MATELYS Research Lab

SilentProp

Clean Sky 2

Aeroacoustic modelling of rotating propeller interaction with porous treatments using LBM simulations

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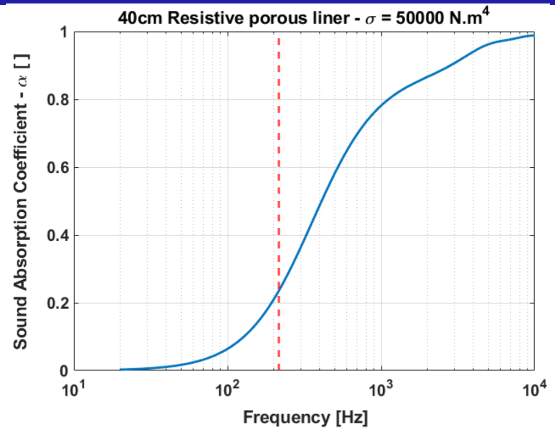
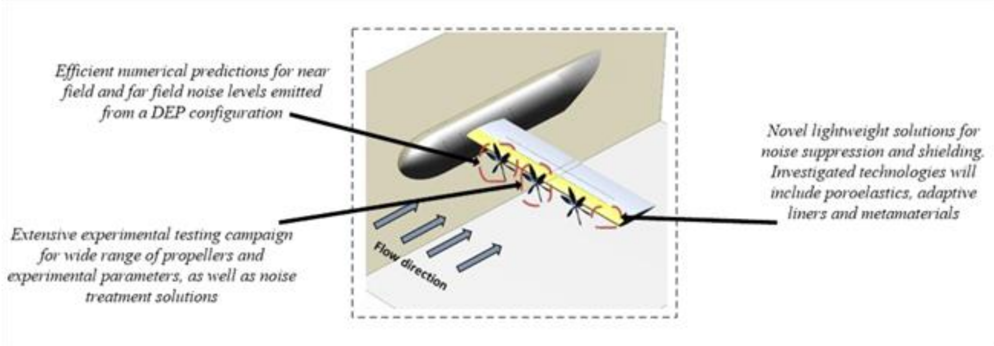
Sorrento SAPEM'23 常熟

Introduction

- Increasing use of porous treatments in presence of flow for noise control
- Design criteria: **only** acoustic dissipation properties
- In presence of flow, possible changes of aerodynamics properties:
  - Modification of the main acoustic source
  - Generation of secondary sources



- Incapacity of most of modelling methods to handle the interaction with the main source
- The Lattice Boltzmann Method: possible solution
- LBM used in framework of SilentProp project to investigate among others, this interaction
- SilentProp project: **Assessing noise generation in aircraft with distributed electric propulsion**



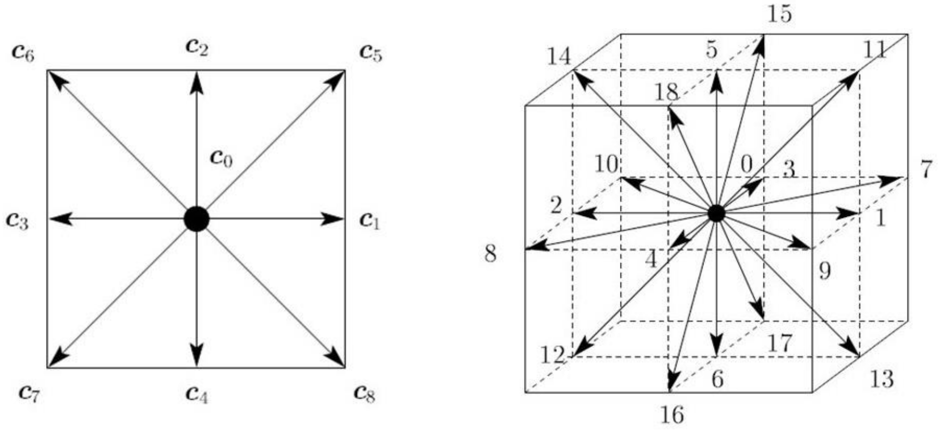
Outline of the presentation

- Lattice Boltzmann Method (LBM)
- Noise sources of wing-mounted propeller
- Silentrop project ProLB (LBM) model overview
- Untreated wing-mounted propeller noise
- Porous treatments on wing:
  - Leading edge treatment
  - Trailing edge treatment
- Ducted propeller treatments
  - Bare duct
  - porous lining
  - porous and perforated plate lining
- Conclusion

Lattice Boltzmann method (LBM)

LBM method principle

- Macroscopic behavior of fluids by using a **simple mesoscopic model**
- Based on statistical mechanics
  - Successive collisions and propagations of particles
- Very low numerical dissipation algo
  - Adapted to Large Eddy Simulations (LES)
  - Flow and acoustic quantities computed in a single run
- Immersed boundary conditions
  (ability to handle complex boundaries)
- Adapted to parallel computations (HPC)



D2Q9 D3Q19

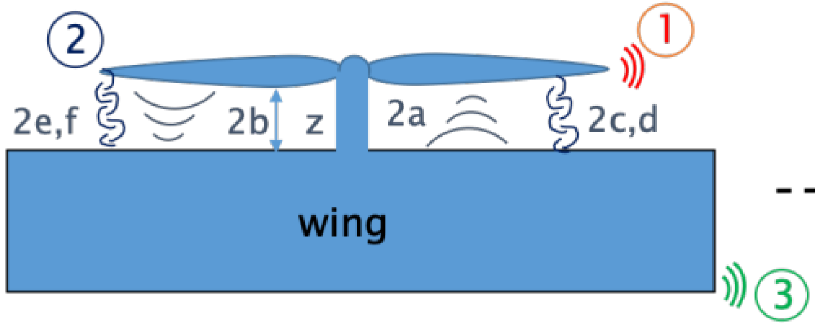
[Stefano Ubertini/Scholarpedia]

- LBM implemented in ProLB used by Matelys for SilentProp project.
- **POROUS module of ProLB by Matelys**
- Highlights
  - All LBM advantages (Parallel solver, etc.)
  - \+ Parallel meshing (volumetric mesher)

Noise sources of wing-mounted propeller

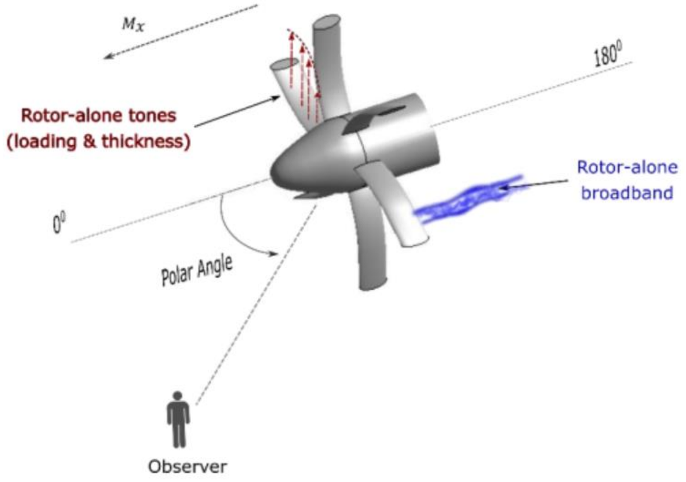
Noise sources of wing-mounted propeller

- 3 Main noise categories
  - Propeller self-noise
  - Propeller-wing installation noise
  - Wing self-noise



-- *[Chaitanya et al. AIAA/CEAS 2022]*

- Major sources are:
  - Tonal self-noise: volume displacement and aerodynamic loading on blade
  - Blade-vortex interaction (BVI) noise
  - Blade-wake interaction (BWI) noise
  - Broadband self-noise: interaction between the blade TE and TBL
  - Tonal propeller-wing interaction noise (wake & near-field)



[Akiwate et al., 2021]

TBL: Turbulent Boundary Layer
TE: Trailing Edge

SilentProp project ProLB (LBM) model overview

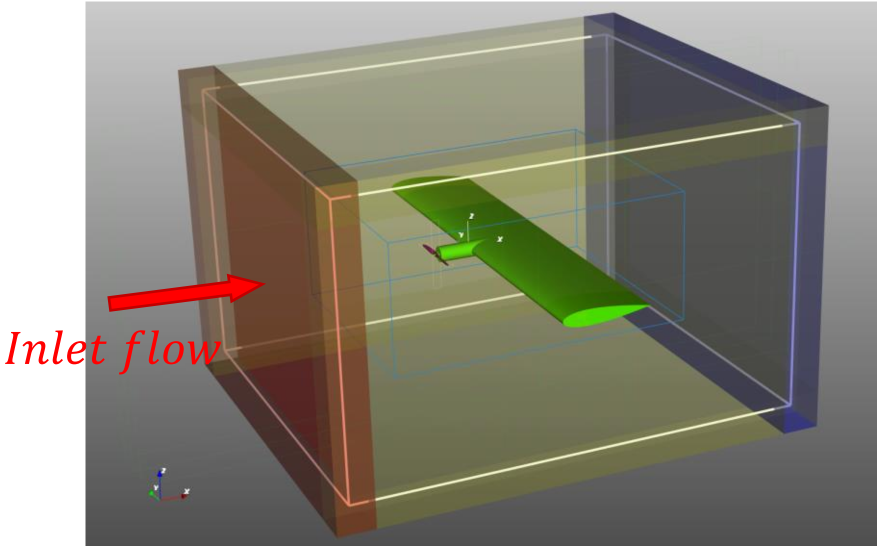
SilentProp project ProLB (LBM) model overview

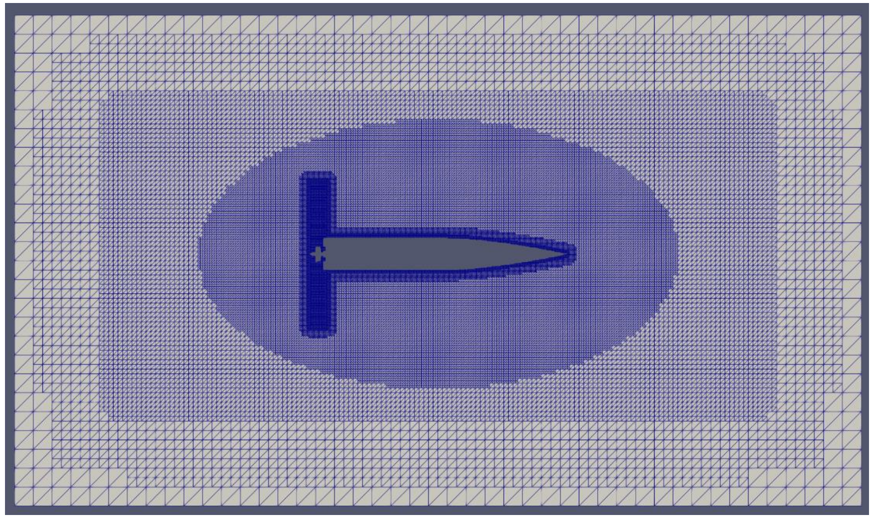
- 2 blades single propeller: $D = 228.62\ mm$
- Wing (NACA0018): $c = 302.77\ mm$
- Computational domain: $1732 \times 1208 \times 1208\ mm$
- Boundary conditions
- Resolution domains defined by their mesh size
- Mesh defined by a refinement level: 1 is the finest
- Growth rate of levels mesh sizes (octree): 2

$$dx_N = dx_{min} \times 2^{N-1}$$

- Time step

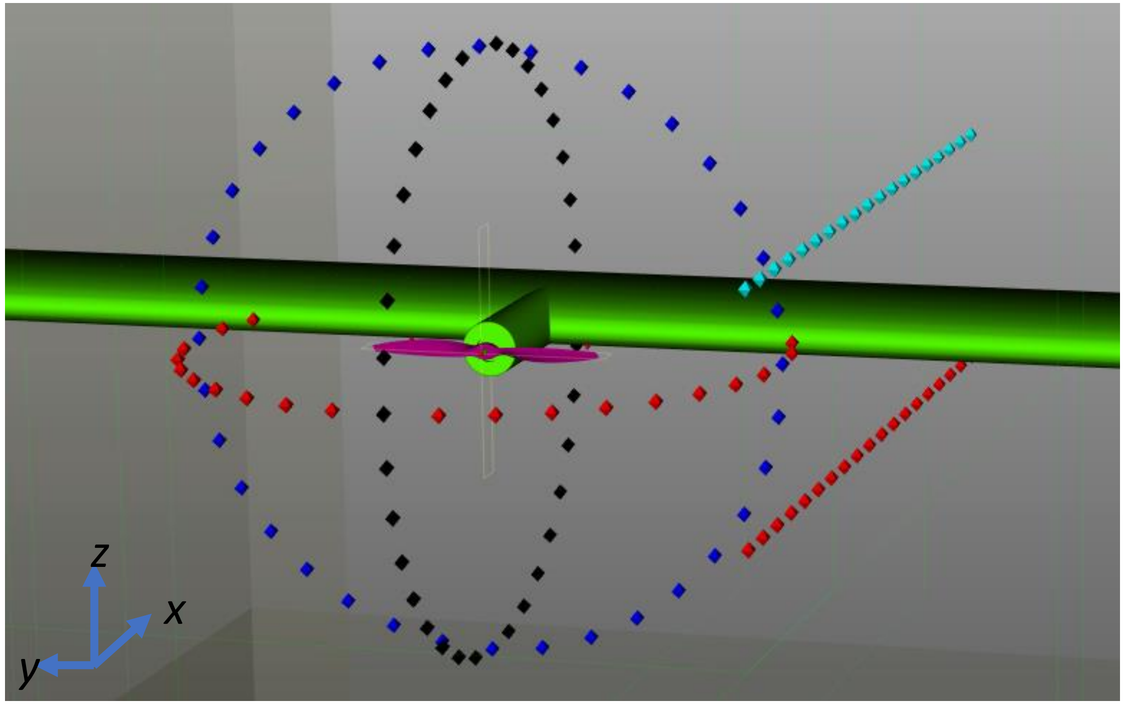
$$dt = \frac{1}{\sqrt{3}} \frac{dx_{min}}{c_0}$$





Silentprop LBM simulations: Numerical parameters and data recording

- Resolution domains (minimal mesh size: $dx = 1mm$)
  - Level 1: $dx_1 = 1mm$
  - Level 2: $dx_2 = 2mm$
  - Level 3: $dx_3 = 4mm$
  - .
  - .
- Inlet flow velocity: $v_0 = 12\ m/s$
- Propeller velocity: $\Omega = 6500\ RPM$
- $dt = 1.68224 \times 10^{-6}\ s$
- Point Data recording
  - Circular points array ($R \approx 30\ cm$)
  - Liner points array
  - Sampling freq. $f_s = 25000\ Hz$



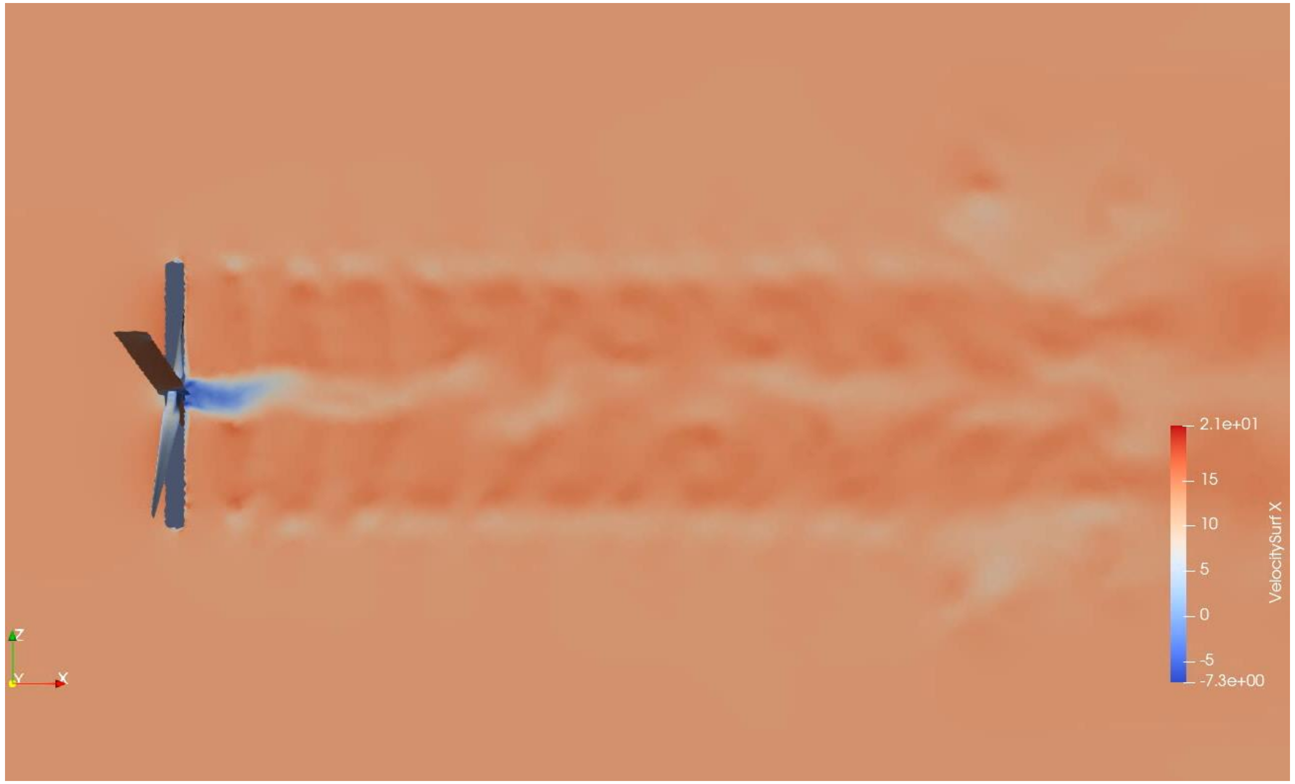
Sound Pressure Level: $\boldsymbol{SPL}\ (\boldsymbol{x}, \boldsymbol{f}) = \mathbf{10}\ \mathbf{log_{10}}(\boldsymbol{p^2}/\boldsymbol{p_0^2})\ [\boldsymbol{dB}]$

Overall SPL : $\boldsymbol{OASPL}(\boldsymbol{x}) = \mathbf{10}\ \mathbf{log_{10}}\left(\sum_{f_1}^{f_2} \mathbf{10}^{SPL_i/10}\right)\ [\boldsymbol{dB}]$

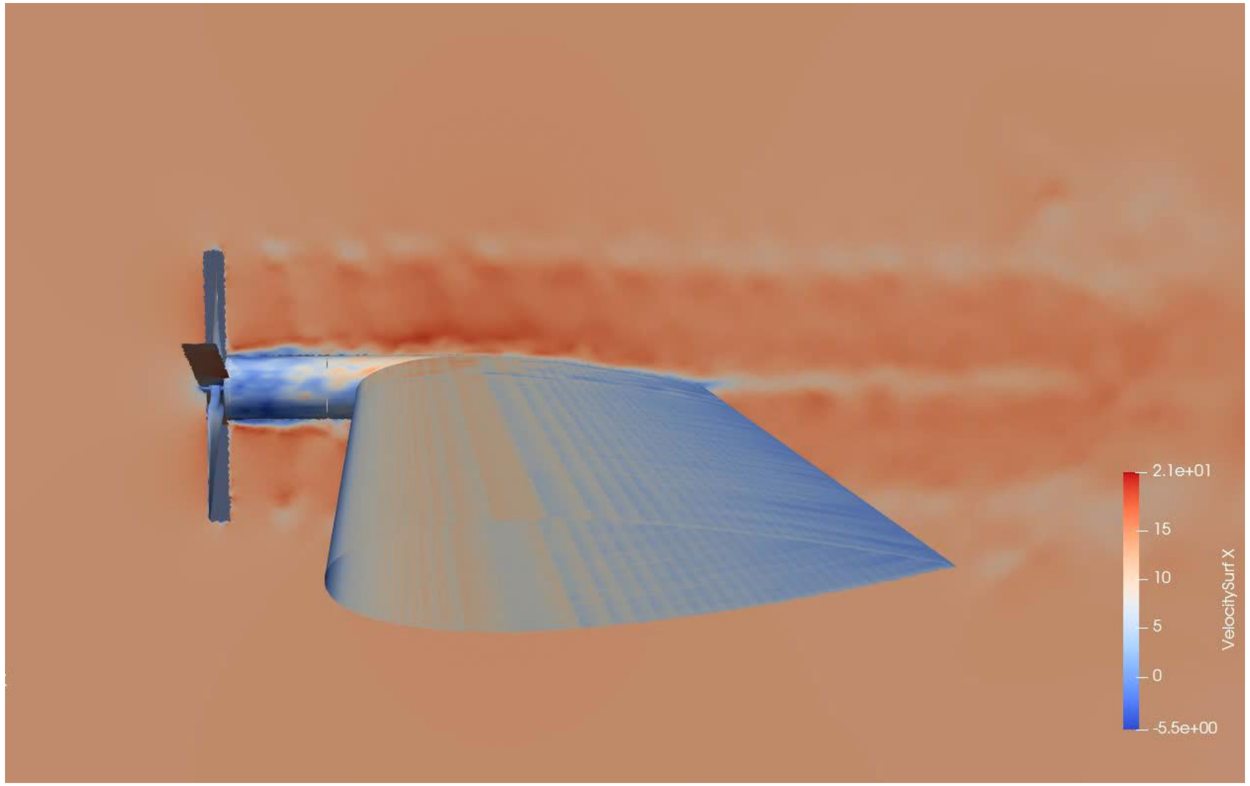
Untreated wing-mounted propeller noise

LBM simulations for installed propeller: Results

Flow x-velocity on vertical plan

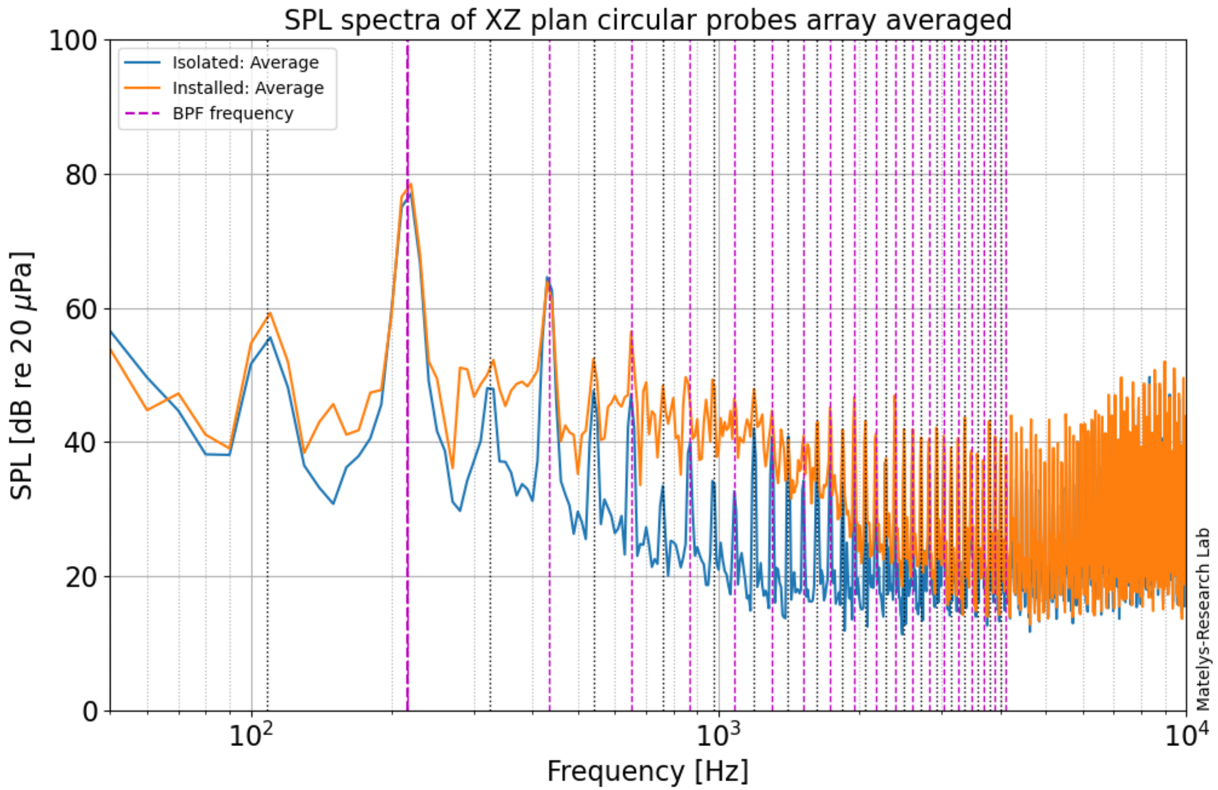


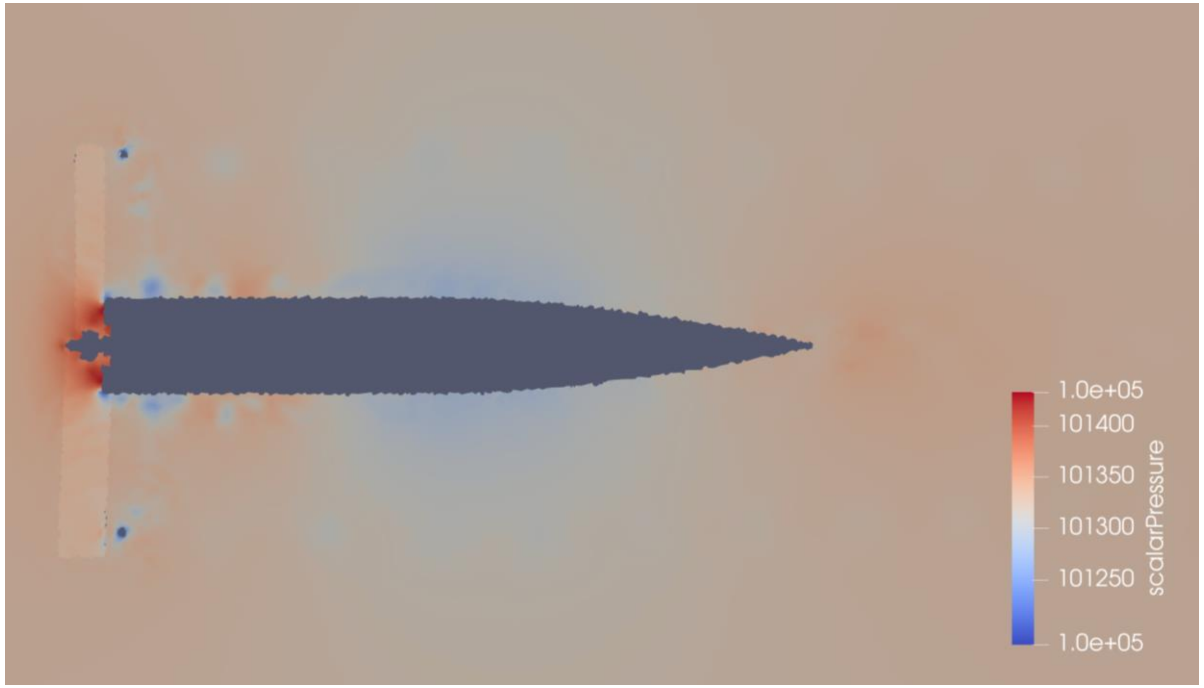
Isolated propeller



Installed (mounted) propeller

LBM simulations for installed propeller: Results





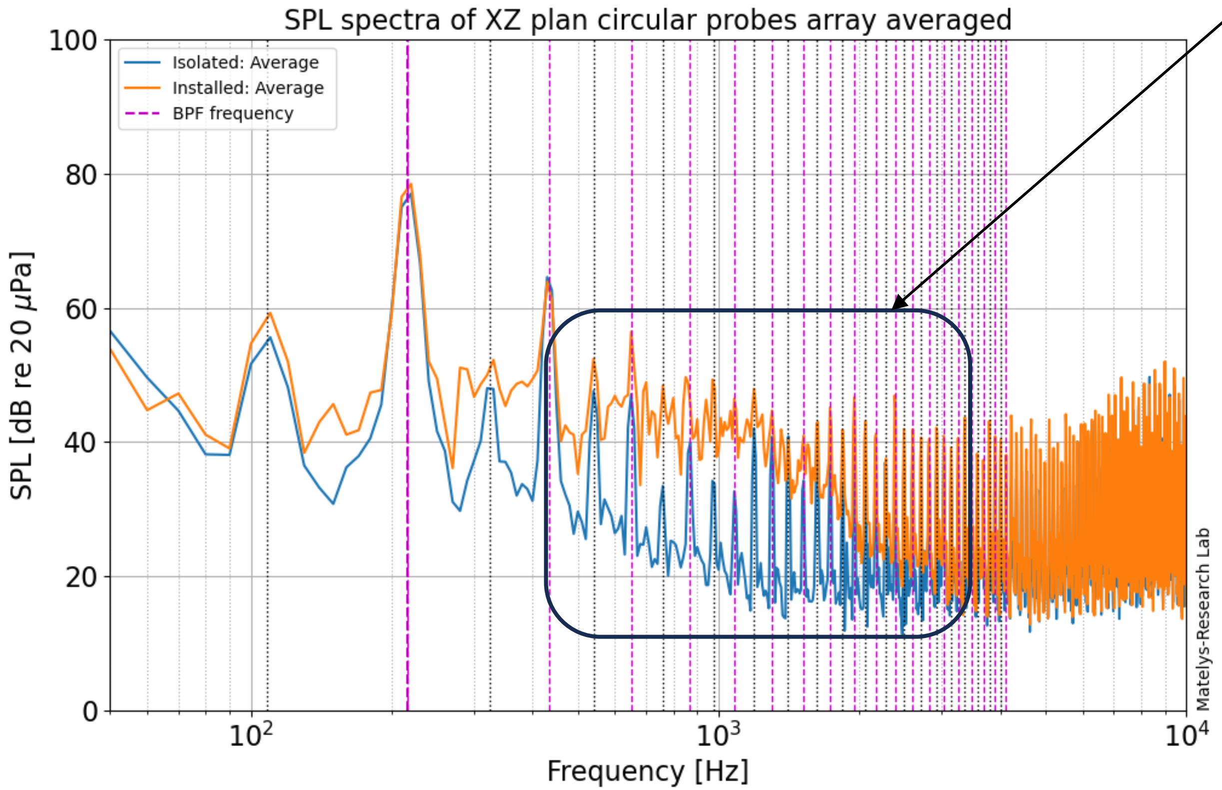
Installed wing pressure field

BPF (blade passing frequency) and harmonics

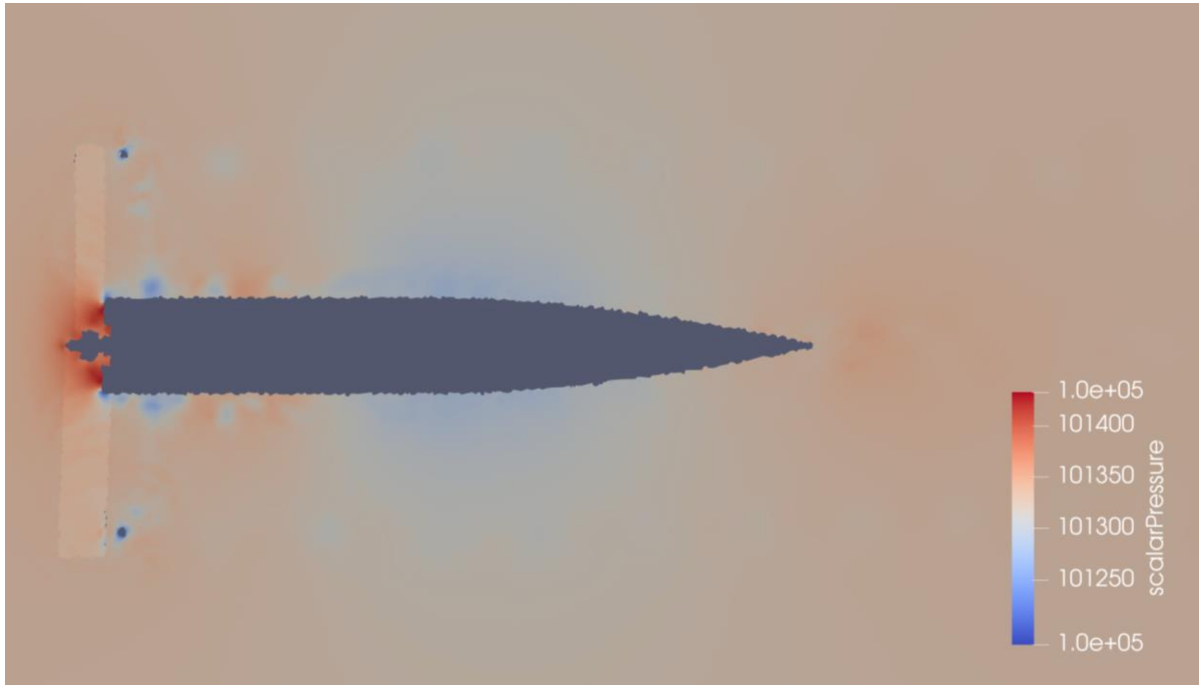
Rotational frequency and harmonics not in BPF

$$f_{BPF} = n_b * f_{rot}$$

LBM simulations for installed propeller: Results



Interaction and wing contribution



Installed wing pressure field

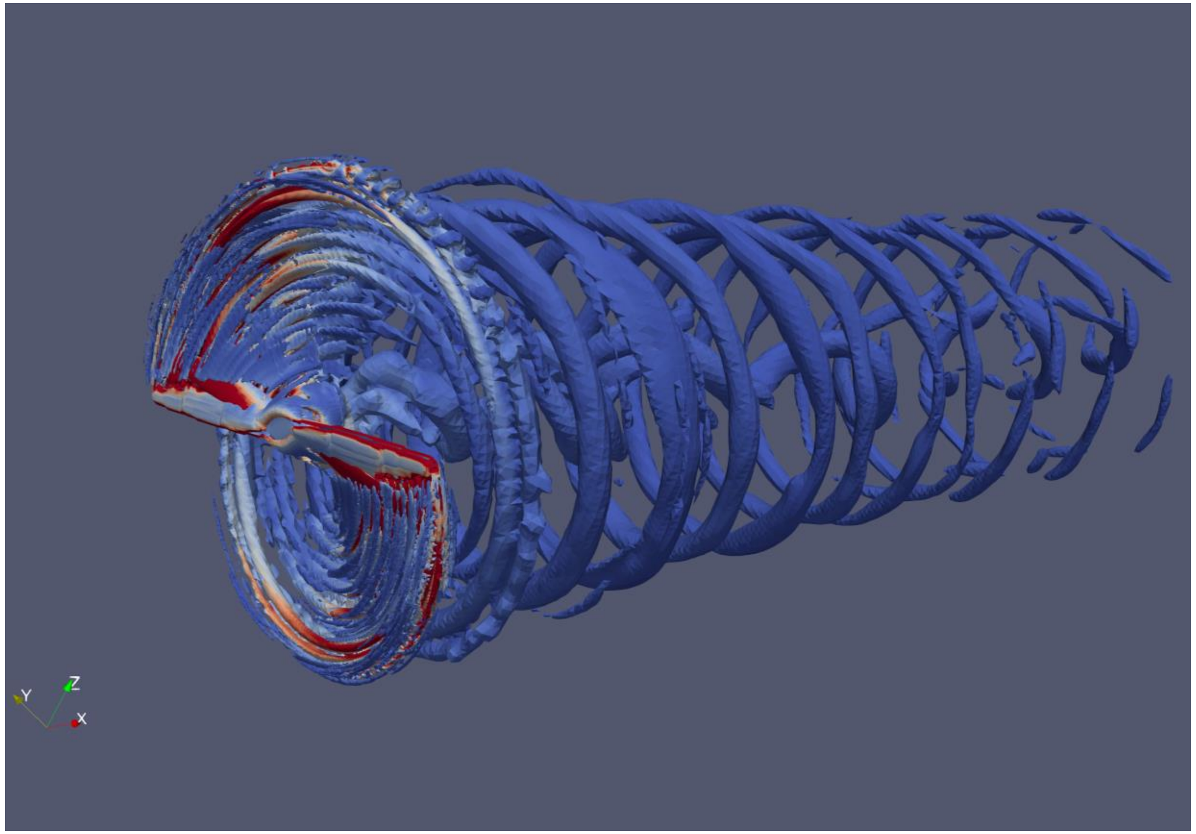
- - - - - - BPF (blade passing frequency) and harmonics

.... Rotational frequency and harmonics not in BPF

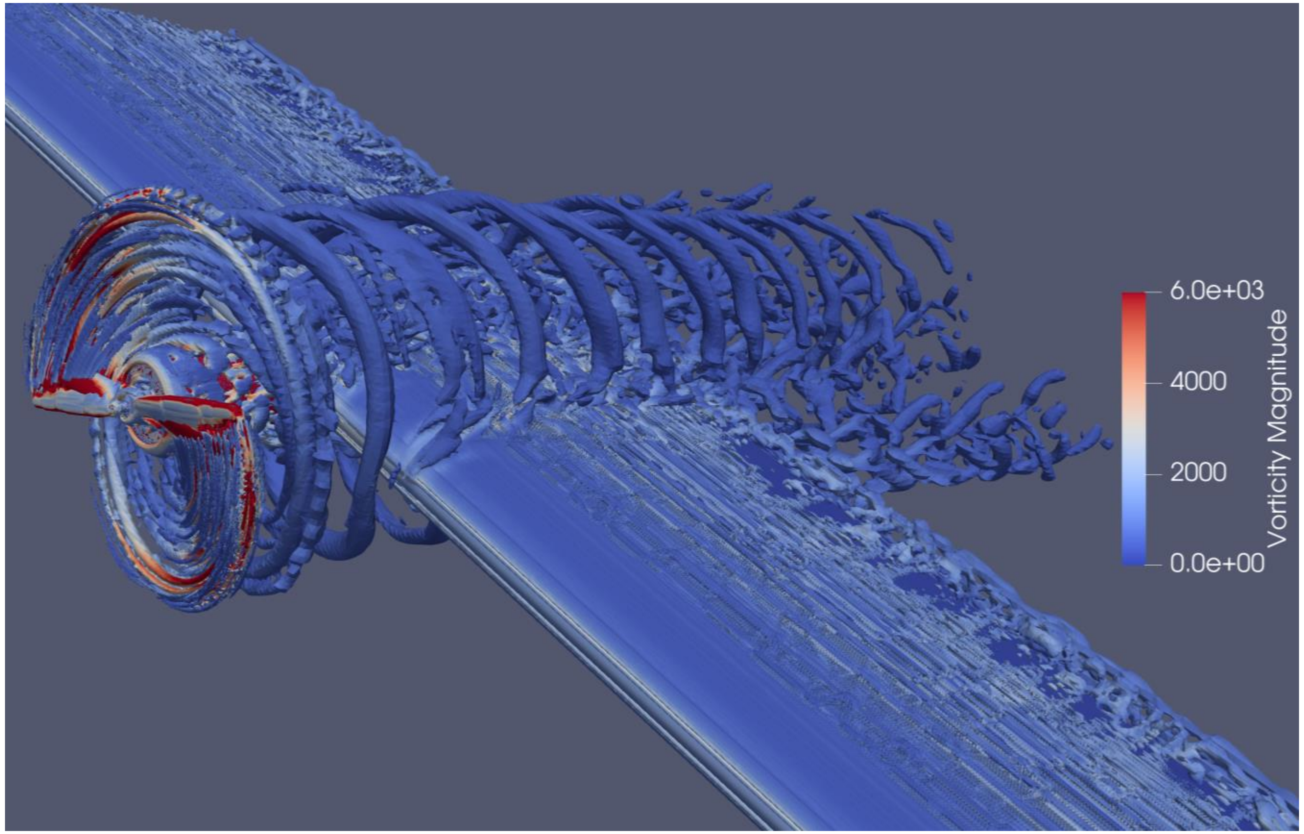
⇒ **Dominant propeller tonal noise !**

LBM simulations for installed propeller: Results

Q – criterion colored by the vorticity: effect of wing installation

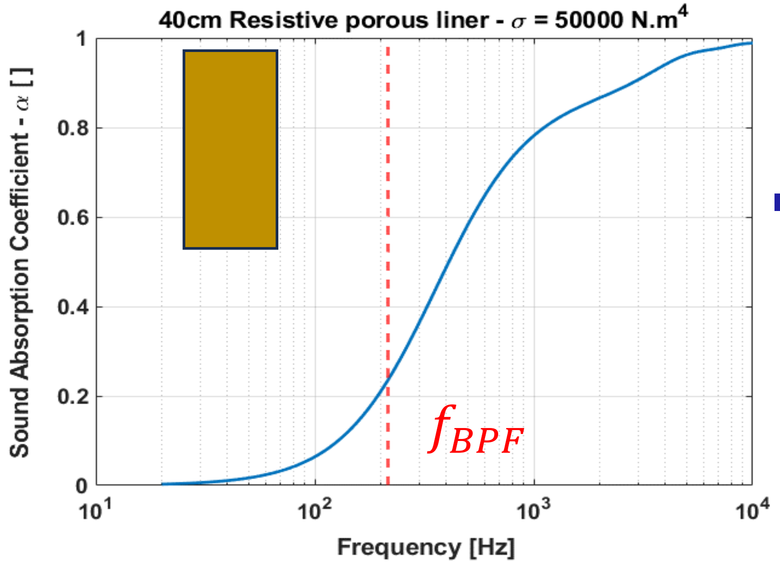


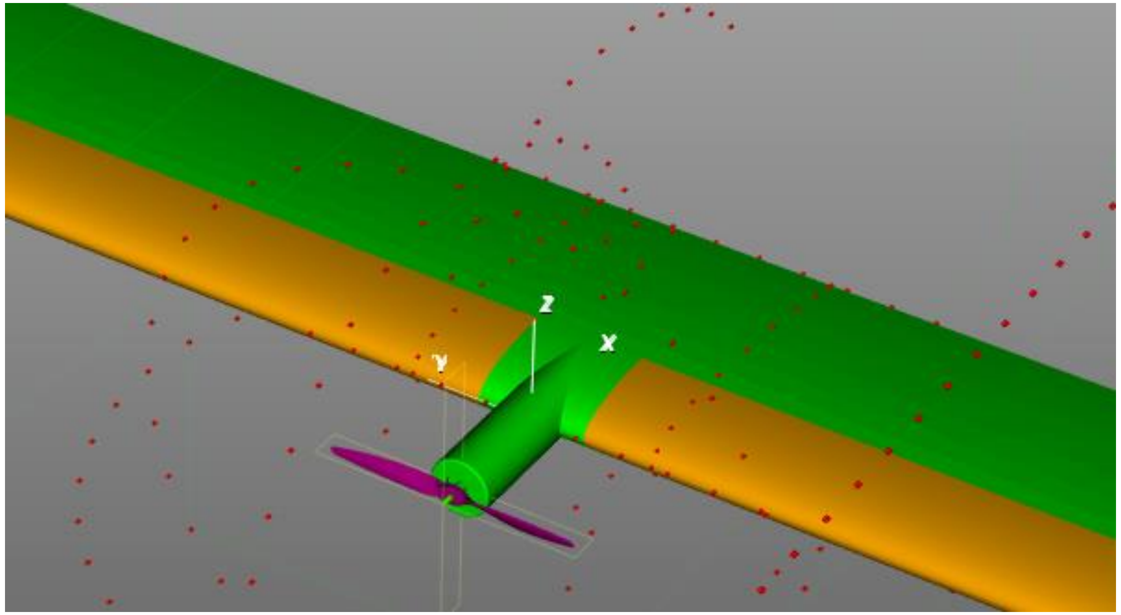
Isolated propeller



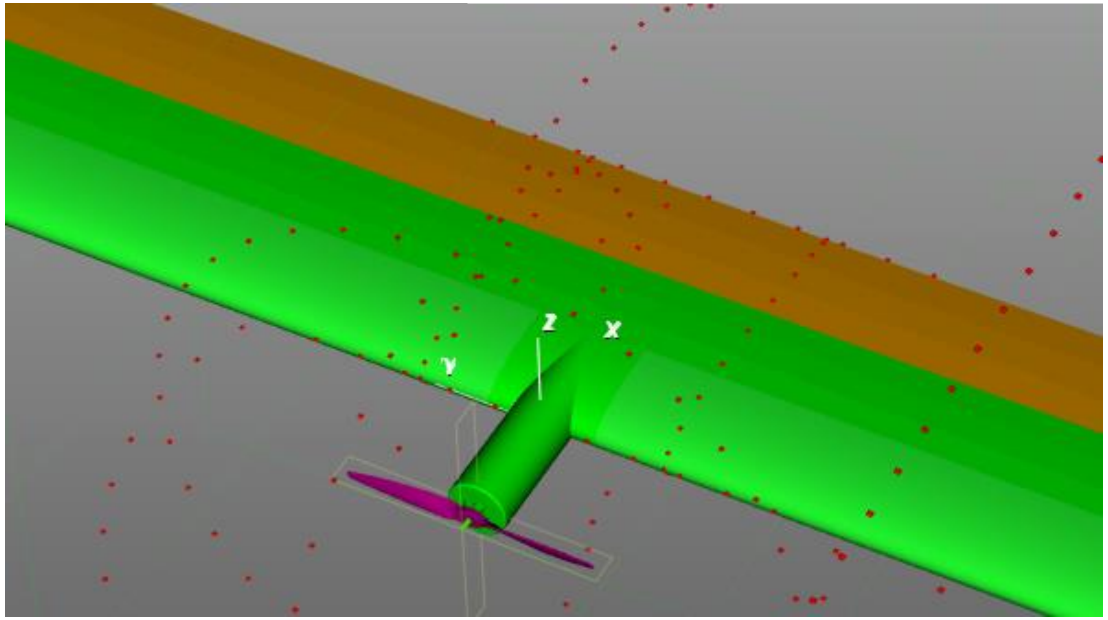
Installed (wing-mounted) propeller

Porous treatments on wing





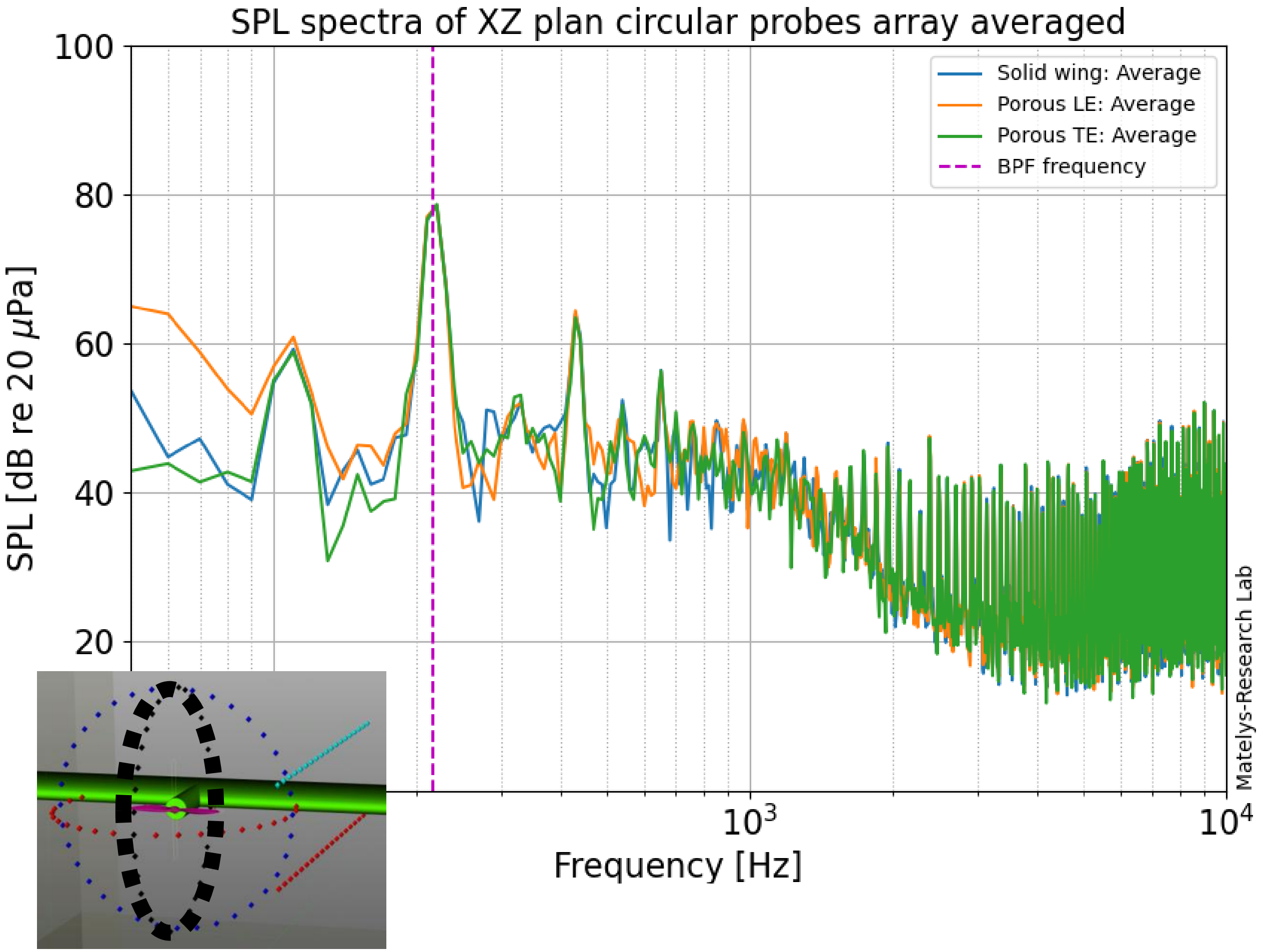
Porous Leading Edge

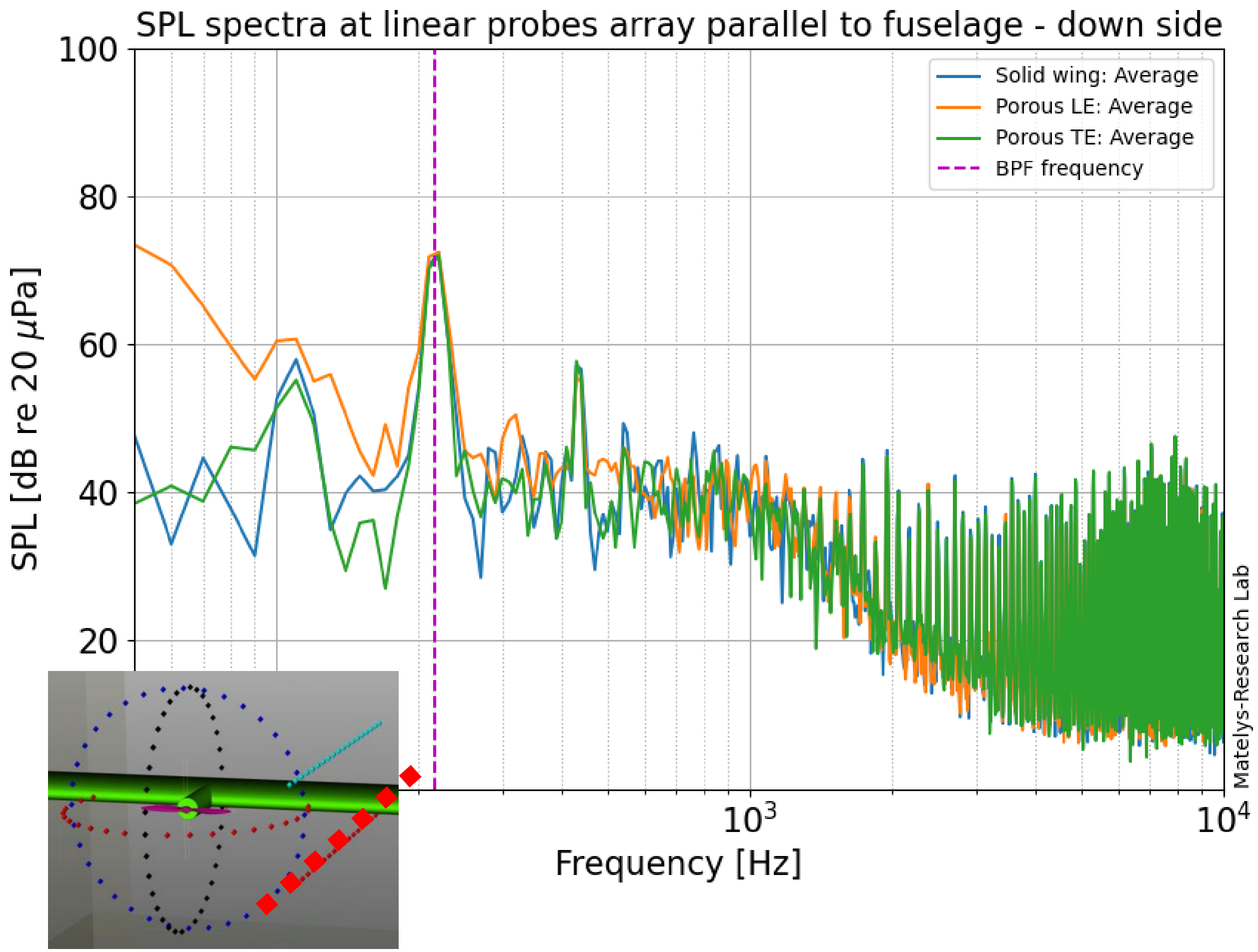


Porous Trailing Edge

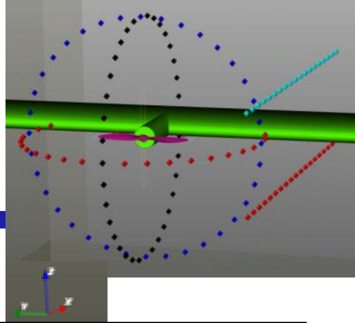
LBM simulations for installed propeller: Porous treatment of the wing

Sound pressure spectra



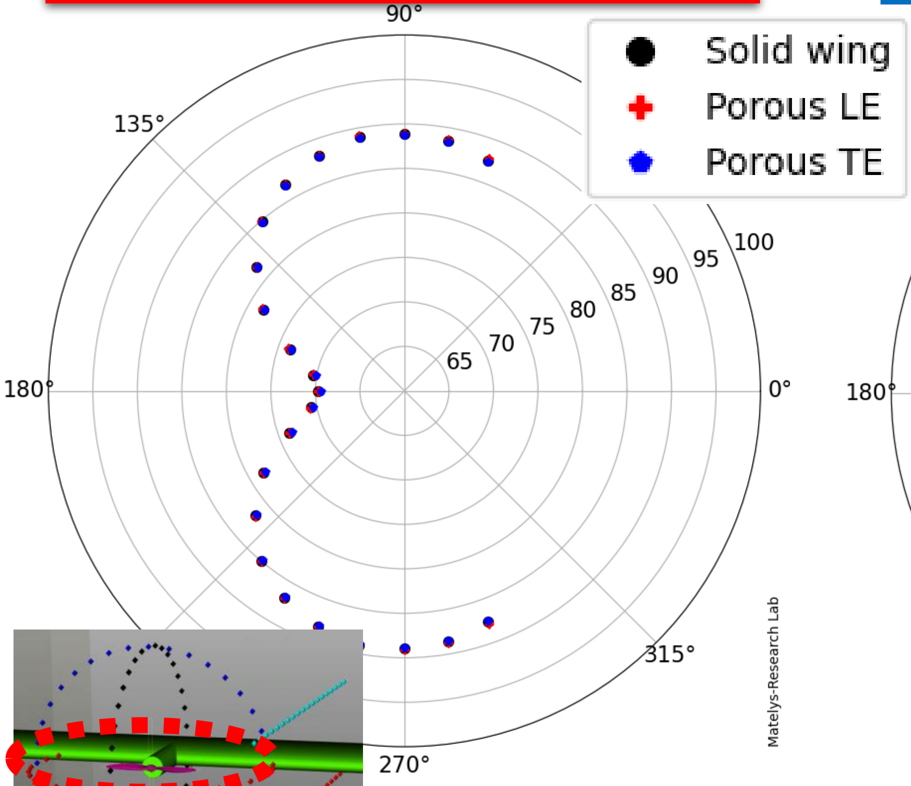


LBM simulations for installed propeller: Porous treatment of the wing

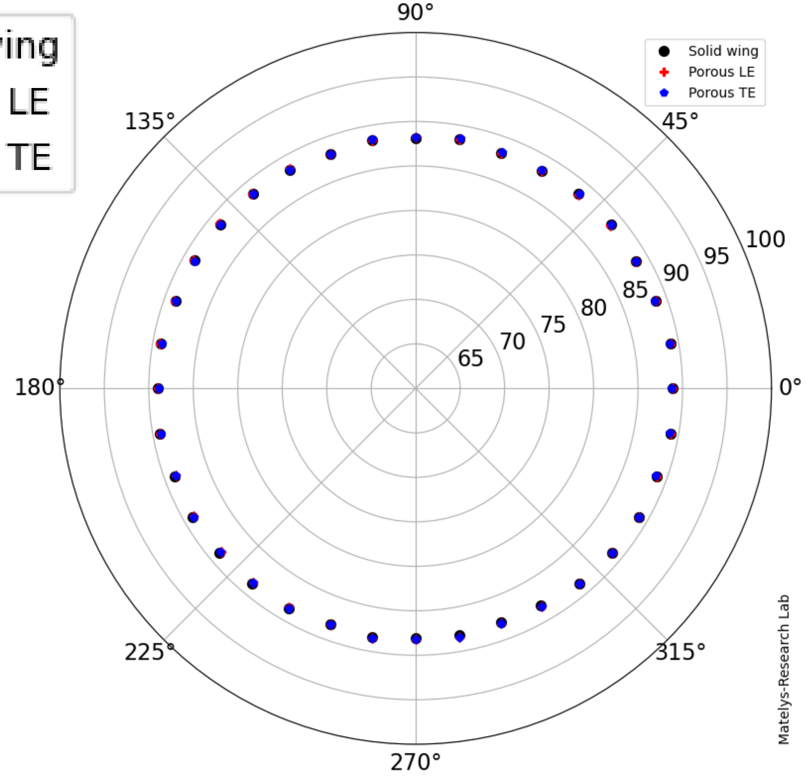


Propeller Near-field sound pressure directivity

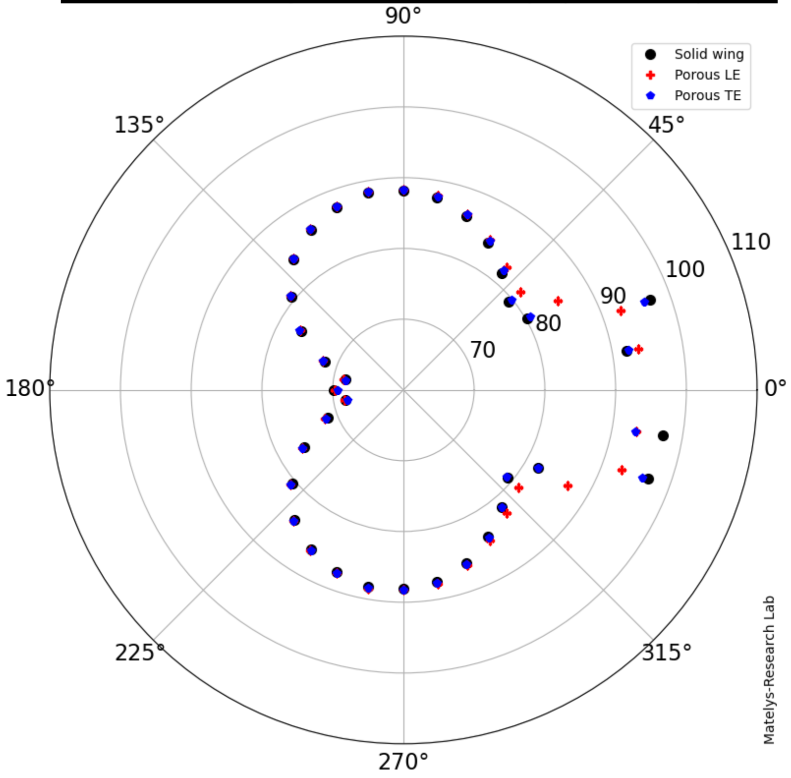
OASPL around propeller in XY plan



OASPL around propeller in YZ plan



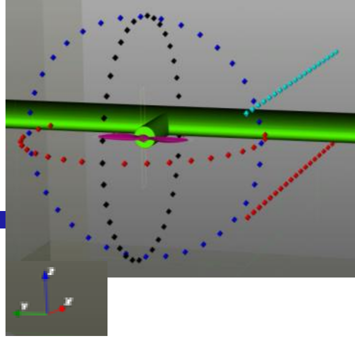
OASPL around propeller in XZ plan



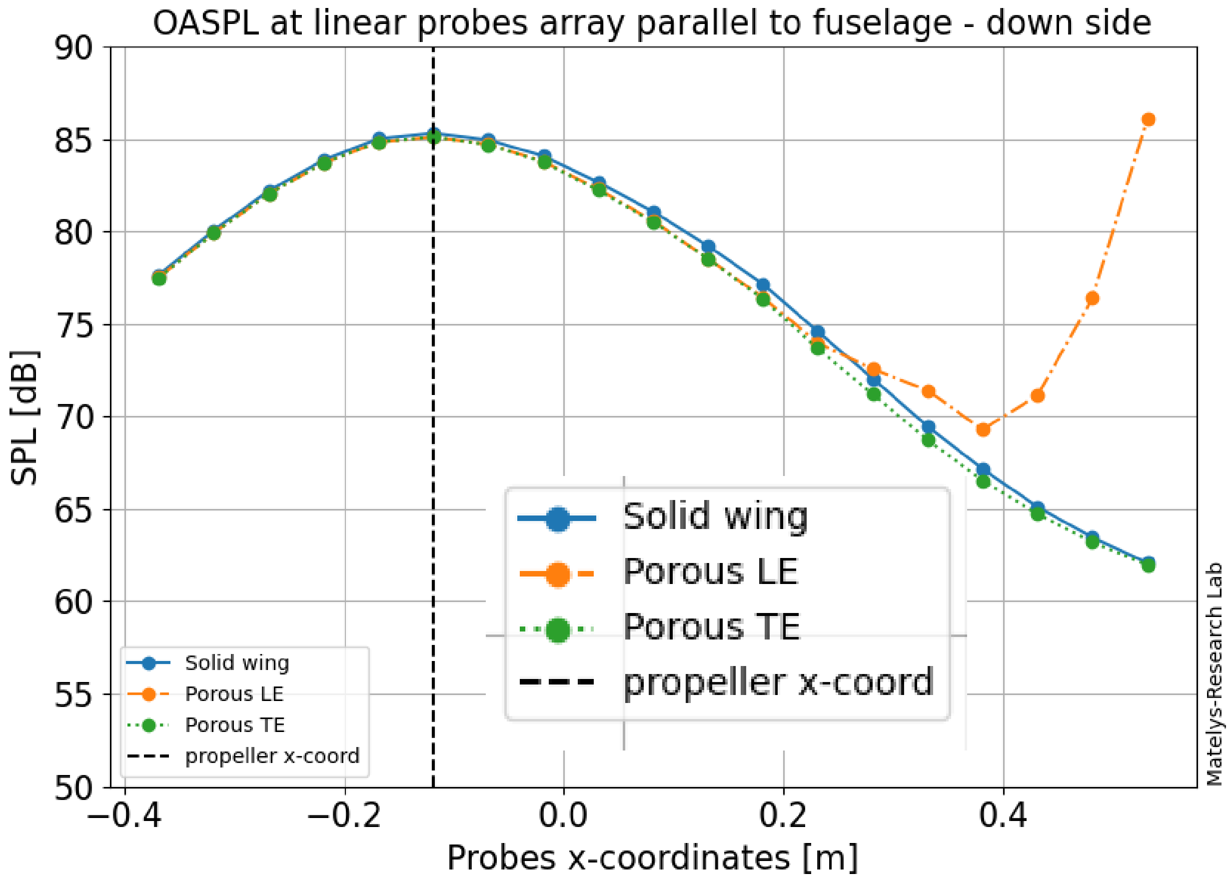
● Solid wing ✚ Porous LE ✸ Porous TE

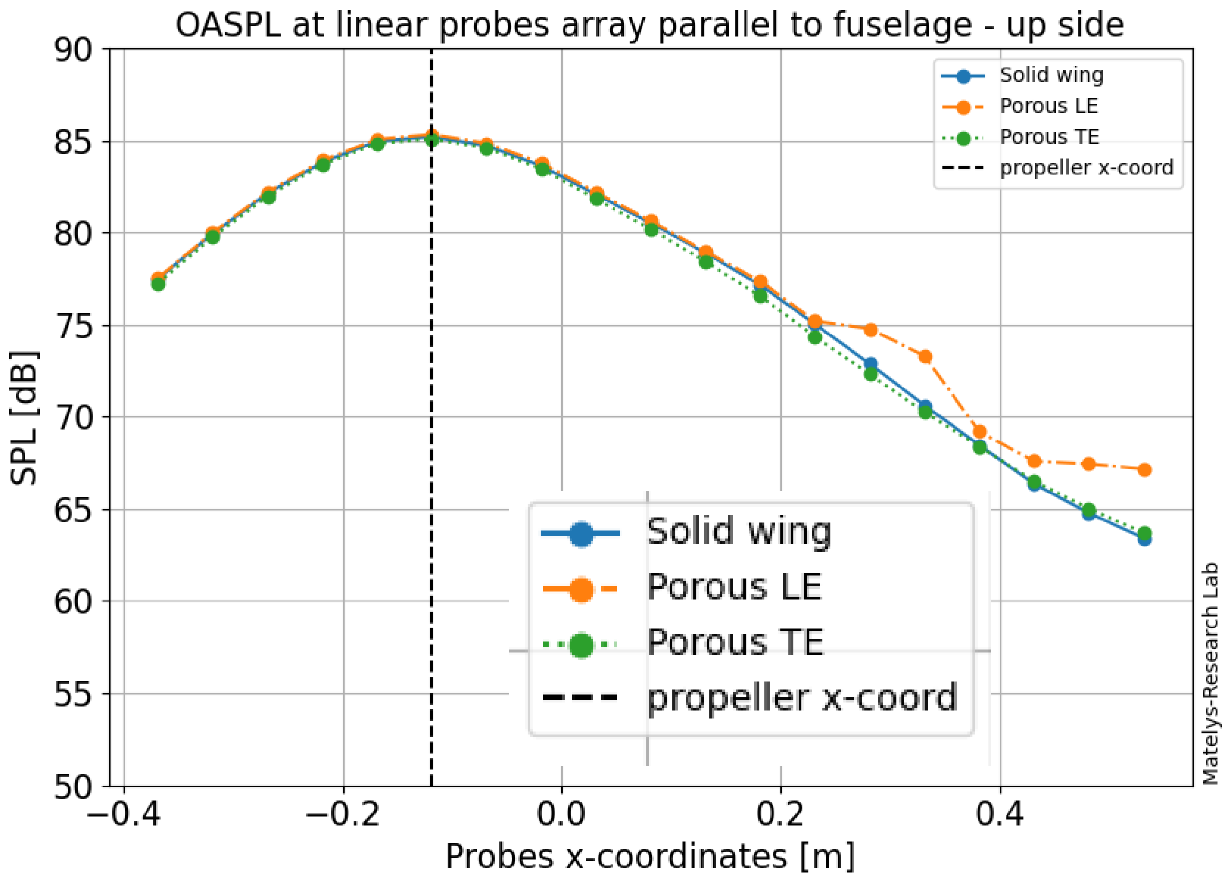
No effects on the propeller noise sources.

LBM simulations for installed propeller: Porous treatment of the wing



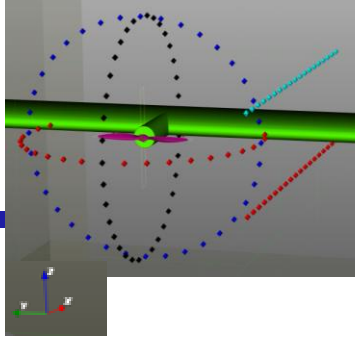
Near-field sound pressure Level



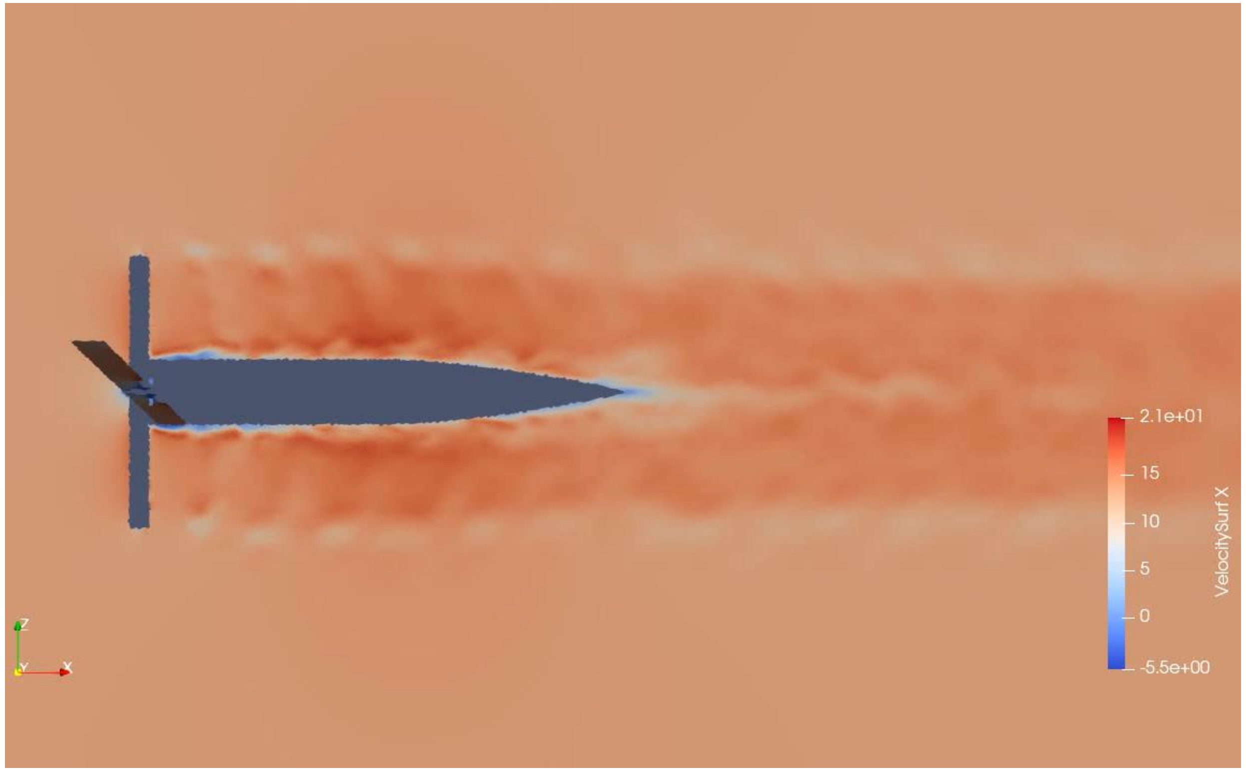


porous treatment of wing leading edge: can increase noise level

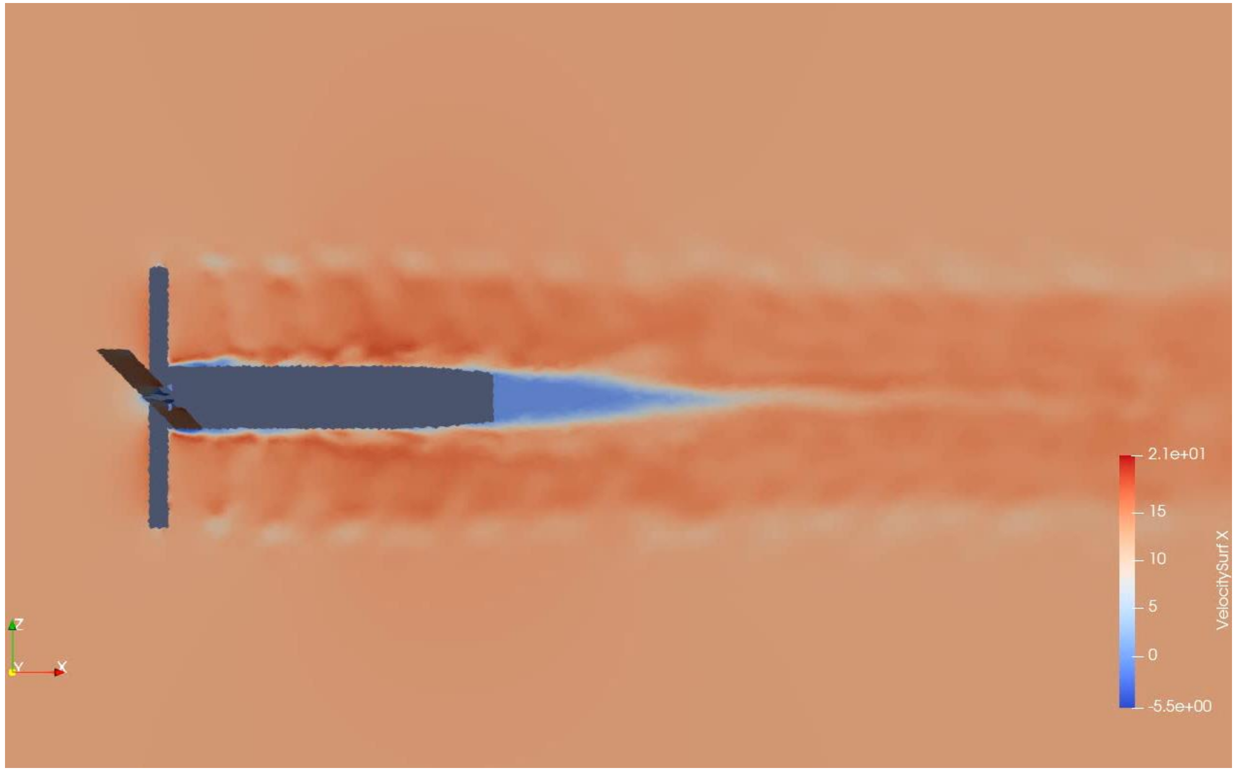
LBM simulations for installed propeller: Porous treatment of the wing



Velocity field



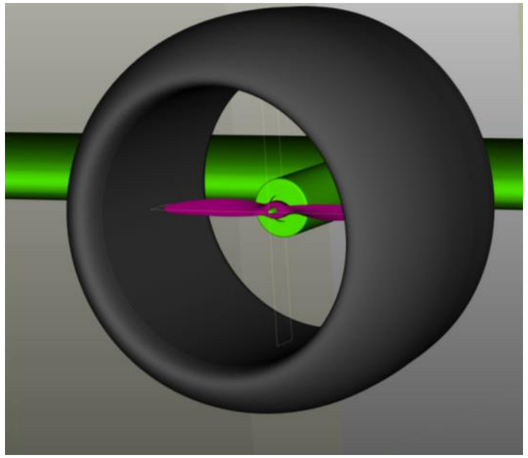
Porous Leading Edge



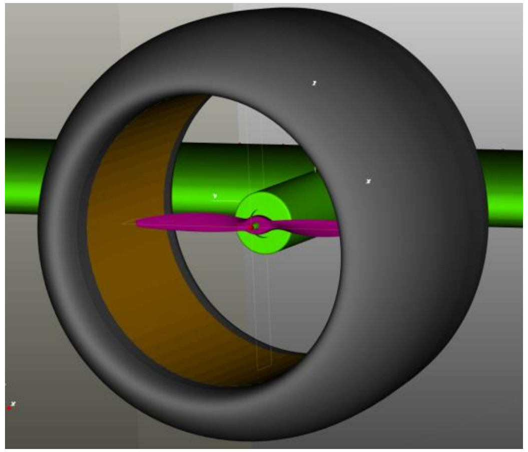
Porous Trailing Edge

Ducted propeller treatments

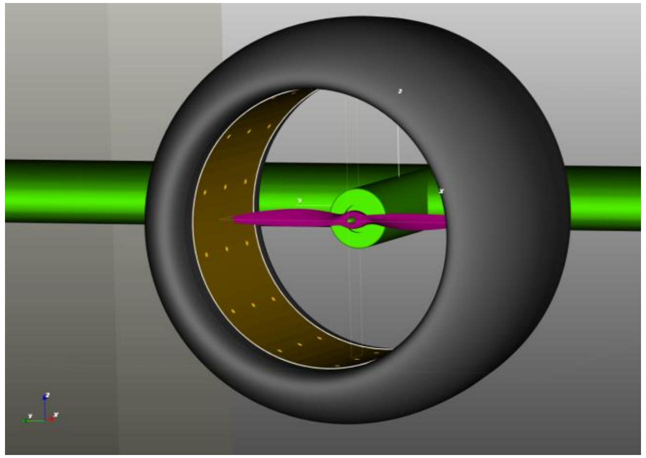
Ducted propeller treatments - Configurations



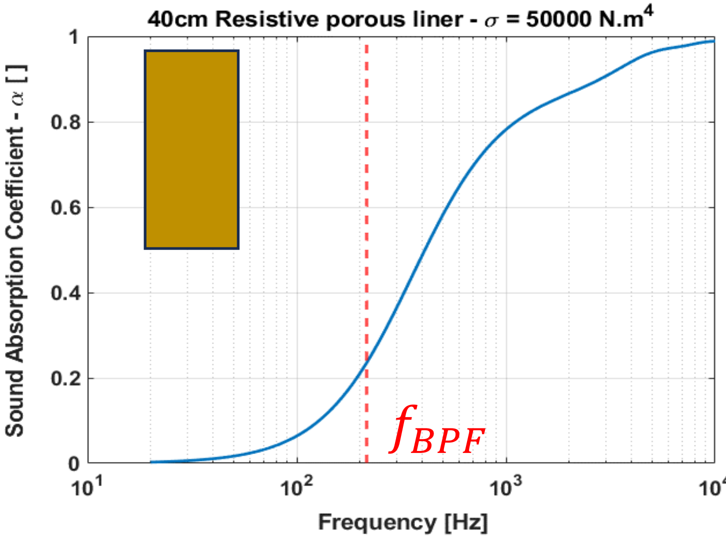
Bare NACA4312 Shroud

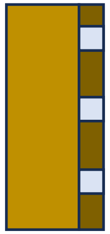


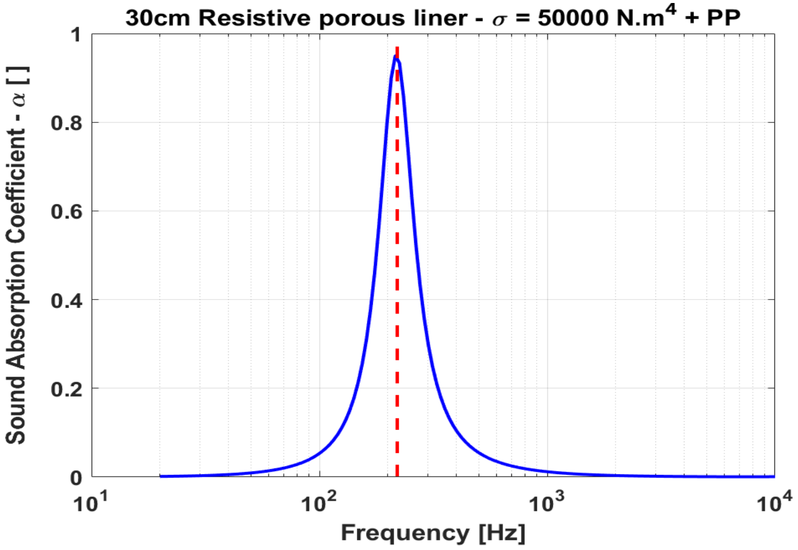
NACA4312 Shroud with porous liner



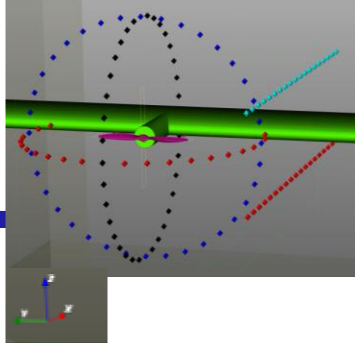
Shroud with porous and perforated plate liner



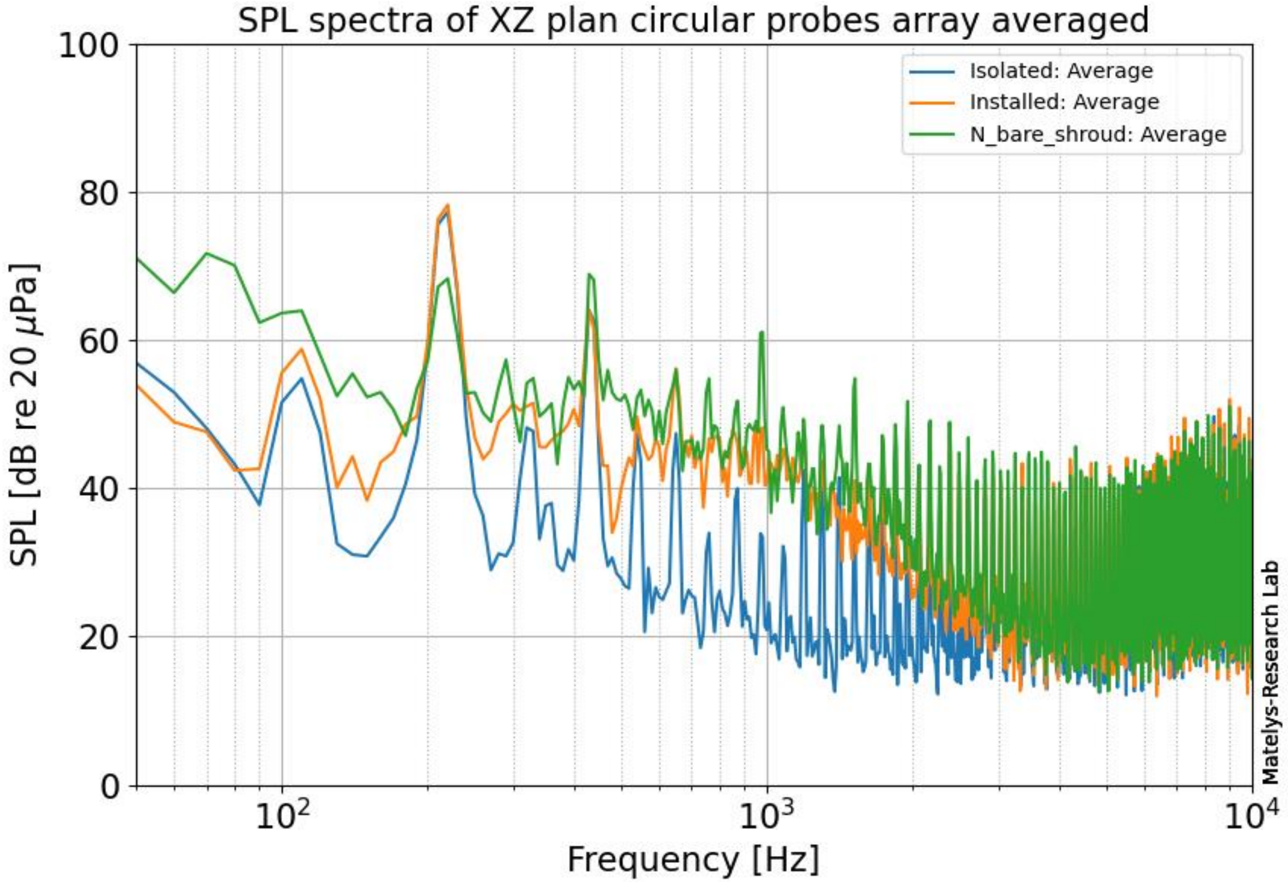




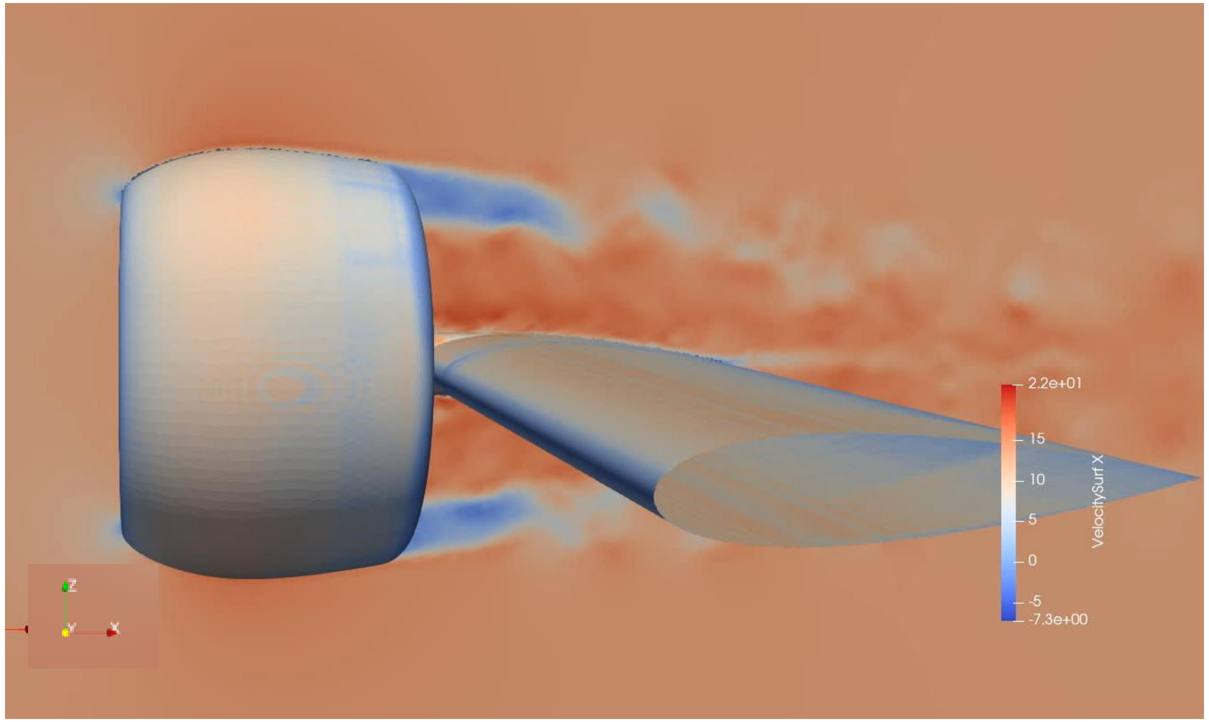
LBM simulations for noise reduction: duct based treatment



- **Case of a bare NACA4312 Shroud**



Sound pressure spectra

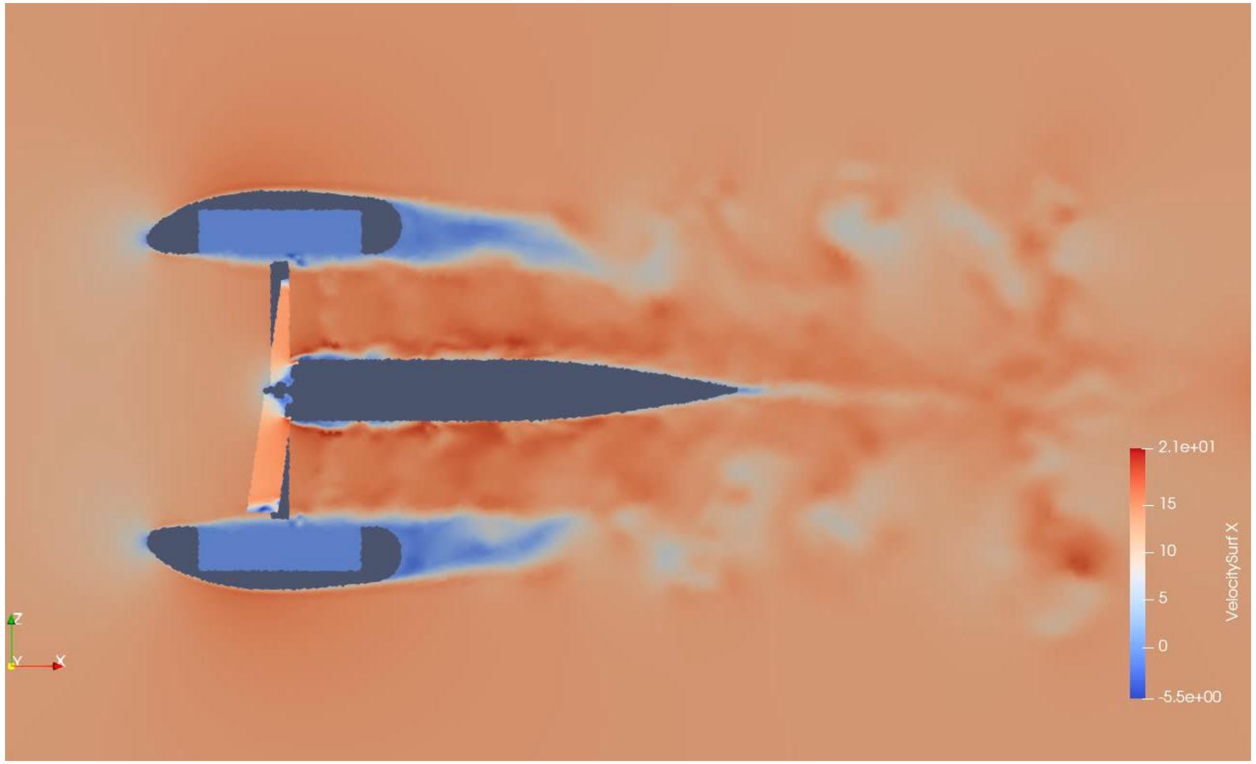


x-velocity on the vertical plan

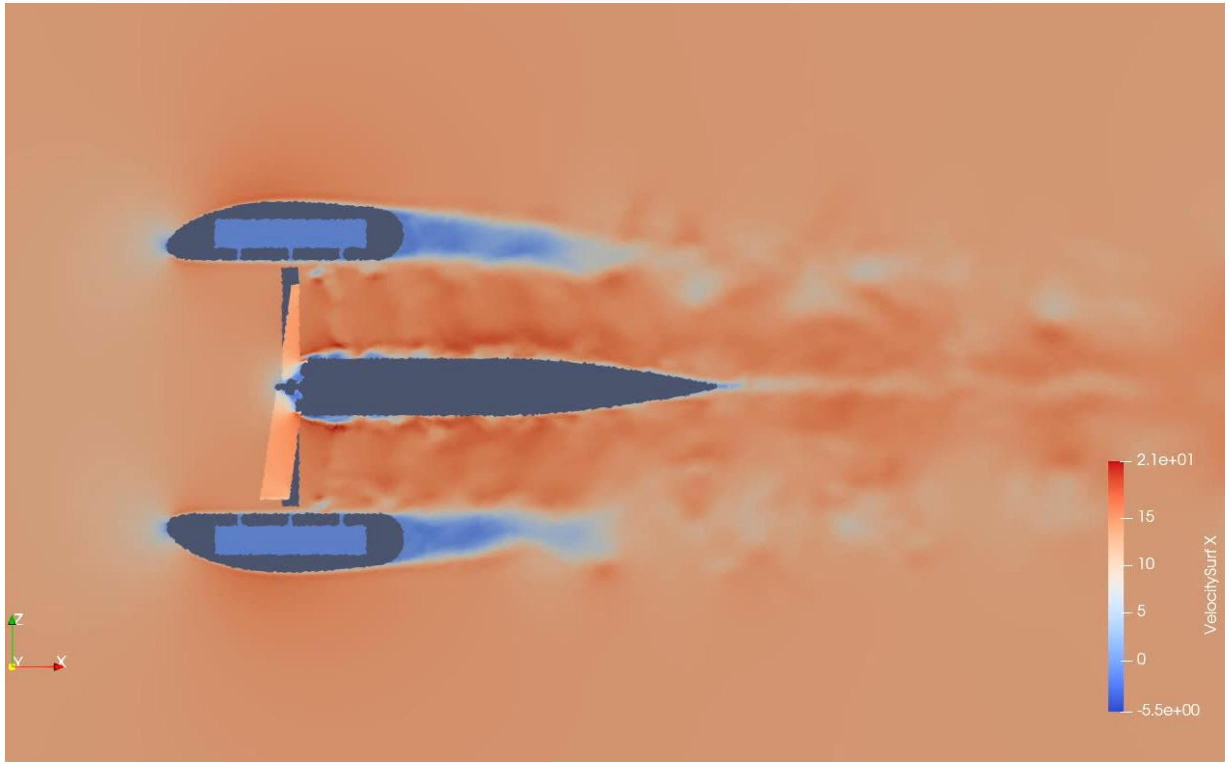
LBM simulations for noise reduction based on shroud: Results

Shroud and porous liner vs Shroud and porous liner + perforated plate

x-velocity flow

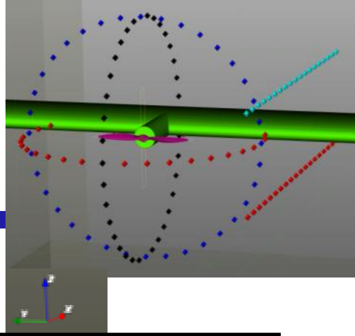


Shroud with porous liner



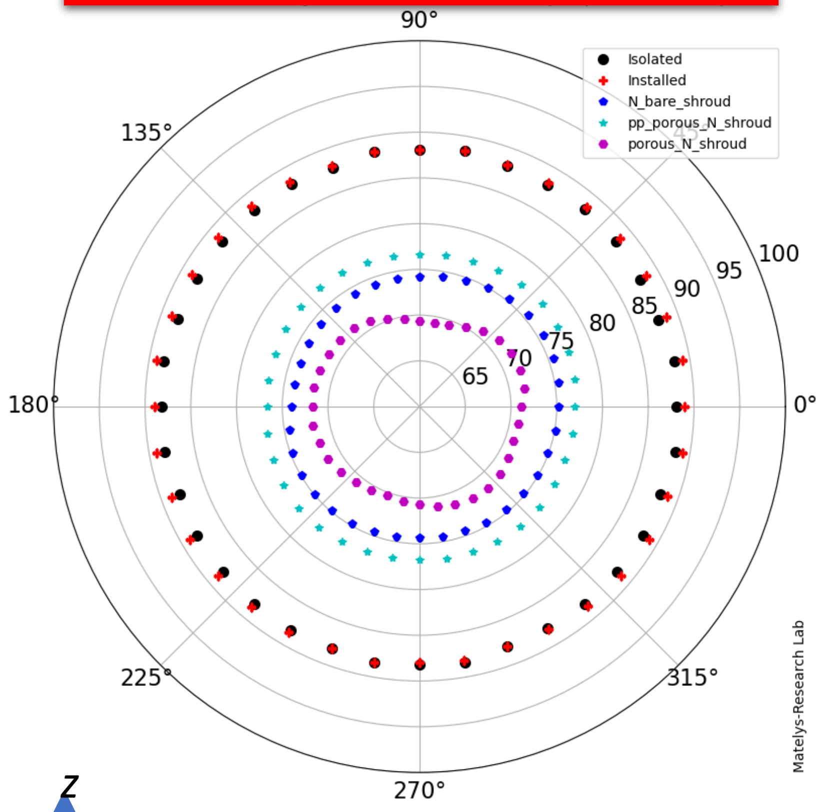
Porous liner covered by perforated cylinder

Shroud (duct) based treatment of propeller Noise – LBM Results

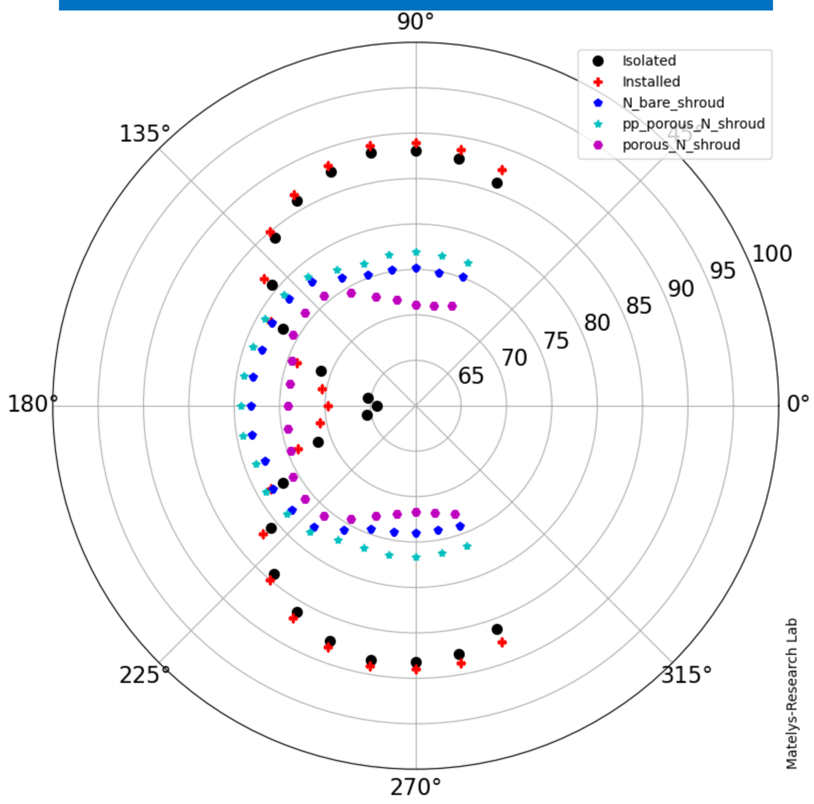


- **Comparison of different configurations: Near field directivity**

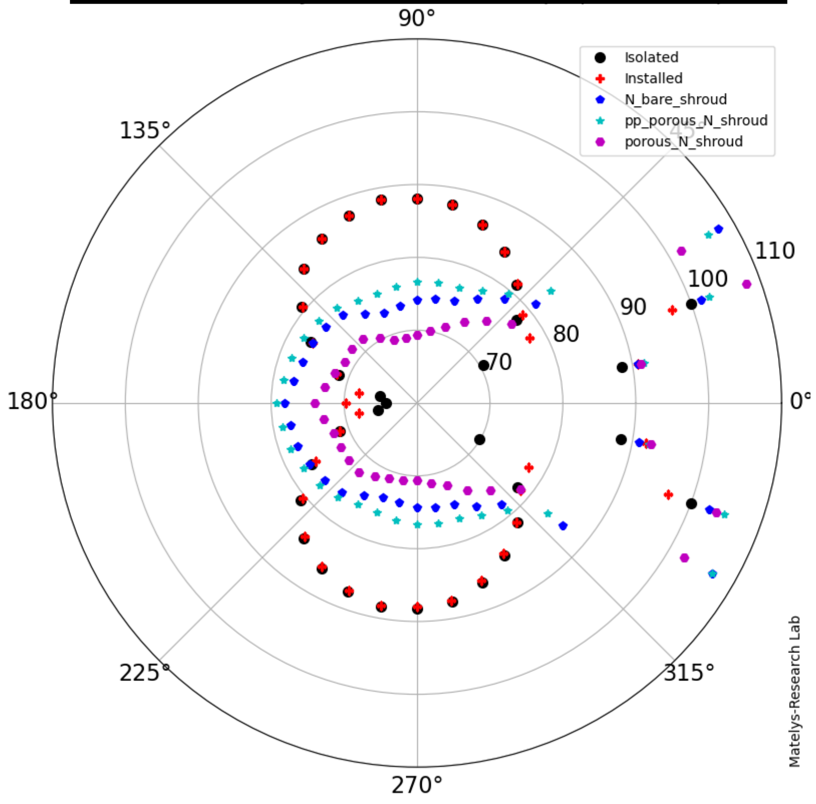
OASPL around propeller in XY plan

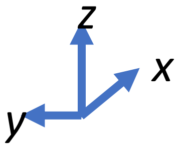


OASPL around propeller in YZ plan



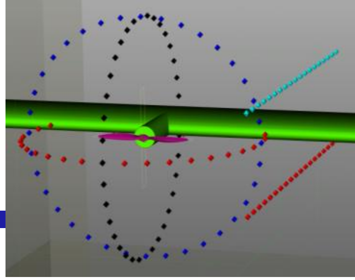
OASPL around propeller in XZ plan



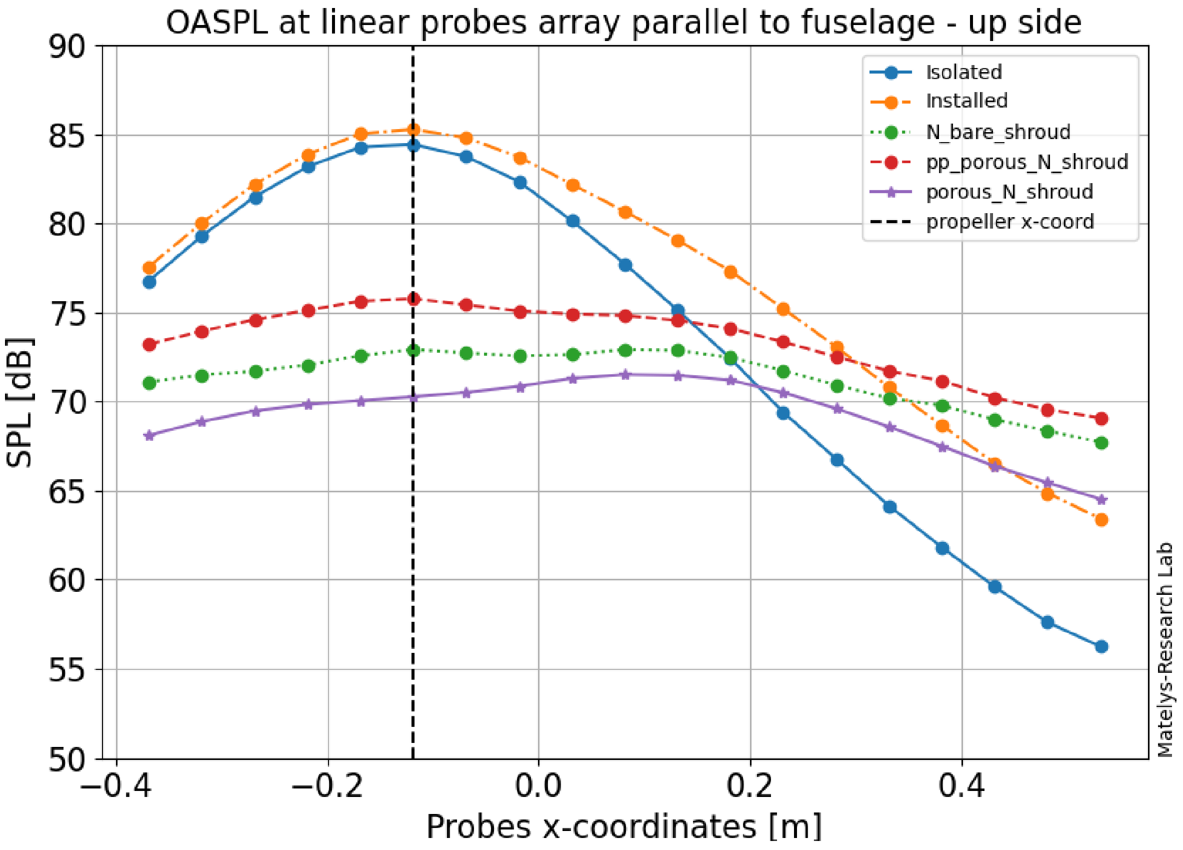


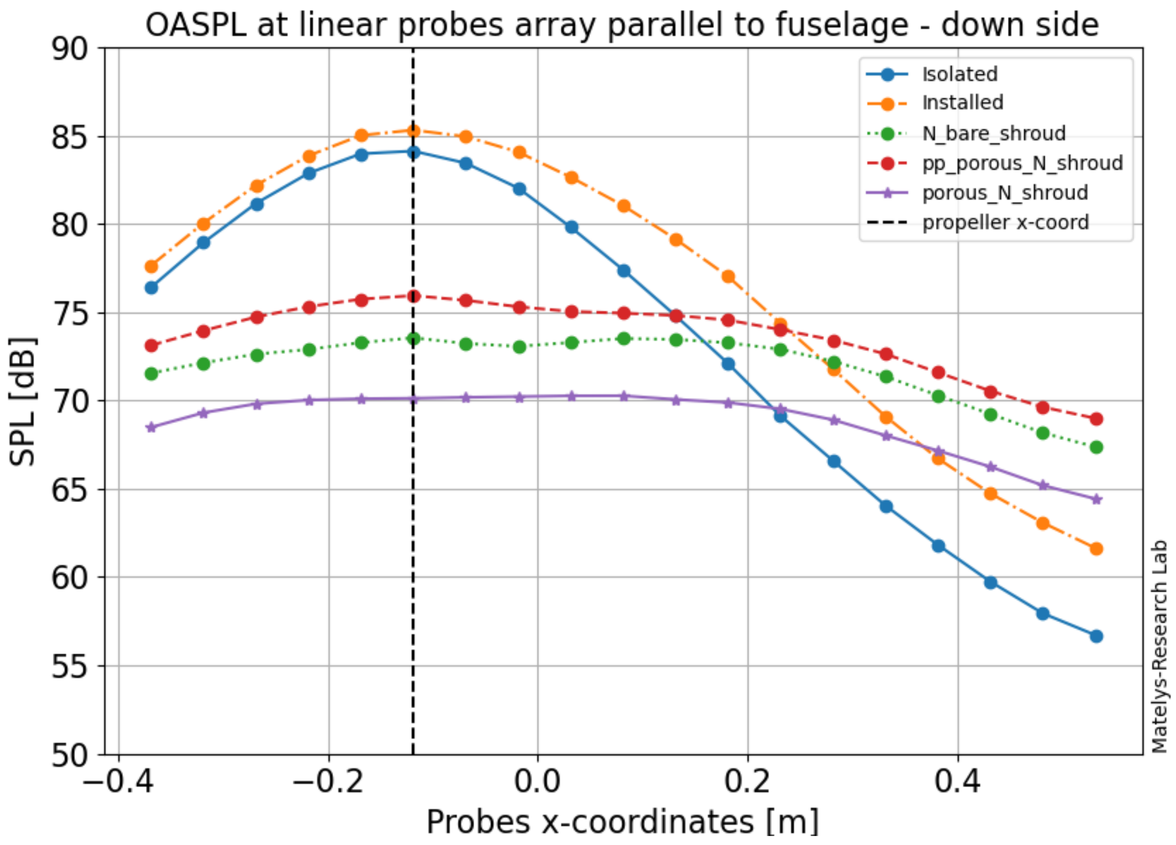
Isolated   Installed   N. bare shroud   PP porous N. shroud   Porous N (Naca) shroud

Shroud (duct) based treatment of propeller Noise – LBM Results

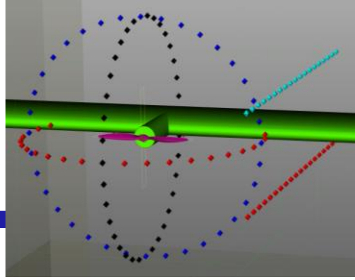


- **Comparison of different configurations: Near field pressure**

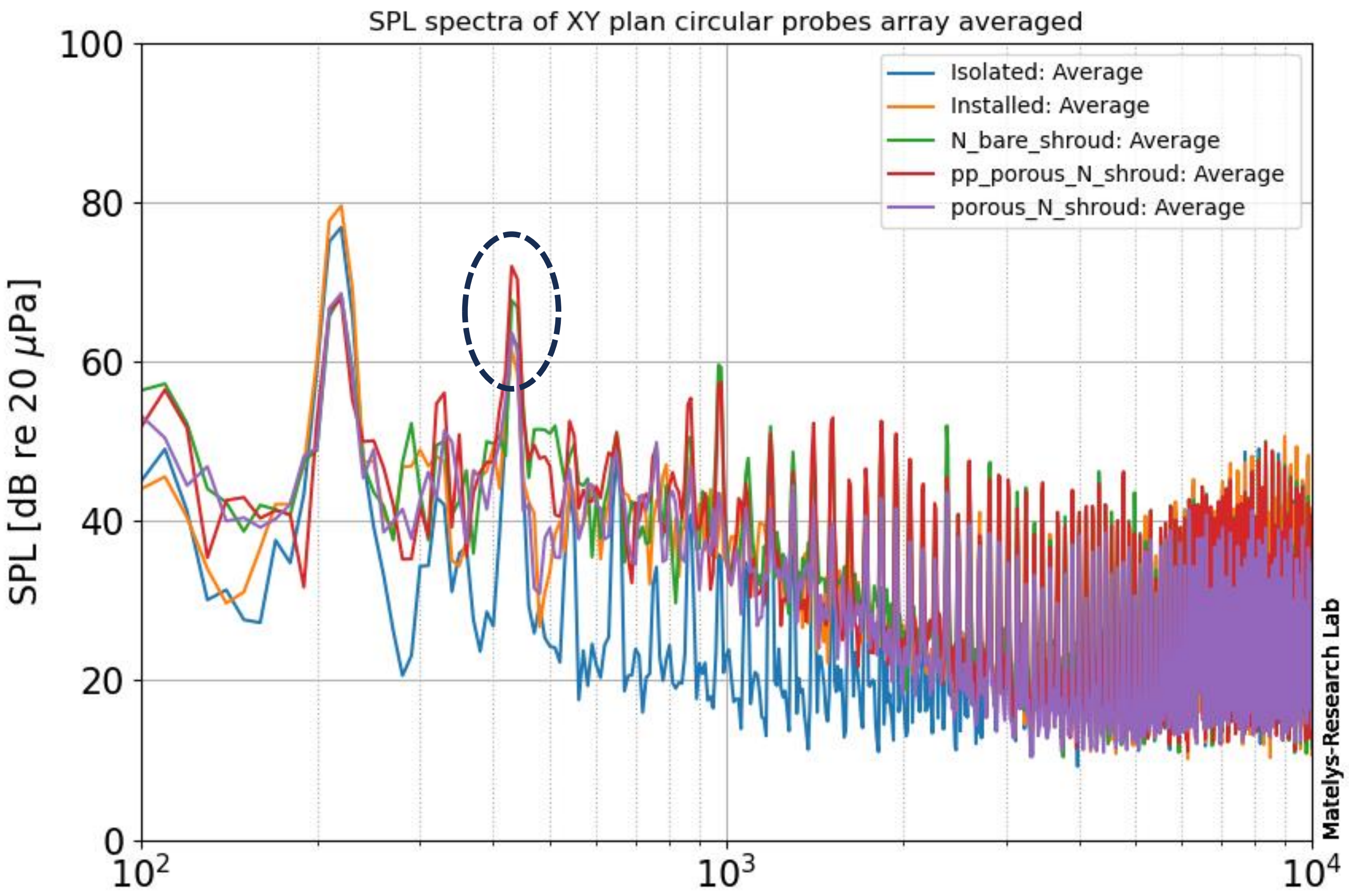




Shroud (duct) based treatment of propeller Noise – LBM Results



- **Comparison of different configurations: *Sound pressure spectra***



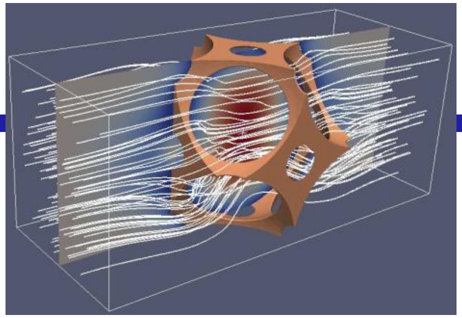
- PP : noise increase at following harmonics
- Diffuser behavior
- Regular distribution?

Concluding remarks and perspectives

Concluding remarks

- LBM as implemented in ProLB:
  - Well adapted for LES simulations of industrial cases
  - Including rotating elements
  - Highlighting noise sources of wing-propeller in presence of a flow
  - **Taking into account flow-porous material interaction**
  - Investigating various sound absorbing treatments
- Installation of the treatments
  - On the leading edge : low impact
  - On the trailing edge: better than on the leading edge
  - Inside the shroud (reduction of propeller self-noise):
    - Porous treatment to address broadband noise
    - Perforated plate to address BPF provided it is finely tuned

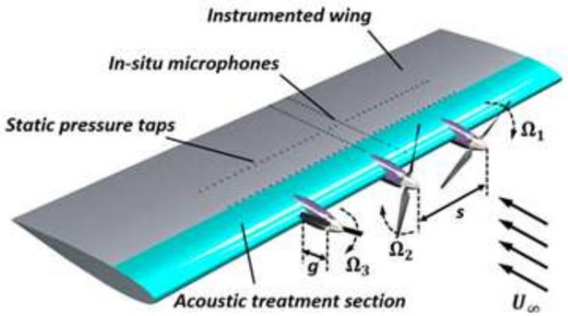
Perspectives



- Microscopic modelling of porous treatment under flow conditions

- Modelling MDOF using ProLB
- Continuing investigations on porous + perforated plate liners

- Investigating multiple blades propeller (3, 4, 5, etc.) configuration and regimes
- Modelling multiple propellers including sound absorbing treatment



Thank you for your attention!

fulbert.mbailassem@matelys.com