A SIMPLE SOLUTION OF SOUND TRANSMISSION THROUGH AN ELASTIC WALL TO A RECTANGULAR ENCLOSURE, INCLUDING WALL DAMPING AND AIR VISCOSITY EFFECTS

Amir N. Nahavandi, Benedict C. Sun, and W. H. Warren Ball
New Jersey Institute of Technology

SUMMARY

This paper presents a simple solution to the problem of the acoustical coupling between a rectangular structure, its air content, and an external noise source. This solution is a mathematical expression for the normalized acoustic pressure inside the structure. The paper also gives numerical results for the sound-pressure response for a specified set of parameters.

INTRODUCTION

The formulation of the problem is based on the following assumptions:

1. The structure consists of a three-dimensional chamber, oriented with respect to a Cartesian coordinate system as shown in figure 1. The boundaries of the chamber are rigid except for an elastic wall, of homogeneous material, exposed to an external noise source and clamped at all edges.

2. The external noise source is assumed to be a pure-tone (i.e., single-frequency) signal of known amplitude and frequency.

3. The air inside the chamber is considered to behave as a compressible viscous fluid undergoing oscillations of small magnitude.

4. The elastic wall is considered to behave as a vibrating plate with linear damping.

The external, incident noise-pressure disturbance causes the elastic wall to vibrate in the transversal direction, inducing pressure fluctuations inside the chamber with a subsequent internal pressure loading on the elastic wall. The solution for the acoustic pressure inside the chamber, when damping and viscous effects are neglected, has been presented in reference 1; the effects of air viscosity and wall damping are included in the analysis given in this paper.

SYMBOLS

a,b,c	height, width, and length of the chamber
a_{ij}	coefficients in the expression for the elastic-wall deflection
C	speed of sound
D	elastic-wall bending stiffness; $D = Eh^3/12(1-\sigma^2)$
E	Young's modulus for the elastic wall
f	a function of $\bar{\alpha}$, $\bar{\beta}$, $\bar{\gamma}$, and $\bar{\delta}$, defined by equation (28)
h	thickness of the elastic wall
i	$i^2 = -1$
k_a	air viscosity damping coefficient
$K_1 \ldots K_6$	constants of integration
K_{mn}	coefficients in the expression for the acoustic pressure
p	sound-pressure level inside the chamber
p_c	sound-pressure level at $z = c$
$p_{c/2}$	sound-pressure level at $z = c/2$
p_o	external sound-pressure level acting on the elastic wall
P_o	amplitude of the time-harmonic, external sound-pressure level
R	weighting function used in the weighted-residual method
t	time
v_x, v_y, v_z	components of air velocity inside the chamber
W	deflection of the elastic wall in the positive z-direction
w	mode shape of the elastic wall
x,y,z	Cartesian coordinates
$\bar{\alpha}$	wall-to-air mass ratio
$\bar{\beta}$	wall-to-air stiffness ratio
$\bar{\gamma}$	wall-to-air interaction damping ratio
$\bar{\delta}$	dimensionless air viscosity damping
∇^4	$= \dfrac{\partial^4}{\partial x^4} + 2\dfrac{\partial^4}{\partial x^2 \partial y^2} + \dfrac{\partial^4}{\partial y^4}$
ζ_w	wall damping coefficient
η	chamber width-to-height ratio
λ, μ, ν	separation constants
ν_{mn}	separation constants in the expression for the acoustic pressure

ξ dimensionless parameter defined by equation (29-b)

ρ density

σ Poisson's ratio for the elastic wall

ω circular frequency of the external noise

Subscripts:

a refers to the air inside the chamber

max denotes "maximum value"

w refers to the elastic wall

Superscript:

– refers to dimensionless quantities

MATHEMATICAL FORMULATION

The governing dynamic equation for the elastic wall is:

$$\nabla^4 W + \frac{\zeta_w}{D}\frac{\partial W}{\partial t} + \rho_w \frac{h}{D}\frac{\partial^2 W}{\partial t^2} = \frac{1}{D}(p_c - p_o) \tag{1}$$

The acoustic wave equation for the air contained in the chamber is:

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} = \frac{1}{C_a^2}\left(\frac{\partial^2 p}{\partial t^2} + k_a \frac{\partial p}{\partial t}\right) \tag{2}$$

The boundary conditions for the problem are as follows:

a) The edges of the elastic wall are considered to be clamped:

$$W(0,y,t) = W(a,y,t) = W(x,0,t) = W(x,b,t) = 0 \tag{3}$$

$$\frac{\partial W}{\partial x}(0,y,t) = \frac{\partial W}{\partial x}(a,y,t) = \frac{\partial W}{\partial y}(x,0,t) = \frac{\partial W}{\partial y}(x,b,t) = 0 \tag{4}$$

b) The normal component of the internal air velocity near a rigid boundary is zero:

$$v_x(0,y,z,t)=v_x(a,y,z,t)=v_y(x,0,z,t)=v_y(x,b,z,t)=v_z(x,y,0,t)=0 \tag{5}$$

c) The normal component of the internal air velocity near the elastic wall is equal to the wall velocity:

$$v_z(x,y,c,t)=\frac{\partial W}{\partial t} \tag{6}$$

The relationship between the internal air pressure and components of internal air velocity are:

$$\frac{\partial v_x}{\partial_t} = -\frac{1}{\rho_a}\frac{\partial p}{\partial x} - k_a v_x \;, \quad \frac{\partial v_y}{\partial_t} = -\frac{1}{\rho_a}\frac{\partial p}{\partial y} - k_a v_y \;, \quad \frac{\partial v_z}{\partial_t} = -\frac{1}{\rho_a}\frac{\partial p}{\partial z} - k_a v_z \tag{7}$$

The external noise pressure is considered to be harmonic in time and expressed by:

$$p_o = P_o\ e^{i\omega t} \tag{8}$$

and the objective is to find:

$$W = W(x,y,t) \quad \text{and} \quad p = p(x,y,z,t) \tag{9}$$

The solution of equation (2), by separation-of-variables technique, is:

$$p(x,y,z,t) = e^{i\omega t}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} K_{mn}\ \mathrm{Cos}\frac{m\pi x}{a}\ \mathrm{Cos}\frac{n\pi y}{b}\ \mathrm{Cos}\ \nu_{mn} z \tag{10}$$

$$\text{where} \quad \nu_{mn}^{\ 2} = \frac{\omega^2 - i\omega k_a}{C_a^{\ 2}} - \left(\frac{m\pi}{a}\right)^2 - \left(\frac{n\pi}{b}\right)^2 \tag{11}$$

Application of equations (6) and (7) yields:

$$\frac{\partial W}{\partial t} = \frac{e^{i\omega t}}{\rho_a(k_a + i\omega)}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} K_{mn}\ \nu_{mn}\ \mathrm{Cos}\frac{m\pi x}{a}\ \mathrm{Cos}\frac{n\pi y}{b}\ \mathrm{Sin}\ \nu_{mn} c \tag{12}$$

The value of $\frac{\partial W}{\partial t}$ is found by integrating equation (1) under the loading conditions as indicated below:

$$\nabla^4 W + \frac{\zeta_w}{D}\frac{\partial W}{\partial t} + \rho_{wD}\frac{h}{}\frac{\partial^2 W}{\partial_t^{\ 2}} = \frac{e^{i\omega t}}{D}\left[\left(\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} K_{mn}\ \mathrm{Cos}\frac{m\pi x}{a}\ \mathrm{Cos}\frac{n\pi y}{b}\ \mathrm{Cos}\ \nu_{mn} c\right) - P_o\right] \tag{13}$$

For a solution of the form:

$$W(x,y,t) = w(x,y)e^{i\omega t} \tag{14}$$

equation (13) reduces to:

$$\nabla^4_w + \frac{i\omega\zeta_w}{D} w - \rho_w\omega^2\ \frac{h}{D}w = \frac{1}{D}\left[\left(\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} K_{mn}\ \mathrm{Cos}\frac{m\pi x}{a}\ \mathrm{Cos}\frac{n\pi y}{b}\ \mathrm{Cos}\ \nu_{mn} c\right) - P_o\right] \tag{15}$$

Galerkin's method is used to find an approximate solution to equation (15). In this method, an approximate solution which satisfies the boundary conditions of equations (3) and (4) is first assumed as follows:

$$w(x,y) = \sum_{i=1}^{M} \sum_{j=1}^{N} a_{ij} \left[1 - \text{Cos}\frac{(2i-1)2\pi x}{a}\right] \left[1 - \text{Cos}\frac{(2j-1)2\pi y}{b}\right] \tag{16}$$

Coefficients a_{ij} are found such that equation (16) satisfies equation (15) and the sum of the weighted residuals is identically zero over the region of integration, i.e.:

$$\int_0^a \int_0^b \left\{ \nabla^4 W + \frac{i\omega\zeta_w}{D} w - \rho_w \omega^2 \frac{h}{D} w - \frac{1}{D}\left[\left(\sum_{m=0}^{\infty} \sum_{n=0}^{\infty} K_{mn} \text{Cos}\frac{m\pi x}{a} \text{Cos}\frac{n\pi y}{b} \text{Cos}\, \nu_{mn} c\right) - P_o\right]\right\} R \, dxdy = 0 \tag{17}$$

This process is known as the weighted residual method and R is the weighting function. In Galerkin's method, the weighting function is made equal to the shape function defining the approximation. In general, this leads to the best approximation when

$$R = \left[1 - \text{Cos}\frac{(2i-1)2\pi x}{a}\right] \left[1 - \text{Cos}\frac{(2j-1)2\pi y}{b}\right] \tag{18}$$

Equation (17) applies for every pair of integers i and j. Generally there are $M \cdot N$ simultaneous equations of this form to be solved for the coefficients a_{ij}. For the case of low-frequency, normally-incident external noise only the diaphragm motion of the wall (first mode) will be excited. For this case, $M = 1$ and $N = 1$, and integration of equation (17) leads to:

$$a_{11} = \frac{\frac{K_{22}}{4} \text{Cos}\, \nu_{22} c - \frac{K_{20}}{2} \text{Cos}\, \nu_{20} c - \frac{K_{02}}{2} \text{Cos}\, \nu_{02} c + K_{00} \text{Cos}\, \nu_{00} c - P_o}{D\left\{\frac{3}{4}\left[\left(\frac{2\pi}{a}\right)^4 + \left(\frac{2\pi}{b}\right)^4\right] + \frac{1}{2}\left(\frac{2\pi}{a}\right)^2 \left(\frac{2\pi}{b}\right)^2 - \frac{9}{4}\frac{\omega}{D}\left(\rho_w h\omega - i\zeta_w\right)\right\}} \tag{19}$$

$$\text{and} \quad W(x,y,t) = a_{11} \left(1 - \text{Cos}\frac{2\pi x}{a}\right) \left(1 - \text{Cos}\frac{2\pi y}{b}\right) e^{i\omega t} \tag{20}$$

The values of K_{22}, K_{20}, K_{02}, and K_{00} are found by substituting the deflection from equation (20) into equation (12):

$$(-\omega^2 + ik_a\omega)\rho_a \, a_{11}\left(1 - \text{Cos}\frac{2\pi x}{a}\right)\left(1 - \text{Cos}\frac{2\pi y}{b}\right) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} K_{mn} \nu_{mn} \text{Cos}\frac{m\pi x}{a} \text{Cos}\frac{n\pi y}{b} \text{Sin}\, \nu_{mn} c \tag{21}$$

When the left and right sides of equation (21) are equated term by term, it is found that all the constants K_{mn} are zero except K_{00}, K_{02}, K_{20}, and K_{22}. These are easily found and substituted in equation (19) to give:

$$a_{11} = - P_o \Big/ D \left\{ \frac{3}{4}\left[\left(\frac{2\pi}{a}\right)^4 + \left(\frac{2\pi}{b}\right)^4\right] + \frac{1}{2}\left(\frac{2\pi}{a}\right)^2\left(\frac{2\pi}{b}\right)^2 - \frac{9}{4}\frac{\omega}{D}\left(\rho_w h\omega - i\zeta_w\right) + \frac{\rho_a(\omega^2 - ik_a\omega)}{D}\left(\frac{\text{Cot}\ \nu_{22}c}{4\nu_{22}} + \frac{\text{Cot}\ \nu_{20}c}{2\nu_{20}} + \frac{\text{Cot}\ \nu_{02}c}{2\nu_{02}} + \frac{\text{Cot}\ \nu_{00}c}{\nu_{00}}\right)\right\} \tag{22}$$

Referring to equation (10), the acoustic pressure inside the chamber can now be written as:

$$p(x,y,z,t) = e^{i\omega t}\left(K_{00}\ \text{Cos}\ \nu_{00}z + K_{02}\ \text{Cos}\frac{2\pi y}{b}\ \text{Cos}\ \nu_{02}z + K_{20}\ \text{Cos}\frac{2\pi x}{a}\ \text{Cos}\ \nu_{20}z + K_{22}\ \text{Cos}\frac{2\pi x}{a}\ \text{Cos}\frac{2\pi y}{b}\ \text{Cos}\ \nu_{22}z\right) \tag{23}$$

To generalize the solution obtained above, the following dimensionless quantities are introduced:

$$\bar{x} = \frac{x}{c},\quad \bar{y} = \frac{y}{c},\quad \bar{z} = \frac{z}{c},\quad \bar{a} = \frac{a}{c},\quad \bar{b} = \frac{b}{c},\quad \bar{c} = 1,\quad \bar{h} = \frac{h}{c} \tag{24}$$

$$\bar{t} = \frac{tC_a}{c},\quad \bar{\omega} = \frac{\omega c}{C_a},\quad \bar{C} = \frac{C_w}{C_a},\quad \bar{p} = \frac{p}{P_o},\quad \bar{D} = \frac{D}{P_o c^3} \tag{25}$$

$$\bar{a}_{11} = \frac{a_{11}}{c},\quad \bar{\rho}_w = \frac{\rho_w C_a^2}{P_o}\quad \bar{\rho}_a = \frac{\rho_a C_a^2}{P_o},\quad \bar{\rho} = \frac{\bar{\rho}_w}{\bar{\rho}_a},\quad \bar{\delta} = \frac{k_a c}{C_a} \tag{26}$$

Using the above dimensionless quantities, equation (23) can be written as:

$$\bar{p}(\bar{x},\bar{y},\bar{z},\bar{t}) = e^{i\bar{\omega}\bar{t}}\ f(\bar{\alpha},\bar{\beta},\bar{\gamma},\bar{\delta})\left[\frac{\text{Cos}\ \bar{z}\sqrt{\bar{\omega}^2 - i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2 - i\bar{\delta}\bar{\omega}}\ \text{Sin}\sqrt{\bar{\omega}^2 - i\bar{\delta}\bar{\omega}}}\right.$$

$$+ \frac{\text{Cos}\frac{2\pi\bar{y}}{\bar{b}}\ \text{Cos}\ \bar{z}\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{b}}\right)^2 - i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{b}}\right)^2 - i\bar{\delta}\bar{\omega}}\ \text{Sin}\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{b}}\right)^2 - i\bar{\delta}\bar{\omega}}} + \frac{\text{Cos}\frac{2\pi\bar{x}}{\bar{a}}\ \text{Cos}\ \bar{z}\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{a}}\right)^2 - i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{a}}\right)^2 - i\bar{\delta}\bar{\omega}}\ \text{Sin}\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{a}}\right)^2 - i\bar{\delta}\bar{\omega}}}$$

$$\left. - \frac{\text{Cos}\frac{2\pi\bar{x}}{\bar{a}}\ \text{Cos}\frac{2\pi\bar{y}}{\bar{b}}\ \text{Cos}\ \bar{z}\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{a}}\right)^2 - \left(\frac{2\pi}{\bar{b}}\right)^2 - i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{a}}\right)^2 - \left(\frac{2\pi}{\bar{b}}\right)^2 - i\bar{\delta}\bar{\omega}}\ \text{Sin}\sqrt{\bar{\omega}^2 - \left(\frac{2\pi}{\bar{a}}\right)^2 - \left(\frac{2\pi}{\bar{b}}\right)^2 - i\bar{\delta}\bar{\omega}}}\right] \tag{27}$$

$$\text{where}\quad f(\bar{\alpha},\bar{\beta},\bar{\gamma},\bar{\delta}) = -1\Bigg/\left\{\frac{\bar{\beta}\xi}{\bar{\omega}^2-i\bar{\delta}\bar{\omega}} - \frac{9\bar{\alpha}\bar{\omega}^2}{4(\bar{\omega}^2-i\bar{\delta}\bar{\omega})} + i\,\frac{9\bar{\gamma}\bar{\omega}}{4(\bar{\omega}^2-i\bar{\delta}\bar{\omega})} + \right.$$

$$\frac{\text{Cot}\sqrt{\bar{\omega}^2-\left(\frac{2\pi}{\bar{a}}\right)^2-i\bar{\delta}\bar{\omega}}}{2\sqrt{\bar{\omega}^2-\left(\frac{2\pi}{\bar{a}}\right)^2-i\bar{\delta}\bar{\omega}}} + \frac{\text{Cot}\sqrt{\bar{\omega}^2-\left(\frac{2\pi}{\bar{b}}\right)^2-i\bar{\delta}\bar{\omega}}}{2\sqrt{\bar{\omega}^2-\left(\frac{2\pi}{\bar{b}}\right)^2-i\bar{\delta}\bar{\omega}}} + \tag{28}$$

$$\left.\frac{\text{Cot}\sqrt{\bar{\omega}^2-\left(\frac{2\pi}{\bar{a}}\right)^2-\left(\frac{2\pi}{\bar{b}}\right)^2-i\bar{\delta}\bar{\omega}}}{4\sqrt{\bar{\omega}^2-\left(\frac{2\pi}{\bar{a}}\right)^2-\left(\frac{2\pi}{\bar{b}}\right)^2-i\bar{\delta}\bar{\omega}}} + \frac{\text{Cot}\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}\right\}$$

and

$$\bar{\alpha} = \bar{\rho}\,\bar{h} = \frac{\rho_w h}{\rho_a c}\ ,\quad \bar{\beta} = \frac{(1+1.056\eta^5)\bar{\rho}\bar{C}^2\bar{h}^3}{0.0284\bar{b}^4}\ ,\ \bar{\gamma} = \frac{\zeta_w}{\rho_a C_a} \tag{29-a}$$

$$\bar{\delta} = \frac{k_a c}{C_a}\ ,\quad \eta = \frac{b}{a} = \frac{\bar{b}}{\bar{a}}\ ,\quad \xi = \frac{0.9221(3\eta^4+2\eta^2+3)}{(1-\sigma^2)\ (1+1.056\eta^5)} \tag{29-b}$$

Equations (27),(28), and (29) constitute the analytical solution to the acousto-structural problem. These equations show that the normalized pressure distribution within the chamber is a harmonic function of time and depends on the following dimensionless parameters:

1) wall-to-air mass ratio, $\bar{\alpha}$
2) wall-to-air stiffness ratio, $\bar{\beta}$
3) wall-to-air interaction damping ratio, $\bar{\gamma}$
4) dimensionless air viscous damping, $\bar{\delta}$
5) dimensionless frequency, $\bar{\omega}$
6) dimensionless space coordinates, $\bar{x},\bar{y},\bar{z}$
7) enclosure dimensions, $\bar{a},\bar{b},\bar{c}$

NUMERICAL RESULTS

To obtain quantitative values of sound-pressure level as a function of external noise frequency, a cubical chamber (a=b=c) is assumed, and the amplitude of the dimensionless sound pressure at the center of the chamber (x=y=z=c/2) is found:

$$\bar{p}_{c/2_{max}} = \frac{\text{Numerator}}{\text{Denominator}} \tag{30}$$

where, Numerator

$$= \frac{1}{2\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}\;\mathrm{Sin}\tfrac{1}{2}\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}} + \frac{1}{\sqrt{\bar{\omega}^2-4\pi^2-i\bar{\delta}\bar{\omega}}\;\mathrm{Sin}\tfrac{1}{2}\sqrt{\bar{\omega}^2-4\pi^2-i\bar{\delta}\bar{\omega}}}$$

$$+ \frac{1}{2\sqrt{\bar{\omega}^2-8\pi^2-i\bar{\delta}\bar{\omega}}\;\mathrm{Sin}\tfrac{1}{2}\sqrt{\bar{\omega}^2-8\pi^2-i\bar{\delta}\bar{\omega}}} \qquad (30\text{-a})$$

and Denominator

$$= \frac{3.94\bar{\beta}}{\bar{\omega}^2-i\bar{\delta}\bar{\omega}} - \frac{9\bar{\alpha}\bar{\omega}^2}{4(\bar{\omega}^2-i\bar{\delta}\bar{\omega})} + i\,\frac{9\bar{\gamma}\bar{\omega}}{4(\bar{\omega}^2-i\bar{\delta}\bar{\omega})} + \frac{\mathrm{Cot}\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}$$

$$+ \frac{\mathrm{Cot}\sqrt{\bar{\omega}^2-4\pi^2-i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2-4\pi^2-i\bar{\delta}\bar{\omega}}} + \frac{\mathrm{Cot}\sqrt{\bar{\omega}^2-8\pi^2-i\bar{\delta}\bar{\omega}}}{4\sqrt{\bar{\omega}^2-8\pi^2-i\bar{\delta}\bar{\omega}}} \qquad (30\text{-b})$$

The response of this "advanced" three-dimensional model, as given by equation (30), is compared with that of a "simplified" one-dimensional model obtained by replacing the elastic wall by a simple spring-mass system. For this simplified model the amplitude of the sound pressure at the center of the cubical chamber is:

$$\left(\bar{P}_{c/2}\right)^{s}_{max} = \frac{\dfrac{1}{2\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}\;\mathrm{Sin}\,\tfrac{1}{2}\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}}{\dfrac{\bar{\beta}}{\bar{\omega}^2-i\bar{\delta}\bar{\omega}} - \dfrac{\bar{\alpha}\bar{\omega}^2}{\bar{\omega}^2-i\bar{\delta}\bar{\omega}} + i\,\dfrac{\bar{\gamma}\bar{\omega}}{\bar{\omega}^2-i\bar{\delta}\bar{\omega}} + \dfrac{\mathrm{Cot}\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}{\sqrt{\bar{\omega}^2-i\bar{\delta}\bar{\omega}}}} \qquad (31)$$

If the effects of wall damping and air viscosity are neglected, the results given by equations (30) and (31) agree with the solution in reference 1, in which damping effects were not considered. Figures 2 and 3 show the frequency response, for a particular set of dimensionless parameters $\bar{\alpha}$ and $\bar{\beta}$, over the audio-frequency range, for the special case of $\bar{\gamma} = 0$ and $\bar{\delta} = 0$, i.e., when damping effects are neglected. These figures show that at intermediate frequencies and at the high-frequency end of the audible spectrum, the predictions of "advanced" and "simplified" models are quite similar.

When damping effects are included, i.e., when both $\bar{\gamma}$ and $\bar{\delta}$ are not zero, the digital computer program for the frequency response is very complicated, involving complex numbers and requiring double-precision (16 digits) accuracy. Results for this case will be published later.

REFERENCE

1. Nahavandi, A. N.; Sun, B. C.; and Ball, W. H. W.: A Simple Solution of Sound Transmission Through an Elastic Wall to a Rectangular Enclosure. Internoise 76 Proceedings, 1976 International Conference on Noise Control Engineering, April 5-7, 1976, pp. 251-254.

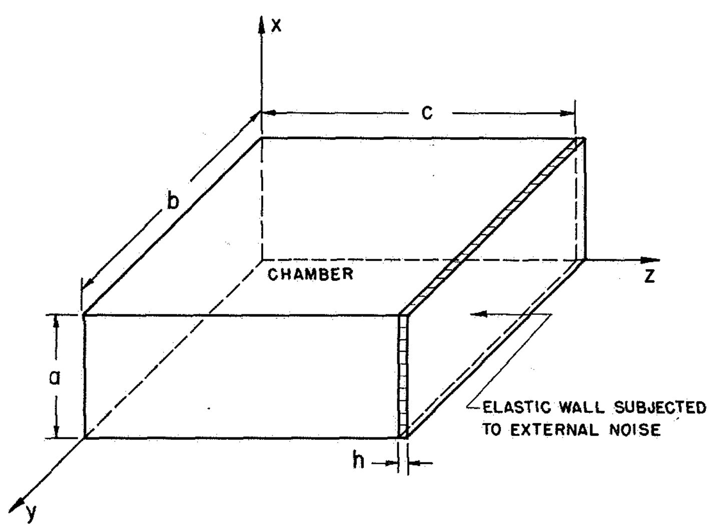

Figure 1.- Three dimensional model of sound transmission through an elastic wall to a rectangular chamber.

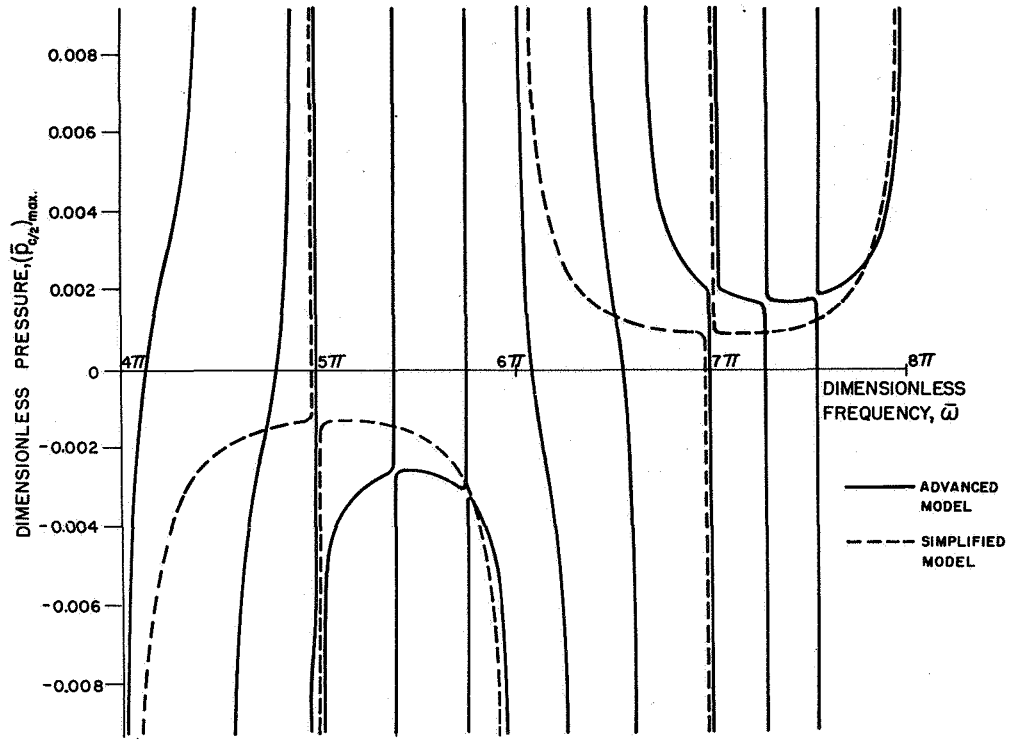

Figure 2.- Chamber frequency response to external noise source at low frequency for $\bar{\alpha}$ = 25 , $\bar{\beta}$ = 3.125, $\bar{\gamma}$ = 0, and $\bar{\delta}$ = 0.

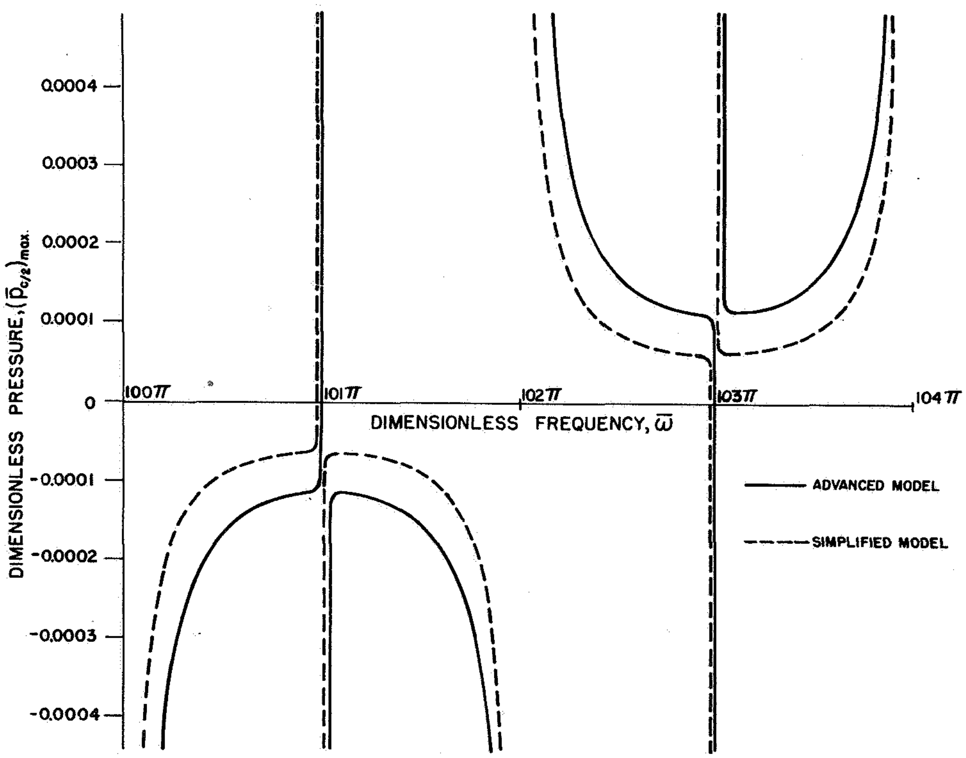

Figure 3.- Chamber frequency response to external noise source at high frequency for $\bar{\alpha}$ = 25 , $\bar{\beta}$ = 3.125, $\bar{\gamma}$ = 0, and $\bar{\delta}$ = 0.