EXPERIMENTAL CHARACTERIZATION OF ACOUSTIC MATERIALS IN THE PRESENCE OF AIRFLOW AT HIGHER SOUND PRESSURE EXCITATIONS USING A TRANSFER MATRIX METHOD

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1 Introduction

The measurement with two microphones using transfer function method [1] can provide acoustic properties such as reflection coefficient and the sound absorption coefficient of a tested material. For the transmission performance characterization, more than two microphones are required. Munjal and Doige [2] presented theoretical expressions of two source-location method using four-microphone technique and transfer function approach to evaluate the four pole parameters of an acoustic element in the presence of airflow. The two-load method of ASTM E2611-09 [3] can be used experimentally to obtain the transfer matrix and transmission loss of a sample. However, the effect of the airflow is not included in this standard.

In this study, an experimental methodology based on transfer matrix approach is presented to evaluate the acoustic properties of materials at high sound pressure level (SPL) in the presence of airflow. The equations of ASTM E2611-09 are modified to account for the airflow effect. Two experimental measurements with two different termination loads under flow are required to derive the four-pole parameters of the tested material. The transfer matrix components are given as function of the pressures and velocities at both faces of the material. The proposed method shows good agreement with two-source method for different experimental measurements performed with airflow at high sound pressure levels.

2 Description of the measurement method with airflow

The present method to characterize acoustic materials in the presence of airflow at high SPL with airflow requires two experimental measurements with two different termination loads to retrieve the transfer matrix coefficients of the tested material. The first termination load can be an anechoic termination and the second an opened termination as shown in Fig. 1 that illustrates the sample and the forward and backward traveling waves A, B, C, and D.

In Fig. 1, d is the thickness of the sample, s_1 and s_2 represent the distance between each pair of microphones. The distance between microphone 2 and the front surface of the sample is denoted by L_1 while L_2 is the distance between microphone 3 and the front surface of the sample. The acoustic pressure and particle velocity upstream and downstream the

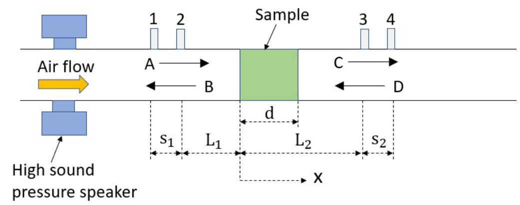

Figure 1: Two-load measurement method with open termination.

sample can be given as

$$\begin{aligned} p_u(x) &= \mathrm{A}e^{-jk_u^+x} + \mathrm{B}e^{jk_u^-x}\,, \\ p_\mathrm{d}(x) &= \mathrm{C}e^{-jk_\mathrm{d}^+x} + \mathrm{D}e^{jk_\mathrm{d}^-x}, \\ v_u(x) &= \frac{1}{Z_u}\left(\mathrm{A}e^{-jk_u^+x} - \mathrm{B}e^{jk_u^-x}\right), \\ v_\mathrm{d}(x) &= \frac{1}{Z_\mathrm{d}}\left(\mathrm{C}e^{-jk_\mathrm{d}^+x} - \mathrm{D}e^{jk_\mathrm{d}^-x}\right), \end{aligned} \tag{1}$$

with $j^2 = -1$, Z_u, k_u^+, and k_u^- are respectively the characteristic acoustic impedance and wavenumbers upstream the material, Z_d, k_d^+, and k_d^- the characteristic acoustic impedance and wavenumbers downstream the material. The wave numbers k_u^+ and k_d^+ are calculated using the models proposed by Howe [4] to account for the damping effects of the acoustic wave in the present of airflow. Two measurements with anechoic and opened terminations are performed under flow using the setup described in Fig. 2. These two terminations are denoted by load «a» and load «b». The setup is made of two anechoic terminations and two acoustic sources that can provide a high SPL up to 150 dB. The airflow through the duct is generated by a compressor. A temperature sensor is mounted in the tube to measure the temperature and two static pressure sensors are used to measure the static pressure upstream and downstream the sample. Then, the speed of sound in air c_0 and the density of the fluid ρ_u and ρ_d as well as the airflow Mach numbers upstream and downstream the sample are obtained

$$M_u = \frac{Q_m}{\rho_u c_0 S} \text{ and } M_\mathrm{d} = \frac{Q_m}{\rho_\mathrm{d} c_0 S} \tag{2}$$

with Q_m the mass airflow rate in kg/s and S the cross-sectional area of the tube. Four ¼ '' microphones PCB 378A14 are mounted flush with the inner wall of the tube and a NI CompactDAQ system is used for all signals acquisition. The distance between each pair of microphones is 40 mm and the inner diameter of the tube is 54 mm. The distance between microphone 2 and the sample is equal to the one between microphone 3 and the sample, which is 50 mm. A phase and amplitude calibration are done to minimize the error measurement of the microphones.

For the experimental measurements with loads «a» and «b», the complex amplitudes of the acoustic pressure A, B, C, D in Fig. 1 are expressed from Eq. (1) as function of the microphones measurement transfer functions and then the

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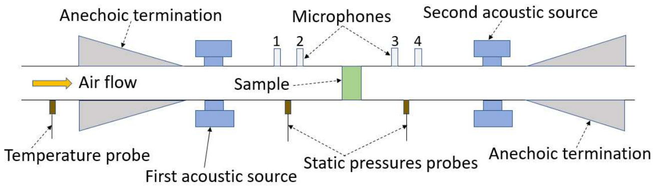

Figure 2: Experimental measurement setup.

pressures and velocities at both face of the material are deduced. From the two measurements with the two different termination loads, the transfer matrix components of the sample in the presence of the airflow are obtained,

$$T_{11} = \frac{p_{oa}u_{db} - p_{ob}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} \text{ and } T_{12} = \frac{p_{ob}p_{da} - p_{oa}p_{db}}{p_{da}u_{db} - p_{db}u_{da}} \quad (3)$$

$$T_{21} = \frac{u_{oa}u_{db} - u_{ob}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} \text{ and } T_{21} = \frac{p_{da}u_{ob} - p_{db}u_{oa}}{p_{da}u_{db} - p_{db}u_{da}} \quad (4)$$

The transmission loss is then calculated using the four components of the transfer matrix in Eqs. (3) and (4).

3 Comparison of the present method with two source method

A perforated silencer containing a single chamber is tested at 145 dB. The inner diameter of the perforated tube and the outer diameter of the silencer are respectively 54 = mm and 149 mm and the length of the perforated tube is 243 mm. The chamber of the silencer is filled with fibrous wool with a mass of 394.2 g. Figure 3 shows the comparison of the transmission loss of the perforated silencer filled with fibrous wool for mass airflow rate of 158 kg/h, which corresponds to airflow Mach number of 0.049. The present method is compared with two-source method that is de-scribed in Ref [2].

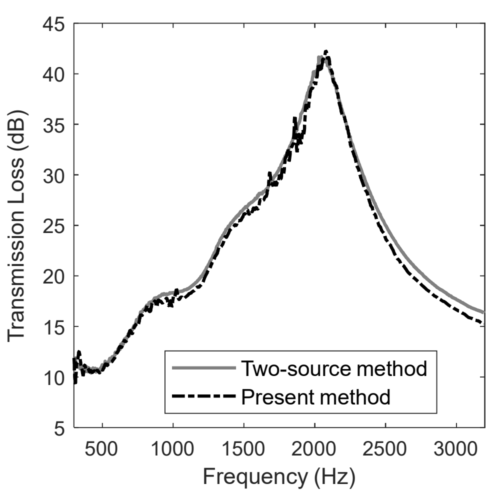

Figure 3: Comparison of the transmission loss of a perforated silencer filled with fibrous wool.

The result of the present method in Fig. 3 agrees well with two-source method. Figure 4 shows the transmission loss of a micro perforated panel absorber made of a panel with slit-shaped holes with a thickness of 0.6 mm backed by a honeycomb structure with thickness of 17.75 mm and a rigid wall. The measurement is performed at grazing incidence for a SPL of 140 dB and airflow Mach number of 0.103.

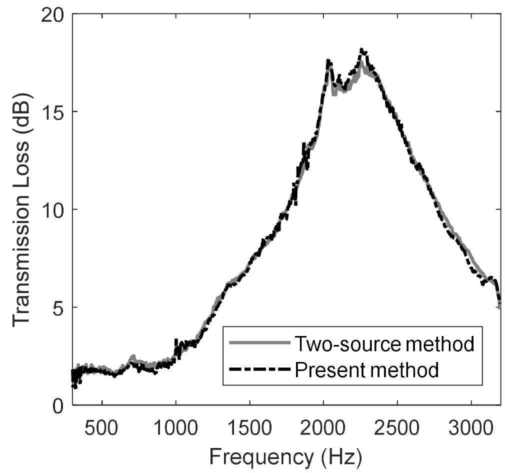

Figure 4: Comparison of the transmission loss of perforated panel absorber with slit-shaped holes at grazing incidence.

In Fig. 4, the present method and two-source method results are in good agreement.

4 Conclusions

An experimental method based on ASTM E2611-09 standard is presented to measure the acoustic properties of material at higher sound pressure excitations in airflow environment. Two experimental measurements with two different termination loads are performed to retrieve the four-pole parameters of the tested material. The proposed method shows good agreement with two-source method. It can be used to characterize experimentally acoustic materials in the presence of airflow at high SPL.

Acknowledgments

This study was performed under the framework of the dXBel project, funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) and Bombardier Recreational Products (BRP).

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