Aerodynamics of Iced blades:
a 2D wing section investigation

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Cold Climate ☺s and ☹s

- Load unbalance, fatigue
- Ice throw and possible operational shutdowns
- Significant impact on WT output: up to 90% loss is reported*
- Favorable aspects: density, wind speed, less neighbors.

https://www.windpowerengineering.com/detecting-ice-on-wind-turbine-blades/

* https://greensolver.net/ice-throw-from-wind-turbines/

Ice forms

Rime

- Super cooled liquid water droplets -> white feather
- - 0 °C to -20°C.

Glaze

- Freezing water -> smooth and transparent
- 0 °C to -6°C.
- Heavy, and hard to remove

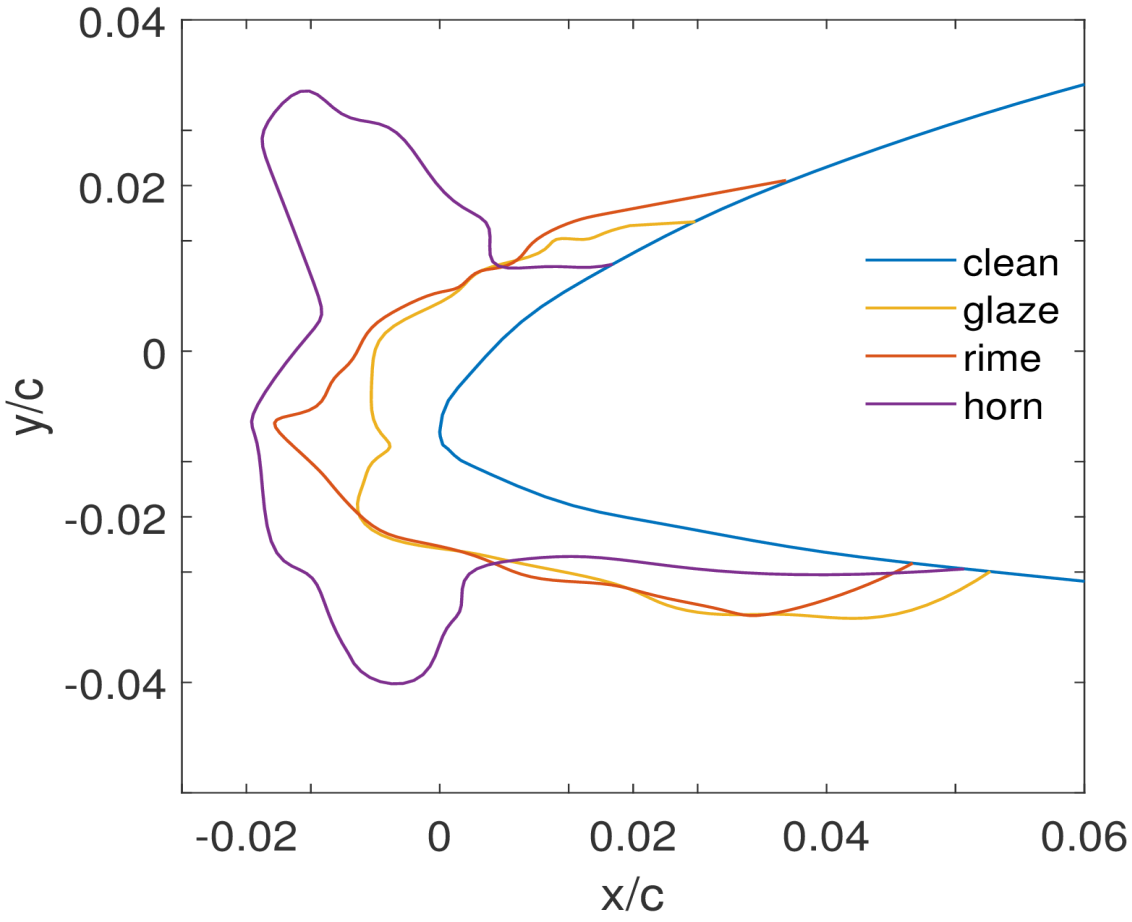
Horn

- Normally formed at glaze conditions.
- Critical aerodynamic feature arising from separation bubble.

Rime (left) and glaze ice (right). Source: Adriána Hudecz (2014).

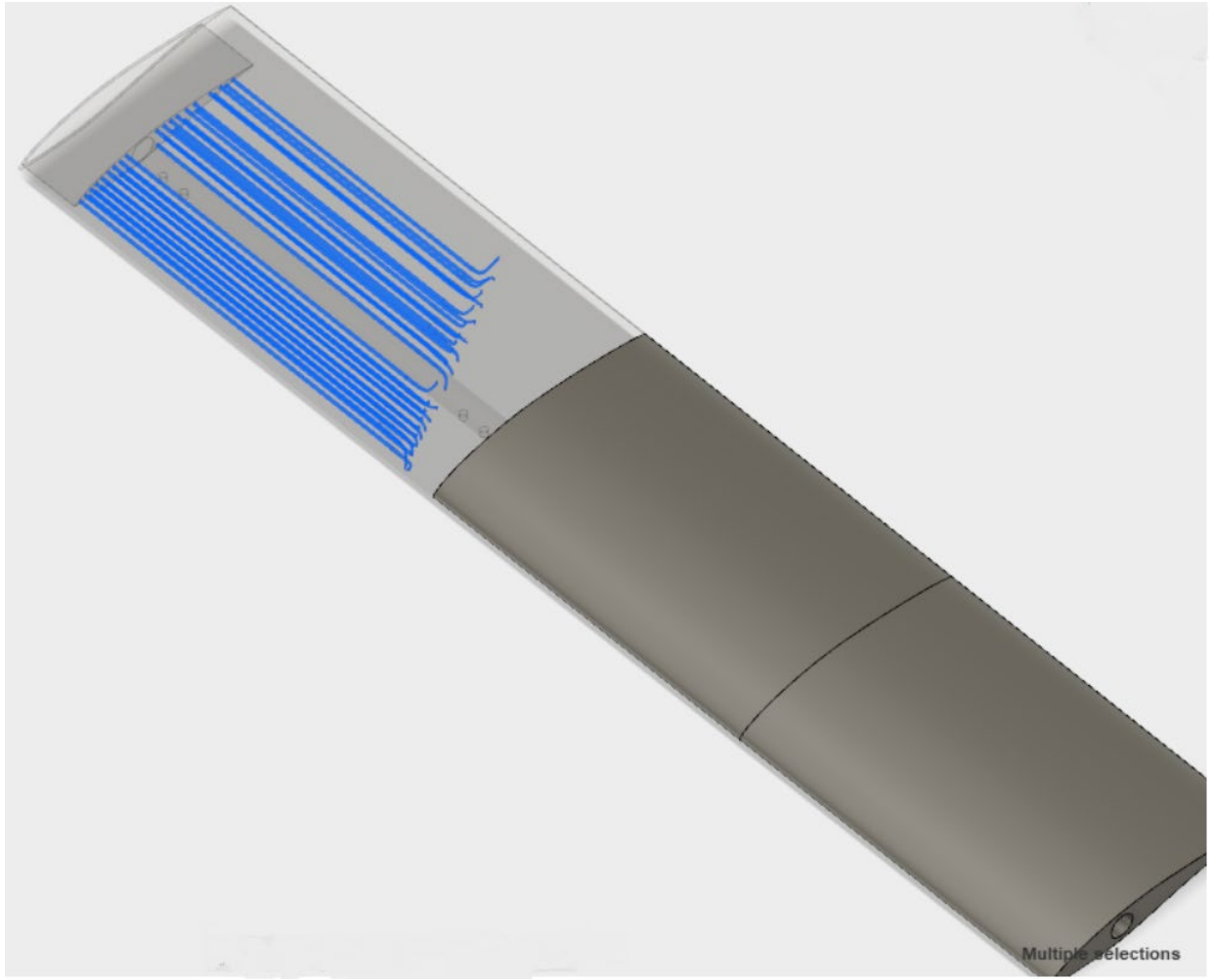
Test cases

- Rime and glaze ice experimentally at AoA=0°, -8°C and -3°C, from Hudecz (2014).
- Horn ice numerically generated with TURBICE software at AoA=0°, at -4°C, from Branderup & Krøgenes (2017)
- Same horn ice geometry used for DU 06-W-200 airfoil.



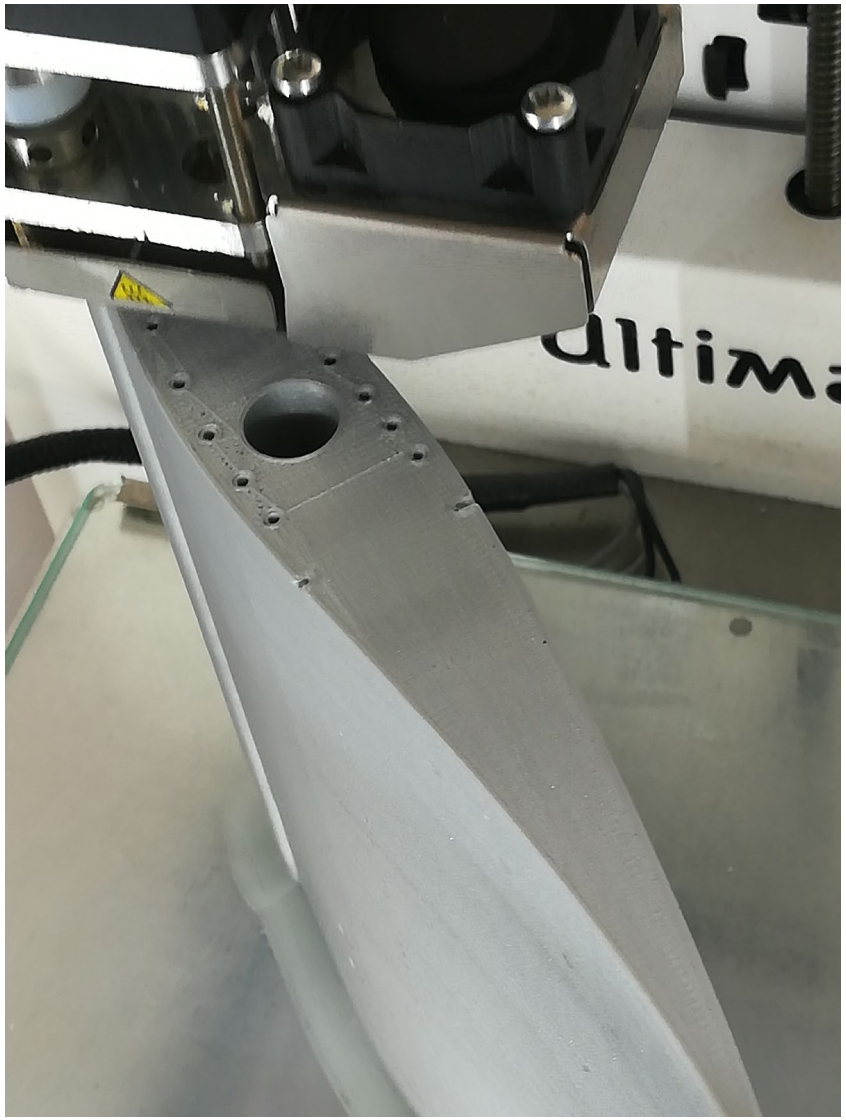
3D Modelling

- Autodesk Fusion 360
- 3 pieces
- 498mm span
- Clean airfoil: 100mm chord
- Iced airfoils: 150mm chord
- Pressure channels in blue



Test preparations

- FABLAD DTU
- FDM method
- Layer height: 0.1mm
- PLA (cheaper) and ABS (more expensive) plastic



Modelling

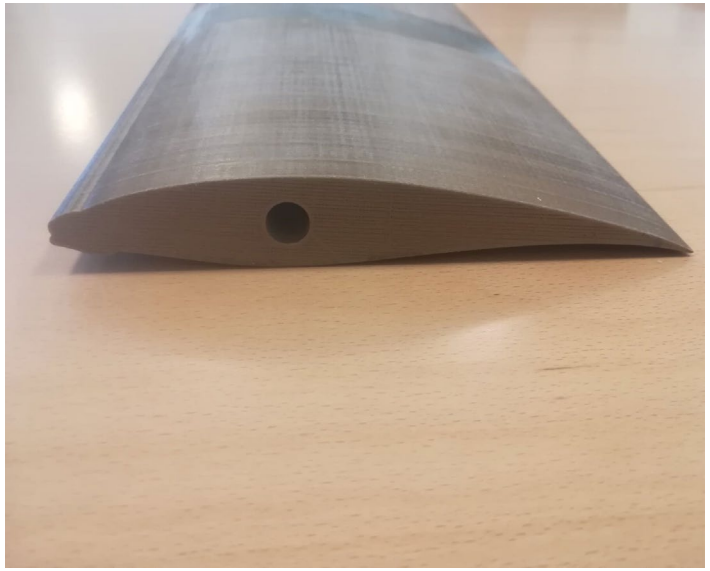
- Numerically and experimentally Investigating the aerodynamic effects of rime, glaze and horn ice geometry attached on the airfoil leading edge:

- Rime
- Glaze

NREL S826

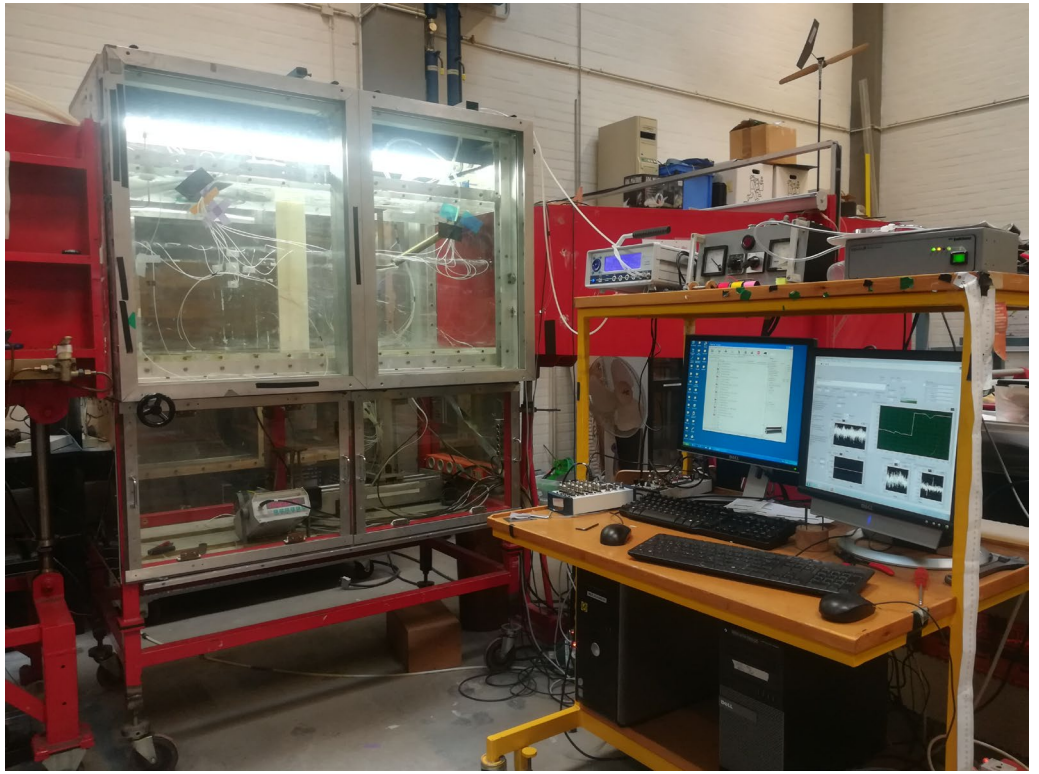
- Horn

NREL S826
DU 06-W-200



Pt. 1: Experimental Investigations

- Open-loop, low wind speed.
- Wake rake for drag measurements.
- Force gauge for lift measurements.
- 0.5m x 0.5m x 1.3m test section.
- Re = 60,000 to 300,000.
- AoA = -10 to 20 degrees, 10s/AoA.
- Pressure sampling of 312.5Hz.
- Lift force sampling of 125 Hz.



NREL S826 airfoil: Tunnel Experiments

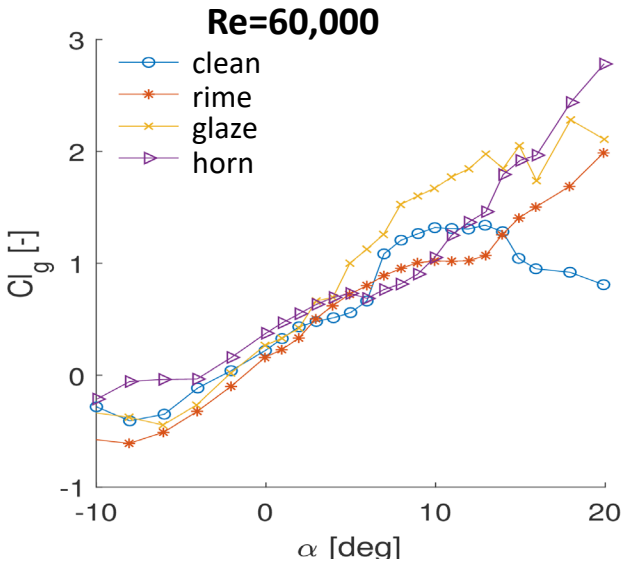
Lift

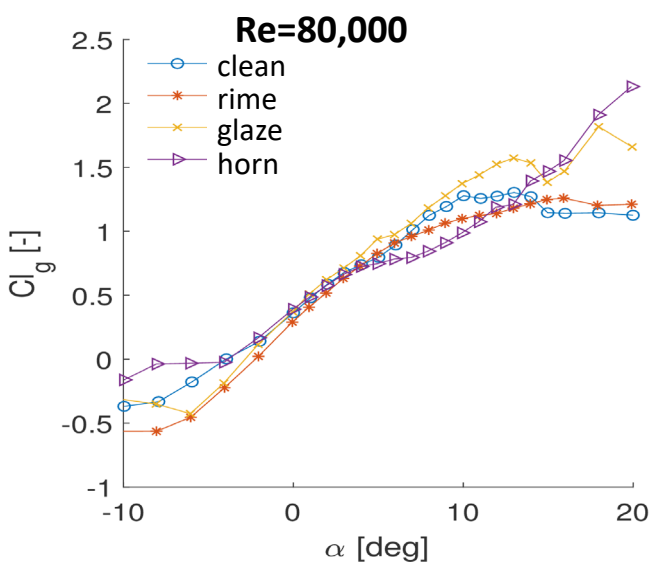
AoA= 10°

Rime:-22%

Glaze:+27%

Horn:-20%





AoA= 10°

Rime:-14%

Glaze:+7%

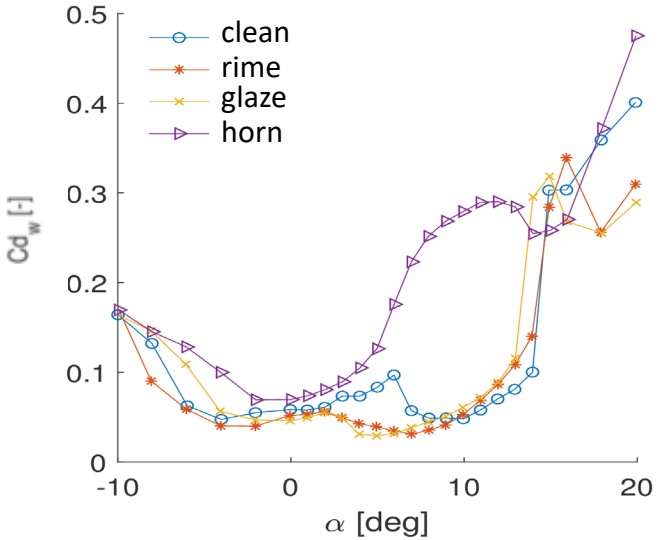
Horn:-23%

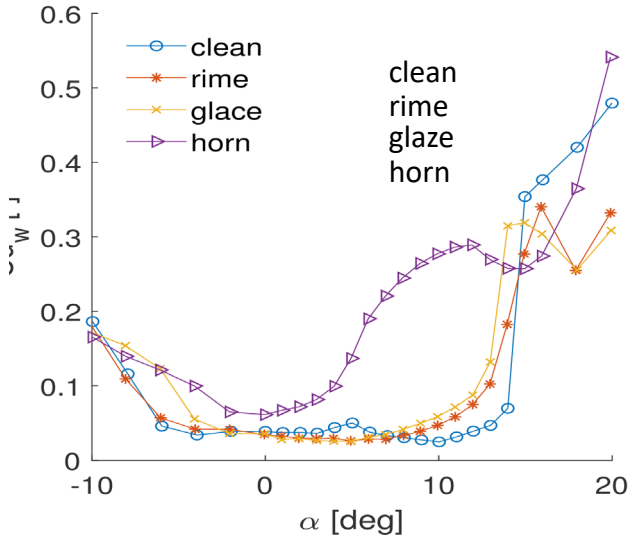
Drag

Rime:+10%

Glaze:+26%

Horn:+478%





Rime:+89%

Glaze:+136%

Horn:+990%

NREL S826 airfoil: Tunnel Experiments

Re=100,000

Re=300,000

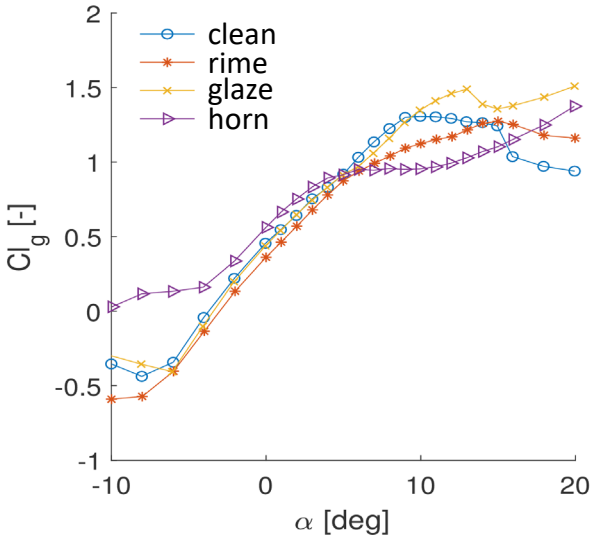
Lift

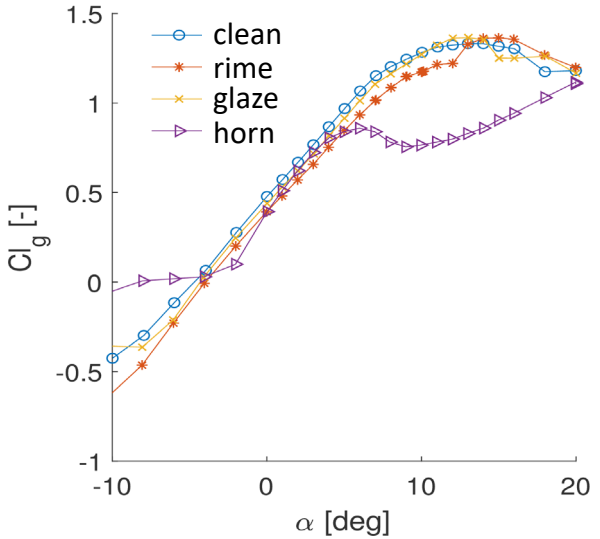
AoA = 10°

Rime:-14%

Glaze:+3%

Horn:-27%





AoA= 10°

Rime:-9%

Glaze:-1%

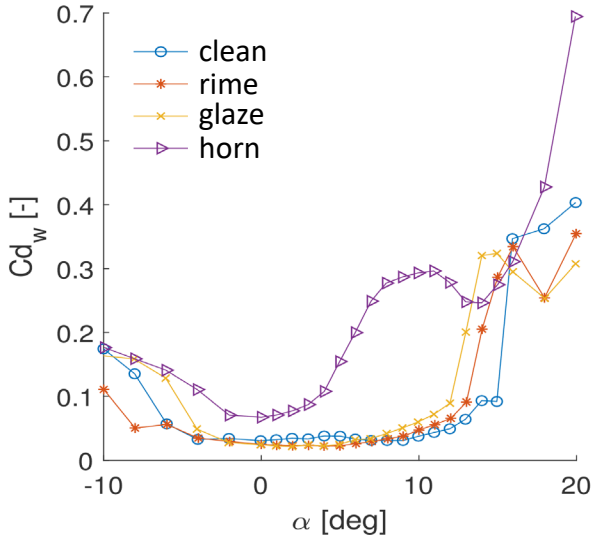
Horn:-4%

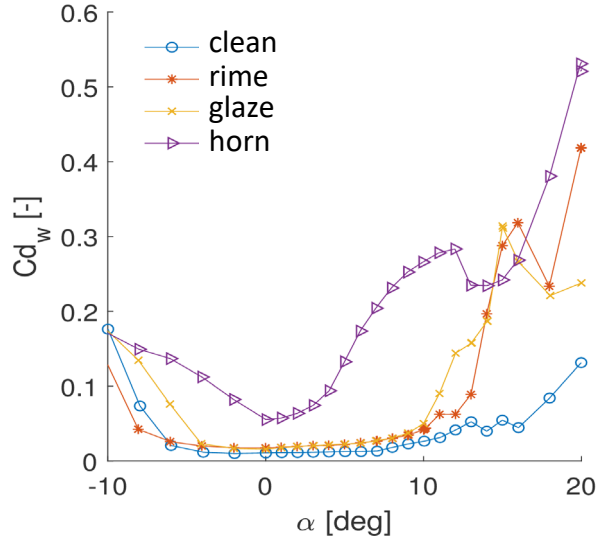
Drag

Rime:+26%

Glaze:+59%

Horn:+681%





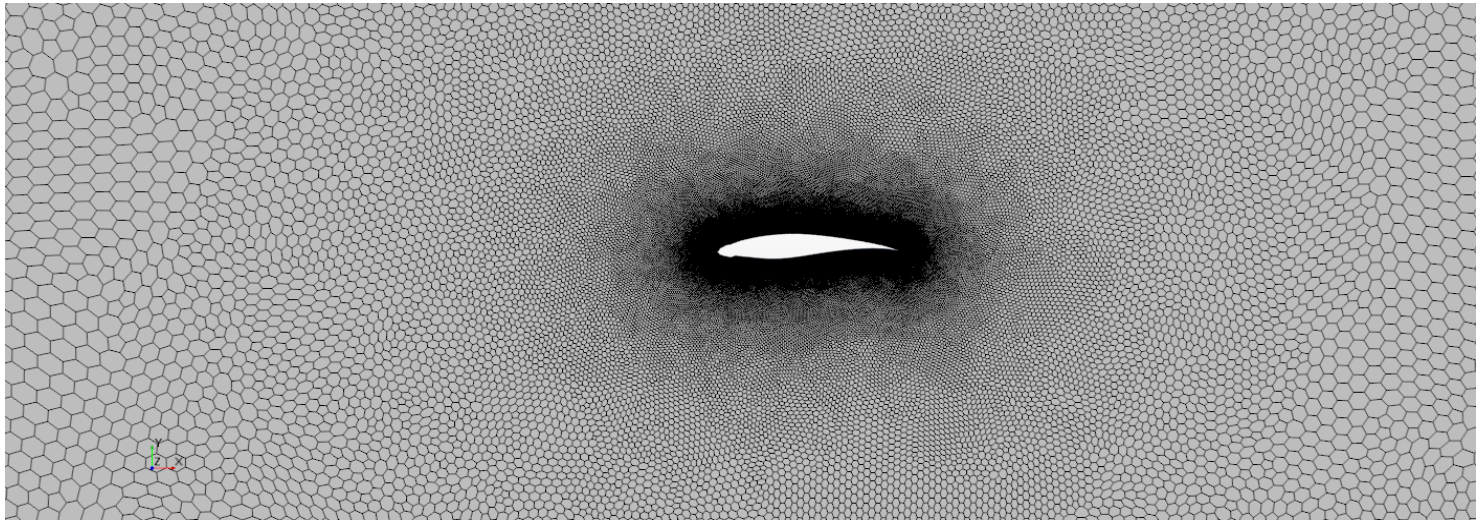
Rime:+65%

Glaze:+88%

Horn:+900%

Pt. 2: Numerical Investigations

- StarCCM+
- 2D test section
- Tunnel mesh
- RANS with k-ω SST model
- Unsteady (CFL<1)
- Smooth surface
- Polygonal grid with boundary layers
- Ca. 120.000 cells



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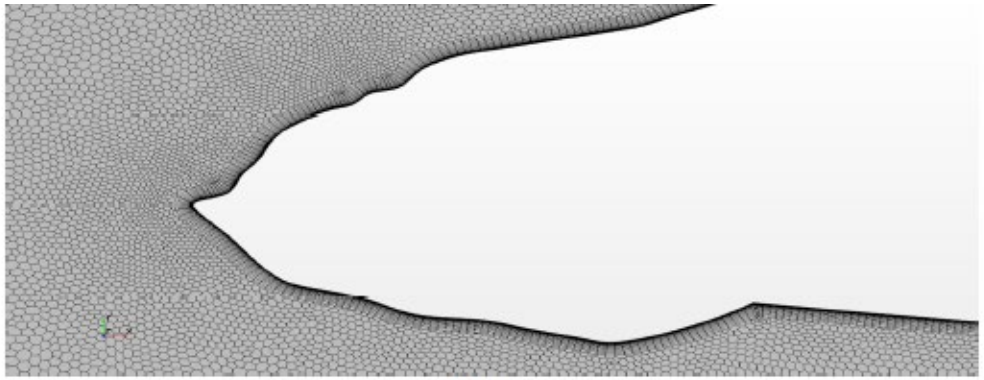
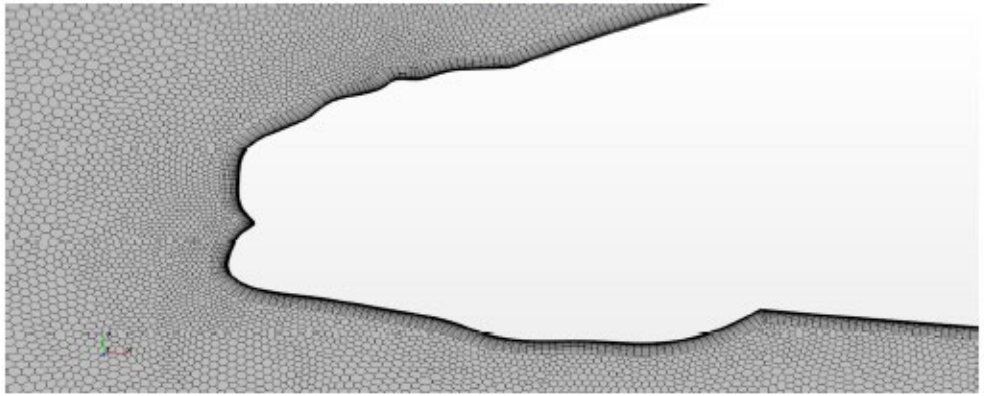
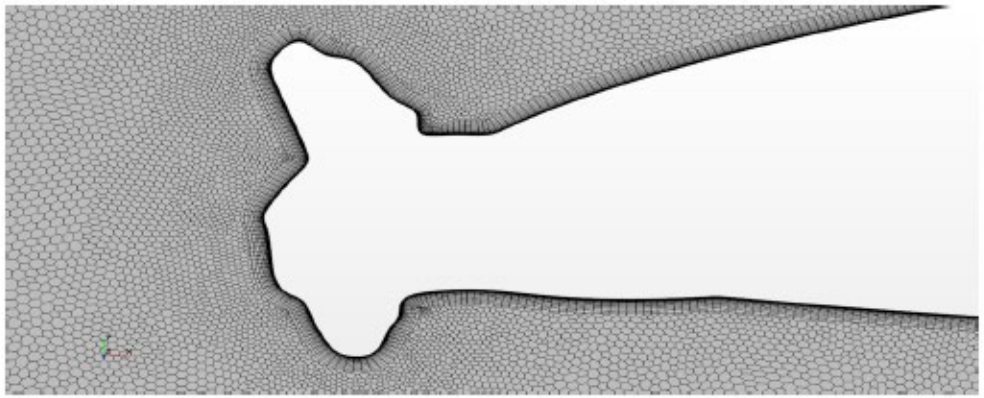


(a) Rime ice.



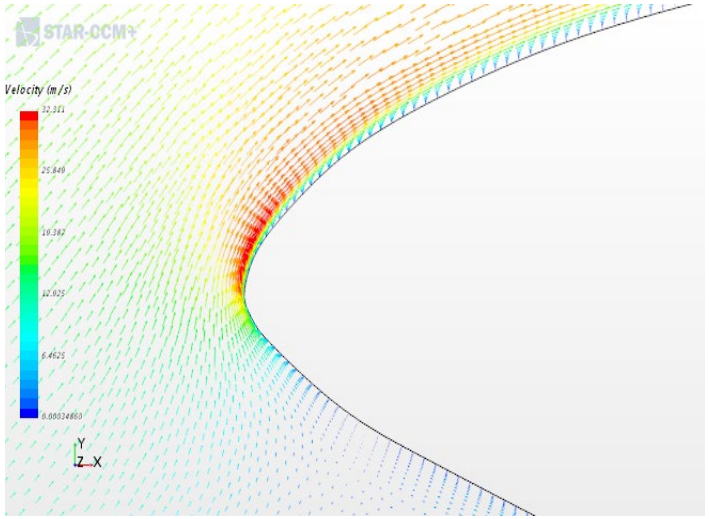
(b) Glaze ice.



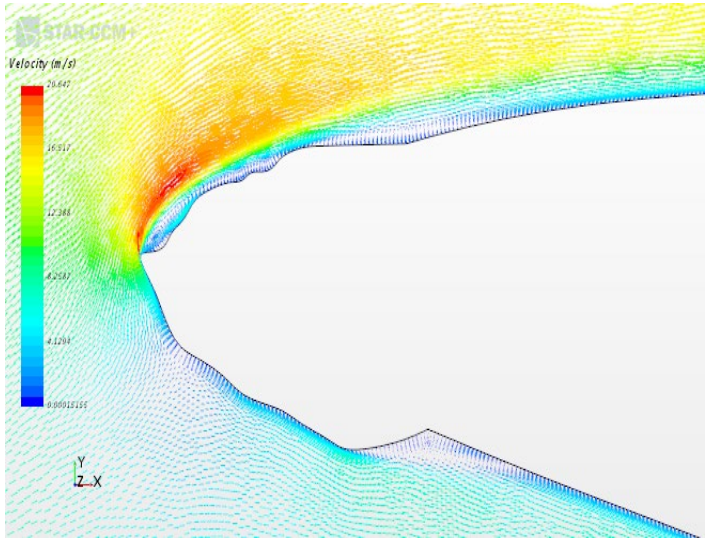
(c) Horn ice.

Velocity vectors at Re = 100,00 AoA=11°

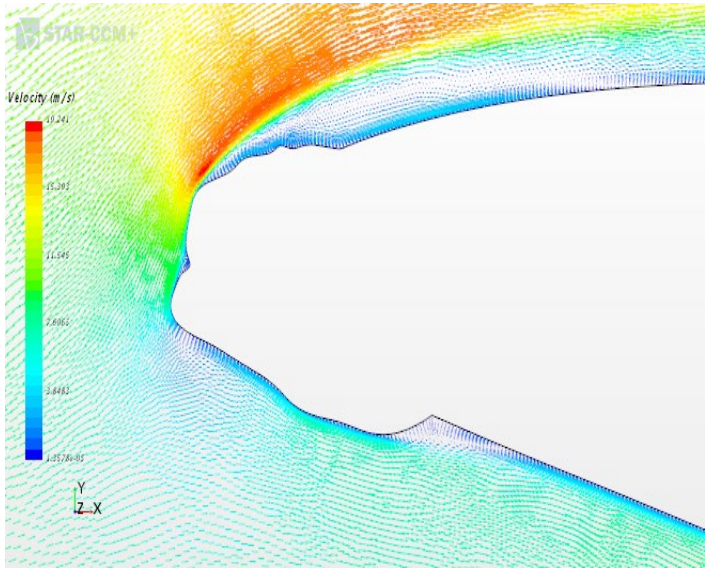
Clean



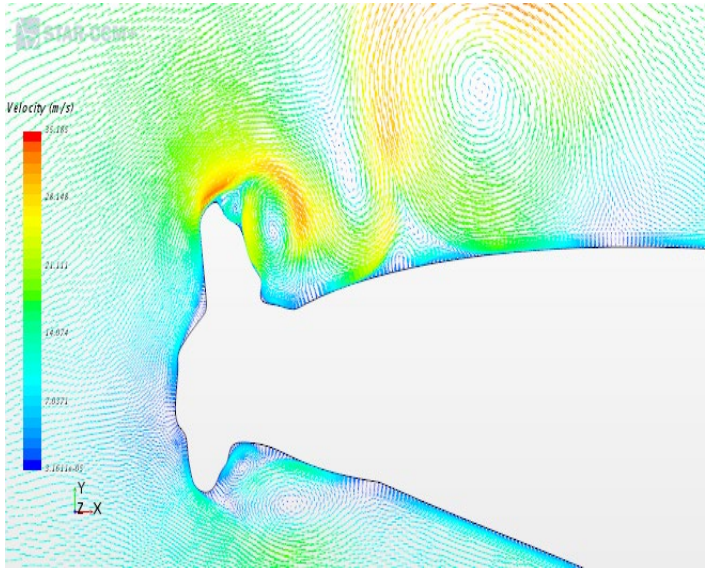
Rime



Glaze

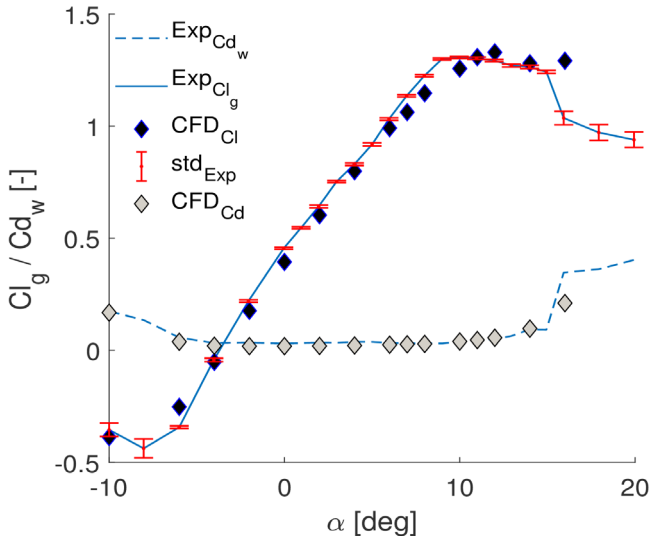


Horn

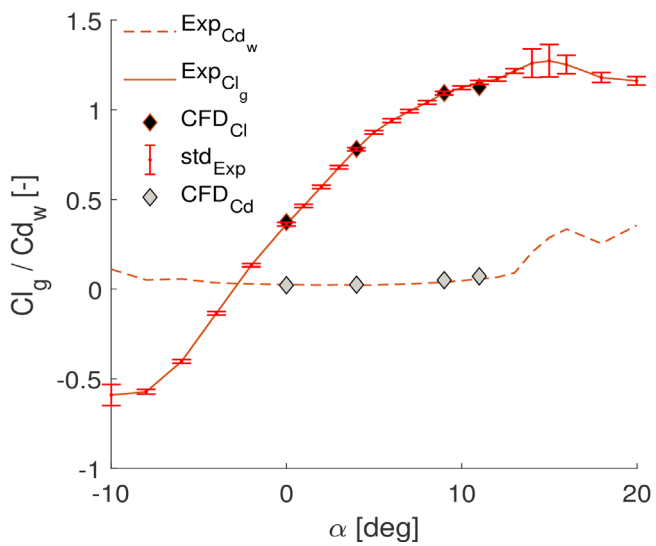


Pressure coefficients

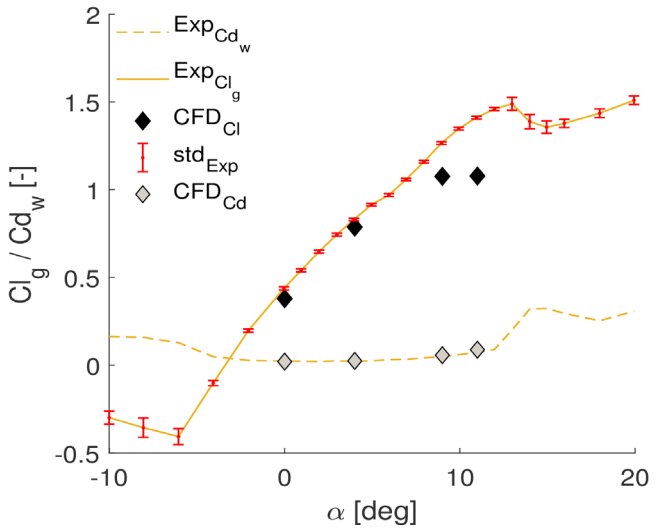
Clean



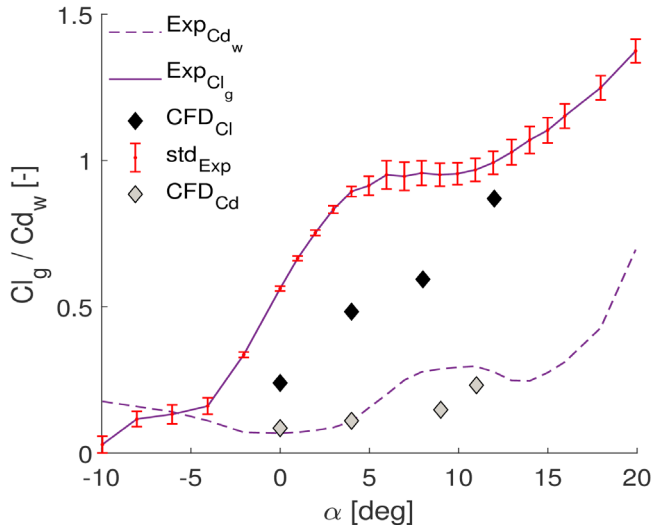
Rime



Glaze



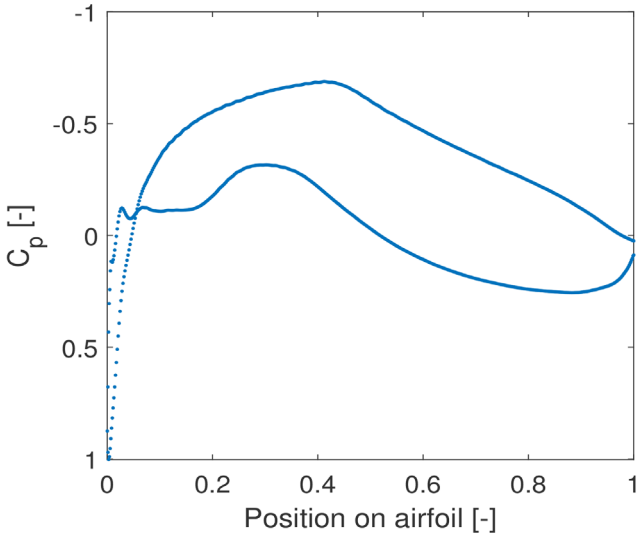
Horn



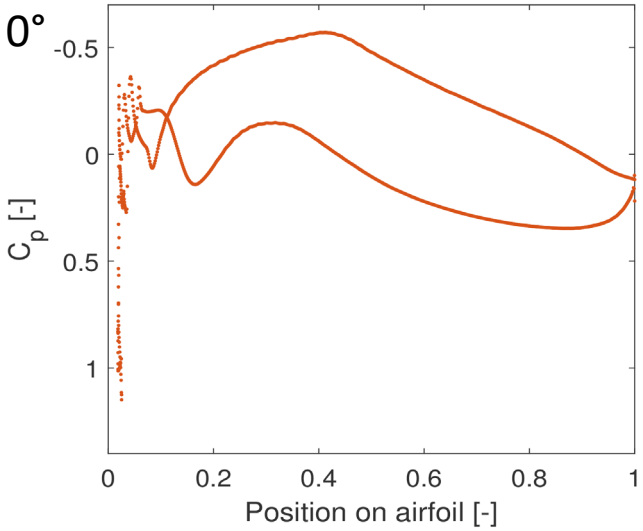
Pressure coefficients

Re=100,000 and AoA = 0°

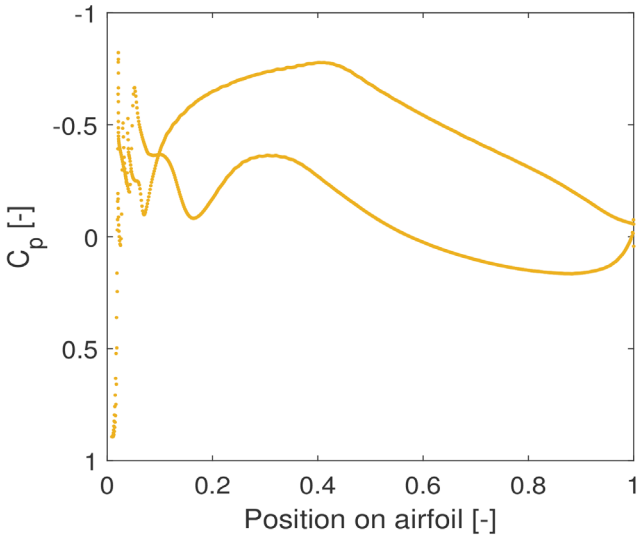
Clean



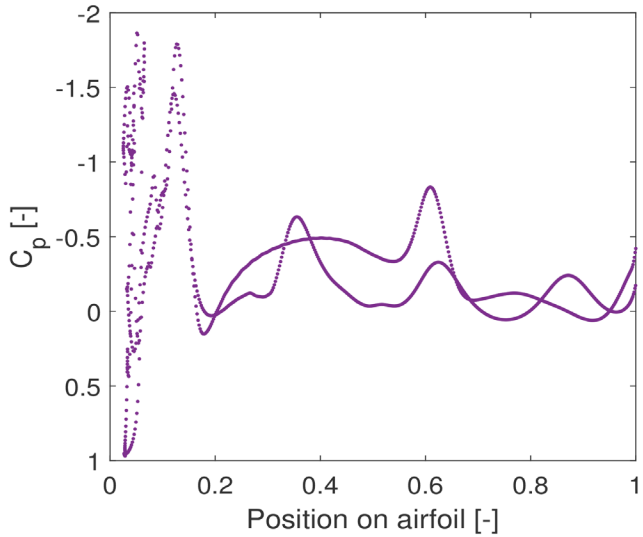
Rime



Glaze



Horn



Summary

- Modelled, 3D printed, wind tunnel tests and numerical simulations.
- Ice geometries caused decrease in lift and increase in drag
- Glaze ice caused increase in lift for lower Re
- Significant change in aerodynamics for horn ice geometry
- Time dependency for the horn ice aerodynamics

- CFD reproduced aerodynamics for clean and rime ice geometry, while glaze and horn ice under predicted.
- CFD of horn ice geometry need more attention.

In the future …

- Surface pressure measurements
- Flow visualization from experiments
- Ice accretion and benchmarking

- Surface roughness
- Numerical sensitivity analysis
- 3D CFD to capture 3D effects along the span.

DTU

Thanks for the attention. For more information, contact me at hsar@dtu.dk