Icephobic coating for prevention of secondary icing

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Secondary Icing

Secondary icing is defined as

> ice formation by refreezing of molten water produced by a heater in an icing prevention process.

- Secondary icing normally occurs on unheated leeward or downward surfaces of a body of interest with a heater with the insufficient thermal capacity or the limited extent of heating element.
- The property of ice of this kind is similar to Glaze so that the ice sticks to a surface *tenaciously*.

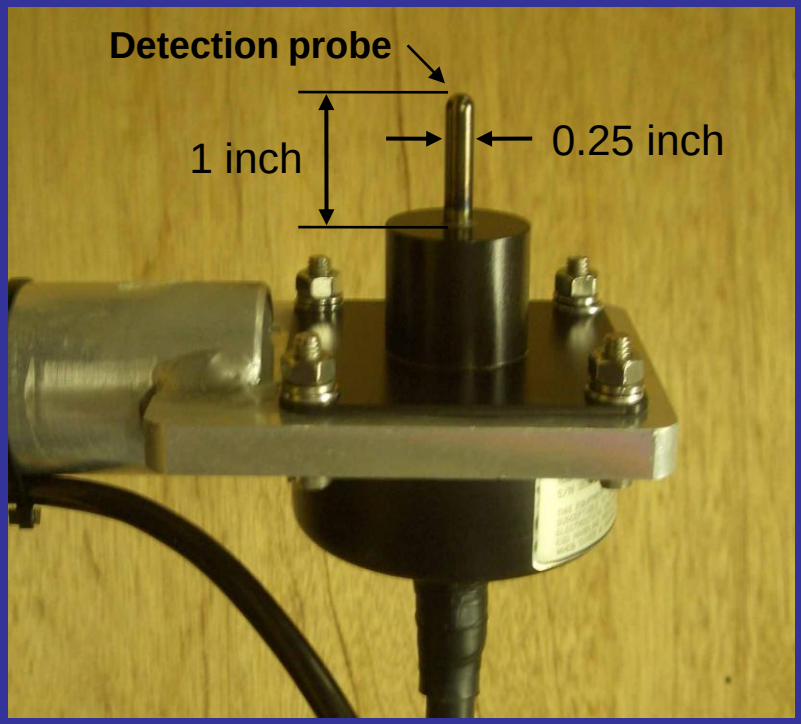
Examples of Secondary Icing

- Ice detection sensor
  - BF Goodrich/Rosemount 0871LH1
  - HoloOptics T26 Icing rate sensor

Dealt with by COST727 Action

- Airfoil model
  - NACA0015 airfoil wind-tunnel test models
- Ultrasonic anemometer
  - Gill Wind Observer Ice-Free type
  - VAISALA WS425 Heated-type

BF Goodrich/Rosemount 0871LH1



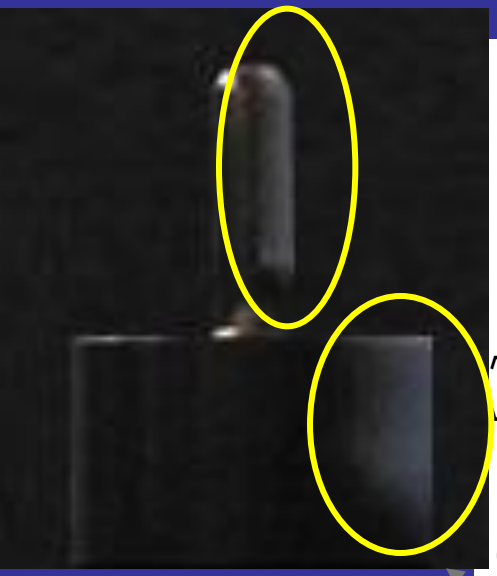
thanks go to Alain

Specifications

- Detection
  ice mass
- Vibration frequency
  40kHz
- Heater
  detection probe

the frequency change due to the additional mass on the probe

Surface conditions during the pr etection



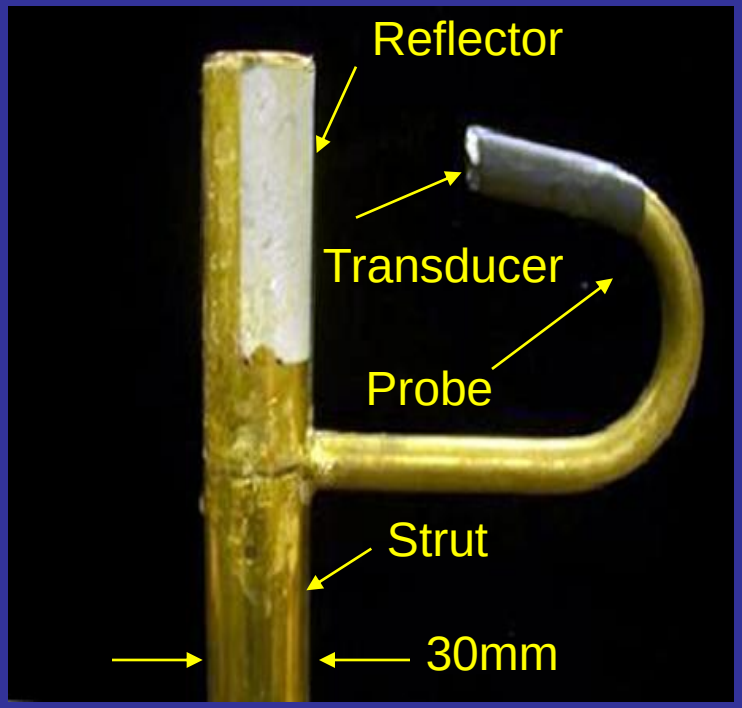
Secondary icing

Wind direction

BF Goodrich/Rosemount 0871LH1

Airspeed: 12m/s
LWC: 0.3 gm^{-3}
MVD: 20 microns
Temp.: -15 deg.

HoloOptics T26 Icing rate sensor



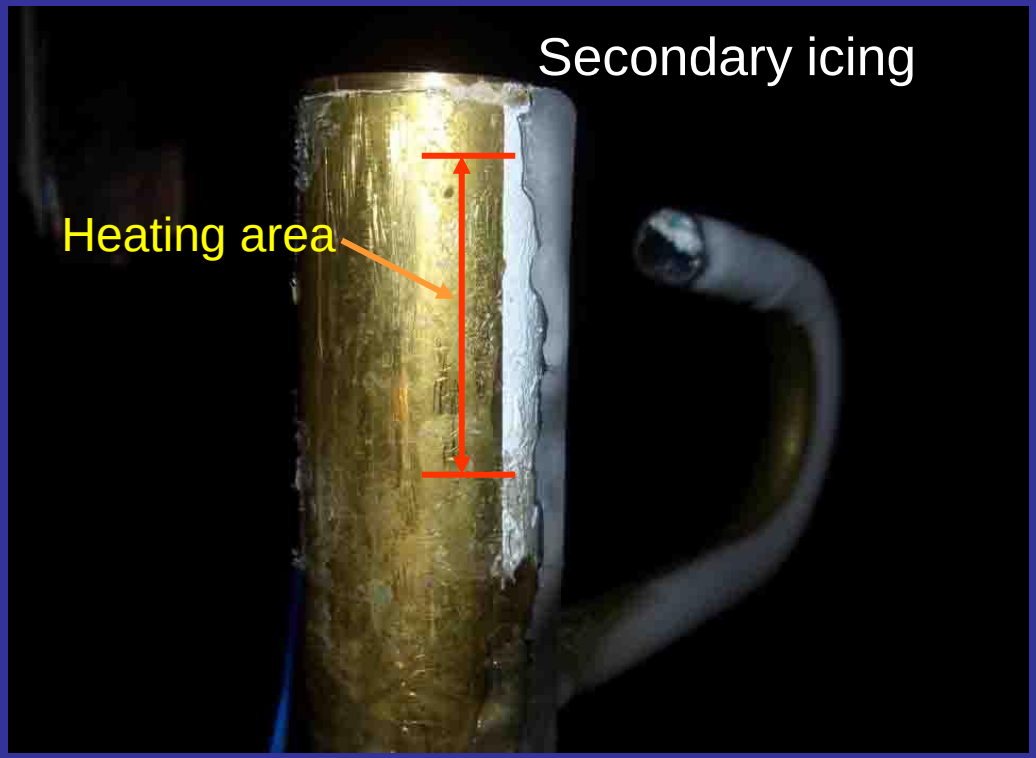
thanks go to Rolf & Goran.

Specifications

- Detection
  reflection on ice
- Minimum thickness
  0.05mm by calculation
- Heater
  upper part of the strut

The rate of reflection of infrared on the reflector on the strut

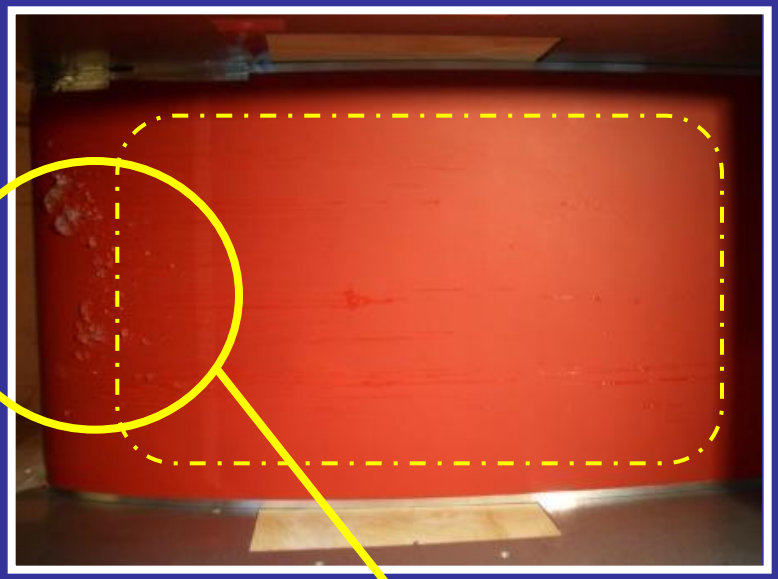
Ice bridge on the strut

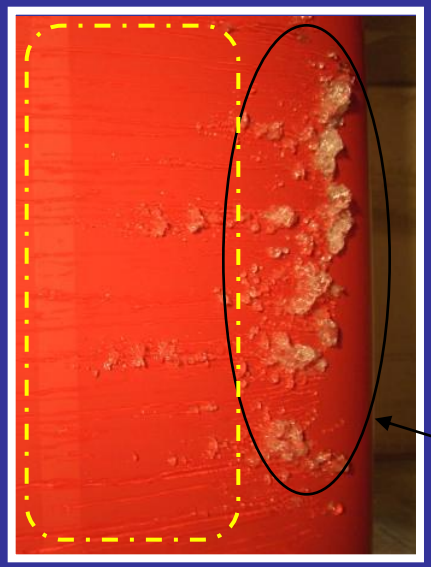


Even though the strut was heated, an ice bridge connecting two unheated parts was made.

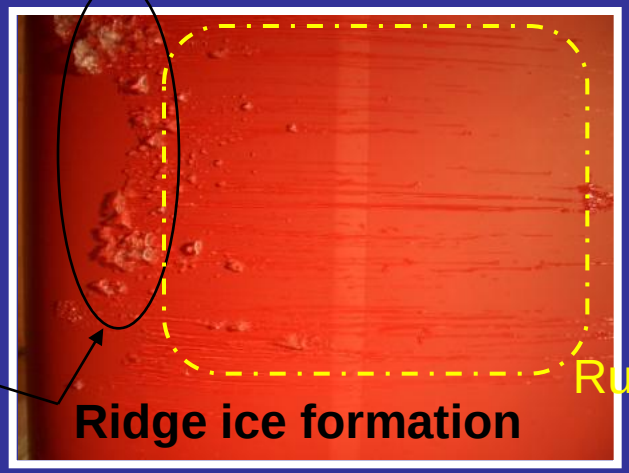
Ice accretes on the reflector of the revised version.

Airfoil Model





Port side



Starboard side

- Icing Wind Tunnel at NRC, Canada
- A wing section: NACA0015.
- Polyurethane coated surface

- Test conditions:

Airspeed: 90m/s
Temperature: -5 deg. Cel.
MVD: 20 microns
LWC: 0.5 g/m3
Duration: 5 min.
Angle of attack: 0 deg.
With a heater of 84W

Runback ice formation

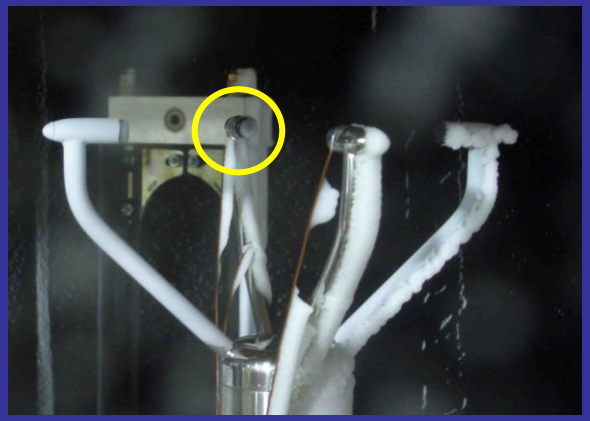
Secondary icing

Ultrasonic Anemometer

Gill WindObserver
Ice-Free type

VAISALA WS425
Heated-type

Ice on a transducer

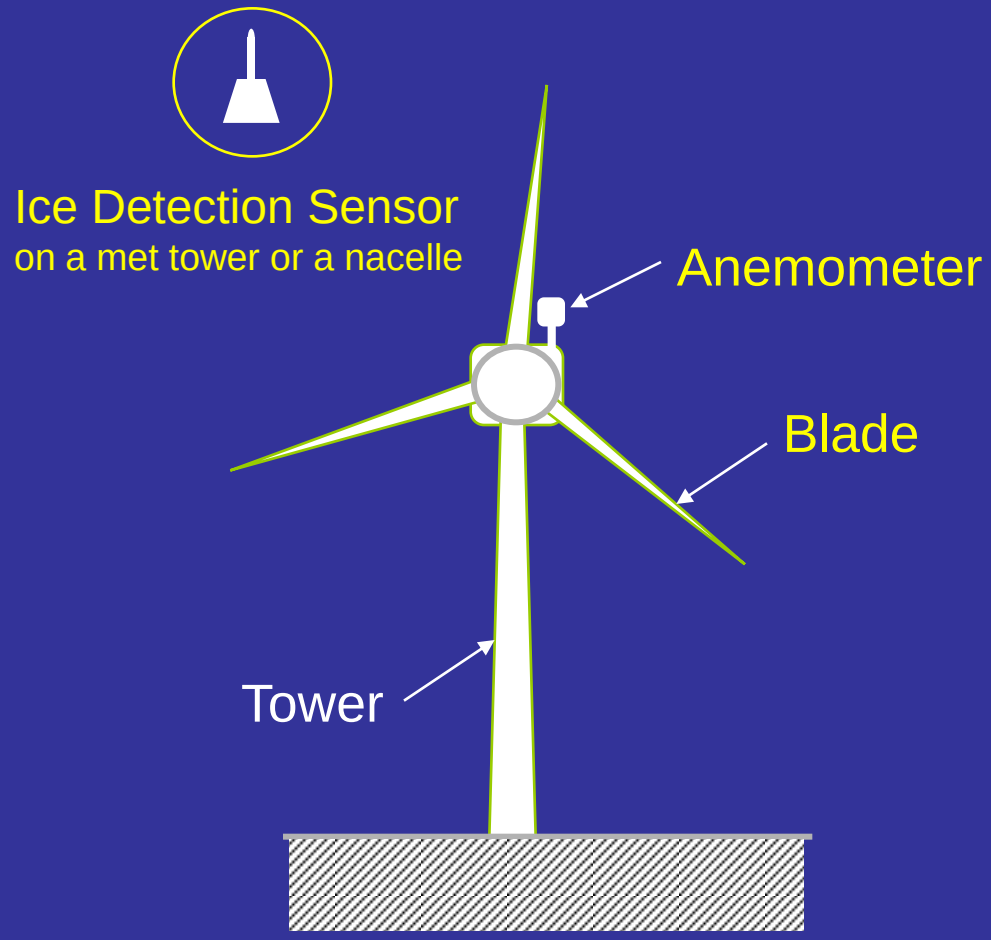


Ice-bridge formation

Field measurement

Measures for icing prevention

In a wind turbine,
icing may occur on



For icing prevention

- Heating by an electric heater or a hot-air blower
  Most of anemometers and IDSs have an electric heating system in order to clear ice away from a measuring part
- Ice-break by a mechanical ice breaker
- Surface coating

- Shutdown of operation

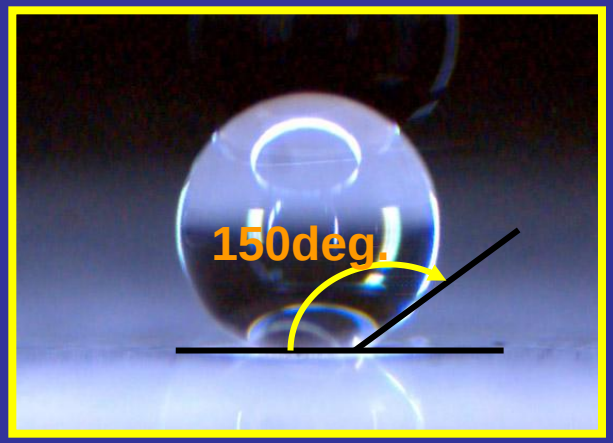
Danger of secondary icing

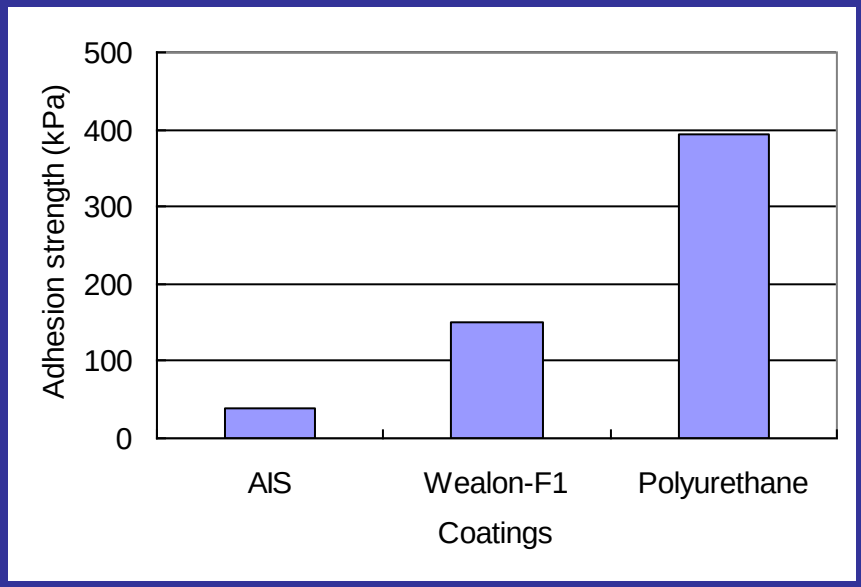
➡ by surface coating

AIS (Anti icing Surface)

is a surface coating primarily developed for aircraft (wings, stabilizers, fuselage) icing prevention .

- Produced by Fuji Heavy Industries and NTT-AT
- Super hydrophobicity with a 150-degree contact angle
- 2H pencil hardness (same as Polyurethane)
- Weakening the adhesion strength
- Durability can be controlled by thickness



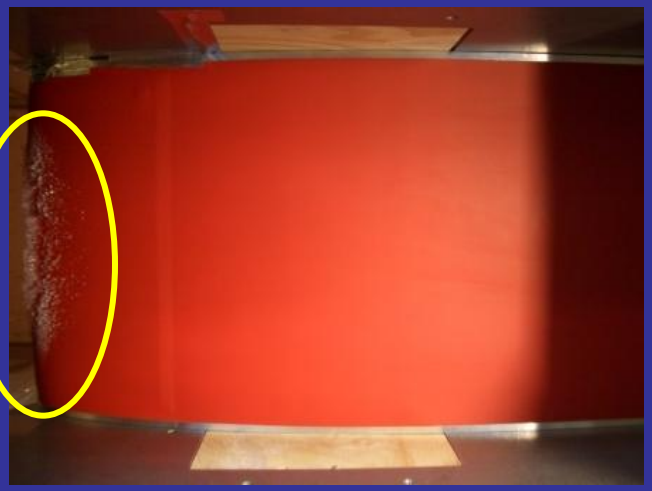


Adhesion strength (kPa)

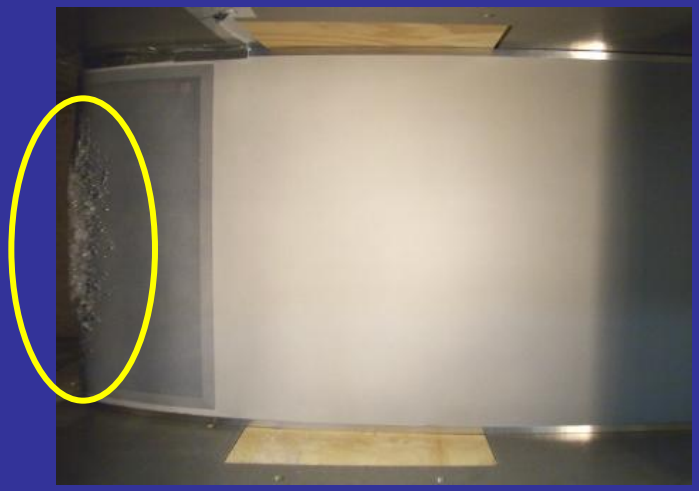
Lateral force applied

Ability of icephobic coating in icing prevention

Any icephobic coating may have no capability to avoid ice accretion.



Polyurethane



AIS

Test cond.

Air speed: 90m/s
Temp.: -5 deg.
LWC: 0.5g/m3
MVD: 20 microns
Heater: off
Duration: 5 min.

- Icing occurs at the leading edge.
- No significant difference in terms of shape and property of ice

Ability of icephobic coating in prevention of secondary icing

Test cond.

Air speed: 110m/s
Temp.: -5 deg.
LWC: 0.5g/m3
MVD: 20 microns
Heater: 84W
Duration: 5 min.

Polyurethane

AIS

- No ice at L.E.
- No secondary icing

- No ice at the leading edge (LE)
- Ridge and runback ice formation (secondary icing)
- Ice at the trailing edge

Adhesion strength weakened by AIS

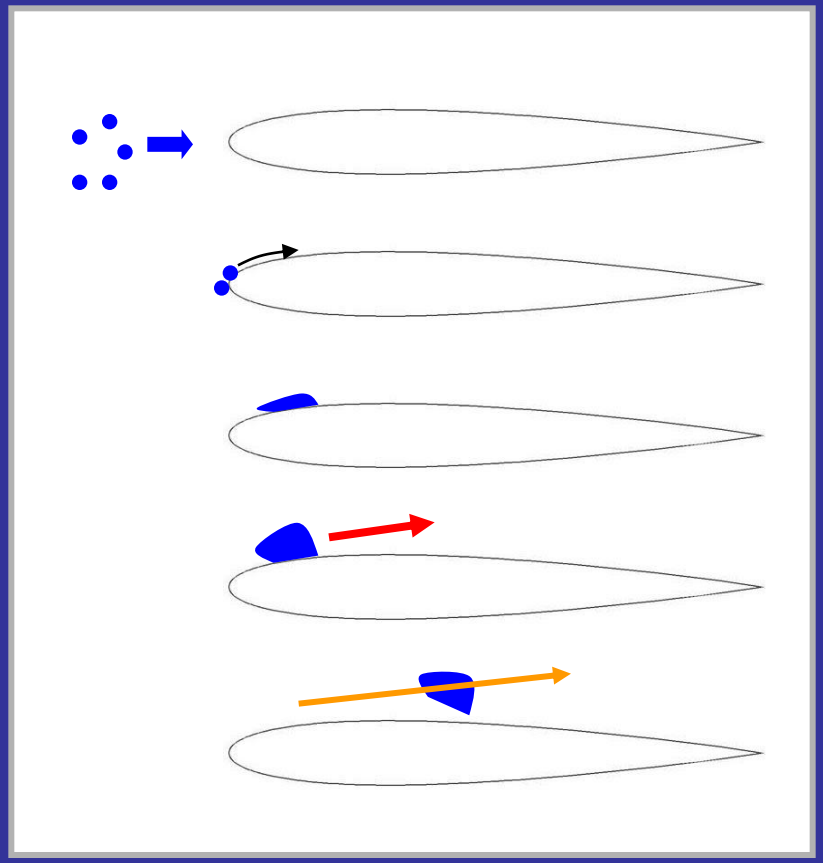
Test cond.

Air speed: 110m/s
Temp.: -5 deg.
LWC: 0.5g/m3
MVD: 20 microns
Heater: 84W
Duration: 5 min.

Polyurethane coated model

AIS coated model

Scenario of blown-off of an ice deposit on the test model



Icing starts at LE.

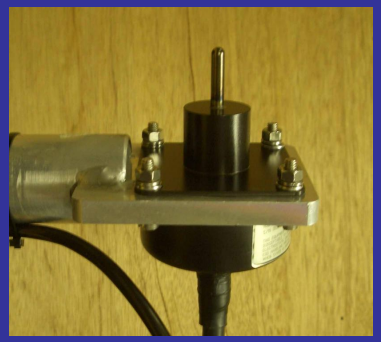
Ice melts by heat. Molten water flows backwards.

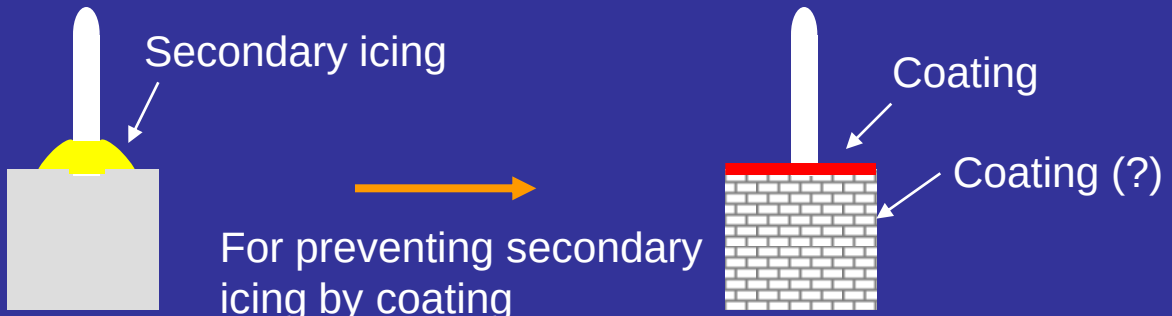
Water freezes to ice.

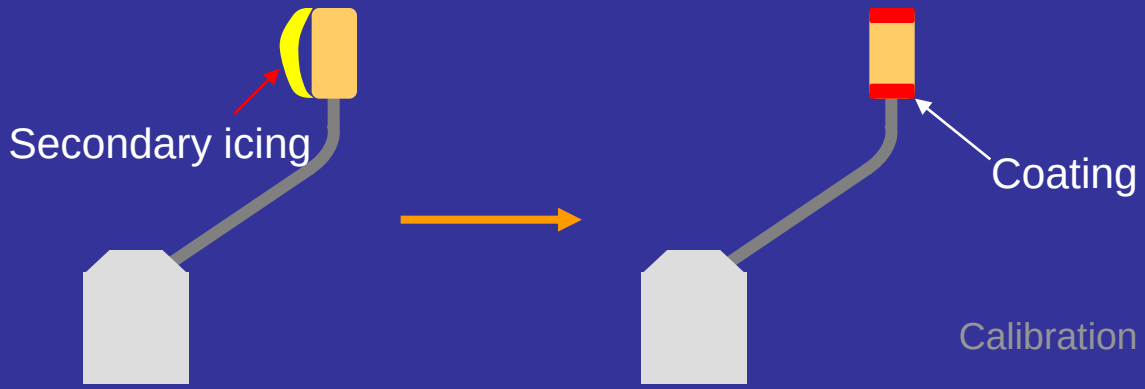
Ice grows and drag increases.

An ice deposit gets flown by drag acting on it.

Applied to







Calibration needed

Conclusions

- *Secondary icing* was defined as ice formation by refreezing of molten water.
- A heating system is widely used for icing prevention. However because of the insufficient thermal capacity of heating elements or the limited extent, refreezing of molten water occurs on unheated surfaces of a body of interest which may cause another type of icing and accelerate the icing event on the body
- By *applying icephobic coating* to the surface as widely as possible, molten water may be let to run leeward or downward rapidly without refreezing even on a unheated area. Moreover removing ice deposits from the surface may become much easier.