Aeroelastic Tailored Blade Design and Validation

Lars Hedegaard, August 2018

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Presentation Outline

0. Company Profile
1. What is a Aeroelastic Tailored Blade (AeTB)?
2. Why is AeTB Design and Validation Important?
3. How to Design AeTB?
4. How to Validate AeTB?

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Siemens Gamesa – Key Facts[1]

84.5 GW
Globally Installed

25k
Employees

11 €B
Annual Revenue

8 GW
Order Entry

7.8 €B
Market Capitalization

21.3 €B
Order Book

True **global,** modern and scalable **footprint**

Advanced **digital** capabilities

Portfolio covering all requirements

[1] End of December 2017

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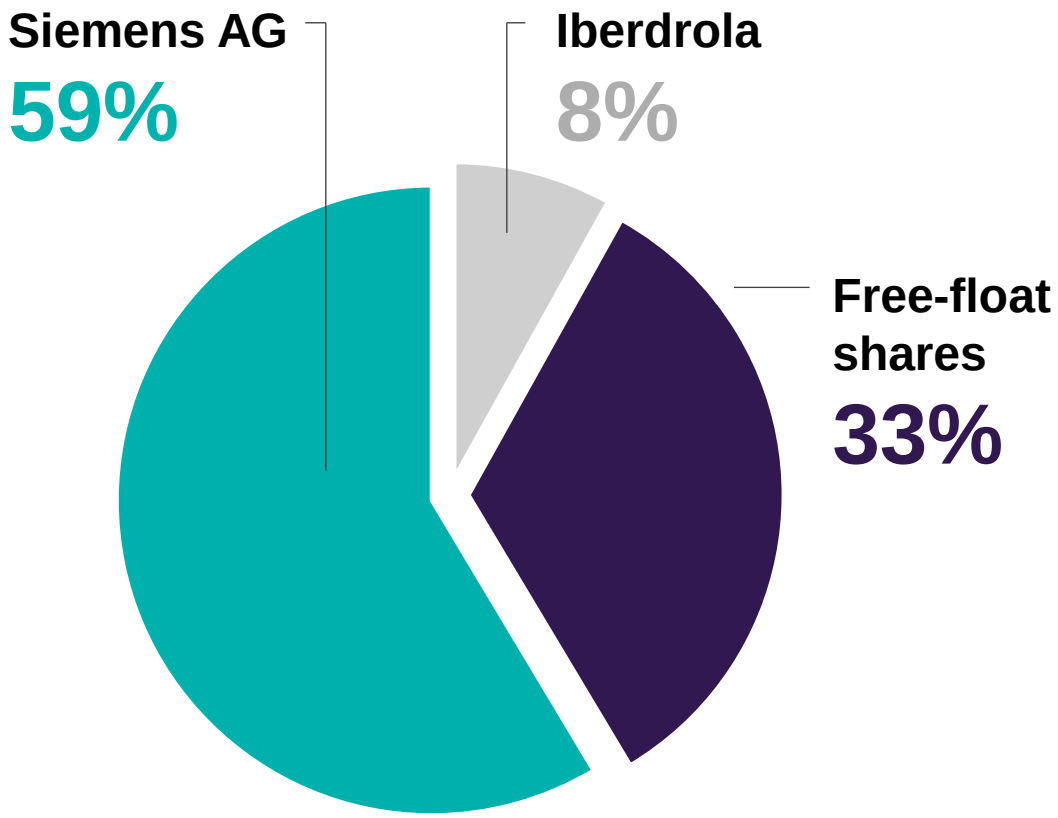
Ownership Structure



Siemens Gamesa is a company listed on the **Spanish Stock Exchange**.

Member of **IBEX 35**, is traded on Madrid, Barcelona, Valencia and Bilbao.

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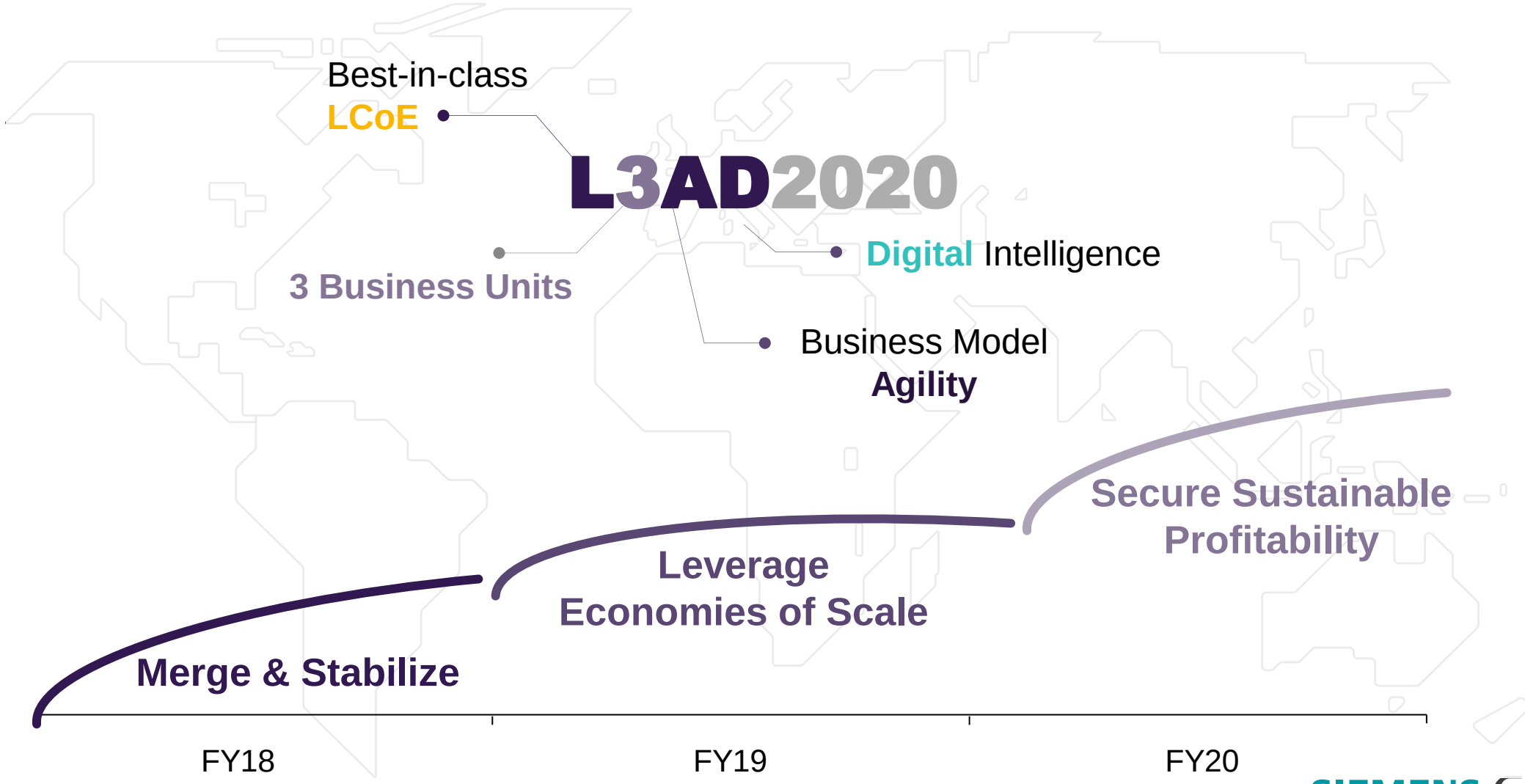
L3AD2020: Our program to lead the industry



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Technology & Innovation

>400 M€/year
R&D Investment

+5,500
Patents granted

~50,000
manufactured & installed turbines

+1,500
Pending patents

+3,000
R&D dedicated engineers

- **7 Technology Centers**: **Bangalore** (India), **Boulder** (USA), **Brande** (Denmark), **Hamburg** (Germany), **Bilbao**, **Madrid** & **Pamplona** (Spain)

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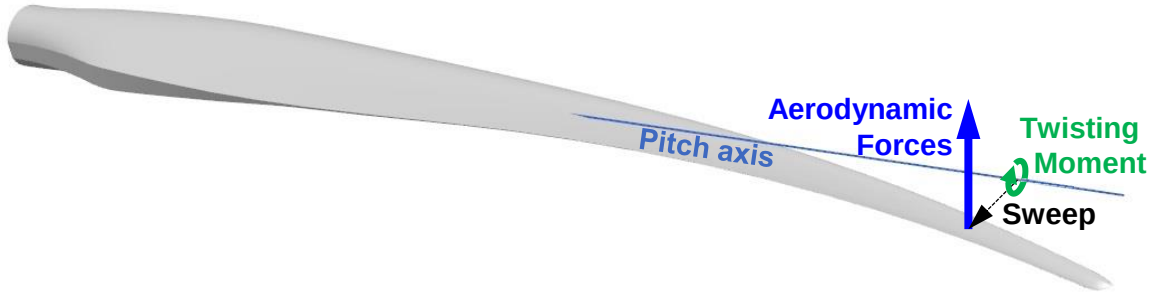
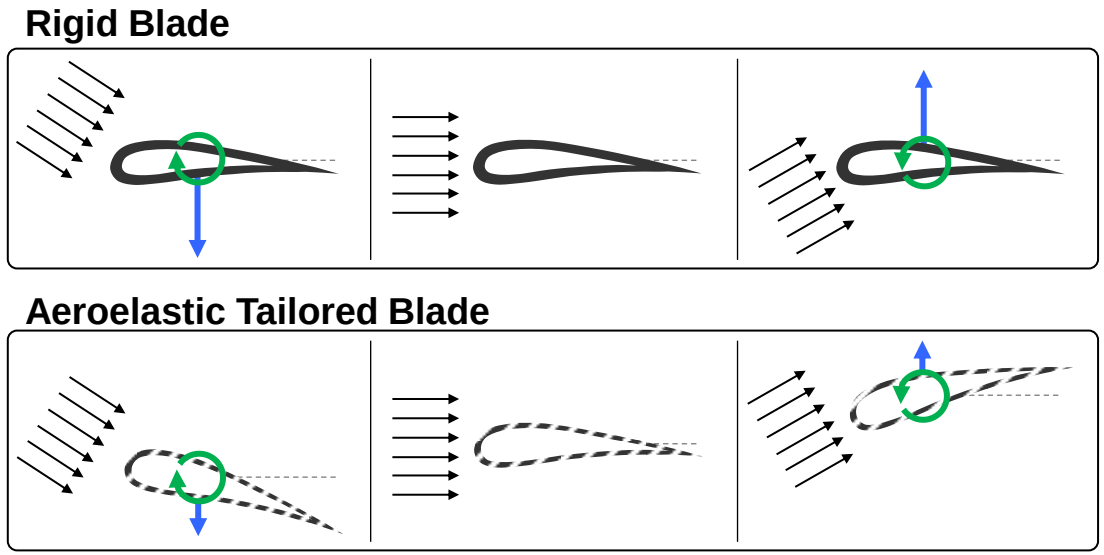
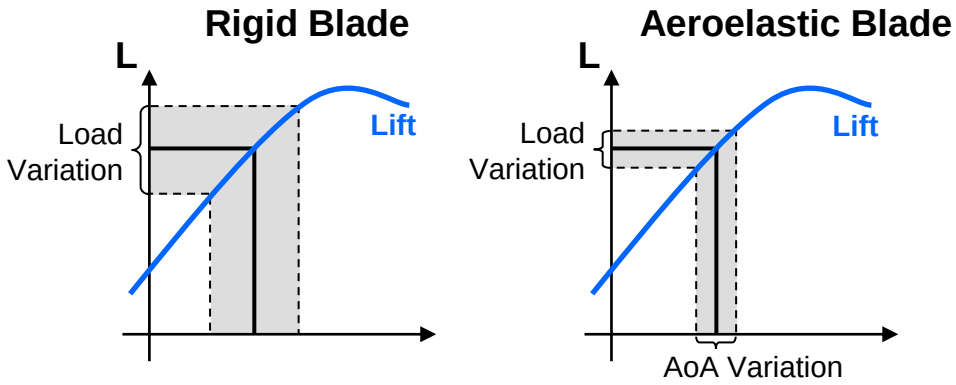
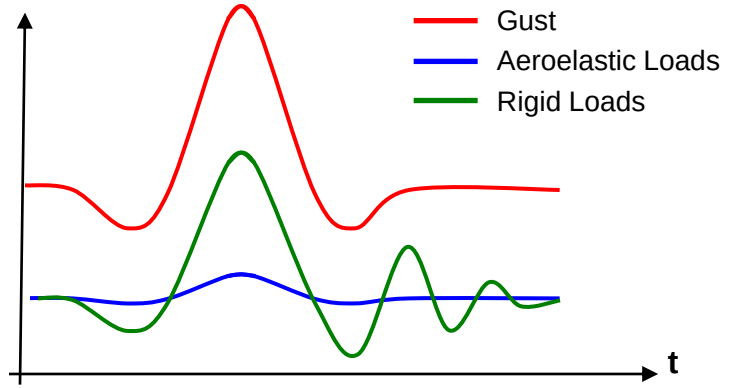
Aeroelastic Tailored Blade Design

A blade that is designed to twist under aerodynamic loading to alleviate extreme and fatigue load damage.









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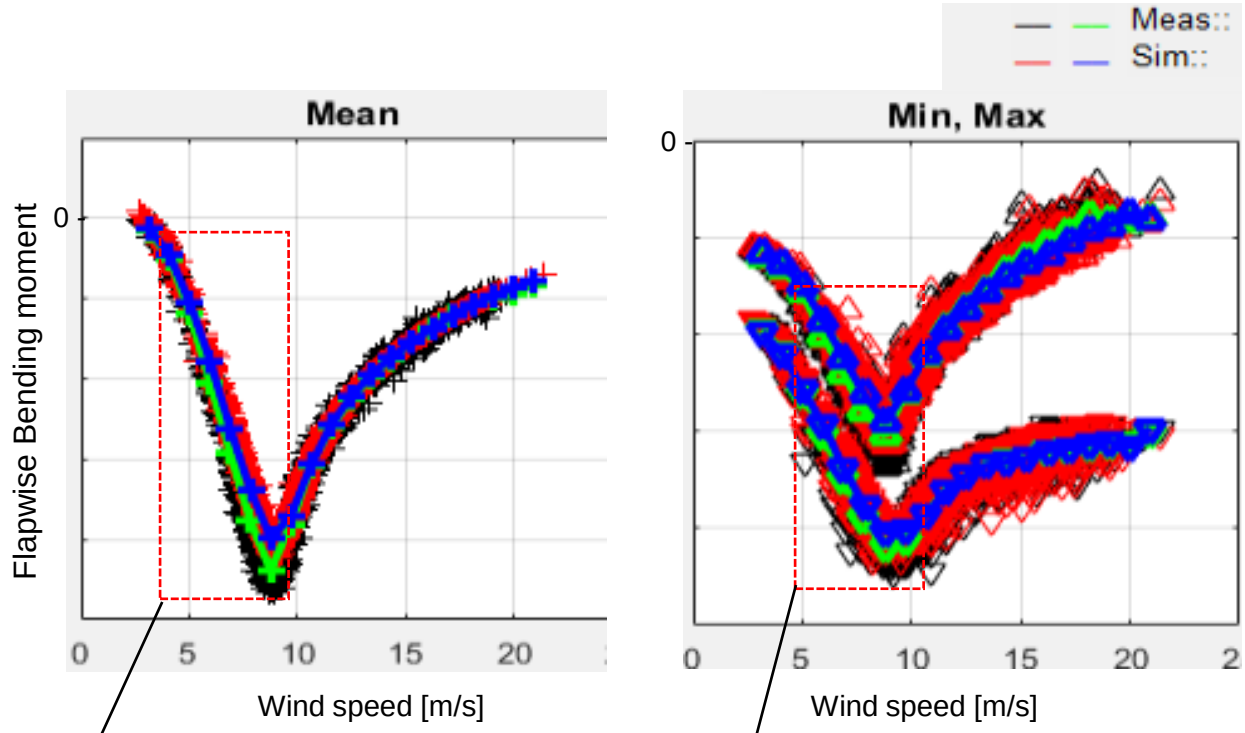
Consequence of in-accurate AeTB modelling

In-accurate modelling of AeTB effect can result in increased blade and turbine loads.

In present case:

- AeTB effect was over-predicted in models (real blade had less twist response).



Flapwise Mean: +8%

Flapwise Min, Max: +5%

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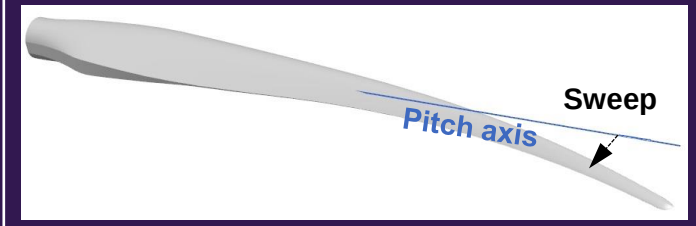
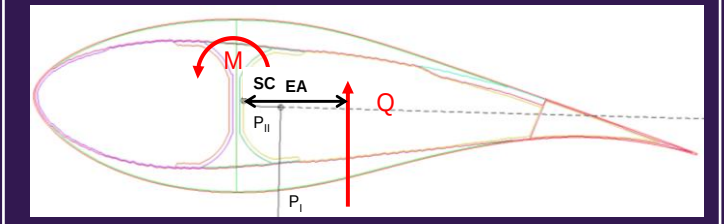
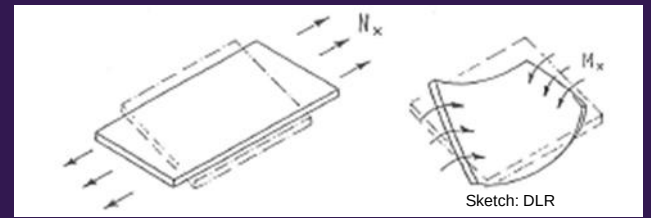
Concepts of AeTB design

	1) Blade Geometry	2) Internal Structure Geometry	3) Anisotropic Composite Layup
			
Design handles	• Sweep distribution (angle, curvature)	• Spar-cap location • Web locations • Local reinforcements	• Fiber orientation • Layup sequence
Effects	• Twist from torsional moment generated by sweep offset. • Twist component from flapwise deflection, when blade axis do not follow pitch axis.	• Local shear center location → Shear-Twist coupling	• Shell extension-shear coupling → blade Bend-Twist coupling

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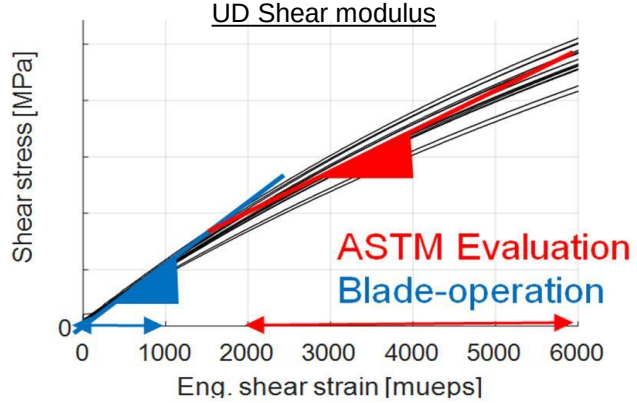
Challenges in AeTB Design and Modelling

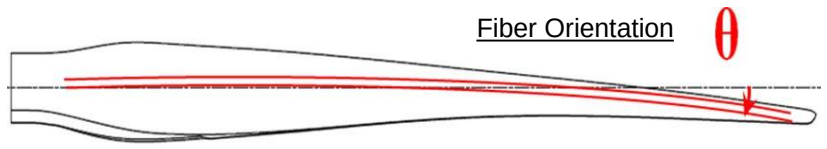
Error in tip twist response is a accumulation of errors along the whole blade span!

Material behavior	• Nonlinear shear modulus of UD materials response • Shear stiffness
As–Built Properties	As-built fiber-orientation, Small plies, Tolerances, etc.
Modelling	Cross-sectional modelling: • Geometry details, Layup modelling, anisotropic materials, calculation of equivalent beam properties Beam modelling: • Effect of spanwise taper, curvature and discontinuities.
Reference-frame consistency	• Consistent reference-axis between models and test measurements • Effect of deformed shape

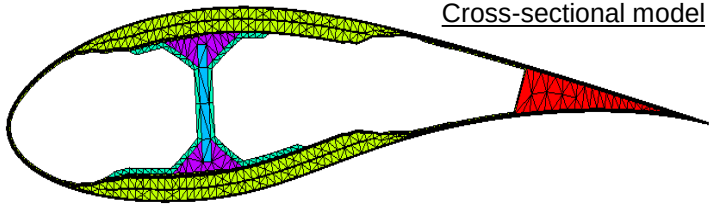
UD Shear modulus



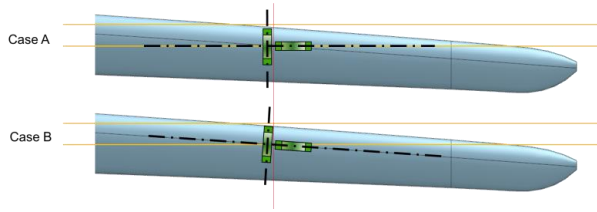
Fiber Orientation



Cross-sectional model



Reference-axis



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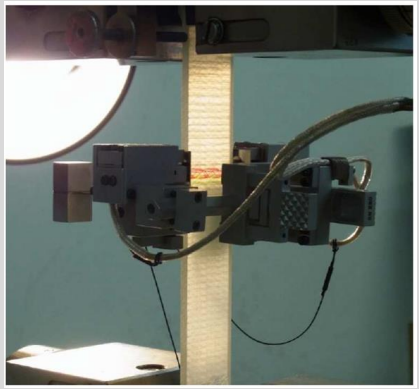
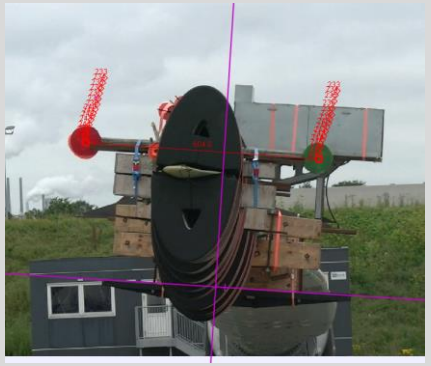
Multi Scale Validation methods for AeTB

	Coupon Test	Small Scale	Full Scale Static	Full Scale Dynamic	Full Turbine
Method					
Purpose	Determination of: • Material stress-strain relationship	Validation of: • Effect of manufacturing process and details • Tool validation	Validation of: • Torsion and bending stiffness • Coupling behavior	Validation of: • Multibody simulation	Validation of: • Structural model • Multibody simulation • Aero-model

Complexity

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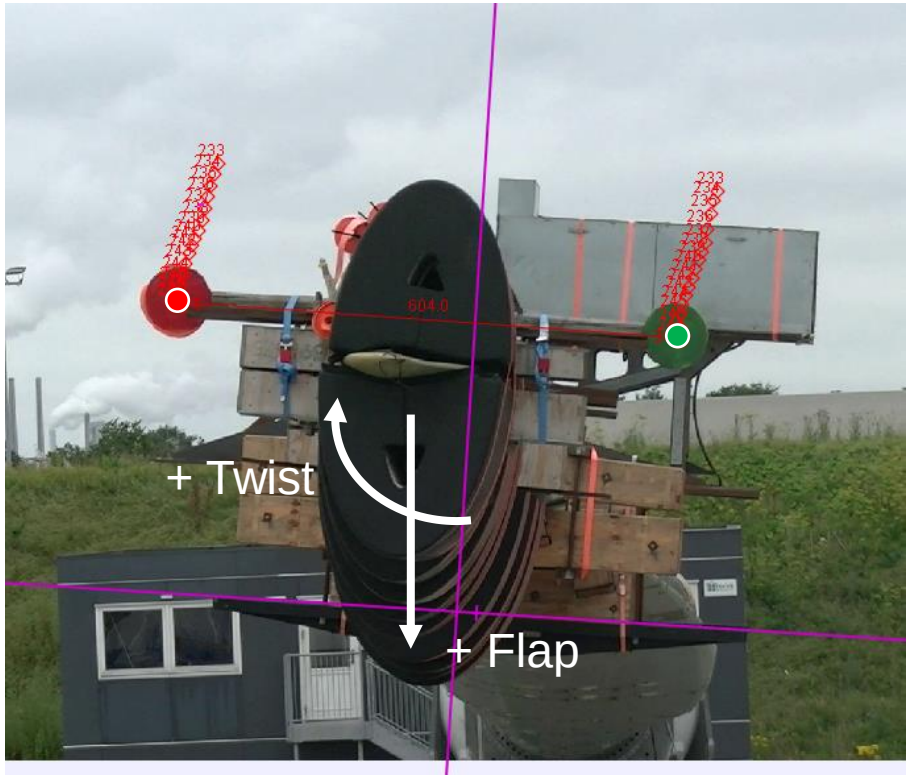
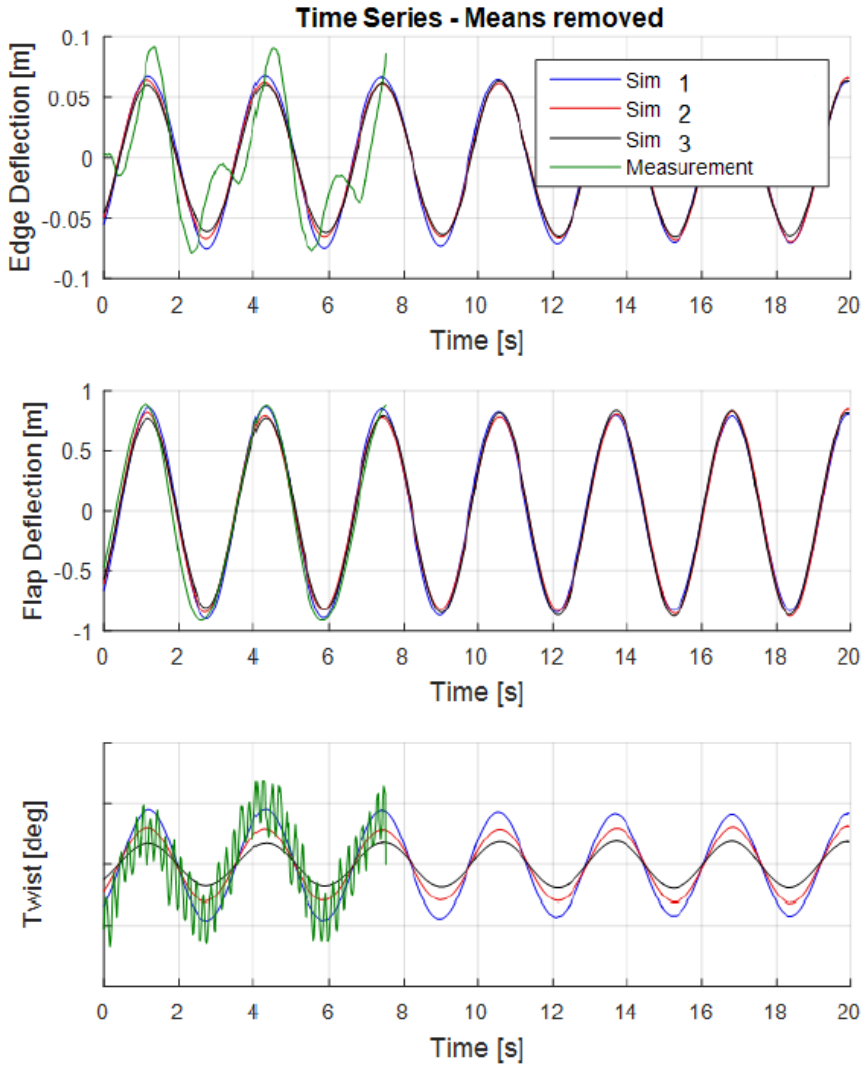
Full Scale Dynamic AeTB Validation

Deflection and twist response measured using image tracking technique.



Tracker_Example_lowRes.mp4



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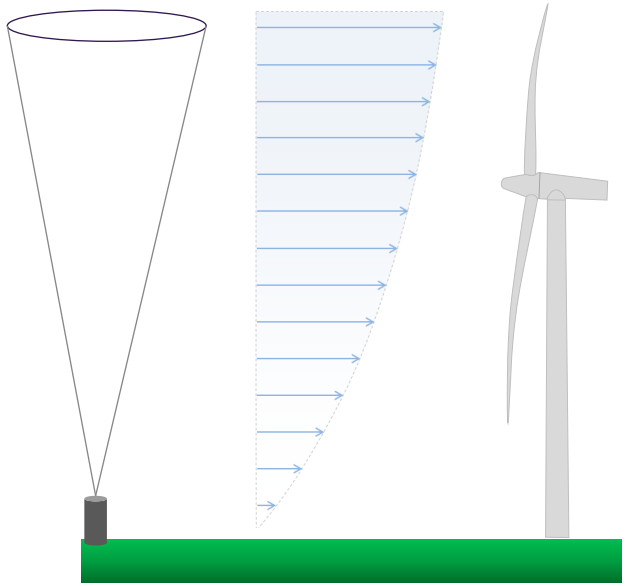
Turbine One-to-One Loads Validation

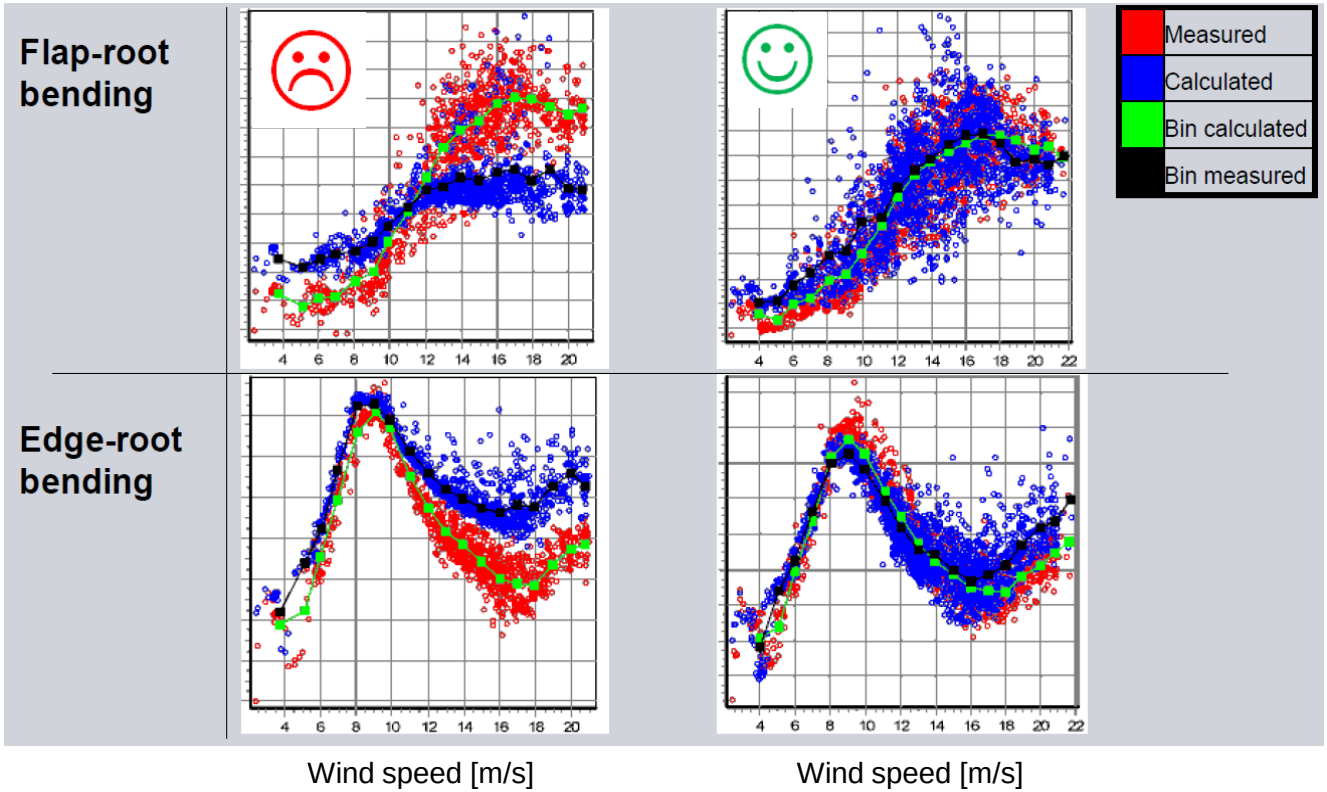
Lidar → Wind inflow box



Sequence for One-to-One

1. Ground based Lidar measures wind inflow
2. Turbulent inflow box generated
3. Aeroelastic response simulated
4. Comparison with measurement

Fatigue load comparison (short term eqv. loads)



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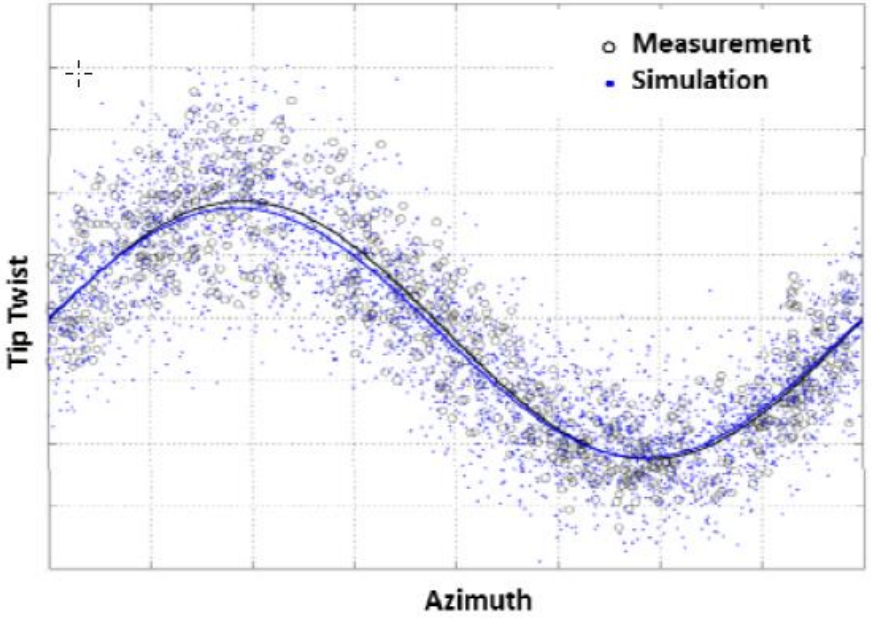
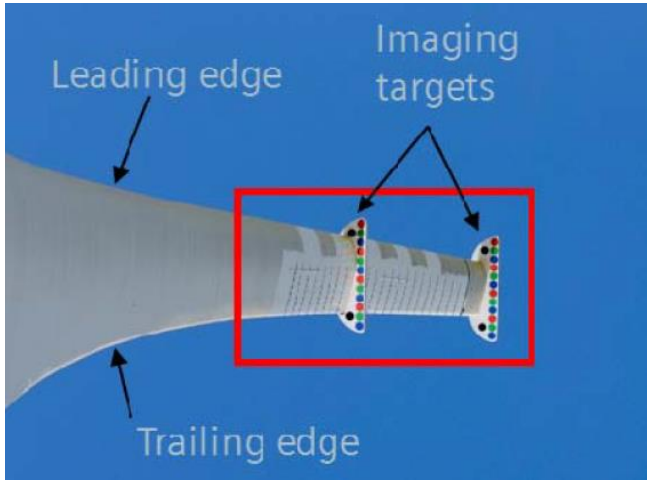
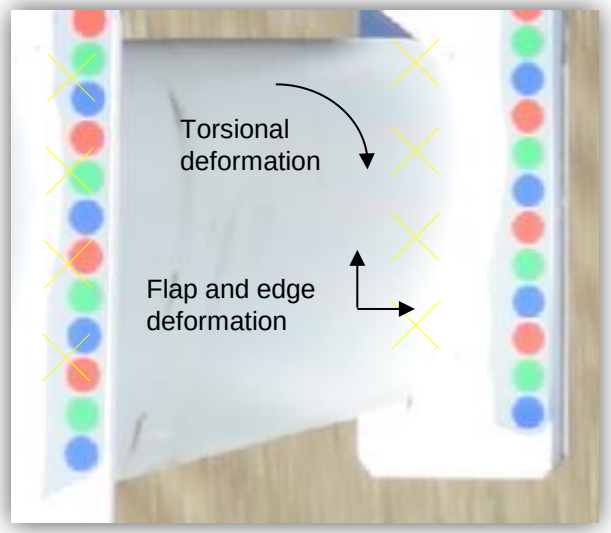
Turbine AeTB Validation

Image tracking technique and One-to-One simulation used for AeTB twist response validation.







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Summary

Correct blade deformation modelling is important for correct load prediction.

Important factors:

- Precise knowledge of material properties
- Accurate modelling of cross-section geometry and lay-up
- Capable tools to extract equivalent beam properties, including coupling terms
- Test-validation at every level of modelling to identify potential error sources related to properties or modelling assumptions
- Consistent reference frame for deformation and loads application in models and tests.

SiemensGamesa has developed a field-proven design tools and validation methods to leverage Aeroelastic tailoring to enable increased rotor size.

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Open Engineering Positions in Boulder Colorado

Structural Blade Design Engineer (entry level)

- Composite structure modelling and design of new blades

Aerodynamic Blade Design Engineer (mid level)

- Aerodynamic modelling and design of new blades

Loads Blade Design Engineer (entry level)

- Turbine multi-body dynamics modelling and loads simulation

More info: www.siemensgamesa.com/career

Interested?

Email your resume and/or catch me for a chat at the conference.

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Thank you!

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