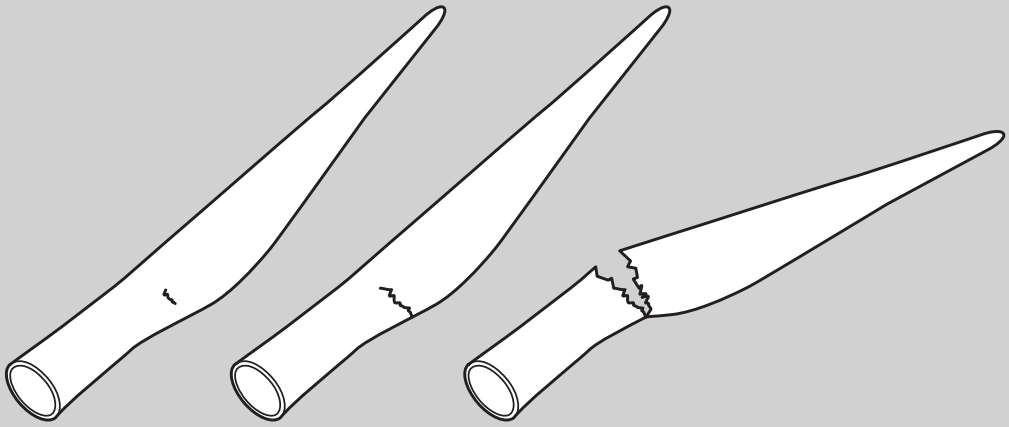
CORTiR

POSTER COLLECTION

CORTIR PROJECT
FINAL 2021



UNIVERSITIES

AALBORG UNIVERSITET

DTU Mechanical Engineering
Department of Mechanical Engineering

ENERGY UTILITIES

RWE · HOFOR · ENGIE · acciona · Ørsted · equinor · enel · ARISE · EWII · Statkraft · Falck Renewables · EDF renewables

SERVICE COMPANY

GLOBAL WIND SERVICE

INSURANCE

CODAN

BLADE MANUFACTURES

NORDEX We've got the power. · LM WIND POWER · Vestas

MARKET ANALYST

G2D GUIDE2DEFECT

R&D CONSULTANCIES

KIRT› THOMSEN · ECC

SOLUTION PROVIDER

Bladena PROJECT MANAGER

INDEX

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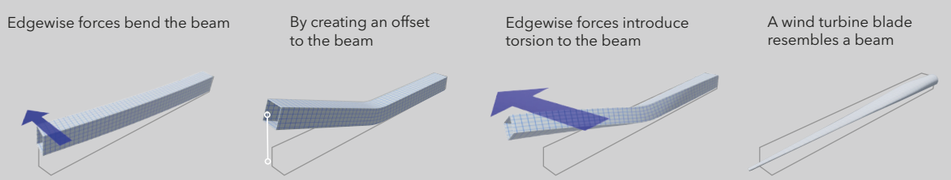
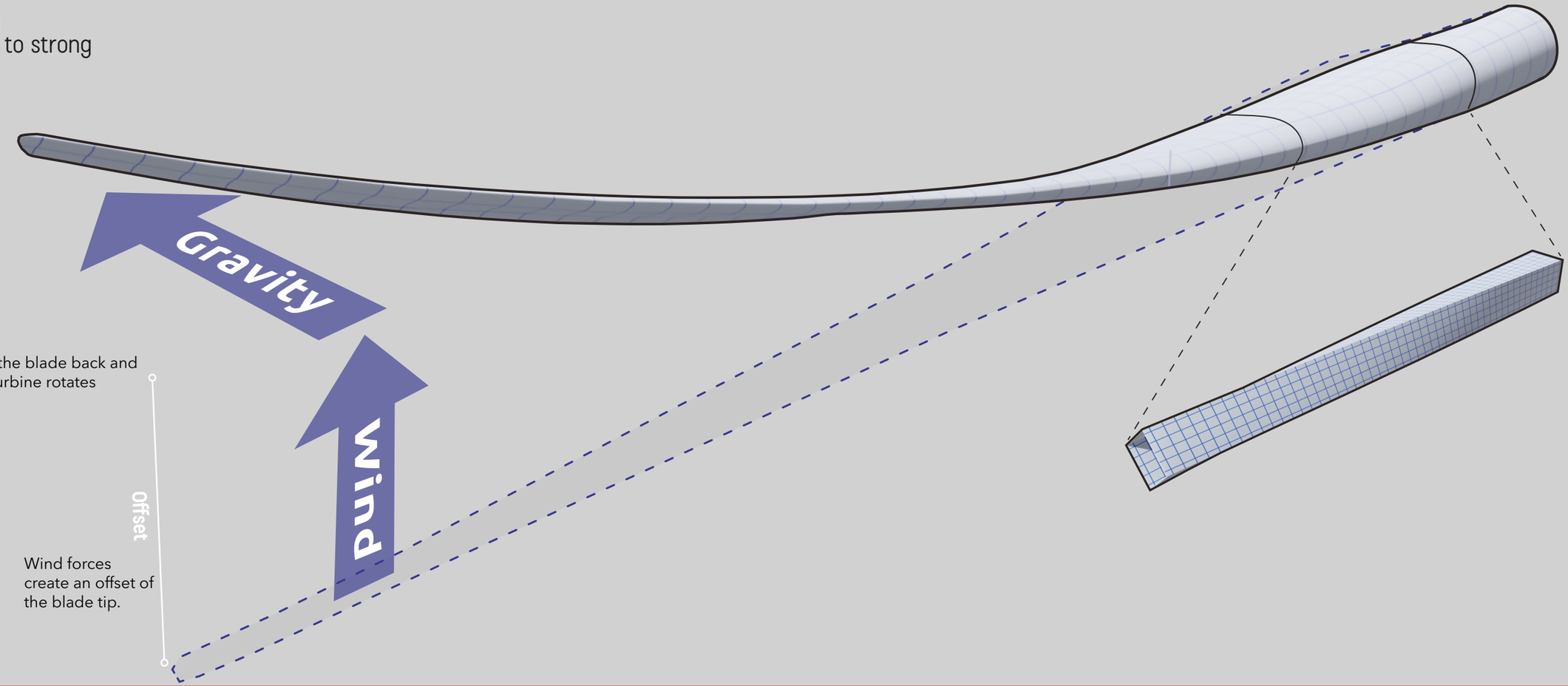
TORSION ON BLADES

Wind turbine blades in operation deform due to strong forces.

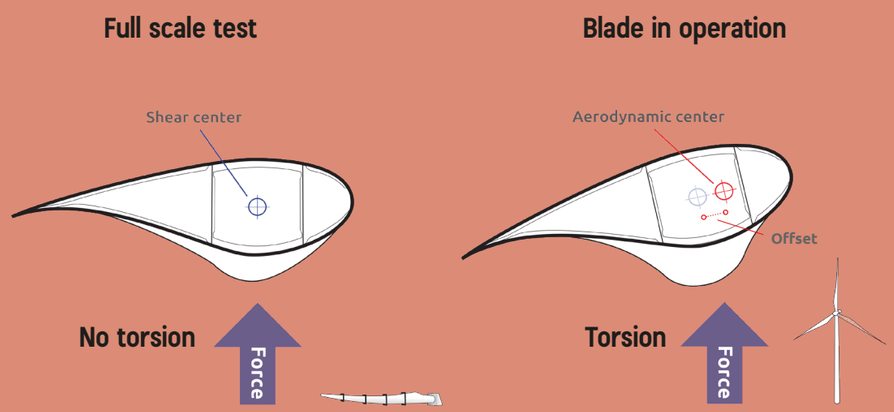




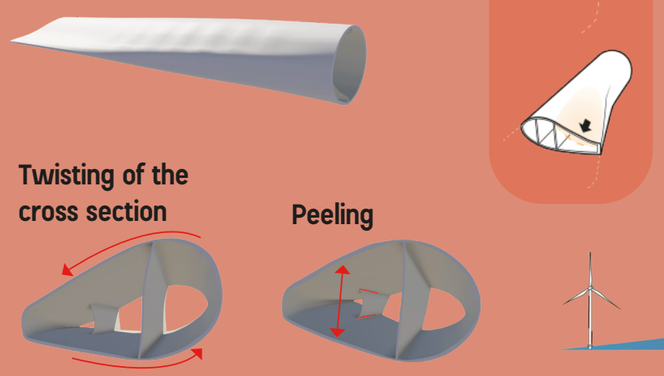
Gravity pulls the blade back and forth as the turbine rotates

Wind forces create an offset of the blade tip.

AERODYNAMIC FORCES CREATE ADDITIONAL TORSION

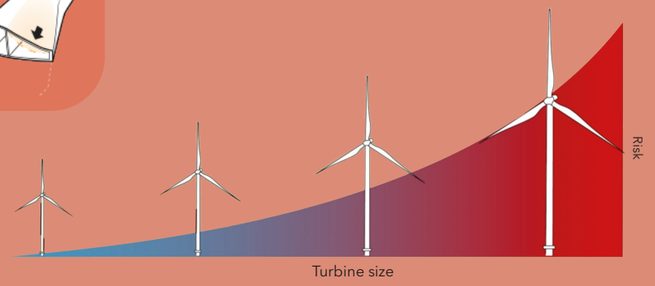


IMPACT ON BLADES



RISK

Torsion becomes incresingly relevant as blades grow in size.



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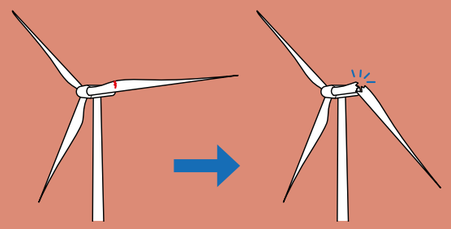
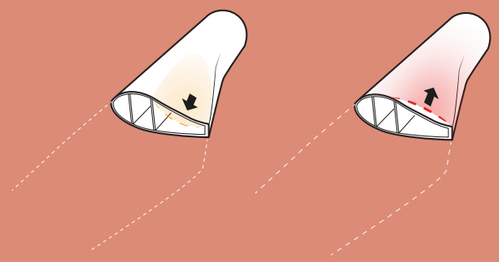
TRANSVERSE CRACKS HIGH RISK DAMAGE

RISK
High risk with catastrophic outcome

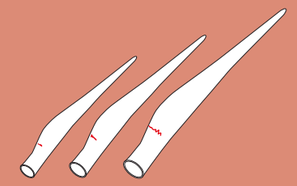


Transverse cracks lead to catastrophic blade failure

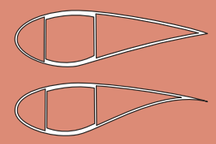
AIM
Narrow down root cause



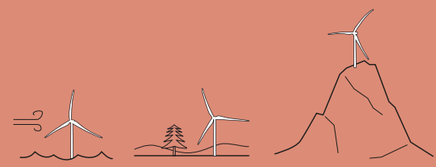
Understand parameters driving deformations in the cracks region



Influence on blade size

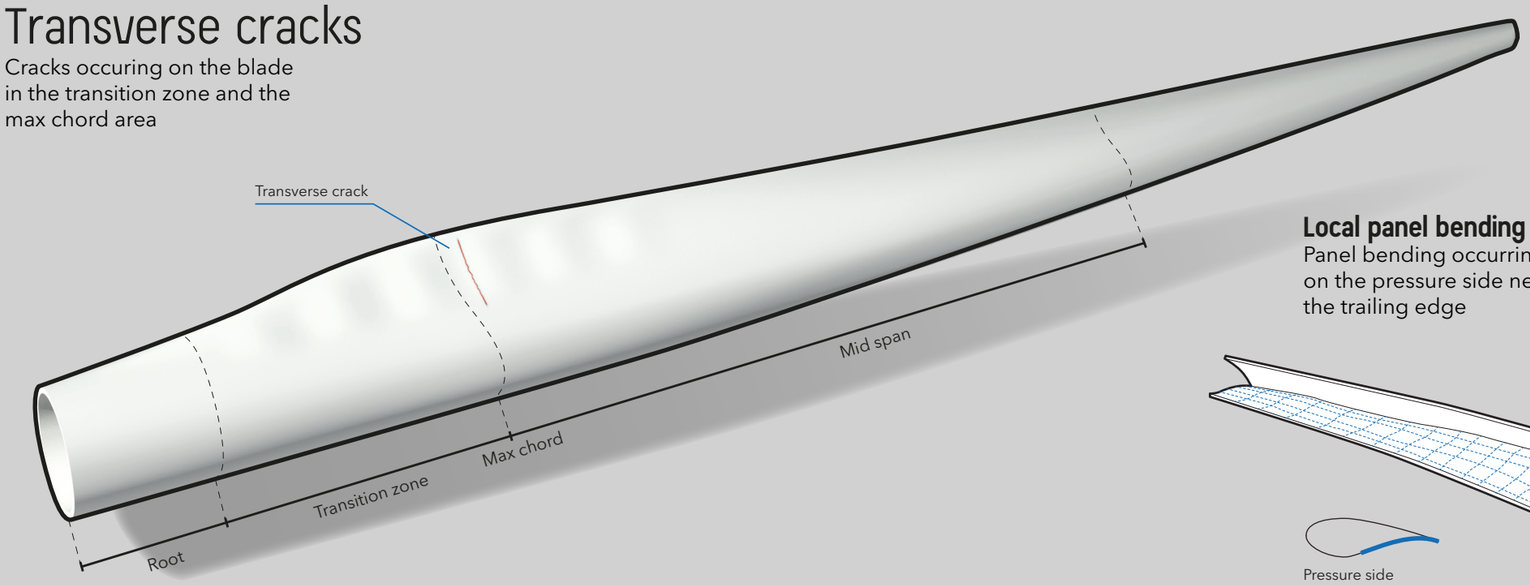


Different pressure side side curvatures



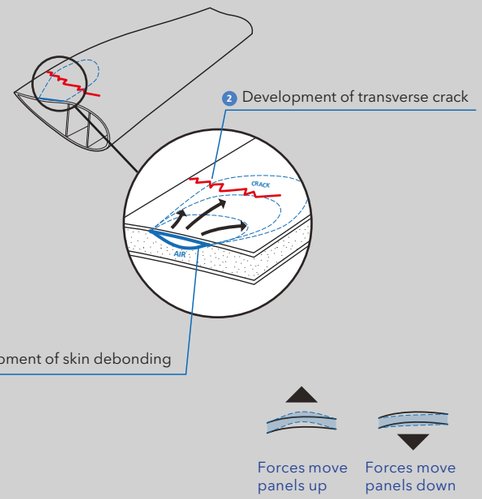
Site conditions

Transverse cracks
Cracks occuring on the blade in the transition zone and the max chord area

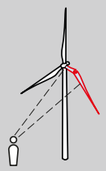


Local panel bending
Panel bending occurring on the pressure side near the trailing edge

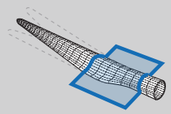
Skin debonding



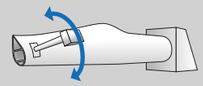
HISTORY



1 **Field observations**
Damage observed in the field

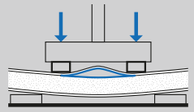


3 **Structural simulation**



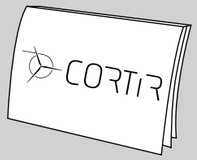
5 **Large-scale testing**
Large-scale test with debonded area

2 **Full-scale testing**
Local panel bending observed and measured



4 **Sub-component test**

6 **Conclusions**
A hypothesis was established



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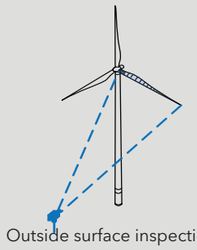
FIELD DATA & INSPECTION

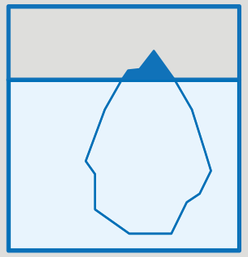
STATE OF PRACTICE

INSPECTION **LEVELS**

With outside surface inspections you only see the tip of the iceberg.



Outside surface inspection

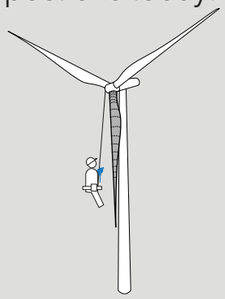


Outside surface inspection

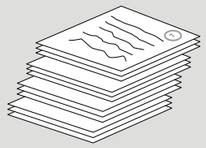
INSPECTION **DATA HANDLING**

There are two ways of handling inspections today:

1.

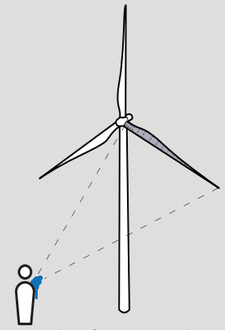


Photos taken directly on each blade



Inspection reports

2.

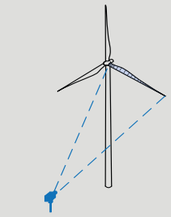


Photos taken from ground.
No data handling afterwards.

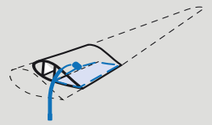
TRENDS

INSPECTION **LEVELS**

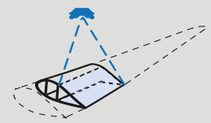
Using both NDT, outside and inside surface inspection you get the full picture of the blade's condition.



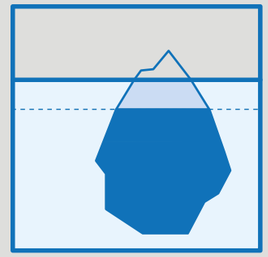
Outside surface inspection



Inside surface inspection



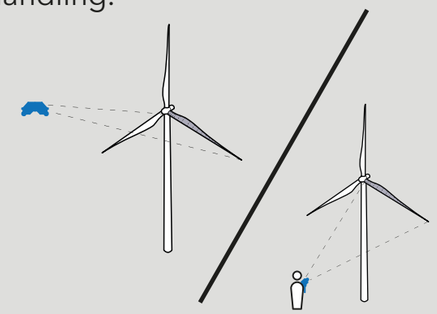
NDT (Non-destructive Testing)



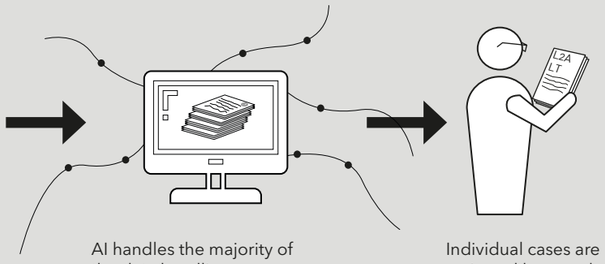
Outside surface inspection
Inside surface inspection
NDT (Non-destructive Testing)

INSPECTION **DATA HANDLING**

Artificial Intelligence (AI) for data handling.



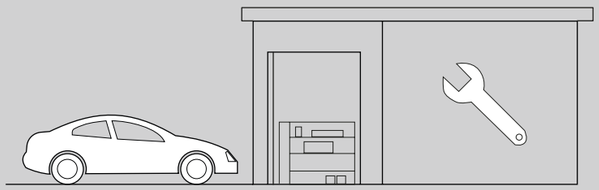
Photos taken with drones or from ground.

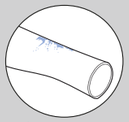


AI handles the majority of the data handling

Individual cases are reviewed by people

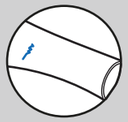
DAMAGE INSPECTION





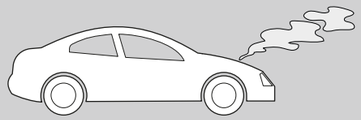
Surface erosion

1. SURFACE EROSION
Only cosmetic issue.
No need to check the engine.

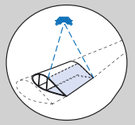


Indicator

Smoke from the engine

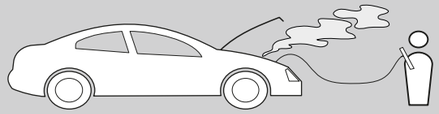


2. INDICATOR
No way of determining root cause without lifting the hood.



NDT

Hood lifted to determine issue.



3. DETERMINING ROOT CAUSE
Detailed investigation of failure.

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CAR TOOL A DECISION SUPPORT TOOL

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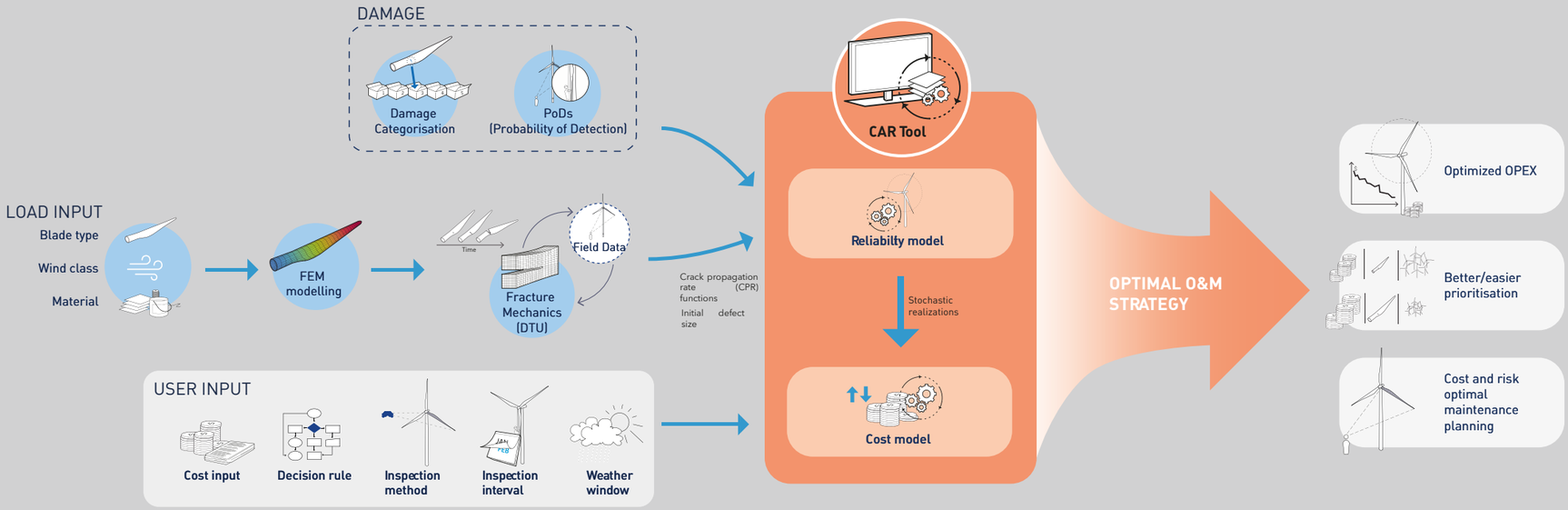


ROADMAP

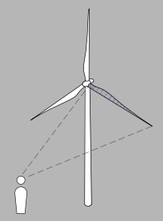
MVP

- simple investment calculations
- no repair type evaluation
- two inspection methods
- limited to one blade
- simplified load case
- one failure mode
- one blade type

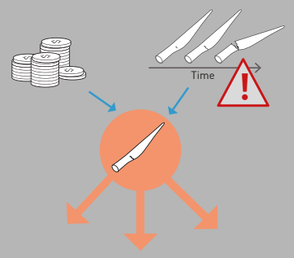
Holistic CAR Tool

- advanced investment calculations
- repair type evaluation
- additional inspection methods
- wind farm level
- load improvements
- additional failure modes
- additional blade types

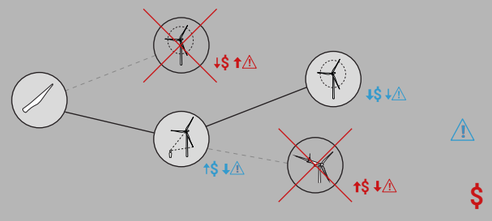
CURRENT VALUES



Operational & maintenance decisions
Preventive maintenance.

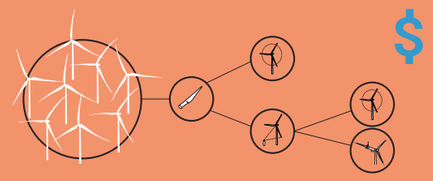


Risk considerations
Risk and reliability considered in the decision-making.



Cost & risk optimal maintenance strategy
More strategic decisions for WTO's.

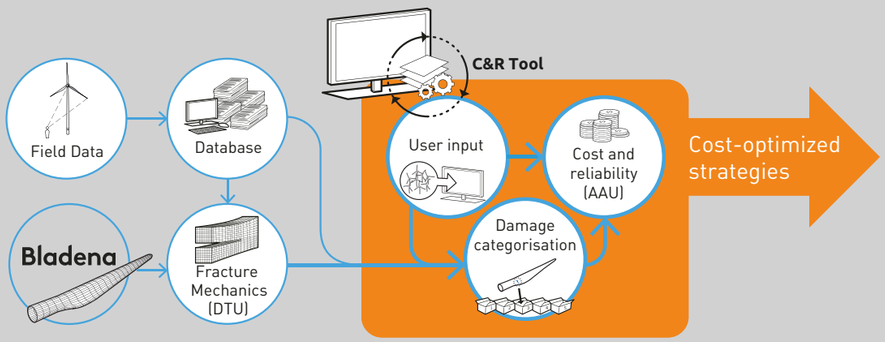
FUTURE VALUES



Cost-optimal strategy for WTG-Farm
Best cost-optimal strategy for a specific wind turbine farm.

Strategic decisions for WTO's
Find the farm where the most gain is obtainable.

DATA FLOW



ROADMAP TIMELINE

1 — 2021 August
- Initiation of CapEx and LCoE calculations
- Initiation of Lightning and Erosion aspects
- Shear web disconnection

2 — 2021 December
- Finalized CapEx and LCoE calculations
- First version of Lightning and Erosion considerations
- Starting the Improved Load Environment (ILE)

3 — 2022 February
- Initiation of Wind farm considerations
- Initiation of Power curve implementations
- First draft of the ILE
- New standardised damage categorization

4 — 2022 June
- Finalization of Power curve
- First draft of the Wind farm functionality
- Second draft of ILE

5 — 2022 September
- Finalized Erosion and Lightning additions

6 — 2022 December
- First draft version of the additional structural defect
- Finalized model of ILE

7 — 2023 February
- Second draft version of wind farm considerations
- Second version of the additional structural defects

8 — 2023 May
- Final version of wind farm considerations
- Final version of additional structural defects

9 — 2023 June
- GUI update
- Documentation
- Trial period

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UNCERTAINTIES

In relation to the wind industry

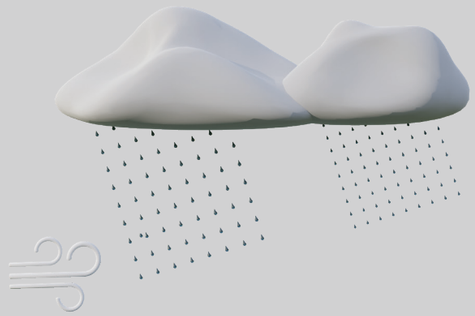
CORTIR

WEATHER UNCERTAINTIES

Define the available weather windows available to perfom operation and maintenance on a wind turbine blade.

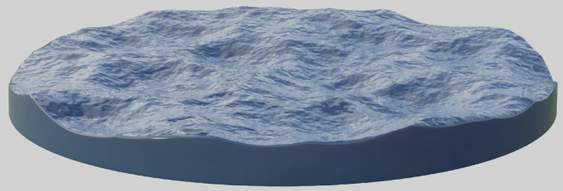
PARAMETERS

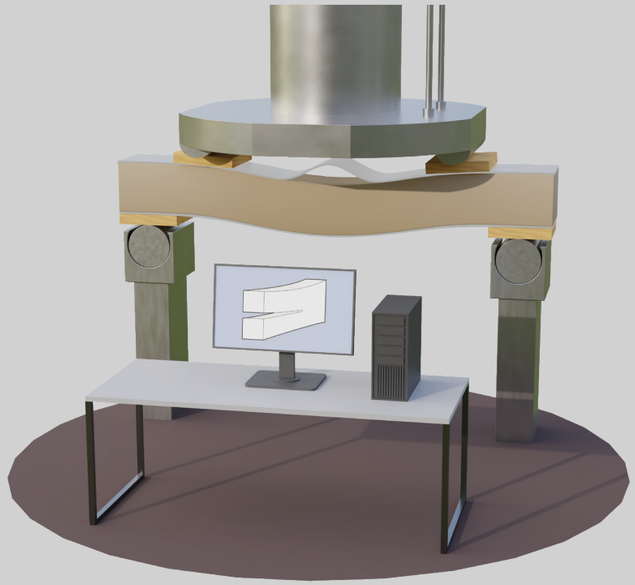
Rain or snow



Wind

Waves





MODEL UNCERTAINTIES

Physics models, e.g. fracture mechanics models and loads.

MEASUREMENT UNCERTAINTIES

The probability of detection (PoD) varies with the type of defect and the different on site detection methods.

VISUAL INSPECTION

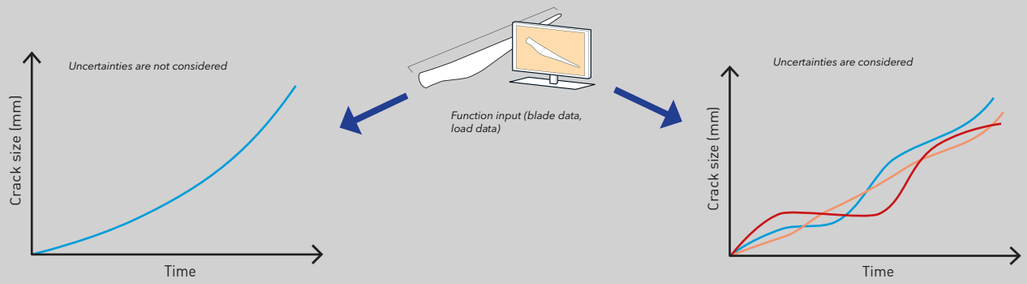
Very low accuracy for debonds. For surface cracks it is highly dependent on the user experience and the size of the damage.

NDT

Low accuracy for surface cracks, but increased accuracy for debonds.

DETERMINISTIC VS PROBABILISTIC MODELING

Randomness not applied vs randomness applied in modeling



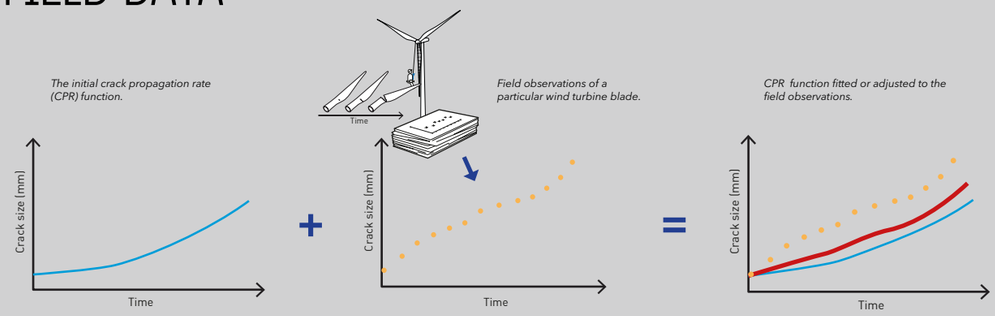
Deterministic

A deterministic crack propagation rate (CPR) function doesn't take uncertainty into account because randomness is not applied. It outputs the same values as the input.

Probabilistic

The probabilistic crack propagation rate (CPR) function works by considering the uncertainties. This is because randomness is applied. The function outputs average values of the different inputs.

FIELD DATA



Improve crack predictions with field data

The field data can be used to adjust the CPR (crack propagation rate) function according to the field recordings. In order to achieve this, repair/inspection reports from a particular damage type on a specific blade should be used.

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RISK COST & PROBABILITY

What is risk about in wind industry

RISK

Probability

Cost

Risk in decision making

MAINTENANCE STRATEGY	REPAIR ACTION	INSPECTION FREQUENCY	INSPECTION COSTS	DOWNTIME COSTS	REPAIR COSTS	OVERALL COST	RISK
1	Size above *X* mm	1y	x1	x1	x1	x1	x1
2	Size above *X* mm	2y	x2	x2	x2	x2	x2
3	Size above *X* mm	3y	x3	x3	x3	x3	x3
4	Size above *X* mm	4y	x4	x4	x4	x4	x4
5	Size above *X* mm	5y	x5	x5	x5	x5	x5

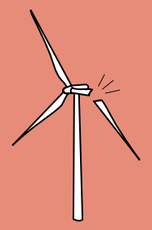
Better decision making can be achieved this way, as it includes both cost and PoF (Probability of Failure).

By calculating the risk for each maintenance scenario, the final decision could be made easier even when the individual costs do not significantly differ

Risk examples

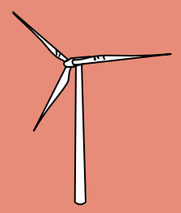
Risk scenarios

Cost ↓ PoF ↑ — Risk 1



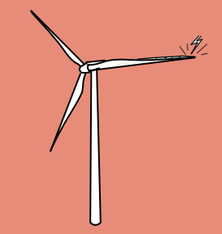
Keep it running with risk of replacing the blade.

Cost ↑ PoF ↓ — Risk 2



Allow damage under a certain size and then perform repair actions

Cost ↓ PoF ↑ — Risk 3



Repair everything, apply inspections fully preventive

RISK = PROBABILITY x COST

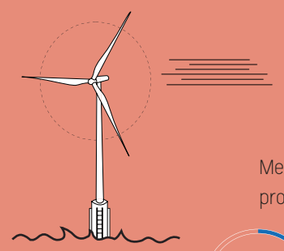
PROBABILITY

Probability of blade failure

- Or likelyhood

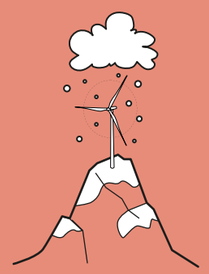
Low probability

Onshore decent conditions



Medium probability

Offshore conditions

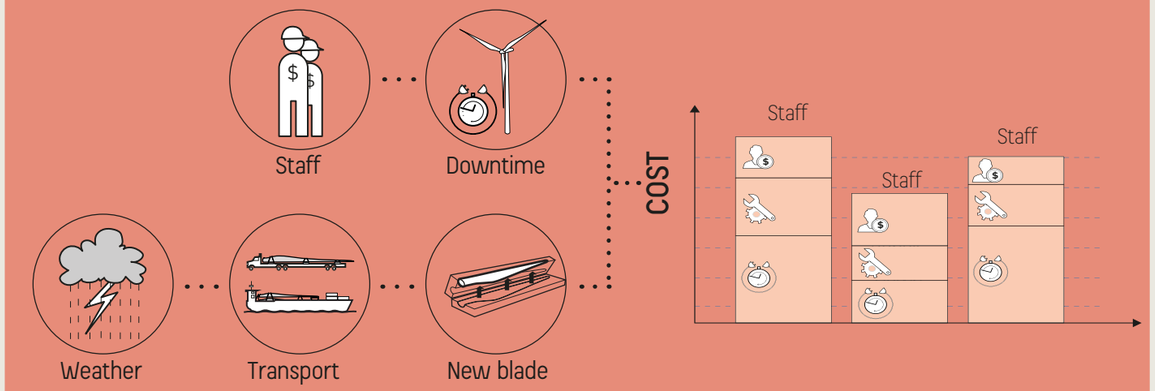


High probability

Onshore extreme conditions

COST

Cost decision alternatives



Expenses

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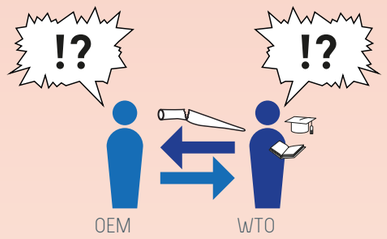
VALUE CHAIN BLADES

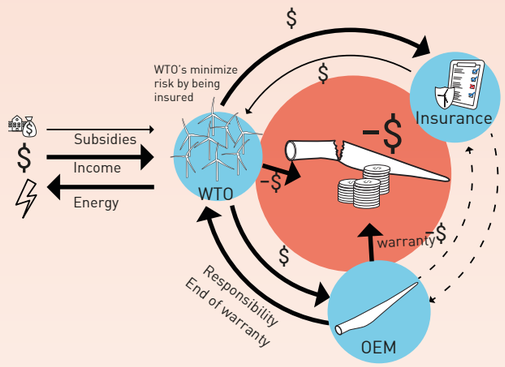
An overview in time over O&M in wind industry

CORTiR

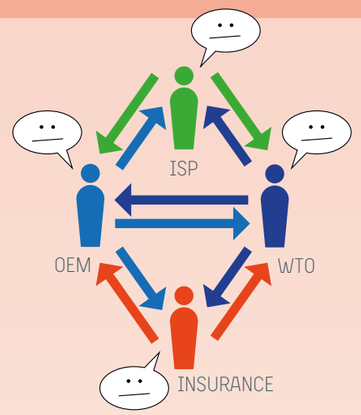
PAST



There is a direct link between WTOs and OEMs. WTOs have limited knowledge and there is a big conflict between parties regarding who will take the responsibility in case of a claim.



PRESENT



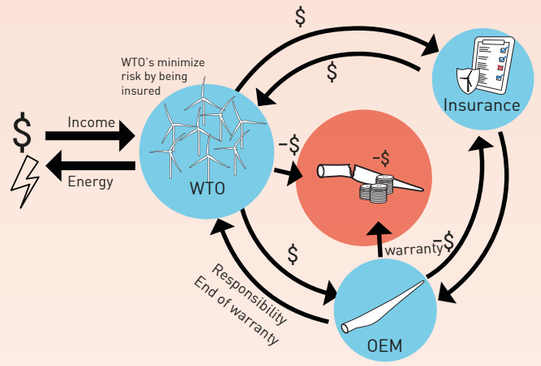
The market is more mature and all partners are working on minimizing the risk and maximizing the energy output (AEP).

In the post EOW period WTOs can select between service agreements by OEMs or stand-alone O&M.

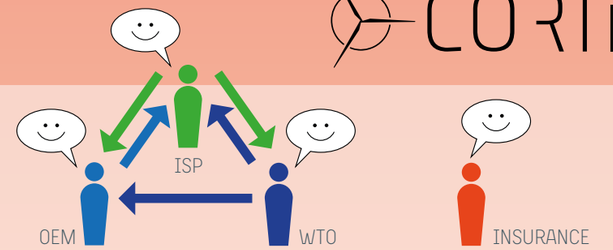
Some ISPs have a strong collaboration with OEMs. Others work with WTOs or both segments.

Motivation

No subsidies + More competitiveness + Higher cost pressure



FUTURE



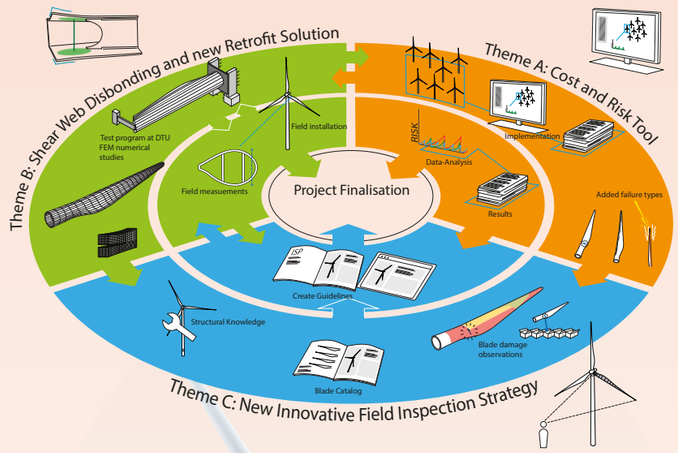
Analyze maintenance strategies through the Cost and Risk Tool (CAR Tool).

CAR Tool will provide data to NIFIS about the cost and risk of applying different maintenance strategies.

ISPs will obtain the needed engineering support, acquiring the ability to support the WTOs and increasing the effectiveness of their collaboration with the OEMs.

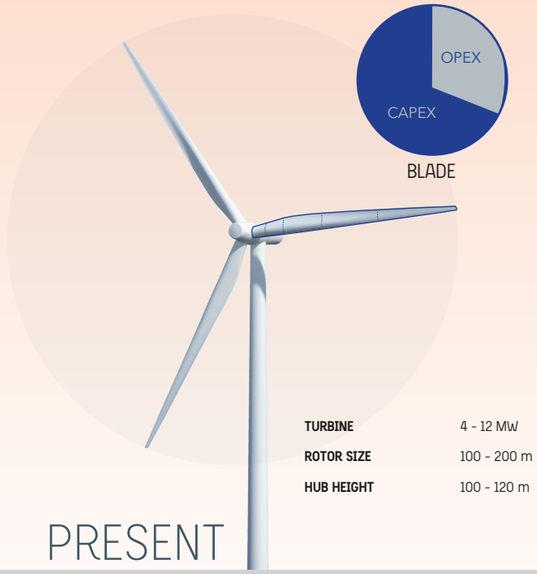
Address the true root cause and select reliable retrofit solutions.

An improved categorization scheme takes a damage tolerance approach into account.



TURBINE	0 - 3 MW
ROTOR SIZE	20 - 100 m
HUB HEIGHT	80 m

PAST



TURBINE	4 - 12 MW
ROTOR SIZE	100 - 200 m
HUB HEIGHT	100 - 120 m

PRESENT

TURBINE	+12 MW
ROTOR SIZE	+220 m
HUB HEIGHT	130 - 160 m

FUTURE

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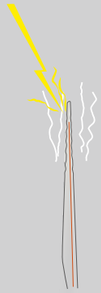
LIGHTNING PROTECTION HIGH RISK DAMAGE

CORTiR

LIGHTNING SCENARIOS

NOTHING IS DONE

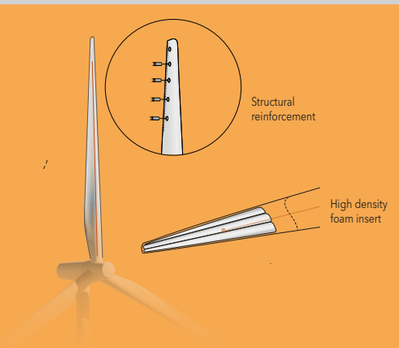
No preventive repair
No preventive action taken against lightning.



Lightning strikes
Lightning hits blade.

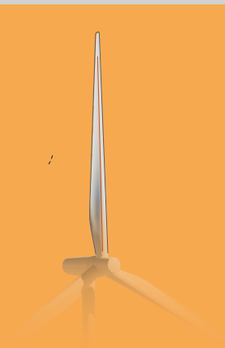
Tip split open
Complete blade failure. Rotor stops until repair is possible.

PREVENTION



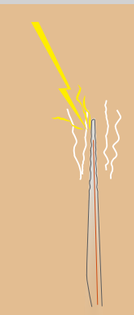
Preventive repair
Repair solution installed to prevent lightning damage.

Lightning strikes
Lightning hits blade.

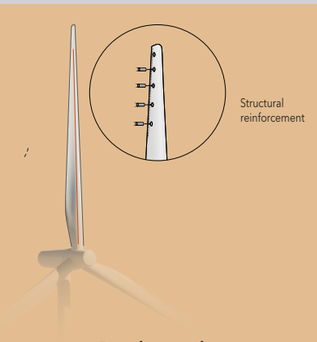


Turbine continues
No further repair necessary.

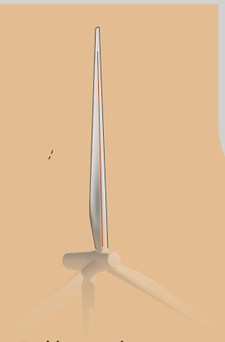
INTERIM SOLUTION



Lightning strikes
No preventive action taken against lightning.

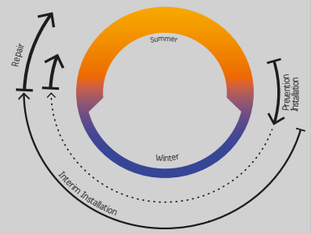


Interim repair
Temporary repair solution is installed.

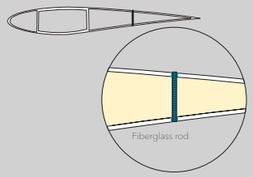
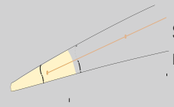
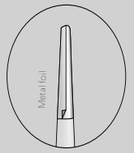
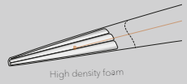
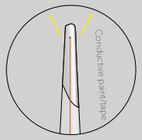


Turbine continues
Until weather enables a full repair.

Interim vs preventive cycles



POTENTIAL REPAIR SOLUTIONS

	Concept	Preventive	Interim	Strength	Weakness
	Structural reinforcement	X	X	Extra support to adhesive.	May prove difficult to remove after installation. If a full repair is to be performed.
	Low-temperature adhesive		X	Can be applied to rejoin the tip of the blade.	Could prove difficult to apply in harsh weather conditions.
	Shock absorbing material	X		Absorb energy from the shock wave overpressure.	Difficult to install.
	Aluminum/Metal foil around the blade	X		Will provide protection from direct lighting arc.	Difficult to install and fit the blade's surface.
	High density foam insert at the tip.	X		It will keep the area dry and consequently preventing the arc penetrating through the tip.	Possible weight issues and difficult to apply.
	Conductive paint/ tape	X		Will keep the current at the surface.	Uncertain regarding feasibility.

A combination of two above mentioned could also be a possibility.

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CORTIR

POSTER COLLECTION

CORTIR Project

Cost and Risk Tool for Interim and Preventive Repair - includes the development of a sophisticated, yet user friendly, numerical tool (CAR-Tool) to optimize the management of turbine blade maintenance in terms of risks and costs, with the main focus to reduce the Levelized Cost of Energy and secure alignment towards maintenance throughout the full value chain.

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