Thesis proposal: Non-linear acoustic behaviors in a lined flow duct

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Research background:

Reducing the noise radiated by a duct in the presence of flow is a problem encountered in many industrial applications. This is for example the case of jet engine nacelles, exhaust pipes, ventilation systems, ... In some cases, high sound pressure levels are generated in the duct (up to 170 dB in nacelles). The main objective of this thesis is to define effective control strategies to reduce the noise in this context. Metallic liners (e.g. perforated sheets on honeycomb) are usually installed on the wall, but other types of absorbers are being studied, such as periodic media, metamaterials able to block the transmission in a specific frequency range. These passive structures can also be combined with active means to increase their efficiency.

In order to design these liners, the acoustic propagation in such a duct must be described accurately. However, state-of-the-art studies assume that the propagation remains linear and that the liner behavior is linear as well. In fact, there are different sources of non-linearities in such applications:

- For high sound pressure levels, propagation is non-linear and wave fronts tend to steepen during propagation. For frequencies of interest between 500 and 3500 Hz, the shock formation distance is about one meter and thus comparable to the size of the facility. Non-linear effects are then expected to be significant.

- The acoustic behavior of liners depends on the acoustic pressure amplitude for sound pressure levels (SPL) of 110-120 dB, even if the propagation is essentially linear for such levels. The non-linear behavior (impedance, absorption...) of these liners can lead to non-classical acoustic responses (non-periodic for example) with important effects in the transient leading to undesirable effects or on the contrary allowing to increase the dissipation as shown in [4] for Helmholtz resonators submitted to high levels.

Thesis:

The study of non-linear effects encountered in the propagation of acoustic waves in a lined flow duct is therefore a relevant research topic for a thesis. This study will be performed both experimentally and numerically.

From an experimental point of view, the CAIMAN wind tunnel of the LMFA at Ecole Centrale de Lyon will be used. This is a straight duct with a rectangular cross-section, developed to characterize acoustic treatments in the presence of flow. Flow speeds up to 100 $m.s^{-1}$ can be obtained. The experimental techniques currently used on CAIMAN assume a linear propagation. In this PhD, a bibliographic study will be done to analyze the methods developed in the literature to characterize acoustic liners with high sound pressure levels. The most relevant method will be implemented on CAIMAN to characterize the acoustic efficiency at high SPL of several types of liners and for several flow speeds. As absorbers have a non-linear behavior for high levels, it will be necessary to apply and develop methods considering the generation of harmonics due to non-linearities

From a numerical point of view, the Euler equations will be solved in the time domain by finite difference methods. In previous projects, the LMFA has developed similar numerical tools to predict acoustic propagation in a lined flow duct in the linear regime [1] as well as acoustic propagation in outdoor environment in the nonlinear regime [2]. A preliminary work has allowed to develop a nonlinear impedance boundary condition in the time domain. The aim of this thesis is to extend this study to the case of a duct with flow, and to the case of nonlinear acoustic propagation.

The PhD student will also be able to take advantage of the new analytical tools developed within the LTDS for the dynamic transient analysis of nonlinear resonators [4] and apply the temporal methods mainly developed in mechanics at the present time. Comparisons will be made with results from the recent literature on the subject [3], as well as by using other numerical codes and frequency approaches such as the commercial software COMSOL. The results of the numerical simulations can therefore be compared with each other and with the experimental results. Parametric studies will be carried out in order to study in detail the non-linear propagation in a lined flow duct.

References:

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[2] Karzova M.M., Lechat T., Ollivier S., Dragna D., Yuldashev P.V., Khokhlova V.A., Blanc-Benon P., 2019, Effect of surface roughness on nonlinear reflection of weak shock waves, J. Acoust. Soc. Am., 146(5), EL438-433.

[3] Monteghetti, F., Matignon, D., Piot, E., 2018, Energy analysis and discretization of nonlinear impedance boundary conditions for the time-domain linearized Euler equations, J. Comp. Phys., 375, 393-426.

[4] Gourdon, E., Ture Savadkoohi, A., Alamo Vargas, V. Targeted energy transfer from one acoustical mode to an Helmholtz resonator with nonlinear behavior (2018). Journal of Vibration and Acoustics, Transaction of the ASME, 140 (6), art. No. 061005.