Porous Trailing Edge for Airfoil and Fan Noise Reduction at Low-Speed Stall Conditions

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Introduction

❑ Fan noise is present in our daily lives.



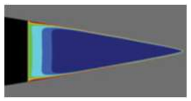
❑ Separation/stall noise may not be avoidable and flow control devices are utilized to reduce noise.


Serrations [1]

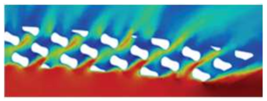

porous media

❑ Computational Fluid Dynamics (CFD) Approaches

Volume-Averaged [2]


+Computationally efficient
+Good estimation tool

Pore Scale

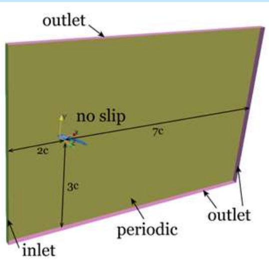

+Highly accurate and detailed
+Suitable for complex flow

Methods

Computational

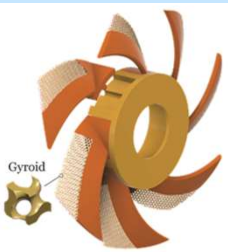
Simulation Procedure

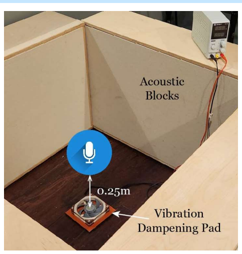
1. Create wall resolving mesh using snappyHexMesh.
2. Model the time-averaged flow field.
3. Model the transient flow field
4. Calculate acoustic data from pressure fluctuations



Reynolds Number: 15,000
Chord Length: 31.15 mm
Angle of Attack: 25°
Pore Diameter: 1 mm

Experimental



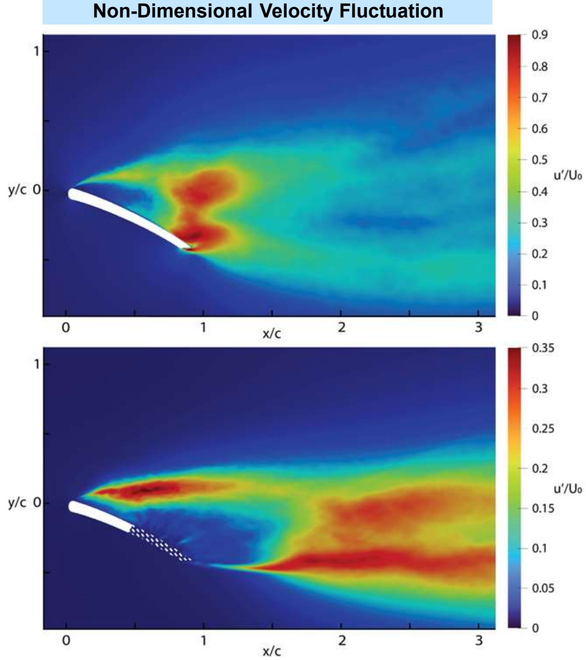


Abstract

Porous materials have been reported for their role in flow control and noise reduction of airfoils at low angles of attack; however, a porous trailing edge at stall conditions remains unexplored. This numerical study adopts a pore-scale approach using Large-Eddy Simulation (LES) to better understand the flow field within the porous media and the effects on the wake. We find that the laminar flow that permeates through the airfoil forms a thick shear layer in the near wake. The resulting pressure field is almost uniform in the wake, and the velocity fluctuations are almost negligible. Consequently, the vortex shedding due to the stalled airfoil is delayed further downstream and suppresses aeroacoustic noise. Experimental investigation of fans with blades featuring porous trailing edges indeed results in up to 4.3% reduction in the overall sound pressure level.

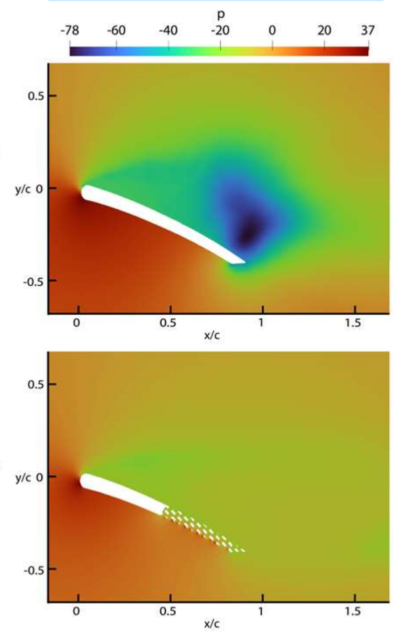
Results: Flow Field of Porous Airfoil

Non-Dimensional Velocity Fluctuation



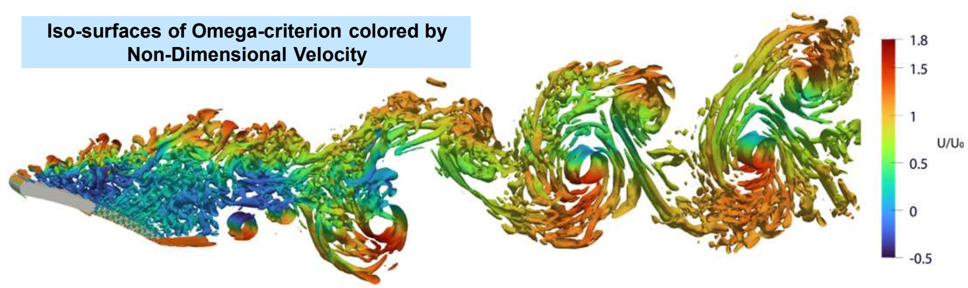
reduced velocity fluctuations

Average Pressure Field



time-average pressure field is nearly uniform

Iso-surfaces of Omega-criterion colored by Non-Dimensional Velocity



vortex shedding suppressed downstream

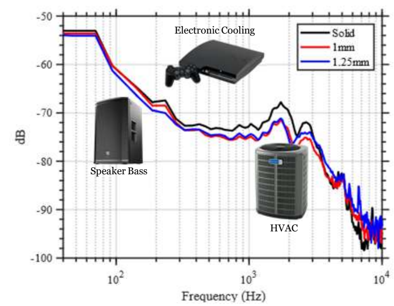
Results: Fan Noise Reduction

3D-Printed Fan and Noise Generated

51 dB | 48.8 dB | 49.1 dB

up to 4.3% noise reduction

Frequency Analysis



reductions in low-mid frequency range

Conclusion and Future Work

❑ A porous trailing edge on an airfoil can reduce aeroacoustics noise in separated/stalled conditions.

❑ The mechanism of noise reduction is similar to Sato and Hattori's work on cylinder with porous coating [3]. The porous media reduces velocity fluctuations in the shear layer and dampens surface pressure fluctuations.

❑ The average pore size and permeability affects the effects the noise reduction properties.

❑ The next step in this research work is the frequency analysis of the CFD results at various observer positions.

❑ Future numerical work can focus on studying the flow field modelled using a volume-averaged approach to investigate the accuracy at a lower computational cost.

References

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[2] Teruna, C., Manegar, F., Avallone, F., Ragni, D., Casalino, D., and Carolus, T., "Noise Reduction Mechanisms of an Open-Cell Metal-Foam Trailing Edge," Journal of Fluid Mechanics, Vol. 898, 2020, p. A18. https://doi.org/10.1017/jfm.2020.363

[3] Sato, Y., and Hattori, Y., "Mechanism of Reduction of Aeroacoustic Sound by Porous Material: Comparative Study of Microscopic and Macroscopic Models," Journal of Fluid Mechanics, Vol. 929, 2021, p. A34. https://doi.org/10.1017/jfm.2021.884

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