

A Parametric Investigation of Louvered Terminations for Rectangular Ducts

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ABSTRACT

The insertion loss of louvered terminations positioned at the end of a rectangular duct is determined using acoustic finite element analysis. Insertion loss was determined by taking the difference between the sound power with and without the louvers at the termination. Analyses were conducted in the plane wave regime and the acoustic source was anechoic eliminating any reflections from the source. The effect of different louver configurations on insertion loss was examined. Parameters investigated included louver length, angle, and spacing between louvers. Based on the analyses, equations were developed for the insertion loss of unlouvered ducts.

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INTRODUCTION

Louvers often cover the openings of enclosures or ends of ducts as a rain jacket or for safety reasons. They also have an acoustic function acting as a partial barrier while also introducing a reactive effect due to the area change through the louvered opening. Placing sound absorbing material on the louvers can further augment the attenuation.

The most suitable metric for gaging the acoustic performance of a louver is insertion loss [1]. Insertion loss depends on other factors besides the louver geometry. For example, it also is contingent on the nature of the source (plane wave, diffuse field). If louvers are installed at the ends of a duct, insertion loss will also be affected by whether the termination is baffled or unbaffled.

The transmission loss of panels is normally measured using the method detailed in ASTM E90 [2]. The panel is placed between a source and a receiving room. The source room is a reverberant room and the receiving room may either be a reverberant or anechoic room. However, reverberant room methods are inappropriate for low insertion loss devices like louvers due to coupling between the source and receiver rooms. Accordingly, Viveiros et al. [1] developed an alternative impulse method for determining the transmission loss of louvers. In follow up work, Viveiros and Gibbs [3] demonstrated that results from impulse response tests could be used to predict the insertion loss of louvers mounted between two rooms.

Watts et al. [4] measured and predicted the insertion loss of louvered road barriers using two-dimensional boundary element analysis (BEA). Insertion loss measurements were performed using a scale model approach with and without a strip of sound absorption plugging the gap between louvers. Boundary element results were compared to experimentation with good agreement.

Martinus et al. [5] used BEA to determine the transmission loss of a partial enclosure with a louvered opening. A loudspeaker was connected to the enclosures via an impedance tube and the incident sound power in the tube was determined using wave decomposition. The sound power escaping from the opening was measured and subtracted from the incident sound power. Martinus et al. [5] investigated changing the angle of the louvers and adding sound absorptive lining to one or both sides of the blades. The BEA transmission loss results compared well with measurement. Though the results had limited application because they were dependent on the size and shape of the enclosure, the research validated that numerical analysis could be used to assess the acoustics of a partial enclosure with louvered opening.

The aim of the current work is to determine the effect of louvers at the termination of a duct using acoustic finite element analysis. Plane wave propagation is assumed in the duct. This research will especially interest the heating, ventilating, and air conditioning (HVAC) industry. However, the same approach could be used to determine the acoustic effect of a louvered termination for the HVAC duct attached to the passenger compartment of an automobile or construction vehicle.

TERMINATION IMPEDANCE

There has been considerable research on terminations and the determination of termination impedance. Probably the most notable work is that of Levine and Schwinger [6] who developed an equation for the termination impedance of a circular unflanged duct below the plane wave cutoff. Pierce [7] did the same for a flanged circular duct later considering rectangular cross-sections [8]. Selamet et al. [9] determined the reflection coefficient of several duct termination configurations using BEA. Configurations included ducts extending past a baffle, ducts at an angle to a baffle, bellmouths, and stepped annular terminations.

In work for ASHRAE, Michaud and Cunefare [10] measured the end reflection loss (ERL) for different HVAC duct terminations. ERL was defined as

$$ERL = -10 \log(1 - |R|^2) \quad (1)$$

where R is the reflection coefficient. The sound pressure reflection coefficient can be expressed as

$$R = \frac{Z_r + \rho c}{Z_r - \rho c} \quad (2)$$

where Z_r is the termination or radiation impedance, ρ is the mass density of the fluid, and c is the speed of sound. Several rectangular duct sizes typical of HVAC applications were tested with a couple configurations including commercial diffusers placed at the duct end, which are a type of louvered termination.

The current paper details an acoustic finite element analysis approach to determine the insertion loss of louvered terminations. Insertion loss is defined as the difference in sound power without and with louvers installed. As such, the reported insertion loss would add directly to the ERL of a termination without louvers. Several louvered terminations were analyzed and empirical equations were developed.

METHODOLOGY

Acoustic finite element analysis (FEA) was performed using the LMS Virtual.Lab [11] software. Finite element models were created both without and with louvers and insertion loss was defined as the difference in sound power at the termination.

Special consideration was given to insure that the source was reflection free. If not, there will be resonances in the duct that depend on the duct length. In the model, the source was a sound pressure boundary condition of $p_s = 1$ Pa with a source impedance (z_s) equal to the characteristic impedance of the medium.

Accordingly,

$$z_s = \rho c \quad (3)$$

where ρ is the mass density of the fluid and c is the speed of sound.

Source impedance can be thought of as a special case of a series or transfer impedance. A transfer impedance is defined as shown in Fig. 1a according to the equation

$$z_{tr} = \frac{p_1 - p_2}{u} \quad (4)$$

where p_1 and p_2 are the sound pressures on either side of the impedance and u is the particle velocity of the source. Note that it is assumed that the source velocity is the same on both sides of the impedance. For the special case of a source impedance, Equation (4) can be rewrote as

$$z_s = \frac{p_s - p_L}{u_L} \quad (5)$$

where p_L and u_L are the load pressure and particle velocity respectively. This concept is illustrated using the electrical analogy shown in Fig. 1b.

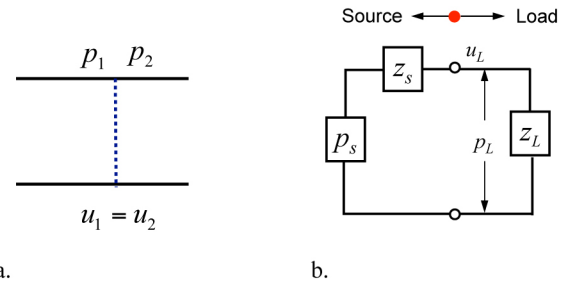


Figure 1. a) Schematic illustrating transfer impedance. b) Schematic showing electrical analogy for acoustic source impedance.

The way this is implemented in the FEA is illustrated in Fig. 2. A transfer relation is used to define the constraint equations between element face Sides 1 and 2. In LMS Virtual.Lab, a transfer relationship is defined using the convention

$$\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{bmatrix} \alpha_1 & \alpha_2 \\ \alpha_4 & \alpha_5 \end{bmatrix} \begin{Bmatrix} p_1 \\ p_2 \end{Bmatrix} + \begin{Bmatrix} \alpha_3 \\ \alpha_6 \end{Bmatrix} \quad (6)$$

where u_1 , u_2 , p_1 , and p_2 are defined in Fig. 1a. α_1 , α_2 , α_3 , α_4 , α_5 and α_6 are complex constants. For the particular case of a source impedance, $\alpha_3 = \alpha_6 = 0$, $\alpha_1 = \alpha_5 = \frac{1}{z_s}$, and $\alpha_2 = \alpha_4 = -\frac{1}{z_s}$.

Fig. 3 is a schematic showing the modeling approach and the boundary conditions. Note that the source side consists of two separate meshes (shown in Fig. 2), which are linked together using the aforementioned constraint equations. The leftmost mesh can be arbitrary in length. The source pressure boundary condition of $p_s = 1$ is specified on Side 1 as shown in Fig. 2. The particle velocity can be assumed to be zero on the left hand side of the mesh.

The baffled termination is modeled using a hemispherical mesh with an automatically matched layer (AML) to deal with the radiation boundary condition. The AML is a non-reflective boundary that will function properly even for high angles of incidence. The AML permits a conformal mesh to be used and is mathematically equivalent to a perfectly matched layer (PML). However, an AML automatically adjusts the thickness and resolution of the mesh at the boundary so that that the boundary is non-reflecting at both low and high frequencies. Reference 12 includes a thorough summary PML theory for acoustics and readers are encouraged to look there for more information.