MEASUREMENT OF ACOUSTIC RESISTANCE OF PERFORATED PLATES SUBJECTED TO A PULSATED GRAZING FLOW

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1 Introduction

High porosity macro-perforations can be found in the silencers of the intake and exhaust systems of various fluid machines. In linear acoustics, because their dimensions are much larger than viscous boundary layer, their impedance is mainly reactive. At high amplitude non-linear effects [1-5] are associated with an additional resistance, proportional to the acoustic velocity in perforations. In presence of a grazing flow, the resistance increases linearly and the reactance decreases with friction velocity in the main pipe [6-8]. In highly pulsated flows the two problems are coupled. It is admitted [5] that when the mean velocity of the flow is higher than the acoustic velocity in perforates this tends to linearized the impedance (Goldman criteria). Most of these results were based on experiments limited to 160 dB. However, in some practical applications, levels can reach 180 dB, Mach number can reach 0.3 and porosity from 5% to 40%. These are the orders of magnitude of pulsated flow that we propose to explore in this study.

As described in the section 2, an electropneumatic source was built specially for this application. In section 3, the impedance extraction method is presented. In section 4, the results are analyzed as function of the mean flow velocity in main pipe and the acoustic velocity in perforations. The aim is to understand the balance between these two parameters for high porosity macro-perforations.

2 Experimental set-up

The experimental set up illustrated in Fig. 1 consists of a harmonic acoustic pneumatic source [9]. Compressed air flows from a plenum chamber through the entire line which is made of a rotating control valve, a flow chopper and the grazing flow section. The air in the plenum is generated by a compressor and a venturi flowmeter measures the mass flow rate q_m. The alimentation pressure P_{alim} in the plenum is regulated by a regulator placed upstream. The flow chopper constituted by a wheel with 6 or 8 apertures is driven in rotation by a brushless motor. The apertures generate noise at a frequency of six or eight times the rotation frequency of the motor. Four dynamic pressure sensors are used to measure the transfer matrix of the grazing flow section using the two-load method [10]. The first measurement is made with an anechoic termination as shown in Fig. 1 and the second measurement is made with an opened termination. Four different 250 mm long plates were tested, perforated with 3mm diameter holes with different porosities (5%, 10%, 23% and 40%). They were backed with eight cavities 50 mm long.

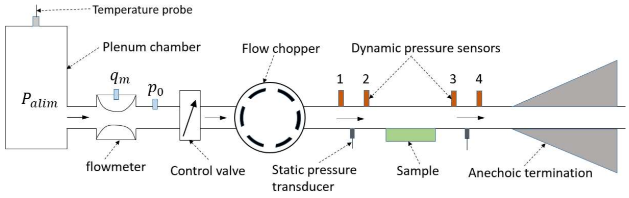

Figure 1: Experimental set up using harmonic acoustic pneumatic source

3 Determination of the grazing impedance

After the measurement of the transfer matrix using the two-load method, the grazing flow impedance of the perforated plate is calculated using an indirect method. In a first step, the two axial wavenumbers are calculated from the experimental transfer matrix. Afterward using Ingard-Myers boundary condition [11], an overdetermined system with 4 equations and 2 unknowns, is obtained. This can be solved using a least square method and the surface impedance of the perforates can be calculated. The transfer impedance is calculated by removing the impedance of the backing cavities.

4 Experimental data analysis

In this chapter, the measured impedance is analyzed as function of the mean flow velocity in main pipe and the acoustic velocity in the perforations. Because this parameter cannot be measured directly, it was decided to compute it numerically with GT-POWER [12]. The whole set-up was modeled in 1D, as compressed air flowing from a reservoir through a periodically fluctuating orifice area before entering into the grazing flow section and finally emerges into the atmosphere. By averaging the acoustic velocity in front of all the 8 cavities, the acoustic velocity across the grazing flow section was computed.

Because reflection coefficients of both terminations were quite close in low frequency, only results above 400 Hz were considered and averaged in the frequency range [400Hz, 800Hz]. With the different configurations of diaphragm, vessel pressure and plate porosity, different combinations (Flow Mach number, Acoustic Mach number) are obtained. Flow Mach number is ranging from 0.025 to 0.275 and acoustic Mach number from 0.027 to 0.245. Considering the

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noise levels that were measured in the section, non-linear effects can be expected. In order to quantify them, the linear component of the resistance has to be removed from the experimental data. Because the linear resistance was not measured directly, the Cummings model [7] were used. Once the non-linear resistance was extracted, is was interpolated as a linear function of the acoustic velocity in perforates, as it is admitted in literature. As shown in Fig. 2, it is possible to compare the linear component of the resistance with the non-linear component as functions of the flow and acoustic Mach numbers. As it was stated by Goldman but for low porosity [5], when the flow in the main pipe decreases, the non-linear effects tend to appear much "faster". It is possible to draw a line separating the dominance of both domains.

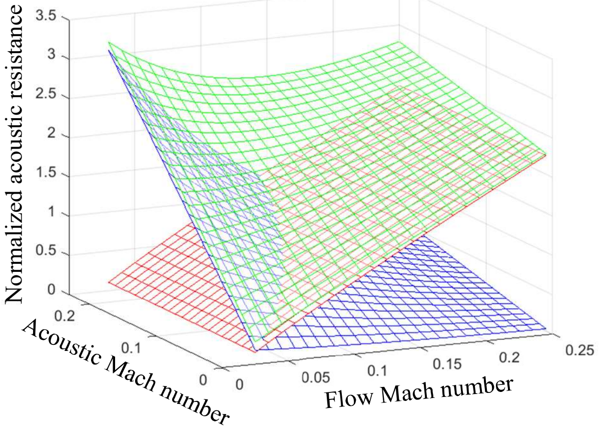

Figure 2: Acoustic resistance and its components as function of the acoustic Mach number and the flow Mach number. 🟩 Total resistance, 🟦 Nonlinear component, 🟥 linear component.

5 Conclusion

The objective of this study was to investigate the behavior of a macro-perforated plate subjected to a pulsated grazing flow. In order to explore noise levels up to 180dB, an electropneumatic source was built. By changing the flow, the acoustic output of the source and the plate porosity, it was possible to tune acoustic Mach number in perforates between 0.023 and 0.245 and main flow Mach number between 0.025 and 0.275. The transfer matrix of the section was measured using a two-load method, then the impedance of the plate was calculated using a least square method. In order to highlight possible non-linear effects, the results were compared to an existing linear model. The measured acoustic resistance is much higher than the linear one for low Mach numbers, showing the competition between nonlinear effects and the main flow. These results agree qualitatively with the Goldman criteria defined for micro-perforated plates.

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