



Change in Failure Type when Wind Turbine Blades Scale-up

Sandia Wind Turbine Workshop 2012

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Outline



- Motivation
- Overview of failure modes which are expected to be design driven for future blades
- How can these problems be addressed and solved in the future?
- Example on how to find the root cause of failures
- Summary

Bladena in brief



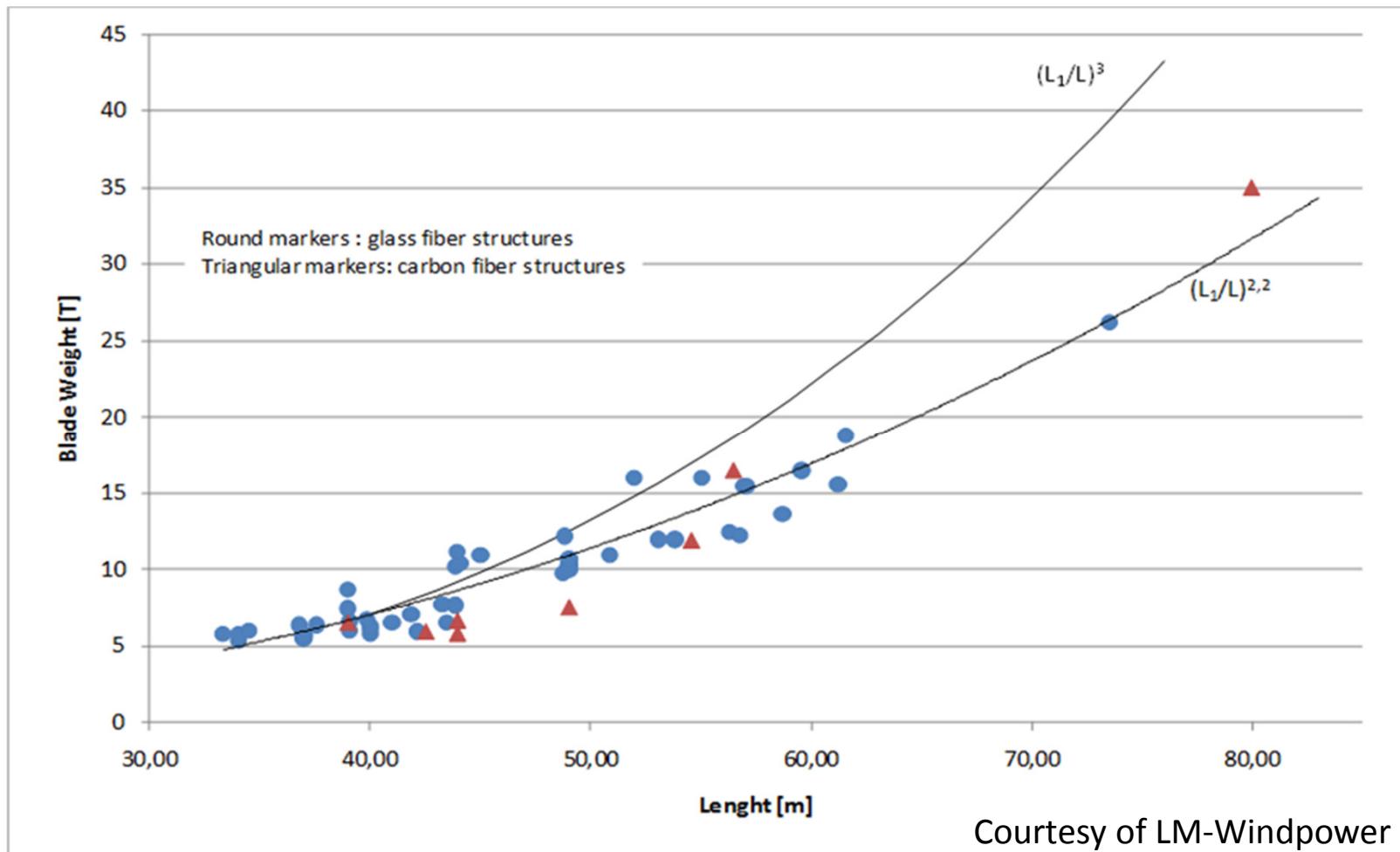
- Spin-out from Risø DTU – one of the leading research instituts in wind energy
- Our mission is to empower designers, manufacturers, service organisation and owners to make their blades stronger
- Unique technological platform from a decade of research and 7 founding patents.
- We will be bridging between the world class research and competitive applied solutions.



Motivation

Bladlena
BLADE ENABLER

The weight becomes more important when the blades get larger



Motivation – Cont.

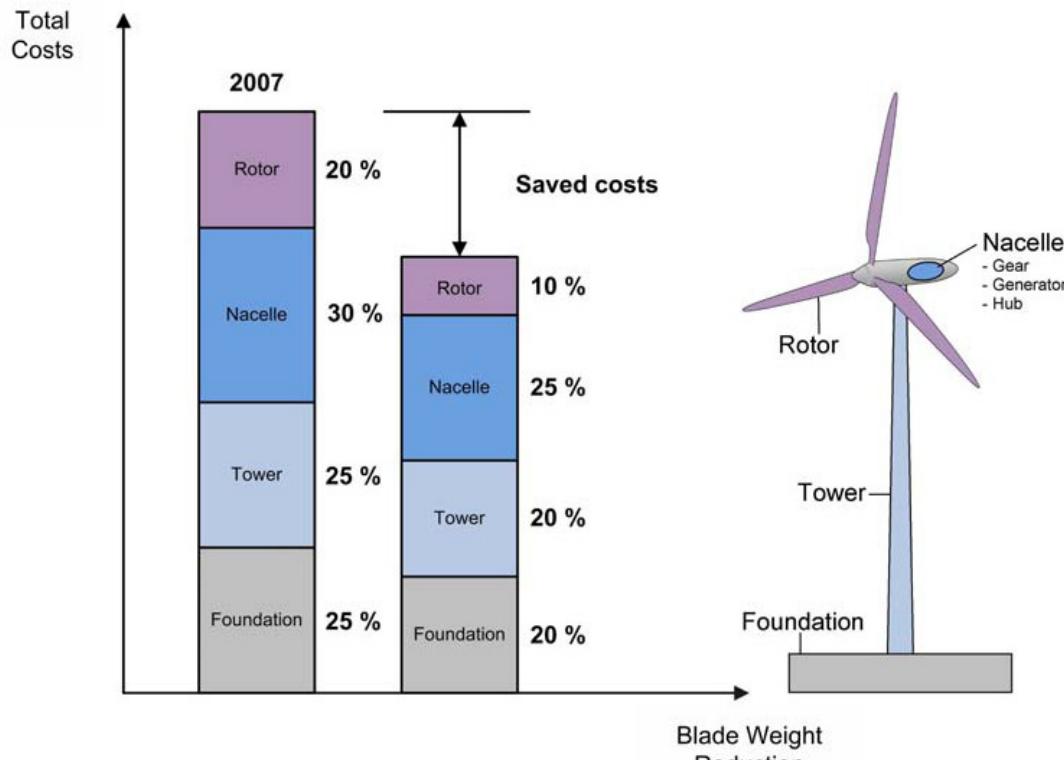


Figure from F.M. Jensen, PhD-thesis, Risø DTU-2008

Conclusions from Upwind project (Task: Cost simulation) show that the weight of the rotor becomes much more important in the future

Motivation – Cont.



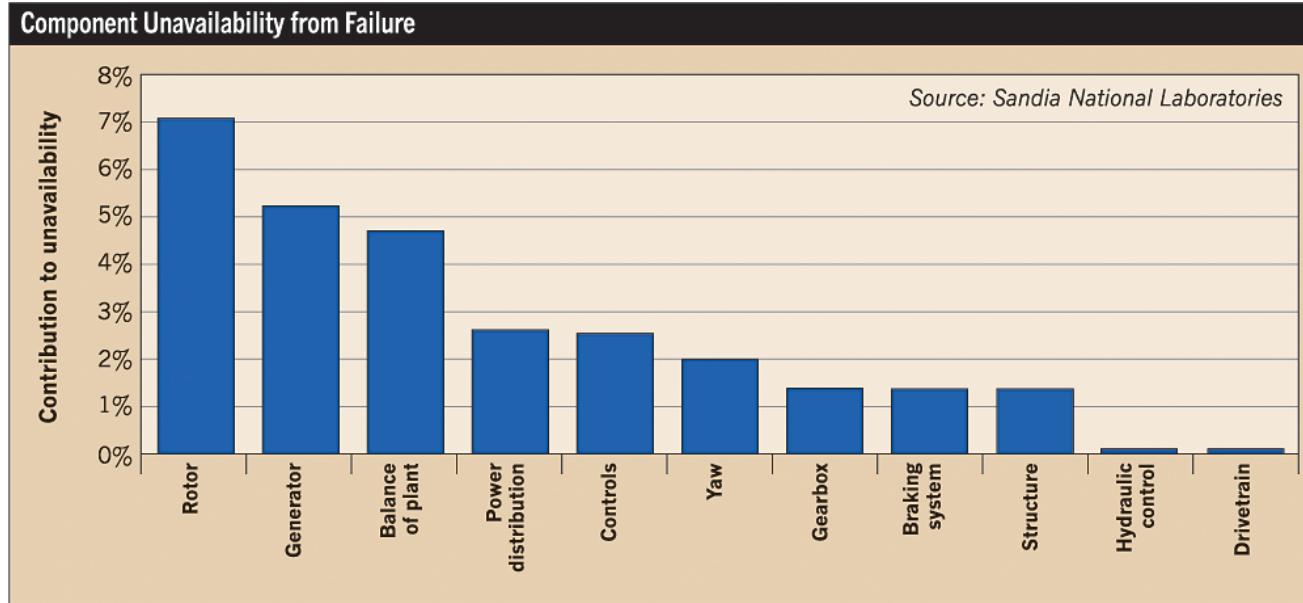
In order to avoid buckling and out-of-plane deformations of the caps the shear webs are positions close to each other.

The thicknesses of the load carrying laminates (caps) have increased in thicknesses which make it difficult to manufacture. The consequences are lower quality and higher process cycles (and more energy consumption).

Motivation – Cont.



Cost
of
failure
?



Shift in trends



The consequence of going offshore change the cost for repair and replacement significantly.

Next generation of blade design are based on designs which still not have proven to be reliable in operation over 20years.

In the past when blades were small the blades were mainly designed to be aerodynamic optimal. Today, the consequence of having too thin aerodynamic profiles result in heavier blades.

Tip deflection was a major design driver when the blades were small. Today this do not drive the design in the way and there exist solutions which can “compensate” for a too large tip deflections.

Overview of failure modes which are expected to be design driven for future blades



We see a significant change in which failure modes are the most critical when the blades grow larger:

Effects due to blade scaling				Blade Length			
	Design Driver	Critical Area	Scaling Law	30m	60m	90m	120m
Load	Aerodynamic loads	Cap	$F_{aero} \sim R^2$	5	4	3	2
	Gravity loads	Root, TE	$F_{grav} \sim R^3$	3	4	5	5
	Centrifugal load	No critical	$F_{cent} \sim R$	2	1	0	0
Load case	Bending flapwise	Brazier	Caps	3	4	5	5
		Buckling	Cap	5	4	3	3
		Tip Deflection	Tip	5	4	3	2
	Bending edgewise	Stiffness (resonance)	Root, transition	3	4	5	5
	Torsion	Flutter		2	3	4	4
	Bending flapwise+edgewise	Buckling+Distortion	Cap+Cross sec.	3	4	5	5
	Bending flapwise+edgewise+torsion	Distortion+Flutter	Cap+Cross sec.	3	4	5	5
(failure) mode	Interlaminar failure caused by Brazier	Caps		3	4	5	5
	Buckling	Cap		5	4	3	3
	Tip deflection	Tip		5	4	3	2
	Transverse Shear Distortion	Cross section		1	2	3	4
	Web failure	Webs		2	3	3	4
	Fatigue failure in root connection	Root	$F_{root} \sim R^4$	3	4	5	5
	Fatigue failure in root transition area	Transition area	$F_{root} \sim R^4$	3	4	5	5
	Fatigue failure in bondlines	Bondl.in TE area	$F_{grav} \sim R^3$	3	4	5	5
	Flutter	Entire blade		1	2	3	4
	Trailing edge Buckling	Trailing edge	$F_{grav} \sim R^3$	3	4	5	5

9 The numbers indicates the importance of the failure mode. 1 is lowest.

Increased edgewise loads cause "new" problems



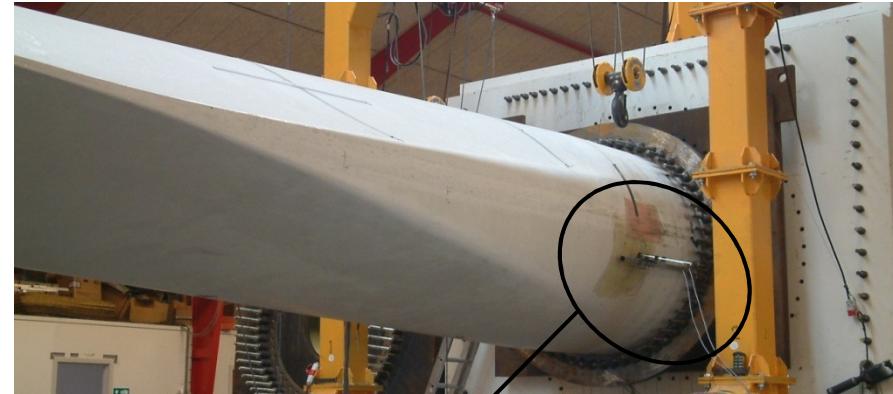
Buckling of the trailing edge has become a problem



Increased edgewise loads cause "new" problems

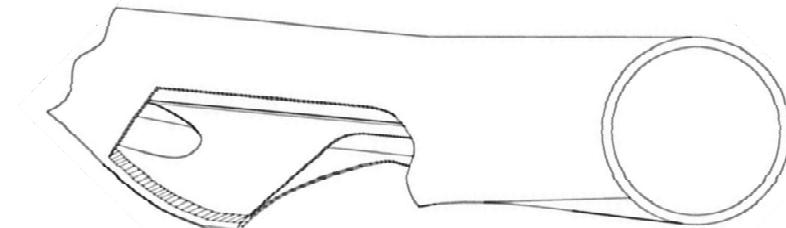


Fatigue failure in root region is an increasing problem due to the higher gravity induced edgewise loads



Large loads transfer to the root region often results in fatigue damages

The Load Distribution Floor, minimizes deformation of the aerofoil and transfer shear loads from the trailing edge to the main structure.

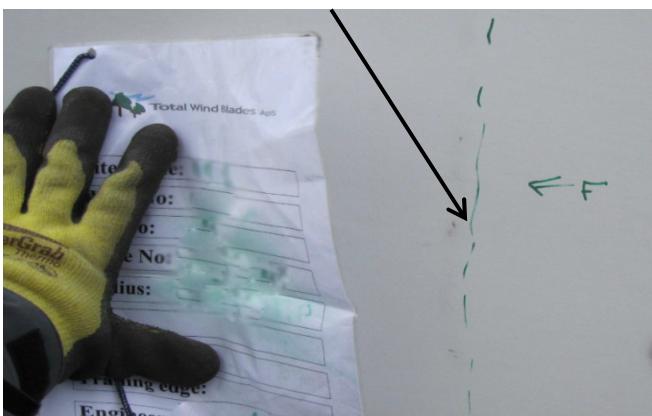


Load Distributing Floor

Failure in Bond lines



Cracks near the trailing edge and box girder corner discovered at almost all blades at large offshore park in Denmark. Source Vattenfall

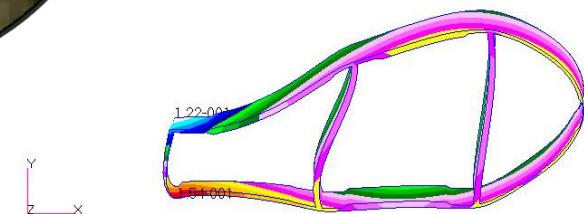
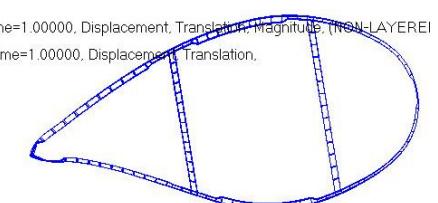
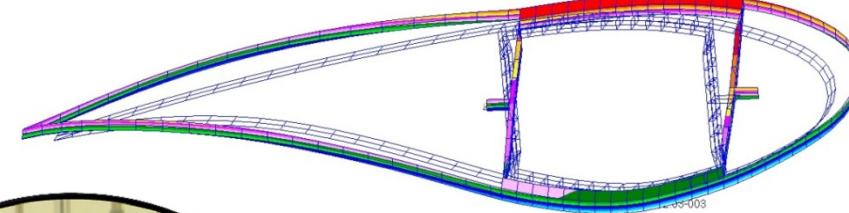
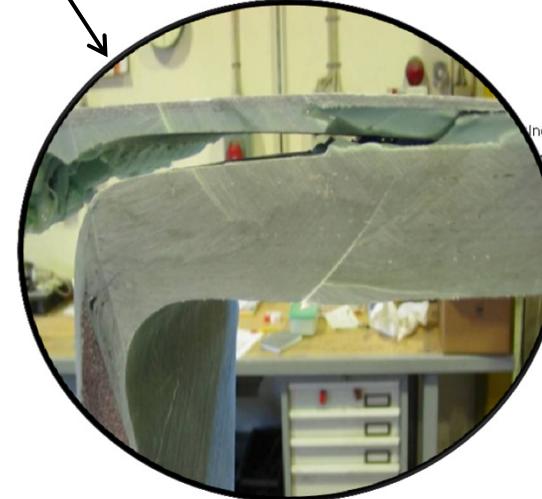
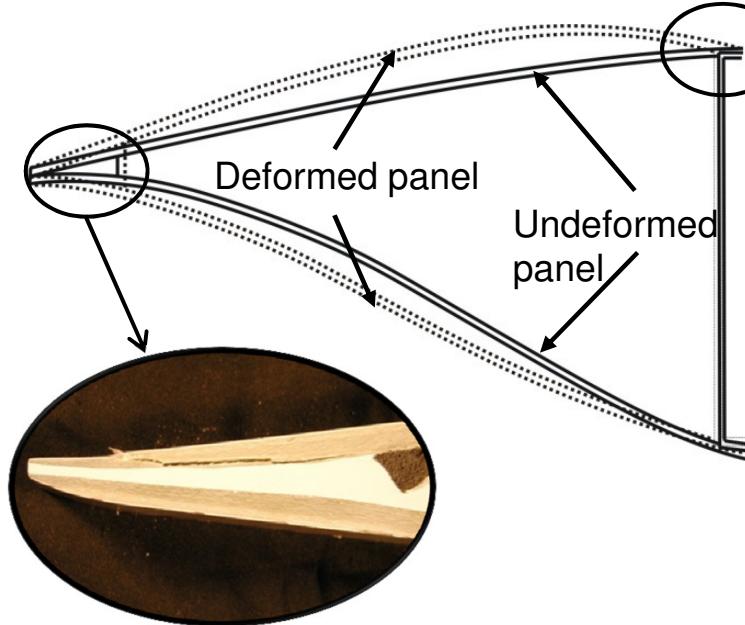


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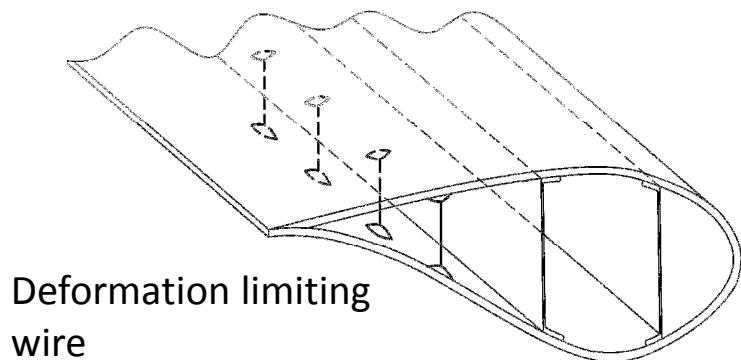
Together, we make your blade stronger

Deformations of trailing edge panels reduce the lifetime in the adhesive joints



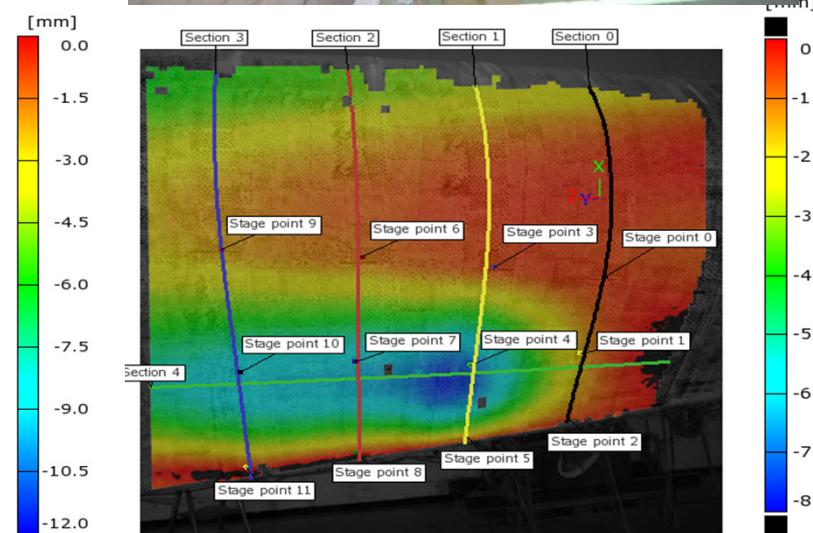
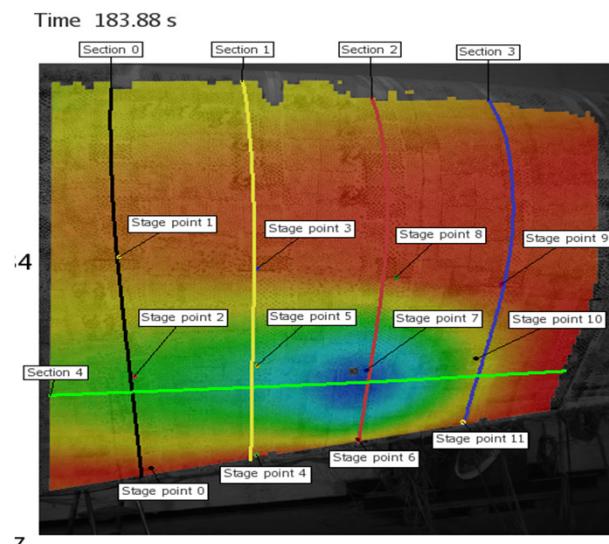
The problem with adhesive joints are expected to be even more dominant in the future when the wind turbine upscales

Bladena enhancer reduce the fatigue problems in the adhesive joints



Deformation limiting
wire

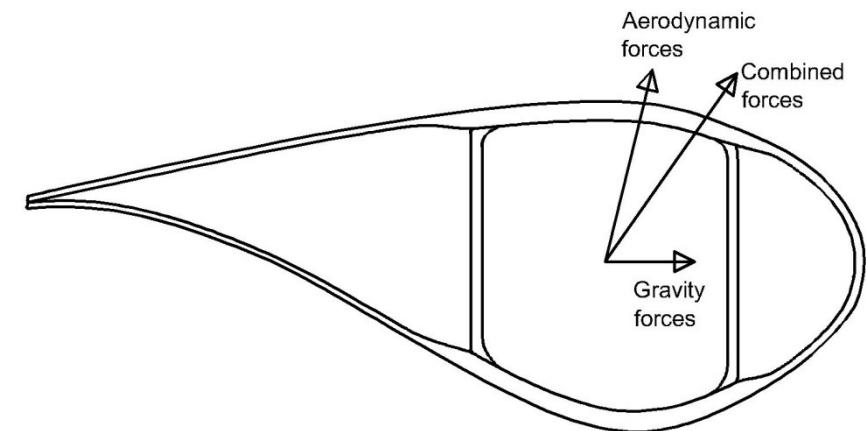
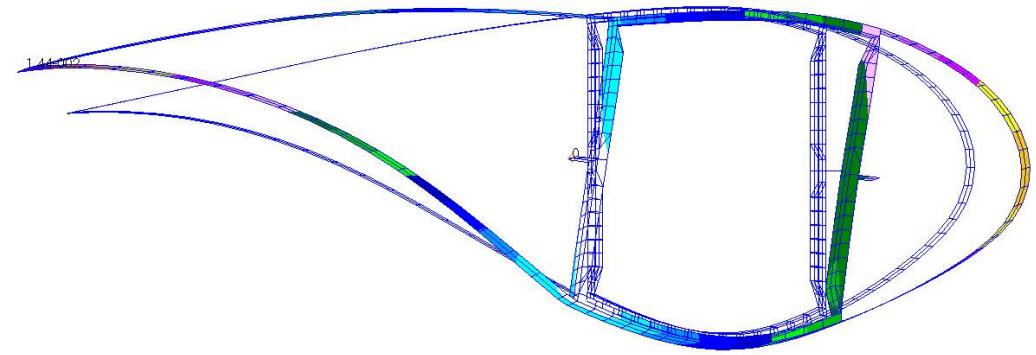
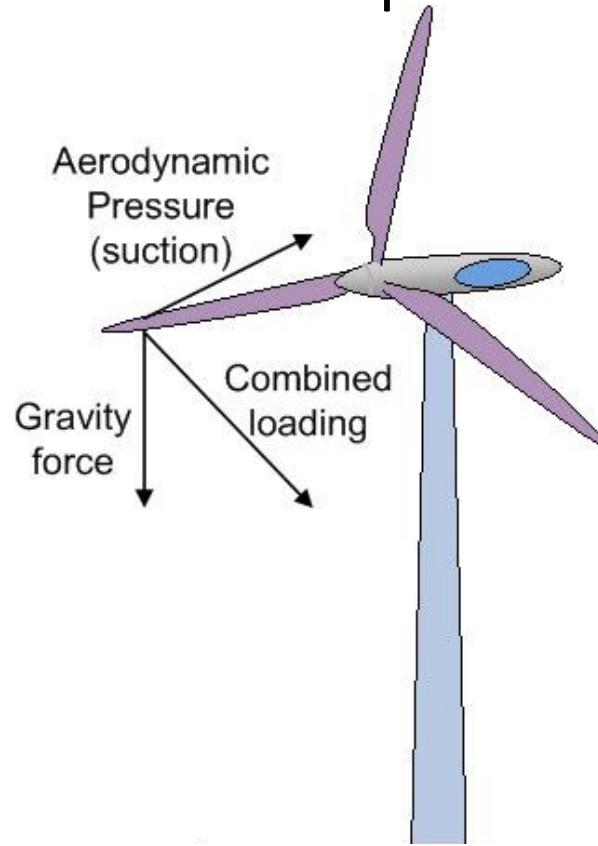
Full-scale test
performed at
Risø DTU



The outward deformation of the panels were reduced by 30-40%, using the Bladena enhancer

Reference: "Full Scale Test of SSP 34m blade, edgewise loading LTT. Extreme load and PoC_inv E. Risø-R-1748(EN). September 2010 ISBN978-87-550-3846-2.

Combined flap- and edgewise loads distort the profile

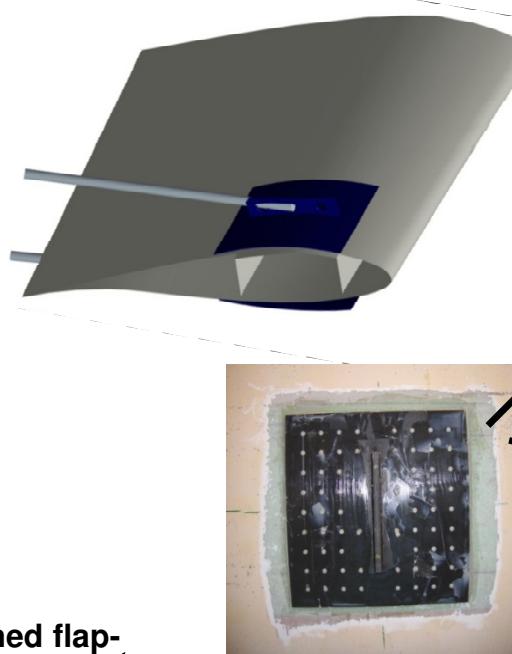


Combined gravity and aerodynamic forces result in a load component different from the traditional flap- and edgewise loads

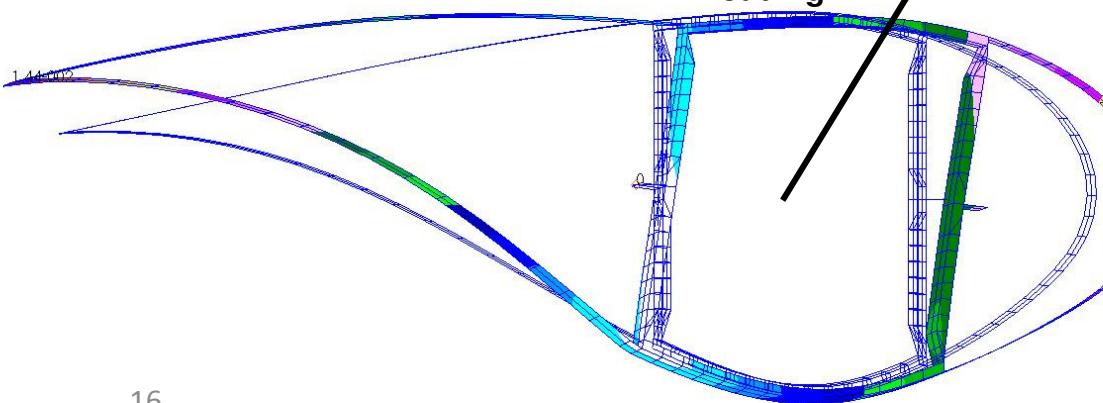
Clamps which are used in full-scale test prevent shear distortion failure



Loading clamps
which are used in
commercial test



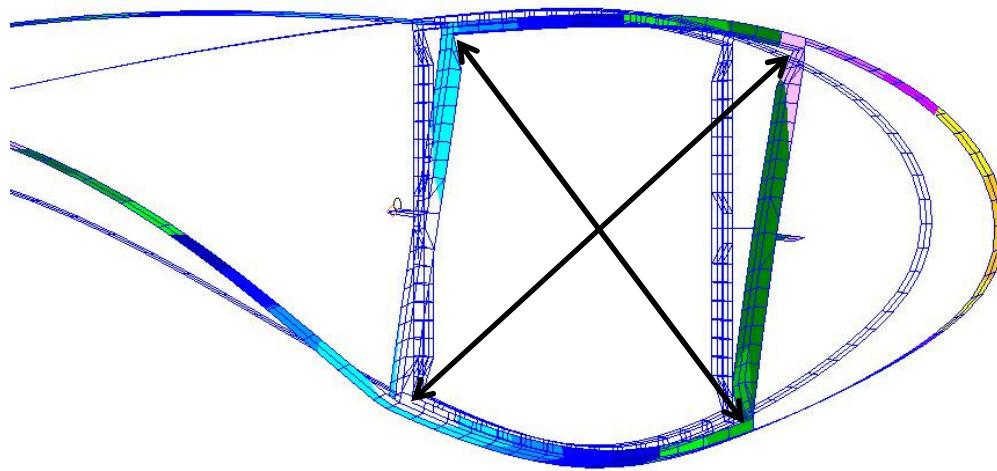
Combined flap-
and edgewise
loading



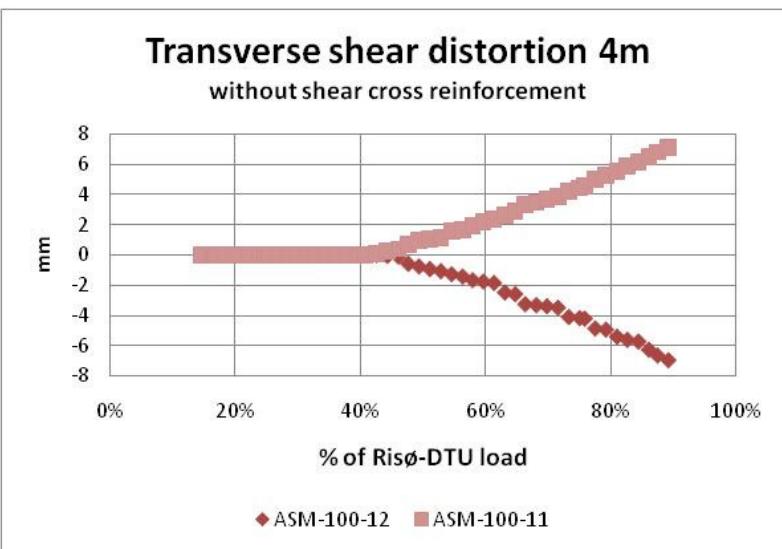
New load clamps are used in the full-scale test facility at Risø DTU. The anchor plates allow the blade to distort.

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Transverse shear distortion of the cross section

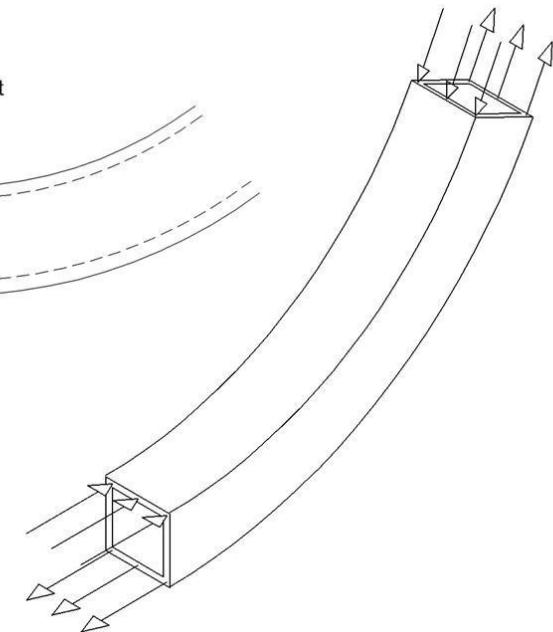
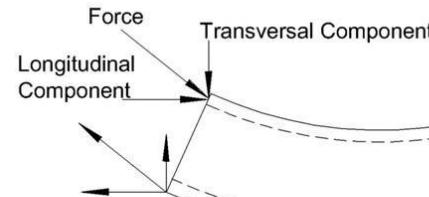
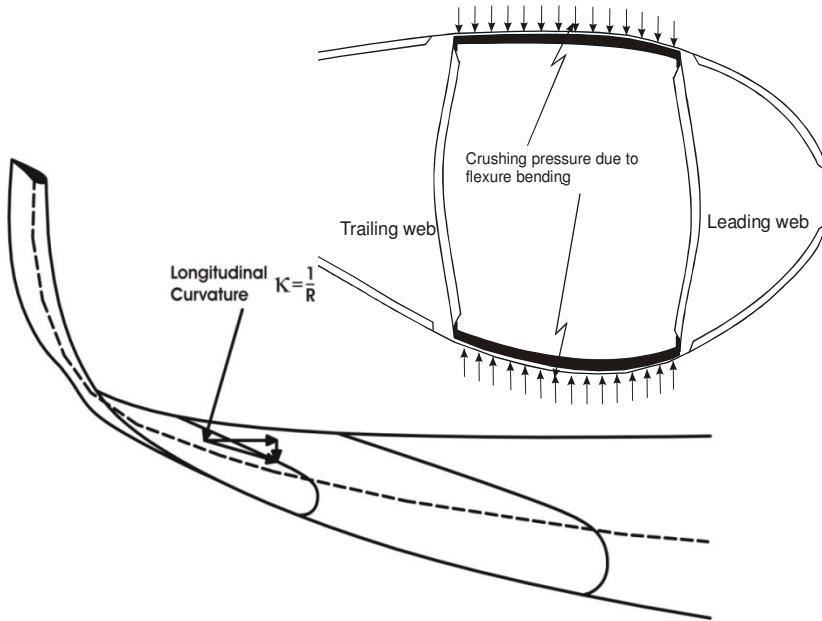


Diagonal displacement sensors measure transverse shear distortion



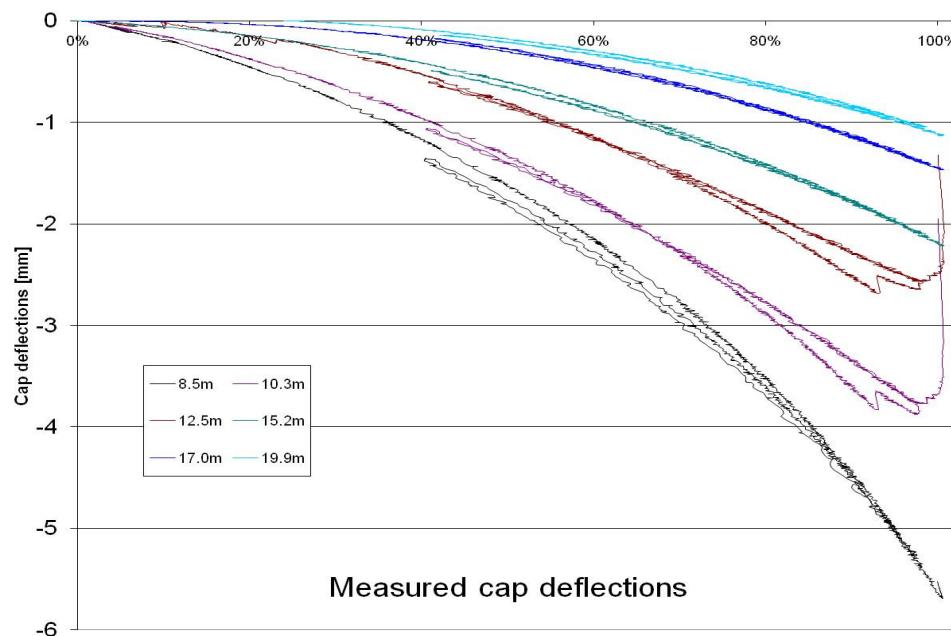
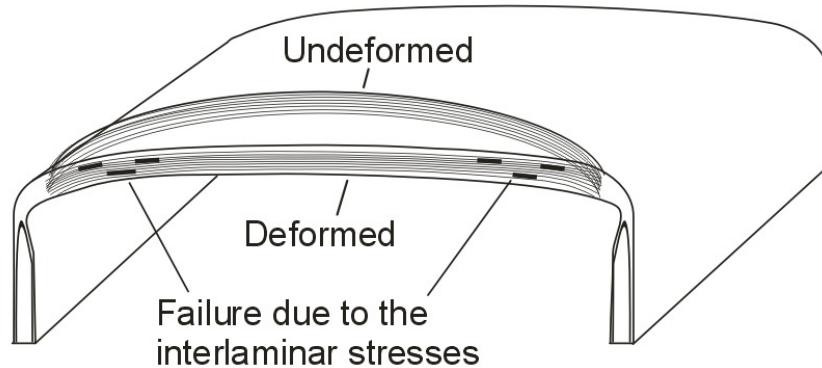
The 34m blade showed shear distortion but did not fail. This is expected to be critical for larger blades.

Non-linear phenomena becomes more critical with flexible blades

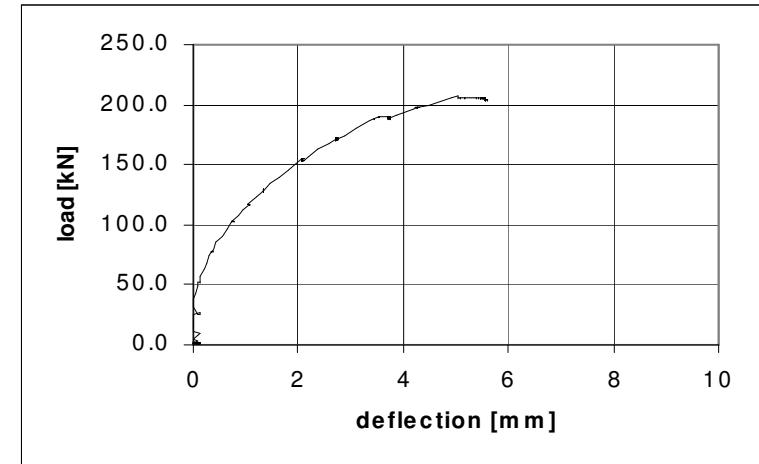
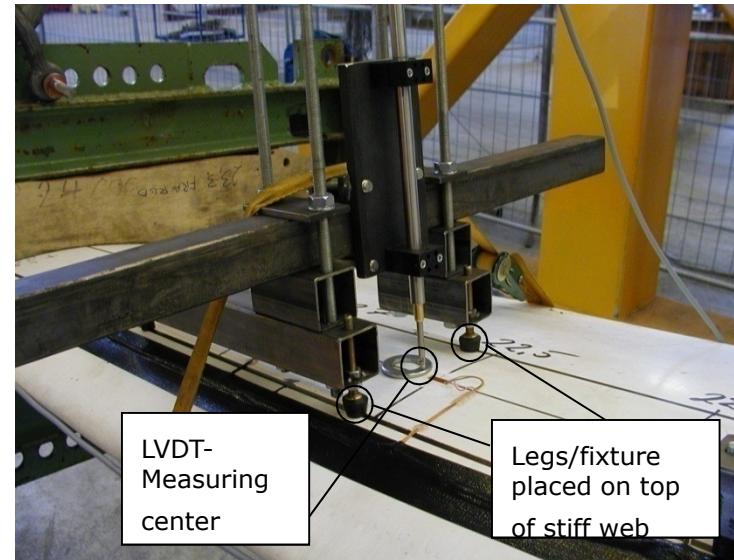


- Collapse appears when the blade, at the same time, is exposed to flapwise load, which gives a large “crushing pressure”
- “Crushing pressure” rises in the second power with the longitudinal curvature and when it is expected that the blades will be significantly more flexible in the future, such problem will be of increasingly importance

Interlaminar failures in the load carrying laminate

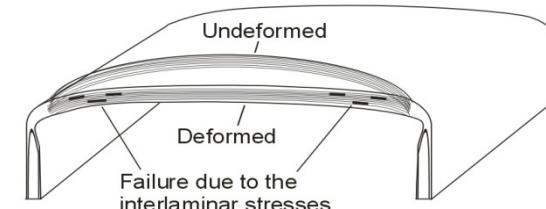
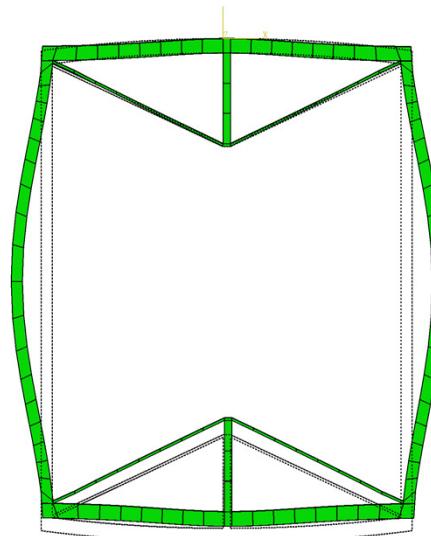
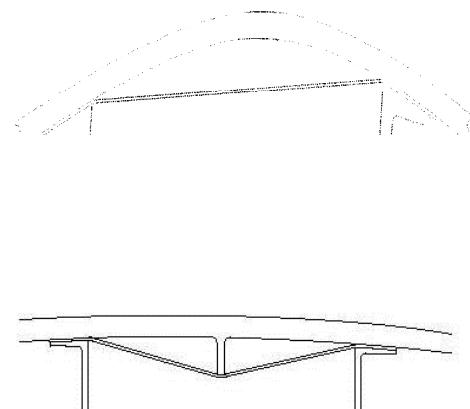


Results from a 34m blade from SSP-Technology



Results from a 24m blade from Vestas

Transverse Cap Stiffener



The Transverse Cap Stiffener prevents failure in the caps.

Innovative structural solution



44m prototype (box spar only) designed by Risø DTU
resulted in 40% thinner cap laminates

Shear Cross
Stiffener

Transverse Cap
stiffener

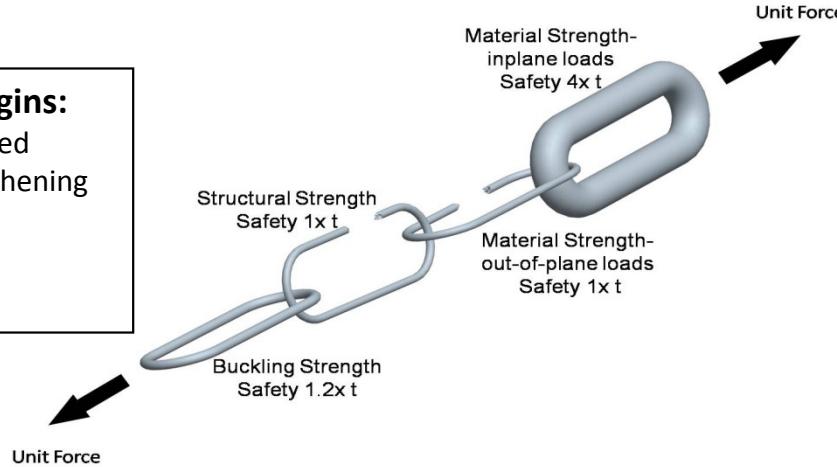
longitudinal
stiffener

The blade is not stronger than the weakest link



Typical chain of margins:

Weaknesses are perceived compensated by strengthening other links.



Optimized design:

Strict focus on strengthening the weakest link and optimising the other links. .

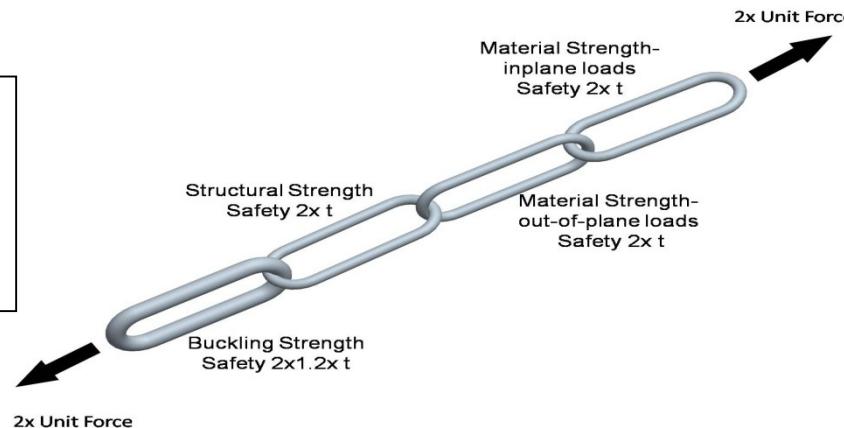


Table showing the most suitable tool for the design and certification process



	Failure modes	Tools			
		Numerical simulations (FEM)	Other simulation tools incl. analytical solutions	Full-scale test	Sub component test
1	Buckling	4	3	4	3
2	Global bending stiffness to avoid collapse with tower	5	5	5	-
3	Failure in root region	2	1	5	3
4	Strain failure in cap laminates in fibre (longitudinal direction)	3(5)	3(5)	5	5
5	Adhesive joints in trailing edge region	3	-	4(3)	4
6	Transverse shear distortion	(4)	-	4(2)	3
7	Interlaminar failure or transverse strain failure in cap laminates	4	-	5	4
8	Flutter (including torsional +distortion stiffness)	(3)	(3)	(3)	-

Failure modes covered by the certification process Failure modes which are not covered by the certification process

FEM has one big disadvantages since no reliable failure criteria are available for fibre composite materials. Experimental testing must be performed to get reliable results regarding failure.

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How can Bladena provide help?



Bladena Services:

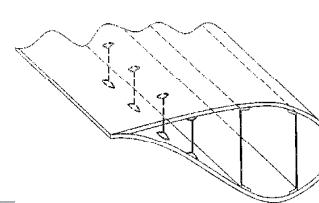
BladeScope™ Blade Enhancements

- **Structural Risk Assessment**
(of a new design, a current design or a design in progress)
- **Weight Reduction Project (8-12%)**
(of a current design or a design in progress)
- **Considered Design Specification**
(for a new design)
- **Blade Design Due Diligence**
(for procurer / owners)
- **Structural Health Check**
(for all designs)
- **Diagnosis**
(for a current troubled design)
- **Enhancer Retrofits**
(for installed blades)

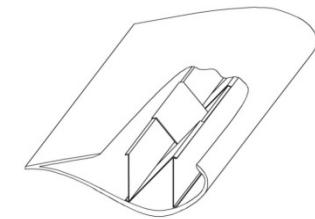


Bladena Structural Enhancers™

Patented (partly pending)



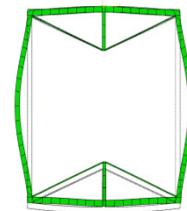
Deformation Limiting Wire Shear Cross Stiffener



Deformation Limiting Wire Shear Cross Stiffener



Load Distributing Floor Transverse Cap Stiffener



Together, we make your blade stronger

Services offered via Service Partners



Guide to Defects

An continuously updated guide supporting the inspector in writing an inspection report to make the first and immediate categorization of the damages into damages and defects.

Defect Data Sheets

Detailed data sheets describing known defects including probable underlying failures and root causes, risk profile, possible treatment solutions and next step recommendations.

Defect Report

Detailed report analyzing the defect and the possible underlying failures and root causes, and producing a specific next step recommendation, either recommendation for repair, retrofit, refurbishment or replacement, or diagnosis.

Diagnosis

Plan based on prioritized step for diagnosing the defects and identifying the underlying failure and root causes. Included budget, partners and time line. Bladlena can also support the actual diagnosis and prepare a failure report with the found conclusions and treatment options.

Inspections



A service company has been asked to inspect some blades on a wind park where blades has suffered damage.

Based on traditional approach the observation made by the service company would have led to the repair of the surface coating, the only “visible” sign of the underlying problem.

Bladena offers , through a service partner, a systematic approach on how to identify the root cause of key issues seen on blades in service, and suggests solutions aimed at reducing the impact of the problem in order to increase the residual life of the damaged blades.

The analysis process



- 1) The service partner find damages on a blade.
- 2) The damage may be “recognized” to be one of the failure types addressed in this presentation, or another known defect. This is done by using standard defect data sheets. The data sheets include a list of root causes and some guidance on what needs to be done.
- 3) If one or more of the failures that are addressed may be related to structural causes, a “defect report” is suggested.
- 4) In this “defect report”, Bladena analyze the available results including the load history and failure type in more detail. The analysis will probably help in excluding some root causes. Other will become more relevant a more likely to be the source of the problem.
- 5) The few root causes remaining will be further analyzed in a “diagnostic plan”. In this plan, a proposal on how the problem can be solved is presented.

Example

- 1) The service partner finds longitudinal cracks in the gel coat close to the trailing edge of a number of blades.

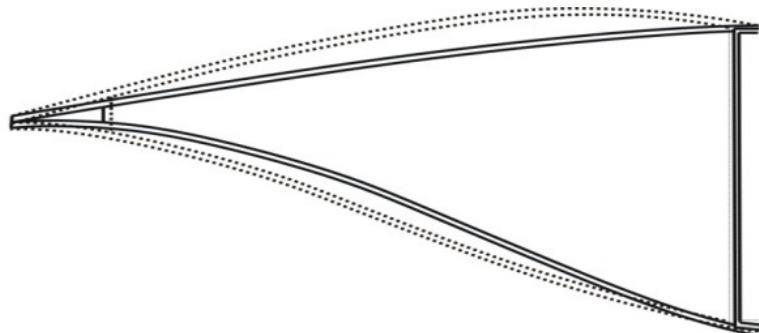


- 2) The crack looks similar to the one in a data sheet. The root cause can either be due to manufacturing reason or fatigue cracks in the bond line due to out-of-plane deformation. A “defect report” is recommended.

Example – cont.

3) No extreme load events have occurred. Failure has happened during normal operation. The longitudinal cracks are in areas where “pumping” movements are usually significant. The most likely root cause is determined as a fatigue failure in the bond line due to pumping. Another potential root cause is that different types of plies are overlapping each other in the backing laminate. In both cases, a reduction of the out-of-plane deformation will reduce the problem.

In case that the problem is an issue with overlapping plies and drop-off, then it might be sufficient to improve the manufacturing process for future blades, but in order to “solve” the problem, either repairs have to be done frequently or the deformations must be reduced.



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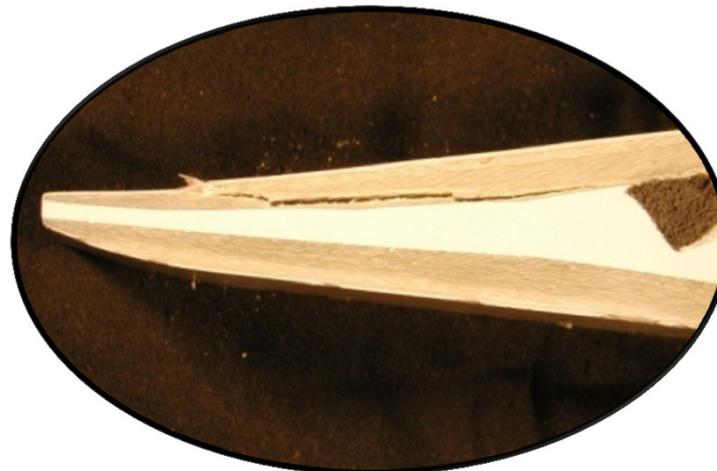
Example – cont.



4) In order to verify this assumption a “diagnostic plan” is recommended. In this particular case, two actions are required:

- A sample cut-out from the blade must be analyzed in the lab (burn-out-test)
- Further inspection of the bond line either visually from inside the blade (e.g. by using an endoscope) or by using NDT.

5) After step 4, adhesive failure was confirmed in the bond line.

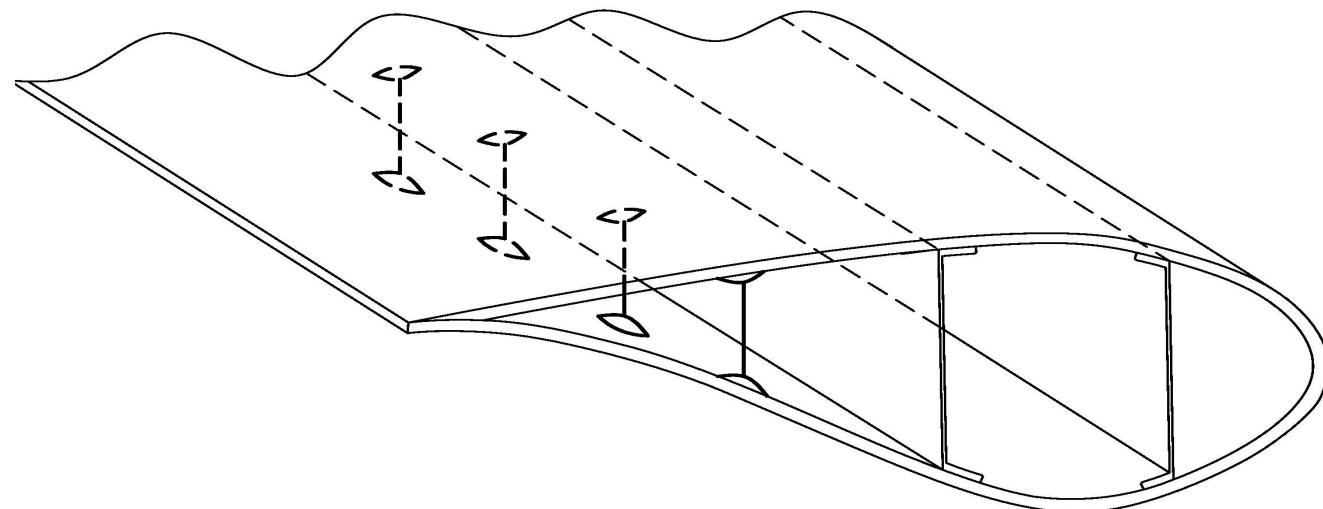


Together, we make your blade stronger

Example – cont.



- 6) A deformation limiting wire solution is recommended to be retrofitted to the blade



Summary



The growing size of the blades have resulted in a change in which type of loading which is critical and especially the edgewise gravity induced fatigue loads are more dominant.

Also transverse shear distortion and tension failure in the UD-laminates become more important.

The increased size of wind turbine blades demanding a better understanding of their structural behaviour e.g. more complex test loads and non-linear FEA.

New design and testing procedures must be implemented if the full potential of the material should be used.



Thank you for your attention

Any Questions?

Any questions please contact:

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