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An Acoustical Finite Element Model of Perforated Elements

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Outline

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- Theoretical background
- Acoustical resonators
- Perforated elements in mufflers
- Concluding remarks

Introduction

Resonating systems are widely used in several noise control applications

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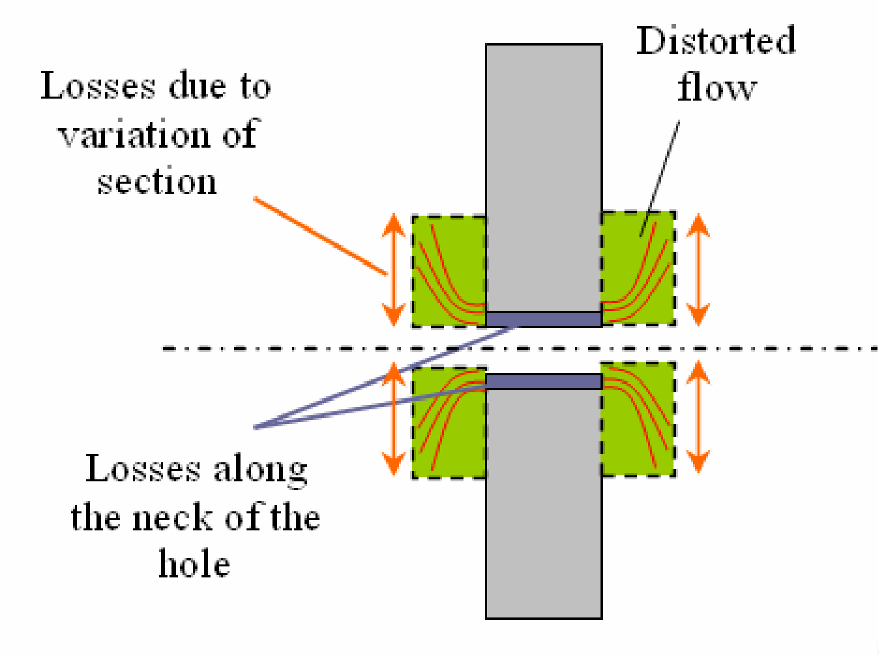
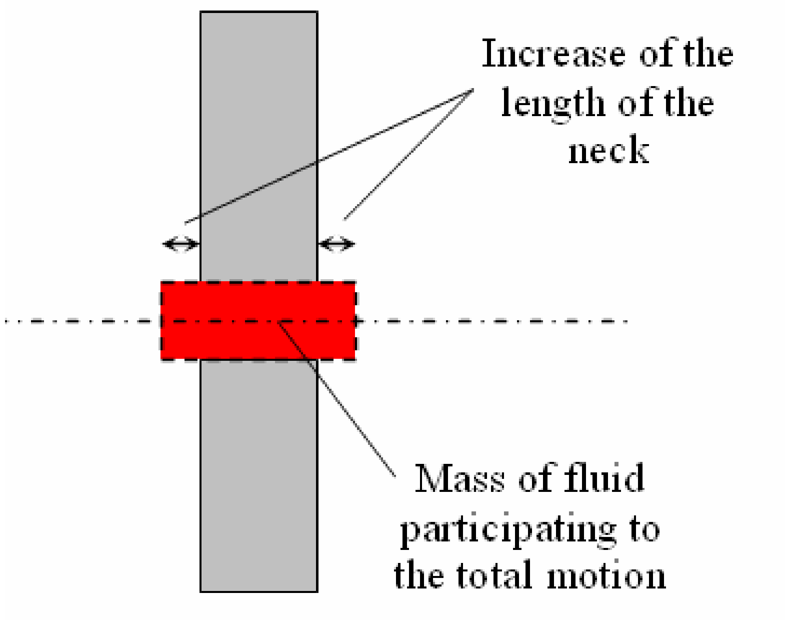
In literature it is possible to find analytical formulas based on fluid-dynamics concepts for evaluating losses occurring across the holes of these panels.

An acoustical FE formulation for modeling losses in the openings will be presented and validated against experimental tests.

Theoretical background

Physics involved in the process





In modeling sound propagation through perforated sheets, losses are accounted by introducing corrections related to the distortion of flow and increment of the mass participating to the total motion of air

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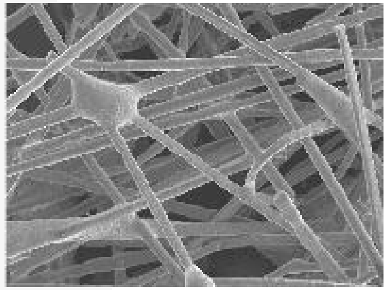
Theoretical background

The formulation is based on the equivalent dissipative fluid approach.



Used for modeling porous media

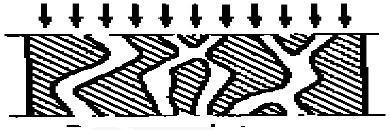
In the widely used equivalent fluid model of Johnson-Champoux-Allard

$$\rho = \frac{\alpha_\infty \rho_0}{\phi} + \frac{\sigma}{i\omega}\sqrt{1 + \frac{4 i \alpha_\infty{}^2 \eta \rho_0 \omega}{\sigma^2 \Lambda^2 \phi^2}}$$

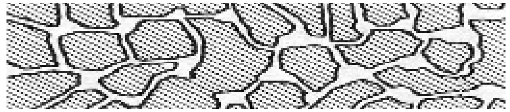
$$c = \sqrt{\frac{\kappa \cdot P_0 / \phi\rho}{\kappa - (\kappa - 1)\left[1 + \frac{8\eta}{i\rho_0 \omega N_p \Lambda'^2}\sqrt{1 + \frac{i\rho_0 \omega N_p \Lambda'^2}{16\eta}}\right]^{-1}}}$$

Theoretical background

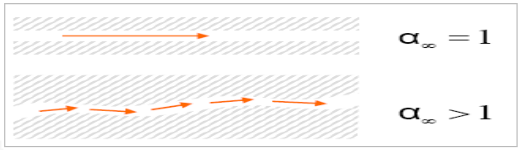
Airflow resistivity σ



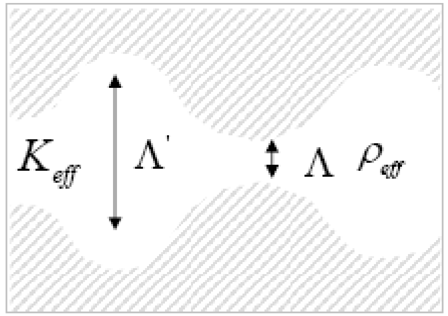
Open porosity ϕ



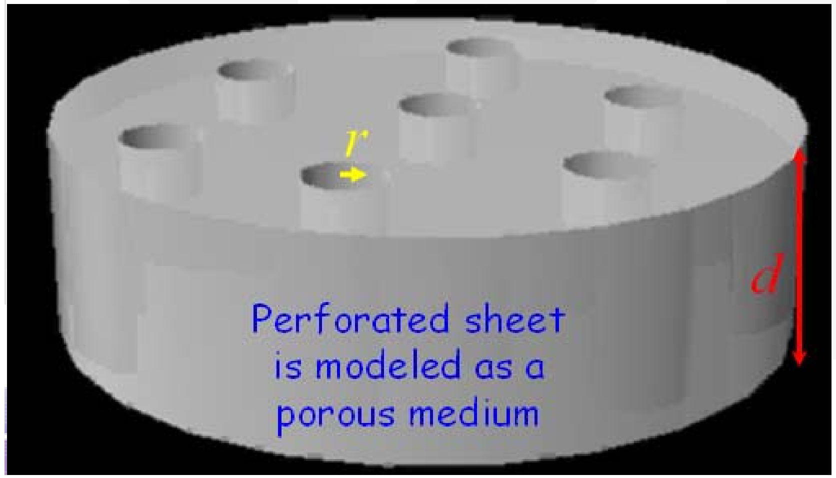
Tortuosity α_∞



Viscous and thermal characteristic lengths Λ and Λ'



For each hole:



$$\sigma = \left(\frac{2d}{r} + 4 \right) \frac{\sqrt{2 \eta \omega \rho_0}}{2 \phi d}$$

$$\phi = 1$$

$$\alpha_\infty = 1$$

$$\Lambda = \Lambda' = r$$

Acoustical resonators

In order to validate the formulation a FEM model of simple acoustical resonators have been created in Comsol Multiphysics 3.5a.

Sound absorption coefficient and reflection coefficient have been calculated in a virtual impedance tube by means of the well established Transfer Function method using two microphones.

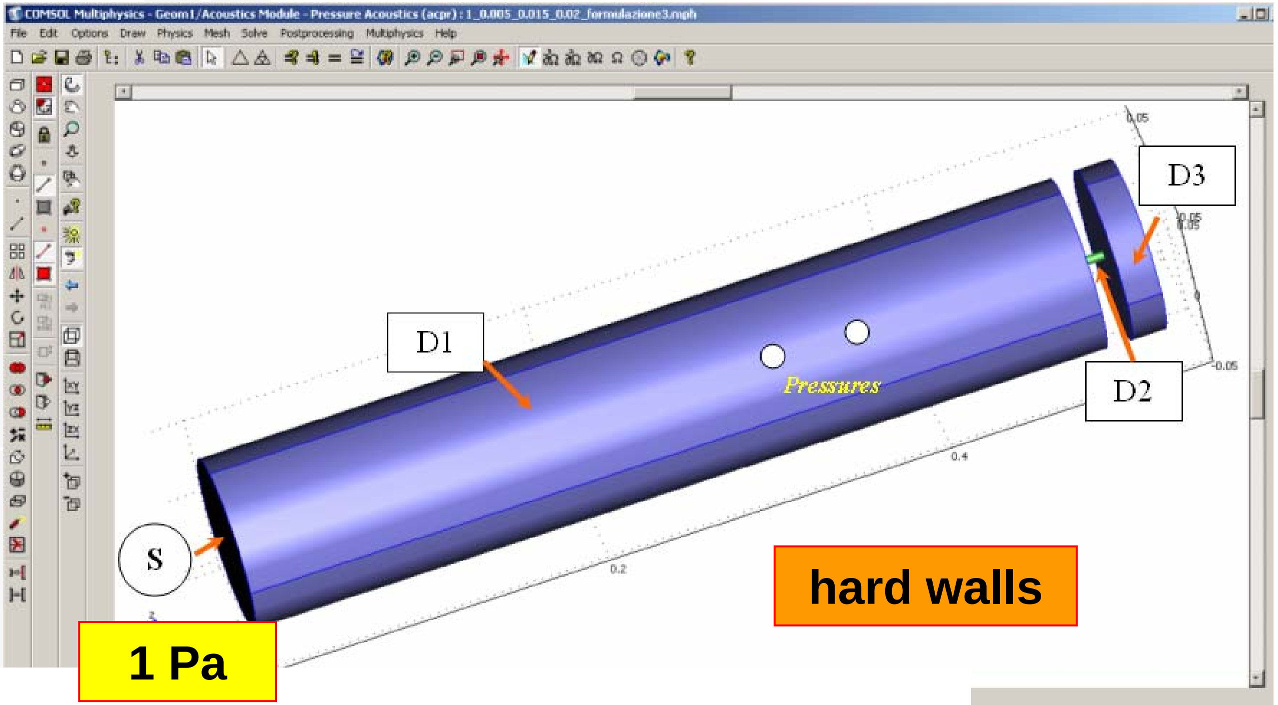
Result have been compared with experimental tests.

Five different resonators have been tested in 42 different configurations (in terms of perforation ratio, radius of the holes, thickness of the plate and air gaps).

Acoustical resonators

FEM Model

Mesh has been created according to the rule of 10 finite elements per wavelength.



domains:

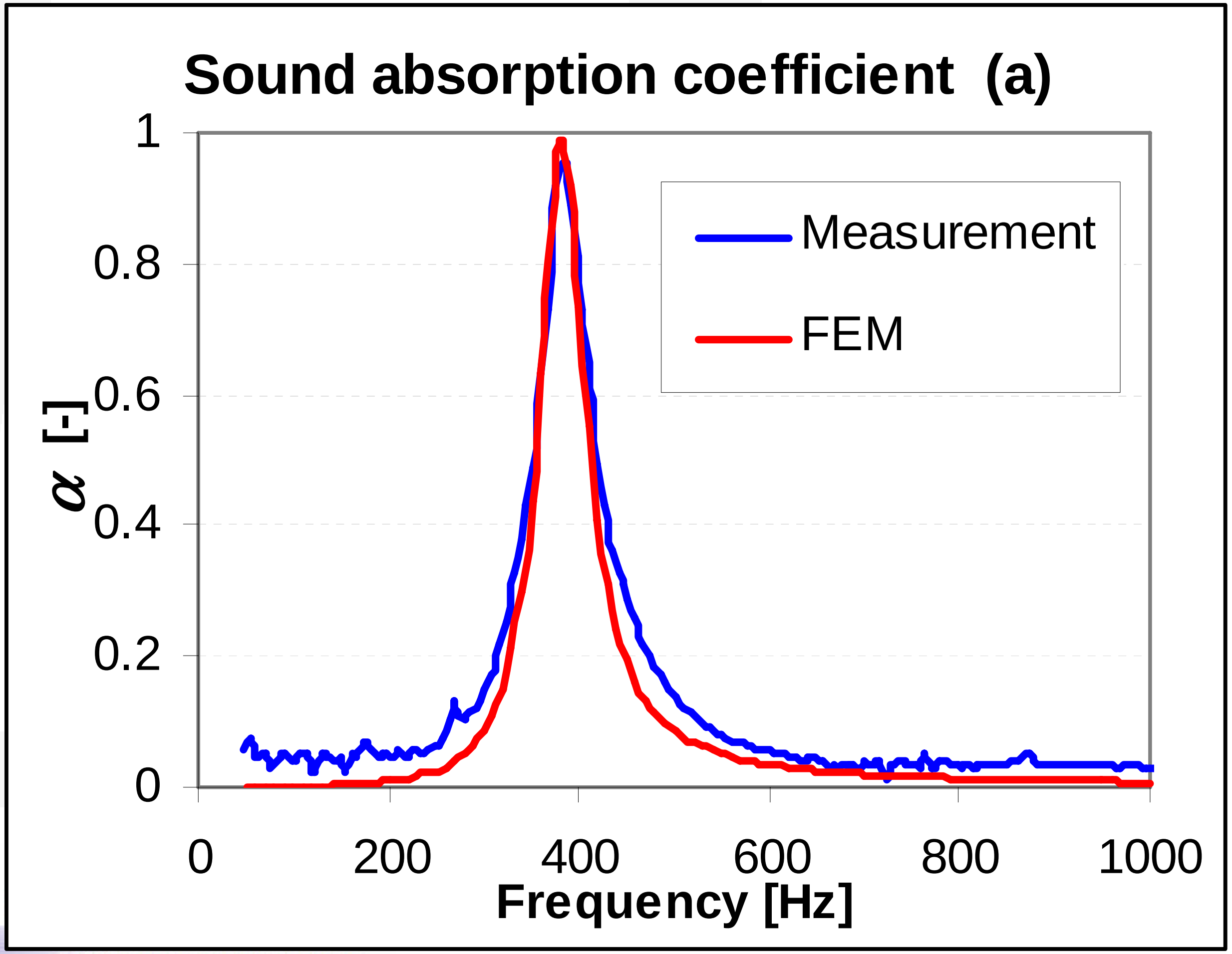
D1 (tube): ρ = 1.21 kg/m^3 and ***c*** = 343 m/s

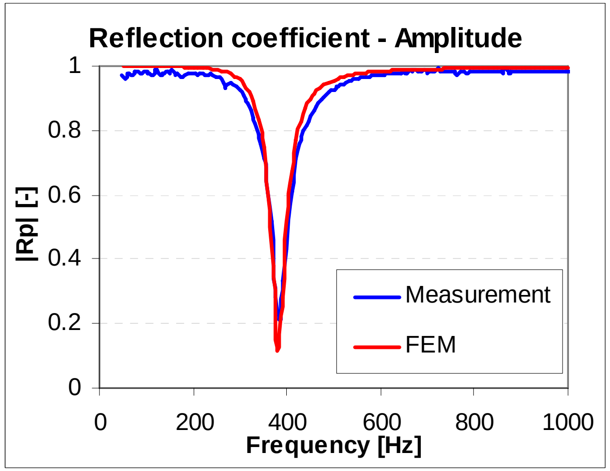
D2 (hole): ρ and ***c*** from the model

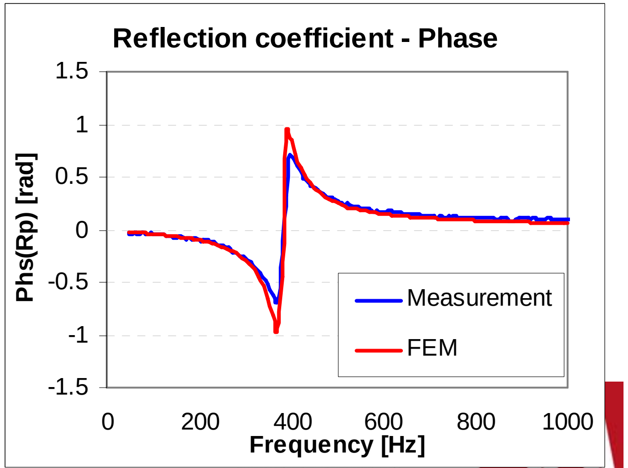
D3 (air gap): ρ = 1.21 kg/m^3 and ***c*** = 343 m/s

Acoustical resonators

Results







Perforated elements in mufflers

Once the acoustical formulation has been validated for modeling losses in plane perforated panels, it has been applied for predicting the sound transmission loss of reactive mufflers.

Note: Perforates in mufflers could be implemented in a finite element code by substituting the 3D perforated shells with a 2D layer having a given impedance “jump”

Perforated elements in mufflers

Tested mufflers

perforation ratios
- 3.86% (hole radius 3mm)
- 6.86% (hole radius 4mm)
- 7.71% (hole radius 3mm).

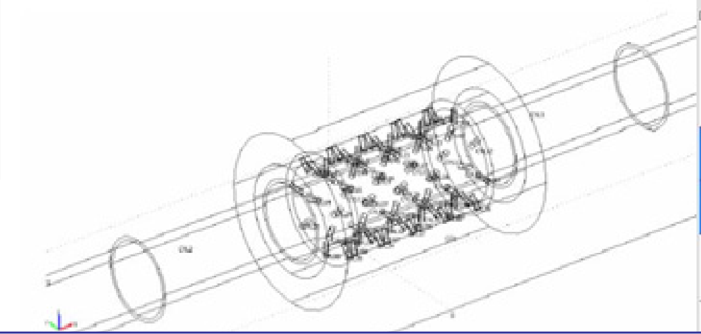
The muffler has been tested also with the back cavity filled with low density polyester fiber (10 kg/m3).

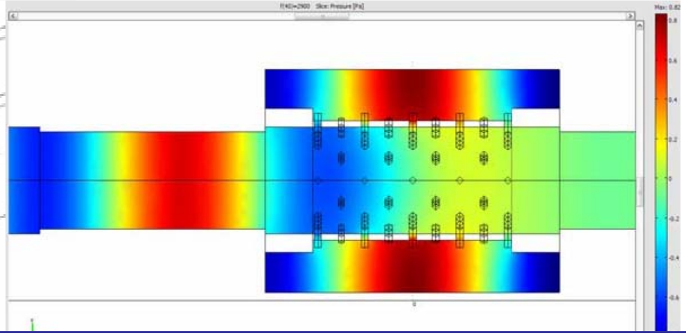
The normal incidence sound transmission loss has been determined in the frequency range between 50 and 4000 Hz in a plane wave tube by means of a transfer matrix approach and four microphones

Perforated elements in mufflers

FEM model

The model of the plane wave tube and the reactive muffler has been developed in Comsol Multiphysics 3.5a





Mesh has been created according to the rule of 10 finite elements per wavelength.

Domain conditions:

•holes: ρ and ***c*** from the model

•Air: ρ=1.21 kg/m^3 and c=343 m/s.

•Fibrous materials: equivalent dissipative fluid approach: density and sound velocity have been determined by using a semi-empirical model developed for polyester fiber materials.

Boundary conditions:

•Sound source at the inlet (Pressure 1Pa)

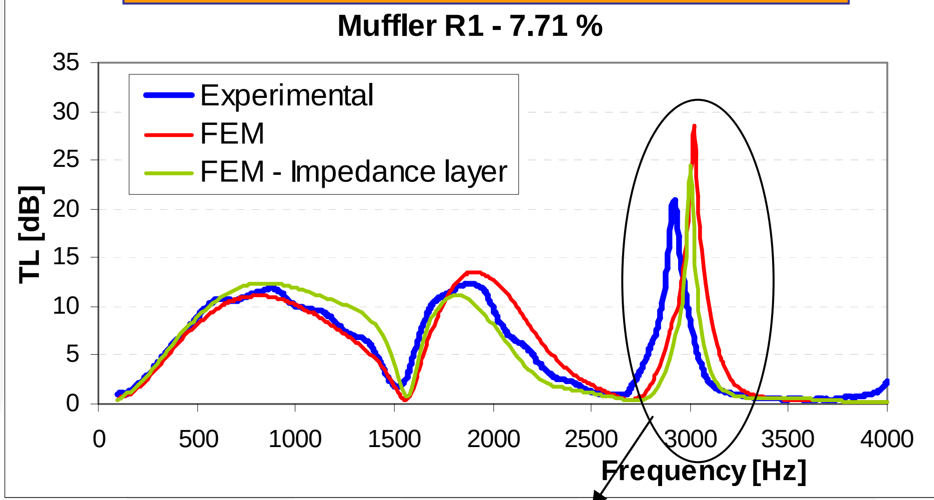
•Hard lateral walls

• impedance (415 rayls) at the outlet

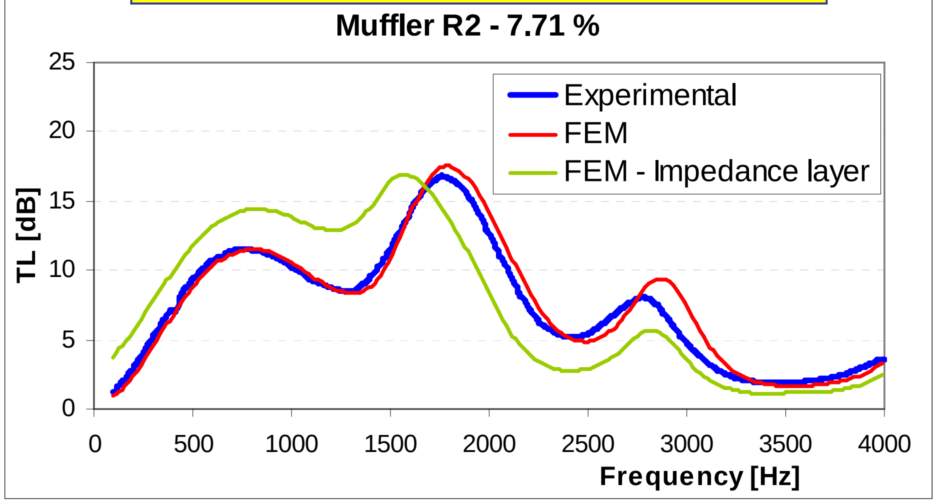
Perforated elements in mufflers

Results

Without material in the back-cavity



With material in the back-cavity



Discrepancies could be mainly due to small geometrical differences between real muffler and numerical model.

Difference : 2-3 dB

Note: The boundaries of the FEM model are completely reflective and energy can not outgoing the solid structure of the muffler; a full coupled structural-acoustical FEM model of the muffler should be implemented to account this effect.

Concluding remarks

- An acoustical formulation (based on the conept of equivalent dissipative fluid) for the FEM modeling in Comsol Multiphysics 3.5a of the losses in perforates.
- Initially the formulation has been applied to plane acoustical resonators and sound absorption coefficient has been calculated with satisfying accuracy at normal incidence.
- Successively the same formulation has been utilized to model perforates within a muffler and to predict its normal incidence sound transmission loss. The FEM model has permitted a reliable prediction of the sound transmission loss also in the case of back cavity filled with fibrous material.
- Future effort will be devoted to include mean flow and temperature effects through the holes of the perforates as well as the absorbing materials.