输配电装备及系统安全与新技术国家重点实验室
State Key Laboratory of Power Transmission Equipment and System Security
SKL-PES

3-D Numerical Simulation of MWs Wind Turbine Blade's Icing

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Contents

1.1 Why we study MWs wind turbine blade's icing

Great development of wind energy

↓

The establishment of lots of MWs wind turbine

↓

Facing serious icing problem in some weather condition

↓

To study the law of the coagulated ice on blades

Fig.1.1 Icing on the wind turbine blade

Fig.1.2 Icing on the wind turbine blade

1.2 How to study 3-D Numerical Simulation of Blade's Icing

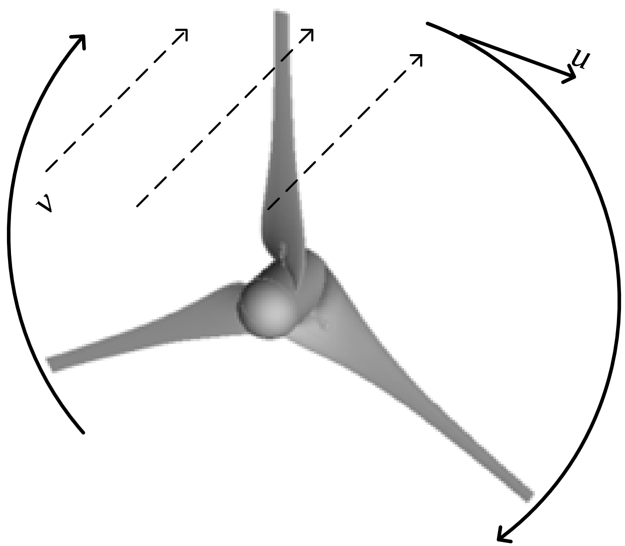


Fig.1.3 Flow field of wind turbine

① Spanwise flow may be ignored in the present 2-D simulation. The results of 3-D simulation can offer more complete information of droplet trajectories.

② The droplets trajectories are solved using the MRF model and the DPM.

③ the calculation of ice shape is based on the results of 3-D simulation.

2.1 the wind turbine model, the mesh and the boundary condition of computation domain

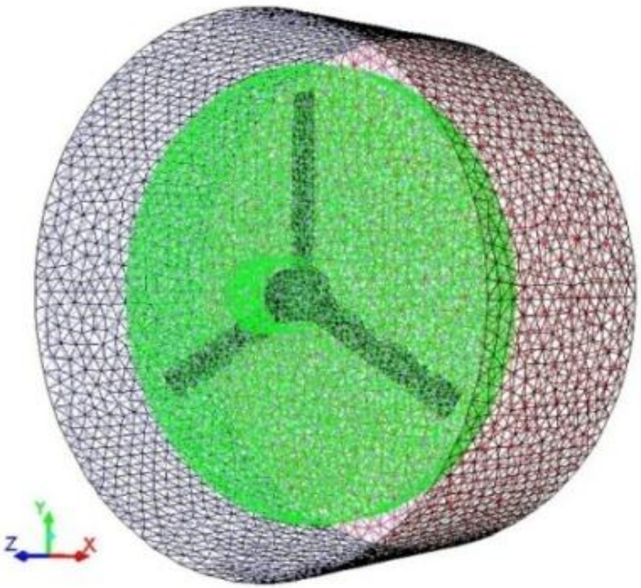


Fig 2.1 The mesh of computation domain

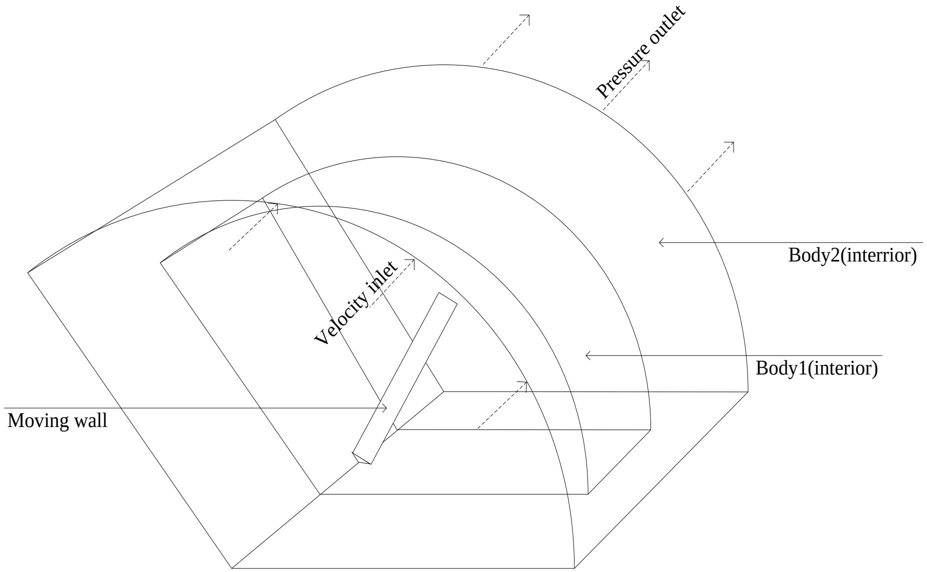


Fig.2.2 Boundary conditions of 3-D simulation

3.1 Calculation of air flow caused by the rotating blade

The characteristics of the 3-D flow fields:

It is a typical flow field including the rotor. To calculate the fluid phase with Eulerian method and the dispersed phase with Lagrangian method respectively.

MRF model:

MRF model is a steady computation model. It is supposed that the grid cell moves with a constant velocity. The domain is distributed into the rotating domain and the static domain.

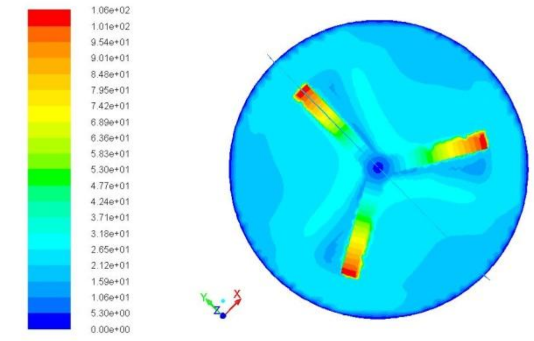


Fig3.1 The contour of velocity

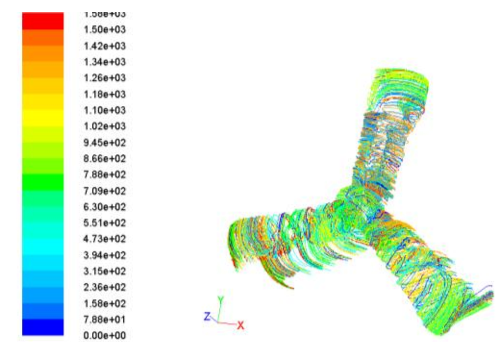


Fig3.2 The air flow pathlines around blades

3.2 Calculation of droplet tajectory

Lagrangian method:

Each particle can be tracked in the process of movement with Lagrangian method. And every moment and every position of the change of physical quantity can be recorded.

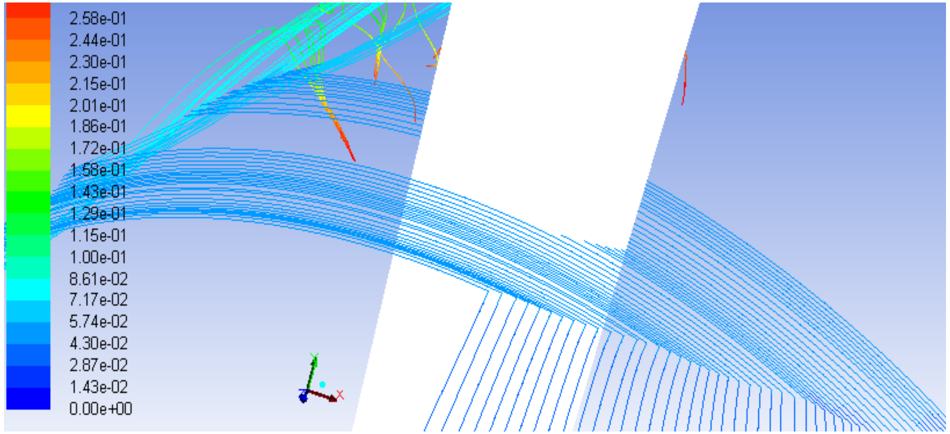


Fig3.3 The droplet trajectories around blades

3.2 Calculation of droplet tajectory

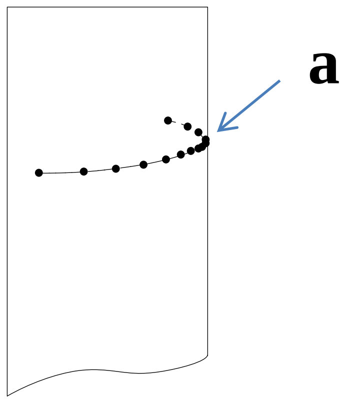


Fig3.4 The coordinate of water droplets impingement

① Ignore the radial coordinate difference of other collision point.

② Get the water droplets collision coordinates of the section.

3.2 Calculation of droplet tajectory

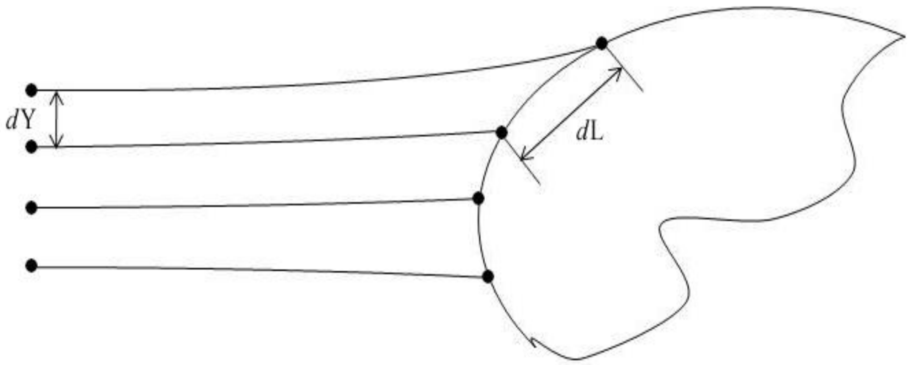


Fig.3.5 the definition of local collision efficiency

① **The collision coefficient**

② **The local Collision coefficient**

$$\alpha_1 = \frac{dY}{dL} \qquad (2.1)$$

α_1

3.2 Calculation of ice accretion

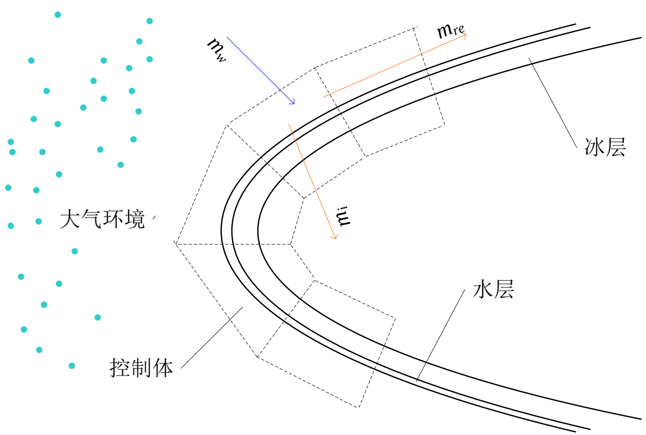


Fig.3.6 The mass conservation on the blade surface

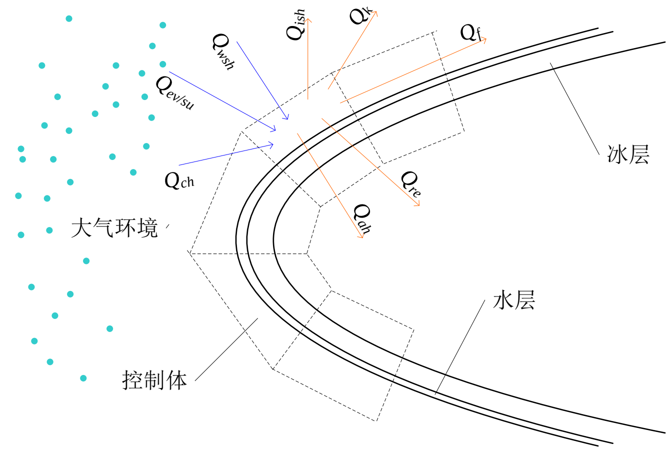


Fig.3.7 The conservation of energy on the blade surface

Mass transfer equation :

$$m_w = m_{re} + m_i$$

Energy transfer equation:

$$Q_{ch} + Q_{ev/su} + Q_{wsh} = Q_k + Q_f + Q_{ah} + Q_{ish} + Q_{re}$$

$$\alpha_3$$

3.2 Calculation of ice accretion

$$\begin{cases} m_i = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot LWC \cdot V \cdot A & (2.2) \\ d = \dfrac{m_i t}{\rho_i A} & (2.3) \end{cases}$$

α_1 : Collision coefficient
V : Relative velocity

Flow field simulation

α_3 : Accretion coefficient

Calculation of mass and energy transfer equation

α_2 : Collection , LWC : liquid water content,
A : The cross-sectional area of the object relative to V
t : icing time , ρ_i : ice density

4.1 the process analysis of ice accretion on blade

4.1.1 the analysis of two-phase fluid

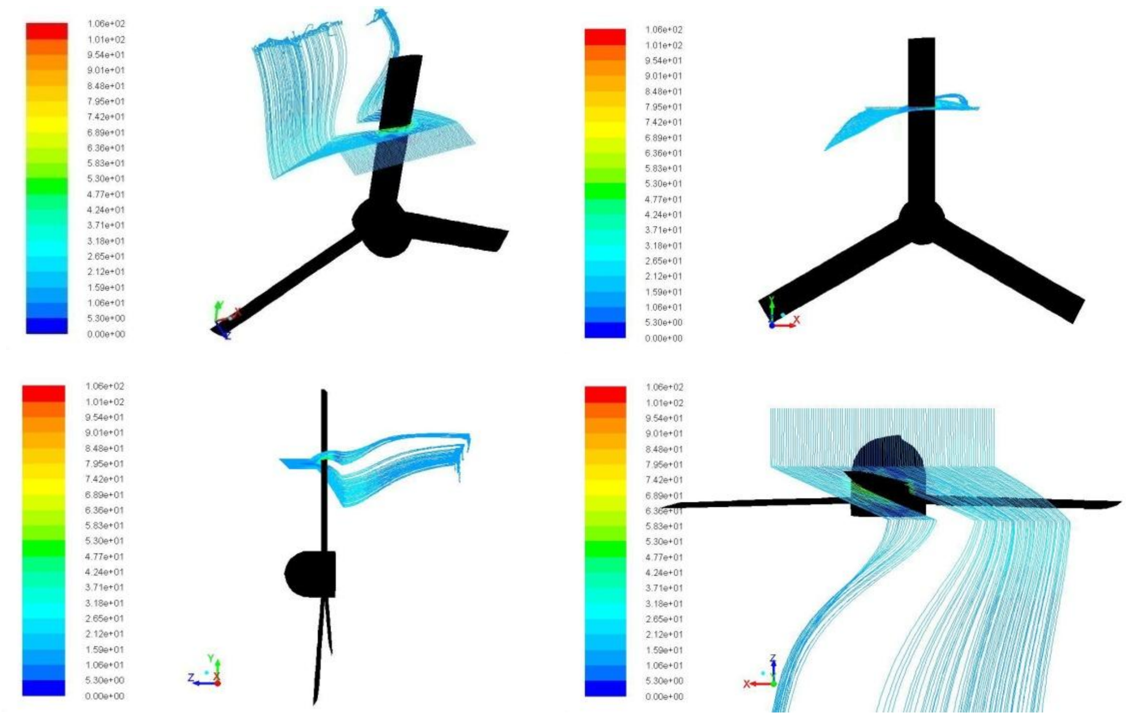


Fig.4.1 Water droplets trajectories around wind turbine blade

① Most droplets impinge on the leading edge and the downwind side of blade.

② The droplet trajectories are arc with the change of tangential, radial, and axial component.

4.1 the process analysis of ice accretion on blade

4.1.2 the analysis of ice accretion

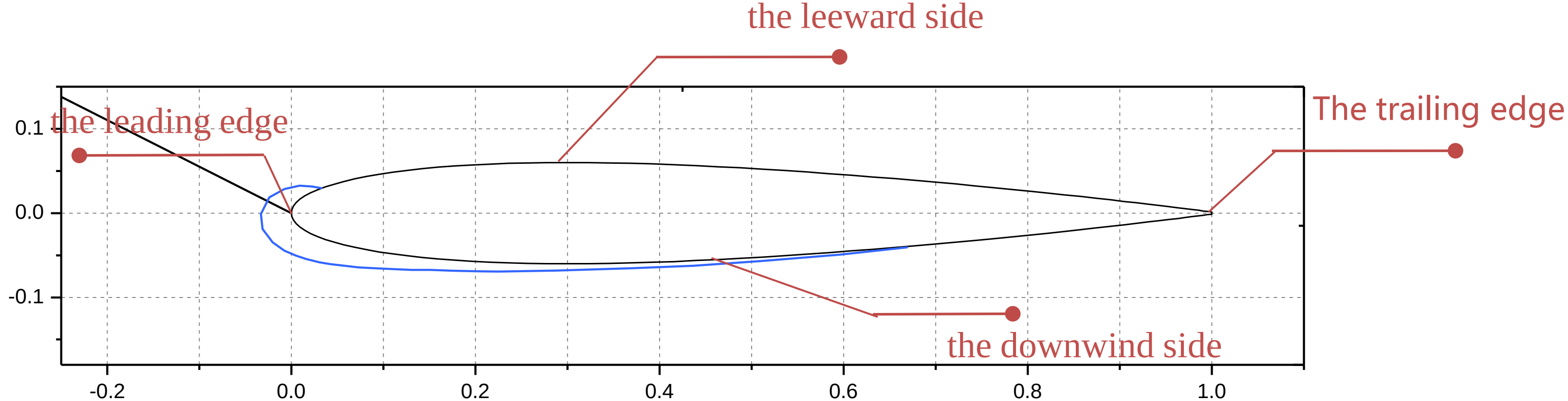
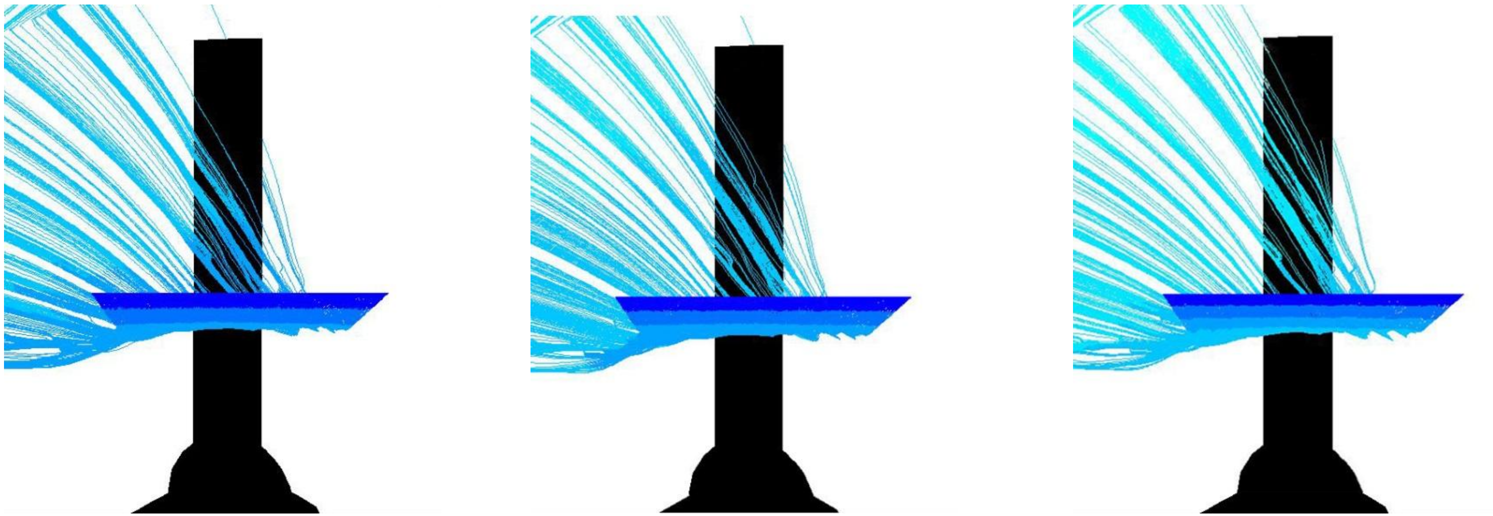


Fig.4.2 Calculation of ice accretion on the blade profile

① Most ice deposit on the leading edge of blade and the downwind side.

② The ice area and the amount of droplets impinging on the surface mainly depend on the droplet trajectory while ice shape, ice mass and icing rate are contingent on the thermodynamic calculation.

4.2 the analysis of ice accretion on MWs wind turbine blade



(a) d=77m (b) d=88m (c)d=110m

Fig.4.3 Droplet trajectories at blades with different radiu

Water droplets trajectories are relatively concentrated with the small size blade, while the droplet trajectories are more dispersed with the bigger size.

4.2 the analysis of ice accretion on MWs wind turbine blade

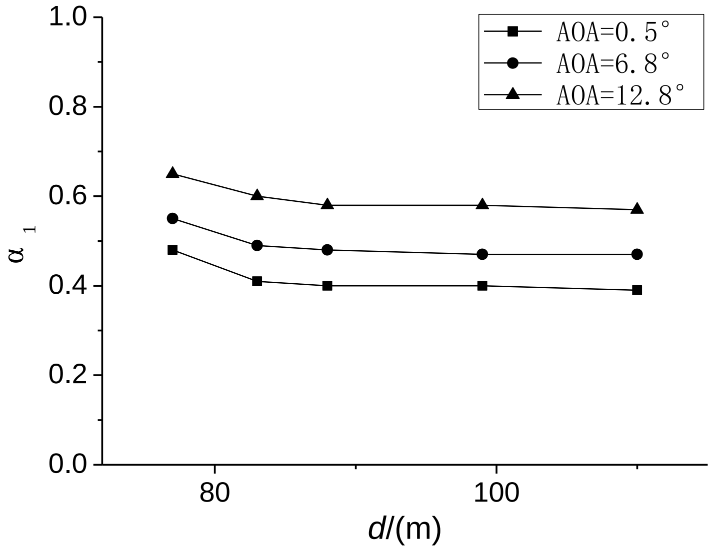


Fig.4.4 Water collection at blades with different radius

With the increase of blade size, the collision coefficient is smaller. Usually in the design of blade, in order to maintain a range of tip speed ratio, the speed will be slower with the larger size of the blade. So the swept area in the unit time is smaller, the trapped droplets will be also less.

4.2 the analysis of ice accretion on MWs wind turbine blade

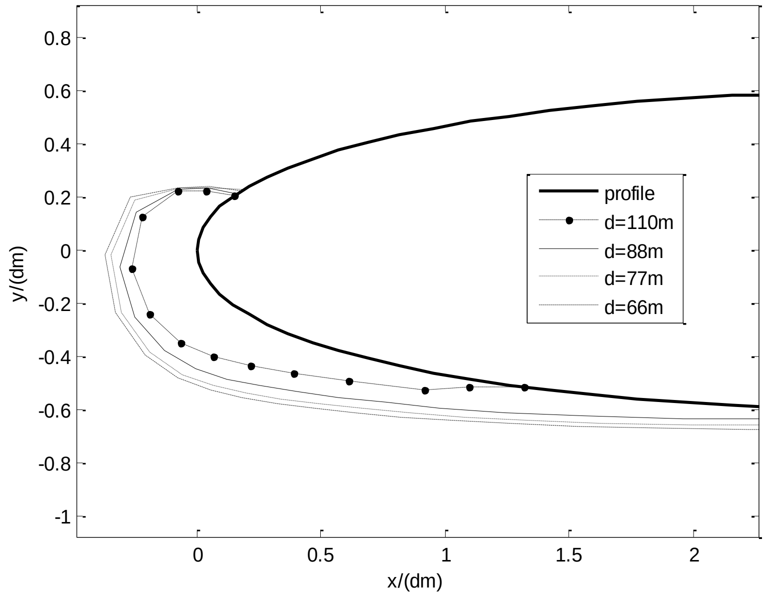


Fig.4.5 Ice shapes obtained at varying wind speed

With the increase of blade size, the ice thickness is smaller.

5 Conclusion

①

- The downwind side of blade is almost covered with ice, while there is barely ice appeared on the leeward side of blade.
- Most ice deposit on the leading edge of blade, and the ice layer of blade tip is much thicker than the blade root.

②

- With the increase of blade size, the ice thickness is smaller.

③

- Usually in the design of blade, in order to maintain a range of tip speed ratio, the speed will be slower with the larger size of the blade. So the swept area in the unit time is smaller, the trapped droplets will be also less.

Thanks！