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NONLINEAR BROADBAND TIME-DOMAIN ADMITTANCE BOUNDARY CONDITION APPLIED TO A FLOW DUCT WITH PERFORATED LINER

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ABSTRACT

Perforated plates experience a nonlinear response at high excitation levels. They are largely used in duct applications, such as aircraft engine nacelles, for which broadband noise and the presence of flow must be considered. Time-domain methods are well-suited to predict sound propagation under such conditions. Recently, a time-domain admittance boundary condition (TDABC) was proposed by Diab et al. (J. Sound. Vib., 528, 2022) [1] to account for the nonlinear response of perforated plates and was implemented in a finite difference time-domain solver of the linearized Euler equations. A numerical study on sound propagation in a lined duct was performed in the absence of flow. This paper extends the TDABC to a lined duct with flow. First, the time-domain model is experimentally validated with a perforated plate placed in an impedance tube at normal incidence. Second, a flow duct lined with the perforated plate is considered. Numerical simulations are performed to evaluate noise reduction due to the liner for several incident sound pressure levels. Subsequently, experiments are carried out in the Caïman wind-tunnel of Ecole Centrale de Lyon and the experimental and numerical results are compared.

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1. INTRODUCTION

In many industrial applications, the study of perforated plate liners used for reducing noise is particularly pertinent. The liner exhibits non-linear behavior at high acoustic levels, as shown in [2] [3] [4], even if the propagation remains linear. Properties are no longer just dependent on the excitation frequency but also on the excitation sound level. Impedance models have been proposed in the literature to characterise perforated plates in the non-linear regime [5] [6]. Recently, Laly proposed a model on the non-linear behaviour of plates based on an equivalent fluid model [7]. This study first presents a characterisation of a perforated plate (PP) in a Kundt tube at different sound pressure levels (SPL) values, based on a modification of Laly's model. Then, application is made to a lined, two-dimensional (2D) duct. The performance of the liner is investigated at different excitation levels and comparisons with the numerical model are performed.

2. METHODS

2.1 Experimental study

The first part of this study is experimentally conducted. A perforated plate made of galvanised steel is considered. The plate has a diameter of 29 mm and a thickness of 1 mm. The plate presents 3 perforations with a diameter of

2 mm and spaced 1.5 mm apart. The perforation ratio ϕ of the plate is of the order of 1.43%. The plate was then tested in a Brüel & Kjaer Type 4206 impedance tube. An air gap of 30 mm was left behind the plate. The behaviour of the plate was tested at different levels of incident pressure from linear to non-linear range. The absorption coefficient α and the admittance Y of the perforated plate were measured and their evolution with increasing sound pressure level was analysed.

Later, a perforated plate liner inserted inside an acoustic wind tunnel was considered. Specifically, the duct considered is the Caïman wind-tunnel of the *Centre Acoustique du LMFA, Ecole Centrale de Lyon*. The properties of the liner (perforation diameter, thickness and perforation ratio) are the same as the perforated plate studied in the impedance tube. The acoustic performance of the liner was evaluated by considering the transmission loss TL in the direction of the flow and in the opposite direction. First, different acoustic pressure levels were considered in the absence of flow, and then flow at different Mach numbers was introduced.

2.2 Numerical simulation

Numerical simulations are carried out for comparison with the measurements. The linearized Euler equations (LEE) are solved by a high-order finite-difference time-domain technique. A time-domain admittance boundary condition is used to take into account the non-linear behaviour of the PP liner [8]. The admittance is written as a multipole model, whose coefficients and poles are allowed to vary with the value of the rms velocity in the perforations v_{rms}:

$$Y(\omega, v_{\text{rms}}) = Y_{\infty}(v_{\text{rms}}) + \sum_{k=1}^{p} \frac{A_k(v_{\text{rms}})}{\lambda_k(v_{\text{rms}}) - j\omega} \quad (1)$$

where ω is the pulsation, Y_{∞} is a coefficient corresponding to the high-frequency limit of Y , λ_k are the poles of the admittance, A_k the associated coefficients and P denotes their number. First, the admittances found experimentally in a Kundt tube for several incident SPL were used to fit the parameters of an impedance model [9] based on modified Laly's model [7]. The limitations of the model have been highlighted in previous studies [1]. Once these parameters were found, the poles and coefficients of the admittance are determined using a fitting algorithm [10].

3. RESULTS

3.1 1D case

The purpose of the following part is to confirm that the technique presented in Sec.2.2 permits a precise description of the surface impedance in the nonlinear regime. The SPL corresponds to the level of the incident pressure measured inside of the impedance tube using a broadband excitation, (see Fig.1).

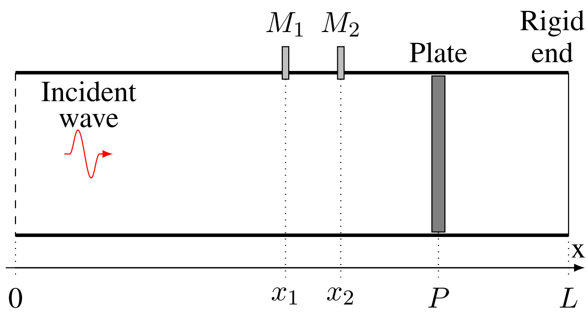

Figure 1: Sketch of the impedance tube

First, the plate's behavior was examined at a linear regime of 77 dB. Then, the non-linear behaviour was observed at 117 dB and 127 dB. A comparison between the measurements and numerical results is presented. Fig.2 shows the absorption coefficient at different SPLs, and Fig.3 presents the real and imaginary part of the admittance.

It can be seen that the numerical model predicts the experimental results. In the non-linear regime, the numerical results are in good agreement with the experiments. The trend is coherent with the behaviour in the admittance observed in Fig.3, where a deviation is noticeable in the 127 dB case. This fact can also be seen in the values of v_{rms}, as presented in Tab.1. From the impedance tube pressure measurement in two microphones, it was possible to derive the experimental values of v_{rms} at the perforations. The numerical values turn out to be higher than the experimental values at high SPLs.

3.2 2D case

This section considers a two-dimensional (2D) lined duct. The goals are to assess the numerical model in this case that incorporates nonlinear TDABC and to examine how the non-linear behaviour of the liner affects the sound attenuation and propagation in a 2D lined duct. As seen in Fig.4, a 2D lined duct with dimensions L = 1.3 m and h =

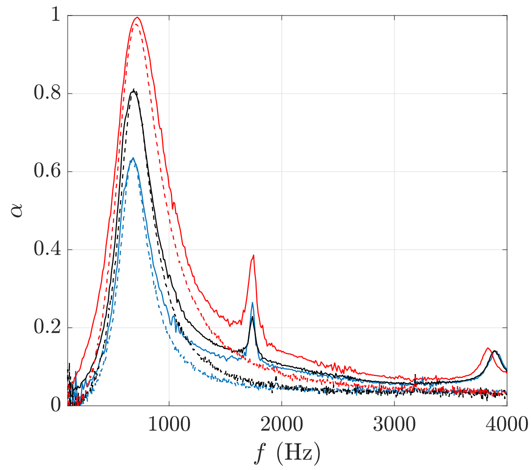

Figure 2: Comparison of experimental (solid line) and numerical (dashed line) absorption coefficient α for several incident SPL: ▬ 77 dB, ▬ 117 dB and ▬ 127 dB

Table 1: Comparison between experimental and numerical v_{rms} values

	v_{rms} [m/s]	
SPL [dB]	Experimental	Numerical
77	0.016	0.019
117	1.36	1.66
127	3.87	4.80

0.11 m is under consideration. The PP liner is placed on the upper wall of the duct, between $x = L_1 = 0.5$ m and $x = L_2 = 0.8$ m. The other walls of the duct are rigid. An incident plane wave propagates along the x-direction. A non-reflecting boundary condition is implemented at x = L. A harmonic excitation is used in the simulation. Three incident SPL levels (94 dB, 114 dB and 123 dB) are considered, each with a driving frequency range between 400 Hz and 1400 Hz, all without the presence of flow. Concerning the experiments, a preliminary analysis without flow was conducted by observing the trend of the transmission loss as the excitation level of the source increased.

Values of the transmission loss obtained experimentally and numerically are presented in Fig.5. It can be seen that

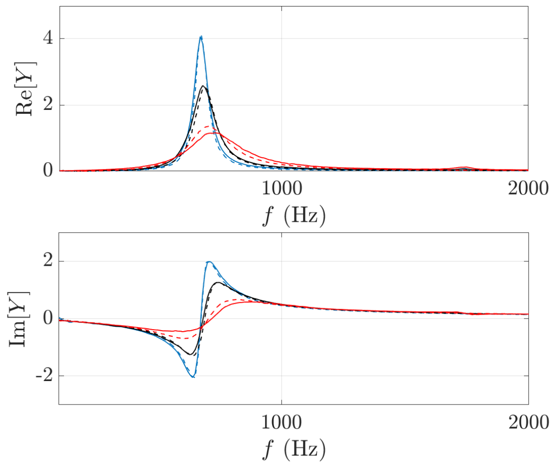

Figure 3: Comparison of experimental (solid line) and numerical (dashed line) admittance Y for several incident SPL: ▬ 77 dB, ▬ 117 dB and ▬ 127 dB

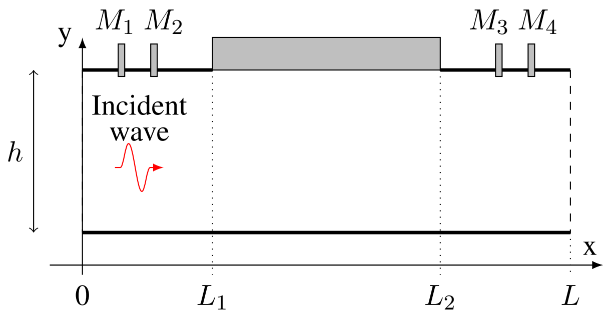

Figure 4: 2D schematic representation of the lined duct

the TL in the experiments tends to decrease as the source excitation level increases, although in the numerical simulations the maximum TL is obtained for SPL level which is not the lowest, and at a lower frequency. However, it can be seen that in both numerical and experimental case, the transmission loss is reduced at high excitation levels.

4. CONCLUSIONS

This paper presents a numerical characterisation of the non-linear behaviour of a perforated plate liner in an acoustic wind tunnel. After acoustically characterising the material inside an impedance tube, the performance of

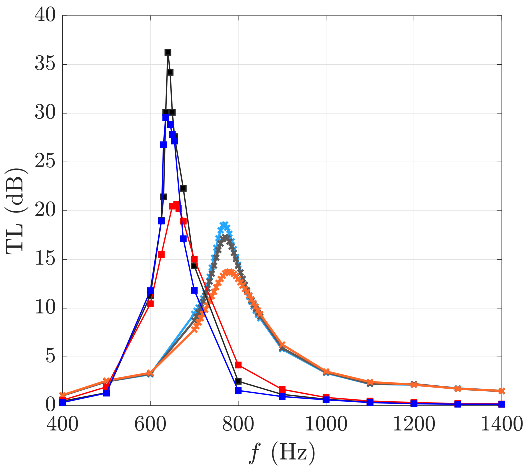

Figure 5: Numerical (■) TL values at SPL = 94 dB, SPL = 114 dB and SPL = 123 dB and experimental (×) TL measurements at low, medium and high excitation levels

the liner on a duct wall was analysed. A numerical time-domain multipole model was developed to predict the non linear behaviour of the perforated plate. Results are presented for different sound pressure levels without flow, showing that the numerical model predicts the PP material behaviour in both linear and non linear cases. The model also traces the trend of the behaviour of the liner performance in an acoustic duct, despite differences related to the limitations of the model. Cases in the presence of flow at several Mach numbers are currently being investigated by the authors and comparisons with experimental results obtained in the flow duct will be presented.

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6. REFERENCES

[1] D. Diab, D. Dragna, E. Salze, and M. A. Galland, "Nonlinear broadband time-domain admittance boundary condition for duct acoustics. application to perforated plate liners," *Journal of Sound and Vibration*, vol. 528, pp. 111–222, 2022.

[2] T. H. Melling, "The acoustic impendance of perforates at medium and high sound pressure levels," *Journal of Sound and Vibration*, pp. 1–65, 1973. Volume 29.

[3] R. Roncen, F. Méry, E. Piot, and P. Klotz, "Spatially-varying impedance model for locally reacting acoustic liners at a high sound intensity," *Journal of Sound and Vibration*, vol. 524, no. 116741, 2022.

[4] H. Bodén, Y. Guo, and H. B. Tözün, "Experimental investigation of nonlinear acoustic properties for perforates," *12th AIAA/CEAS Aeroacoustics Conference (27th AIAA Aeroacoustics Conference)*, pp. 127–132, 2006. `https://doi.org/10.2514/6.2006-2404`.

[5] D.-Y. Maa, "Potential of microperforated panel absorber," *The Journal of the Acoustical Society of Amer- ica*, pp. 2861–2866, 1998. 104 (5).

[6] A. W. Guess, "Calculation of perforated plate liner parameters from specified acoustic resistance and reactance," *Journal of Sound and Vibration*, pp. 119–137, 1975. Volume 40.

[7] Z. Laly, N. Atalla, and S.-A. Meslioui, "Acoustical modeling of micro-perforated panel at high sound pressure levels using equivalent fluid approach," *Journal of Sound and Vibration*, vol. 427, pp. 134–158, 2018.

[8] R. Troian, D. Dragna, C. Bailly, and M.-A. Galland, "Broadband liner impedance eduction for multimodal acoustic propagation in the presence of a mean flow," *Journal of Sound and Vibration*, vol. 392, pp. 200–216, 2017.

[9] E. Sarpero, D. Dragna, E. Gourdon, and M. A. Galland, "Experimental characterisation of perforated plates in a duct with flow in non-linear regime," *29th International Congress of Sound and Vibration*, Prague, 9th-13th July 2023.

[10] B. Gustavsen and A. Semlyen, "Rational approximation of frequency domain responses by vector fitting," *IEEE Trans. Power Deliv.*, vol. 14, pp. 1052–1061, 1999.