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Development of numerical models for ice accretion predictions

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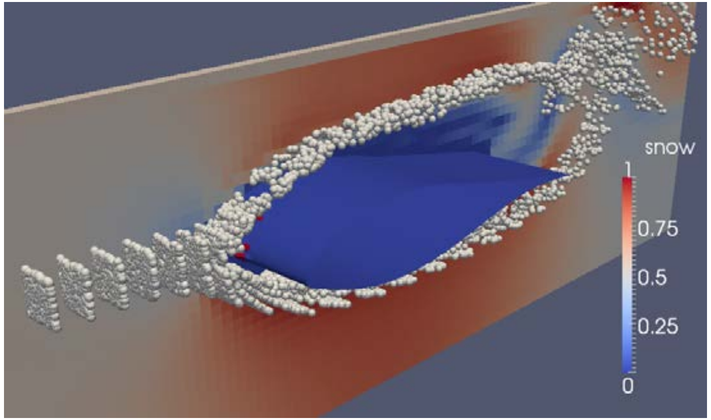
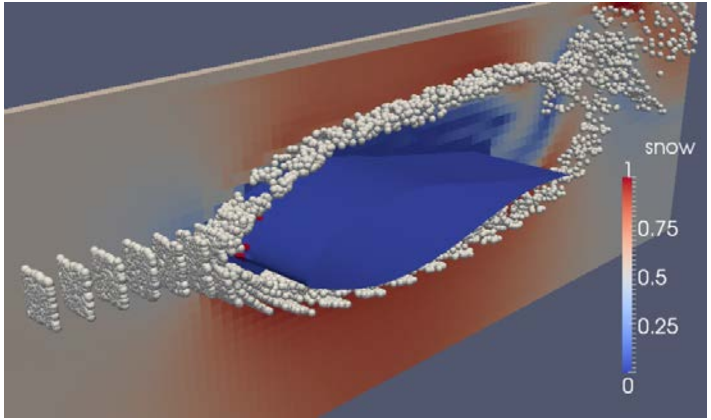
Goals



- Develop tool to model simultaneously flow and ice accretion
  - Efficient (relative)
  - Flexible
    - Avoid/fewer model coefficients
    - Complex/moving geometries
  - Combine with other modules
    - Performance
    - Noise

Outline



- Ice accretion simulations
  - Rime ice
  - Glaze ice
- Full turbine simulations
  - From 2D to 3D
  - Turbine acoustics

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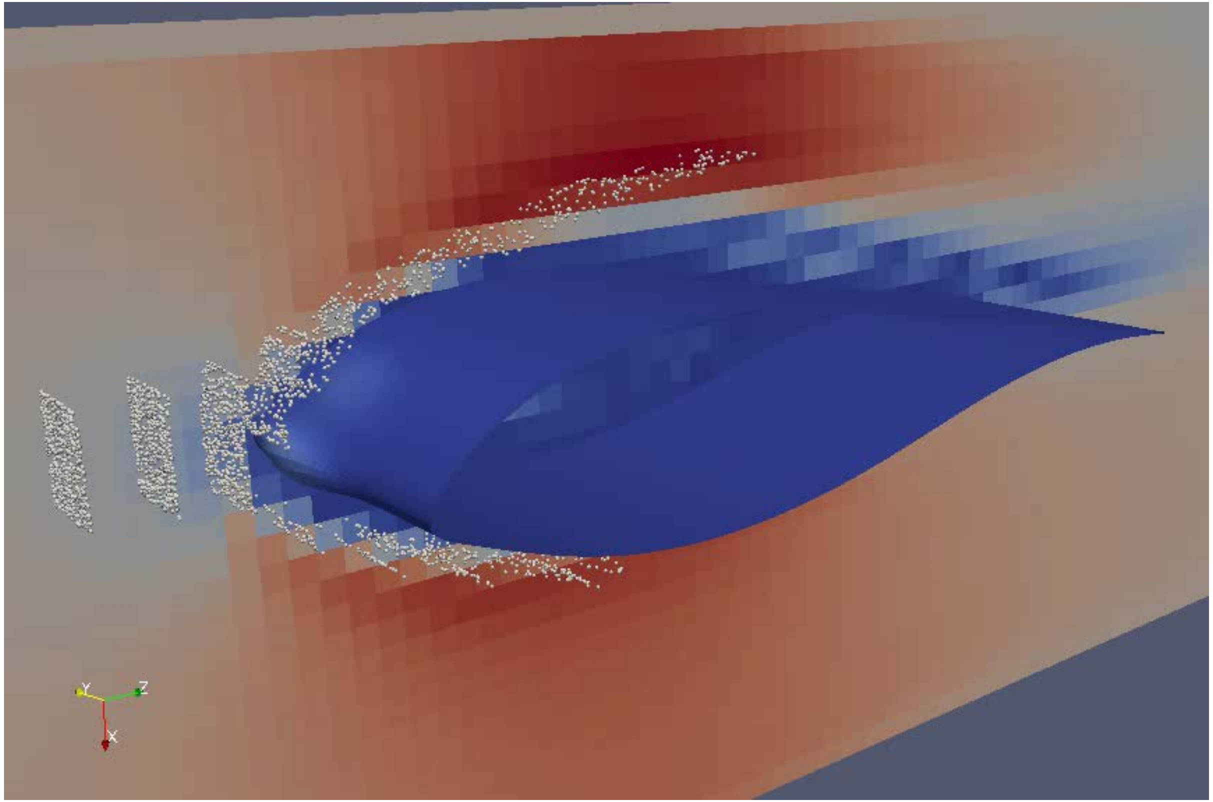
Method

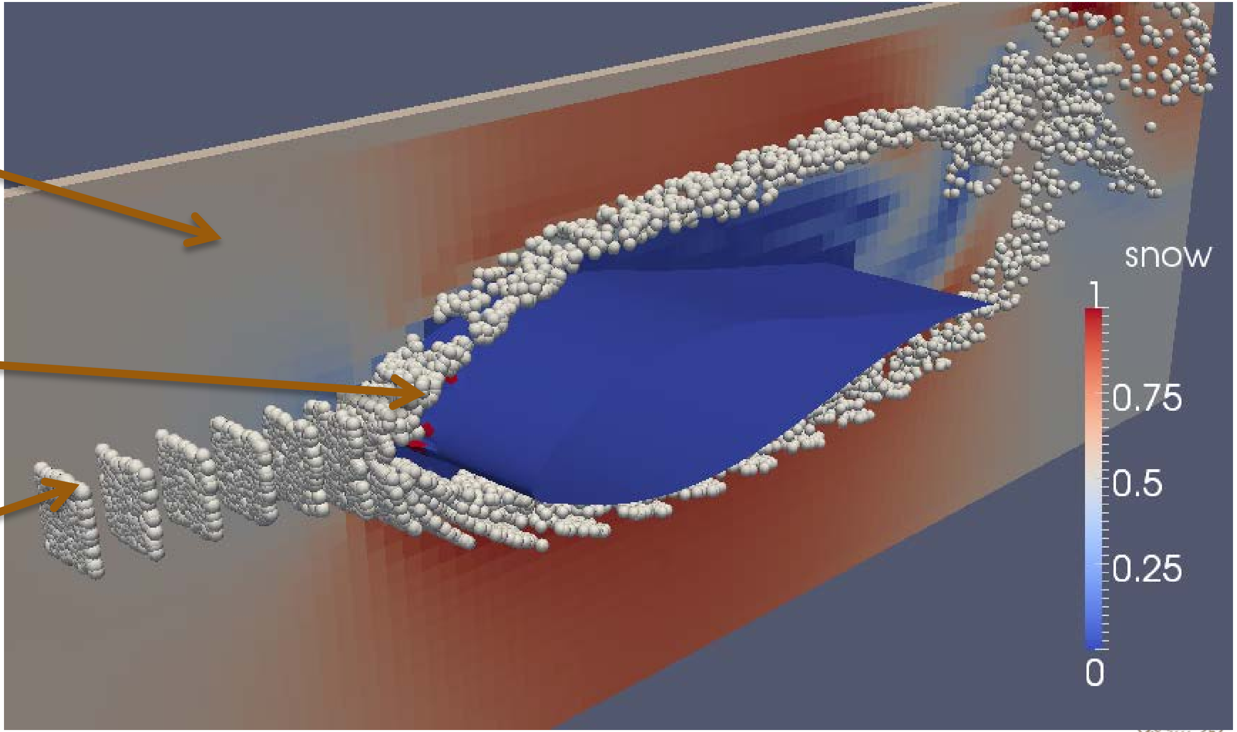


Method

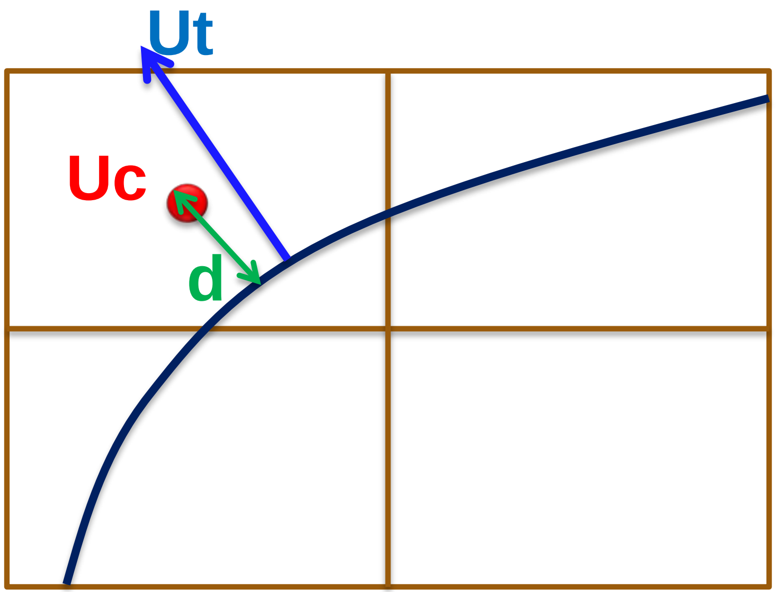
Flow: LES + Im.Bound.

Accretion: Impacting droplets freeze instantaneously

Droplets: LPT

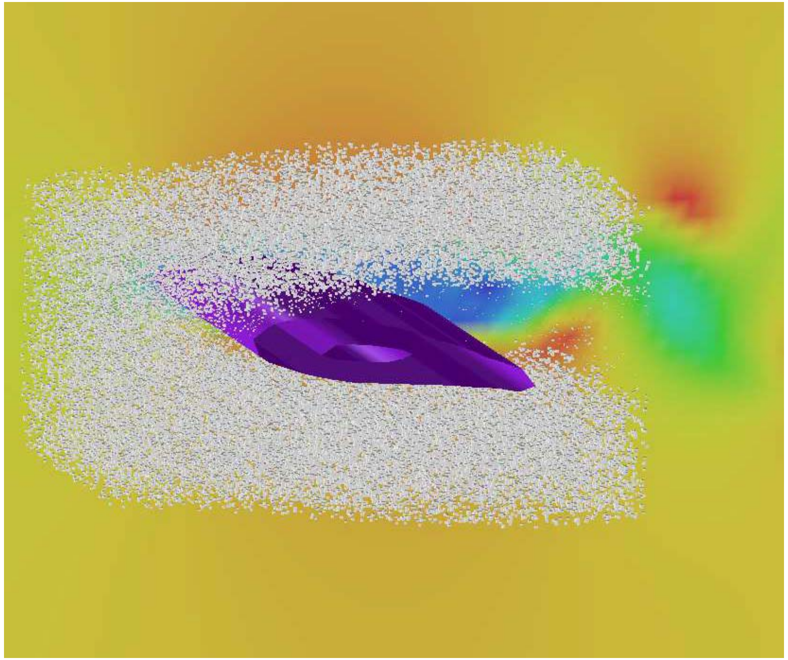


Flow



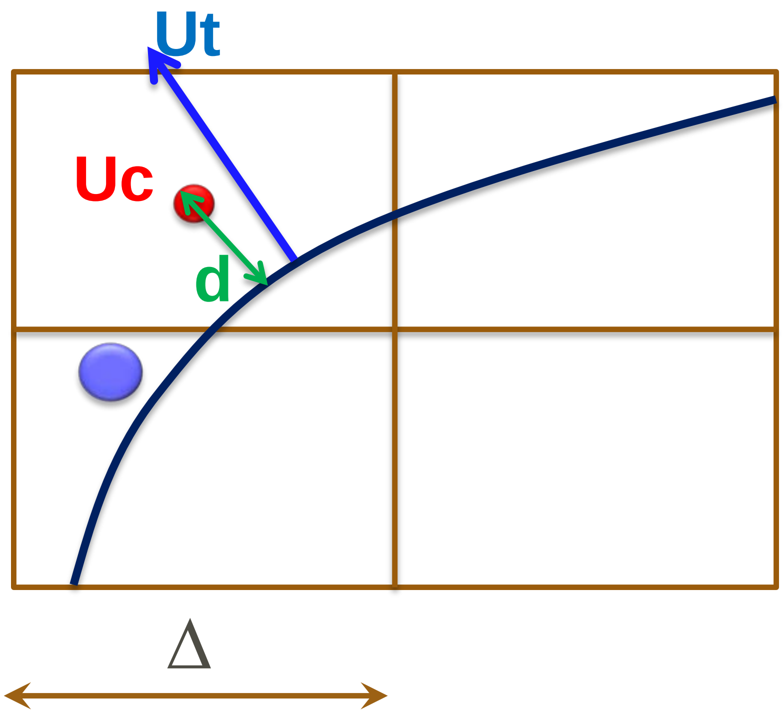
- Incompressible Navier Stokes
- Finite Differences (3rd, 4th)
- LES (implicit)
- Equidistant Cartesian grid
- Immersed Boundary

Droplet transport



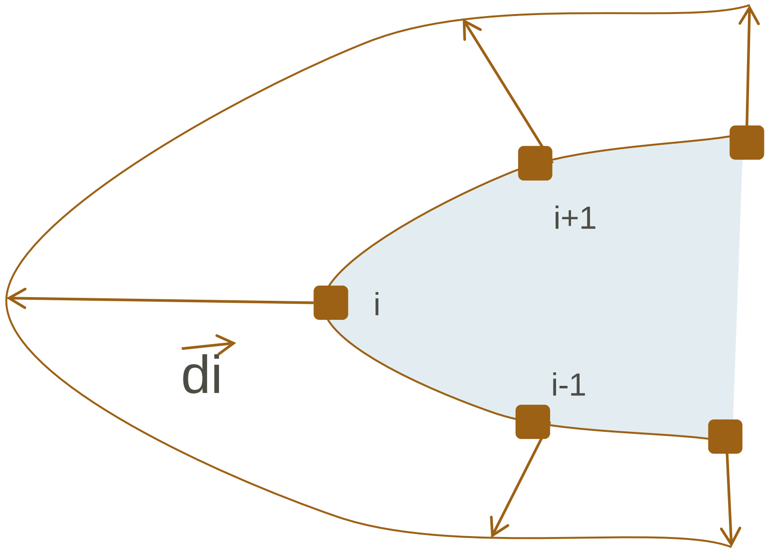
- Lagrangian Particle Tracking
- Typically low LWC
  - Only drag force
  - No collision
  - No break-up
- Release: rectangular area, random distribution
- Removal: accretion or max streamwise position
- Impact parameters logged

Ice Accretion



- All droplets impacting on the surface freeze instantaneously
  - Rime-ice conditions
  - For other conditions heat transfer must be included
- Distance from distance function used for IBM
  - Efficient but slightly lower accuracy
- Critical distance
  - $d_{cr}=f\Delta$

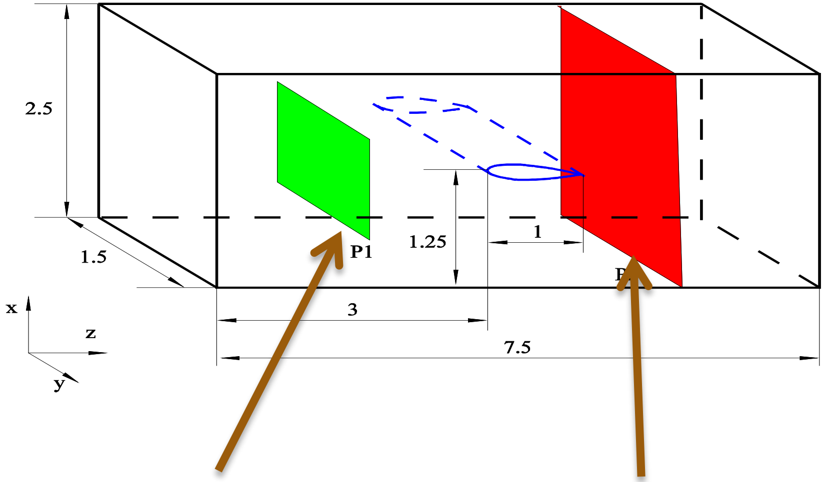
Changing the surface shape



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

- CFD: N,x,y,z,d,m
- every Nth timestep
  - Can be extrapolated in time: $V_{ice}=V_{ice}*C_{time}$
  - Trapped air can be accounted for here
- Filtering
- Iterative algorithm
  - Towards outer normal
  - Assure added V_{ice}
  - Only a few iterations needed

Case set-up



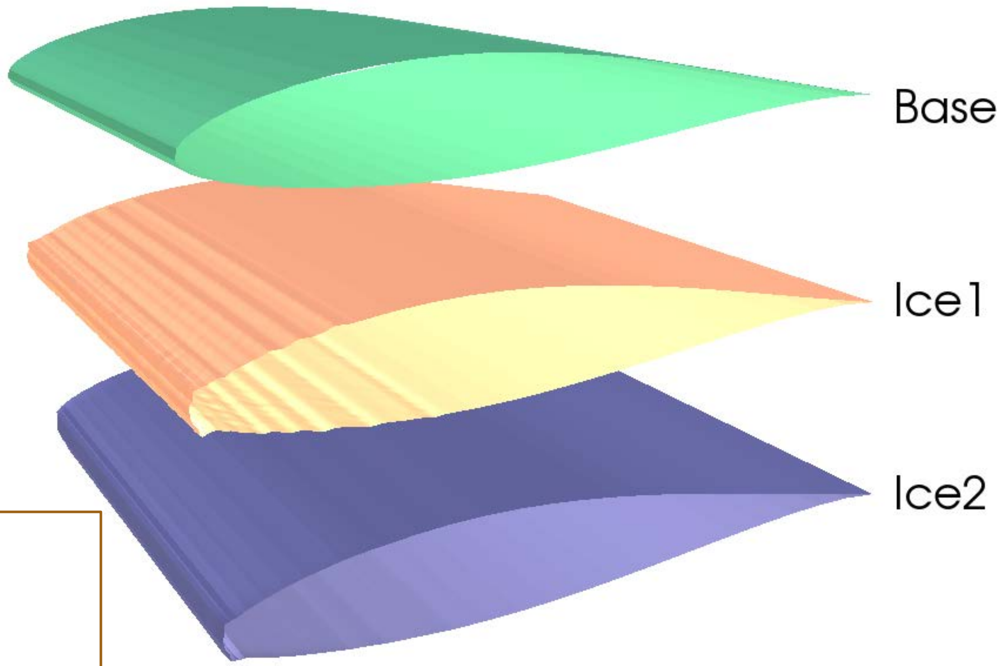
Droplets released here

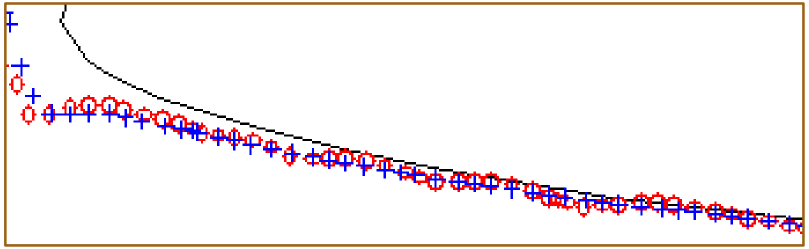
Droplets removed here

- 'In-fog icing event 2' [Hochart2008]

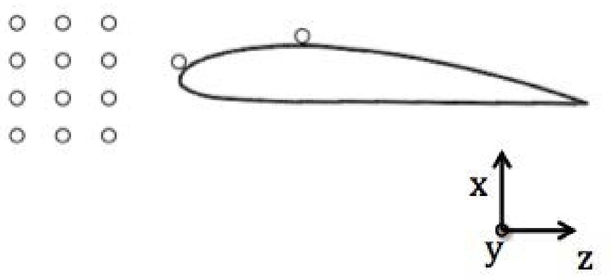
Parameter	Value
Profile	NACA 63415
Angle of attack	3°
LWC	0.37g/m^3
MVD	27.6 μm
Vrel	18.7 m/s
Re	2.49e5
Time	10.6 min
Mass of accreted ice	24±1.75 g

Rime ice distribution



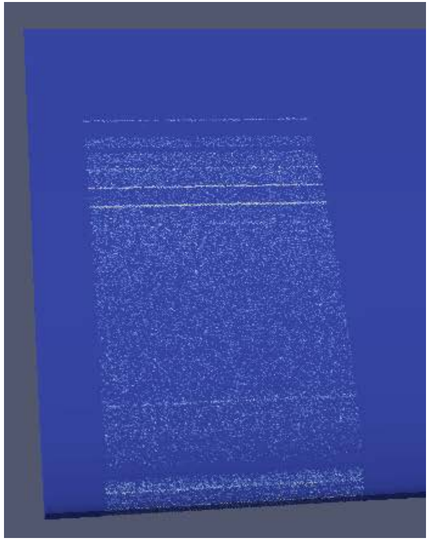


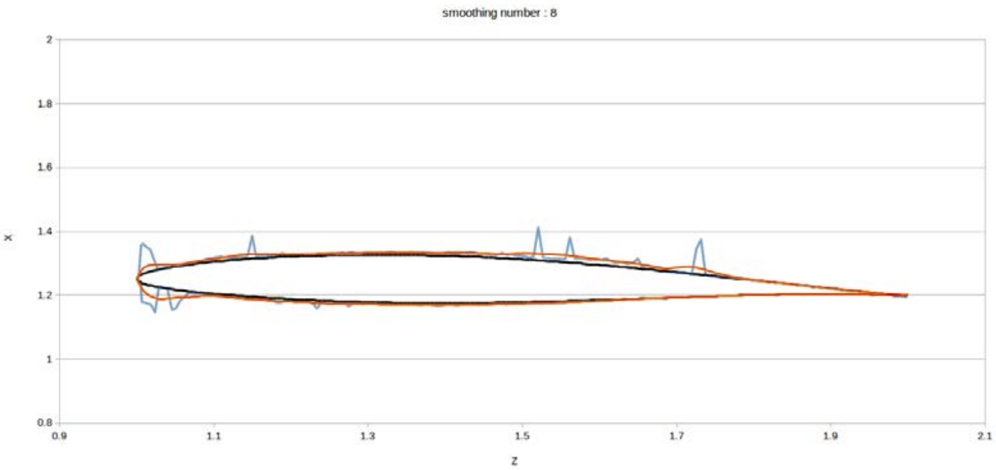
Modeling glaze ice



- Idea
  - Do NOT freeze instantaneously
  - Estimate time needed to freeze based on a simplified model of a spherical droplet

Glaze ice results





- Qualitatively reasonable
- Smoothing needed
- More advanced models needed
  - Heat transfer
  - Fluid film

Simulation of an iced turbine

- Experiments and computations often focusing on 2D airfoils
- Full 3D computations/measurements often complicated/expensive
- Need to have data along a full blade but only a few radial positions available

Simulation of an iced turbine

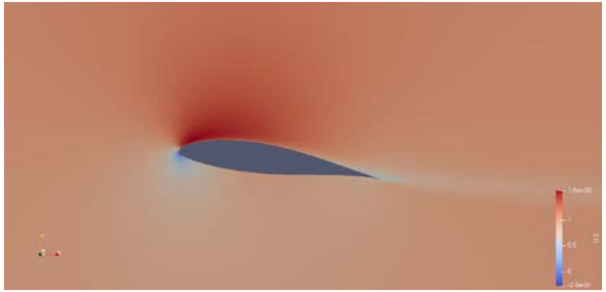
Strategy

- Iced profiles at a few radial positions
- Create CD and CL data for profiles
- Extrapolate data to full blade
- Use this in actuator line model
- Simulate turbine using LES and extract acoustic sources
- Use therse sources in an acoustic solver

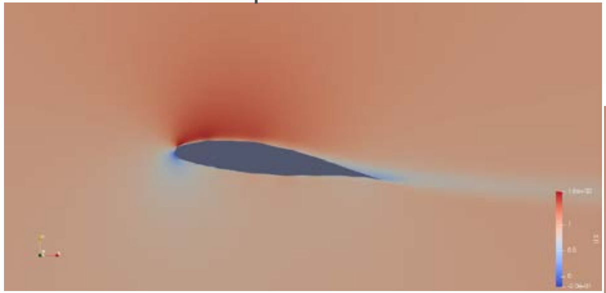
Iced profiles

2D RANS simulations based on the shapes from Hochart et al (2008). AOA=8 degrees

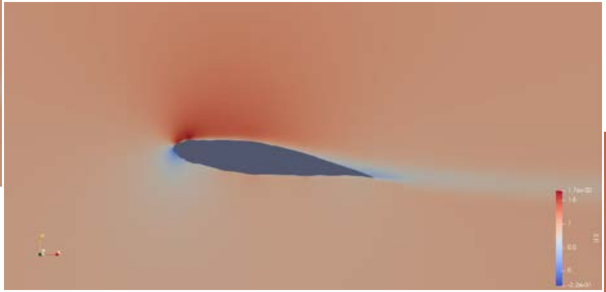
Clean NACA 63415



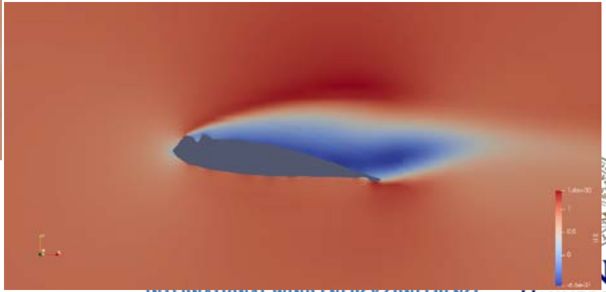
Ice shape 1



Ice shape 2

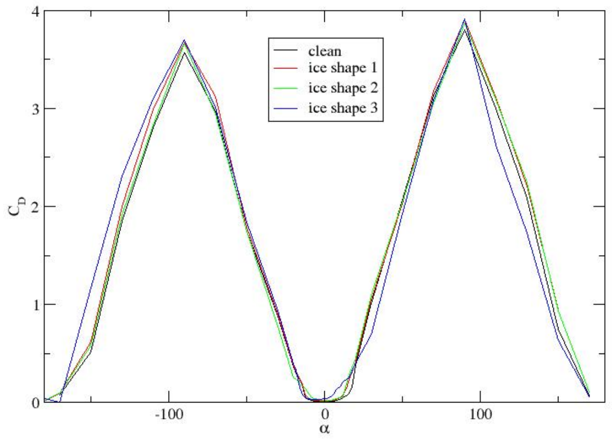


Ice shape 3

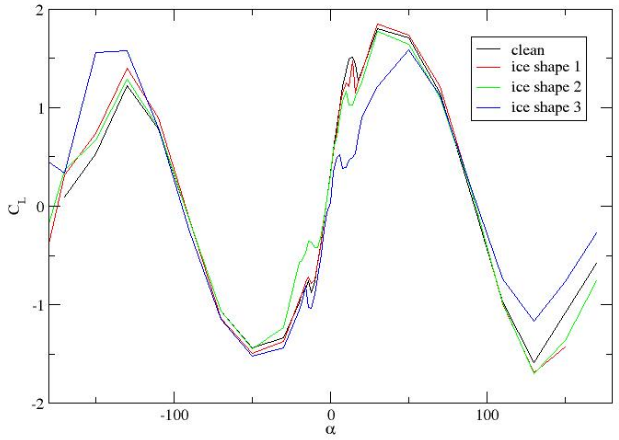


Lift and drag data

Drag



Lift



2D -> 3D Method

- Input
  - Profile
    - Clean
    - With Ice
  - Cd, Cl
  - Rmin,max
  - Omega
  - Twist a.

  @random AoA,r

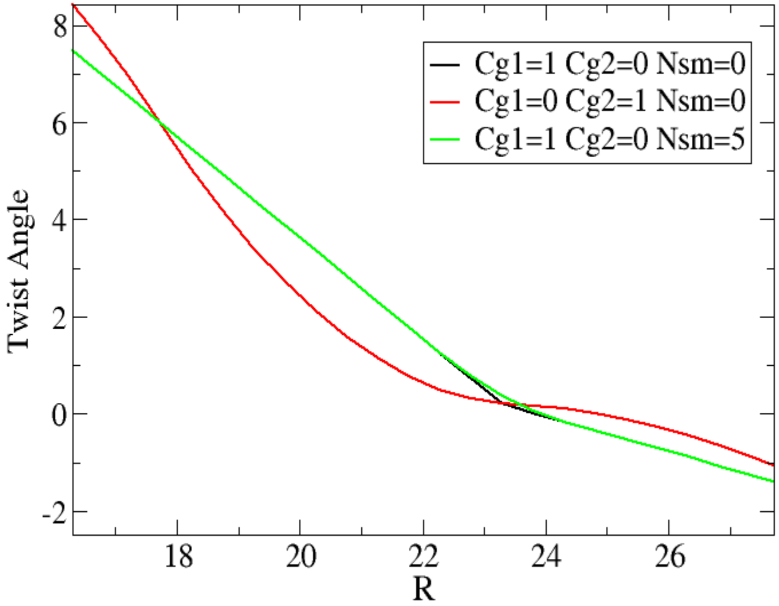
Poisson solver

- Output
  - 3D blade
    - Clean
    - With Ice
- For all AoA,r
  - Cd, Cl
  - Twist a.
- Estimate of m_ice

Difference between clean and accreted profile

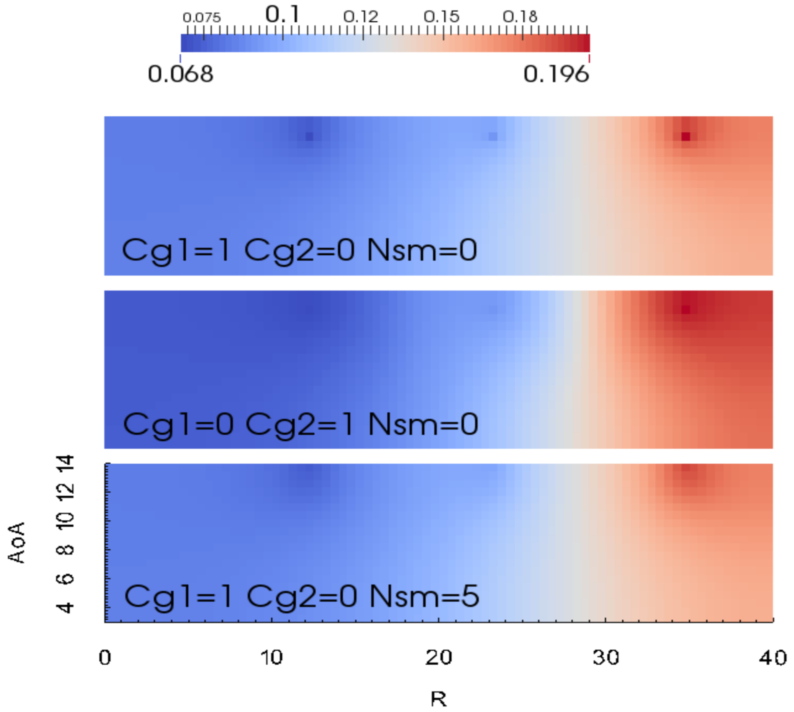
2D->3D Results

Twist angle extrapolated along the radius with three different settings



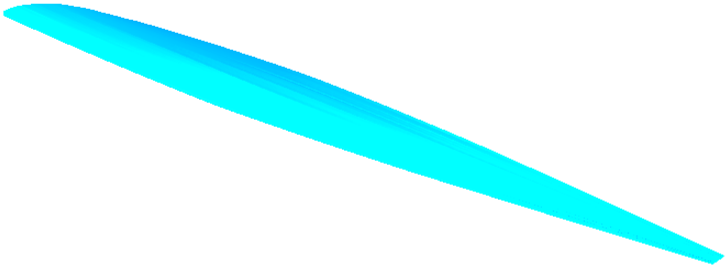
2D->3D Results

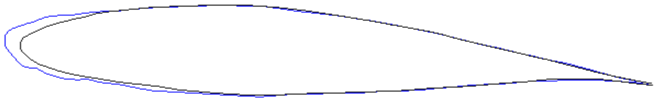
Drag coefficient for different R and AoA extrapolated with three different settings



2D->3D Results

Reconstructed rotor blade and cross section at half the rotor radius (black clean, blue with ice)





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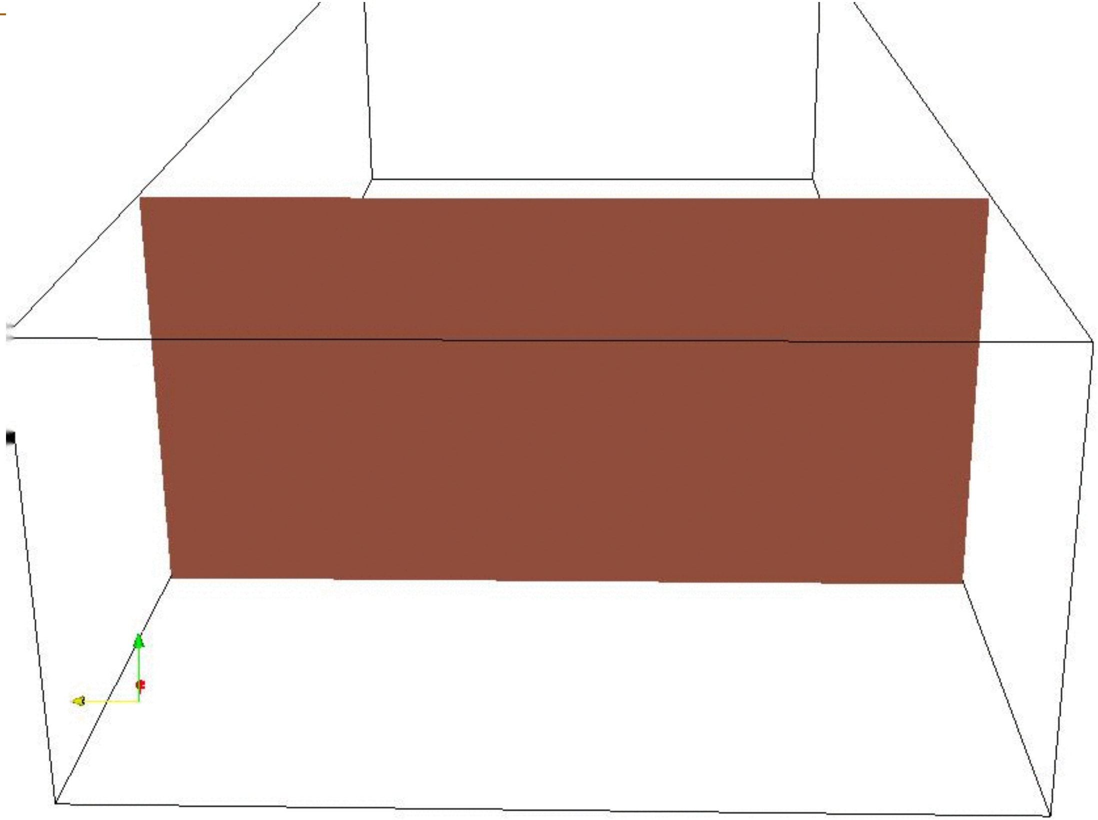
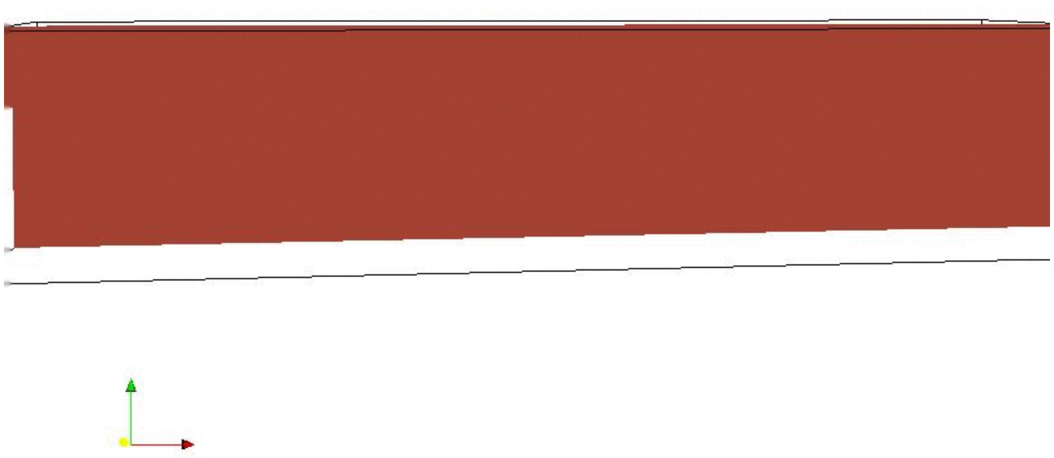
Pressure fluctuations, clean turbine



Pressure fluctuations, clean turbine



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Next step

- Run with iced blades
- Alter terrain properties for sound propagation studies
- Include acoustic sources from blade turbulence
- Multiple turbines

Acknowledgements

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- Computing resources: SNIC/Lunarc (Lund Univ.)

Thank you!