FEM for viscothermal acoustics

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Introduction

Viscothermal boundary layer effects can not be neglected in acoustic problems with small characteristic dimensions. Such problems can be modeled by one of the existing viscothermal FEM models (FLNS, BLI, LRF) or by the new SLNS model.

The FLNS model (Full Linear Navier-Stokes, [1]) is the most general, but computationally expensive because it solves five coupled DOFs.

The BLI model (Boundary Layer Impedance, [2]) is computationally much more efficient, but only valid for relatively large geometries.

The LRF model (Low Reduced Frequency, [3]) is computationally even more efficient, but only valid for uniform or smoothly varying waveguides below the cut-off frequency.

The new SLNS model (Sequential Linear Navier-Stokes) is introduced on this poster. Its validity is not limited by strong geometric constraints. Furthermore, it is computationally less costly than the FLNS model because it only solves three uncoupled DOFs.

Demonstration

The new SLNS model and the other FEM models are demonstrated on a custom designed sample for an impedance tube [4], see figure 1. This sample has a rapidly varying cross-section and narrow passages where viscothermal effects are prevalent.

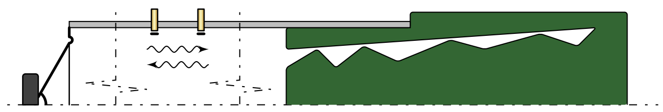

Figure 1 : Impedance tube with custom sample. The setup is axisymmetric, except for the microphones.

Accuracy

The absorption coefficient of the impedance tube sample is measured and calculated with the four FEM models; see figure 2.

The LRF model fails because the sample's cross-section varies rapidly.

For another reason, the BLI model fails: the thickness of the sample's narrowest passages is comparable to the boundary layer thickness.

In contrast to the BLI and the LRF models, the SLNS model performs very well.

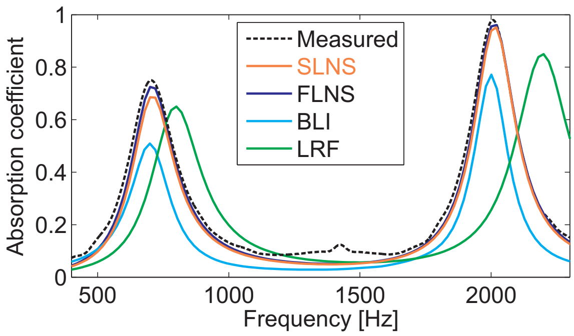

Figure 2 : Measured and calculated absorption coefficient: the SLNS model is accurate.

Computational costs

The calculation time per frequency and the number of DOFs of the models are compared in table 1.

The SLNS model is computationally more efficient than the FLNS model. This difference in computational costs will be even larger in true 3D models, as opposed to this axisymmetric (2D) case.

The calculation time for the (1D) LRF model is relatively large because the annular cross-section of the sample needs 20 Hankel function evaluations per integration point.

Model	Time/frequency	# of DOFs
FLNS	44 s	$178{\cdot}10^3$
SLNS	7 s	$3 \times 55{\cdot}10^3$
BLI	0.7 s	$2 \times 11{\cdot}10^3$
LRF	0.5 s	$2{\cdot}10^3$

Table 1 : Computational costs: the SLNS model is more efficient than the FLNS model

Acknowledgement

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References

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