Smart Mitigation of flow-induced Acoustic Radiation and
Transmission for reduced Aircraft, Surface traNSport,
Workplaces and wind enERgy noise

Trailing Edge Noise Reduction with Permeable Materials:

Description of Noise Scattering Mechanism

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I. INTRODUCTION

Power vs Noise

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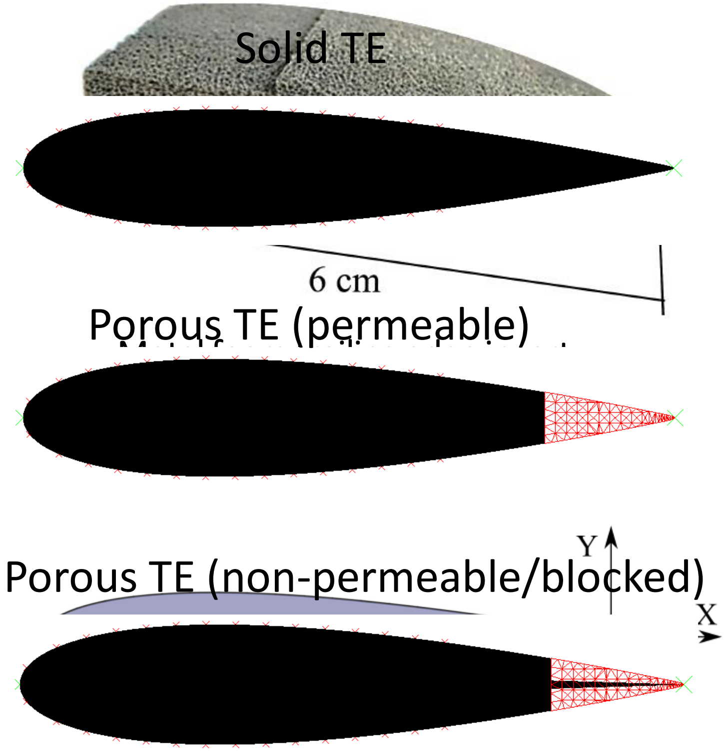
Trailing edge serrations installed on a wind turbine blade

Retain the noise level and increase the power production

[1] http://www.windenergy.org.nz/improvements-in-technology
[2] http://www.ewea.org/events/workshops/wp-content/uploads/2012/12/EWEA-Noise-Workshop-Oxford-2012-1-1-Stefan-Oerlemans.pdf
[3] http://www.windfarmbop.com/serrations-or-how-to-reduce-those-noisy-vortexes/

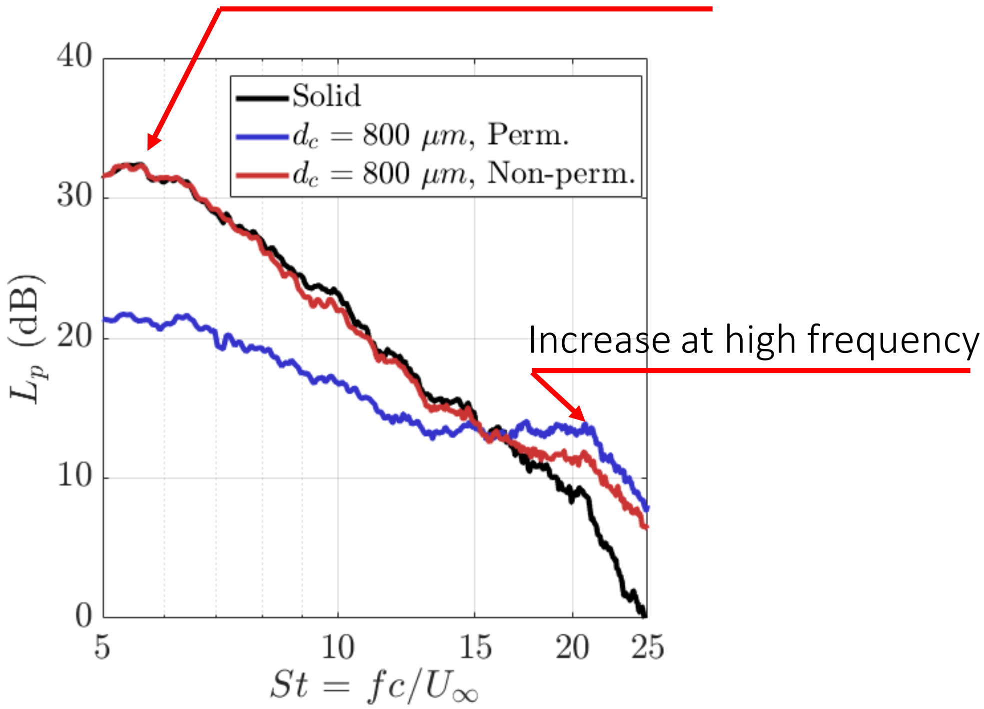
Metal-Foam Trailing Edge



NACA 0018 with metal-foam trailing edge [1]
Different types of trailing edge treatment

Reduction at low frequency

Increase at high frequency



Far field sound spectra comparison [1]

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[1] Rubio Carpio *et al.*, "On the role of the flow permeability of metal foams on trailing edge noise reduction", *2018 AIAA/CEAS Aeroacoustics Conference*

[2] Rubio Carpio *et al.*, "Mechanisms of Broadband Noise Generation on Metal Foam Edges", *Physics of Fluids*, *under review.*

The Questions

- Trailing-edge permeability affects noise reduction, but how?

- Some parameters that are proportional to far-field noise according to Amiet's model [1,2] :

Spanwise correlation length

Airfoil response function

$$S_{pp}(\boldsymbol{x},\omega) \sim \Phi_{pp}(\omega) L_{pp}^{Z}(\omega)\, \mathcal{L}^2\left(\frac{\omega}{U_c}, K_y\right)$$

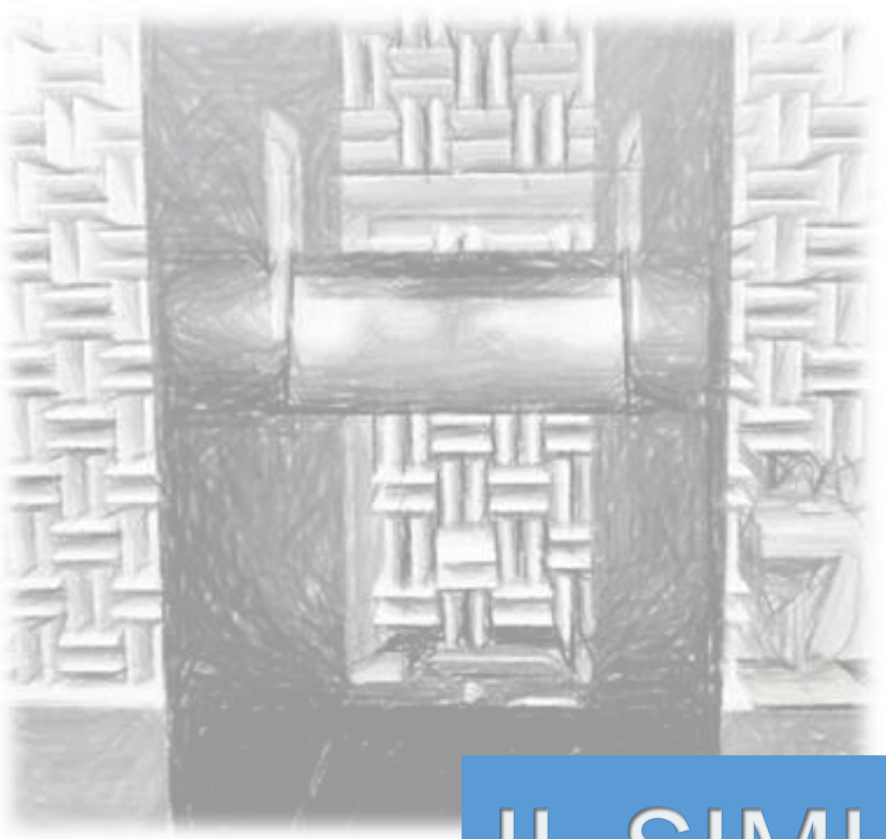
Spectra of the wall-pressure fluctuation

- Could the changes in these parameters be linked to the noise reduction?

- To gain more insights into the aeroacoustics of porous trailing edge, a numerical study is performed using **PowerFLOW 5.4b**.

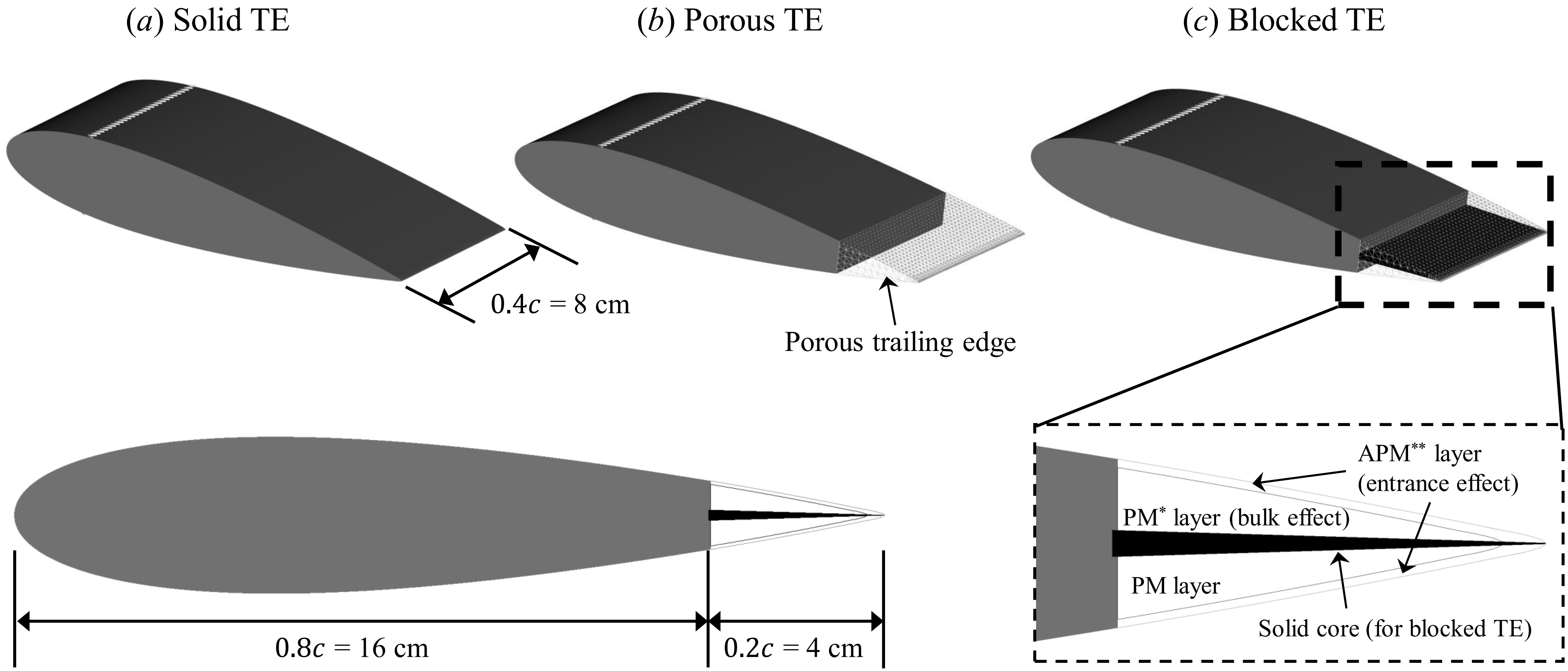
[1] Amiet, R. K, Noise due to turbulent flow past a trailing edge. *Journal of sound and vibration*, *47*(3), 387-393, 1976

[2] Roger, M., & Moreau, S., Back-scattering correction and further extensions of Amiet's trailing-edge noise model. Part 1: theory. *Journal of Sound and Vibration*, *286*(3), 477-506, 2005



II. SIMULATION AND RESULTS

NACA 0018 TE Noise Case



- The porous material is modelled using equivalent fluid regions governed by Darcy's law.

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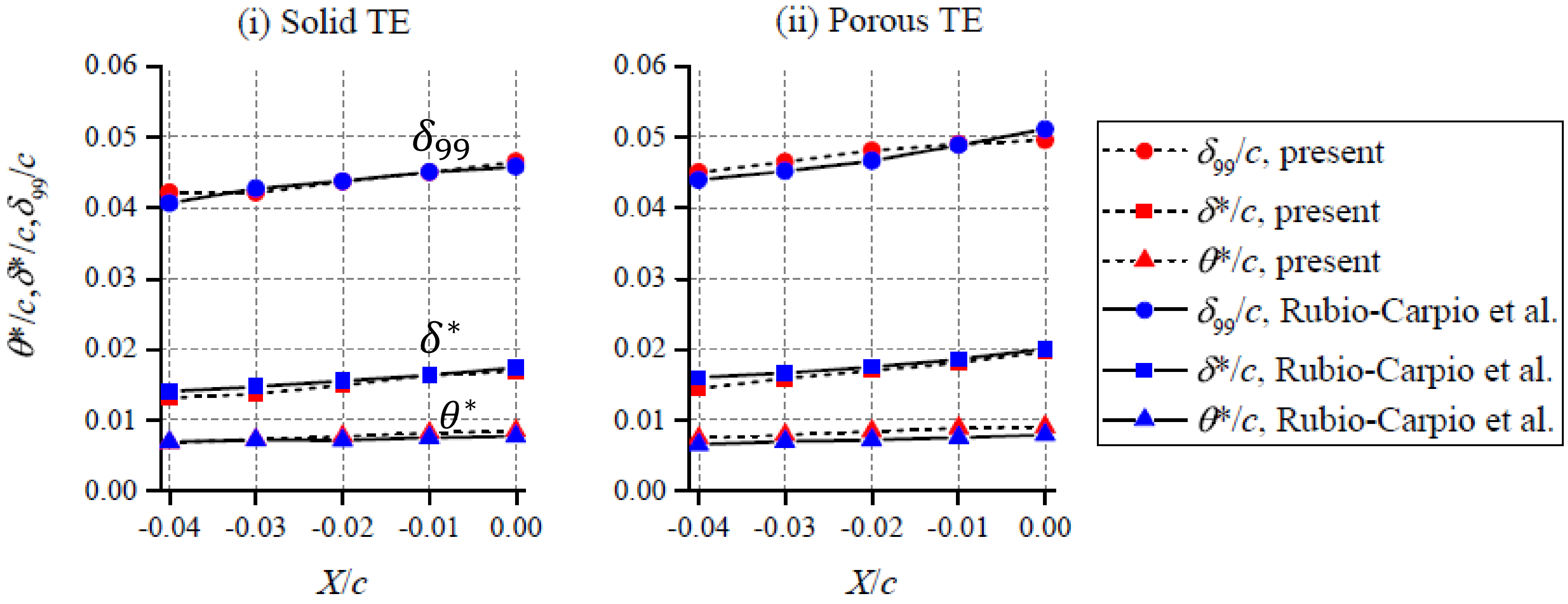
* PM (Porous Material) – an equivalent fluid region where certain mechanical impedance can be specified, subjecting the permeating fluid to viscous and inertial losses.

** APM (Acoustics Porous Material) – a model similar to the PM with the addition of porosity, which governs the mass flow of transpiration across the porous medium surface

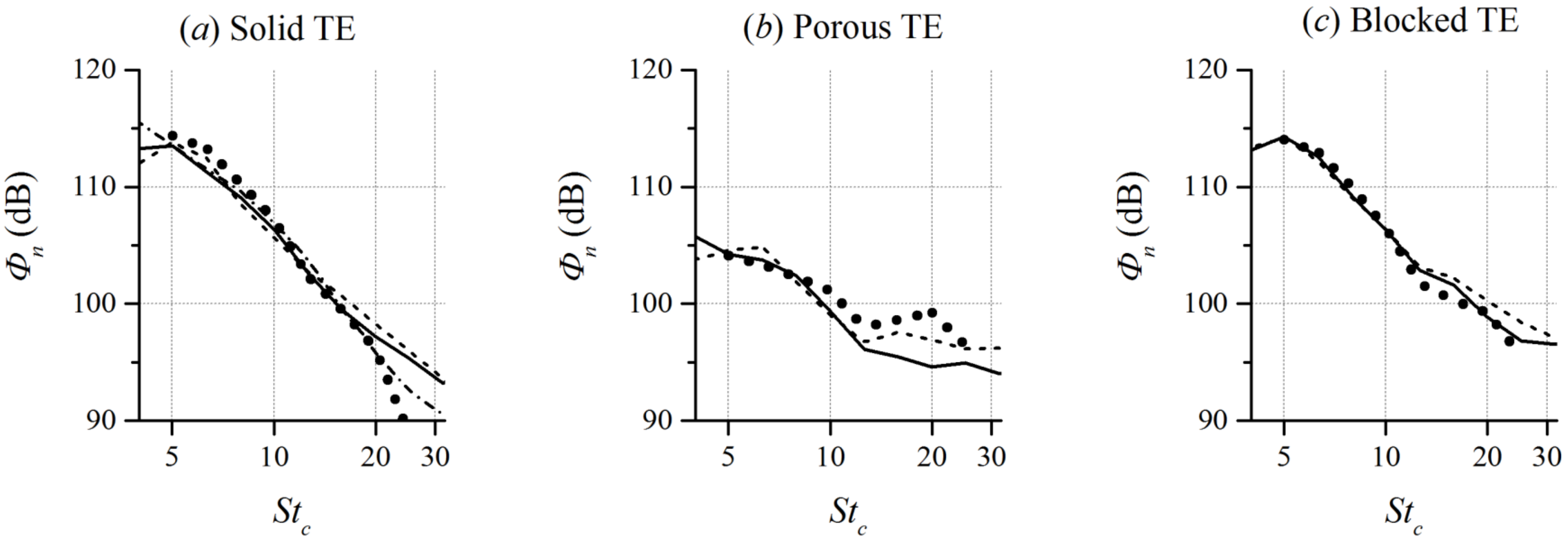
Integral Boundary Layer Parameters



Comparison of boundary layer integral parameters between the simulation and the experiment

[1] Carpio, A. R., Martínez, R. M., Avallone, F., Ragni, D., Snellen, M., & Van Der Zwaag, S. Broadband trailing edge noise reduction using permeable metal foams. In *46 th International Congress and Exposition of Noise Control Engineering* (pp. 27-30), 2017.

Far-field Sound at Reference Location



$$\Phi_n = \Phi_o + 10\log_{10}\frac{R^2}{bM_\infty^5}$$

$$St_c = \frac{fc}{U_\infty}$$

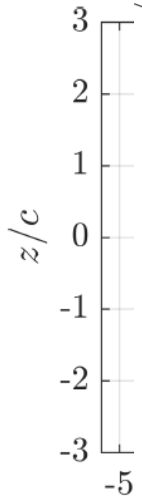
Far-field sound spectra from the three trailing edge treatments

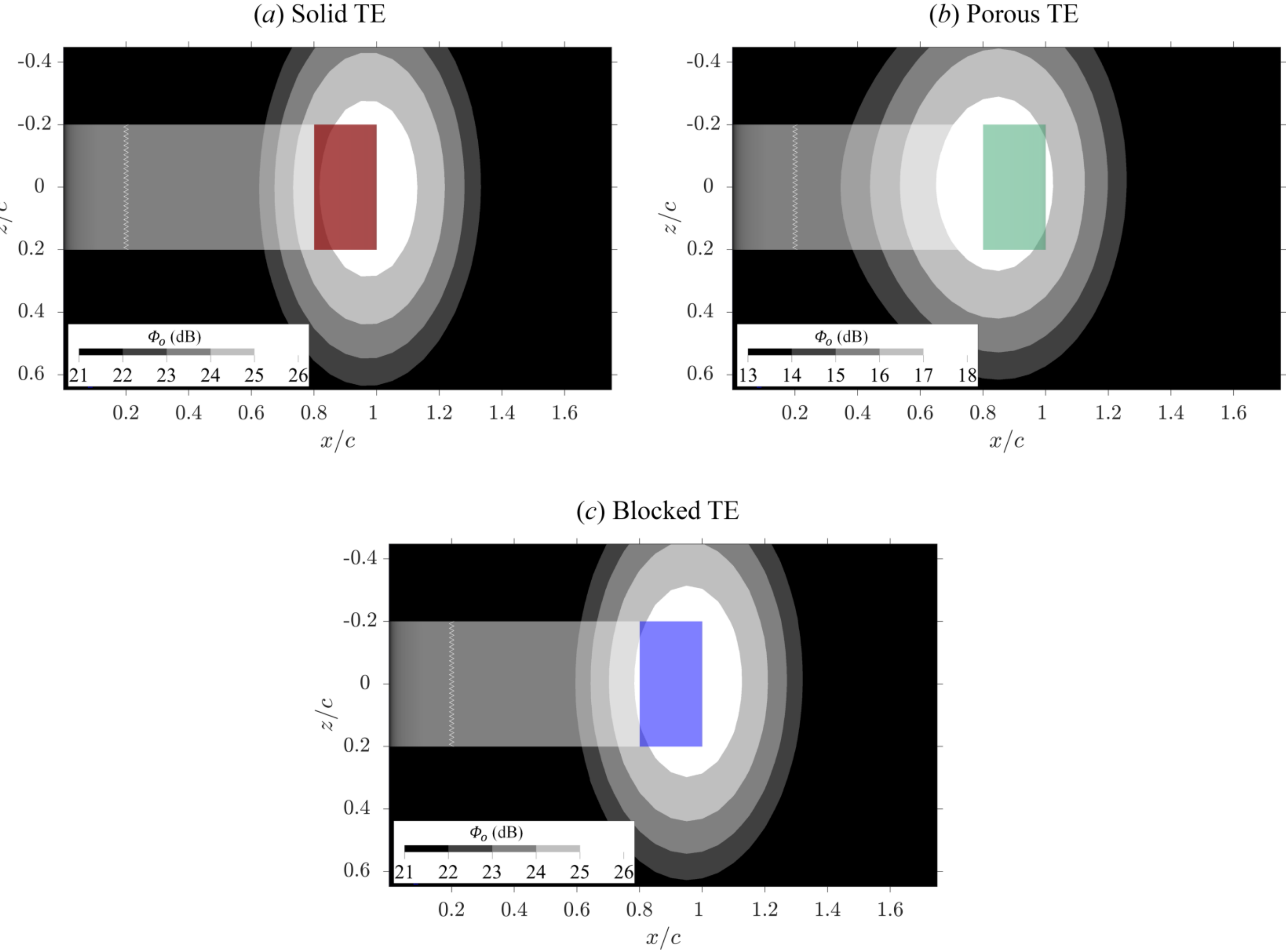
- There are discrepancies, mainly in the high frequency, however simulation results remain in trend with the experiment.

[1] Rubio Carpio *et al.*, "On the role of the flow permeability of metal foams on trailing edge noise reduction", *2018 AIAA/CEAS Aeroacoustics Conference*

[2] León, C. A., Merino-Martínez, R., Ragni, D., Avallone, F., & Snellen, M., Boundary layer characterization and acoustic measurements of flow-aligned trailing edge serrations. *Experiments in Fluids*, *57*(12), 182, 2016.

Numerical Beamforming





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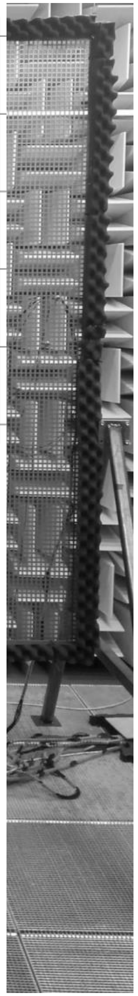
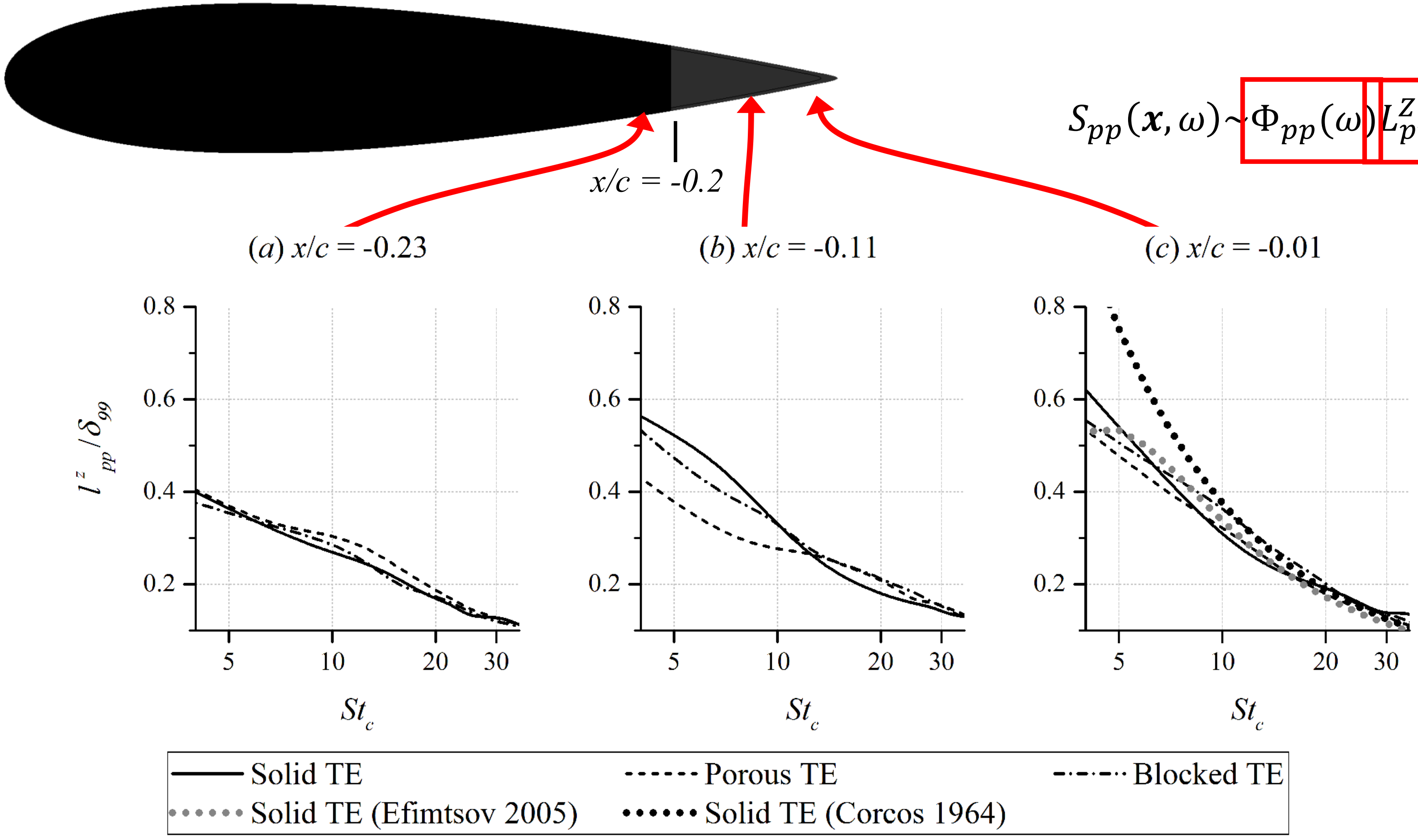


Tunnel

Beamforming maps at St_c = 12.5

Surface Pressure Statistics

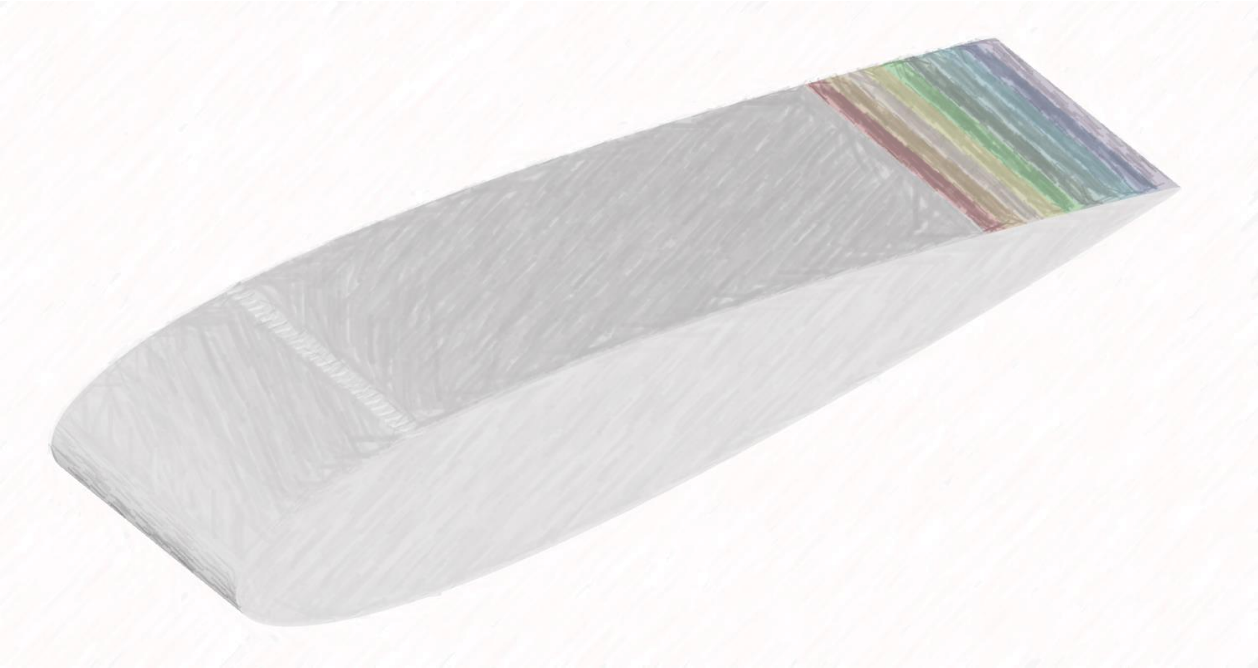
$$S_{pp}(\boldsymbol{x},\omega)\sim\boxed{\Phi_{pp}(\omega)}\boxed{L_{pp}^{Z}(\omega)}\,\mathcal{L}^2\left(\frac{\omega}{U_c},K_y\right)$$



Autospectra of surface pressure fluctuation

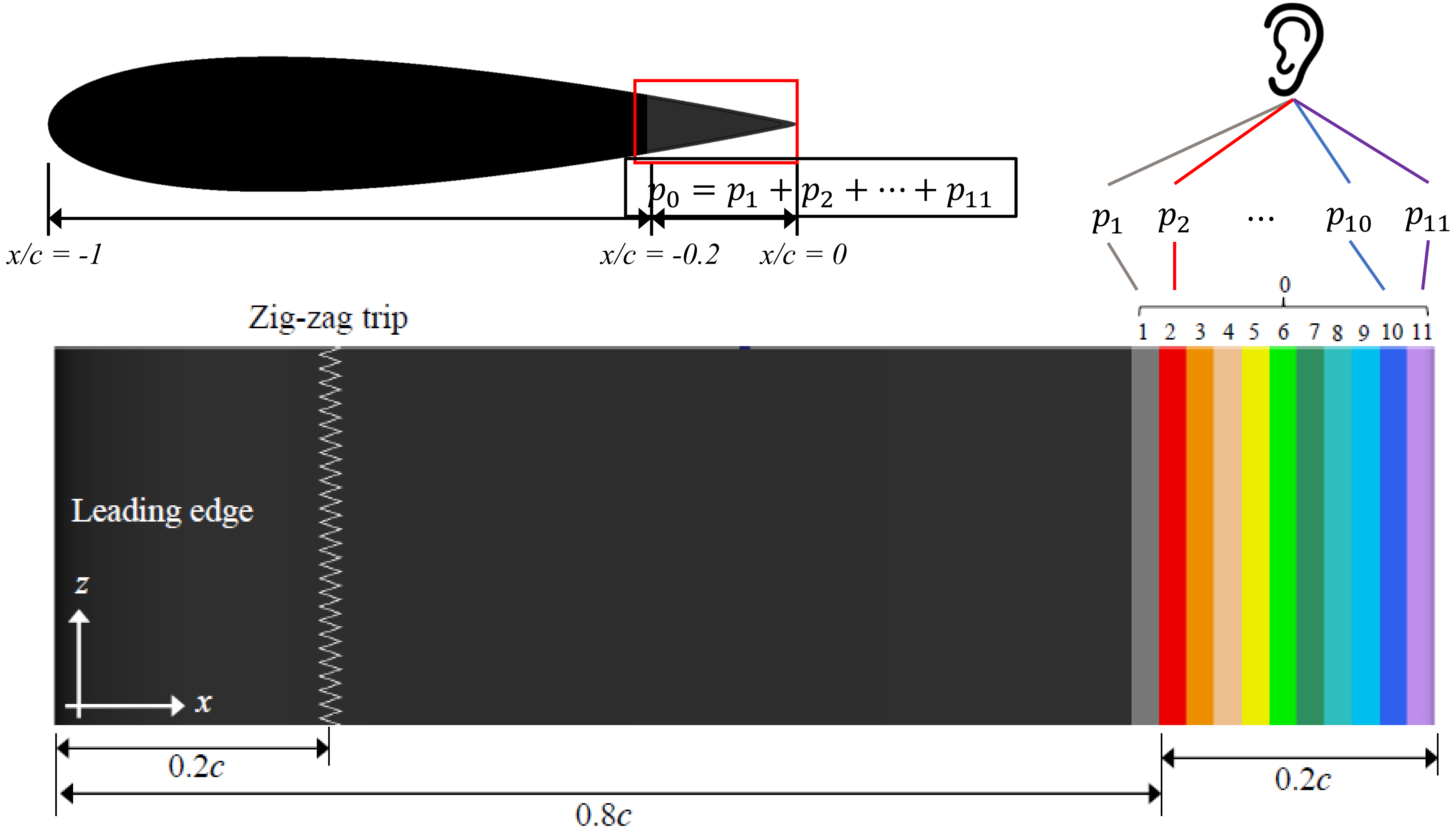
Spanwise coherence length

- The changes in the surface pressure statistics do not warrant the noise reduction of the porous TE.



IV. ACOUSTIC SCATTERING ANALYSES

Sub-dividing the TE into Strips

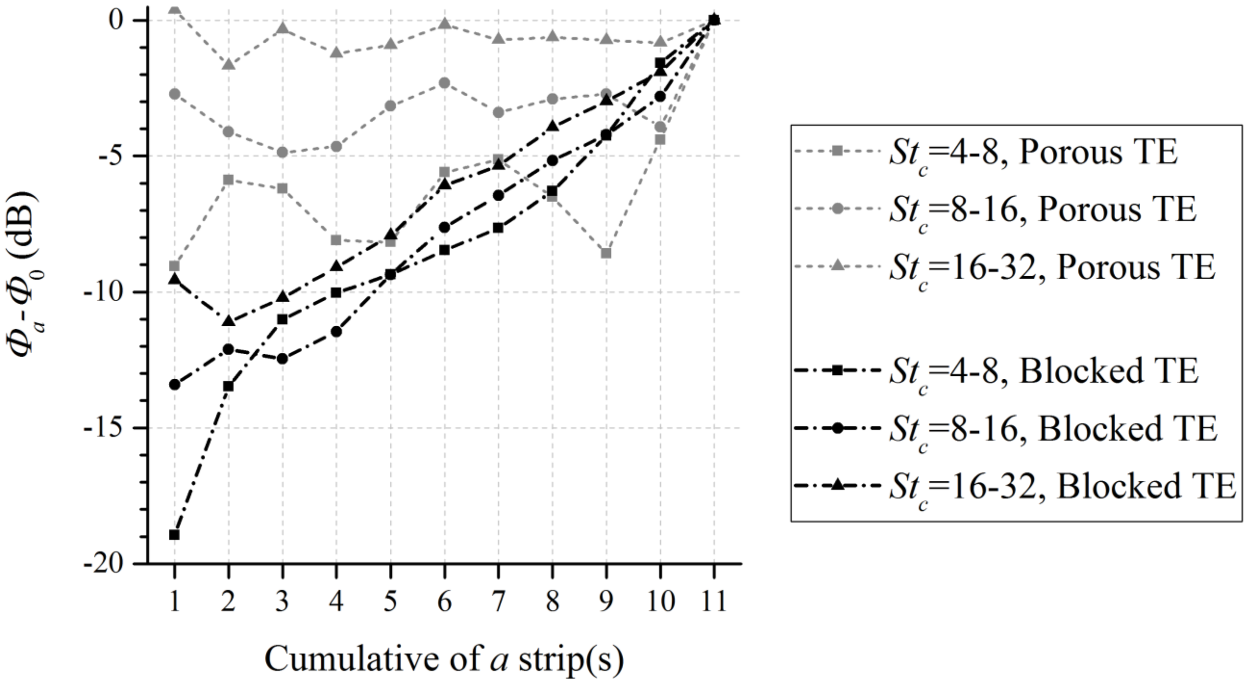


- The trailing edge is sub-divided into strips to quantify their far-field noise contributions.

Cumulative Contribution of the Strips

$$\Phi_a = \Phi(p_1 + \cdots + p_a)$$

$$\Phi_0 = \Phi(p_1 + \cdots + p_{11})$$



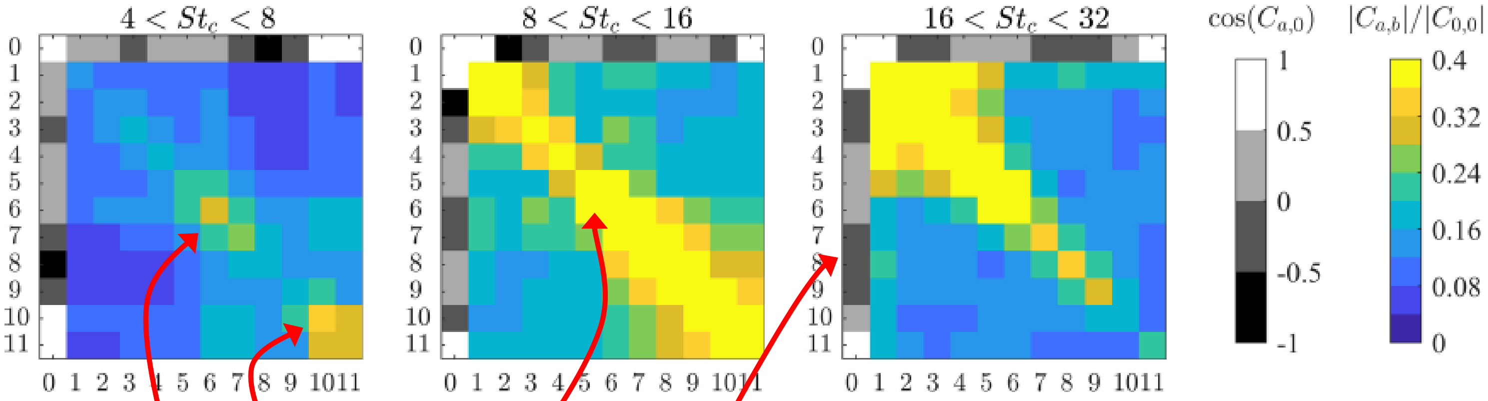
Cumulative far-field noise contribution of strips

- Strip 1 and 2 of the porous TE (i.e., solid-porous junction) have more dominant contributions than those of the blocked TE.

- Porous TE shows a large variation of slope, indicating the presence of destructive interference.

Cross-correlation analysis

(a) Porous trailing edge



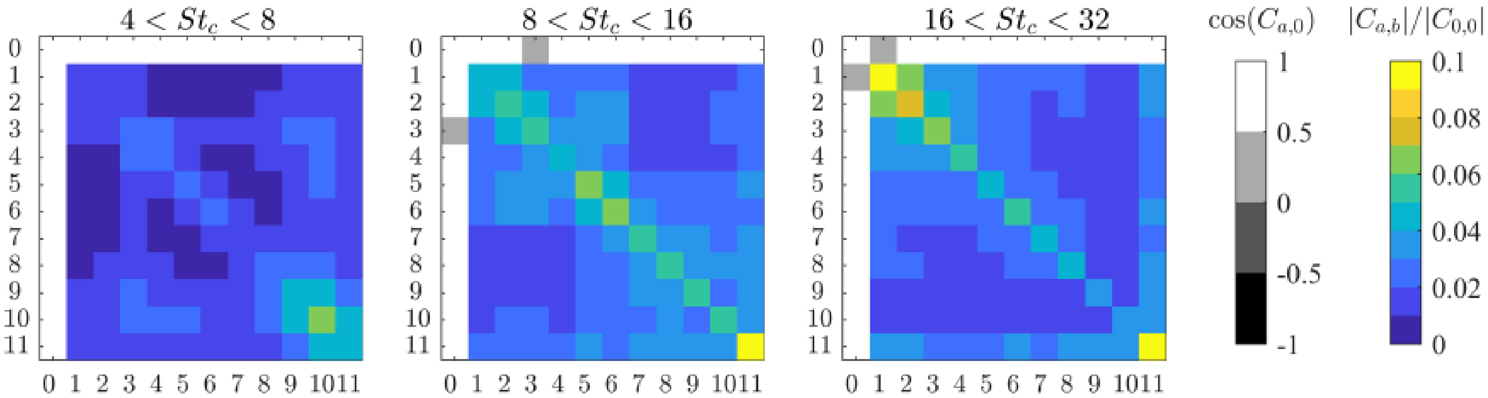
1. More uniform distribution of sound sources

2. More numbers of strips with out-of-phase relationship

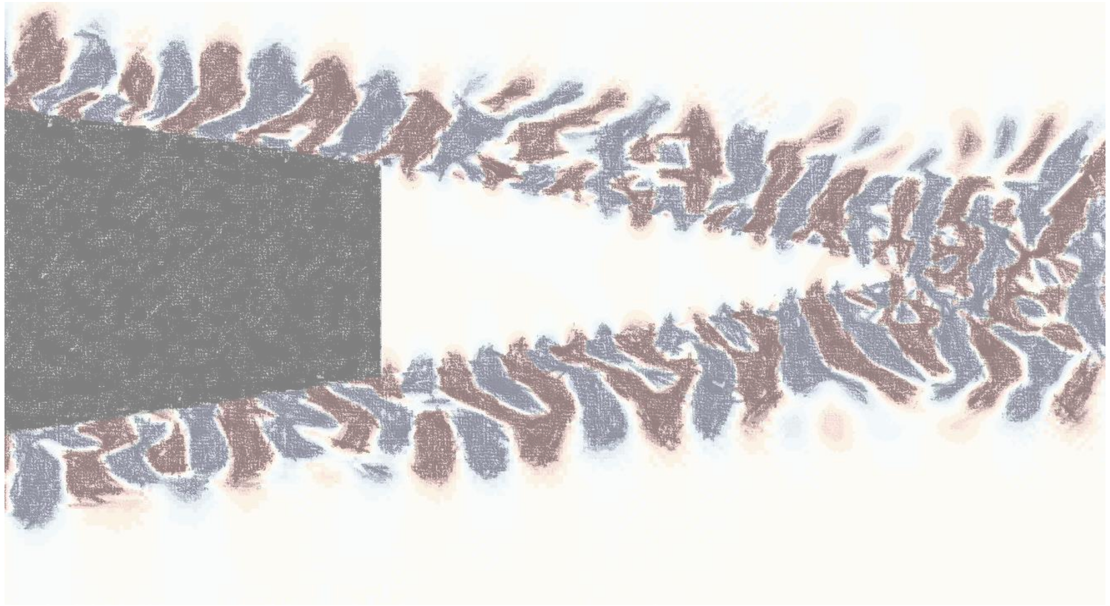
Phase angle between strip *a* and 0

CPSD of strip *a* and *b* normalized with autospectrum of strip 0

(b) Blocked trailing edge

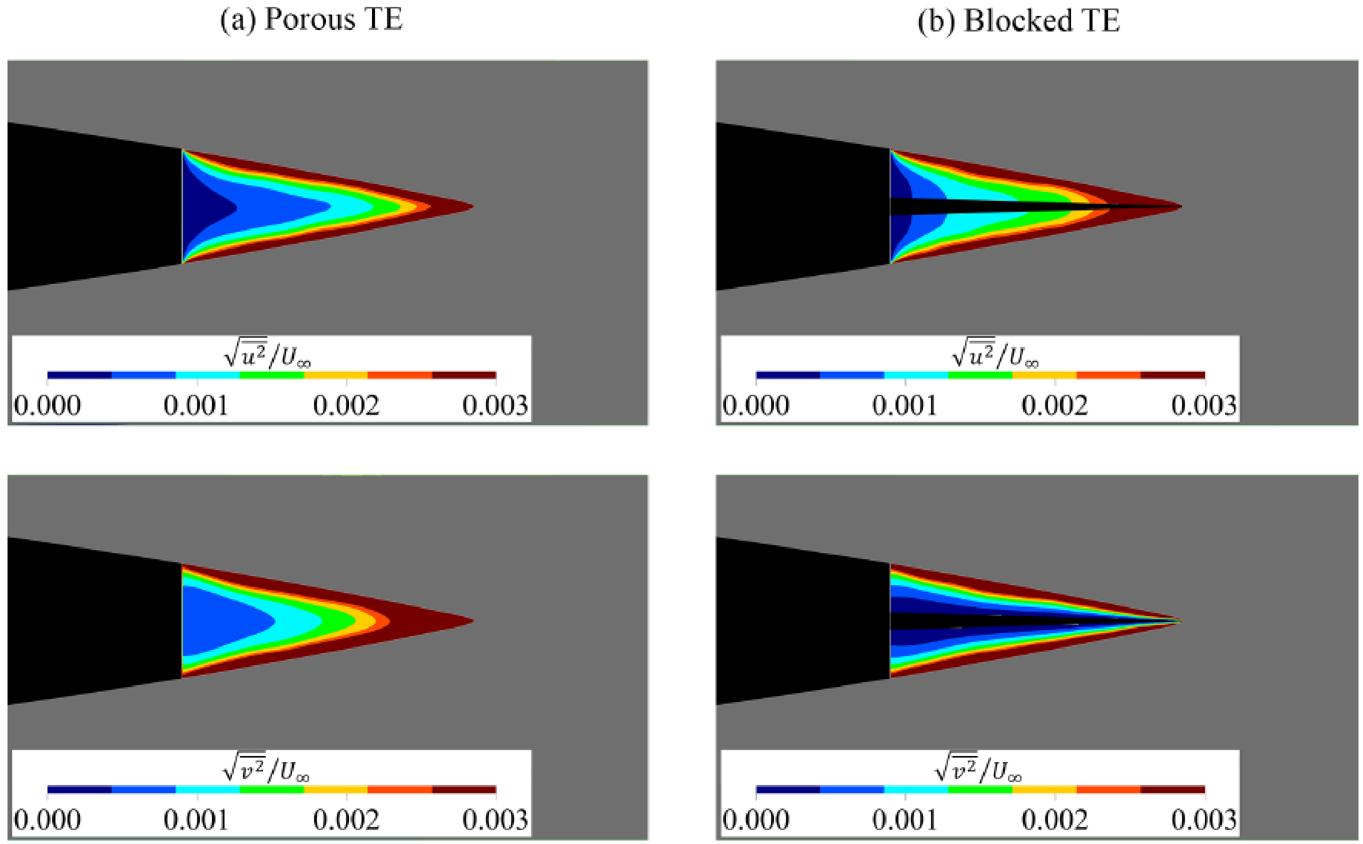


Cross-power spectral density (CPSD) matrix between strips for different TE treatments



V. THE EFFECTS OF PERMEABILITY

Contours of Velocity Statistics



Contours of mean freestream-parallel and freestream-normal velocity components

Contours of freestream-parallel and freestream-normal velocity fluctuations components

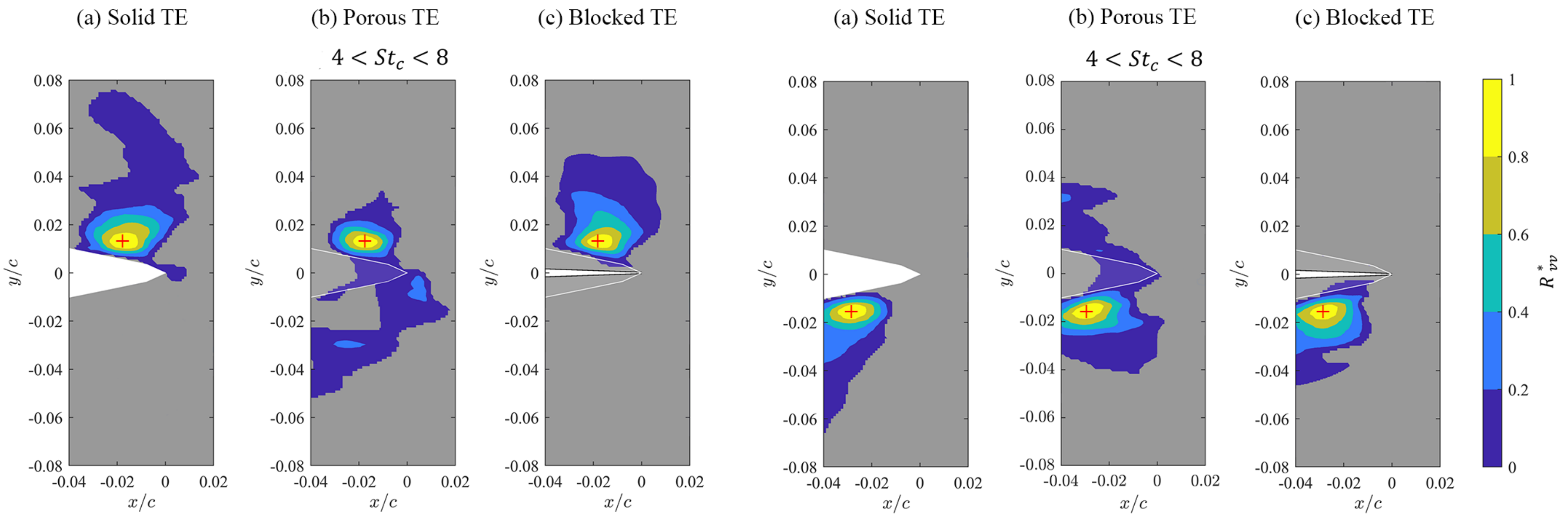
- The contours show weak recirculating flow-field inside the porous medium.
- Nevertheless, the freestream-normal velocity fluctuations are quite different between both cases.

Contours of Velocity Statistics

- The permeability of the porous TE might allow the flow-field from both sides of the airfoil to “communicate” through the porous medium.

- The correlation of the wall-normal velocity R^*_{vv} is defined as: $R^*_{vv}(x, x+\Delta x) = \frac{\overline{v(x)v(x+\Delta x)}}{\overline{v(x)^2}}$

(*i*) $x/c = -0.018$ (*ii*) $x/c = -0.028$

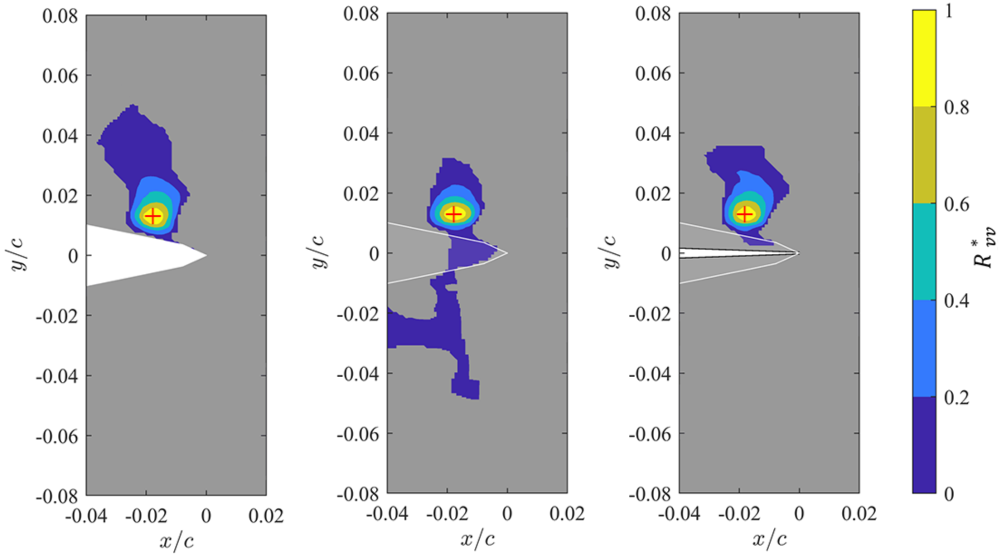


Cross-correlation of wall-normal velocity fluctuations

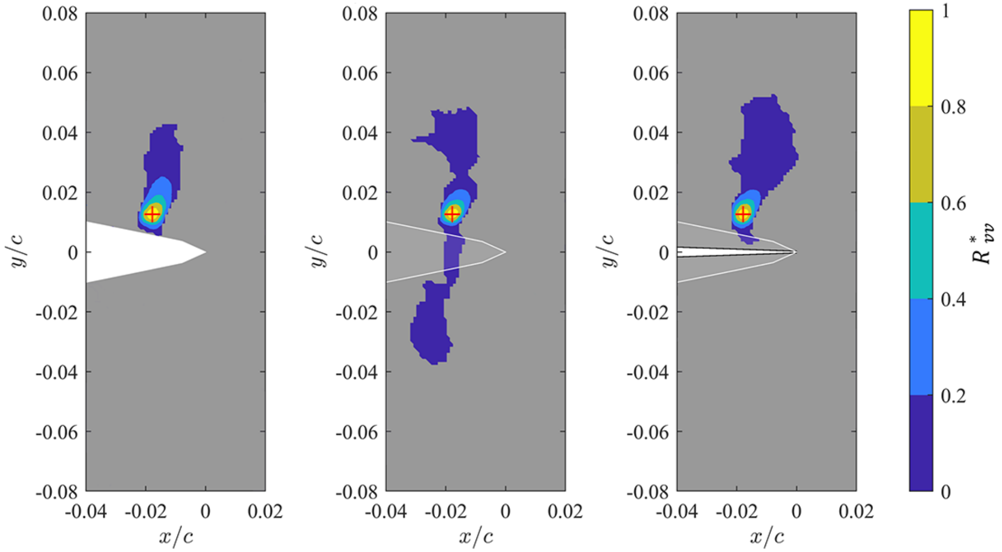
Contours of Velocity Statistics

(*i*) $x/c = -0.018$

$8 < St_c < 16$

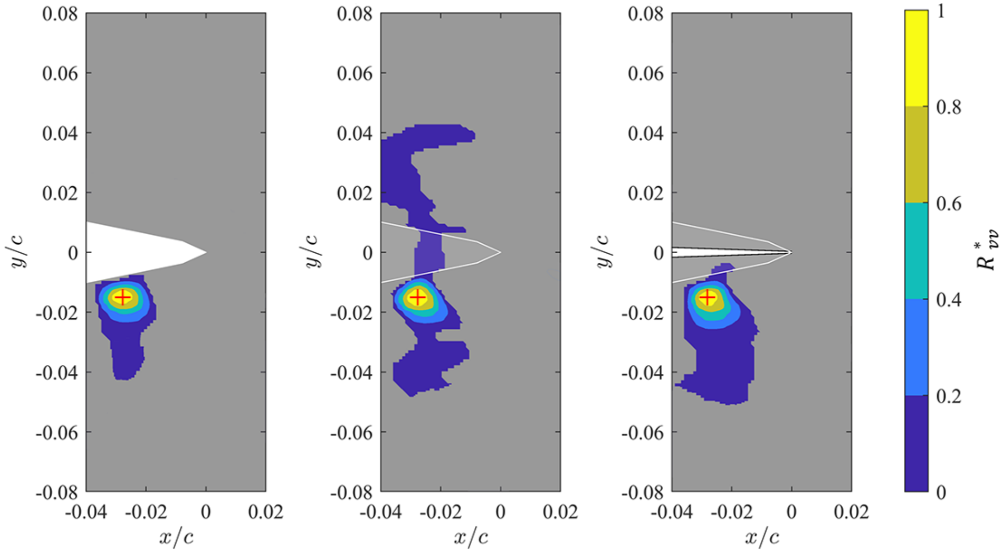


$16 < St_c < 32$

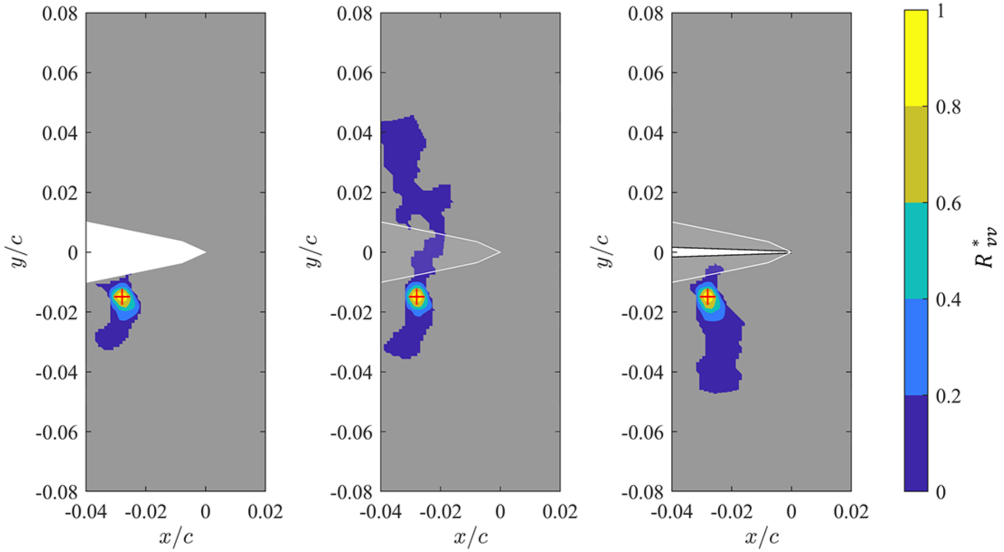


(*ii*) $x/c = -0.028$

$8 < St_c < 16$



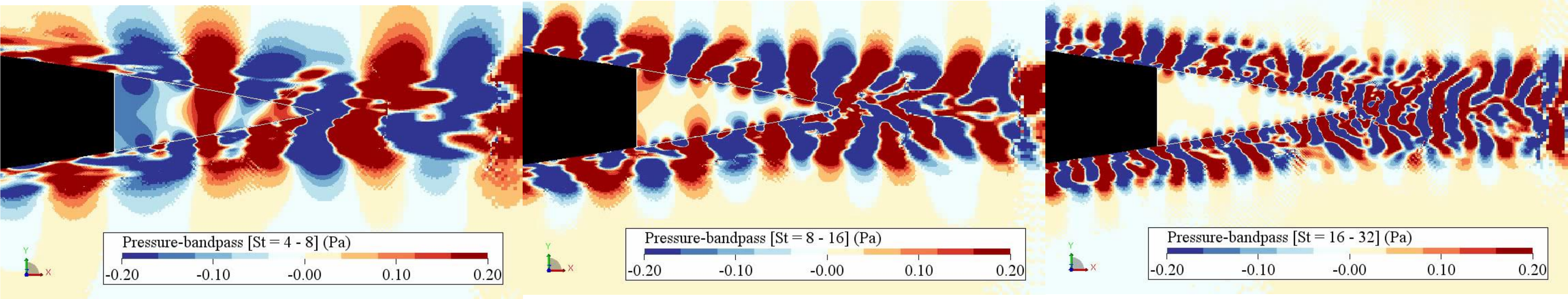
$16 < St_c < 32$



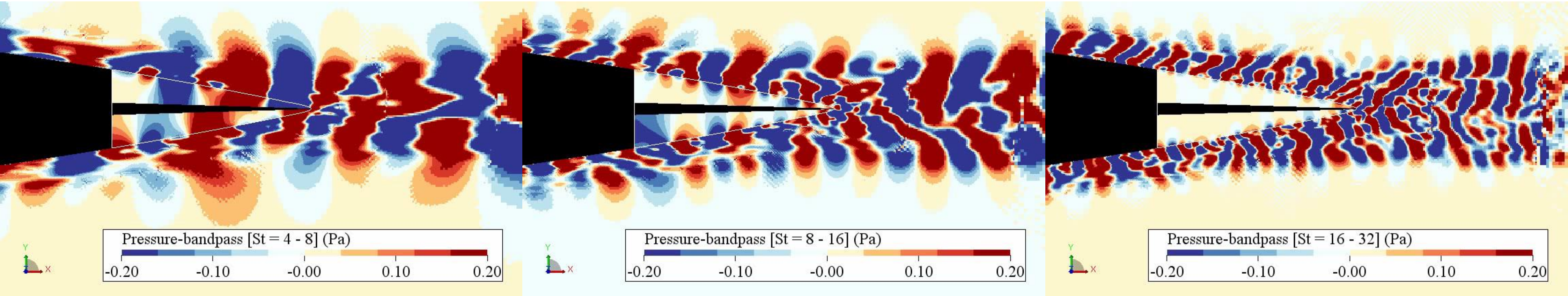
Near-Field Pressure

$4 < St_c < 8$ $8 < St_c < 16$ $16 < St_c < 32$

(a) Porous TE

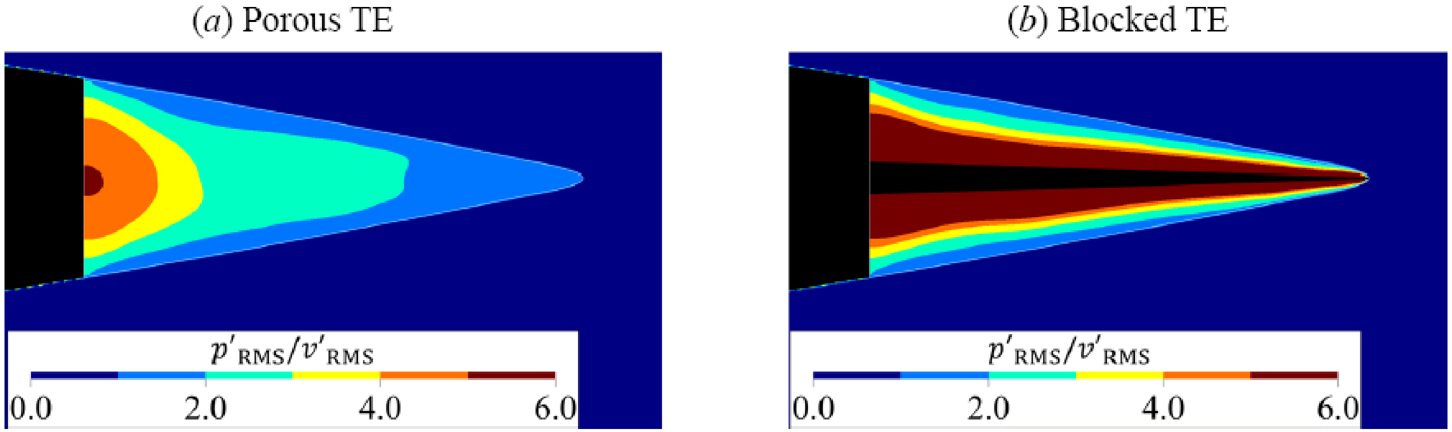


(b) Blocked TE



Porous Material Impedance

- p'_{RMS}/v'_{RMS} is proportional to the impedance of the porous material[1,2].



The comparison of p'_{RMS}/v'_{RMS} contour between porous and blocked TE

- Inside the porous TE, the ratio decreases in the streamwise direction, which appears to cause milder impedance jump at the actual trailing edge → less efficient scattering at the trailing edge.

- The variation of p'_{RMS}/v'_{RMS} in the porous TE might be interpreted as a continuous impedance mismatch → acoustic scattering at multiple chordwise locations [3].

[1] Maria, A. K., & James, C. J., "Acoustic absorption in porous materials", *Report No. NASA/TM, 316995*, 2011.
[2] Koh, S. R., Meinke, M., & Schröder, W., "Numerical analysis of the impact of permeability on trailing-edge noise". *Journal of Sound and Vibration*, *421, 348-376*, 2018.
[3] Kisil, A., & Ayton, L. J. Aerodynamic noise from rigid trailing edges with finite porous extensions. *Journal of Fluid Mechanics*, *836*, 117-144, 2018.

VI. CONCLUSION & OUTLOOK

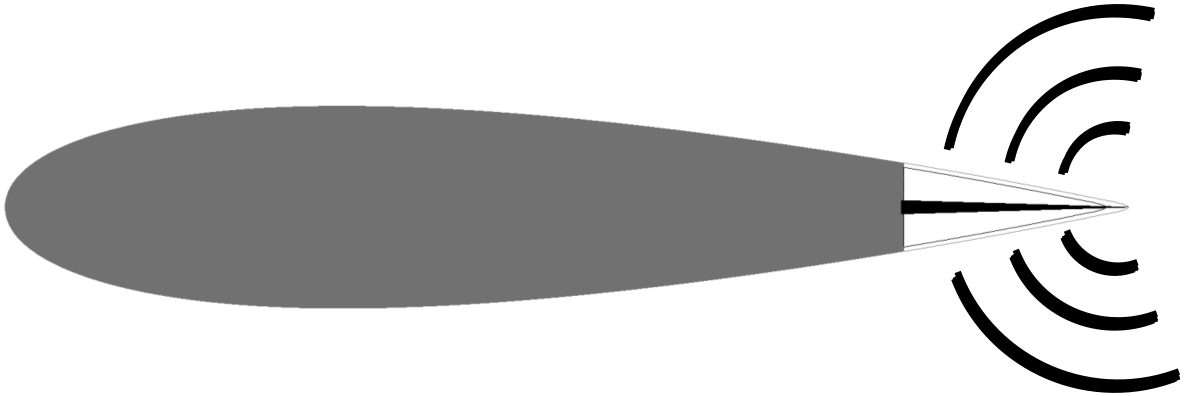
Conclusions

- The application of metal-foam to reduce trailing edge noise has been studied using lattice-Boltzmann method.

- Conventional solid trailing edge models can not be used directly to predict noise reduction of the porous TE.

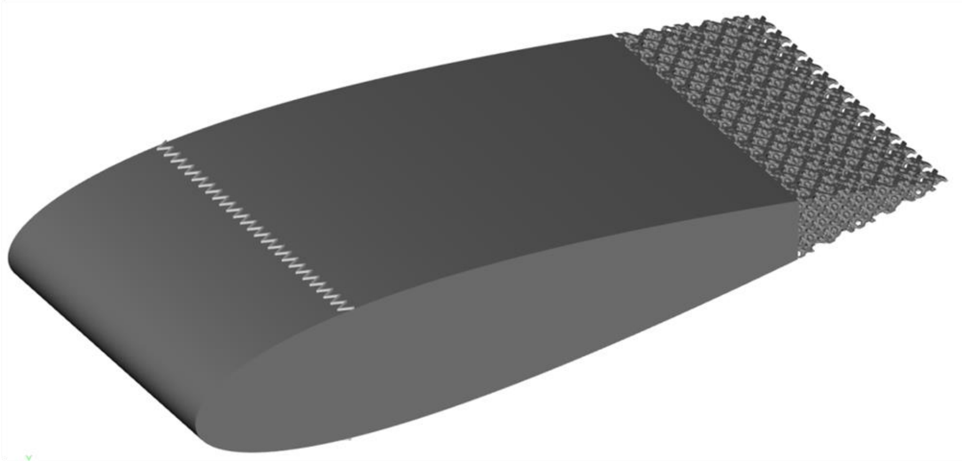
- The flow-field interaction across the porous trailing edge is a necessary condition to achieve noise reduction.

- The noise reduction of the porous TE might be caused by the combination of destructive interference between distributed sound sources as well as the reduction of scattering efficiency at the trailing edge.

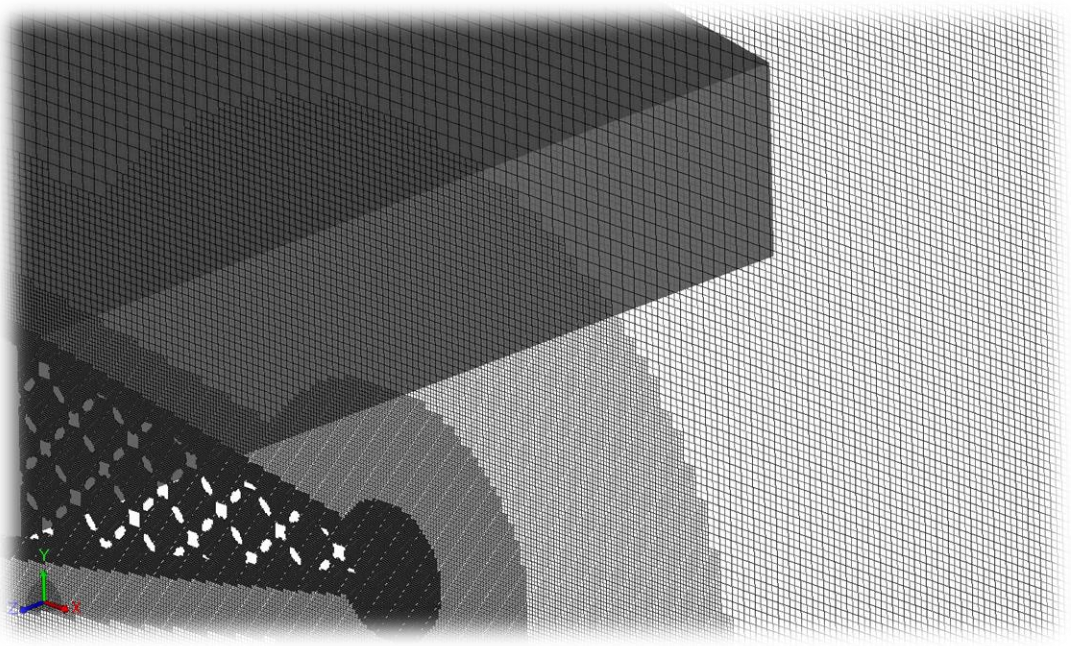


Outlook

- Numerical study of a 3D-printed porous trailing edge for one-to-one comparison against the experiments.



NACA 0018 with 3D-printed trailing edge



Mesh distribution in the simulation domain

Thank you for your attention !

This study is supported by the project **SMARTANSWER** (**S**mart **M**itigation of flow-induced **A**coustic **R**adiation and **T**ransmission for reduced **A**ircraft, surface tra**NS**port, **W**orkplaces and wind en**ER**gy noise) which has received funding from the European Unions Horizon 2020 research and innovation program under the **Marie Skodowska-Curie grant agreement No. 722401**. More information can be found on https://www.h2020-smartanswer.eu/