Functional Coatings for the Improvement of the Performance of Wind Turbines - Latest Developments

Dr. Volkmar Stenzel, Fraunhofer IFAM, Bremen
Nadine Rehfeld, Fraunhofer IFAM, Bremen
Dr. Dorothea Stübing, Fraunhofer IFAM, Bremen

Paint Technology: From Raw material to functional coating

Development Raw Materials and Paints

- Raw materials
- Paint systems
- Formulation

Functional Coatings

- Developing smart coatings:
  - Anti-Ice
  - Anti-Drag
  - Micro-/Nanosurface
  - Self Healing
  - Anti-Fouling
  - Anti-Soiling

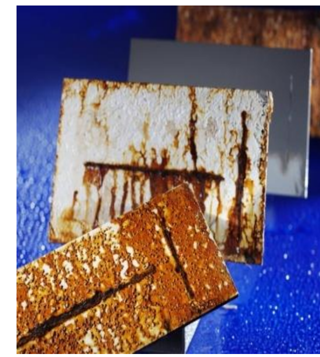
Application and process engineering

- Treatment/Cleaning
- Proces optimisation
- Qualification and characterisation of coatings
- Application, Mixing and Drying

Testing

- Developing of special testing device

Trouble Shooting



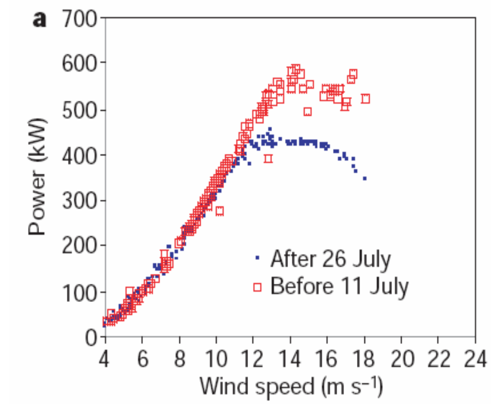
- Corrosion test
- Weathering test
- Outdoor weathering

Anti-Soiling and Anti-Icing Surfaces

Example: Wind Energy

- Soiling (mainly insect debris) reduces annual earnings by approx. **5%**

- Icing could reduce annual earnings by **24%** (even in German climate) due to aerodynamic influences, safety issues and noise



Quelle: **Dalili, N.; Edrisy, A., Carriveau, R.;**
"A review of surface engineering issues critical to wind turbine performance"
Renewable and Sustainable Energy Reviews, 2007

Quelle: **Corten, P.G., N.; Veldkamp, H.F.**
"Insects can halve wind-turbine power"
Nature, Vol. 412, 2001, 41-42

Insect-repelling surfaces

Test device for the application of insects onto surfaces with defined speed.

Example: Insect-repelling surfaces - testing

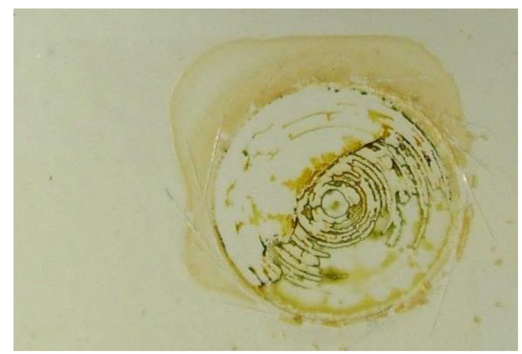
…by air gun in lab under controlled conditions

… by aircraft to investigate performance in real flight conditions

(performed by DLR)

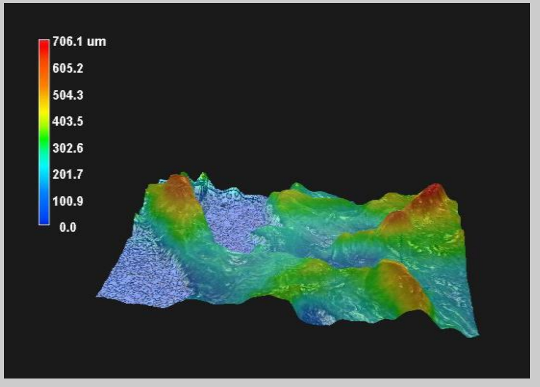
…by car to compare impact cha-racteristics on different surfces

… by alterna-tive fluids for reproducible contamination cases

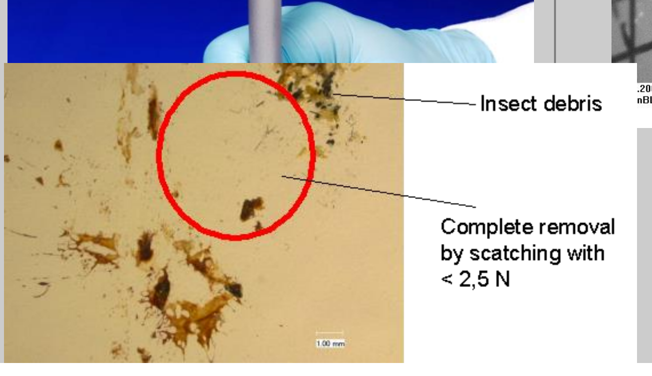


Example: Insect-repelling surfaces - testing

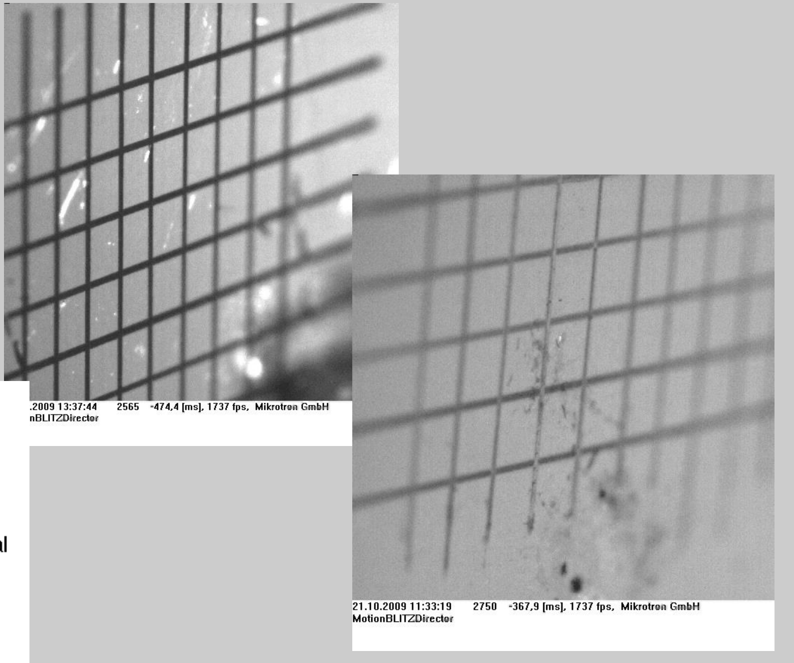
Height determination via microscope



Adhesion assessment via Finger nail / Modified scratch tester

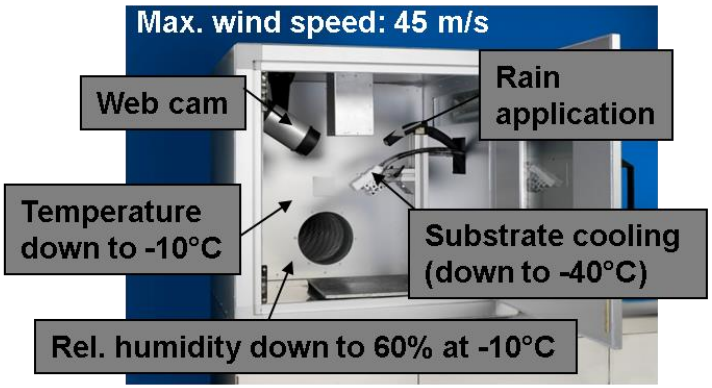


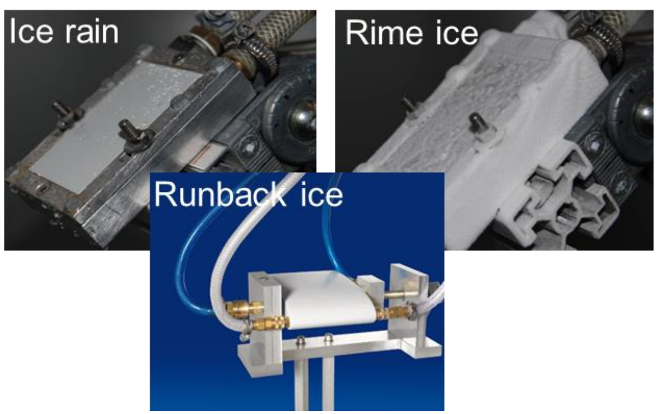
High-speed camera to observe impact behaviour:



Ice test facilities

IFAM ice chamber:





Ice adhesion tests:

Outdoor winter test:

Testing of ice adhesion

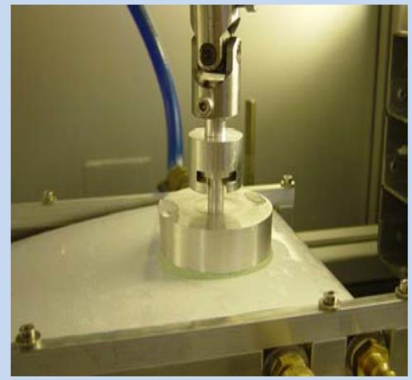
Pendulum test:

Ice removal by impact

→ Ice adhesion is correlated to pendulum amplitude after ice removal

Centrifuge test:

Ice removal by shear stress;
→ laser detection of ice detachment and correlation to rotation speed



Pull-off test:

Ice removal by pulling

→ Measurement of ice adhesion force derived from established paint-related test methods

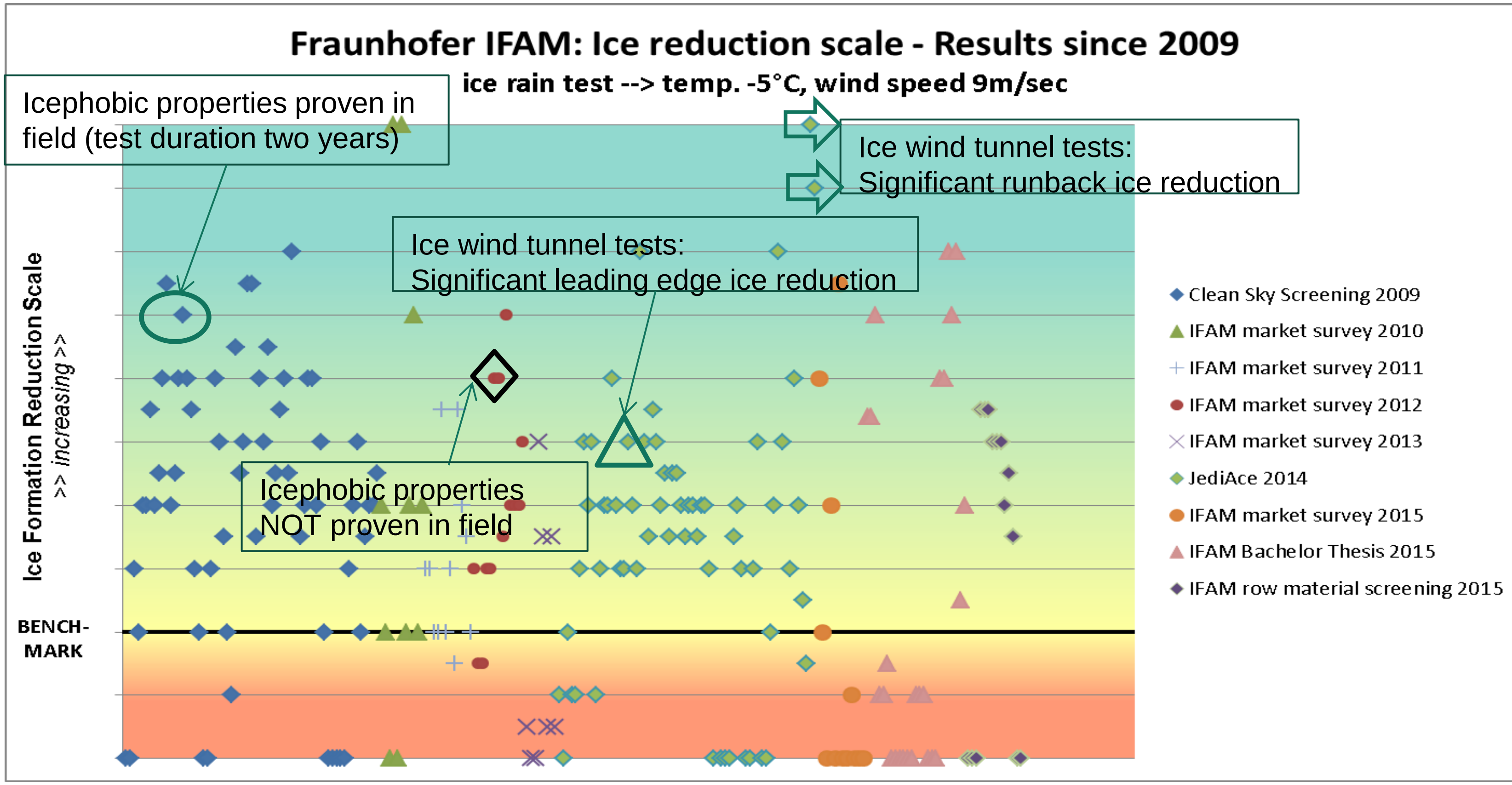
Rime ice adhesion:

Ice removal by scraping

→ Rime ice simulation with subsequent removal by modified mar resistance tester

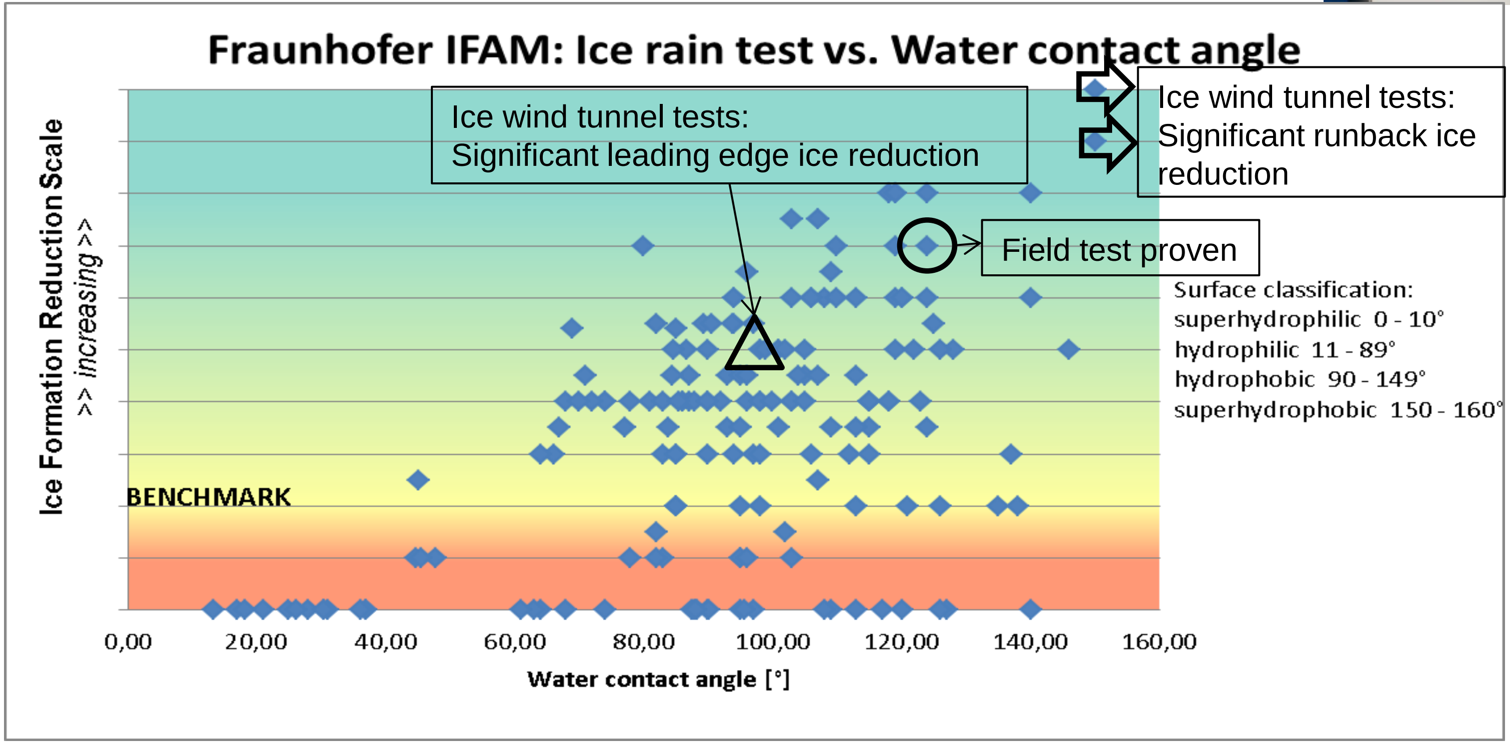
Anti-Icing Surfaces

Ice-rain test results since 2009



Anti-Icing Surfaces

Relevance of water contact angle



→ Water contact angle (surface hydrophobicity) is NOT the key property for icephobic coatings

→ Parameters such as (1) Surface free energy, (2) contact angle hysteresis, (3) sliding angle are currently being discussed / evaluated in terms of correlations to icephobicity

New Ice-Lab with included wind tunnel

- Temperature down to -30°C (±1°C)
- Wind speed up to 350km/h
- Creation of supercooled water droplets

New Ice-Lab with included wind tunnel

Anti-Icing Surfaces

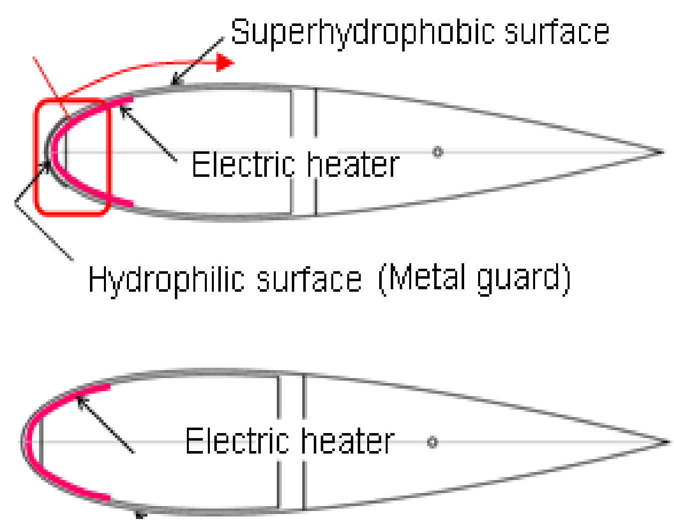
Exemplary Results out of European-Japanese cooperation:

Anti-icing coatings development

- Support of selected heating devices
- Improve ice prevention on heated / unheated surfaces
- Lower energy consumption

Different **coating approaches**

- Superhydrophobic coatings for areas behind leading edge
- Elastomeric hydrophobic coatings for all areas

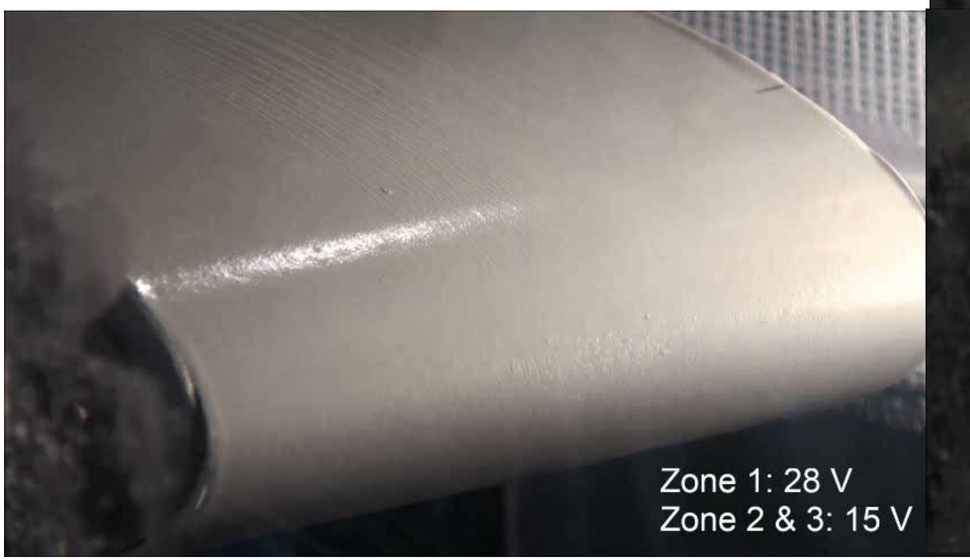


JEDI ACE

State-of-the-art coating
(benchmark)

Fraunhofer IFAM - IWT results

Formation of ice at leading edges, equipped with heating devices and covered with different coatings



Elastomeric anti-icing coating

Superhydrophobic anti-icing coating

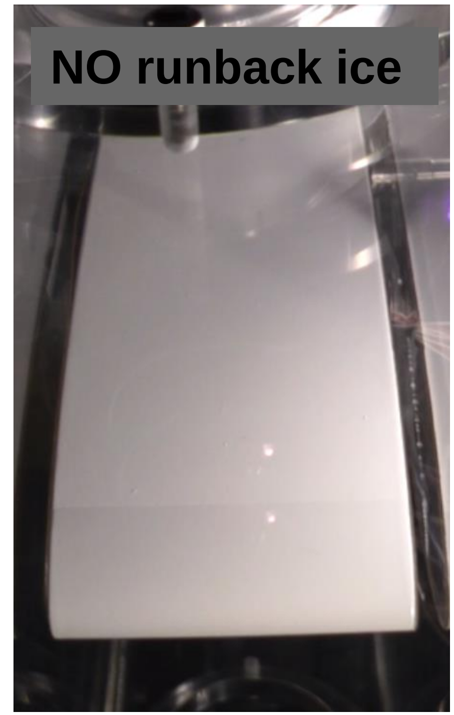
DASSAULT AVIATION
SUBARU
FUJI HEAVY INDUSTRIES LTD.
AEROSPACE COMPANY
JAXA Japan Aerospace Exploration Agency
KAIT
Universitat Rovira i Virgili
Fraunhofer IFAM

KAIT - IWT results

Formation of runback ice on mock-ups, equipped with heating devices and covered with different coatings

State-of-the-art coating (benchmark)

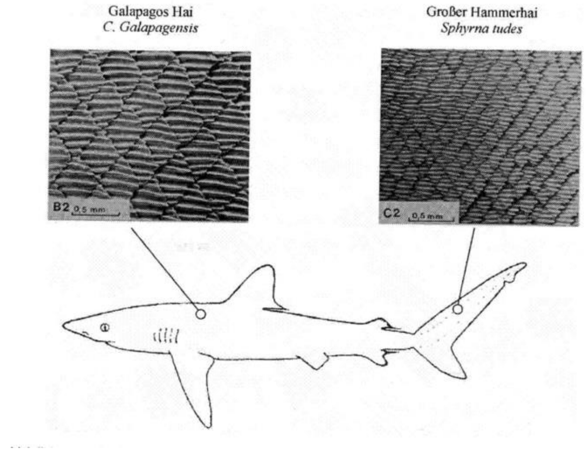
Elastomeric anti-icing coating



Superhydrophobic anti-icing coating

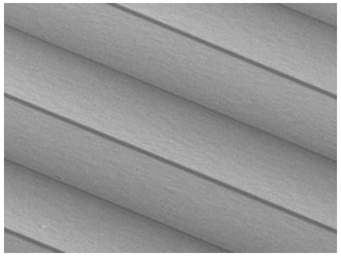
Drag-reducing microstructures

It is known for decades that the skin of fast sharks carries riblets for improvement of velocity and reduced energy consumption. The working principle is understood.
A reduction of surface-drag up to 10% is possible and proven trough several experiments.



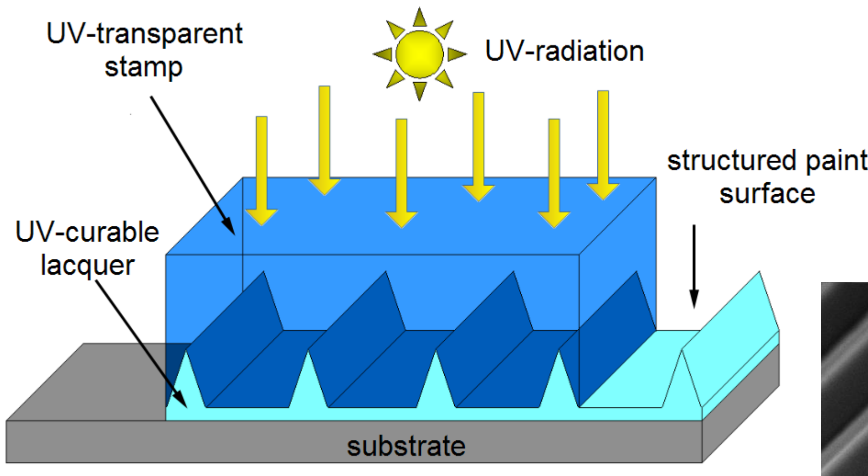
Source:
Dissertation W. Hage, Berlin, 2005

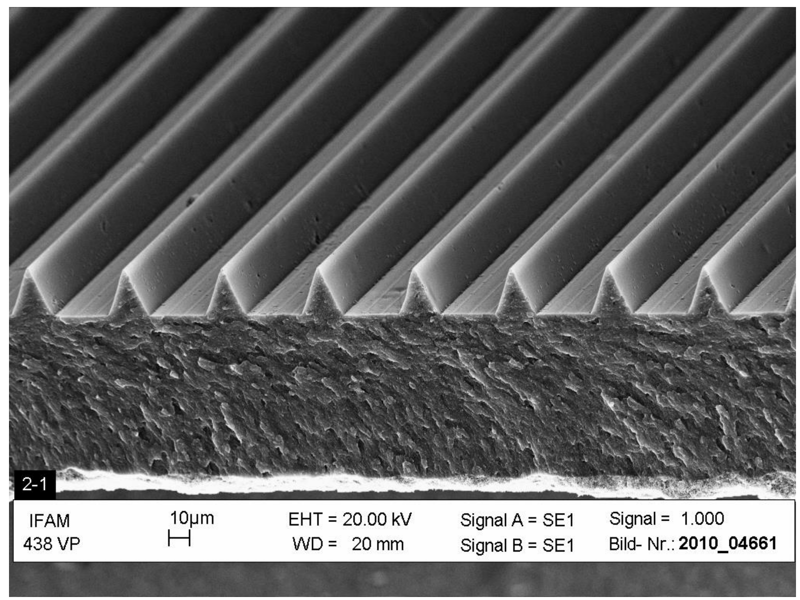
Microstructured paint – challenges



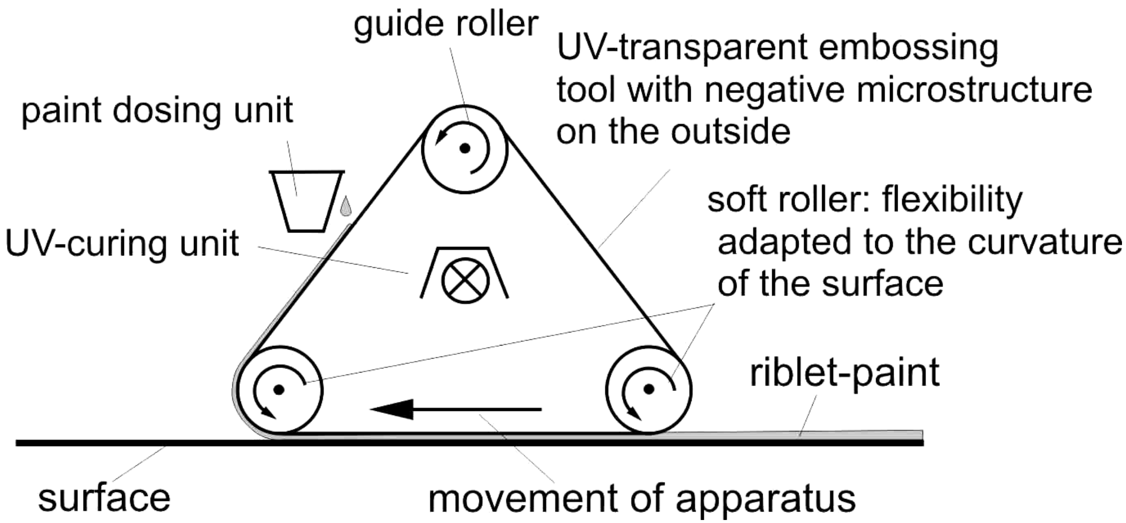
- Exact reproduction of the topography
- Huge surfaces to be coated (wind turbine rotorblades, aircrafts, ship-hulls etc.)
- Automated application
- Curved surfaces
- Durability of the microstructures

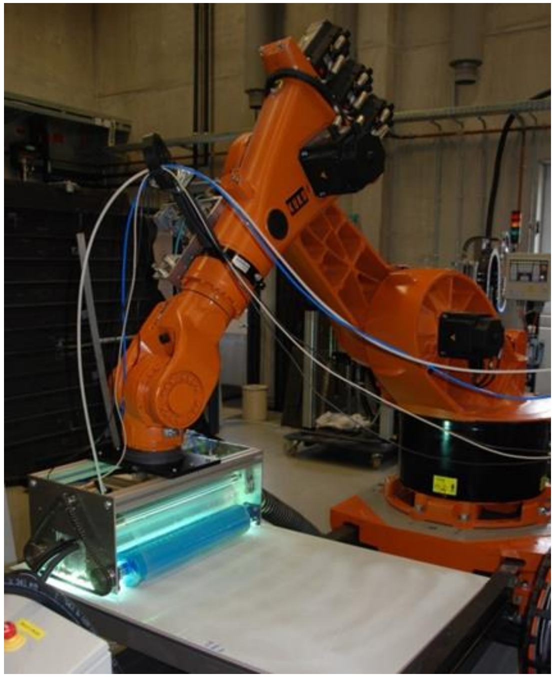
Approach: Embossing and curing in one single step





Continuous application on large objects





Patent: DE 103 46 124 B4

Prototypical paint used for feasibility studies

Paint requirements:

- No tack after UV curing
- No running after UV curing
- High resistance to weathering (main component polyurethane)
- Solids content almost 100%
- Improved erosion resistance by incorporating nanoparticles

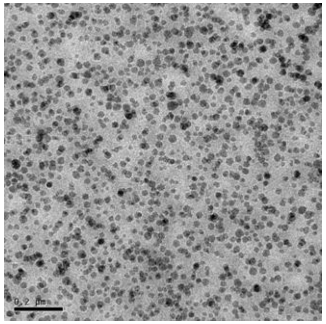
Component A:

No.	Raw material	Percentage of component in applicable paint
1	Low branched hydroxyl group-containing polyester	13,10
2	Branched hydroxyl group-containing Polyester	35,00
3	Solvent	9,10
4	Urethane-acrylate (UV-curing resin)	21,80
5	UV-Initiator	0,80
6	UV-Initiator	0,20
Amount of component A		80,00

Component B:

No.	Raw material	Percentage of component in applicable paint
1	Aliphatic polyisocyanate	20,00
Amount of component B		20,00

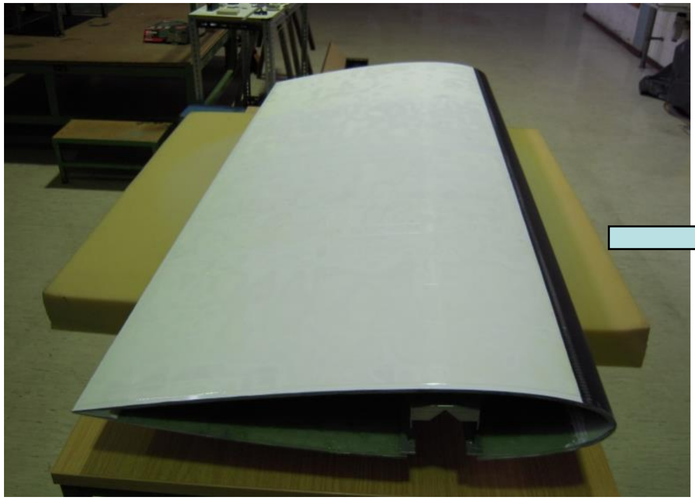
Components A+B:	100,00



TEM micrograph of a dual-cure lacquer with 100% solids and 20% inorganic nano-particles.

Wind-tunnel experiment with coated wing-profile

Comparison smooth wing with riblet-coated wing
(riblet-spacing 150µm, height: 75µm)

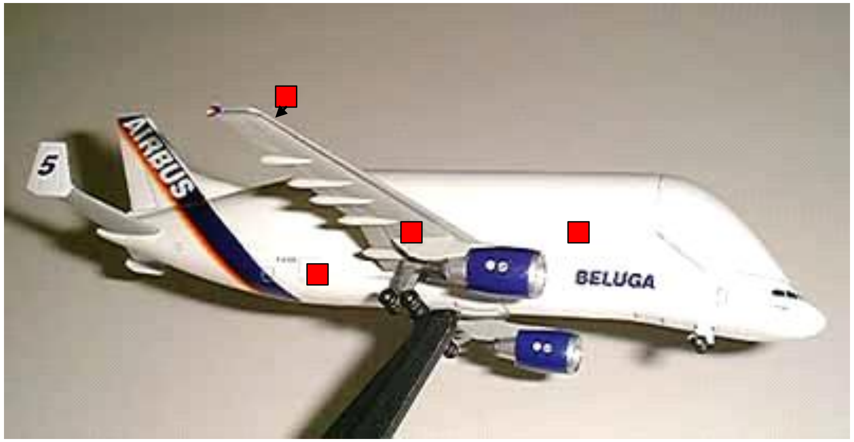


Result:

- **Reduction of total drag by 6.25%**

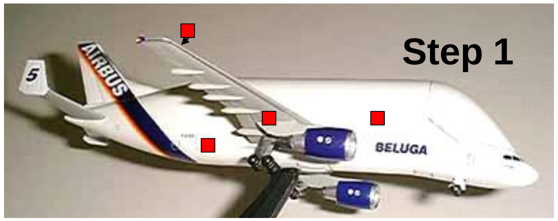
In-service wear tests

Lab wear tests (QUV, brush tests etc.) show a notably robust aerodynamic effect, but the realistic data can only be achieved through in-service tests.



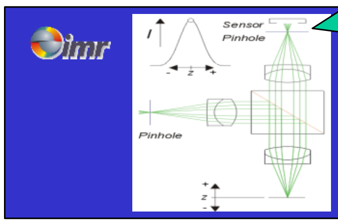
Test-patches (10x10cm) on a Beluga-Aircraft, in service since February 2009

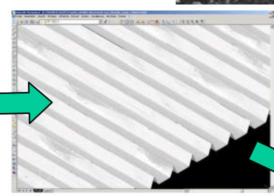
Procedure for in-service wear investigations



Step 1

Step 2



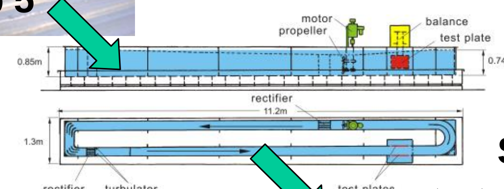


3D-measurement → 3D CAD data

scaling factor: approx. 100

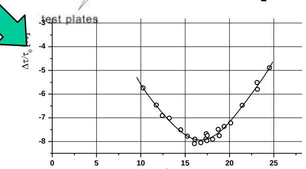
Step 4

SLA rapid prototype model



oil channel measurement

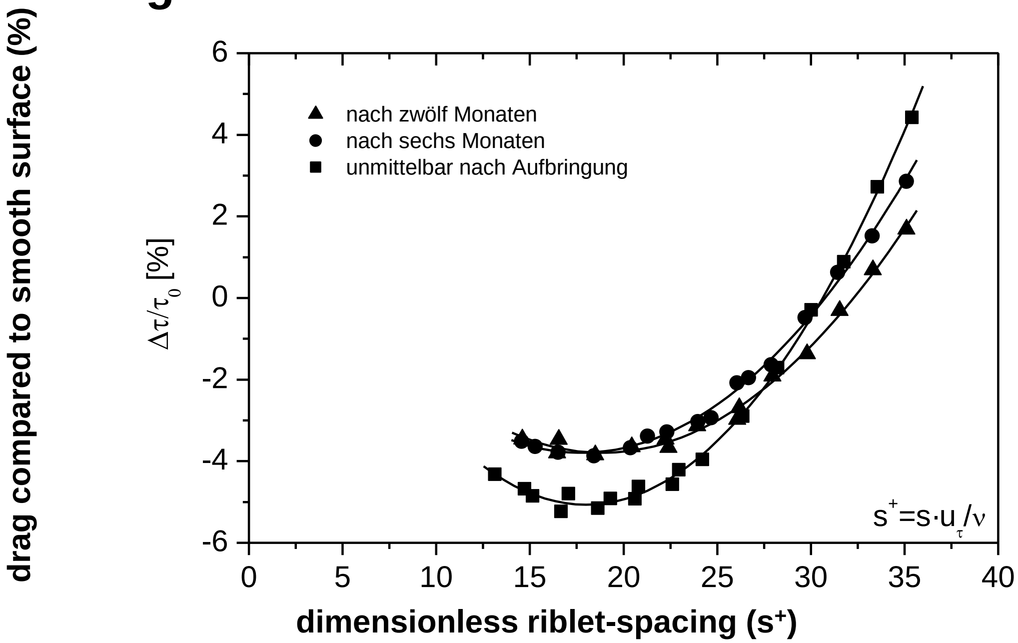
Step 6



drag reduction data

In-service wear tests

Drag-measurements in oil-channel

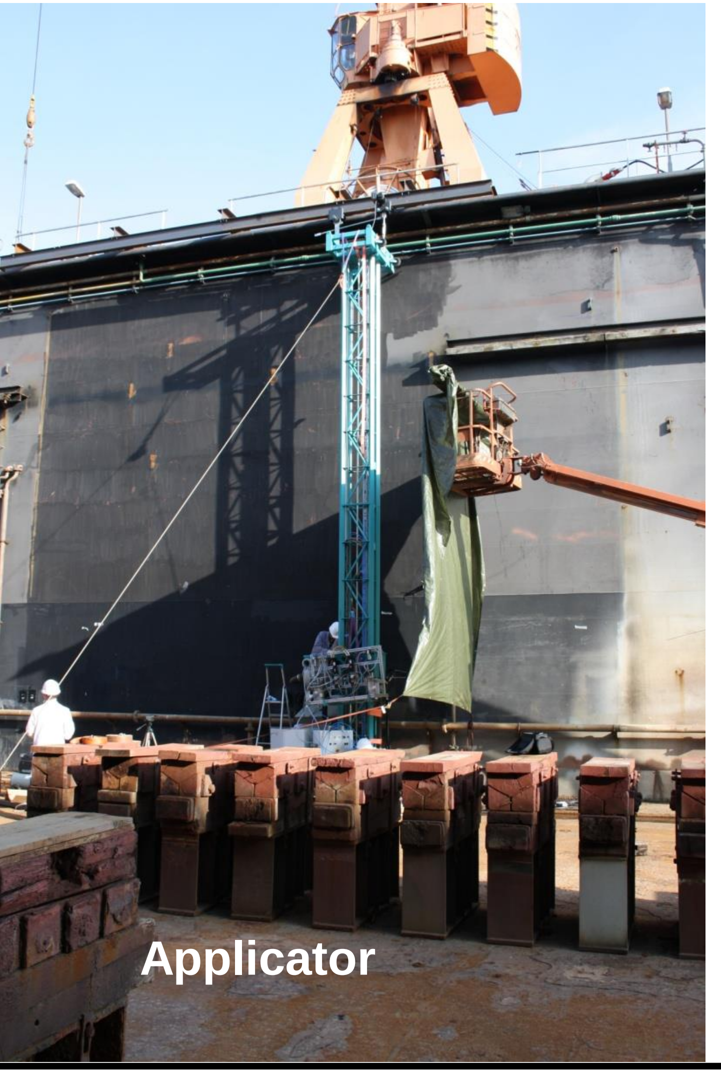


Results:

- Slight reduction due to wear in the first six month.
- Stable drag reducing properties until the end of the experiment after 24 months

Appearance of the paint

Application Trials in Floating Dock in Emden



Drag Reducing Surfaces

Applicaton wind energy:

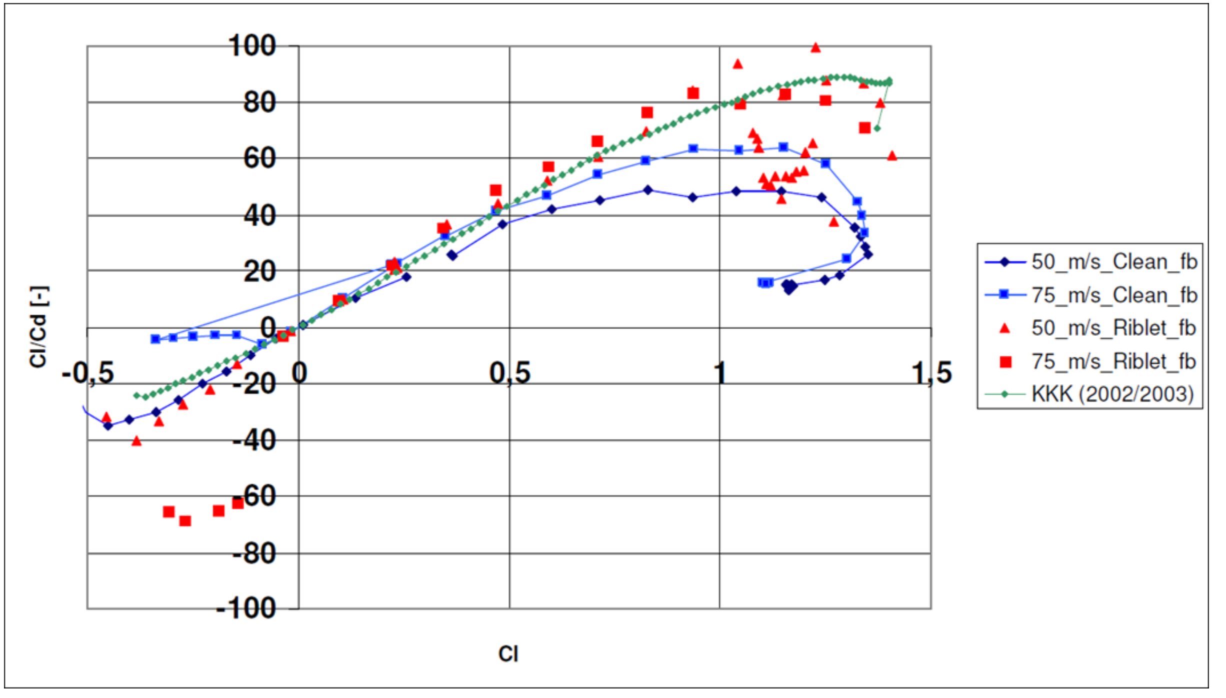
- Measurements in wind channel by Deutsche WindGuard GmbH (Bremerhaven)

Comparison: Profile DU-W -300

1. Smooth
2. Riblet-Coated

Measurements in wind channel by WindGuard GmbH (Bremerhaven)

Glide-Ratio:
Relation of lift (Cl) and drag (Cd)



Result:

- Improvement of glide-ratio by more than 30%!

Current Project: Riblet4Wind – Riblet-Surfaces for Improvement of Efficiency of Wind Turbines (657652)

- **Goal:** Proof of perfomance increase and noise reduction by full-scale testing of painted riblets on rotorblades

- **Partners:**
  - Muehlhan, Denmark (application of riblet-surfaces)
  - EC&R, UK (wind park operator)
  - Mankiewicz, Germany (paint manufacturing)
  - Eltronic, Denmark (automation)
  - University of Barcelona, Spain (application technology stream B)
  - bionic surface technologies, Austria (aerodynamic calculations/simulations)
  - Fraunhofer IFAM, Germany (lead) (application technology stream A)

- Start: June 1, 2015
- End: November 30, 2018

Research Concept (I)

Starting points:
- Riblet-Coating technology for aircraft application (TRL 6-7)
- Wind channel experiments with riblet-surfaces on rotorblade model (TRL 5)

Aerodynamics
- Calculation of riblet geometries
- Numerical simulation of riblet effect
- Determination of number of riblets and positions

Technology-Stream A
Painted Riblets

- Preparation of embossing molds
- Development/adaption and qualification of paint
- Development/Aadaption and qualification of application technology

Technology-Stream B
Riblets by Cold-Spray (GCS)

- Development of appropriate paramete for riblet generation
- Investigation of quality of microstrictur
- Investigation of durability
- Concept of application device for rotorblades

Drag Reducing Surfaces

Research Concept (II)

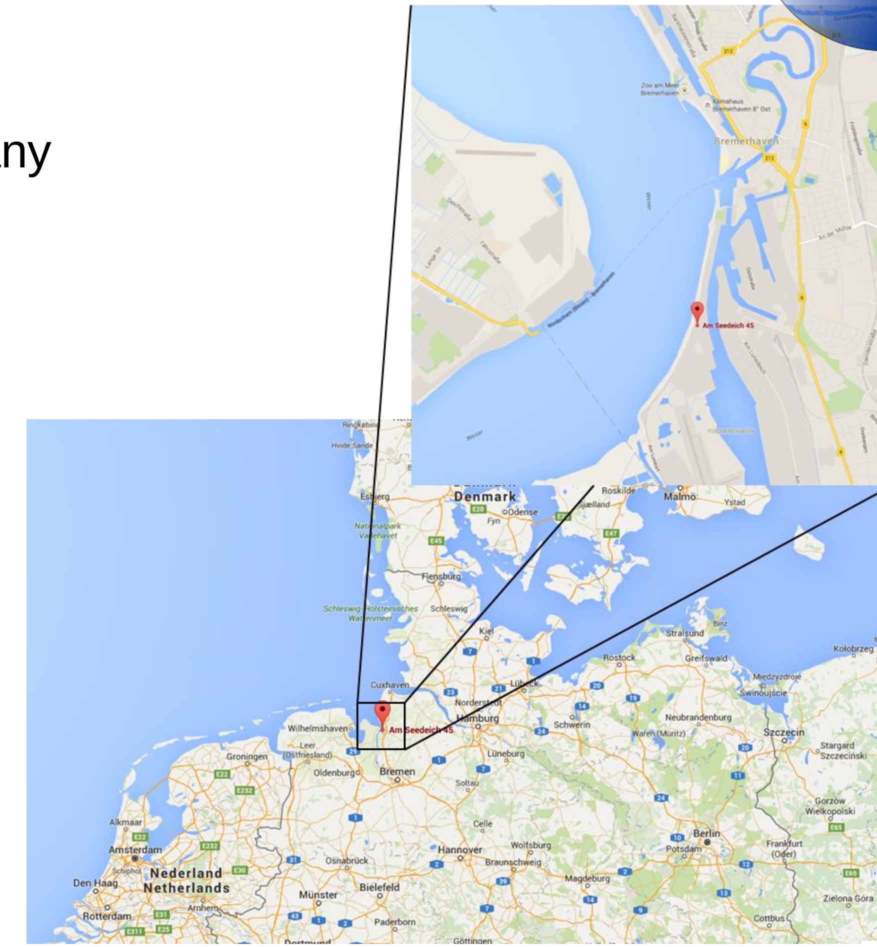
Assessment of TS A and B
- Surface properties and application technology
- Cost
- Selection of Technologies

Pilot-line and production of prototypes
- Construction and test operation of a pilot line
- Production of riblet-coated blades for in-service test campaign

In-service test operation of prototypes and business case evaluation
- Determination of performance of exisiting turbines (power and noise)
- Determination of performance of modified turbines (carrying rotor prototypes)
- Evaluation of the business case

Currently targeted WTG

- Location: Bremerhaven, Germany



- 2 turbines AN BONUS 450 kW, LM 17

Acknowledgements:

The authors would like to thank the following institutions:

- The *VolkswagenStiftung* for the financial support of prototype development and wear investigations

- The *European Regional Development Fund* and the *Federal State of Bremen* for the financial support of basic investigations regarding micro- and nanostructuring

- *Airbus Deutschland GmbH* for support of the in-service tests

- The European Commission for funding of the H2020 collaborative project “Riblet4Wind – Riblet-Surfaces for Improvement of Efficiency of Wind Turbines” (657652)

- The European Commission for funding of the FP7 collaborative project “JEDI-ACE– Japanese-European De-Icing Aircraft Collaborative Exploration” (314335)