Bio-Inspired Trailing Edge Noise Control

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Motivation

Wind turbines are regulated for noise which limits their size, location, and operation.

A significant percentage of wind turbines are de-rated to comply with these regulations.

This results in a loss of Annual Energy Production for each decibel of noise reduction required.

We seek to reduce or eliminate the dominant noise source of wind turbines, which is trailing edge noise at the outer portion of the blades (where the most power is produced).

Inspiration

Certain species of owl that fly silently above 1.5kHz have down-like hairs on their feathers.

These hairs tend to form a canopy suspended over the surface of the feather.

A similar structure has been shown to attenuate pressure fluctuations at the underlying surface.

Canopy height $\approx 0.5\text{mm}$

Individual hair $Re \approx 7$

Canopy open area ratio $\approx 70\%$
Unidirectional Fabric Canopy

Flow

$129^\circ$

Flow

$\Phi_{pp}$ $(\text{SPL})$

Increasing $U_j$

$U_j = \ldots$

60 m/s

50 m/s

40 m/s

30 m/s

20 m/s

Solid – Roughness

Dotted – Roughness with Canopy

$G_{pp}$ $(\text{SPL})$

Increasing $U_j$

$F_{req.}\ (\text{Hz})$

$F_{req.}\ (\text{Hz})$
The Idea

The canopy can greatly suppress surface pressure fluctuations. Would it therefore not also suppress trailing edge noise?

How could a canopy be applied to an airfoil?

Could the hoped-for beneficial effects be achieved without significant adverse effects on the aerodynamics?
Two Practical Concepts

Flow-aligned elements on top and bottom surfaces manipulate boundary layers ahead of the trailing edge.

Finlets

Rails

- Flow
- Trailing edge region
- Flow
- Trailing edge region

- height
- spacing
- thickness
- extension

- spacing
- diameter
- height
- extension
The Experiment

- 117 microphone phase array for far field acoustics
- Surface pressure taps for $C_l$ and lift
- Wake rake for drag measurements

- 0.8-m chord DU96-W180 airfoil
- Tripped (0.5mm zigzag tape) at 5%/10% chord
- Flow conditions - $M=0.15, 0.18$ ($Re \approx 2.5M, 3M$)
- $\alpha$ from $-4^\circ$ to $15^\circ$, $\alpha_{\text{zero lift}} = -2.5^\circ$
Clean Airfoil

Re = 3M, Tripped, 3000 Hz

Airfoil
Test Section
TE
Integration Region

-0.5°
Clean Airfoil

Integrated Spectra

SPL (dB) (re: 20×10^-6 Pa)

Frequency (Hz)

-2.5°
-0.5°
3.0°
6.9°

3000 Hz
Finlets – Configuration 5

Thickness – 0.5mm
Spacing – 4mm

Height – 4mm
10mm Extension

![Image of Finlets](image_url)

![Graph](graph_url)

- Thickness – 0.5mm
- Spacing – 4mm
- Height – 4mm
- 10mm Extension
Finlets – Configuration 5

Re = 3M, Tripped, 3000 Hz

Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension ($\delta \approx 20mm$)

Airfoil
Test Section
TE
Treatment Location

-SPL [dB]-
30
29
28
27
26
25
24
23
22
21
20

Virginia Tech Center for Renewable Energy and Aerodynamic Testing
**Finlets – Configuration 5**

- **Re** = 3M, Tripped, 3000 Hz

- Thickness – 0.5mm
- Spacing – 4mm
- Height – 4mm
- 10mm Extension ($\delta \approx 20$mm)

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**Diagram Details:**
- **Airfoil**
- **Test Section**
- **TE**
- **Integration Region**

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**Legend:**
- **SPL [dB]**
  - 30
  - 29
  - 28
  - 27
  - 26
  - 25
  - 24
  - 23
  - 22
  - 21
  - 20
Effect of Configuration 5 Finlet

Integrated Spectra

- Clean
- Finlets-Config5

Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension ($\delta \approx 15mm$)
Effect of Configuration 5 Finlet

Integrated Spectra

- **Clean**
- **Finlets-Config5**

**Specifications:**
- **Thickness**: 0.5mm
- **Spacing**: 4mm
- **Height**: 4mm
- **10mm Extension** ($\delta \approx 30$mm)

*Frequency (Hz)*

*SPL (dB) (re: 20e-6 Pa)*

*3.0°*
Effect of Configuration 5 Finlet

Integrated Spectra

Frequency (Hz)

SPL (dB) (re: 20e-6 Pa)

- Clean
- Finlets-Config5

Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension ($\delta \approx 40$mm)

6.9°
Effects of Finlet Geometry

- **Spacing**
  - In general, smaller finlet spacing improves performance
  - However, very small spacings cause vortex shedding
- **Height**
  - Increased height improves performance, particularly at high angle of attack
- **Trailing Edge Extension**
  - Removing the trailing edge extension improves performance, particularly at high angle of attack

![Graph showing SPL vs Frequency for different finlet heights](image)
Effects of Finlet Geometry

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Effects of Finlet Geometry

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  - In general, smaller finlet spacing improves performance
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- **Trailing Edge Extension**
  - Removing the trailing edge extension improves performance, particularly at high angle of attack
What physical mechanisms are we exploiting?

Break up of the boundary layer eddies?
Displacing those structures away from the surface/edge?
Shear sheltering of the edge?
Suppression of trailing edge shedding?
Conclusions

1. A new, bio-inspired surface treatment for the suppression of trailing edge noise has been demonstrated.

2. The treatment could be combined with existing trailing edge modifications (serrations, etc.) to maximize noise control.

3. The treatment is effective throughout a wide parameter range and is not highly dependent on a particular geometry, but there appears to be strong potential for optimization.

4. The treatment has been shown to be effective over an angle of attack range that extends over 8 degrees from zero lift.

5. Drag data suggests that the impact of finlets is limited to an increase in skin friction from the additional wetted area.
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<thead>
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<th>Config#</th>
<th>Runs</th>
<th>Type</th>
<th>Height</th>
<th>Spacing</th>
<th>Thickness</th>
<th>TE extension</th>
<th>Substrate</th>
<th>Suction only</th>
<th>Cp/lift</th>
<th>Drag</th>
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# Configurations - Rails

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**Notes:**
- CP: Coefficient of Pressure
- Lift: Lift Force
- Drag: Drag Force
- Acoustics: Sound Absorption

**Dimensions:**
- **Substrate:** 101.6 x 114.3
- **Spacing:**
- **Diameter:**
- **Extension:**

**Comments:**
- Rod anchor case
- Effect of extension w. C14
- Effect of height w. C14
- Effect of dia. & spacing w. C14
- Effect of spacing w. C17
- Effect of fractal length w. C14
BL Thickness

$U=50\text{m/s}, \delta$ at 100% Chord, Suction Side

$U=50\text{m/s}, \delta$ at 100% Chord, Pressure Side

Separation
Effect of Configuration 5 Finlet

Integrated Spectra

Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension ($\delta \approx 15$mm)
Finlets – Effect of Spacing

Integrated Spectra

- Thickness – 0.5mm
- Spacing – 1, 4, 6, 10mm
- Height – 4mm
- 10mm Extension

SPL (dB) (re: 20e-6 Pa)

Frequency (Hz)

- 0.5°
Finlets – Effect of Height

Integrated Spectra

Thickness – 0.5mm
Spacing – 4mm
Height – 4, 8mm
10mm Extension

SPL (dB) (re: 20e-6 Pa)

Frequency (Hz)

-0.5°
Finlets – Effect of Height

Integrated Spectra

- Thickness – 0.5mm
- Spacing – 4mm
- Height – 4, 8mm
- 10mm Extension

6.9°
Finlets – Effect of Extension

Integrated Spectra

Thickness – 0.5mm
Spacing – 1mm
Height – 4mm
0, 10mm Extension
Integrated Spectra

Thickness – 0.5mm
Spacing – 1mm
Height – 4mm
0, 10mm Extension
Rails vs Finlets

Integrated Spectra

SPL (dB) (re: 20\times10^{-6} Pa)

Frequency (Hz)

-0.5°