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PREDICTION AND MEASUREMENT OF THE TRANSMISSION LOSS OF A SLIT IN A WALL

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ABSTRACT
This paper reports a calculative and experimental study about the transmission of sound through narrow slits having a rectangular cross section. The calculation was based both on an analytical model, as reported by Chen [1], and a DBEM numerical model. Experiments were carried out by terminating one end of a steel duct with a slotted plate in a baffle. A loudspeaker, that produced the sound in the duct, closed the other end. Calculation results show a good agreement but only a fair agreement is found between the predicted and measured values for the tested slits.

1 - INTRODUCTION
The work reported herein is a contribution to the study of the sound transmission through narrow slit-shaped apertures in a wall. Various researchers have paid attention to this topic. To the knowledge of the authors the most recent study about the title subject was published by Chen [1]. Like the majority of previous models, Chen's model assumes a one-dimensional sound field that is constituted by the superposition of two undamped plane waves travelling along the axis of the slit. One wave propagates toward the exit and the other one toward the entrance. To solve for the amplitude of the sound pressure in the slit, the radiation impedance at the transition from the slit to the free space is needed. Previously, the theory of diffraction by an aperture had been used by Furue [2] to determine the radiation impedance. Due to inaccuracies of the results yielded by the diffraction theory at low frequencies, Chen used a spatial wave-number transform technique to obtain the sound pressure related to a uniform particle velocity at the open end of an aperture to the free space. Thereafter, the equality of the acoustic impedance at the outlet section to the radiation impedance of this section was used as a boundary condition at the exit of the slit. The continuity of the sound pressure − and particle velocity, as well − was assumed as the boundary condition at the entrance of the slit, that is the sound pressure of the incident field summed to the reflected and radiated pressures must equal the sound pressure just inside the slit. These boundary conditions allowed the calculation of the unknown sound pressure in the slit. By following this line of thought, Chen developed formulas for calculating the transmission loss of a slit in a wall, both for normal and random sound incidence. He performed also measurements of the 1/3 octave band transmission loss for three rectangular slits located in a wall of a reverberation room. The incident sound on the slit entrance was assumed to be a diffuse sound field. The considered slits had the same width (1.2 m), the same depth (0.3 m) but different heights. These were chosen as 7.8 mm, 15 mm and 66 mm. The observed frequency range spanned from 100 to 1250 Hz. According to Chen, the differences between measured and calculated data lay within 4 dB except at a few discrete frequencies.
This paper reports a comparison between the predicted and the measured values of the transmission loss for the case of normal incidence. Various slits in a wall are considered. Predictions were performed using both Chen's normal-incidence model and a Direct Boundary-Element Method (DBEM) for comparison. Measurements were carried out using a plane-wave duct terminated with the test slit.

2 - TESTED SLITS
As the study was planned for the case of a plane wave impinging on the entrance of the slit, the experimental part required the use of a suitable duct terminated by a slit in a wall.
Considerations related to the frequency range of the tests (100 − 1200 Hz) and the need of a small ratio of height to width of the slit cross-section, led to the geometrical choices reported in table 1.

	Depth (mm)	Height (mm)	Width (mm)
1	40	1	144
2	40	2	144
3	40	4	144
4	120	1	144
5	120	2	144
6	120	4	144

Table 1: Geometric data of the tested slits.

3 - EXPERIMENTAL APPARATUS AND MEASUREMENT PROCEDURE

A steel duct, 1.5 m long and 3 mm thick, was used to realize axial plane waves in the observed frequency range. It had a 150 mm × 100 mm rectangular cross section. Steel flanges were soldered flush with each end section of the duct. A loudspeaker in a wooden box was connected with one end-flange to excite the sound field inside the duct. Two aluminum blocks with narrow spacers were connected with the other end-flange to form the tested slits. In order to simulate the condition of a slit in a wall, a wooden baffle, 1.5 m × 1.8 m, was mounted flush with the end section of the slit radiating into the free space. Figure 1 shows a sketch of the measurement duct.

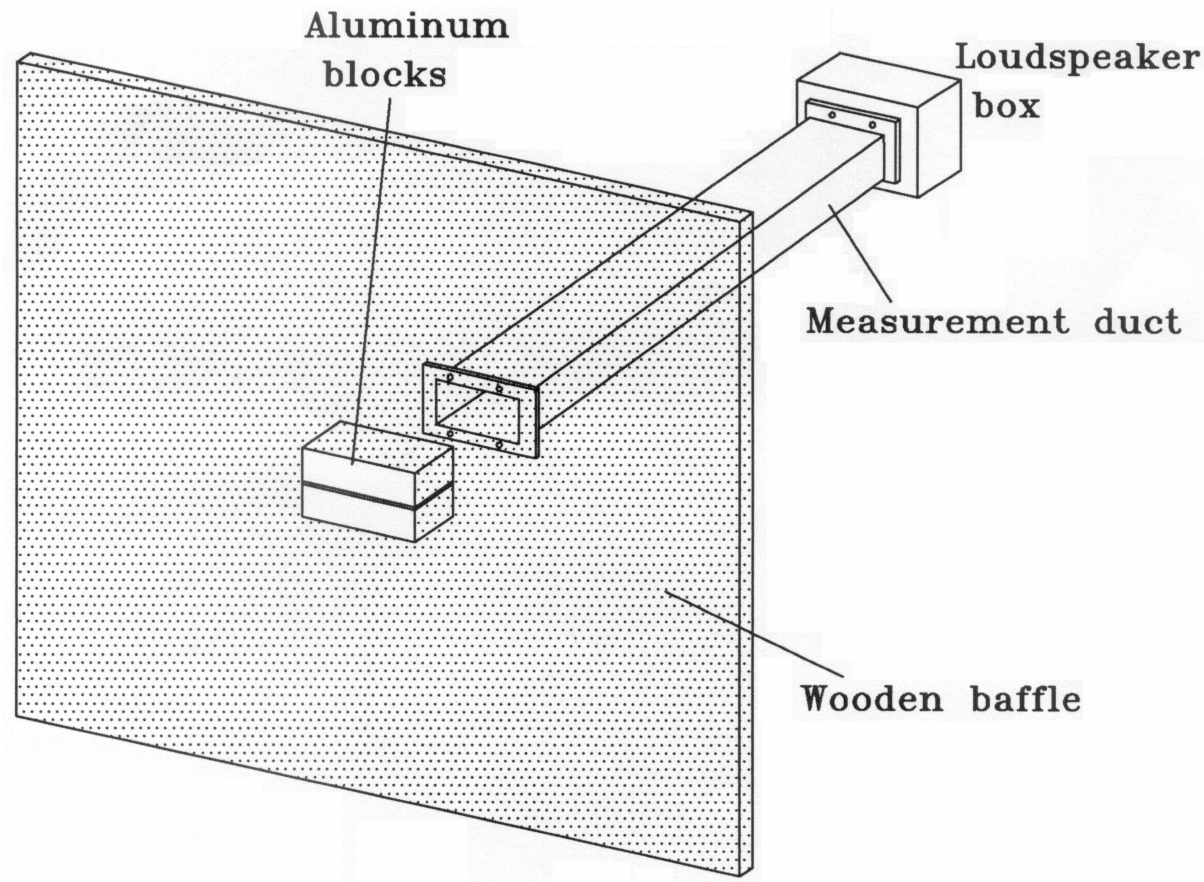

Figure 1: Sketch of the measurement duct with the aluminum blocks and the wooden baffle.

The transmission loss of a slit is defined as:

$$TL = 10\log\left(W_{in}/W_{rad}\right) \qquad \text{(dB)} \qquad (1)$$

W_{rad} is the sound power radiated by the exit section of the slit into the free space. It was measured by an intensity based technique. W_{in} is the sound power incident on the slit entrance. For an impinging plane wave:

$$W_{in} = p_{in-\mathrm{RMS}}^2 S/\rho c = p_{in}^2 S/2\rho c \qquad \text{(W)} \qquad (2)$$

where $p_{in-\mathrm{RMS}}$ (Pa) is the root-mean-square value of the sound pressure of the incident plane wave. S (m ^{2}) is the area of the entrance of the slit, and ρc (kg/m^{2}s) is the characteristic impedance of air. As assumed by Chen, the amplitude of the incident plane wave p_{in} can be taken as half the amplitude of the sound pressure on the rigid wall containing the entrance section of the slit.

Some holes were pierced into the walls of the duct near the entrance section of the slit to insert a B&K type 4135 1/4" microphone into the duct. This microphone was used for probing the sound pressure maximum near the duct quasi-rigid termination. During the sound pressure measurement at a certain location the other holes were sealed with suitable screws.

The loudspeaker was fed with a powered random noise (electrical white noise signal) generated by a B&K type 1027 generator. A Larson & Davis type 3100 dual channel FFT analyzer was used both for measuring the in-duct sound pressure level and the radiated sound intensity when connected with the intensity probe Larson & Davis type 2250. The microphones were calibrated carefully with a B&K type 4228 pistonophone.

For each mounted slit the radiated sound power was obtained by sampling the sound intensity normal to a surface having the shape of a parallelepiped (69 cm $\times$ 56 cm $\times$ 16 cm). A square-mesh wire web defined physically the five faces of the measurement surface. The sixth face of the parallelepiped being a portion of the baffle surface that contained the radiating end of the slit. The radiated sound power level was measured by two operators independently, both with the fixed point and the constant-speed sweep techniques. The FFT-based measurements of the sound power level vs. frequency yielded values within ± 1.5 dB in the tested frequency range 100-1200 Hz.

4 - HIGHLIGHTS OF THE NUMERICAL MODEL

The numerical part of the study was carried out using a version of the software Sysnoise 5.2 that was limited to a model size of 1000 nodes/elements [3]. The shortage of calculation resources prevented the use of a number of elements suitable to build an accurate discrete model of the whole physical system described before. Therefore, the solution was sought by reducing the problem to an in-duct one. Figure 2 shows one of the meshes representing the discrete version of the boundary of the air in the duct and in the slit. The elements of the face at the loudspeaker side were given a constant normal velocity. The other bounding elements were assigned zero normal velocity except those belonging to the exit section of the slit. These last elements were given an impedance condition corresponding to the real part and the imaginary part of the radiation impedance reported by Chen (Eqs. 14 and 15 in ref. [1]). The DBEM model yielded the sound pressure field in the duct and the connected slit. Half the amplitude of the sound pressure averaged over a cross section 20 mm from the slit entrance was inserted into Eq. 2 to calculate the incident sound power. The sound pressure and the normal component of the particle velocity at the exit section were used to calculate the radiated sound power.

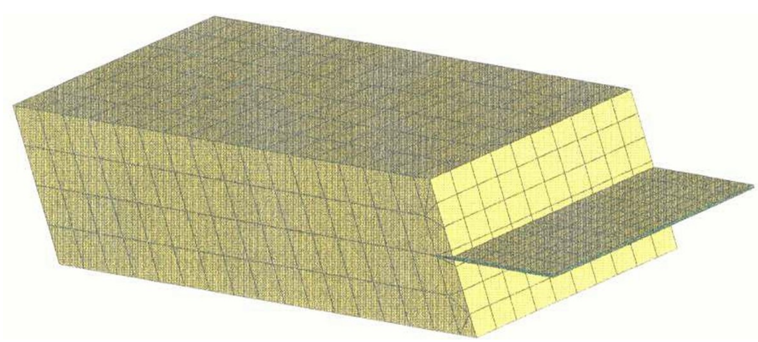

Figure 2: Typical meshing of the air boundary in the duct and in the slit.

5 - CALCULATION AND MEASUREMENT RESULTS

Figure 3 shows the analytical, the numerical and the measurement results for the considered baffled slits. By observing the calculation results, it can be noted that the values of the transmission loss calculated with Chen's model are in good agreement with those obtained with the DBEM model. The larger the height of the slit, the closer they are. This can be seen for both the 40 mm and the 120 mm depths. The experimental data discloses a general fair agreement with the calculation results. Higher differences are evident in the first half of the considered frequency range systematically. At the moment no proved explanation is available for this. Probably, because of the narrowness of the chosen slits, the losses due to the viscous boundary layer and to the heat conduction as well may be responsible of a higher measured transmission loss at lower frequencies. Both the viscous and the thermal boundary layers depend inversely on the square root of the frequency. It is worth noting that neither Chen's model nor the DBEM model as implemented here take into account the above mentioned dissipation effects.

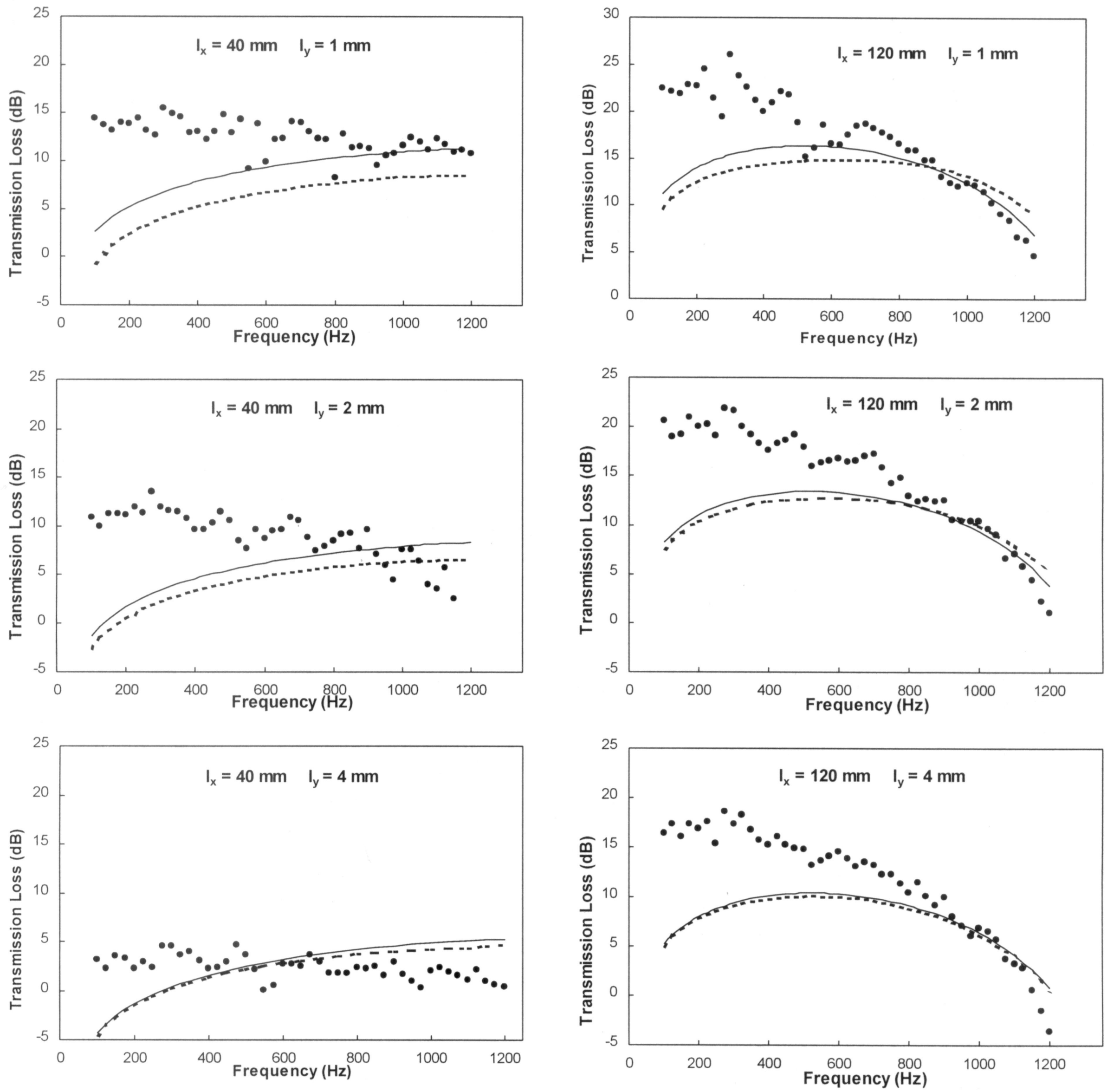

Figure 3: Measured and calculated transmission loss of slits; measured (• • • •); Chen's model (−−−); DBEM model (—).

6 - CONCLUSION

In the light of the findings reported above, a possible conclusion is that the analytical model is a manageable means to predict the transmission loss of a rectangular slit in a wall having the height like those considered herein. Probably, prediction ameliorates if losses are taken into account.

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