Numerical and experimental investigation of sound propagation in porous media for aeronautics

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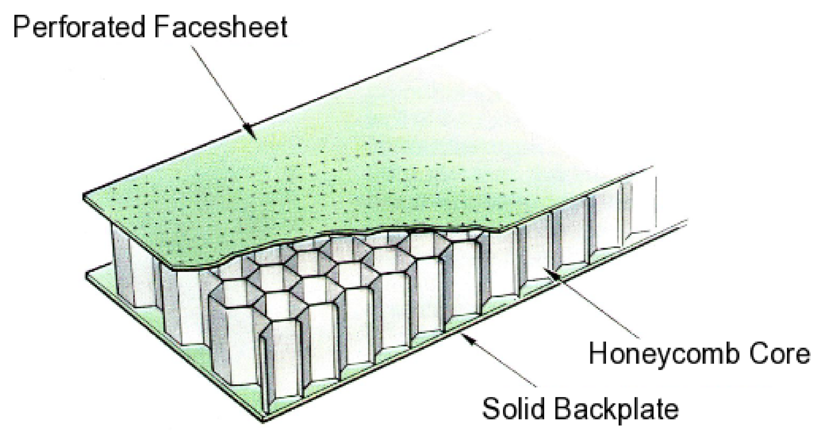
Context of the internship

Commercial aircraft.

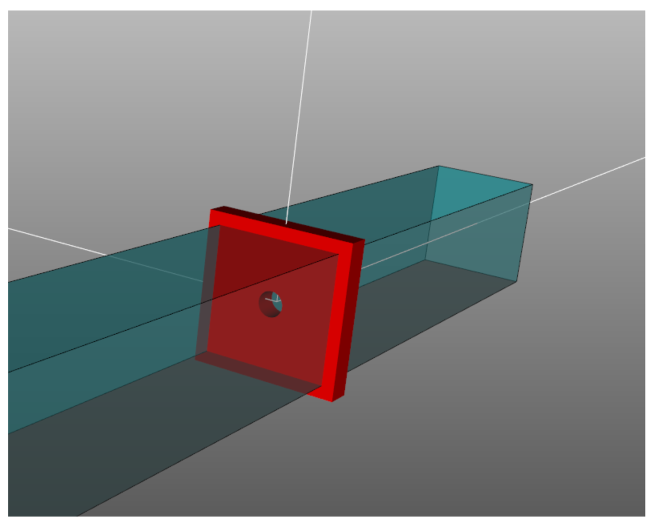
- Understanding the sound damping system of a turbofan.

Acoustic liner: micro perforated panel.



- Acoustic response at high sound pressure level under normal incidence.

Single perforation: (r, L_{cav}, ϕ, d).



- Studying the micro-structure.

Model

- 5 parameters porous media description: (σ, ϕ, α_∞, Λ, Λ').
- Acoustic surface impedance:

$$Z(\omega) = \frac{p(\omega)}{\mathbf{v}(\omega)\cdot\mathbf{n_S}} = R(\omega) + j\chi(\omega).$$

- Nonlinearity $\Rightarrow$ resistance increase & reactance decrease.

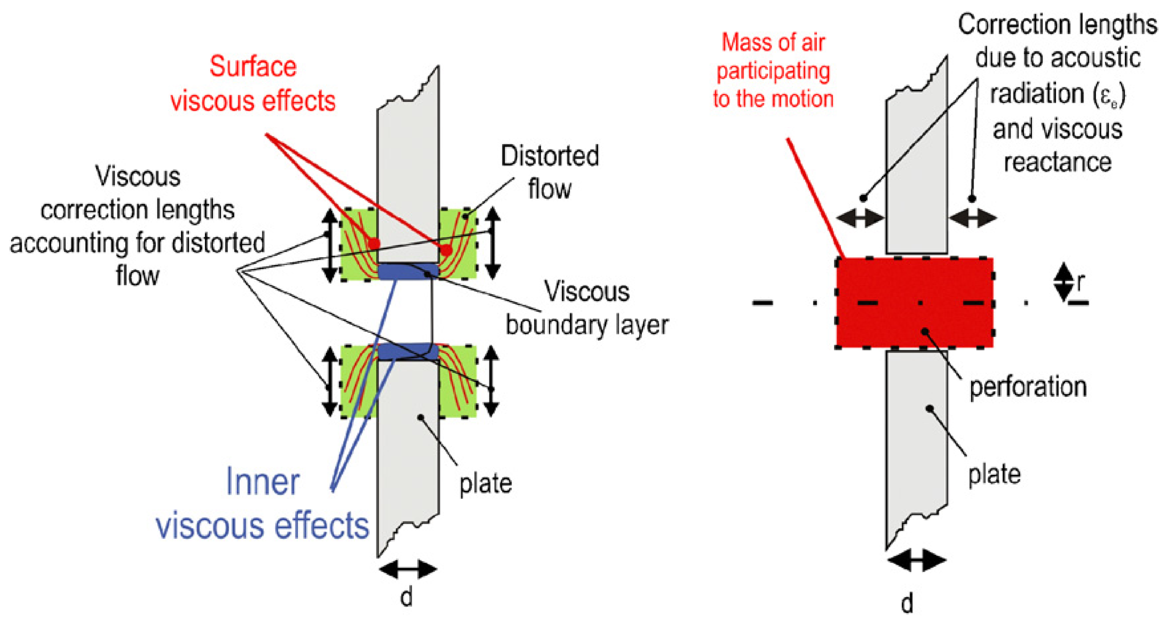


Fig. 1 – Physical phenomena involved in a perforated plate[1].

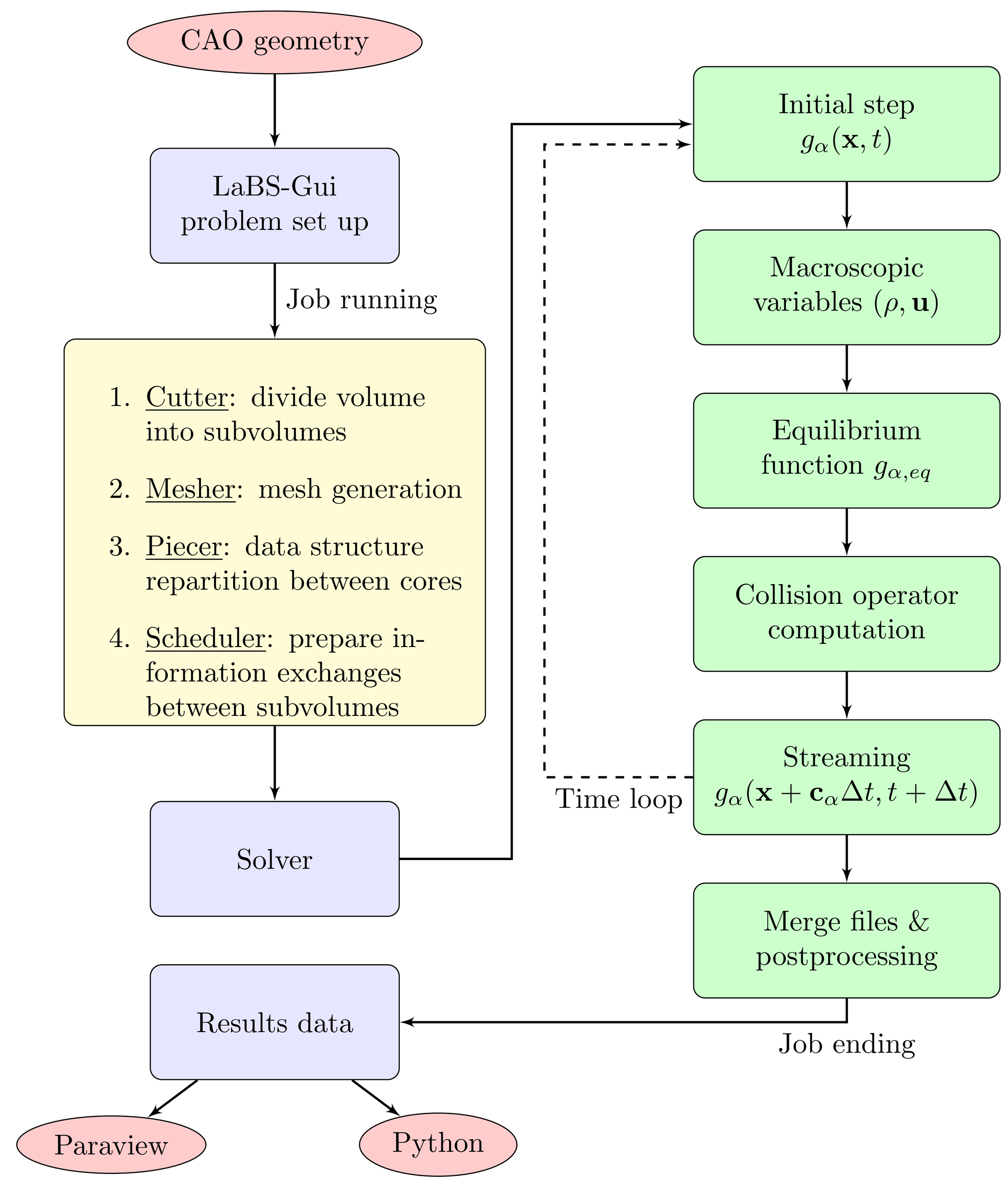
A Lattice Boltzmann Method: ProLB

- Statistical mechanics.
- Mesoscopic particle description.
- Particle probability distribution $f(\mathbf{x}, \mathbf{c}, t)$.
- Macroscopic variables $\Rightarrow$ first moments of $f(\mathbf{x}, \mathbf{c}, t)$.

Boltzmann equation

$$\underbrace{\frac{\partial f}{\partial t} + c_i \frac{\partial f}{\partial x_i}}_{\text{streaming}} = \underbrace{-\frac{1}{\tau}(f - f_{eq})}_{\text{collision}}$$

- Valid for low mach numbers.
- Multi-scale expansion $\Rightarrow$ Navier-Stokes equations.



Numerical & experimental results

Harmonic excitation

- Computations: 110dB to 170dB / 1600, 2500 & 4000 Hz.

Radius r	Cavity length L_{cav}	Porosity ϕ	Width d
0.15 mm	20 mm	5%	0.8 mm

- Vortex shedding absorption mechanism.

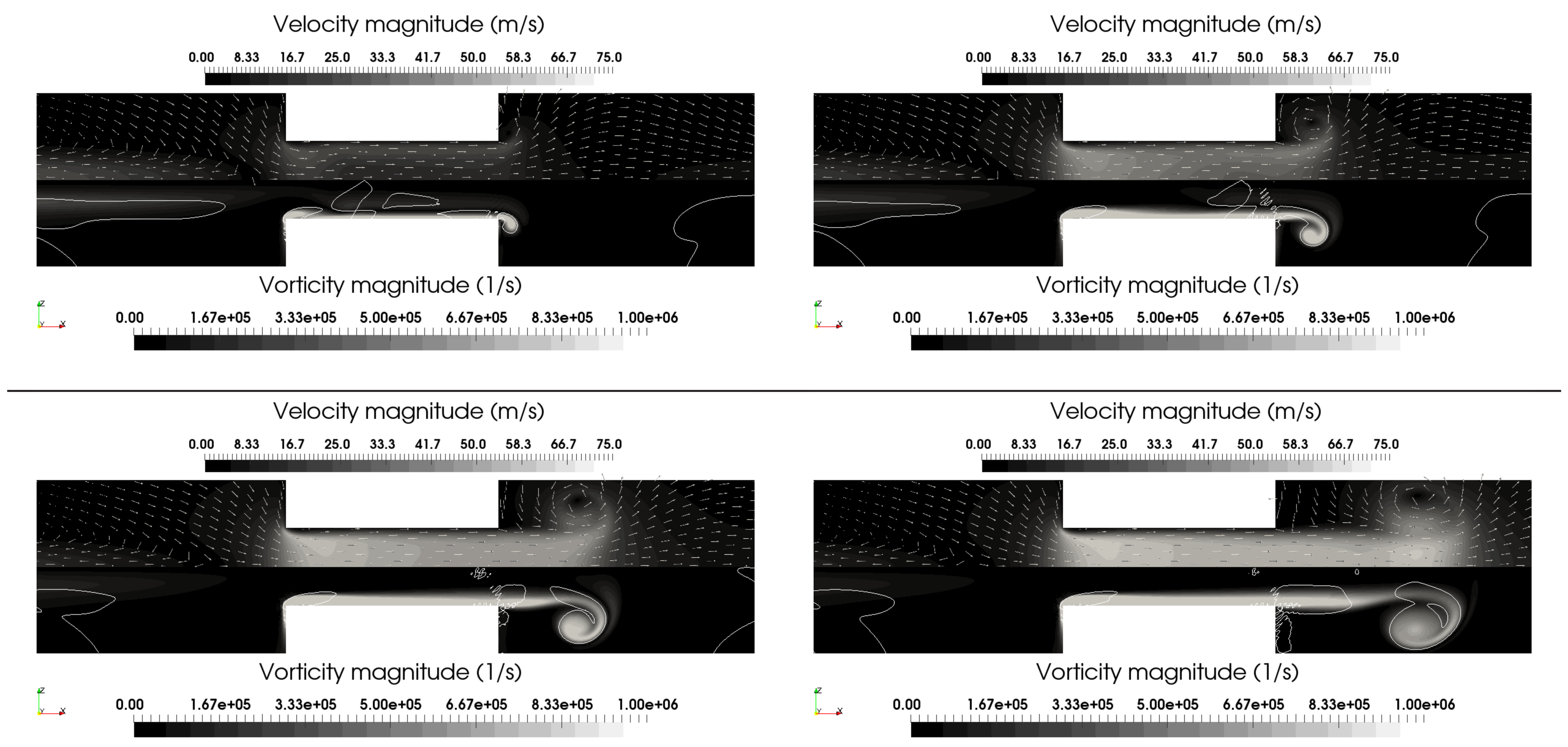


Fig. 2 – Time evolution of velocity and vorticity fields at 160 dB and 4000 Hz. Arrows: flow direction. Contours: Q-criterion. $\Delta t = 1/20$ T.

Broadband excitation

- Excitation by a linear chirp signal.

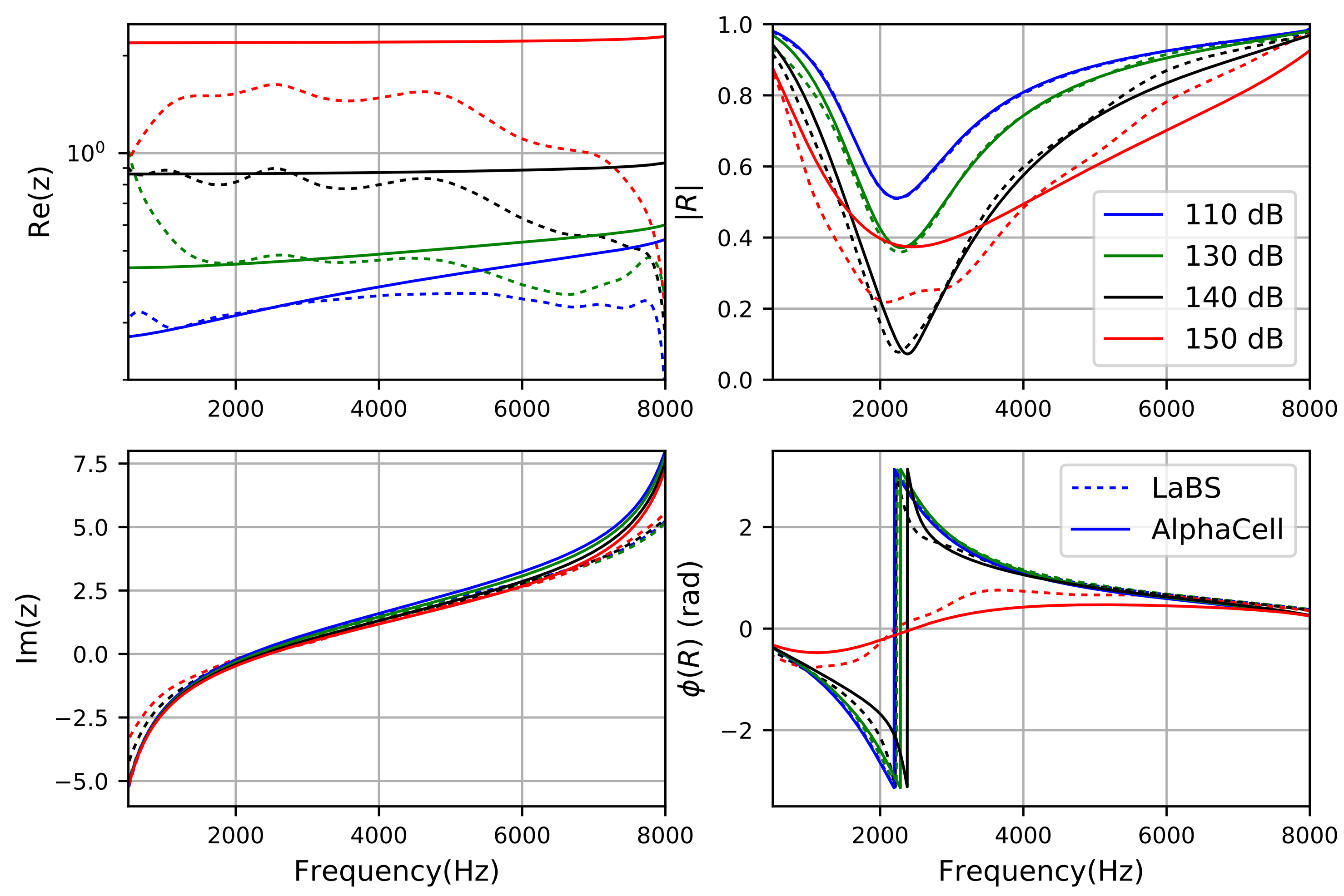


Fig. 3 – Acoustic properties of the perforated panel for different sound pressure levels. AlphaCell model and ProLB comparison.

- Measurements in an impedance tube $\Rightarrow$ good agreement.

[1] N. Atalla, F. Sgard, "Modeling of perforated plates and screens using rigid frame porous models", *Journal of Sound and Vibration*, 2007.
[2] T.H Melling, "The acoustic impendance of perforates at medium and high sound pressure levels", *Journal of Sound and Vibration*, 1973.
[3] J-M. Roche, "Simulation numérique de l'absorption acoustique de matériaux résonants en présence d'écoulement", *PhD*, 2011.
[4] P. Sagaut, "Méthodes LBM. Introduction et exemples d'application", *Lecture notes*, CERFACS, 2016.