Trailing edge noise for rotating blades

Analysis and comparison of two classical approaches

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Motivation

Outline

Isolated airfoil theory

Amiet's theory for rotating airfoils

Kim-George's theory for rotating airfoils

Results

Conclusions

Review

Trailing edge for isolated airfoils

- Amiet 1974, 1975, 1976
- Roger and Moreau 2005, 2009

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Trailing edge for rotating airfoils

- Amiet 1976
- Schlinker and Amiet 1981
- Kim and George 1982
- Blandeau and Joseph 2011

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Isolated airfoil theory

$$S_{pp} = \boxed{a} \quad \boxed{|\Psi|^2} \quad \boxed{l_y} \quad \boxed{S_{qq}}$$

Isolated airfoil theory

- Amplitude

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Isolated airfoil theory

- Amplitude
- Acoustic lift

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- Spanwise correlation length

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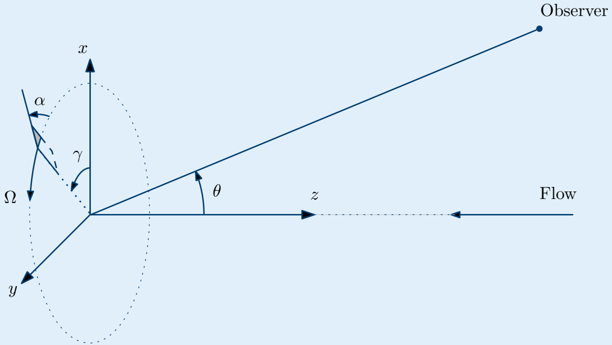
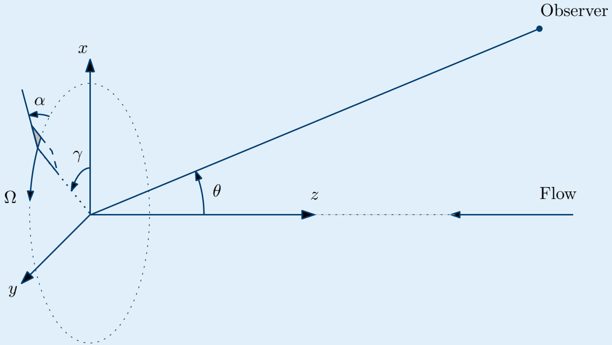
Rotating airfoil

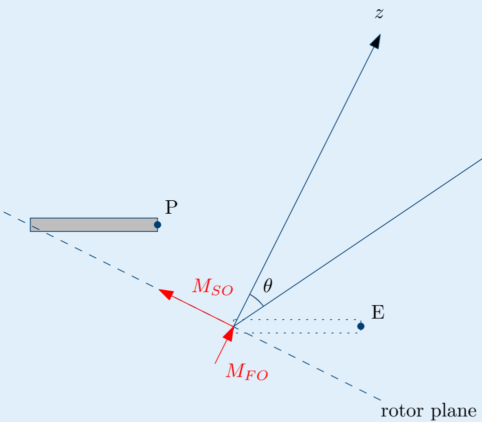


Rotating airfoil



$$S_{pp}(\omega) = \int S_{pp}(\omega, \gamma)\,dt$$

Change of reference frame



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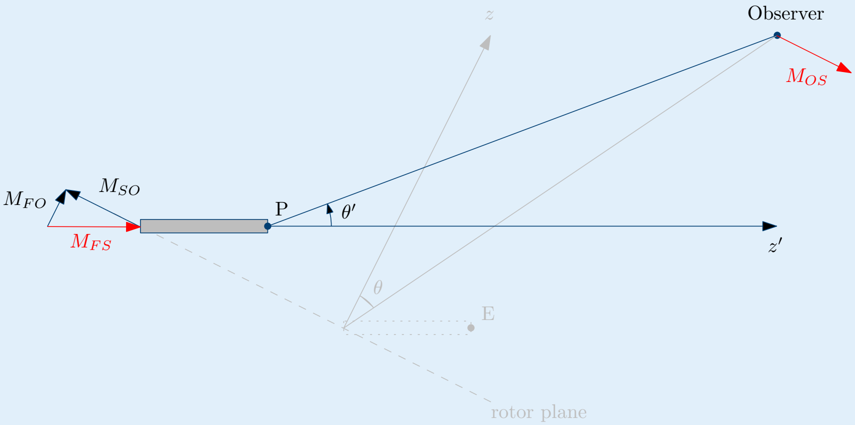

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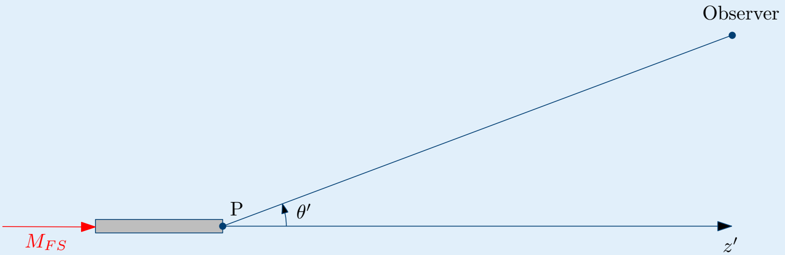

Moving observer in wind tunnel

- $p(\mathbf{x}, t)$: no effect
- $p(\mathbf{x}, \omega)$: Doppler shift $\quad \omega' \rightarrow \omega$

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PSD for moving observer

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Time for moving observer

$$dt = \frac{\omega'}{\omega} dt'$$

Amiet's theory for rotating blade

$$S_{pp}(\omega) = \frac{1}{2\pi}\int_0^{2\pi} \left(\frac{\omega'}{\omega}\right)^2 S'_{pp}(\omega', \gamma)\, d\gamma$$

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But... not everyone agrees

$$S_{\mathrm{pp}}(\omega) = \frac{1}{2\pi}\int_0^{2\pi} \left(\frac{\omega'}{\omega}\right)^{e} S'_{\mathrm{pp}}(\omega',\gamma)\,\mathrm{d}\gamma$$

Source	Exponent e
Amiet (1976)	1
Rozenberg et al (2010)	1
Schlinker and Amiet (1981)	2
Blandeau and Joseph (2011)	-2

Outline

Kim-George approach

$$\begin{array}{c} p(\mathbf{x}, t) \\ \downarrow \\ p(\mathbf{x}, \omega) \\ \downarrow \\ S_{pp}(\mathbf{x}, \omega) \end{array}$$

Kim-George approach

$$S_{pp} = \sum_{m} \boxed{B} \quad \boxed{|\Psi|^2} \quad \boxed{l_y} \quad \boxed{S_{qq}}$$

Kim-George approach

- Amplitude

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Summary

Amiet:

$$S_{pp} = \int A \quad |\Psi|^2 \quad l_y \quad S_{qq} \; d\gamma$$

Kim-George:

$$S_{pp} = \sum_m B \quad |\Psi|^2 \quad l_y \quad S_{qq}$$

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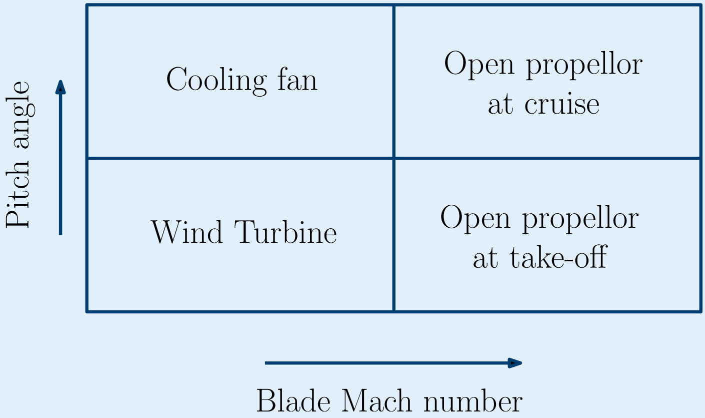
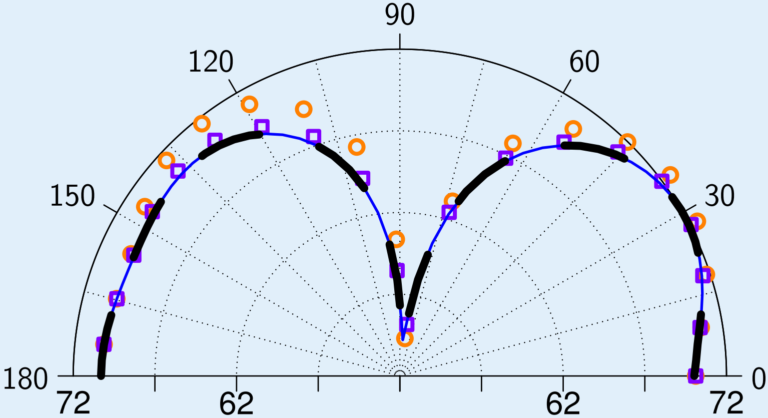
Outline

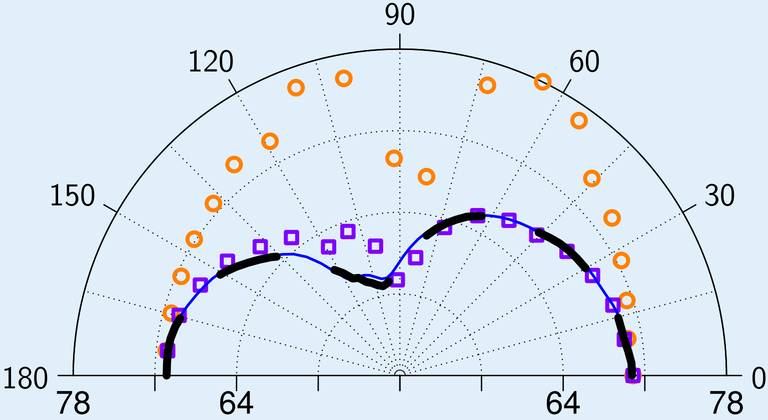
Blade elements



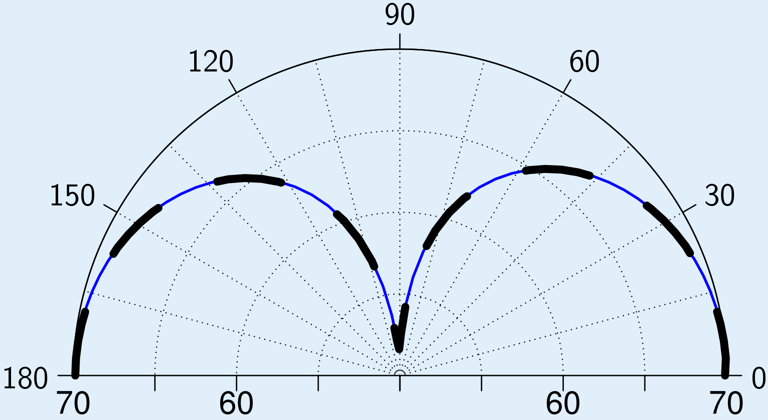
Wind turbine $kc = 5$



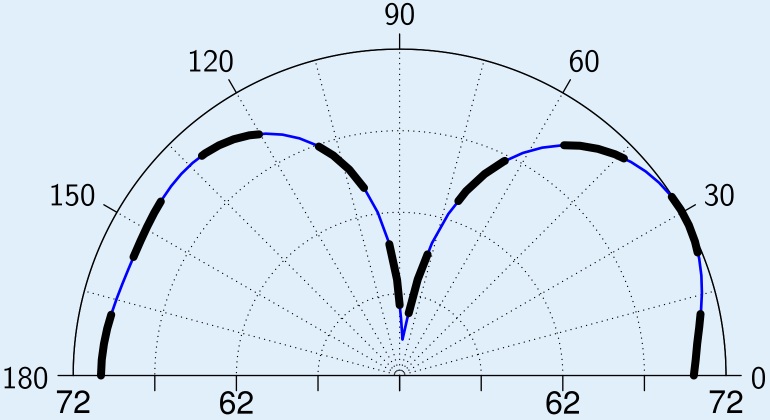
Open propellor takeoff $kc = 5$



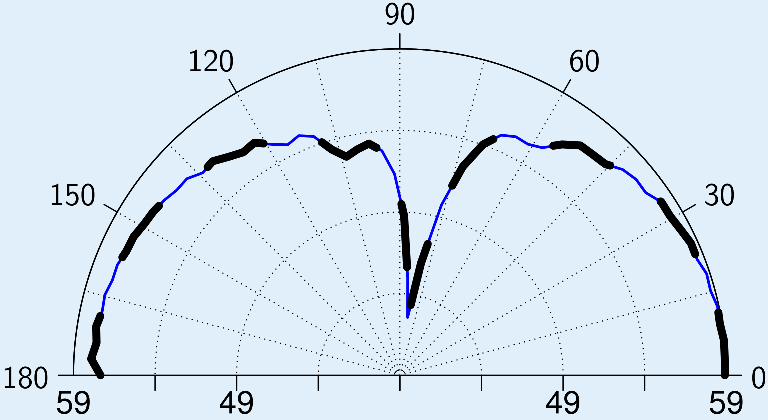
Wind turbine kc=0.5



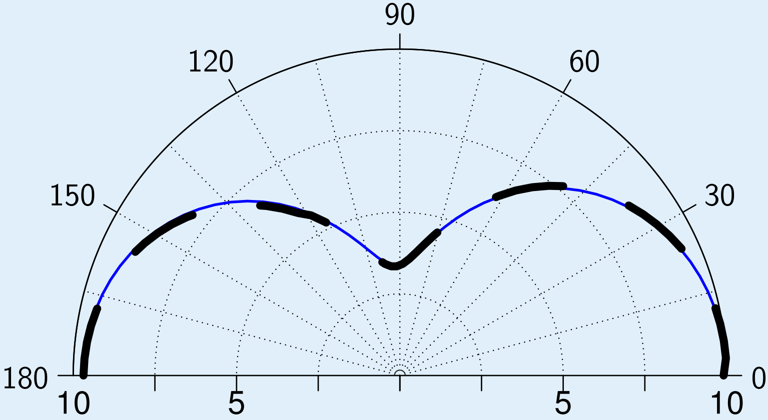
Wind turbine kc=5



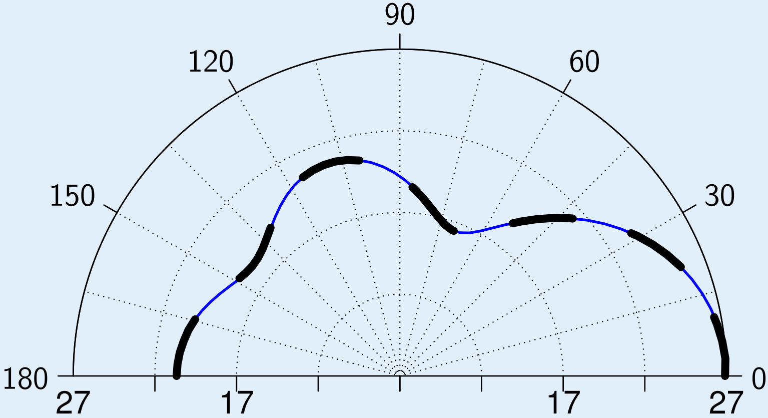
Wind turbine kc=50



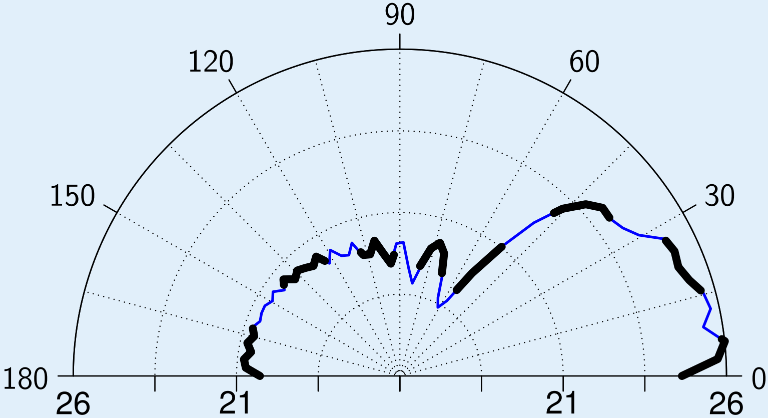
Cooling fan kc=0.5



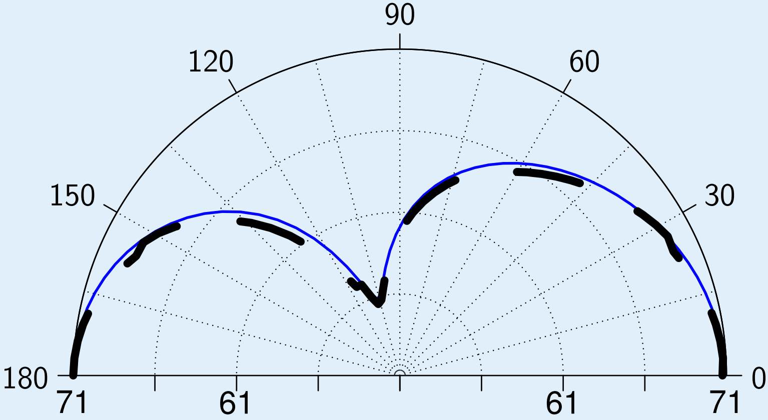
Cooling fan kc=5



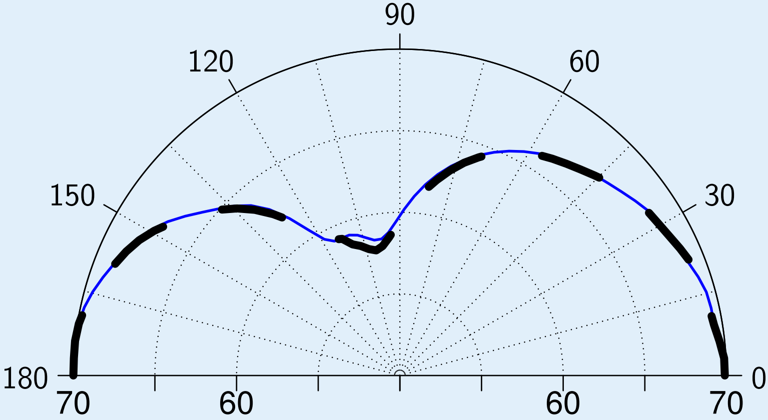
Cooling fan kc=50



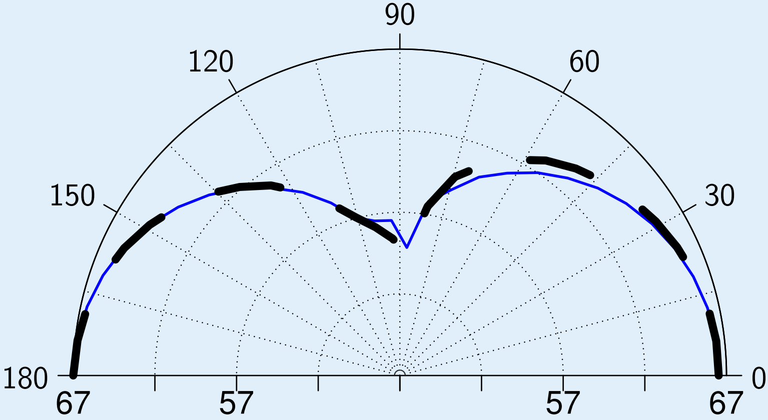
Open propellor take-off kc=0.5



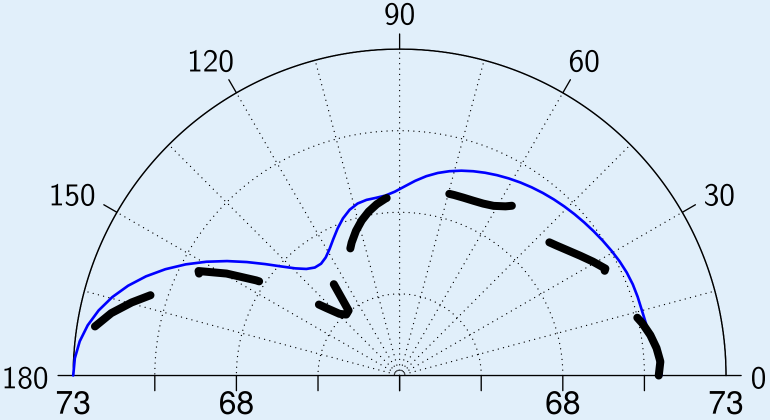
Open propellor take-off kc=5



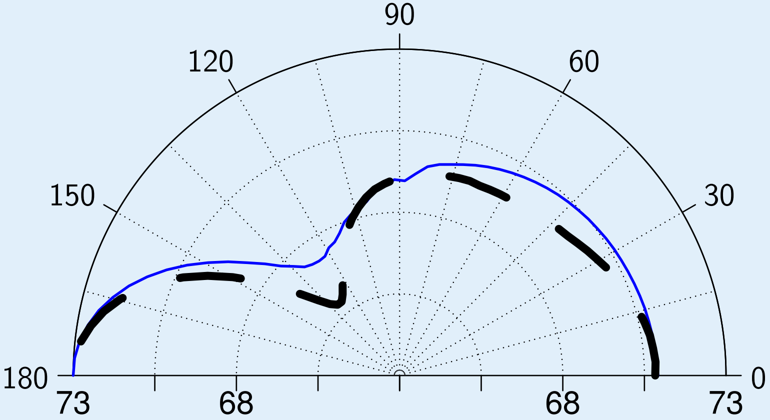
Open propellor take-off kc=50



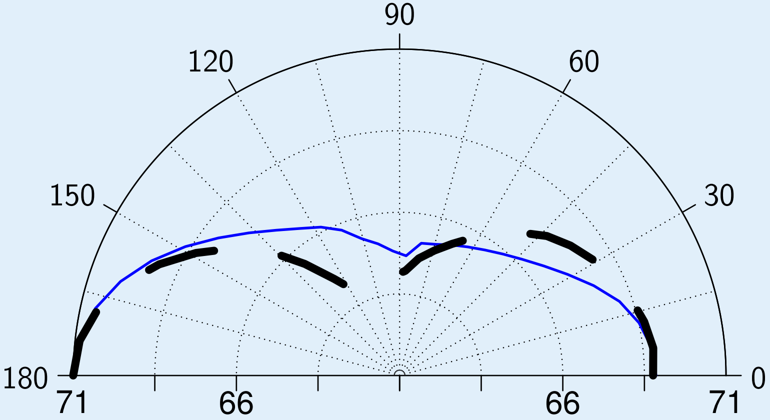
Open propeller cruise kc=0.5



Open propeller cruise kc=5



Open propeller cruise kc=50



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1. Right exponent in Amiet's theory is 2

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2. Amiet's approach exact if $M_{ch} \leqslant 0.85$ and $kc > 0.5$

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1. Right exponent in Amiet's theory is 2
2. Amiet's approach exact if $M_{ch} \leqslant 0.85$ and $\mathrm{kc} > 0.5$
3. Applicable to a wide range of applications

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