Numerical simulation of ice accretion on an airfoil

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Introduction

➔ **Wind turbines in cold climate**

➔ **Ice**

- Ice throwing
- Decreased power production
- Life time
- Acoustics

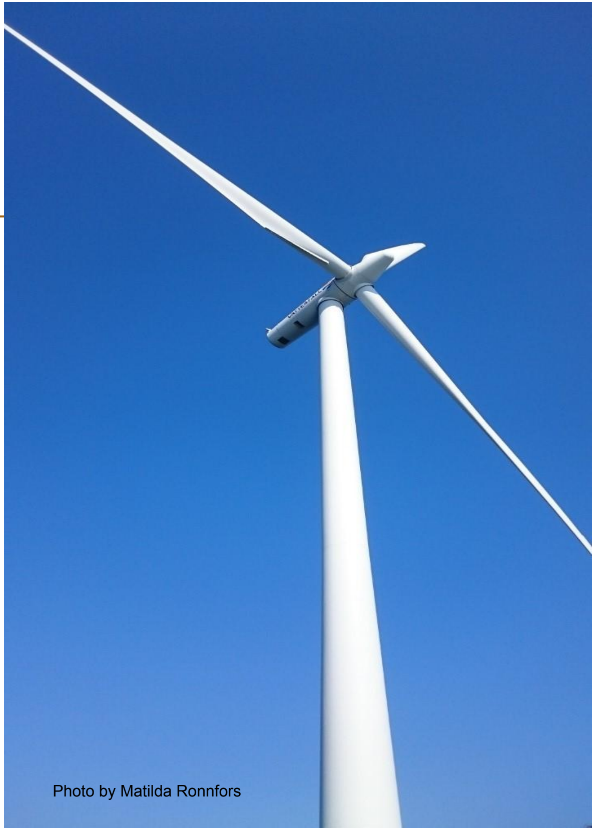
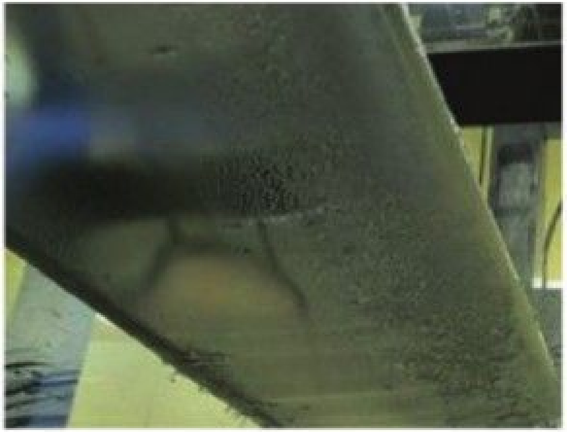


Photo by Matilda Ronnfors

Simulations of ice accretion

- ➔ **Why numerical simulations?**
  - Wind tunnels expensive
  - Predict ice accretion shape and mass
  - Easy to change separate parameters
    - Systematic studies



Clement Hochart, Guy Fortin, Jean Perron. Wind Turbine Performance under Icing Conditions, Wiley Interscience 2007

- ➔ **Impact of ice on radiated noise**
- ➔ **Can the acoustics indicate ice?**
  - **Project STEM:** Wind Turbines in Cold Climate: Fluid Mechanics, Ice Accretion and Terrain Effects

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Wind turbine blades vs. aircraft wings

- ➔ **Programs for ice accretion on aircraft wings**
  - ◆ Not optimal for wind turbines
- ➔ **Differences in**
  - ◆ Incompressible vs compressible
  - ◆ Subsonic vs supersonic
  - ◆ High AOA vs low AOA
  - ◆ Small chords vs big chords

Source: pixabay.com

- ➔ **Need better tools to predict ice on wind turbine blades**

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Methods ice accretion

- ➔ **1. In-house code**
  - LPT (Lagrangian Particle tracking)
  - LES (Large Eddy Simulation)
  - Immersed Boundary Method
    - Move surface with source terms, same mesh
- ➔ **2. OpenFoam (OpenSource, free CFD software)**
  - Makkonen (Euler-Euler approach)
  - LPT (Lagrangian Particle tracking), **FUTURE WORK**
  - LES (Large Eddy Simulation)
  - Dynamic mesh
    - Move mesh with surface

➔ Compare programs and models

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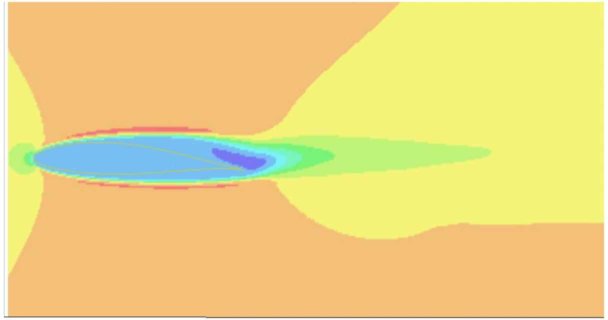
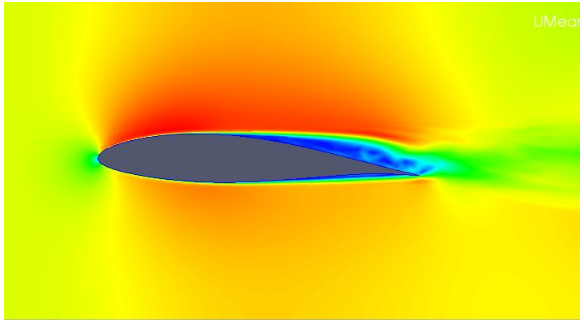
Methods ice accretion

- ➔ **Method 1 In-house code**
  - ◆ Incompressible N-S
  - ◆ LES
  - ◆ Finite differences (3:rd, 4:th)
    - Faster
  - ◆ Equidistant cartesian grid
    - No refinement around wing



- ➔ **Method 2 OpenFoam**
  - ◆ Incompressible N-S
  - ◆ LES
  - ◆ FVM (2:nd order)
    - Slower
  - ◆ Hexahedral grid
    - Refined around the wing



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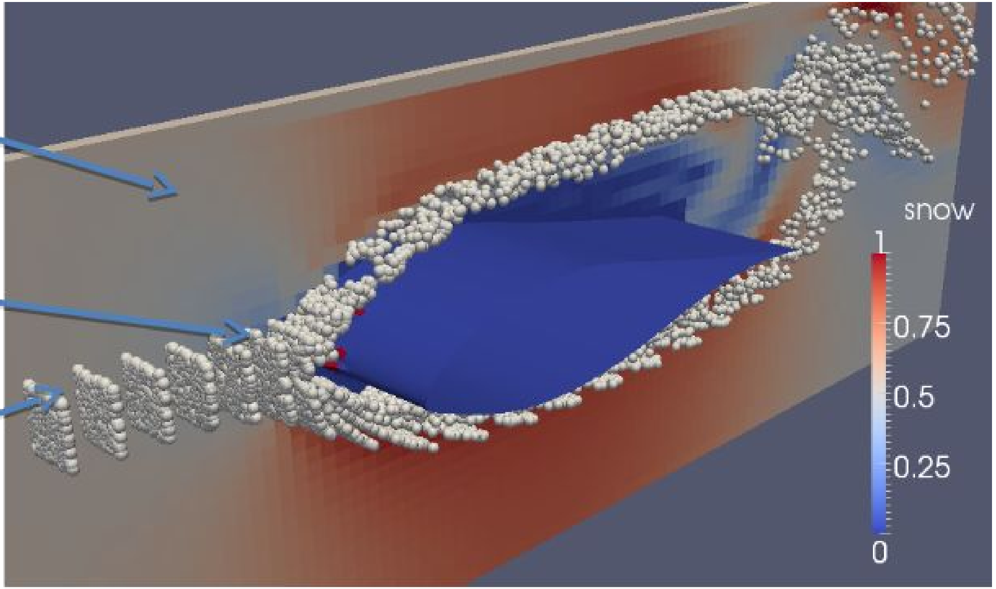
Method 1 In-house code

Flow: LES + Im.Bound.

Accretion: Impacting droplets freeze instantaneously

Droplets: LPT



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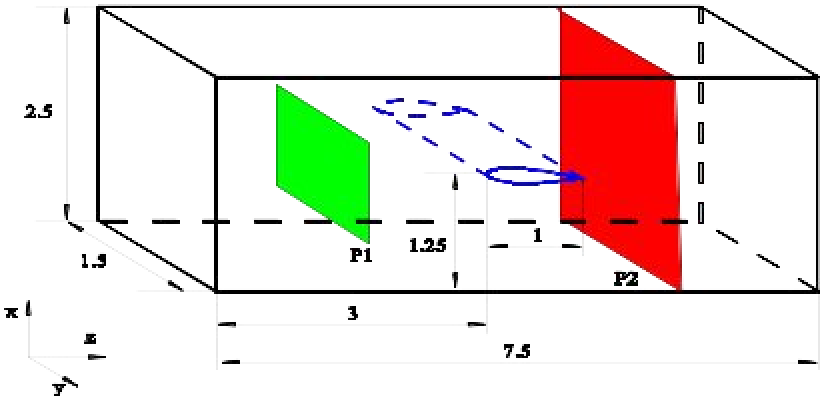
Set-up



Parameter	Value
Profile	NACA 63415
Angle of attack	3°, 9°
LWC	0.37 g/m^3
MVD	27.6 µm
V_{rel}	18.7 m/s
Re	2.49e5
Time	10.6 min
Mass of ice	24 g

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Method 2 OpenFoam

- Makkonen model
  - Euler-Euler approach
    - Looking at the flow field at fixed locations
  - Based on
    - Free stream velocity *u*,
    - Concentration of particles in the cell *φ*,
    - Area of the cell face *A*,
    - Three factors collision/sticking/accretion α_i

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \phi u A$$

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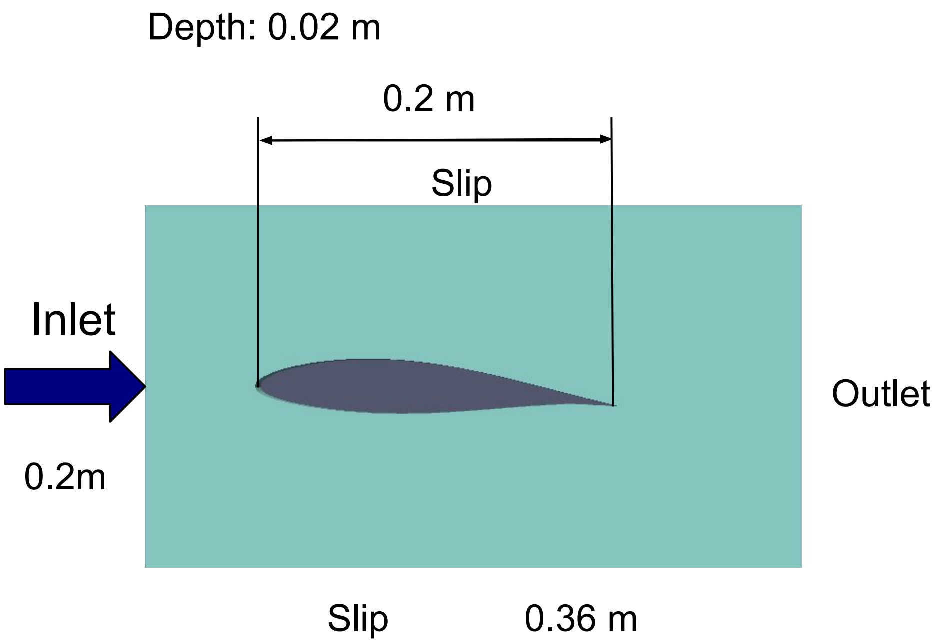
Set-up



Parameter	Value
Profile	NACA 63415
Angle of attack	3°
LWC	0.37 g/m^3
MVD	27.6 µm
V_{rel}	18.7 m/s
Re	2.49e5
Time	10.6 min
Mass of ice	24 g

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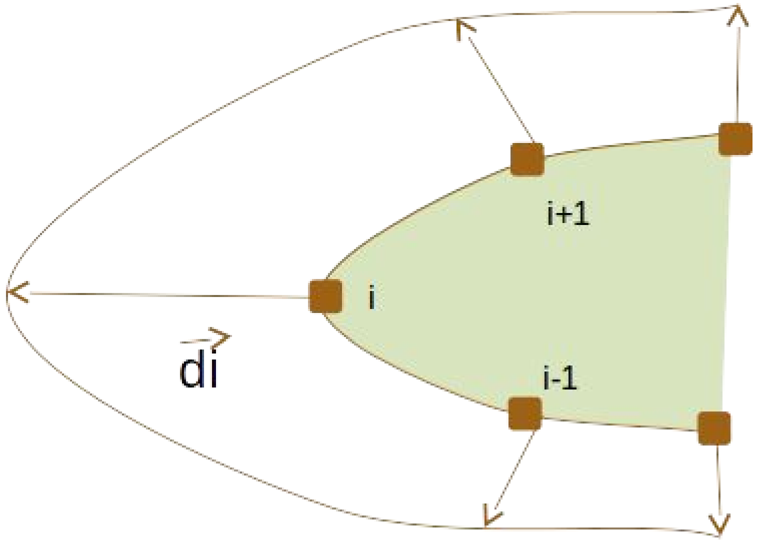
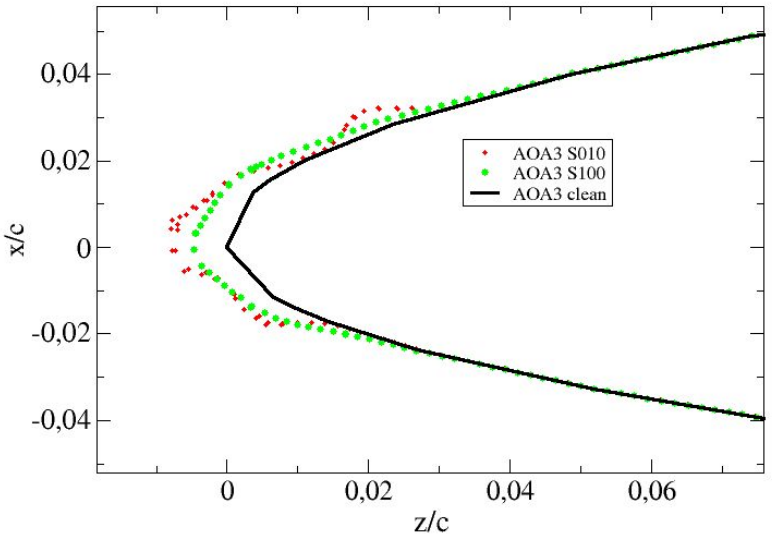
Change the surface shape

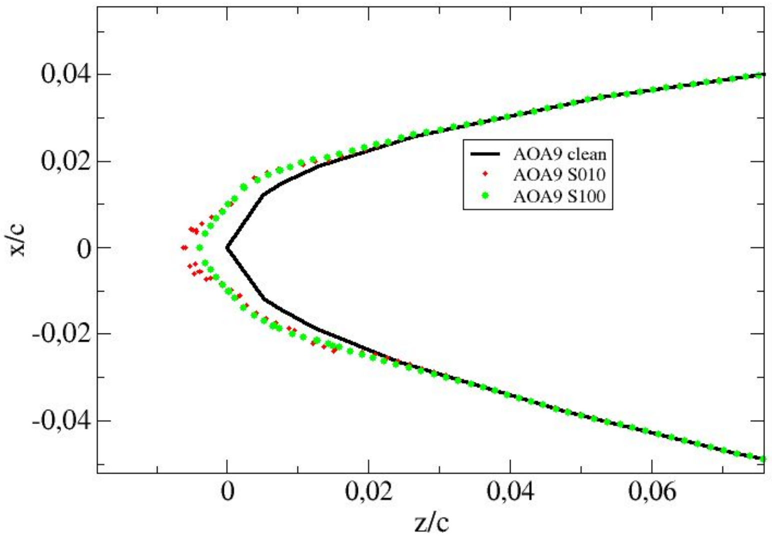


$\vec{Di} \approx V_{ice\_i} / A_{dualcell}$

- ➔ Every n:th time step
  - ◆ Can be extrapolated in time: $V_{ice} = V_{ice}$ * time
  - ◆ Trapped air can be accounted for

Results Method 1, ice shapes





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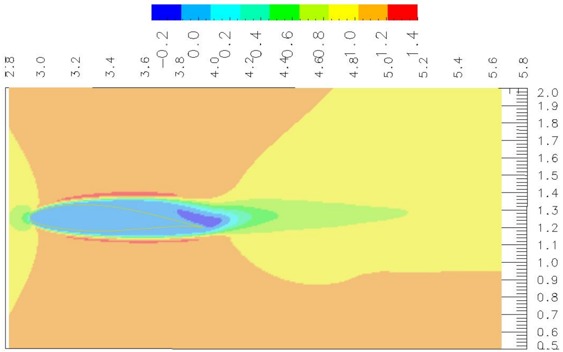
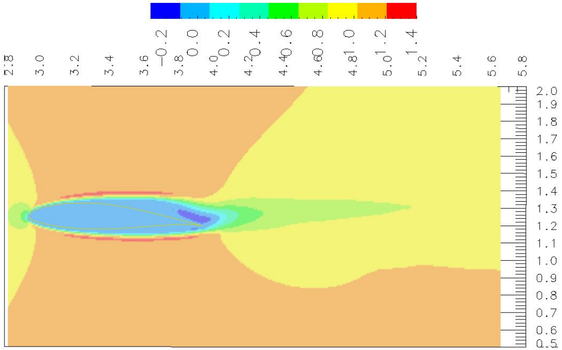
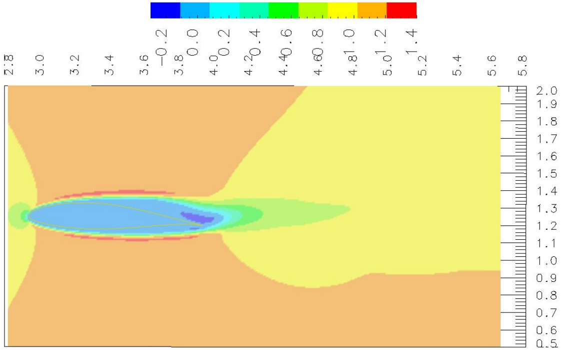
Results Method 1, Average Velocity, 3°



Clean airfoil



Rough ice



Smooth ice

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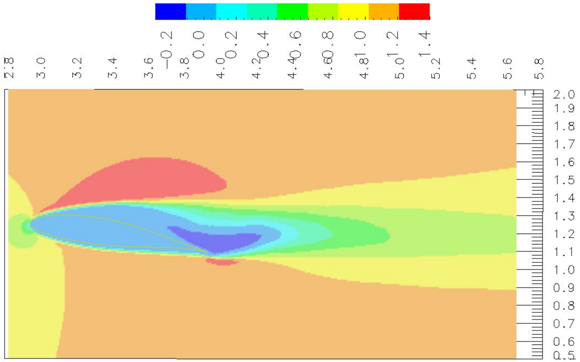
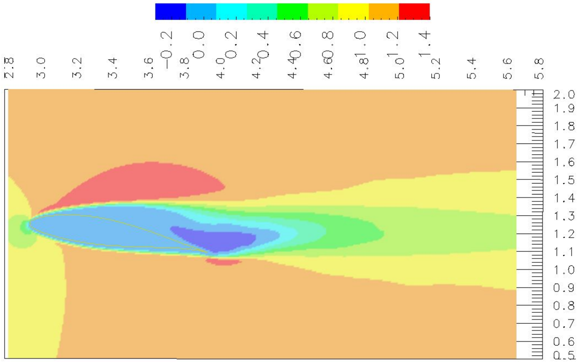
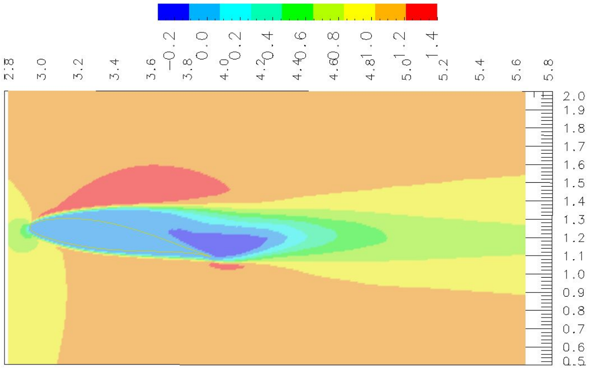
Results Method 1, Average velocity, 9°



Clean airfoil



Rough ice



Smooth ice

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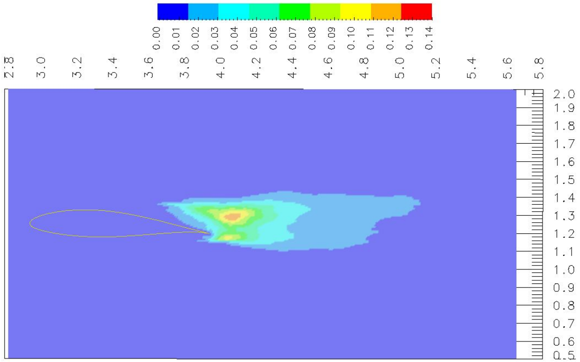
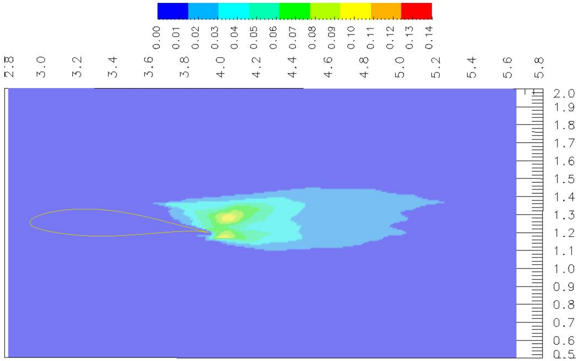
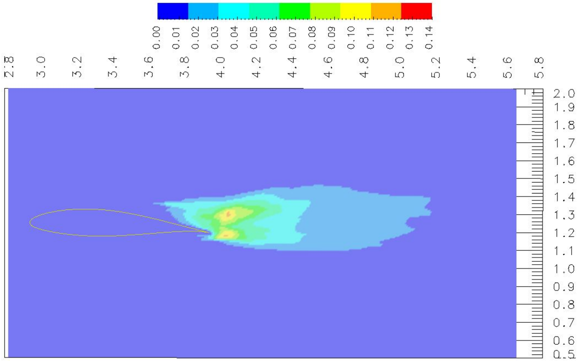
Results Method 1, Velocity fluctuations, 3°



Clean airfoil



Rough ice



Smooth ice

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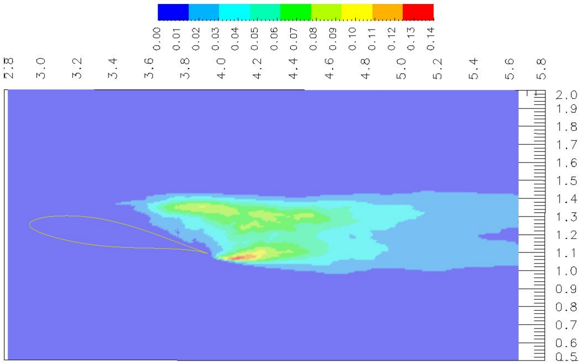
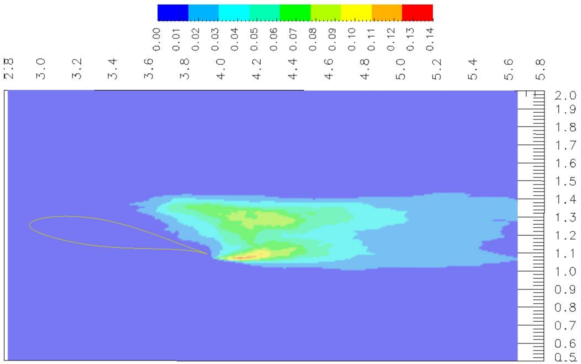
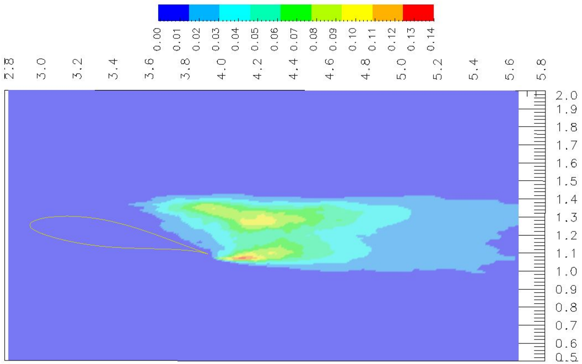
Results Method 1, Velocity fluctuations, 9°



Clean airfoil



Rough ice



Smooth ice

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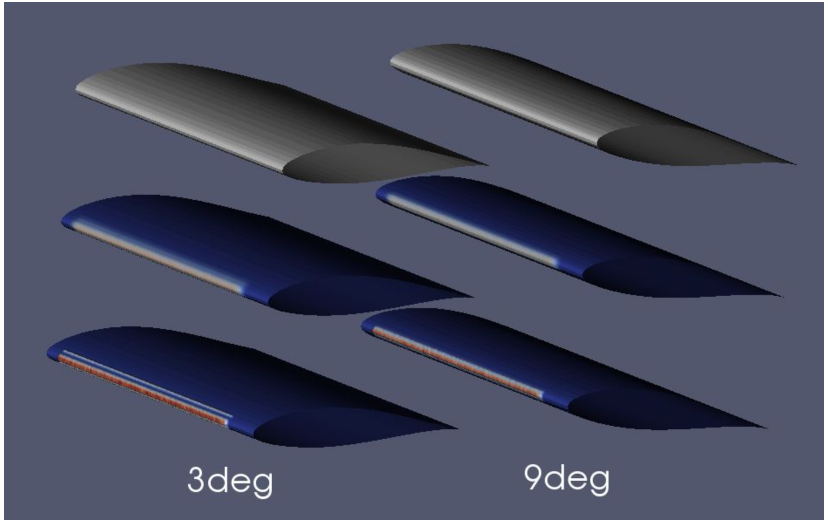
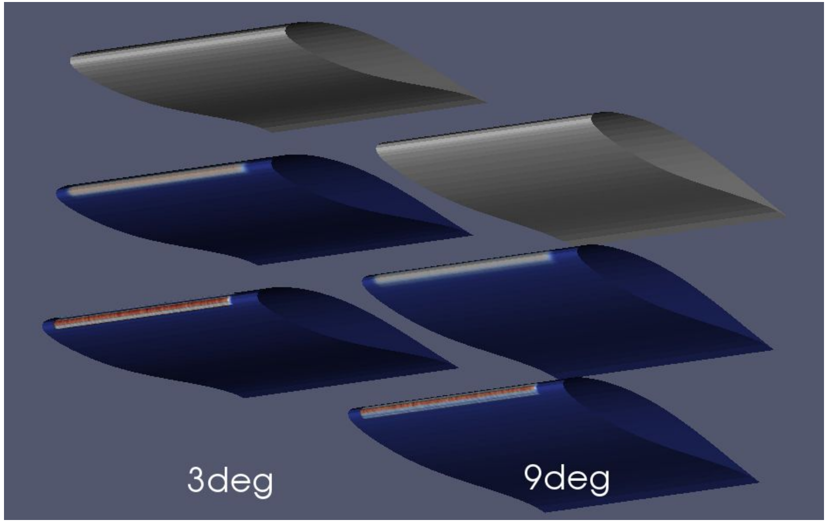
Results Method 1, Icing on airfoil





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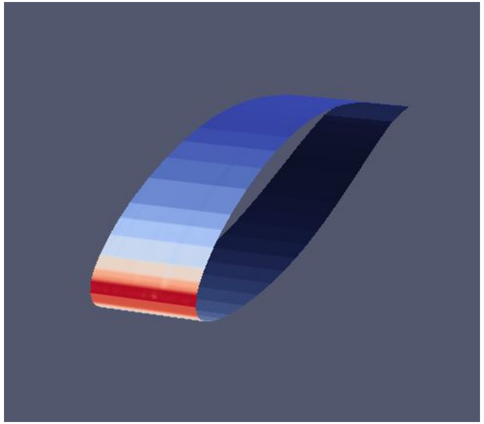
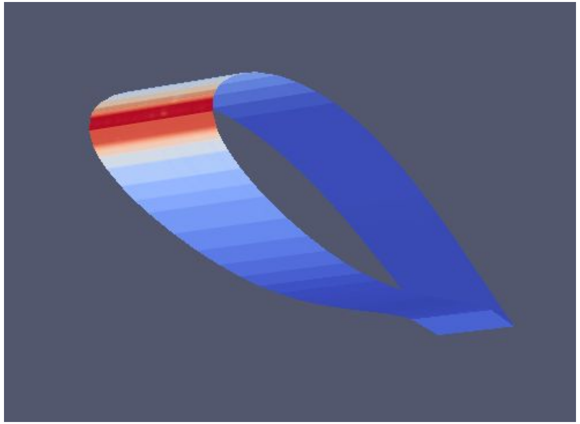
Results Method 2, Icing on airfoil





➔ Ice mass after 10.6 min
- Experiments (Hochart et al) 24 g
- Simulation 64 g
  - α=0.375

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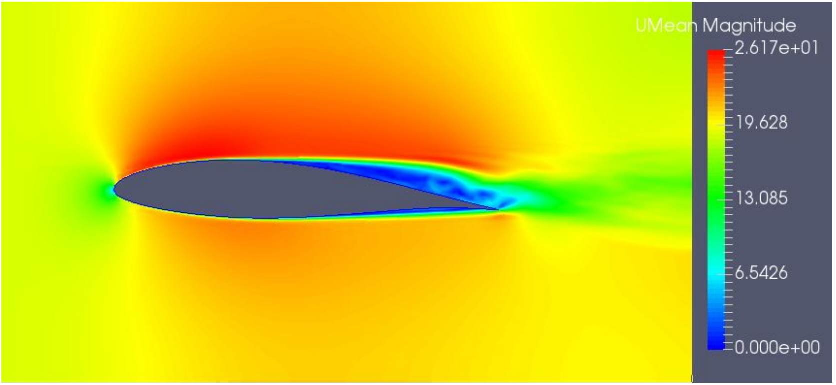
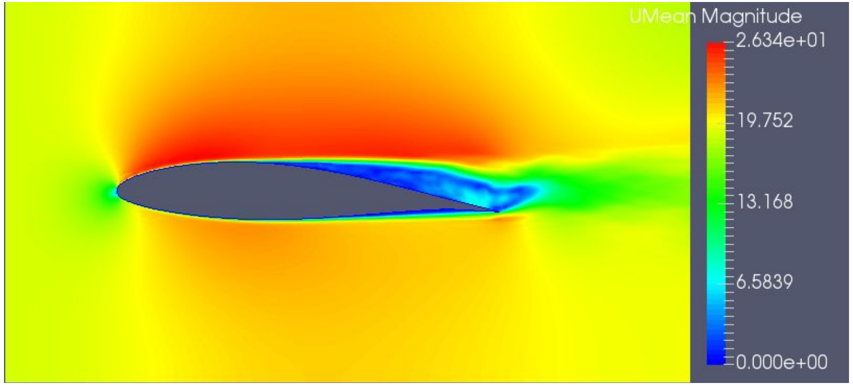
Results Method 2, Average velocity



Clean profile



Iced profile

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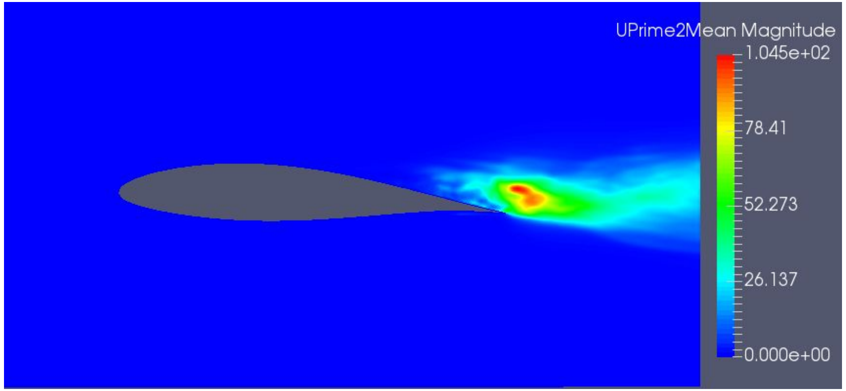
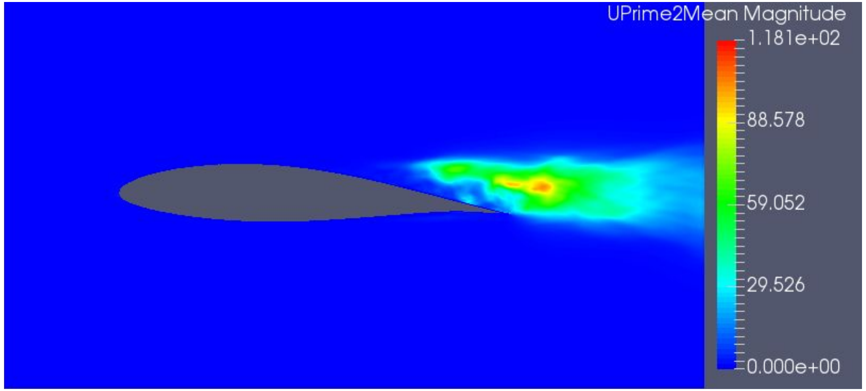
Results Method 2, Velocity fluctuations



Clean profile



Iced profile

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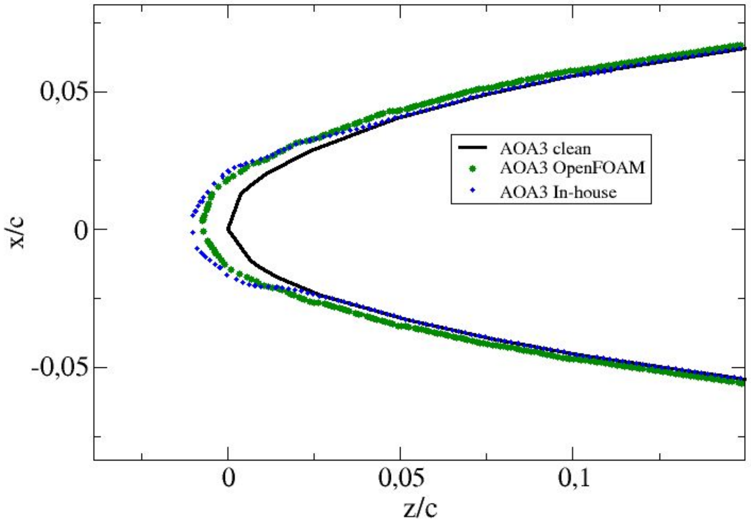
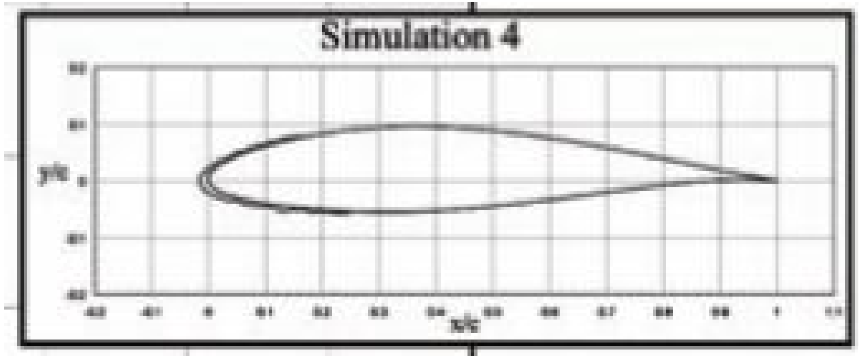
Comparing ice shapes, 3°, method 1 and 2





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Conclusions and Future Work

- **Conclusions:**
  - Method 1 and 2 are similar in terms of ice shape
  - The shape of the accreted ice in method 2 match better with the experiments

- **Future Work**
  - Run LPT in OpenFoam
  - How does the ice affects the acoustics?

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Acknowledgements

- ➔ Financing: STEM, Wind Turbines in Cold Climate: Fluid Mechanics, Ice Accretion and Terrain Effects
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Energimyndigheten

Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

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