WESC 2021
25 – 28 MAY web conference from Hannover

OST Ostschweizer Fachhochschule

ETH zürich

AEROSENSE

Development of a method for obtaining local inflow angle from pressure gradient at leading edge on operating wind turbine blades

Julien Deparday, Yuriy Marykovskiy, and Sarah Barber

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Full-scale measurements

Advantages:

- Turbulent inflow conditions
- Influence of rotational speed
- Real load cases

- Comparison with simulations
- Comparison with controlled environment (wind tunnel)

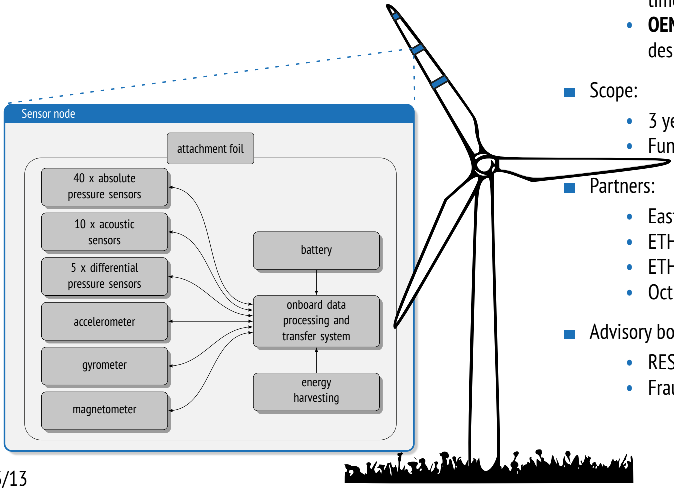
⇒ Need to know input, properties of incoming flow (AoA and speed)

Figure: Installation of measurement system of DANAERO - DTU Wind Energy

Troldborg et al. 2013

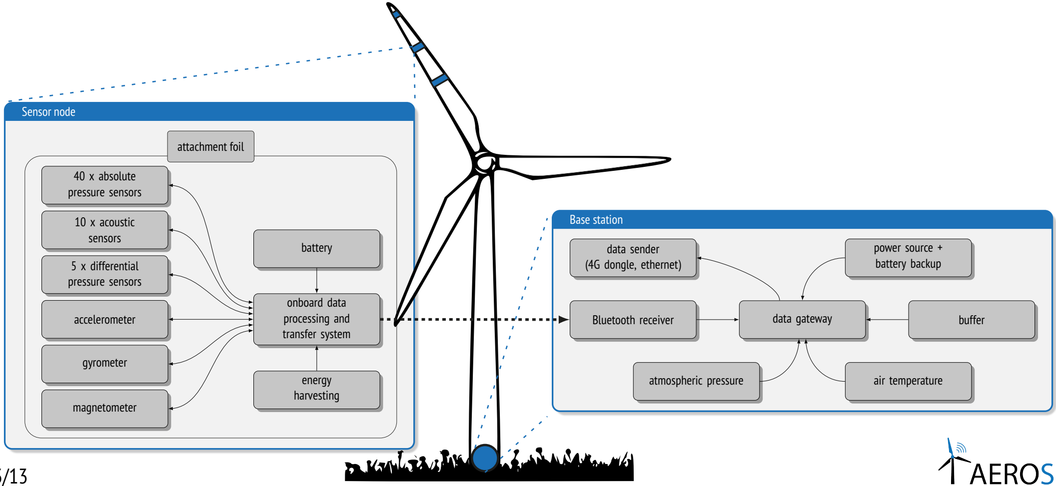
The Aerosense project

Project goal: develop a first ever MEMS-based surface pressure and acoustic smart measurement system that is thin, non-intrusive, robust, modular, low power and self-sustaining, wirelessly transmitting, easy to install and cost-effective for wind turbines.

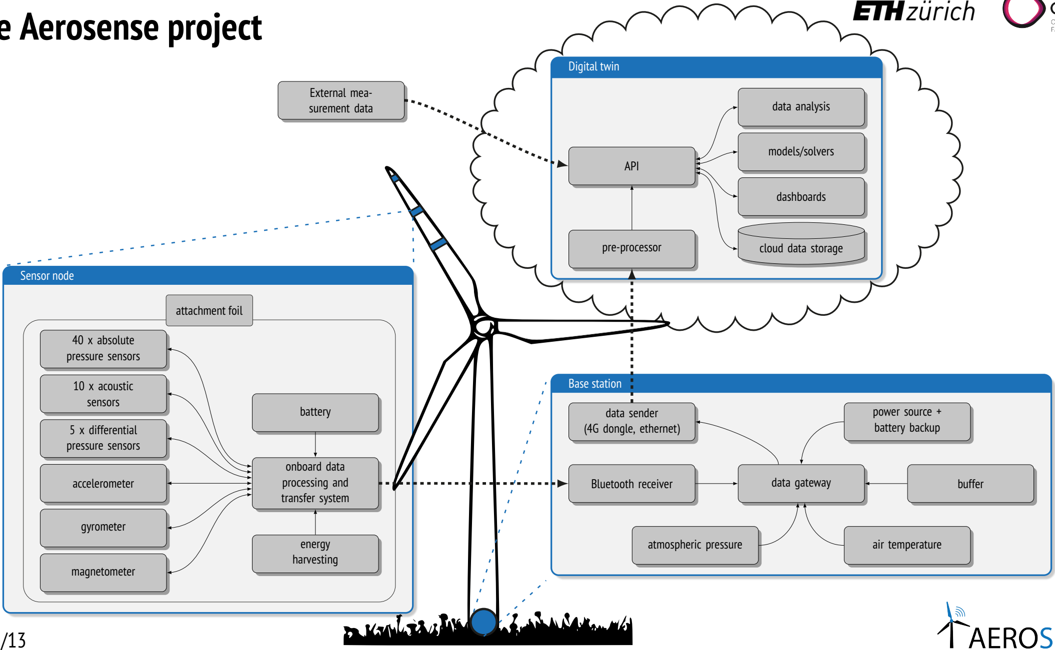


- Use cases:
  - **Operators:** blade surface damage detection, performance optimisation, amplitude modulation detection (increase operating time).
  - **OEMs:** optimisation of aeroacoustic design tools and wind turbine designs, understanding 3D field aerodynamics
- Scope:
  - 3 years May 2020 – April 2023
  - Funding from SNF/Innouisse BRIDGE programme: CHF 2.3 m
- Partners:
  - Eastern Switzerland University of Applied Sciences (OST)
  - ETH Zürich Chair of Structural Mechanics and Monitoring
  - ETH Zürich Center for Project-Based Learning
  - Octue (UK)
- Advisory board:
  - RES, EKZ Renewables, Enercon, GE (LM), Brüel&Kjaer
  - Fraunhofer IWES, ECN, DTU, TU Delft, NREL.

The Aerosense project

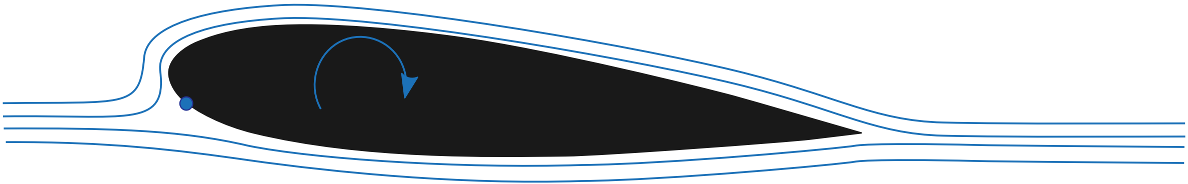


The Aerosense project



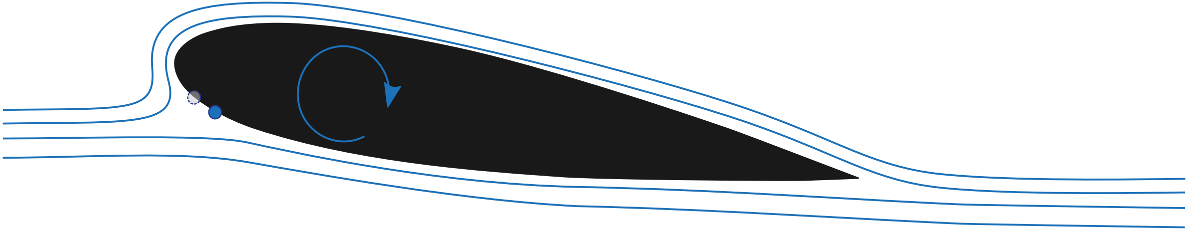
Angle of attack and stagnation point

Angle of attack = 5°



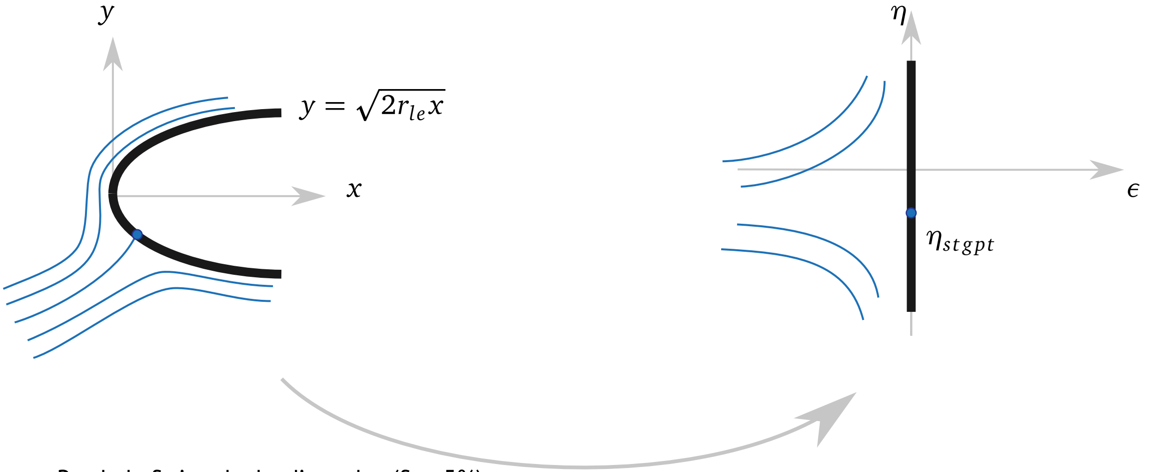
Angle of attack and stagnation point

Angle of attack = 10°



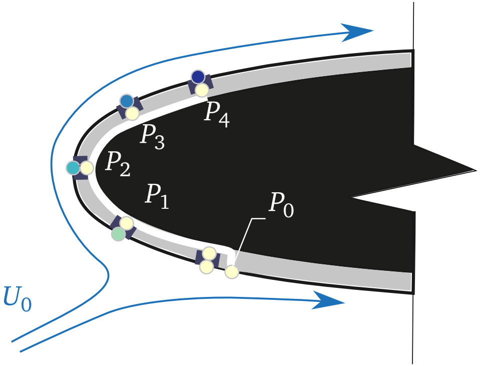
- At leading edge, change of angle of attack ⇒ change of position of stagnation point

Leading edge region as potential flow

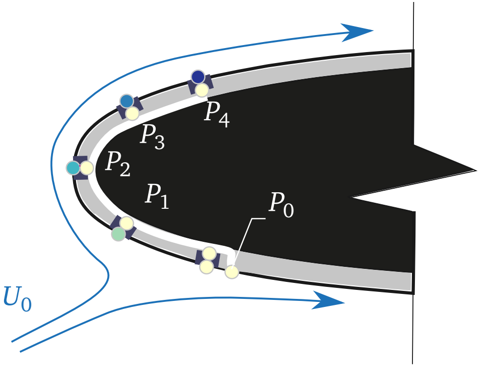


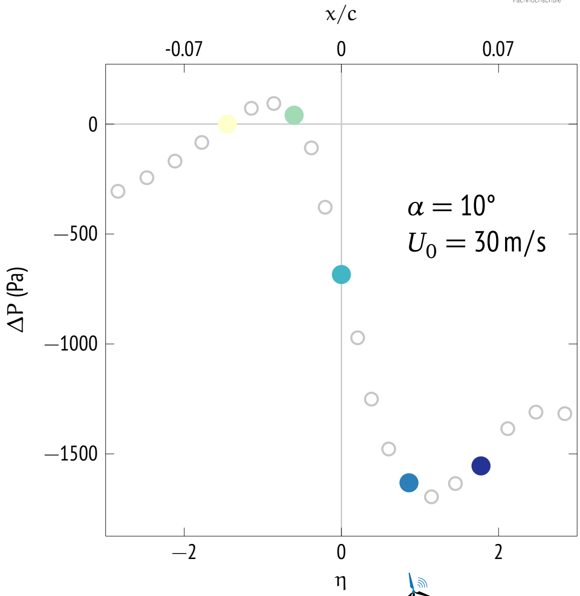
- Parabola fitting the leading edge (first 5%)
- Potential model with analytical solution Saini and Gopalarathnam 2018; Ramesh 2020

Pressure and velocity at leading edge

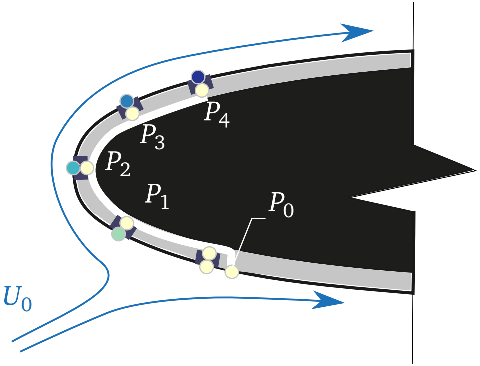


Pressure and velocity at leading edge

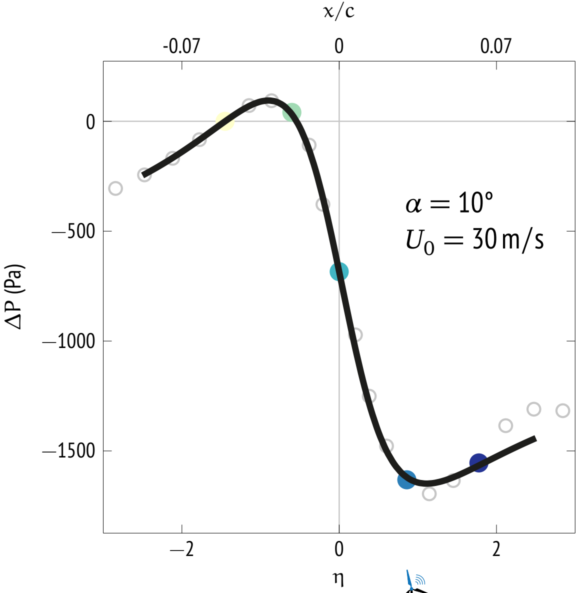




Pressure and velocity at leading edge

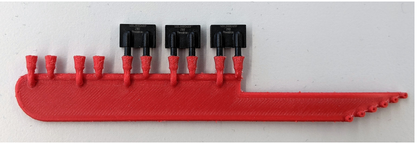


$$\Delta P = \frac{1}{2}\rho U_0{}^2\left[\frac{(\eta_0-\eta_S)^2}{1+\eta_0^2} - \frac{(\eta-\eta_S)^2}{1+\eta^2}\right]$$



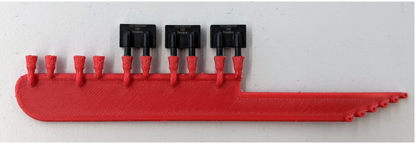
How to measure pressure difference at leading edge?

Prototypes with MEMS differential pressure sensors



How to measure pressure difference at leading edge?

Prototypes with MEMS differential pressure sensors



- 40 flush pressure taps
- 5 of them used for next results
- $U_0 = 10$ m/s to 50 m/s / $Re = 10^5 - 10^6$

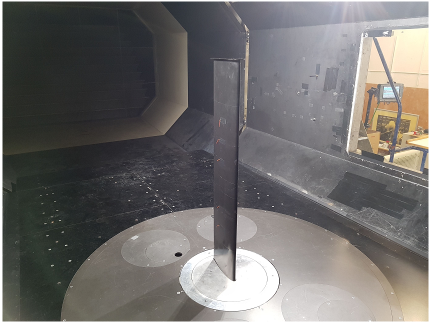


Figure: Test section of the ETHZürich wind tunnel

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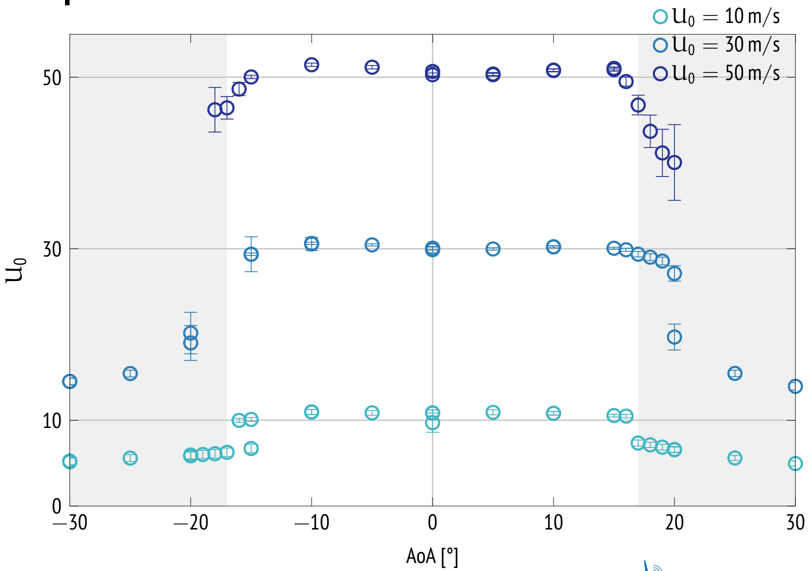
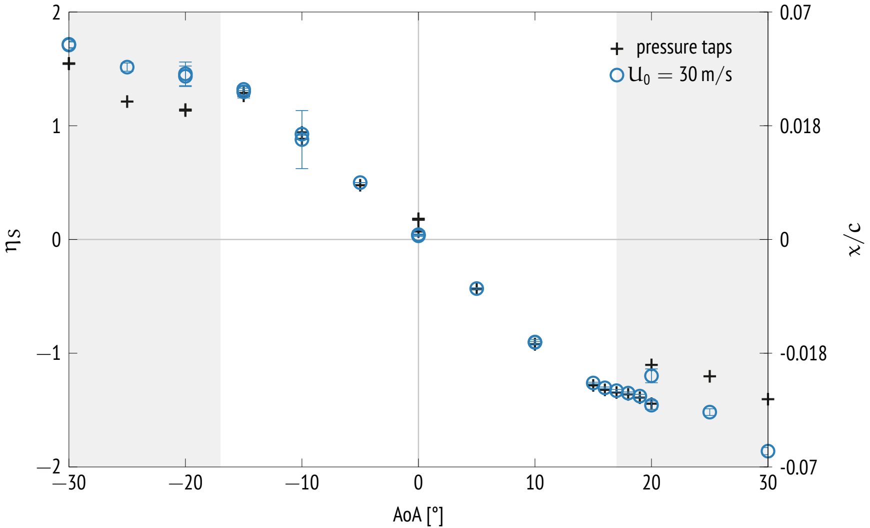
Estimation of incoming wind speed

- 10% accuracy for $U_0 =$ 10 m/s when flow is attached.
- 2% accuracy for $U_0 =$ 30 m/s and 50 m/s when flow is attached.



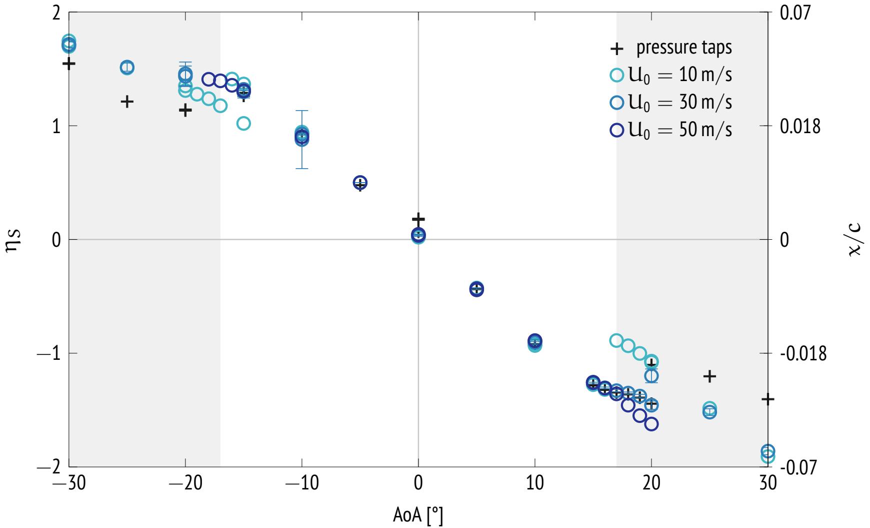
Estimation of stagnation point position

- Less than 2% of error for estimation of stagnation point position

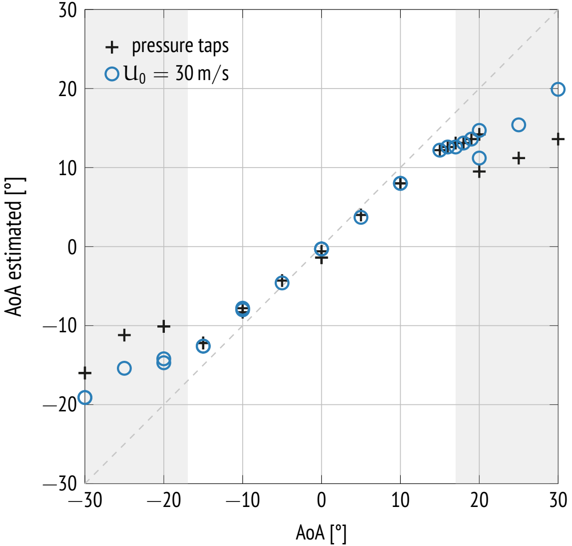


Estimation of stagnation point position

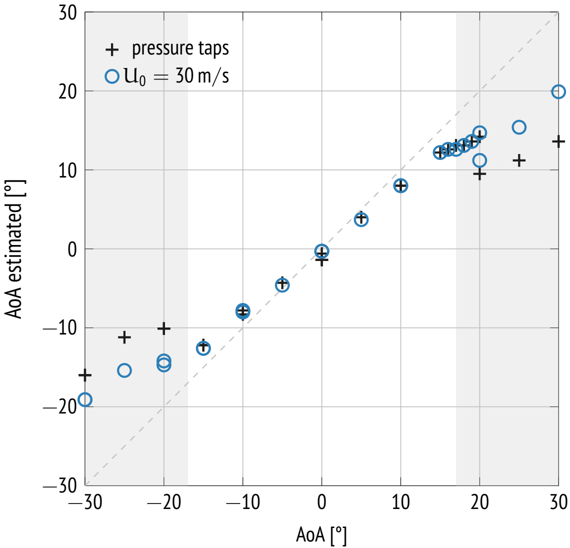
- Less than 2% of error for estimation of stagnation point position
- Method works for different wind speeds when flow is attached

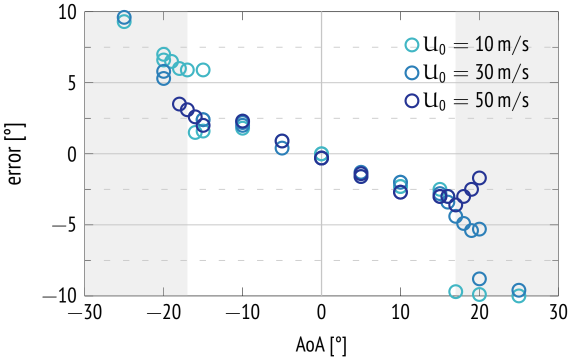


Estimation of angle of attack using XFOIL



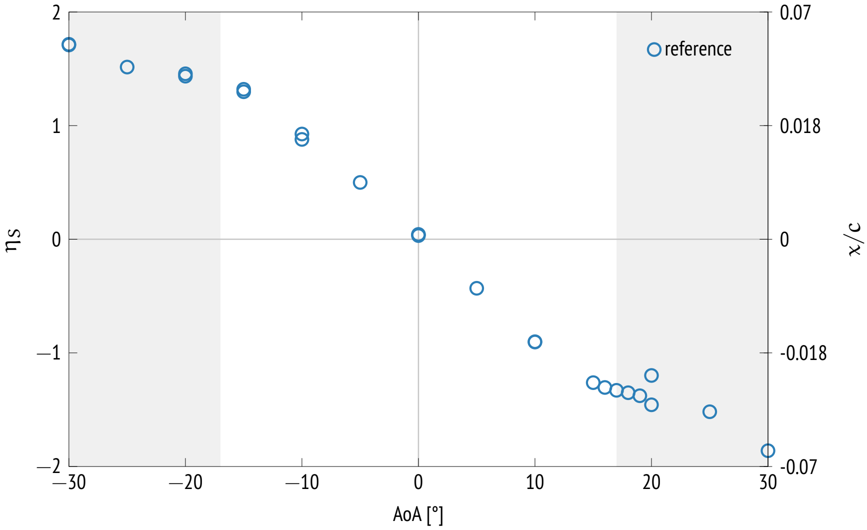
Estimation of angle of attack using XFOIL





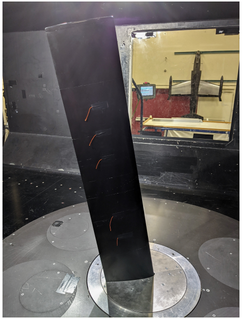
- Look-up table with XFOIL quite limited
- Error of less than 2.5° for AoA < 10°
- Error of less than 5° when no stall

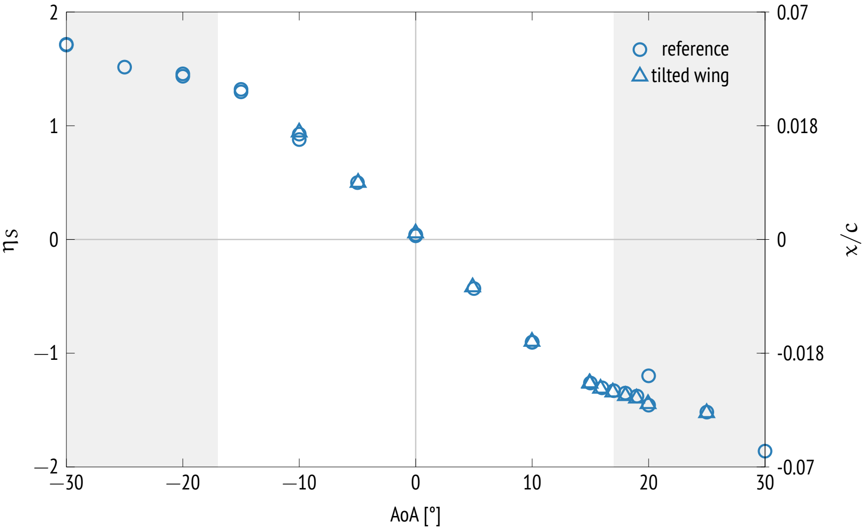
Influence of external conditions



Influence of external conditions

- Method not affected by a spanwise-component flow





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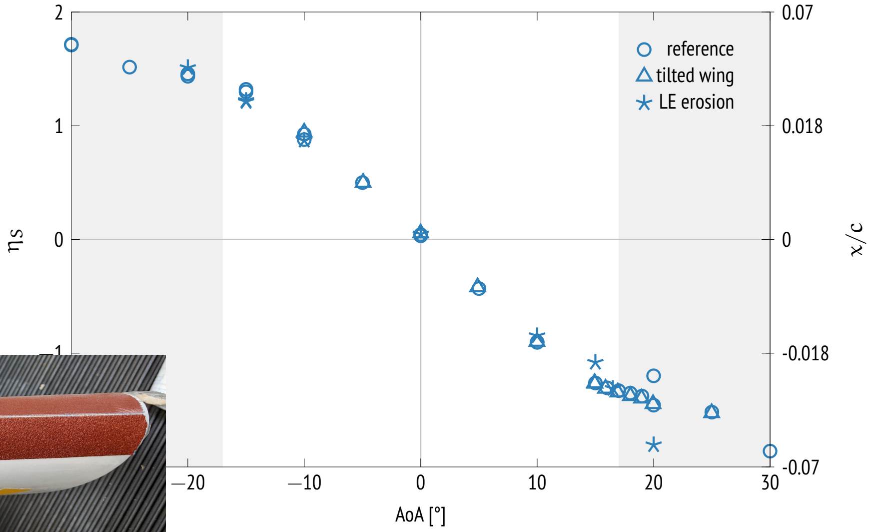
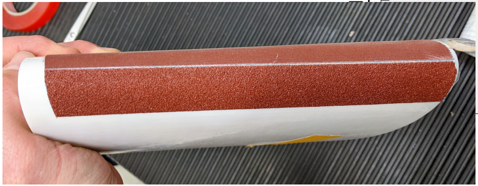
Influence of external conditions

- Method not affected by a spanwise-component flow
- Method detecting detachment when roughness at leading edge for AoA > 10°





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Conclusions

- Experimental method to infer angle of attack and local wind speed
- Based on potential flow at leading edge
- Stagnation point position and incoming wind speed in wind tunnel estimated with less than 2% of error
- Possibility to obtain angle of attack if careful corrections done
- Robust estimation (tilted wing or LE erosion)

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Thank you for your attention

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Other presentations on the Aerosense project:

- Yuriy Marykovskiy, *Mini-Symposium: Digital Twin Technology*, 14:25 on Tuesday
- Gregory Duthé, *Mini-Symposium: Structural Health Monitoring: Applications and Potential in Wind Energy*, 15:05 on Tuesday
- Tommaso Polonelli, *Novel Sensing and New Measurement Concepts for Wind Turbines*, 14:15 on Friday

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- Kiran Ramesh. “On the leading-edge suction and stagnation-point location in unsteady flows past thin aerofoils”. In: **Journal of Fluid Mechanics** 886 (2020). ISSN: 0022-1120. DOI: 10.1017/jfm.2019.1070.
- Aditya Saini and Ashok Gopalarathnam. “Leading-Edge Flow Sensing for Aerodynamic Parameter Estimation”. In: **AIAA Journal** 56.12 (2018), pp. 4706–4718. ISSN: 0001-1452. DOI: 10.2514/1.J057327.
- Niels Troldborg et al. **DANAERO MW II: Final Report**. DTUWind Energy E-0027. DTU Wind Energy, 2013.