Trailing edge serrations effect on the aerodynamic performance of airfoils

February 2021

Introduction

Trailing edge serrations

- Well known solution for reducing wind turbine noise and extended in the wind turbine industry.

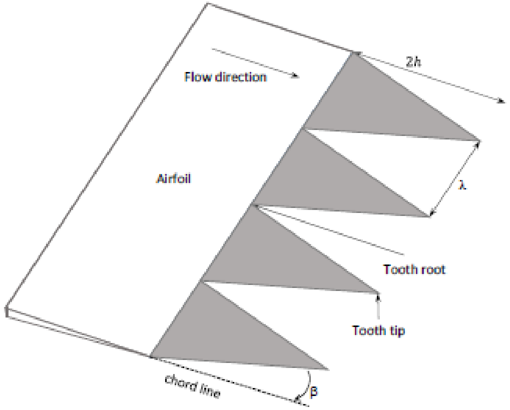
- Devices for aerodynamic noise reduction caused by trailing edge noise
- Change the vortex structure at the trailing edge
- Noise reduction up to 7dBA

Theoretical study

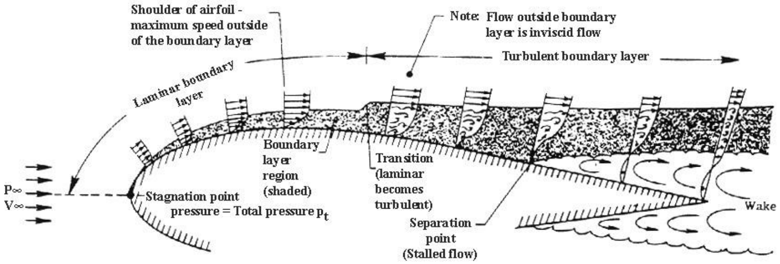
Serrations design

- Design parameters
  - Tooth length, 2h
  - Amplitude, λ
  - Flap angle, β

λ/2h = 0.75



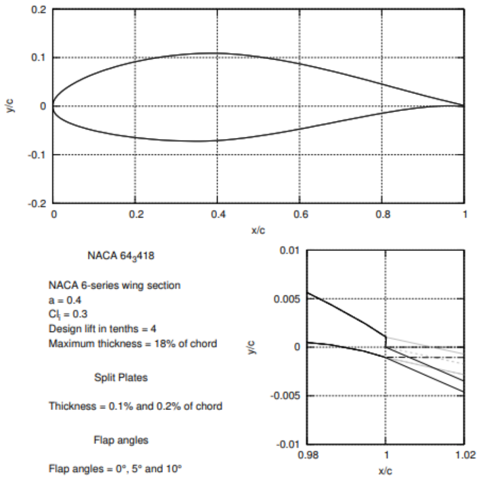
- Required data
  - Wind turbine operation point
  - Airfoils boundary layer characteristic → 2h, β



Theoretical study

CFD simulations

- RANS simulations NACA64$_3$418 airfoil
  - Different configurations simulated



NACA 64$_3$418

NACA 6-series wing section
a = 0.4
Cl$_i$ = 0.3
Design lift in tenths = 4
Maximum thickness = 18% of chord

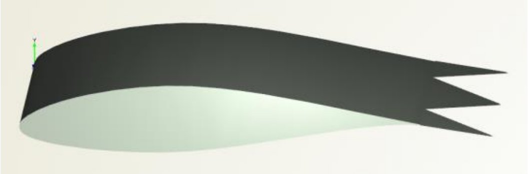
Split Plates

Thickness = 0.1% and 0.2% of chord

Flap angles

Flap angles = 0°, 5° and 10°

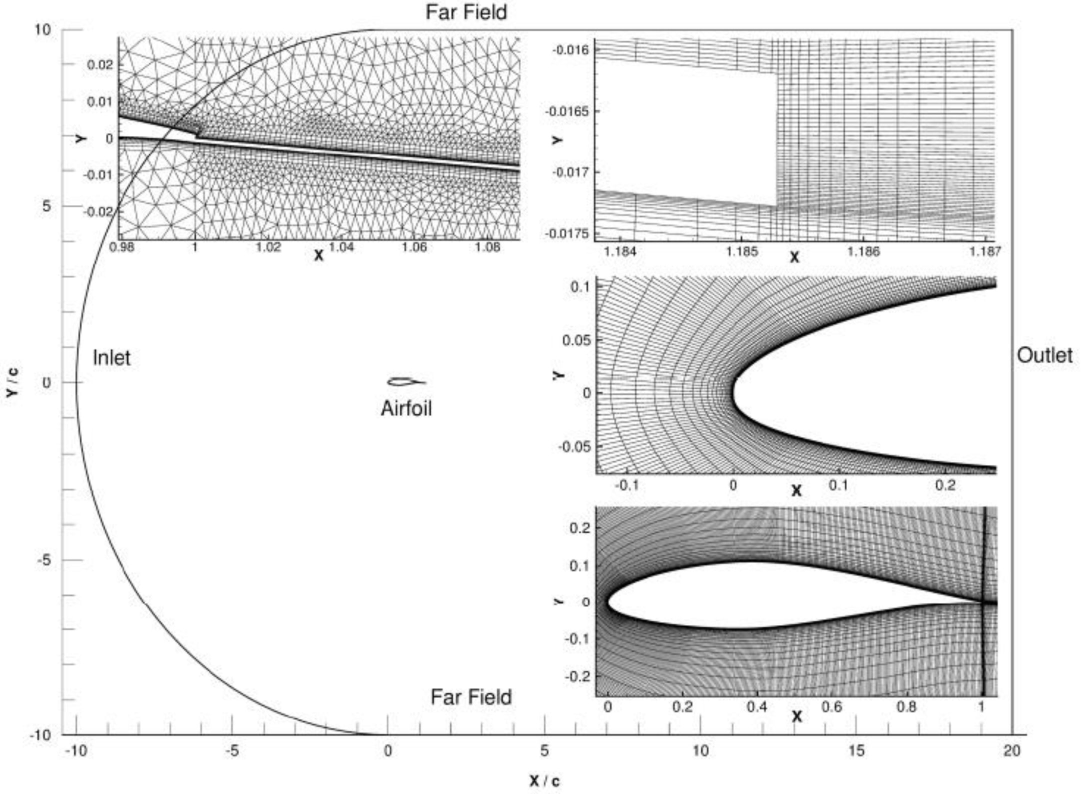
  - 2D and 3D geometries



Theoretical study

CFD simulations

- ICEM CFD ®
  - C type mesh ,
    10*chord upstream
    20*chord downstream
  - Mesh sensitivity study
  - Boundary conditions



Theoretical study

CFD simulations

- ANSYS FLUENT ®
  - Three different turbulence models:
    - ✓ Spalart Allmaras
    - ✓ K-w SST

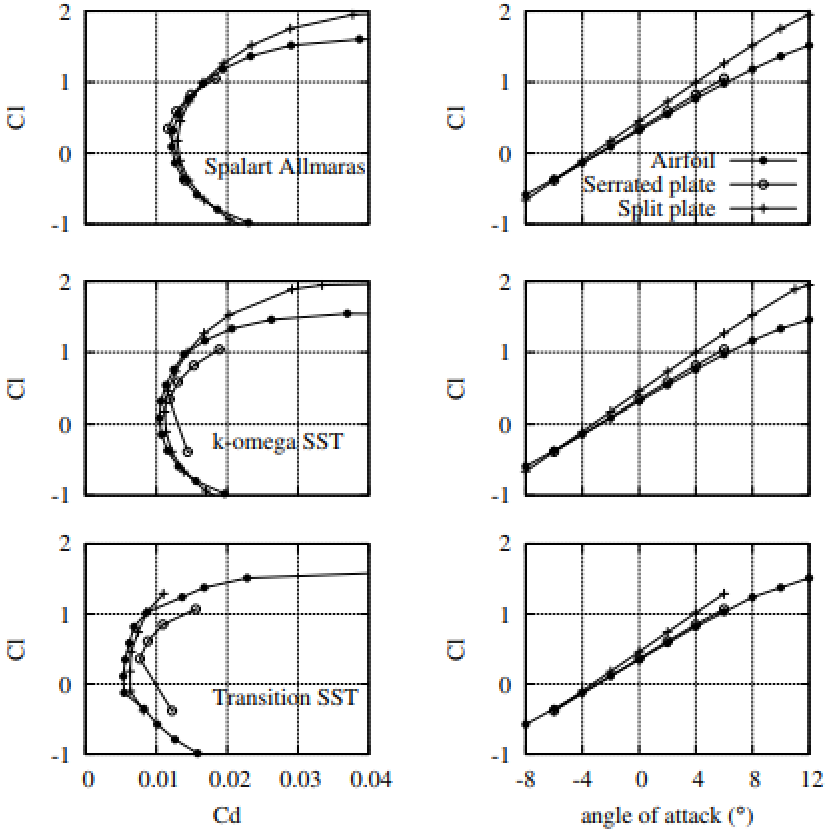
      Fully turbulent models
    - ✓ Transition SST

      Transition model

Theoretical study

CFD simulations

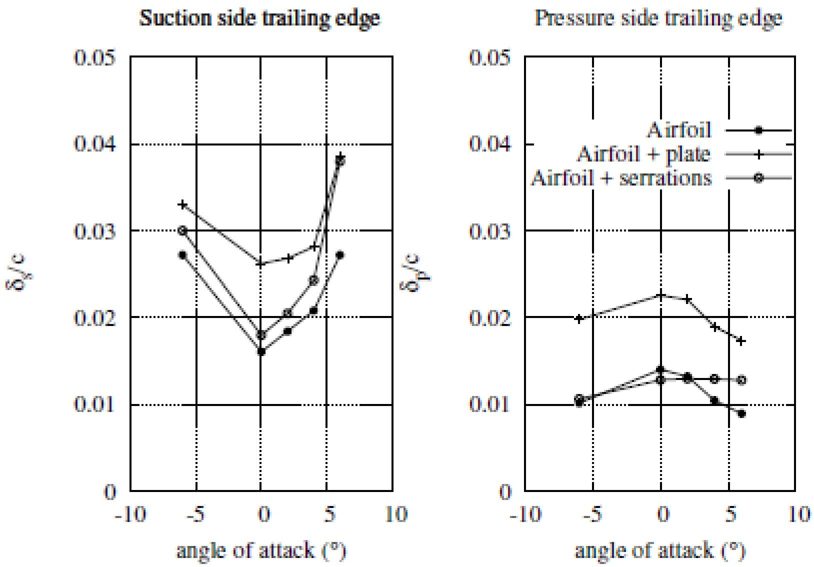
- Results
  - Aerodynamic forces

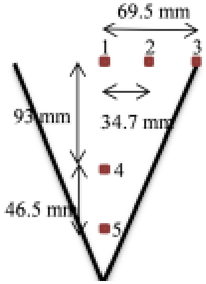


Theoretical study

CFD simulations

- Results
  - Boundary Layer





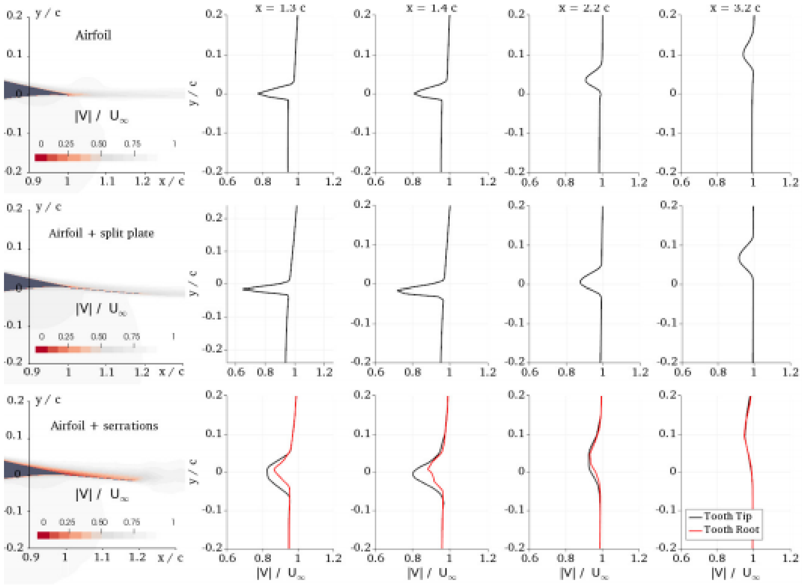
Point	δ_s/c
1	0.0205
2	0.0203
3	0.0195
4	0.021
5	0.023

Theoretical study

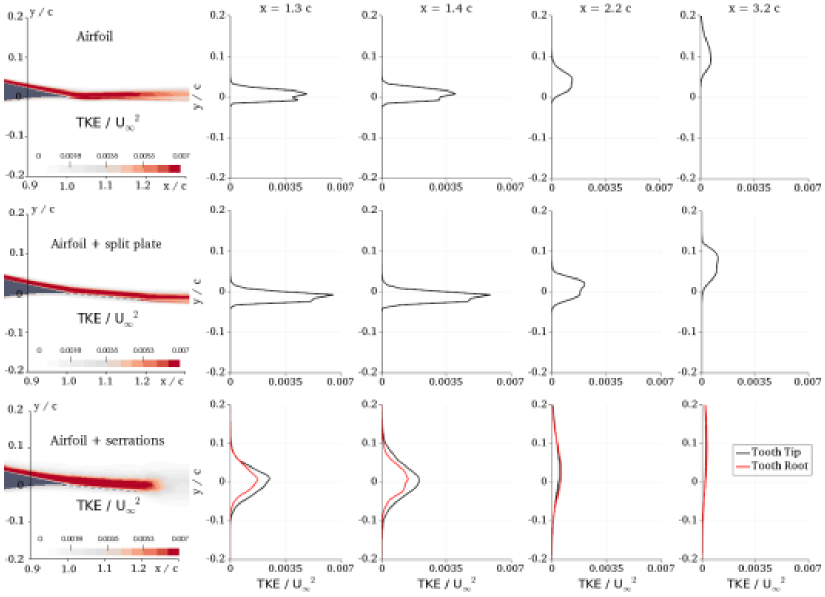
CFD simulations

- Results
  - Wake development

Non dimensional velocity magnitude



Turbulent kinetic energy

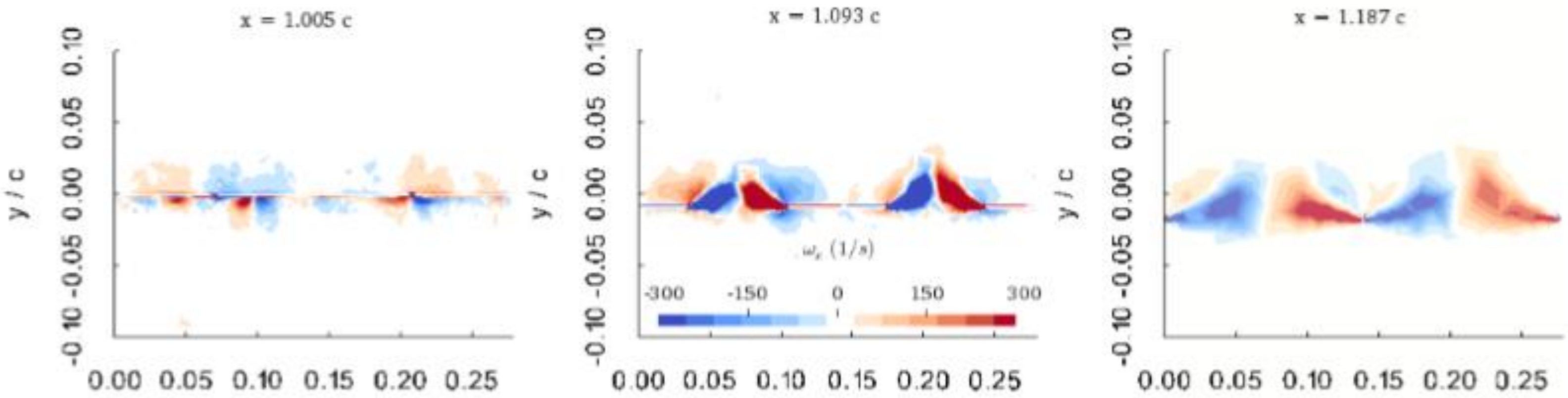


Theoretical study

CFD simulations

- Results
  - Wake development

Streamwise vorticity

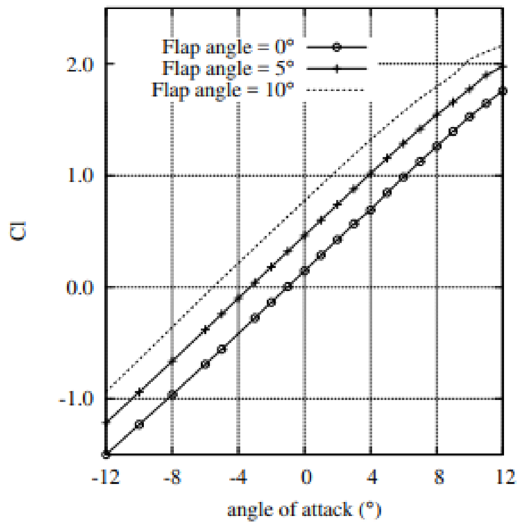


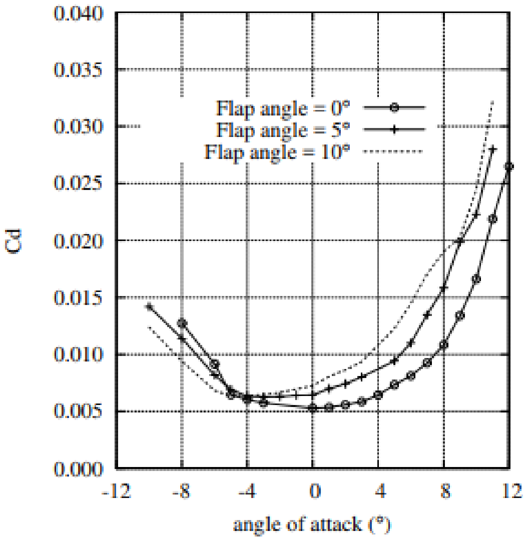
Theoretical study

CFD simulations

- Results
  - Effect of the flap angle

Aerodynamic coefficients



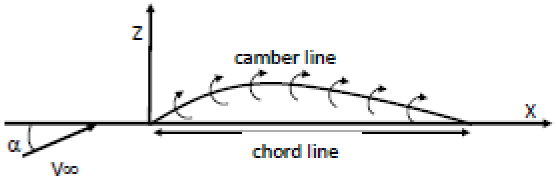


Theoretical study

Lift prediction model

- Thin Airfoil Theory (TAT)
  - Airfoil ⟶ vortex sheet placed along the camber
  - Calculate the variation of $\gamma(s)$
  - Kutta condition ⟶ $\gamma(s)(TE) = 0$

Γ airfoil



$$Cl = 2\pi\left[\alpha + \frac{1}{\pi}\int_0^{\pi}\frac{dz}{dx}(cos\theta_0 - 1)d\theta_0\right]$$

$$\frac{dCl}{d\alpha} = 2\pi$$

$$\Rightarrow$$

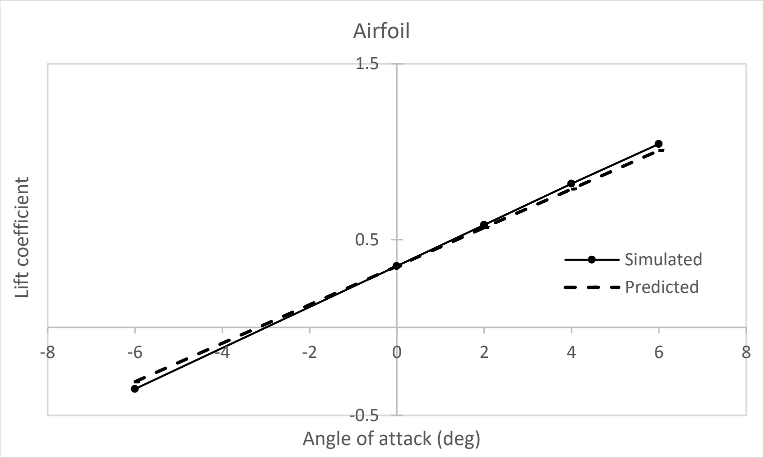
$$Cl_a = 2\pi\alpha + Cl_0$$

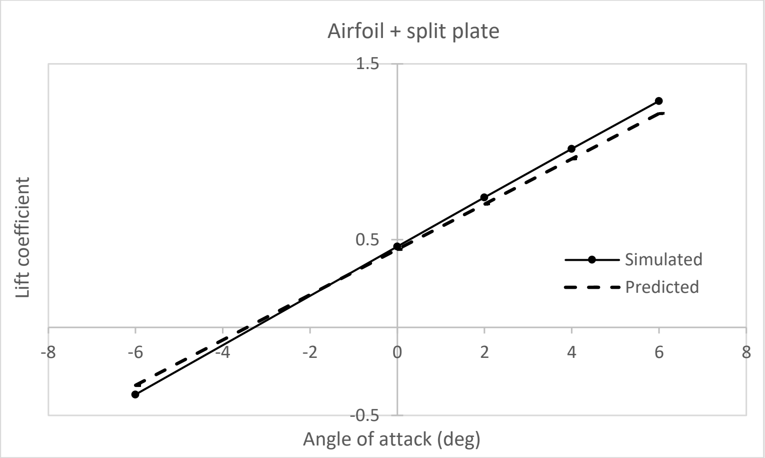
$$Cl_p = 2\pi\alpha\left(1 + \frac{l}{c}\right) + 2\pi\beta\frac{l}{c} + Cl_0$$

$$Cl_s = 2\pi\alpha\left(1 + \frac{l_s}{c}\right) + 2\pi\beta\frac{l_s}{c} + Cl_0$$

Theoretical study

Lift prediction model





$$Cl_a = 2\pi\alpha + Cl_0$$

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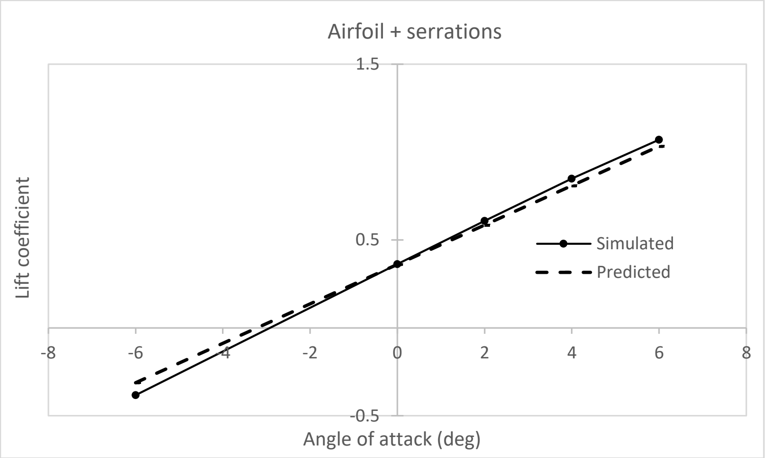
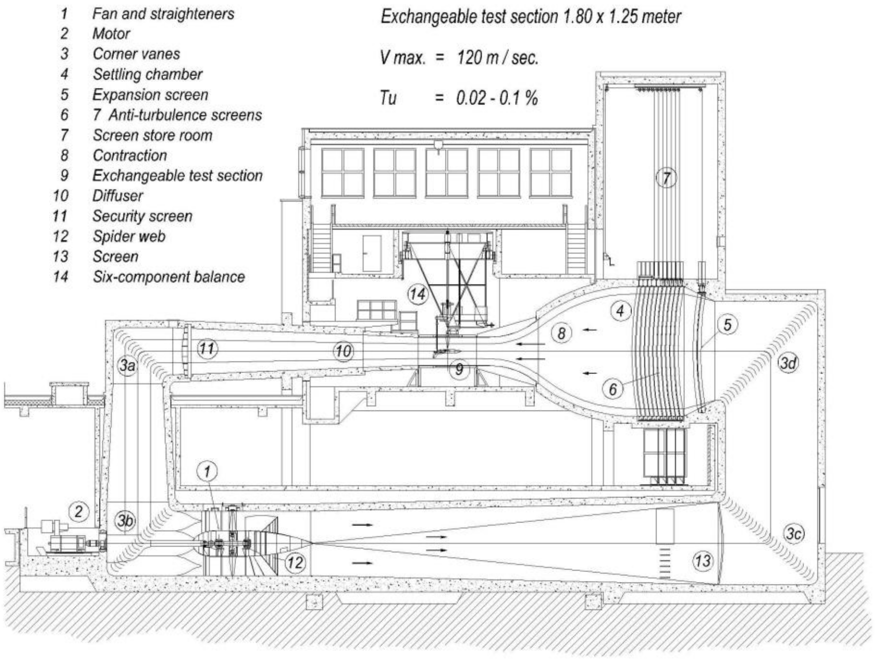


Experimental validation

Wind tunnel tests

- Wind tunnel tests ⟶ Low speed low turbulence WT TU-Delft

Schematic LST wind tunnel TU-Delft



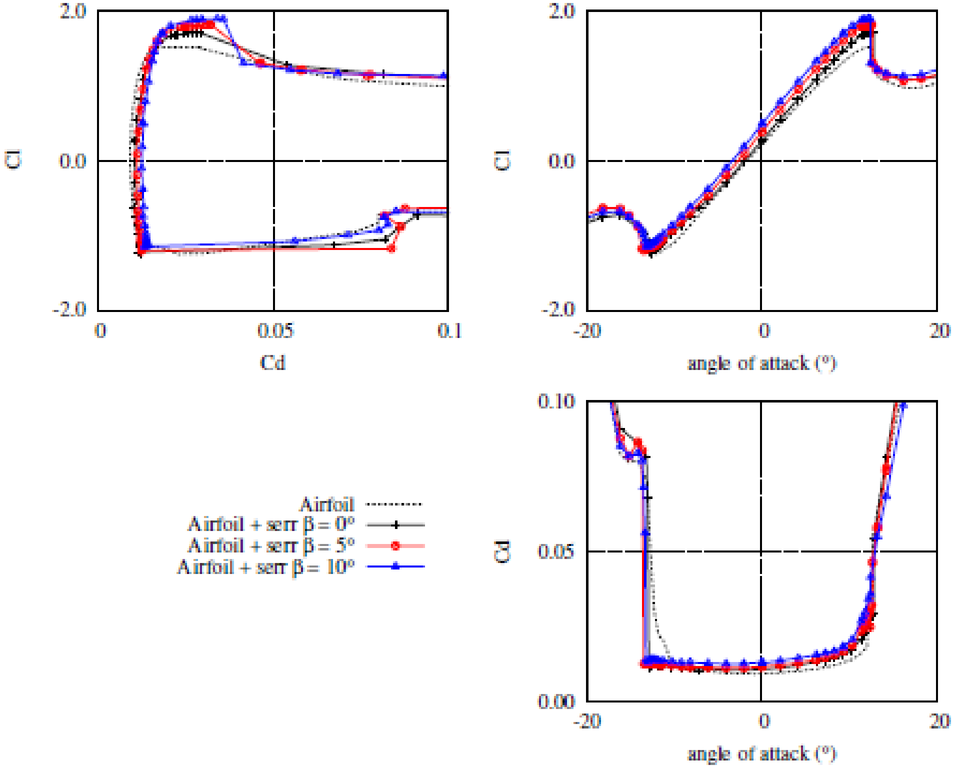
Tested model

NACA 64$_3$418

Experimental validation

Wind tunnel tests

- Results
  - Aerodynamic coefficients NACA 64_3418



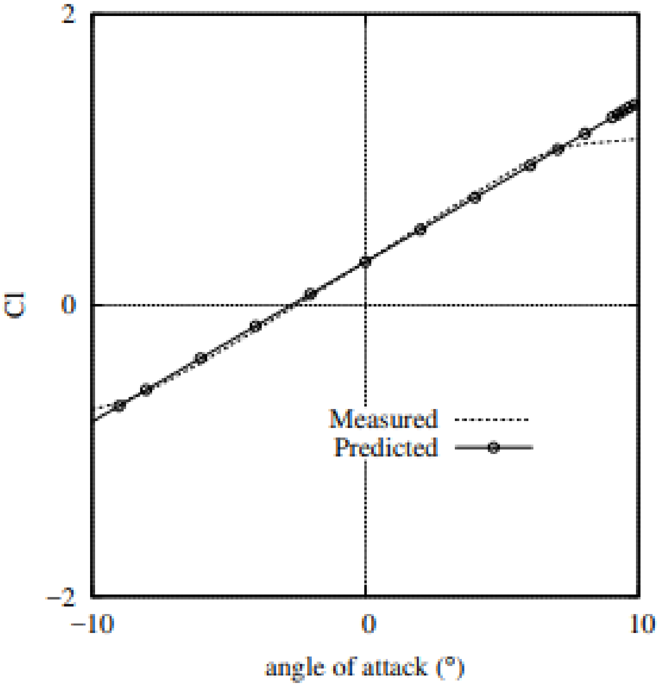
Experimental validation

Lift prediction model validation clean conditions

- Lift coefficient comparison without serrations

$$Cl_a = 2\pi\alpha + Cl_0$$

NACA 64_3418



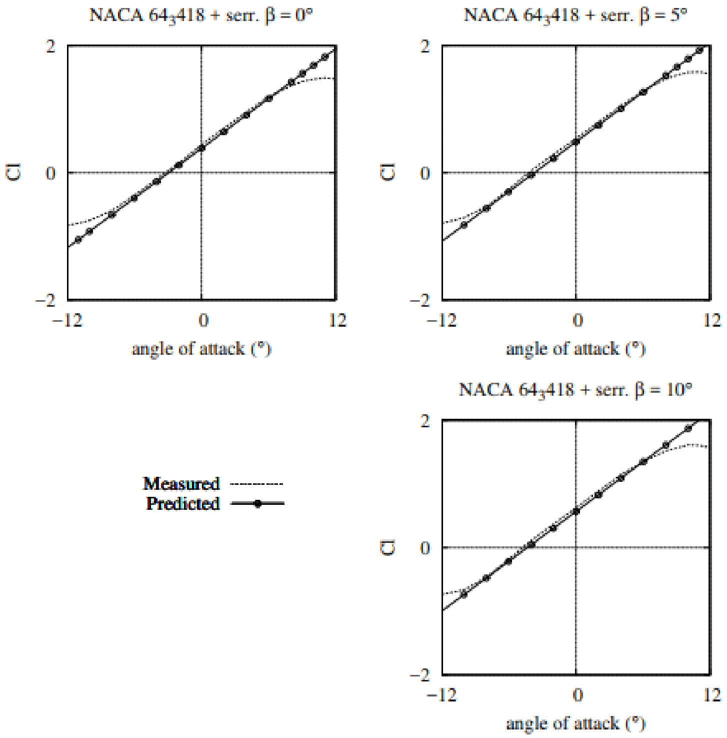
Experimental validation

Lift prediction model validation clean conditions

- Lift coefficient comparison with serrations

$$Cl_s = 2\pi\alpha\left(1+\frac{l_s}{c}\right)+2\pi\beta\frac{l_s}{c}+Cl_0$$

NACA 64_3418



Conclusions

- Analysis of the aerodynamic impact of the trailing edge serrations
- 2D and 3D RANS simulations of the original airfoil, the airfoil with a split plate and with trailing edge serrations
- Impact in lift and drag coefficients due to the presence of serrations
- Significant influence of the flap angle on the aerodynamic coefficients
- Derived prediction law for the lift coefficient

$$Cl_s = 2\pi\alpha\left(1 + \frac{l_s}{c}\right) + 2\pi\beta\frac{l_s}{c} + Cl_0$$

- The lift coefficient of the serrated airfoil can be easily derived from the data of the original airfoil
- Good agreement between CFD results and predicted data
- Good agreement between the experimental results and predicted data

Thank you!

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