Design guidelines for the acoustic performance improvement of a periodic porous material

DESIGN GUIDELINES FOR THE ACOUSTIC PERFORMANCE IMPROVEMENT OF A PERIODIC POROUS MATERIAL

D. Magliacano[1,2], M. Ouisse[1], S. De Rosa[2], F. Franco[2] and A. Khelif[1]

[1] FEMTO-ST Institute, Univ. Bourgogne Franche-Comté, Besançon, FRANCE
Email: dario.magliacano@univ-fcomte.fr, morvan.ouisse@univ-fcomte.fr, abdelkrim.khelif@univ-fcomte.fr

[2]DII – Sez. Ing. Aerospaziale, Università degli Studi di Napoli "Federico II", Naples, ITALY
Email: sergio.derosa@unina.it, francesco.franco@unina.it

ABSTRACT

In this paper, some guidelines are provided in order to predict at which frequency the 1st performance peak (related to periodicity effects: half of the wavelength = periodicity dimension) appears, together with its amplitude, as functions of the unit cell dimensions. Conversely, also the link between the unit cell dimensions and the 1st performance peak amplitude as functions of the design frequency is shown. Furthermore, some additional guidelines are provided in order to predict at which frequency the 1st performance peak appears, together with its amplitude, as functions of the foam airflow resistivity.

1 INTRODUCTION

The design based on periodic elements is a powerful strategy for the achievement of lightweight sound packages and represents a convenient solution for manufacturing aspects [1]. An interesting research target is the inclusion of vibroacoustic treatments at early stage of product development through the use of porous media with periodic inclusions, which exhibit proper dynamic filtering effects [2]; this address different applications in transportation (aerospace, automotive, railway), energy and civil engineering sectors, where both weight and space, as well as vibroacoustic comfort, still remain as critical issues. Here we propose some design guidelines in order to tune the performances of a JCA-modeled foam [3], [4], which make possible to obtain a device whose frequency efficiency outperforms existing designs.

2 DESIGN GUIDELINES

Some guidelines are provided in order to predict at which frequency the 1st performance peak (related to periodicity effects: half of the wavelength = periodicity dimension) appears, together with its amplitude, as functions of the unit cell dimensions. Conversely, also the link between the unit cell dimensions and the 1st performance peak amplitude as functions of the design frequency is shown. The test campaign is carried out in the 0 – 18000 Hz frequency range, through the use of a repetition of five 3D unitary cells constituted by a 2 cm cube with a 0.5 cm radius perfectly rigid cylindrical inclusion, where the dimension of the inclusion changes accordingly to those of the unit cell (the ratio between the unit cell and the inclusion dimensions is kept constant).

Density [kg/m^3]	Prandtl number	Dynamic viscosity [kg/(m*s)]	Adiabatic bulk modulus [kg/(m*s^2)]	Specific heat ratio
1.205	0.713	1.983*10^{-5}	1.42*10^5	1.401

Table 1: Air properties.

Porosity	Tortuosity	Resistivity [Pa*s/m^2]	Viscous characteristic length [mm]	Thermal characteristic length [mm]
0.99	1.02	8430	0.138	0.154

Table 2: Acoustic parameters of the foam used for the numerical test campaign.

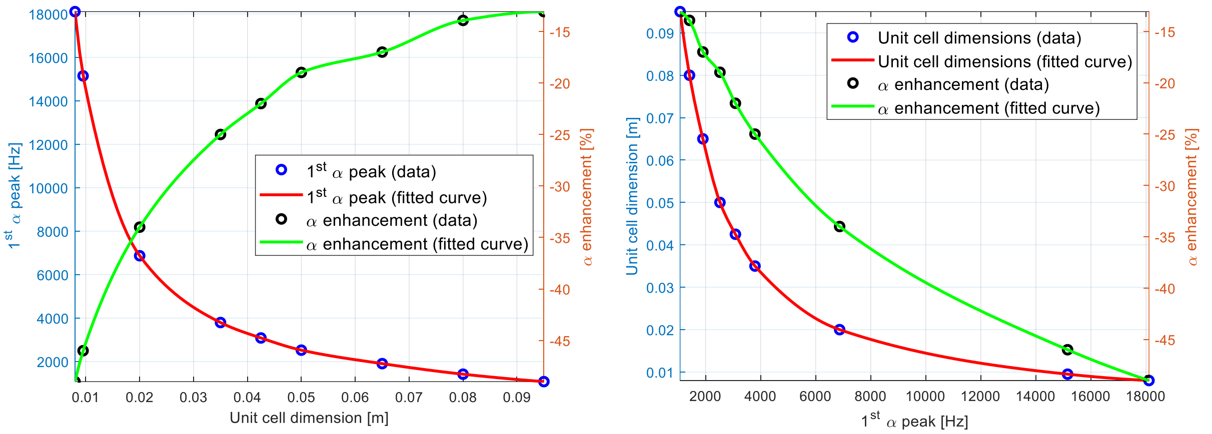

Figure 1: Absorption coefficient design curves as a function of the unit cell dimension (on the left) and the frequency of the 1st peak (on the right).

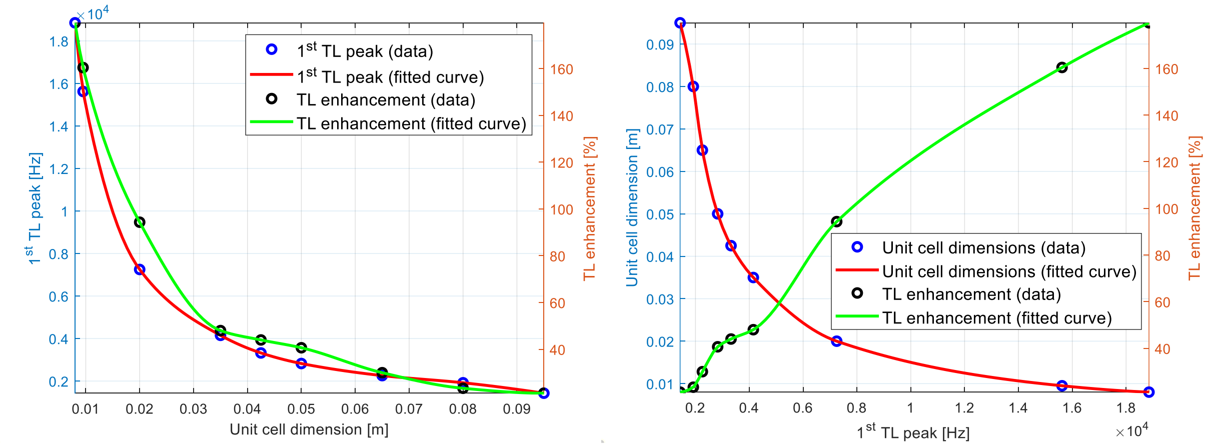

Figure 2: Transmission loss design curves as a function of the unit cell dimension (on the left) and the frequency of the 1st peak (on the right).

According to the results obtained in Figure 1 and Figure 2, and considering that a typical acoustic excitation in aeronautics lays in the range of 20 – 2000 Hz [5], one should choose a unit cell dimension between 0.065 m and 0.1 m in order to obtain a transmission loss improvement of averagely 25% respect to the use of a simple foam layer of the same thickness. Considering an automotive application, instead, the typical acoustic excitation lays in the range of 20 – 4000 Hz [6], and therefore one should choose a unit cell dimension between 0.035 m and 0.1 m in order to obtain a transmission loss improvement of averagely 35% respect to the use of a simple foam layer of the same thickness.

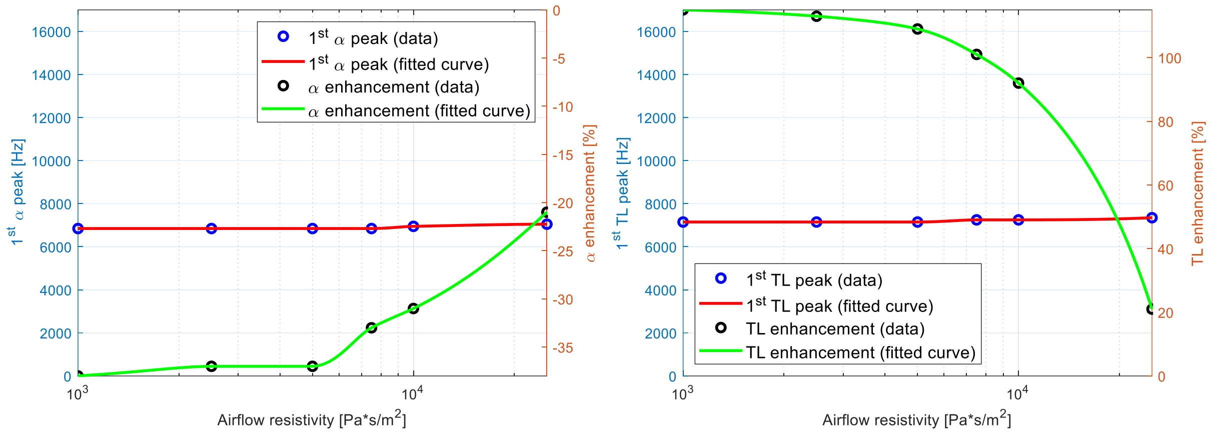

Figure 3: Absorption coefficient (on the left) and transmission loss (on the right) design curves as functions of the foam airflow resistivity value.

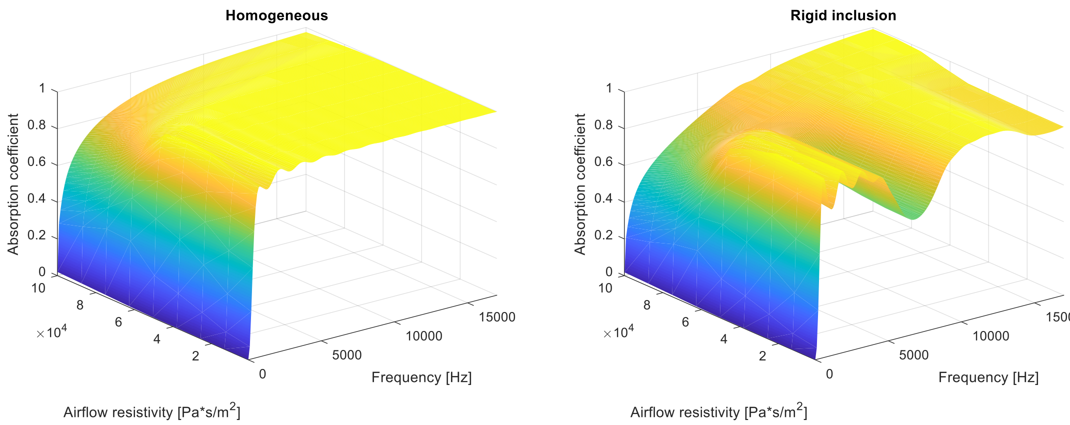

Figure 4: Absorption coefficient value as a function of frequency and foam airflow resistivity; homogeneous case (on the left) and case with a cylindrical perfectly rigid inclusion (on the right).

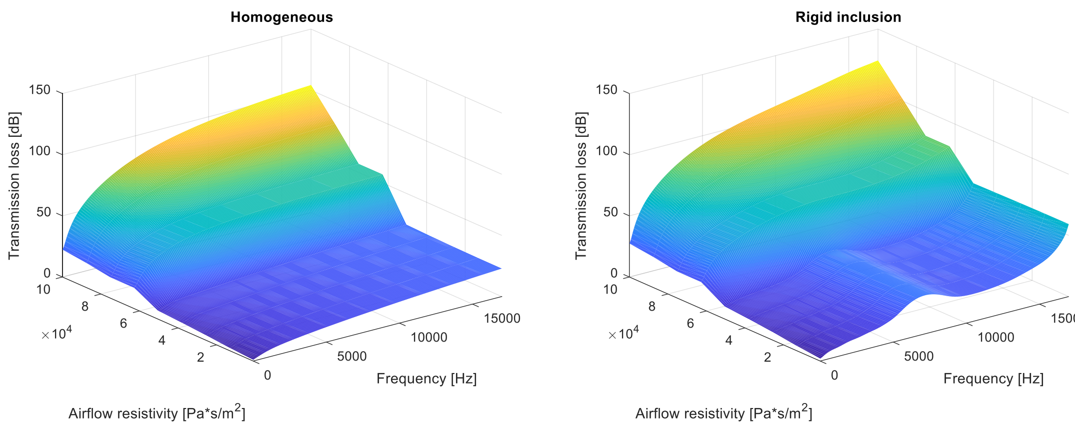

Figure 5: Transmission loss value as a function of frequency and foam airflow resistivity; homogeneous case (on the left) and case with a cylindrical perfectly rigid inclusion (on the right).

Furthermore, some guidelines are also provided in order to predict at which frequency the 1st performance peak appears, together with its amplitude, as functions of the airflow resistivity value of the foam. The test campaign is carried out in the 0 – 17000 Hz frequency range, by comparing a repetition of five melamine unit cells, where the airflow resistivity value is artificially changed. Looking at Figure 3, it is clear that the static airflow resistivity has no meaningful impact on the position of the periodicity peak in the frequency range. Instead, one may notice that σ has a non-negligible effect on the variation of the non-homogeneous values, compared to the homogeneous ones, in correspondence of the periodicity peak: in particular, this variation reduces its amplitude at increasing airflow resistivity values, both for absorption coefficient and transmission loss performances. This is probably due to the fact that, as shown in Figure 4 and, in an even more evident manner, in Figure 5, for a homogeneous layer of foam, when σ increases absorption coefficient performances decrease, while transmission loss ones gets better. This is an expected phenomenon, since the airflow resistivity parameter may be considered as an "acoustical hardness" indicator of a foam, in the sense that, the higher it is, the less air permeability there is. It is evident, then, that the general effect of the presence of any external inclusion in the foam reduces at increasing σ, and the non-homogeneous curves tends to assume the same behavior of the homogeneous one, still maintaining a bias difference in the average value (as it can be clearly seen from Figure 5). Indeed, already starting from $\sigma = 50000\ \frac{\mathrm{Pa*s}}{\mathrm{m}^2}$, periodicity peaks are no more precisely identifiable.

3 CONCLUSIONS

In this paper, some guidelines are provided in order to predict at which frequency the 1st performance peak appears, together with its amplitude, as functions of the unit cell dimensions and of the airflow resistivity; conversely, also the link between the unit cell dimensions and the 1st performance peak amplitude as functions of the design frequency is shown. Results are very promising for aeronautic and automotive applications.

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