Comparison of Computational Methods for Rectangular Silencer Insertion Loss Prediction

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1.0 INTRODUCTION

The insertion loss (IL) of duct silencers with absorbent material can be predicted by a number numerical techniques. Two of the most common methods are the Boundary element method (BEM) and the Modal Finite Element Method (FEM). These two procedures are applied to predict the IL of rectangular silences and the comparative results are presented in this paper.

2.0 THEORETICAL BACKGROUND

Example of a typical rectangular silencer is shown in Figure 1. Silencers with sound absorbing baffles are commonly used in HVAC system ducts. The main aim for HVAC system duct designers is to compute the silencer IL spectrum for a given silencer configuration.

The IL of a duct silencer is made of three components namely: entrance loss, exit loss and the loss due to the sound absorbing material. The BEM method can model all the three components whereas the FEM procedure presented here can take into account only the loss due to the absorbing material

2.1 Boundary Element Method

The boundary element method models only the boundary surface of the acoustic region of interest, unlike conventional FEM techniques which subdivide the domain into a mesh of three dimensional brick type elements. The BEM technique considers the problem of an enclosed acoustic domain as a potential field problem and uses Green's theorem to reduce the steady state, three dimensional Helmholtz equation (1) to a two dimensional surface integral [1].

$$\nabla^2 p + k^2 p = 0 \tag{1}$$

where p is the sound pressure,
$k = \omega/c$ is the wave number
and c = speed of sound in air.

The BEM model consists of two dimensional plate type elements forming an enclosing surface. The dimensions of each element must be less than approximately one quarter of the wavelength of interest. (See Figure 2. Note - only half of the silencer boundary is modelled, since the BEM algorithm can take advantage of the symmetry of the silencer in the width direction.)

At each surface element (including the plane of the outlet), the specific acoustic impedance, Z_S, is specified. Assigning each element a Z_S value implicitly makes the assumption that the absorptive surfaces are locally reacting. The Z_S values for the sound absorbing material are derived from characteristic impedance and propagation constant obtained from Bies and Hanson [2]. Over the inlet elements, a unit normal particle velocity condition is specified.

The BEM algorithm then numerically solves the reduced Helmholtz equation over the boundary surface at the frequency of interest using a Gauss quadrature integration technique.

2.2 Finite Element Method

The acoustical evaluation follows conventional methods [3,4,5]. The methodology requires a complete description of the sound absorbing material. The material is considered to be homogeneous, isotropic and made up of either fibrous or foam type material. It is also considered to be bulk reacting unlike the locally reacting model assumed by the BEM model. The propagation in the material is thus included with proper accounting of the bulk properties of the acoustic material.

The sound field in the duct is evaluated by the following set of wave equations:

$$\frac{\partial^2 p}{\partial z^2} + \frac{\partial^2 p}{\partial x^2} - \frac{1}{c_1^2}\frac{\partial^2 p}{\partial t^2} = 0 \tag{2}$$

$$\frac{\partial^2 p}{\partial z^2} + \frac{\partial^2 p}{\partial x^2} - \frac{1}{c_2^2}\frac{\partial^2 p}{\partial t^2} = 0 \tag{3}$$

Equation (1) is valid in the open airway with c_1 being the sound speed and equation (2) is valid in the sound absorbing material with a complex sound speed of c_2. Pressure and velocity continuity are applied at two interfaces between the absorbing material and the open airway. The two equations are solved for the common axial wave number k_z by applying a cubic finite element algorithm [6]. The characteristic impedance and propagation constant in the sound absorbing material are obtained from Bies and Hanson [2] and Beranek [7]. The real part of the axial wave number k_z is directly proportional to the attenuation rate per unit length of the silencer.

All possible modes up are evaluated at each frequency of interest. Only those modes with slow rates of attenuation are summed to determine the final decay rate per unit length by assuming that these modes carry equal amount of the incident sound energy.

The silencer shown in Figure 1 consists of two section: the straight portion and a tapered divergent diffuser section. The decay rate calculated in the straight section is multiplied by its length to predict the IL of the straight section. The modes are evaluated at two additional points, the mid-section and the tail end of the diffuser. The averaged decay rate (average of the three final decay rates) is multiplied by the length of the diffuser section to predict the diffuser IL. The silencer IL is the sum of the above two predictions.

3.0 RESULTS AND DISCUSSION

IL values for two typical silencers were modelled for four octave bands (ranging from 125 to 1000 Hz) using BEM and FEM. The results are presented in Table I. Also given in Table I, are IL values from ASTM standard test E477-90. The predictions agree reasonably well with test data. The silencers employed fibreglass fill with a flow resistivity of 20 000 mks rayl as the absorptive medium.

The agreement between BEM predictions and test data becomes poorer at frequencies approaching 1 kHz or greater. This may be explained by the fact that the assumption of locally reacting sound absorbing material tends to become inaccurate as frequency increases [5]. The high frequency accuracy can be improved by constructing a multi-domain BEM model which treats the absorptive material as a separate domain, taking into account the bulk reacting properties of the material. The multi-domain approach would, of course, increase computation time.

Difference between FEM predictions and test data can be attributed primarily to the fact that the FEM model does not account for entrance and exit effects at the inlet and outlet of the silencers. Correction factors can be added to the FEM prediction to improve agreement with tests.

The computation time for both techniques were comparable; one to two hours to obtain IL values in each of four octave bands for each silencer configuration. The algorithms were executed on a PC/386 type machine. The BEM computation becomes increasingly slower as the test frequency increases, since the mesh dimensions must always be less than approximately one quarter wavelength of the test frequency.

4.0 CONCLUSIONS

BEM and FEM models were applied to the problem of predicting rectangular silencer insertion loss. The results were found to be in reasonable agreement with test data.

The BEM method was found to be best suited to low frequency applications, (i.e., f ≤ 500 Hz) in which the absorptive material may be considered to be locally reacting and computation speed is greatest.

The FEM technique, while its accuracy and computation time are less sensitive to frequency, does not consider entrance and exit effects. The FEM approach is practical if proper corrections for entrance and exit effects are added to the predicted insertion loss.

5.0 REFERENCES

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Figure 1. Cut-away Showing Rectangular Silencer Construction

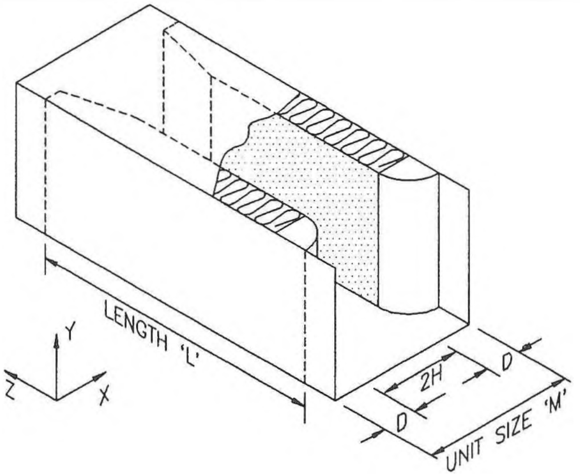

Figure 2. BEM Model S1 - 91 Elements

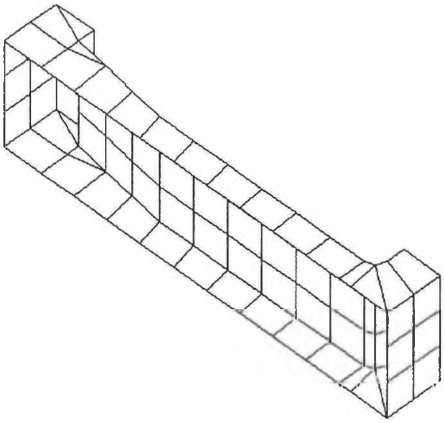

Table I

Model # M, mm	D/H	L mm	Insertion Loss, dB in Octave Bands				
				2	3	4	5
S1 458	1.13	1525	Test	5	12	20	26
			BEM	6	12	17	28
			FEM	6	14	21	29
S2 305	1	1525	Test	4	12	27	41
			BEM	3	9	22	33
			FEM	4	12	26	44