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TECHNICAL MEMORANDUM 70-4

INVESTIGATION OF ANOMALOUS BEHAVIOR
OF SOUND ABSORPTION BY
MOLECULAR RELAXATION

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INVESTIGATION OF ANOMALOUS BEHAVIOR
OF SOUND ABSORPTION BY
MOLECULAR RELAXATION

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and
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Work Performed Under Contract DAH C04-69C 0088

Chief Investigators' Conference and Review of the Military Theme
"HELICOPTER AND V/STOL AIRCRAFT RESEARCH"
U.S. Army Research Office - Durham
Durham, North Carolina

May 1970



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ACKNOWLEDGEMENTS

We would like to express appreciation to the Army Research Office-Durham for the financial support for this study. We are also indebted to Dr. J. K. Angell of ESSA for the meteorological data from Pendleton, Oregon, and to Dr. Steve Scott of this Laboratory for Figures 9 and 12.

ABSTRACT

Experimental measurements of the absorption of sound in still air exhibit a distinct deviation from the theoretical predictions based on known classical and molecular relaxation absorption losses. Investigation of published laboratory data has verified that Kneser's theory for molecular relaxation accurately describes the absorption loss near and above the relaxation frequency. At frequencies less than about 0.1 of the relaxation frequency, a different mechanism becomes predominant and results in an absorption loss component which varies directly with the frequency and is essentially independent of humidity. The objective of the effort in this contract is to carry out a detailed experimental and analytical investigation of this anomaly to allow numerical calculations to be made of air absorption for a variety of atmospheric conditions in still air.

An extensive literature survey has revealed that the anomaly is probably due to an as yet undefined vibrational relaxation process in moist air. With this in mind experimental measurements of audible sound in air were made over the humidity range of 0%- 100% relative humidity. Preliminary analysis of the data from these measurements show the same type anomaly and the same agreement with Kneser's relaxation theory (single relaxation). The anomaly in these measurements does not at this time appear as large as that of previous investigators; however, further analysis is required. It is thought that the anomaly is due to the vibrational relaxation of nitrogen by water vapor. To verify this a multiple relaxation theory needs to be applied to the data. Experimental measurements were also made on nitrogen over the same humidity range but these measurements have not as yet been analyzed. It is hoped that these moist nitrogen measurements will give some insight into the low frequency behavior of air.

A scheme based on previous data has been devised for predicting sound absorption in still air. This technique will be modified according to the results of the experimental data from this work. Vertical profiles of air absorption utilizing real weather conditions have been made and reveal that the absorption coefficient at a given frequency on the ground quite often does not at all describe the sound absorption at higher altitudes. Also some effort has been made to correlate existing field data to laboratory measurements.

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1.0 INTRODUCTION

In open air, effects such as thermal inhomogeneities, turbulence, dust, fog, ground reflections, scattering, diffraction, and inverse-square law spreading are all mechanisms which can change the character of sound propagation from laboratory predictions. However, in any attempt to analyze open air sound absorption data, the base line provided from laboratory measurements of sound absorption is needed as a starting point. Laboratory studies have provided information about sound absorption as a function of humidity, frequency, pressure, and some limited information about the temperature dependence (References 1-3). So, an understanding of laboratory measurements and the theories of the loss mechanisms involved is a necessary prerequisite to meaningful outdoor, open air measurements.

When a sound wave propagates through a molecular gas such as air, the intensity of the wave is attenuated by both classical effects, i.e., viscosity, heat conduction, diffusion, and heat radiation, and molecular effects caused by the internal structure of the gas molecules. For diatomic molecules such as nitrogen, N_2 , and oxygen, O_2 , which are the chief constituents of air, the molecular effects are the vibrations between the two atoms of each molecule and the molecular rotations about the center of gravity.

The intensity of a plane wave, I , received a distance, x , from the source, I_0 , is given by

$$I = I_0 e^{-2\alpha x} = I_0 e^{-mx}$$

where α is the total amplitude absorption coefficient and m is the total intensity absorption coefficient and is equal to 2α . This total absorption coefficient can be broken into several additive terms as long as the transport properties of the gas are not frequency dependent, and the frequency regions important to vibration and rotation are not coupled. These conditions are met in the case of air at all frequencies below several hundred magahertz.

The absorption coefficient is then given by

$$\alpha = \alpha_{cl} + \alpha_{mol}$$

where α_{cl} is the absorption due to classical effects and α_{mol} is the absorption due to the internal structure of the molecule.

The classical absorption can be further broken down into several parts

$$\alpha_{cl} = \alpha_{\eta} + \alpha_{\kappa} + \alpha_{diff} + \alpha_{rad}$$

where α_η is the viscosity effect; α_κ is the thermal conductivity effect; α_{diff} is due to diffusion; and α_{rad} is due to heat radiation.

The parts due to viscosity and thermal conductivity are commonly known as the Stokes-Kirchhoff (References 1-3) absorption and are given by

$$\alpha_\eta + \alpha_\kappa = \frac{2\pi^2 f^2}{\gamma P_0 V_0} \left[\frac{4}{3} \eta + \frac{\gamma - 1}{C_p} \kappa \right]$$

The diffusion term has been predicted by Kohler (Reference 4) as

$$\alpha_{\text{diff}} = \frac{2\pi^2 f^2}{\gamma P_0 V_0} (\gamma a_d D_{12} \rho)$$

where D_{12} is the diffusion coefficient and a_d is a molecular constant for an O_2 and N_2 mixture.

The radiation term is still somewhat of an unknown quantity; however, it is only important at frequencies at least below 100 Hz (Reference 5) and probably is not important except for frequencies below 15 Hz (Reference 6).

So, the total absorption due to classical effects can be written as

$$\alpha_{\text{cl}} = \frac{2\pi^2 f^2}{\gamma P_0 V_0} \left[\frac{4}{3} \eta + \frac{\gamma - 1}{C_p} \kappa + \gamma a_d D_{12} \rho \right]$$

and this expression can be evaluated in terms of the viscosity as

$$\alpha_{\text{cl}} = \frac{2\pi^2 f^2}{\gamma P_0 V_0} [1.900] \eta$$

- Molecular Absorption

The molecular or internal absorption is attributed to the vibrational and rotational degrees of freedom of the molecules. The molecular absorption is given by (see for example Reference 1).

$$\alpha_{\text{mol}} = \frac{\pi c' (\gamma - 1)}{V_0 C_p} \frac{f^2 f_m}{f^2 + f_m^2}$$

where

V_0 is the low frequency velocity

c' is the internal specific heat

C_p is the specific heat at constant pressure

f is the frequency

f_m is the frequency of maximum absorption

γ is the ratio of specific heats

In general the above equation is applicable to any region of molecular absorption by proper definition of the internal specific heat c' . For the case of air at audio-frequencies, c' is the vibrational specific heat of the diatomic components; however, there is also some absorption due to the rotational degrees of freedom even at low frequencies (Reference 7). The rotational degrees of freedom relax at very high frequencies and for the case of air the regions of vibrational and rotational relaxation are well separated and the excess absorption due to the rotational degrees of freedom can be simply subtracted from the total molecular absorption, i.e.,

$$\alpha_{\text{mol}} = \alpha_{\text{vib}} + \alpha_{\text{rot}}$$

- Rotational Absorption

Inspection of the equation for molecular absorption reveals that at frequencies well below the frequency of maximum absorption, i.e., $f \ll f_m$

$$\alpha_{\text{mol}} = \frac{\pi c' (\gamma - 1)}{V_0 C_p} \frac{f^2}{f_m}$$

Also for air the internal specific heat, c' , due to rotation is equal to R , and C_p and γ are given by $7/2R$ and $7/5$, respectively. So

$$\alpha_{\text{rot}} \approx \frac{4}{35} \frac{\pi}{V_0 f_m} f^2$$

which is valid only at low frequencies, i.e., $f \ll f_m$. Values of f_m can be taken from Sessler (Reference 8) or Winter and Hill (Reference 9).

Experimental values for the sum of α_{cl} and α_{rot} for air at low frequencies can be predicted from Greenspan's (Reference 10) data as

$$\alpha_{cl} + \alpha_{rot} = \frac{2\pi^2 f^2}{\gamma P_0 V_0} [2.50] \eta$$

or in terms of temperature it can be expressed to a close approximation over the normal temperature range by:

$$\alpha_{cl} + \alpha_{rot} \approx 18.0 \times 10^{-12} (1 + 0.001 \text{ } ^\circ\text{C}) \frac{f^2}{P}, \text{ m}^{-1}$$

where f is in Hertz and P is in atmospheres.

- **Vibrational Absorption**

All that remains to be evaluated is the molecular absorption due to the vibrational energy states. Remembering that for temperatures in the range expected outdoors, the internal specific heat for O_2 and N_2 are quite small so that C_p can be closely approximated by $7/2R$ and γ by $7/5$. The absorption equation due to vibration is then given by

$$\alpha_{vib} = \frac{4\pi c'}{35RV_0} \frac{f}{f_m/f + f/f_m}$$

and the absorption per wavelength $\alpha_{vib} \lambda$ is given by

$$\alpha_{vib} \lambda = \frac{4\pi c'}{35R} \frac{1}{f_m/f + f/f_m}$$

The maximum absorption occurs when $f_m = f$ and this gives

$$2(\alpha_{vib} \lambda)_{max} \equiv \mu_{max} = \frac{4\pi c'}{35R}$$

It is obvious from this that the maximum absorption due to vibrational effects is only a function of the vibrational specific heat which is directly related to temperature. So, it is seen that the peak of the molecular absorption curve is controlled only by temperature. The internal specific heat of nitrogen at room temperature is approximately $0.002R$ while that for oxygen is about $0.03R$. From this it is determined that the molecular absorption in air is due almost entirely to the oxygen content; however, at frequencies such that $f/f_m < 0.1$, Sutherland (Reference 11) has shown an anomalous excess absorption which can perhaps be attributed to the nitrogen content (Reference 12).

- Humidity Dependence

The frequency of maximum absorption in air has been found to be highly dependent on the amount of water vapor present in the air. Several investigators (References 13-16) in the past have developed equations to predict f_m as a function of humidity. The most recently developed equation and also the one with the widest range of applicability has been derived by Monk (Reference 16). The relationship is

$$\frac{f_m}{P} = 1750h + 61400h \left[\frac{1.12 + 10h}{10.4 + 10h} \right]$$

where h is the mole percent of water vapor and P is the ambient pressure in atmospheres.

Monk has suggested that the preceding equation can be closely approximated for $0.1 < h < 1.0$ by

$$\frac{f_m}{P} = 38,600h^{1.45}$$

However, close inspection of the accumulated data of Knotzel, Pennsylvania State University, Evans and Beazley, Pohlman, Harris, and Monk (References 13-20) as shown in Figure 1 reveals that

$$\frac{f_m}{P} = 40,000h^{1.45}$$

is a better approximation over a wider humidity range.

- Temperature and Pressure Variation in Relaxation Frequency

For prediction of sound through the stratosphere or for sound propagating under unusual weather conditions, some rational method is required for predicting the variation in f_m with temperature and pressure. Harris has provided significant data on these effects (References 13 and 14). His data on f_m at reduced pressure confirm theoretical predictions that f_m is directly proportional to ambient pressure (Reference 21). This variation with pressure will be significant when attempting to compute relaxation losses for propagation of sound through the atmosphere.

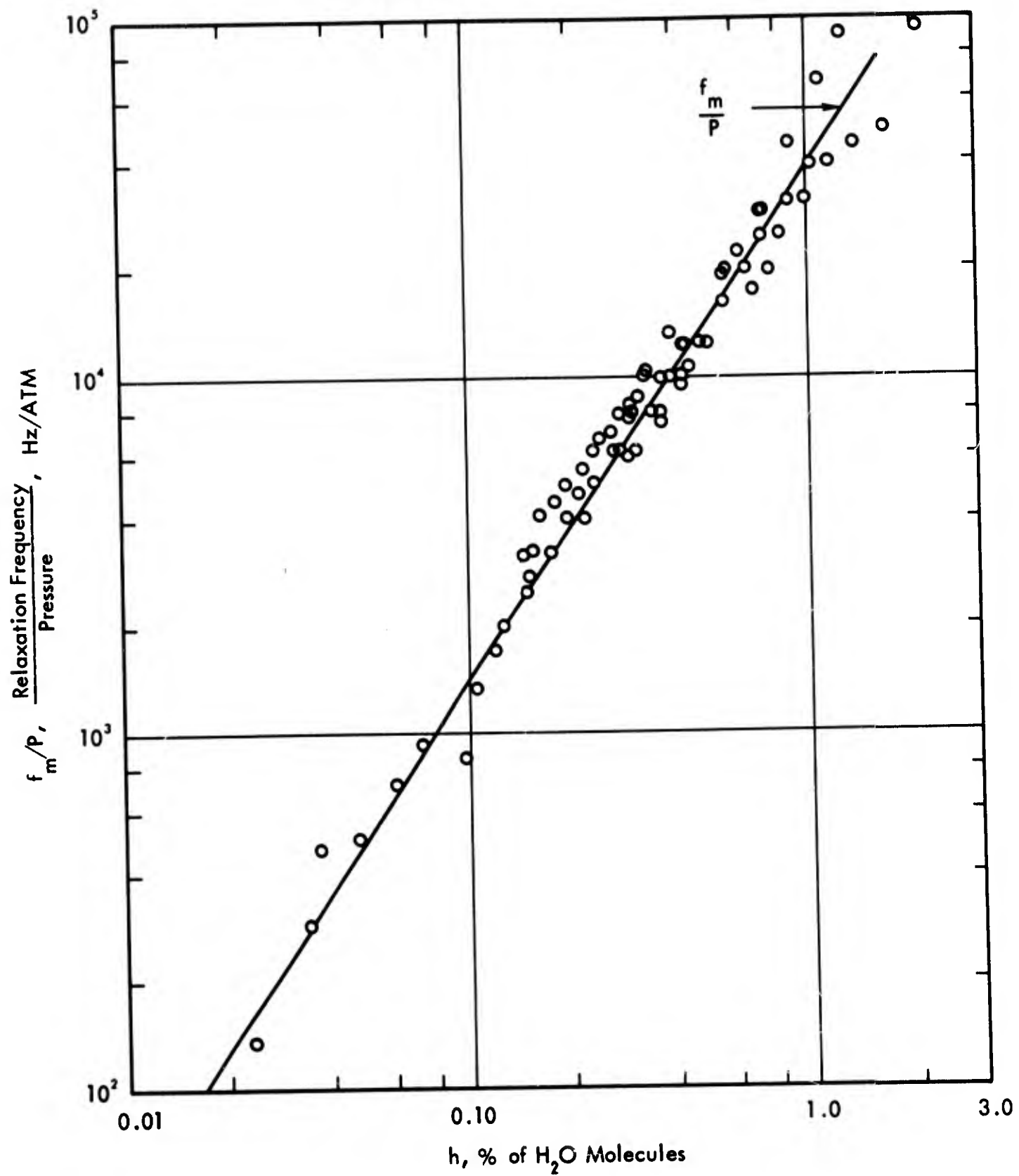


Figure 1. Observed Relaxation Frequency in Air

The absorption equation is given by

$$\alpha_{\text{vib}} \lambda = \frac{4 \pi c'}{35R} \frac{1}{\frac{f_m/P}{f/P} + \frac{f/P}{f_m/P}}$$

or if we normalize $\alpha_{\text{vib}} \lambda$ we have

$$\frac{2 \alpha_{\text{vib}} \lambda}{\frac{4 \pi c'}{35R}} \equiv \frac{\mu}{\mu_{\text{max}}} = \frac{(f/P) (f_m/P)}{(f/P)^2 + (f_m/P)^2}$$

Data on the variation in relaxation frequency in air with temperature are not as definitive as those for pressure effects. In fact, an accepted theoretical model is not available for temperature effects on relaxation frequency in a composite mixture of gases, such as air. The temperature dependence of f_m is still somewhat of an unanswered question. Knudsen (Reference 22) found f_m to be independent of temperature while Harris (Reference 23) has found a negative temperature dependence, i.e., f_m decreases with increasing temperature.

- Comparison of Previous Molecular Absorption Data with Theory

Based on the preceding techniques for defining μ_{max} and f_m , the detailed results of Harris (Reference 24) and Harris and Tempest (Reference 14) have been analyzed. The normalized data are compared in Figure 2 with Kneser's (Reference 25) theoretical prediction (single relaxation theory). It appears that theory does indeed predict the observed results very well for $f/f_m \geq 0.3$ but that below this normalized frequency, the data exhibit a definite and systematic deviation. The latter can be described by an added loss term which varies directly with the first power of frequency instead of the second power. A purely empirical expression, shown in Figure 2, has been developed to describe the data over the entire range of f/f_m for which results are available. Several points should be emphasized about the results in Figure 2.

- 1) A careful analysis of the data (based on smoothed values presented by Harris and Tempest) rejects the possibility of simply adding a new linear term. This would have caused a significant deviation, on the order of 20 percent, between data and theory for $f/f_m \approx 0.3$.
- 2) The normalized data for $f/f_m < 0.05$ are insensitive to f_m . The latter is a normalizing factor in the denominator of both abscissa and ordinate scales. Thus, any change in f_m causes the normalized data point to shift along a line with the same unity slope as the empirical line. This indicates that the anomalous loss is insensitive to humidity content.

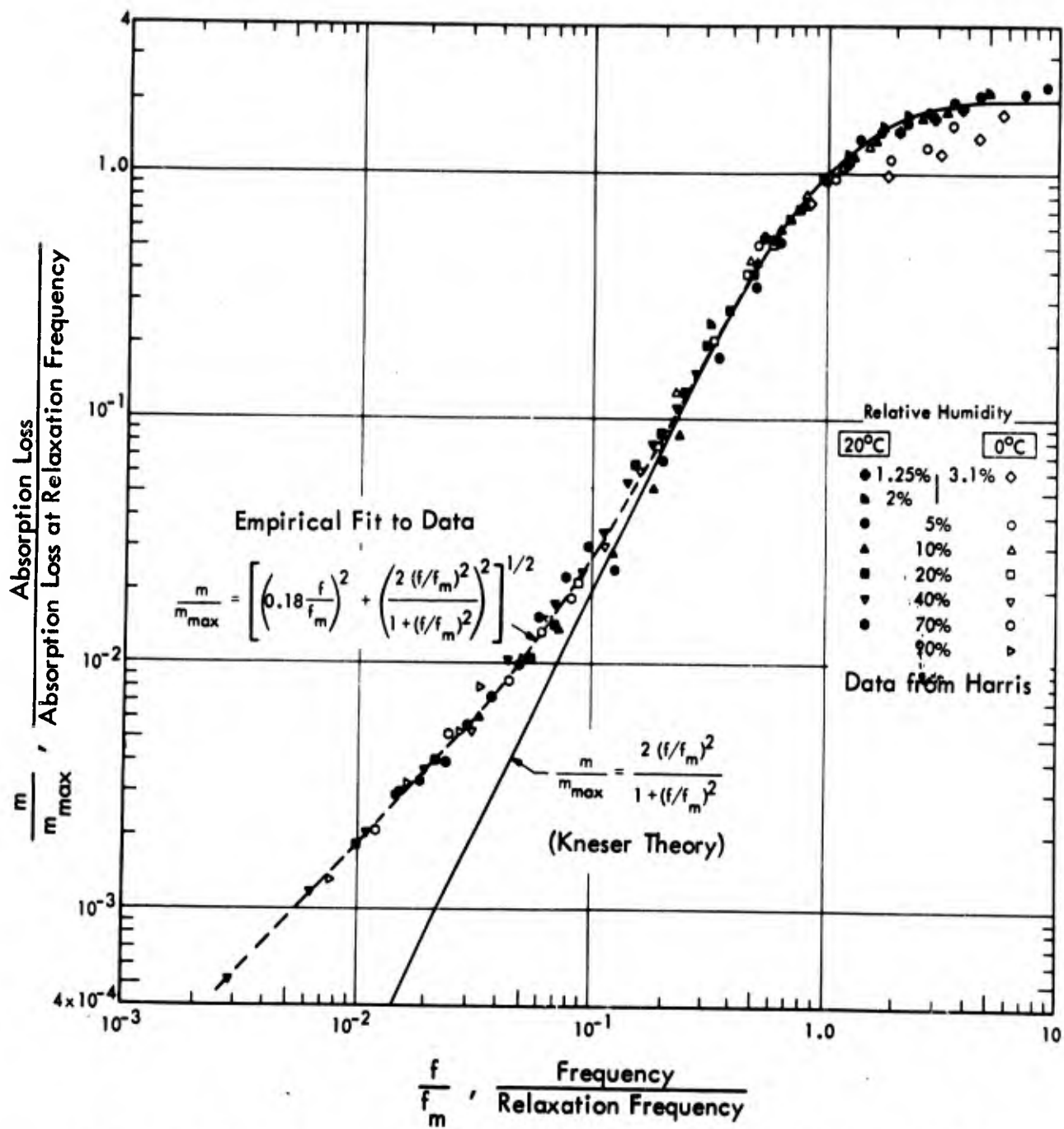


Figure 2. Comparison of Laboratory Measurements of Molecular Absorption Loss With Kneser Theory

- 3) There is insufficient data to validate the accuracy of the empirical expressions for $f/f_m \geq 3$.
- 4) A brief review of other published data on laboratory measurements of air absorption indicates a similar trend to that shown in Figure 2.
- 5) The empirical expression shown in this figure is only one possible form that might be used. An alternate form might consist of an added linear (with frequency) term which approaches a maximum value near a value of $f/f_m \geq 0.1$.
- 6) There is no available theoretical guidance for selection of any one empirical form.

The purpose of this study was to investigate the anomalous low frequency absorption. The study was to consist of an extensive literature survey, an experimental investigation, and the development of a set of equations to predict the absorption of audible sound in still air.

2.0 APPROACH TO THE PROBLEM

Of the different types of absorption mechanisms applicable to air the only two which were thought to possibly have bearing on the low frequency anomalous absorption were heat radiation or an, as yet, undefined molecular absorption. Effects of heat radiation on sound absorption in gases has not been extensively studied experimentally. However, it seems plausible that if heat radiation is the cause of the anomalous absorption then it must be due to an infrared active band in one of the polar molecules in air, i.e., carbon dioxide, water vapor, or ozone. Neglecting ozone, the principle regions responsible are expected to be the rotation and 6- μ bands of water vapor, and the 15- μ band of carbon dioxide (Reference 5). These regions do not overlap to any great degree, so their contributions to the acoustic absorption will be additive. According to Kyle (Reference 26) of these two molecules, the most important is water vapor since it is usually present in larger quantities than CO_2 . This indicates that if the anomalous absorption in air is due to thermal radiation then the effect should also appear in oxygen-water vapor sound absorption data. Figure 3 shows the $\text{O}_2\text{-H}_2\text{O}$ data of Harris and Tempest (Reference 14) and it is apparent that at low normalized frequency ratios the data is well behaved and is well described by single relaxation theory. This then eliminates thermal radiation as a cause of the anomalous low frequency absorption.

Having eliminated all the parts of classical absorption this leaves only relaxation effects due to molecular absorption. As has been pointed out, oxygen is responsible for most of the molecular absorption in air. However, since the low frequency anomalous absorption is well below the absorption peak it is felt that perhaps nitrogen may also contribute significantly at the lower frequencies. To closer investigate the low frequency absorption an experiment on sound absorption in humid air was performed.

• Experimental Approach

To measure the absorption coefficient of audible sound in air the decay time of a reverberant sound field was measured. The reverberation chamber was of approximately five hundred cubic feet volume and had vacuum capabilities. Measurement were made on dry nitrogen to account for the wall losses of the chamber (see, for example, Reference 24). These wall losses were then subtracted from the losses found in the decay times measured in humid air. The humidity range in air was varied from approximately 2 percent relative humidity to 100 percent relative humidity. The chamber was excited with random noise and the decay times were recorded by one-third octave analysis on a high speed level recorder. At some of the lower frequencies pure tones were excited and these decay times were also recorded.

Figure 4 shows the normalized absorption per wavelength versus frequency for ~ 1.8 percent relative humidity. The absorption peak is at approximately 440 Hz. Figures 5-7 show similar curves for 49 percent, 71 percent, and 90 percent relative humidity. The interesting fact about these curves other than the shift of the absorption peak with humidity is the relative constancy of the low frequency absorption values. These values appear to be independent of humidity content and all have a value of approximately 0.1.

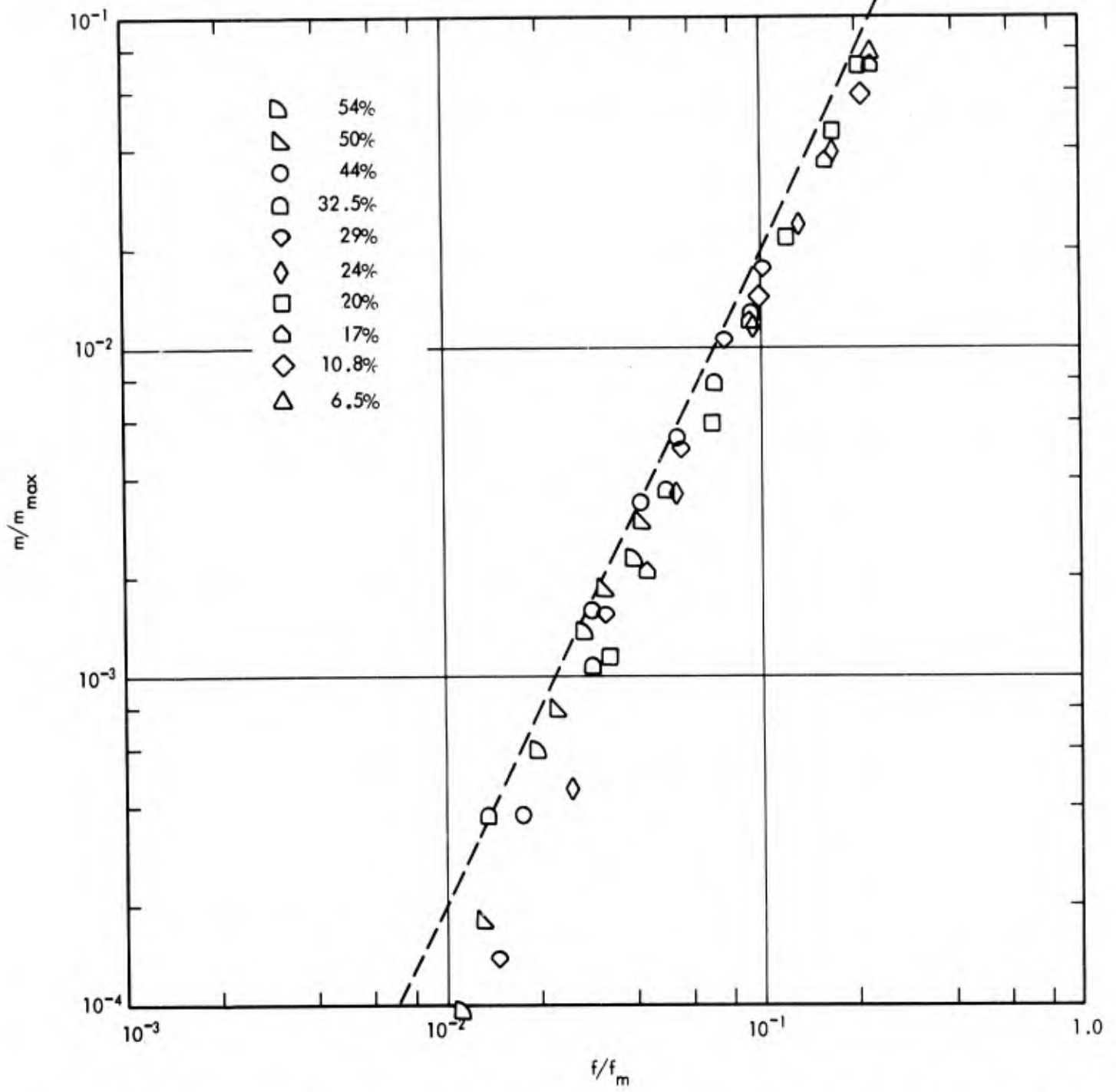


Figure 3. Comparison of Laboratory Measurements of Molecular Absorption Loss with Single Relaxation Theory (Kneser Theory). From Harris and Tempest (Reference 14)

Figure 8 shows a plot of the normalized intensity absorption versus the normalized frequency. It is evident that at frequency ratios greater than approximately 0.1, single relaxation theory adequately describes the data. However, below that ratio there is a definite deviation from the single relaxation curve. It is interesting to note that the deviation in this data is somewhat less than that in Harris' data. An empirical curve which seems to fit this data best is

$$\frac{m}{m_{\max}} = \left\{ (0.1 f/f_m)^2 + \left[\frac{2 (f/f_m)^2}{1 + (f/f_m)^2} \right]^2 \right\}^{1/2} .$$

This differs from the fit Sutherland (Reference 11) made to Harris' smoothed data, only in the numerical coefficient of the first term. Again, one must remember that there is no theoretical basis for this type of empirical fit. This is just a modification of the single relaxation equation which seems to predict the general trend of the observed sound absorption data.

Since classical effects have been eliminated as a cause of this anomalous absorption and since single relaxation theory does not describe all of the data, the next step is to assume that there is another relaxation process occurring. Inspection of Harris' data and the present data both reveal that this may well be the case.

Classical, rotational, and vibrational absorption for oxygen have all been subtracted from Harris' air data and the remainder fitted to single relaxation theory assuming that the peak is caused by the nitrogen content. The results of this effort are shown in Figure 9 as a plot of the relaxation frequency of nitrogen versus the percent mole ratio of water vapor. Even though the values are quite scattered the results do show a significant shift in the relaxation frequency with increasing humidity. The best straight line fit to the data is given by

$$\left(\frac{f}{P} \right)_{N_2} \approx 450 h$$

where h is the percent mole ratio of water vapor. At this time this technique has not been applied to the data from the present study.

The differences found in this data from that of Harris could be caused by any of several factors. The air which Harris used had 300 ppm carbon dioxide while in this experiment breathing air was used which probably had something less than 300 ppm CO_2 . It is well known that there is a near vibrational resonance between CO_2 and N_2 (Reference 27) and this could account for the difference. It is also possible that since the anomaly occurs at low frequencies where in both experiments very few modes were excited in the reverberation chambers, that the calibration using pure nitrogen may have excited modes which were slightly different than those excited in air. This could cause differences in the observed data. However, in this experiment measurement were also made on moist nitrogen which when analyzed may show if this is the cause of the discrepancy.

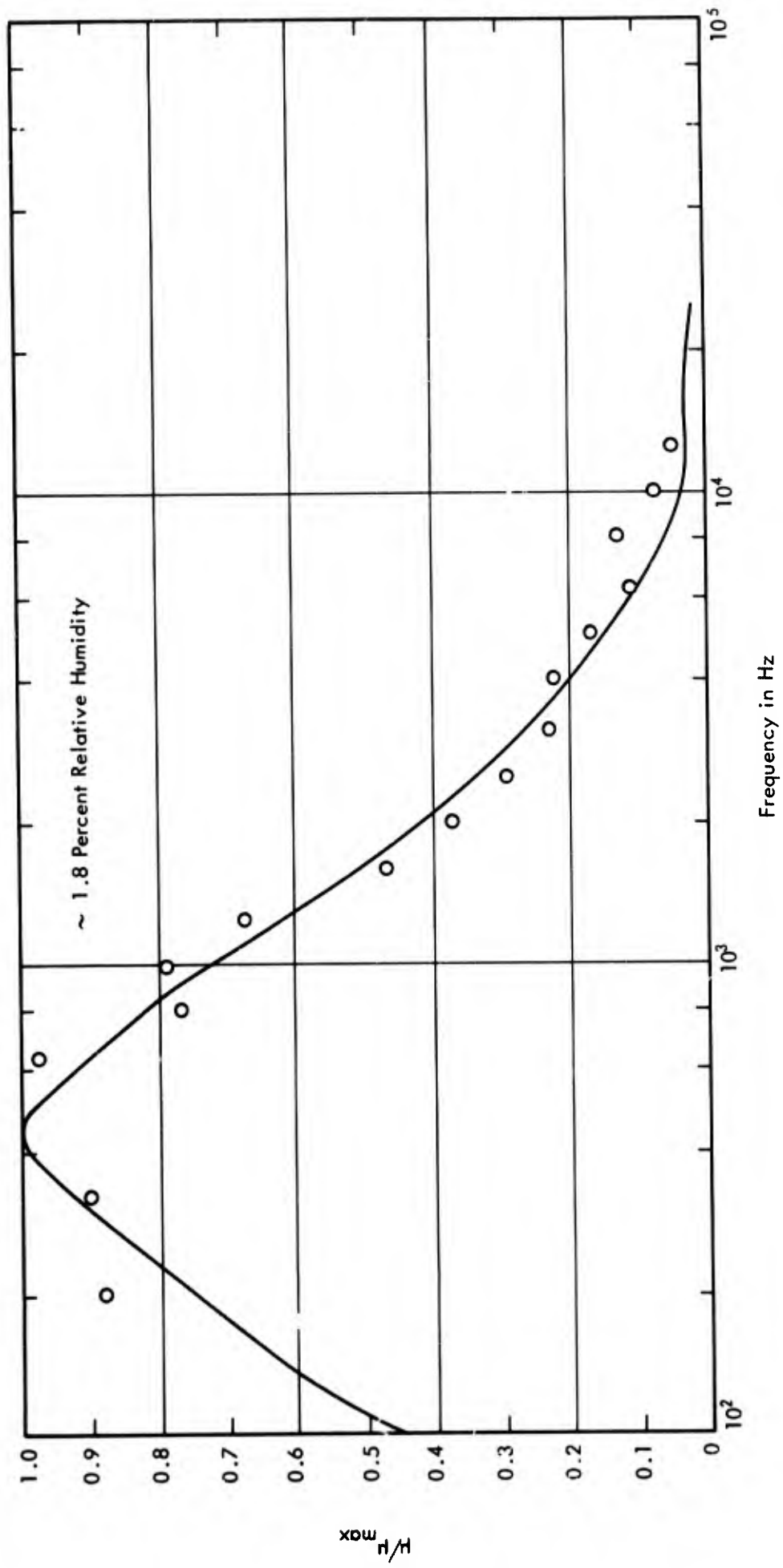


Figure 4. Comparison of Laboratory Measurements of Molecular Absorption Loss with Single Relaxation Theory for Air Containing Approximately 1.8 Percent Relative Humidity

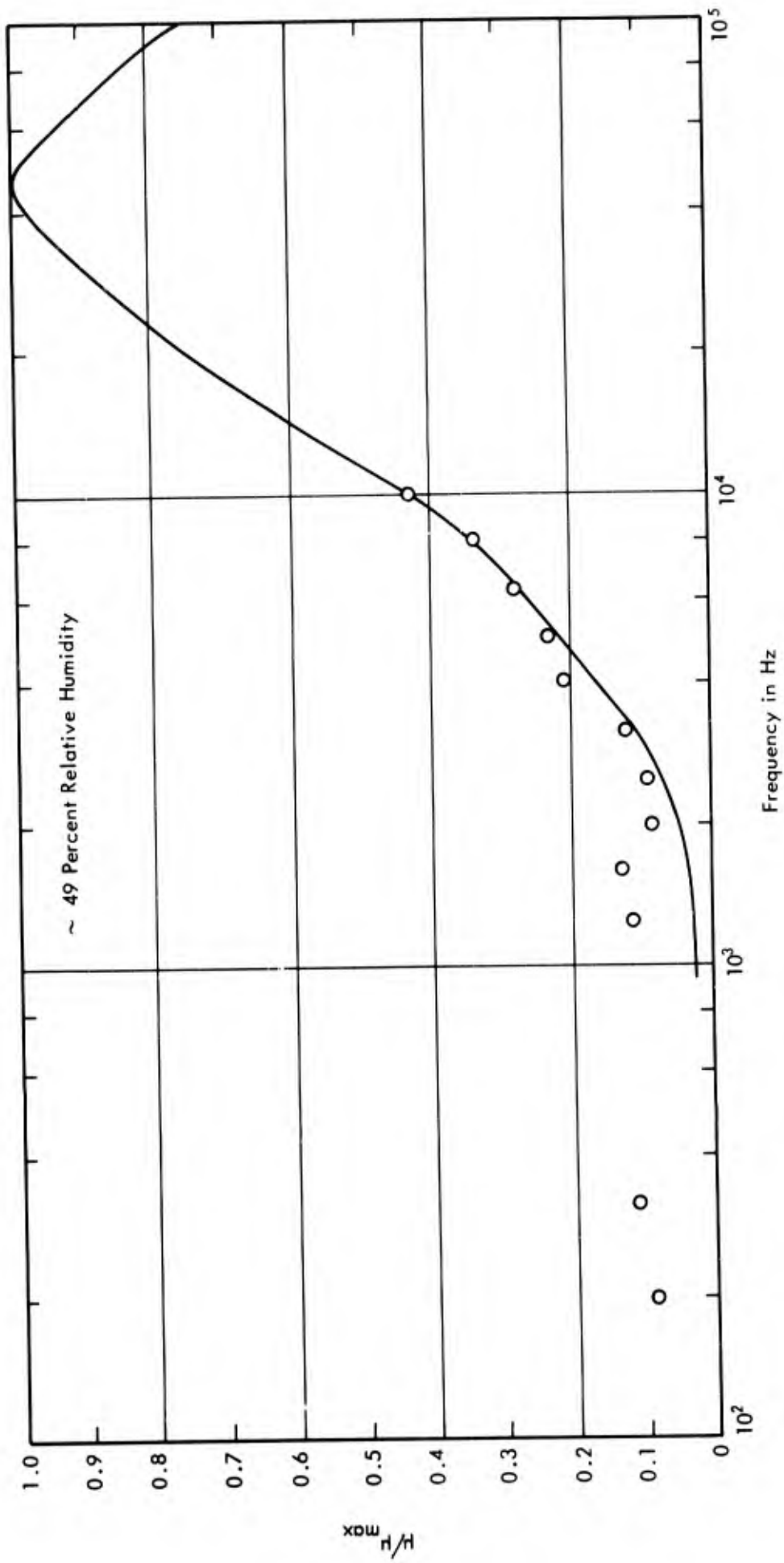


Figure 5. Comparison of Laboratory Measurements of Molecular Absorption Loss with Single Relaxation Theory for Air Containing 49 Percent Relative Humidity

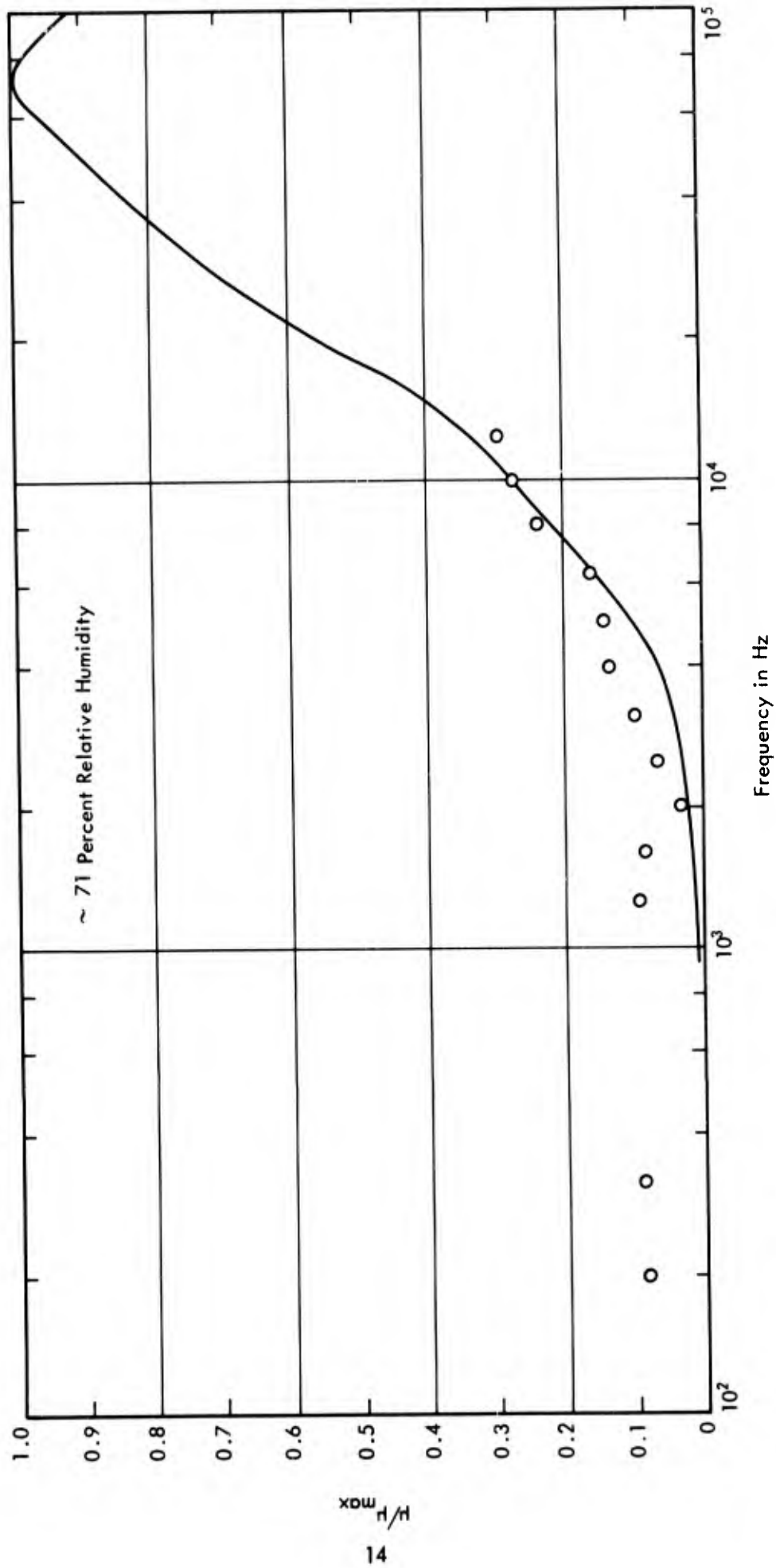


Figure 6. Comparison of Laboratory Measurements of Molecular Absorption Loss with Single Relaxation Theory for Air Containing 71 Percent Relative Humidity

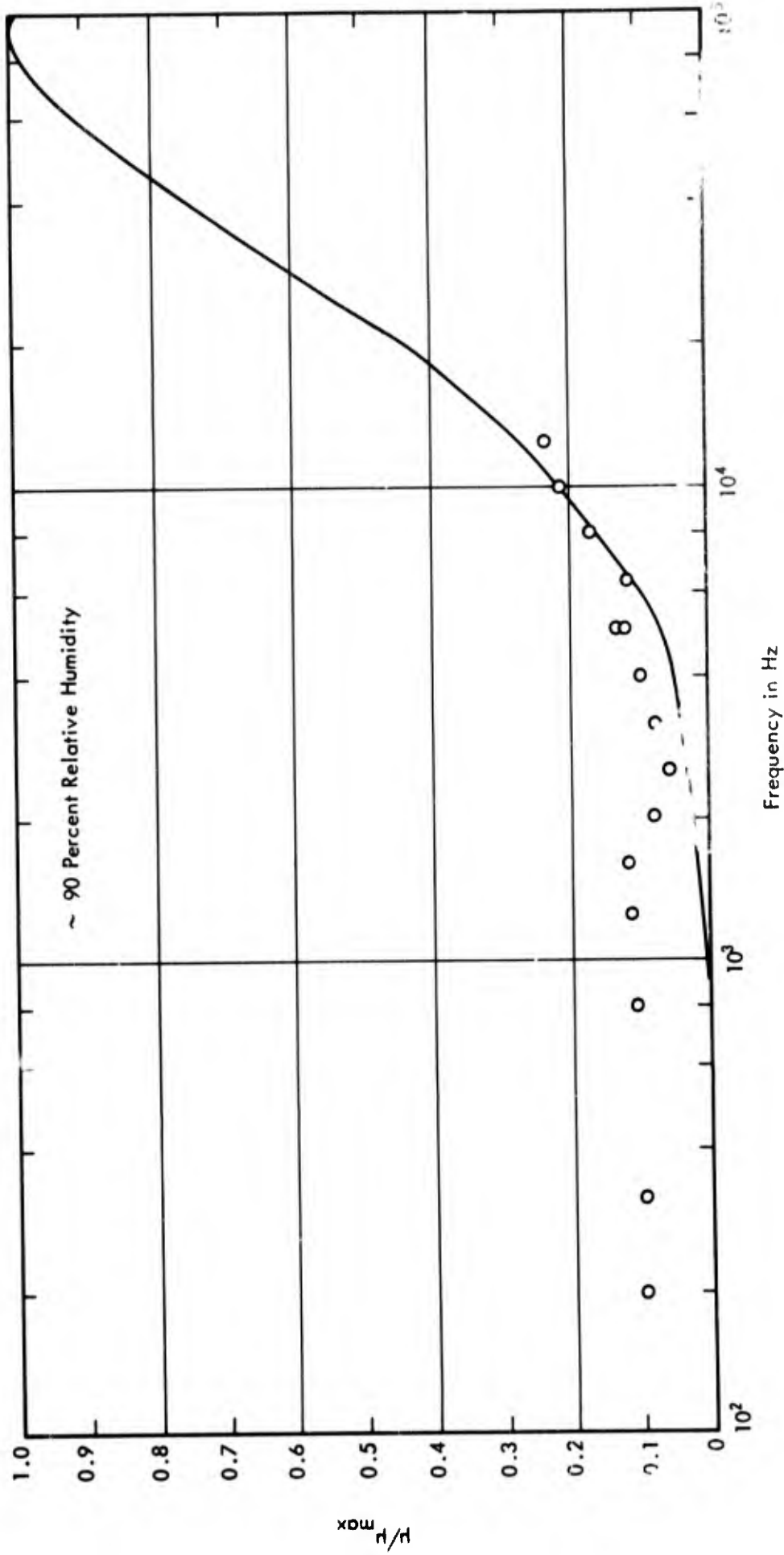


Figure 7. Comparison of Laboratory Measurements of Molecular Absorption Loss with Single Relaxation Theory for Air Containing 90 Percent Relative Humidity

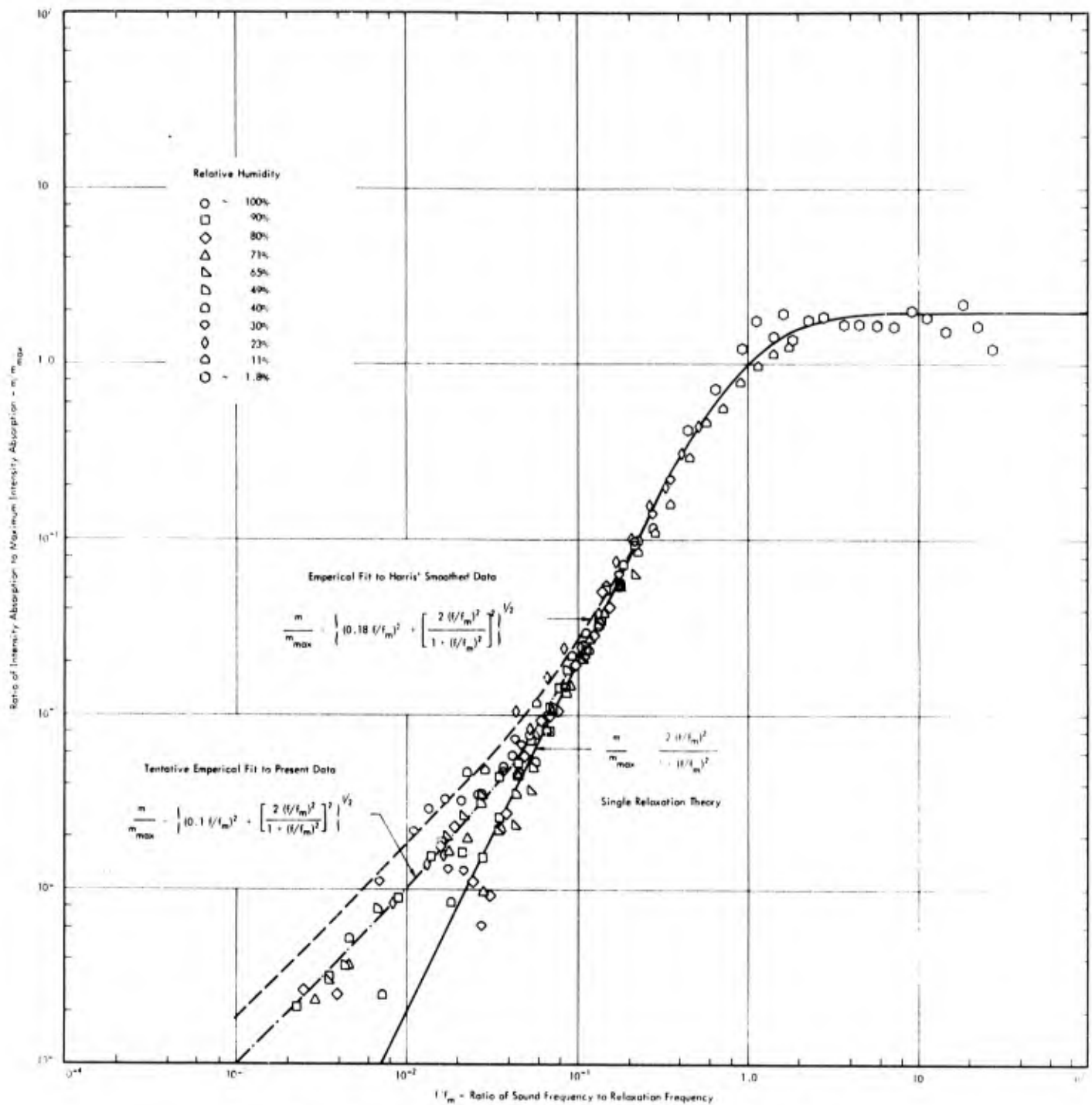


Figure 8. Comparison of Laboratory Measurements of Molecular Absorption Loss with Single Relaxation Theory

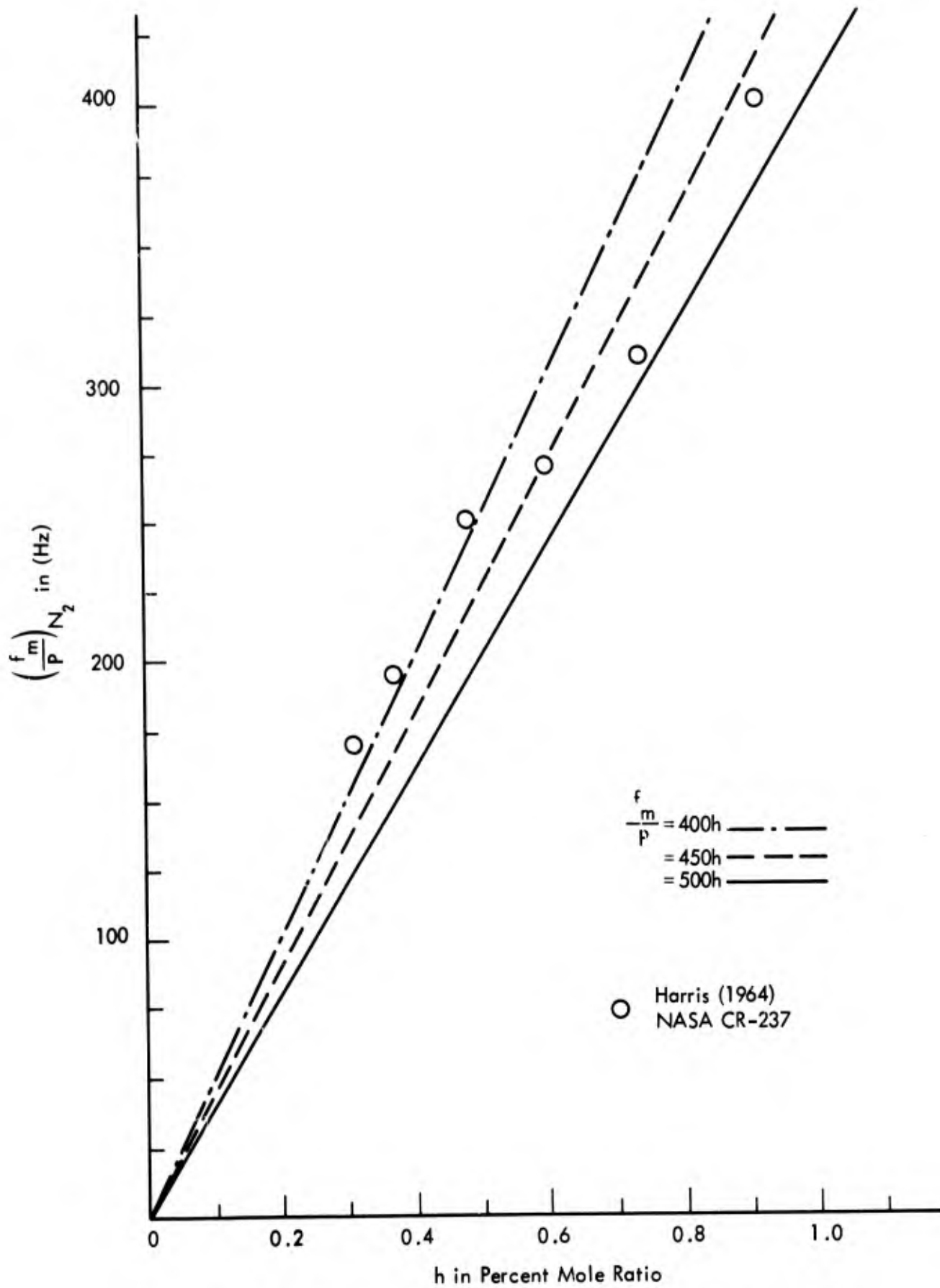


Figure 9. Relaxation Frequency of N_2 Versus Percent Mole Ratio of Water Vapor as Reduced from Humid Air Data

3.0 TENTATIVE PREDICTION METHOD FOR ATMOSPHERIC ABSORPTION IN STILL AIR

Quite often in practical engineering problems it is important to be able to correct outdoor sound level measurements for the effects of atmospheric absorption. As has been previously pointed out effects such as thermal inhomogeneities, turbulence, dust, fog, ground reflections, scattering, diffraction, and inverse square law spreading are all mechanisms which can change the character of sound propagation from laboratory predictions. However, laboratory predictions of the classical and molecular absorptions can be applied with success to a still atmosphere. The ability to make such a correction depends upon the available meteorological data. If for noise measurement from aircraft flyovers the temperature and humidity are known as a function of altitude then the atmosphere can be broken into layers. If on the other hand only ground meteorological data is available some information is still obtainable but not with the same reliability as when the vertical profiles are known.

To make corrections for classical and molecular effects the temperature and water vapor content are both needed. Usually the water vapor content is either given in percent relative humidity or as the dew point. If the dew point temperature is given, the relative humidity can be obtained by referring to tables such as those in the Handbook of Chemistry and Physics (Reference 28). The water vapor content is actually needed in the percent mole ratio of water vapor in air. This can be calculated from the relative humidity by

$$h = \frac{H}{\left(\frac{\rho}{h_s} \frac{M_w}{M} - 1 \right)}$$

where

- h = percent mole ratio
- H = percent relative humidity
- ρ = the density of dry air in gm/cm³
- h_s = the saturated vapor density in gm/cm² at ambient temperature
- M_w = mass of water vapor in gm/mole
- M = mass of air in gm/mole

Over the temperature range of 32°F - 77°F (0°C - 25°C) this can be reduced to

$$h = \frac{H}{\left\{ (5.6) [30 - T/10] e^{-0.0665T} - 1 \right\}}$$

where T is in degrees centigrade.

Next calculate the frequency of maximum molecular absorption from the relationship given by Monk (Reference 16)

$$f_m = 1750h + 61400h \left[\frac{1.12 + 10h}{10.4 + 10h} \right],$$

and then calculate the value of maximum molecular absorption per wavelength by

$$\mu_{\max} = (0.075) \left(\frac{2239}{T} \right)^2 \frac{e^{2239/T}}{(e^{2239/T} - 1)^2}$$

where T = temperature in $^{\circ}\text{K}$.

Now calculate the maximum molecular absorption at any frequency f by

$$\alpha_{\text{mol}} = (1.32) \left[(0.18 f/f_m)^2 + \left(\frac{2 (f/f_m)^2}{1 + (f/f_m)^2} \right)^2 \right]^{1/2} \left(\frac{\mu_{\max} f_m}{(331.5 + 0.607T)} \right)$$

where T is in $^{\circ}\text{C}$ and the units of α_{mol} are in dB/ft.

The classical absorption plus the rotational absorption can be calculated at any frequency f by

$$\alpha_{\text{cl}} + \alpha_{\text{rot}} = 47.7 \times 10^{-12} (1 + 0.001 T) f^2$$

where the units are dB/ft and T is in $^{\circ}\text{C}$.

The total atmospheric absorption in dB/ft is then

$$\alpha_{\text{total}} = \alpha_{\text{mol}} + \alpha_{\text{cl}} + \alpha_{\text{rot}}.$$

There are several points in this prediction scheme at which errors are inherent. The largest error is probably due to not knowing the temperature dependence of the frequency of maximum absorption. This is an area in which further experimental work is needed. Also the α_{mol} expression given is that from Harris' data. This has been used until a closer inspection has been made of the present data. Another small error is introduced in using the Plank-Einstein relationship to predict μ_{\max} . However, the outlined procedure should be fairly accurate over the temperature range $0^{\circ}\text{C} - 30^{\circ}\text{C}$.

4.0 FIELD MEASUREMENTS

In Figure 10 the vertical temperature and humidity profiles are shown for two different times of day. These were taken from actual data supplied by ESSA for Pendleton, Oregon (Reference 29). Also shown are the molecular absorption coefficients as a function of altitude for the two different times of day. As can be readily seen, ground measurement may have little or no correlation to values at higher altitudes. Figure 11 shows the molecular absorption coefficient as a function of height for two days approximately three months apart. These were also calculated from actual meteorological data for Pendleton, Oregon.

Figure 12 depicts a set of field sound level measurements. The value α_{tot} has been calculated by the method outlined. The line $\alpha_{mol} + \alpha_{cl}$ are the values obtained if only oxygen is considered as having contributions to the molecular absorption. While the agreement here is quite good, it may be completely fortuitous since only ground meteorological data were available.

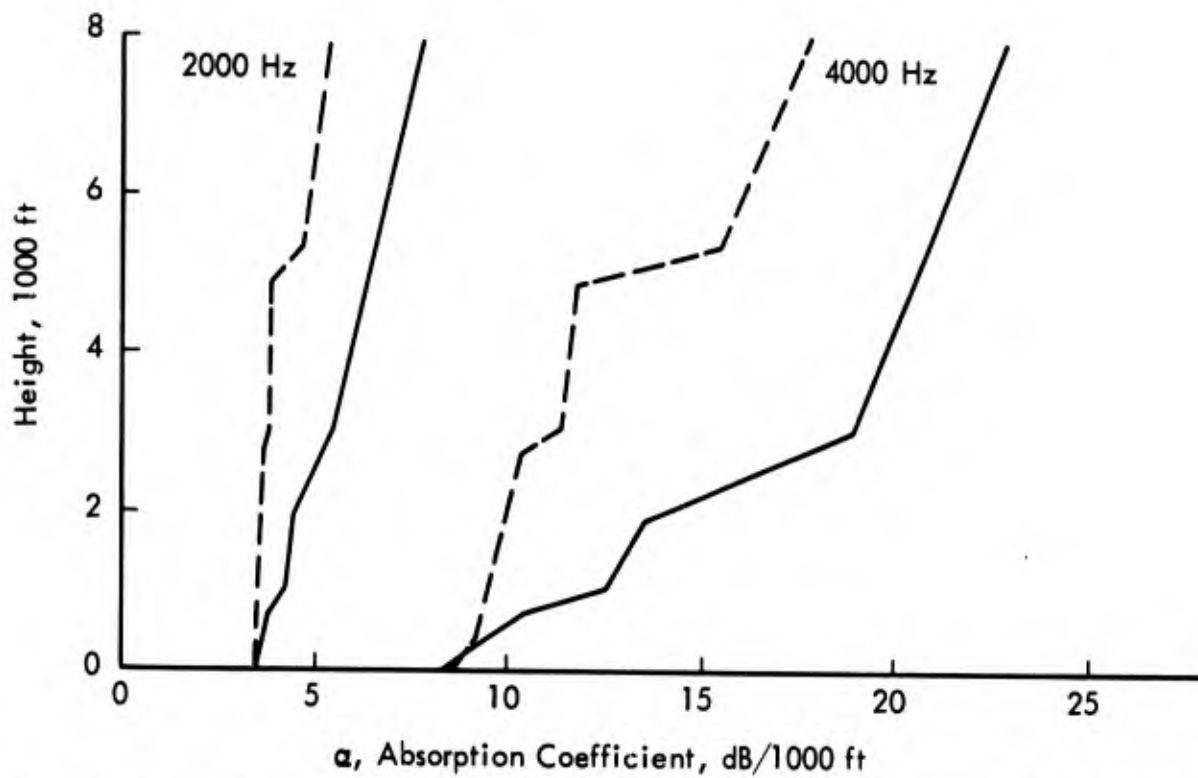
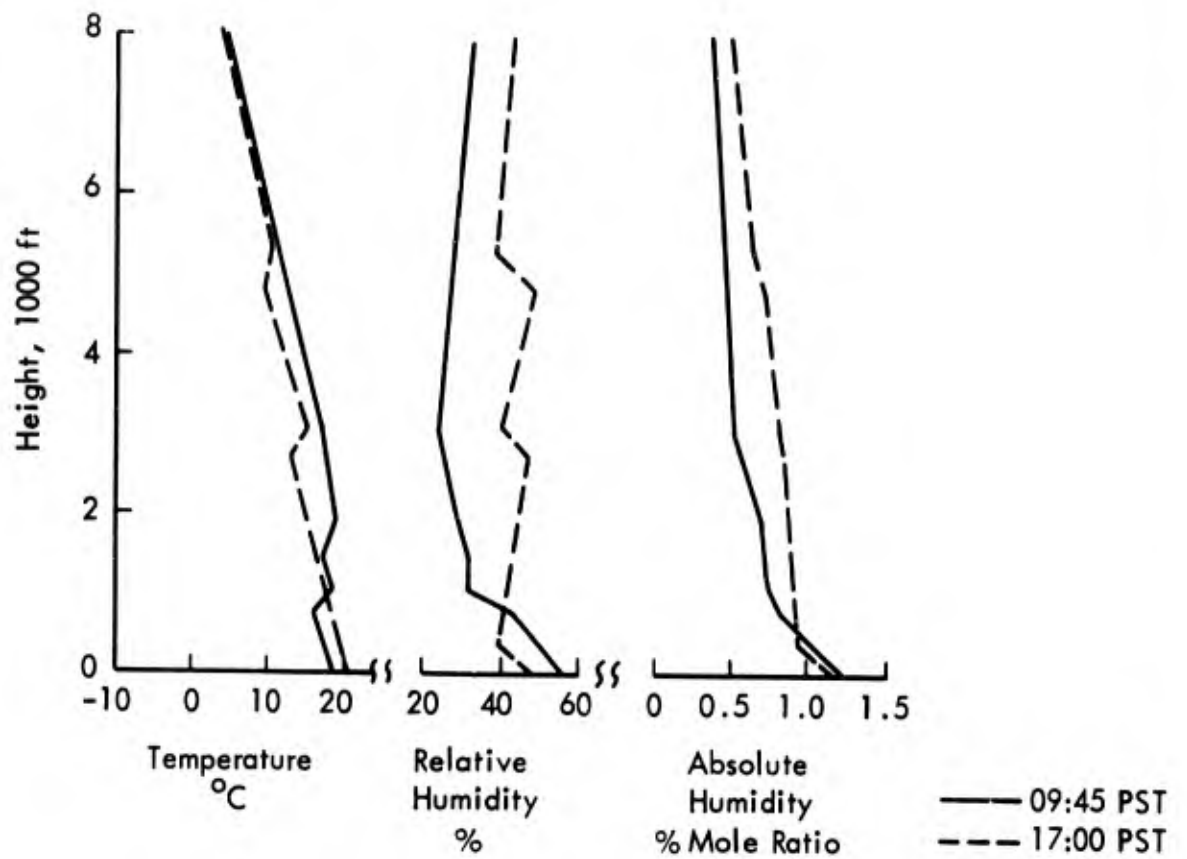


Figure 10. Vertical Profile of Weather and Computed Atmospheric Absorption Coefficient for ESSA Site, Pendleton, Oregon, Over 7 Hour Time Span on October 22, 1969

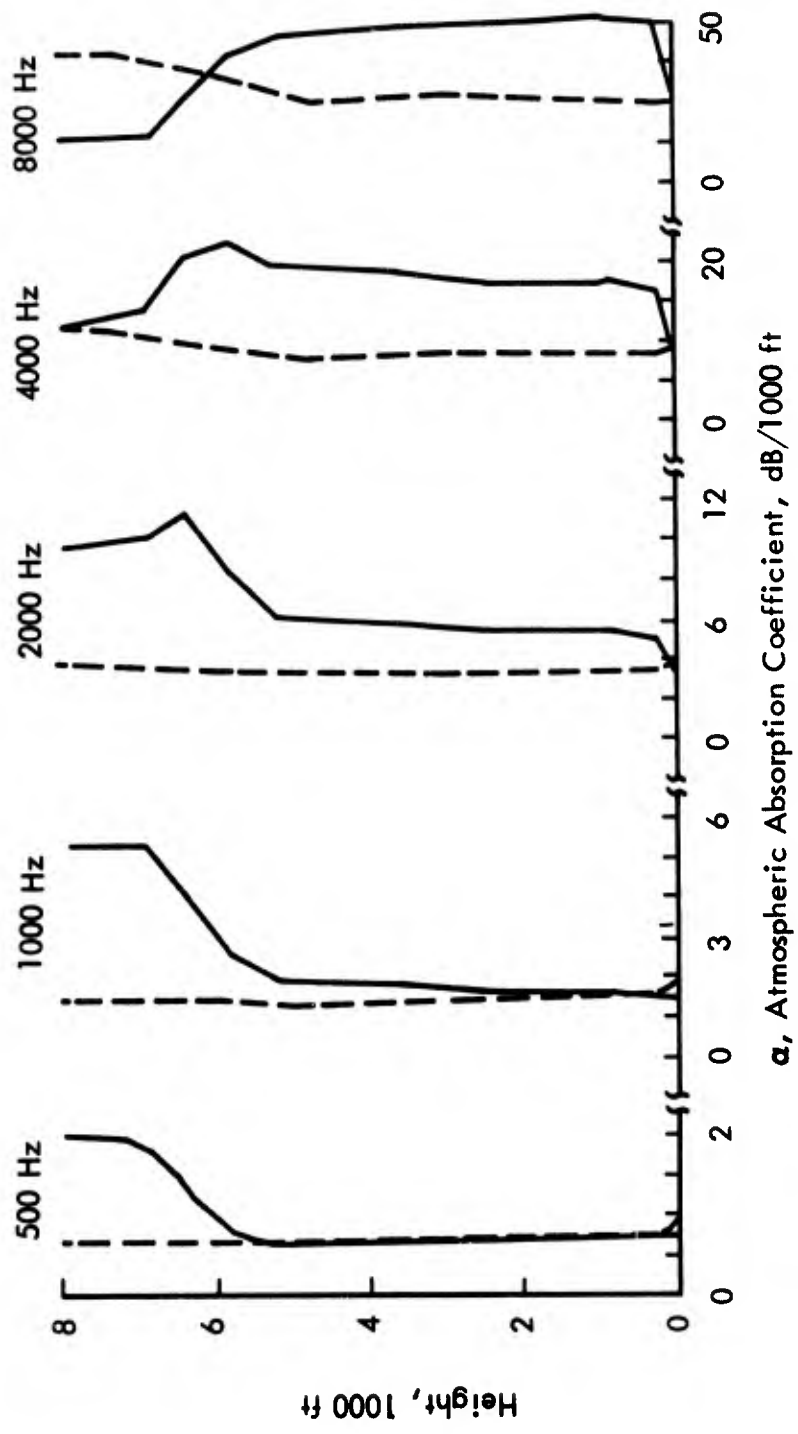


Figure 11. Vertical Profile of Variation in Computed Atmospheric Absorption Coefficient for ESSA Site, Pendleton, Oregon (Solid Lines for April 1, 1969, Dashed Lines for July 2, 1969)

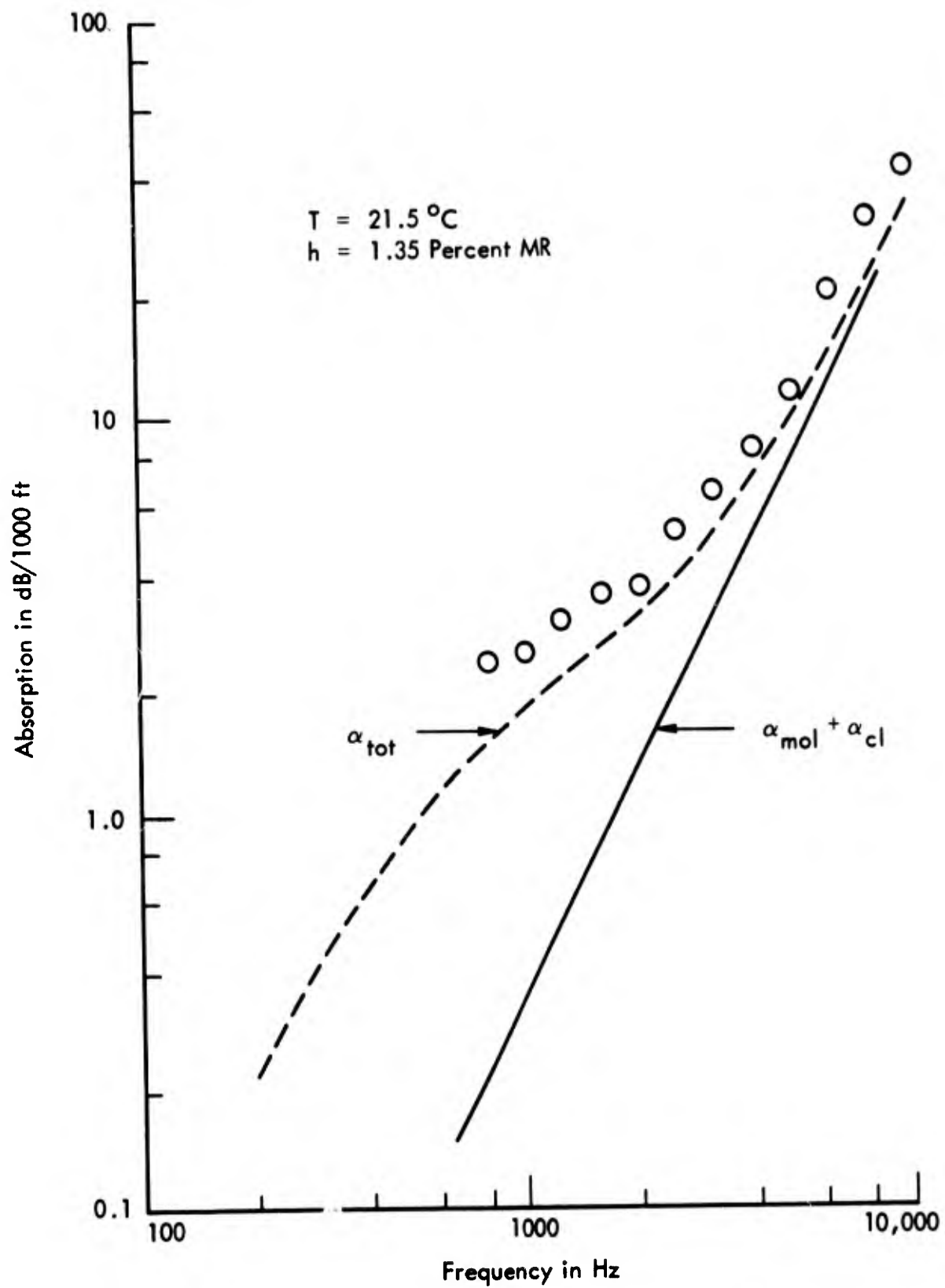


Figure 12. Comparison of Molecular Relaxation Reduced from Field Data to Single Relaxation Theory

5.0 AREAS OF FUTURE STUDY

There are two main areas which still need study on both an experimental and theoretical basis. The first of these is the temperature dependence of the maximum absorption. Little experimental data exists in this area and almost no effort has been exerted to produce a reasonable theoretical model. The second area is the apparent discrepancy in the low frequency data from this set of experiments and those of Harris. Since both of these experiments were reverberation time measurements it would be of interest for future experimental studies to approach the problem from a different experimental basis. It would also be of interest to vary the CO₂ content of the air to see if this could account for the differences in this experiment and that of Harris.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing classification must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
Wyle Laboratories		Unclassified	
3. REPORT TITLE		2b. GROUP	
Investigation of Anomalous Behavior of Sound Absorption by Molecular Relaxation		NA	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report			
5. AUTHOR(S) (Last name, middle initial, first name)			
I. B. Evans I. C. Sutherland			
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS	
May 1970	26		
8a. CONTRACT OR ORDNANCE NO.		9. ORIGINATOR'S REPORT NUMBER(S)	
DAHC04 69 C 0088			
b. PROJECT NO.		9b. OTHER REPORT NUMBER (Any other numbers that may be assigned this report)	
c.		8725.1-E	
d.			
10. DISTRIBUTION STATEMENT			
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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
		U. S. Army Research Office-Durham Box CM, Duke Station Durham, North Carolina 27706	
13. ABSTRACT			
<p>Experimental measurements of the absorption of sound in still air exhibit a distinct deviation from the theoretical predictions based on known classical and molecular relaxation absorption losses. Investigation of published laboratory data has verified that Kneser's theory for molecular relaxation accurately describes the absorption loss near and above the relaxation frequency. At frequencies less than about 0.1 of the relaxation frequency, a different mechanism becomes predominant and results in an absorption loss component which varies directly with the frequency and is essentially independent of humidity. The objective of the effort in this contract is to carry out a detailed experimental and analytical investigation of this anomaly to allow numerical calculations to be made of air absorption for a variety of atmospheric conditions in still air.</p>			
14. KEY WORDS			
<p>Acoustic Absorption Sound Waves Humidity Molecular relaxation Air</p>			

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