PERFORMANCE EVALUATION OF LINED DUCT BENDS –EXPERIMENT VS. THEORY

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1. INTRODUCTION

Acoustical performances of simple elbow (round and rectangular) silencers, used in building HVAC systems, have been conventionally evaluated using empirical relations based on laboratory and/or field measurements[1,2]. Preliminary results of a simulation model had been presented already[3]. Experiments were conducted using a standing-wave-tube set-up at Concordia University. The experimental results from the liner set-up are applied to calibrate and validate simulation results of COMSOL Multiphysics application software[4]. The results of the validation will be presented in this paper.

2. BACKGROUND

The schematic details of a lined elbow fitting are shown in Figure 1. The liners are symmetric in Figure 1. The liner details are: liner depth is 'd'; the open air-way width is 'h'; and the liners are used for a minimum of two-duct width on either side. Ξ is the flow resistivity of the liner per unit thickness and ρc is the characteristic impedance of air.

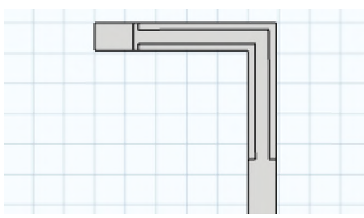

Figure 1. Details of a Lined Elbow.

The sound propagates along the centre axis from left to right. The baffle materials are bulk reacting and hence appropriate complex wave speed and material density (complex in this case) can be obtained from Bies and Hanson[5]. The mathematical modelling details were presented in Ramakrishnan and Watson[6].

3. EXPERIMENTAL SETUP

An existing standing wave tube, built in the 1980s, was modified to fit a vertical duct to simulate a lined elbow. The duct cross-section was 10" X 10". One inch duct foam liner (24" long) was used to line the end of the standing wave tube on all four sides. One four foot long 10" square tube was placed vertically over the end of the standing wave tube to simulate the lined-elbow configuration. The first 24" of the vertical pipe was also lined on all four sides with the one inch liner material.

The loud speaker at the far-end of the standing wave tube was used to generate, pink noise, white noise and band-filtered random noise. The sound pressure levels upstream and downstream of the liner section were measured to evaluate the noise reduction of the lined elbow.

4. COMSOL MODEL

The current investigation has made use of COMSOL, a powerful multiphysics numerical analysis tool and has attempted to provide results based on multi-dimensional analysis.

The elbow geometry can be easily modelled as 3-D. In this investigation, however, the elbow is modelled in a 2-D configuration as shown in Figure 1. The liner material is assumed to be isotropic and homogeneous fibrous material of given flow resistivity, 'Ξ'. The acoustic propagation in the liner material uses the complex propagation constant and complex density of bulk reacting material. A given acoustic field was assumed at the inlet of the elbow and the outlet is connected to a long anechoic termination. To accommodate high frequency calculation, COMSOL suggests using a length of pipe in front of the elbow within which scattered acoustic field is calculated to provide the required acoustic field at the inlet of the lined (or unlined) elbow. The application of COMSOL for simple rectangular ducts with baffles was validated in Ramakrishnan[7].

The elbow attenuation is given in Equation (1) below.

$$\boldsymbol{IL = \frac{W_{in}}{W_{out}}, dB} \quad (1)$$

where, W_{in} is the sound power at elbow inlet and W_{out} is the sound power at the elbow outlet. The acoustic propagation from COMSOL model and the experimental results are presented in the next section.

A simple schematics of the lined elbow modelled in COMSOL and the FEM Mesh are shown Figure 2.

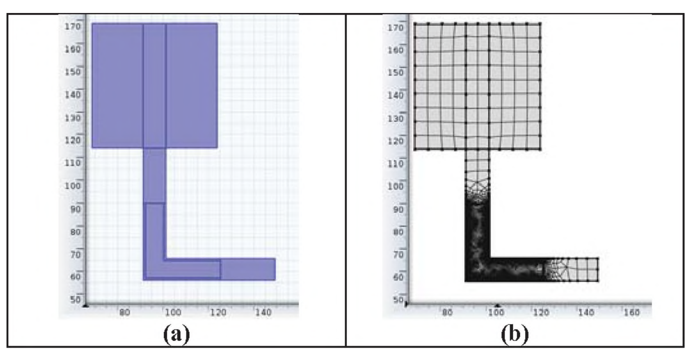

Figure 2. COMSOL Model- a) Geometry; and b) FEM Mesh

The small inlet extension is to allow high frequency solutions and the large volume at the outlet is to simulate anechoic termination.

5. RESULTS AND DISCUSSION

The simulation software allows various results to be generated. The SPL (sound pressure level) variation inside the elbow at 500 Hz is shown in Figure 3 and it can be seen that the termination conditions are functioning properly.

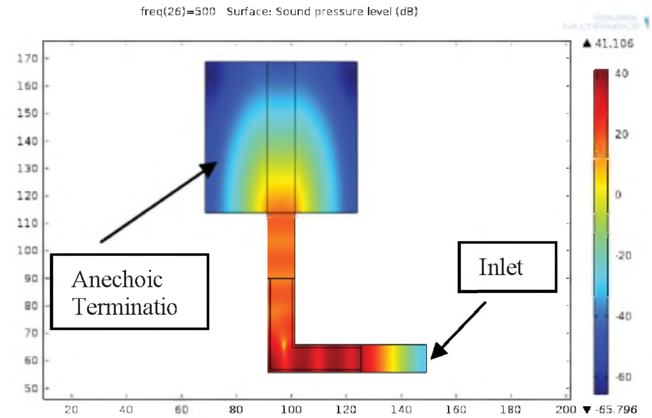

Figure 3. SPL Distribution.

The insertion loss of the lined elbow is calculated using Equation 1. The IL is calculated from 200 Hz till 5500 Hz in 5 Hz steps and the corresponding values in 1/3 octave bands are evaluated using conventional procedures.

The IL results are shown in Figure 4 below. The IL values from two simulations of the Ξ, the flow resistivity of the liner are presented in Figure 4. Figure 4 also shows the test results from the standing-wave-tube experimental setup.

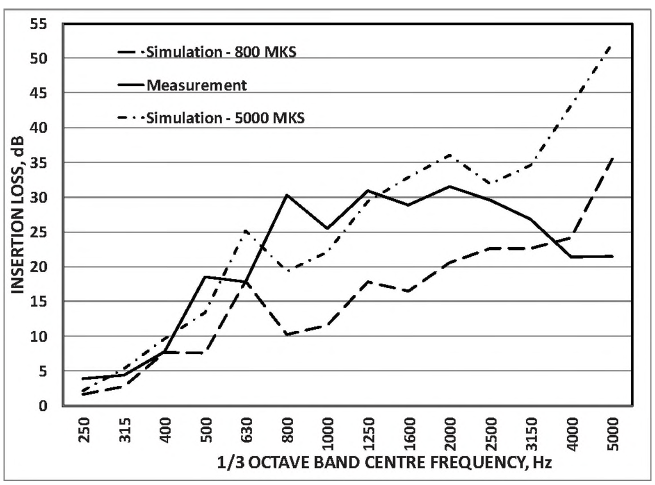

Figure 4. Attenuation of Lined Elbows.

It can be seen from the figure comparisons are reasonable in the low frequency, but differences are quite large in the high frequency range. The peak at 630 Hz band is mainly due to an anomaly in the model set-up. The 630 Hz is a duct mode of the large anechoic box and the larger the box, the anomaly will be diminished. The reasons for the large differences are highlighted below:

a) The noise floor of the test set-up both in low frequencies and in high frequencies was high. The ambient noise levels of the room were quite high. Further, the sound generator had limitations above 2500 Hz bands;

b) The true value of Ξ of the liner is unknown;

c) Only a 2-D model of the application software was applied. The duct sizes were quite small and 3-D model may provide better results; and finally,

d) The complex wave speed and density were obtained by using the elementary model of Delaney and Bazely [8]. It is seen that updated representations given by Bies and Hansen [5] for foams may provide more realistic results.

6. CONCLUSIONS

Attenuation results for duct elbow fittings were evaluated using two-D representation in commercial application software, COMSOL Multiphysiscs[3]. COMSOL model results were seen to be closer to the test data in low frequency, but diverge in the high frequency band. The simulation model needs further refining.

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