Développement d'un métamatériau pour la réduction du bruit sous-marin rayonné par des structures cylindriques

Journées Techniques en Acoustique et Vibrations (JTAV) 2026

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METACOUSTIC

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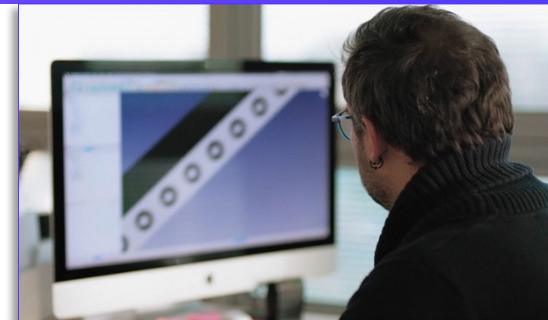
Our Company

Metacoustic

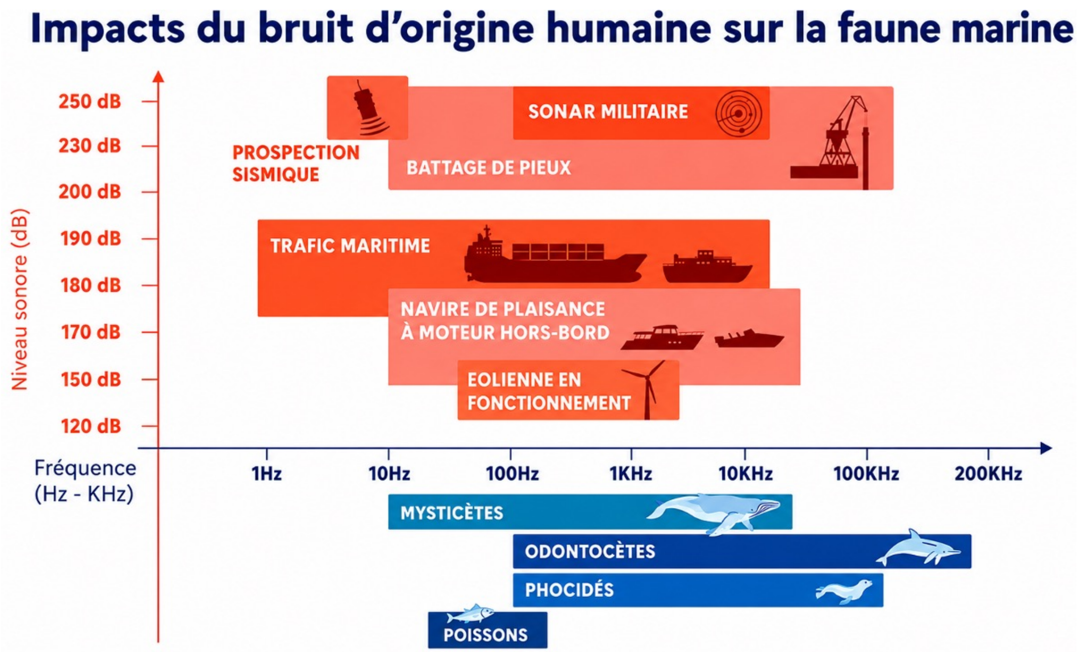
ACOUSTIC R&D SERVICES FOR THE INDUSTRY

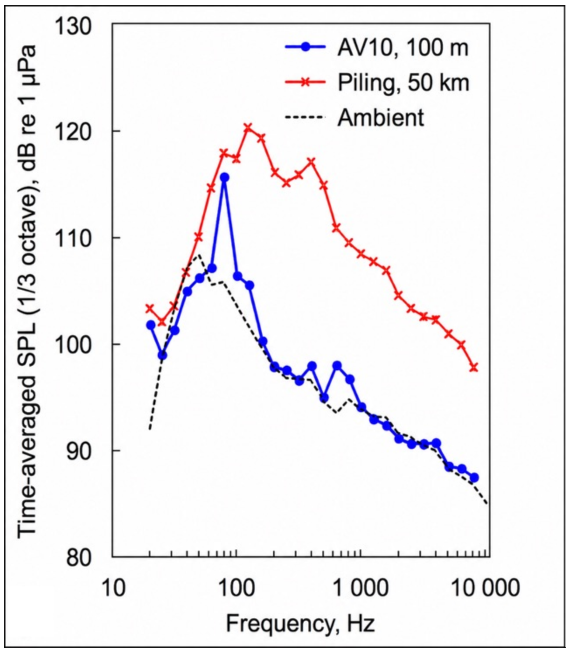
- Offices in Le Mans (France)
- Vibroacoustic engineering company
- A team of 8 doctors and engineers
- 50% applied research / 50% consulting
- Custom-made acoustic metamaterials



Introduction

- The ocean **anthropogenic noise pollution** is an ever-growing concern that is proven to negatively affect marine life [1,2]





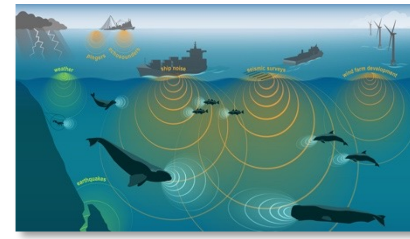
Focus on the 100 Hz – 1 kHz range

[1] Petit *et al.*, "The Acoustic Impacts of Offshore Wind Projects on Marine Wildlife", CNRS Report, 2022.
[2] Carey *et al.*, "Ocean Ambient Noise", Springer, 2011.

Outline

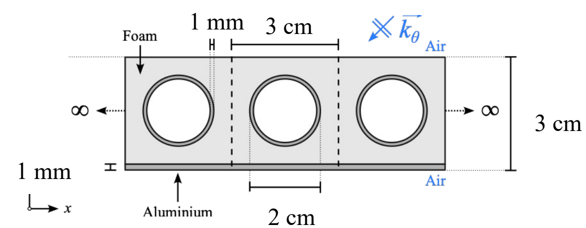
1. Context

- Anthropogenic noise pollution
- Underwater solution necessity

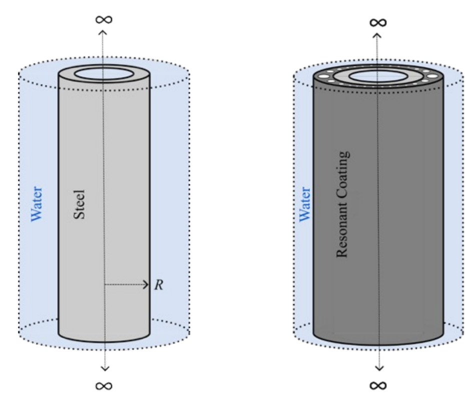


2. Metamaterial solution development

- In air
- In water



3. Cylindrical structure acoustic radiation

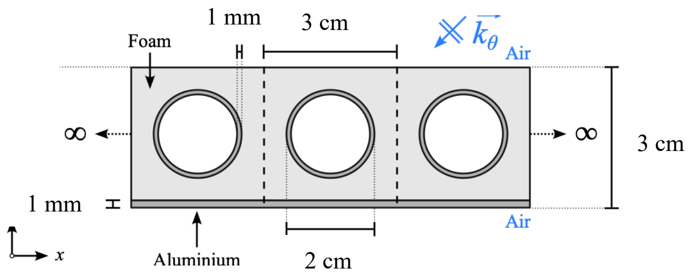


4. Efficiency of the proposed solutions

- Homogeneous coating
- Metamaterial (resonant) coating

The “Metablocker” (1)

- At Metacoustic, we have developped a **metamaterial solution** that enables vibroacoustic attenuation of a specific frequency band [11,12]



Fabricated Sample

[11] Aberkane-Gauthier *et al.*, “Soft solid subwavelength plates with periodic inclusions: Effects on acoustic Transmission Loss”, JSV, 2024.
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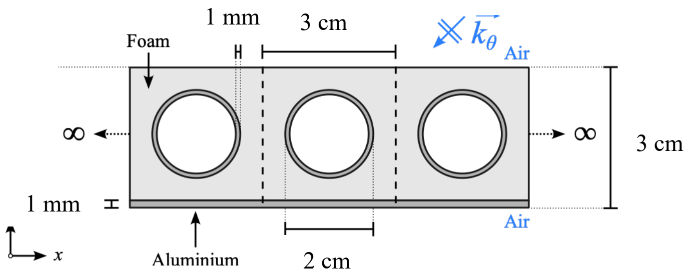

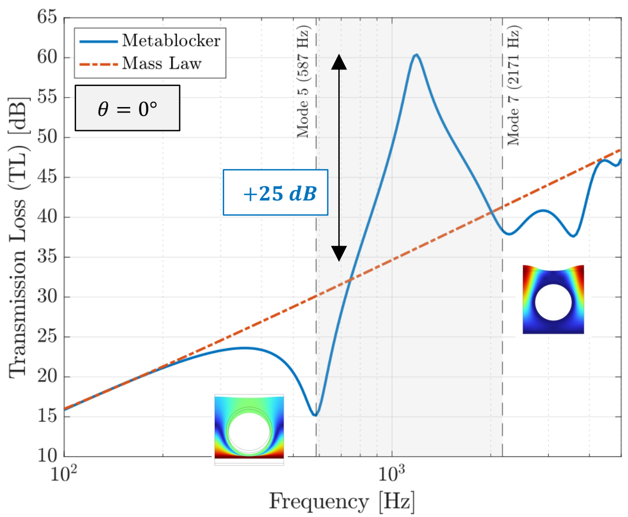

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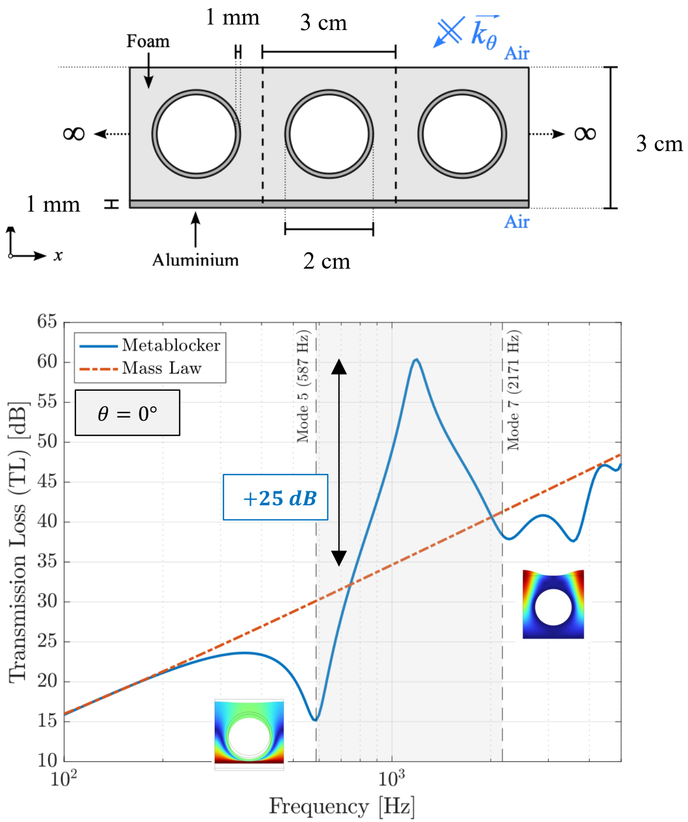

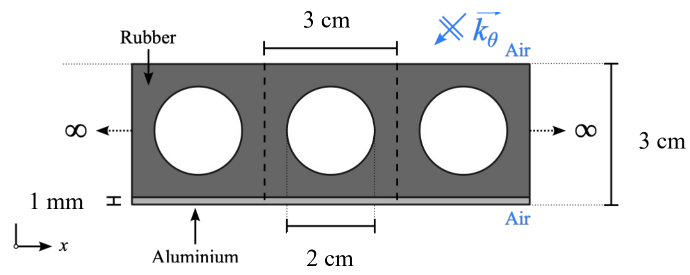

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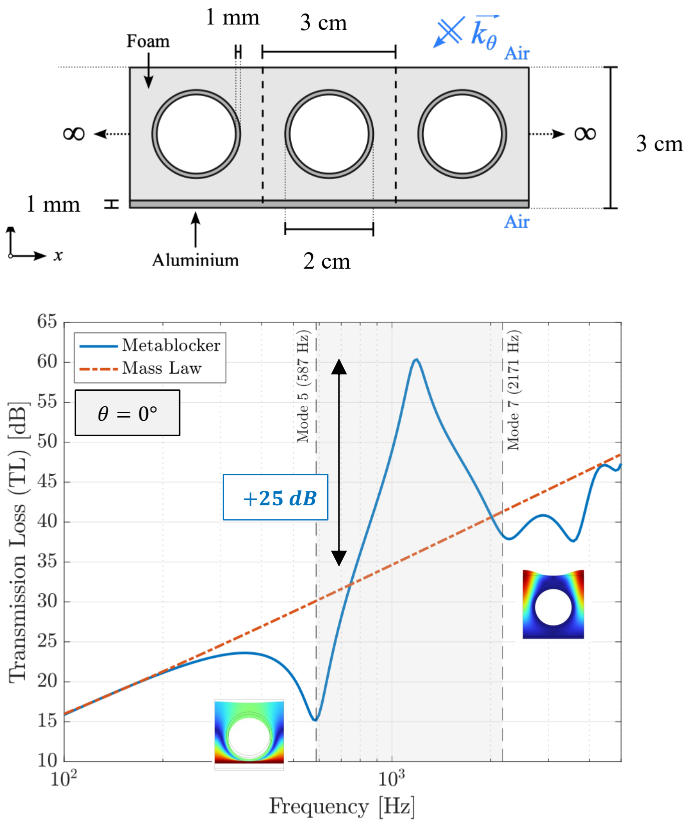

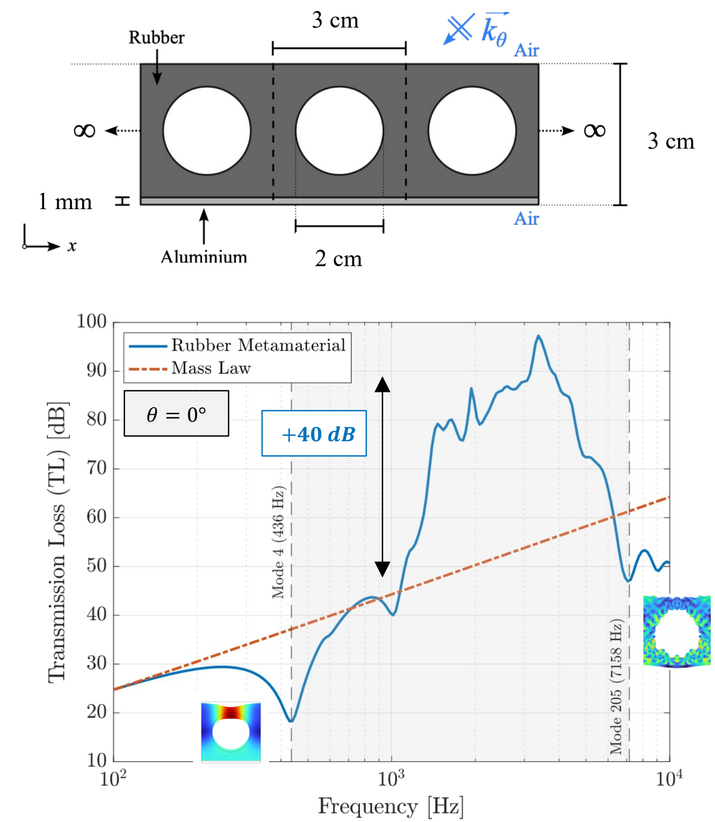

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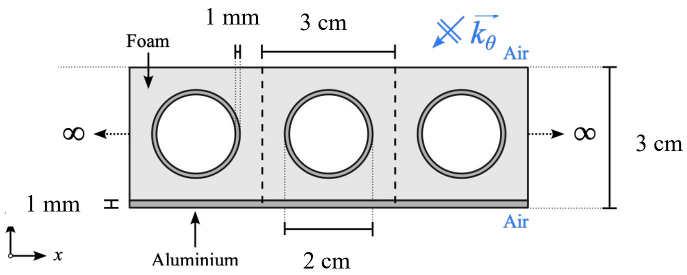
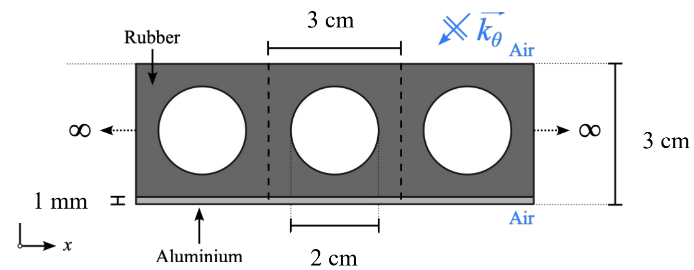
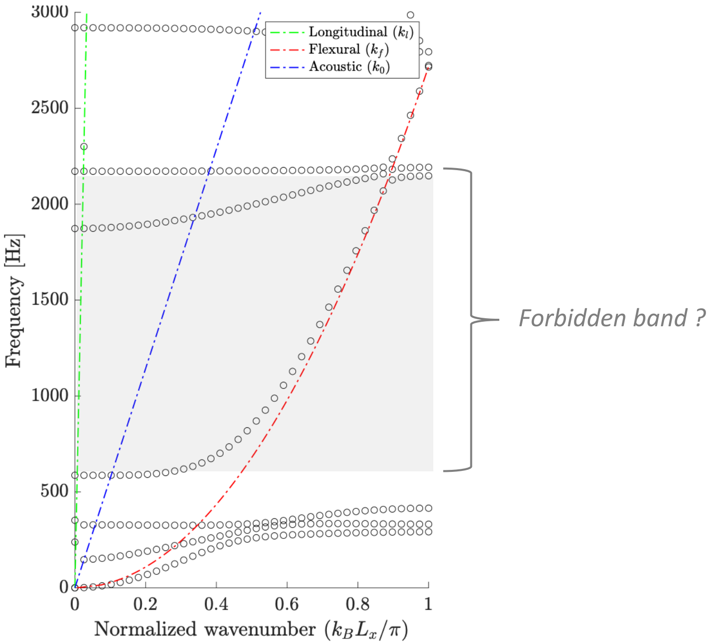
The “Metablocker” (2)

- A common approach to further analyse the origin of the **vibroacoustic bandgaps**, is to observe the structural dispertation relations







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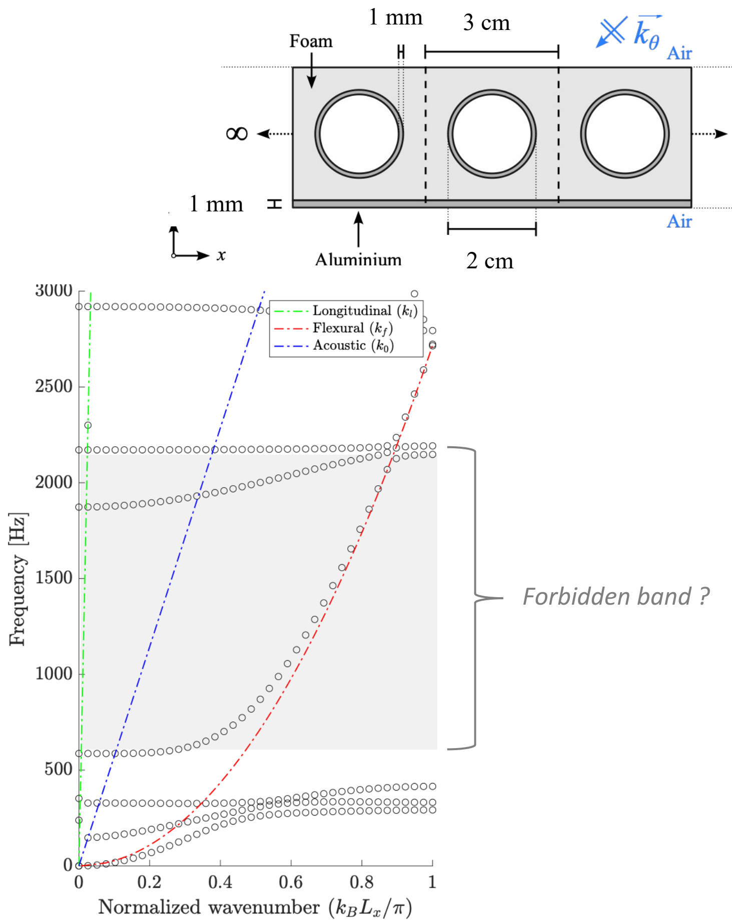

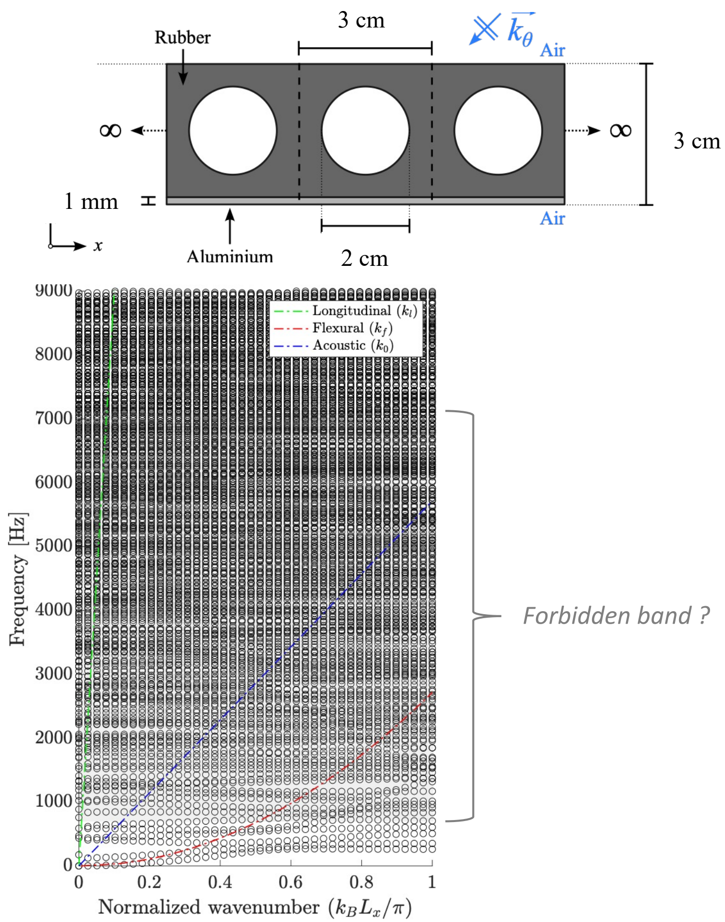

Vibroacoustic Modelling

- To enable a clear visual representation of the dispersion relations, we have implemented a **vibroacoustic modal decomposition** model [13]

$$\tau = \frac{W_{out}^{(ij)}}{W_{in}} = \sum_{i=1}^{\infty} \tau^{(ii)} + \sum_{i=1}^{\infty} \sum_{\substack{i=1 \\ j \neq i}}^{\infty} \tau^{(ij)} = \tau_{diag} + \tau_{inter}$$

→

τ : sound power coefficient
W : acoustic power
TL : sound transmission loss

$$TL = 10 \log_{10} \left(\frac{1}{\tau} \right)$$

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- We define two new indices :

1. Self-modal contribution

Do the structural modes individually radiate ?

$$\kappa_{self}(\omega_i, \theta) = \begin{cases} \dfrac{\tau^{(ii)}(\omega_i, k_B)}{\tau_{diag}(\omega_i, k_B)} & \text{If } \omega_i \geq c_0 k_B \\ 0 & \text{Otherwise} \end{cases}$$

2. Inter-modal contribution

Do the structural modes interfere destructively ?

$$\kappa_{dest}(\theta) = \begin{cases} \left| \dfrac{\tau_{inter}(\theta)}{\tau_{diag}(\theta)} \right| & \text{If } \tau_{inter}(\theta) < 0 \\ 0 & \text{Otherwise} \end{cases}$$

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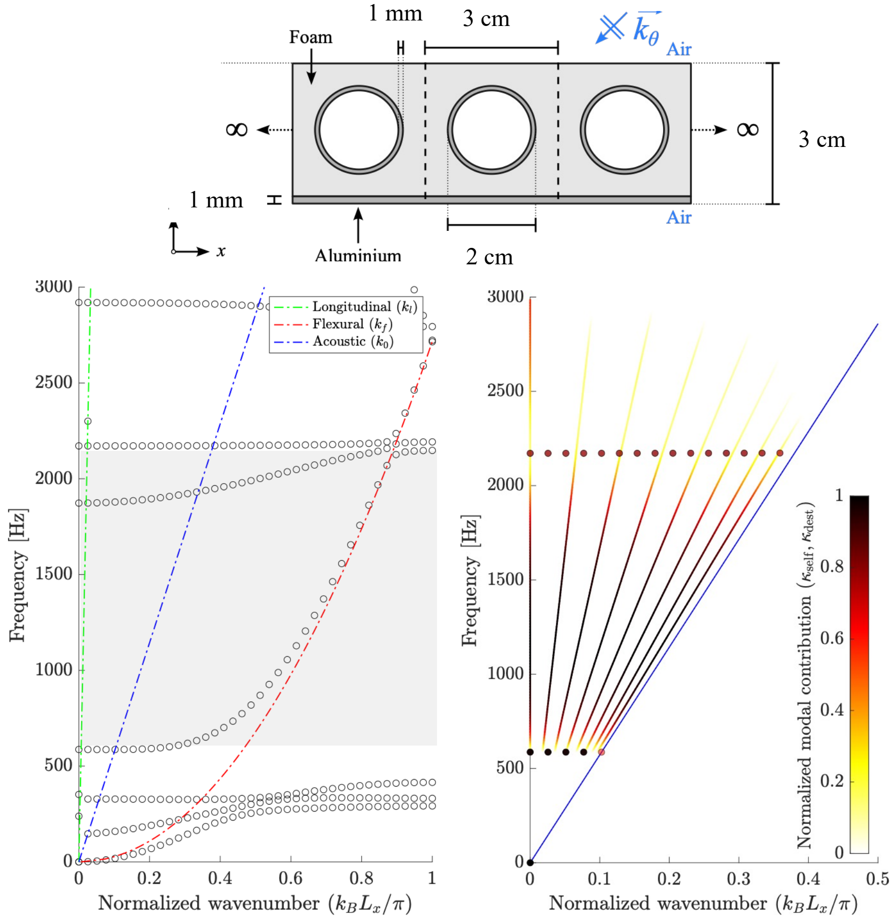

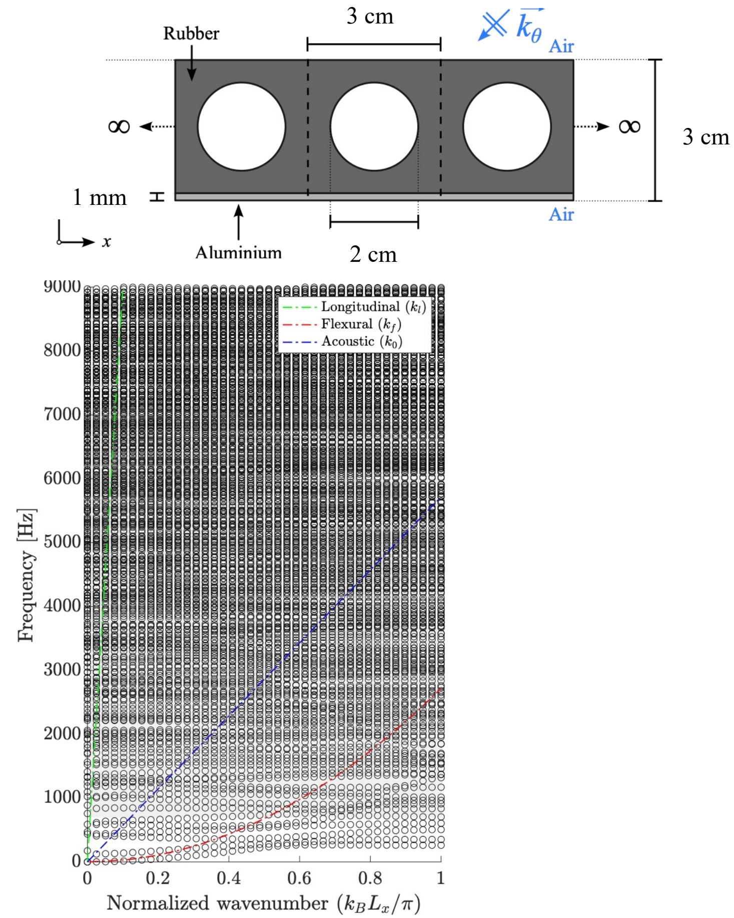

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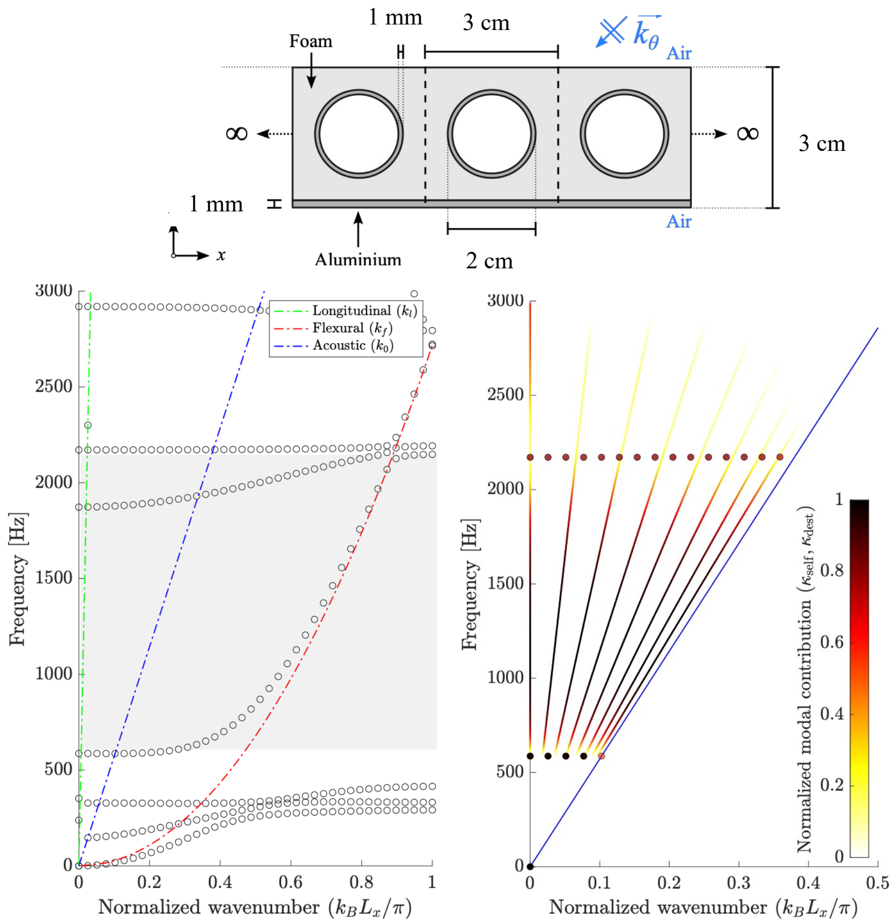
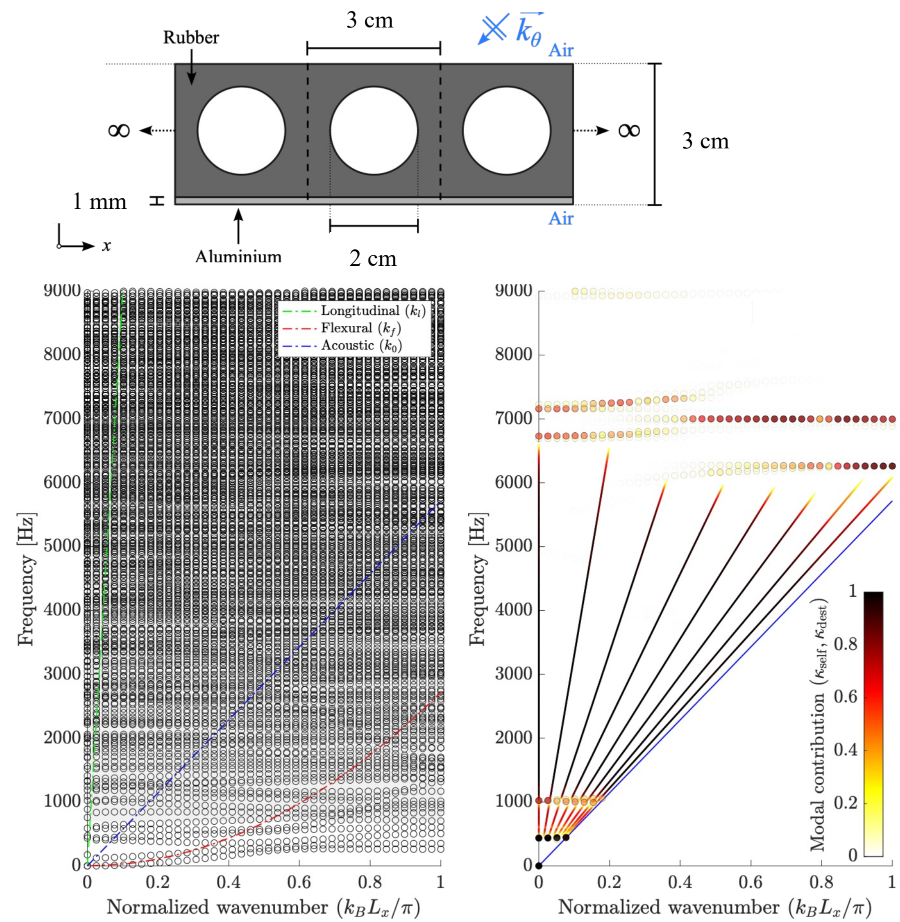
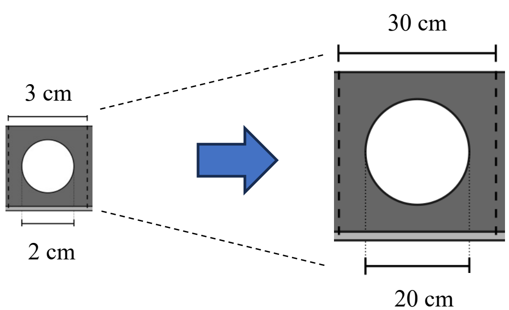




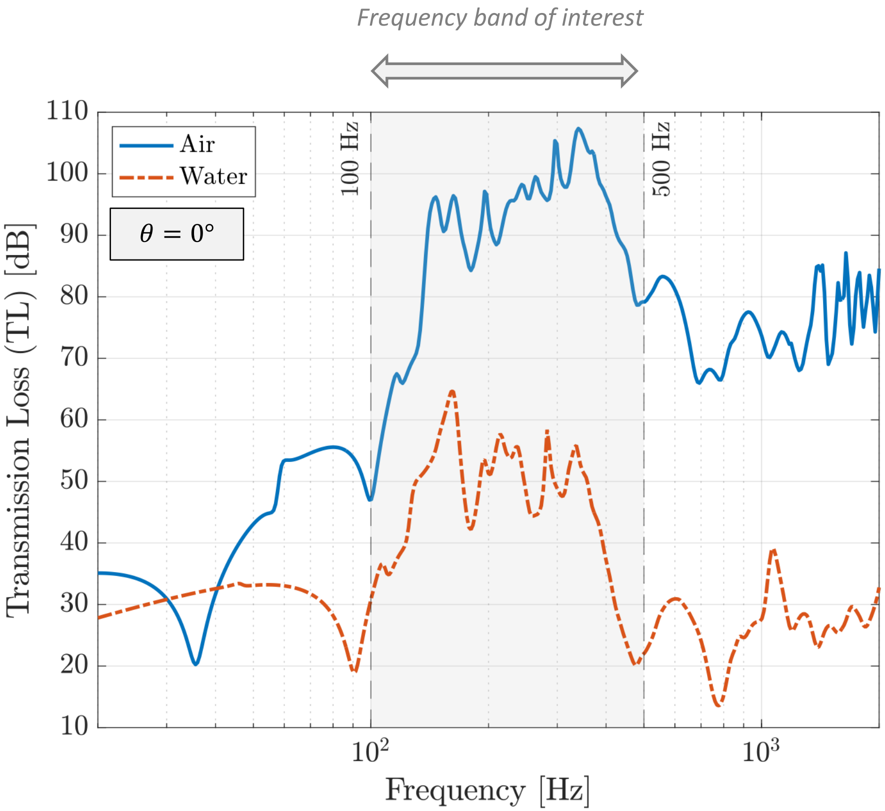
Solution Scale-Up

- Acounting for the fluid coupling, we have optimized the solution at the unit cell scale to target the **low frequency range**

- Model assumptions :
  - Voided inclusions
  - Perfect plate / coating bonding
  - Infinite / periodic structure



Unit cell scale size increase (x10)



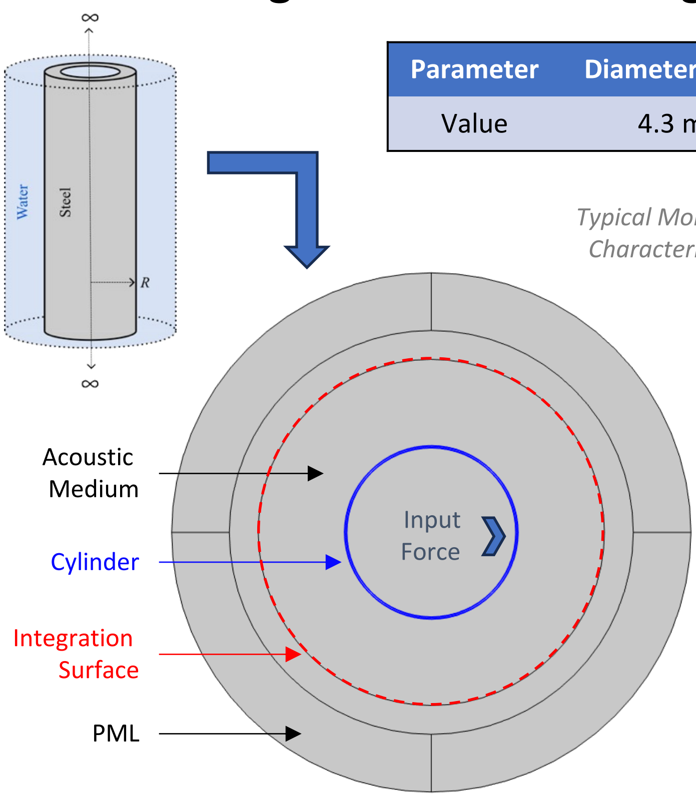
Cylinder Radiation

- The **structure-borne** radiation characteristics of a steel cylinder is investigated in water using a radial line excitation

Parameter	Diameter ($2R$)	Thickness	Ring Frequency*	Line Excitation
Value	4.3 m	4.5 cm	300 Hz	1 N/m

** Theoretical Value*

Typical Monopile Characteristics



Infinite Multiphysics 2D Model

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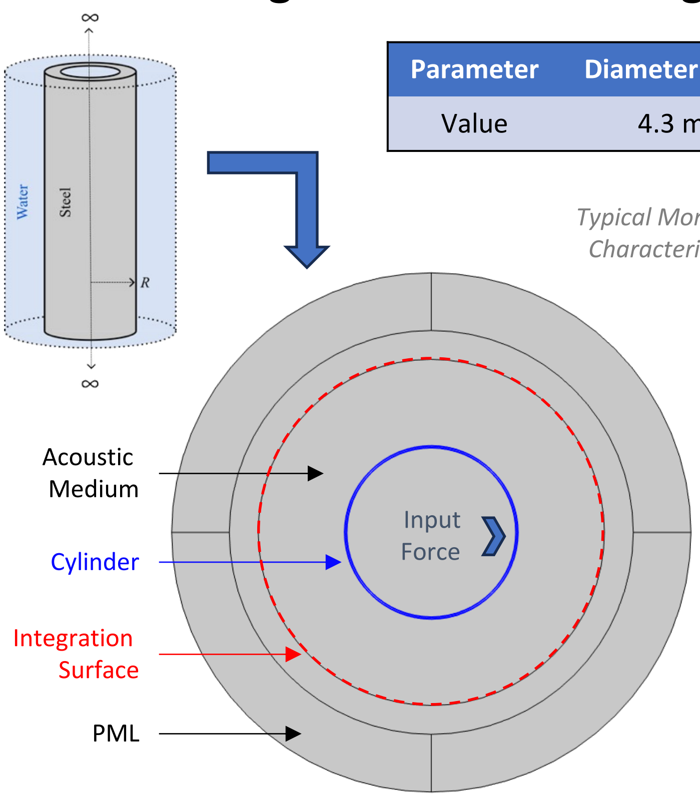

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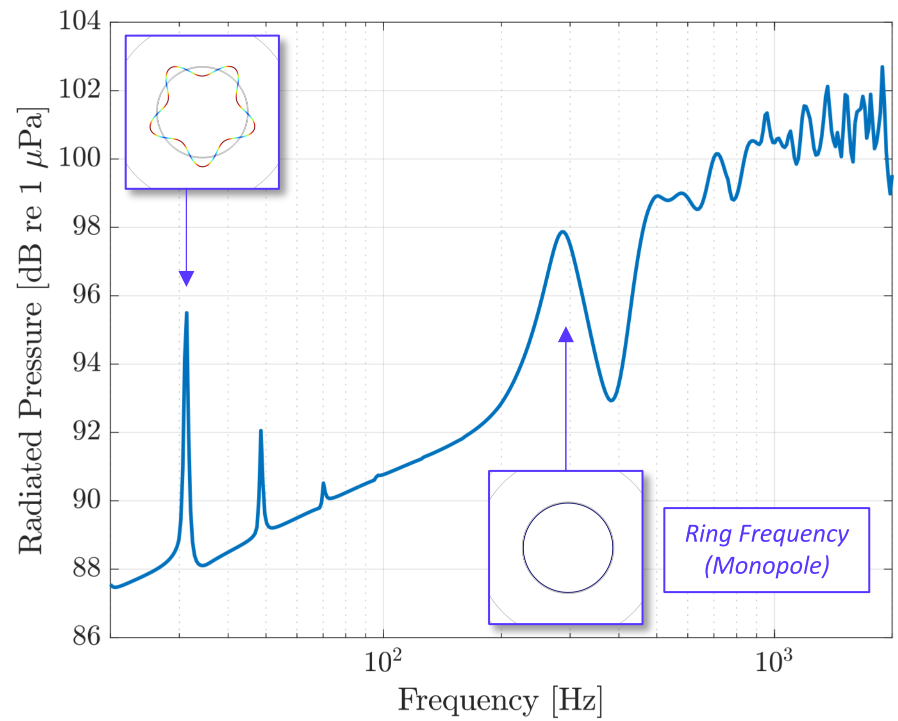

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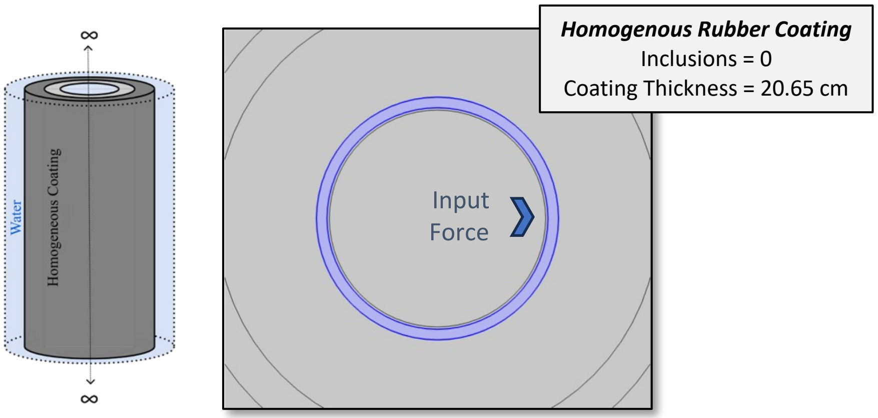
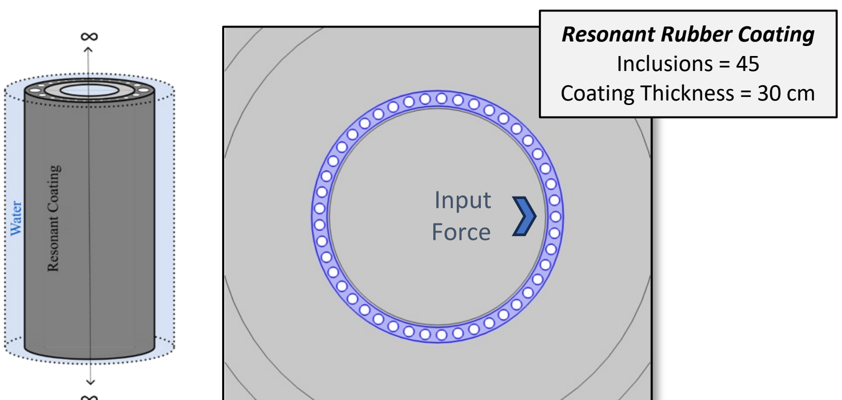
Insertion Loss Results

- Using the same excitation, the vibroacoustic performance the **rubber metamaterial** and its **isomass** version without inclusions are evaluated



$$IL = 20\log_{10}\left(\frac{p_{ref}}{p_{coat}}\right)$$

Coatings = same linear mass density (kg/m)



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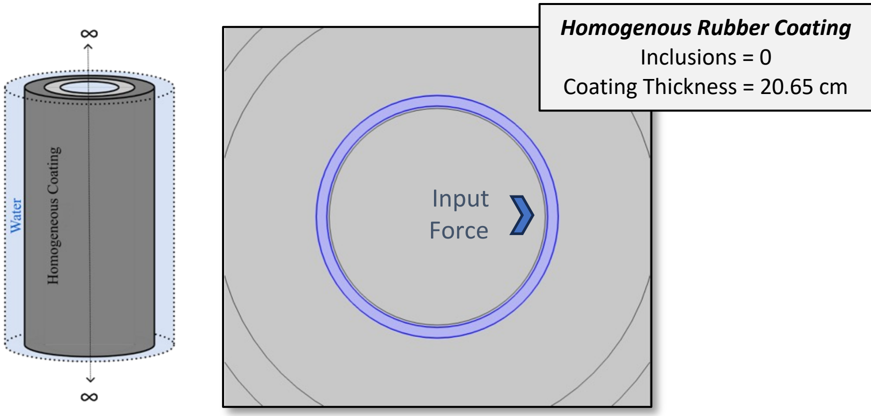

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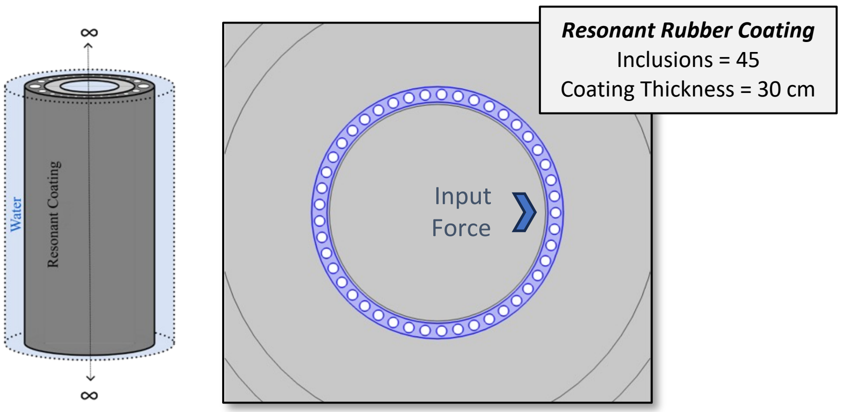

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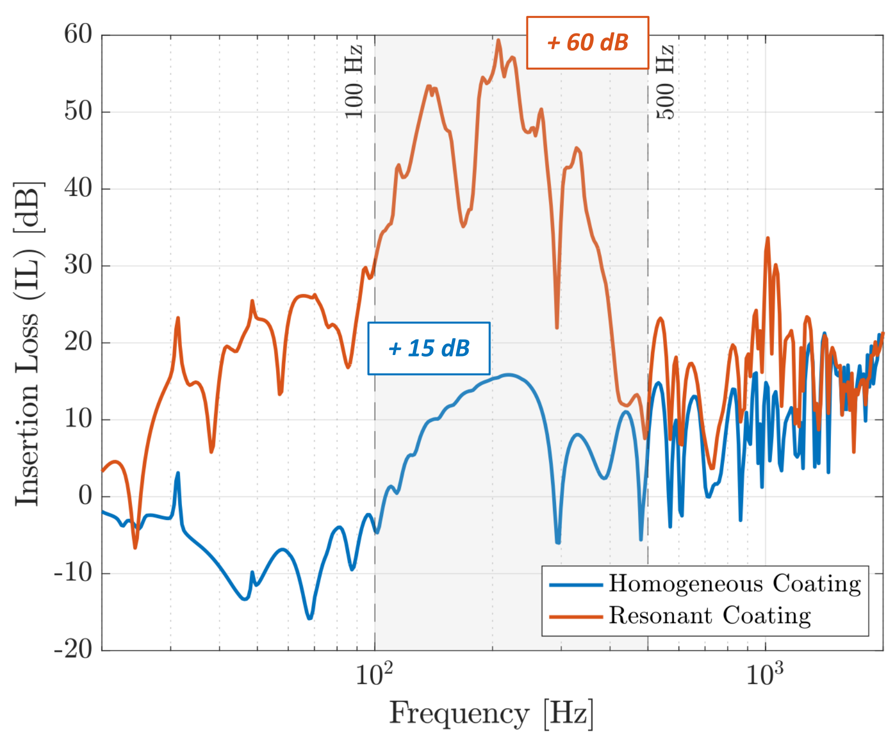

Conclusion / Perspectives

Conclusion :

- **Anthropogenic noise pollution** heavily affect marine life with transient (*e.g.,* pile driving) or continuous (*e.g.,* offshore wind turbines) sources
- A **rubber metamaterial** with cylindrical inclusions has been investigated :
  - ✓ Dedicated to underwater noise mitigation
  - ✓ A vibracoustic model was developed to investigate the bandgap origin
  - ✓ The solution was scaled to perform in the low frequency range
  - ✓ An insertion loss of $+60\ dB$ was achieved

The fabricated sample

Perspectives :

- A prototype was fabricated and is soon to be experimentally tested
- A measurement campaign will begin (Autumn 2026) to characterize the noise radiated by an offshore wind turbine
- The solution will be tested on a reduced scale wind turbine

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Projet MALO : « Réduction du bruit par métamatériaux acoustique pour éolienne offshore en fonctionnement »

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