In-Situ Measurement of Acoustic Impedance in Presence of Grazing Flow

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1 Introduction

Perforated plates are used in many engineering applications for noise reduction. The high sound pressure level (SPL) and the airflow have considerable impacts on their acoustic performances. Numerical, experimental and theoretical methods have been used to characterize perforated plates [1-6]. Lee et al. [1] proposed an empirical impedance model of perforated plate under grazing flow using nonlinear regression analysis. The model was validated by comparison with experiments. Goldman et al. [2] studied the acoustic impedance of an orifice under a turbulent boundary layer. They observed a significant interaction that depends on the frequency and friction velocity between the acoustic and turbulent motions. Shah et al. [4] used an experimental three-port technique to study the transfer impedance of a perforated plate with and without the presence of grazing flow and analyzed the effect of acoustic incidence relative to the flow directions.

In this paper, a direct in-situ method is implemented and used to investigate experimentally the grazing airflow and higher SPL effects on the acoustic impedance of perforated plates. The measurements are validated by comparison with theoretical models and the effects of the grazing airflow and high SPL on the acoustic resistance are demonstrated.

2 Description and results of the in-situ measurement method with airflow

Figure 1 shows the experimental set up of the in-situ measurement method under grazing airflow. High sound pressure speakers capable of delivering a high SPL up to 145 dB are used and the airflow through the duct is generated by a compressor. One temperature probe OMEGA HX94C is mounted in the tube with a static pressure sensor MEAS U5244-000005-030PA to determine the environmental condition parameters during the measurement. An anechoic termination is mounted at one end of the tube to minimize the acoustic wave reflection. A controlled flow meter measures the airflow rate. The sample holder consists of two cavities of 9 mm deep that are separated by a rigid wall. The lateral dimensions of each cavity are 50.8 mm x 20 mm. Four 1/4'' microphones PCB 378A14 denoted by M_1 to M_4 are mounted flush with the inner wall of the tube. One microphone is mounted flush in the bottom of each cavity and two microphones are flush mounted in the tube just above the sample as shown in Fig. 1. All the signals acquisitions are done by a NI Compact DAQ system.

A phase and amplitude calibrations are performed to minimize the error measurement of the microphones. From

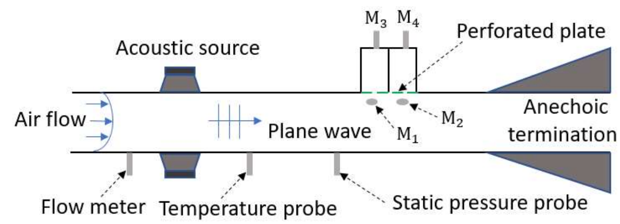

Figure 1: In-situ measurement set up.

the acoustic pressures P_1 to P_4 that are measured by the 4 microphones, the normalized acoustic impedance of the perforated plate is determined using the following relation

$$Z_n = (H_{ij} - \cos kD) / (j \sin kD), \quad (1)$$

where H_{ij} is the transfer function, k the wavenumber and D the cavity depth that is 9 mm. For the first cavity, the impedance Z_1 was calculated using in Eq. (1) $H_{31} = P_1/P_3$ and for the second cavity Z_2 is calculated using $H_{42} = P_2/P_4$ and the impedance Z of the tested sample is obtained by averaging Z_1 and Z_2.

Figure 2 shows the normalized flow induced resistance of a micro perforated panel (MPP) with a thickness of 1 mm, a perforation diameter of 1 mm and a perforation open area of 5%. The measurement is perforated at 140 dB with airflow Mach number M of 0.15. The resistance in Fig. 2 is obtained by subtracting the resistance without flow from the resistance with Mach 0.15. A frequency-dependent contribution of grazing flow is obvious. The result correlates fairly with the theoretical model proposed by Lee et al. [1]. The dip around 2700 Hz should be caused by the interaction between the nonlinear and grazing flow effects [2]. The presence of grazing flow can partially reduce the nonlinearity. Therefore, when subtracting the resistance without flow, an extra part is subtracted and the dip appears.

The normalized resistance and reactance of the previous micro perforated panel at 140 dB are presented in Figs. 3 and 4 for different airflow Mach numbers. The grazing flow increases the resistance and this effect is decreasing with respect to the frequency until a critical frequency, after which the flow effect can be neglected (therefore the higher frequency part of the curve will superpose on the one without flow). The critical frequency is found to be proportional to the Mach number [1]. In Figure 3, for different Mach numbers of 0.0.3, 0.09 and 0.15, the critical frequency corresponds respectively to 700 Hz, 2100 Hz and 3500 Hz. In Figure 4, for frequency f >1000 Hz, the reactance decreases with the Mach number and the slope remains almost the same.

The impact of the high SPL on the normalized acoustic impedance of the previous MPP is illustrated in Fig. 5. The measurement is performed at different SPL without airflow. The nonlinear effect is observed with the increase of the SPL, especially around the Helmholtz resonance (2700 Hz), where

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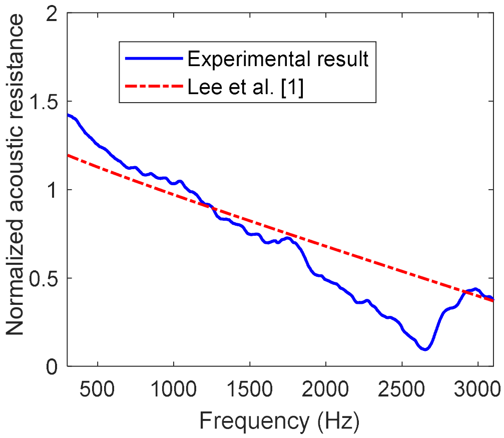

Figure 2: Resistance introduced by the airflow.

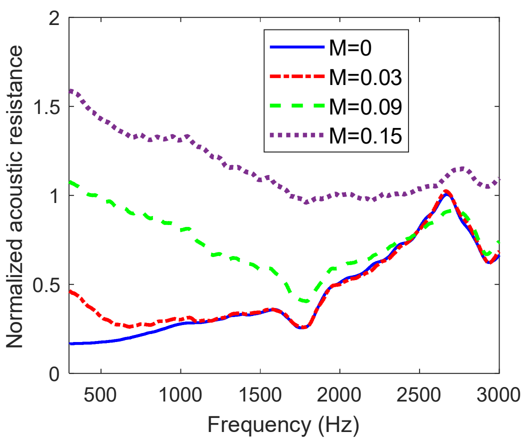

Figure 3: Effect of grazing airflow on the acoustic resistance.

the acoustic velocity in the perforation reaches its maximum. At higher SPL, the jet formation and vortex at the exit of the orifices increase the resistance and reduce the orifice end correction, which induces a decrease of the reactance [5].

The grazing flow and the high SPL have a significant impact on the acoustic impedance of the micro perforated plates as illustrated in figures 3 to 5. The in-situ method used in this work can help to investigate the acoustic performance of these perforated plates.

3 Conclusions

An in-situ measurement method is presented and used to investigate the impacts of the grazing flow and high SPL on the acoustic impedance of micro perforated plates. The theoretical result shows generally good correlation with the measurement. It is demonstrated that the high SPL and grazing airflow increase the acoustic resistance of micro perforated plates while the reactance is reduced. This in-situ method can be used to identify the acoustic properties of macro perforated plates and others materials with airflow at high SPL.

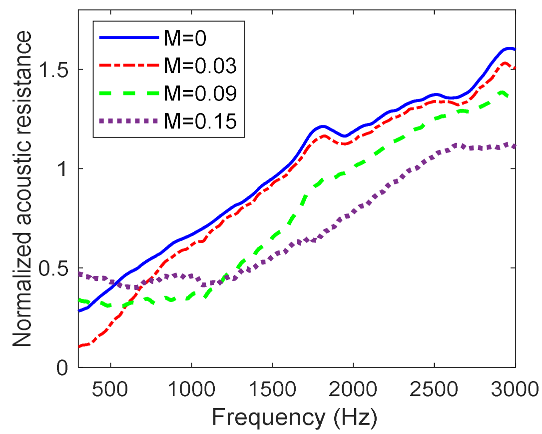

Figure 4: Effect of grazing airflow on the acoustic reactance.

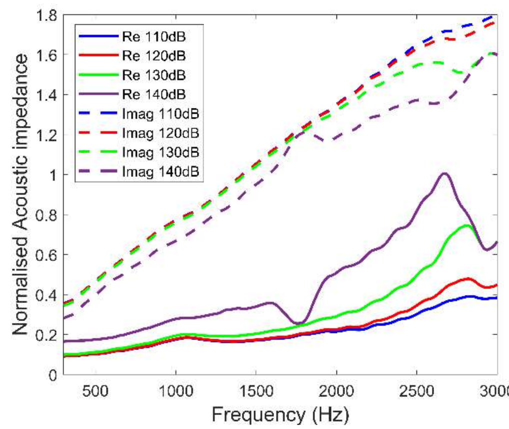

Figure 5: Effect of High SPL on the acoustic impedance.

Acknowledgments

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