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NON-LINEAR EFFECTS OF THIN STRUCTURES WITH SLITS FOR LOW-FREQUENCY ACOUSTIC ABSORPTION

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ABSTRACT

Acoustic liners for future aircraft engines will have to achieve contradictory goals: maintaining a strong absorption at low frequencies while reducing the treated surface area and liner thickness. The purpose of this thesis is to review several concepts in the development of transducer-based acoustic liners. The use of transducers enables the coupling of several physical processes: acoustics, mechanics and electronics. As shown in previous work, this can lead to very efficient devices enabling low-frequency absorption with thin liners. The present work aims at better understanding the key phenomena governing acoustic absorption and frequency range available for a given liner thickness. This can be achieved by considering a thin mechanical structure with thin slits. These slits are cut in the structure and form an acoustic short-cut between the front and the back of the device. Coupled with a back-end cavity, it has been shown that adding thin slits could be beneficial in terms of acoustic absorption, bandwidth and frequency shifting. In order to study those phenomena, the Transfer Matrix Method (TMM) is compared to experimental results in order to validate the model and better understand the effects of fluid inertia and visco-thermal losses in the slits.

1. INTRODUCTION

The aim of this work is motivated by the results from Houdouin *et al.* [1] who studied the use of electrodynamic transducers for acoustic absorption with a semi-passive strategy. It demonstrated very good performance in terms of absorption but only for normal incidence and without modelling of, or insight into, the underlying physical phenomena. The performance of such a device is expected to be due to the presence of slits. The present communication offers an analytical modelling of these slits and comparisons with experimental results. In particular, the influence of high sound pressure levels will be discussed.

2. EXPERIMENTAL SET-UP

The cell used for this experiment is an Helmholtz resonator where a thin structure is compressed between the two top plates, see Fig. 1. Several types of structures have been

considered, ranging from a simple rectangular slit, to validate the models, to more complex shapes. In order to study the influence of the sound pressure level on the impedance of the structure, a controlled wave-guide will be used, as shown in Fig. 2. The device is placed at the end of the tube with the help of an adaptor.

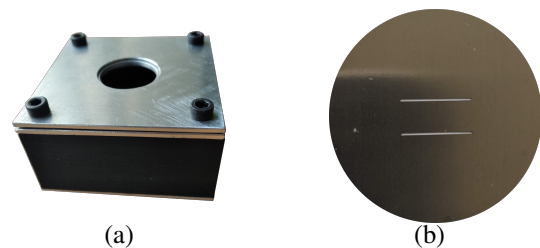


Figure 1. Photograph of the cell used comprising several circular waveguides of different radius coupled to a back cavity. (b) Photograph of one kind of structure studied corresponding to rectangular slits with length $d_s = 10$ mm, width $w_s = 300 \mu\text{m}$ and thickness $l_s = 100 \mu\text{m}$.

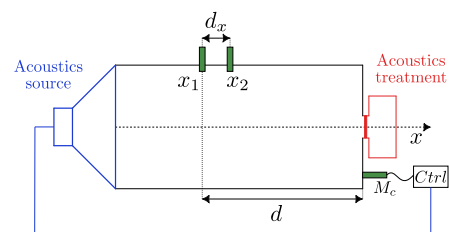


Figure 2. Impedance tube with a back-ended microphone used in order to control the sound pressure level on the system and two microphones to measure the acoustic pressure along the guide.

3. MODEL FOR THE LINEAR REGIME

To simulate the impedance of this thin structure, a Transfer Matrix Method (TMM) formalism is used. It allows to establish the link between the acoustic pressure and acoustic flux at the inlet and outlet of the system. To take the visco-thermal losses into account, the model by Stinson [2] is used. Due to the fact that the device is a combination of circular and rectangular waveguides, the calculation of the

losses is based on the on the perimeter and hydraulic diameter of each waveguide. Then, the parallel assembly of the slits is modelled using the method developed by Verdière [3].

4. RESULTS

The first series of measurements was performed at a low sound pressure level in order to verify the model in the linear regime. By doing so, the model of the visco-thermal losses has been validated with other formulations, in particular to take into account different shapes of the waveguides and slits. A plate with two parallel slits as well as a moving device such has a cantilever beam have been tested and validated.

However, after carrying out tests at high sound pressure levels, the slits structures appears to have a strongly non-linear behaviour. To understand and try to adjust the model for this effect, it has been chosen to assess this non-linear behaviour in a simpler environment (i.e. in normal incidence and without mean flow Fig.2) with a controlled pressure incoming on the system. The results of this series of measurements can be seen in Fig.3. There is a significant non-linear effect on the resistance and reactance which can be incorporated into the model.

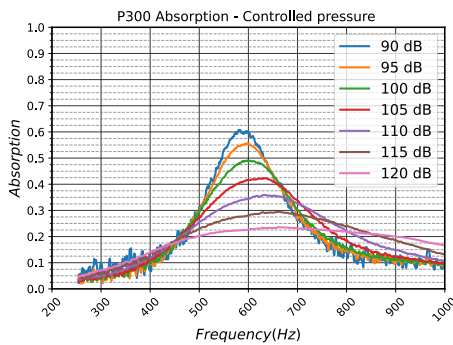


Figure 3. Acoustic absorption of two parallel rectangular slits (length $d_s = 10$ mm, width $w_s = 300 \mu\text{m}$ and thickness $l_s = 100 \mu\text{m}$) coupled with an Helmholtz resonator excited by a sweep sinusoidal signal controlled in acoustics pressure on the beginning of the treatment.

5. MODELS FOR THE NON-LINEAR REGIME

The previous results lead to an update of the current model by adding a dependence of the impedance on the acoustic level. The work done by Auregan [4] suggests a formulation for large (> 1) Reynolds number (Eq.1) and for low Reynolds number (Eq.2).

$$\Re(Z_{NL}) = \Re(Z_L)((1 - \delta) + C_1 Re) \quad (1)$$

$$\Re(Z_{NL}) = \Re(Z_L)(1 + C_2 Re^2) \quad (2)$$

The different constants are determined by a fitting procedure (using a least square technique) based on the experimental data for different thin structures. The main issue

with this procedure is the fact most of the prior work in the literature is concerned with the non-linear response of circular apertures, and comparatively little is available on long and thin rectangular slits. The other point, highlighted by Auregan, is the fact that in this model only the real part of the impedance is impacted by the sound pressure level, which is not the case in the experimental data. The variation on the reactance is also observed by Roche [5], and he suggests to decrease the end correction of the neck due to vorticity shedding and the ‘vena contracta’ effect.

6. CONCLUSION

The present communication reported the validation of a linear model of a mechanical-acoustics absorbing system composed of a thin structure with slits. However, it has been observed that a strong non-linear behaviour modifies the resistance and reactance depending of the incoming sound pressure level. A first proposal to take this effect on the resistance has been presented. The effect on the reactance need to be further investigated in order to propose a new end correction for long and thin rectangular slits so as to take into account the vorticity shedding and a ‘vena contracta’ effect.

7. ACKNOWLEDGMENTS

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