Numerical simulation of ice throw from horizontal-axis wind turbines

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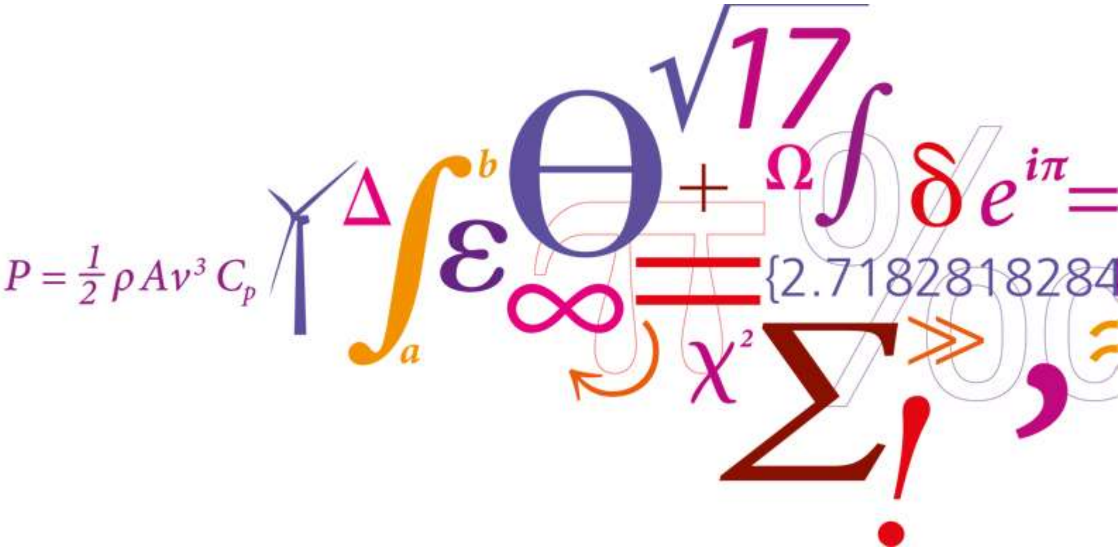
Winterwind 2018 – Åre, Sweden

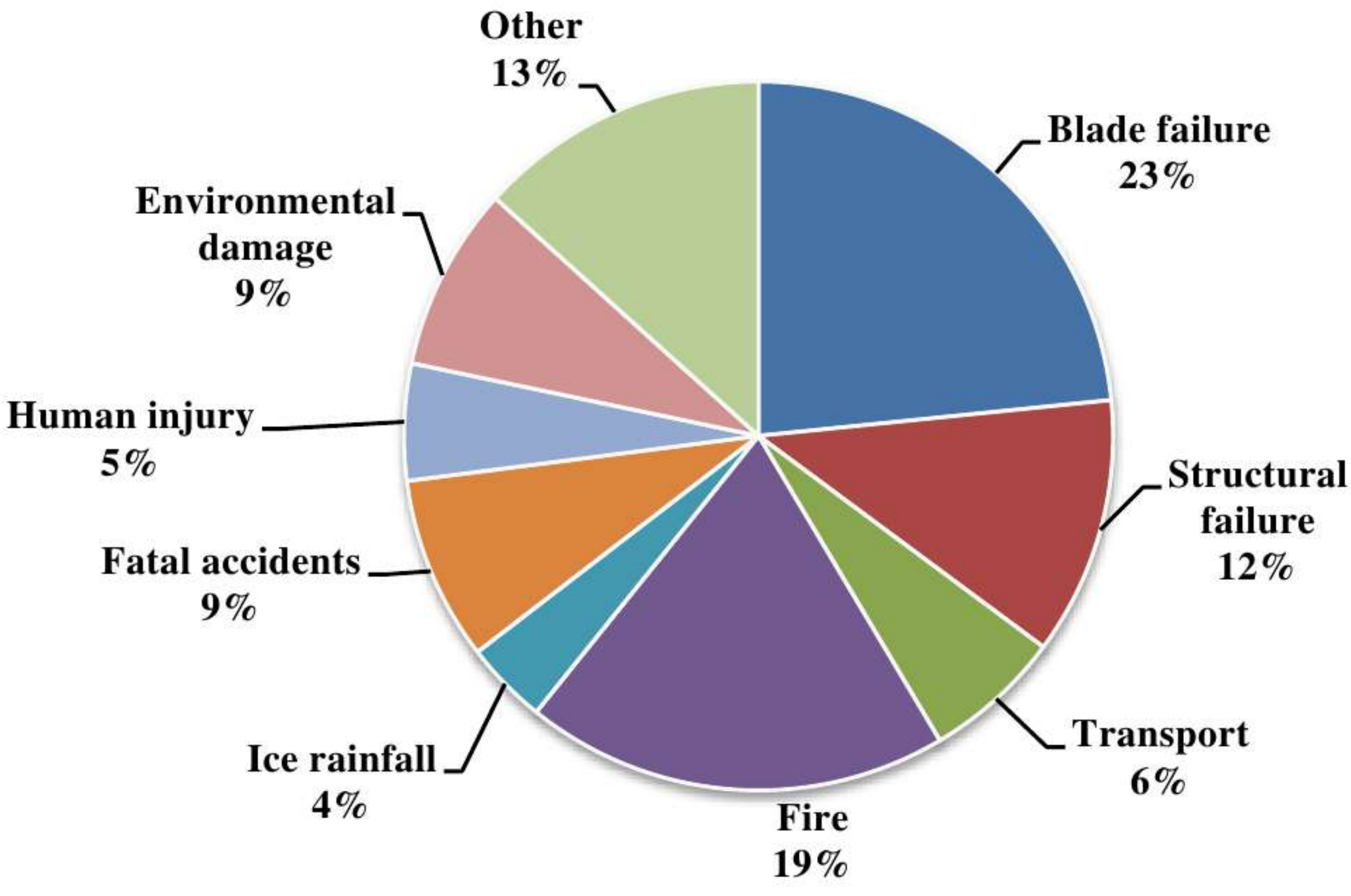


Background

- A code originally developped in the 80s for blade throw
- Reviewed and revised in 2010
- Initial results published in 2015 and it was decided to make the code open source

Motivation

Types of WT failure



J.-S. Chou, W.-T. Tu / Engineering Failure Analysis 18 (2011) 295–313

Why considering icing

- Increases in fatigue loads
- Decrease in power production
- Risks of ice throw
  - Ice risks are much more significant than blade/fragment failure (Frequency blade failure 10^{-3}/year; ice throw > 10/year)
- According to the legislations, the danger of getting hit by ice fragments needs to be assessed already during planning phase
- The aim is to minimize accidents

C. Robinson 2013 Advances and Cases Studies in Wind Turbine Risk Assessments Icing – how big a hazard? RenewableUK Health & Safety Conf.

Media considerations

"No one wants to leave the house because they are frightened and worried about the ice falling."

"My son's partner is pregnant and she is now worried sick about her unborn baby."

You can call it the influence of media, in any case WE NEED TO CONSIDER IT!

http://www.peterboroughtoday.co.uk/news/local/wind-turbine-s-deadly-ice-shower-1-120837

Peterborough Telegraph
PeterboroughToday.co.uk

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Sunday 20 January 2013

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Wind turbine's deadly ice shower

Spon

Published on **Saturday 29 November 2008 13:07**

Residents were left fearing for their safety after shards of melting ice fell on homes and gardens from the blades of a giant wind turbine.

Residents were left fearing for their safety after shards of melting ice fell on homes and gardens from the blades of a giant wind turbine.For about four hours people in King's Dyke, Whittlesey, had to take cover as huge lumps – some two feet long – showered them from the 80 metre high tower on

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Failed sensor caused ice shards

The failure of a sensor to halt a giant wind turbine when temperatures fall is blamed for shards of ice crashing into nearby homes in Cambridgeshire.

Residents collected some of the smaller shards of ice that fell

The Cornwall Light and Power 80m (262ft) turbine was put up in August, near an industrial estate and close to homes in King's Dyke, Whittlesey.

On 29 November chunks of ice started crashing into gardens.

DTU

WIND ENERGY PRODUCTION IN COLD CLIMATE (WECO) Tammelin, Cavaliere, Holttinen, Morgan, Seifert, Säntti, FINNISH METEOROLOGICAL INSTITUTE.

iea wind

Ice throw examples

Swedish cold climate wind energy projects Göran Ronsten, WindREN

Icing examples

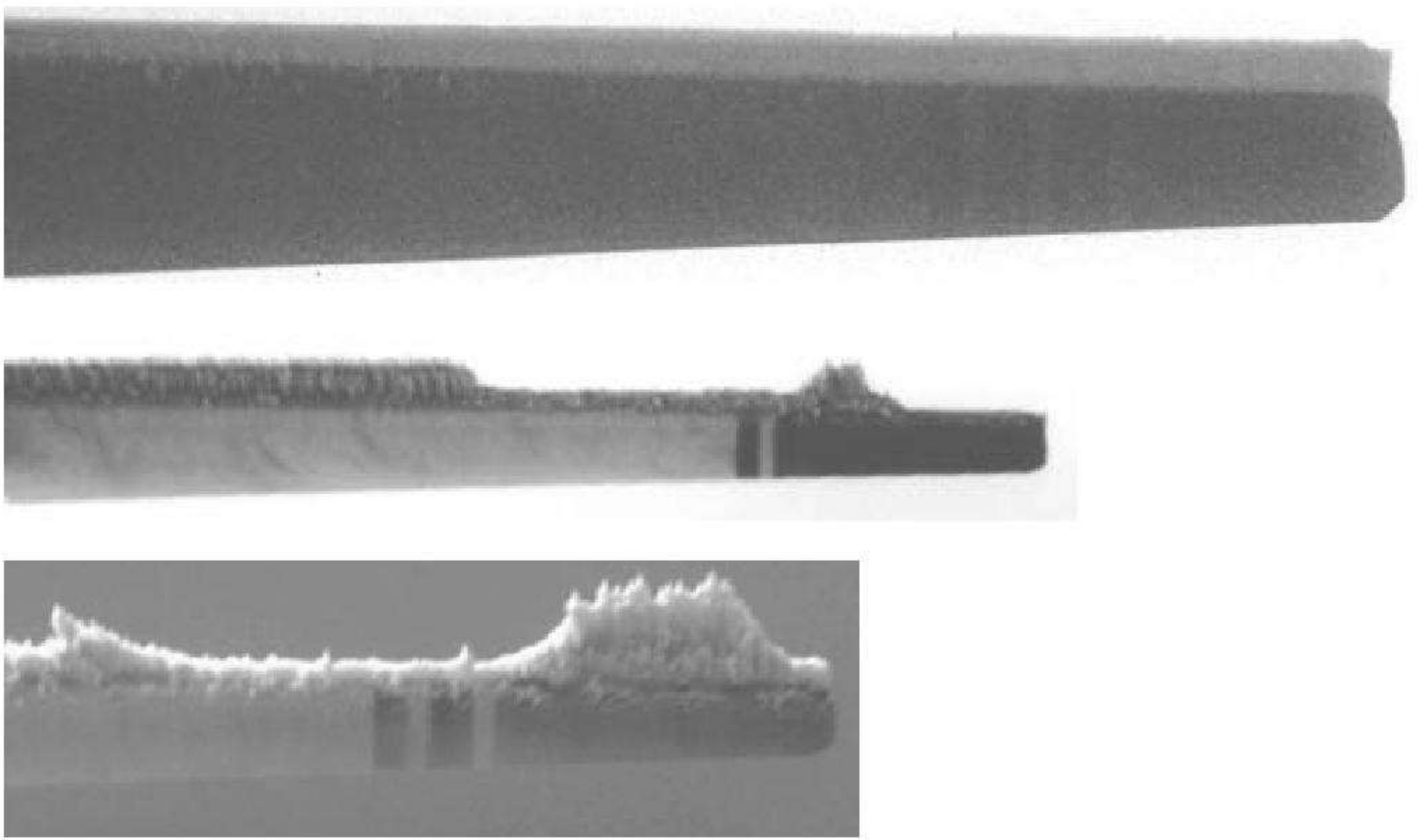

Figure 9. Icing under different modes of operation. Top: Beginning of icing during operation; middle: re-icing after ice throw during operation; bottom: icing during idling.

WIND ENERGY PRODUCTION IN COLD CLIMATE (WECO) Tammelin, Cavaliere, Holttinen, Morgan, Seifert, Säntti, FINNISH METEOROLOGICAL INSTITUTE.

Icing examples

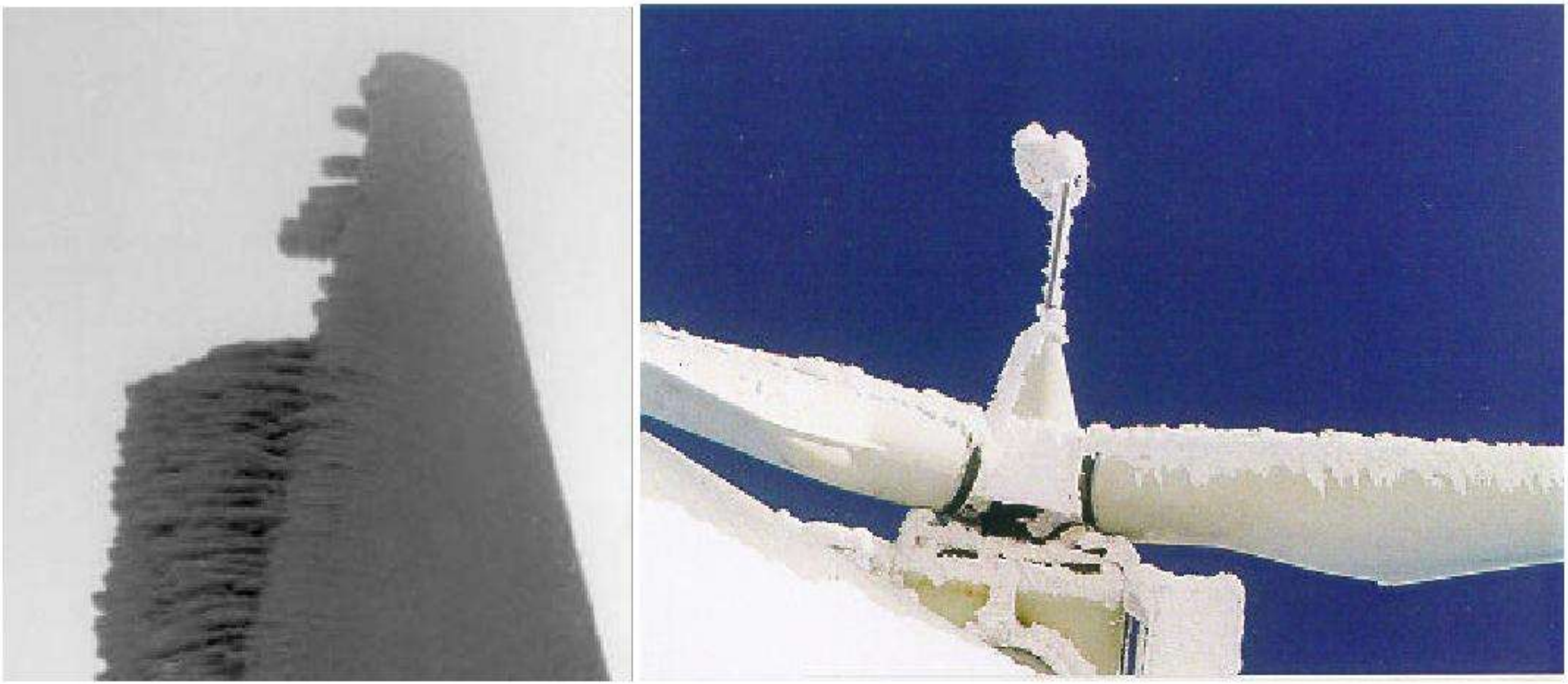

Figure 1. An example of extremely iced leading edge of a rotor blade in Germany (Photo: Kranz, in[1], left side).

WIND ENERGY PRODUCTION IN COLD CLIMATE (WECO) Tammelin, Cavaliere, Holttinen, Morgan, Seifert, Säntti, FINNISH METEOROLOGICAL INSTITUTE.

A real example of ice throw

Conditions:
– Cat II wind turbine; hub ~ 80 m; rotor diameter ~ 90 m.
– Data collected on 16.01.2013; there had been heavy snowfall on 14.01.2013 for around 4 hours, though the temperature was relatively high and some of this snow had melted back (at ground level; no observation was made of the WT at that time). Further snow fall on 15.01.2013 with lower temperature. Cold conditions -5°C or below followed and little or no wind. On 16.01.2013 the temperature remained below zero; there was ~10cm snow lying on the ground; little or no wind; WTs motionless or moving very slowly.

Observations:

Two types of ice was found fallen from turbine blades:
1. **Compacted snow** in plate-like formation, less dense than water-ice, typically 7 – 20 cm side length, 1 cm thickness, up to around 0.100 kg.
2. Harder **snow-ice** partially transformed into water ice, but density still probably < 917 kg/m3. Tended to be in longer shards, up to 1.0 m long, 7 – 10 cm wide and around 1 cm thick.

Snow/ice was observed to fall within 30 m of the tower bases.

C. Robinson 2013 Advances and Cases Studies in Wind Turbine Risk Assessments Icing – how big a hazard? RenewableUK Health & Safety Conf.

Pieces thrown from WTs

These pieces were all found adjacent to one another and broke as they were pulled from frozen ground. They are likely to have fallen as a single shard, 0.7 – 1.0 m in length. Scale: they are lined up on the roof of a VW Polo.

Compacted snow fallen from turbine blades

Ice throw calculation

- <u>Empirical formulas:</u>

$$d = 1.5(D+H)$$ Operating

$$d = v\frac{(D/2+H)}{15},$$ Stand still

- <u>Simple ballistic models</u>
- <u>More detailed aerodynamic models</u>
- <u>CFD simulations (impractical ?)</u>

Increase level of complexity/fidelity

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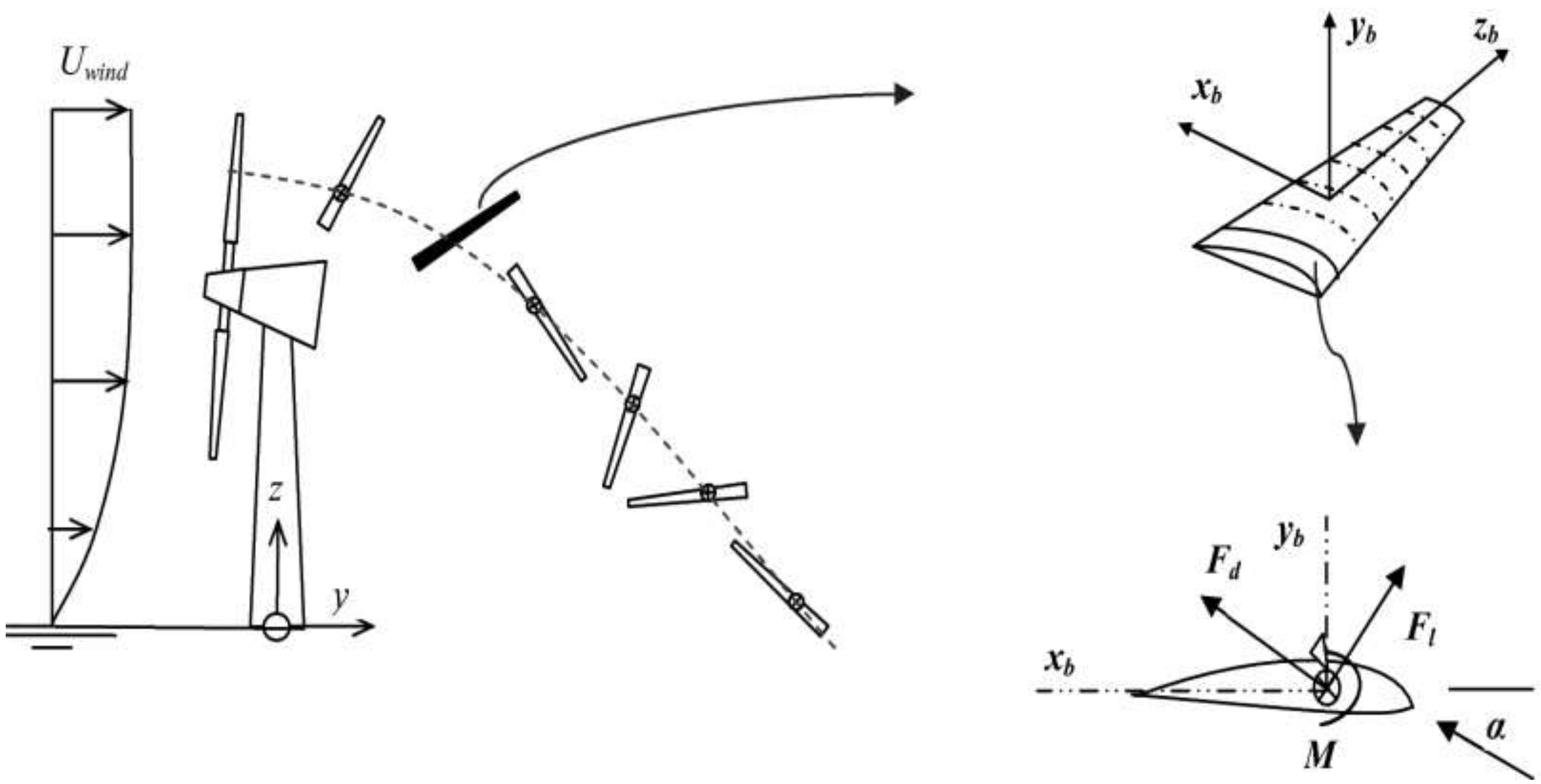
Aerodynamic model



H. Sarlak and J. N. Sørensen, 2014, Aerodynamics of run-away detachments from horizontal axis wind turbines, J Wind Energy (submmitted)

Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines, RR968, Research Report, HSE Books 201

Pseudo-code

Program SAVBAL(*ABL and turbine parameters, initial conditions*)

    Call initiate *! Evaluate initial position, orientation and velocities of fragment at t_0 in it's local coordinate*

    while $z_g \leq 0$ ***do*** *! main loop of the program, iteration until the body hits the ground*

        Call *trans1* $\vec{Y}^{old} \leftarrow [\mathbf{R}, \overline{og}_b, \vec{v}_b, \vec{\omega}_b]^{old}$ *! Arrange a set of 18 ODE's*

        Call *local velocity* $\vec{v}_{local} \leftarrow \mathbf{R}, \vec{v}_b, \vec{\omega}_b, \vec{v}_{wind}(h,t)$ *! Calculate relative velocities*

        Call *aerodynamics* $\vec{F}_{total}, \vec{M}_{total} \leftarrow \mathbf{R}(\alpha), \vec{v}_{local}, \vec{\omega}_b$ *! Calculate loads*

        Call *RungeKutta* $\vec{Y}^{new} \leftarrow [\vec{Y}, \vec{F}_{total}, \vec{M}_{total}]^{old}$ *! time integration*

        Call *Trans2* $[\mathbf{R}, \overline{og}_b, \vec{v}_b, \vec{\omega}_b]^{new} \leftarrow Y^{new}$ *! update new values*

    End while

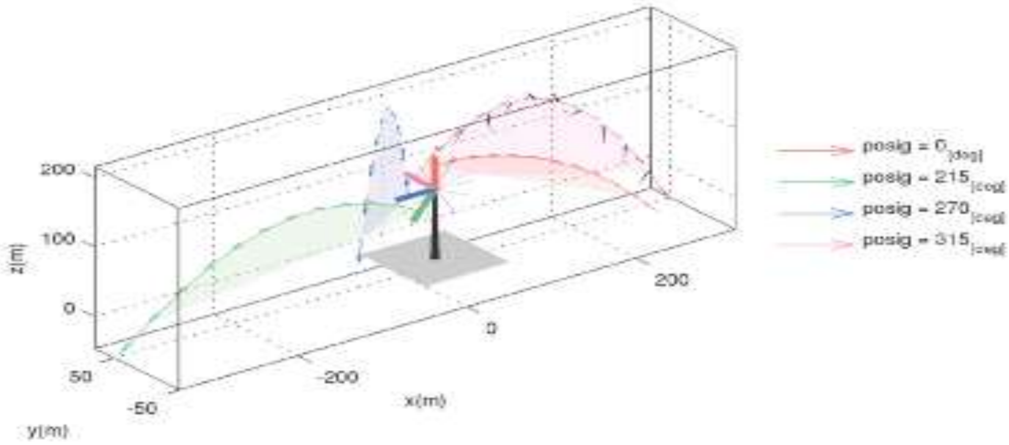
End Program

Figure 2. SAVBAL's pseudocode procedure

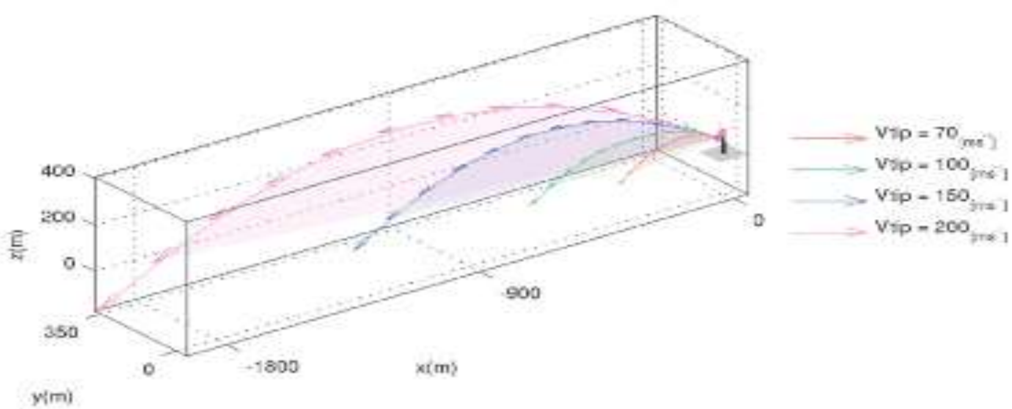
H. Sarlak and J. N. Sørensen, 2014, Aerodynamics of run-away detachments from horizontal axis wind turbines, J Wind Energy (submmitted)

H. Sarlak and J. N. Sørensen, 2014, Investigation of flying detachments from horizontal axis wind turbines ,AIAA Conf. (submmitted)

Qualitative simulations



(a)



(b)

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Inputs

Lift coef. =0
Drag: Flat plate

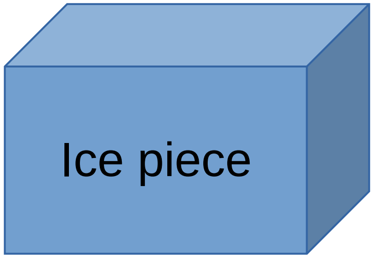

Table III. Aspect Ratios, reference chord length C_{ref} and detached mass m) of the ice fragments ($\rho_{ice} = 0.7kg/m^3$) used for throw simulation of turbines of different sizes

	2.3 MW		*5 MW*		*10 MW*		*20 MW*	
$Cases - AR$	$C_{ref}[m]$	$m[kg]$	$C_{ref}[m]$	$m[kg]$	$C_{ref}[m]$	$m[kg]$	$C_{ref}[m]$	$m[kg]$
AR=1		0.18		0.43		0.97		2.16
AR=2	0.1	0.36	0.15	0.87	0.2	1.95	0.3	4.33
AR=3		0.54		1.31		2.94		6.49

Results

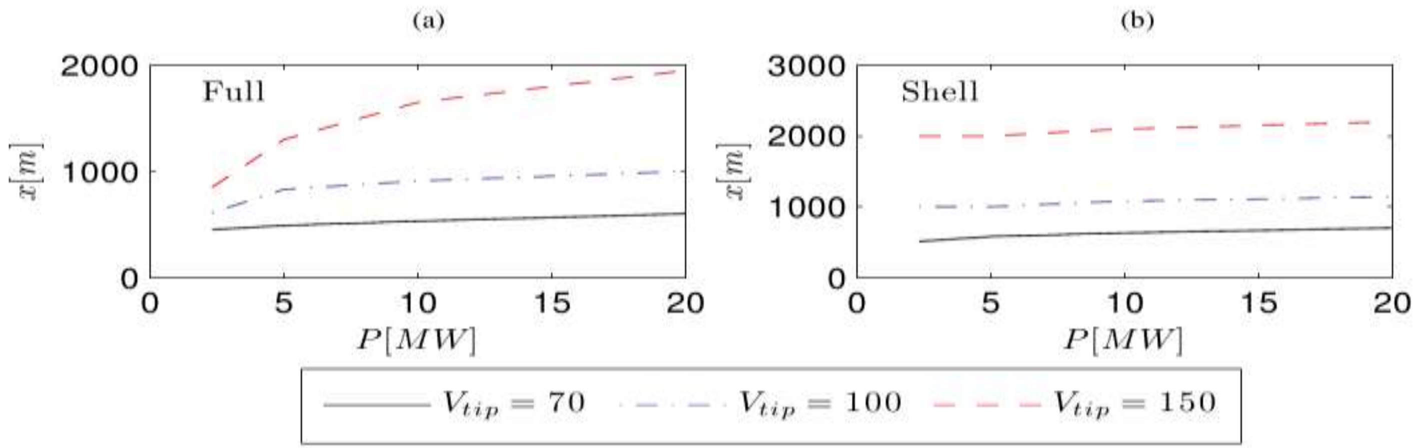

Figure 18. Maximum throw distances obtained for (a) full-blade and (b) blade shell in different operating conditions. (blue) $V_{tip} = 70m/s$ as a function of turbines power.

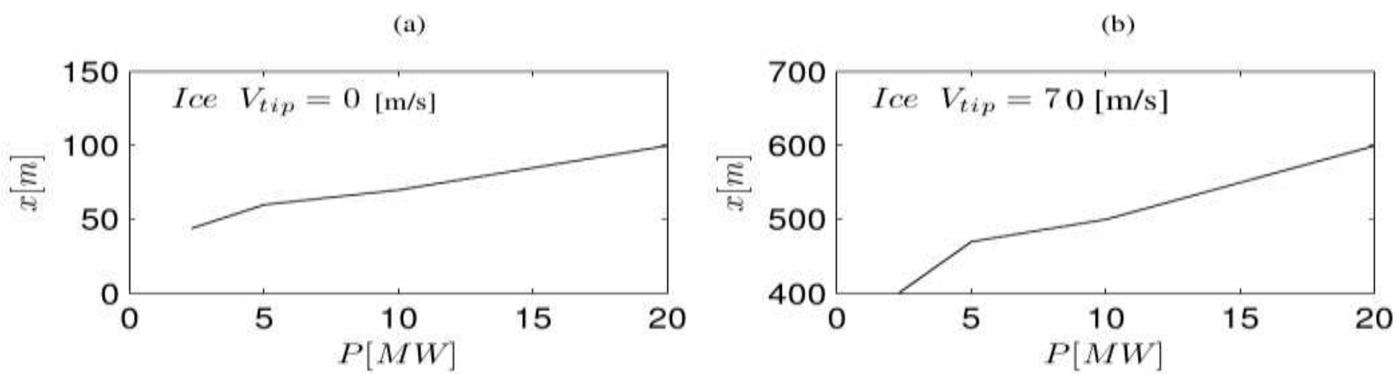

Figure 19. Maximum throw distances obtained for the ice-throw in (a) stand-still operation i.e. $V_{tip} = 0m/s$ and (b) normal operating condition i.e. $V_{tip} = 70m/s$ as a function of turbines power.

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Future work

- Realistic ice accretion shapes and densities:
  - Experimental studies in climatic wind tunnels
  - Validation of SAVBAL against the current and future databases
  - Numerical modeling of ice accretion on WT blades
- Integration with risk assessment tools
- … ?

Probability of fatality by indirect impact in a 5m x 5m cell

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