Prediction of Breakout Noise from a Rectangular Duct with Compliant Walls

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Breakout noise from HVAC ducts is important at low frequencies, and the coupling between the acoustic waves and the structural waves plays a critical role in the prediction of the transverse transmission loss. This paper describes the analytical calculation of breakout noise by incorporating three-dimensional effects along with the acoustical and structural wave coupling phenomena. The first step in the breakout noise prediction is to calculate the inside duct pressure field and the normal duct wall vibration by using the solution of the governing differential equations in terms of Green's function. The resultant equations are rearranged in terms of impedance and mobility, which results in a compact matrix formulation. The Green's function selected for the current problem is the cavity Green's function with modification of wave number in the longitudinal direction in order to incorporate the terminal impedance. The second step is to calculate the radiated sound power from the compliant duct walls by means of an "equivalent unfolded plate" model. The transverse transmission loss from the duct walls is calculated using the ratio of the incident power due to surface source inside the duct to the acoustic power radiated from the compliant duct walls. Analytical results are validated with the FE-BE numerical models.

NOMENCLATURE

$[\mathbf{Y_s}]$	Uncoupled structural modal mobility matrix
Λ_n	Normalization factor
$\mathbf{a}$	Modal acoustic pressure vector
$\mathbf{b}$	Modal vibration amplitude vector
$\mathbf{g_a}$	Modal force vector acting on the acoustic system
$\mathbf{g}$	Generalized modal force vector due to the external force distribution
$\mathbf{q_S}$	Modal source vector due to vibration of the structure
$\mathbf{q}$	N-length modal source strength vector
ν	Poisson's ratio
ω	Exciting frequency
ω_n, ζ_n	Natural frequency and damping ratio of the nth acoustic mode, respectively
$\overline{\Psi}_n(\mathbf{x})$	Orthonormal function
$\phi_m(\mathbf{z})$	Uncoupled vibration mode shape function
$\Psi_n(\mathbf{x})$	Uncoupled acoustic mode shape function
ρ_0	Density of air
ρ_S	Density of the duct wall material or the structural subsystem
ζ	Transverse wall displacement
a_1, b_1	Dimensions of hypothetical piston
A_{m1m2}	Eigen expansion function
$a_n\omega$	Complex amplitude of the nth acoustic pressure mode
$B_m(\omega)$	Structural mode resonance term
$b_m(\omega)$	Complex amplitude of the m$^{\text{th}}$ structural vibration velocity mode of the compliant wall
c_0	Speed of sound in air
$C_{n,m}$	Coupling coefficient of the acoustic-structural mode shape
D	Flexural rigidity
E	Young's modulus
$f(\mathbf{z}, \omega)$	External force distribution on the surface of the plate
h	Thickness of the duct wall
$H(.)$	Heaviside function
$k = \omega/c_0$	Acoustic wave number
L	Perimeter of the duct wall
L_1, L_2, L_3	Dimensions of the acoustic subsystem in the x_1, x_2 and x_3 coordinate directions, respectively
m_1, m_2	Structural mode numbers with positive integers
n_1, n_2, n_3	Acoustic mode number integers
$p(\mathbf{z}, \omega)$	Acoustic pressure inside the acoustic system as function of location and frequency
$p(\vec{x})$	The sound pressure inside the acoustic subsystem as function of position vector
q_n	Generalized acoustic source strength