Syrdal, A. K., and Gopal, (**1986**). "A perceptual model of vowel recognition based on the auditory representation of American English vowels," J. Acoust. Soc. Am. **79**, 1086–1100.
Traunmüller, H. (**1981**). "Perceptual dimension of openness in vowels," J. Acoust. Soc. Am. **69**, 1465–1475.
Traunmüller, H. (**1988**). "Paralinguistic variation and invariance in the characteristic frequencies of vowels," Phonetica **45**, 1–29.
Traunmüller, H., Branderud, B., and Bigestans, A. (**1989**). "Paralinguistic speech signal transformations," PERILUS X, Inst. Linguist., Univ. Stockholm, 47–64,
Traunmüller, H., and Lacerda, F. (**1987**). "Perceptual relativity in two-formant vowels," Speech Commun. **5**, 143–157.

Atmospheric absorption of sound: Update

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Best current expressions for the vibrational relaxation times of oxygen and nitrogen in the atmosphere are used to compute total absorption. The resulting graphs of total absorption as a function of frequency for different humidities should be used in lieu of the graph published earlier by Evans *et al.* [J. Acoust. Soc. Am. **51**, 1565–1575 (1972)].

PACS numbers: 43.35.Ae, 43.35.Fj

In 1972, Evans *et al.* published a family of curves for absorption of sound in a still atmosphere.[1] Since that time, Fig. 8 of that paper for total amplitude absorption has appeared in a number of publications. Now that improved analytical expressions are available, we want to present these expressions as well as updated total amplitude absorption curves.

Reference 2 gives the absorption of sound in still air in nepers per meter as

$$\alpha = f^2\Bigg[1.84\times10^{-11}\left(\frac{p_s}{p_{so}}\right)^{-1}\left(\frac{T}{T_0}\right)^{1/2} + \left(\frac{T}{T_0}\right)^{-5/2} \times\{1.278\times10^{-2}[\exp(-2239.1/T)]/ [f_{r,\mathrm{O}} + (f^2/f_{r,\mathrm{O}})] + 1.068\times10^{-1} \times[\exp(-3352/T)]/[f_{r,\mathrm{N}} + (f^2/f_{r,\mathrm{N}})]\}\Bigg], \qquad (1)$$

where f is the acoustic frequency in Hz, p_s is the atmospheric pressure, p_{so} is the reference atmospheric pressure (1 atm), T is the atmospheric temperature in K, T_0 is the reference atmospheric temperature (293.15 K), $f_{r,\mathrm{O}}$ is the relaxation frequency of molecular oxygen and $f_{r,\mathrm{N}}$ is the relaxation frequency of molecular nitrogen.

Since publication of Ref. 2, additional experimental measurements[3] have given better estimates for $f_{r,\mathrm{O}}$ and $f_{r,\mathrm{N}}$. The best estimates are now

$$f_{r,\mathrm{N}} = \frac{p_s}{p_{so}}\left(\frac{T_0}{T}\right)^{1/2}\left(9 + 280h\exp\left\{-4.17\left[\left(\frac{T_0}{T}\right)^{1/3} - 1\right]\right\}\right) \qquad (2)$$

and

$$f_{r,\mathrm{O}} = (p_s/p_{so})[24 + 4.04\times10^4 h(0.02 + h) \times(0.391 + h)^{-1}], \qquad (3)$$

where h is the molar concentration of water vapor in percent. Equations for calculating h from the relative humidity h_r follow

$$h = h_r(p_{\mathrm{sat}}/p_{so})/(p_s/p_{so}) \text{ in } \%, \qquad (4)$$

where the saturated vapor pressure p_{sat} divided by the ambient pressure p_{so} is given by

$$\log_{10}\frac{p_{\mathrm{sat}}}{p_{so}} = 10.79584\left(1 - \frac{T_{01}}{T}\right) - 5.02808\log_{10} \times(T/T_{01}) + 1.50474\times10^{-4}\{1 - 10^{-8.29692} \times[(T/T_{01}) - 1]\} + 0.42873\times10^{-3}\{10^{-4.76955} \times[1 - (T/T_{01})] - 1\} - 2.2195983, \qquad (5)$$

and $T_{01} = 273.16$ K.

Figures 1 and 2 present updated absorption curves based upon Eqs. (1)–(3).

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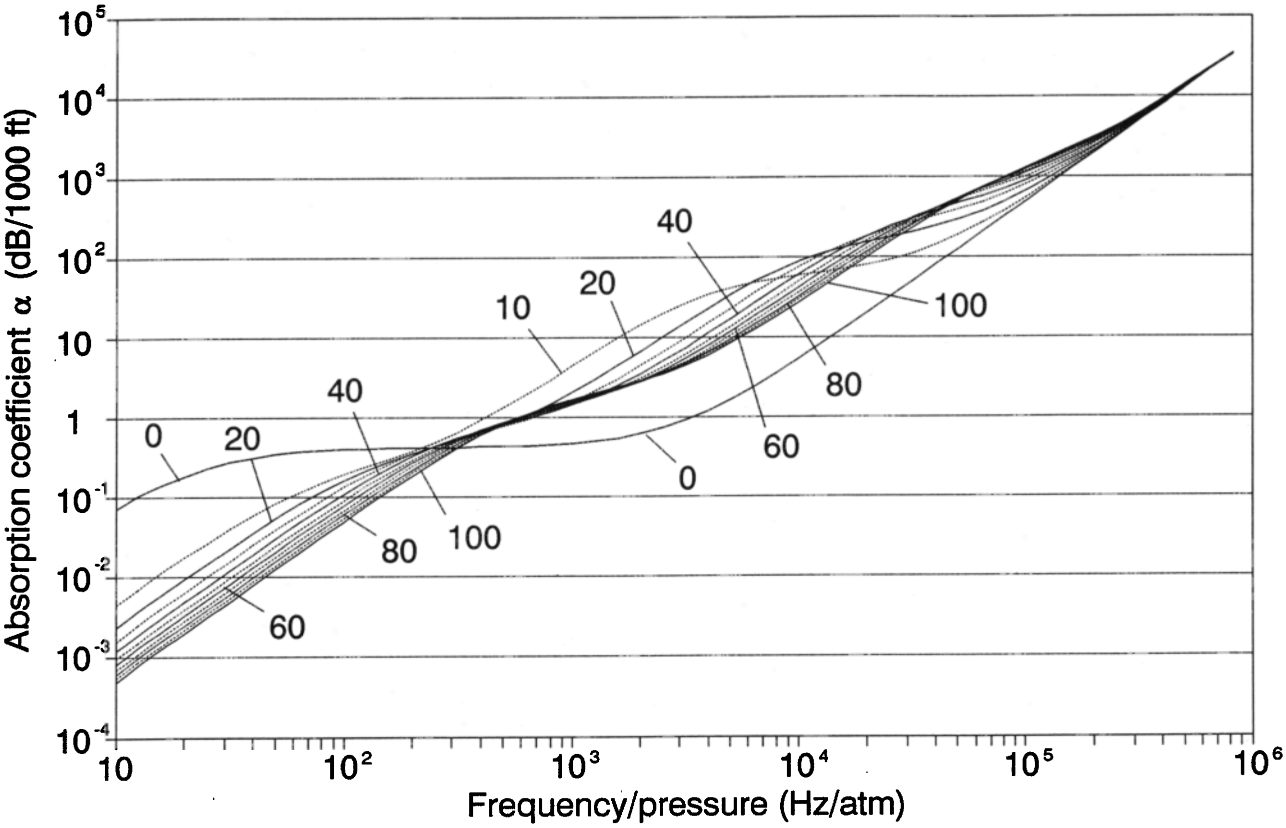

FIG. 1. Sound absorption coefficient in air (dB/1000 ft) versus frequency/pressure ratio for various percent relative humidities at 20 °C.

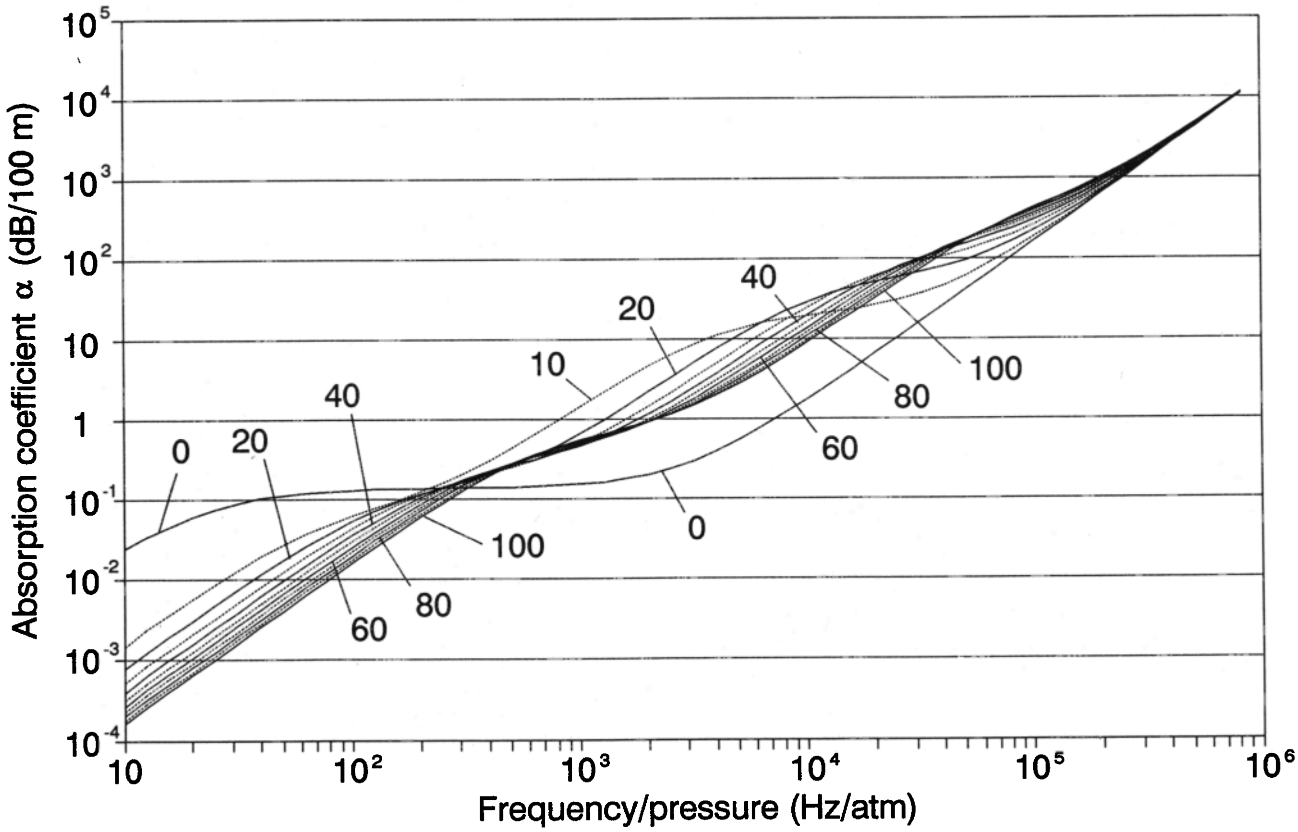

FIG. 2. Sound absorption coefficient in air (dB/100 m) versus frequency/pressure ratio for various percent relative humidities at 20 °C.

[1] L. B. Evans, H. E. Bass, and L. C. Sutherland, "Atmospheric Absorption of Sound: Theoretical Predictions," J. Acoust. Soc. Am. **51**, 1565–1575 (1972).
[2] ANSI S1.26-1978, "American National Standard Method for the Calculation of the Absorption of Sound by the Atmosphere" (American National Standards Institute, New York, 1978).
[3] A. J. Zuckerwar and R. W. Meredith, "Low-frequency absorption of sound in air," J. Acoust. Soc. Am. **78**, 946–955 (1985).

Reflection and scatter of acoustic waves from a thin, rough elastic plate on the surface of a fluid: Theory and experiment

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When the wavelength of an incident plane wave is greater than the plate thickness h and the scale a of the roughness ($kh < 1$, $ka < 1$), one may combine the generalized smoothed boundary condition technique with the classic Germain thin plate equation to obtain a simple and compact theory of scatter. The predictions of the theory are in substantial agreement with recently reported model experiments.

PACS numbers: 43.30.Hw, 43.30.Ma, 43.20.Fn

INTRODUCTION

A recent paper by McClanahan and Diachok,[1] based upon McClanahan's thesis work,[2] has described the effects of small-scale corrugations (half-cylinders) on the scatter of acoustic waves from a thin lucite plate on the surface of a fluid. These results were obtained by measuring the coherent reflection coefficient as a function of grazing angle with a matched pair of transducers. Measurements were made over many realizations of thin plates with parallel, randomly spaced half-cylinders, and thus represent an ensemble average of many reflections. The relevant parameters for the problem are defined in Fig. 1. The experimentally significant results are shown here in Figs. 2 and 3.

As shown elsewhere,[3] the problem may be modeled with the use of generalized Biot smoothed boundary conditions with Germain's thin plate equation, to write a set of boundary conditions describing the scatter at wave number k, for low frequencies:

$$D\frac{\partial^4 w}{\partial x^4} + \rho_p h \frac{\partial^2 w}{\partial t^2} = \lambda_1 \nabla^2 \Phi_1, \quad kh < 1, \quad z = 0 \tag{1}$$

$$\frac{\partial \Phi_1}{\partial z} - w = \eta \Phi_1, \quad z = 0, \tag{2}$$

wherein, it is assumed that

$$ka < 1, \tag{3}$$

and w is the vertical displacement, Φ_1 is the acoustic displacement potential, h is the plate thickness, ρ_p its density, D an elastic constant related to Young's modulus E, and Poisson's ratio ν: $D = Eh^3/12(1-\nu^2)$, λ_1 is the fluid bulk modulus. Here, η is, in general, complex

$$\eta = \eta_r + i\eta_i, \tag{4}$$

and can be calculated from first principles, with the following results.

(1) Corresponding to the coherent plane-wave solution, generalization of Biot's boundary condition[4–6] always yields the *real part* of η in the form,

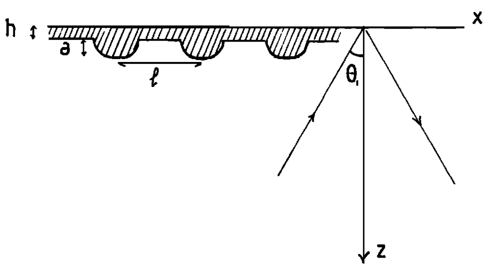

FIG. 1. Parameters of the scattering model.

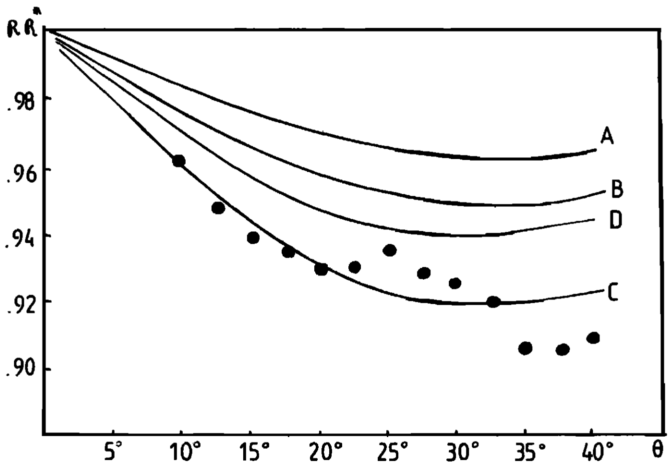

FIG. 2. Observed reflectivity of a lucite plate versus angle of incidence for a plane wave of frequency 100 kHz, for the four sets of plate constants shown in Table I. This suggests that the mass-loading factor given by Eq. (34) is necessary and that, furthermore, the ribbing (corrugations) acts as a plate stiffener although, in view of the uncertainties mentioned in the text, it is not possible to estimate this effect quantitatively.