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Key partner in Design Process Innovation

Prediction of production losses in cold climates and Ice Protection System design by CFD

Massimo Galbiati

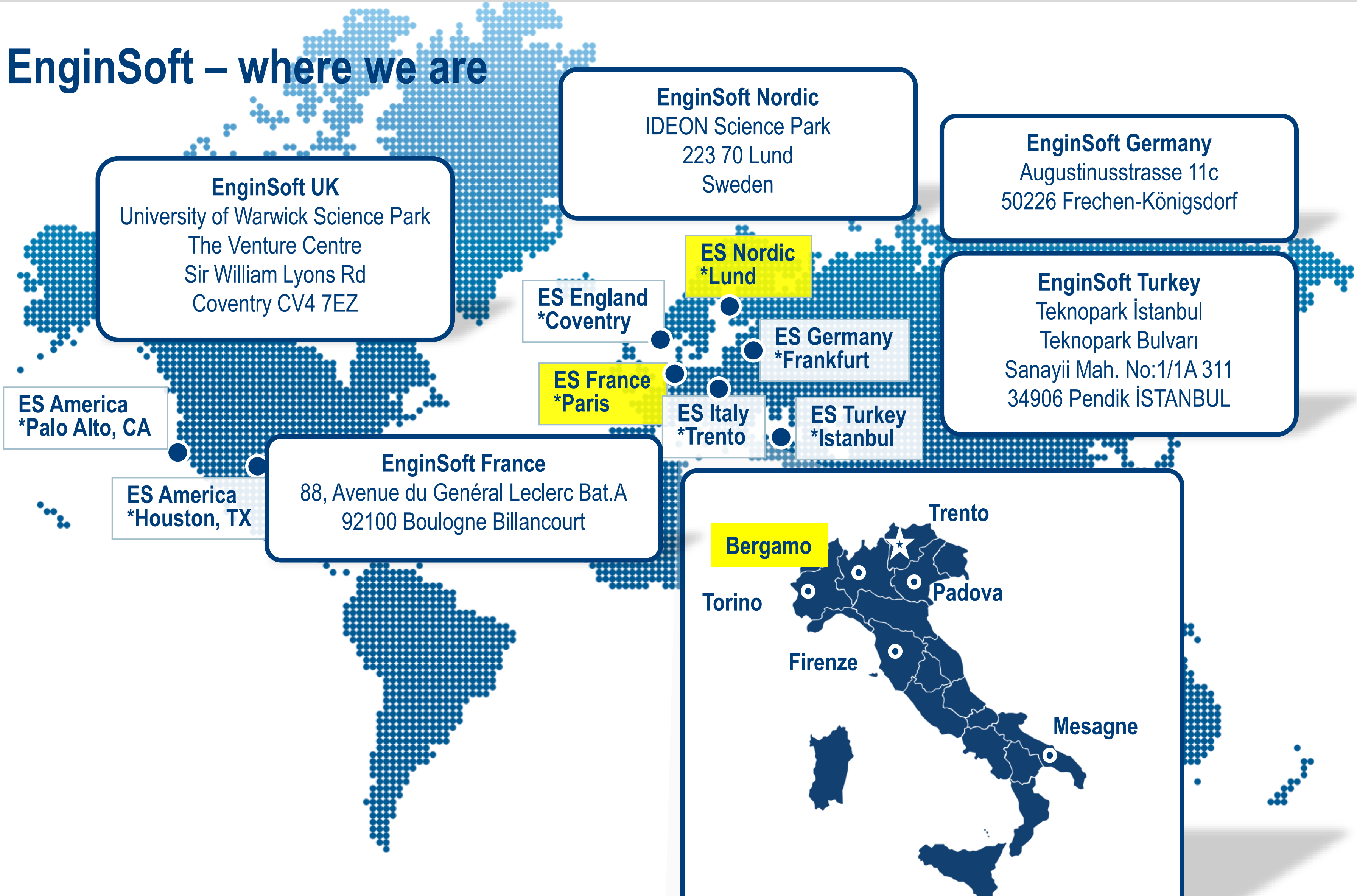
February 9, 2016

Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Agenda

- EnginSoft introduction & offering for Wind turbines in cold climates
- Performance degradation in icing conditions
- Ice Protection System: design supported by simulation
- Cost and benefit of Ice Protection Systems
- Conclusions

EnginSoft – where we are



EnginSoft UK
University of Warwick Science Park
The Venture Centre
Sir William Lyons Rd
Coventry CV4 7EZ

EnginSoft Nordic
IDEON Science Park
223 70 Lund
Sweden

EnginSoft Germany
Augustinusstrasse 11c
50226 Frechen-Königsdorf

EnginSoft Turkey
Teknopark İstanbul
Teknopark Bulvarı
Sanayii Mah. No:1/1A 311
34906 Pendik İSTANBUL

EnginSoft France
88, Avenue du Genéral Leclerc Bat.A
92100 Boulogne Billancourt

Competence Center

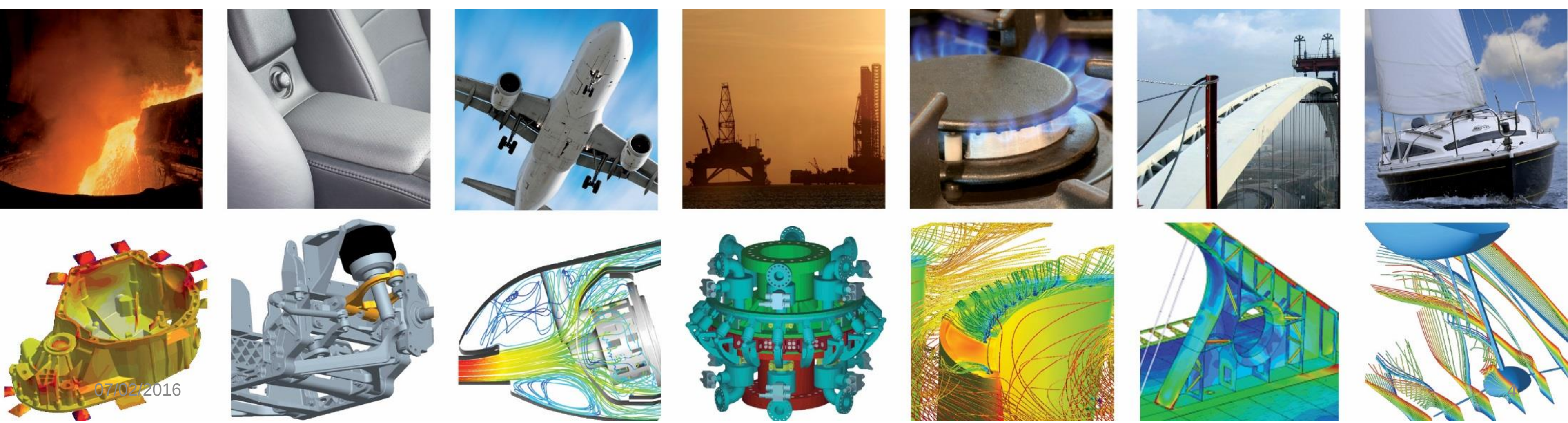
EnginSoft - who we are

CONSULTING
4.000

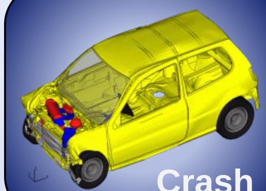
SOFTWARE
1.500+

TRAINING
130+

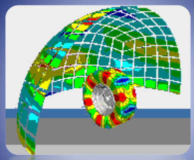
RESEARCH
60+

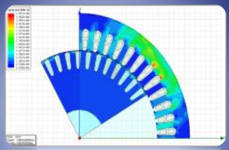


EnginSoft – what we do

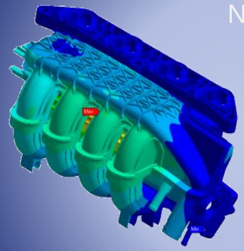

Crash


Multibody


Acoustic


Electro-magn.

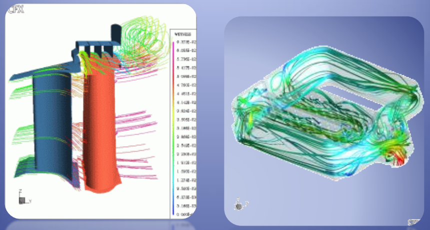

1-D Fluid mechanics

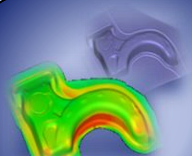

Linear Structural
Non-Linear Structural
Linear Dynamics
Nonlinear Dynamics
Explicit Dynamics
Coupled Physics

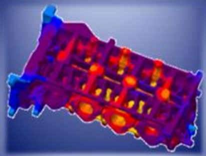
FEA

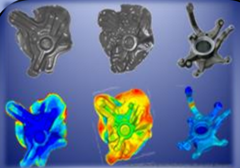
Steady State Thermal
Transient Thermal


Process Integration and Design Optimization

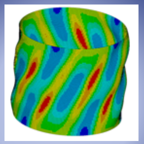

CFD
Thermo Fluid Dynamics
Fluid Structure Interaction
Multi Phase Fluid Dynamics
Turbulence Models


Stamping


Casting

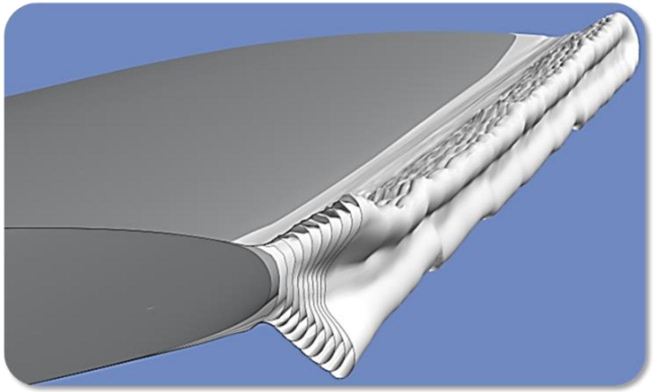

Forging

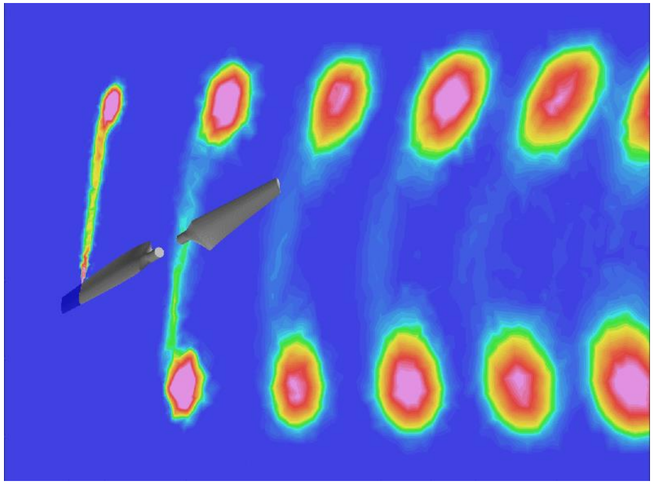

Injection


Composites

Wind energy in cold climates

- Blade Icing Protection System Design
  - Simulation of ice accretion in different environmental scenarios
  - Simulation in anti-icing and de-icing conditions
  - Simulation and optimization of hot air de-icing systems
  - Simulation and optimization of electro-thermal heating: power distribution and coverage
  - Support to the the design of ice detection systems





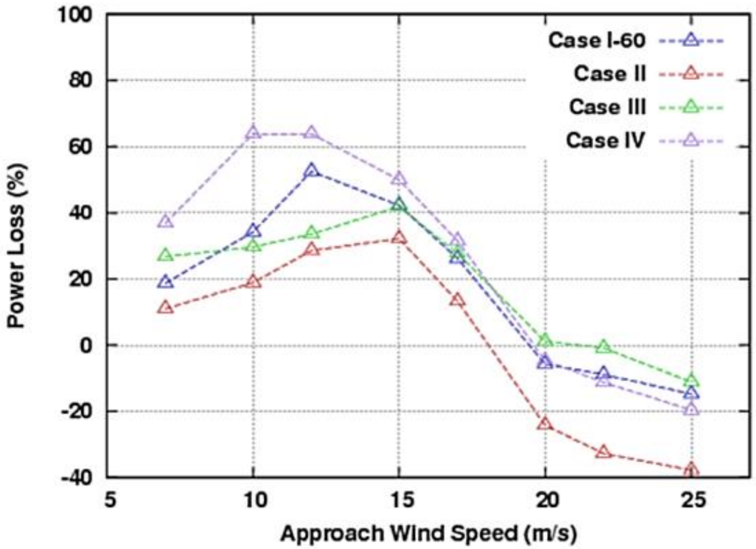
- Wind Farm Site Assessment for Icing
  - Simulation of long icing events
  - Prediction of annual production loss due to icing
  - Assessment of investment risk in cold climates (cost vs benefit of Ice Protection Systems)

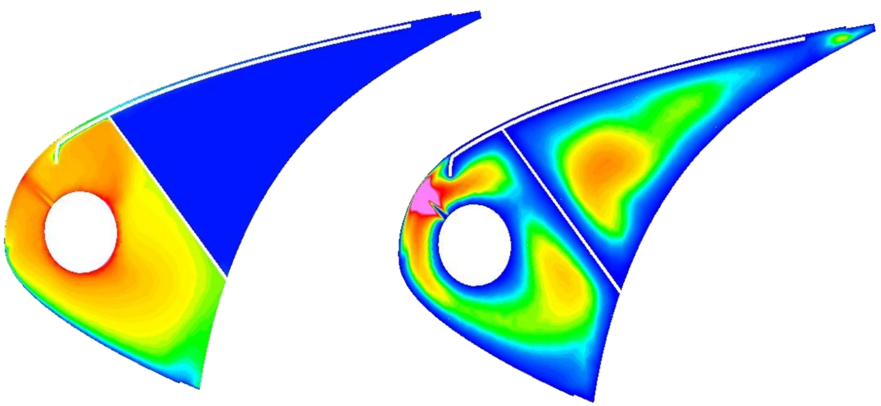
Ice effect and prevention

Ice Accretion Simulation

Performance degradation

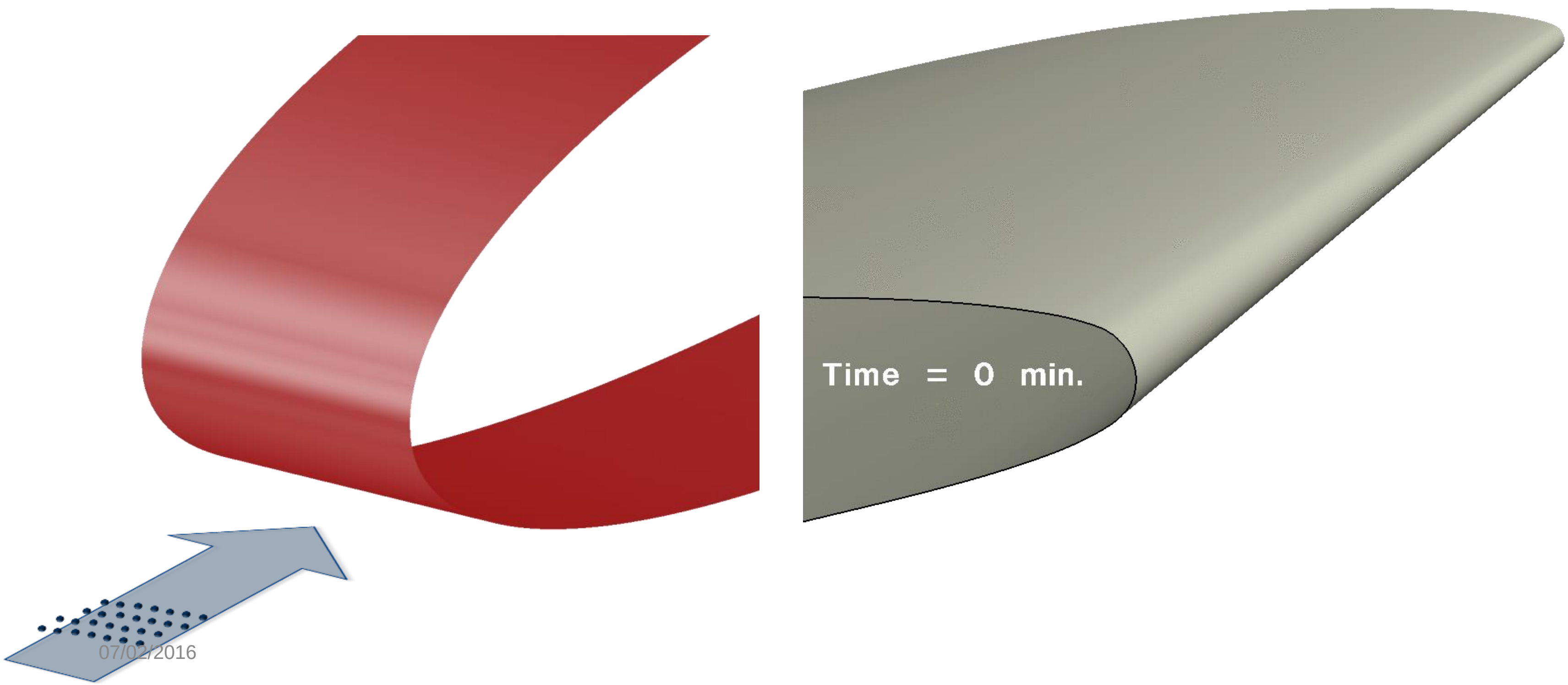
Design of Ice Protection Systems



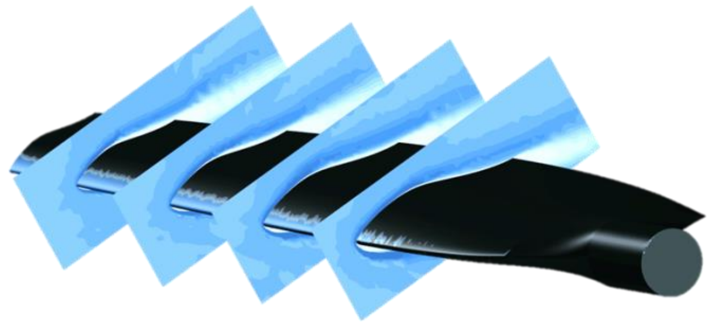


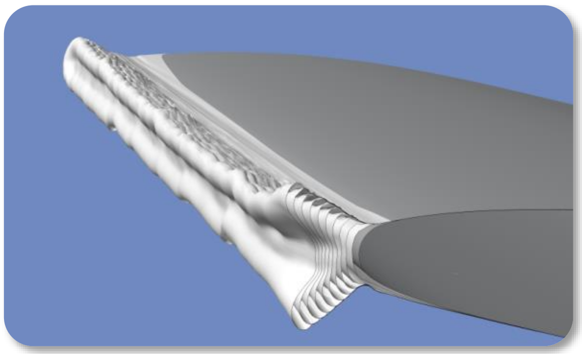
Icing simulation

ICE SHAPE AND ROUGHNESS → DRAG&LIFT, TORQUE, NOISE, LOADING, ICE THROW, …



Ice accretion simulation





FLOW & HEAT TRANSFER → DROPLETS IMPINGEMENT → WATER FILMING, EVAPORATION, ICE FORMATION

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Performance degradation in icing conditions

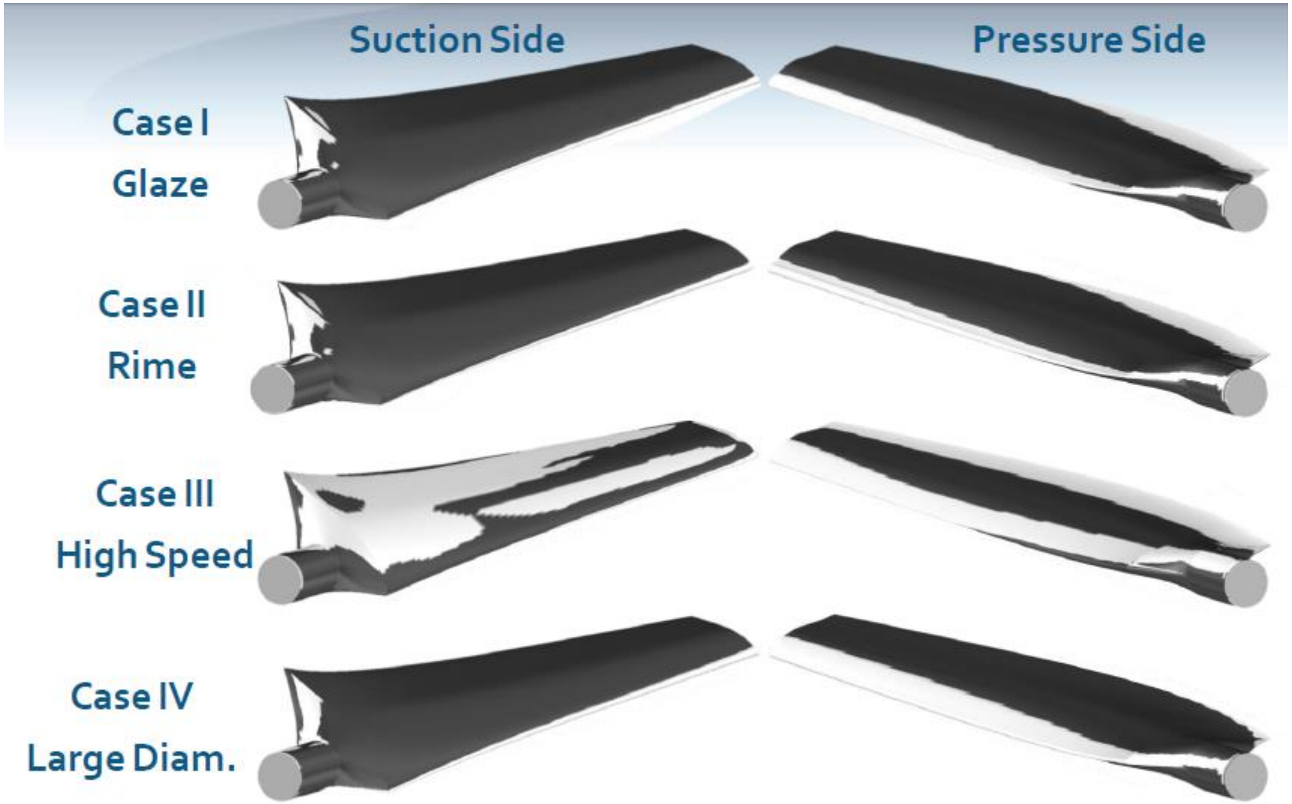
NREL Phase VI Rotor Icing

- Large performance database publicly available
- Experimental measurements: NASA Ames 80 x 120 ft. wind tunnel
- 5 meter blade, fixed-pitch, fixed-speed, stall regulated

http://wind.nrel.gov/amestest/

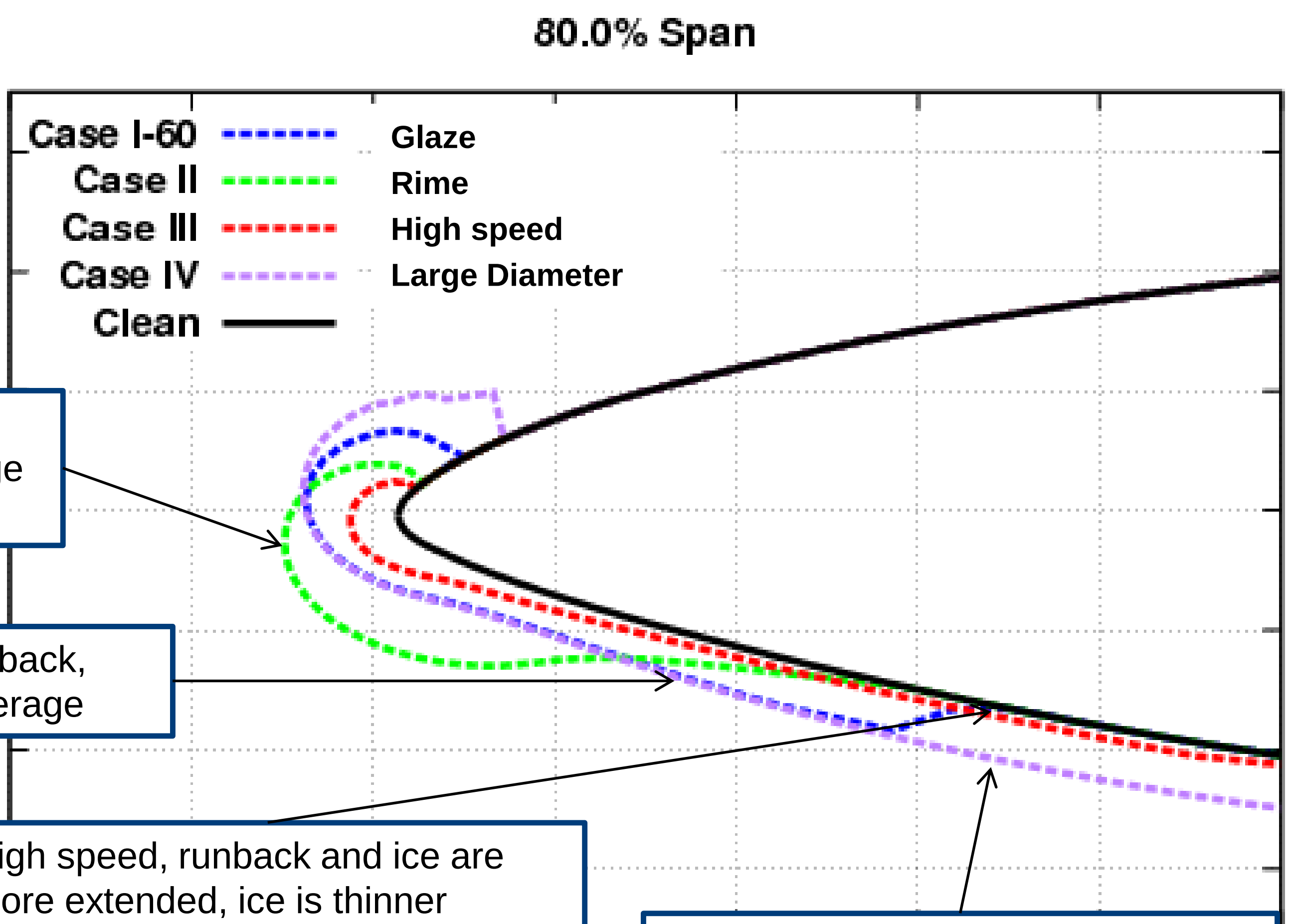
Different icing scenarios

Highly separated flow



	Case I	Case II	Case III	Case IV
	Glaze	Rime	High Speed	Large Diam.
Approach speed	7 m/s	7 m/s	22 m/s	7 m/s
Static air temperature	-3 °C	-15°C	-3 °C	-3 °C
Droplet diameter	20 µm	20 µm	20 µm	30 µm
Liquid water content	0.5 g/m^3	0.5 g/m^3	0.5 g/m^3	0.5 g/m^3
Icing time	60 min	60 min	60 min	60 min

Ice shape



Rime at the Leading Edge and thicker

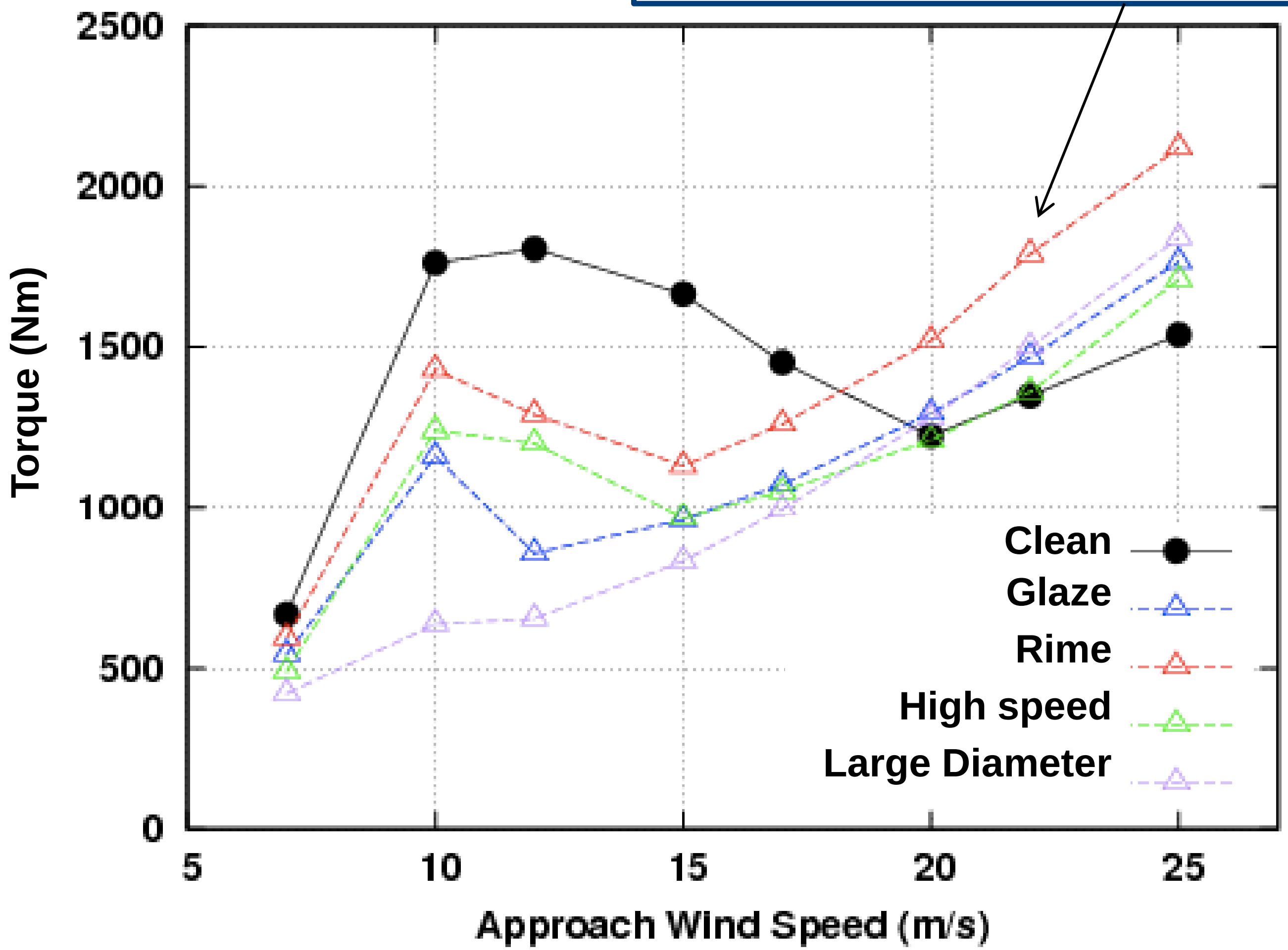
Glaze, runback, larger coverage

High speed, runback and ice are more extended, ice is thinner

Large Diam. → higher collection and thicker ice

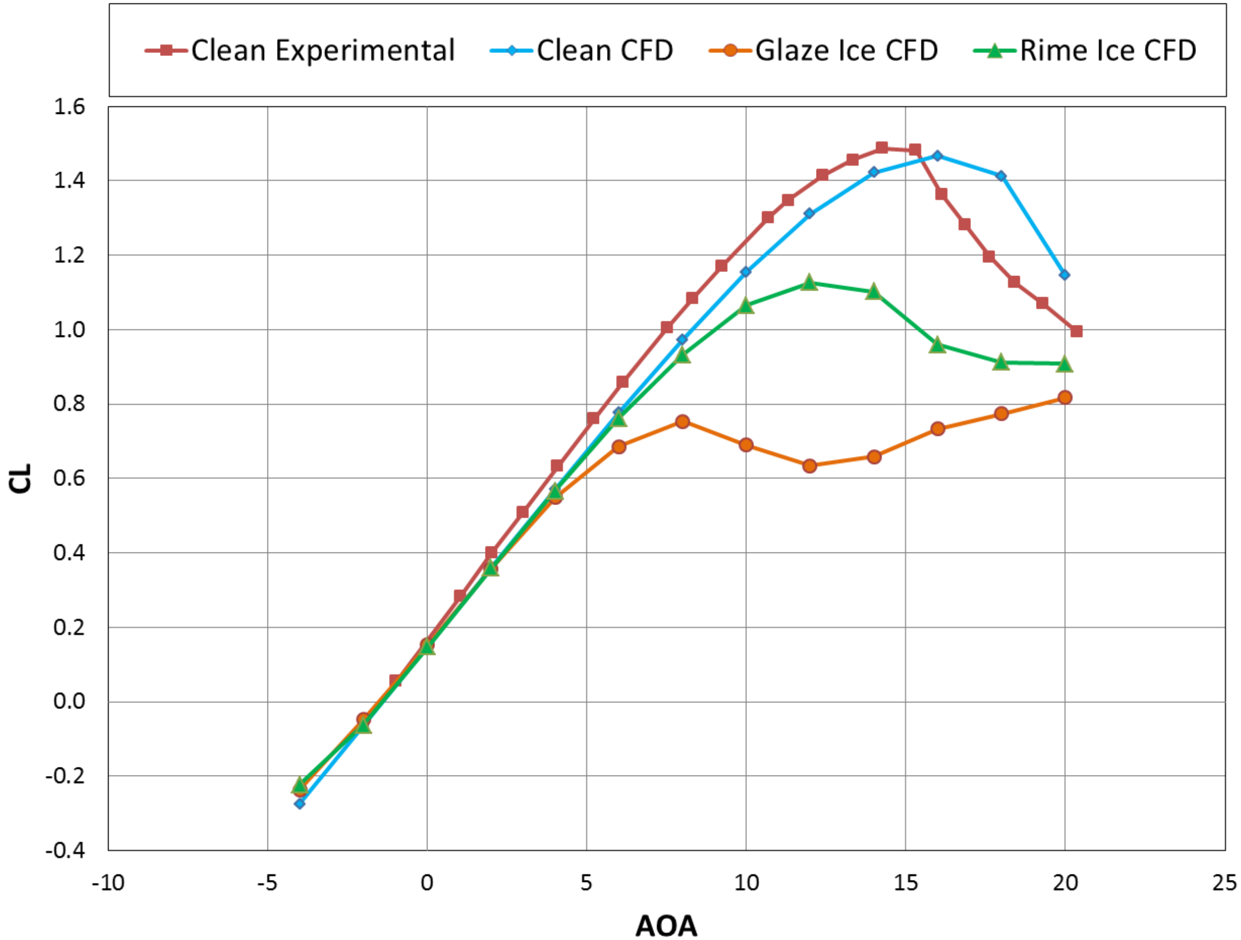
Performance Degradation

1. Increased curvature of the ice shape results in an increased acceleration of the airflow near the leading edge, which in turn increases local suction forces
2. Clean blade in fully separated regime. The ice shape cannot increase the extent of the separated flow
3. Shaft loading and damage



Performance degradation

- Comparison of CD, CL, torque in iced conditions vs clean conditions



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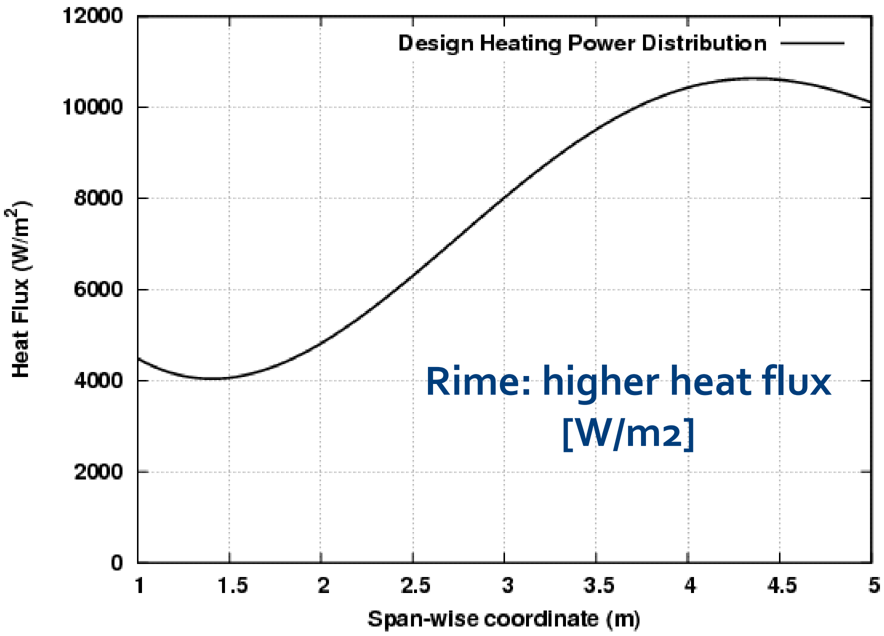
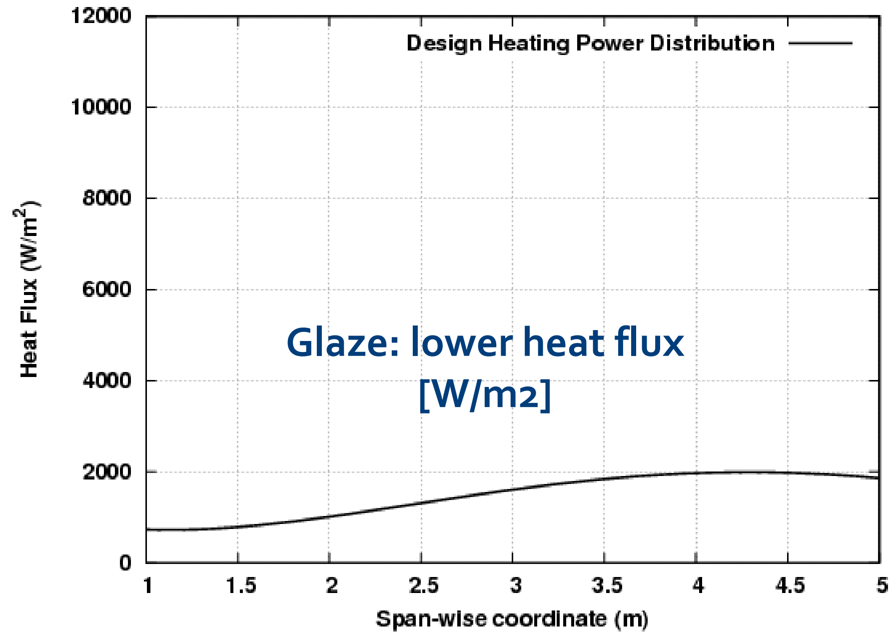
Ice Protection System

Spanwise Anti-Icing Power Distribution Requirement

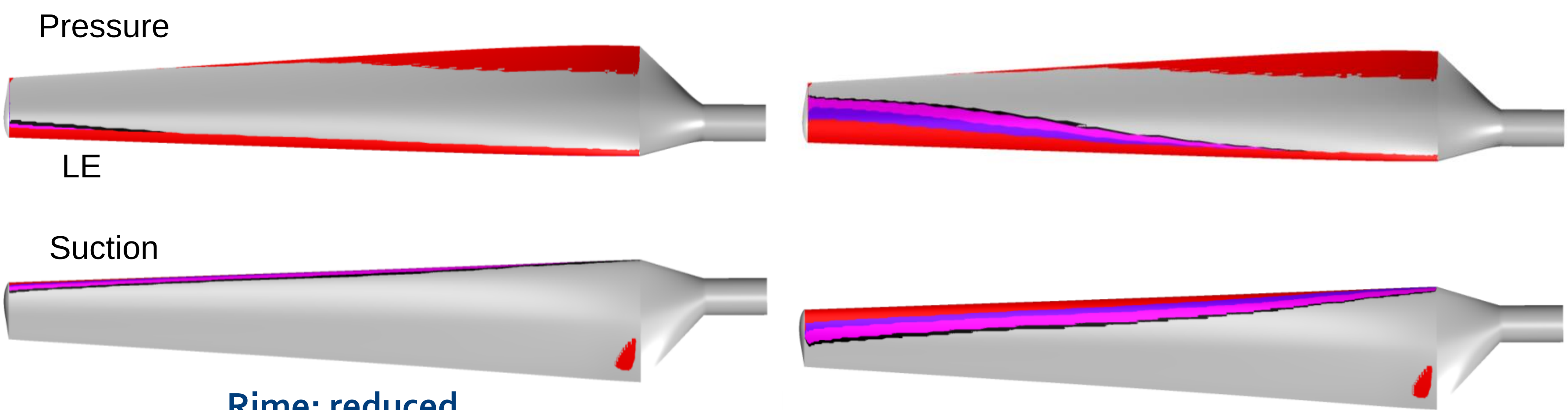
- Running-wet power requirements.
- Power distribution that must be applied to the blade to avoid freezing.





IPS: effective Coverage

- Surface heat flux is applied and evaporation is accounted for
- Area needed to evaporate all the water = coverage
- Trade-off between power level and coverage – Temperature constraints



Rime: reduced coverage

Glaze: larger coverage

Coverage decreases if the heat flux is increased

Hot air de-icing

- Hot air distribution and pressure losses
- Power needed to de-ice
- Temperature distribution on the blade surface
- Fraction of the blade surface where T > TMELTING
- Time needed to de-ice

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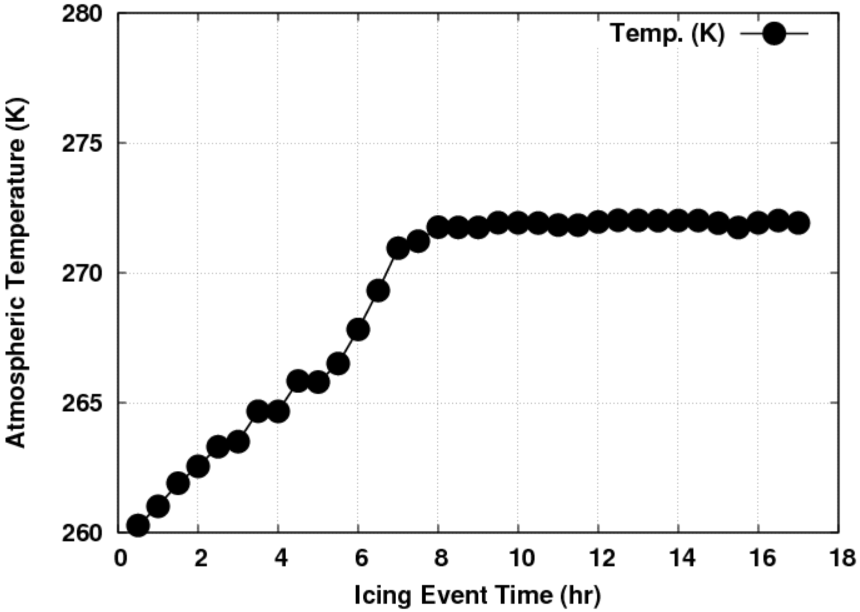
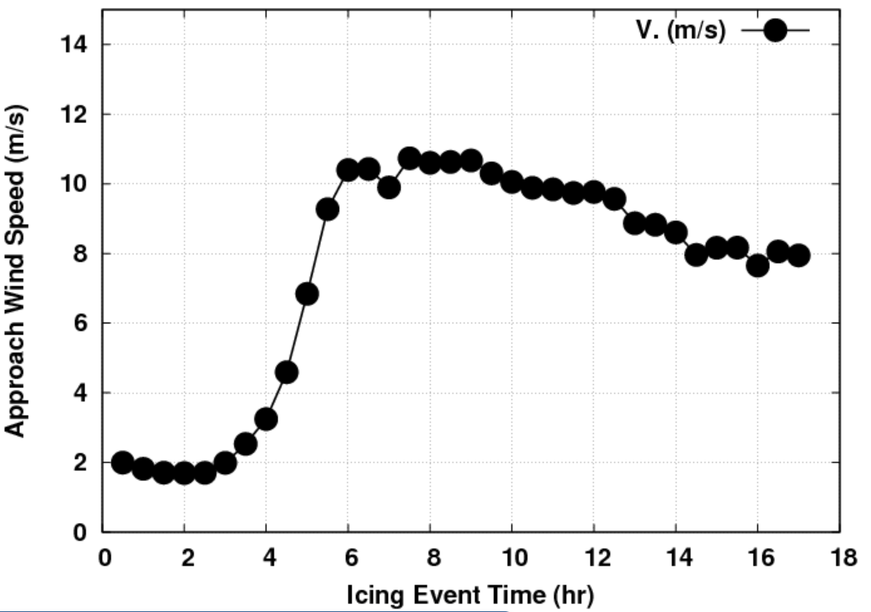
Cost and benefit of Ice Protection Systems

Long icing event – production losses

- Gaspesie Peninsula of Quebec
- 67 GE 1.5 MW Turbines
- 12% loss of potential annual production





17h ICING EVENT, February 2009

Production losses and IPS cost

ICE ACCRETION AND PERFORMANCE DEGRADATION

DESIGN OF ICE PROTECTION

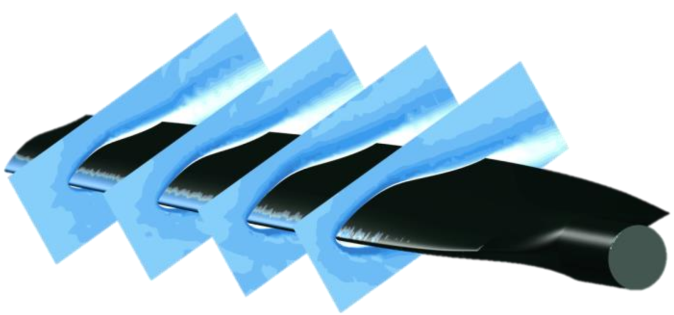
ENERGY RECOVERY

-

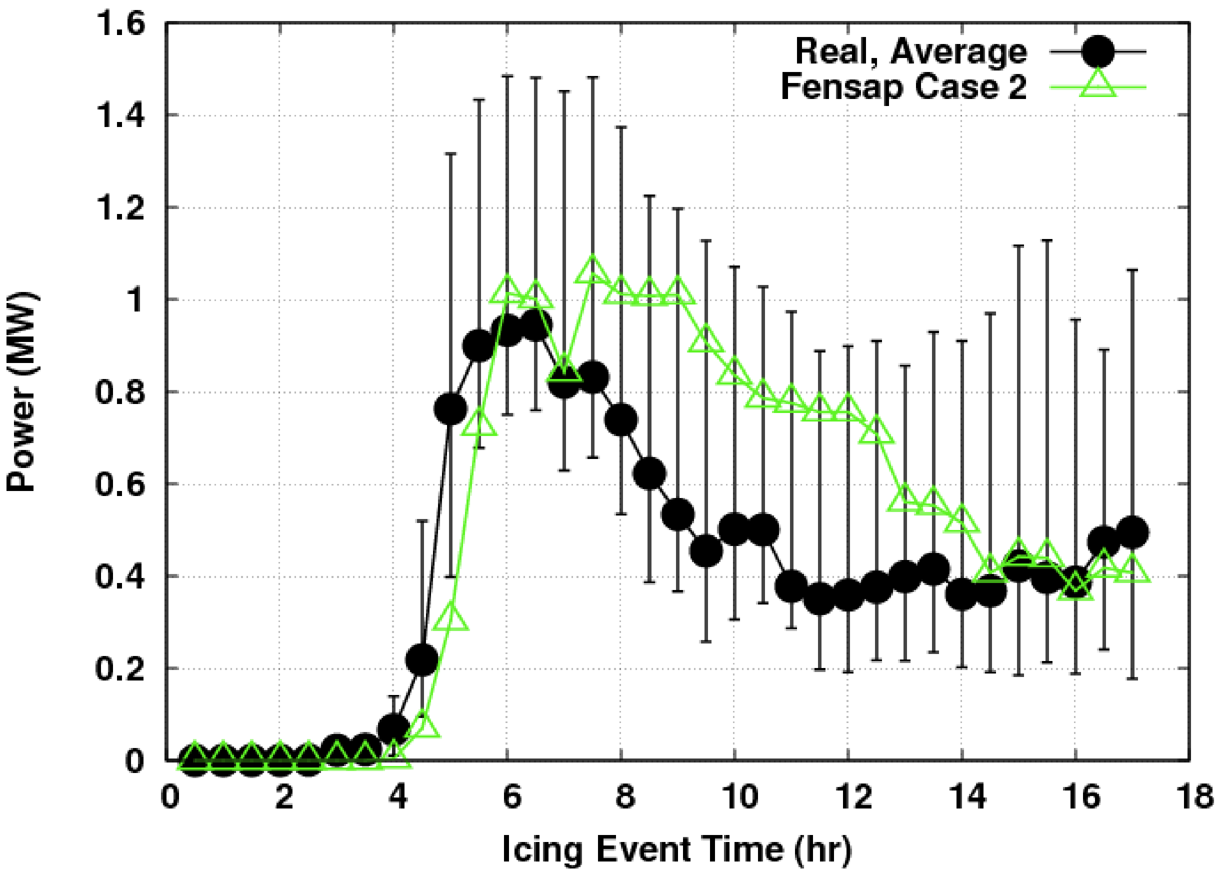
COST OF ICE PROTECTION

=

NET ENERGY GAIN



Power Output – Simulation vs reality



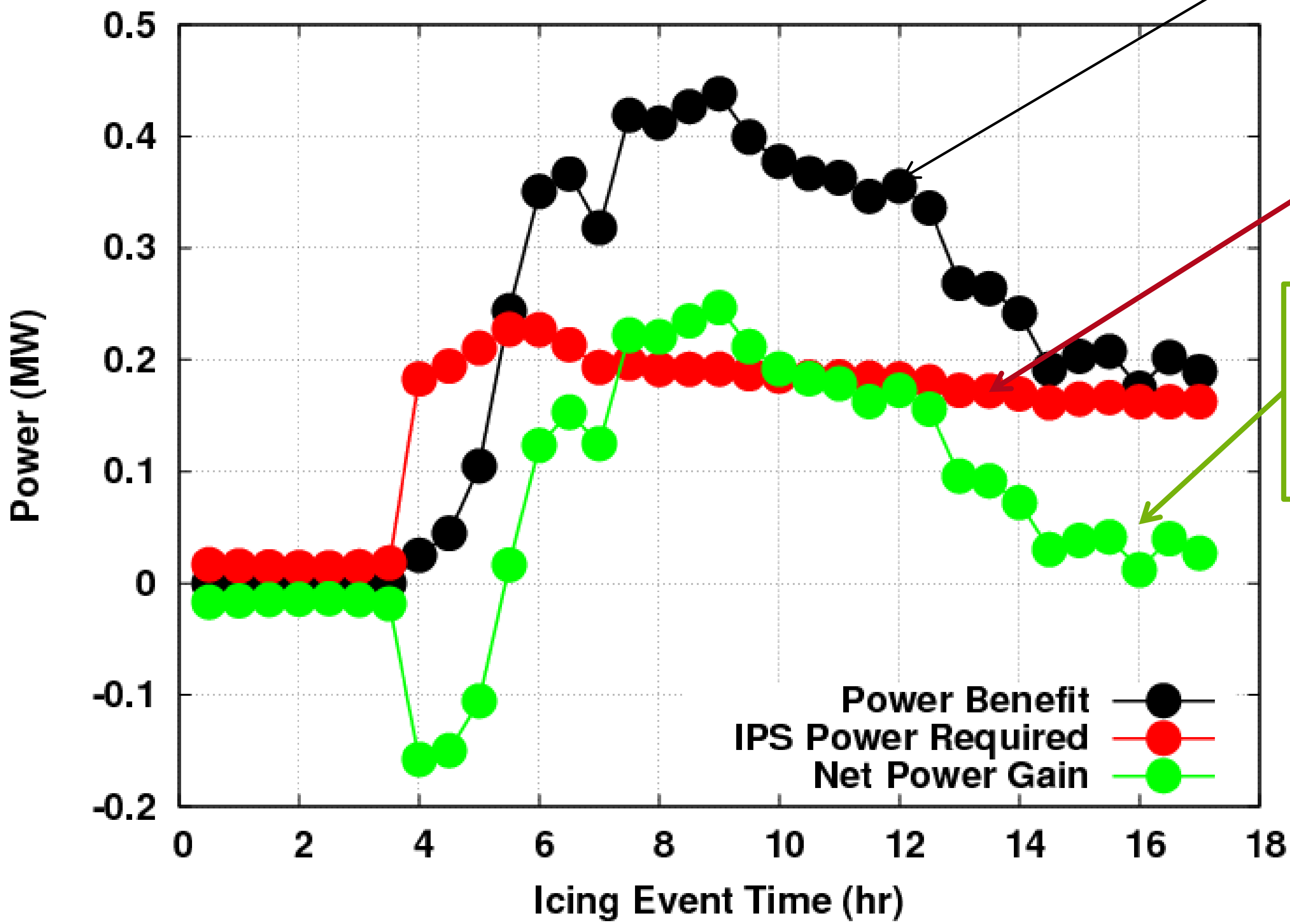
- Sources of uncertainty:
  - Liquid water content
  - Droplets diameter
  - Surface roughness
  - Terrain topology
  - Local turbine conditions

Net energy gain

Production increment thanks to IPS

Cost of IPS

Net Power Gain: the integral of this curve is the Energy Gain and is > 0



Conclusions

- CFD simulation has been validated and used on industrial applications for:
  - The prediction of performance degradation and energy loss due to icing
  - The design and optimization of de-icing and Ice Protection Systems
  - The assessment of cost and benefit of Ice Protection Systems
- EnginSoft has specific competence and experience in CFD simulation with ice accretion

THANK YOU – TACK!

Visit our booth in the exhibition area

Massimo Galbiati – m.galbiati@enginsoft.it
+39 347 75 233 79

Susanne Glifberg – s.glifberg@enginsoft.se
+46 760 042 003

www.enginsoft.com