Evaluation of improved correction factors for the prediction of Helmholtz resonances

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Abstract

It is well-known that there is an increasing growing interest on the environmental noise reduction. Aiming at this goal, different approaches could be investigated and adopted: for example, porous media, whose foam cavities dissipate the energy by viscous and thermal losses, show very good performance at high frequencies [1], while tunable acoustic devices, such as Helmholtz resonators, perform better at low frequencies.

A Helmholtz resonator is a tunable device with rigid walls and filled of fluid, whose geometry is usually represented by a neck followed by a cavity. With reference to acoustic applications, Helmholtz resonators exhibit a single resonance frequency; thus, they are commonly defined as 1-Degree-of-Freedom (DoF) systems. Indeed, Helmholtz resonators may be conceptually assimilated to a mass-spring system, in which the fluid in the neck represents the mass, while those in the cavity constitutes the spring.

Innovative meta-materials offer great flexibility for manipulating sound waves and assure unprecedented functionality in the context of acoustic applications, ranging from transformation acoustics, super-resolution imaging to acoustic cloaking. More specifically, Helmholtz resonators are exploited in several applications with the aim to reduce noise transmission. However, the design of acoustic meta-materials with exciting functionality still represents a challenge, therefore there is a huge interest about the conceptualization and design of innovative acoustic solutions making use of meta-material resonance effects.

A first attempt of obtaining an approximate mathematical estimation of a Helmholtz resonator tuning frequency, starting from its fundamental geometrical characteristics, was proposed by Rayleigh [2]. Successively, Ingard [3] modified Rayleigh's formula by increasing its complexity in order to provide an alternative estimation of Helmholtz resonator frequency, which has explicit dependance on the ratio between the representative lengths in the section plane of the neck and the cavity.

The main target of the present research work is to obtain an accurate prediction of the tuning frequency of a Helmholtz-resonating device, numerically modeled through a Finite Element approach. In this context, it is performed an investigation on a correction factor c_f for the classical formulation used to estimate the Helmholtz resonance frequency starting from its geometrical characteristics, accounting for different-shaped resonators with varying neck/cavity ratios ξ:

$$f_{HR} = \frac{c_0}{2\pi}\sqrt{\frac{S_{neck}}{V_{cavity} l_{neck}\left(1 + c_f \xi\right)}}$$

More specifically, a set of analyses are performed, and results in terms of correction factor (Figure 1) are provided in both graphical and polynomial form, also demonstrating their good accuracy respect to Finite Element ones (Figure 2).

Acknowledgments

The authors acknowledge the support of the Italian Ministry of Education, University and Research (MIUR) through the project DEVISU, funded under the scheme PRIN-2107 – grant agreement No. 22017ZX9X4K006.

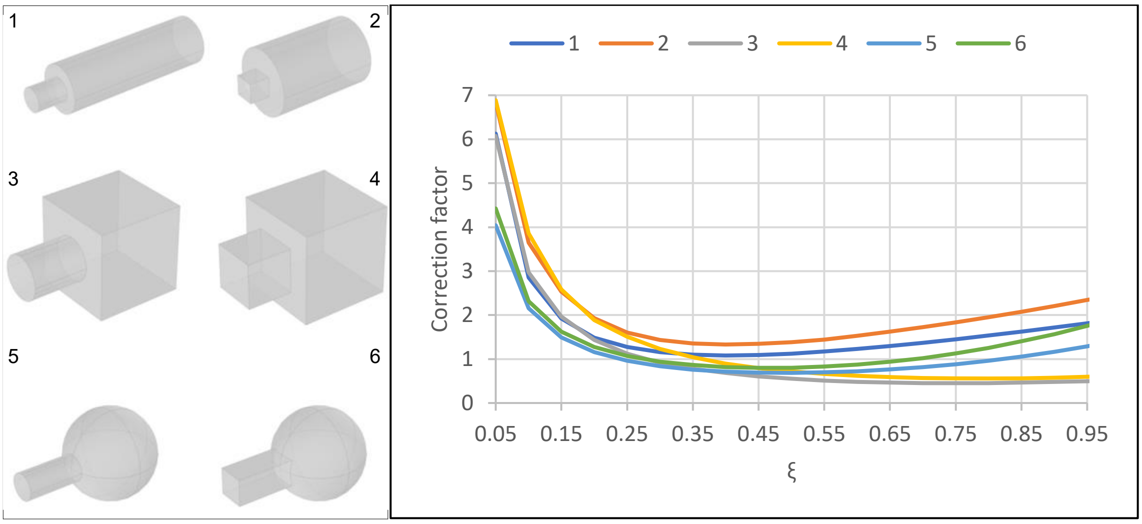

Figure 1: Representation of the studied configurations (on the left); estimation of the correction factor for the six studied Helmholtz resonator configurations (on the right).

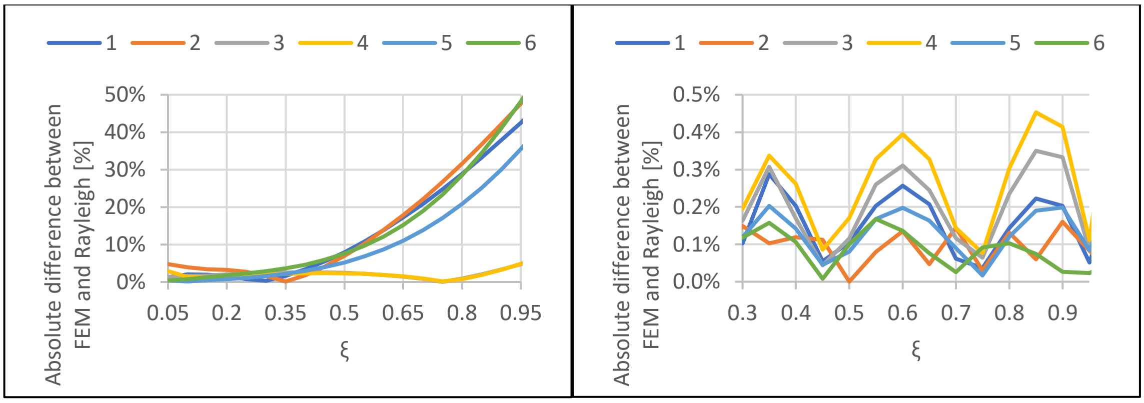

Figure 2: Evaluation of the absolute errors of Rayleigh's formula (on the left) and of the proposed polynomial approximation (on the right), with reference to Finite Element results, for the six studied Helmholtz resonator configurations.

References

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