Trailing Edge Noise Reduction with Permeable Materials: Description of Noise Scattering Mechanism

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I. INTRODUCTION
Power vs Noise

Retain the noise level and increase the power production.

Larger turbine = more power

Trailing edge serrations installed on a wind turbine blade

Metal-Foam Trailing Edge

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

Far field sound spectra comparison [1]

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]:

\[ S_{pp}(\mathbf{x}, \omega) \sim \Phi_{pp}(\omega) L_{pp}^Z(\omega) L^2 \left( \frac{\omega}{U_c}, K_y \right) \]

  - Spectra of the wall-pressure fluctuation
  - Airfoil response function
  - Spanwise correlation length

• 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**.

II. SIMULATION AND RESULTS
The porous material is modelled using equivalent fluid regions governed by Darcy’s law.

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.

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.

Numerical Beamforming

A modified Underbrink beamforming array of 64 microphones (Spatial resolution of $c/2$ in the streamwise direction)

Beamforming maps at $St_c = 12.5$
Surface Pressure Statistics

\[ S_{pp}(x, \omega) \sim \Phi_{pp}(\omega) \gamma_{pp}(\omega) L^2 \left( \frac{\omega}{U_c}, K_y \right) \]

- 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

\[
\Phi_a = \Phi(p_1 + \cdots + p_a) \\
\Phi_0 = \Phi(p_1 + \cdots + p_{11})
\]

- 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

Phase angle between strip $a$ and 0

1. More uniform distribution of sound sources

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

(b) Blocked trailing edge

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

CPSD of strip $a$ and $b$ normalized with autospectrum of strip 0
V. THE EFFECTS OF PERMEABILITY
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: $R_{vv}^*(x, x + \Delta x) = \frac{v(x)v(x+\Delta x)}{v(x)^2}$

\[(i) \frac{x}{c} = -0.018\]
\[(ii) \frac{x}{c} = -0.028\]

Cross-correlation of wall-normal velocity fluctuations
Contours of Velocity Statistics

(i) $x/c = -0.018$

(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
• $p'_{RMS}/v'_{RMS}$ 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].

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!

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