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**Standard Values of Atmospheric Absorption
as a Function of Temperature and Humidity**

RATIONALE

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FOREWORD

ARP 866, issued in August 1964, has served as the basis for many analyses of noise propagation and for correcting sound pressure levels measured under given atmospheric conditions to specified reference atmospheric conditions. It has been apparent for some time, however, that some changes were required to improve the consistency of determining atmospheric absorption coefficients over a wide range of temperatures and humidities.

In the original ARP 866, atmospheric absorption coefficients were presented for 1/1- and 1/3-octave bands of noise, but only in a graphical form and for a few selected values of relative humidity. It was necessary, in many practical cases, to interpolate between the plotted curves. This need to interpolate or extrapolate, resulted in problems with repeatability and accuracy in the determination of absorption coefficients. This revision of ARP 866 preserves the original concepts of the 1964 version but replaces the various curves with mathematical representations more suitable for machine computation. It also provides tabulated values of atmospheric absorption coefficients in dB/1000 feet for 1/1- and 1/3-octave bands of noise, with center frequencies between 50 and 10,000 Hertz, for temperatures ranging from 1 to 100°F (in 1-degree intervals) and for relative humidities ranging from 1 to 100% (in 1-percent intervals). Procedures are also indicated for calculation in International Units with temperatures in degrees Celsius and absorption coefficients in dB/100 meters.

Use of the modifications described in this document should eliminate some of the inconsistencies that resulted from use of the August 1964 version of ARP 866 and should thereby provide for improved uniformity in analyses of the propagation of noise under varying atmospheric conditions.

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ILLUSTRATIONS

Figure		Page
1	Classical Absorption Coefficient as a Function of Frequency for Various Air Temperatures	33
2	Absolute Humidity as a Function of Relative Humidity for Various Air Temperatures	34
3	Absolute Humidity for Maximum Molecular Absorption as a Function of Frequency	35
4	Maximum Molecular Absorption Coefficient as a Function of Frequency for Various Air Temperatures. (Kneser's Values from Reference 1).	36
5	Normalized Molecular Absorption Coefficient as a Function of Normalized Absolute Humidity. (Kneser's Values from Reference 1).	37
6	Normalized Molecular Absorption Coefficient as a Function of Normalized Absolute Humidity. (Kneser's Values from Reference 1 and Harris' Values from Reference 4).	38
7	Theoretical and Modified Maximum Molecular Absorption Coefficients as a Function of Temperature for Three Frequencies	39
8	Maximum Molecular Absorption Coefficient as a Function of Frequency for Various Air Temperatures	40
9	Normalized Molecular Absorption Coefficient as a Function of Normalized Absolute Humidity	41
10	Atmospheric Absorption Coefficients for 1/1-Octave Bands of Noise for Different Temperatures and Humidities . .	42
11	Atmospheric Absorption Coefficients for 1/3-Octave Bands of Noise for Different Temperatures and Humidities	50

TABLES

Table		Page
1	Atmospheric Absorption Coefficients for 1/1-Octave Bands of Noise	75
2	Atmospheric Absorption Coefficients for 1/3-Octave Bands of Noise	177

STANDARD VALUES OF ATMOSPHERIC ABSORPTION AS A FUNCTION OF TEMPERATURE AND HUMIDITY

1. INTRODUCTION

There are a number of factors which influence the propagation of noise from an aircraft to a point on the ground. The purpose of this ARP, however, is to consider only the classical and molecular absorption of sound energy by the atmosphere. Spherical divergence, scattering, refraction, and other effects should be treated separately.

This ARP describes a method by which values can be obtained for the absorption of sound in air over a wide range of temperature and humidity conditions. Although it was developed primarily for use in evaluating aircraft flyover noise measurements, the information should be applicable to other noise problems as well.

The method presented is based on the theories of Kneser (References 1 and 2) and Evans and Bazley (Reference 3), the laboratory results of Harris (References 4-7), and field data from various sources (References 8-10). Although the final information was used from these sources only, the works of many other individuals and groups were used to arrive at a selection of the present method.

The experimental results of Harris (Reference 4), were obtained for a single temperature of 20°C (68°F). Essentially, these data were used and curves based on Kneser's theory were modified to fit them. The modified curves then served as a basis for obtaining values over a wide range of temperatures, humidities and frequencies. Once these curves were established, they were compared with field results to select a method for predicting absorption values for bands of noise by using the absorption value for a single frequency.

Since ARP 866 was first published in 1964, considerable data on the atmospheric absorption of sound have been collected, e. g., References 11, 12, 13 and 14. Most of these studies have indicated that, on the average, the atmospheric absorption coefficients determined by the method described herein are quite close to the measured values over a reasonably wide range of air temperatures and relative humidities.

The purpose of this reissue of ARP 866 is to describe a mathematical procedure for determining atmospheric absorption coefficients that is suitable for use with machine computation techniques. Use of the mathematical representations of the various curves involved in the calculation routine should improve the precision and repeatability of determining atmospheric absorption coefficients. The calculation procedure is used to determine atmospheric absorption coefficients for 1/1- and 1/3-octave bands of noise, for air temperatures ranging from 1 to 100°F and relative humidities from 1 to 100 percent. The calculated coefficients are presented in tabular and graphical forms. The tabulated coefficients provide a convenient method of reading all 1/1- or 1/3-octave band coefficients on one page for a variety of temperatures for a given relative humidity. The graphical forms use expanded scales for improved legibility and for easy comprehension of the dependence of the absorption coefficients on frequency, temperature, and humidity.

2. SYMBOLS

freq	Frequency, Hz
h_a	Absolute humidity, gm/m ³
h_{molmax}	Absolute humidity for maximum molecular absorption, gm/m ³
$h_{normalized}$	Normalized absolute humidity, ratio of h_a to h_{molmax}
RH	Relative humidity, percent
temp	Air temperature, degrees Fahrenheit or Celsius
α_{class}	Classical absorption coefficient, dB/1000 ft or dB/100 meters
α_{mol}	Molecular absorption coefficient, dB/1000 ft or dB/100 meters
α_{molmax}	Maximum molecular absorption coefficient, dB/1000 ft or dB/100 meters
$\alpha_{normalized}$	Normalized molecular absorption coefficient, ratio of α_{mol} to α_{molmax}
α	Atmospheric absorption coefficient, sum of α_{class} and α_{mol} , dB/1000 ft or dB/100 meters.

3. BACKGROUND

According to the theory presented in Reference 1, there are two principal mechanisms by which sound energy is absorbed when propagating through the atmosphere. These mechanisms are termed classical absorption, which is a function of frequency and temperature, and molecular absorption which is a function of frequency, temperature and humidity. Both mechanisms can be expressed as a loss, in decibels, per unit distance that a sound wave has travelled.

3.1 CLASSICAL ABSORPTION

Classical absorption results from energy dissipation through the effects of heat conduction and viscosity. It is relatively unimportant except at higher frequencies and varies only slightly with temperature; however, it has to be considered in an analysis since at 10,000 Hz the classical absorption amounts to a little over 4 dB/1000 feet. Values of classical absorption from References 1 and 2 are given in Figure 1.

Molecular absorption results principally from a rotational and vibrational relaxation process of oxygen and nitrogen molecules. It varies over a wide range of values and may be as high as 100 dB/1000 feet at 10,000 Hz.

Both theoretical and experimental results indicate that for a given frequency there is a value of absolute humidity at which molecular absorption has a maximum value. Relative humidity is a more familiar term than absolute humidity, because it has significance to weather and comfort. It is the ratio, in percent, of the amount of water in a parcel of air at a given temperature divided by the amount of water that parcel of air would have at the condensation point. However, molecular absorption is concerned with the actual amount of water in the air regardless of how much there could be. A nomogram from Reference 2 relating absolute humidity, relative humidity, and air temperature is given in Figure 2.

Reference 1 presented an empirical formula relating the absolute humidity at which maximum molecular absorption occurs to the frequency of a sound

wave. This relationship is shown in Figure 3. Reference 1 also provided values of maximum molecular absorption as a function of frequency and temperature; these values are given in Figure 4.

Given the information in Figures 2 through 4, the remaining problem would be to determine what fraction of the maximum molecular absorption occurs at absolute humidities other than that at which the maximum absorption occurs. Figure 5 indicates the relationship, from Reference 1, between normalized molecular absorption and normalized absolute humidity that can be used to determine the molecular absorption coefficient for a given frequency, air temperature, and absolute humidity.

4. MODIFICATIONS TO LABORATORY RESULTS

4.1 TEMPERATURE AND HUMIDITY EFFECTS

Most of the experimental test results reported in the literature show trends which agree with the theoretical predictions given in References 1 and 2. For specific conditions, however, many of the experimental results do not agree with the theoretical values nor with one another. The results from laboratory experiments were usually obtained only over a limited range of temperature and humidity. In order to obtain absorption coefficients over a wide range of temperature and humidity, it has been general practice to alter the theoretical curves to fit the experimental results. The procedure used here was to make use of the precise and systematic laboratory data from Reference 4 to modify the theoretical curves from References 1 and 2.

Because the determination of atmospheric absorption depends on several curves, one must be arbitrary in deciding which of these curves should be altered to make the theoretical curves agree with experimental data. The approach taken here was to accept the classical absorption curve (Figure 1) and the curve of absolute humidity at which maximum absorption occurs as a function of frequency (Figure 3). The curve presenting maximum molecular absorption values for different frequencies and temperatures (Figure 4) and the theoretical curve relating normalized molecular absorption to normalized absolute humidity (Figure 5) were then adjusted to fit the data of Reference 4.

The total absorption values (i. e., a combination of molecular and classical) in Figure 3 of Reference 4 were used as presented. However, in Figure 4 of Reference 4, the plot of normalized absorption as a function of normalized humidity includes the effects of classical absorption. Classical absorption was subtracted from the total absorption values and a modified curve relating normalized molecular absorption as a function of normalized humidity was obtained. This curve is plotted in Figure 6 along with the curve from Figure 4 of Reference 4, and Kneser's theoretical curve. The modified Harris curve was selected for the currently proposed method.

In Figure 5 of Reference 4 a comparison was made between experimental values and Kneser's theoretical values for maximum absorption coefficient as a function of frequency. However, Harris' values once again included classical absorption and the theoretical values do not. Comparing only the molecular absorption of Harris' total absorption values showed them to be lower than theory would predict. Harris' data were approximately parallel to the theoretical curve of maximum molecular absorption as a function of frequency (Figure 4).

Theoretical values of maximum molecular absorption for three frequencies were plotted as functions of temperature in Figure 7. Data from Reference 4 obtained at 20°C (68°F) were plotted and modified curves parallel to the theoretical curves were drawn through them. The modified curves in Figure 7 were used to obtain the complete set of modified data presented in Figure 8.*

The curves in Figures 1, 3 and 8, and the curve in Figure 9, which is taken from the modified curve in Figure 6, then supply a complete set of curves for use in determining total atmospheric absorption coefficients for a wide range of frequencies, temperatures and humidities.

4.2 FREQUENCY EFFECTS

The theoretical and the modified theoretical curves described above and presented in Figures 1, 3, 8 and 9 are strictly applicable to pure-tone, single-frequency sounds. For wide-band noise, with or without strong discrete-frequency components, it is necessary to consider frequency bands that may contain several frequency components. The most commonly used frequency band has a constant percentage bandwidth, either that of a full or 1/1-octave band filter or that of a 1/3-octave band filter. In order to develop a procedure for determining atmospheric absorption coefficients for bands of

*Note that Figures 7 and 8 differ slightly from the corresponding Figures 6 and 7 in the August 1964 version of ARP 866. The differences are due to inconsistencies that occurred in the plotting of the previous curves for air temperatures near 0°F. These inconsistencies have been removed by the use of Equation (4) (Paragraph 5.4) to determine α_{molmax} .

noise it was necessary to compare absorption coefficients from field measurements to those determined from the curves of Figures 1, 3, 8 and 9.

Although laboratory data are obtained under comparatively carefully controlled conditions, field values of atmospheric absorption coefficients are obtained under a fairly wide range of conditions which may not be carefully measured. These data are usually obtained from a series of tests in which the sound pressure levels are measured on the ground as a particular type of airplane flies over the measurement point at heights ranging from a few hundred to a few thousand feet. The measured sound pressure levels (in 1/1- or 1/3-octave bands) are plotted as a function of height overhead, inverse-square spherical-divergence losses are removed, and the excess attenuation is attributed to atmospheric absorption. It is usually assumed that temperatures and relative humidities measured near the surface of the earth are representative of conditions to a height greater than the maximum height during the flyover and that the sound propagation is in all cases vertical.

Three fairly complete sets of atmospheric absorption values obtained from field tests of aircraft flyover noise levels are described in References 8-10. These three sets of data, taken by completely independent groups and under a variety of atmospheric conditions, indicated that by making certain general assumptions fairly reliable predictions of absorption values could be made. It was assumed that the absolute humidity was constant over the height range and that the air temperature decreased with height at the lapse rate given by an International Civil Aviation Organization standard atmosphere, Reference 15. It was also assumed that, because the spectrum of the flyover noise slopes down rapidly with frequency (especially for long distance measurements), the sound pressure levels in the high-frequency bands would be controlled by energy in the lower frequency range of the band.

Analyses of the flyover noise data from References 8-10 indicated that the following general rules for the frequency to use in the analyses gave the best agreement between absorption coefficients determined from the field data and values determined from the curves of Figures 1, 3, 8 and 9.

In Figures 1, 3 and 8, the frequencies to use are:

1. For 1/1-octave bands:
 - a. Geometric mean frequency for bands centered:
at 53, 106, 212, 425, 850, 1700, and 3400 Hz (commercial), or
at 63, 125, 250, 500, 1000, 2000, and 4000 Hz (preferred).
 - b. 1.05 times the lower limiting frequency for bands centered:
at 6800 Hz (commercial) - i.e., $1.05 \times 4800 = 5040$ Hz, or
at 8000 Hz (preferred) - i.e., $1.05 \times 5600 = 5880$ Hz.
2. For 1/3-octave bands:
 - a. Geometric mean frequency for bands with center frequencies at and below 4000 Hz.
 - b. The lower limiting frequencies for bands with center frequencies above 4000 Hz, i.e., 4500, 5600, 7100, and 9000 Hz for the bands centered at 5000, 6300, 8000, and 10,000 Hz.

The geometric mean frequencies and the lower limiting frequencies were the standard values recommended in Reference 16 for 1/1- and 1/3-octave frequency bands.

5. PROCEDURE FOR CALCULATING ABSORPTION COEFFICIENTS

A seven-step procedure is used to determine the total atmospheric absorption coefficients as the sum of a classical absorption component and a molecular absorption component. The steps are set forth first for temperatures in degrees Fahrenheit and absorption coefficients in dB/1000 ft and then for degrees Celsius and dB/100 meters.

5.1 CLASSICAL ABSORPTION COEFFICIENT, α_{class}

Based on the data in Figure 1 as a function of frequency and temperature the classical absorption coefficients are determined from

$$\alpha_{\text{class}} = 10 \left[2.05 \log_{10} (\text{freq}/1000) + 6.33 \times 10^{-4} \times \text{temp} - 1.45325 \right] \quad (1)$$

in dB/1000 ft for freq in Hz and temp in °F.

5.2 ABSOLUTE HUMIDITY, h_a

From Figure 2, the mathematical representation of the relationship between absolute humidity, h_a , relative humidity, RH, and air temperature, temp, is

$$h_a = 10 \left[\log_{10} (\text{RH}) - B \right] \quad (2)$$

in gm/m³ for RH in percent and where B is the value of $\log_{10} (\text{RH})$ for an absolute humidity of 1.0 gm/m³. The quantity B is determined from the following relationship:

$$B = b_0 + b_1 \times \text{temp} + b_2 \times \text{temp}^2 + b_3 \times \text{temp}^3 \quad (2a)$$

The coefficients in Eq. (2a) were determined by a least-squares curve fitting technique for a third-order polynomial (over the temperature range from 0°F to 100°F) to be

$$b_0 = 1.97274664$$

$$b_1 = -2.288074 \times 10^{-2}, \text{ } ^\circ\text{F}^{-1}$$

$$b_2 = 9.589 \times 10^{-5}, \text{ } ^\circ\text{F}^{-2}$$

$$b_3 = -3 \times 10^{-7}, \text{ } ^\circ\text{F}^{-3}$$

5.3 ABSOLUTE HUMIDITY FOR MAXIMUM MOLECULAR ABSORPTION, h_{molmax}

From References 1 and 2, the absolute humidity for maximum molecular absorption as a function of frequency is

$$h_{\text{molmax}} = (\text{freq}/1010)^{1/2} \quad (3)$$

in gm/m^3 with freq in Hz.

5.4 MAXIMUM MOLECULAR ABSORPTION COEFFICIENT, α_{molmax}

From Figure 8, the relation between the maximum molecular absorption coefficient, frequency, and air temperature is determined using

$$\alpha_{\text{molmax}} = 10^{\left[\log_{10} (\text{freq}/1) + 4.6833 \times 10^{-3} \times \text{temp} - 2.4215 \right]} \quad (4)$$

5.5 NORMALIZED MOLECULAR ABSORPTION COEFFICIENT, $\alpha_{\text{normalized}}$

From Figure 9, corresponding values of normalized absolute humidity (ratio of h_a to h_{molmax}) and normalized molecular absorption coefficient (ratio of α_{mol} to α_{molmax}) are as follows.

$h_{\text{normalized}}$	$\alpha_{\text{normalized}}$
0.00	0.000
0.25	0.315
0.50	0.700
0.60	0.840
0.70	0.930
0.80	0.975
0.90	0.996
1.00	1.000
1.10	0.970
1.20	0.900
1.30	0.840
1.50	0.750
1.70	0.670
2.00	0.570
2.30	0.495
2.50	0.450
2.80	0.400
3.00	0.370
3.30	0.330
3.60	0.300
4.15	0.260
4.45	0.245
4.80	0.230
5.25	0.220
5.70	0.210
6.05	0.205
6.50	0.200
7.00	0.200
10.00	0.200

For calculation purposes, these coordinate pairs may be stored in the memory of the digital computer. Values of $\alpha_{\text{normalized}}$ at intermediate values of $h_{\text{normalized}}$ can then be determined by a quadratic interpolation technique.

5.6 MOLECULAR ABSORPTION COEFFICIENT, α_{mol}

The values of the molecular absorption coefficient for given frequency, temperature and relative humidity are determined by multiplying the corresponding values of α_{molmax} (determined in step 4) and $\alpha_{\text{normalized}}$ (determined in step 5). That is,

$$\alpha_{\text{mol}} = \alpha_{\text{molmax}} \times \alpha_{\text{normalized}} \quad (5)$$

5.7 TOTAL ATMOSPHERIC ABSORPTION COEFFICIENT, α

The total atmospheric absorption coefficient for corresponding values of frequency, temperature, and relative humidity is determined by adding together the values of α_{class} from step 1 and α_{mol} from step 6. That is

$$\alpha = \alpha_{\text{class}} + \alpha_{\text{mol}} \quad (6)$$

5.8 MODIFICATIONS FOR INTERNATIONAL UNITS

For some noise propagation analyses it is more convenient to deal with air temperatures in degrees Celsius and absorption coefficients in decibels per 100 meters. Modifications to the above equations to accomplish this are described below. The frequencies to use for analyses in 1/1- and 1/3-octave bands are the same as those given in Section 4. The modifications use the following conversion factors:

$$\begin{aligned} 1 \text{ meter} &= 3.281 \text{ feet} \\ ^\circ\text{F} &= 9/5 ^\circ\text{C} + 32 \\ \text{dB}/100\text{m} &= 1/10 \times 3.281 \text{ ft}/\text{m} \times \text{dB}/1000 \text{ ft} \\ &= 0.3281 \times \text{dB}/1000 \text{ ft} \\ &= (10^{-0.48399}) (\text{dB}/1000 \text{ ft}) \end{aligned}$$

5.8.1 Classical Absorption Coefficient, α_{class}

From Equation (1),

$$\begin{aligned}\alpha_{\text{class}} &= [10 \exp(-0.48399)] [10 \exp(2.05 \log_{10}(\text{freq}/1000) \\ &\quad + 6.33 \times 10^{-4} \times (9/5) \times \text{temp} + 6.33 \times 10^{-4} \times 32 \\ &\quad - 1.45325)] \\ &= 10^{[2.05 \log_{10}(\text{freq}/1000) + 1.1394 \times 10^{-3} \times \text{temp} - 1.916984]} \quad (7)\end{aligned}$$

in dB/100m for frequency in Hz and temperature in $^{\circ}\text{C}$.

5.8.2 Absolute Humidity, h_a

From Equation (2),

$$h_a = 10^{[\log_{10}(\text{RH}) - B]} \quad (8)$$

in gm/m^3 for RH in percent and temperature in $^{\circ}\text{C}$.

From Equation (2a), the nondimensional quantity B is:

$$B = b_0 + b_1 \times \text{temp} + b_2 \times \text{temp}^2 + b_3 \times \text{temp}^3. \quad (8a)$$

The appropriate constants can be determined from those given in Equation (2a) by substitution as follows:

$$\begin{aligned}&- 2.288074 \times 10^{-2} (9/5 \text{ temp} + 32) \\ &\quad 9.589 \times 10^{-5} (9/5 \text{ temp} + 32)^2 \\ &\quad - 3 \times 10^{-7} (9/5 \text{ temp} + 32)^3\end{aligned}$$

Expanding and collecting terms including the constant of 1.97274664 from Equation (2a) gives

$$\begin{aligned}b_0 &= 1.328924 \\ b_1 &= -3.179768 \times 10^{-2}, \text{ } ^{\circ}\text{C}^{-1} \\ b_2 &= 2.173716 \times 10^{-4}, \text{ } ^{\circ}\text{C}^{-2} \\ b_3 &= -1.7496 \times 10^{-6}, \text{ } ^{\circ}\text{C}^{-3}\end{aligned}$$

5.8.3 Absolute Humidity for Maximum Molecular Absorption, h_{molmax}

Same as Equation (3),

$$h_{\text{molmax}} = (\text{freq}/1010)^{1/2} \quad (9)$$

in gm/m³ with frequency in Hz.

5.8.4 Maximum Molecular Absorption Coefficient, α_{molmax}

From Equation (4),

$$\begin{aligned} \alpha_{\text{molmax}} &= [10 \exp(-0.48399)] [10 \exp(\log_{10}(\text{freq}/1) \\ &\quad + 4.6833 \times 10^{-3} \times (9/5) \times \text{temp} \\ &\quad + 4.6833 \times 10^{-3} \times 32 - 2.4215)] \\ &= 10^{[\log_{10}(\text{freq}/1) + 8.42994 \times 10^{-3} \times \text{temp} - 2.755624]} \quad (10) \end{aligned}$$

in dB/100m with freq in Hz and temp in °C.

5.8.5 Normalized Molecular Absorption Coefficient, $\alpha_{\text{normalized}}$

Use the same table of coordinate pairs and quadratic interpolation technique described in Paragraph 5.5.

5.8.6 Molecular Absorption Coefficient, α_{mol}

Combine α_{molmax} from Paragraph 5.8.4 and $\alpha_{\text{normalized}}$ from Paragraph 5.8.5 as follows:

$$\alpha_{\text{mol}} = \alpha_{\text{molmax}} \times \alpha_{\text{normalized}} \quad (11)$$

in dB/100m.

5.8.7 Total Atmospheric Absorption Coefficient, α

Combine α_{class} from Equation (7) and α_{mol} from Equation (11) as follows:

$$\alpha = \alpha_{\text{class}} + \alpha_{\text{mol}} \quad (12)$$

in dB/100m for temperatures in $^{\circ}\text{C}$, relative humidity in percent, and frequency in Hz.

6. ATMOSPHERIC ABSORPTION COEFFICIENTS

Atmospheric absorption coefficients were calculated for 1/1- and 1/3-octave bands for air temperatures ranging from 1 to 100°F and for relative humidities ranging from 1 to 100 percent. The 1/1-octave bands are for the preferred frequencies; values for the old commercial octave band frequencies would have to be calculated separately using the technique described above. The results of these calculations are shown in graphical form in Figures 10 and 11 and in tabular form in Tables 1 and 2. The tables present the calculated values for temperature intervals of 1°F and relative humidity intervals of 1 percent. For most analyses, the tabular format will be more useful than the graphical format, although the graphical format does provide an easy visualization of the relationship between the variables. Note also that the curves in Figures 10 and 11 have been faired through the calculated values. As a result, there may be minor differences between atmospheric absorption coefficients read from the curves and those in Tables 1 and 2. In case of a discrepancy, the calculated values in Tables 1 or 2 should be used.

The absorption coefficients in Figures 10 and 11 and in Tables 1 and 2 were calculated by a digital computer. The program statements for generating these values are given in Appendixes A and B. The statements are in FORTRAN and include the quadratic interpolation routine used to determine values of $\alpha_{\text{normalized}}$ from values of $h_{\text{normalized}}$. The statements include Eqs. (1) through (6) and the table of Paragraph 5.5.

If absorption coefficients in dB/100m with temperatures in °C are desired, it would be feasible to retain the same statements but make an internal change of variable to change TEMP from °F to °C and to change ALPHA from dB/1000 ft to dB/100m. Alternatively, the program statements could be rewritten to incorporate the revised values for the constants in Eqs. (7), (8), and (10).

7. VALUES FOR REFERENCE CONDITIONS

Two reference atmospheric conditions are commonly used for aircraft noise analyses. These are (1) an air temperature of 59°F (15°C) and a relative humidity of 70 percent, and (2) an air temperature of 77°F (25°C) and a relative humidity of 70 percent. The first condition uses the international standard day temperature at sea level from Reference 15 and a relative humidity that represents an average of the relative humidities encountered at the major airports around the world. The second condition is widely used for aircraft noise certification and for describing noise levels around airports, References 17 to 19.

7.1 59°F (15°C) AND 70-PERCENT RELATIVE HUMIDITY

From Tables 1 and 2 the absorption coefficients are:

Band Center Frequency, Hz	Atmospheric Absorption Coefficient			
	1/1-Octave Band		1/3-Octave Band	
	dB/1000 ft	dB/100 m	dB/1000 ft	dB/100 m
50	-	-	0.1	0.0
63	0.1	0.0	0.1	0.0
80	-	-	0.1	0.0
100	-	-	0.1	0.0
125	0.2	0.1	0.2	0.1
160	-	-	0.2	0.1
200	-	-	0.3	0.1
250	0.4	0.1	0.4	0.1
315	-	-	0.5	0.1
400	-	-	0.6	0.2
500	0.7	0.2	0.7	0.2
630	-	-	0.9	0.3
800	-	-	1.2	0.4
1,000	1.5	0.5	1.5	0.5
1,250	-	-	1.9	0.6
1,600	-	-	2.4	0.8
2,000	3.0	1.0	3.0	1.0
2,500	-	-	4.0	1.3
3,150	-	-	5.4	1.8
4,000	7.6	2.6	7.6	2.5
5,000	-	-	9.1	3.0
6,300	-	-	12.7	4.2
8,000	13.7	4.6	18.5	6.1
10,000	-	-	27.4	9.0

7.2 77°F (25°C) AND 70-PERCENT RELATIVE HUMIDITY

Again from Tables 1 and 2 the absorption coefficients are:

Band Center Frequency, Hz	Atmospheric Absorption Coefficient			
	1/1-Octave Band		1/3-Octave Band	
	dB/1000 ft	dB/100 m	dB/1000 ft	dB/100 m
50	-	-	0.1	0.0
63	0.1	0.0	0.1	0.0
80	-	-	0.1	0.0
100	-	-	0.2	0.1
125	0.2	0.1	0.2	0.1
160	-	-	0.3	0.1
200	-	-	0.3	0.1
250	0.4	0.1	0.4	0.1
315	-	-	0.6	0.2
400	-	-	0.7	0.2
500	0.9	0.3	0.9	0.3
630	-	-	1.1	0.4
800	-	-	1.4	0.5
1,000	1.8	0.6	1.8	0.6
1,250	-	-	2.2	0.7
1,600	-	-	2.9	0.9
2,000	3.6	1.2	3.6	1.2
2,500	-	-	4.6	1.5
3,150	-	-	5.9	1.9
4,000	7.6	2.5	7.6	2.5
5,000	-	-	8.7	2.9
6,300	-	-	11.0	3.6
8,000	11.7	3.9	14.9	4.9
10,000	-	-	20.6	6.8

8. LIMITATIONS

The atmospheric absorption coefficients and calculation procedures described herein should be used with caution in estimating sound propagation losses. When long propagation distances are involved there may be large discrepancies between observed and estimated sound pressure levels unless careful consideration is given to the actual spectrum shape of the noise source, the true propagation path length, the actual condition of the atmosphere between the source and the receiver, and the actual level of the background noise that may be present. In the high-frequency bands, it is possible for the losses due to atmospheric absorption to reduce the level of the sound from the noise source to below the level of the background noise.

For the analyses considered herein, the atmosphere was assumed to be still and homogeneous with no thermal or humidity inversions, no wind or wind gradients, no inhomogeneities, and no turbulence. If these conditions are not approximately satisfied, the sound can be refracted and scattered with the result that measured sound pressure levels can be significantly different from predicted sound pressure levels.

The acoustic propagation path should not be too close to horizontal. The elevation angle between the source and the receiver should not be less than approximately 25 degrees. When the elevation angle is small, there are losses in addition to the atmospheric losses described herein due to propagation over the ground and over any grassy or wooded terrain. These additional losses can be substantial and are outside the scope of this document.

The analyses presented herein are for atmospheric pressures near the standard, sea-level pressure of 760 mm of mercury (29.92 in. Hg). Additional research is needed to develop an explicit method to account for atmospheric pressures much different from the standard sea level value such as might be encountered at a high-altitude airport.

As a final limitation it should be pointed out that because of the curve-fitting techniques used to obtain the mathematical representations presented herein, it is not recommended that any extrapolations be made for temperatures colder than 0°F (-18°C) or warmer than 100°F (38°C).

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10. APPENDIX A

This appendix contains a listing of the computer program statements for calculating atmospheric absorption coefficients for sound pressure levels in 1/1-octave bands. The program was written in FORTRAN for operation on an IBM model 65 System 360 digital computer. The coefficients are in dB/1000 ft with temperatures in degrees Fahrenheit and relative humidities in percent.

APPENDIX A

1/1 OCTAVES

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C C ATMOSPHERIC ABSORPTION COEFFICIENT CALCULATION AS A FUNCTION OF TEMPERATURE AND RELATIVE HUMIDITY FOR FULL OCTAVE BANDS.  
C C NOTE- TEMPERATURE IS IN DEGREES FAHRENHEIT, RELATIVE HUMIDITY IS  
C C IN PERCENT, AND ABSORPTION COEFFICIENTS ARE IN LB/1000 FEET.  
THIS PROGRAM DOES NOT USE ANY INPUT DATA.  
DIMENSION IFREQ(8),FREQ(8),DEGREE(50),TABLE(59)  
DIMENSION MMOLMX(8,100),AMOLMX(8,100),HMURAT(8,100),ALPRAT(8,100)  
DIMENSION ALPMOL(8,100),ALPLCA(8,100),ALPHA(8,100)  
EQUIVALENCE (MM,TABLE(1))  
DATA TABLE /29,0.0,0.00,0.00,0.250,0.315,0.50,0.70,0.6,0.84,0.7,0.93,  
1.0,0.9,0.975,0.9,0.996,1.0,1.0,1.1,0.97,1.2,0.9,1.3,0.84,1.5,0.75,  
21.7,0.67,2.0,0.57,2.3,0.495,2.5,0.45,2.8,0.4,3.0,0.37,3.30,0.33,  
33.6,0.3,4.15,0.26,4.45,0.245,4.80,0.23,5.25,0.22,5.7,0.21,6.05,  
40.205,6.5,0.2,7.0,0.2,10.0,0.2/  
DATA IFREQ/63,125,250,500,1000,2000,4000,8000/  
DATA FREQ/63.0,125.0,250.0,500.0,1000.0,2000.0,4000.0,5880.0/  
DATA DEGREE/1M ,1M ,1M ,1M ,1M ,1M ,1M ,1M ,1MT,1ME,1MH,1MP,  
1 ME,1MR,1MA,1MT,1MU,1MN,1ME,1M ,1M ,1MJ,1MG,1MO,  
2 ME,1ME,1MS,1M ,1MF,1MA,1MH,1MP,1ME,1MY,1MM,1ME,1MI,  
3 MT,1M ,1M ,1M ,1M ,1M ,1M ,1M ,1M ,1M ,1M /  
55 FORMAT(1M1, 27X,'ATMOSPHERIC ABSORPTION COEFFICIENTS IN DB PER 100  
LB FT FOR FULL OCTAVE BANDS',/30X,'OF NOISE AS A FUNCTION OF TEMPER  
ATURE FOR ',I4,' PERCENT RELATIVE HUMIDITY')  
60 FORMAT(1MD,21X,'BAND CENTER FREQUENCY, MZ',36X,'BAND CENTER FREQUE  
NCY, MZ')  
65 FORMAT(1M ,8X,816,13X,816/)   
70 FORMAT(1M ,3X,A1,I3,1X,MF6.1,8X,A1,I3,1X,MF6.1)   
NN=29  
DO 180 IPH=1,100  
RELHUM=IRM  
DO 160 K=1,100  
TEMP=M  
B = 1.97274664 - 0.02288074 * TEMP + 0.0009589 * TEMP ** 2 - 0.0000003 * TEMP ***  
ABSMU = 10.0 *(LOG10(RELHUM)- R)  
DO 150 J=1,8  
MMOLMX(J,K)=10.3*(ALOG10(FREQ(I))) + 0.00469333 * TEMP - 2.42151  
AMOLMX(J,<) = (FREQ(J)/ 1010.0)**0.5  
HMURAT(J,K) = ABSMU/MMOLMX(J,K)  
L=3  
IF(HMURAT(J,K).LE.TABLE(2))GO TO 130  
DO 90 I=4,58,2  
L=L+1  
80 IF(TABLE(L) - HMURAT(J,K))90,130,110  
90 CONTINUE  
GO TO 130  
110 L=L-2  
IF(L.GE.4)GO TO 120  
L=L+2  
120 XA1 = HMURAT(J,K) - TABLE(L)  
XA0 = HMURAT(J,K) - TABLE(L-2)  
XA2 = HMURAT(J,K) - TABLE(L+2)  
XO1 = TABLE(L-2) - TABLE(L)  
XO2 = TABLE(L-2) - TABLE(L+2)  
XI2 = TABLE(L) - TABLE(L+2)  
ALPRAT(J,K)=TABLE(L-1)*(XA1/XO1)*(XA2/XO2)+  
TABLE(L+1)*(XA0/XO1)*(XA2/XI2)+  
TABLE(L+3)*(XA0/XO2)*(XA2/XI2)  
GO TO 140  
130 ALPRAT(J,K) = TABL(E)L)  
140 CONTINUE  
ALPMOL(J,<)= ALPRAT(J,K) * AMOLMX(J,K)  
ALPLCA(J,<)=10.0**((2.35*ALOG10(FREQ(J))/1000.0)+(7.000633)*TEMP-  
1.45325)  
150 ALPHA(J,K)= ALPLCA(J,K)+ALPMOL(J,K)  
160 CONTINUE  
WRITE(6,55) IPH  
WRITE(6,60)  
WRITE(6,65) (IFRQ(J),J=1,8),(IFFRQ(J),J=1,8)  
DO 170 K=1,50  
ITEMP1 = K  
ITEMP2 = K+50  
170 WRITE(6,70) DEGRFF(K),ITEMP1,(ALPHA(J,K),J=1,8),DEGREE(K),ITEMP2,  
1(ALPH(A(J,K+50),J=1,8)  
180 CONTINUE  
STOP  
END
```

11. APPENDIX B

This appendix contains a listing of the computer program statements for calculating atmospheric absorption coefficients for sound pressure levels in 1/3-octave bands. The program was written in FORTRAN for operation on an IBM model 65 System 360 digital computer. The coefficients are in dB/1000 ft with temperatures in degrees Fahrenheit and relative humidities in percent.

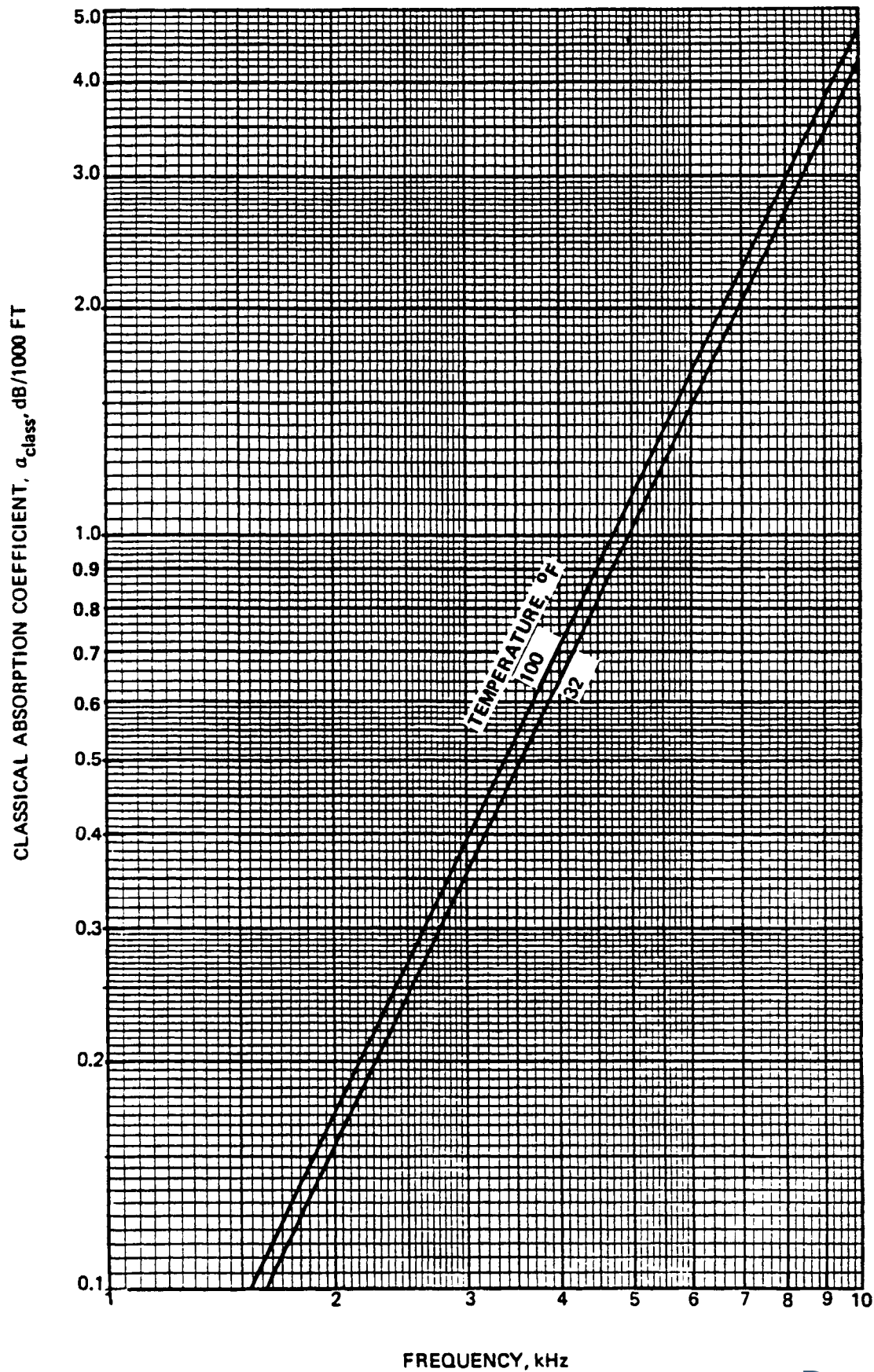


FIGURE 1. CLASSICAL ABSORPTION COEFFICIENT AS A FUNCTION OF FREQUENCY FOR VARIOUS AIR TEMPERATURES



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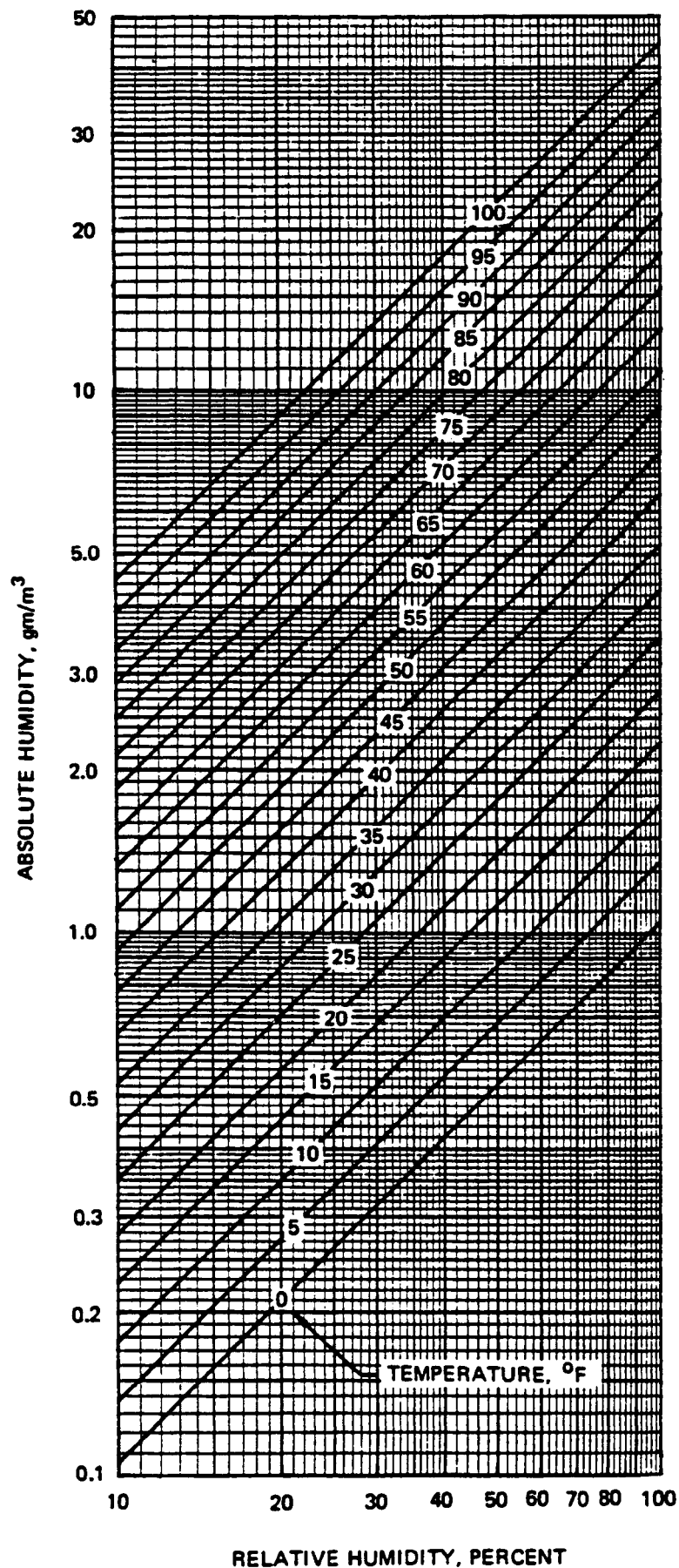


FIGURE 2. ABSOLUTE HUMIDITY AS A FUNCTION OF RELATIVE HUMIDITY FOR VARIOUS AIR TEMPERATURES

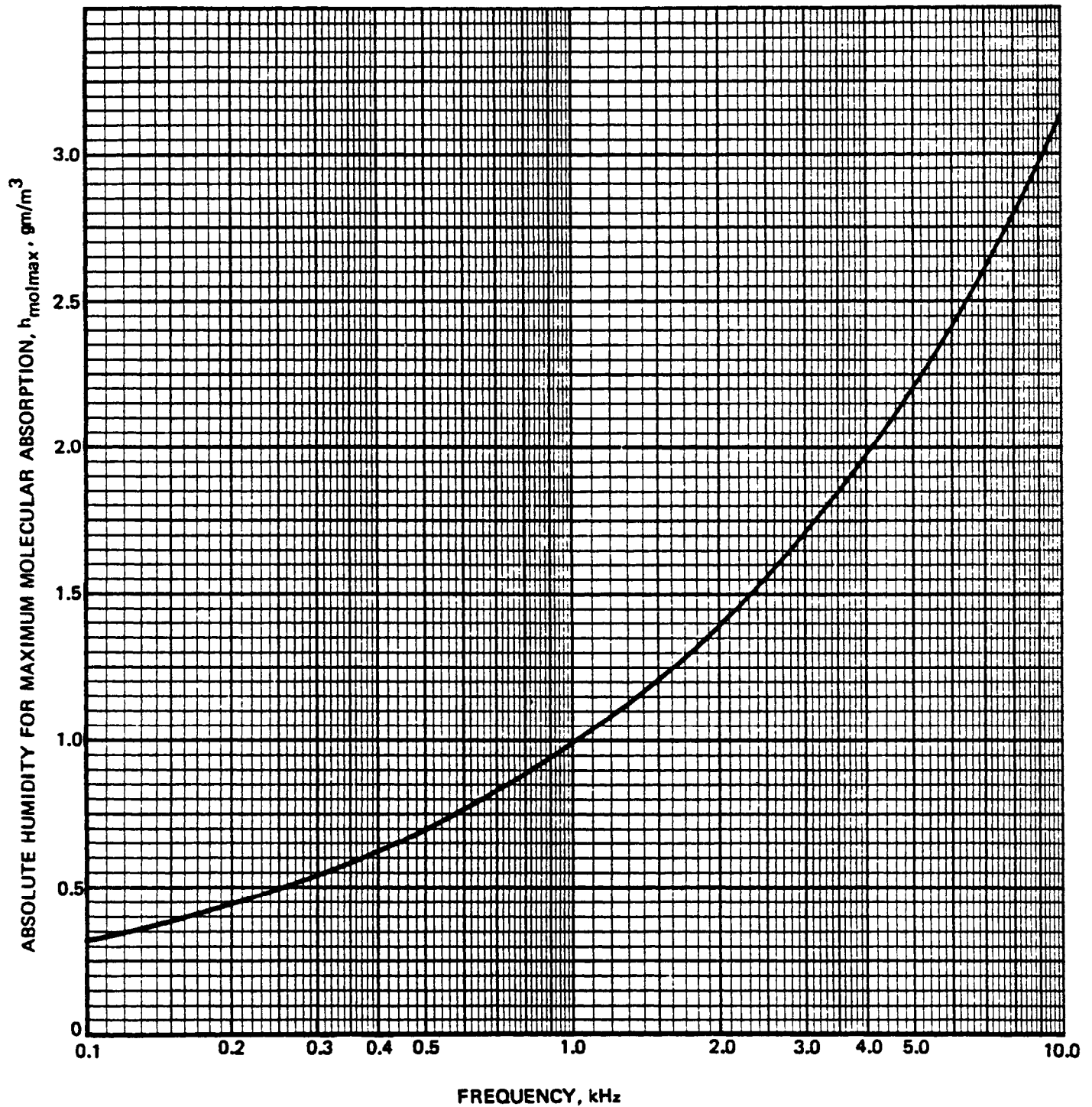


FIGURE 3. ABSOLUTE HUMIDITY FOR MAXIMUM MOLECULAR ABSORPTION AS A FUNCTION OF FREQUENCY

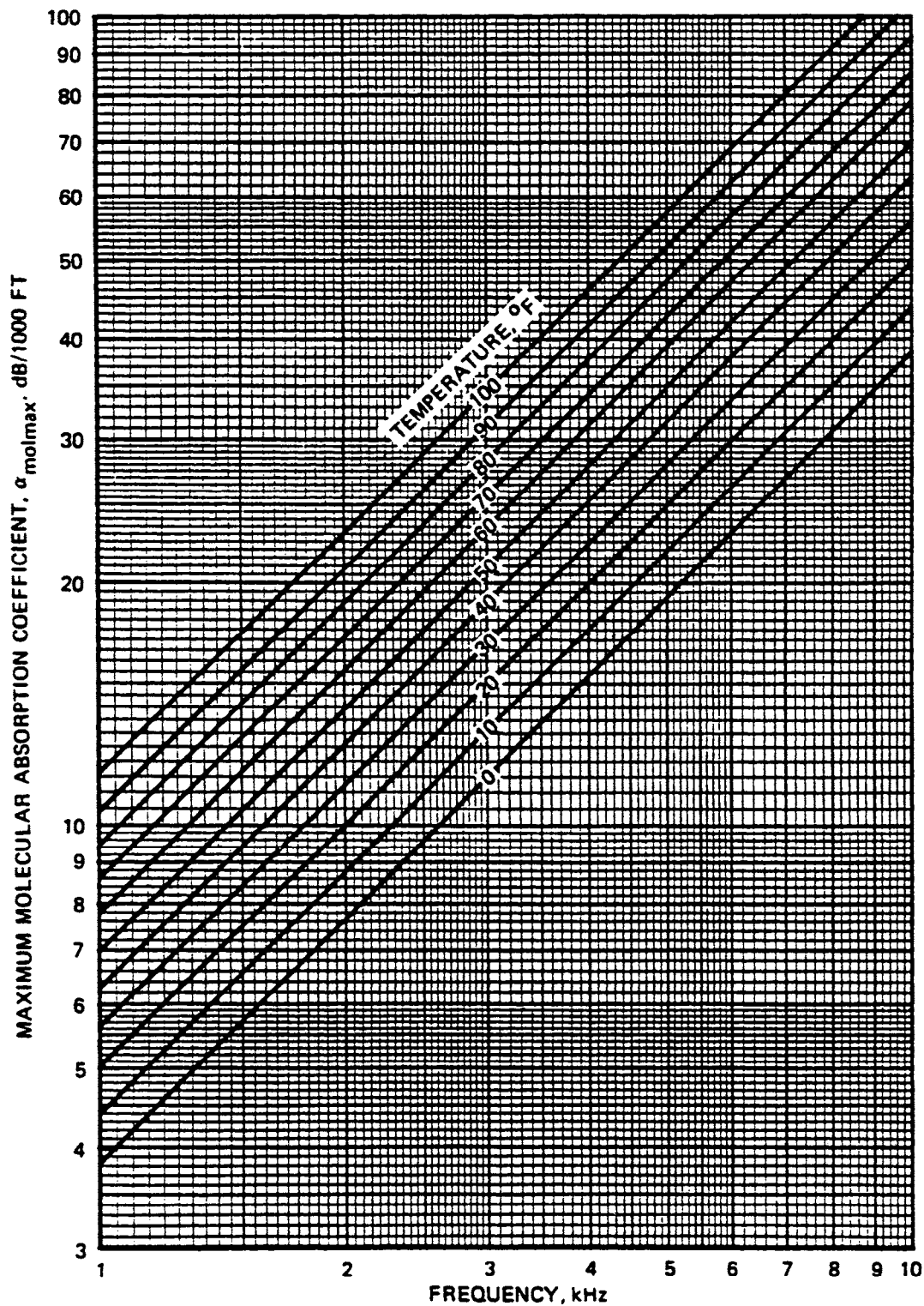


FIGURE 4. MAXIMUM MOLECULAR ABSORPTION COEFFICIENT AS A FUNCTION OF FREQUENCY FOR VARIOUS AIR TEMPERATURES. (KNESER'S VALUES FROM REFERENCE 1.)

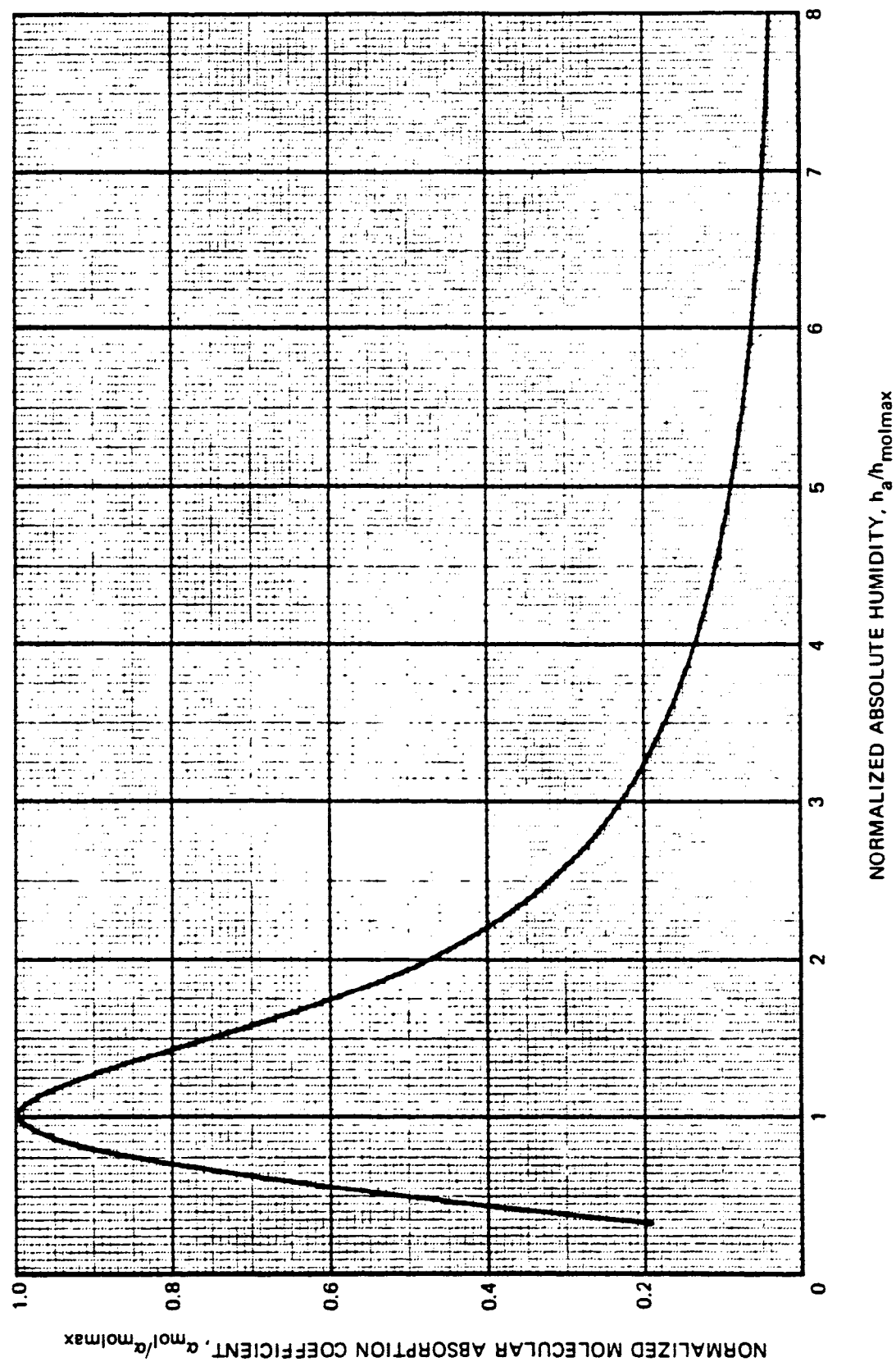


FIGURE 5. NORMALIZED MOLECULAR ABSORPTION COEFFICIENT AS A FUNCTION OF NORMALIZED ABSOLUTE HUMIDITY. (KNESER'S VALUES FROM REFERENCE 1.)

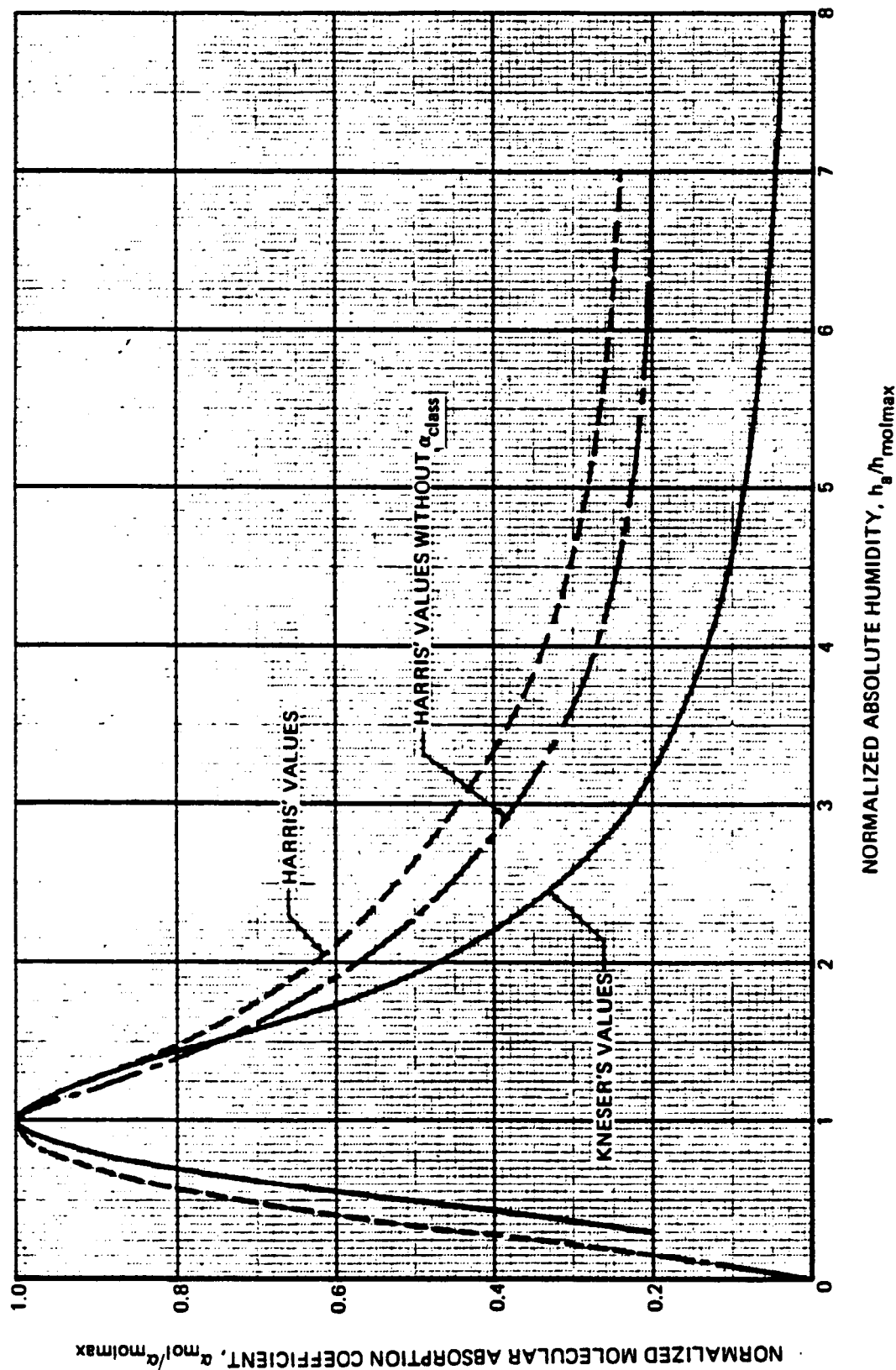


FIGURE 6. NORMALIZED MOLECULAR ABSORPTION COEFFICIENT AS A FUNCTION OF NORMALIZED ABSOLUTE HUMIDITY. (KNESER'S VALUES FROM REFERENCE 1; HARRIS' VALUES FROM REFERENCE 4.)

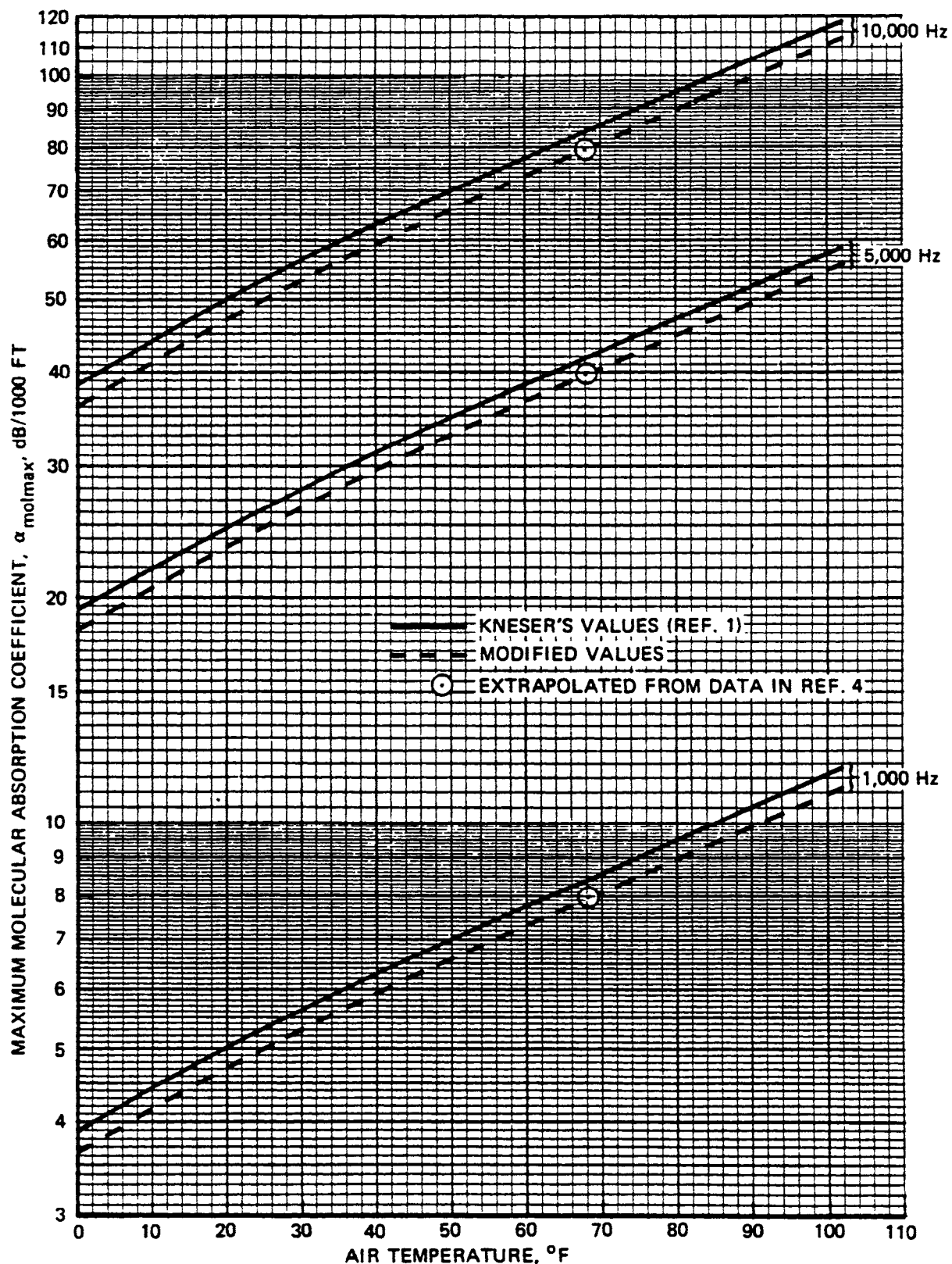


FIGURE 7. THEORETICAL AND MODIFIED MAXIMUM MOLECULAR ABSORPTION COEFFICIENTS AS A FUNCTION OF TEMPERATURE FOR THREE FREQUENCIES

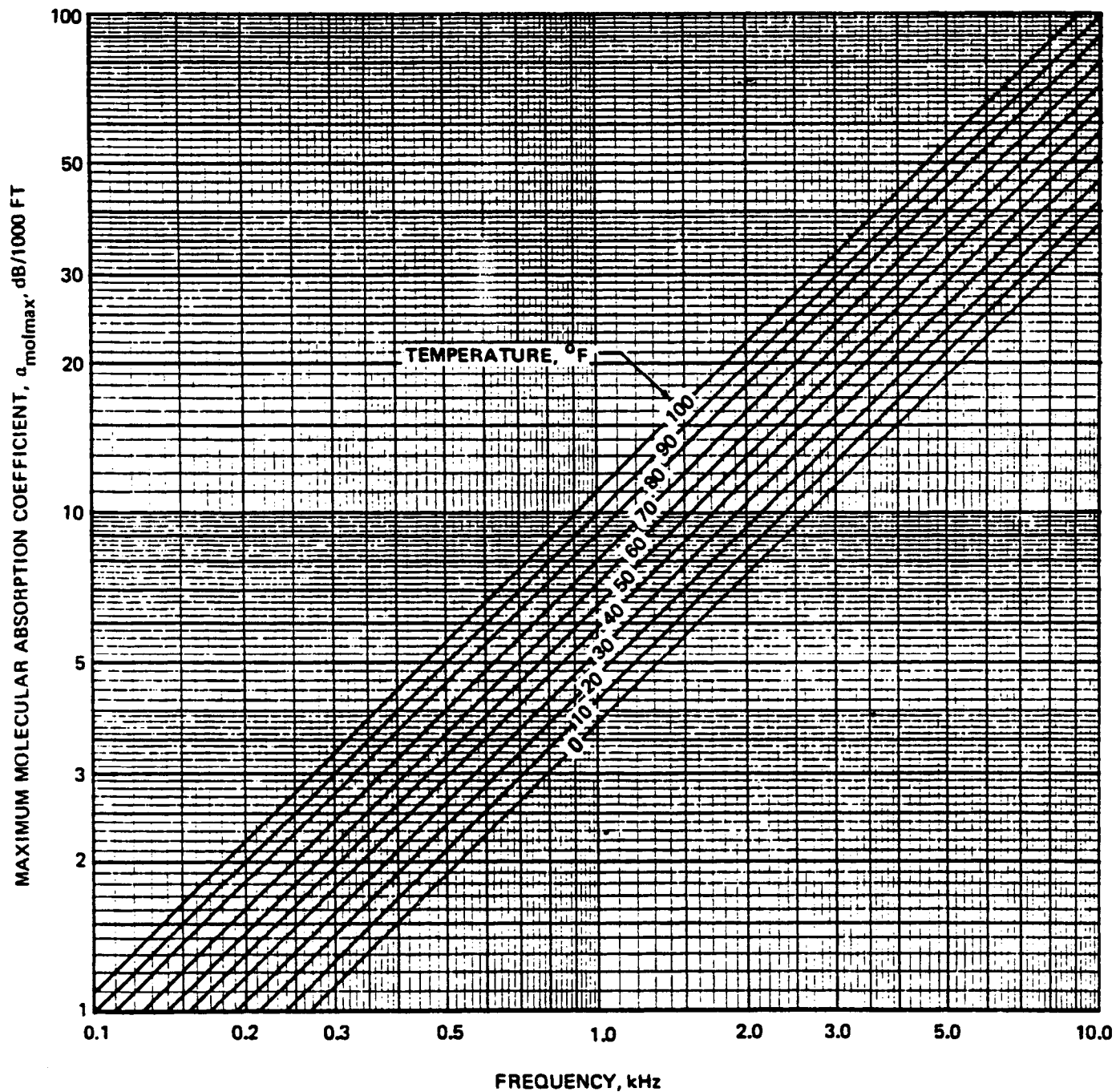


FIGURE 8. MAXIMUM MOLECULAR ABSORPTION COEFFICIENT AS A FUNCTION OF FREQUENCY FOR VARIOUS AIR TEMPERATURES

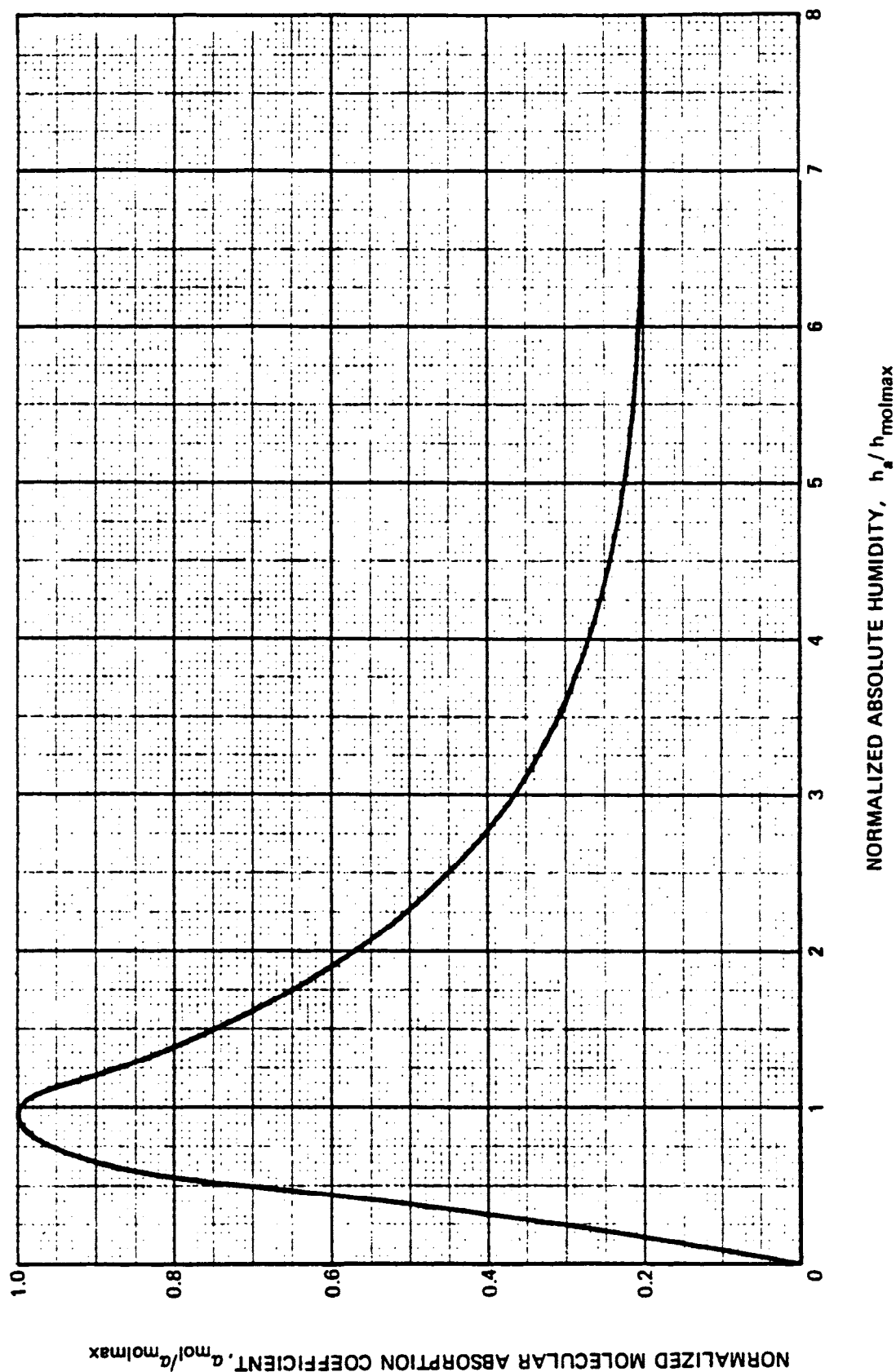


FIGURE 9. NORMALIZED MOLECULAR ABSORPTION COEFFICIENT AS A FUNCTION OF NORMALIZED ABSOLUTE HUMIDITY

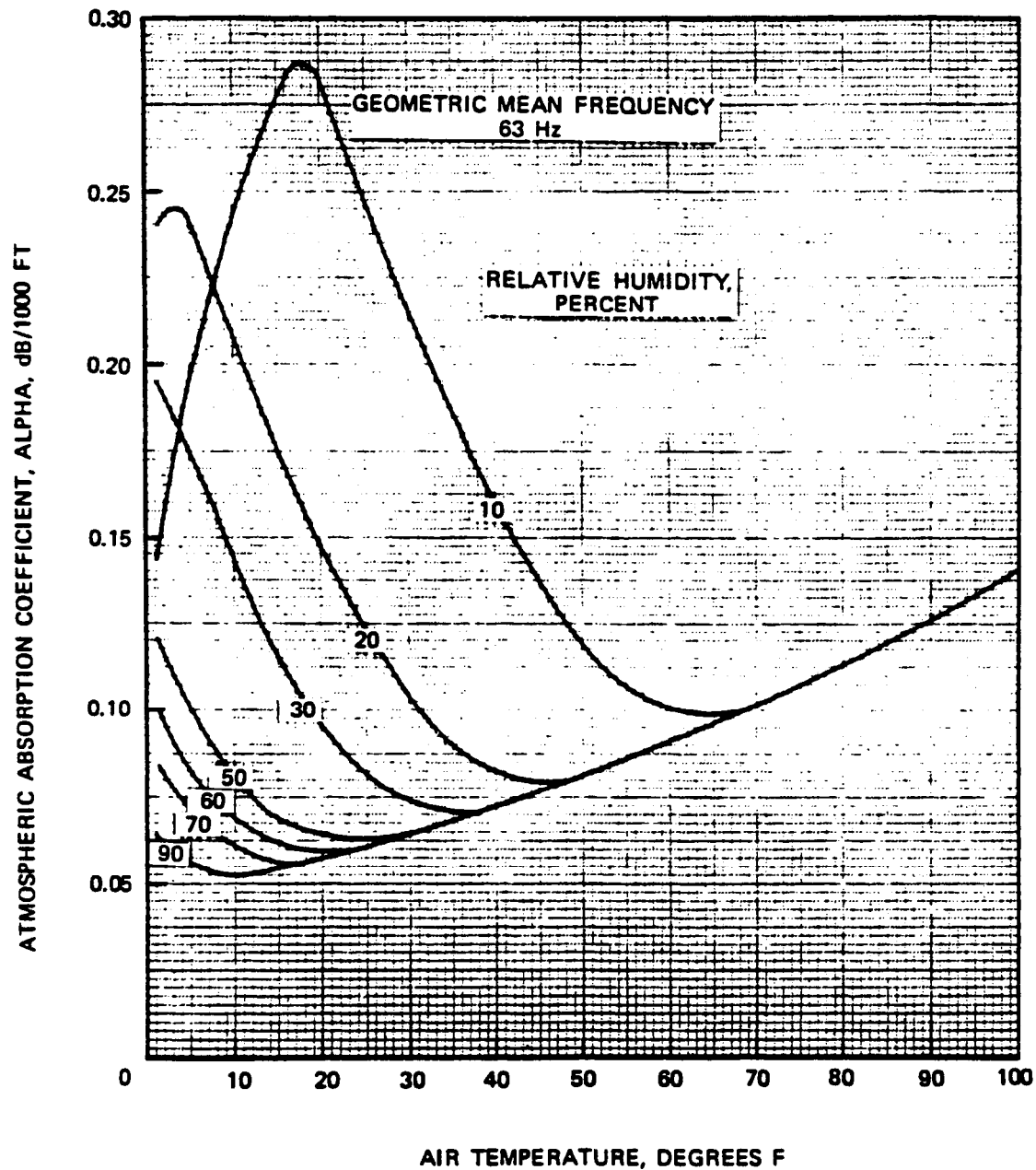


FIGURE 10. ATMOSPHERIC ABSORPTION COEFFICIENTS FOR 1/1-OCTAVE BANDS OF NOISE FOR DIFFERENT TEMPERATURES AND HUMIDITIES

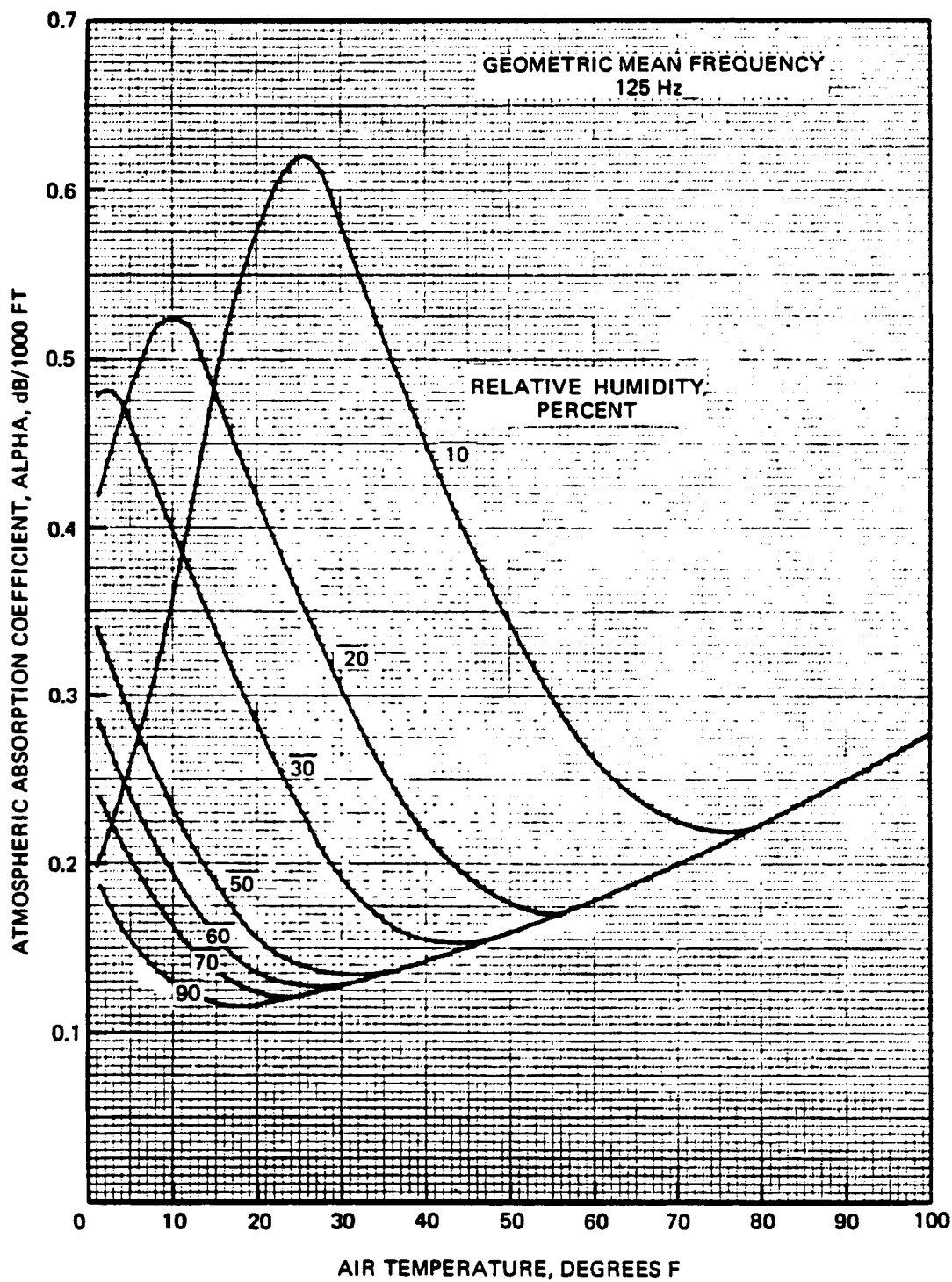


FIGURE 10. CONTINUED

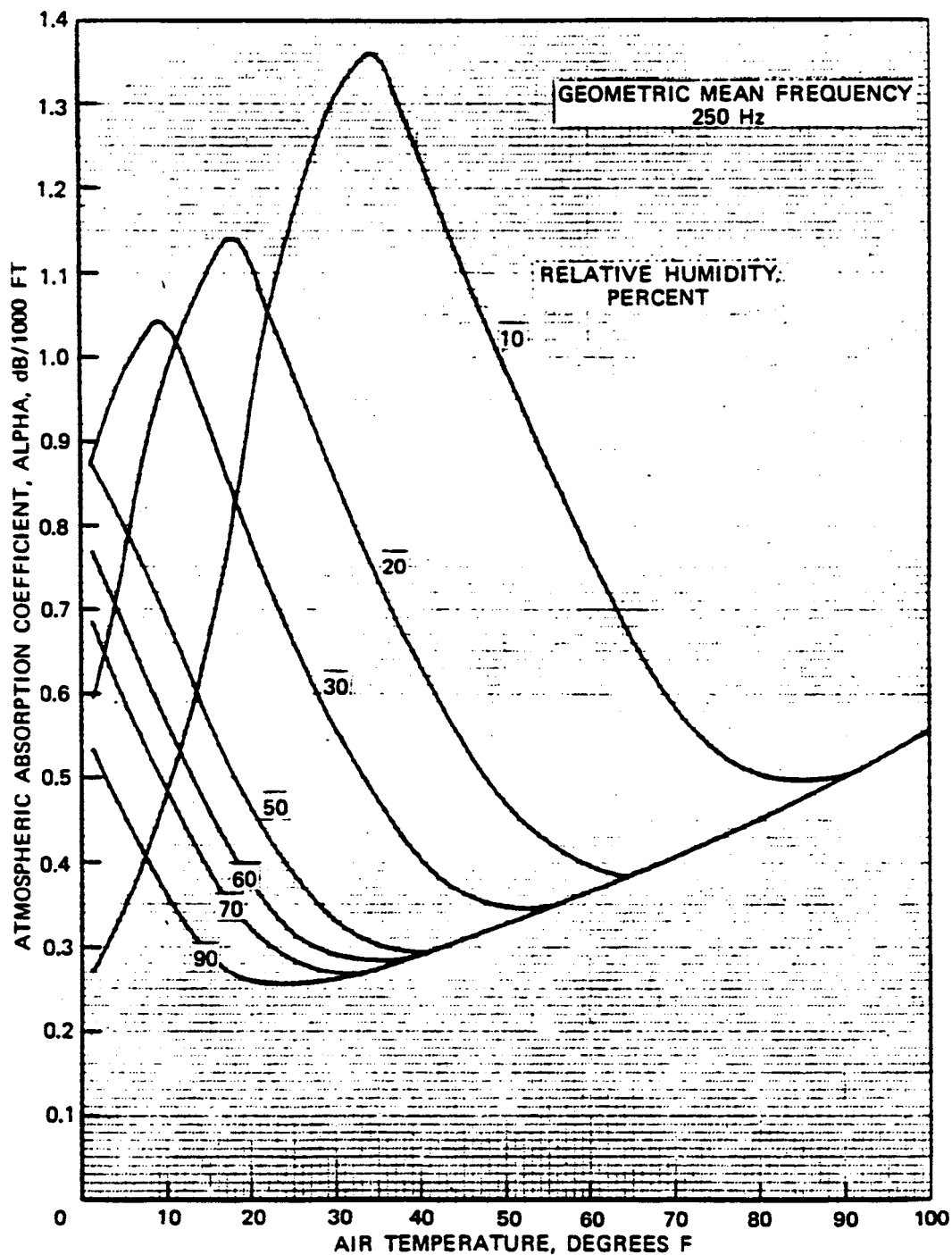


FIGURE 10. CONTINUED

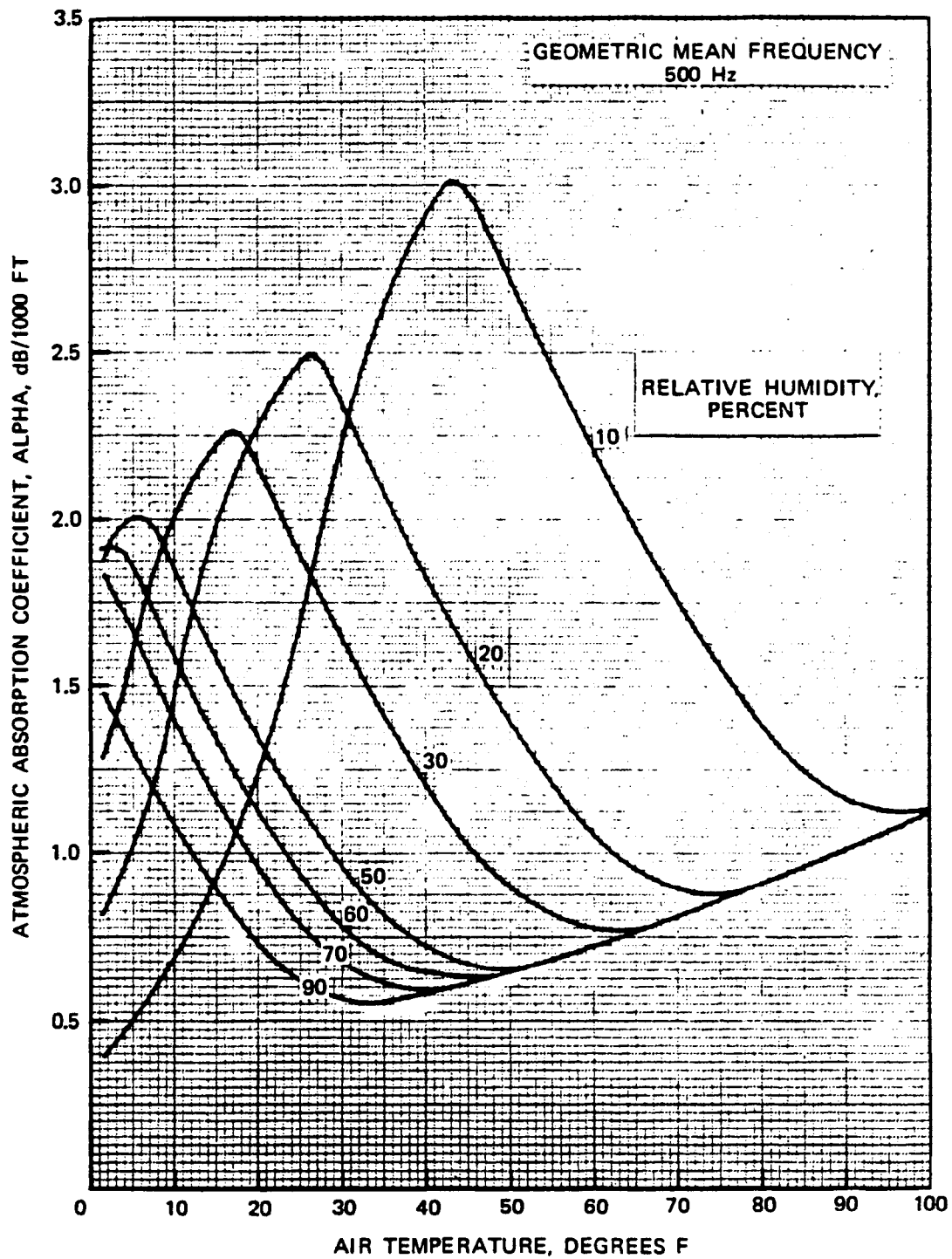


FIGURE 10. CONTINUED