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Analysis of Sound Propagation in Lined Ducts by means of a Finite Element Model

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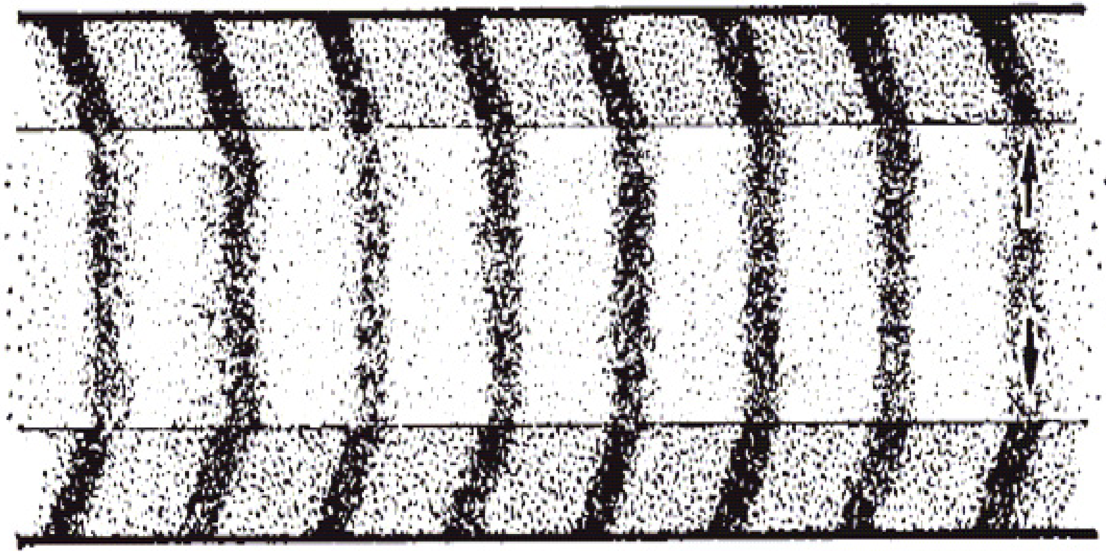
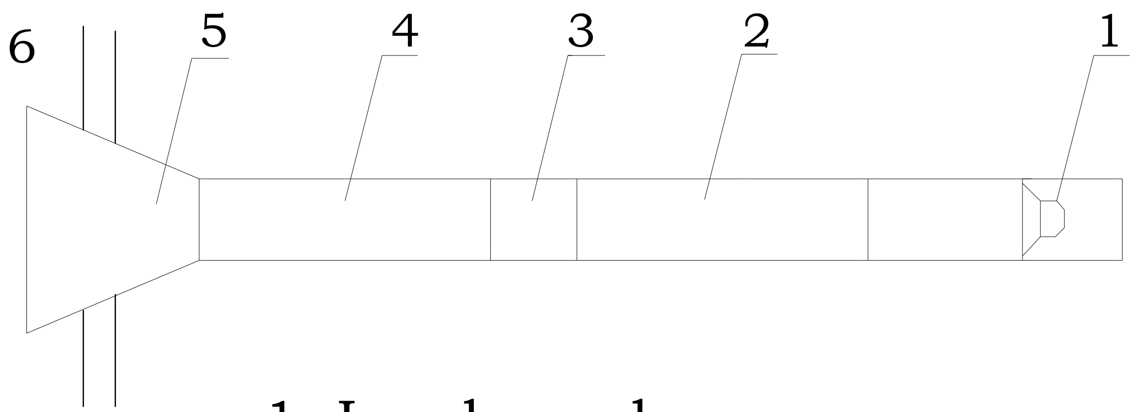
Lined ducts



Dissipation of energy at ends of plane waves in a lined duct

Experimental setup: sketch



1: Loud speaker
2,4: Test duct
3: Substitution duct – silencer
5: Transition element
6: Reverberating room

Experimental setup: picture

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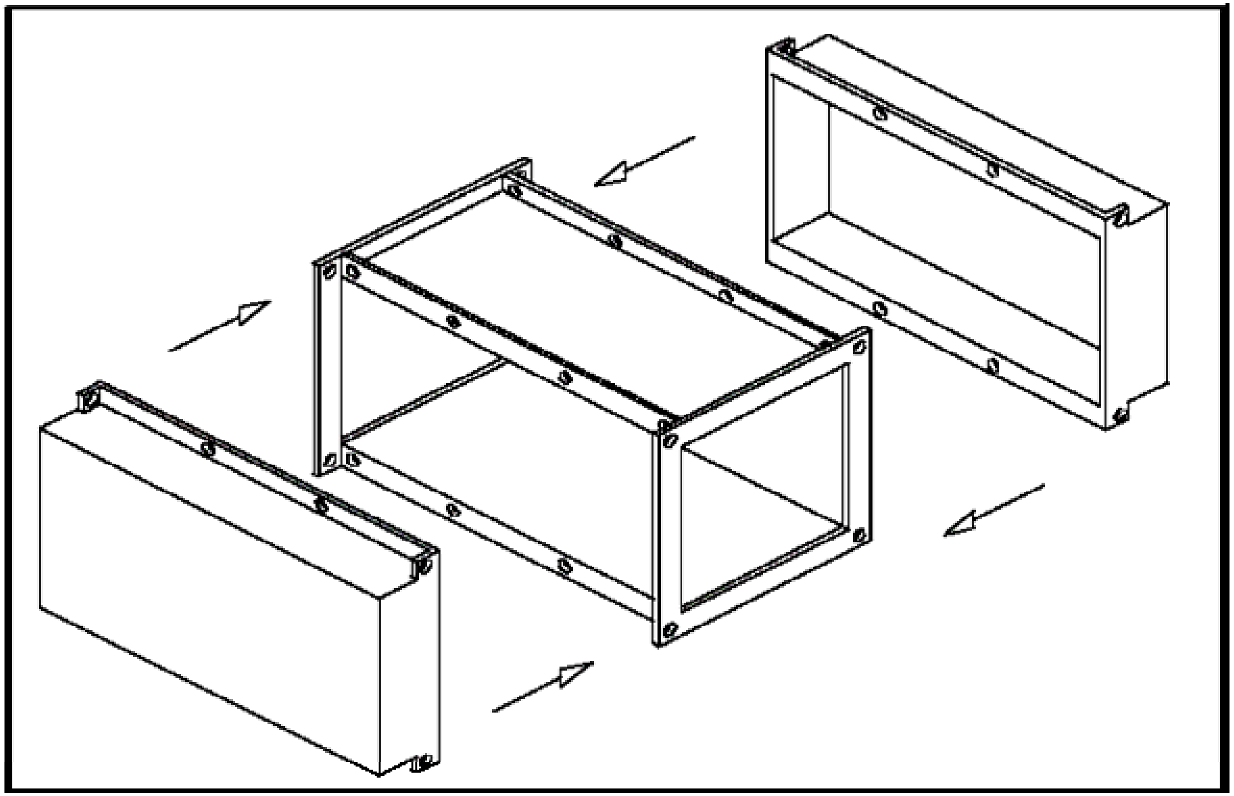


Substitution duct with replaceable symmetrical side pockets

Experimental procedure

- Pink noise was generated at the closed end of the channel by means of a broad-band loudspeaker
- The generated signal was picked up by a microphone positioned in three different points inside the reverberation room, according to ISO standards
- The signal was elaborated by means of a sound level meter and its data analysis software
- Measurements were taken by alternatively mounting on the experimental set-up the substitution duct or the muffler

$$IL = SPL_1 - SPL_2$$

Numerical modelling

- Time-harmonic analysis
- *Sound-hard boundary* condition to model rigid surfaces
- The *radiation* condition has been used in the entrance section and the ending section
- The *Delany-Bazley model* for porous media has been used to model the sound damping inside the simmetrical side pockets of the simulated lined duct
- *Brick mesh* with cuboid shaped elements
- PARDISO solver
- Macintosh computer with 2.16 GHz dual-core Intel CPU and 4 GB of RAM

Delany-Bazley model for porous media

$$\nabla \cdot \left(-\frac{1}{\rho_c} (\nabla p - q) \right) - \frac{\omega^2}{\rho_c c_c^2} p = Q$$

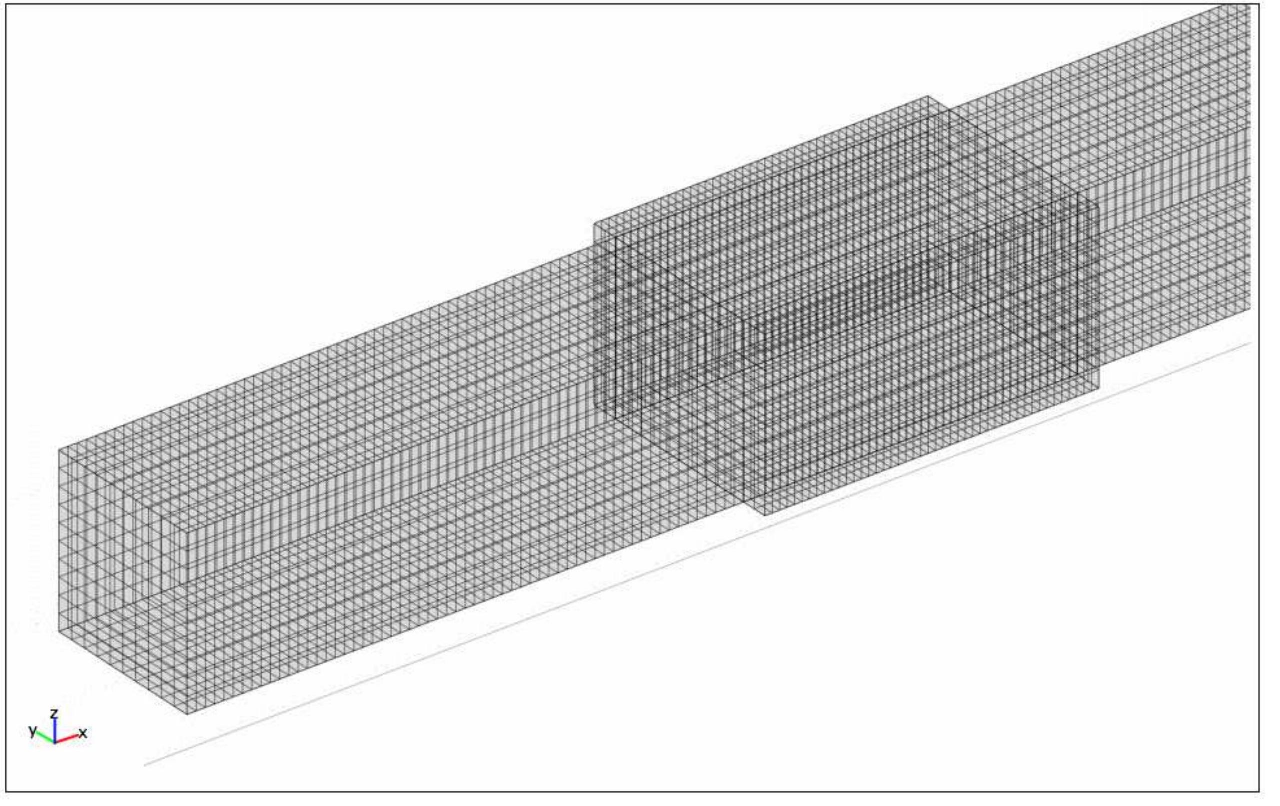
$$\rho_c = \frac{Z_c k_c}{\omega} \qquad c_c = \frac{\omega}{k_c}$$

$$k_c = \frac{\omega}{c_s} \left[1 + C_1 \left(\frac{\rho_0 f}{R_f} \right)^{-C_2} - i C_3 \left(\frac{\rho_0 f}{R_f} \right)^{-C_4} \right]$$

$$Z_c = \rho_0 c_s \left[1 + C_5 \left(\frac{\rho_0 f}{R_f} \right)^{-C_6} - i C_7 \left(\frac{\rho_0 f}{R_f} \right)^{-C_8} \right]$$

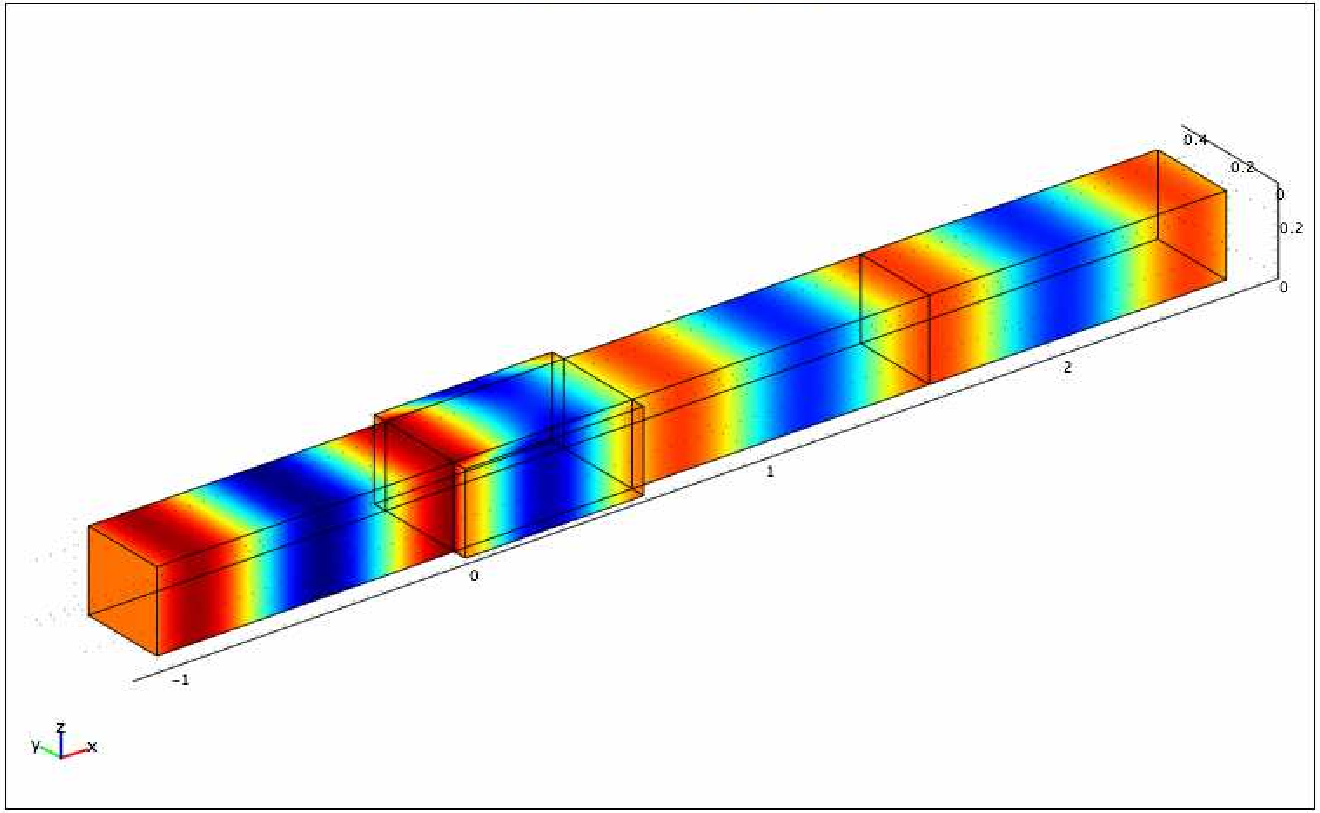
$$R_f = \frac{\rho_{rw}^{1.53} K}{d_{rw}^2}$$

Brick mesh

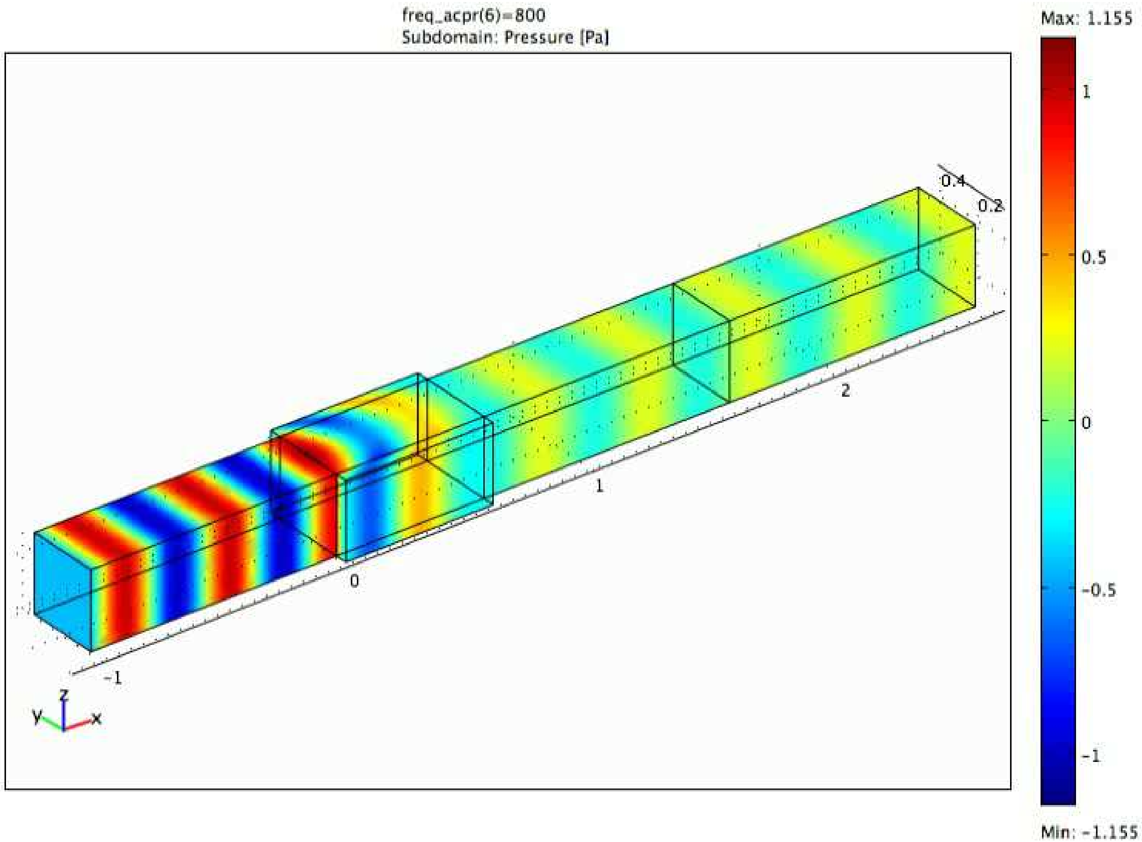


Calculated pressure distribution

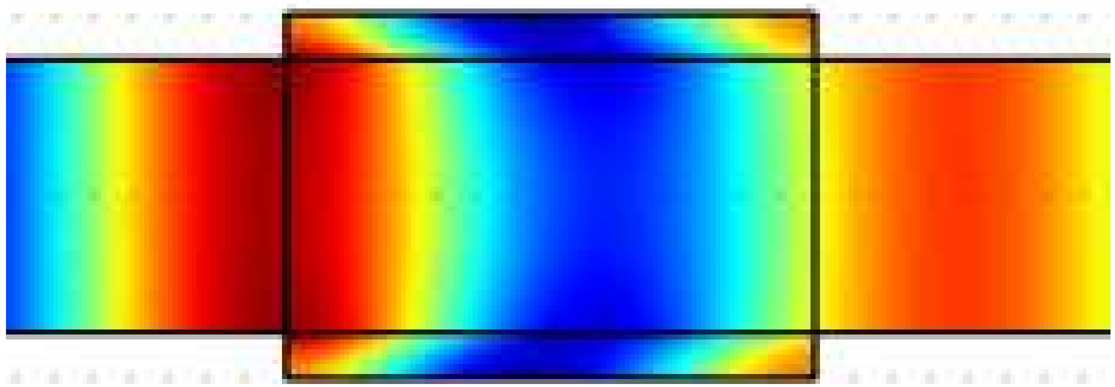
freq_acpr(3)=400 Subdomain: Pressure [Pa]



Incoming wave propagation



Dissipation of energy at ends of plane waves in a lined duct



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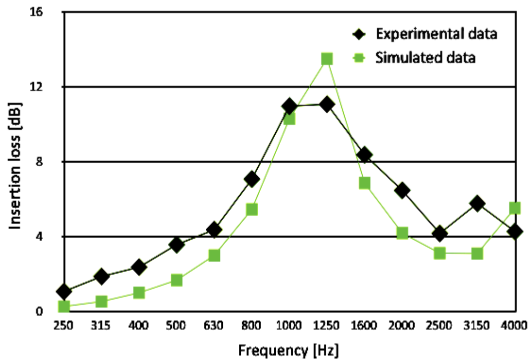
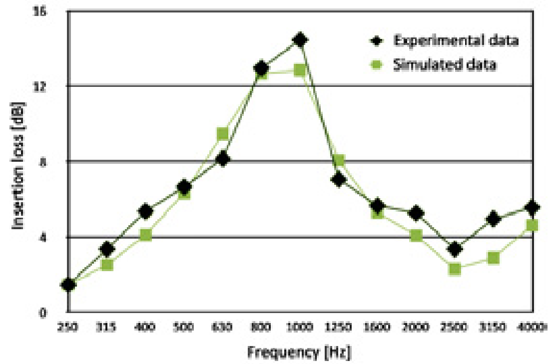
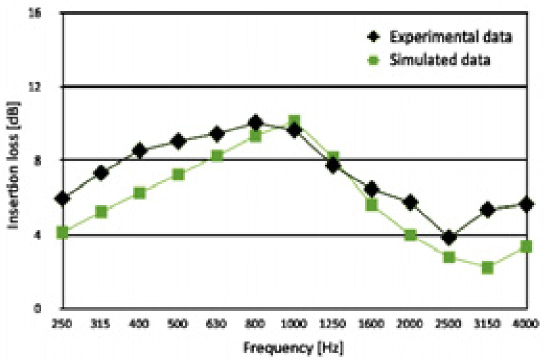
Comparison between experimental and simulated data for different thickness



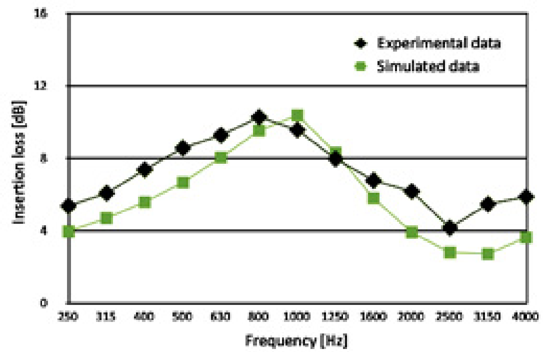
a) Thickness: 25 mm



b) Thickness: 50 mm

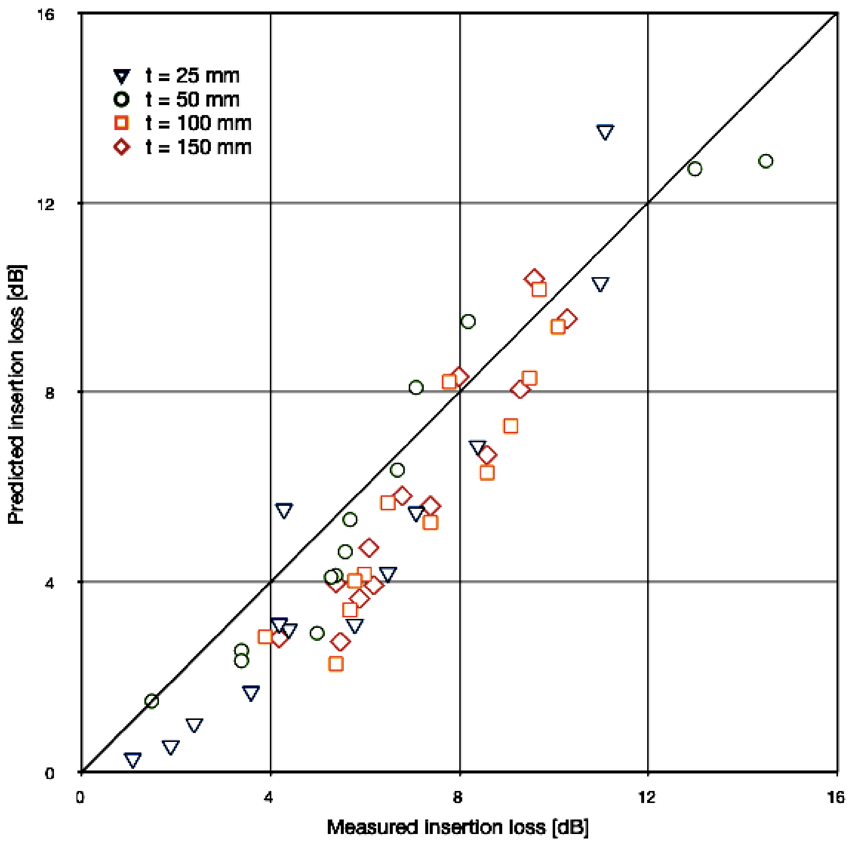


c) Thickness: 100 mm

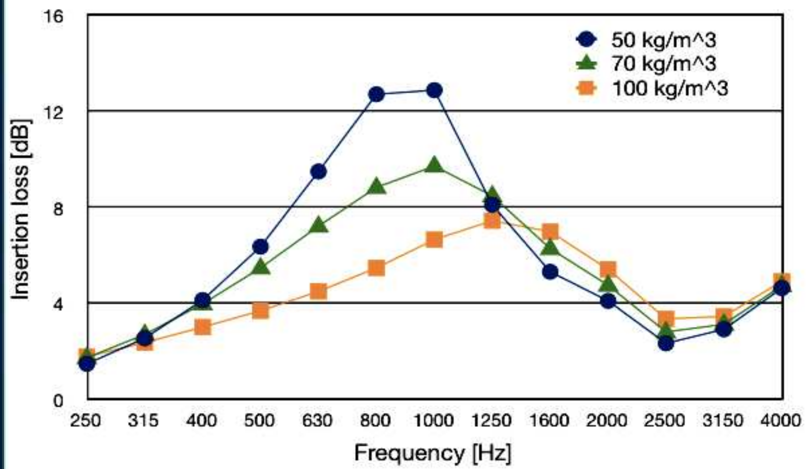


d) Thickness: 150 mm

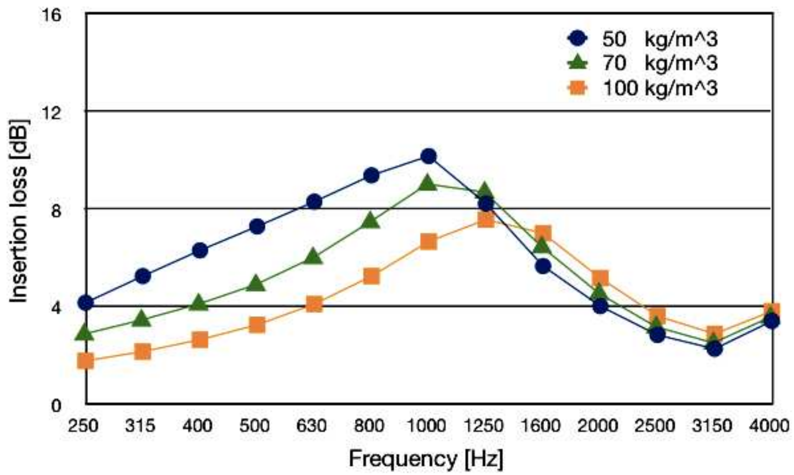
Comparison between measured and predicted insertion loss for the different lining thicknesses



Effect of the density of the mineral-wool for different thicknesses



a) Thickness: 50 mm



b) Thickness: 100 mm

Conclusions

- Sound propagation in rectangular lined ducts has been described and analyzed
- The numerical model was validated by comparing predicted data with experimental results
- The performance of the PARDISO solver has has been much better than the one of other solvers
- Finite Element Model correctly described the effect of lining thickness on sound propagation
- Next step: include fluidodynamics into the numerical model