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Thermal Analysis of a Heated Rotor Blade for Wind Turbines

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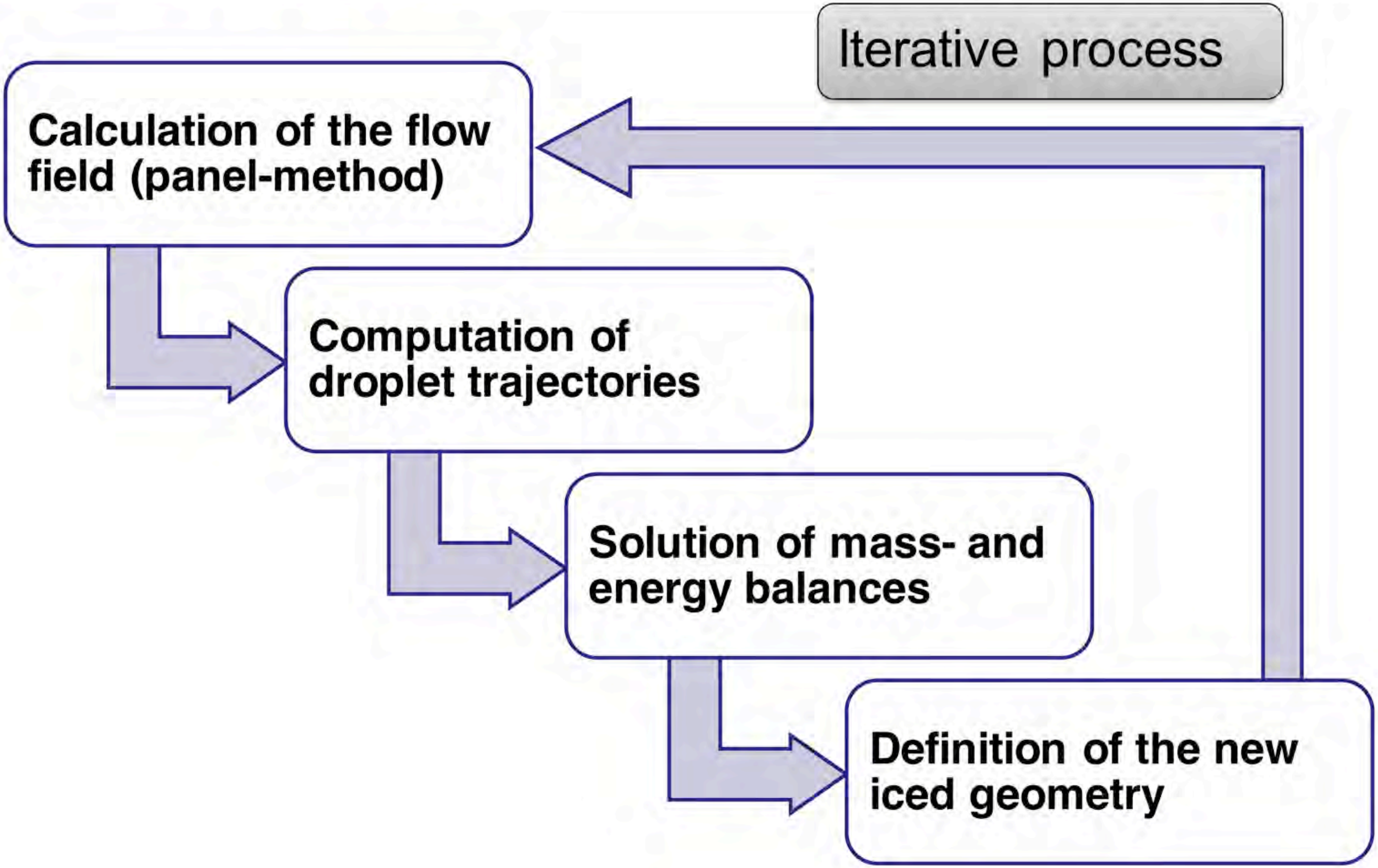
About this publication

- Results of the final year thesis of Richard Hann at the University of Stuttgart
- Cooperation with KENERSYS GmbH (Germany)
- Cooperation with VTT (Finland)

Content

- CFD-simulation of an iced airfoil
- Analysis of the heat transfer on an iced airfoil
- Analysis of the required heat for an electro-thermal anti-icing system

Numerical approach



Numerical codes

LEWICE 3.2.2 (NASA)

- Developed for aircraft icing
- 2D ice accretion and anti-icing
- Extensive exerimental validitation

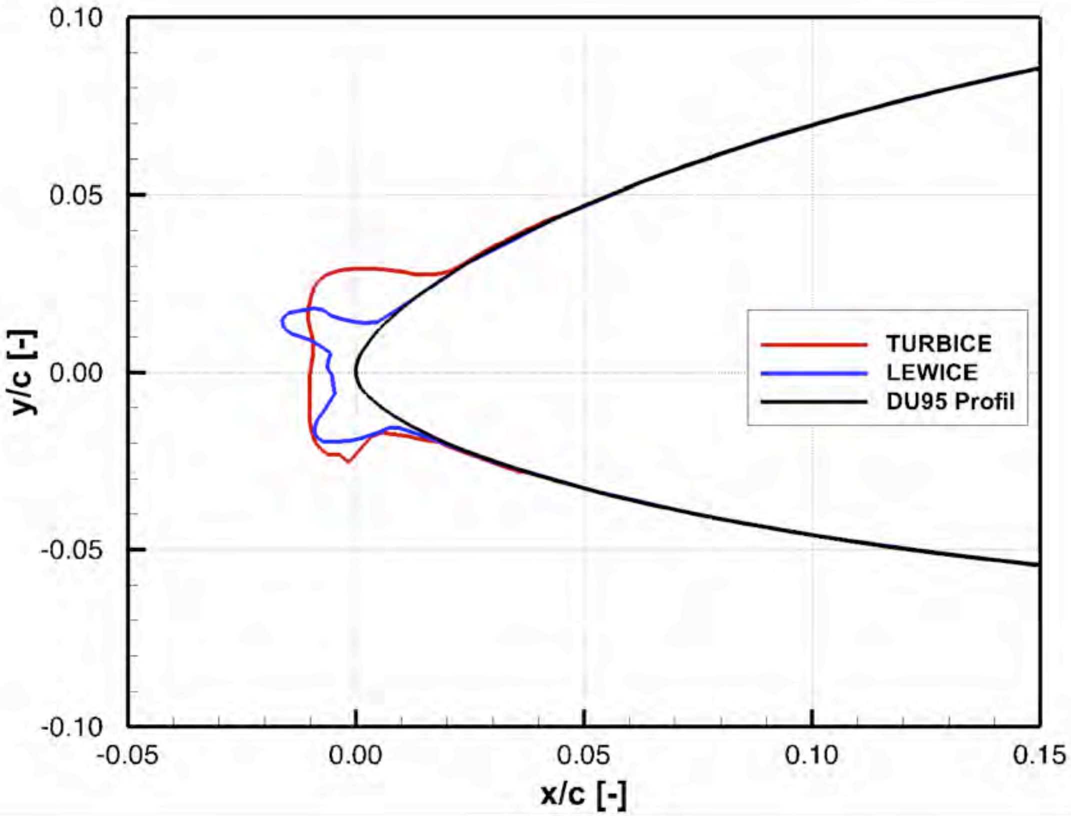
TURBICE 6.0 (VTT)

- Developed specifically for the wind energy
- 2D ice accretion and anti-icing
- Advanced roughness and ice density models

Reference case for the investigation

Reference case: In-Cloud Icing

Wind speed:13m/s | Rotatinoal speed: 14rpm,
Icing time: 45min | Temperature: -5°C
Droplet size (MVD): 20µm | Water content (LWC): 0.53g/m³



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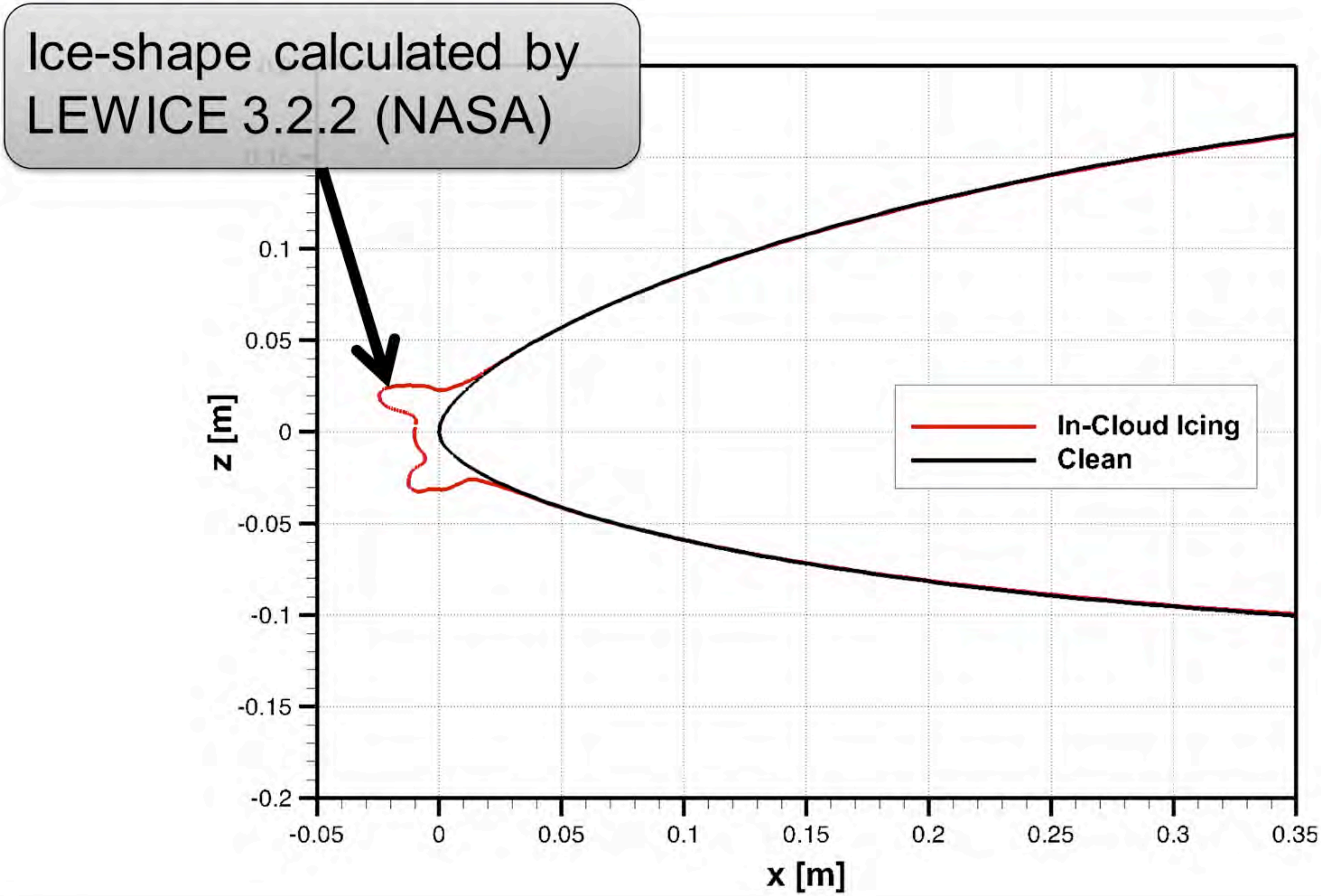
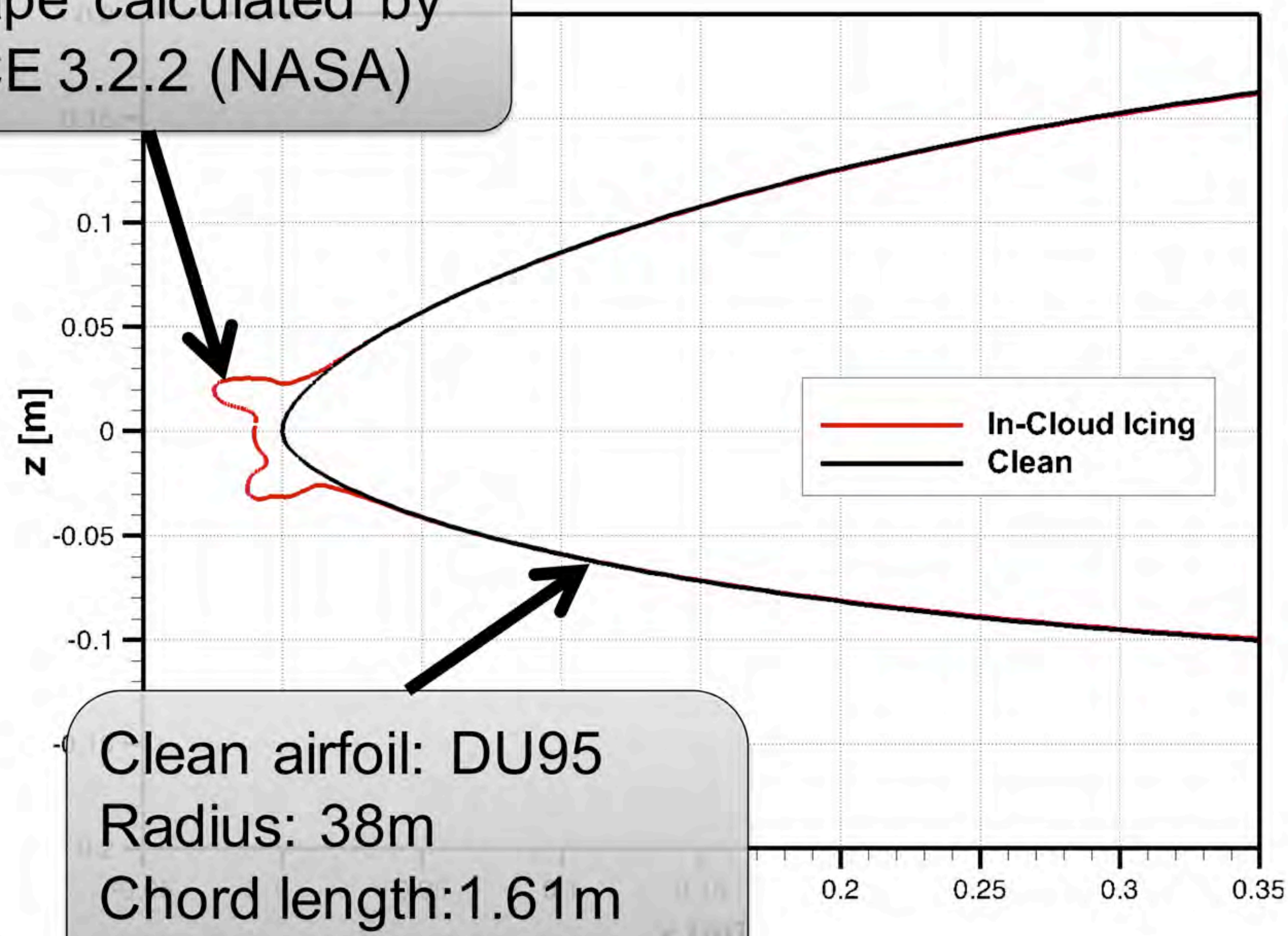
„What is the effect of ice accretion on the aerodynamics of an airfoil?“

1st step: Define an icing case



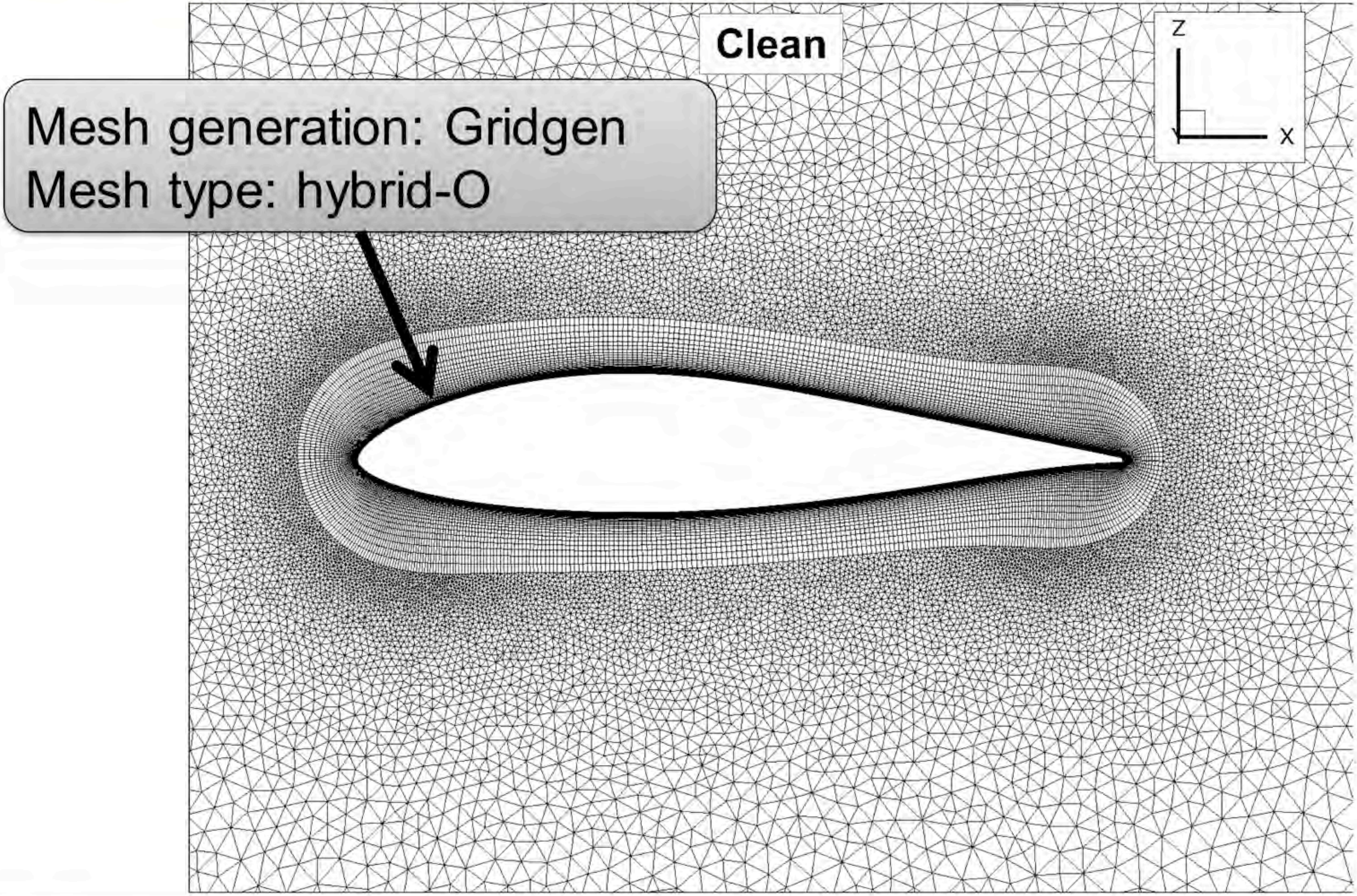
1st step: Define an icing case

Ice-shape calculated by LEWICE 3.2.2 (NASA)

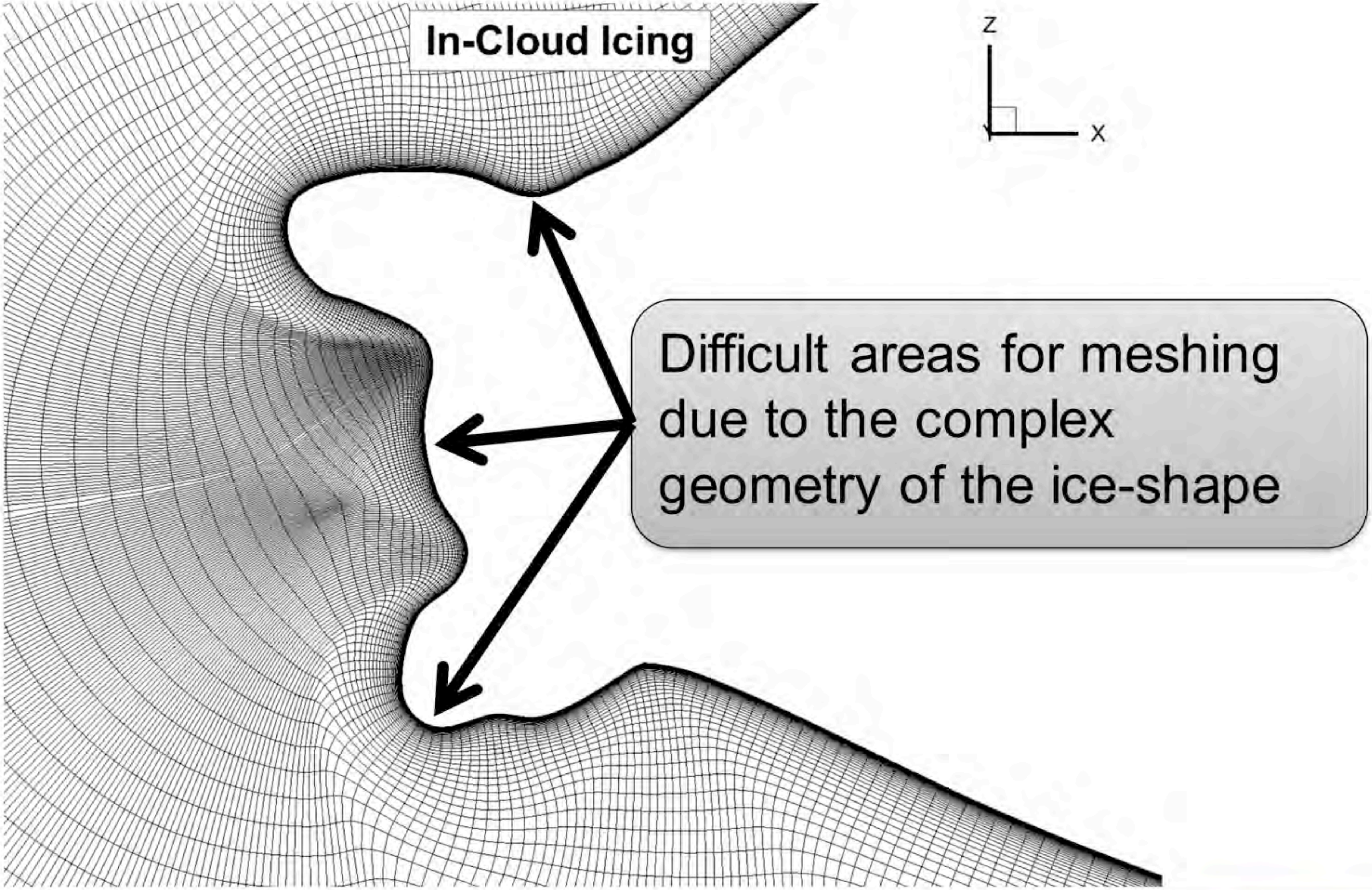


Clean airfoil: DU95
Radius: 38m
Chord length:1.61m
Thickness ratio: 18.0%

2nd step: Spatial discretization



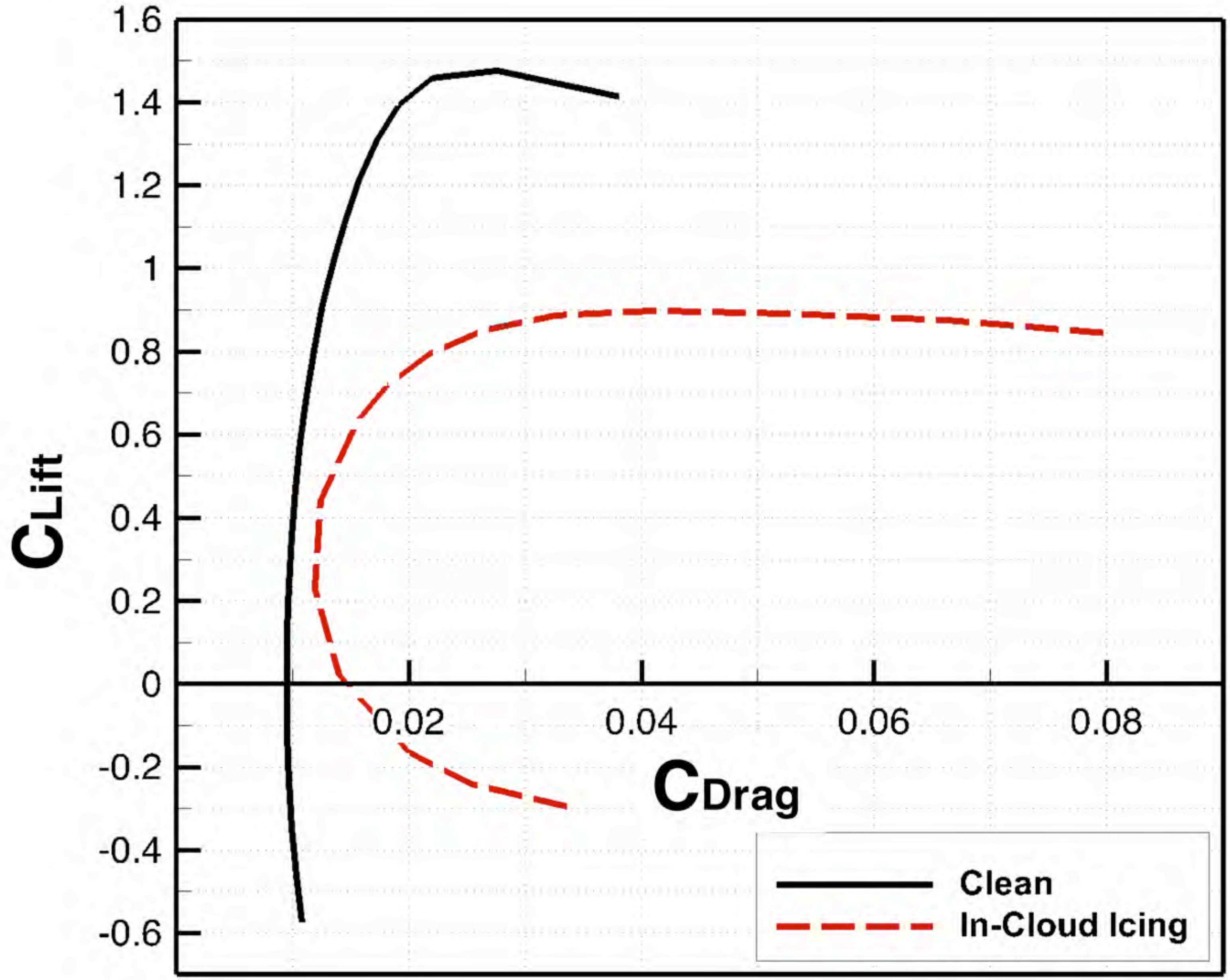
2nd step: Spatial discretization



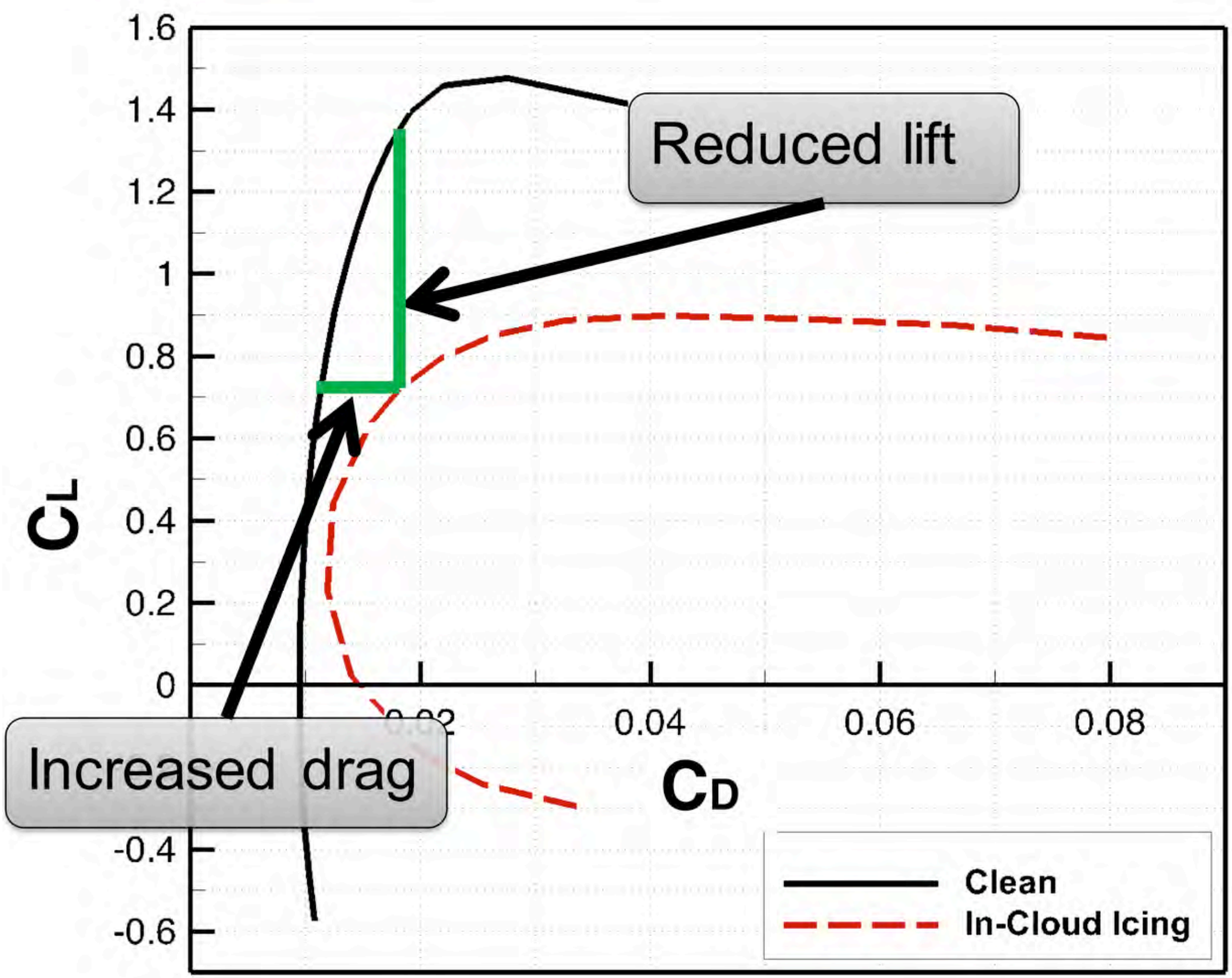
3rd step: Numerical setup

- CFD-solver: TAU (developed by the German Aerospace Center, DLR)
- Flow parameters:
  - Reynolds number = $3*10^6$
  - Mach number = 0.2
- Numerical parameters:
  - Turbulence model: Menter SST
  - Time discretization: Backward Euler (CFL=100)
  - Spatial discretization: central Jameson (scalar dissipation)
  - Multigrid: 3v
  - Transition: 4% of chord for clean / turbulent for iced

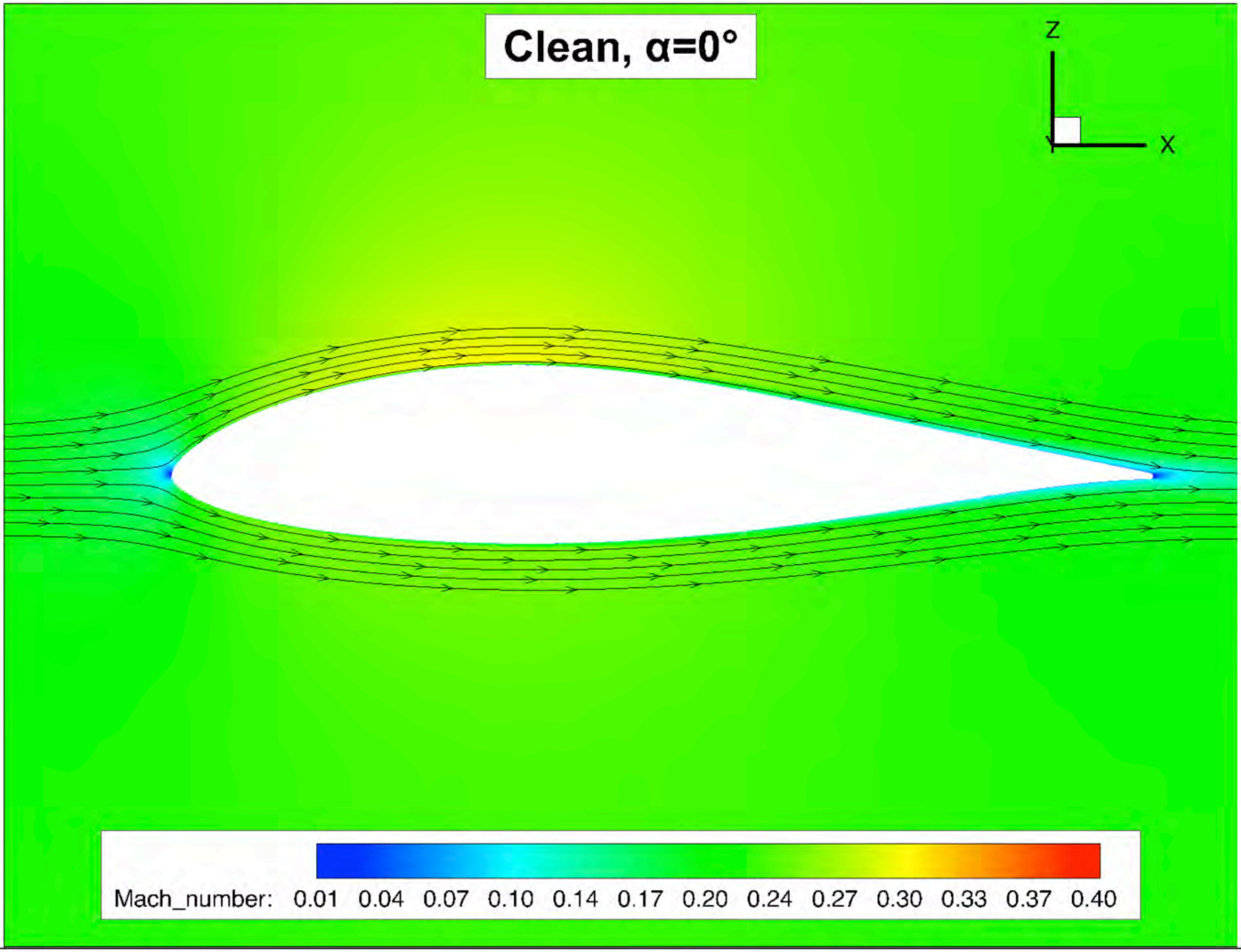
4th step: Results



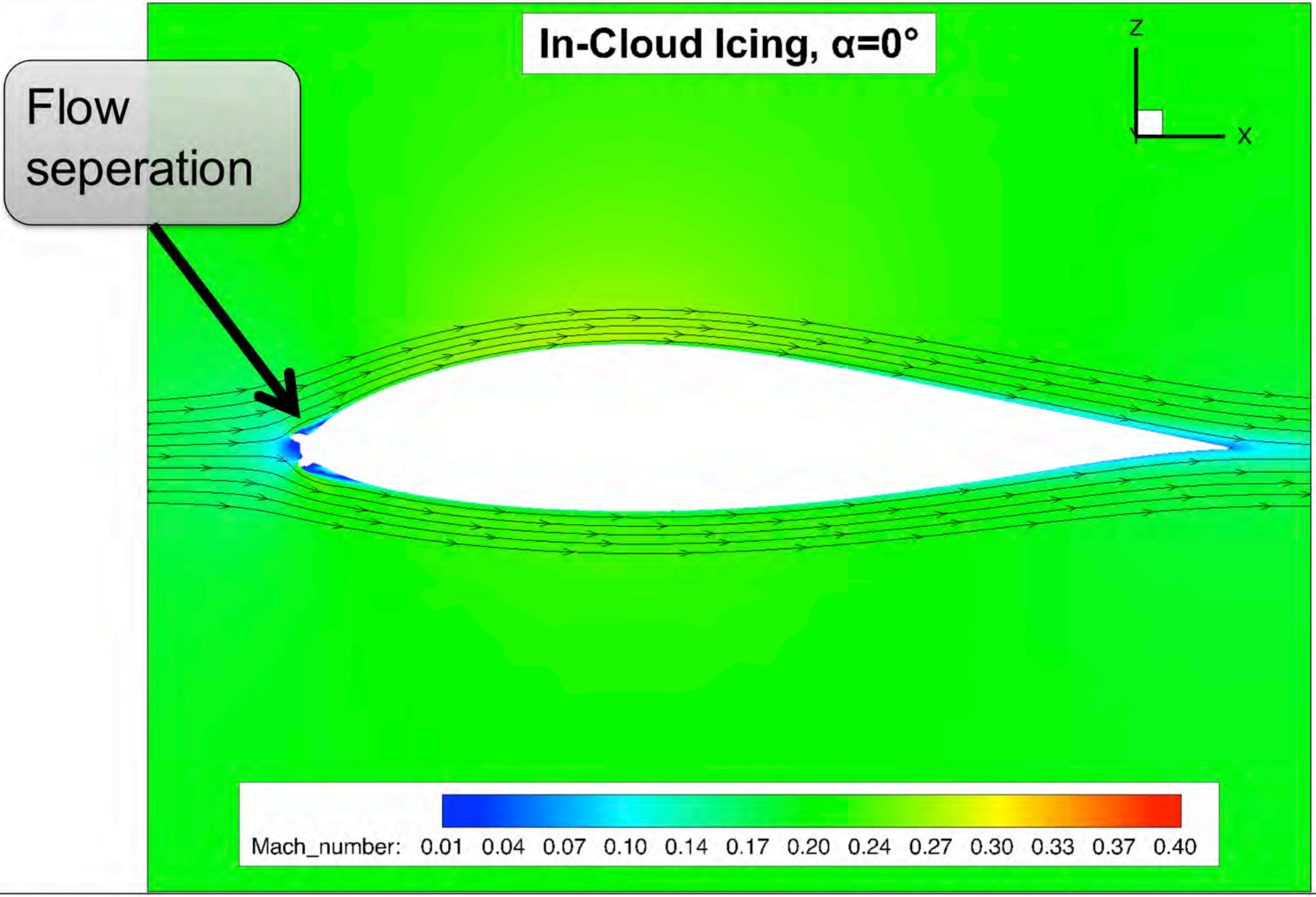
4th step: Results



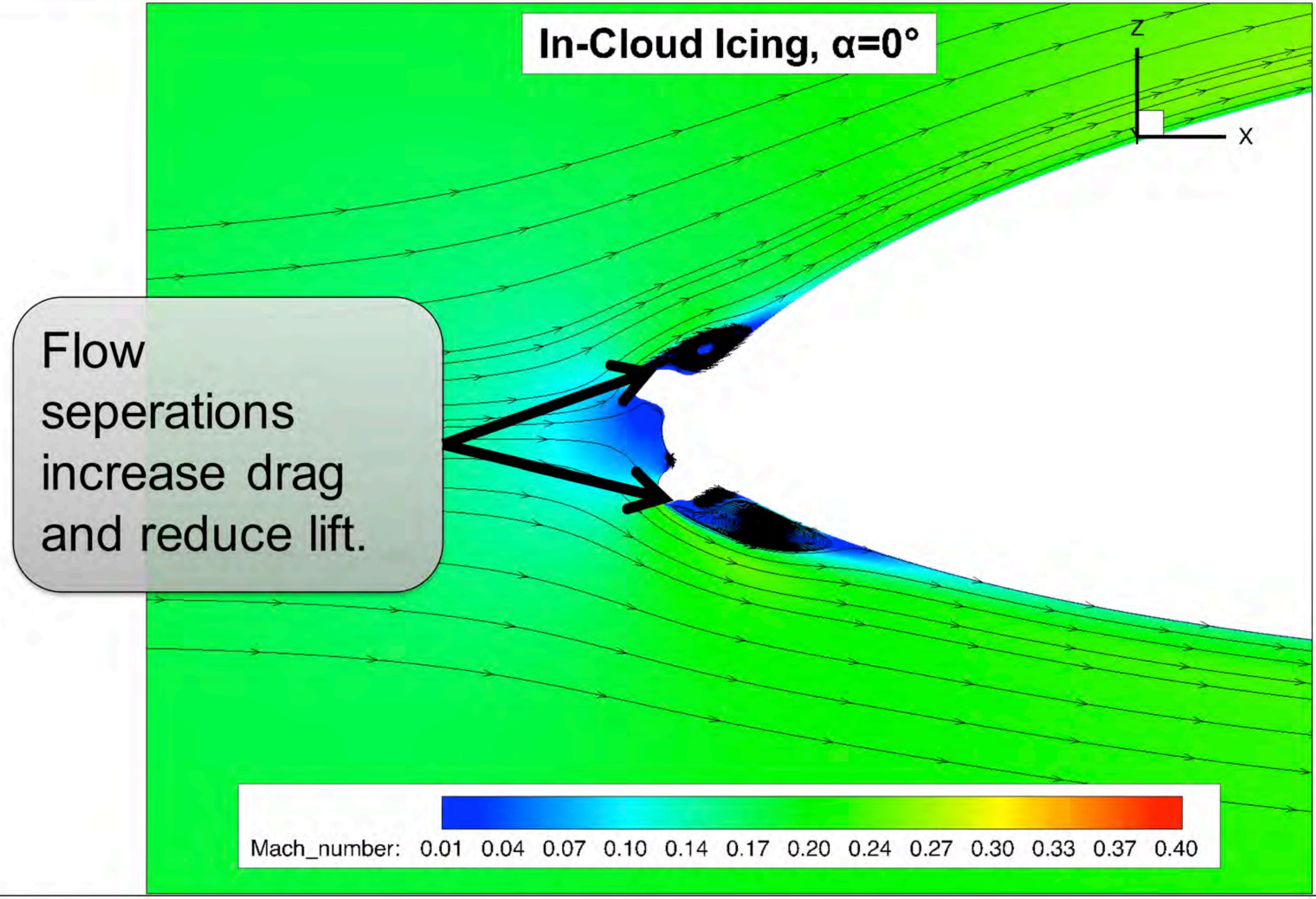
4th step: Results



4th step: Results

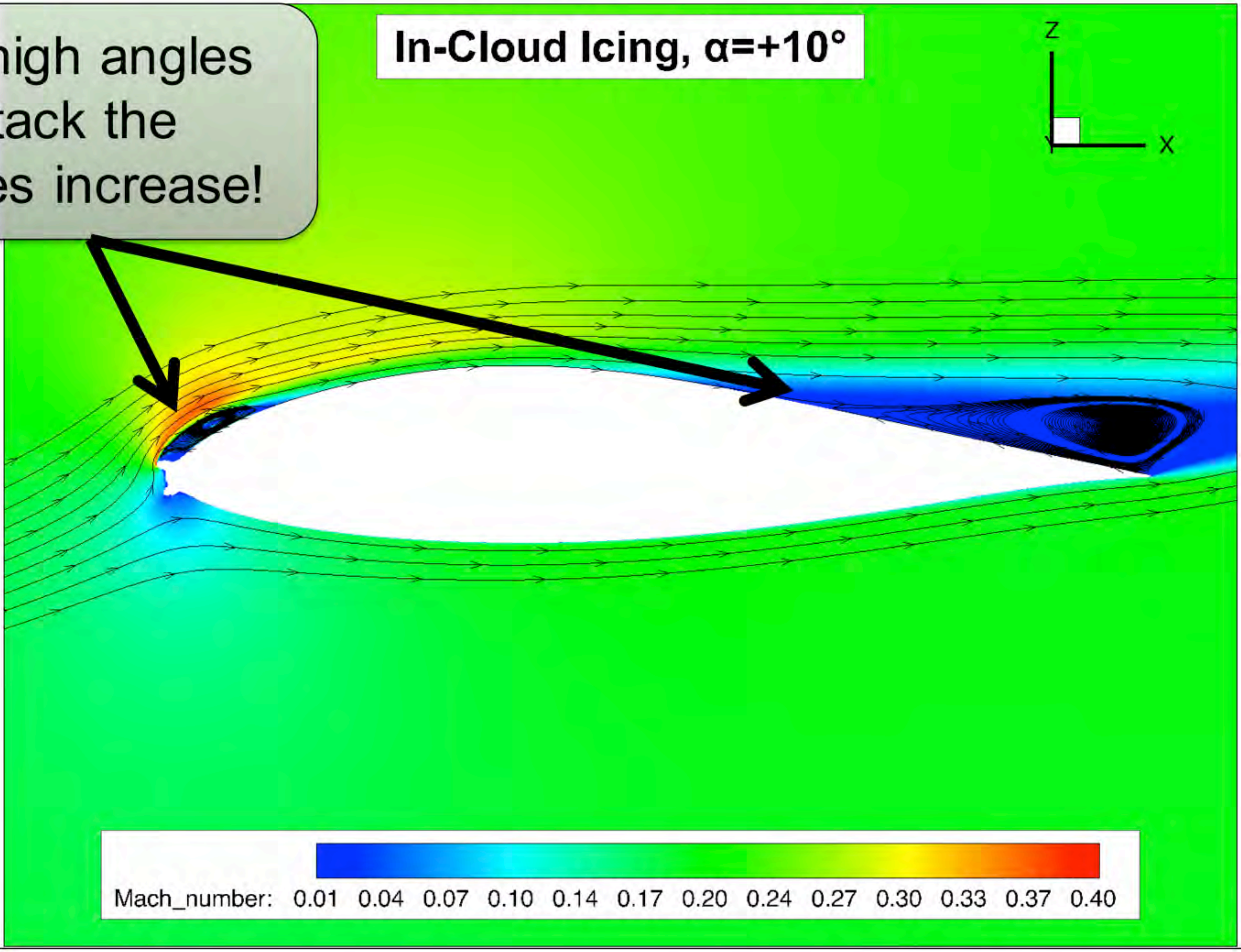


4th step: Results



4th step: Results

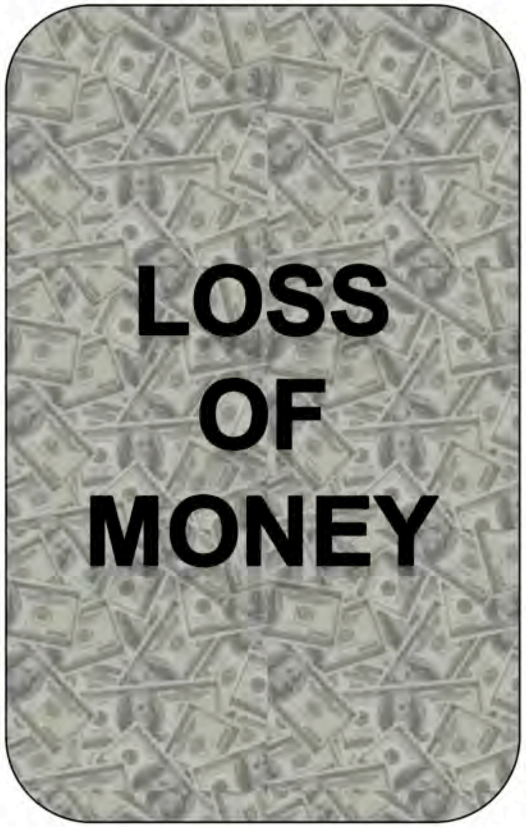
For high angles of attack the losses increase!



5th step: Effects on a wind turbine

Lift reduced → Power output reduced

Drag increased → Mechanical loads increased → Shutdown due to structural safety



„Why is the heat transfer on an iced-airfoil important?“

Importance of heat transfer

- Heat transfer
- Ice accretion
- Required power for anti-icing
- Boundaries for designing a thermal anti-icing system

„What does the process of heat transfer on an iced airfoil look like?“

Characteristic numbers

W. Nusselt
(1882-1957)

Nusselt number = heat transfer

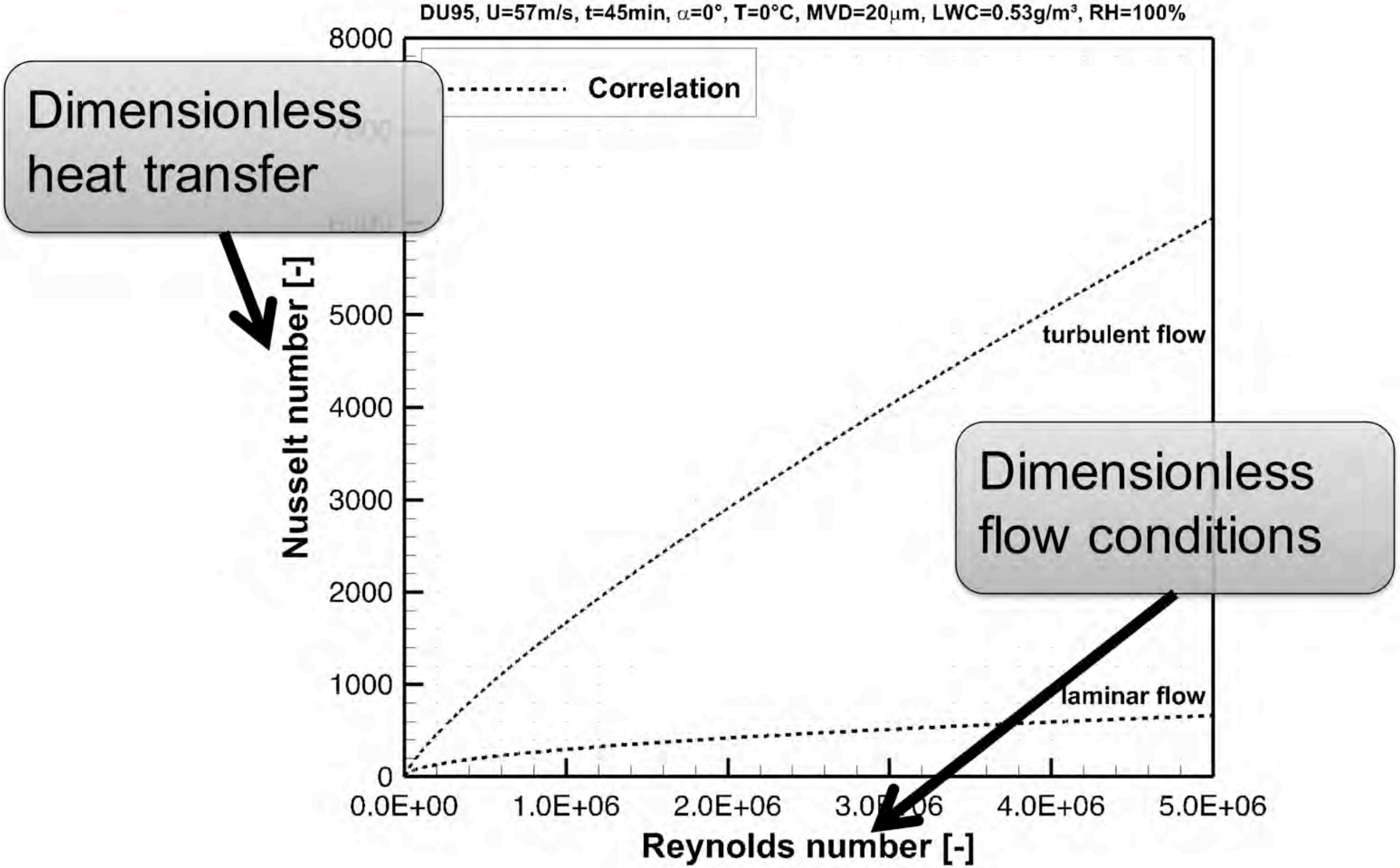
Nu: Nusselt number [-]
htc: total heat transfer coefficient [W/m² K]
x: distance from stagnation point [m]
λ: thermal conductivity [W/m K]

O. Reynolds
(1842-1912)

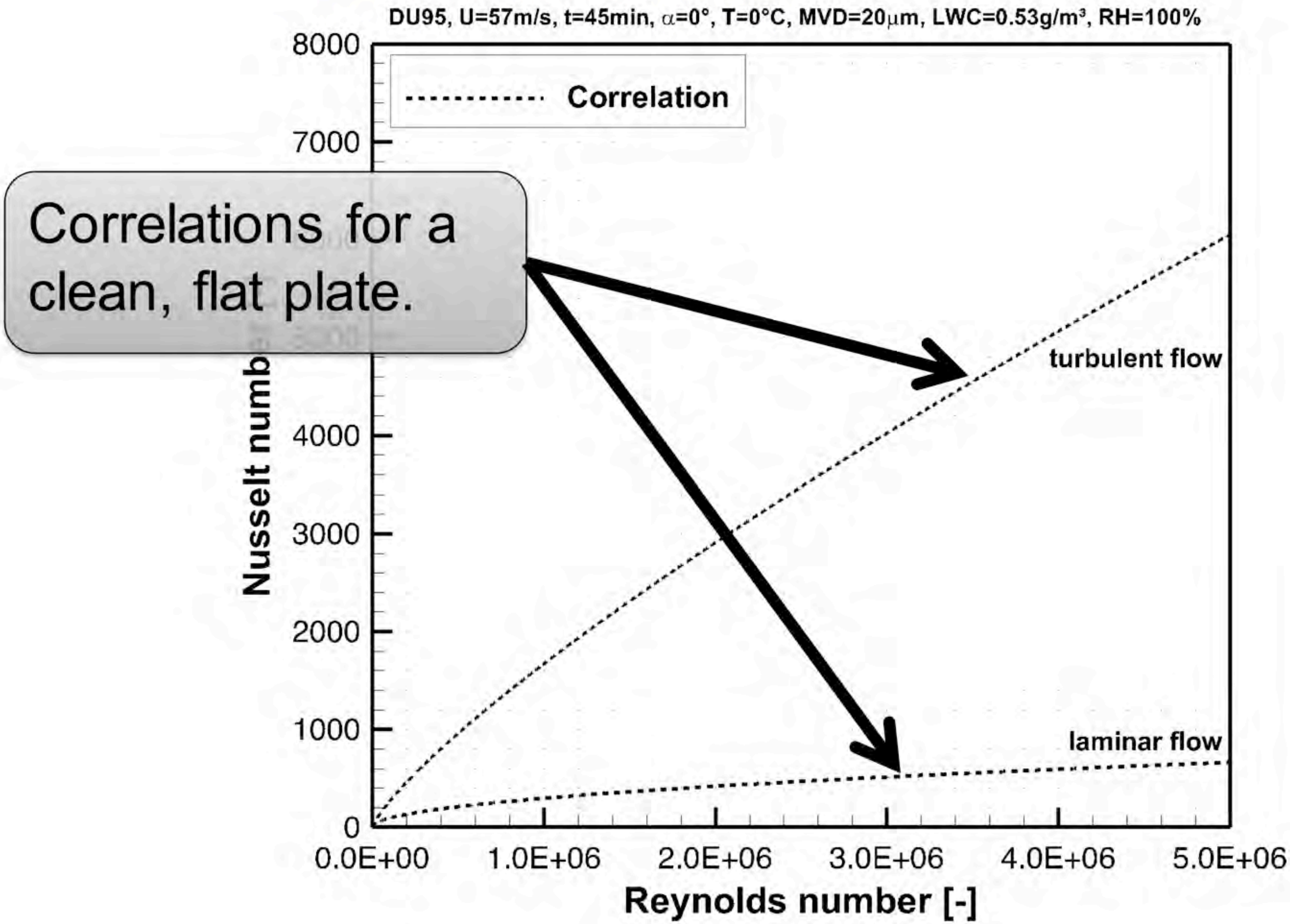
Reynolds number = local flow condition

Re: Reynolds number [-]
: air velocity [m/s]
x: distance from stagnation point [m]
ν: kinematic viscosity [m²/s]

Heat transfer on an iced-airfoil

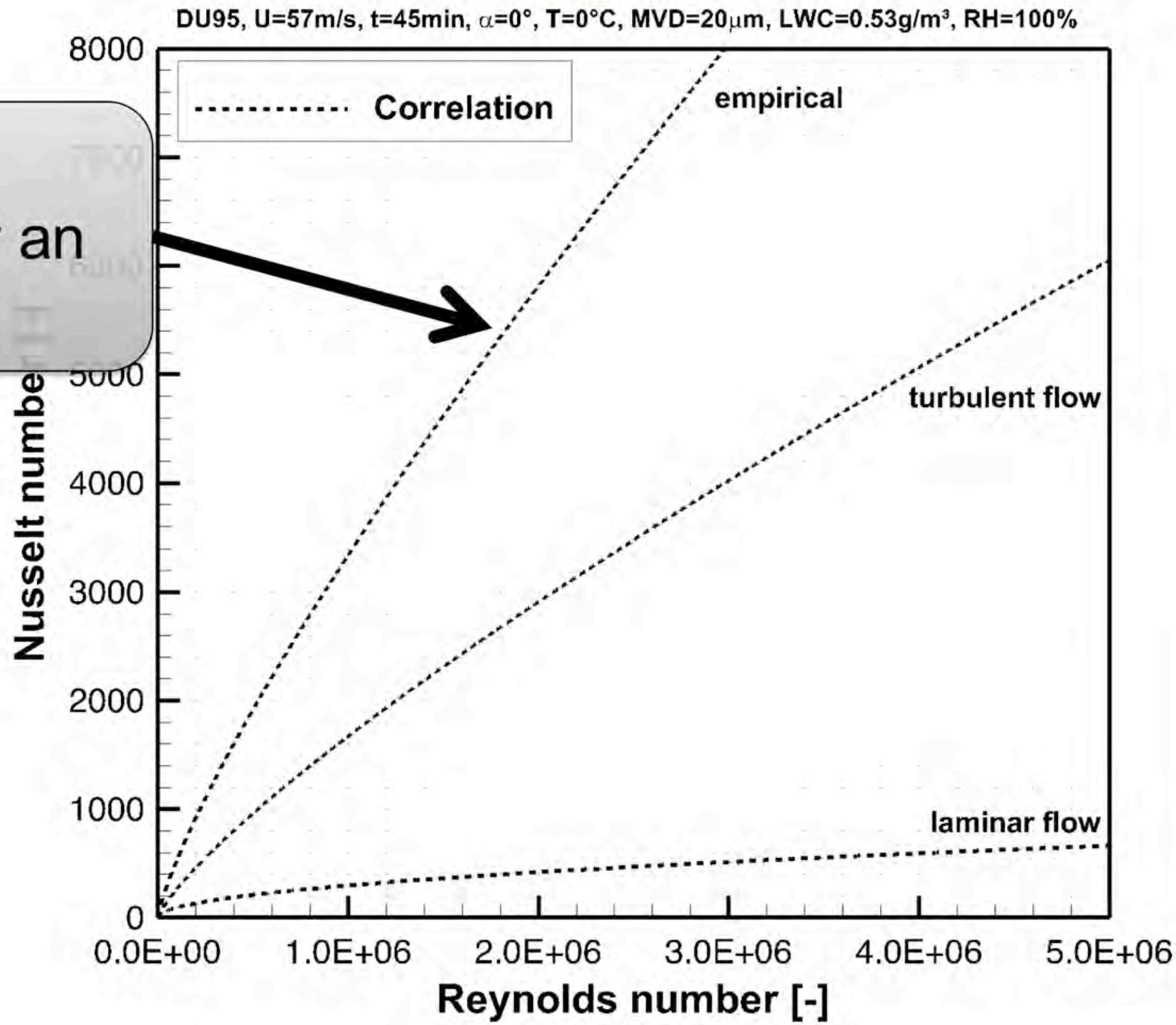


Heat transfer on an iced-airfoil



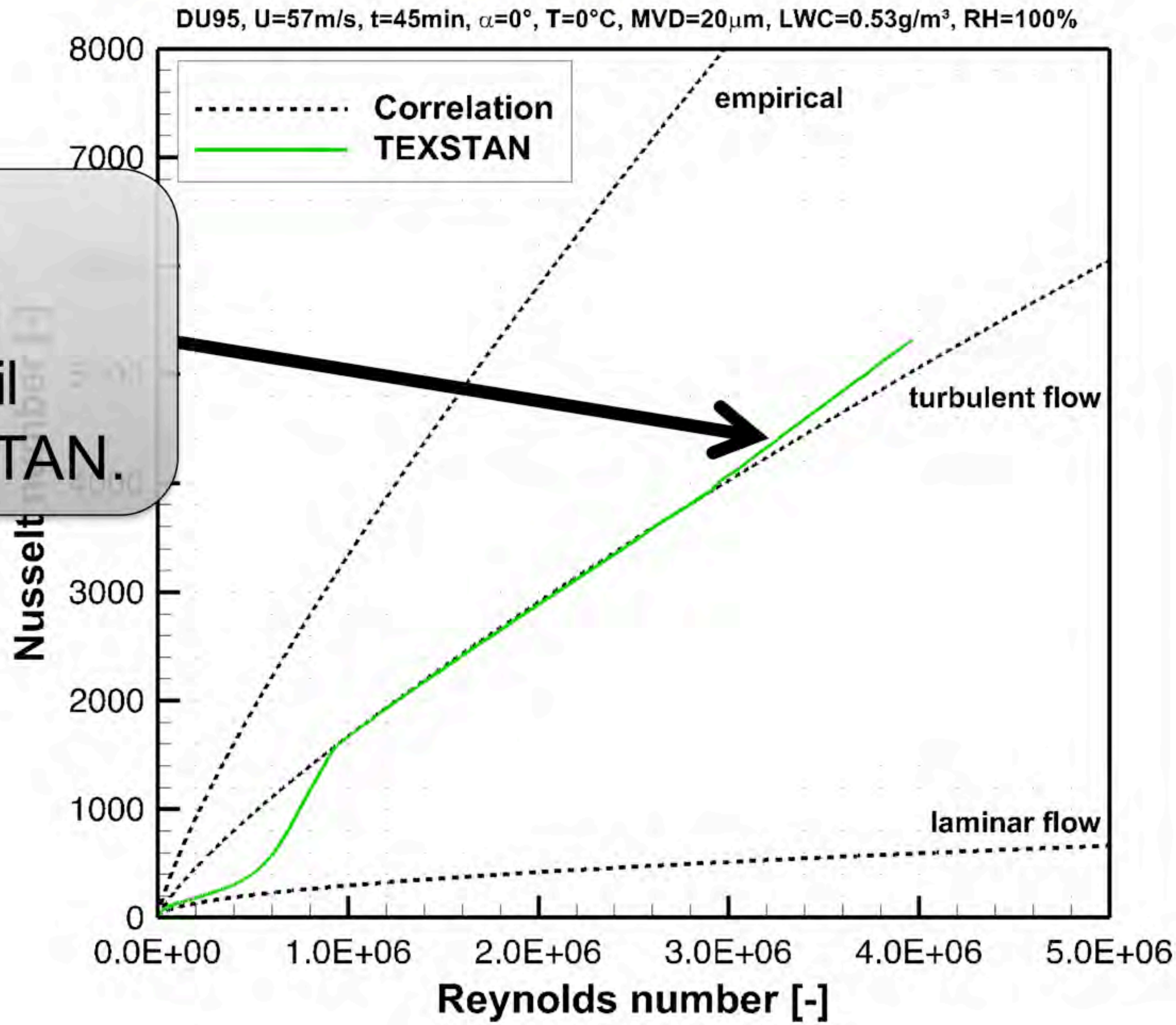
Heat transfer on an iced-airfoil

Empirical solution for an iced-airfoil.



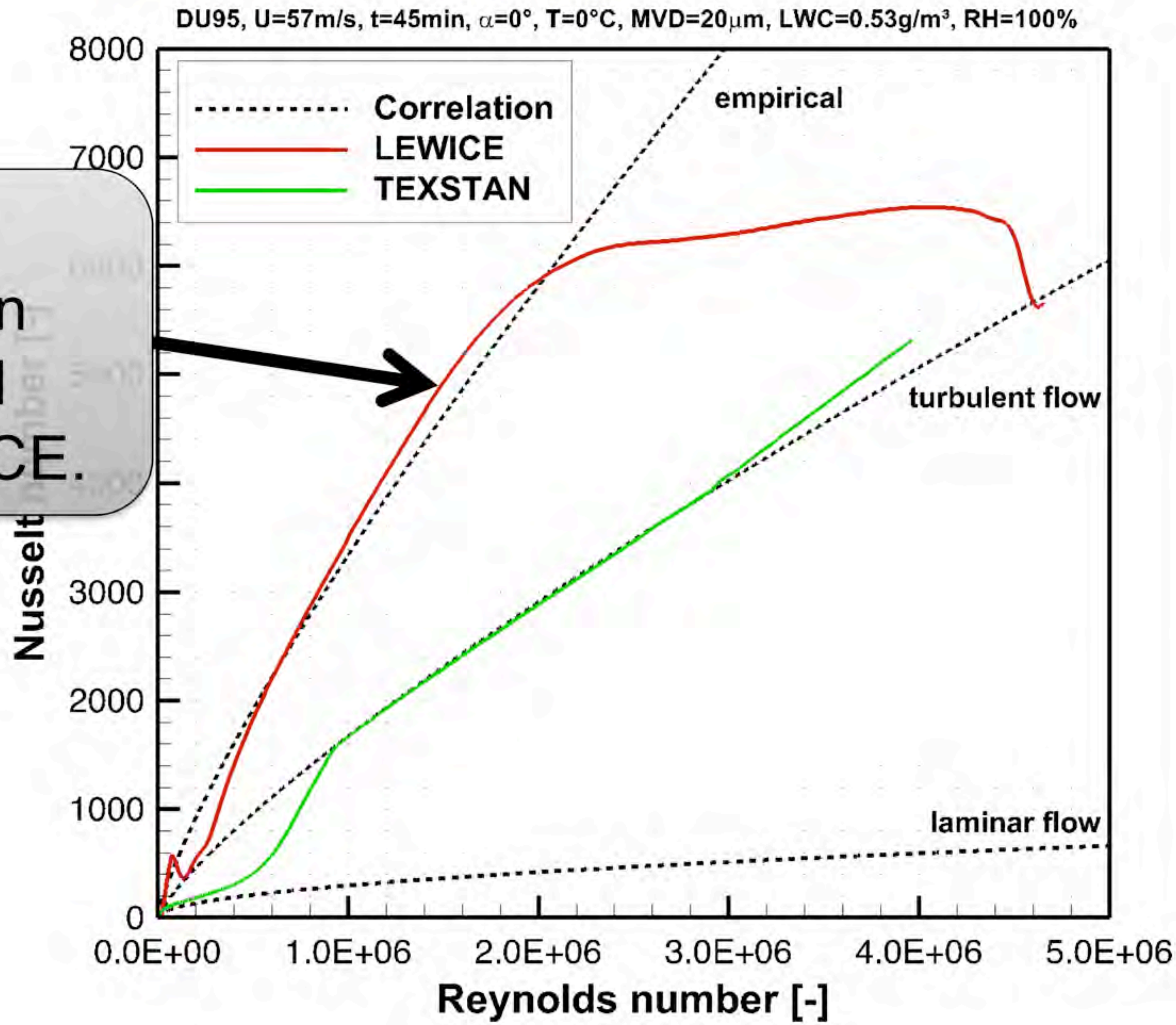
Heat transfer on an iced-airfoil

Simulation result for a **clean** airfoil with TEXSTAN.

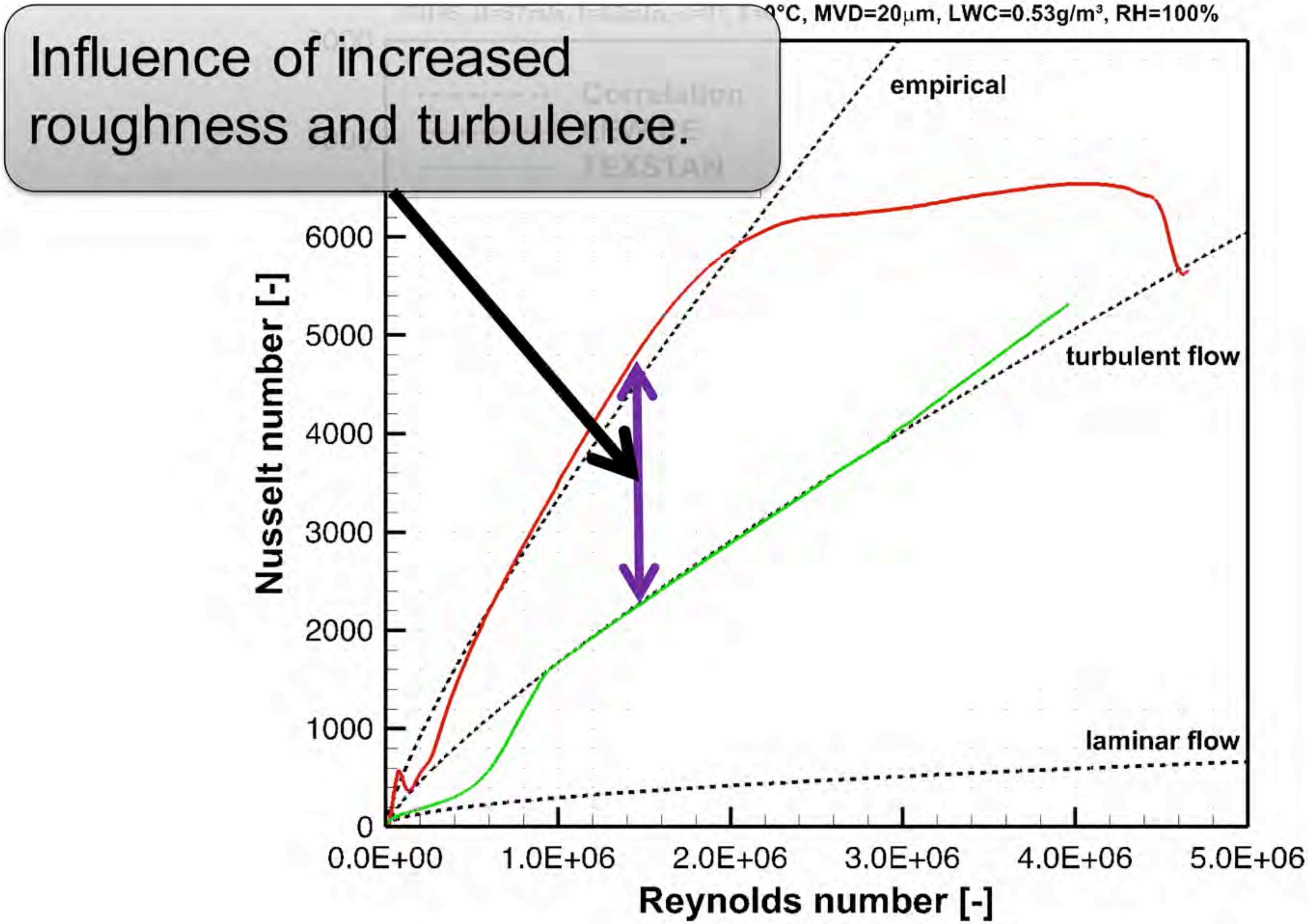


Heat transfer on an iced-airfoil

Simulation result for an **iced-airfoil** with LEWICE.

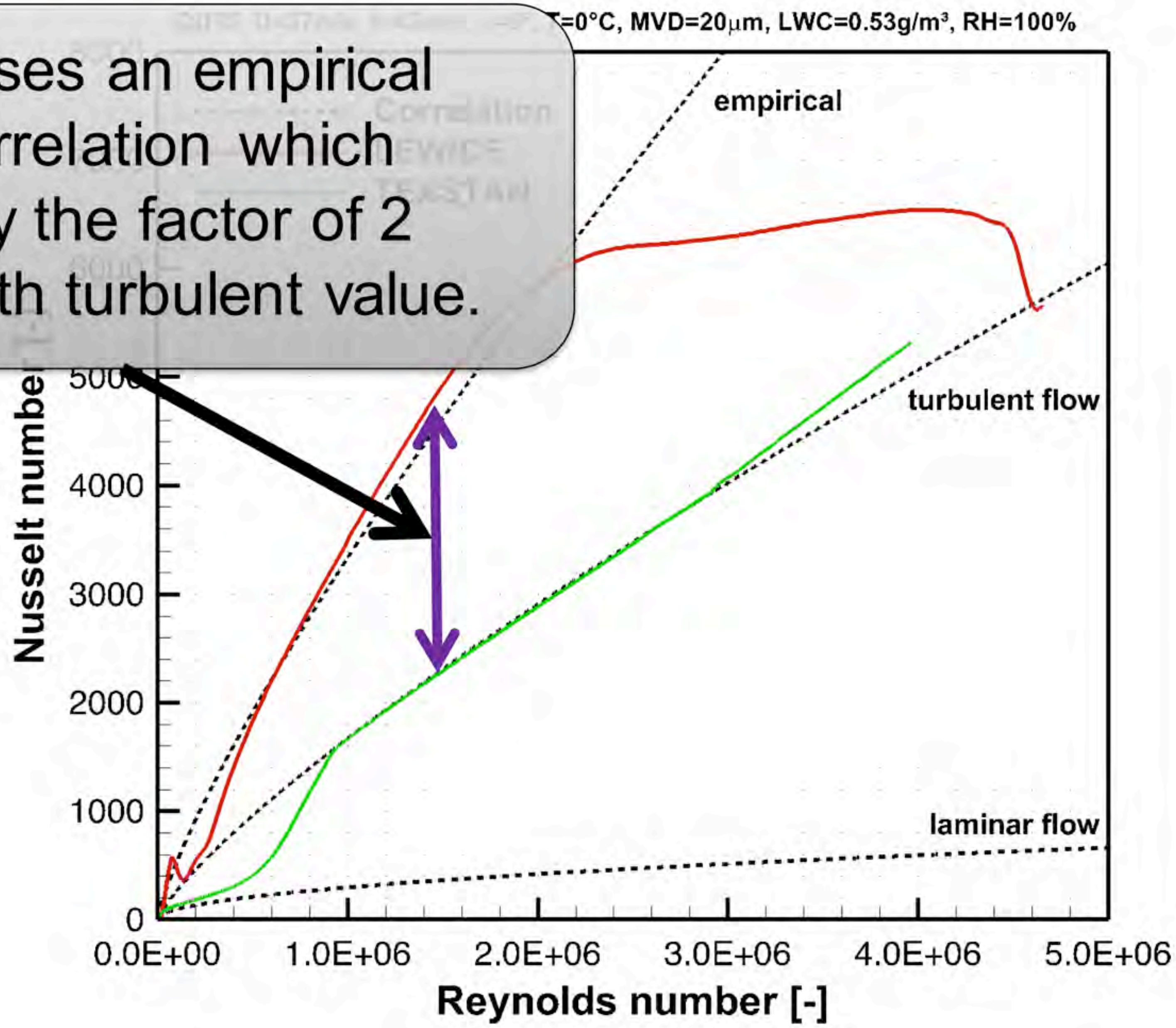


Heat transfer on an iced-airfoil

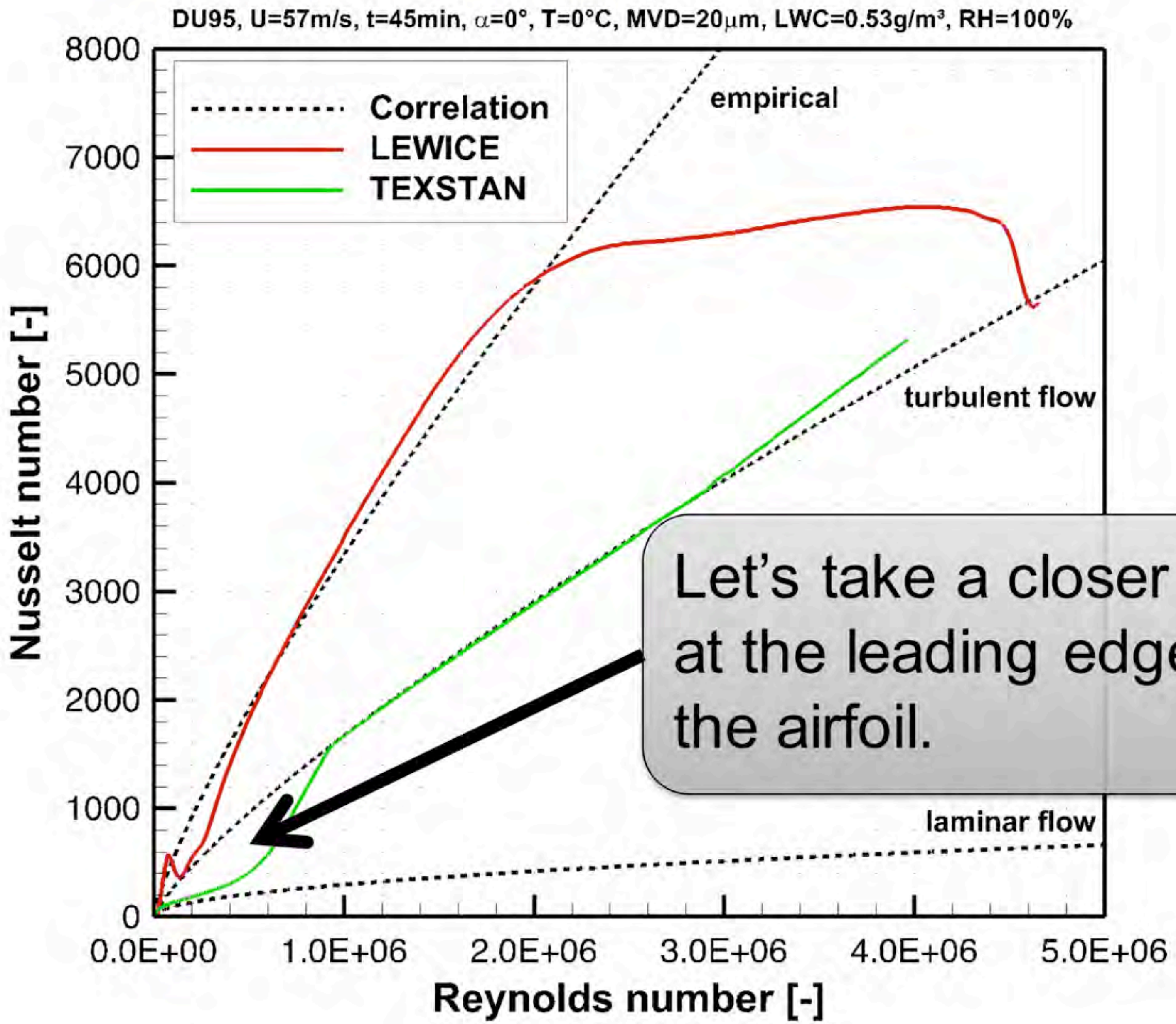


Heat transfer on an iced-airfoil

LEWICE uses an empirical Nusselt-correlation which deviates by the factor of 2 from smooth turbulent value.

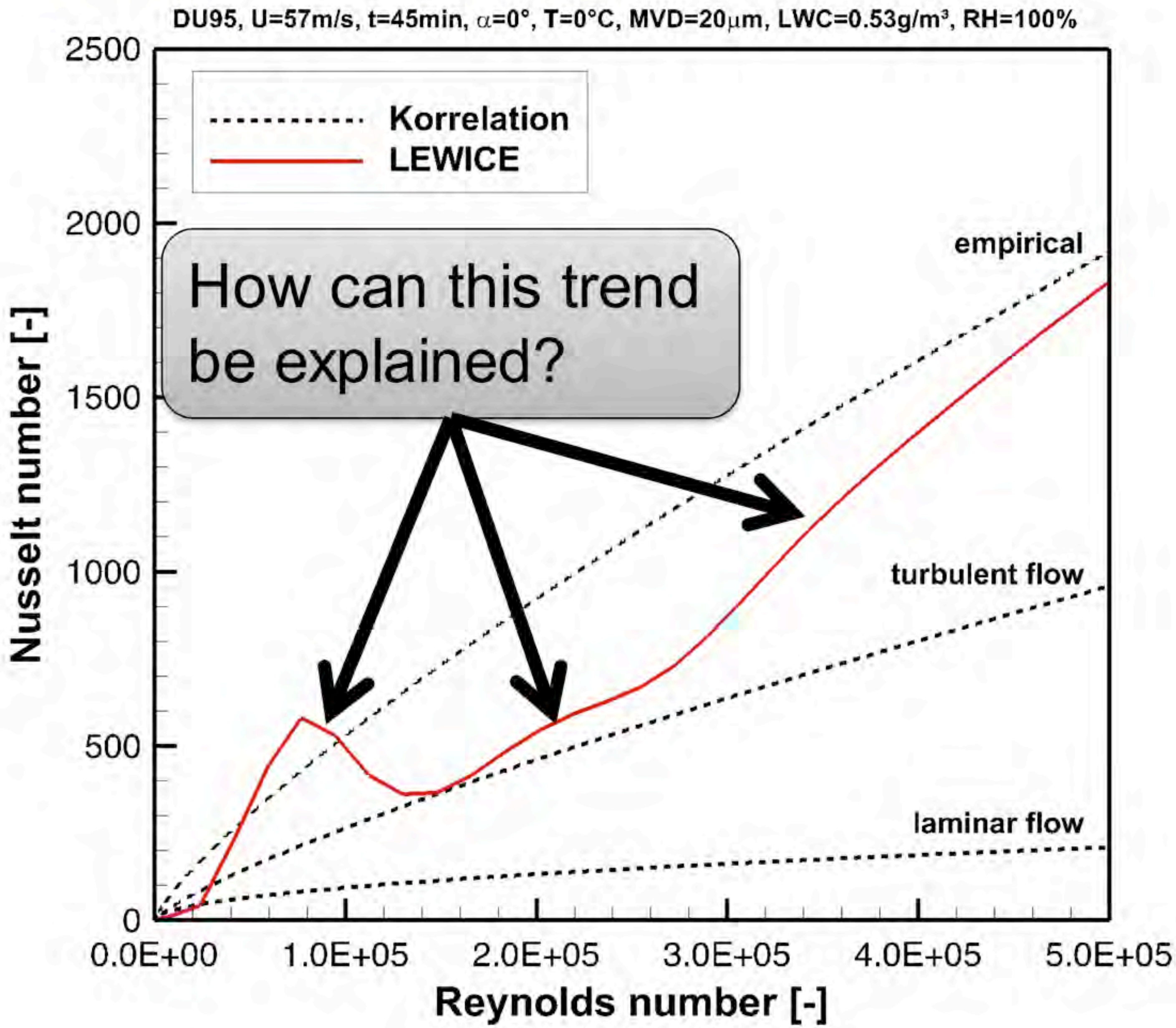


Heat transfer on an iced-airfoil

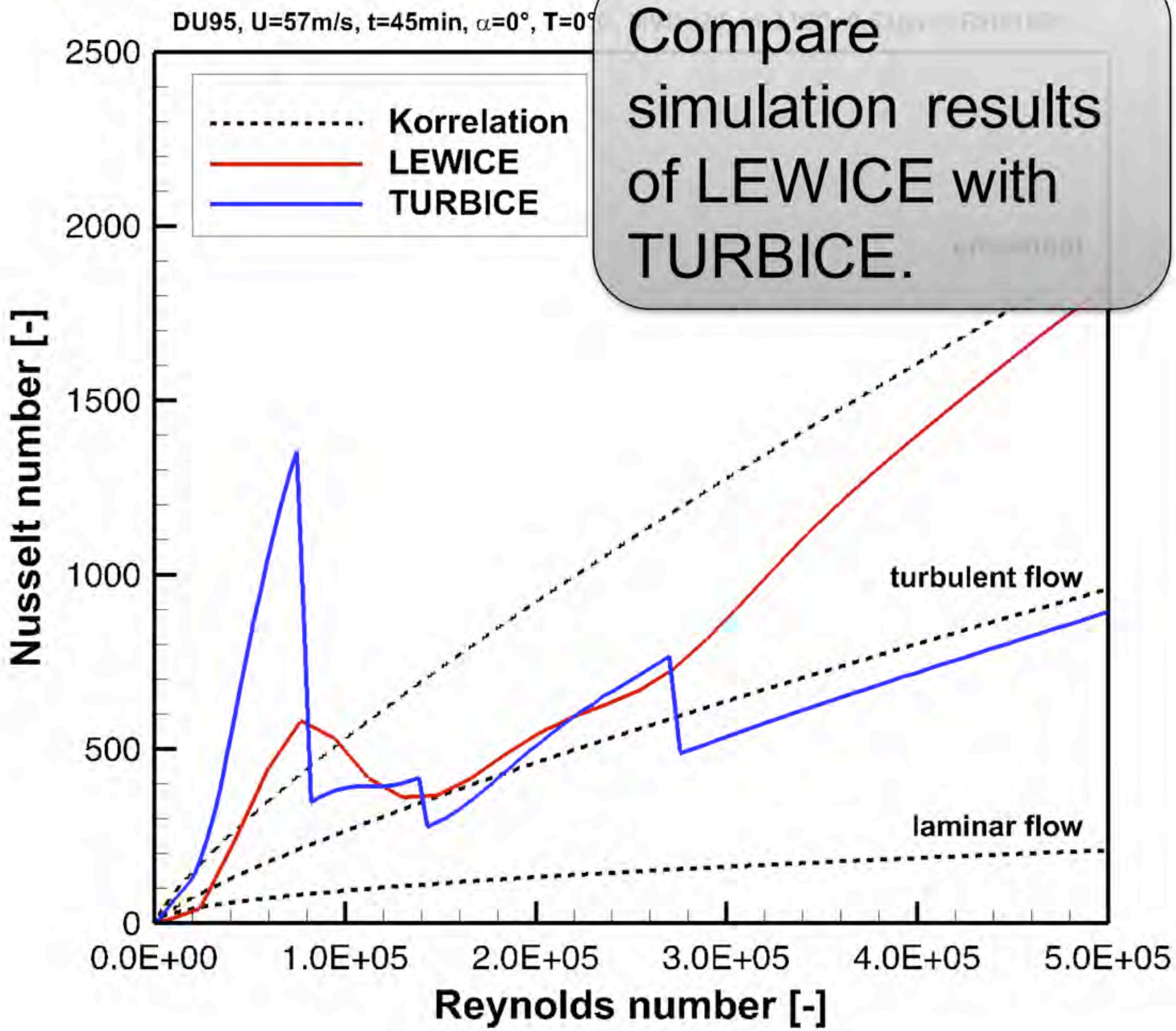


Let's take a closer look at the leading edge of the airfoil.

Heat transfer on an iced-airfoil

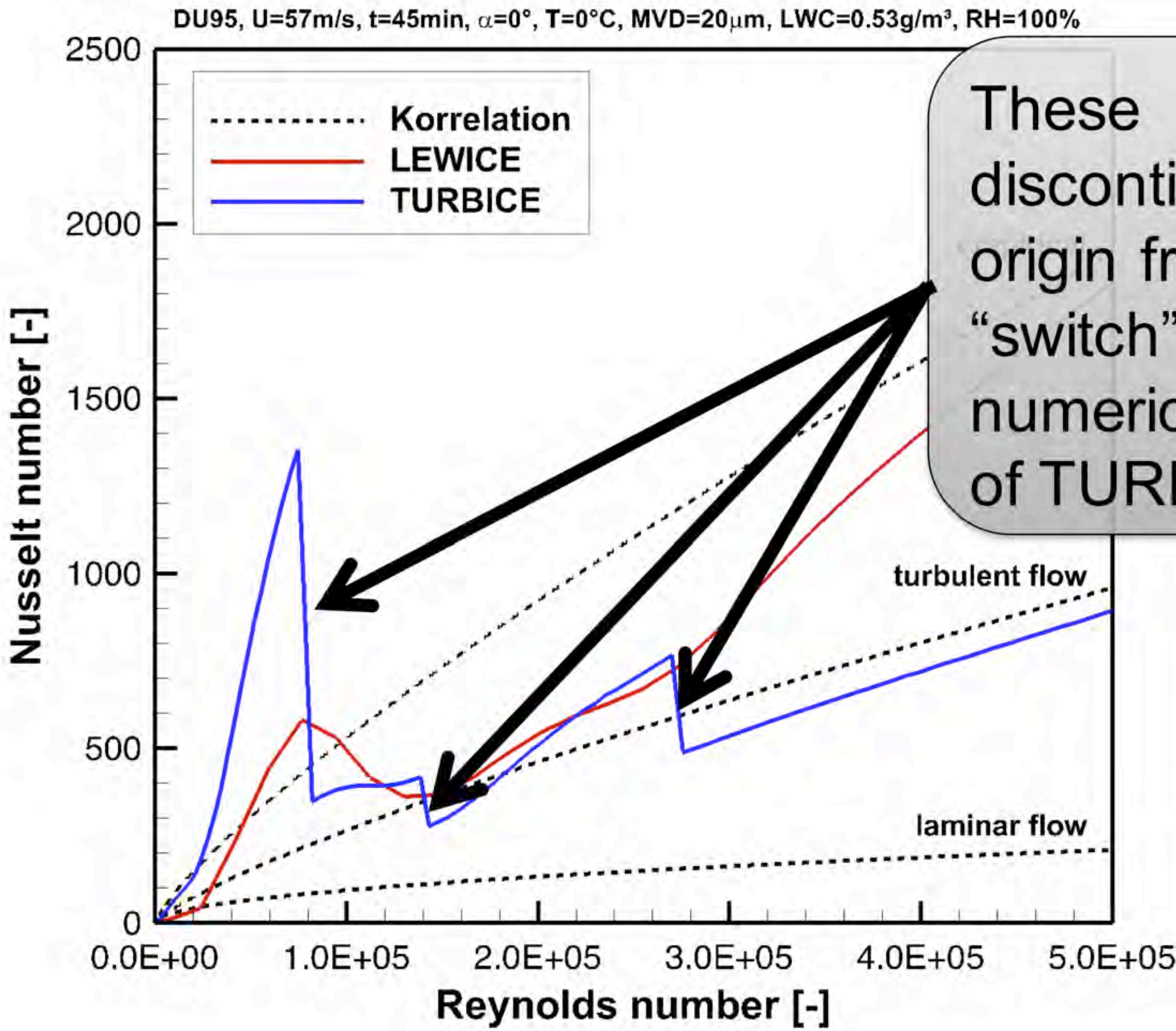


Heat transfer on an iced-airfoil



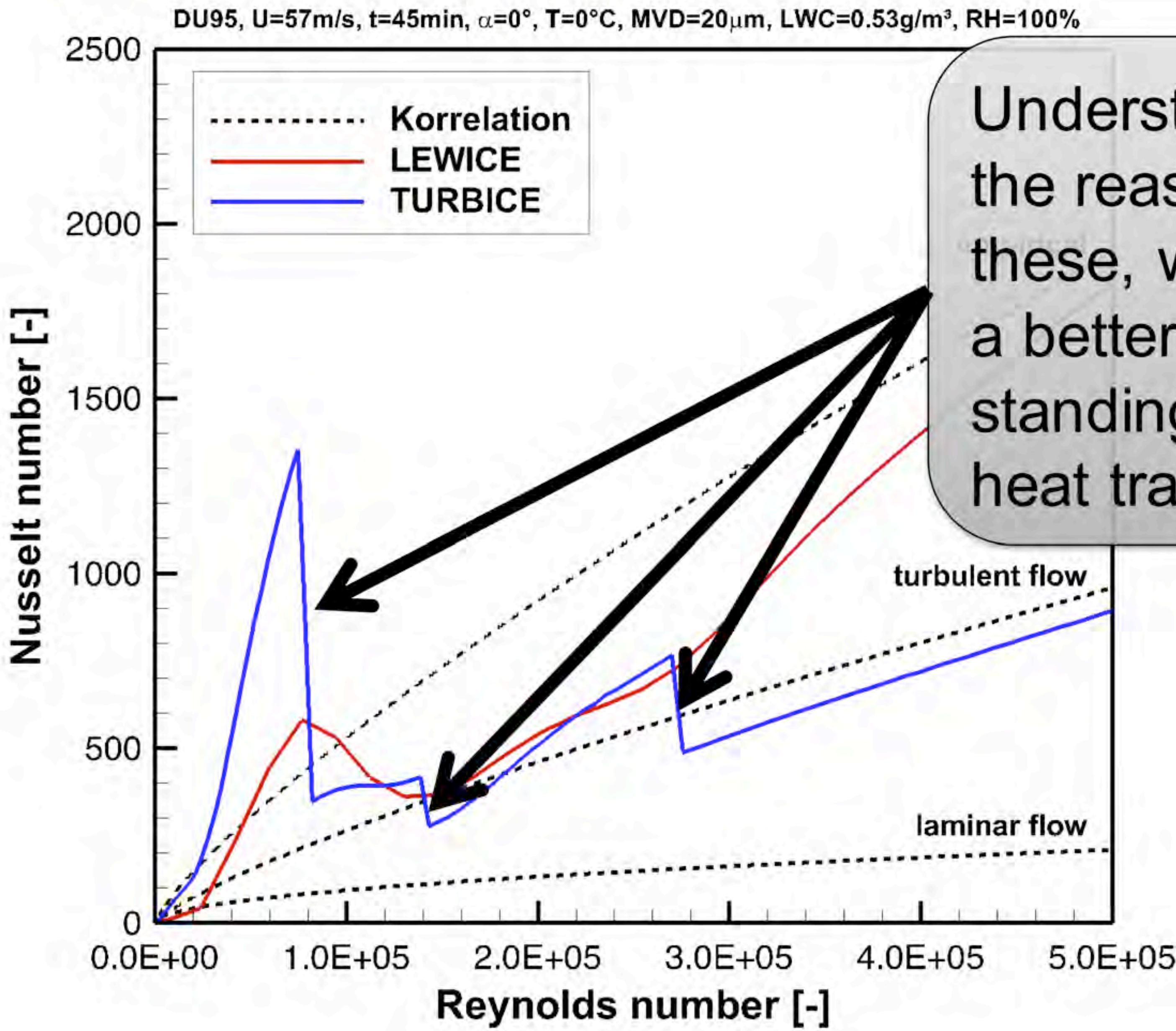
Compare simulation results of LEWICE with TURBICE.

Heat transfer on an iced-airfoil



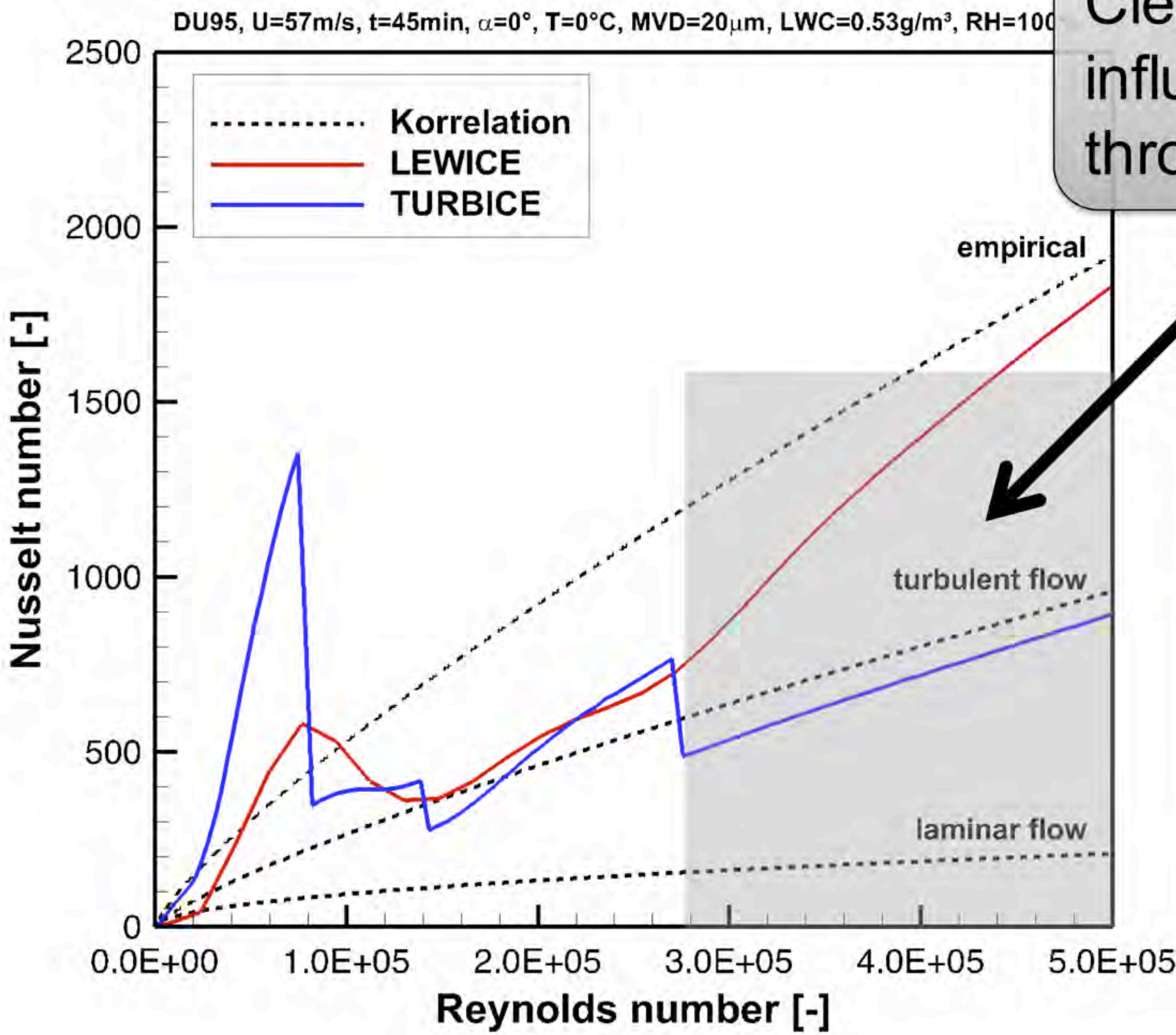
These discontinuities origin from a “switch” in the numerical model of TURBICE.

Heat transfer on an iced-airfoil



Understanding the reason for these, will lead to a better understanding of the heat transfer.

Heat transfer on an iced-airfoil

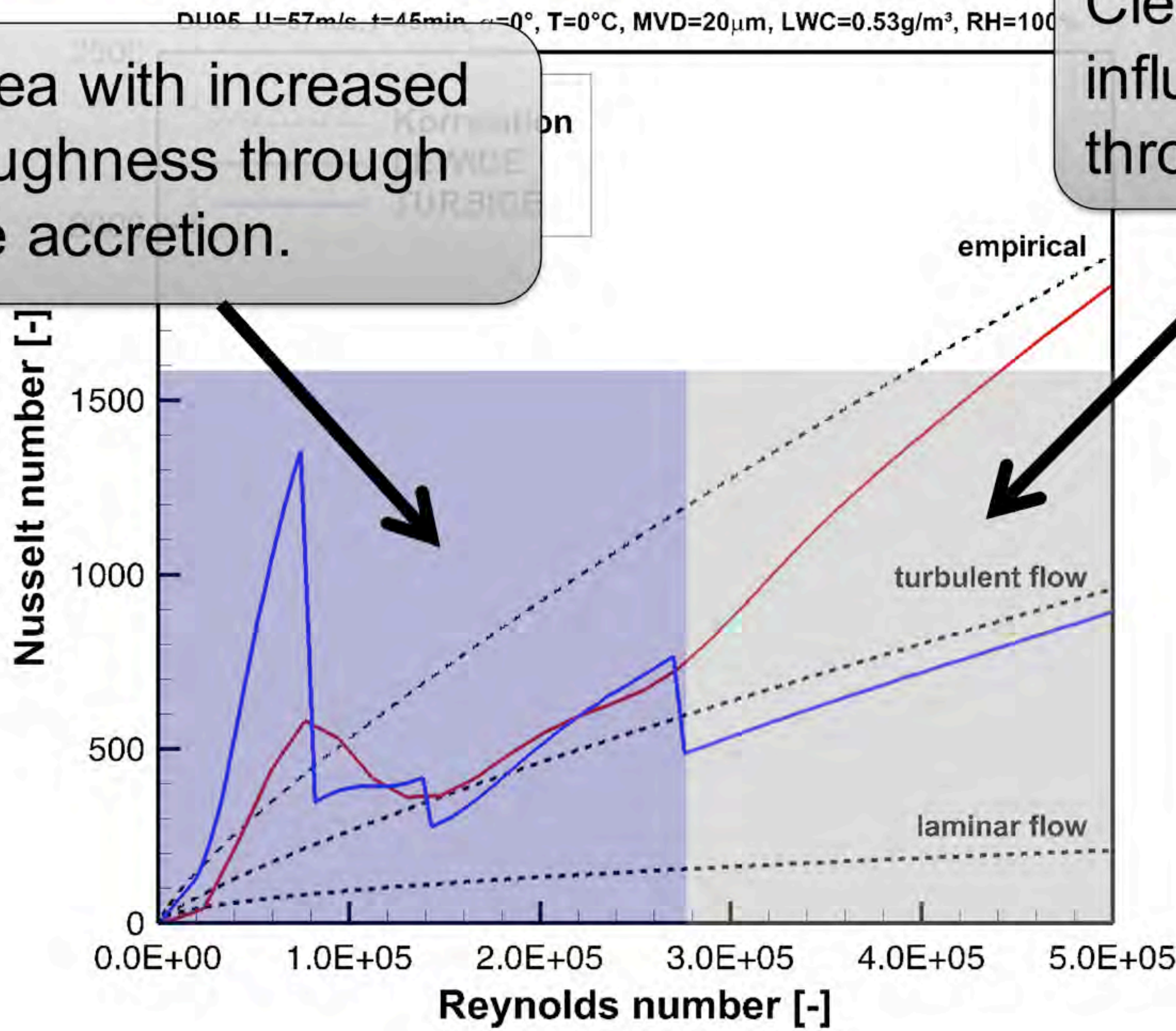


Clean area. No influence through icing.

Heat transfer on an iced-airfoil

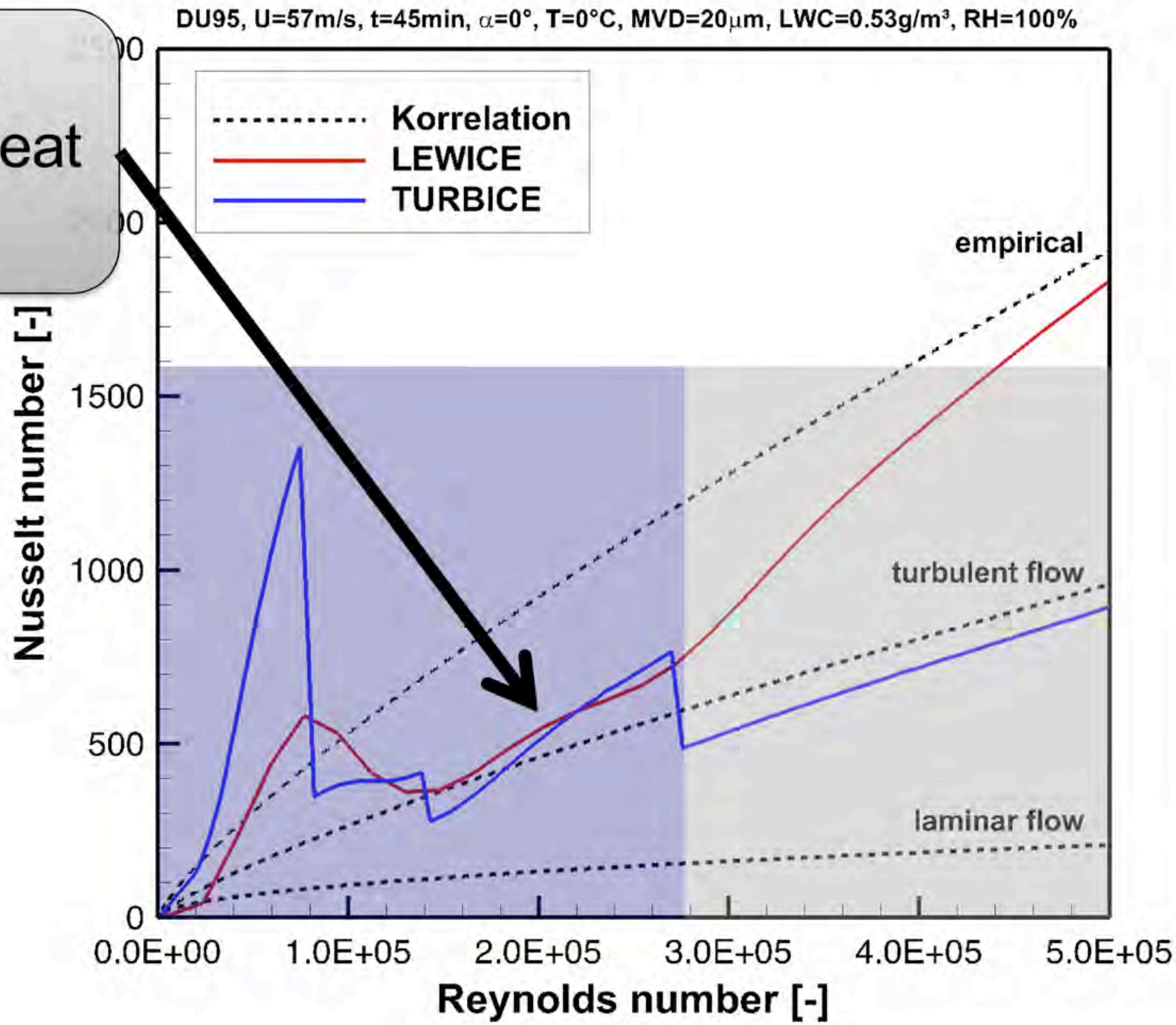
Area with increased roughness through ice accretion.

Clean area. No influence through icing.

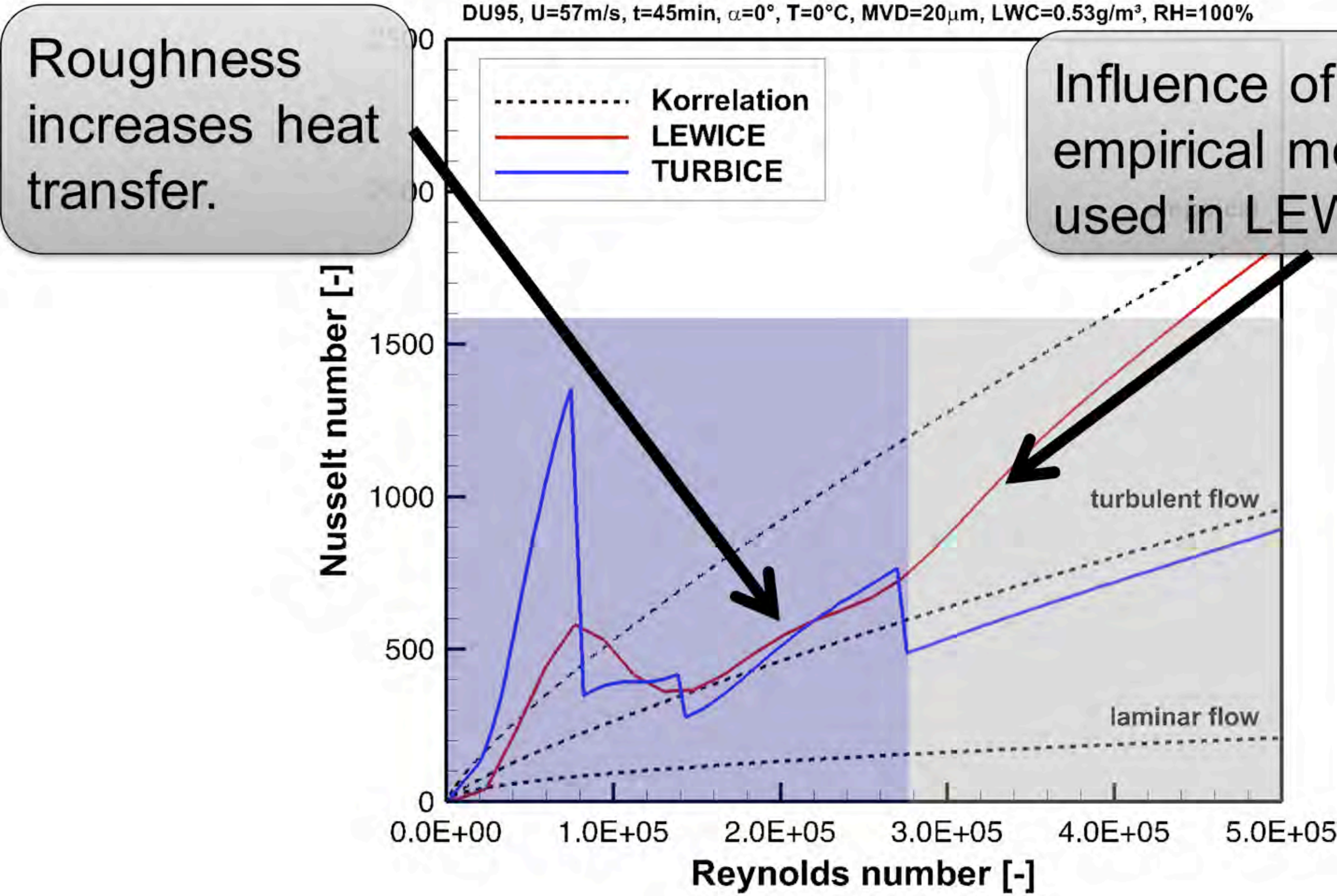


Heat transfer on an iced-airfoil

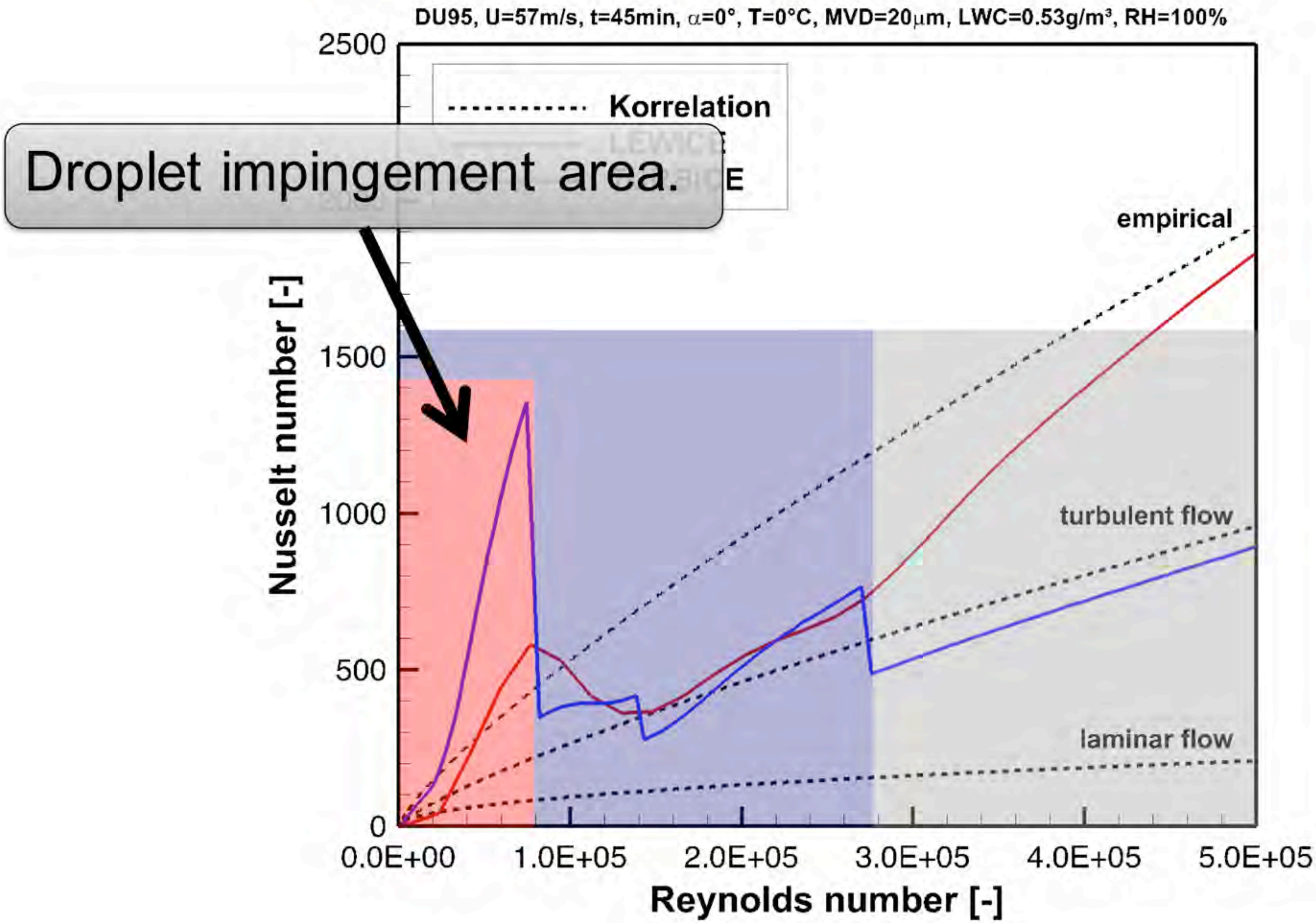
Roughness increases heat transfer.



Heat transfer on an iced-airfoil

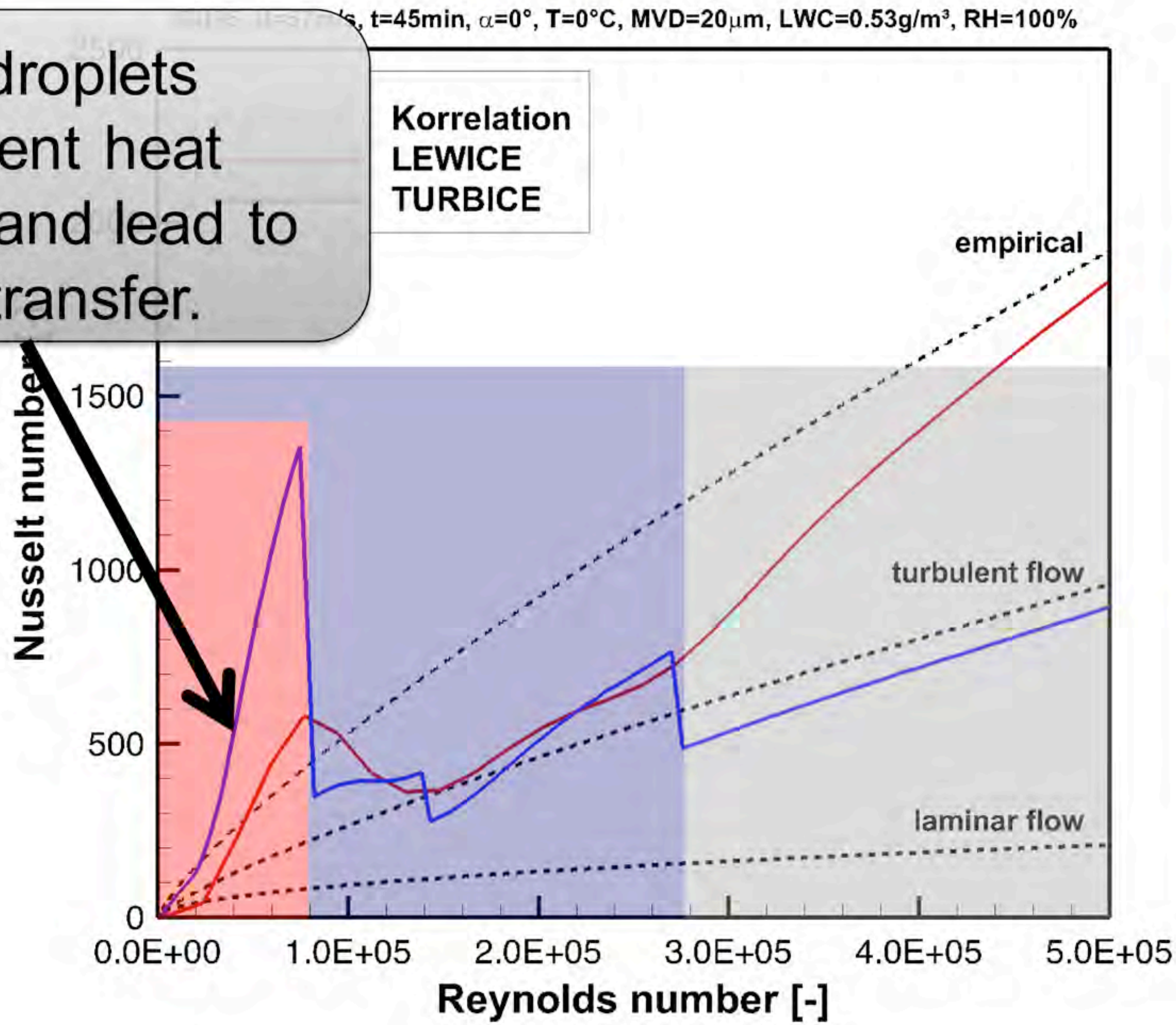


Heat transfer on an iced-airfoil

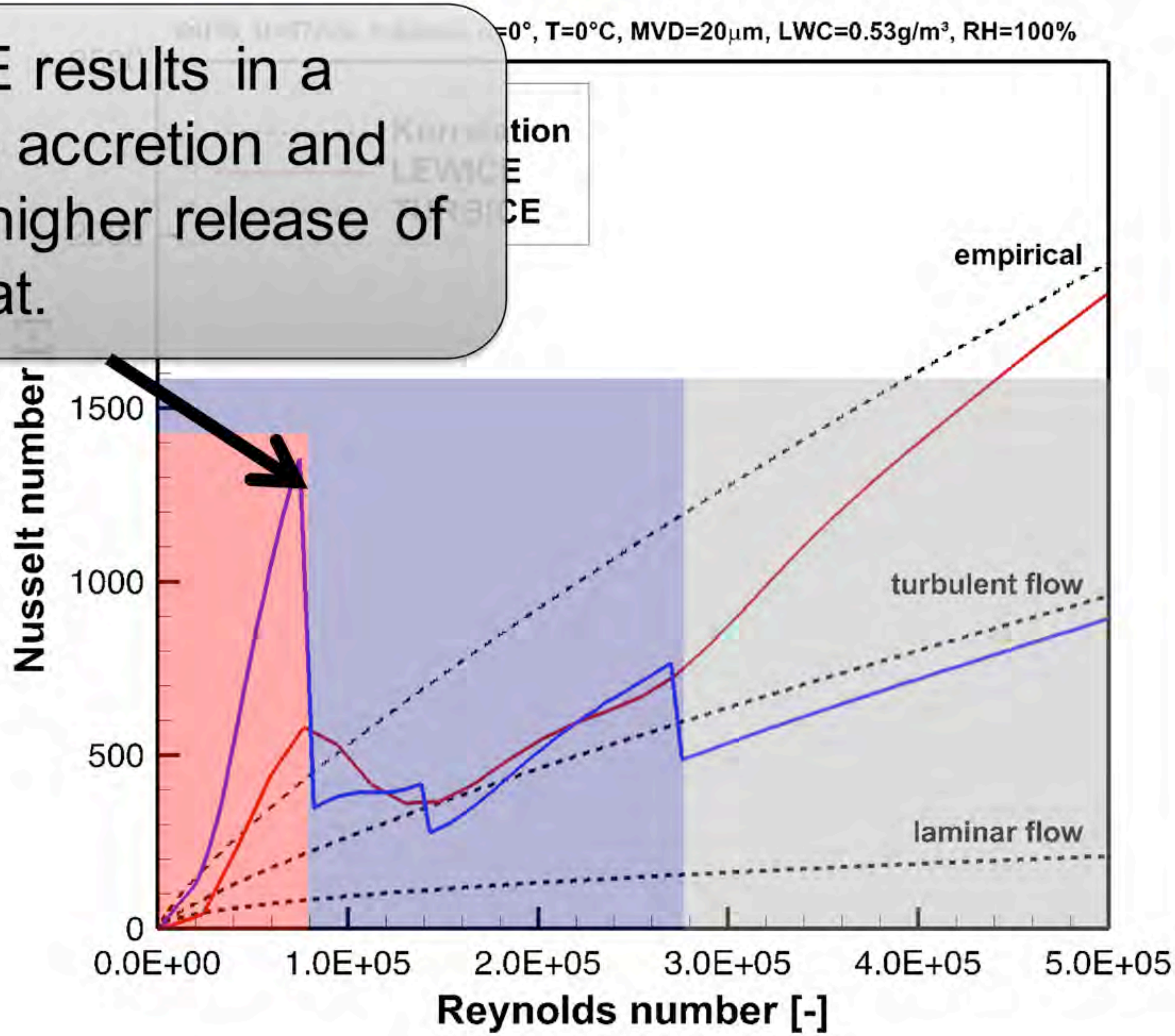


Heat transfer on an iced-airfoil

Incoming droplets release latent heat (freezing) and lead to high heat transfer.



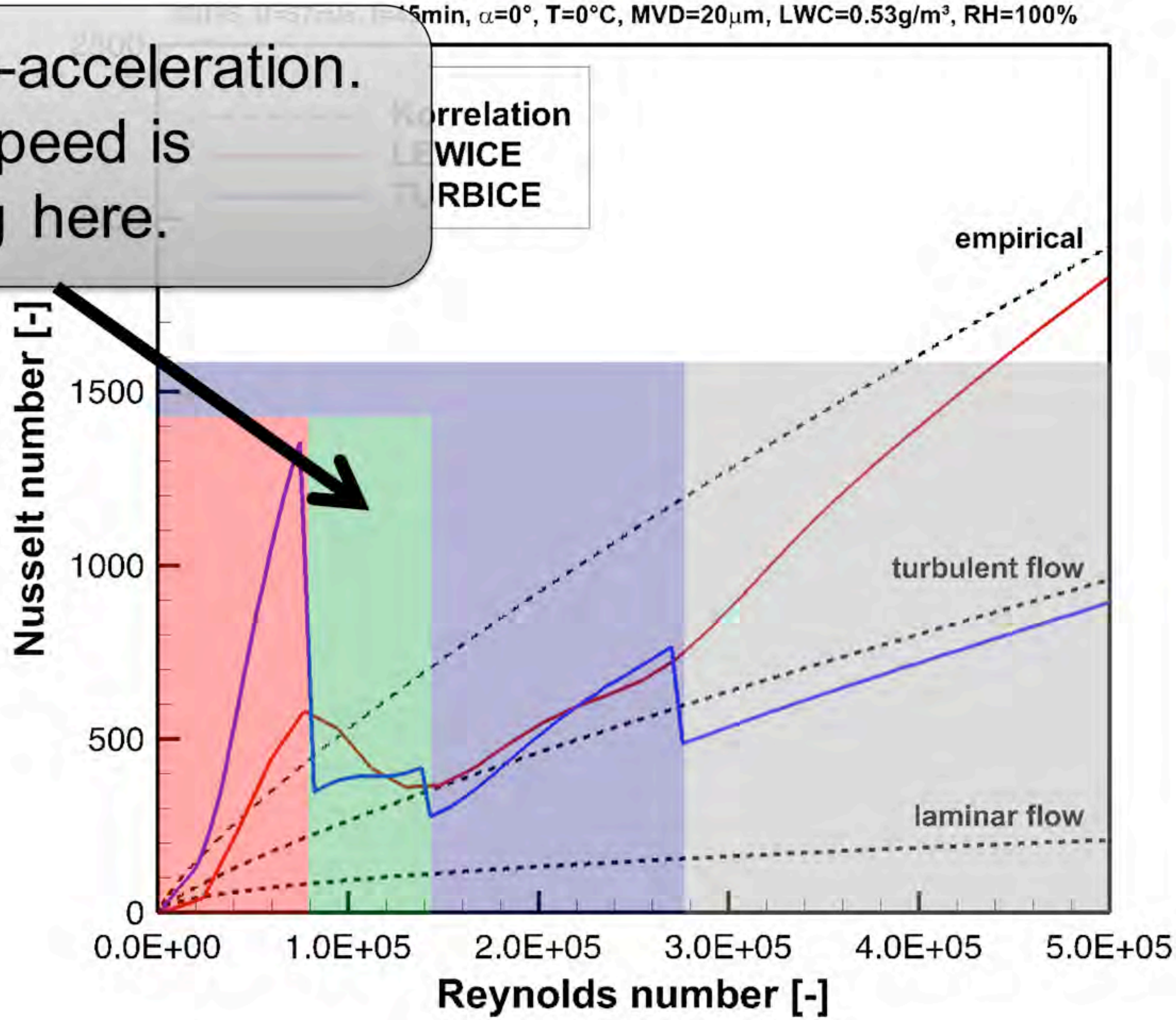
Heat transfer on an iced-airfoil



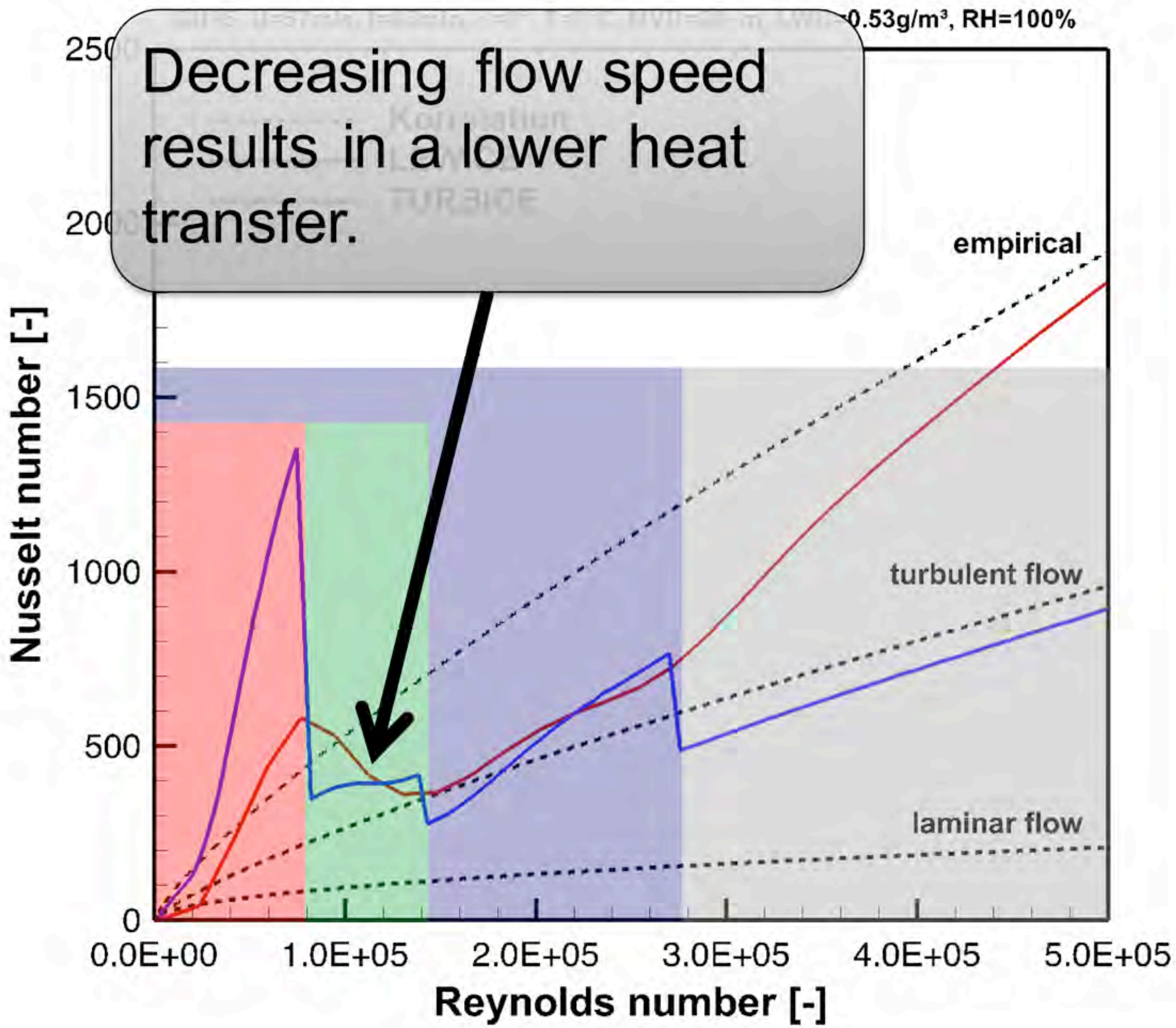
TURBICE results in a larger ice accretion and hence a higher release of latent heat.

Heat transfer on an iced-airfoil

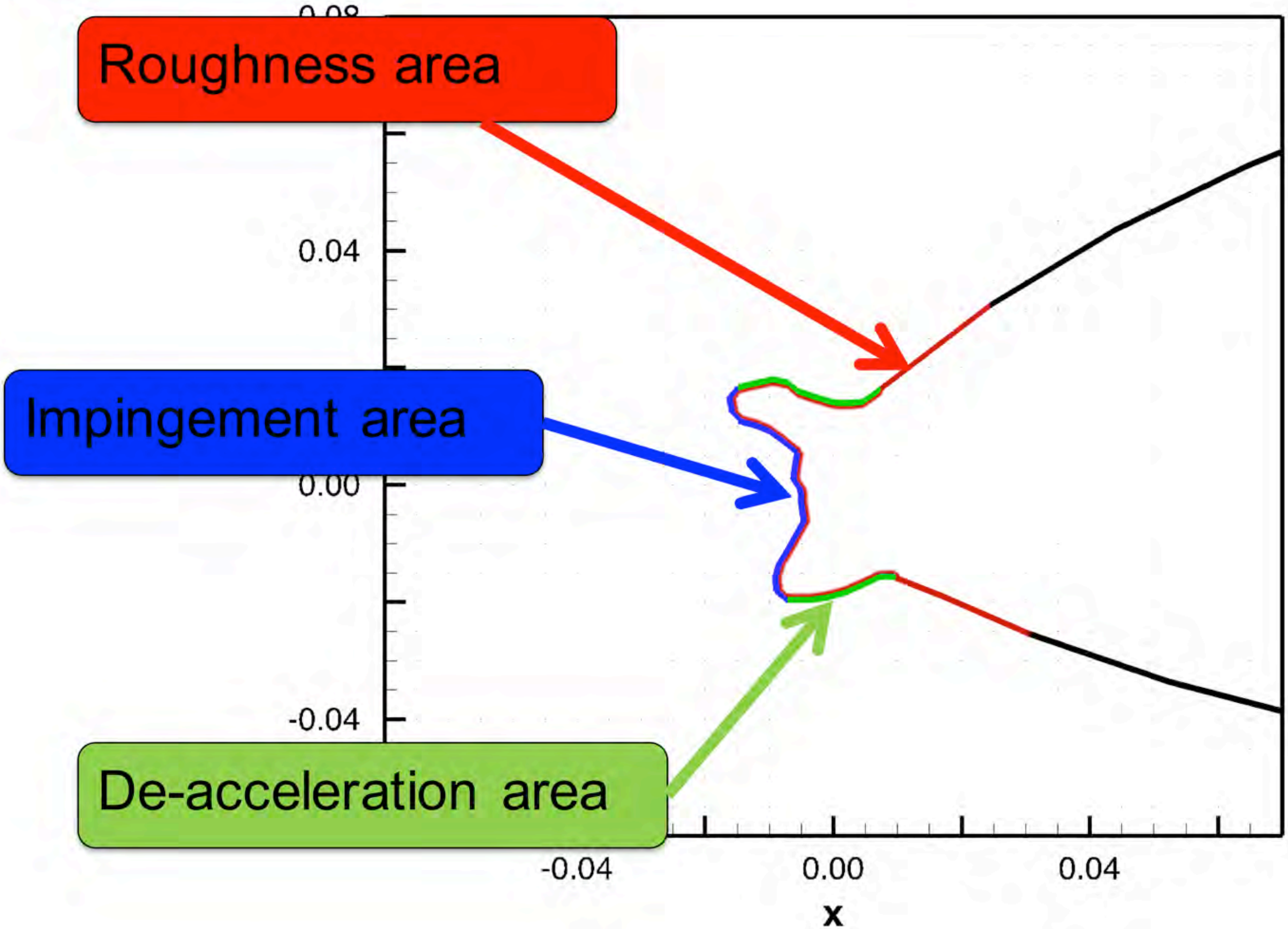
Area of de-acceleration. The flow speed is decreasing here.



Heat transfer on an iced-airfoil



Characteristic areas on an iced airfoil



Results of the thermal analysis

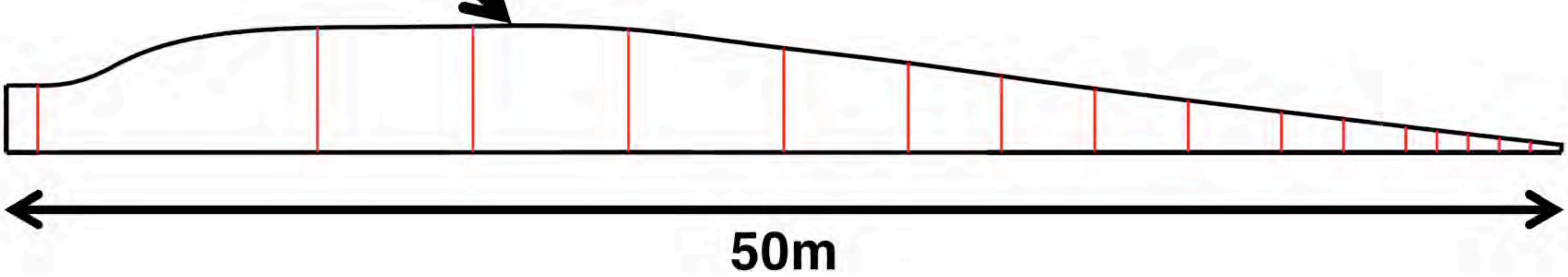
!

- The numerical models used for the heat transfer are highly influenced by empirical correlations.
- Closer investigation of the physical processes is required!
- BUT: the numerical models of LEWICE and TURBICE are still valid. Just because empirical correlations are used does not mean that the results are incorrect.

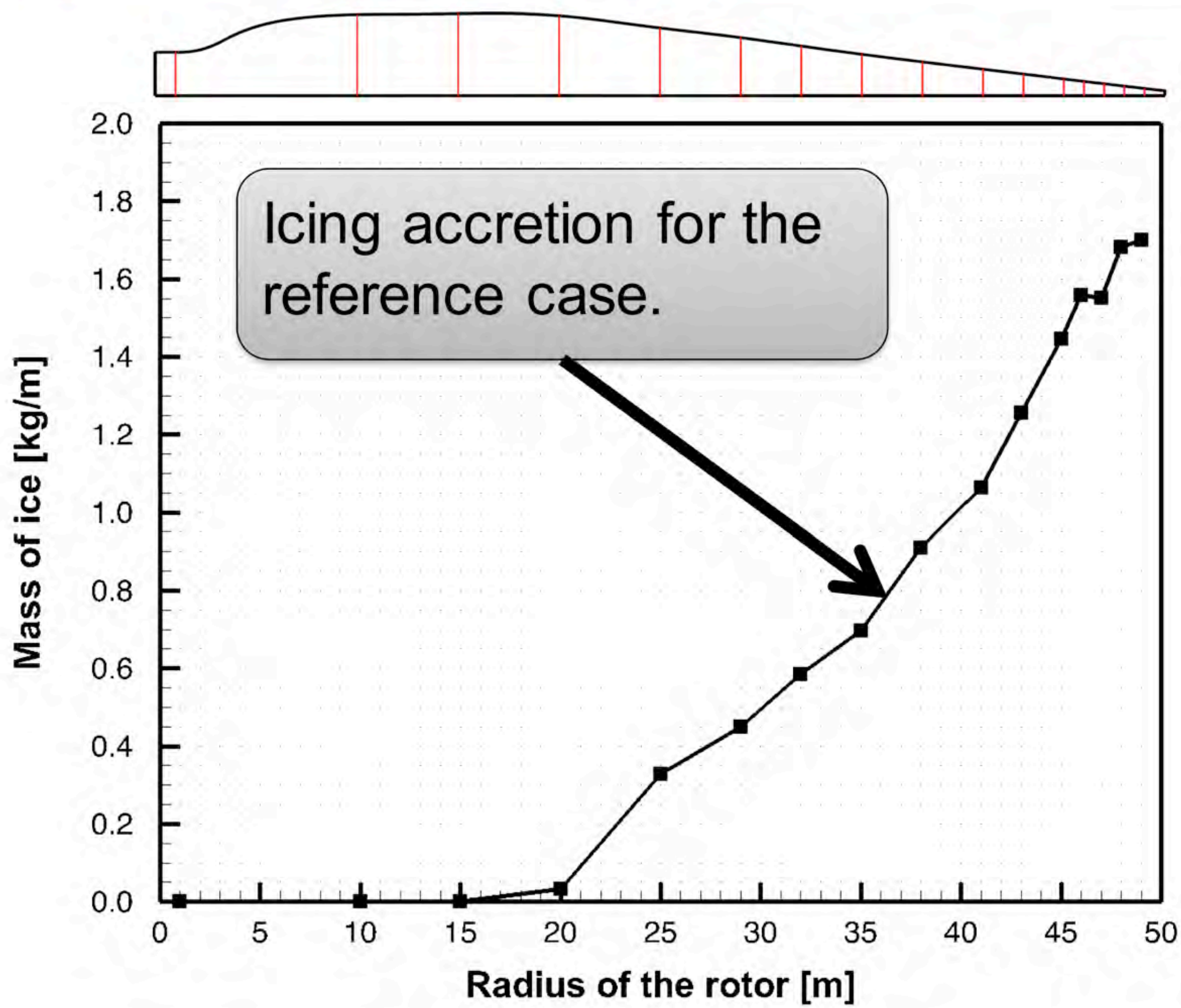
„Where does ice accrete on a rotor blade?“

Definition of a rotor blade

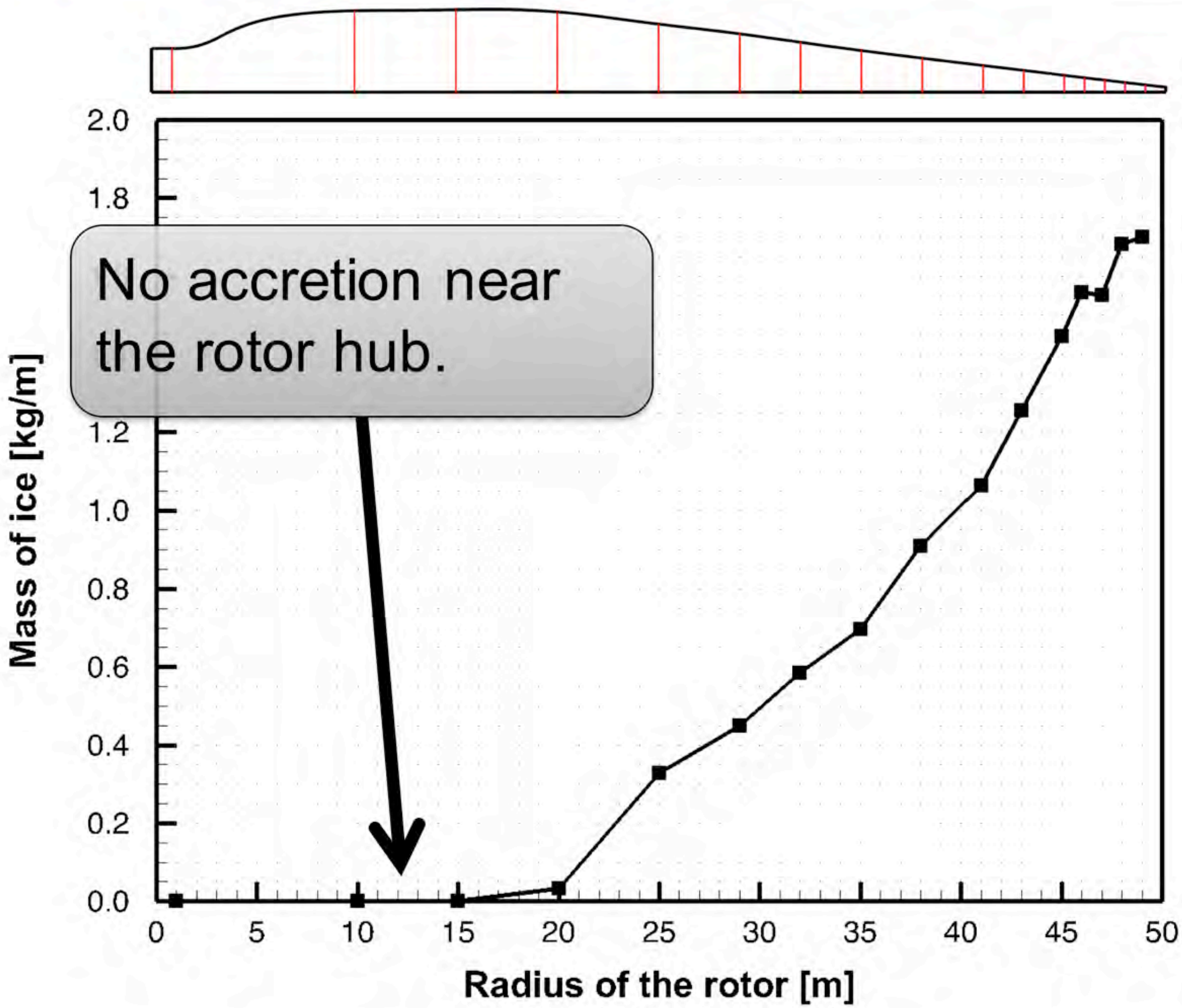
Generic rotor blade for a 2.5MW wind turbine.
16 sampling points.



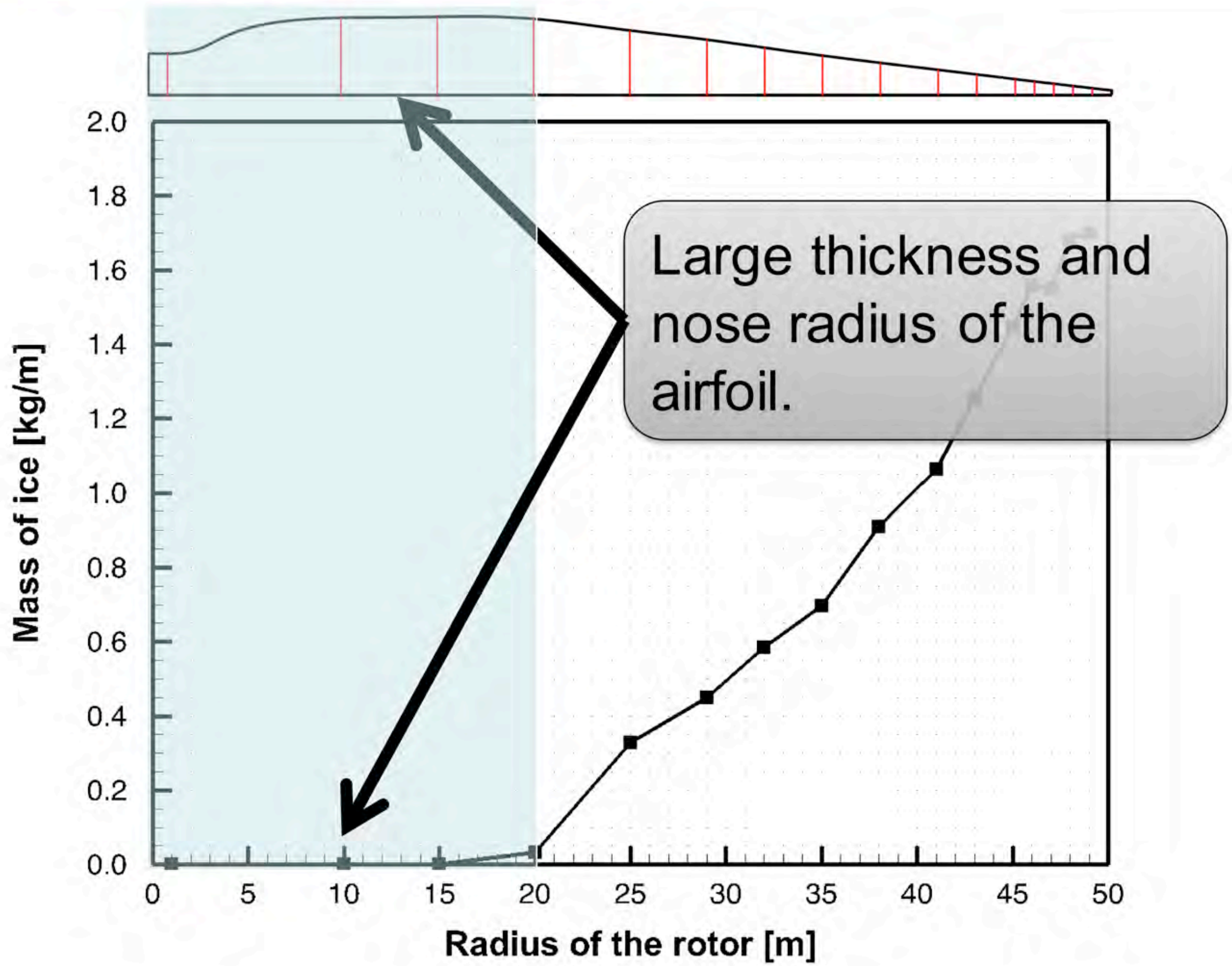
Ice accretion on a rotor blade



Ice accretion on a rotor blade

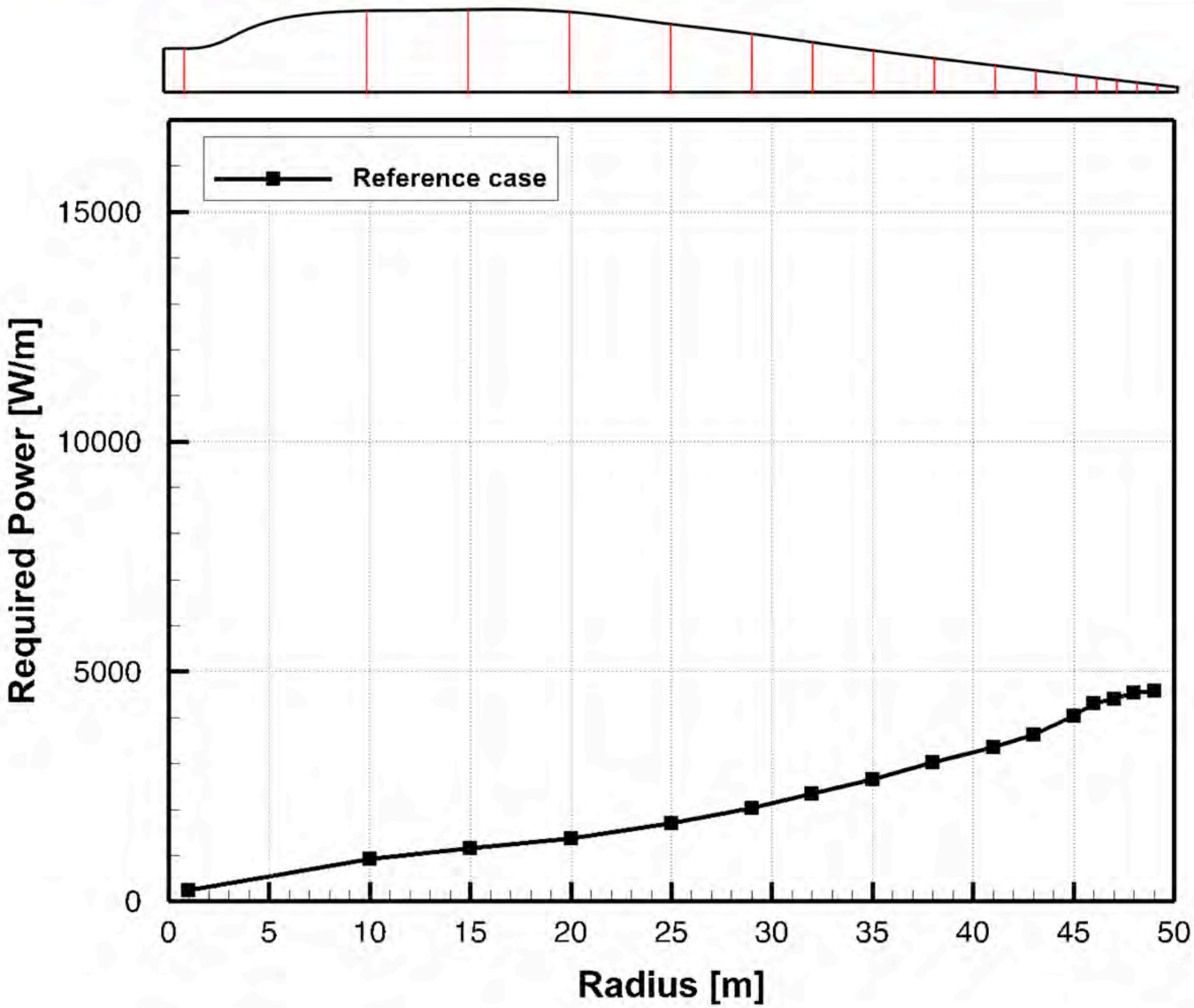


Ice accretion on a rotor blade

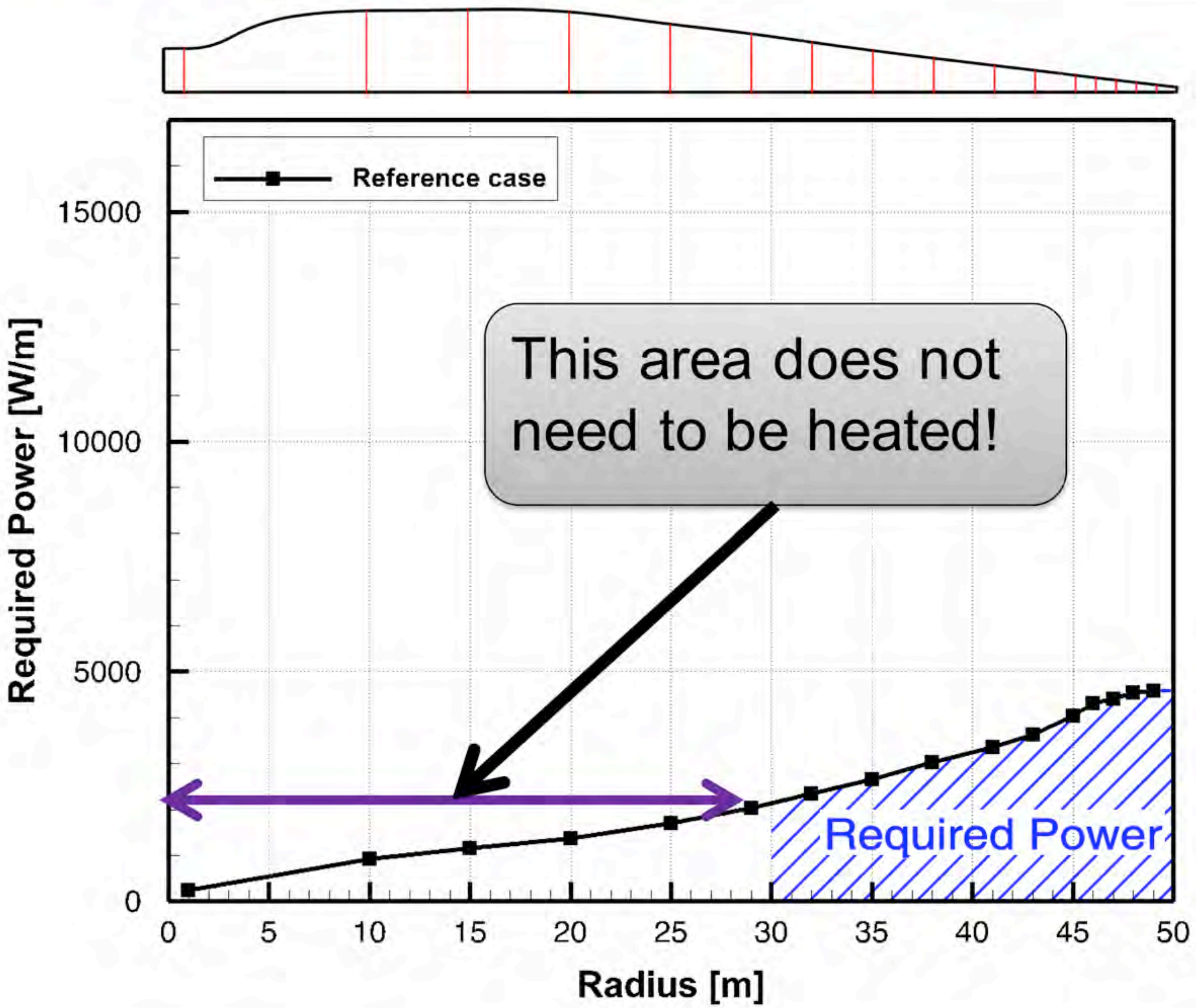


„How much power is required for anti-icing?"

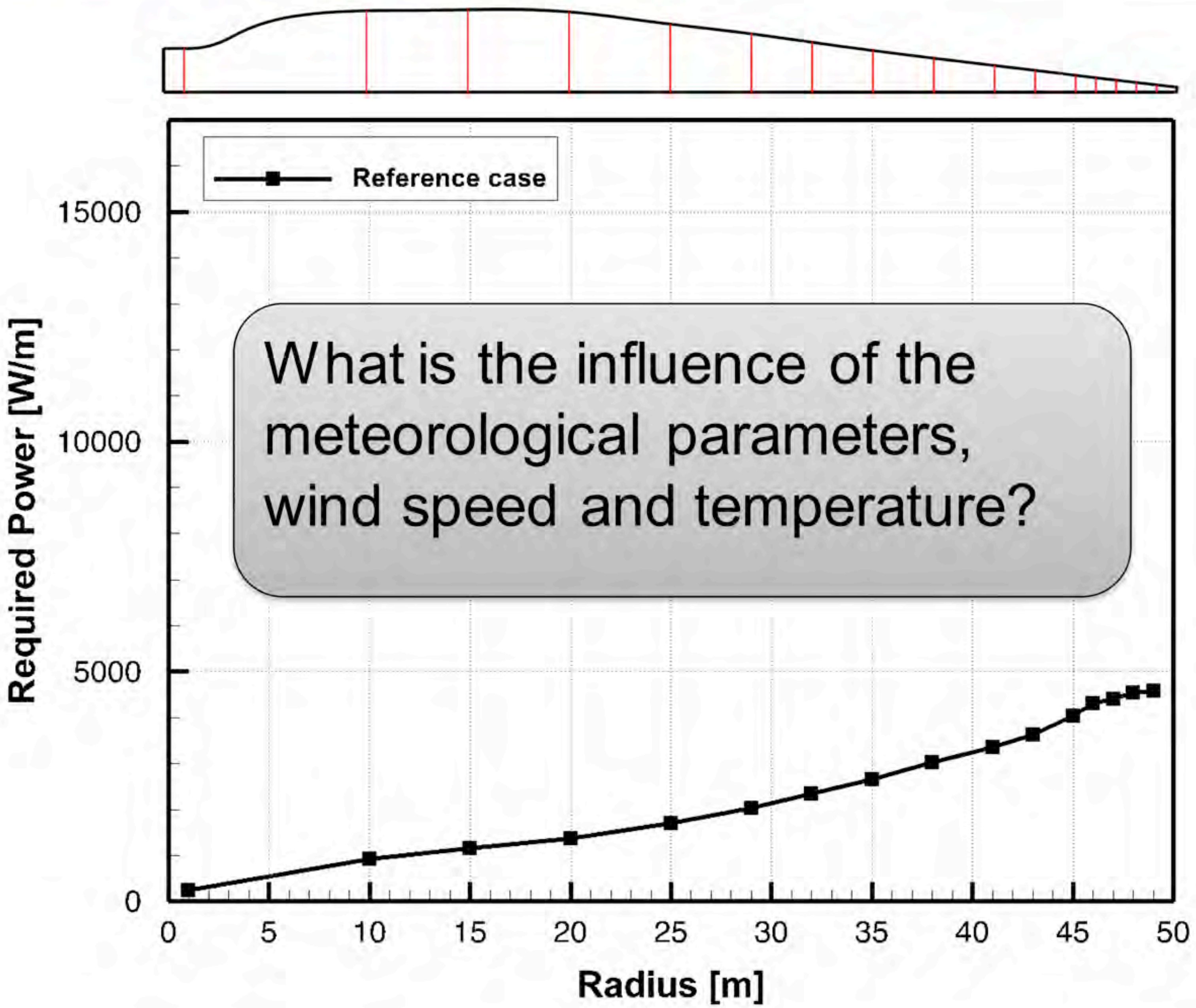
Required power for Anti-Icing



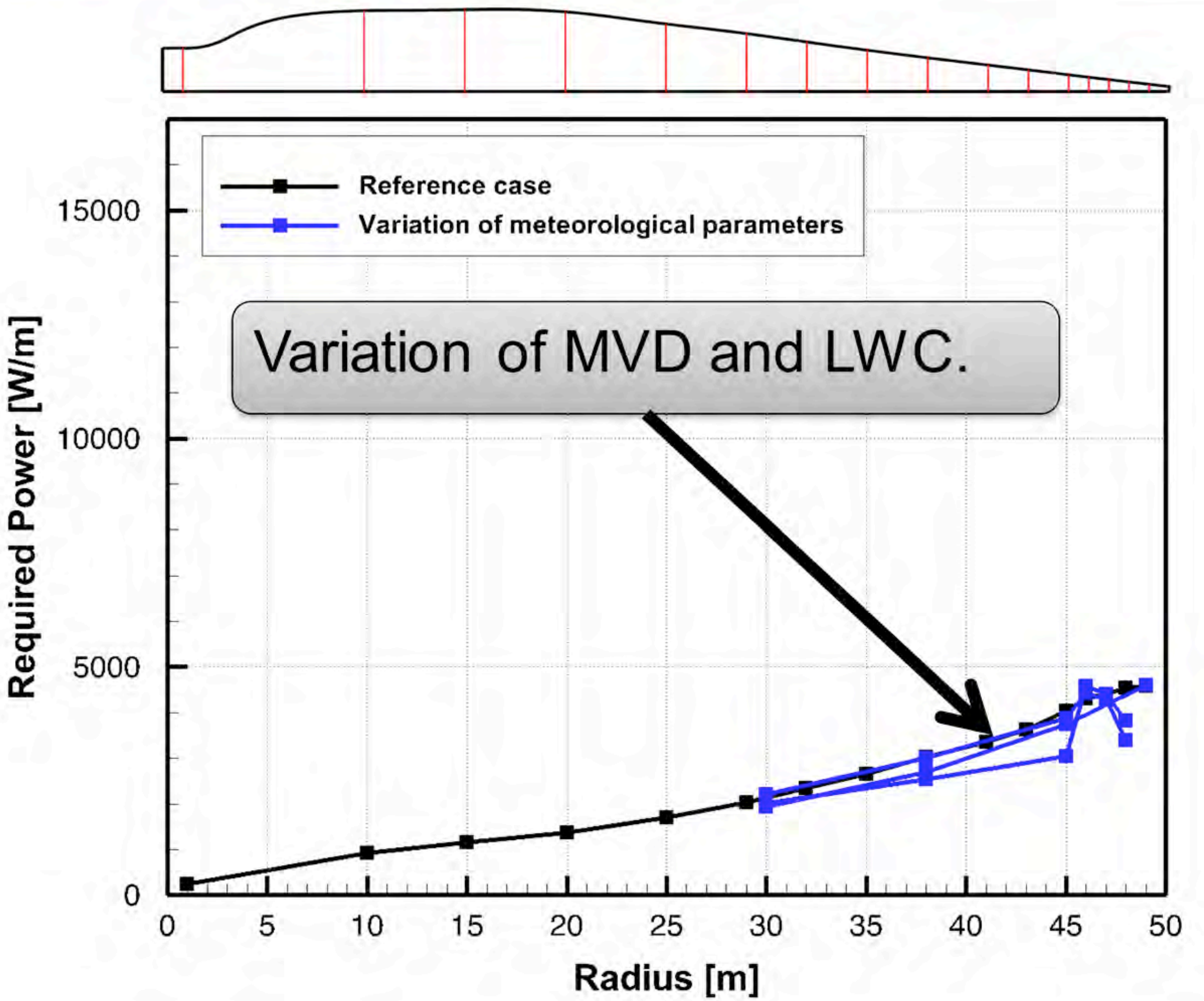
Required power for Anti-Icing



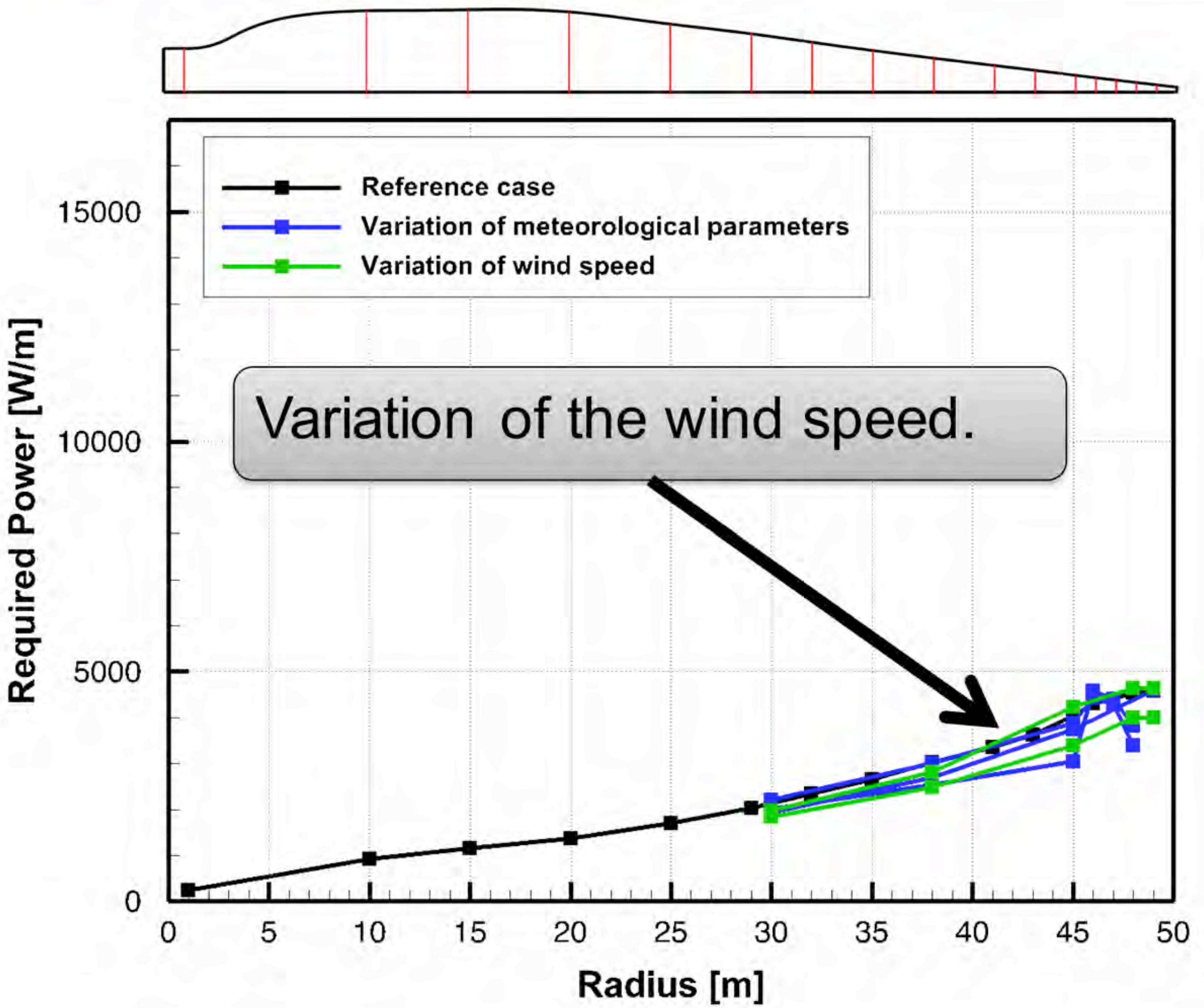
Required power for Anti-Icing



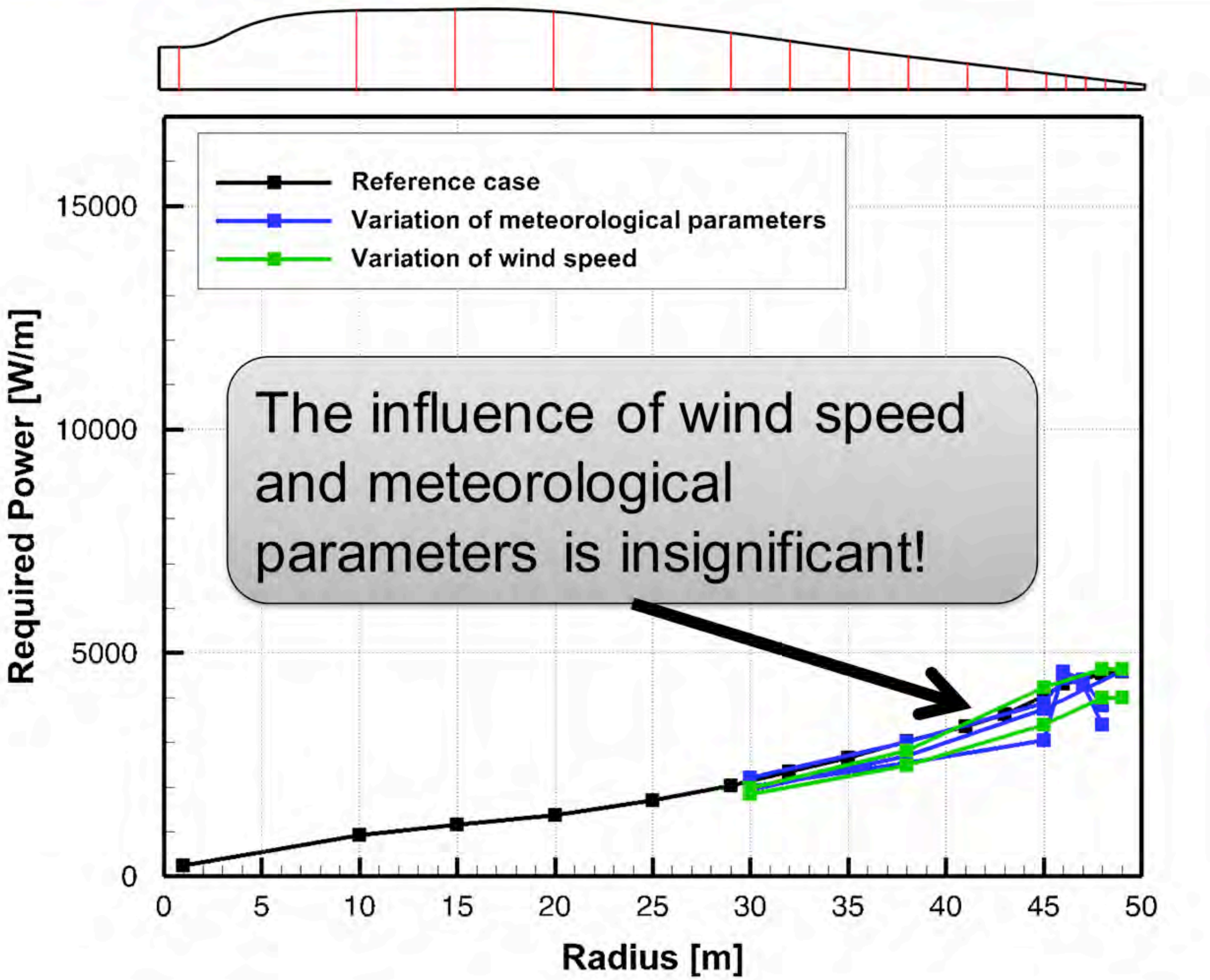
Required power for Anti-Icing



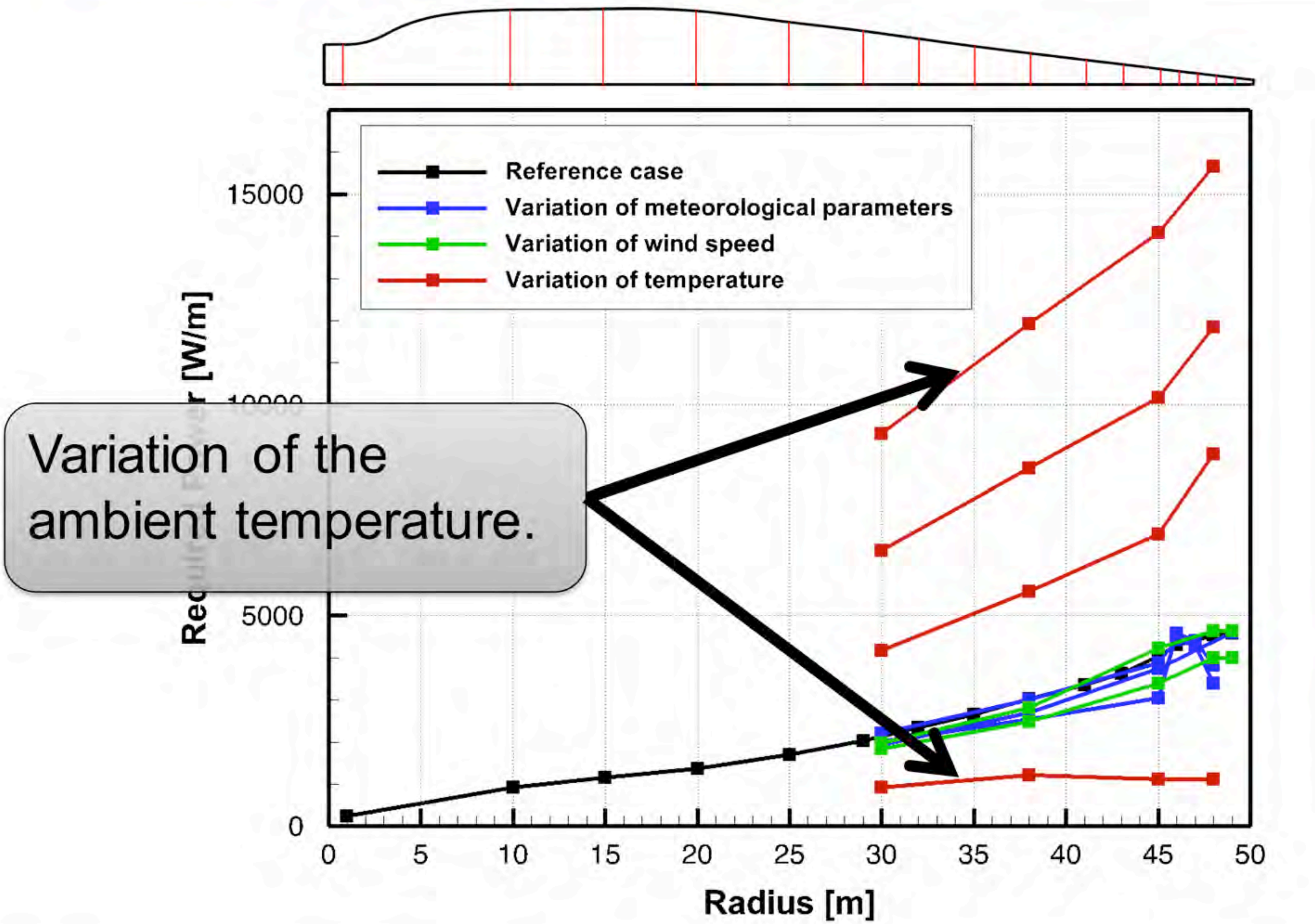
Required power for Anti-Icing



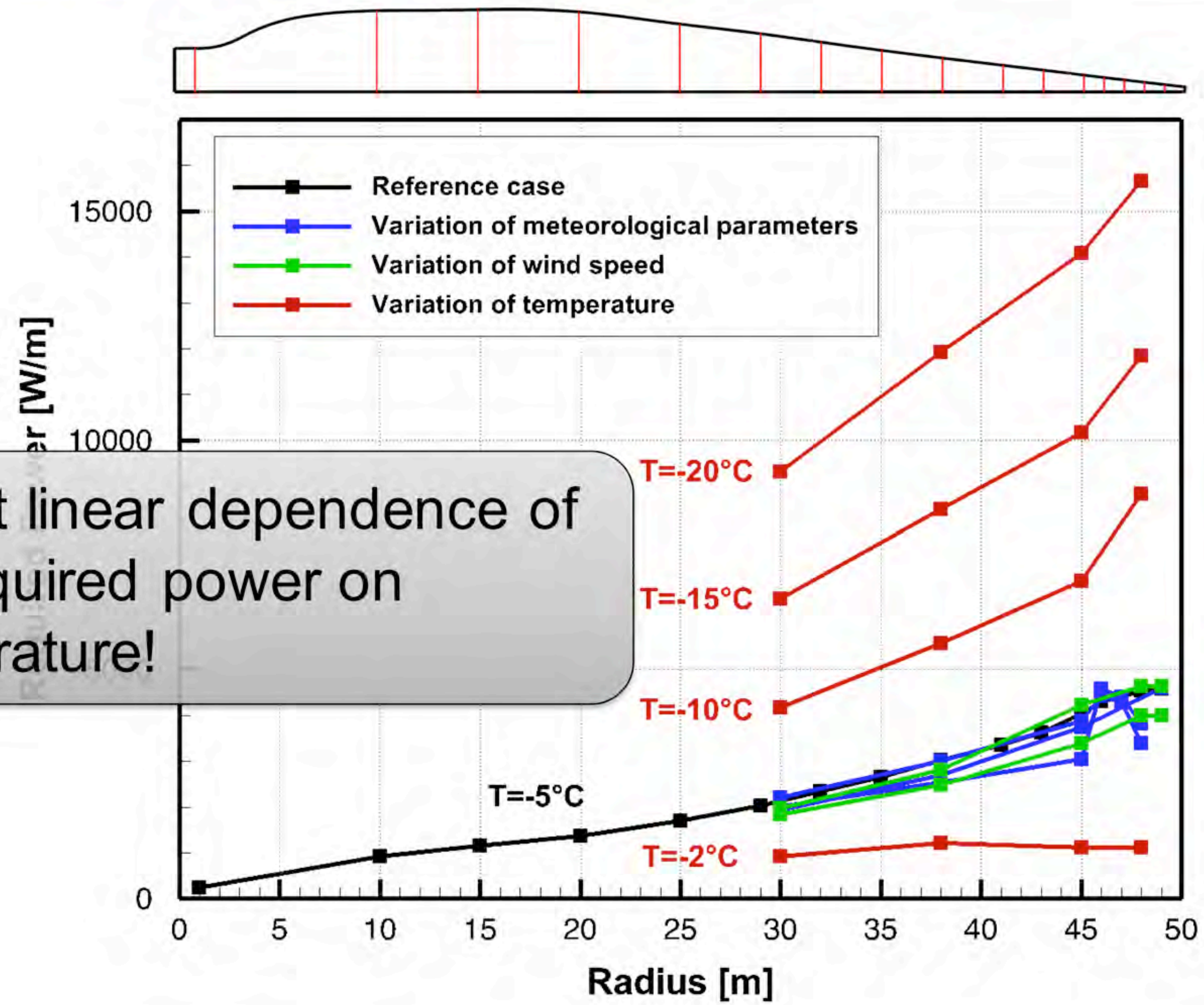
Required power for Anti-Icing



Required power for Anti-Icing

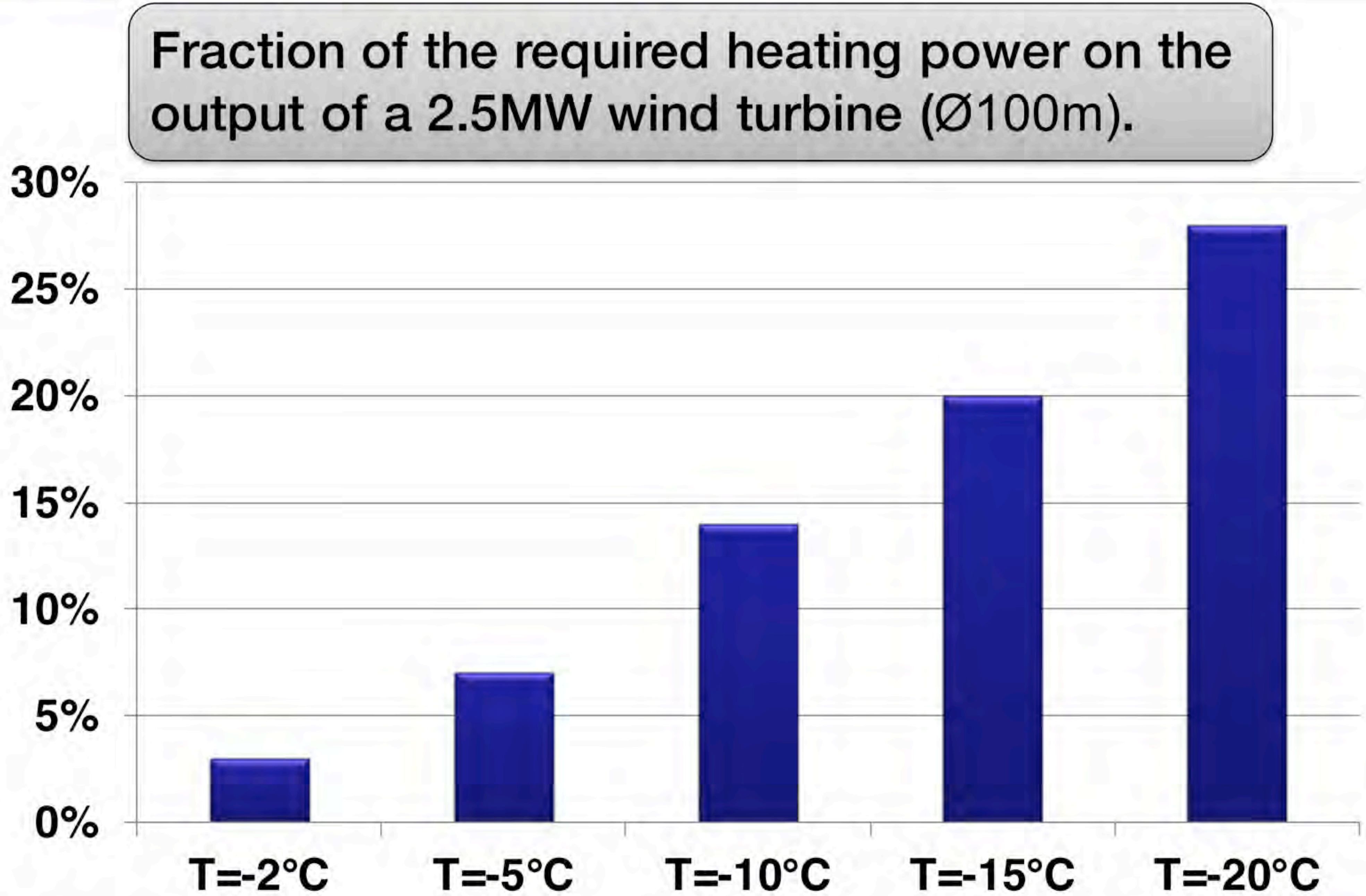


Required power for Anti-Icing



Almost linear dependence of the required power on temperature!

Efficiency of the anti-icing system



Results of the thermal analysis

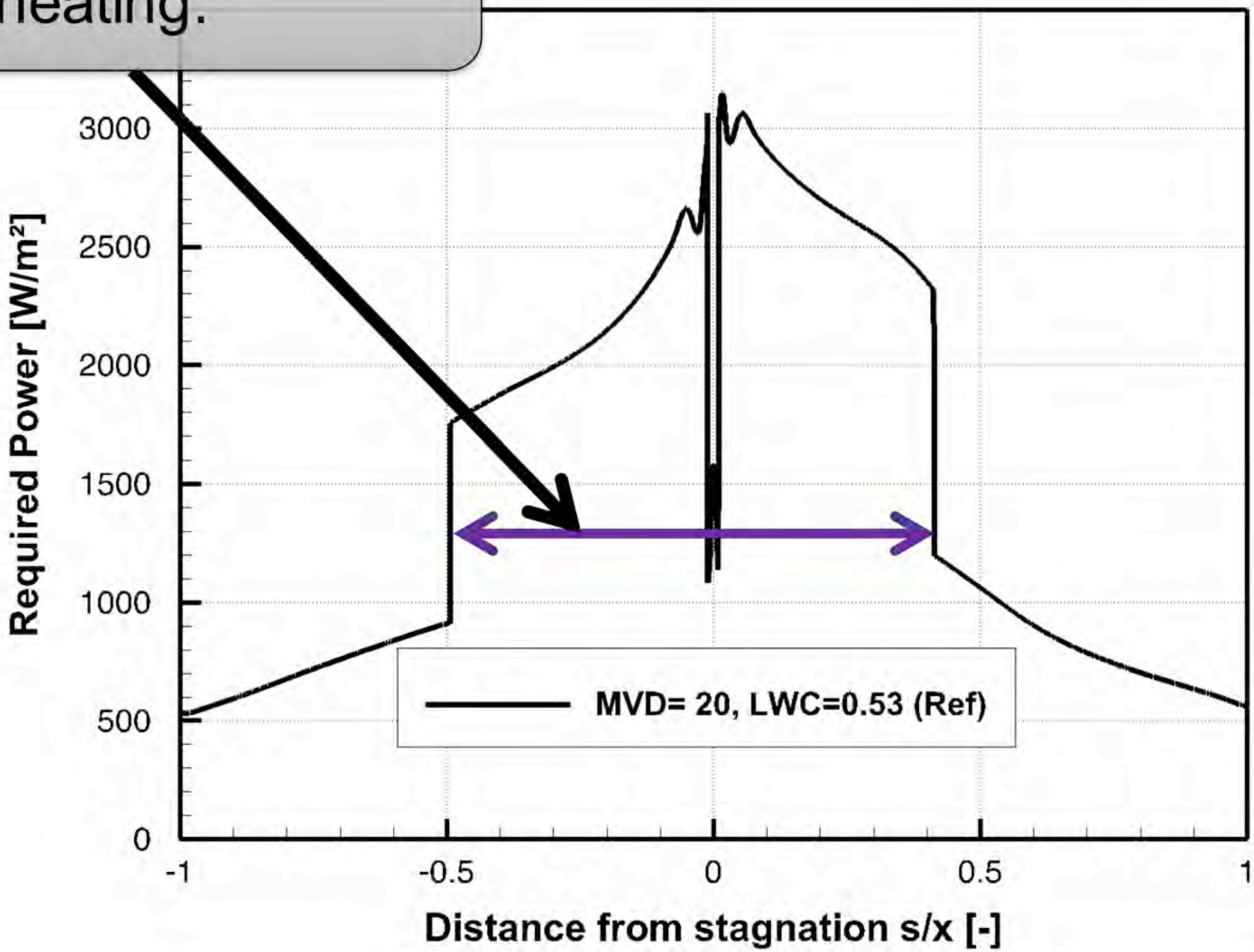
!

- The amount of required power for anti-icing mainly depends on the ambient temperature and the size of the rotor.
- Very low ambient temperatures will result in very high required heating amounts.
- Efficiency can be increased by only heating the outer parts of the blade.

Further improvement of the efficiency can be obtained by only heating the leading edge.

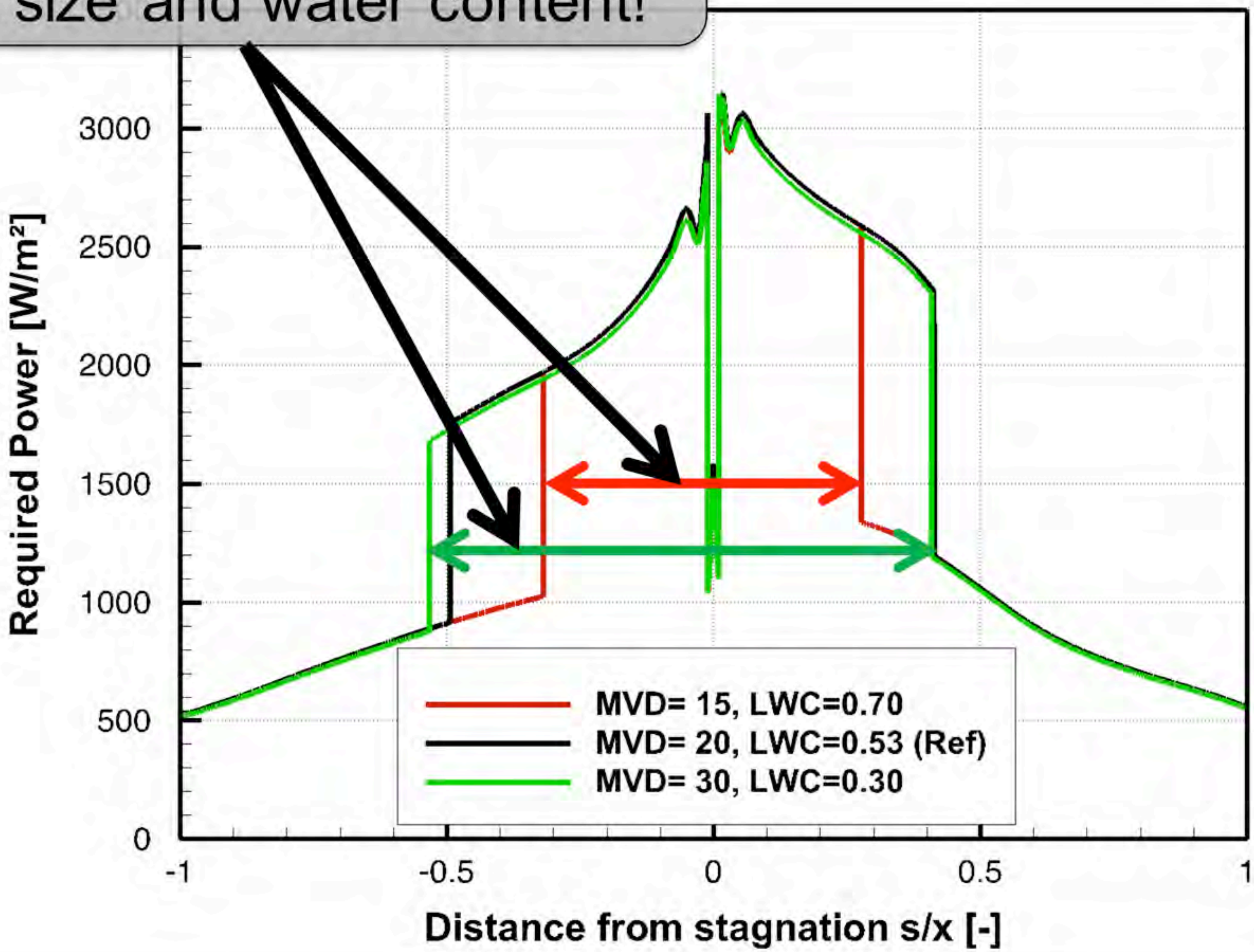
Heat transfer on an airfoil

Only the leading edge needs heating.



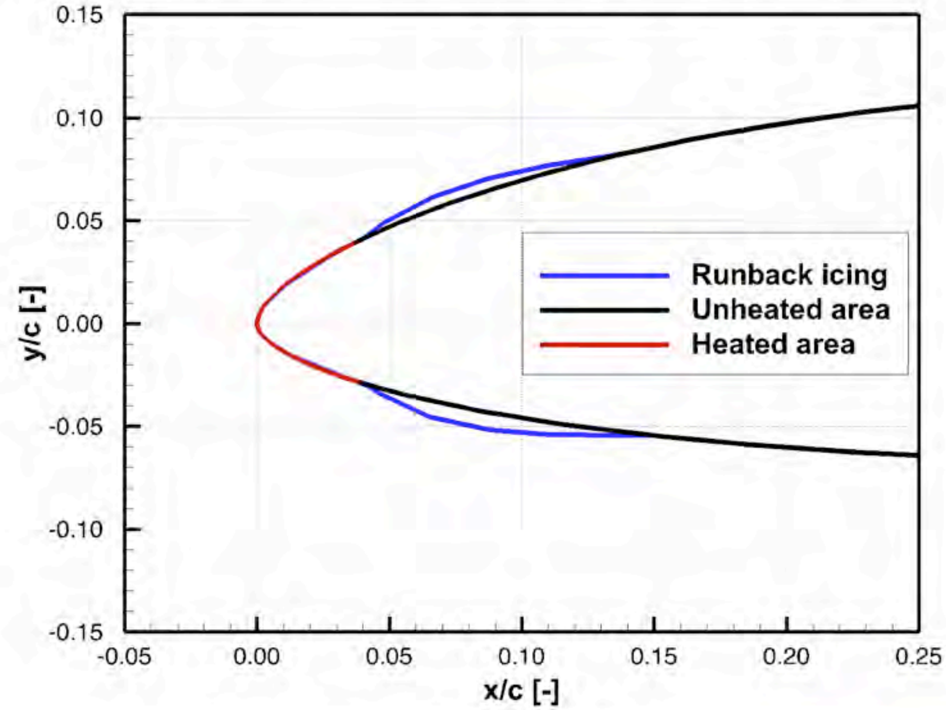
Heat transfer on an airfoil

Heated area is depended on droplet size and water content!



Improving efficiency

- It is sufficient to only heat the leading edge of an airfoil to prevent icing.
- The area that is required to be heated is depending on the droplets.
- Insufficient heating may lead to icing due to runback water.



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