessary inputs required not specified here will be those controlling the output options which are discussed in the next paragraph. For this example it was assumed that sound pressure levels in the third and eitht octave bands were desired to be printed out.

OUTPUT

There are several possible combinations of output with this program. It will print out full octave band data for each receiver point and/or dBA levels at each receiver point. These values are printed in the same arrangement as the receiver points which were determined throughout the room.

The first index controlling output is IP entered on the first data card. If IP is equal to zero, no output of any kind is produced. However, if IP is any number other than zero control of the output shifts to the index IDBA. If IDBA is equal to 2 only dBA levels will be printed. If IDBA is equal to 1 only octave band levels will be printed. However, if IDBA is any other number both octave band and overall dBA sound pressure levels are printed out.

If octave band sound pressure levels are to be printed out the user must specify the total number of octave bands desired and what particular octave bands these are. The variable NPOB is the total number of octave bands at which sound pressure levels are desired to be printed out. The numbers OB(1)-OB(NPOB) are the particular octave bands at which print-out is desired.

The output produced by the preceding example is shown in Figure A.3. It is hoped that enough information has been provided to enable the user to successfully run this program. It is also hoped that the program so used provides solutions to meaningful acoustics problems.

APPENDIX II

COMPUTER PROGRAM LISTING

```
      COMMON/POSITN/X1(25),Y1(25),Z1(25),Z
      COMMON/FORVES/MFP(26)
      COMMON/WALLS/ISURF(26,11),SA(26,11)
      COMMON/SPECTR/NSPEC(25),DBA(25),FSPL(25,11)
      COMMON/ABSORP/ABAR(26,11),AA(26,11)
      COMMON/LEVEL2/AHOLD(250,11)
      COMMON/DBAVAL/DBAL(250)
      COMMON/DISTAN/R1(25),R(25,250)
      COMMON/POSIT2/X4(25),Y4(25),Z4(25)
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
      COMMON/IRRITS/X2(5),Y2(5),Z2(5),X3(5),Y3(5),Z3(5)
      COMMON/TBP/TEMP(26),T(26),BP(26),HUMID(26)
      COMMON/LEVEL1/SPL(250,11),SWL(25,11)
      DIMENSION XLABEL(5),YLABEL(5),HEAD(5)
      DIMENSION XIN(16),YIN(16)
C
C    PURPOSE--- THIS PROGRAM IS DESIGNED TO CALCULATE SOUND PRESSURE LEVELS
C               IN A ROOM WITH GIVEN ROOM CHARACTERISTICS AND EITHER SOURCE
C               PRESSURE LEVELS,SOUND POWER LEVELS,OR DBA VALUES.
C
C
C    N= NUMBER OF SOUND SOURCES (25 MAX)
C
C    NSWL= NUMBER OF SOUND POWER LEVELS SOUND SOURCES (25 MAX)
C
C    NSPL= NUMBER OF SOUND PRESSURE LEVELS SCUND SOURCES (25 MAX)
C
C    NOB= NUMBER OF OCTAVE BANDS BEING USED, THIS IS ANY NUMBER FROM 1-11.
C    STARTING WITH 16 HZ. GOING TO 16000 HZ.
C
C    NIR= NUMBER OF IRREGULARITIES IN THE ROOM AT THE PRESENT STAGE THIS
C    NUMBER MUST BE ZERO
```

```
C
C   IP= INDEX FOR PRINTING, IF IP=0 NO PRINTED OUTPUT, IF IP GREATER THAN 0
C   OUTPUT IS PRINTED
C
C   NC= NUMBER OF CORRECTION FOR TEMPERATURE AND BAROMETRIC PRESSURE TO
C   BE MADE
C
C   NSURF= NUMBER OF SURFACES TO BE CONSIDERED  FOR SOUND ABSORPTION
C
    1 READ(5,10)N,NSWL,NSPL,NOB,NIR,IP,NC,NRUN,NSURF,Z
   10 FORMAT (9I3,F10.0)
      WRITE(6,11)N,NSWL,NSPL,NOB,NIR,IP,NC,NRUN,NSURF
   11 FORMAT('0','N=',I3,2X,'NSWL=',I3,2X,'NSPL=',I3,2X,'NOB=',I3,2X,'NI
     1R=',I3,2X,'IP=',I3,2X,'NC=',I3,2X,'NRUN=',I3,2X,'NSURF=',I3)
      IY=0
C
C   Z= THE POSITION OF RECIEVER POINTS IN THE VERTICAL DIRECTION
      WRITE (6,12) Z
   12 FORMAT('0','Z=',F10.2)
      IF(NOB.EQ.0) GO TO 18
      GO TO 19
   18 NOB=10
   19 CONTINUE
C
C   THIS IS A SECTION WHERE VALUES USED THROUGHOUT THE PROGRAM ARE DETERMINED
C
      IN=NSPL+NSWL
      IG=N-IN
      NTERM=N-NSWL
      IH=NTERM+1
      NCOF=N-NSWL+1
      IF(NSWL.EQ.0) GO TO 55
```

```
      DO 23 J=1,NSWL
C
C    SWL= THE SOUND POWER LEVELS FOR THE APPRCPRIATE SOURCES
C
      READ(5,20)(SWL(J,IJ),IJ=1,NOB)
   20 FORMAT (11F6.0)
      WRITE(6,21)(SWL(J,IJ),IJ=1,NOB)
   21 FORMAT('0','SWL=',11F6.1)
   23 CONTINUE
   55 IF(NSPL.EQ.0) GO TO 28
      DO 27 J=1,NSPL
C
C    SPL= THE SOUND PRESSURE LEVELS FOR THE APPROPRIATE SOURCES
C
      READ(5,24)(SPL(J,IJ),IJ=1,NOB)
      WRITE(6,25)(SPL(J,IJ),IJ=1,NOB)
   24 FORMAT (11F6.0)
   25 FORMAT('0','SPL=',11F6.1)
   27 CONTINUE
   28 IF (N.EQ.IN) GO TO 35
C
C    NSPEC= IS AN INDEX FOR SELECTING THE APPROPRIATE SPECTRUM FOR A GIVEN
C    DBA VALUE.
C
C    DBA= THE DBA LEVEL FOR A SOURCE FOR WHICH A SPECTRUM IS DESIRED
C
      READ(5,30) (NSPEC(J),DBA(J),J=1,IG)
      WRITE(6,31)(NSPEC(J),DBA(J),J=1,IG)
   30 FORMAT (12I3,12I3)
   31 FORMAT('0','NSPEC=',12I3,3X,'DBA=',12I3)
C
C NORMALLY SUBROUTINE WOULD BE CALLED TC
```

```
C CONVERT DBA INTO A SPECTRUM OF SPL'S
C
   35 CONTINUE
C
C   ISURF= AN INDEX FOR DETERMENING WHAT THE CORRECT SOUND ABSORPTION
C   COEFFICIENTS ARE (SEE SUBROUTINE ABSORB)
C
      DO 893 J=1,NCOF
   36 FORMAT(31I2)
      READ(5,36) (ISURF(J,K),K=1,NSURF)
      WRITE(6,130) (ISURF(J,K),K=1,NSURF)
  130 FORMAT('0','ISURF=',31I2)
  893 CONTINUE
C
C   THE FOLLOWING STATEMENTS READ THE VALUES OF THE INDEXES DETERMINING WHAT
C   UNITS THEIR ASSOCIATED VARIABLES ARE IN. THE LETTERS AFTER I INDICATE
C   WHAT VARIABLES THESE INDEXES ARE CONCERNED WITH
C
   37 READ(5,38) ITEMP,IBP,ISA,IXYZ,IXYZ1,IXYZ2,IXYZ3,IR1,IXYZ4
   38 FORMAT(9I3)
      WRITE(6,131) ITEMP,IBP,ISA,IXYZ,IXYZ1,IXYZ2,IXYZ3,IR1,IXYZ4
  131 FORMAT('0','ITEMP=',I2,1X,'IBP=',I2,1X,'ISA=',I2,1X,'IXYZ=',I2,1X,
     1'IXYZ1=',I2,1X,'IXYZ2=',I2,1X,'IXYZ3=',I2,1X,'IR1=',I2,1X,'IXYZ4='
     2,I2)
      CALL OUTPUT(IXX,IY,IP,NOB,IYY,IH)
C
C   TEMP= THE TEMPERATURE IN THE ROOM INVOLVED FOR FURTHER DETAILS SEE SUB-
C   ROUTINE UNITS
C
C   HUMID= THE RELATIVE HUMIDITY IN THE ROOM INVOLVED FOR FURTHER INFOR-
C   MATION SEE SUBROUTINE UNITS
C
```

```
      READ(5,51) (TEMP(J),HUMID(J),J=1,NCOF)
      WRITE(6,132) (TEMP(J),HUMID(J),J=1,NCOF)
  132 FORMAT('0','TEMP=',F6.1,3X,'HUMID=',F6.1)
   39 FORMAT (8F10.0)
C
C    XX= THE SMALLER HORIZONTAL DIMENSION OF THE ROOM
C
C    YY= THE LARGER HORIZONTAL DIMENSION OF THE ROOM
C
C    ZZ= THE VERTICAL DIMENSION OF THE ROOM
C
      READ(5,42)(XX(J),YY(J),ZZ(J),J=1,NCOF)
   42 FORMAT(3F10.0)
      WRITE (6,298)(XX(J),YY(J),ZZ(J),J=1,NCOF)
  298 FORMAT('0','XX=',F10.2,2X,'YY=',F10.2,2X,'ZZ=',F10.2)
C
C    SA= THE SURFACE AREA OF VARIOUS ABSORPTIVE SURFACES IN THE ROOM
C
      READ(5,39)((SA(J,K),K=1,NSURF),J=1,NCOF)
      WRITE(6,134)((SA(J,K),K=1,NSURF),J=1,NCOF)
  134 FORMAT('0','SA=',F6.1)
      IF(NCOF.EQ.1) GO TO 41
C
C    R1= THE DISTANCE FROM SOURCE TO RECEIVER ASSOCIATED WITH THE MEASUREMENT
C    OF SOUND PRESSURE LEVELS GIVEN FOR SOME OF THE SOURCES
C
      READ(5,39) (R1(J),J=1,NTERM)
      WRITE(6,135) (R1(J),J=1,NTERM)
      READ(5,691) (X4(I),Y4(I),Z4(I),I=1,NTERM)
      WRITE(6,692) (X4(I),Y4(I),Z4(I),I=1,NTERM)
  691 FORMAT (3F10.0)
  692 FORMAT('0','X4=',F10.2,2X,'Y4=',F10.2,2X,'Z4=',F10.2)
```

```
 135 FORMAT('0','R1=',F6.1)
  40 FORMAT(3F10.0)
  41 CONTINUE
C
C    X1= THE SOURCE POSITION FROM AN ARBITRARY ZERO POINT CONSISTENT WITH XX
C
C    Y1= THE SOURCE POSITION FROM AN ABRTRARY ZERO POINT CONSISTENT WITH YY
C
C    Z1= THE SOURCE POSITION FROM AN ARBITRARY ZERO POINT CONSISTENT WITH ZZ.
C
      READ(5,40) (X1(J),Y1(J),Z1(J),J=1,N)
      WRITE(6,137)(X1(J),Y1(J),Z1(J),J=1,NCOF)
 137 FORMAT('0','X1=',F6.1,3X,'Y1=',F6.1,3X,'Z1=',F6.1)
C
C    HERE IF THERE ARE NO IRREGULARITIES SWITCHING OCURRS
C
      IF(NIR.GT.0) GO TO 45
C
C    ALSO IF NO CORRECTIONS FOR TEMPERATURE AND BAROMETRIC PRESSURE ARE TO
C    BE MADE SWITCHING OCURRS HERE
C
      IF (NC.GT.0) GO TO 50
      GO TO 70
  45 CONTINUE
C
C    X2= THE POSITION OF THE IRREGULARITY IN THE X-DIRECTION
C
C    Y2= THE POSITION OF THE IFREGULARITY IN Y-DITECTION
C
C    Z2= THE POSITION OF ANY IRREGULARITIES IN THE Z-DIRECTION
C
      READ(5,46) (X2(J),Y2(J),Z2(J),J=1,IR)
```

```
      WRITE(6,138)(X2(J),Y2(J),Z2(J),J=1,IR)
   46 FORMAT(3F10.0)
  138 FORMAT('0','X2=',F10.2,3X,'Y2=',F10.2,3X,'Z2=',F10.2)
C
C    X3,Y3,Z3= THE DIMENSIONS OF THE IRREGULARITY IN RELATION TO THE POSITIONS
C
      READ(5,46) (X3(J),Y3(J),Z3(J),J=1,IR)
      WRITE(6,139) (X3(J),Y3(J),Z3(J),J=1,IR)
      IF(NC.EQ.0) GO TO 70
  139 FORMAT('0','X3=',F10.2,3X,'Y3=',F10.2,3X,'Z3=',F10.2)
   50 CONTINUE
C
C    T= THE TEMPERATURE IN THE ROOM IF TEMPERATURE CORRECTIONS ARE GOING TO
C    BE MADE TO THE SOUND PRESSURE OF POWER LEVELS
C
C    BP= THE BAROMETRIC PRESSURE IF BAROMETRIC PRESSURE CORRECTIONS ARE
C    GOING TO BE MADE TO THE SOUND PRESSURE OR POWER LEVELS
C
      READ(5,52) (BP(J),J=1,NC)
      WRITE(6,140) (BP(J),J=1,NC)
  140 FORMAT('0','BP=',F6.1)
   52 FORMAT(F6.0)
   51 FORMAT(2F6.0)
   70 CONTINUE
C
C    THE SUBROUTINE ARRANG IS CALLED TO ARRANGE ALL OF THESE VARIABLES IN THE
C    PROPER MANNER TO BE USED IN THE VARIOUS SUBROUIINES
C
      CALL ARRANG (NSPL,NOB)
C
C    THE SUBROUTINE UNITS IS CALLED TO PUT EVERY VARIABLE IN THE PROPER UNITS
C    TO BE USED THROUGHOUT FOR FURTHER EXPLANITION SEE THE SUBROUTINE
```

```
C
      CALL UNITS(ITEMP,IBP,ISA,IXYZ,IXYZ1,IXYZ2,IXYZ3,IXYZ4,IR1,NC,N,NSU
     1RF,NIR,IH)
C
C   SUBROUTINE ABSORB IS CALLED TO DETERMINE THE CORRECT ABSORPTION COEF-
C   FICIENTS AND THE VALUES FOR AIR ABSORPTION AT THE VARIOUS FREQUENCIES
C   INVOLVED.
C
      CALL ABSORB(N,NSURF,NOB,IH)
C
C   THE SUBROUTINE MFPF HAS THE PURPOSE OF DETERMINING THE VALUE OF MEAN
C   FREE PATH.-POSSIBLY AT A FUTURE TIME  THIS QUANTITY MIGHT BE MODIFIED TO
C   VARY WITH FREQUENCY  OR THE ROOM GEOMETRY ETC.
C
      CALL MFPF(IH,N)
C
C   THE SUBROUTINE DIMEN'S PURPOSE IS TO DETERMINE THE POSITION OF THE
C   VARIOUS RECEIVER POINTS AND THE DISTANCE FROM EACH OF THESE TO THE
C   VARIOUS SOURCES
C
   75 CALL DIMEN(IY,N,IXX,IYY)
      IF(NIR.EQ.0) GO TO 80
C
C   THE IRRGRM SUBROUTINE WOULD BE CALLED ONLY IF IRREGULARITIES ARE
C   PRESENT
C
      CALL IRRGRM(N,NOB,NIR)
   80 CONTINUE
C
C   THE PURPOSE OF THIS LOGIC BLOCK IS TO DETERMINE THE CORRECT VALUE OF IND
C   BEFORE  ENTERING INTO THE CALCULATIONS OF THE SPWL SUBROUTINE IF IND=1---
C   THE PORTION CALCULATING SPL'S IS ENTERED IF IND=0--- THE PORTION CAL-
```

```
C     CALCULATING SWL'S IS ENTERED
C
      IF (N.EQ.NSWL) GO TO 324
      GO TO 325
  324 IND=1
      GO TO 327
  325 IND=0
  327 CONTINUE
C
C     THE SUBROUTINE SPWL IS CALLED TO PERFORM THE CALCULATIONS TO CONVERT FROM
C     SOUND PRESSURE TO SOUND POWER LEVELS OR VICE VERSA
C
      CALL SPWL(IND,IY,N,NC,NSPL,NSWL,NOB,IXX,IYY,IH)
      CONTINUE
      IF (IND.EQ.1) GO TO 354
      IND=1
      CALL SPWL(IND,IY,N,NC,NSPL,NSWL,NOB,IXX,IYY,IH)
  354 CONTINUE
      IF(IP.EQ.0) GO TO 99
C
C     THE SUBROUTINE ADLEV IS CALLED TO ADD THE SOUND PRESSURE LEVELS CAUSED BY
C     THE VARIOUS SOURCES TO GIVE THE SOUND PRESSURE LEVEL DUE TO ALL SOURCES AT
C     EACH RECEIVER POINT
C
      CALL ADLEV(N,IXX,NOB)
C
C     SUBROUTINE OUTPUT IS CALLED TO SELECT CORRECT MEANS OF OUPTUTING THE
C     VALUES OBTAINED FROM THESE CALCULATIONS
C
      CALL OUTPUT(IXX,IY,IP,NOB)
      ITS=IYY+1
   99 IF(IY.LE.ITS) GO TO 75
```

```
      NRUN=NRUN-1
  100 IF(NRUN.GT.0) GO TO 1
C
  309 STOP
      END
```

```
      SUBROUTINE DBALEV(NOB,IXX)
C
C   PURPOSE--- THE PURPOSE OF THIS SUBROUTINE IS TO CALCULATE OVERALL DBA
C   LEVELS FROM OCTAVE BAND SOUND PRESSURE LEVELS
C
C   NECESSARY INPUTS--- IN THE CASE THE COMMON BLOCKS ARE NOT USED THE
C   FOLLOWING VARIABLES ARE REQUIRED BY THIS SUBROUTINE
C
C   AHOLD(I,J)= A REGISTER CONTAINING THE SOUND PRESSURE LEVELS AT THE
C   VARIOUS RECEIVER POINTS DUE TO ALL THE SOURCES PRESENT.  I= POSITION IN
C   THE X-DIRECTION  J= NUMBER OF THE OCTAVE BAND
C
C   NECESSARY OUTPUTS--- IN THE CASE THE COMMON BLOCKS ARE NOT USED THE
C   FOLLOWING VARIABLES ARE PRODUCED AS OUTPUTS
C
C   DBAL(I,J)= THE CALCULATED DBA SOUND PRESSURE LEVELS
C
      COMMON/LEVEL2/AHOLD(250,11)
      COMMON/DBAVAL/DBAL(250)
C
C   ADDITION OR SUBTRACTION OF THE ANSI PRESCRIBED VALUES FROM THE VARIOUS
C   OCTAVE BAND LEVELS
C
      DO 12 J=1,IXX
      STOR=0.0
      STOR=10.**((AHOLD(J,1)-56.7)/10.)+STOR
      STOR=10.**((AHOLD(J,2)-39.4)/10.)+STOR
      STOR=10.**((AHOLD(J,3)-26.2)/10.)+STOR
      STOR=10.**((AHOLD(J,4)-16.1)/10.)+STOR
      STOR=10.**((AHOLD(J,5)-8.60)/10.)+STOR
      STOR=10.**((AHOLD(J,6)-3.20)/10.)+STOR
      STOR=10.**((AHOLD(J,7)-0.00)/10.)+STOR
```

```
      STOR=10.**((AHOLD(J,8)+1.20)/10.)+STOR
      IF(NOB.LT.9) GO TO 11
      STOR=10.**((AHOLD(J,9)+1.00)/10.)+STOR
      IF(NOB.LT.10) GO TO 11
      STOR=10.**((AHOLD(J,10)-1.1)/10.)+STOR
      IF (NOB.LT.11) GO TO 11
      STOR=10.**((AHOLD(J,11)-6.6)/10.)+STOR
C
C    ADDITION OF THESE CALCULATED LEVELS TO ACHEIVE OVERALL DBA LEVELS
C
   11 DBAL(J)=10.*ALOG10(STOR)
   12 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE UNITS(ITEMP,IBP,ISA,IXYZ,IXYZ1,IXYZ2,IXYZ3,IXYZ4,IR1,NC
     1,N,NSURF,NIR,IH)
C
C     PURPOSE--- THE PURPOSE OF THIS SUBROUTINE IS TO CONVERT THE INPUTED
C     QUANTITIES INTO THE  PROPER UNITS FOR THE CALCULATIONS TO FOLLOW
C
C     FOR EXAMPLE---IXYZ=1 INDICATES XX,YY,ZZ ARE IN METRIC UNITS (METERS)
C     VARIABLES BEGINNING IN I ARE INDEXES TO DETERMINE UNITS
C     NAME AFTER I IS THE VARIABLE(S) TO WHICH IT PERTAINS
C
C     IXYZ=0 INDICATES XX,YY,ZZ, ARE IN ENGLISH UNITS (FEET)
C     ALL ONES ARE THE UNITS THE PROGRAN USES ZEROS ARE THOSE WHICH HAVE TO
C     BE CONVERTED
C
C     NECESSARY INPUTS--- IN THE CASE THE COMMON BLOCKS ARE NOT USED THE
C     FOLLOWING VARIABLES ARE REQUIRED BY THIS SUBROUTINE IN ADDITION TO THOSE
C     IN THE CALLING ARGUMENT.
C
C     NC= THE NUMBER OF CORRECTIONS FOR TEMPERATURE AND/OR BAROMETRIC PRESSURE
C     TO BE MADE
C
C     N= THE NUMBER OF SOURCES BEING CONSIDERED
C
C     XX(I),YY(I),ZZ(I)= THE DIMENSION OF THE ROOM, I=THE NUMBER OF THE SOURCE
C
C     T(I)= TEMPERATURE IN ROOM, I= THE NUMBER OF SOURCE
C
C     BP(I)= BAROMETRIC PRESSURE IN THE ROOM, I= NUMBER OF SOURCE
C
C     SA(I)= THE SURFACE AREA OF ABSORPTIBE MATERIALS I= NUMBER OF SOURCE,
C     J= NUMBER OF SURFACE
C
```

```
      CONTINUE
C
C     X1(I),Y1(I),Z1(I)= THE POSITICNS OF SOURCES, I= NUMBER OF SOURCE
C
C     X2(I),Y2(I),Z2(I)= THE PCSITION OF IRREGULARITIES, I= NUMBER CF
C     IRREGULARITY
C
C     X3(I),Y3(I),Z3(I)= THE DIMENSION OF IRREGULARITIES, I= NUMBER OF IR-
C     REGULARITIES
C
C     TEMP(I)= THE TEMPERATURE OF THE RCOM, I= NUMBER OF SOURCE
C
      COMMON/WALLS/ISURF(26,11),SA(26,11)
      COMMON/POSITN/X1(25),Y1(25),Z1(25),Z
      COMMON/POSIT2/X4(25),Y4(25),Z4(25)
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
      COMMON/IRRITS/X2(5),Y2(5),Z2(5),X3(5),Y3(5),Z3(5)
      COMMON/TBP/TEMP(26),T(26),BP(26),HUMID(26)
C
C     SWITCH IF THERE IS TEPERATURE OR BAROMETRIC PRESSURE CORRECTIONS TO BE
C     BE MADE
C
      IF (NC.EQ.0) GO TO 26
C
C     SWITCH FOR THE UNITS OF BP
C
   16 IF (IBP.EQ.1) GO TO 26
C
C     CINVERSICN FROM MM. OF HG. TO IN. HG.
C
   21 DO 25 I=1,NC
      BP(I)=BP(I)*0.0393700784
```

```
      25 CONTINUE
C
C      SWITCH FOR THE UNITS OF SA
C
      26 IF (ISA.EQ.1) GO TO 31
         DO 30 I=1,IH
         DO 30 J=1,NSURF
C
C     CONVERSION FROM SQ. FT. TO SQ. METERS
C
         SA(I,J)=SA(I,J)*0.09290340
      30 CONTINUE
C
C      SWITCH FOR THE UNITS OF XX,YY,ZZ
C
      31 IF(IXYZ.EQ.1) GO TO 34
         DO 38 I=1,IH
C
C     CONVERSION FROM FT. TO METERS
C
         XX(I)=XX(I)*0.3048
         YY(I)=YY(I)*0.3048
         ZZ(I)=ZZ(I)*0.3048
         Z=Z*0.3048
      38 CONTINUE
C
C      SWITCH FOR THE UNITS OF TEMP
C
      34 IF(ITEMP.EQ.1) GO TO 40
         DO 35 I=1,IH
C
C      CONVERSION FROM DEGREES FARENHEIT TO DEGREES CENTIGRADE
```

```
C
      T(I)=TEMP(I)
      TEMP(I)=(TEMP(I)-32.)/1.8
   35 CONTINUE
C
C     CONVERSATION FROM DEGREES CENTIGRADE TO DEGREES FARENHEIT FOR
C     CORRECTIONS TO SOUND POWER AND PRESSURE LEVELS
C
   40 DO 36 I=1,IH
      T(I)=(TEMP(I)*5./9.)+32.
   36 CONTINUE
C
C     SWITCH FOR THE UNITS OF X1,Y1,ANDZ1
C
   41 IF (IXYZ1.EQ.1) GO TO 46
      DO 45 I=1,N
C
C     CONVERSION FROM FEET TO METERS
C
      X1(I)=X1(I)*0.304800
      Y1(I)=Y1(I)*0.304800
      Z1(I)=Z1(I)*0.304800
   45 CONTINUE
C
C     SWITCH IF NO IRREGULARITLES ARE TO BE CONSIDERED
C
   46 IF(NIR.EQ.0) GO TO 56
C     SWITCH FOR THE UNITS OF X2,Y2,ANDZ2
C
      IF (IXYZ2.EQ.1) GO TO 51
      DO 50 I=1,IR
C
```

```
C     CONVERSION FROM FEET TO METERS
C
        X2(I)=X2(I)*0.3048
        Y2(I)=Y2(I)*0.3048
        Z2(I)=Z2(I)*0.3048
   50 CONTINUE
C
C     SWITCH FOR THE UNITS OF X3,Y3,ANDZ3
C
   51 IF(IXYZ3.EQ.1) GO TO 56
        DO 55 I=1,IR
C
C     CONVERSION FROM FEET TO METERS
C
        X3(I)=X3(I)*0.3048
        Y3(I)=Y3(I)*0.3048
        Z3(I)=Z3(I)*0.3048
   55 CONTINUE
   56 CONTINUE
C
C     SWITCH FOR THE UNITS OF X4,Y4,AND Z4
C
        IF(IXYZ4.EQ.1) GO TO 60
        NUM=IH-1
C
C     SWITCH IF NO SOUND PRESSURE LEVELS SOURCES GIVEN
C
        IF(NUM.EQ.0) GO TO 80
        DO 58 I=1,NUM
C
C     CONVERSION FROM FEET TO METERS
C
```

```
      X4(I)=X4(I)*0.3048
      Y4(I)=Y4(I)*0.3048
      Z4(I)=Z4(I)*0.3048
   58 CONTINUE
   60 CONTINUE
   60 IF(IR1.EQ.1) GO TO 80
C
C    CONVERSION  FROM FEET TO METERS
C
      DO 85 I=1,NUM
      R1(I)=R1(I)*0.3048
   85 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DIRECT(IY,IXX,I,J,IJ,IND,ALAMBA,INDX,IH,IYY)
C
C     PURPOSE--- TO DETERMINE THE DIRECTIVITY FACTOR Q USED IN THE ROOM
C     ACOUSTICS EQUATION.  IN THIS CASE THESE Q FACTORS ARE DIFFRENT FROM
C     THOSE COMMONLY FOUND SINCE UNUSUAL CASES ARE TREATED AND THE Q FACTOR
C     IS CONSTANTLY MODIFIED AS THE DISTANCE FROM THE SOURCE OF THE
C     RECEIVER POINT CHANGES
C
C
C     NECESSARY INPUTS--- IN THE CASE THE COMMON BLOCKS ARE NOT USED THE
C     FOLLOWING VARIABLES ARE REQUIRED BY THIS SUBROUTINE
C
C     XX(I),YY(I),ZZ(I)= ROOM DIMENSIONS, I= NUMBER OF SOURCE
C
C     R(I,IJ)= DISTANCE FROM SOURCE TO RECEIVER POINT, I= SOURCE NUMBER AND
C     IJ= POSITION IN THE X-DIRECTION
C
C     N=NUMBER OF SOURCES
C
C     NSWL= NUMBER OF SOUND POWER LEVEL SOURCES
C
C     IXX= NUMBER OF POSITIONS IN THE X-DIRECTION, I= NUMBER OF SOURCE
C
C     NOB= NUMBER OF OCTAVE BANDS BEING USED
C
C
C     NECESSARY OUTPUTS--- AGAIN THESE ARE PRESENTED IN THE EVENT THE DESIGNATED
C     COMMON  BLOCKS ARE NOT USED
C
C
C     Q= THE DIRECTIVITY INDEX FOR CONBERSION FROM SOUND POWER TO SOUND
C     PRESSURE LEVELS
```

```
      CONTINUE
C
C    Q1= THE DIRECTIVITY INDEX FOR CONVERSION FROM SOUND PRESSURE TO
C    SCUND PCWER LEVELS,
C
C
C    DATA READ BY SUBROUTINE--- THIS SECTION IS PRESENTED TO INFORM THE USER
C    OF NICESSARY DATA INPUT AND FORM
C
C    IXMAX(I)= INDEX TO INCICATE A WALL IS VERY ABSORPTIVE AND SHOULD
C    NOT BE CONSIDERED AS A REFLECTING SURFACE, IN THIS CASE FOR THE X=
C    O WALL, I=NUMBER OF SOURCE
C    IXMAX(I),IYO(I),IYMAX(I),IZO(I),ANDIZMAX(I) SAME AS ABOVE BUT FOR
C    DIFFRENT WALLS
C
      COMMON/POSITN/X1(25),Y1(25),Z1(25),Z
      COMMON/POSIT2/X4(25),Y4(25),Z4(25)
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
      COMMON/DISTAN/R1(25),R(25,250)
      COMMON/DIRECI/Q1,Q
      DIMENSION ALAMBA(11)
      DIMENSION IXO(26),IXMAX(26),IYO(26),IYMAX(26),IZO(26),IZMAX(26)
      IF(IY.GT.1) GO TO 110
      IF(IJ.GT.0.AND.IH.GT.1) GO TO 110
      IF(IJ.EQ.0.AND.I.LT.3) GO TO 111
      IF(IJ.GT.1) GO TO 110
      IF(I.GT.1) GO TO 110
  111 CONTINUE
      IF (J.GT.1) GO TO 110
      READ(5,101)(IXO(L),IXMAX(L),IYO(L),IYMAX(L),IZO(L),IZMAX(L)
  101 FORMAT (I2,I2,I2,I2,I2,I2)
      IREG1=0
```

```
      IREG2=0
      IREG3=0
  110 CONTINUE
C
C   ROUTINE TO SENSE PROXIMITY TO THE VARIOUS WALLS
C
      IF(IND.EQ.0) GO TO 100
      D=1.0
      IF(INDX.GT.0) D=ALAMBA(J)
      RX=XX(1)-X1(I)-R(I,IJ)
      RX1=X1(I)-R(I,IJ)
      RY=YY(1)-Y1(I)-R(I,IJ)
      RY1=Y1(I)-R(I,IJ)
      RZ=ZZ(1)-Z1(I)-R(I,IJ)
      RZ1=Z1(I)-R(I,IJ)
      IX=IJ
      IF(IXO(1).GT.0) RX1=D+10.
      IF(IXMAX(1).GT.0) RX=D+10.
      IF(IYO(1).GT.0) RY1=D+10.
      IF(IYMAX(1).GT.0) R|=D+10.
      IF(IZO(1).GT.0) RZ1=D+10.
      IF(IZMAX(1).GT.0) RZ=D+10.
      IF(IX.EQ.1) RX1=0.0
      IF(IX.EQ.IXX) RX=0.0
      IF(IY.EQ.1) RY1=0.0
      IYK=IYY+2
      IF(IY.EQ.IYK) RY=0.0
      IF(RX.LT.D.OR.RX1.LT.D) IREG1=1
      IF(RX.LT.D.AND.RX1.LT.D) IREG1=7
      IF(RY.LT.D.OR.RY1.LT.D) IREG2=1
      IF(RY.LT.D.AND.RY1.LT.D) IREG2=7
      IF(RZ.LT.D.OR.RZ1.LT.D) IREG3=1
```

```
      IF(RZ.LT.D.AND.RZ1.LT.D) IREG3=7
      IPICK=IREG1+IREG2+IREG3
      IF(IREG1.EQ.7) WID=XX(1)
      IF(IREG2.EQ.7) EID=YY(1)
      IF(IREG3.EQ.7) WID=ZZ(1)
      IF(IREG1.EQ.7.AND.IREG2.EQ.7) D=XX(1)*YY(1)
      IF(IREG1.EQ.7.AND.IREG3.EQ.7) D=XX(1)*ZZ(1)
      IF(IREG2.EQ.7.AND.IREG3.EQ.7) D=YY(1)*ZZ(1)
      IF(IPICK.EQ.0) Q=1.
      IF(IPICK.EQ.1) Q=2.
      IF(IPICK.EQ.2) Q=4.
      IF(IPICK.EQ.3) Q=8.
      IF(IPICK.EQ.7) Q=2.*R(I,IJ)/WID
      IF(IPICK.EQ.8) Q=4.*R(I,IJ)/WID
      IF(IPICK.EQ.9) Q=8.*R(I,IJ)/WID
      IF(IPICK.EQ.14) Q=2.*3.14159*(R(I,IJ)**2.)/D
      IF(IPICK.EQ.15) Q=4.*3.14159*(R(I,IJ)**2.)/D
      IF(IPICK.EQ.21) Q=100.
      GO TO 300
  100 CONTINUE
      K=I-1
C
C    FOR THE CASE OF A SOURCE WITH GIVEN SOUND POWER LEVEL CALCULATION
C    OF THE CORRECT Q FACTOR
C
      D=1.0
      IF(INDX.GT.0) D=ALAMBA(J)
      RX=XX(I)-X4(K)-R1(I)
      RX1=X4(K)-R1(I)
      RY=YY(I)-Y4(K)-R1(I)
      RY1=X4(K)-R1(I)
      RZ=ZZ(I)-Z4(K)-R1(I)
```

```
      RZ1=Z4(K)-R1(I)
      IF(IXO(I).GT.0) RX1=D+10.
      IF(IXMAX(I).GT.0) RX=D+10.
      IF(IYO(I).GT.0) RY1=D+10.
      IF(IYMAX(I).GT.0) R|=D+10.
      IF(IZO(I).GT.0) RZ1=D+10.
      IF(IZMAX(I).GT.0) RZ=D+10.
      IF(IX.EQ.1) RX1=0.0
      IF(IX.EQ.IXX) RX=0.0
      IF(IY.EQ.1) RY1=0.0
      IYK=IYY+2
      IF(IY.EQ.IYK) RY=0.0
      IF(RX.LT.D.OR.RX1.LT.D) IREG1=1
      IF(RX.LT.D.AND.RX1.LT.D) IREG1=7
      IF(RY.LT.D.OR.RY1.LT.D) IREG2=1
      IF(RY.LT.D.AND.RY1.LT.D) IREG2=7
      IF(RZ.LT.D.OR.RZ1.LT.D) IREG3=1
      IF(RZ.LT.D.AND.RZ1.LT.D) IREG3=7
      IF(IREG1.EQ.7) WID=XX(I)
      IF(IREG2.EQ.7) WID=YY(I)
      IF(IREG3.EQ.7) WID=ZZ(I)
      IF(IREG1.EQ.7.AND.IREG2.EQ.7) D=XX(I)*YY(I)
      IF(IREG1.EQ.7.AND.IREG3.EQ.7) D=XX(I)*ZZ(I)
      IF(IREG2.EQ.7.AND.IREG3.EQ.7) D=YY(I)*ZZ(I)
      IPICK=IREG1+IREG2+IREG3
C
C    FOR THE CASE OF A SOURCE WITH GIVEN SOUND PRESSURE LEVEL CALCULATION OF THE
C    CORRECT Q FACTOR
C
      IF(IPICK.EQ.0) Q1=1.
      IF(IPICK.EQ.1) Q1=2.
      IF(IPICK.EQ.3) Q1=8.
```

```
      IF(IPICK.EQ.2) Q1=4.
      IF(IPICK.EQ.7) Q1=2.*R1(I)/WID
      IF(IPICK.EQ.8) Q1=4.*R1(I)/WID
      IF(IPICK.EQ.9) Q1=8.*R1(I)/WID
      IF(IPICK.EQ.14) Q1=2.*3.14159*(R1(I)**2.)/D
      IF(IPICK.EQ.15) Q1=4.*3.14159*(R1(I)**2.)/D
      IF(IPICK.EQ.21) Q1=100.
  200 CONTINUE
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ABSORB (N,NSURF,NOB,IH)
C
C     PURPOSE--- THE PURPOSE OF THIS SUBROUTINE IS TWO FOLD ---FIRST BEING THE
C     VALUE OF ISURF GIVEN IT SELECTS THE CORRECT ABSORPTION COEFFICIENTS,
C     SECONDLY FROM THE TEMP AND HUMID GIVEN IT SELECTS THE CORRECT VALUE
C     OF AIR ABSORPTION
C
C
C     NECESSARY INPUTS--- IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C     FOLLOWING VARIABLE ARE REQUIRED BY THIS SUBROUTINE
C
C
C     NSURF= NUMBER OF SURFACES BEING CONSIDERED (31 MAX)
C
C     NOB= NUMBER OF OCTAVE BANDS (11 MAX)
C
C     TEMP(I)= TEMPERATURE IN THE ROOM, I= SOURCE NUMBER
C
C     HUMID(I)= RELATIVE HUMIDITY IN THE ROOM, I= SOURCE NUMBER
C
C
C     NECESSARY OUTPUTS--- AGAIN IN THE EVENT THE COMMON BLOCKS ARE NOT
C     USED THE FOLLOWING ARE THE OUTPUTS GENERATED BY THIS SUBROUTINE
C
C     ABAR(I,J)= THE ABSORPTION COEFFICIENTS FOR THE WALL SURFACES, I= NUMBER
C     OF SOURCE, J= OCTAVE BAND NUMBER
C
C     AA(I,J)= THE AIR ABSORPTION, I= NUMBER OF SOURCE, J= NUMBER OF OCTAVE
C     BAND
C
      COMMON/ABSORP/ABAR(26,11),AA(26,11)
      COMMON/WALLS/ISURF(26,11),SA(26,11)
```

```
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
C
C    SELECTION OF THE CORRECT ABSORPTION COEFFICIENT
C
      DO 20 J=1,IH
      DO 20 K=1,NSURF
      IF(ISURF(J,K).EQ.1) GO TO 12
      ABAR(J,1)=0.05
      ABAR(J,2)=0.08
      ABAR(J,3)=0.12
      ABAR(J,4)=0.15
      ABAR(J,5)=0.13
      ABAR(J,6)=0.17
      ABAR(J,7)=0.22
      ABAR(J,8)=0.24
      ABAR(J,9)=0.24
      ABAR(J,10)=0.30
   15 CONTINUE
      GO TO 20
   12 DO 19 JK=1,NOB
      ABAR(J,1)=0.10
      ABAR(J,2)=0.12
      ABAR(J,3)=0.17
      ABAR(J,4)=0.16
      ABAR(J,5)=0.17
      ABAR(J,6)=0.22
      ABAR(J,7)=0.29
      ABAR(J,8)=0.31
      ABAR(J,9)=0.31
      ABAR(J,10)=0.32
   19 CONTINUE
   20 CONTINUE
```

```
C
C   SELECTION OF THE CORRECT AIR ABSORPTION COEFFICIENTS
C
      DO 50 I=1,IH
      DO 50 J=1,NOB
      AA(I,J)=0.0
      VS=(XX(I)*YY(I)*ZZ(I))/(((XX(I)*YY(I))*2.0)+((YY(I)*ZZ(I))*2.)+((X
     1X(I)*ZZ(I))*2.))
      AA(I,4)=0.00030
      AA(I,5)=0.00068
      AA(I,6)=0.00158
      AA(I,7)=0.00386
      IF(NOB.LT.8) GO TO 25
      AA(I,8)=0.00963
      IF(NOB.LT.9) GO TO 25
      AA(I,9)=0.02388
      IF(NOB.LT.10) GO TO 25
      AA(I,10)=0.07105
   25 CONTINUE
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ADLEV(N,IXX,NOB)
C
C    PURPOSE--- TO ADD SOUND LEVELS DUE TO EACH SOURCE TO OBTAIN THE TOTAL
C    OCTAVE BAND SOUND PRESSURE LEVELS AT EACH POINT
C
C    NECESSARY INPUTS--- IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C    FOLLOWING VARIABLES ARE REQUITED BY THIS SUBROUTINE
C
C    N= NUMBER OF SOURCES (25 MAX)
C
C    IXX= NUMBER OF RECEIVER POINTS IN THE X-DIRECTION (250 MAX)
C
C    NOB= NUMBER OF OCTAVE BANDS BEING USED
C
C    SPL(I,IJ)= SOUND PRESSURE LEVELS, I= NUMBER OF SOURCE, IJ= NUMBER OF
C    RECEIVER POSITION IN THE X-DIRECTION
C
C
C    NECESSARY OUTPUT--- AGAIN IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C    FOLLOWING ARE THE OUTPUTS PRODUCED BY THIS SUBROUTINE
C
C    AHOLD(I,J)= THE COMBINED SOUND PRESSURE LEVEL, I= POSITION IN X-DIR-
C    ECTION, J= NUMBER OF THE OCTAVE BAND
C
      COMMON/LEVEL1/SPL(250,11),SWL(25,11)
      COMMON/LEVEL2/AHOLD(250,11)
C
C    ADDITION OF SOUND PRESSURES
C
      DO 8 KI=1,N
      DO 8 I=1,IXX
      DO 8 J=1,NOB
```

```
      AHOLD(I,J)=0.0
    8 CONTINUE
      DO 10 IJ=1,N
      DO 10 J=1,IXX
      DO 10 K=1,NOB
      KJ=J*IJ
      AHOLD(J,K)=10.**(SPL(KJ,K)/10.)+AHOLD(J,K)
   10 CONTINUE
C
C    CONVERSION BACK TO TOTAL SOUND PRESSURE LEVELS
C
      DO 20 J=1,IXX
      DO 20 K=1,NOB
      AHOLD(J,K)=10.*ALOG10(AHOLD(J,K))
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE IRRGRM(N,NOB,NIR)
      COMMON/IRRITS/X2(5),Y2(5),Z2(5),X3(5),Y3(5),Z3(5)
      WRITE(6,10)
   10 FORMAT (' ','IRR. ROOM SUBROUTINE CALLED')
      RETURN
      END
```

```
      SUBROUTINE DIMEN(IY,N,IXX,IYY)
C
C   PURPOSE--- TO SELECT RECEIVER POINTS THROUGHOUT THE ROOM AND TO DETERMINE
C   THE DISTANCE FROM EACH SOURCE TO EACH OF THESE POINTS.
C
C   N= NUMBER OF SOURCES
C
C   IXX= NUMBER OF RECEIVER POINTS IN THE X-DIRECTION
C
C   IYINC= INTERVAL OF SPACING FOR RECEIVER POINTS IN THE Y-DIRECTION
C
C   DINCR= INTERVAL OF SPACING FOR RECEIVER POINTS IN THE X-DIRECTION
C
C
C   X1(I),Y1(I),Z1(I)= THE POSITIONS OF VARIOUS SURFACES, I= NUMBER OF SOURCE
C
C   XX(I),YY(I),ANDZZ(I)= DIMENSIONS OF ROOM, I= NUMBER OF SOURCES
C
C   NECESSARY OUTPUTS--- AGAIN IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C   FOLLOWING ARE THE OUTPUTS PRODUCED BY THIS SUBROUTINE
C
C   IXX= NUMBER OF RECEIVER LEVELS IN THE X-DIRECTION
C
C   IYY= NUMBER OF RECEIVER LEVELS IN THE Y-DIRECTION
C
C   R(I,IJ)= DISTANCE FROM EACH RECEIVER POINT TO EACH SOURCE FOR SOUND
C   POWER TO SOUND PRESSURE CONVERSIONS
C
      COMMON/DISTAN/R1(25),R(25,250)
      COMMON/POSITN/X1(25),Y1(25),Z1(25),Z
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
      IF(IY.GE.1) GO TO 10
```

```
C
C     DINCR= INCREMENT FOR POSITIONING RECEIVER POINTS IN THE X-DIRECTION
C
C     IYINC= INCREMENT FOR POSITIONING RECEIVER POINTS IN THE Y-DIRECTION
C
      READ(5,14) DINCR,IYINC
   14 FORMAT (F6.0,I6)
      WRITE(6,15)DINCR,IYINC
   15 FORMAT('0','DINCR=',F6.1,3X,'IYINC=',I6)
C
C     THE SELECTION OF DISTANCE INCREMENTS FOR  THE POSITIONING OF SOURCES
C     IS CARRIED OUT HERE
C
C
C     IF IYIND=0 IT DEFAULTS AUTOMATICALLY TO 2
C     IF DINCR=0.0 THE PROGRAM AUTOMATICALLY SELECTS A DISTANCE INCREMENT.
C
      DO 193 I=1,N
      IF(IYINC.EQ.0) IYINC=2
      IYY=YY(1)/IYINC
      MAX=250./N
      IF(DINCR.GT.0) GO TO 500
      IF(XX(1).LE.5) DINCR=1.0
      IF(XX(1).GT.5.AND.XX(1).LE.20) DINCR=2.0
      IF(XX(1).GT.20.AND.XX(1).LE.50) DINCR=5.0
      IF(XX(1).GT.50.AND.XX(1).LE.100) DINCR=10.0
      IF(XX(1).GT.100.AND.XX(1).LE.250) DINCR=25.0
  500 IXX=(XX(1)/DINCR)+1.5
      IF(IXX.GT.MAX) GO TO 501
      GO TO 193
  501 IXX=MAX+0.5
      DINCR=XX(1)/(IXX-1)
```

```
  193 CONTINUE
   10 CONTINUE
      IX=0
C
C   DETERMING THE NECESSARY DISTANCE TO EACH OF THE RECEIVER POINTS FROM
C   EACH SOURCE
C
      DO 50 I=1,N
      K=IXX+1
      DO 50 J=1,K
      IX=J-1
      ITB=IYY+1
      IF(IX.EQ.IXX) GO TO 8
      IF(IY.EQ.ITB) GO TO 24
      D=((DINCR*IX)-X1(I))**2+((IYINC*IY)-Y1(I))**2+(Z-Z1(I))**2
      GO TO 49
    8 IF(IY.EQ.ITB) GO TO 16
      D=(XX(1)-X1(I))**2.+((IYINC*IY)-Y1(I))**2+(Z-Z1(I))**2
      GO TO 49
   16 D=(XX(1)-X1(I))**2+(YY(1)-Y1(I))**2+(Z-Z1(I))**2
      GO TO 49
   24 D=((DINCR*IX)-X1(I))**2+(YY(1)-Y1(I))**2+(Z-Z1(I))**2
   49 R(I,J)=SQRT(D)
   50 CONTINUE
      IY=IY+1
      RETURN
      END
```

```
      SUBROUTINE SPWL(IND,IY,N,NC,NSPL,NSWL,NOB,IXX,IYY,IH)
C
C    PURPOSE--- THE PURPOSE OF THIS SUBROUTINE IS TO MAKE THE NECESSARY
C    CALCULATEIONS TO CONVERT SOUND PRESSURE LEVELS TO SOUND POWER LEVELS
C    AND TO MAKE ANOTHER SET OF CALCULATIONS TO CONVERT SOUND POWER LEVELS
C    TO SOUND PRESSURE LEVELS
C
C    NECESSARY INPUTS--- IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C    FOLLOWING VARIABLES ARE REQUIRED BY THIS SUBROUTINE
C
C    NC= NUMBER OF CORRECTIONS FOR TEMPERATURE AND BAROMETRIC PRESSURE TO
C    SOUND PRESSURE LEVELS
C
C    N= NUMBER OF SOURCES
C
C    BP(I)= BAROMETRIC PRESSURE IN ROOM IF CORRECTIONS ARE TO BE MADE, I=
C    NUMBER OF SOURCE
C
C    TEMP(I)= TEMPERATURE IN ROOM WHETHER CORRECTIONS ARE TO BE MADE OF NOT,
C    I= NUMBER OF SOURCE
C
C    IND= INDEX TO DETERMINE WHETHER CONVERSIION FROM SOUND PRESSURE LEVELS TO
C    SOUND POWER LEVEL OR FROM SOUND POWER LEVELS TO SOUND PRESSURE LEVELS
C
C    NSWL= NUMBER OF SOURCES WITH GIVEN SOUND POWER LEVELS GIVEN
C
C    NOB= NUMBER OF OCTAVE BANDS
      CONTINUE
C
C    MFP(I)= MEAN FREE PATH, I= NUMBER OF SOURCE
C
C    XX(I),YY(I),AND ZZ(I)= DIMENSIONS OF ROOM, I= NULBER OF SOURCE
```

```
C
C     ABAR(I,J)= ABSORPTION COERFICIENT OF WALLS, I= NUMBER OF SOURCE, J=
C     NUMBER OF OCTAVE BAND
C
C     AA(I,J)= AIR ABSORPTION, I= NUMBER OF SCURCE, J= NUMBER OF  OCTAVE BAND
C
C     R1(I)= DISTANCE FROM SOURCE TC RECEIVER IN GIVEN SOUND PRESSURE LEVEL, I=
C     NUMBER
C
C     R(I,IJ)= DISTANCE FROM EACH SOURCE TO EACH RECEIVER IN CONBERSION FROM
C     SOUND POWER TO SOUND PRESSURE LEVEL, I= SOURCE NUMBER, IJ= POSITION IN X-
C     DIRECTICN
C
C     IXX= NUMBER OF POSITIONS IN THE X-DIRECTION,
C
C     SPL(I,J)= SOUND PRESSURE LEVEL, I= NUMBER OF SOURCE, J= NUMBER OF OCTAVE
C     BAND
C
C     SWL(I,J)= SCUND POWER LEVEL, I= NUMBER OF SOURCE, J= NUMBER OF OCTAVE
C     BAND
C
C     IY= POSITION IN Y-DIRECTION
C
C     IYY= TOTAL NUMBER OF POSITIONS IN THE Y-DIRECTION, I= NUMBER OF SOURCE
C
       CONTINUE
C
C     NECESSARY OUTPUTS--- AGAIN IN THE EVENT THE COMMON BLOCKS ARE NOT
C     USED THE FOLLOWING ARE THE OUTPUTS PRODUCED BY THIS SUBROUTINE
C
C     SWL(I,J)= SOUND POWER LEVEL, I= NUMBER OF WOURCE , J= NUMBER OF
C     OCTAVE BAND
```

```
C
C     DEPENDING CN IND IT CCULD BE EITHER
C
C     SPL(I,J)= SCUND PRESSURE LEVEL, I= POSITION IN X-DIRECTION MULTIPLIED
C     BY THE SOURCE NUMBER, J=CCTAVE BAND NUMBER
C
C
C     DATA READ IN THIS SUBROUTINE--- THESE VARIABLES ARE READ FROM THIS SUB-
C     ROUTINE  AND ARE PRESENTED HERE TO INFORM THE USER THAT THEY WILL BE
C     REQUIRED
C
C     IWALLS(I)= INDEX TO INDICATE PROXIMITY OF A RECEIVER POSITION TO A
C     WALL IN THE CASE SCUND PRESSURE LEVELS ARE GIVEN FOR THE SOURCES
C     IF IWALLS(I)=0--- NO WALLS NEAR BY
C     IF IWALLS(I)=1--- NEAR ONE WALL
C     IF IWALLS(I)=2--- NEAR 2 WALLS
C     IF IWALLS(I)=3--- NEAR 3 WALLS
C
      COMMON/TBP/TEMP(26),T(26),BP(26),HUMID(26)
      COMMON/FORVES/MFP(26)
      COMMON/ABSORP/ABAR(26,11),AA(26,11)
      COMMON/DISTAN/R1(25),R(25,250)
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
      COMMON/DIRECT/Q1,Q
      COMMON/LEVEL1/SPL(250,11),SWL(25,11)
      COMMON/POSITN/X1(25),Y1(25),Z1(25),Z
      DIMENSION IWALLS(25)
      DIMENSION ALAMBA(11)
      DIMENSION COR(25)
      INDX=0
      IF(IH.GT.1.AND.IND.EQ.1) GO TO 200
      IF(IY.GT.1) GO TO 200
```

```
      IF(NSPL.EQ.0) GO TO 7
      READ(5,201) (IWALLS(I),I=1,NSPL)
  201 FORMAT(25I2)
      WRITE(6,202) (IWALLS(I),I=1,NSPL)
  202 FORMAT('0','IWALLS=',25I2)
    7 CONTINUE
C
C     CALCULATION OF WAVELENGTH IN METERS
C
      DO 8 I=1,N
      TEMP(I)=TEMP(I)+273.2
      ALAMBA(1)=20.05*SQRT(TEMP(I))/16.
      ALAMBA(2)=20.05*SQRT(TEMP(I))/31.5
      ALAMBA(3)=20.05*SQRT(TEMP(I))/63.
      ALAMBA(4)=20.05*SQRT(TEMP(I))/125.
      ALAMBA(5)=ALAMBA(4)/2.
      ALAMBA(6)=ALAMBA(5)/2.
      ALAMBA(7)=ALAMBA(6)/2.
      ALAMBA(8)=ALAMBA(7)/2.
      ALAMBA(9)=ALAMBA(8)/2.
      ALAMBA(10)=ALAMBA(9)/2.
      ALAMBA(11)=ALAMBA(10)/2.
    8 CONTINUE
  200 CONTINUE
      IF(NC.EQ.0) GO TO 15
C
C     CALCULATION OF TEMPERATURE AND/OR BAROMETRIC PRESSURE CORRECTION
C
      DO 10 I=1,NC
      COR(I)=10.*ALOG10((SQRT((T(I)+460.)/(527.)))*((30.)/(BP(I))))
   10 CONTINUE
      DO 12 J=NC,IH
```

```
      COR(J)=0.0
   12 CONTINUE
      GO TO 20
   15 DO 16 J=1,IH
      COR(J)=0.0
   16 CONTINUE
   20 CONTINUE
      IF(IND.EQ.1) GO TO 30
C
C    CONVERSION FROM SOUND PRESSURE TO SOUND POWER LEVELS
C
      DO 26 I=2,IH
      DO 26 J=1,NOB
      IK=I-1
      E=MFP(I)/4.
      V=XX(I)*YY(I)*ZZ(I)
      IF(XX(I).GE.YY(I)) GO TO 504
      IF(YY(I).GE.ZZ(I)) GO TO 505
  506 LD=ZZ(I)
      GO TO 507
  504 IF (ZZ(I).GE.XX(I)) GO TO 506
      LD=XX(I)
      GO TO 507
  505 LD=YY(I)
  507 CONTINUE
      K=NSWL+I-1
      INDX=0
      IF(ALAMBA(J).GT.XX(I)) INDX=1
      IF(ALAMBA(J).GT.YY(I)) INDX=INDX+1
      IF(ALAMBA(J).GT.ZZ(I)) INDX=INDX+1
      IF(INDX.GE.1) GO TO 22
      IF(R1(I).GT.E) GO TO 23
```

```
      RT=1./(V*((ABAR(I,J)/MFP(I))+AA(I,J)))
      GO TO 25
   23 RT=1./((V*R1(I)/MFP(I))*((ABAR(I,J)/MFP(I))+AA(I,J)))
      GO TO 25
C
C     SECTION WHERE CORRECTIONS FOR WAVELENGHS GREATER THAN ROOM DIMENSIONS ARE
C     MADE
C
   22 CONTINUE
      R1X=MFP(I)
      MFP(I)=LD
      RT=1./((V*R1(I)/MFP(I))*((ABAR(I,J)/MFP(I))+AA(I,J)))
   25 CONTINUE
      IJ=0
      CALL DIRECT (IY,IXX,I,J,IJ,IND,ALAMBA,INDX,IH,IYY)
      DT=Q1*EXP((-1.)*R1(I)*AA(I,J))/(4.*3.14159*(R1(I)**2.))
      SWL(K,J)=SPL(I,J)-10.*ALOG10(DT+RT)+COR(I)
C
C     SECTION WHERE THE CORRECTION FOR RECEIVER POINTS NEAR A WALL ARE MADE
C
      IF(IWALLS(IK).EQ.1) SWL(K,J)=SWL(K,J)-3.0
      IF(IWALLS(IK).EQ.2) SWL(K,J)=SWL(K,J)-4.77
      IF(IWALLS(IK).EQ.3) SWL(K,J)=SWL(K,J)-6.02
   26 CONTINUE
      GO TO 50
C
C     CONVERSION FROM SOUND POWER TO SOUND PRESSURE LEVELS
C
   30 DO 40 I=1,N
      DO 40 J=1,NOB
      K=IXX
      DO 40 IJ=1,K
```

```
      INDX=0
      IF(ALAMBA(J).GT.XX(1)) INDX=1
      IF(ALAMBA(J).GT.YY(1)) INDX=INDX+1
      IF(ALAMBA(J).GT.ZZ(1)) INDX=INDX+1
  103 CONTINUE
      E=MFP(1)/4.
      V=XX(1)*YY(1)*ZZ(1)
      IF(XX(1).GE.YY(1)) GO TO 604
      IF(YY(1).GE.ZZ(1)) GO TO 605
  606 LD=ZZ(1)
      GO TO 607
  604 IF(ZZ(1).GE.XX(1)) GO TO 606
      LD=XX(1)
      GO TO 607
  605 LD=YY(1)
  607 CONTINUE
      IF(INDX.GE.1) GO TO 32
      IF(R(I,IJ).GT.E) GO TO 33
      RT=1./(V*((ABAR(1,J)/MFP(1))+AA(1,J)))
      GO TO 35
C
C    SECTION WHERE CORRECTIONS FOR WAVELENGHS GREATER THAN ROOM DIMENSIONS ARE
C    MADE
C
   32 CONTINUE
      R1Z=MFP(1)
      MFP(1)=R1Z
      RT=1./((V*R(I,IJ)/MFP(1))*((ABAR(1,J)/MFP(1))+AA(1,J)))
      MFP(1)=R1Z
      GO TO 35
   33 RT=1./((V*R(I,IJ)/MFP(1))*((ABAR(1,J)/MFP(1))+AA(1,J)))
   35 CONTINUE
```

```
      CALL DIRECT (IY,IXX,I,J,IJ,IND,ALAMBA,INDX,IH,IYY)
      DT=Q*EXP((-1.)*R(I,IJ)*AA(1,J))/(4.*3.14159*(R(I,IJ)**2.))
      KI=IJ+((I-1)*IXX)
      SPL(KI,J)=SWL(I,J)+10.*ALOG10(DT+RT)-COR(I)
      IF(J.GT.5) GO TO 40
C
C   CORRECTION FOR THE PROXIMITY OF A RECEIVER POINT TO A WALL
C
      ITEL=0
      IX=IJ
      IKY=IYY+2
      IF(IY.EQ.IKY) ITEL=1
      IF(IY.EQ.1) ITEL=ITEL+1
      IF(IX.EQ.IXX) ITEL=ITEL+1
      IF(IX.EQ.1) ITEL=ITEL+1
      IF(Z.EQ.ZZ(1)) ITEL=ITEL+1
      IF(Z.EQ.0) ITEL=ITEL+1
C
C   SECTION WHERE THE CORRECTION FOR RECEIVER POINTS NEAR A WALL ARE MADE
C
      IF(ITEL.EQ.1) SPL(KI,J)=SPL(KI,J)+3.
      IF(ITEL.EQ.2) SPL(KI,J)=SPL(KI,J)+4.77
      IF(ITEL.EQ.3) SPL(KI,J)=SPL(KI,J)+6.02
   40 CONTINUE
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MFPF(IH,N)
C
C   PURPOSE--- THE PURPOSE FOR THIS SUBROUTINE IS TO CALCULATE THE MEAN FREE
C   PATH OF THE ROOM AND POSSIBLY AT A FUTURE DATE MAKE SOME ALTERATIONS
C   TO THIS NUMBER BECAUSE OF ROOM GEOMETRY
C
C   NECESSARY INPUTS--- IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C   FOLLOWING VARIABLES ARE REQUIRED
C
C   N= NUMBER OF SOURCES
C
C   XX(I),YY(I),AND ZZ(I)= ROOM DIMENSIONS, I= NUMBER OF SOURCE
C
C   NECESSARY OUTPUTS--- IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C   FOLLOWING  VARIABLES ARE PRODUCED AS OUTPUT
C
C   MFP(I)= MEAN FREE PATH, I=NUMBER OF SOURCE
C
      COMMON/FORVES/MFP(26)
      COMMON/SIZE/XX(26),YY(26),ZZ(26)
      DO 10 I=1,IH
C
C   CALCULATION OF MEAN FREE PATH USING THE 4V/S RELATION
C
      MFP(I)=4.*XX(I)*YY(I)*ZZ(I)/(((XX(I)*YY(I))*2.)+((YY(I)*ZZ(I))*2.)
     1+((XX(I)*ZZ(I))*2.))
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(IXX,IY,IP,NOB)
C
C     PURPOSE--- TO SELECT THE PROPER OUTPUT DESIRED
C
C     NECESSARY INPUTS--- IN THE EVENT THE COMMON BLOCKS ARE NOT USED THE
C     FOLLOWING VARIABLES ARE REQUIRED
C
C     IXX= THE NUMBER OF RECEIVER POINTS IN THE X-DIRECTION
C
C     AHOLD(I,J)= THE COMBINED SOUND PRESSURE LEVEL, I= POSITION IN X-DIRECTION
C     J= NUMBER OF THE OCTAVE BAND
C
C     IY= THE NUMBER OF THE POINT IN THE Y-DIRECTION
C
C
C     DATA READ BY THE SUBROUTINE--- THESE VARIABLES ARE READ BY THE SUBROUTINE
C     AND ARE PRESENTED HERE SO THE USER WILL BE AWARE OF THEIR BEING NEEDED
C
C     IDBA= INDEX TO DETERMINE WHAT IS OUTPUTED
C     IF IDBA=0--- BOTH OCAAVE BAND AND OVERALL DBA SOUND PRESSURE LEVELS WILL BE
C     PRINTED OUT
C     IF IDBA=2--- ONLY DBA VALUES WILL BE PRINTED OUT
C     IF IDBA=1--- ONLY OCTAVE BAND DATA WILL BE PRINTED OUT
C
C     NPOB= THE NUMBER OCTAVE BANDS TO BE PRINTED
C
C     OB(J)= THE VARIOUS BAND NUMBERS TO BE PRINTED, J= THE NUMBER PRINTED
C
      COMMON/LEVEL2/AHOLD(250,11)
      COMMON/DBAVAL/DBAL(250)
      INTEGER OB(11)
      K=IXX
```

```
      IF(IY.GT.1) GO TO 93
      WRITE (6,91)
   91 FORMAT('0','O. B.',9X,'SOUND PRESSURE LEVELS')
      READ(5,94)IDBA,NPOB
      IF(IDBA.EQ.2) GO TO 350
   94 FORMAT (I3,I3)
      READ(5,96) (OB(J),J=1,NPOB)
   96 FORMAT (11I3)
   93 CONTINUE
      IF (IY.EQ.1) GO TO 307
      WRITE(6,97)
   97 FORMAT (12X,'NEXT POSITION')
  306 DO 303 J=1,NPOB
      LD=OB(J)
  301 WRITE(6,302) LD,(AHOLD(IJ,LD),IJ=1,K)
  302 FORMAT (1X,I3,3X,20F6.1)
  303 CONTINUE
      IF (IDBA.EQ.1) GO TO 100
  350 CALL DBALEV(NOB,IXX)
      CONTINUE
      WRITE (6,389)
  389 FORMAT (1X,'SOUND PRESSURE LEVELS EXPRESSED IN DBA')
      WRITE (6,390) (DBAL(J),J=1,K)
  390 FORMAT (1X,20F6.1)
      GO TO 100
  307 CONTINUE
      WRITE(6,308)
  308 FORMAT(12X,'FIRST POSITION')
      GO TO 306
  100 RETURN
      END
```

```
      SUBROUTINE ARRANG(NSPL,NOB)
      COMMON/LEVEL1/SPL(250,11),SWL(25,11)
      COMMON/DISTAN/R1(25),R(25,250)
      IF(NSPL.EQ.0) GO TO 20
      DO 15 I=1,NSPL
      DO 15 J=1,NOB
      K=I+1
      SPL(K,J)=SPL(I,J)
      R1(K)=R1(I)
   15 CONTINUE
   20 RETURN
      END
```

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THE DEVELOPMENT OF A COMPUTER PROGRAM USING A MODIFIED

ROOM ACOUSTICS APPROACH TO DETERMINE

SOUND LEVELS IN REGULAR ROOMS

by

James Kent Thompson

(ABSTRACT)

A program was developed which calculated sound pressure levels at an array of points in a room. Necessary inputs are the room dimensions, sound power or sound pressure levels for the sources, absorption coefficients for the room surfaces, the temperature, relative humidity, and if sound pressure levels are given for the source a description of the room in which this measurement was taken. This program allowed a maximum of twenty-five sources. Calculations were made at eleven octave bands from 16 Hz. to 16,000 Hz. and converted to dBA levels.

The basis for these calculations was a modified room acoustics equations. The modifications were: a factor modifying the reverberant term, continually monitoring directivity with respect to changing distance of receiver points from the source, the inclusion of air absorption on the direct term and corrections for receiver points in close proximity to room surfaces. The modification to the reverberant term was to simulate the departure from the assumption of constant energy density in irregularly proportioned rooms. The modification when receiver points were near a room surface was simply the addition of corrections to calculated sound pressure levels.

Figure A.1(a) Input Forms for the Computer Program

Area

PROGRAMMER	DATE	PAGE OF

COMMENT	STATEMENT NUMBER	CONTINUATION	FORTRAN STATEMENT	IDENTIFICATION
1	2 5	6	7 72	73 80

The input forms presented here are given using the following arrangement of information.

Card Set #

Variable name, description of the variable

Spacing and	(format)*

*Note: "I" format values must be placed as far as possible to the right of the alloted space. These values also do not have decimal points.

EN 2165

Figure A.1(b)

Area

PROGRAMMER	DATE	PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 1

(1) N, # of sources, (2) NSWC, # of SWL sources, (3) NSPL, # of SPL sources; (4) NOB, # of octave bands; (5) NIR, # of irregularities in room; (6) IP, index for printing, (7) NC, # of temperature and barometric pressure corrections corrections; (8) NRUN, # of runs, (9) NSURF, # of room surfaces considered; (10) Z, vertical position of receiver points in the room being analyzed.

(y)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(I3)	(I3	(I3)	(I3)	(I3)	(I3)	(I3)	(I3)	(I3)	(F10.0)

Card Set 2

SWL, sound power levels of source.

(11 F 6.0)

EN 2165

Figure A.1(c)

Area

PROGRAMMER | DATE | PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 3

SPL, sound pressure levels of sources

(11 F 6.0)

Card Set 4

INSURF, index for selecting correct absorption coefficients

(31 I 2)

Card Set 5

ITEMP, IBP, ISA, IXYZ, IXYZ1, IXXZ2, IXYZ3, IR1, IXYZ4 (in the same order), these are the indexes indicating in what units variables are expressed.

(9 I 3)

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Figure A.1(d)

Area

PROGRAMMER | DATE | PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 6

TEMP, HUMID, temperature and relative humidity in rooms

(2 F 6.0)

Card Set 7

XX, YY, ZZ, dimensions of the rooms

(3F10.0)

Card Set 8

SA, surface areas of absorptive material

(8 F 10.0)

Card Set 9

R1, distance from source to receiver in rooms where sound pressure measurements were made.

(8 F 10.0)

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Figure A.1(e)

Area

PROGRAMMER	DATE	PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 10

X4, Y4, Z4, position of source in SPL measurements

(3 F 10.0)		

Card Set 11

X1, Y1, Z1, position of source in room being analyzed

(3 F 10.0)		

Card Set 12

X2, Y2, Z2, position at irregularities

(3 F 10.0)		

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Figure A.1(f)

Area

PROGRAMMER | DATE | PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 13

X3, Y3, Z3, dimensions of the irregularities

(3 F 10.0)

Card Set 14

BP, barometric pressure in rooms

(F6.0)

Card Set 14

DINCR, IYINC, increments for the array of receiver points in the room being analyzed in the X and Y directions respectively.

(F6.0) (I6)

Card Set 16

IXO, IXMAX, IYO, IYMAX, IZO, IZMAX, indexes indicating room surfaces to be hard (0) or soft (1).

(7 I 2)

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Figure A.1(g)

Area

PROGRAMMER | DATE | PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 17

IWALLS, index indicating the number of room surfaces to which the receiver point is in close proximity in SPL-SWL conversion.

(25 I 2)

Card Set 18

IDBA, NPOB, index indicating the type of printed output and the total number of octave bands for which SPL's are to be printed out respectively.

(2I 3)

Card Set 19

OB, octave bands to be printed out.

(11 I 3)

EN 2165

Figure A.2(a) Sample Data Input Forms

Area

PROGRAMMER	DATE	PAGE OF

COMMENT	STATEMENT NUMBER	CONTINUATION	FORTRAN STATEMENT	IDENTIFICATION
1	2 5	6	7 72	73 80

```
          Card Set 1

   1     0  1  8  0  1  1  1  5


          Card Set 3
  76.        78.  82.   81.  75.   76.   74.   70.

          Card Set 4

   1
   2

          Card Set 5
   0     0 1   0   0   0   0   0   0

          Card Set 6

  70.     50.
  70.     50.
```

Figure A.2(b)

Area

PROGRAMMER | DATE | PAGE OF

COMMENT | STATEMENT NUMBER | CONTINUATION | FORTRAN STATEMENT | IDENTIFICATION

1 2 5 6 7 72 73 80

Card Set 7

12. 10. 100.0

10. 50. 20.0

Card Set 8

Any number is acceptable since it is not actually used in the calculations.

Card Set 9

12.

Card Set 10

5. 25. 0.0

Card Set 11

6. 50.0 0.0

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Figure A.2(c)

Area

PROGRAMMER	DATE	PAGE OF

COMMENT	STATEMENT NUMBER	CONTINUATION	FORTRAN STATEMENT	IDENTIFICATION
1	2 5	6	7 72	73 80

```
      Card Set 14

 29.6

      Card Set 15

   0.0     0

      Card Set 16

 0 0 0 0 0 1
 0 0 0 0 0 0

      Card Set 17

  1

      Card Set 18

  1  2
```

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Figure A.2(d)

Area

PROGRAMMER | DATE | PAGE OF

COMMENT	STATEMENT NUMBER	CONTINUATION	FORTRAN STATEMENT	IDENTIFICATION
1	2 5	6	7 72	73 80
			Card Set 19	
	3	8		

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SAMPLE OUTPUT FROM PROGRAM

FIGURE A.3.1

```
N=  1  NSWL=  0  NSPL=  1  NOB=  8  NIR=  0  IP=  1  NC=  1  NRUN=  1  NSURF=  1

Z=       5.00

SPL=  76.0  78.0  82.0  81.0  75.0  76.0  74.0  70.0

ISURF= 1

ISURF= 2

ITEMP= 0 IBP= 1 ISA= 0 IXYZ= 0 IXYZ1= 0 IXYZ2= 0 IXYZ3= 0 IR1= 0 IXYZ4= 0

TEMP=  70.0   HUMID=  50.0

TEMP=  70.0   HUMID=  50.0

XX=      12.00  YY=     100.00  ZZ=       10.00

XX=      10.00  YY=      50.00  ZZ=       20.00

SA=  10.0

SA=   0.0

R1=  12.0

X4=       5.00  Y4=      25.00  Z4=        0.00

X1=    6.0   Y1=  50.0   Z1=    0.0

BP=  29.6

DINCR=   0.0   IYINC=      0

IWALLS= 1
```

FIGURE A.3.2

O. B. SOUND PRESSURE LEVELS

FIRST POSITION

3	62.8	61.0	61.0	61.0	62.8
8	55.3	55.3	55.3	55.3	55.3

NEXT POSITION

3	61.3	58.4	58.4	58.3	61.3
8	54.9	54.9	54.9	54.9	54.8

NEXT POSITION

3	61.7	58.8	58.8	58.8	61.7
8	55.6	55.6	55.7	55.6	55.6

NEXT POSITION

3	62.3	59.4	59.4	59.3	62.3
8	56.5	56.5	56.5	56.5	56.4

FIGURE A.3.3

NEXT POSITION

3	63.3	60.4	60.4	60.4	63.3
8	57.5	57.6	57.6	57.6	57.4

NEXT POSITION

3	64.6	61.8	61.8	61.7	64.5
8	58.8	59.0	59.1	59.0	58.7

NEXT POSITION

3	66.3	63.8	63.9	63.6	66.1
8	60.6	61.0	61.2	60.9	60.4

NEXT POSITION

3	68.5	67.1	67.8	66.6	68.0
8	62.8	64.4	65.1	63.9	62.3

NEXT POSITION

3	69.0	68.2	69.5	67.4	68.3
8	63.3	65.5	66.8	64.7	62.6

FIGURE A.3.4

NEXT POSITION

3	66.8	64.4	64.6	64.2	66.6
8	61.1	61.7	61.9	61.5	60.8

NEXT POSITION

3	65.0	62.2	62.2	62.1	64.8
8	59.2	59.4	59.5	59.4	59.1

NEXT POSITION

3	63.6	60.7	60.7	60.7	63.5
8	57.8	57.9	57.9	57.9	57.7

NEXT POSITION

3	62.5	59.6	59.6	59.6	62.5
8	56.7	56.8	56.8	56.7	56.7

NEXT POSITION

3	61.9	58.9	58.9	58.9	61.8
8	55.8	55.8	55.9	55.8	55.8

FIGURE A.3.5

NEXT POSITION

3	61.4	58.4	58.4	58.4	61.4
8	55.0	55.1	55.1	55.1	55.0

NEXT POSITION

3	61.1	58.1	58.1	58.1	61.1
8	55.4	55.4	55.4	55.4	55.4

NEXT POSITION

3	62.8	61.0	61.0	61.0	62.8
8	55.3	55.3	55.3	55.3	55.3