EFFECT OF ROUGHNESS ON WIND TURBINE PERFORMANCE

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OUTLINE

- Leading edge erosion
- Modeling effect of erosion
- Validation against theory
- Airfoil results
- Turbine performance analysis
- Future work

LEADING EDGE EROSION

- Due to rain, hail, insects …
- Offshore locations more vulnerable
- Leads to reduction in performance
- Eroded blades modeled as rough surfaces

Image from https://www.grow-offshorewind.nl/project/windcore#modalTrigger1

MODELING EFFECT OF EROSION

- Extent of erosion represented by ***roughness height*** k.
- RANS turbulence models based on ***equivalent sand grain roughness*** k_s derived from k.
- Different roughness regimes identified based on k_s^+:
  - $k_s^+ \leq 5$, ***Hydraulically smooth*** – no effect
  - $5 \leq k_s^+ \leq 70$, ***Transitionally rough*** – shift in velocity profile in the inner boundary layer
  - $k_s^+ \geq 70$, ***Fully rough*** – No viscous sublayer

Shift in velocity profiles.

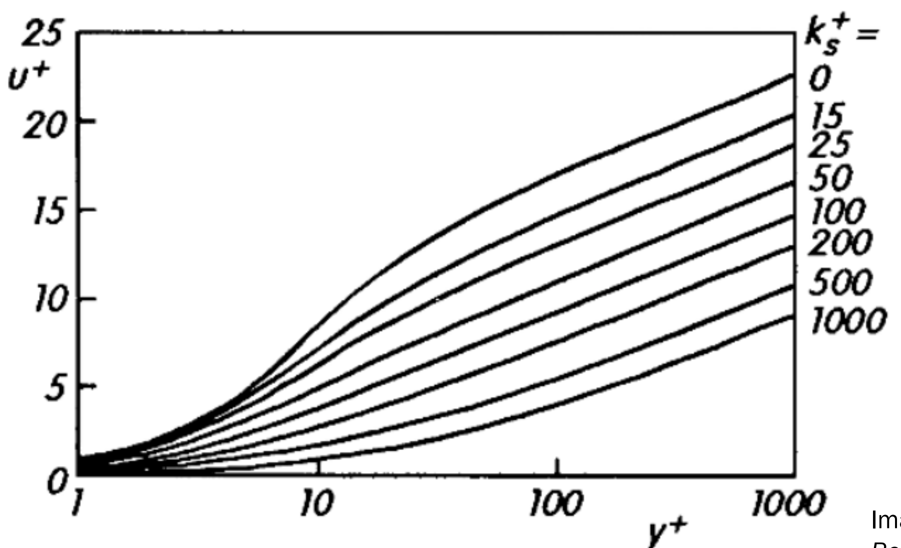


Image from Schlichting, H., & Gersten, K. (2016). *Boundary-layer theory*. Springer.

RANS MODELS FOR ROUGH WALLS

Shift in velocity profile modeled as

SA

- Assume a virtual wall exists above the rough surface.
- Non –zero turbulent viscosity at the wall to account for the shift.

$$\left.\frac{\partial \tilde{\nu}}{\partial n}\right|_w = \frac{\tilde{\nu}_w}{0.03k_s}$$

- Wall distance modified as $d_{new} = d + 0.03k_s$

SST

- Reduce damping in the inner boundary layer by modifying ω at the wall.

$$\omega_w = \frac{\mu^2 S_R}{\nu}$$

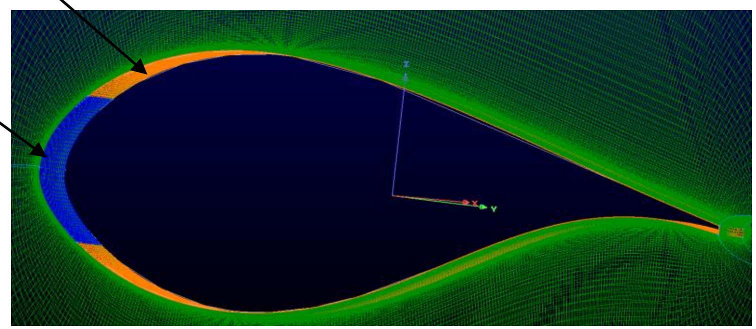
- S_R is a function of k_s^+

ROUGHNESS MODELS IN SU2

- Currently implemented in branch feature_roughwall (pull request under review).

WIP Rough wall boundary condition for SA and SST turbulence models. #877

- Choose the rough and smooth parts of airfoil separately



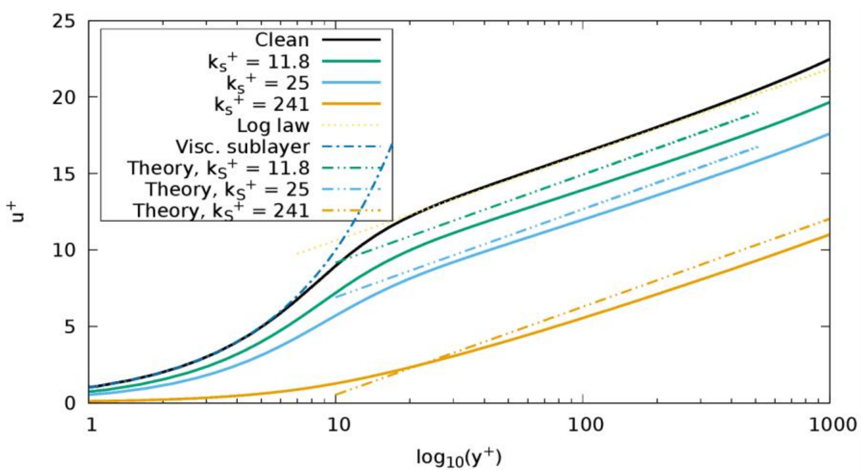
- Specify sand grain roughness (k_s) in config file (input method under review)

```
%
% Navier-Stokes wall boundary marker(s) (NONE = no marker)
MARKER_HEATFLUX= ( airfoil, 0.0, airfoil_rough, 0.0)
WALL_TYPE= SMOOTH, ROUGH
%WALL_ROUGHNESS= 0.0, 0.000154
WALL_ROUGHNESS= 0.0, 0.000308
```

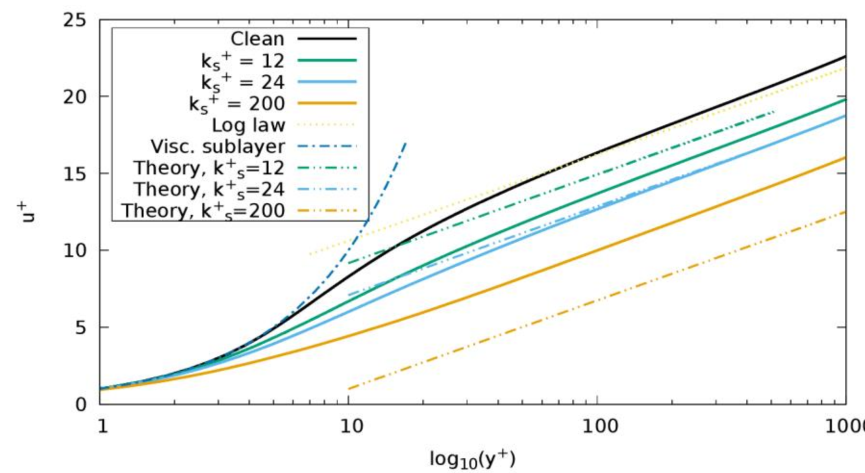
FLOW OVER ROUGH FLAT PLATE

- $Re = 6 \times 10^6$.
- Velocity profiles in the viscous sub layer and log law region compared to theoretical predictions

SA

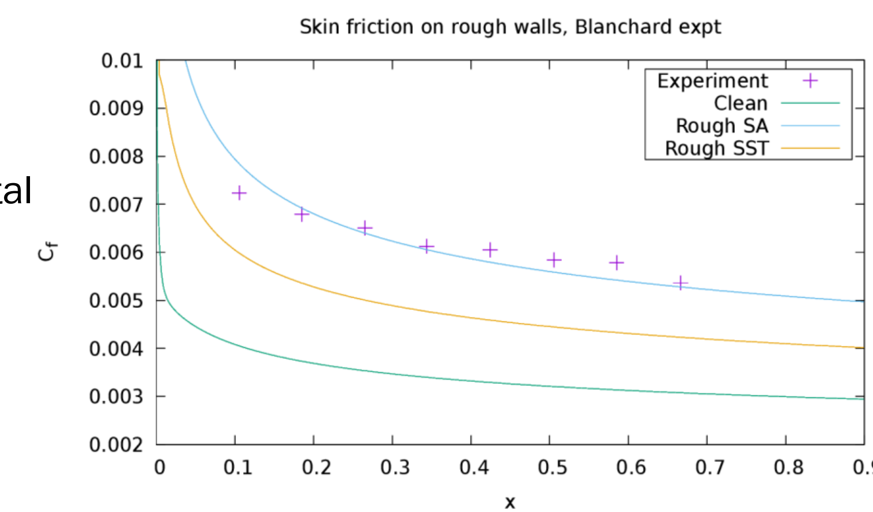


SST

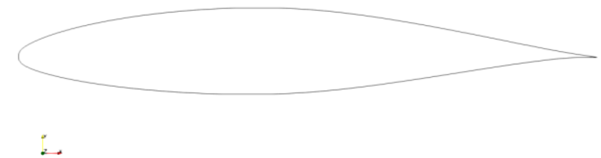


Comparison of predicted skin friction to experimental data from Blanchard.

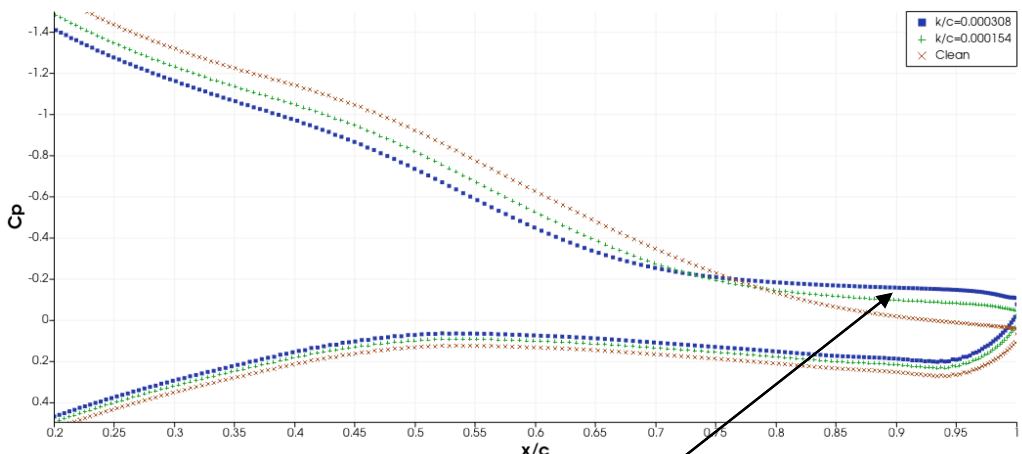
$$k_s = 425 \times 10^{-6} mm$$

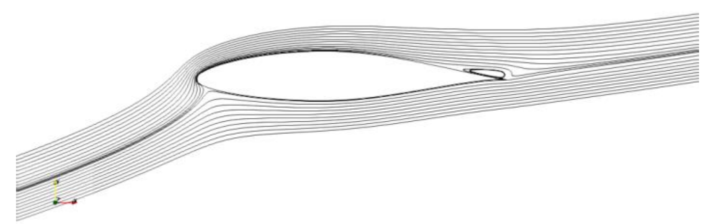


NACA 652215 AIRFOIL



- NACA 652215 airfoil – sharp trailing edge.
- $k_s/c = 154 \times 10^{-6}$, $k_s/c = 308 \times 10^{-6}$ at $Re = 2.6 \times 10^{6}$
- Roughness span $-0.15 \leq \frac{x}{c} \leq 1$ (entire upper surface and part of lower surface)





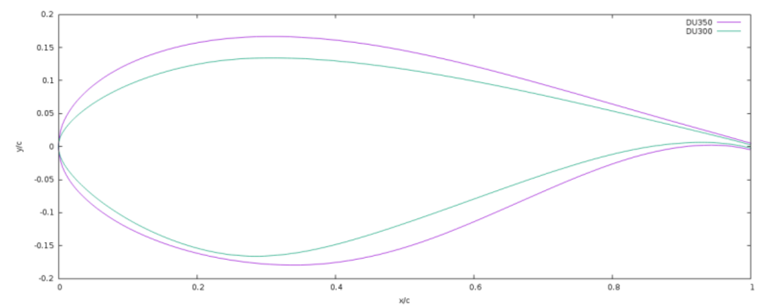
Early separation due to roughness

WIND TURBINE PERFORMANCE - AVATAR

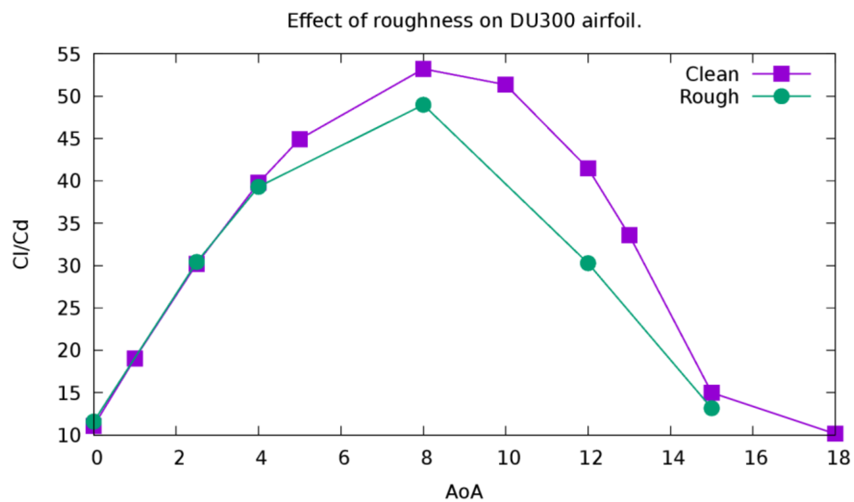
- AVATAR turbine – 10 MW reference blade (https://www.eera-avatar.eu/home/index.html)
- Rotor blade made up of 5 airfoil sections – DU240, DU300, DU350, DU400, DU600.
- Use polars generated from CFD in combination with Blade Element Momentum (BEM) to compute power output.

WIND TURBINE PERFORMANCE - AIRFOIL POLARS

- $Re = 2 \times 10^6$
- Decrease in aerodynamic efficiency with roughness.
- Span of roughness has significant impact.



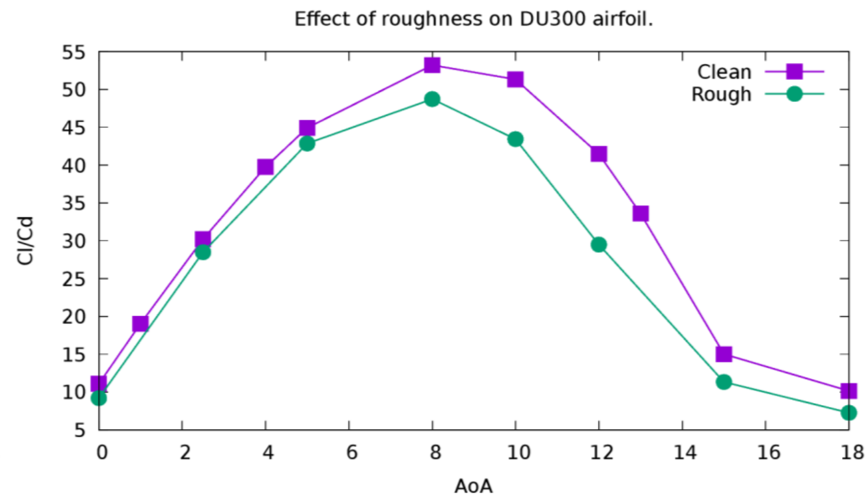
DU airfoils



Rough surface span:

$$-0.015 \leq \frac{x}{c} \leq 0.015$$

$$k_s/c = 600 \times 10^{-6}$$



Rough surface span:

$$-0.02 \leq \frac{x}{c} \leq 0.13$$

$$k_s/c = 400 \times 10^{-6}$$

WIND TURBINE PERFORMANCE - AVATAR

- Only SA model used here since better performance was observed.
- Fully turbulent conditions assumed, incoming velocity of $10\ m/s$.
- Assume rough sections on the LE ($\frac{x}{c} \leq \pm 0.015$) of DU300 and DU350 ($k_s\ =\ 600 \times 10^{-6}$).
- Blade Optimization Tool (BOT) based on Blade Element Momentum theory used to compute power output

	Power (kW)	Loss (%)
Clean	8296	-
Rough DU300	8177	1.4
Rough DU350	8215	0.9
Both Rough	8089	2.4

Power output under various conditions.

FUTURE WORK

- More validation,
- Transition modelling ,
- Corrections to the SST roughness models,
- Power analysis at different roughness levels,
- Full 3-D RANS analysis on turbine blade with real roughness.

THANK YOU FOR
YOUR TIME
TNO innovation for life