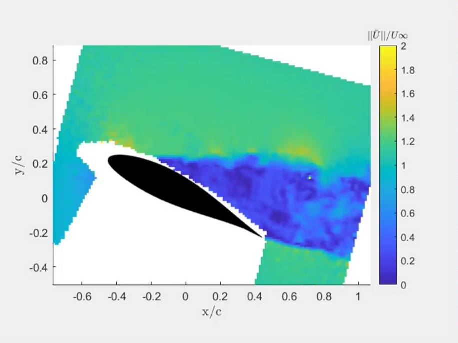
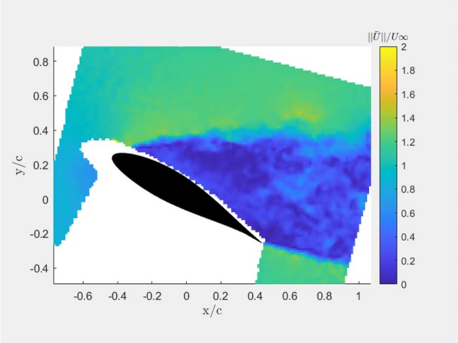
Results for a static airfoil : flow topology

Absolute value of the normalized velocity $\|\underline{U}|/U_\infty$

$\alpha_e = 23.8°$



$\alpha_e = 26.3°$



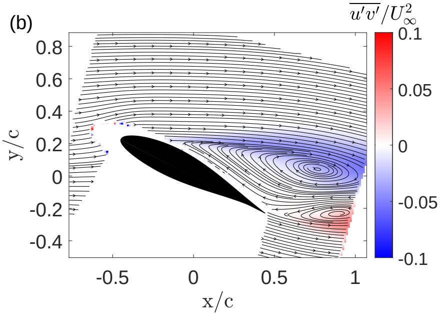
We define the projected Strouhal number as :

$$St = fL_{sep} \sin \alpha_e / U_\infty \quad \text{with} \quad L_{sep} \approx \begin{cases} 3c/4 & \text{for} \quad \alpha_e = 23.8° \\ c & \text{for} \quad \alpha_e = 26.3° \end{cases}$$

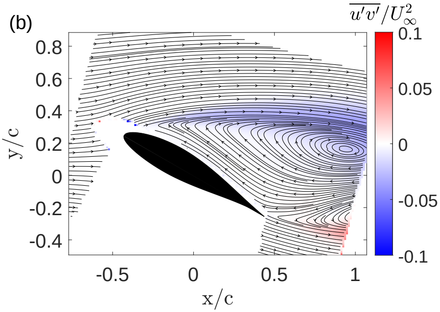
Results for a static airfoil : flow topology

Streamlines of the mean flow and $\overline{u'v'}$ component
of the Reynolds tensor averaged over 10 runs

$\alpha_e = 23.8°$



$\alpha_e = 26.3°$



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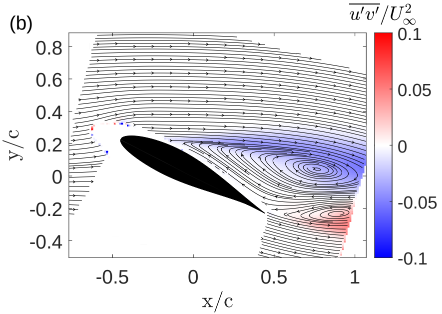
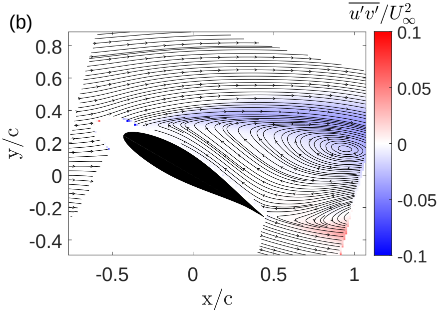
Results for a static airfoil : flow topology

$\alpha_e = 23.8°$



$\alpha_e = 26.3°$



We define the projected Strouhal number as :

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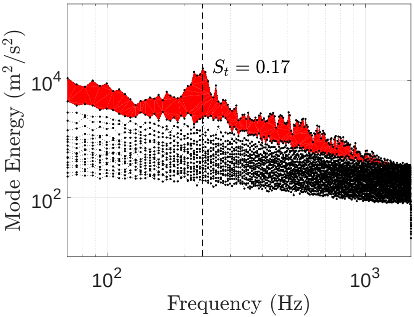
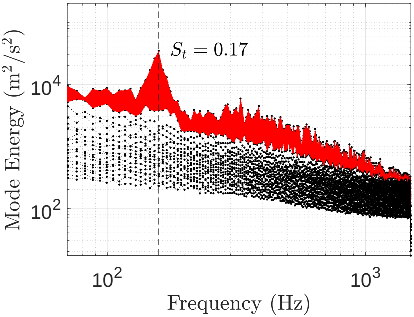
Spectral Proper Orthogonal Decomposition

$$\hat{\boldsymbol{u}}(\boldsymbol{x}, f) = \sum_{j=1}^{\infty} a_j(f)\psi_j(\boldsymbol{x}, f) \quad \text{with} \quad \begin{cases} a_j : \text{expansion coefficient} \\ \psi_j : \text{SPOD mode} \end{cases}$$

$\alpha_e = 23.8°$

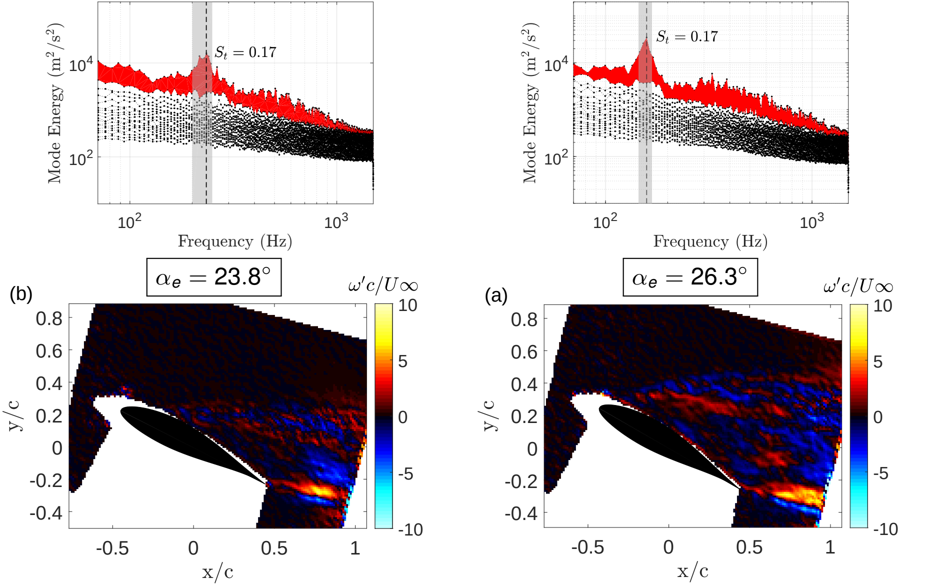


$\alpha_e = 26.3°$



Low-rank behaviour over a wide range of frequency

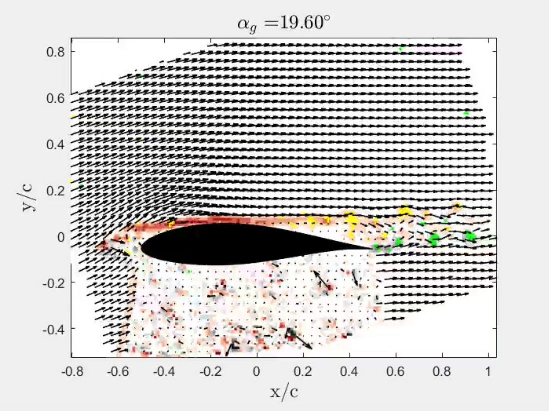
Spectral Proper Orthogonal Decomposition



Flow topology for $k = 0.005$ (quasi-static regime)

Vortex detection criterion Γ_2

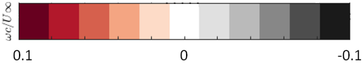
$$\Gamma_2(P) = \frac{1}{N} \sum_S \frac{[\underline{PM} \wedge (\underline{U_M} - \underline{U_P})] \cdot \underline{z}}{||\underline{PM}|| \cdot ||\underline{U_M} - \underline{U_P}||} \quad \text{with} \quad N = 3$$



Flow evolution in the **airfoil reference system**

1) Streamlines

2) Normalized vorticity $\omega c/U_\infty$:



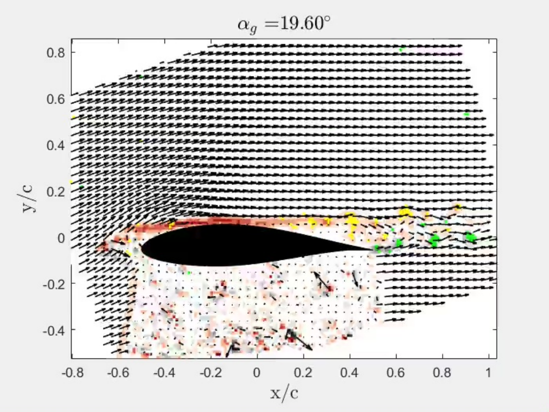
3) Vortex detection criterion :

- yellow circles : clockwise rotating vortices ($\Gamma_2 > 0.7$)
- green circles : counter-clockwise rotating vortices ($\Gamma_2 < -0.7$)

Flow topology for $k = 0.05$ (dynamic regime)

Vortex detection criterion Γ_2

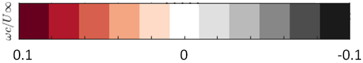
$$\Gamma_2(P) = \frac{1}{N}\sum_S \frac{[\underline{PM} \wedge (\underline{U_M} - \underline{U_P})] \cdot \underline{z}}{||\underline{PM}|| \cdot ||\underline{U_M} - \underline{U_P}||} \quad \text{with} \quad N = 3$$



Flow evolution in the **airfoil reference system**

1) Streamlines

2) Normalized vorticity $\omega c/U_\infty$:



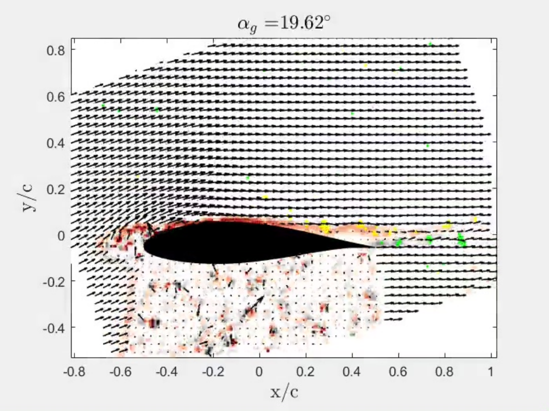
3) Vortex detection criterion :

- yellow circles : clockwise rotating vortices ($\Gamma_2 > 0.7$)
- green circles : counter-clockwise rotating vortices ($\Gamma_2 < -0.7$)

Flow topology for $k = 0.025$ (transition regime)

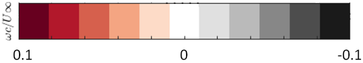
Vortex detection criterion Γ_2

$$\Gamma_2(P) = \frac{1}{N} \sum_S \frac{[\underline{PM} \wedge (\underline{U_M} - \underline{U_P})] \cdot \underline{z}}{||\underline{PM}|| \cdot ||\underline{U_M} - \underline{U_P}||} \quad \text{with} \quad N = 3$$



Flow evolution in the **airfoil reference system**

1) Streamlines
2) Normalized vorticity $\omega c / U_\infty$:

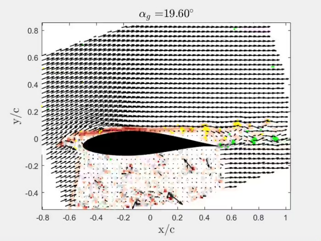


3) Vortex detection criterion :

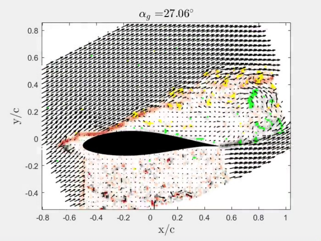
- yellow circles : clockwise rotating vortices ($\Gamma_2 > 0.7$)
- green circles : counter-clockwise rotating vortices ($\Gamma_2 < -0.7$)

Snapshots for $k = 0.005$ (quasi-static regime)

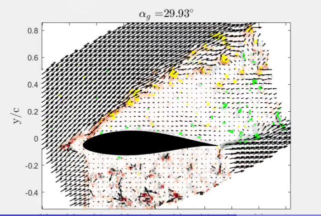
$\alpha_g = 19.6°$



$\alpha_g = 27°$

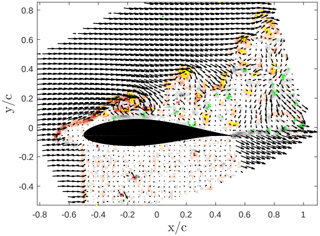


$\alpha_g = 30°$

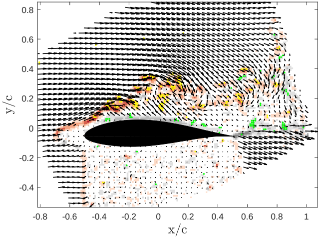


Flow topology at $\alpha_g = 27°$ and $30°$ close to what has been observed in static conditions

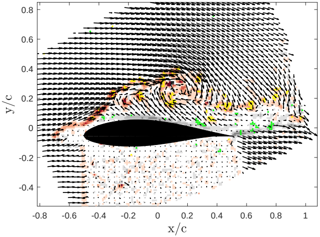
Snapshots for $k = 0.05$ (dynamic regime)



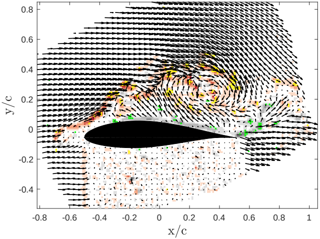
$\alpha_g = 29.66^\circ \uparrow$



$\alpha_g = 29.85^\circ \uparrow$



$\alpha_g = 29.90^\circ \uparrow$



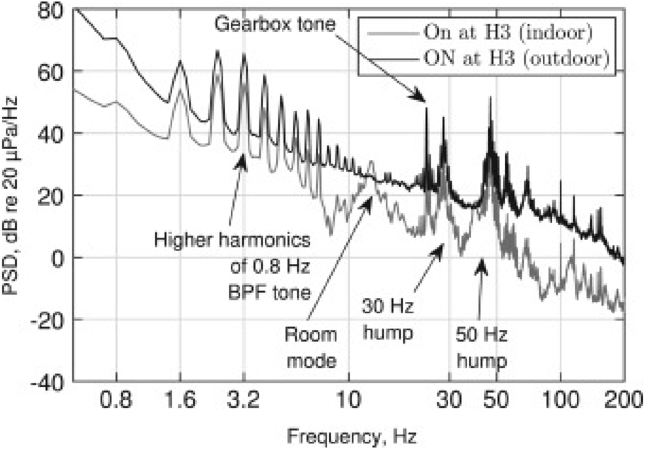
$\alpha_g = 29.97^\circ \uparrow$

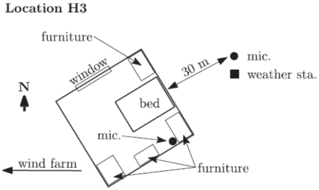
Acknowledgments

This research has been funded by the French National Agency for Research under grant agreement N°ANR-19-CE36-0009

Low frequency noise and infrasound

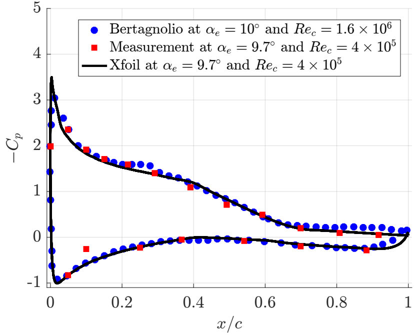
Indoor/outdoor power spectral densities measured by Zajamsek *et al.* (2016) 3 km away from the nearest wind turbine



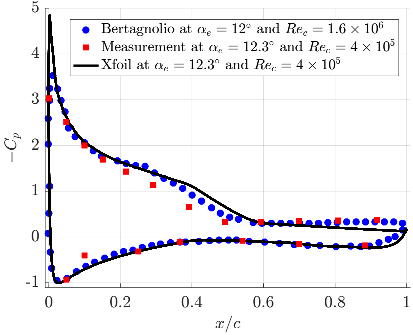


Measurements for the NACA63$_3$418 airfoil

Xfoil calculations using AoA corrections by Brooks *et al.* (1984) : $\alpha_e \approx \alpha_g/1.55$



(a) $\alpha_e \approx 10^\circ$



(b) $\alpha_e \approx 12^\circ$

FIGURE – Pressure coefficient distribution measured by Bertagnolio *et al.* (2017) at $Re_c = 1.6 \times 10^6$, measured in the ECL anechoic wind tunnel at $Re_c = 4 \times 10^5$, and calculated with Xfoil at $Re_c = 4 \times 10^5$.