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Numerical optimization of liner impedance in acoustic duct

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ABSTRACT

The SALUTE project aims at evaluating performance of metacomposites for acoustic smart lining in grazing turbulent flow. Theoretical and numerical investigations are carried out for designing innovative specimen. A specific focus is placed in the realization of prototypes for evaluating the metacomposite liner performances in 2D and 3D liners, its process complexity and robustness. The insight gain in this project is new tools for obtaining innovative samples; the acoustical experimental tests demonstrate efficiency and robustness of such technology for controlling UHBR noise emission. This paper is focused on parametric study based on the maximization of the absorption coefficient in a duct by optimizing the impedance of a treated area.

INTRODUCTION

SALUTE (Smart Acoustic Lining for UHBR Technologies Engines) is a research project funded by the European Union's Horizon 2020 research and innovation programme Clean Sky 2 Joint Undertaking. It aims at developing innovative acoustic treatments for engine nacelles in order to reduce noise pollution of future aircrafts. The main technological objective is the development of a new generation acoustic liner, based on the Electroacoustic Absorber concept.

UHBR Technologies Engines have larger fan and shorter nacelles which present new challenges in terms of noise signature (more low-frequency components and less space for acoustic liners). In order to meet the required noise performance at engine level, next generation acoustic treatments should achieve significant noise reduction with limited surface, break the quarter-wavelength rule. Hence, the development and the optimization of an active acoustic liner prototype (2D arrangement of small electroacoustic transducers used as active membrane sound absorbers). Passive structures are good candidates to reduce high frequency contributions of noise and vibrations while active control technologies¹ are suited to attenuate the low frequency components. In this context, hybrid absorbers for flow ducts have been studied and it appears that the noise reduction is directly linked to the optimal impedance in the treated area. Tester² demonstrated that in the case of a semi-infinite duct with flow, the optimal resistance and the optimal reactance are frequency-dependent. A version, without flow, is also available.³ A hybrid impedance control architecture for an electroacoustic absorber is designed according to a target specific acoustic impedance.⁴ An application of this architecture has been studied with, for example, an acoustic diode.⁵

In this paper, a parametric study based on the maximization of the absorption coefficient has been achieved in a duct by optimizing the impedance of a treated area.

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DUCT DESCRIPTION

The geometry of the numerical duct of this study is inspired by the Phare 2 test rig for fan with 1/3 reduced scale (figure 1) located at Ecole centrale de Lyon in France.

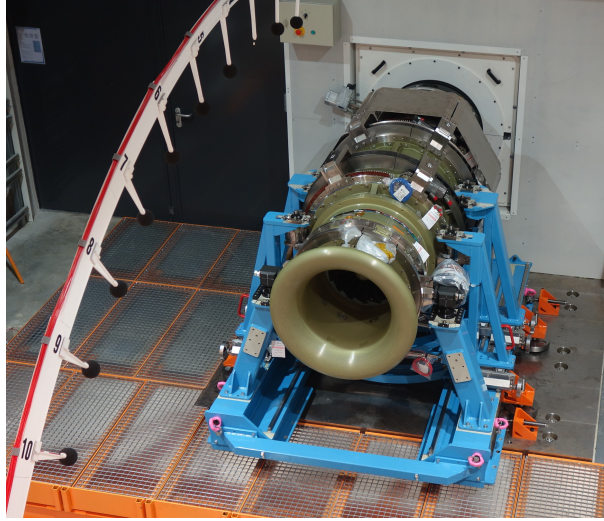


Figure 1. PHARE 2 - TEST RIG FOR FAN WITH 1/3 REDUCED SCALE.

Some assumptions are done compared to the experimental setup. The numerical duct (figure 2) is perfectly cylindrical, the acoustic perturbation is a plane wave without flow, the termination of the duct is anechoic and the treated area is a perfect ring (all impedance of the surface is considered). The cylinder is oriented along the x axis with 3 main parts: the upstream duct, the "sample" duct (treated ring) and the downstream duct. The upstream and downstream ducts have the same length ($L_1 = L_2$) and the same radius (r_{cyl}). The treated ring (in red) has 2 different lengths equal to d or $2d$, commonly called in this paper "1 ring" and "2 rings" and a radius similar to the upstream and downstream ducts. The plane wave radiating surface is located at $-L_1$ and the anechoic termination at $d + L_2$. Finally, 4 microphones (pressure measurement points) are present at $-x_1$, x_2 , $d + x_1$ and $d + x_2$. All geometrical parameters are referred in the table 1. The cutoff frequency (f_c) of the tube is equal to 343 Hz.

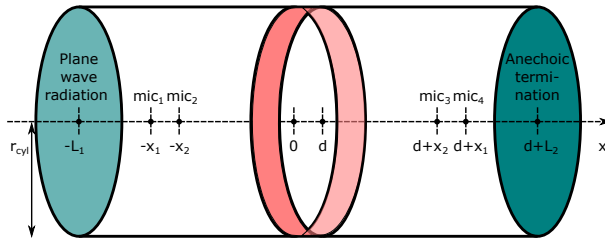


Figure 2. NUMERICAL DUCT.

r_{cyl}	L_1	L_2	d	x_1	x_2
0.25 m	0.5 m	0.5 m	5.5 cm	0.35 m	0.3 m

Table 1. GEOMETRICAL PARAMETERS.

PARAMETRIC STUDY

The objective of this parametric study is the maximization of the absorption coefficient (α) in the duct presented in the previous section. An impedance expresses in frequency domain as:

$$Z(\omega) = a + ib, \quad (1)$$

with a and b respectively the real and the imaginary parts of the impedance, is defined on the surface of the treated area (red ring in figure 2).

Acoustic quantities, described below, are defined following the *B&K* technical review.⁶ The transfer matrix is the link between the pressure and the velocity at $x = 0$ and $x = d$, the 2 sides of the "sample" duct:

$$\begin{pmatrix} P \\ V \end{pmatrix}_{x=0} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} P \\ V \end{pmatrix}_{x=d}. \quad (2)$$

The transfer matrix coefficients are obtained using the 4 microphones pressures at $-x_1$, $-x_2$, $d + x_1$ and $d + x_2$ and then calculating the pressure and velocity: $P(x = 0)$, $V(x = 0)$, $P(x = d)$ and $V(x = d)$.

These coefficients can be used to evaluate the normal incidence pressure transmission (T_a) and reflection (R_a) coefficients for the case of an anechoic termination:

$$T_a = \frac{2e^{1i*k*d}}{T_{11} + \frac{T_{12}}{\rho_0 c_0} + \rho_0 c_0 T_{21} + T_{22}}, \quad (3)$$

where ρ_0 , c_0 and k are respectively the air density, the sound speed and the wave number. And

$$R_a = \frac{T_{11} + \frac{T_{12}}{\rho_0 c_0} - \rho_0 c_0 T_{21} - T_{22}}{T_{11} + \frac{T_{12}}{\rho_0 c_0} + \rho_0 c_0 T_{21} + T_{22}}. \quad (4)$$

The transmission loss (TL) is defined using the transmission coefficient:

$$TL = 10 \log_{10} \left(\frac{1}{|T_a|^2} \right), \quad (5)$$

and the absorption coefficient (α) using both transmission and reflection coefficients:

$$\alpha = 1 - |T_a|^2 - |R_a|^2. \quad (6)$$

Evaluated acoustic quantities (T_a , R_a) has been compared with the method using the pressure and velocity in only 2 points.

The real part ($a = \text{Re}(Z)$) and the imaginary part ($b = \text{Im}(Z)$) of the impedance defined on the treated surface and the length of the treated duct (d) are the 3 parameters of the parametric study. The length of the treated duct is equal to d (1 ring) or $2d$ (2 rings). The parameters' limits were initially defined by a rough calculation. The discretization and the limits were then adjusted. For each frequency, all combinations are tested and the couple (a , b) which gives the best absorption coefficient is selected. Results are presented in the next section.

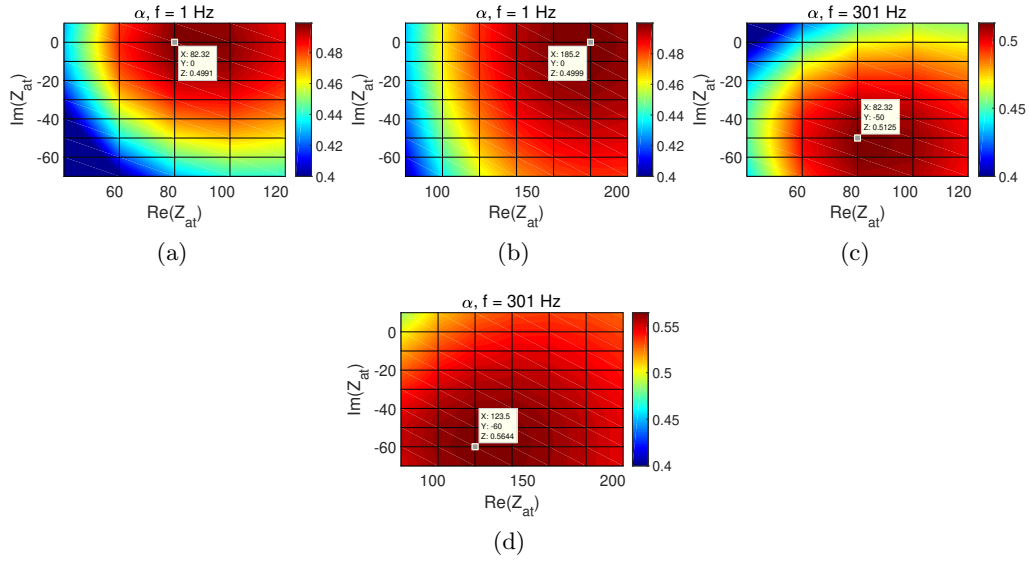


Figure 3. ABSORPTION COEFFICIENT DEPENDING ON THE REAL AND THE IMAGINARY PARTS OF THE IMPEDANCE. a) 1 TREATED RING AT 1 HZ. b) 2 TREATED RING AT 1 HZ. a) 1 TREATED RING AT 301 HZ. b) 2 TREATED RING AT 301 HZ.

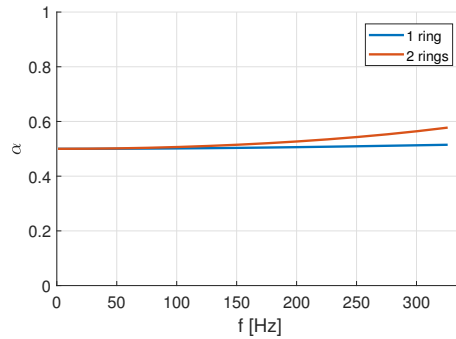


Figure 4. MAXIMIZED ABSORPTION COEFFICIENT.

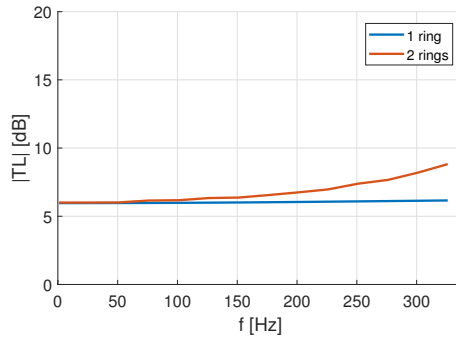


Figure 5. TRANSMISSION LOSS FOR OPTIMIZED IMPEDANCE.

RESULTS

Figures 3 present absorption coefficients depending on the real and the imaginary parts of the impedance for 1 and 2 treated rings at 1 Hz and 301 Hz. The emergence of single maximums has been observed in the different cases in the frequency range. Data cursors on figure 3 indicate maximum absorption coefficients in the 4 presented cases.

The best absorption coefficient can be plotted depending on the frequency, for the 1 and 2 treated rings configurations (figure 4). The absorption coefficient for 2 treated rings is better than 1 treated ring. In both cases, it greater than 0.5, constant for 1 treated ring. For 2 treated rings, an increase with the frequency is observed but without exceeding 0.6.

This parametric study is not focused on the transmission loss. For information, figure 5 shows the transmission loss and no discontinuity is observed.

Figures 6 and 7 show the optimized impedance (Z_{at}) for 1 and 2 treated rings. The active parts ($Re(Z_{at})$) of the impedance (figure 6) are still positive meaning stability. Imaginary part (figure 7, reactive parts of the impedance are negative, decrease with the frequency and are almost similar.

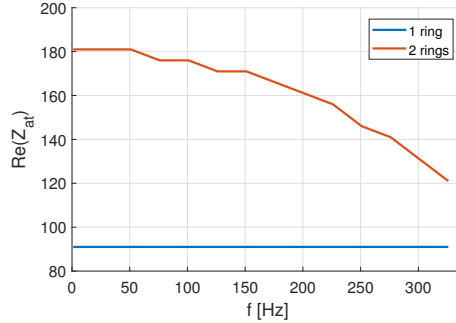


Figure 6. REAL PART OF THE OPTIMIZED IMPEDANCE.

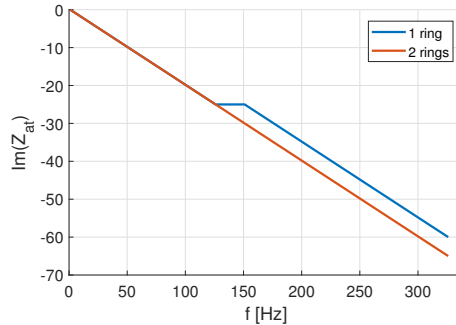


Figure 7. IMAGINARY PART OF THE OPTIMIZED IMPEDANCE.

For the 1 treated ring case, the optimal impedance, fitted from the plot, can be written as follow:

$$Z_{at} = \rho_0 c_0 / 5 - 0.32 \times i\omega. \quad (7)$$

The value of the inertia term is negative. These data will be taken into account in the future implementation.

CONCLUSION

This article presents a parametric study based on the maximization of the absorption coefficient in a duct by optimizing the impedance of a treated area. For 1 and 2 treated rings, active parts of the impedance are still positive that means passivity. The optimized impedance will be adapt in a liner based on arrays of unit cells. Each unit cell will be composed of a transducer (a loudspeaker), 5 microphones and a control card with localized or distributed (non-localized) control strategies.

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