A note on ice detection of wind turbine blades by a rotating-cylinder-type ice sensor

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Introduction

Many on-shore wind turbines are operated in areas prone to icing

Problems

- Decrease of power production
- Ice Throw

Ice protection systems for wind turbines in cold climate: characteristics, comparisons and analysis, Oloufemi Fakorede et al.

Courtesy of A.Heimo, Meteotest, Swiss

Solutions

- Blade heating (after shutdown)
- Reduction in the rotational speed (still ice grows??)
- **Shutdown**

at all events, shutdown could be an adequate measure to prevent blades from icing/further ice growth

⇨ **When to stop operation?**
How to know the timing?

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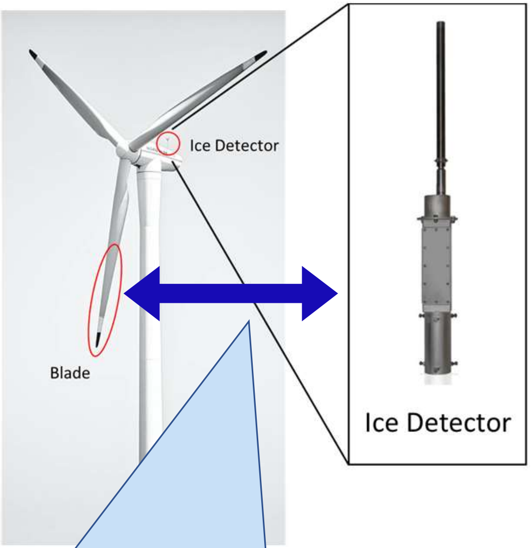
Objective1

Find out how soon the turbine operation would be made stopped by using the information from the ice detector installed on a nacelle

Comments on k-factor approach

K-factor: estimate the mass of accreted ice on the blade from ice mass on ice detector which installed on nacelle



$$k - factor = \frac{Ice\ mass\ on\ a\ blade}{Ice\ mass\ on\ the\ detector}$$

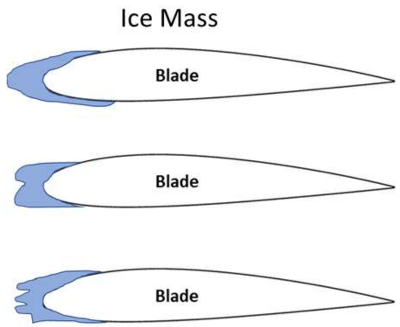
The k-factor approach assumes the detector to be quite idealistic: forced rotation and proper heating of the probe

- Ville Turkia et al. (VTT)

  $k - factor = 20$

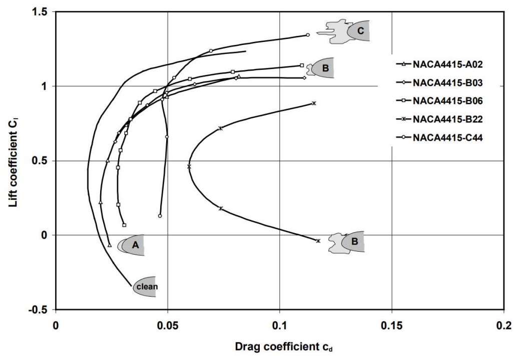
- Pavlo Sokolov et al.

  $k - factor \neq 20$



the same ice mass,
but the different ice shapes

the different aerodynamics



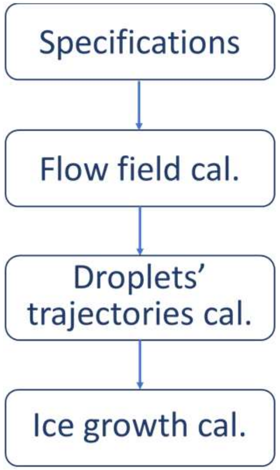
H. Seifert, F. Richert, Germany

the different loss of energy yield

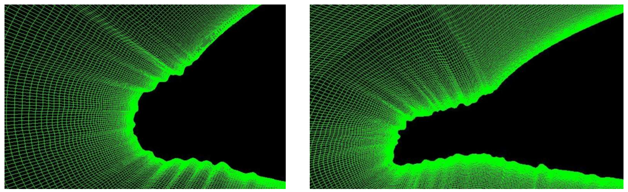
Need to know shape rather than mass

Comments on CFD analysis

Need specifications which are not open to public

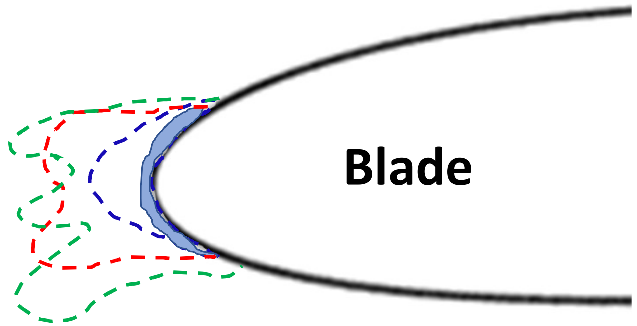


- Radius/Diameter
- Chord distribution
- Rotational speed
- Wind speed
- Wing section
- Incident angle/Twist
- Temperature
- LWC/MVD(+ Langmuir D)



Turkia et al.

Unnecessary the large ice accretion
Just know the early stages of icing



Objective2

Create a simple model to calculate the growth of ice accretion on a wind turbine blade

Objectives

1. Find out how soon the turbine operation would be made stopped by using the information from the ice detector installed on a nacelle

2. Create a simple model to calculate the growth of ice accretion on a wind turbine blade

Remarkable points of new icing calculation on blade

Specifications

- Radius/Diameter
- Chord distribution — representative chord distribution calculated by arithmetic averaging scheme with existing turbine blades
- Rotational speed
- Wind speed
- Wing section — replaced by a circular cylinder with a leading edge radius defined with respect to a NACA-4&5-digit airfoil
- Incident angle/Twist
- Temperature
- LWC/MVD(+ Langmuir D)

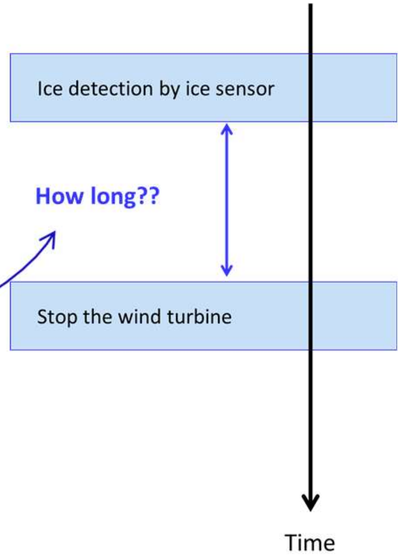
Flow field cal.

Droplets' trajectories cal. — Finstad's empirical formulas

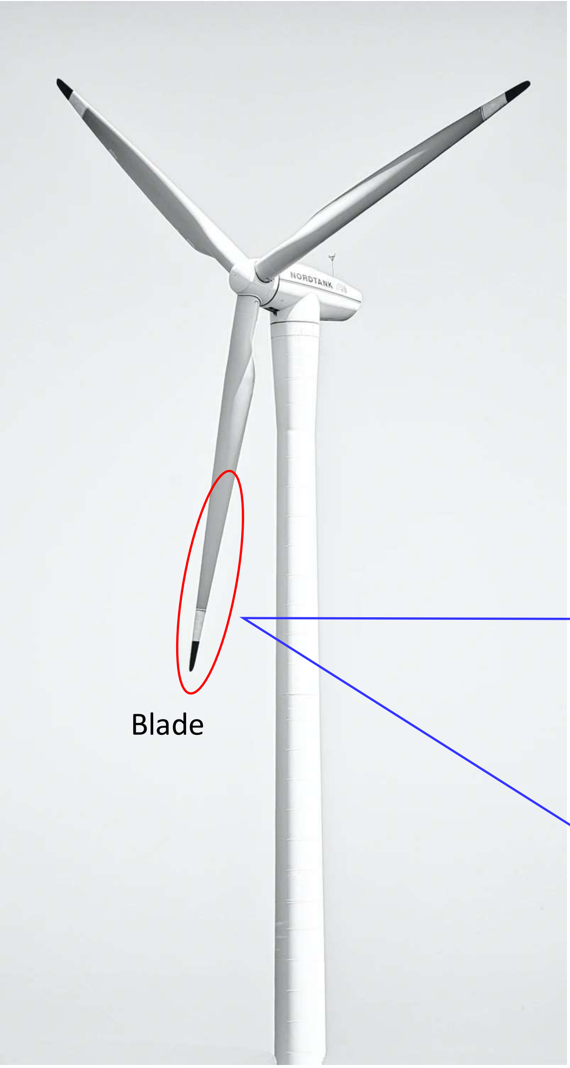
Ice growth cal. — Messinger model

until the ice thickness grows to 5 mm — based on aircraft wing design concept for de-icing

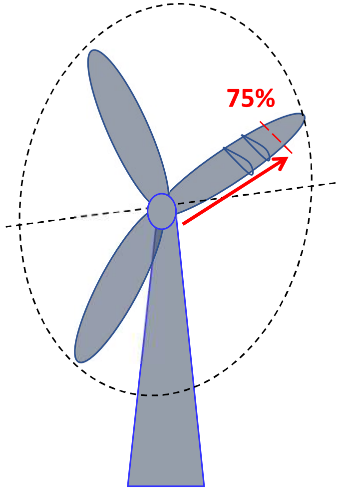
Duration of time

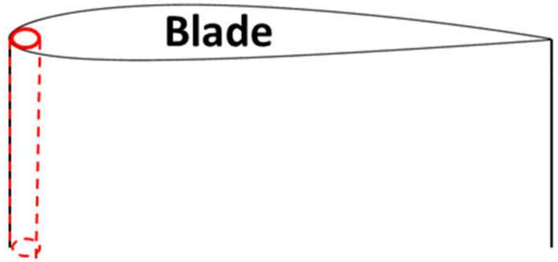


A blade of wind turbines



Blade
(Replaced by a circular-cylinder with leading edge radius)

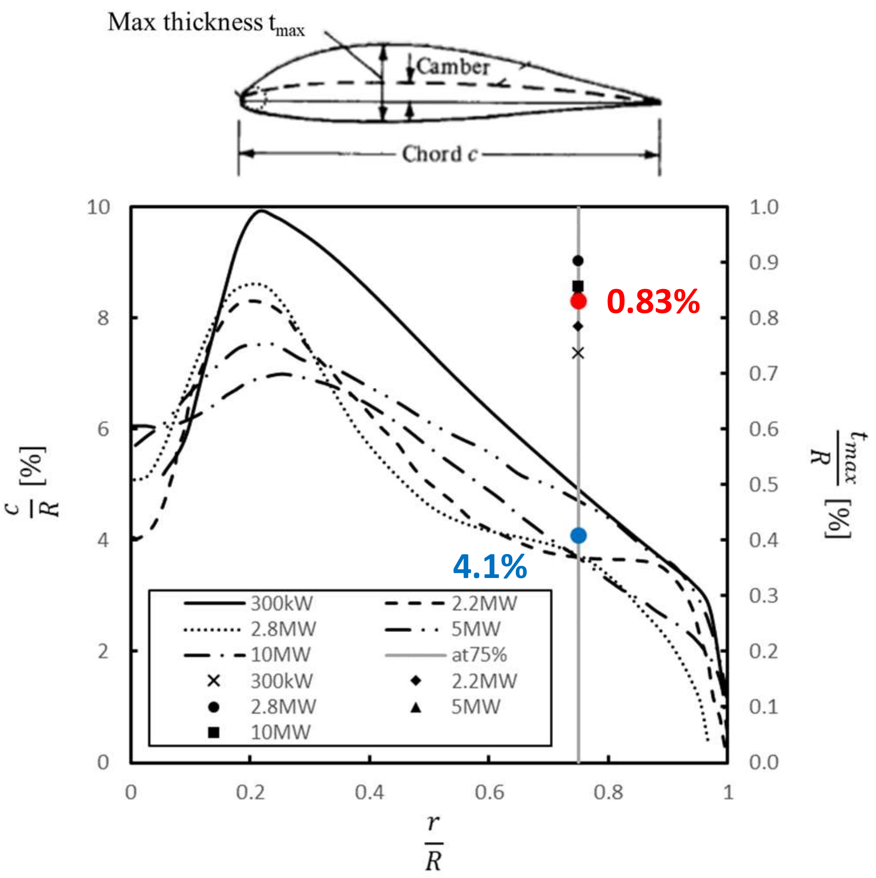




Diameter : Leading edge radius × 2
Length : 1 m
No Rotating
No Heating

The leading edge of radius

Simplified leading edge radius calculated from averaged airfoil data



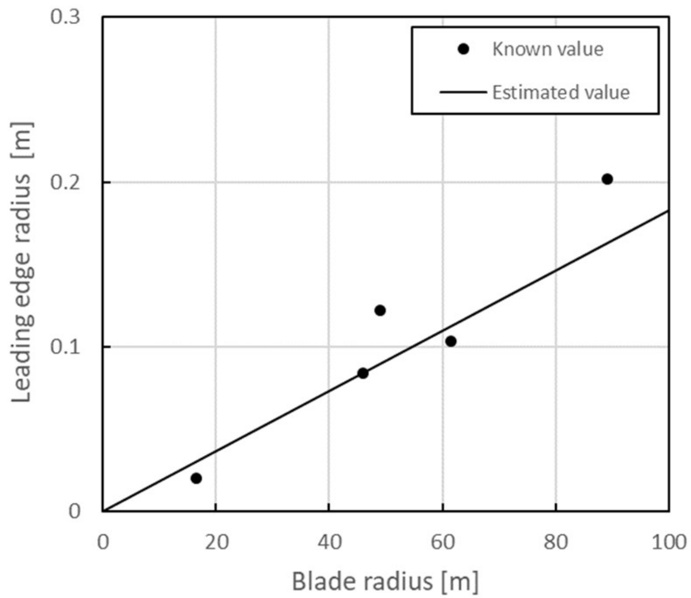
Code distributions for 5 different wind turbines

Simplified leading edge radius

$$r = 0.00185R$$

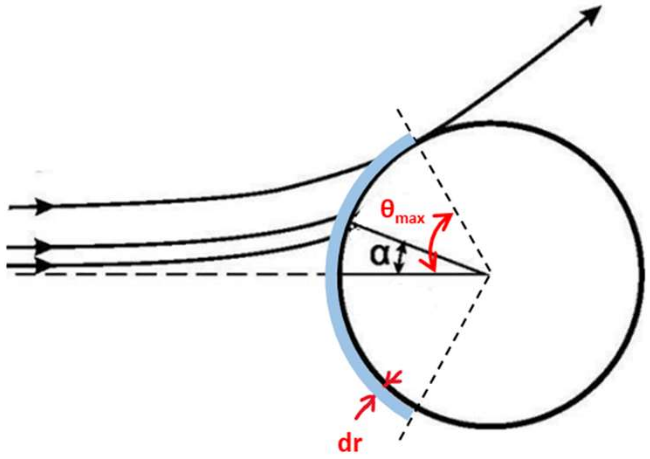
r : Leading edge radius[m]

R : Blade length [m]



Focus on ice thickness on blade

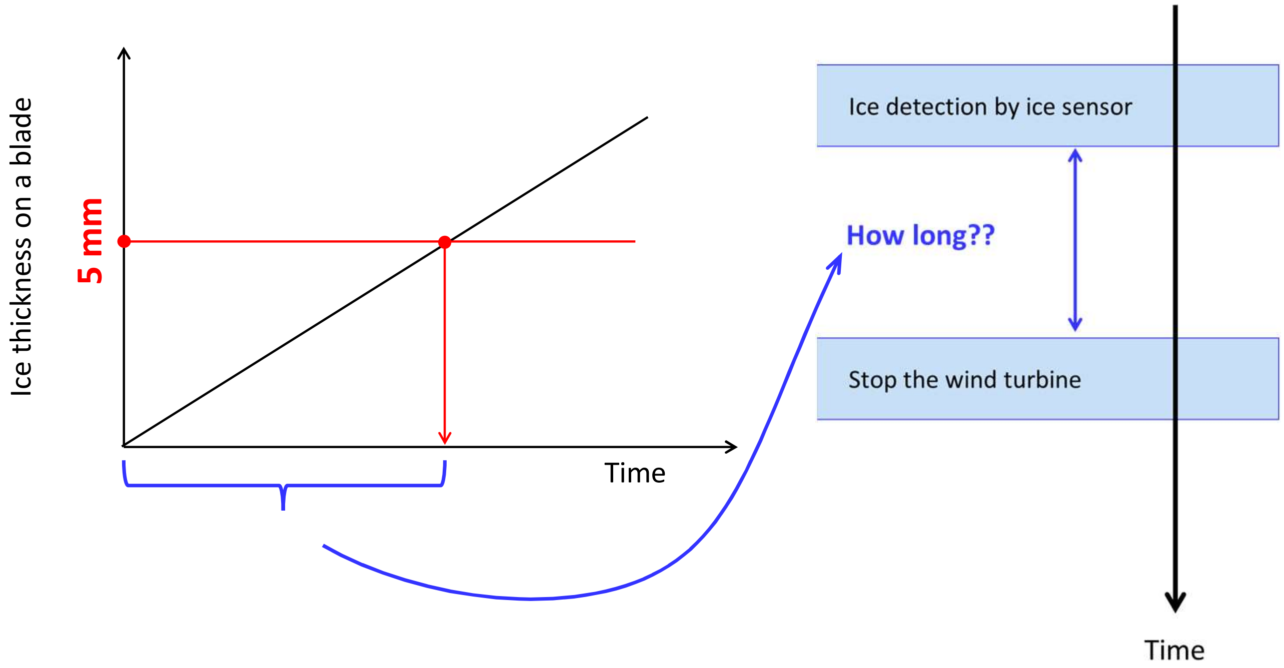
Ice thickness calculation



No rotating circular cylinder

1. Calculate the area of icing based on maximum impact angle of water droplets.
2. Calculate the ice thickness assuming the ice would be evenly distributed over that area.

Threshold was set based on aircraft wing design concept for de-icing



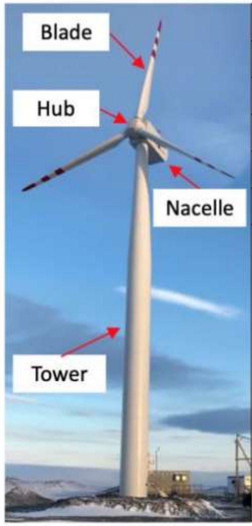
Ice thickness reaches to the threshold

→ stop the wind turbine

Conditions

	Blade
Cylinder diameter [m]	0.06
Wind speed [m/s] (Flow speed [m/s])	5, 7, 15, 20 (41.8, 50.0, 59.0, 60.4)
Temperature [°C]	-10
MVD [μ m]	15~40
LWC [g/m^3]	0.3
Air pressure [Pa]	101300
Time step [s]	1
Icing duration [s]	700
Droplet distribution	Langmuir D

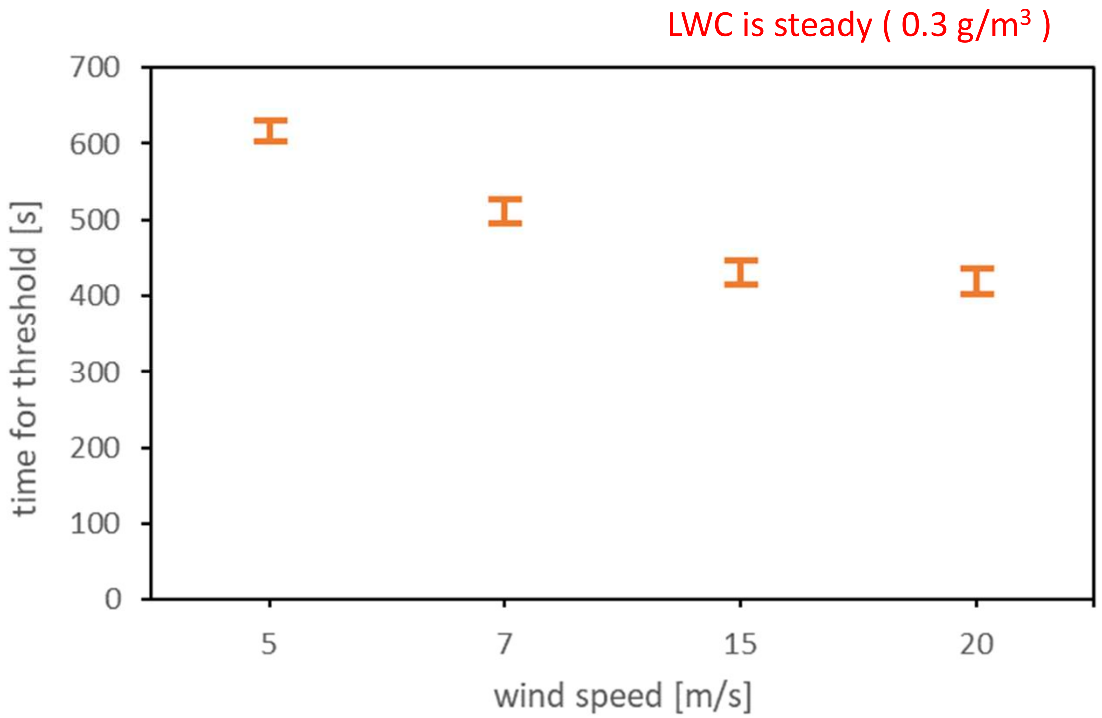
Specifications of KWT300 (KOMAIHALTEC Inc.)

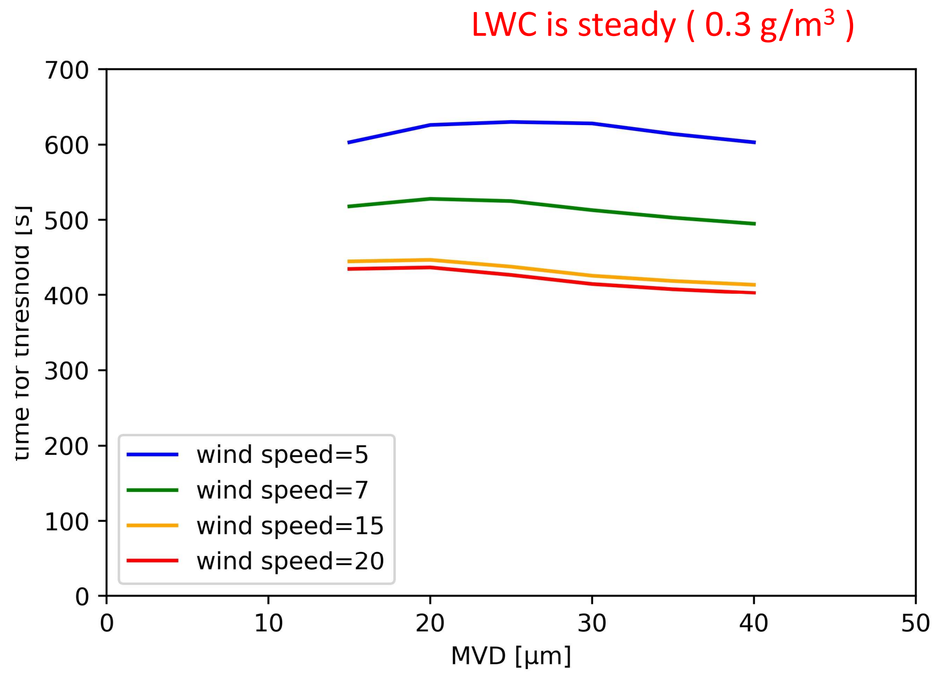


Wind turbine type	3-bladed upwind type
Rated power	300 kW
Cut-in wind velocity	3 m/s
Cut-out wind velocity	25 m/s
Hub height	41.5 m
Blade length	16.5 m
Sensors	- On the nacelle - Ultrasonic Anemometer Cup Anemometer Wind direction Ice Detector Precipitation Sensor(Only No.2) Vibrometer - Base - Thermometer Hydrometer

- Flow speed with respect to blade is combination of wind speed and rotational speed
- MVD and LWC were set based on FAR-25 Appendix C

Result





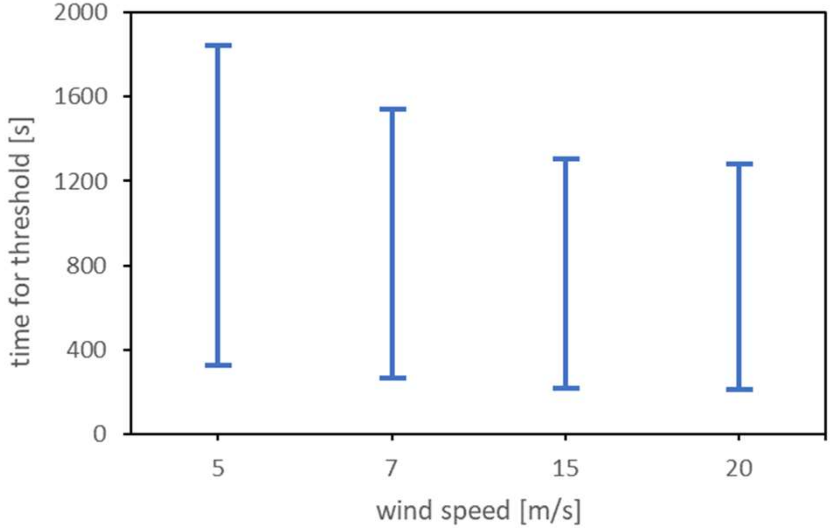
- The time to reach the threshold was about 7～10 minutes
- The dependency on MVD was low

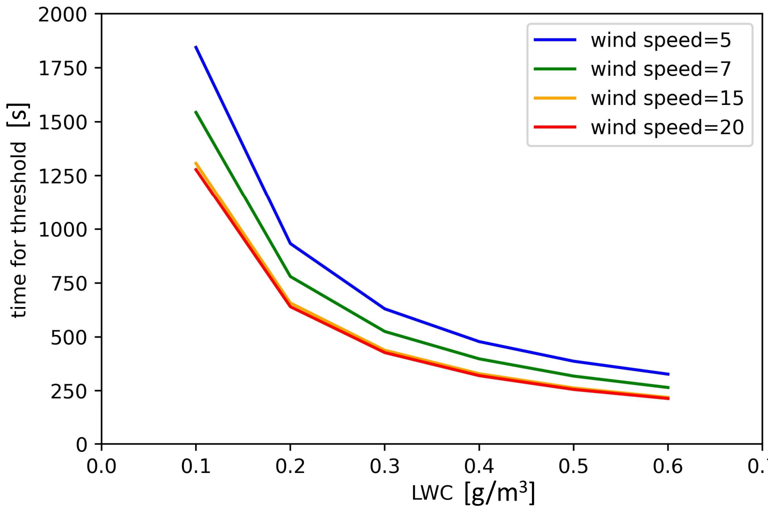
Change the LWC

Conditions

	Blade
Cylinder diameter [m]	0.06
Wind speed [m/s] (Flow speed [m/s])	5, 7, 15, 20 (41.8, 50.0, 59.0, 60.4)
Temperature [°C]	-10
MVD [μ m]	25
LWC [g/m^3]	0.1~0.6
Air pressure [Pa]	101300
Time step [s]	1
Icing duration [s]	2000
Droplet distribution	Langmuir D

Result





- The time to reach the threshold was about 4～30 minutes
- LWC had a large impact to the time for threshold

Summary

Specifications

Flow field cal.

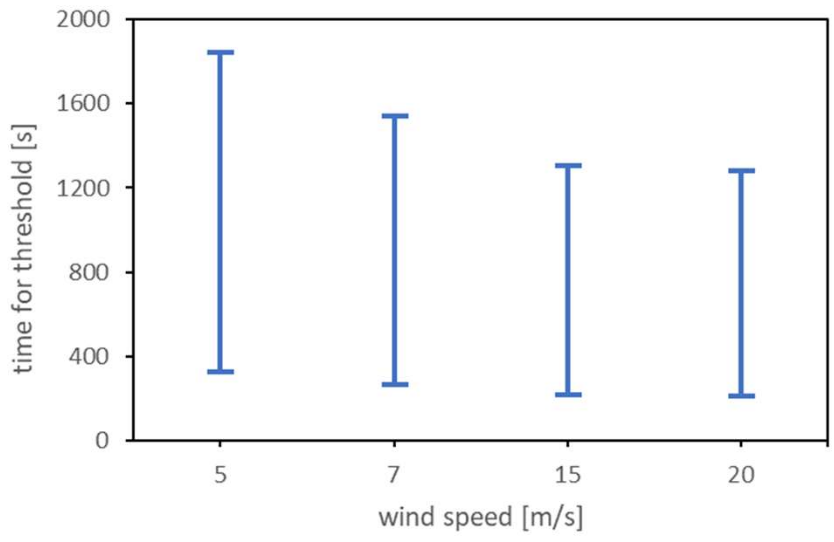
Droplets' trajectories cal.

Ice growth cal.

Duration of time

- Radius/Diameter
- ~~Chord distribution~~
- Rotational speed
- Wind speed
- ~~Wing section~~
- ~~Incident angle/Twist~~
- Temperature
- LWC~~/MVD(+ Langmuir D)~~

until the ice thickness grows to 5 mm



Despite the impact of the LWC, the duration of time when to stop the wind turbine for each wind speed was found.

Created a simple model to calculate

Conclusions

- Created a simple model, and it made possible to simulate without specifications which are not open to public.
  (just need radius/diameter of wind turbine, rotational speed, wind speed, temperature, LWC)
- Despite the impact of the LWC, the duration of time when to stop the wind turbine for each wind speed was found.
- A decision for shutdown needs to be made 4～30 minutes.

Thank you for your attention!