A CFD benchmark: ice accretion on a wind turbine blade

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Kjeller Vindteknikk

Owned by: Norconsult

- High expertise within meteorology, measurements and wind energy
- Established 1998
- 32 employees
- Turnover 2018: ~6.5 M EUR
- Offices: Lillestrøm, Stockholm, Espoo
- Main markets: Norway, Sweden and Finland

Wind energy

Power lines

Bridges

Motivation

- Historically our ice calculations have been based on the standard cylinder
- As a part of the research project IceLoss 2.0 (funded by the Swedish Energy Agency), a blade cylinder model has been developed. This model is for example taking relative air velocity and the icing conditions over the rotor swept area into account, which is not considered for the standard cylinder.
- To assure that our blade cylinder model are able to properly describe ice accretion, a CFD benchmark study has been defined (as part of the IceLoss 2.0 project)
- Describing the right amount of ice is important for the calculation of production losses due to icing but also for correct ice throw risk assessments.

The Makkonen standard cylinder model

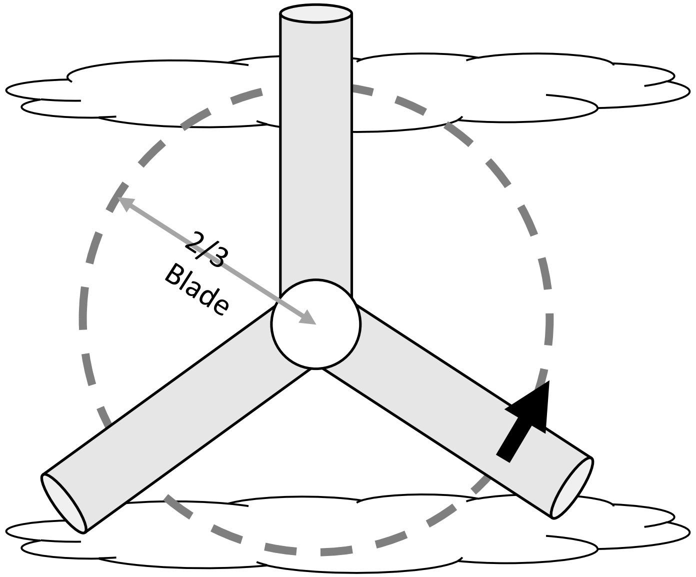
- Originally developed for describing ice accretion on power lines

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \alpha_1\alpha_2\alpha_3 w \boldsymbol{v} A$$

Standard Cylinder	Turbine blade
• Stationary, but rotation along its own axis	• Sweeping through air with varying RPM
• Experiencing real wind	• Experiencing relative air flow due to blade rotation, up to ~70-80 m/s
• Meteorology in one height	• Meteorology in several heights covering the sweep area
• Ice is assumed to be built up evenly	• Ice is built up on the leading edge of the airfoil

KVT Blade Cylinder Model (IceLoss 2.0)

- Based on the paper by Davis (2013) and their iceBlade methodology
- Ice accretion calculated at 2/3 of blade length:
  - Relative air velocity based on wind and RPM
  - Liquid Water Content
  - Temperature
  - Representative diameter
  - Meteorology from different heights
- Growth, sublimation, shedding and melting
- Langmuir-D droplet distribution

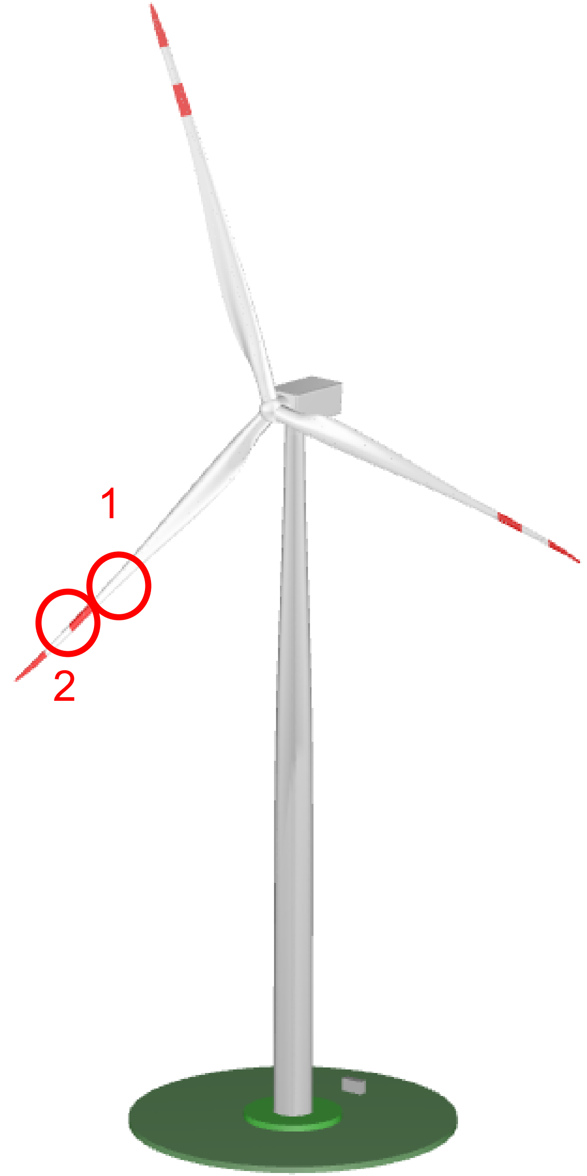


The turbine

- 3.4 MW onshore research turbine (IEA Task 37)
- 130 m rotor diameter, 65 m blade length
- Studied positions:
  - Section 1: 67 % blade length

    Airfoil: DU91-W2-250
  - Section 2: 85 % blade length

    Airfoil: DU08-W-210



CFD Study

- Ice accretion on a turbine blade
  - Different meteorology:

    Typical, Moderate, Extreme
  - Different blade sections:

    67 % and 85 % blade length
  - Different CFD models:

    Collaboration with NTNU, LTH, UiT

NTNU

LUND UNIVERSITY

Table 1. Meteorological cases

	Liquid Water Content (gm^{-3})	Median Volume Diameter (µm)	Temperature (°C)	Wind speed (ms^{-1})
Case Typical	0.25	15	-5	7
Case Moderate	0.50	15	-5	7
Case Extreme	0.50	15	-5	10

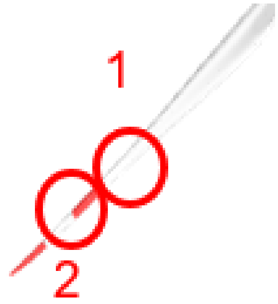
Table 3. Air flow over sections for different cases

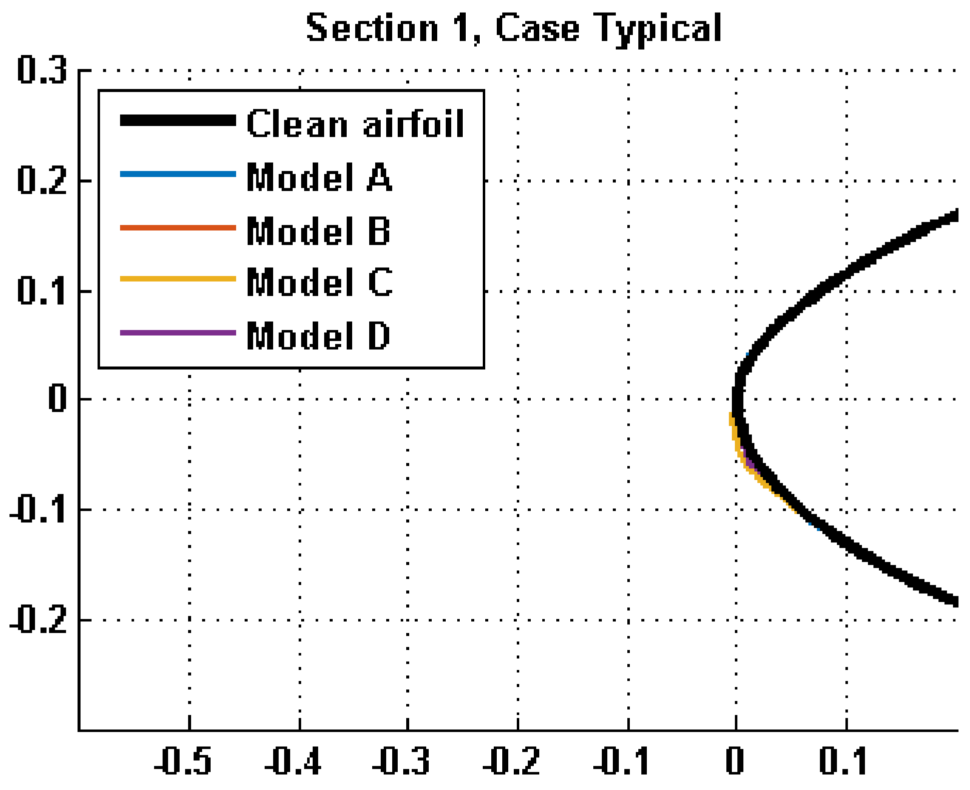
		Section 1		Section 2	
	Turbine RPM	Effective Angle of Attack	Relative air speed	Effective Angle of Attack	Relative air speed
Case Typical	9	5 °	43 ms^{-1}	5 °	55 ms^{-1}
Case Moderate	9	5 °	43 ms^{-1}	5 °	55 ms^{-1}
Case Extreme	11.75	3 °	56 ms^{-1}	3 °	71 ms^{-1}

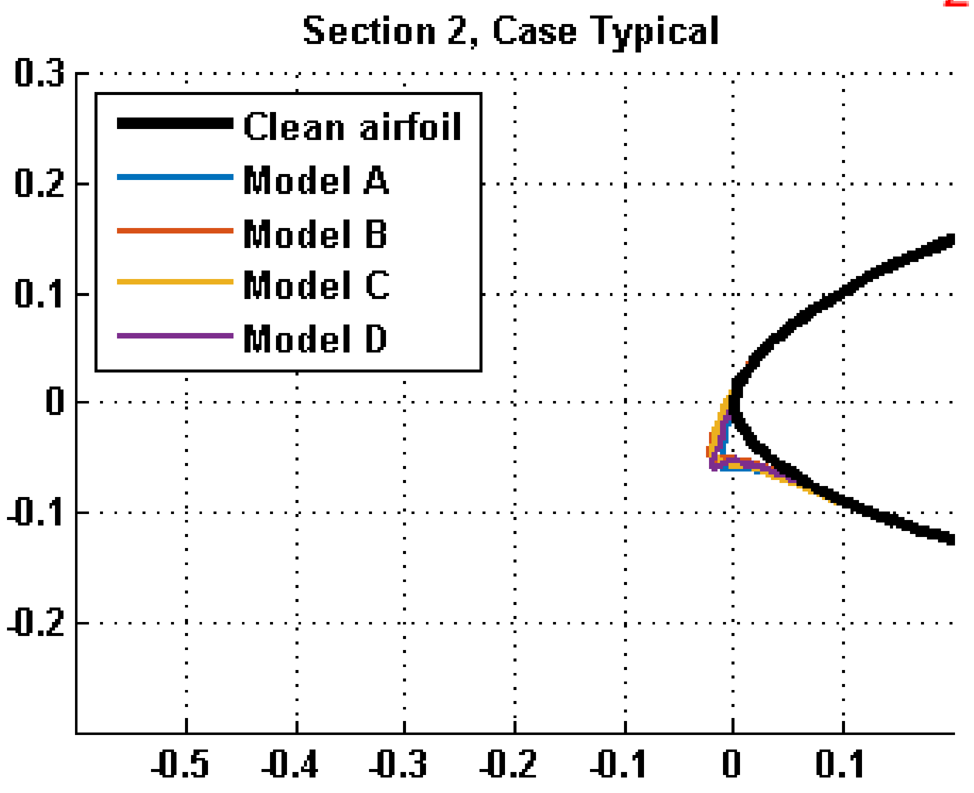
CFD Models

- The CFD groups were given the freedom to choose their best setup
- Monodispersed droplet distribution, with one model doing an additional ice mass run with Langmuir-D distribution.
- Results:
  - Ice mass based on the iced area assuming an ice density of 800 kg/m^3
  - Shape of the iced airfoil after 4h simulation

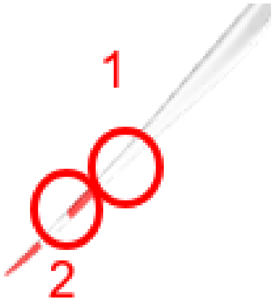
CFD Results – Typical case (after 4 hr simulation)

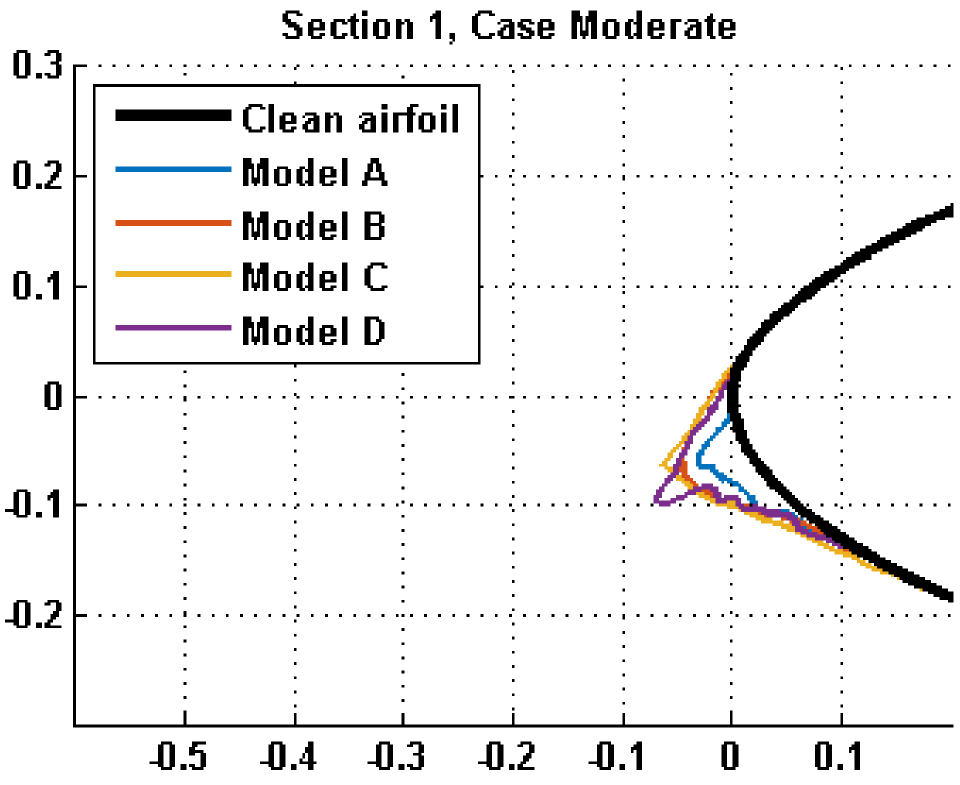


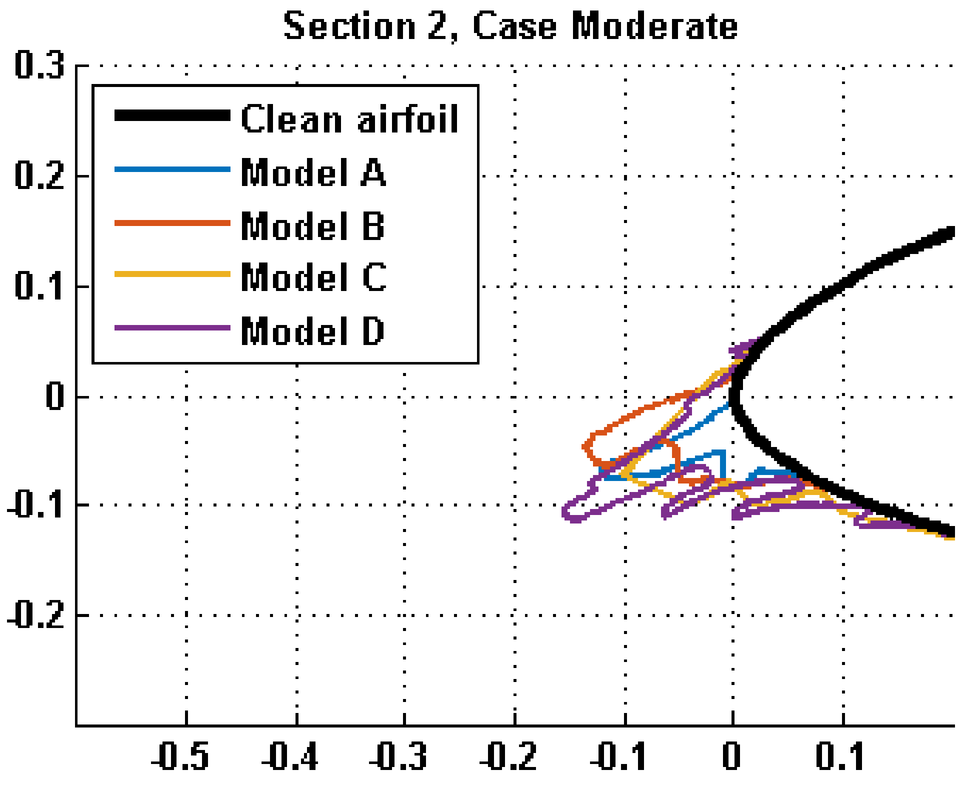




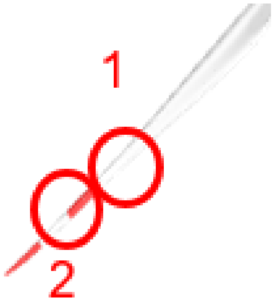
CFD Results – Moderate case (after 4 hr simulation)

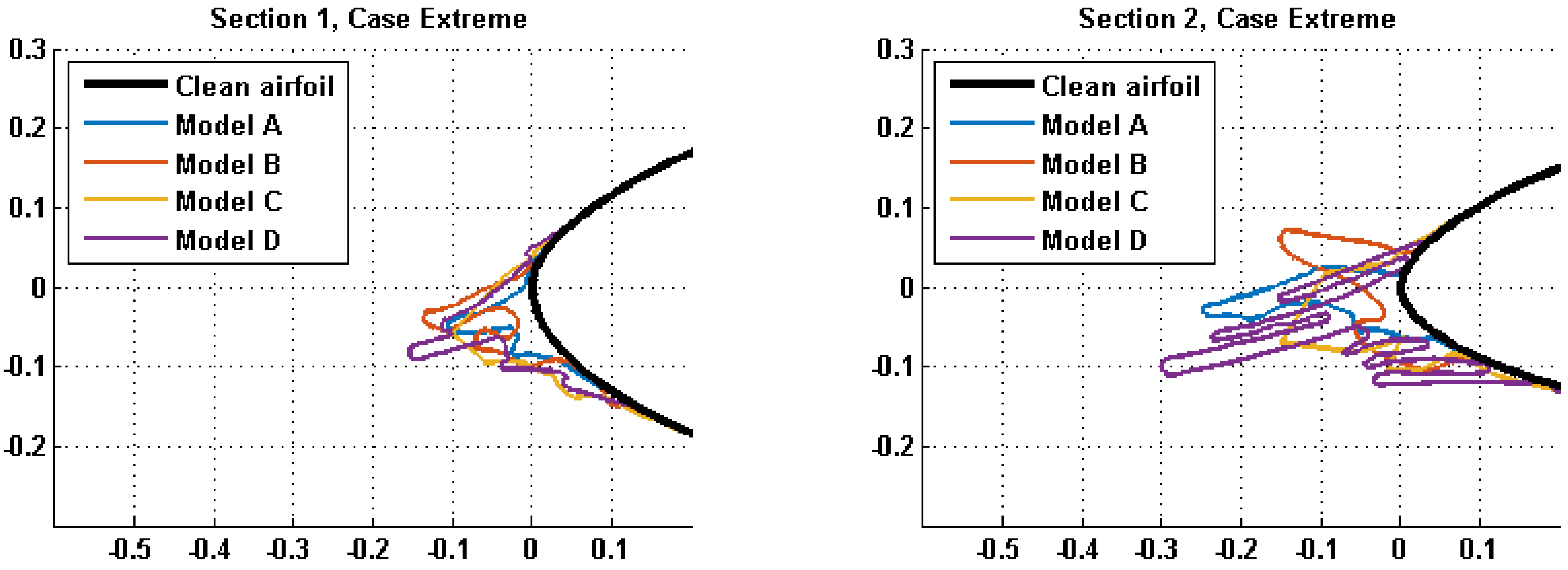




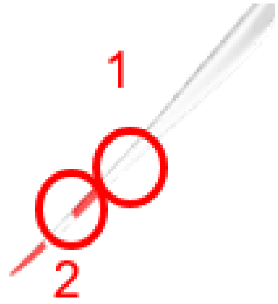


CFD Results – Extreme case (after 4 hr simulation)

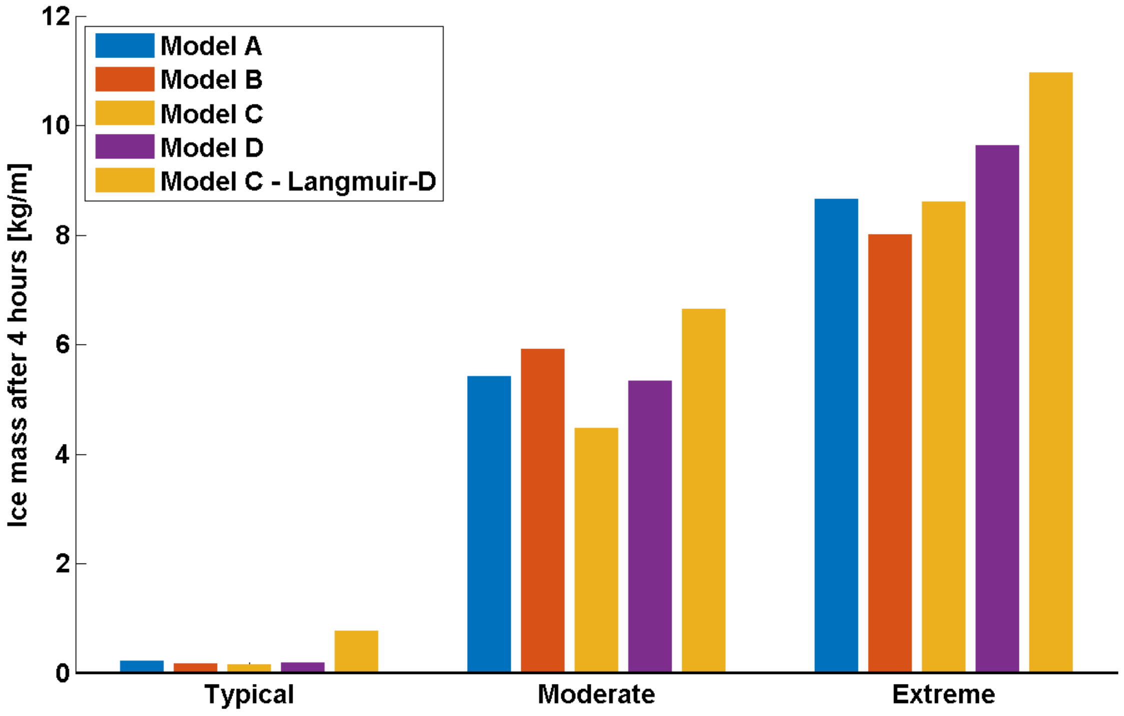




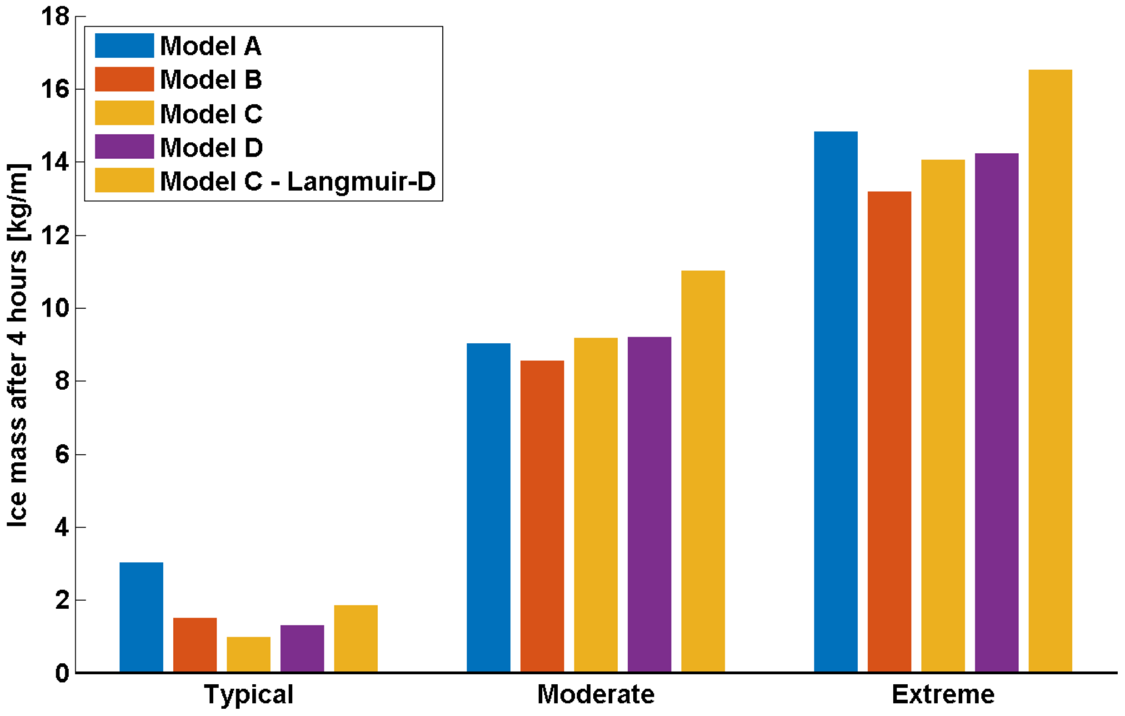
CFD Results – Ice mass (after 4 hr simulation)



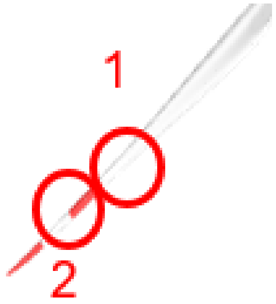
Section 1 (inner)



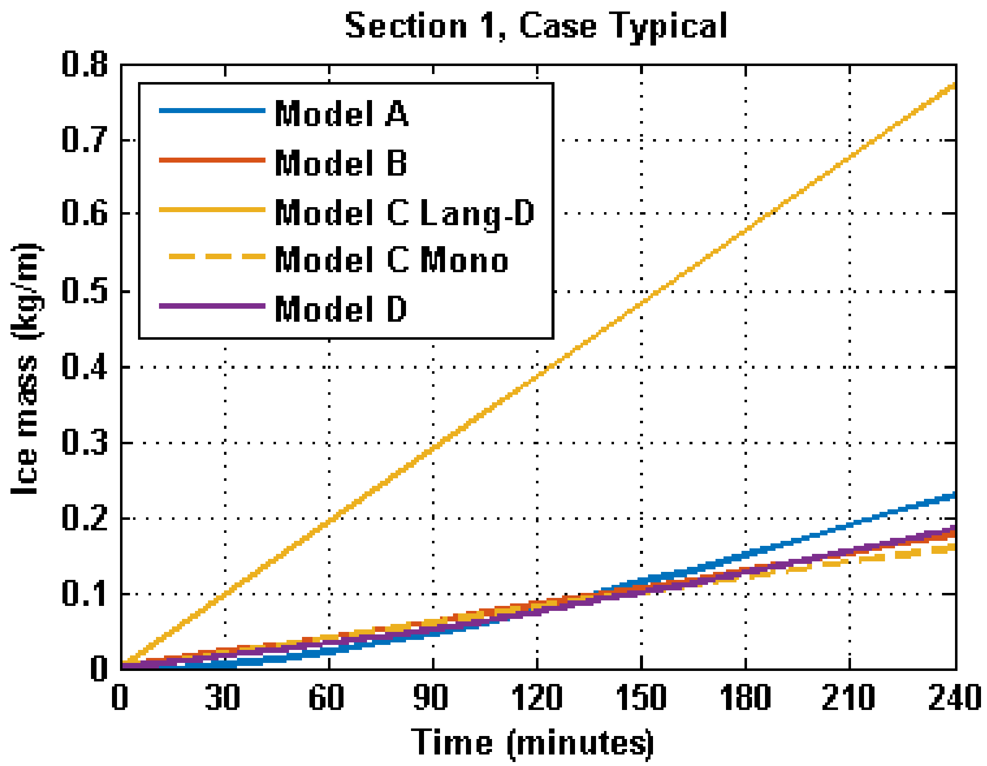
Section 2 (outer)

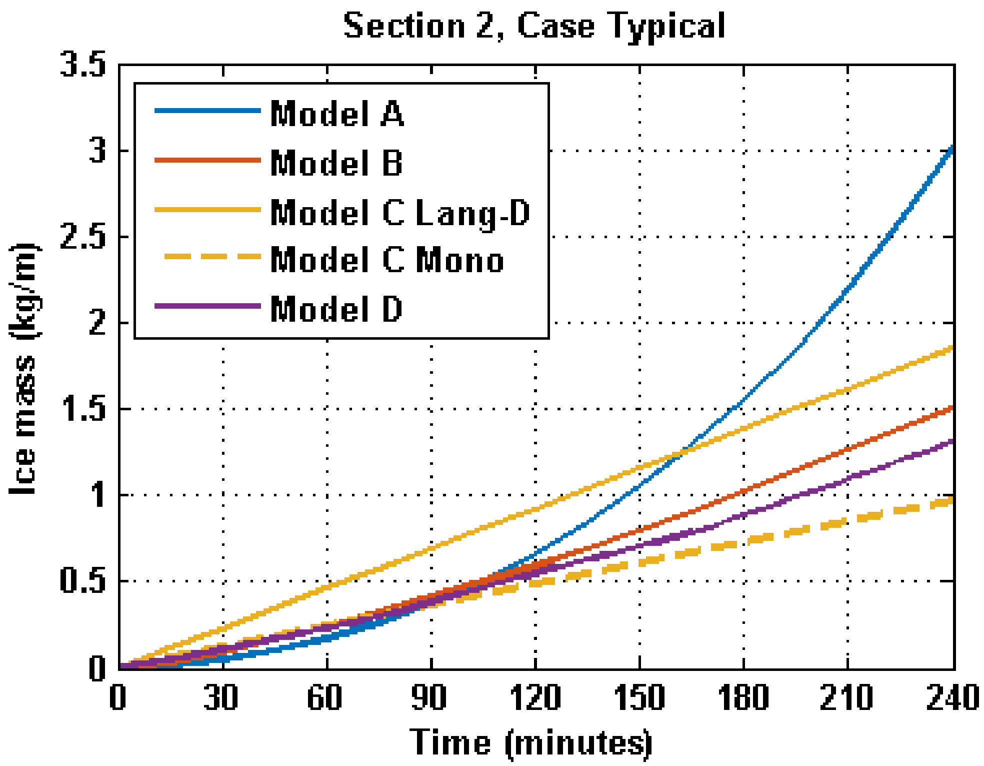


CFD Results – Ice mass (time evolution)

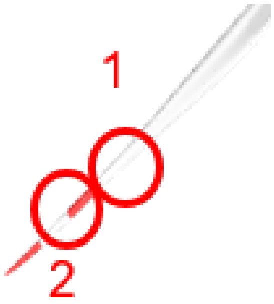


Typical meteorological icing conditions

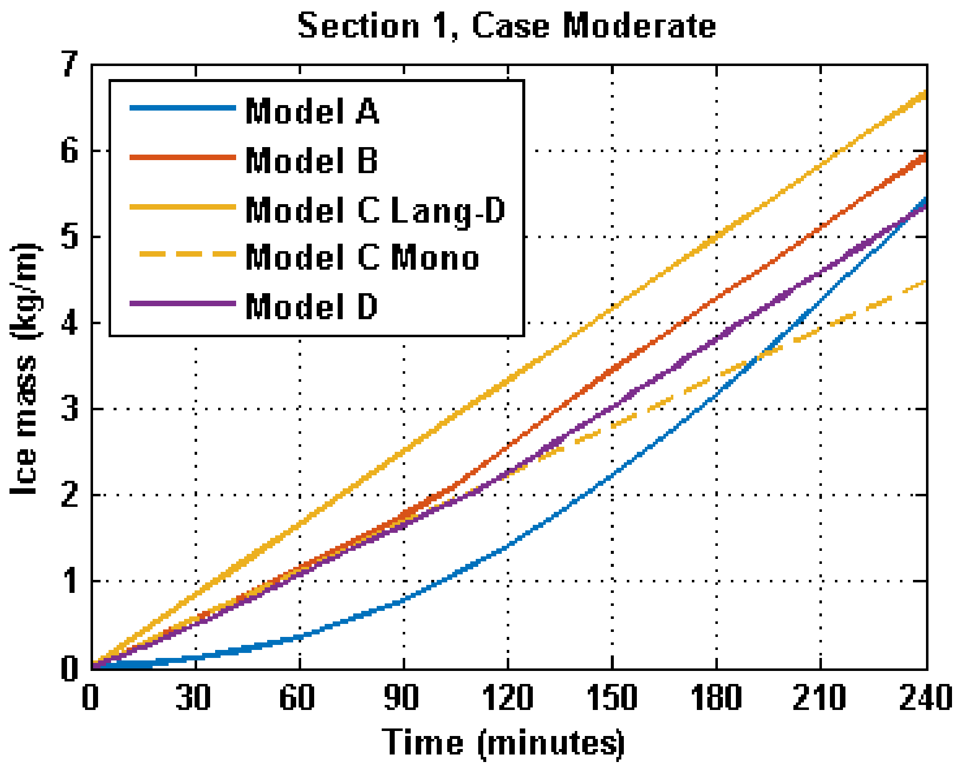


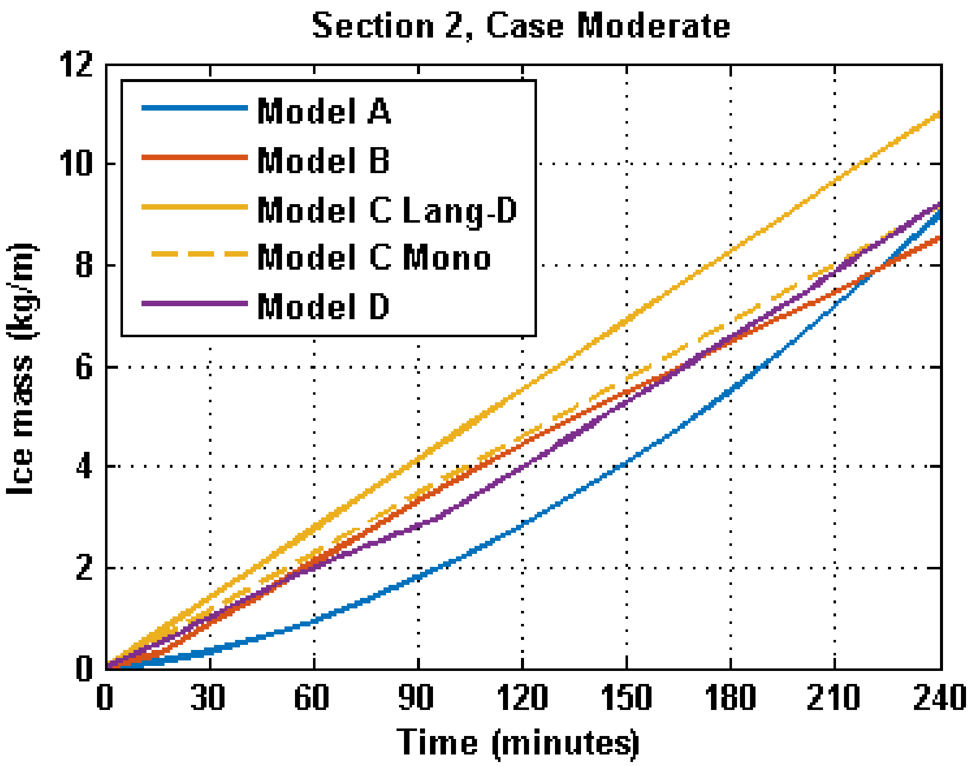


CFD Results – Ice mass (time evolution)

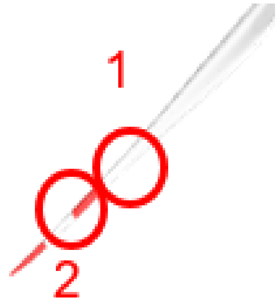


Moderate meteorological icing conditions

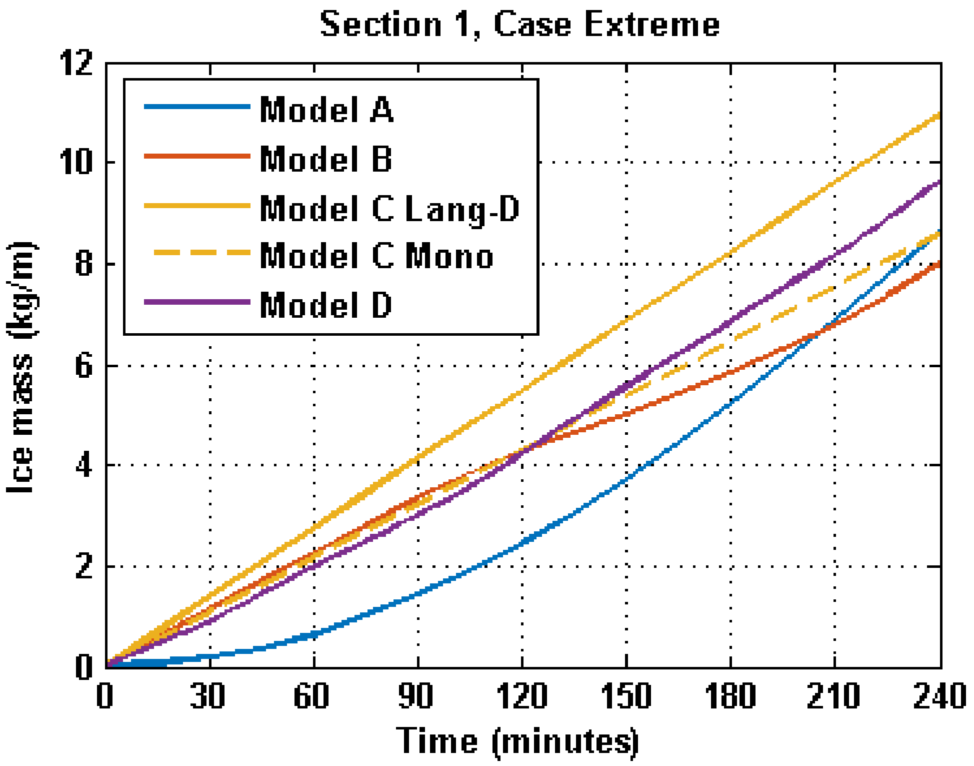


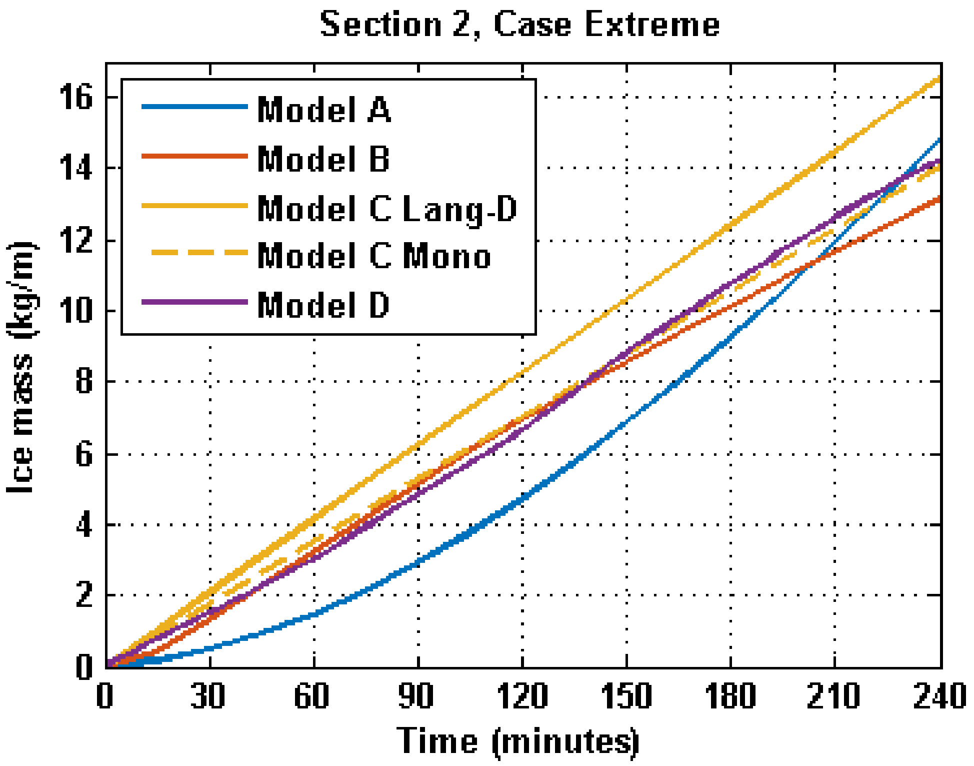


CFD Results – Ice mass (time evolution)



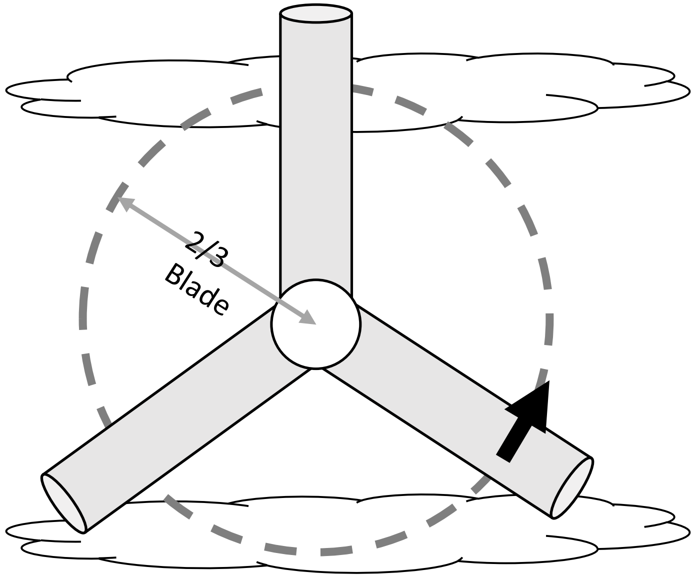
Extreme meteorological icing conditions





KVT Blade Cylinder Model (Benchmark study)

- In this benchmark study:
  - Only accretion considered
  - Meteorology and relative air velocity from the
    different cases is fed in for 4 hours
  - Different cylinder diameter on different sections

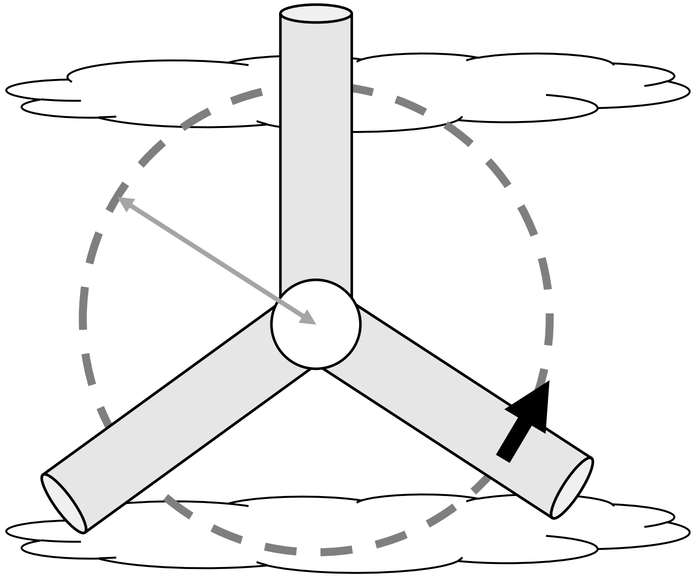


Blade Cylinder Results

	Ice mass after 4 hours [kg/m]					
	Section 1			Section 2		
	Typ	Mod	Ext	Typ	Mod	Ext
CFD – Monodispersed (mean)	0.2	5.3	8.7	1.7	9.0	14.1
CFD – Langmuir-D	0.8	6.7	11.0	1.8	11.0	16.5
Blade Cylinder model	0.9	9.8	15.4	2.7	13.7	13.8
- with modified efficiency terms	0.6	6.8	10.7	1.9	10.9	13.5

Summary

- CFD ice profiles show large diversity with extensive horns and cavities
- In terms of ice mass the CFD models however show good agreement
- For the cases investigated, modified efficiency terms of the blade cylinder model is necessary to describe the ice accretion in accordance with the CFD models



KJELLER VINDTEKNIKK

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Thank you for your attention!