

A non-linear impedance model for micro-perforated liners

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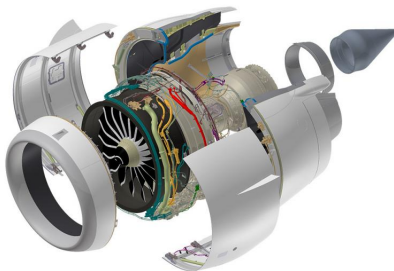
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Context

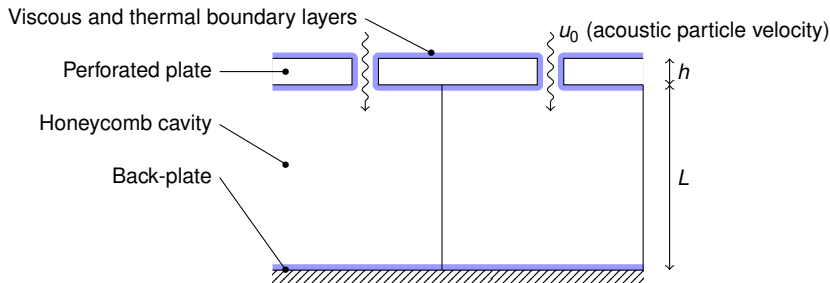
- Maximize sound attenuation.
- Reduce aerodynamic losses due to surface roughness.
- Micro-perforated liners: porosity $\sigma < 5\%$, perforation radius $R_{\text{neck}} < 0.5$ mm.



Nacelles from an A320neo.

Perforated liner

- The liner is locally reacting: no propagation in the transverse direction inside the cavity.
- Linear regime: thermo-viscous dissipation, radiation and back plate reflection.
- Non-linear regime: add dissipation due to vortex shedding from the corners of the perforations. The resistance strongly depends on the acoustic particle velocity u_0 .



Guess semi-empirical model (1975)

Guess¹ provides an explicit expression of the impedance

$$z_{\text{Guess}}(u_0) = \Theta(u_0) + j\chi(u_0). \quad (1)$$

where Θ is the resistance and χ is the reactance:

$$\Theta(u_0) = \text{Re}(z_\nu) + \frac{2\pi^2}{\sigma} \left(\frac{R_{\text{neck}}}{\lambda} \right)^2 + \frac{1 - \sigma^2}{\sigma} \frac{|u_0|}{c_0}, \quad (2)$$

and

$$\chi(u_0) = \text{Im}(z_\nu) - \cot(kL) + \frac{\omega\delta}{\sigma c_0} \quad (3)$$

with

$$\delta = \frac{16R_{\text{neck}}}{3\pi} (1 - 0.7\sqrt{\sigma}) \left(\frac{1 + 5 \cdot 10^3 \left(\frac{|u_0|}{c_0} \right)^2}{1 + 10^4 \left(\frac{|u_0|}{c_0} \right)^2} \right). \quad (4)$$

We focus our interest on the term involving the acoustic particle velocity in the neck u_0 .

¹[Guess, 1975]

Laly's model (2018)

Laly's model ² is derived using an equivalent fluid approach. The impedance of a micro-perforated plate Z_{MPP} is defined as

$$Z_{MPP}(u_0) = j \frac{\omega h}{\sigma c_0} \alpha_{\infty nl}(u_0) \times \left(1 + \frac{R_t(u_0)\sigma}{j\omega\alpha_{\infty nl}\rho_0} \sqrt{1 + \frac{4j\rho_0\omega\mu\alpha_{\infty nl}^2}{\sigma^2 R_t(u_0)R_{neck}}} \right). \quad (5)$$

Here, R_t is the flow resistivity and $\alpha_{\infty nl}$ is the tortuosity. R_t and $\alpha_{\infty nl}$ can be expressed directly as a function of u_0 such that (Non linear term derived from Park³.)

$$R_t(u_0) = \frac{8\mu}{\sigma R_{neck}^2} + \beta \frac{\rho_0}{\pi h C_D^2} \sqrt{2} (1 - \sigma^2) u_0. \quad (6)$$

and

$$\alpha_{\infty nl}(u_0) = 1 + \frac{2\Psi}{h} 0.48 \sqrt{\pi R_{neck}} \left[\sum_{n=0}^8 a_n (\sqrt{\sigma})^n \right] \left(1 + \frac{\sqrt{2}}{c_0} u_0 \right). \quad (7)$$

Finally the impedance of the liner is

$$Z_{Laly}(u_0) = Z_{MPP}(u_0) - j \cot(kL). \quad (8)$$

²[Laly et al., 2018]

³[Park, 2013]

Iteration on the velocity and the impedance

In the non-linear regime, the velocity depends on the impedance

$$u_0 = \frac{\rho_{\text{ref}} 10^{SPL/20}}{\rho_0 c_0 |z|}, \quad (9)$$

and conversely. Therefore, an iteration procedure is used to determine both the impedance and the velocity. This iteration procedure is used by Beck⁴ and Laly⁵.

- For a sine-swept source, the iteration procedure is performed for each frequency.
- For a white noise source, it is performed for all frequency using the root mean square velocity over a given frequency range:

$$u_{0,\text{RMS}} = \sqrt{\sum_i u_{0,i}^2}. \quad (10)$$

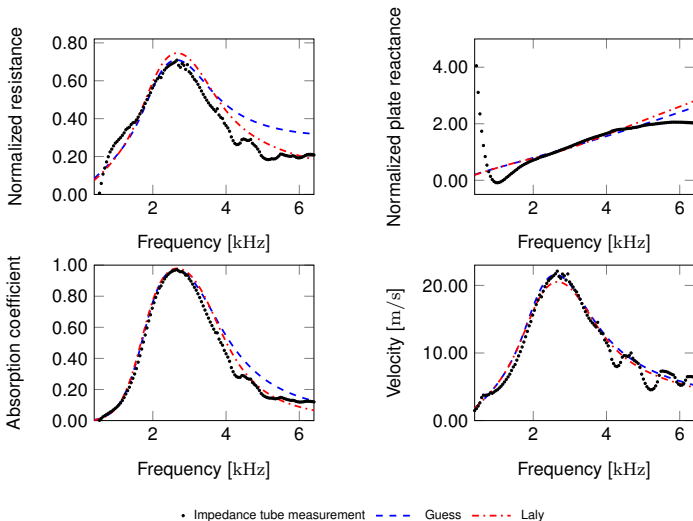
This procedure is implemented for Guess model and Laly's model.

⁴[Beck et al., 2015]

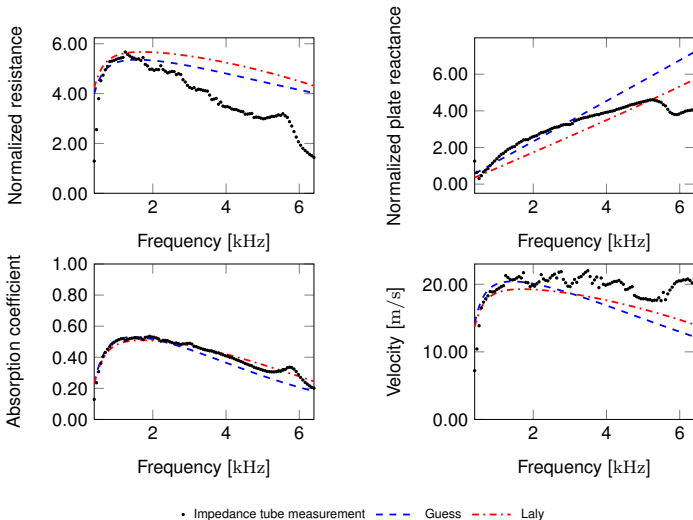
⁵[Laly et al., 2018]

Plane wave with a normal incidence at 150 dB - Sine-swept source

Macro-perforated plate: $R_{\text{neck}} = 0.8$ mm, $\sigma = 10$ %, $h = 1.5$ mm and $L = 16$ mm.

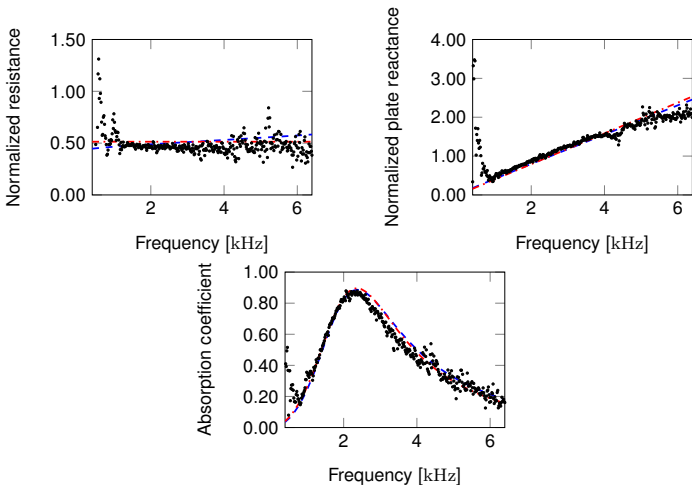


Micro-perforated plate: $R_{\text{neck}} = 0.15$ mm, $\sigma = 1.4$ %, $h = 0.6$ mm and $L = 19$ mm.



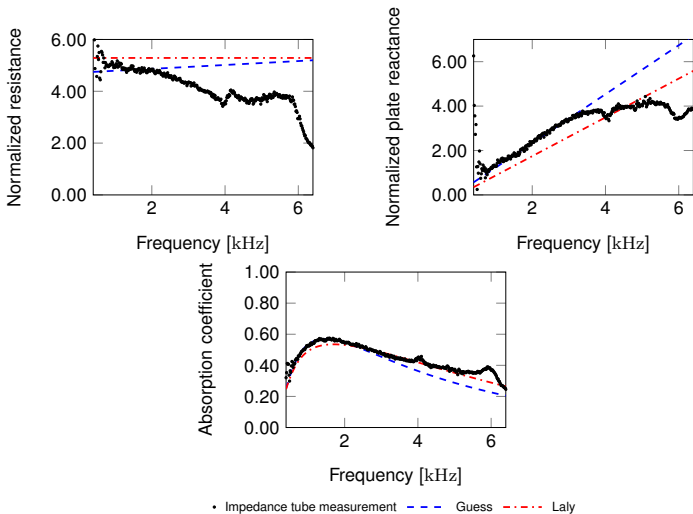
Plane wave with a normal incidence at 150 dB - White noise source

Macro-perforated plate: $R_{\text{neck}} = 0.8$ mm, $\sigma = 10$ %, $h = 1.5$ mm and $L = 16$ mm.



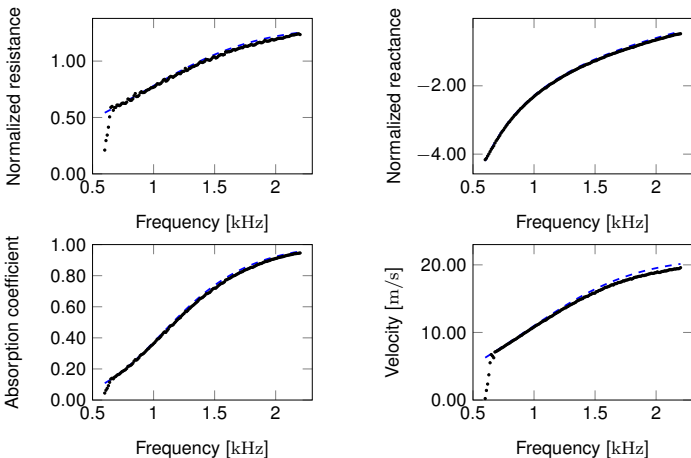
• Impedance tube measurement - - - Guess - . . . Laly

Micro-perforated plate: $R_{\text{neck}} = 0.15$ mm, $\sigma = 1.4\%$, $h = 0.6$ mm and $L = 19$ mm.



Perspectives - In Situ test bench - Grazing incidence - Sine-swept

Micro-perforated plate: $R_{\text{neck}} = 0.1485$ mm, $\sigma = 5.818$ %, $h = 0.5$ mm, $L = 20.69$ mm and $SPL = 150$ dB. **Optical control of the geometry.**



• In situ test bench measurement - - - Guess

Conclusion and perspectives

Conclusions:

- Guess model with iteration validated with measurements with both normal and grazing incidence.
- Room for improvements, control of the geometry is important, especially when the diameter and the porosity are low.

Perspectives:

- Improve Guess predictions when a grazing flow is present.
- Meng⁶ propose a semi-empirical model of the grazing flow effect. It depends on the convection speed of vorticity above the perforations. This velocity appears to depend on the boundary layer displacement thickness.

⁶[Meng et al., 2019]

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Thank you for your attention!



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